Forest Parameter Estimation in Tropical Forests by means of Pol-InSAR: Evaluation of the INDREX II Campaign

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Agenda

Theory Random Volume over Ground Model

Sungai Wain Test Site
  Ground Truth
  Topography
  Inversion Results L Band and P Band

Mawas Test Site
  Ground Truth
  Inversion Results X Band

Summary
Random Volume over Ground (RVoG) Scattering Model

Interferometric Coherence:

\[ \tilde{\gamma}(\tilde{w}) = \exp(i\varphi_0) \frac{\gamma_V + m(\tilde{w})}{1 + m(\tilde{w})} \]

Volume Coherence:

\[ \tilde{\gamma}_V = \frac{I}{I_0} \]

\[ I = \int_0^{h_V} \exp(ik_z z') \exp\left(\frac{2 \sigma z'}{\cos \theta_0}\right) dz' \]

\[ I_0 = \int_0^{h_V} \exp\left(\frac{2 \sigma z'}{\cos \theta_0}\right) dz' \]

G/V Ratio:

\[ m(\tilde{w}) = \frac{m_g(\tilde{w})}{m_V(\tilde{w})I_0} \]

Vertical Wavenumber:

\[ \kappa_z = \frac{\kappa \Delta \theta}{\sin(\theta_0)} \]

4 Parameters:

- Volume height \( h_V \)
- Extinction \( \sigma \)
- Topography \( \varphi_0 \)
- G/V Ratio \( m(\tilde{w}) \)
Test Site: Sungai Wain

- Lowland Dipterocarp Forest
- Hilly Topography
- Forest Height: 10m – 50m
- Biomass around 100 - 400t/ha
- Closed canopy
- Dense
Reference Height Sungai Wain

Plot design: 216m x 672m
5.4 ha plot
Suplots: 24m x 32m

Top Height H100 for each Subplot
Mean height of subplots: 27m
Radar Data Sungai Wain

L Band

Amplitude

Coherence

P Band

Amplitude

Coherence
Topographic Dependency of InSAR Coherence (P band)

Coherence

Topo Lines over Coherence: ridge (blue), valley (green)

Digital Elevation Model
The Effect of Topography on InSAR Coherence

Interferometric Coherence:

\[ \tilde{\gamma}(\tilde{w}) = \exp(i\phi_0) \frac{\tilde{\gamma}_V + m(\tilde{w})}{1 + m(\tilde{w})} \]

Volume Coherence:

\[ \tilde{\gamma}_V = \frac{I}{I_0} \]

\[
\begin{align*}
I &= \int_0^{h_V} \exp(ik_zz') \exp\left(\frac{2\sigma z'}{\cos(\theta_0)}\right) dz' \\
I_0 &= \int_0^{h_V} \exp\left(\frac{2\sigma z'}{\cos(\theta_0)}\right) dz'
\end{align*}
\]

\[ m(\tilde{w}) = \frac{m_\theta(\tilde{w})}{m_V(\tilde{w}) I_0} \]

\[ \kappa_z = \frac{\kappa \Delta \theta}{\sin(\theta_0)} \]
Topography Induced Height Error

Modelling Parameters:
- Extinction: 0dB/m
- Incidence angle: 45°
- Vertical Wavenumber: 0.1
Terrain Compensation: Vertical Wavenumber

Terrain Adaptive Vertical Wave-Number:

\[ k_z = \frac{k \Delta \theta}{\sin(\theta - \alpha)} \quad \text{and} \quad k = \frac{4\pi}{\lambda} \]

where \( \alpha \) is the terrain slope in range.

\( \alpha \) is estimated from the low-pass filtered X-band DEM (to filter-out the DEM variation due to vegetation).
Validation Sungai Wain Plot

Radar Heights

Reference Height from Ground Measurements: 27m

L Band Mean: 26m
P Band Mean: 29m

P – Band

L – Band

Forest Height [m]

60m
37m
25m
12m
0m

Red: L Band
Blue: P Band
**RVoG Inversion at X-band**

Assumption:

\[ m_1(\tilde{w}_1) = m_2(\tilde{w}_2) = m_3(\tilde{w}_3) = 0 \]

\[ \tilde{\gamma}_1(\tilde{w}_1) \approx \tilde{\gamma}_2(\tilde{w}_2) \approx \tilde{\gamma}_3(\tilde{w}_3) \approx \exp(i\phi_0) \gamma_V \]

\[ \gamma_V(h_V, \sigma | \kappa_z) = \left\{ \begin{array}{c} I \vspace{0.2cm} \\ I_0 \end{array} \right\} \]

\[ I = \int_0^{h_V} \exp(i\kappa_z z') \exp \left( \frac{2 \sigma z'}{\cos\theta_0} \right) dz' \]

\[ I_0 = \int_0^{h_V} \exp \left( \frac{2 \sigma z'}{\cos\theta_0} \right) dz' \]

Underdetermined:

1 Equation for 2 Unknowns

| \tilde{\gamma}_i(\tilde{w}_i) | \leq | \gamma_V(h_V, \sigma | \kappa_z) |
Performance of X-band Inversion for DLR E-SAR

Vertical Wavenumber: 0.13

Extinction:
- 0 dB/m
- 0.1 dB/m
- 0.3 dB/m
- 0.5 dB/m
- 1.0 dB/m

Vertical Wavenumber: 0.07
Test Site: Mawas

- Peat swamp forest
- Flat Topography
- Forest Height: 15m – 25m
- Biomass around 100t/ha
- Uniform structure
- Open canopy
Reference Height Mawas

Plot design of Ground truth: 20 squares of 10m x 10m in two Transects
Radar data Mawas X Band

Amplitude  
Phase: $-\pi$ to $\pi$  
Phase difference: $0$ to $\pi$
Comparison Phase Center Height vs. Volume Height

Coherence Height left  Phase Height left  Coherence Height right  Phase Height right

Extinction: 0.1 db/m

Blue: Phase Height
Red: Coherence Height

Ground measurements: 21m – 23m
Summary

Forest height over tropical rainforest was estimated and successfully validated in L band as well as in P band

Topography effects forest height estimation and has to be compensated

Forest height estimation using X band is possible for certain (sparse) forest conditions (such as the mawas peat swamp forests)

X band Phase Scattering Center is lower than Pol-InSAR forest height
Thank you!