Sub-Canopy Topography Estimation With Multibaseline Pol-InSAR Data: A RELAX-Based Solution

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Overview

Introduction

Ground height estimation @ L-band

The RELAX method
  - How it works
  - Comparison with Maximum Likelihood
  - Performance with real data (Traunstein forest):
    - for different baseline distributions
    - for different polarization combinations

Conclusions & future work
**TanDEM-L**
A German mission proposal for monitoring dynamic processes on the Earth surface @ L-band

<table>
<thead>
<tr>
<th>Science Product</th>
<th>Coverage</th>
<th>Product Resolution</th>
<th>Product Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biosphere</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest Height</td>
<td>All forest Areas</td>
<td>50 m (global)</td>
<td>~ 10 %</td>
</tr>
<tr>
<td></td>
<td>(Height ≥ 8 m)</td>
<td>20 m (local)</td>
<td></td>
</tr>
<tr>
<td>Above Ground Biomass</td>
<td></td>
<td>100 m (global)</td>
<td>~ 20 %</td>
</tr>
<tr>
<td></td>
<td>≤ 50 m (regional)</td>
<td>(or 20 t/ha)</td>
<td></td>
</tr>
<tr>
<td>Vertical Forest Structure</td>
<td></td>
<td>50 m (global)</td>
<td>3 layers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 m (local)</td>
<td></td>
</tr>
<tr>
<td>Underlying Topography</td>
<td></td>
<td>50 m</td>
<td>&lt; 4 m</td>
</tr>
</tbody>
</table>
SAR MB-Pol-InSAR data for the vertical structure of forests

**Interferometric Coherence**

\[ \gamma(S_1, S_2) = \frac{E\{S_1^* S_2\}}{E\{S_1 S_1^*\} E\{S_2 S_2^*\}} \]

- \( \gamma_T \): temporal decorrelation
- \( \gamma_{SNR} \): additive noise decorrelation
- \( \gamma_{VOL} \): geometric decorrelation

**Polarization diversity** allows to relate coherent scattering models to the resulting Pol-InSAR coherence

**Baseline diversity** allows to sample the same vertical structure spectrum at different spatial frequencies

The estimated MB-Pol-InSAR coherences contain all the information necessary for the analysis of the vertical structure of forests

**Vertical wavenumber**

\[ k_z = \frac{4\pi}{\lambda} \frac{\Delta \theta}{\sin \theta_0} \]
Ground height estimation

- **Coeherent combination of MB-Pol-InSAR data**
  - Pol-InSAR inversion, single baseline/MB
  - 3-D (Polarimetric) SAR Tomography, MB
  - Adaptive beamforming (ABF), model-based spectral estimation, COMET inversion, …
  - [Papathanassiou-Cloude, IEEE-TGARS ’01]
  - [Neumann-Ferro Famil-et al., IEEE-TGARS ’10]
  - [Lopez Martinez-Papathanassiou, subm. IEEE-TGARS ’11]

- **SAR Tomography techniques mostly tested with P-band data**
  - Metric accuracy achievable (demonstrated over different scenarios)

- **Objective of this work: proposal and testing at L-band of an iterative ground topography estimation technique**
  - Separation of the ground scattering component (~ compact in height) from the dominant one in the canopy
  - At each iteration: estimate the height of one component after the cancellation of the other component (RELAX iteration) [Gini-Lombardini-et al., IEEE-TAES ’02], [Li-Stoica, IEEE-TSP ’98]
  - Advantages: asymptotically statistically efficient with compact scatterers (e.g. the ground), 1D optimization at each iteration, no model is needed for the canopy
  - Improvement w.r.t. classical RELAX: heights are estimated exploiting the ABF spectrum to take advantage of its higher sidelobe suppression capabilities w.r.t. the Fourier-based beamforming
How RELAX works: an example

1. Initialization

2. Iteration

Canopy and ground not resolved!
The “Traunstein” dataset

**Bürgerwald Traunstein**

“Close to Nature”
Temperate managed forest

N. Spruce, E. Beech, White Fir
Height Range (H100): 10 - 40m
Biomass Range: 40 ~ 450 t/ha
Moderate Slopes

**DLR E-SAR dataset**

5 full-pol images (June 2008), L-band
~1 hour time span

Baselines: -15 ,-5 ,5 ,10 m
wrt master acquisition

LIDAR DTM/forest height available
Real data results: Tomographic slices (HH)

RELAX estimates of the ground height and canopy centroid height superimposed to the ABF tomographic slices

Note: For better visualization, the LIDAR DTM has been compensated in the data

**RELAX**
- **Bias (m)**: 0.10
- **Std (m)**: 0.87

**RELAX**
- **Bias (m)**: 0.36
- **Std (m)**: 2.25

**RELAX**
- **Bias (m)**: 0.18
- **Std (m)**: 1.06

*HH polarisation*
Comparison with Maximum Likelihood (ML) estimation

RELAX ground height
Maximum Likelihood (RVOG) ground height [Göransson-Ottersten, IEEE-TSP ‘99]

<table>
<thead>
<tr>
<th>Az. bin</th>
<th>RELAX Bias (m)</th>
<th>RELAX Std (m)</th>
<th>ML Bias (m)</th>
<th>ML Std (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.10</td>
<td>0.87</td>
<td>0.8</td>
<td>1.15</td>
</tr>
<tr>
<td>3200</td>
<td>0.36</td>
<td>2.25</td>
<td>0.1</td>
<td>2.51</td>
</tr>
<tr>
<td>3500</td>
<td>0.18</td>
<td>1.06</td>
<td>-0.61</td>
<td>1.78</td>
</tr>
</tbody>
</table>

HH polarisation
Estimated DTM (1/2)

**LIDAR DTM**

**RELAX DTM**

**InSAR DEM**

10 m
5 m
Master
-5 m
-15 m

**HH polarisation**

**Slant range**

Bias: 0.1 m
Std: 1.7 m

Bias: 0.2 m
Std: 2.8 m

Bias: 13.5 m
Std: 11.6 m
Estimated DTM (2/2)

Long baselines
- 10 m
- 5 m
- Master
- -5 m
- -15 m

Short baselines
- 10 m
- 5 m
- Master
- -5 m
- -15 m

HH polarisation

Bias: 0.1
Std: 2.2

Bias: 0.1
Std: 2.6

Bias: -1.3 m
Std: 6.0 m

Bias: 1 m
Std: 3.1 m

Slant range

Estimated DTM (2/2)
Influence of polarisation

**MB estimated Ground-to-Volume power ratio**

<table>
<thead>
<tr>
<th></th>
<th>HH</th>
<th>HV</th>
<th>HH+VV</th>
<th>HH-VV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>Bias (m)</td>
<td>-1.31</td>
<td>-1.32</td>
<td>-1.47</td>
</tr>
<tr>
<td></td>
<td>Std (m)</td>
<td>3.23</td>
<td>3.29</td>
<td>3.33</td>
</tr>
<tr>
<td>Bare</td>
<td>Bias (m)</td>
<td>0.11</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Std (m)</td>
<td>1.77</td>
<td>1.75</td>
<td>1.74</td>
</tr>
<tr>
<td>Forested</td>
<td>Bias (m)</td>
<td>0.22</td>
<td>0.13</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>Std (m)</td>
<td>2.85</td>
<td>3.03</td>
<td>3.09</td>
</tr>
</tbody>
</table>

**Full baseline set**
In this work:
- A simple (yet effective) RELAX-based estimator of the ground height has been proposed and tested with L-band real data.
- The proposed method has been shown to reach a metric estimation precision and to reduce the vegetation bias with a realistic small number of acquisitions.

Perspectives:
- Tests with airborne datasets acquired over other forests.
- Improvement of the proposed method in order to better handle the polarization diversity.
- … temporal decorrelation (must be afforded sooner or later!)

Further on this topic (and more):
- “Theoretical Performance Bounds on the Estimation of Forest Structure Parameters From Multibaseline SAR data”, by M. Pardini, F. Lombardini & K. Papanasssiou (Poster session, today)
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