Estimation and Monitoring of Tropical Forest Biomass Using Polarimetric Interferometric SAR Data.

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Abstract

The purpose of the proposed work is to examine the feasibility of using Polarimetric Interferometric SAR (PolInSAR) techniques on ALOS PALSAR data to extract forest canopy heights with the ultimate objective of deriving biomass estimates. Previous work [1] has shown that in homogeneous European forest stands, tree height is a reasonably robust estimator of biomass through a simple allometric relationship. Moreover PolInSAR has proven itself as a valuable technology for tree height estimation at L-Band frequencies. The RVoG model (Random Volume over Ground) proposed in [2] and elaborated in [3], permits a separation of ground and canopy scattering components of the interferometric phase. Through model inversion, the canopy height can be derived [4]. Additionally, the bare earth elevation beneath canopy can also be recovered at least in airborne repeat-pass cases where temporal de-correlation is not prohibitive. While the PolInSAR results to date from airborne repeat-pass L-Band campaigns have been impressive, it is not clear to what extent it will be possible to derive similar results from ALOS data, owing to the much longer temporal baseline between acquisitions.

In this work we primarily focus our research on the extraction of DEM underneath canopy and the estimation of tree height and other forest parameters used in biomass calculation. The principal research site is chosen to be Kalimantan, Indonesia in order to overlap the area covered in the INDREX-II airborne campaign for which the PolInSAR technologies have been developed. We use the ground measurements taken during the Indrex-II campaign [5] for validation and verification of our results. Unfortunately at the time this report is being prepared, we do not yet have repeat pass, fully polarimetric ALOS data for the desired area. Therefore we will limit this report to a brief description of the background to the PolInSAR technology and some results extracted from the INDREX-II data set by the authors using this technology.

Introduction

Extraction of digital elevation models (DEM) beneath continuous large forested areas is a difficult task. InSAR has proven itself as a valuable tool for acquiring DEMs relatively inexpensively. The two InSAR-derived elevation data sets available to the public are in C and X bands. These are Digital Surface Models (DSMs) and in forested areas represent the upper portion of the canopy. At long wavelengths (such as P-band, with a wavelength of about 86cm) forest canopy is sufficiently transparent, allowing estimation of 'bald-earth' DEMs [6]. However, bandwidth restriction and large baseline requirements, constrains application of P-band systems. L-band with its 24cm wavelength (approx.) appears an attractive alternative but is also limited because the complex backscatter signal is often a composite of ground and canopy returns. The problem then is to separate the ground and canopy returns in the recovered interferometric phase. According to the RVoG model, the backscattered ground phase is polarization-sensitive, while the canopy (under certain assumptions) is not. The PolInSAR literature [2,3,4,6] indicates a set of methodologies under which the ground elevation and volume height (canopy height) can be inverted from the observed fully-polarimetric complex images received by the interferometric antenna pair.

In this work, we first address the problem of vegetation height extraction and the achievable accuracy at L-Band, using simulated data by PolSARproSim [7] and then apply the RVoG model to INDREX-II data [5] which was acquired during the INDREX-II campaign in Kalimantan, Indonesia in 2004. X-, L- and P-bands were amongst the acquired data sets, including polarimetric and interferometric components. Ground truth data are in the form of forest plot samples, ground photos and some aerial photos [8]. The schematic representation of unit circle for a two layered medium comprising of a volume layer overlaying a ground layer is shown in Figure (1).

In the following sections the approach to theRVoG model [3,4] and its application on simulated and real data are discussed. We compare our findings with direct extraction of interferometric phase derived from P-band (the 'bald-earth' ground return) and X-band (the volume return).

Approach

The key parameter in PolInSAR RVoG model is the complex interferometric coherence, which has been generalized to integrate the polarimetric information [3,4]. The complex coherence, $\gamma(w)$, according to this model, is given by equation (1), where ϕ is the phase related to the ground topography, m is the effective ground-to-volume amplitude ratio (accounting for the attenuation through the volume) and w represents the optimized polarization state vector. $\tilde{\gamma}_V$ denotes the complex coherence for the volume alone (excluding the ground component), and is a function of the extinction coefficient σ for the random volume and its thickness h_V. It is important to note that m is polarization dependent while $\tilde{\gamma}_V$ is not.

$$\gamma(w) = \exp^{j\Phi}\left[\frac{\tilde{\gamma}_v + m(w)}{1+m(w)}\right] \tag{1}$$

Parameters in equation (1) can be recast, as in equation (2), which represents a line equation on the unit circle.

$$\gamma(w) = \exp^{j\Phi}\left[\tilde{\gamma}_v + \frac{m(w)}{1+m(w)}(1-\tilde{\gamma}_v)\right] \tag{2}$$

In the ideal case, the variation of m as a function of polarization, w, will therefore trace out a straight line which when projected onto the unit circle (limit of large m) provides the topographic phase as illustrated in Figure (1). The phase to height conversion is a simple scaling by vertical wave-number (Eq. (3)). In the limit of m=0, the observed coherence is just $\tilde{\gamma}_V$ rotated by the topographic phase. The canopy height can be obtained from $\tilde{\gamma}_V$ by an inversion process [4]. Due to estimation errors, noise and other decorrelating effects, the straight line degenerates to a region surrounding the line. The lowest and highest values of coherence can be calculated through ‘constrained coherence optimization’ [9], forming the coherence region as illustrated in Figure (1).

A ‘well-shaped’ coherence region is normally close to an ellipse (Figure (1)) with high eccentricity. In repeat pass interferometry temporal de-correlation, thermal noise and baseline variation may fatten this region to be more circularly-shaped.

A schematic representation of this model as a two layered medium comprising of a volume layer dominating over a ground layer is shown in Figure (2).

$$\Phi = K_Z.h_v \tag{3}$$

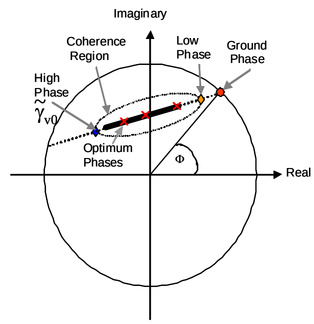

Figure (1) The schematic view of unit circle for two-layer RVOG model.

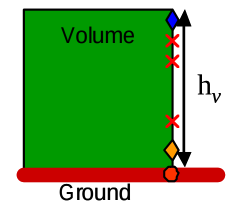

Figure (2). Two-layer vegetation model

Simulated Dataset Results

To test effectiveness of different approaches the RVoG models performance was first examined using PolSARPro simulated data [7].

PolSARPro generates scatter return for different geometric, system, ground condition and forest configurations. The simulated example configuration is given in Table (1). Figure (3) shows a presentation of Pine1 forest in the PolSARPro simulated data.

Configuration Geometric	
Platform Attitude	3000(m)
Incident Angle	45°
Horizantal Baseline	10(m)
Vertical Baseline	0(m)
System Configuration	
Centre Frequency	1.3 (GHz)
Azimuth Resolution	1.5(m)
Slant Range Resolution	1.0605(m)
Ground Surface Configuration	
Surface Properties	0
Ground Moisture Content	4
Ground Azimuth Slope	0%
Ground Range Slope	0%
Forest Configuration	
Trees Species	Pine1
Mean Tree Height	20(m)
Forest Stand Density	300(Stem/Ha)
Forest Strand Area	1(Ha)

Table(1) PolSARPro Simulated data configuration

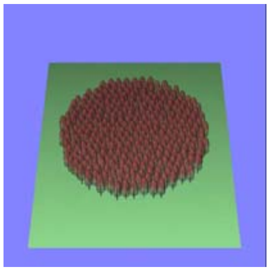

Figure (3) Pine1 configuration

The RVoG optimization model applied on simulated data successfully separates volume and ground phase responses, with accuracy level of within 1m of the average tree height (i.e. 20m±1) and a standard deviation of ±0.81m. The estimated ground phase is very close to the “true” value, zero radians in this case. The results from the RVoG optimization model using the PolSARPro simulated data are shown in Figure (4).

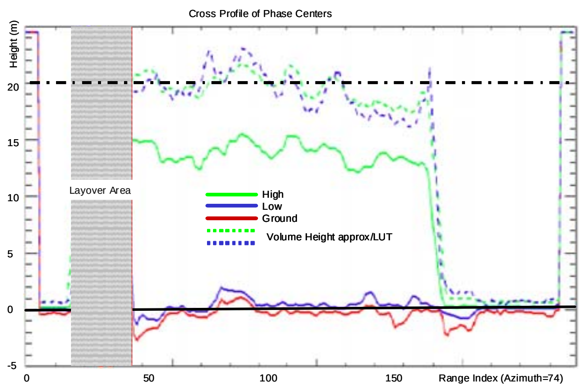

Figure (4) Simulated data: cross profile in range direction

INDREX-II Dataset Results

The ESA sponsored tropical forest research campaign was conducted in 2004 in Kalimantan, Indonesia. DLR’s fully polarimetric repeat pass L and P Band E-SAR data sets, provided by ESA, were utilized. In this Mawas-E test area, the L-Band data has a nominal 10 meters baseline, and a mean vertical wave-number of 0.1282 rad/m. The error sources encountered are slowly varying residual motion errors (i.e. baseline) and wind- induced temporal de-correlation. To normalize our results a local ‘bare patch’ was used as reference area. Figure (5) shows the study area, region of interest, and the bare patch used for our data analysis.

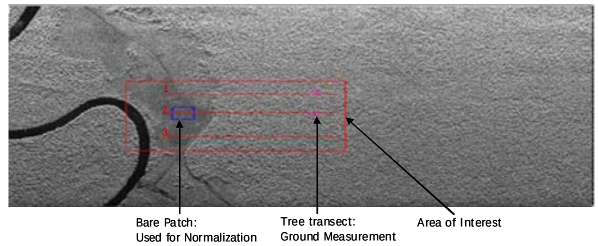

Figure (5) Mawas-E Study Area X-band ORI

The results of tree height estimation using the RVoG model over the area of interest is given in Figure (6).

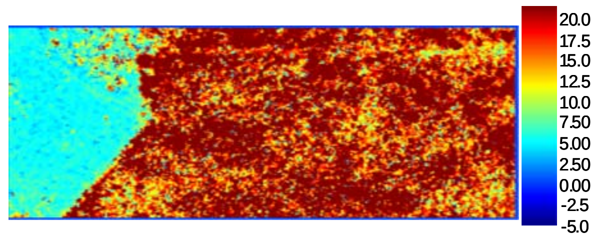

Figure (6) Estimated Tree Height over area of interest, L Band with 10m baseline

Figure (7) shows the height distribution histogram for estimated values. The mean average tree height in this area is 17.5 m.

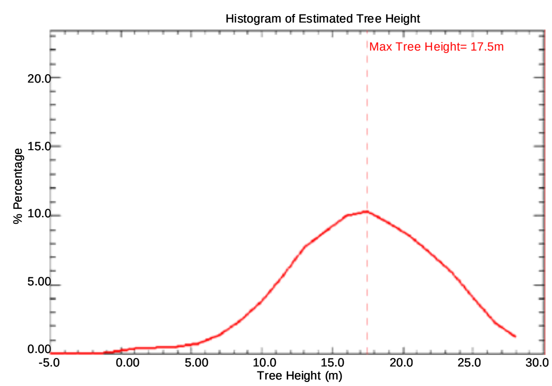

Figure (7)Histogram of Estimated Tree Height with 10m Base line

In comparison with the ground truth data, the estimated height correlates reasonably well with the measured mean height of the tree distribution in the area of interest. Similar distribution is also observed for the tree height measurements obtained from the difference of digital surfaces at X and P bands respectively. (See Figure (8))

In Figure (8), we can see the forest has a very dense low understory with a different distribution pattern peaked around 4m. It appears that the RVoG model was surprisingly successful in estimating the main part of the canopy height distribution despite the understory component which is not incorporated in the model. On the other hand, the extracted ground height (not shown) has a positive bias of 2-3 meters [10] and is relatively noisy compared to the simulation. It is suggested that this is probably due to the combined effects of the understory and temporal de-correlation effects.

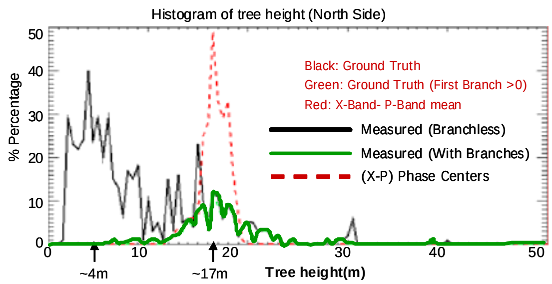

Figure (8) Tree Height Distributions: North Transect

Summary

The main objective of this research was to validate the functionality and application of PolInSAR height extraction RVoG model for L-band fully polarimetric interferometric data. It was shown for simulated data, that the method provides a 'good' estimation under smooth ground conditions. The RVoG model was also applied to L-Band Index-II data. It was observed that the model provided a reasonable estimate of the mean vegetation height in a small ground-truthed area, although the ground elevation accuracy showed a positive bias (~2.5 m) as well as height noise at the 2 m RMS level.

It is planned to follow-up this work using repeat pass ALOS PolInSAR data for the same study area in Kalamantan, Indonesia, to investigate the estimation of vegetation height in relation to our findings from airborne data and that ground truth information.

References

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