INDREX-II – Tropical Forest Height estimation with L and P Band Polarimetric interferometric SAR

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Abstract

Tropical forests are complex, heterogeneous, dense, remote and changing forest ecosystems. Low frequency synthetic aperture Radar (SAR) techniques allow monitoring and potentially estimation of key forest parameters such as vertical structure (height) and biomass. In the frame of INDREX-II repeat-pass SAR data in quad-pol mode (at L, and P Band) SAR data were acquired and simultaneously ground measurements have been collected.
One of the most important - for a wide range of applications - forest parameter is biomass. Biomass appears to be more or less directly related to forest height, which can be estimated from model based inversion of polarimetric and interferometric SAR (Pol-InSAR) data. Indeed, successful height inversion has been demonstrated in several airborne experiments over temperate and boreal forests. In this paper results of model-based L and P Band Pol-InSAR data inversion over tropical forest are shown, including validation against ground measurements.

1 Introduction

Polarimetric interferometric SAR is a technique that allows the estimation of forest heights by means of SAR technology. In this sense, INDREX-II was designed to provide answers about the feasibility of low frequency (L and P Band) Pol-InSAR techniques to estimate forest height in tropical environments. In order to support this, ground measurements have been performed and repeat pass fully-polarimetric interferometric L and P Band SAR data have been acquired with the Experimental Synthetic Aperture Radar (E-SAR) of the German Aerospace Centre (DLR) [4]. In the following first inversion results of the INDREX-II campaign are presented and discussed.

Table 1: Characteristics of the test site

Test Site	Forest Type	Forest height [m]	Forest Biomass [t/ha]
Sungai Wain	Lowland Dipterocarp	10 – 60	100 – 400

2 Test Site Sungai Wain

The Sungai Wain test region is located in the Indonesian Province East Kalimantan close to the province's largest city Balikpapan (see *Table 1*). A 15.4 ha large forest block transect was established in the Sungai Wain dipterocarp forest, 540 m in length and 286 m wide. Within this block 26 sub-blocks (in total 2.1 ha) are being measured.

3 Experimental Data

In a first processing step the interferometric coherences at L and P Band for the available baselines have been calculated. The variation of the interferometric coherence with the spatial baseline depends on the vertical structure of the scatterers within the scene. Volume scatterers (e.g. forests) are characterised by decreasing coherence values with increasing spatial baseline; an effect known as volume decorrelation. In contrast to volume scatterers, the interferometric coherence of surface scatterers (e.g. bare terrain) is - after range spectral filtering - independent from the spatial baseline and in the absence of other decorrelation sources equal to one. In addition, as the effective vertical structure of the scatterers varies with polarisation, the interferometric coherence becomes a function of polarisation, too.
Figure 1 (top row) shows an HH polarised amplitude (SLC) image of the test site at L Band, the variations reflect the changes in topography. On the upper right hand side a X-Band DEM shows the topographic variation within the scene, steep slopes ranging from 60m to 180m altitude mean above sea level. The strong variation can be also seen in the interferometric phase image. In principle the whole image is com-

pletely covered with forest. The corresponding vertical wave-number (kz) image for the 5m spatial baseline is shown on the bottom row. The vertical wave-number expresses the 2-D baseline variation: In the airborne case, from near to far range due to the incidence angle and topographic variations and along azimuth due to the movement of the platform. The strong variations along azimuth are typical for an airborne system at L Band. The interferometric coherence images in the HH, HV, and VV polarisations - scaled from 0 to 1 - are shown on the left hand side (top row). The forest is characterised by volume decorrelation that varies with baseline from near to far range (as indicated by the vertical wave-number image). Note that in contrast to the amplitude images forest structures become visible in the coherence images due to the sensitivity of the coherence to structure. On the bottom of *Figure 1* the three optimum coherence images are shown, indicating the range of coherence variation with polarisation. This variance is a direct indication for the presence of a ground scattering contribution under the forest layer [1]. In *Figure 2* the corresponding images for the 10m baseline are shown. With increasing baseline the volume decorrelation over the forested areas increases. The coherence decreases drastically in near range because of the larger effective baseline. A smaller relative variation of the vertical wave-number along azimuth can be observed.

4 Forest Height

4.1 Quantitative Results

For the Sungai Wain test site, forest height has been estimated by inverting single-baseline fully-polarimetric InSAR data using the Random-Volume-over-Ground Model (RVoGM) [1]. The inversion has been applied at each frequency individually: at L Band using the 10m spatial baseline and at P Band using the (equivalent in terms of wavelength scaling) 30 m spatial baselines. From the inversion process areas affected by geometrical and coherence constrains - that make a meaningful inversion impossible - have been excluded. Three kinds of masks were applied:

1. <u>Coherence mask:</u> Low coherences are affected by large phase variance [2] making accurate inversion at high spatial resolution not-possible. Therefore areas with coherences lower than 0.4 have been excluded. This mask acts across the whole image.
2. <u>Mask for high kz values:</u> At large effective baselines (i.e. large kz values) the sensitivity of the coherence to forest height may saturate at heights lower than the forest heights in the scene. Such areas are masked out. The mask acts primarily in near range (threshold: $kz < 0.15$).
3. <u>Mask for small kz values:</u> At small effective baselines (i.e. small kz values) the unfavourable coherence to height scaling leads to high height errors for small residual (uncalibrated) decorrelations. Such areas are also masked out. This mask acts primarily in far range (threshold: $kz > 0.05$).

After height inversion and masking out of non valid points, the obtained forest height maps at P Band and L Band are shown in *Figure 3.* The height maps are scaled from 0-60m (left image shows the inversion results at L Band, right image the estimates at P Band). Comparing the results at both frequencies, no significant differences appear. Both images cover the same height range and reflect a similar forest height structure. The L Band height variance is higher than in P Band because of the lower coherence level of the L Band data.

4.1 Comparison with Ground Measurements

The white rectangle in the height map (*Figure 3)* represents the location of the ground measurement plot. The forest height varies mainly between 15m and 40m. The ground measurements are represented in three graphs in *Figure 4*. The plot on the right represents the structure and height of the Sungai Wain forest, the upper left plot the height distribution of all measured trees and the lower left plot the diameter at breast height against (DBH) the forest height. At the upper left the plot shows that most of the heights are between 10m and 20m, much lower than the estimated forest heights. However, looking on the other two plots it becomes obvious that the estimated Radar heights do not depend on every single tree. They are more related to the higher trees which form the upper canopy layer. For temperate forests the so called h100 [3] was used as a reference height that represents a good definition of forest height for even aged single species forests, in tropical forests this reference height can not be used due to strong heterogeneity and needs still to be defined. Assuming that the diameter in breast height (DBH) reflects the dominance of a tree within a forest, one can conclude that the canopy of an uneven aged forest is formed by a small number of trees, as indicated by the red circle in the upper left plot of *Figure 4*. The height of these trees fits to the estimated height from the Radar data.

5 Summary and Conclusions

In this work the interferometric coherences at different baselines, polarisations and frequencies have been analysed and forest height estimation from the inversion of single-baseline fully-polarimetric InSAR data using the Random-Volume-over-Ground model has been applied at two frequencies.

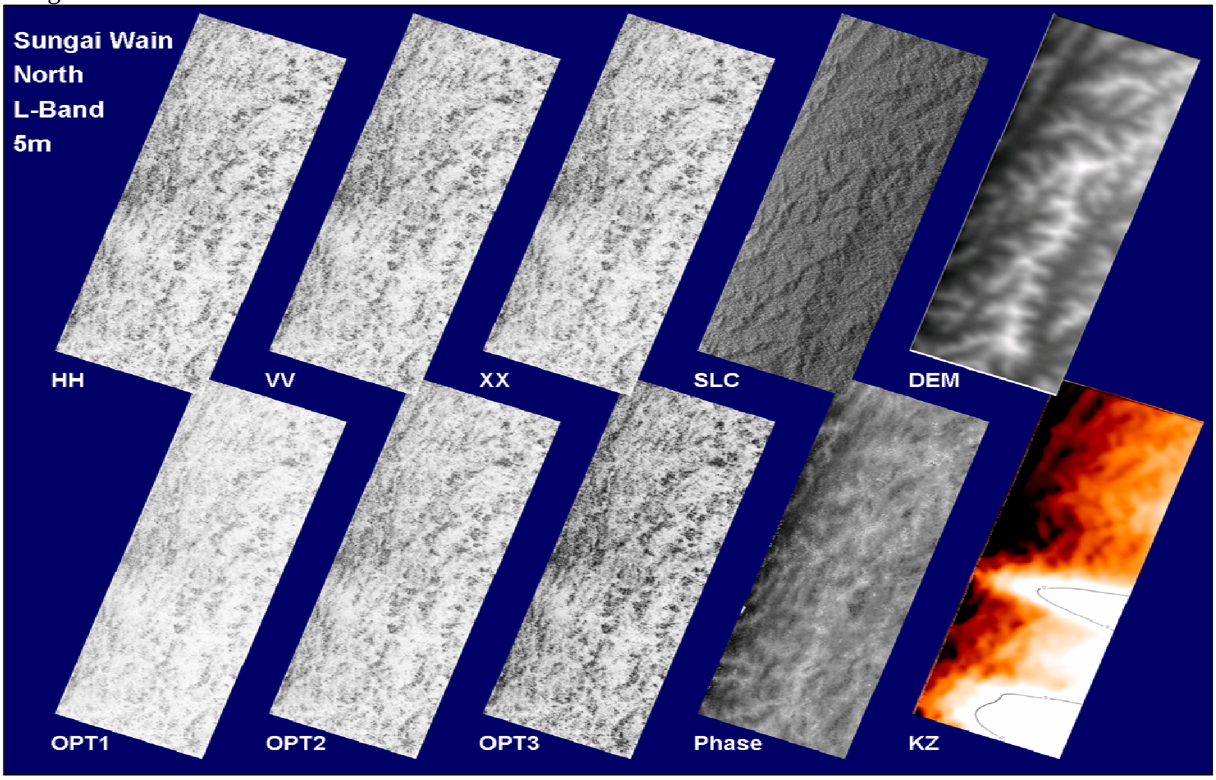

Figure 1: Interferometric coherence for a 5m spatial baseline in L Band; from left to right upper part: coherence in HH, VV, and XX polarisation, amplitude image of HH polarisation, X-Band DEM; from left to right lower part: optimized coherence 1 to 3, interferometric phase of the HH polarisation, vertical wavenumber (kz).

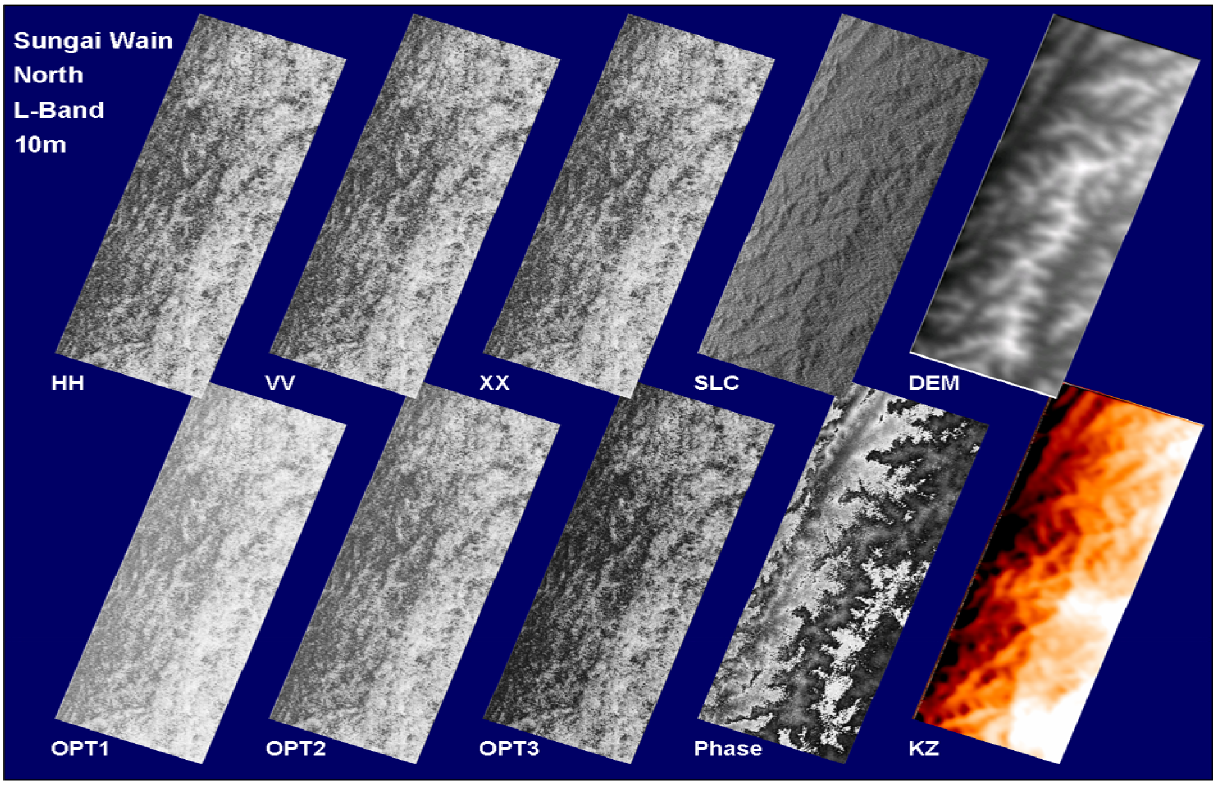

Figure 2: Interferometric coherence for a 10m spatial baseline in L-Band; from left to right upper part: coherence in HH, VV, and XX polarisation, amplitude image of HH polarisation, X-Band DEM; from left to right lower part: optimized coherence 1 to 3, interferometric phase of the HH polarisation, vertical wavenumber (kz)

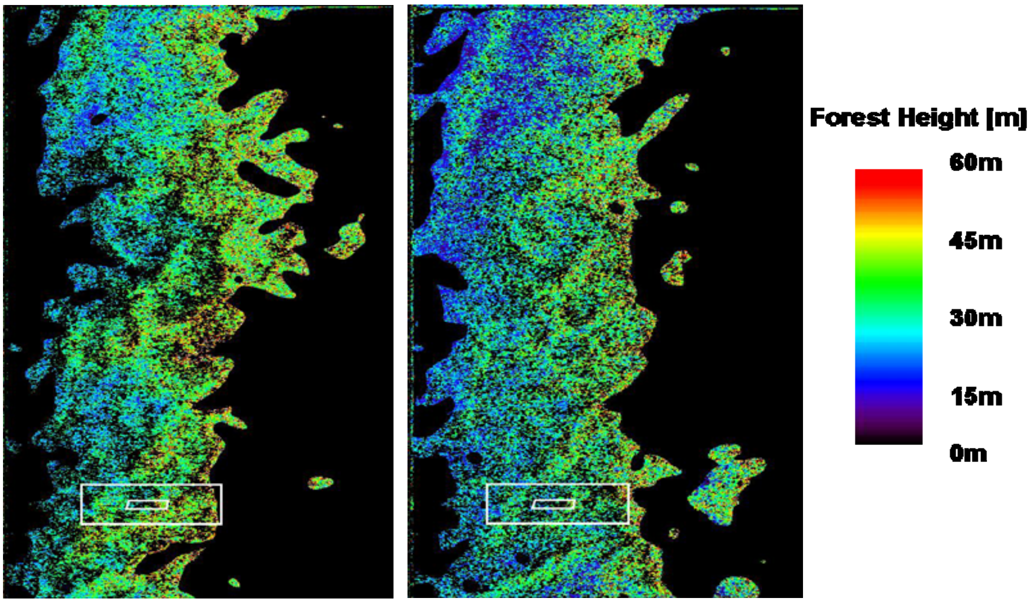

Figure 3: Height map for the Sungai Wain forest: left: L Band 10m baseline, right: P Band 30m baseline. Black are the masked areas; the white rectangle indicates the position of the ground measurements plot.

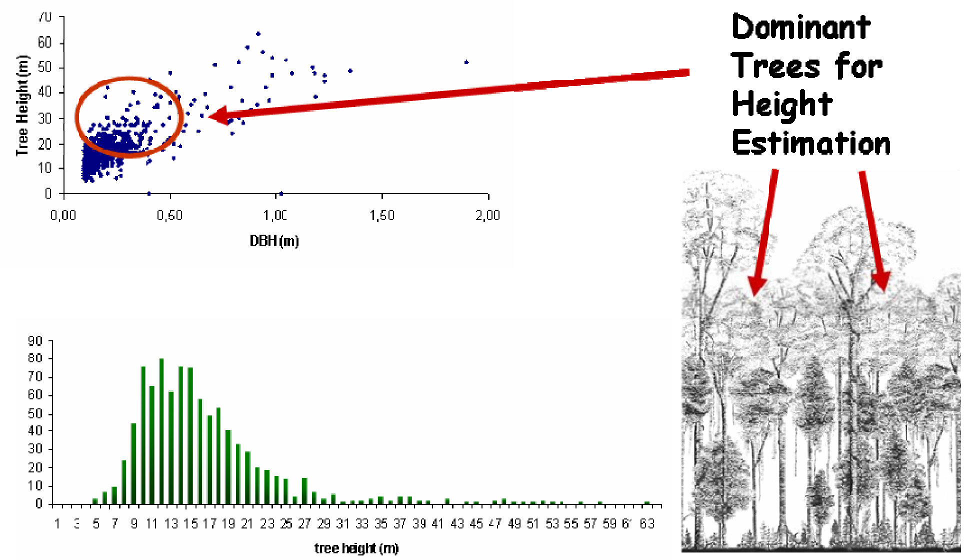

Figure 4: Ground measurements of Sungai Wain plot; upper left: DBH (diameter in breast height) – height distribution; lower left: stem number – tree height distribution; lower right: structural sketch of lowland dipterocarp forest; the red circle in the upper left shows the dominant trees which represent the height of the of the forest

The results demonstrate the potential of Pol-InSAR techniques at longer Radar wavelengths (L and P Band) to provide accurate forest height estimates. For accurate inversion the calibration of system, processing and temporal decorrelation processes that superimpose the volume decorrelation contribution is essential.

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