Forest biomass mapping in Sweden

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Outline

- New National Digital Elevation Model
- Swedish forest map – $k$NN Sweden
- ALOS PALSAR (clear-cuts and biomass)
- TanDEM-X (height and biomass)
- Aerial Photogrammetry (height and biomass)
- Summary
New National Digital Elevation Model

- 400 ALS scanning areas, 25 km × 50 km
- Scanning time span 2009-2013
- At least 0.5 pulse / m², 2.0 m grid
- ALS data not primarily collected to be used for forest variable prediction
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National Forest Inventory

Tract location

Temporary tracts (ca 550 per yr)
Permanent tracts (ca 900 per yr)
Satellite images

Landsat ETM+
Band:
- Blue
- Green
- Red
- Near-infrared
- Mid-infrared (2 bands)
- Thermal

Pixel size: 30 m
Flight altitude: 700 km
**kNN Sweden 2000**

- Landsat TM and ETM+ from 1997-2001
- Field data from the National Forest Inventory
- Forest boundaries according to GSD road map
- Covers 96% of the forest area
- Available via Internet (http://skogskarta.slu.se/)
kNN Sweden 2005

- SPOT images from 2005-2006
- Field data from the National Forest Inventory
- Forest boundaries according to GSD road map
- Covers 96% of the forest area
- Available via Internet (http://skogskarta.slu.se/)
$k$NN Sweden 2010

- SPOT images from ~ 2010
- Field data from the National Forest Inventory
- Forest boundaries according to GSD road map
- Covers 96% of the forest area
- Available via Internet (http://skogskarta.slu.se/)
kNN Sweden 2015?

- Optical + laser + ???
- Field data from the National Forest Inventory
- Forest boundaries according to GSD road map
- Covers 96% of the forest area
- Available via Internet (http://skogskarta.slu.se/)
Accuracy assessment (standing volume)
Users

- SLU
- Swedish Forest Agency
- County councils
- Environmental Protection Agency
- Swedish Tax Agency
- Forestry companies
- Other universities
- Etc.
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First Nordic mosaic – satellite radar

- **ALOS PALSAR (JAXA)**
- **63 strips from 43 orbital tracks**
- **June – October 2009**
- **Fine Beam Dual (FBD34)**
- **Mosaic:**
  - Red (HH-backscatter)
  - Green (HV-backscatter)
  - Blue (HH/HV ratio)

→ Clear-cut detection
→ Biomass estimation
Yearly mosaics of PALSAR strip images covering Sweden
**Project objectives**
To further develop and evaluate methods for large-scale mapping and monitoring of clear-cuts and possibly stem volume for the entire Sweden using ALOS PALSAR data.

**Results**
The LN-GKIT algorithm is tested in combination with a Markovian data fusion approach for detecting changes in dual-pol SAR data. The method is robust for both detection and delineation of clear-cuts, thus representing a substantial improvement with respect to the simple thresholding method developed during Phase 1.

**K&C Science Team members**
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**ALOS PALSAR data used**
Single images: FBS 34.3°HH and FBD 34.3°HH+HV, since ALOS start

Strip data: FBS (1 x year) and FBD (2 x year) 34.3°

**Other data sources**
Forest inventory data, DEM

Performance of clear-cut detection method applied to a pair of FBD images acquired in 2007 and 2008 for a 1.2 × 0.9 km² area. Left column: HH ratio (top), HV ratio (middle) and SPOT-4 HRV-IR red band reflectance difference image (bottom). Right column: detected change from HH ratio (top), HV ratio (middle) and fused HH and HV data (bottom).
Support to JAXA’s global forest mapping effort

Biomass mapping – Phase 3:

- Use PALSAR strip data for the entire Sweden (2008-2010) (base year 2010). Here, a comparison also will be made against the estimates of biomass obtained from combining sample plot data from the Swedish National Forest Inventory and optical satellite data (*kNN*-Sweden 2010)
Backscatter vs. stem volume

\[ \sigma^\circ_{for} = \sigma^\circ_{gr} \times e^{-\beta V} + \sigma^\circ_{veg} \times (1 - e^{-\beta V}) \]

\[ \sigma^\circ_{gr} = -10.5 \text{ dB} \]

\[ \sigma^\circ_{veg} = -6.0 \text{ dB} \]

\[ \beta = 0.003 \text{ ha m}^{-3} \]

ALOS PALSAR FBS 34.3° HH, 2007-01-29
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TanDEM-X

- TerraSAR-X add-on for Digital Elevation Measurement
- Interferometric SAR mission
- German Aerospace Center (DLR) and EADS Astrium GmbH
- Two identical satellites in a closely controlled formation
Surface model from 3D data

- DSM [m a.s.l.]
- DEM [m a.s.l.]
- $\Delta = \text{CHM} [\text{m a.g.l.}]$

Height to backscatter center
National Laser DEM of Sweden

- Produced by Swedish National Land Survey
  2009-2013
- Using Airborne Laser Scanning, > 0.5 pulse / m\(^2\)
- 2.0 m raster grid
- RMSE < 0.5 m
Penetration increases with wavelength
Prediction of height and biomass

• 214 plots used for training and 25 plots for validation (10 m radius)
• Height and biomass **training** sets obtained from field inventory 2010
• Height and biomass **validation** sets obtained from field inventory 2011
• TanDEM-X image used is from June 4, 2011 with VV-polarization and Hoa = 49 m
• Models developed with regression analysis
Regression models

Biomass
\[ AGB = \alpha_0 + \alpha_1 H_{\text{mean}}^2 + \varepsilon \]

Height
\[ H = \alpha_0 + \alpha_1 H_{\text{max}} + \varepsilon \]
Height – validation data (10 m radius)

RMSE = 6.2%
Biomass – validation data (10 m radius)

RMSE = 23.1%
Comparison TanDEM-X & LiDAR

FROM TANDEM-X

FROM LIDAR
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Digital Mapping Camera (Z/I DMC) available in Sweden since 2004
Sensor for 3D-data
Z/I DMC

- Zeiss/intergraph Digital Mapping Camera
- Multispectral and panchromatic sensors
- Operated by Swedish Land Survey for standard photography – 4800 m flight altitude, 60%/30% stereo overlap
Remningstorp study area

- 1600 ha of boreal forest in southern Sweden
- Consisting of mainly Norwegian spruce, Scotts pine and Birch
- Field data: 696 circular plots (10 m radius), geo-referenced by DGPS
- 41 forest stands. Stand delineation made in aerial stereo images. Used for validation.
Data

- Digital Elevation Model from the Topeye ALS
- 3D data from Z/I DMC
  - 4800 m 60%/30% standard altitude and stereo overlap
  - Point cloud generation available using automatic matching of stereo imagery, such as MatchT (Inpho)
Photogrammetric point cloud
Photogrammetric point cloud
Area-based estimation

- Tree height
- Stem volume
- Basal area

![Graphs showing estimated vs. surveyed values for tree height, stem volume, and basal area.](Image)
## Validation

<table>
<thead>
<tr>
<th>Data set</th>
<th>Flight altitude</th>
<th>Image overlap</th>
<th>Dependent variable</th>
<th>Independent variables</th>
<th>R2 Adjusted</th>
<th>Bias</th>
<th>Bias%</th>
<th>RMSE</th>
<th>RMSE%</th>
<th>q</th>
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</thead>
<tbody>
<tr>
<td>Data set (a)</td>
<td>4800 m</td>
<td>60%/30%</td>
<td>Tree height</td>
<td>$p_{80}$</td>
<td>0.86</td>
<td>0.6</td>
<td>3.5</td>
<td>1.6</td>
<td>8.8</td>
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<td></td>
<td></td>
<td>Stem volume</td>
<td>$p_{80}$, $CON$, $d_{40}$</td>
<td>0.72</td>
<td>3.6</td>
<td>1.4</td>
<td>32.8</td>
<td>13.1</td>
<td>1.03</td>
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<td></td>
<td></td>
<td></td>
<td>Basal area</td>
<td>$p_{80}$, $CON$, $d_{50}$</td>
<td>0.78</td>
<td>0.2</td>
<td>0.8</td>
<td>4.0</td>
<td>14.9</td>
<td>1.03</td>
</tr>
</tbody>
</table>

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Summary

• Radar, optical, laser
• Air- and spaceborne systems
• Moving from 2D to 3D (4D) remote sensing
• Tree, plot, stand, regional and national level
• Automated / semi-automated methods
• Forestry applications (biomass, clear-cuts, etc.)

→ Authorities, forest companies, universities, etc.
New possibilities and challenges!!!

National Land Survey’s laser scanning

BIOMASS – ESA Earth Explorer Mission

TanDEM-X

ALOS PALSAR -2

Digital aerial photos

Swedish University of Agricultural Sciences
Department of Forest Resource Management
Thank you for your attention!