On the potential of ALOS PALSAR backscatter and InSAR coherence for forest growing stock volume estimation in Central Siberia

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Forest Cover Mapping Using Intensity and Coherence (IEEE TGRS 2009 Thiel et al.)

- The accuracy assessment for the whole monitoring area is basing on 1,000 point samples
- The random sampling was stratified by class proportion
- Overall accuracy: 90.87%.
Radar backscatter and coherence as function of GSV for the inventory site Hrebtovský Š. The backscatter image (HV) polarisation was acquired at unfrozen conditions, while the data for the coherence image was acquired at frozen conditions.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Site</th>
<th>Data</th>
<th>Conditions</th>
<th>Saturation</th>
<th>RMSE</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kurvonen et al.</td>
<td>Southern Finland</td>
<td>JERS-1 L-band (HH) backscatter, 4 scenes; ERS-1 C-band (VV) backscatter, 4 scenes</td>
<td>unfrozen &amp; frozen</td>
<td>Single images: up to 300 m³/ha (defined as GSV class with highest average backscatter)</td>
<td>Single images: 0.01 (ERS-1) - 0.42 (JERS-1)</td>
<td>Multi-temporal: 0.53</td>
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<tr>
<td>Rauste</td>
<td>South-eastern Finland</td>
<td>JERS-1 L-band (HH) backscatter, 6 scenes</td>
<td>unfrozen &amp; frozen</td>
<td>Single images: 100 - 200 m³/ha (visually estimated)</td>
<td>Multi-temporal: 0.81 (unfrozen) - 0.05 (frozen)</td>
<td>Multi-temporal: 0.85</td>
</tr>
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<td>Santoro et al.</td>
<td>Sweden (Kättböle), Finland (Tuusula), Siberia (B. Murtinsky)</td>
<td>JERS-1 L-band (HH) backscatter, Sweden: 9 scenes Finland: 3 scenes Siberia: 13 scenes</td>
<td>unfrozen &amp; frozen</td>
<td>Single images: 100 m³/ha (Siberia) – 350 m³/ha (Sweden) (visually estimated)</td>
<td>Multi-temporal: 0.76 (Sweden)</td>
<td>Multi-temporal: 0.31-0.73 (Siberia)</td>
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<tr>
<td>Antropov et al.</td>
<td>2 sites in southern Finland</td>
<td>ALOS PALSAR L-band (HH, HV) backscatter, 3 scenes per site</td>
<td>unfrozen</td>
<td>Single images: 150 - 200 m³/ha (visually estimated)</td>
<td>Multi-temporal: 0.65 - 0.71</td>
<td>Multi-temporal: 0.32 - 0.76</td>
</tr>
<tr>
<td>Eriksson et al.</td>
<td>Siberia (B. Murt. N), Siberia (B. Murt. S), Siberia (Chunsky)</td>
<td>JERS-1/ERS-1/2 coherence, B. M. N: 6/2 images B. M. S: 6/2 images Chunsky: 5/3 images</td>
<td>unfrozen &amp; frozen</td>
<td>Single images (JERS): 100 - 130 m³/ha (visually estimated)</td>
<td>Single images (JERS-1): 0.32 - 0.76</td>
<td>Single images (ERS-1/2): 0.55 - 0.76</td>
</tr>
</tbody>
</table>
Outline

1. Area and test sites
2. PALSAR data
3. Summary of observations
4. Map generation approach
5. Results
6. Conclusions
Test Site

1 - Bolshaja Murta
2 - Bogucany
3 - Nizhneudinsk
4 - Tanguj
5 - Bratsk
6 - Vanavara
7 - Vitim
8 - Aginskoe
Site Characteristics

- Middle Siberian Plateau: southern part is dominated by hills up to 1700 m, northern part is plain with heights up to 500 m
- Continental climate, prec. 400-450 mm/y, most of the precipitation occurs in summer
- Territory is characterised by large area changes of forests such as forest fire, insect outbreaks, and intensive human activities
- Characteristic taiga forests (birch, pine, fir, aspen, larch, spruce, cedar) cover about 82% of the region
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SAR data set

- PALSAR L-band (1.27 GHz) data
- 87 acquisitions, mode: FBS  FBD
- Approx. 300 interferograms
- FBS: HH (28 MHz), FBD; HH/HV (14 MHz)
- Repetition rate: 46 days
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Experimental data – Summary

(a) Signatures of clear-cuts

(b) Signatures of dense forest

(c) Correlation of GSV and SAR data

(d) GSV saturation level

- = average; $\bar{\tau}$ = standard deviation; $\pm$ = minimum/maximum; 46, 92, 138 = temporal baseline [d]
Experimental data – Summary

(a) Signatures of clear-cuts

- Number of available samples (1 sample equates 1 data set at 1 site)

(b) Signatures of dense forest

- Coherence vs. Backscatter

(c) Correlation of GSV and SAR data

(d) GSV saturation level

- R²
- Saturation level [m³/ha]

- Frozen vs. Unfrozen
- HH vs. HV

- = average;  = standard deviation;  = minimum/maximum; 46, 92, 138 = temporal baseline [d]
Experimental data – Summary

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- = average; \( \bar{x} \) = standard deviation; \( x_{\text{min}}/x_{\text{max}} \) = minimum/maximum; 46, 92, 138 = temporal baseline [d]
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Delineation of GSV Maps

- Random training data selection (20% of the forest inventory data)
- Training of empirical exponential model
- Pixel based model inversion
- Averaging intermediate GSV maps resulting in one backscatter based and in one coherence based GSV map
- Merging coherence and backscatter based GSV map
- Elimination of pixels with a GSV difference > 100 m³/ha (floodplains, change, water, urban etc.)
- Setting all negative GSV values to zero
- Assessing accuracy using the remaining 80% of the reference data
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Example for delineation of GSV Map (Hrebtovsky site)

Data:

- 3 coherence images (frozen conditions)
- 6 HV backscatter images (unfrozen conditions)
- $R^2$ between coherence and GSV: 0.44 (average)
- $R^2$ between backscatter and GSV: 0.48 (average)
- Coherence saturation level: 250 m$^3$/ha (average)
- Backscatter saturation level: 200 m$^3$/ha (average)
Example for delineation of GSV Map (Hrebtovskiy site)

\[
y = -3.0x^2 - 7.2x - 10.8
\]
\[
R^2 = 0.8
\]
Example for delineation of GSV Map (Hrebtovsky site)
Example for delineation of GSV Map (Hrebtovsky site)

**Backscatter vs. coherence**

- $R^2 = 0.79$
- RMSE = 44 m$^3$/ha
- rel. RMSE = 25%

**SAR vs. inventory**

- $R^2 = 0.54$
- RMSE = 58 m$^3$/ha
- rel. RMSE = 33%

Forest stand level based comparison of two SAR data based GSV maps for Hrebtovsky S
## Results for the other sites

<table>
<thead>
<tr>
<th></th>
<th>Chunsky E</th>
<th>Chunsky N</th>
<th>Shesta</th>
<th>Hrebt S</th>
<th>Nishni</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$ coh + int</td>
<td>0.79</td>
<td>0.79</td>
<td>0.54</td>
<td>0.57</td>
<td>0.83</td>
</tr>
<tr>
<td>$R^2$ coh</td>
<td>0.80</td>
<td>0.78</td>
<td>0.37</td>
<td>0.55</td>
<td>0.82</td>
</tr>
<tr>
<td>$R^2$ int</td>
<td>0.67</td>
<td>0.70</td>
<td>0.56</td>
<td>0.50</td>
<td>0.82</td>
</tr>
<tr>
<td>RMSE [m$^3$/ha] coh + int</td>
<td>56.6</td>
<td>41.2</td>
<td>50.4</td>
<td>57.4</td>
<td>48.9</td>
</tr>
<tr>
<td>RMSE [m$^3$/ha] coh</td>
<td>56.4</td>
<td>42.4</td>
<td>52.7</td>
<td>61.9</td>
<td>50.7</td>
</tr>
<tr>
<td>RMSE [m$^3$/ha] int</td>
<td>71.1</td>
<td>50.3</td>
<td>56.2</td>
<td>59.1</td>
<td>56.1</td>
</tr>
</tbody>
</table>

Corrected rel. RMSE approximately 25% for all sites
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Conclusions

- **Coherence at frozen conditions** offers the largest potential for GSV estimation
  - Saturation at 230 m³/ha, \( R^2 \) between coherence and GSV is 0.58
  - Comparable results were found in other studies using ERS-1/2 Tandem data

- **Backscatter less sensitive**
  - Saturation at 75-100 m³/ha, \( R^2 \) between backscatter and GSV 0.42 (HH) - 0.48 (HV)
Conclusions

- **Coherence at frozen conditions** offers the largest potential for GSV estimation
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- **Combination of backscatter and coherence led to improvement** of GSV estimation, in particular exclusion of areas with contradictory GSV (coherence vs. backscatter) helpful
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- **Demonstrated:** Potential of ALOS PALSAR to map the GSV of the Siberian forest with a precision close to the accuracy of the conventional forest inventory data (corrected relative RMSE approx. 25%)

- **Data availability:** At each region in Siberia in average 4 coherence images (temporal baseline 46 days) acquired at frozen conditions and 6 FBD backscatter images acquired at unfrozen conditions are available
The potential of ALOS PALSAR backscatter and InSAR coherence for forest growing stock volume estimation in Central Siberia

Christian Thiel, Christiane Schmullius

ABSTRACT

The full potential of ALOS PALSAR L-band interferometric (InSAR) coherence data for the estimation of forest growing stock volume (GSV) in the boreal forest has rarely been investigated. Moreover, ALOS PALSAR backscatter and InSAR coherence have yet to be used together in delineate GSV. Due to the observation strategy and the high acquisition success rate over Eurasia, a large amount of high quality ALOS PALSAR L-band data is available over Siberia. Consequently, this paper investigates the capability of ALOS PALSAR backscatter and InSAR coherence for the estimation of GSV in Central Siberia, Russia. The potential of backscatter and coherence are directly compared using the same inventory data. Moreover, both PALSAR images are used and eleven forest inventory sites are investigated.

Based on this large dataset it was observed that InSAR coherence acquired in frozen conditions offer the highest potential for GSV estimation. The saturation level for single coherence images was on average 236 m²/ha, with an average R² between coherence and GSV of 0.58. PALSAR backscatter acquired in unfrozen conditions could also estimate GSV; however, the saturation levels (75–100 m²/ha) and the average R² (0.42–0.48) were lower. HV backscatter offered only a slightly greater potential than HH backscatter.

A simple inversion approach aiming at the delineation of forest GSV maps based on the multipolarized SAR data was developed and applied to five forest inventory sites. This approach combines HV backscatter data acquired in unfrozen conditions and InSAR coherence data acquired in frozen conditions. In general, the produced maps feature a corrected relative RMSE of ~30% which was similar to the accuracy of the forest inventory data. The R² between inventory data and SAR data based maps varied between 0.54 and 0.83.