ALOS / PalSAR Pol-InSAR for Forest Height Estimation: Potential and Limitations

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Random Volume over Ground (RVoG) Scattering Model

\[
\tilde{\nu}(\hat{\nu}) = \exp(i \phi_0) \frac{\tilde{\nu}_V + m(\hat{\nu})}{I + m(\hat{\nu})}
\]

Volume Coherence:

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

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

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

\[
m(\hat{\nu}) = \frac{m_0(\hat{\nu})}{m_\nu(\hat{\nu})} I_0
\]

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

4 Parameters:

- Volume height \( h_V \)
- Extinction \( \sigma \)
- Topography \( \phi_0 \)
- G/V Ratio \( m(\hat{\nu}) \)
RVoG Scattering Model: Geometrical Interpretation

Interferometric Coherence:

\[ \tilde{\nu}(\tilde{\psi}) = \exp(i\varphi_0) \frac{\tilde{\nu}_v + m(\tilde{\psi})}{1 + m(\tilde{\psi})} \]

\[ \tilde{\nu}(\tilde{\psi}) = \exp(i\varphi_0) \left[ \tilde{\nu}_v + \frac{m(\tilde{\psi})}{1 + m(\tilde{\psi})} (1 - \tilde{\nu}_v) \right] \]

Equation of a straight line in the complex plane !!!

- Line Slope := \( f(\text{Baseline, Vegetation Height, and, Extinction}) \)
- Line Length := \( f(\text{Baseline, Vegetation Height, Extinction, and, Ground Scat. Amplitude}) \)

Frequency Dependent Parameters

The optimal polarisations represent the limiting points of the "visible" line part

Random Volume over a 2-dim Surface

Assumption: The ground is a 2-dimensional scatterer

There is a polarisation where the ground is not visible (not necessarily the HV polarisation)

1st Opt. Coherence:

\[ \tilde{\nu}_1(\tilde{\psi}_1) = \exp(i\varphi_0) \frac{\tilde{\nu}_v + m_1(\tilde{\psi}_1)}{1 + m_1(\tilde{\psi}_1)} \]

\[ m_1(\tilde{\psi}_1) < \infty \]

2nd Opt. Coherence:

\[ \tilde{\nu}_2(\tilde{\psi}_2) = \exp(i\varphi_0) \tilde{\nu}_v \]

\[ m_2(\tilde{\psi}_2) = 0 \]

3rd Opt. Coherence:

\[ \tilde{\nu}_3(\tilde{\psi}_3) = \exp(i\varphi_0) \frac{\tilde{\nu}_v + m_3(\tilde{\psi}_3)}{1 + m_3(\tilde{\psi}_3)} \]

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

Unique solutions for all five parameters:

- Volume height \( h \)
- Extinction \( \sigma \)
- Topography \( \varphi_0 \)
- G/V Ratios \( m(\tilde{\psi}) \)
Forest Height Map
Fichtelgebirge Test Site

Pol-InSAR Lite: HH or VV and HV
Random Volume over a 2-dim Bragg Surface

**Assumption:** The ground is a 2-dim scatterer in HH-VV Sub-space

In HV the ground is not visible

\[
\tilde{\gamma}_{HH}(\varphi, \gamma) = \exp(i \varphi_0) \frac{\tilde{\gamma} + m(\tilde{\gamma}_{HH})}{1 + m(\tilde{\gamma}_{HH})}
\]

\[
\tilde{\gamma}_{HV}(\varphi, \gamma) = \exp(i \varphi_0) \tilde{\gamma}(h_V, \sigma)
\]

The two points allow (in principle) to estimate the line and to resolve the RVoG problem

Unique solutions for: Volume height $h_V$, Extinction $\sigma$, and Topography $\varphi_0$

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**Pauli Images**

Temporal Baseline: 48 Hours

SIR-C / Test Site: Kudara, Russia

RGB-Coding

HH-VV

2HV

HH+VV

C-band

L-band

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 microwaves and radar institute
Line Comparison: Quad-Pol vs. Dual-Pol

Temporal Baseline: 48 Hours

STP-C / Test Site: Kudara, Russia

Forest Height Estimation: Quad-Pol vs. Dual-Pol

Temporal Baseline: 48 Hours
Forest Height Estimation: Quad-Pol vs. Dual-Pol

SIR-C / Test Site: Kudara, Russia

Temporal Baseline: 48 Hours

Dual-Pol: HH and HV

Quad-Pol

Temporal Decorrelation
Interferometric Coherence Images

E-SAR / Test Site: Fox Covert, England

L-band HV Image

Force 4 wind speed = 6m/s

Force 3 wind speed = 4m/s

L-band
Temporal Decorelation of the Volume Scatterer

**Temporal Effect:** Random movement of the scattering particles in the volume: Wind Effects.

The 2nd order polarimetric properties of the ground \([T_G]\) and the volume scatterer \([T_V]\) remain the same:

- Ground / Volume amplitude ratios \(m(\tilde{V})\) are unaffected
- \(0 \leq \gamma_T = f(m(\tilde{V})) \leq 1\) is equal for all polarisations !!!

Interferometric Coherence:

\[
\tilde{\nu}(\tilde{V}) = \exp(i\varphi_0) \frac{\gamma_T \tilde{V} + m(\tilde{V})}{1 + m(\tilde{V})}
\]

\[
\tilde{\nu}(\tilde{V}) = \exp(i\varphi_0) \chi(\gamma_T \tilde{V} + m(\tilde{V})) (1 - \gamma_T \tilde{V}) \quad \text{the line is preserved !!!}
\]

- \(\gamma_T\) affects slope of the line but not the position of the points on the line.
- \(\varphi_0\) remain invariant under variations of \(\gamma_T\). The estimation of \(\varphi_0\) is still possible !!!
- \(\gamma_T\) leads to an underestimation of \(\tilde{V}\) and thus a overestimation of volume height.

Line Comparison: C-Band vs. L-Band

Temporal Baseline: 24 Hours

SIR-C / Test Site: Kudara, Russia
**Temporal Decorelation of the Volume Scatterer**

**Volume Height Estimation:**

- Assumption of the mean extinction value $ar{D}$
- Estimate the corresponding $ar{v}_V$ value

\[
\bar{v}_V = \frac{\int_{0}^{h_v} \exp(i\phi_r z') \exp\left(\frac{2 \sigma z'}{\cos \theta_0}\right) dz'}{\int_{0}^{h} \exp\left(\frac{2 \sigma z'}{\cos \theta_0}\right) dz'}
\]

**Forest Height Estimation: C-Band vs. L-Band**

Temporal Baseline: 24 Hours
Unbiased estimation of forest height and underlying topography is in principle possible in a dual-pol (HH or VV and HV) Pol-InSAR scenario.

The estimation accuracy is expected to drop especially in terrain with topographic variations. The availability of a DEM may be advantageous.

Temporal decorrelation makes - in general - accurate unbiased parameter inversion impossible.

Moderate temporal decorrelation of the volume layer can be accounted in the RVoG inversion model and compensated.

However additional regularisation is required in order to obtain unique estimates.

The availability of multiple-baselines (temporal and spatial) may allow a more flexible / accurate regularisation and is a serious option for increasing est. accuracy

Quad-Pol Pol-InSAR offers a higher flexibility in accounting such effects leading to more accurate and robust forest height estimates.