Forest Characterisation by Means of TerraSAR-X and TanDEM-X Polarimetric Interferometric Data

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Tandem-X
System Configuration

Launched in June 2010

First Single Pass
Single- Dual- Quad-
Polarimetric Interferometer
in Space

Pursuit Monostatic
Phase
Dual Pol Acquisition
(HH/VV,HH/HV)
Temporal baseline: 2-3 sec
(20km)

Data used in this study
were acquired in the
Stripmap mode
Krycklan Test Site (Biosar II – Campaign 2008)

Krycklan forest:
Location:
  • middle Sweden
  • boreal forest
  • hilly topography
  • strong slopes

Composition
• maximum forest height: ~ 30m
• mean forest height: 17m
• mean biomass: 90t/ha
• maximum biomass: 220 t/ha
• dominated by Coniferous trees

Lidar Reference Measurements available (2008)

Uniform structure
### Data Base

<table>
<thead>
<tr>
<th>Date</th>
<th>Baseline [m]</th>
<th>Incidence angle</th>
<th>$K_z$</th>
<th>Height of ambiguity</th>
<th>Polarisation</th>
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<tbody>
<tr>
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<td>141</td>
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<td>0.18</td>
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**Vertical Wavenumber:**

\[
K_z = \frac{4\pi}{\lambda} \frac{B}{R \sin(\theta_0)}
\]

HH

VV

Phase
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**Vertical Wavenumber:**

$$K_z = \frac{4\pi B}{\lambda R \sin(\theta_0)}$$

![28. July](image1)

![8. August](image2)

![19. August](image3)

Scaled from 0 to 1
Temporal Decorrelation

28. Juli $K_z = 0.18$
8. August $K_z = 0.15$
19. August $K_z = 0.17$

- 3 sec of Temporal Baseline may lower interferometric coherence significantly
- Two Acquisitions are highly decorrelated
SNR Decorrelation
27. July 2010 $K_Z = 0.17$

$\gamma_{SNR} = \frac{SNR}{1 + SNR}$

NESZ ~ - 20dB to -22dB

Scaled from 0.9 (black) to 1 (white)

Interferometric Coherence before (red) and after (blue) SNR Correction
**Single Channel X-band Inversion**

**Volume Coherence**

\[
\tilde{\gamma}_{\text{Vol}}(f(z)) = \frac{\int_{h_v}^{h_0} f(z) e^{ik_z z} dz}{\int_{h_v}^{h_0} f(z) dz}
\]

**Single pol ➤ 1 Layer Scattering Model (m=0)**

\[
f(z) = \sigma_{v0} \exp\left(\frac{2 \sigma z}{\cos\theta_0}\right)
\]

\[
\tilde{\gamma}(\tilde{w}) = \exp(i\varphi_0) \tilde{\gamma}_V
\]

**Volume Coherence**

\[
\tilde{\gamma}_V = \frac{l}{l_0}
\]

\[
l = \int_{h_v}^{h_0} \exp(\kappa_z z') \exp\left(\frac{2 \sigma z'}{\cos\theta_0}\right) dz'
\]

\[
l_0 = \int_{h_v}^{h_0} \exp\left(\frac{2 \sigma z'}{\cos\theta_0}\right) dz'
\]

**Vertical Wavenumber**: \( \kappa_z = \frac{k\Delta\theta}{\sin(\theta_0)} \)

**Volume Height**: \( h_V \)

**Extinction**: \( \sigma \)

**Topography**: \( \varphi_0 \)
Forest heights obtained from VV polarisation using Lidar ground phase

Number of stands: 216
Low (unsensitive) $K_z$ values due to topography are filtered out.

Unvalid points are filtered (15%)

$r^2 = 0.91$
$r^2 = 0.93$ (harvested area removed)
RMSE = 1.58
RMSE Phase Centre Height = 8.27 = penetration depth

Validation Plots Lidar vs Radar:
\[ \tilde{Y}(S_1, S_2) = \frac{\langle S_1, S_2^* \rangle}{\sqrt{\langle S_1, S_1^* \rangle \langle S_2, S_2^* \rangle}} \]

Volume Coherence

\[ \tilde{Y}_{Vol}(f(z)) = e^{i k_{z_0} z} \int_{0}^{h_v} f(z) e^{i k_{z_0} z} dz \]

Dual pol 2 Layer Scattering Model

\[ f(z) = \sigma_{V0} \exp \left( \frac{2 \sigma z}{\cos \theta_0} \right) + m' G \delta(z - z_0) \]

\[ \tilde{Y}(\tilde{w}) = \exp(i \varphi_0) \frac{\tilde{Y}_{V} + m(\tilde{w})}{1 + m(\tilde{w})} \]

Volume Coherence

\[ \tilde{Y}_V = \frac{I}{I_0} \left\{ \begin{array}{l}
I = \int_{0}^{h_v} \exp(i k_{z'} z') \exp \left( \frac{2 \sigma z'}{\cos \theta_0} \right) dz' \\
I_0 = \int_{0}^{h_v} \exp \left( \frac{2 \sigma z'}{\cos \theta_0} \right) dz'
\end{array} \right. \]

G/V Ratio: \[ m(\tilde{w}) = \frac{m_G(\tilde{w})}{m_V(\tilde{w})} l_0 \]

Volume Height \[ h_V \]

Extinction \[ \sigma \]

Topography \[ \varphi_0 \]

Vertical Wavenumber: \[ k_z = \frac{\kappa \Delta \theta}{\sin(\theta_0)} \]

G/V Ratio \[ m(\tilde{w}) \]
Forest heights using Dual Pol-InSAR (HH & VV)

Low (unsensitive) $K_Z$ values (due to topography) are filtered out

Unvalid points are filtered (21%)

$r^2 = 0.86$
$\text{RMSE} = 2.02\text{m}$

$r^2 = 0.90$ (without harvested areas)

Number of stands: 216

Validation Plot Lidar vs Radar:
\[ \tilde{\gamma}_{\text{Vol}}(f(z)) = e^{ik_z z_0} \frac{\int_{0}^{h_y} f(z) e^{ik_z z} dz}{\int_{0}^{h_y} f(z) dz} \]

Coherence Tomography

\[ f(z) \ldots \text{vertical reflectivity function} \]

Volume Coherence

\[ \tilde{\gamma}_{\text{Vol}}(f(z)) = e^{ik_z z_0} \frac{\int_{0}^{h_y} f(z) e^{ik_z z} dz}{\int_{0}^{h_y} f(z) dz} \]

Fourier Legendre Series:

\[ f(z') = \sum_{n} a_n P_n(z') \quad \text{where} \quad a_n = \frac{2n+1}{2} \int_{-1}^{1} f(z') P_n(z') dz' \]
Coherence Krycklan Test Site (Airborne Data - Biosar II)

<table>
<thead>
<tr>
<th>Ascending</th>
<th>Full Baseline</th>
<th>Descending</th>
<th>Full Baseline</th>
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<tbody>
<tr>
<td>Half Baseline</td>
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<th>$K_z$</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
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<tr>
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<td>0.14</td>
<td>0.26</td>
<td>0.20</td>
</tr>
<tr>
<td>Half</td>
<td>0.07</td>
<td>0.13</td>
<td>0.10</td>
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Scaled from 0 to 1
Comparision of Coefficients Ascending

Single Baseline CT
Half vs Full Baseline

Different Acquisitions (Baselines) estimate similar Coefficients

Full baseline estimates are more noisy due to lower coherence

Dual Baseline CT

Dual vs Single Half Baseline
Dual vs Single Full Baseline
Comparision of Coefficients Descending

Single Baseline CT
Half vs Full Baseline

Different Acquisition (Baselines) estimate similar Coefficients

Full baseline estimates are more noisy due to lower coherence

Dual Baseline CT

Dual vs Single Half Baseline

Dual vs Single Full Baseline
Different Stands can be distinguished
Conclusions

TanDEM-X

- 3 seconds temporal baseline can decorrelate interferometric coherence
- SNR limits inversion performance - needs to be corrected
- Single Pol TanDEM-X data (VV) are sensitive to forest height (with a priori ground phase $r^2=0.91$, RMSE = 1.58)
- Dual Pol TanDEM-X data (HH, VV) allow forest height estimation without any a priori information – at least for boreal forests as found in Krycklan test site ($r^2=0.86$, RMSE = 2.02)
- Forest height estimation is possible using TanDEM-X data

X-band Coherence Tomography

- Coefficients are stable estimated (independent of Baseline)
- Coefficients allow delineation of homogeneous forest stands
- Coefficients describe structural forest parameters (Height)
Physical Interpretation of the Structure Coefficients

Height versus Biomass plots

Forest poor in structure

Forest rich in structure

Height versus Coefficient plots

Differences between Ascending and Descending Acquisition are due to different Incidence Angles and Topography

Ascending

Descending

A1

A2

A3
Physical Interpretation: Evolution of Structure with Forest Height

Curve fit with Polynomial