Airborne Laser Scanning (ALS) for forestry applications

International School on Lidar Technology – 2008 – IIT Kanpur, India

Norbert Pfeifer + I.P.F.-Team

http://www.ipf.tuwien.ac.at/

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Outline

- Which data are required in forestry?
- What is the main output of ALS for forestry applications?
- Which approaches are commonly applied?
- What is the advantage of ALS for the derivation of forest parameter?
- Which accuracies can be derived?
- Who uses ALS for operational forestry applications?
- Which limitations of ALS for operational forestry applications exist?
- Outlook to new ALS sensors and their benefit for forestry applications?

Which data are required for forestry?

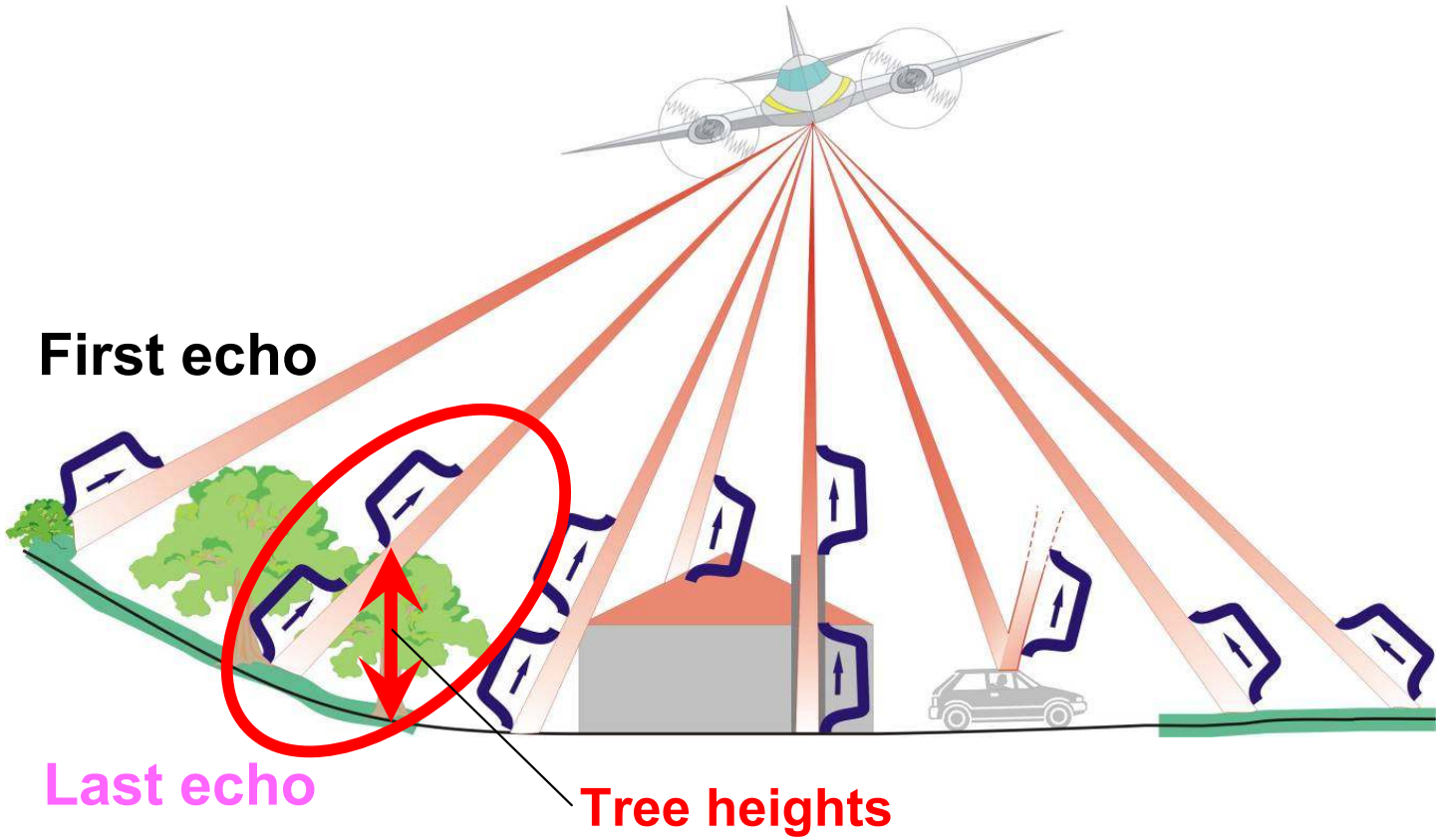
- **Foresters have to know what is where?**
- **What is the size of the forest stands?**
- **Which tree species are available?**
- **How many trees per hectare are available?**
- **What is the crown cover, tree height, diameter at breast height?**
- **How much biomass is available within a forest stand?**
- **…**

- **These information are the basis for**
  - Economic and ecologic forest management and planning
  - Forest policy
  - Scientific studies
  - Management of renewable resources
  - Etc. …

Which information from ALS is important for forestry applications?

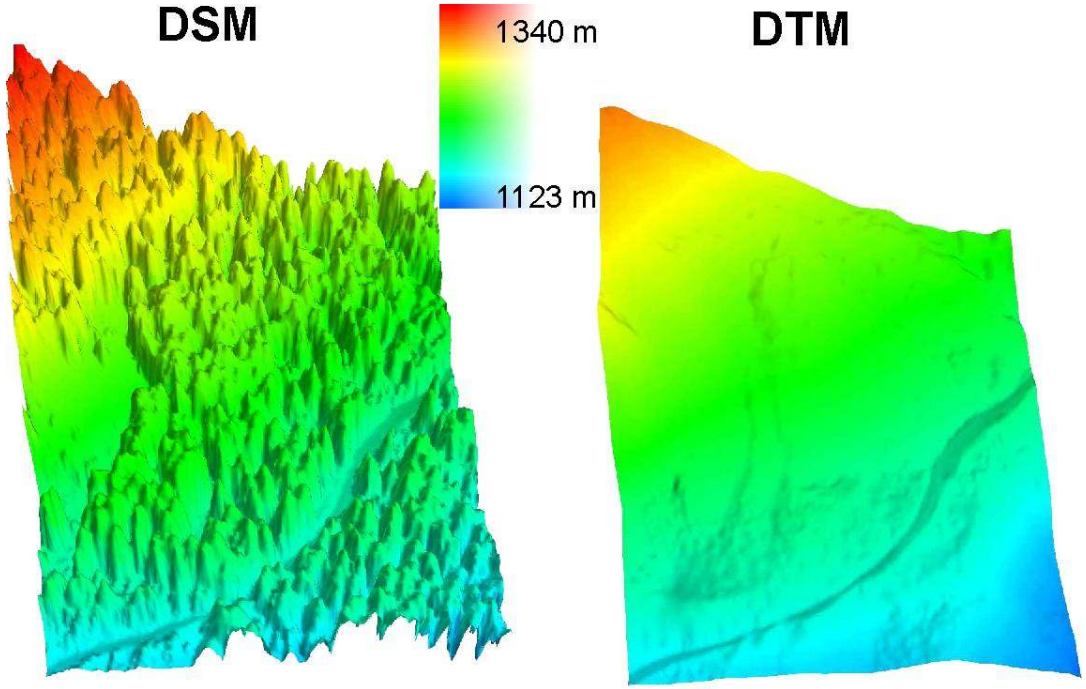
- **Common ALS-systems record the first and the last backscattered echoes**
- **The difference heights between the first and the last echoes represents tree heights**

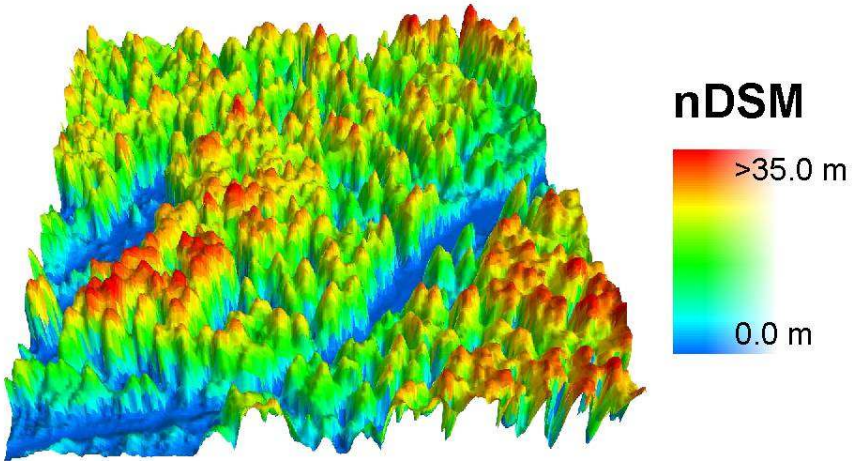
→ ALS delivers quantitative measurements !



Topographic models from ALS data

- Classification of each laser point into terrain and off-terrain points
- Calculation of topographic models (DSM, DTM)
- Calculations of the normalized digital surface model (nDSM)
- A common spatial resolution of these models is 1m
- The nDSM represents objects heights (buildings, trees, …)



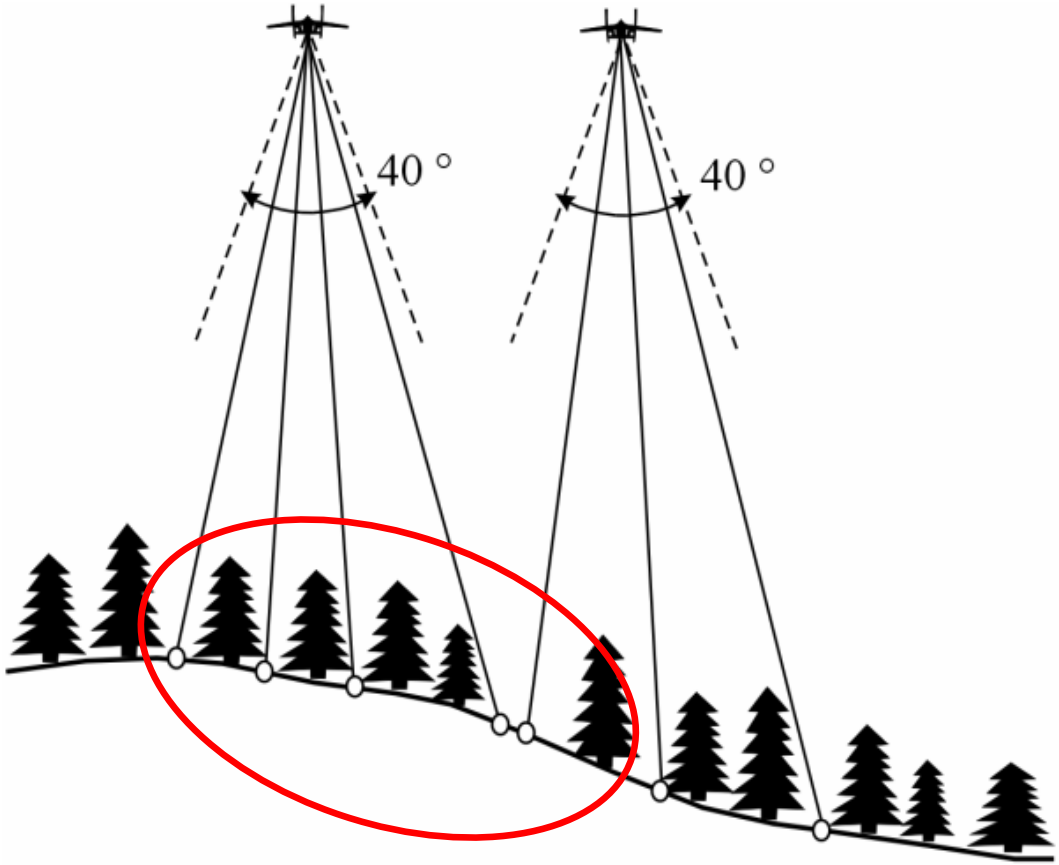


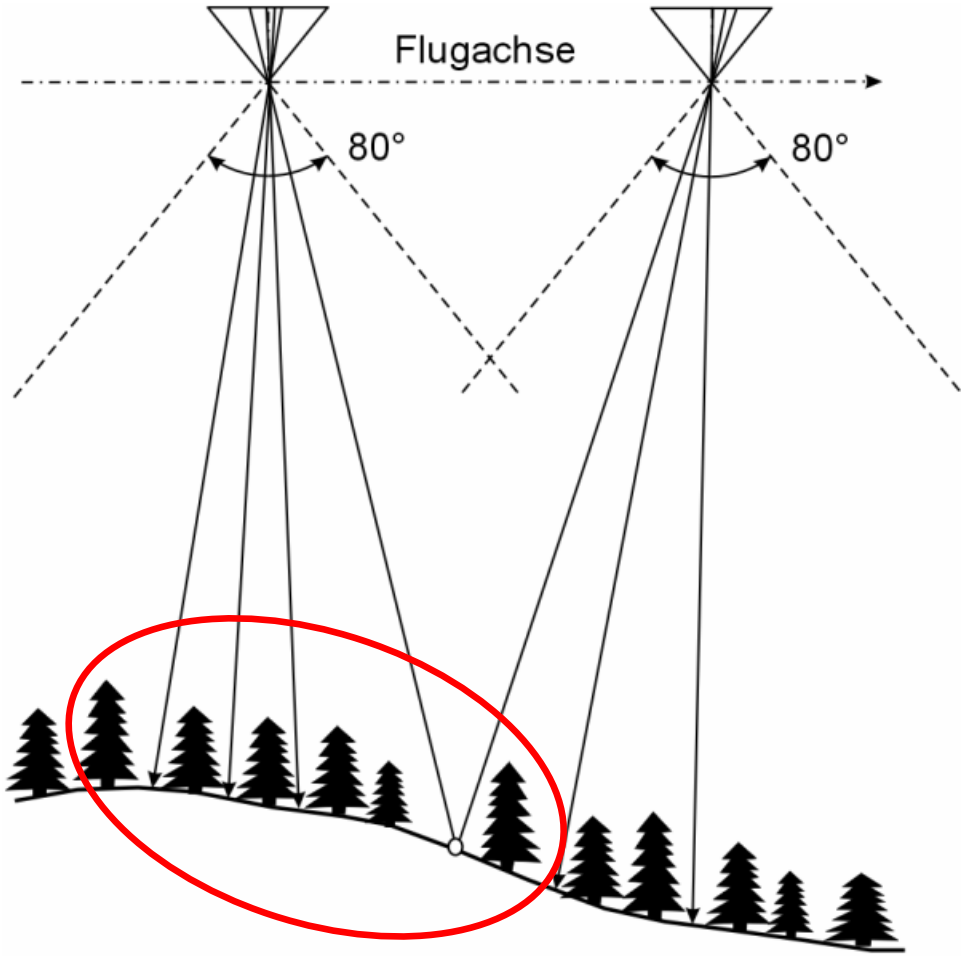
Photogrammetry versus Laserscanning (I)

A C T I V E
Airborne Laserscanning

versus

P A S S I V E
Photogrammetry

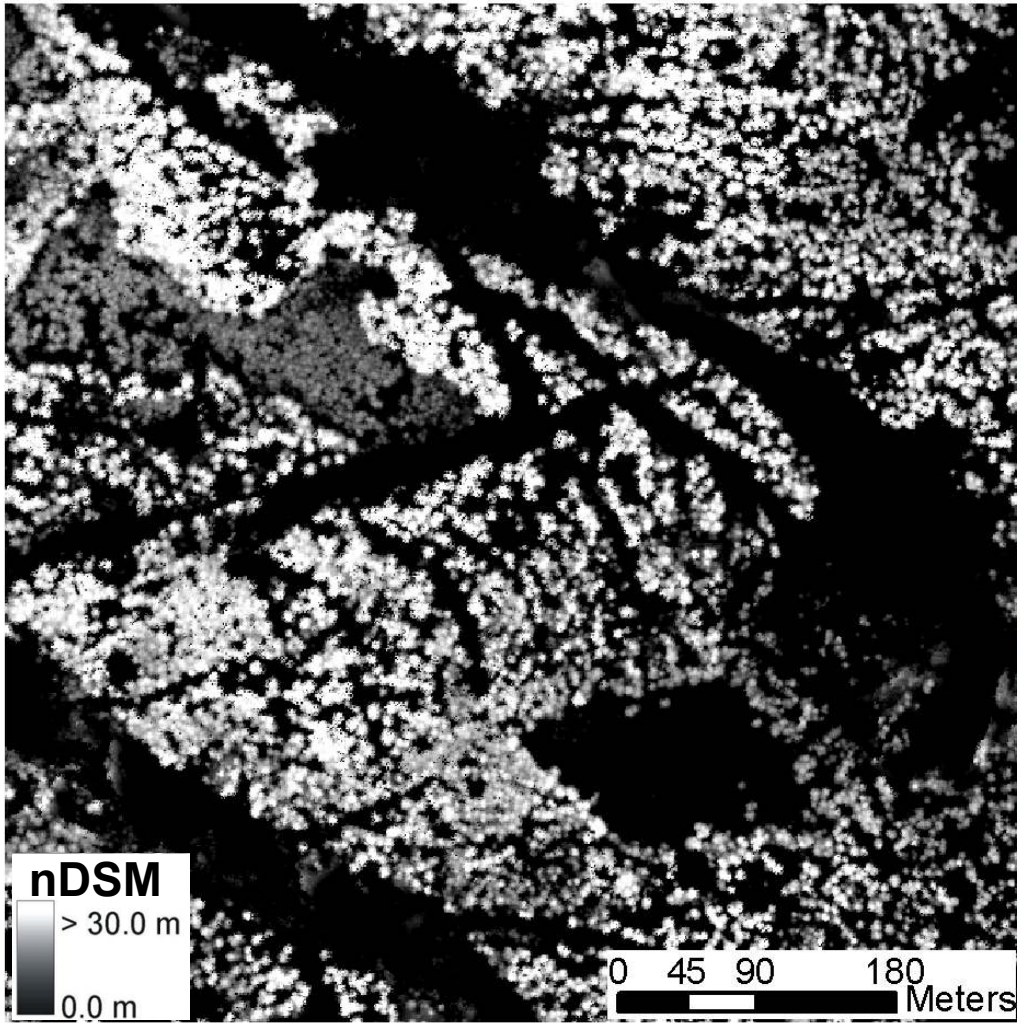




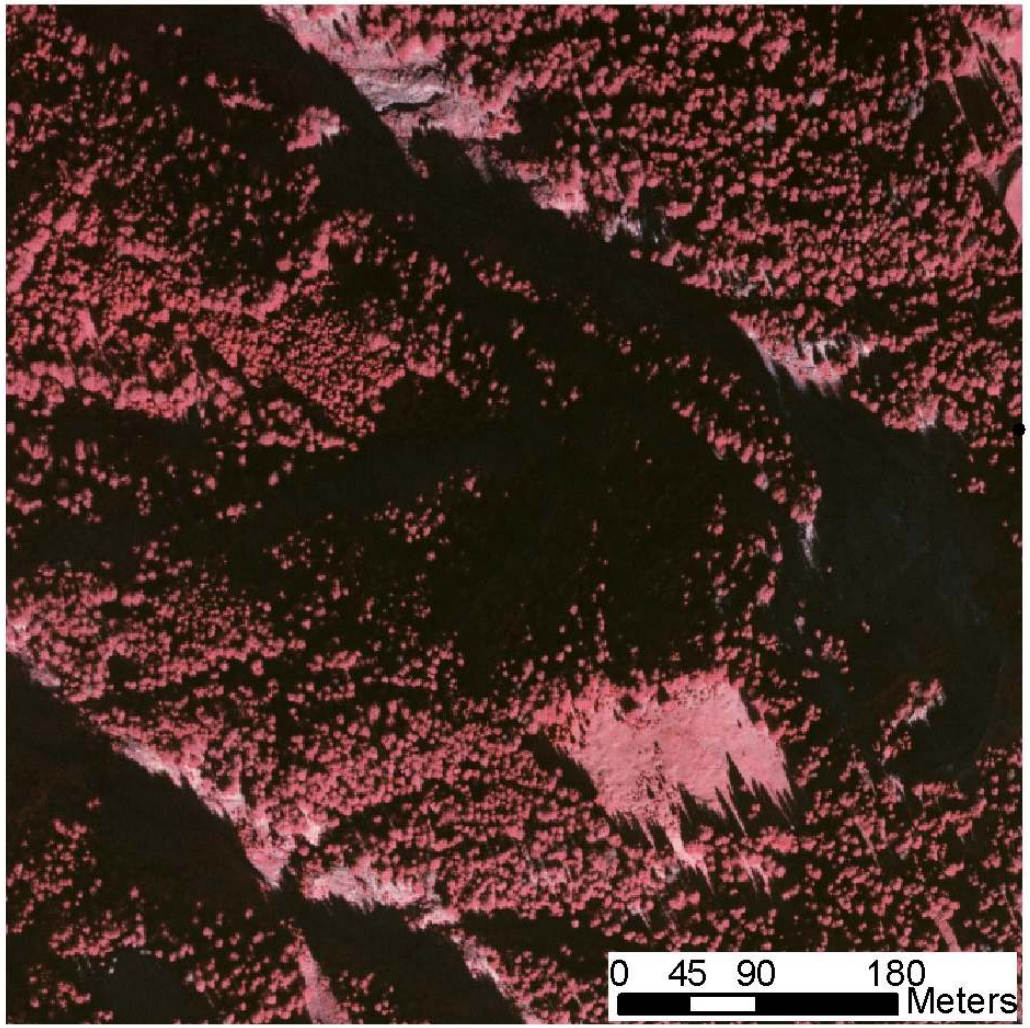
→ Advantage for the derivation of the terrain within forested areas!

Photogrammetry versus Laserscanning (II)

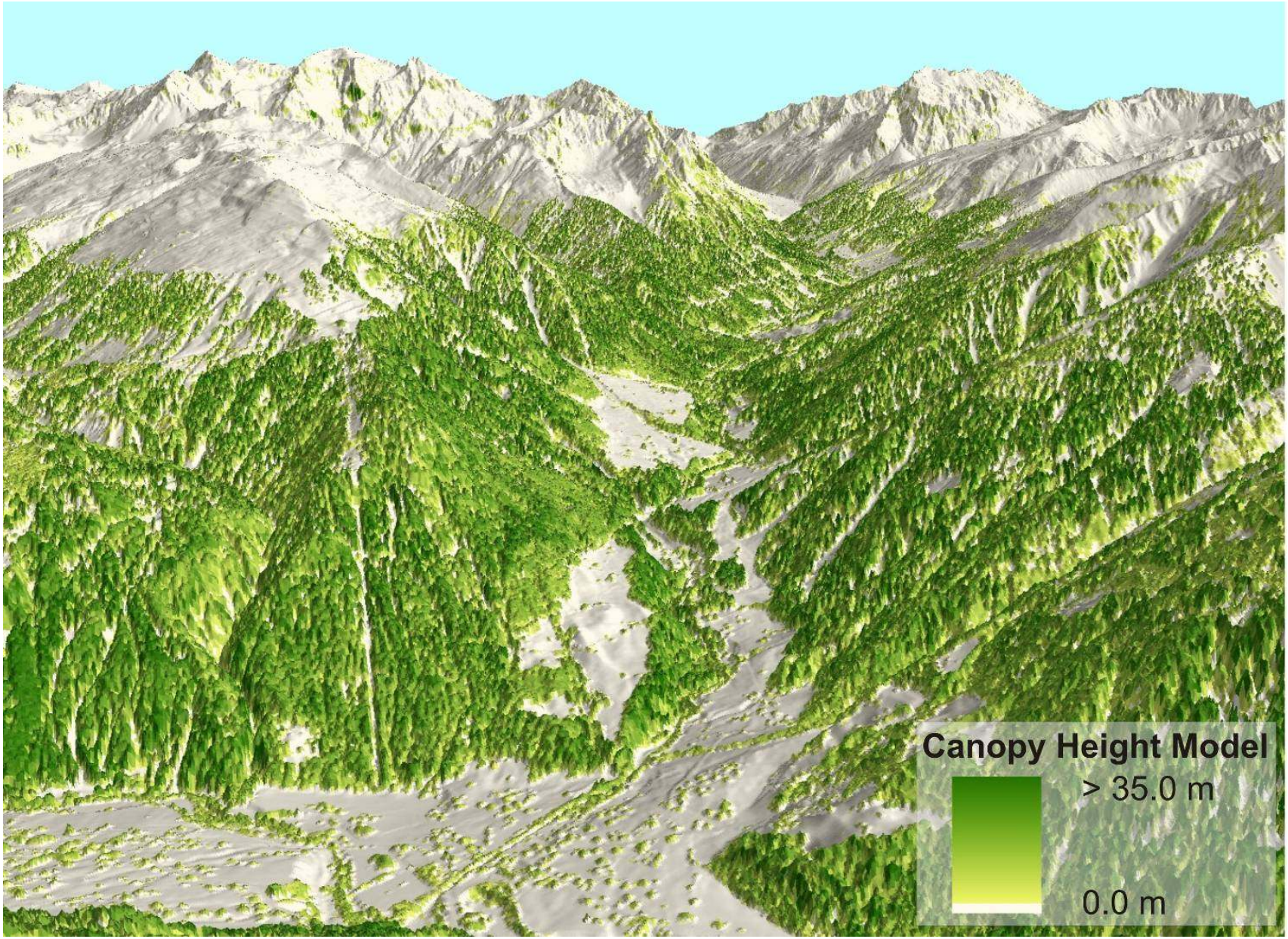
nDSM



Orthophoto

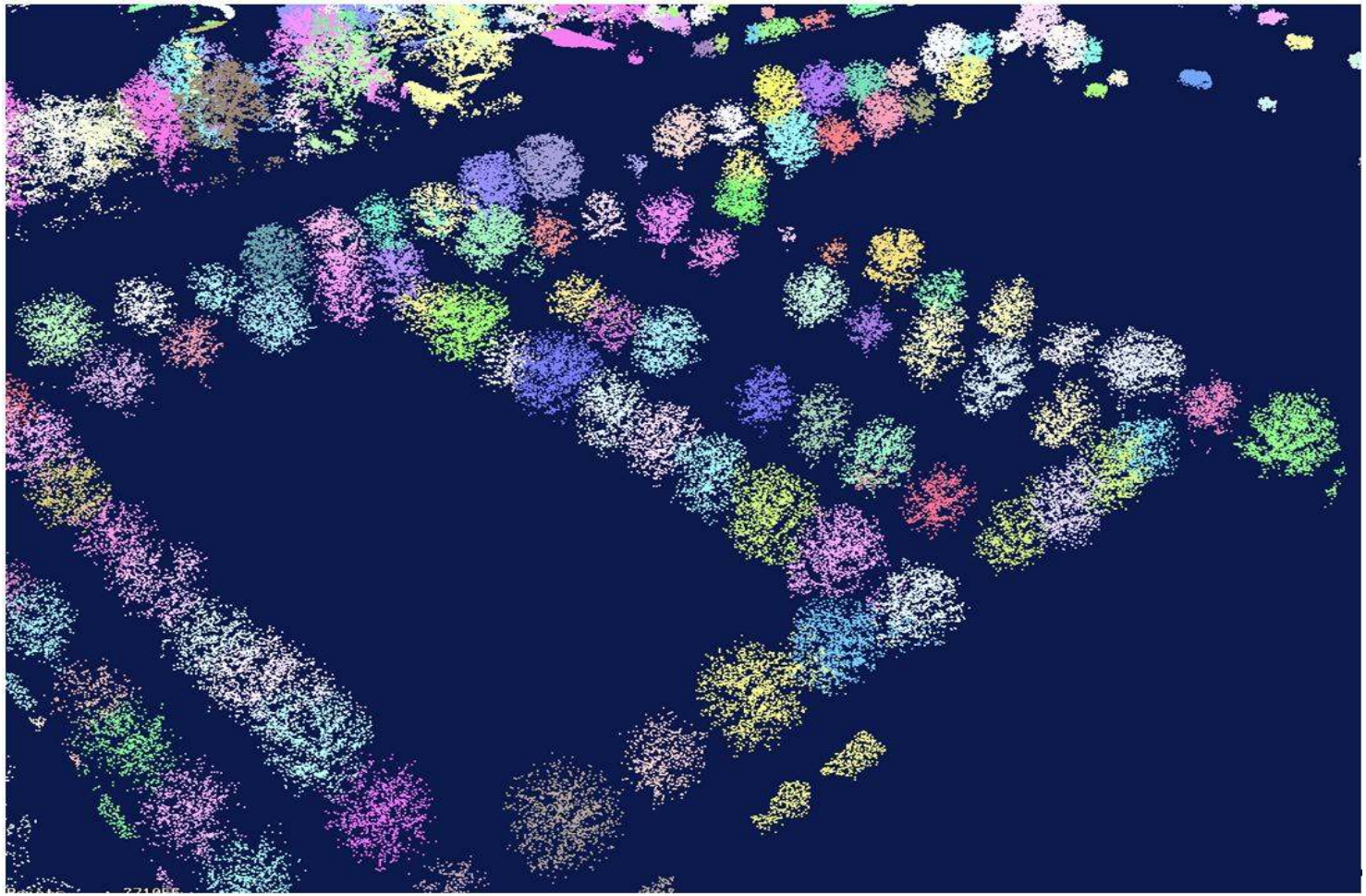


Canopy Height Model (CHM = DSM – DTM)



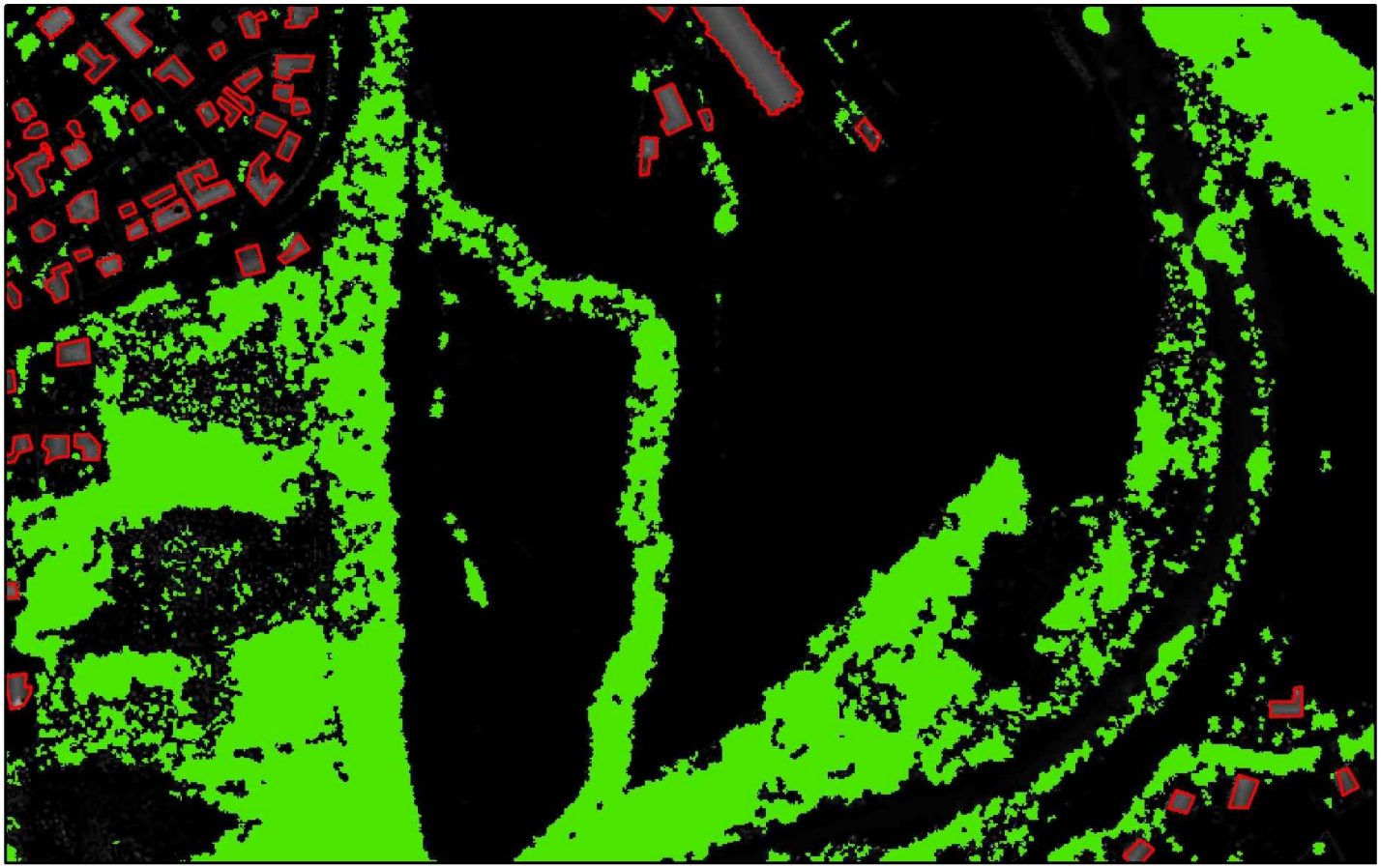
Forest area mapping (I)

- **Forest area mapping based on 3D-Laser Points**
  - E.g.: segmentation of the 3D-point cloud
  - Classification of the derived segments
  - High point density is required; time consuming computations!



Forest area mapping (II)

- **Pixel-based forest area mapping based on the nDSM**
  - E.g.: nDSM > 2M → forest, buildings
  - Removal of buildings (e.g. roofs → smooth surface; forests → rough surface)
  - Removal of small forest areas (e.g. minimum mapping unit 50m²)
  - Smoothing of forest borders (e.g. morphological operations)



Object heights

>25.0 m

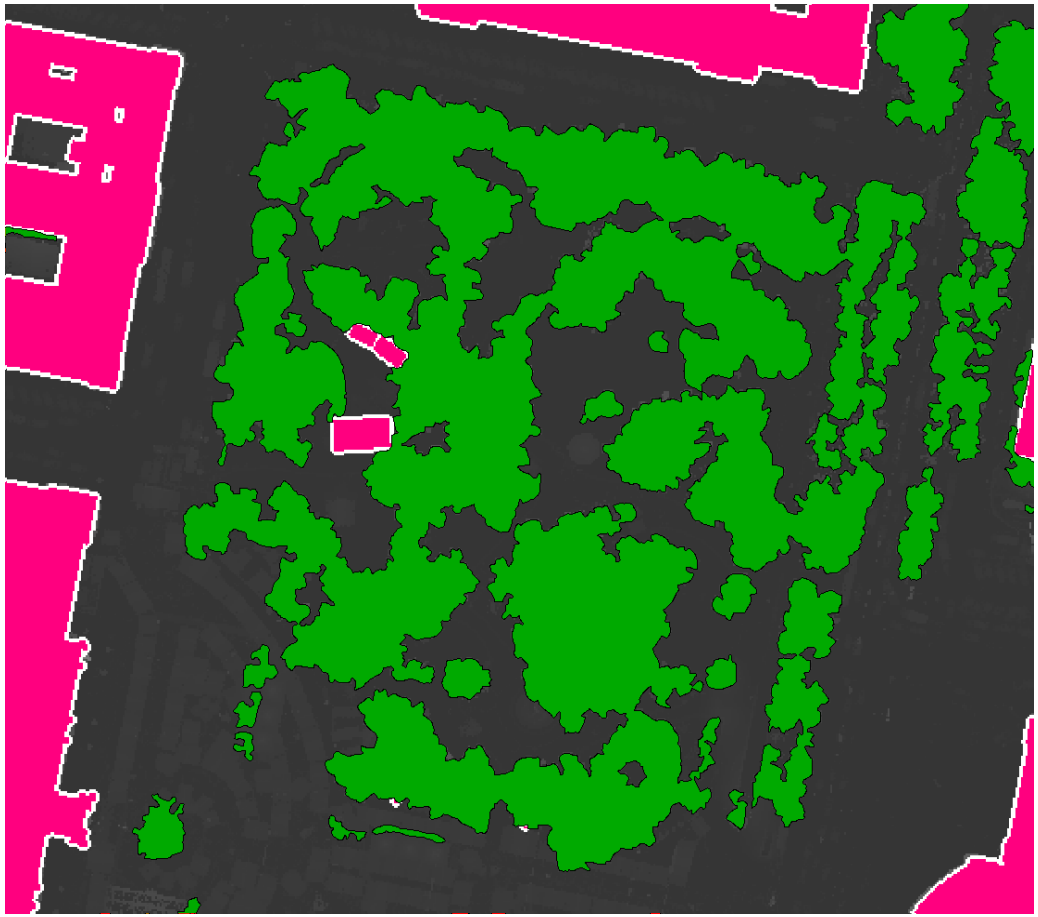
0.0 m

Buildings

Forest (h > 1m)

Forest area mapping (III)

- **Object-based forest area mapping based on the nDSM**
  - Segmentation of the nDSM (e.g. watershed, region growing, …)
  - Object-based classification of the derived segments
  - Removal of small forest areas (e.g. minimum mapping unit 50m²)
  - Smoothing of forest borders (e.g. morphological operations)



Tree segments

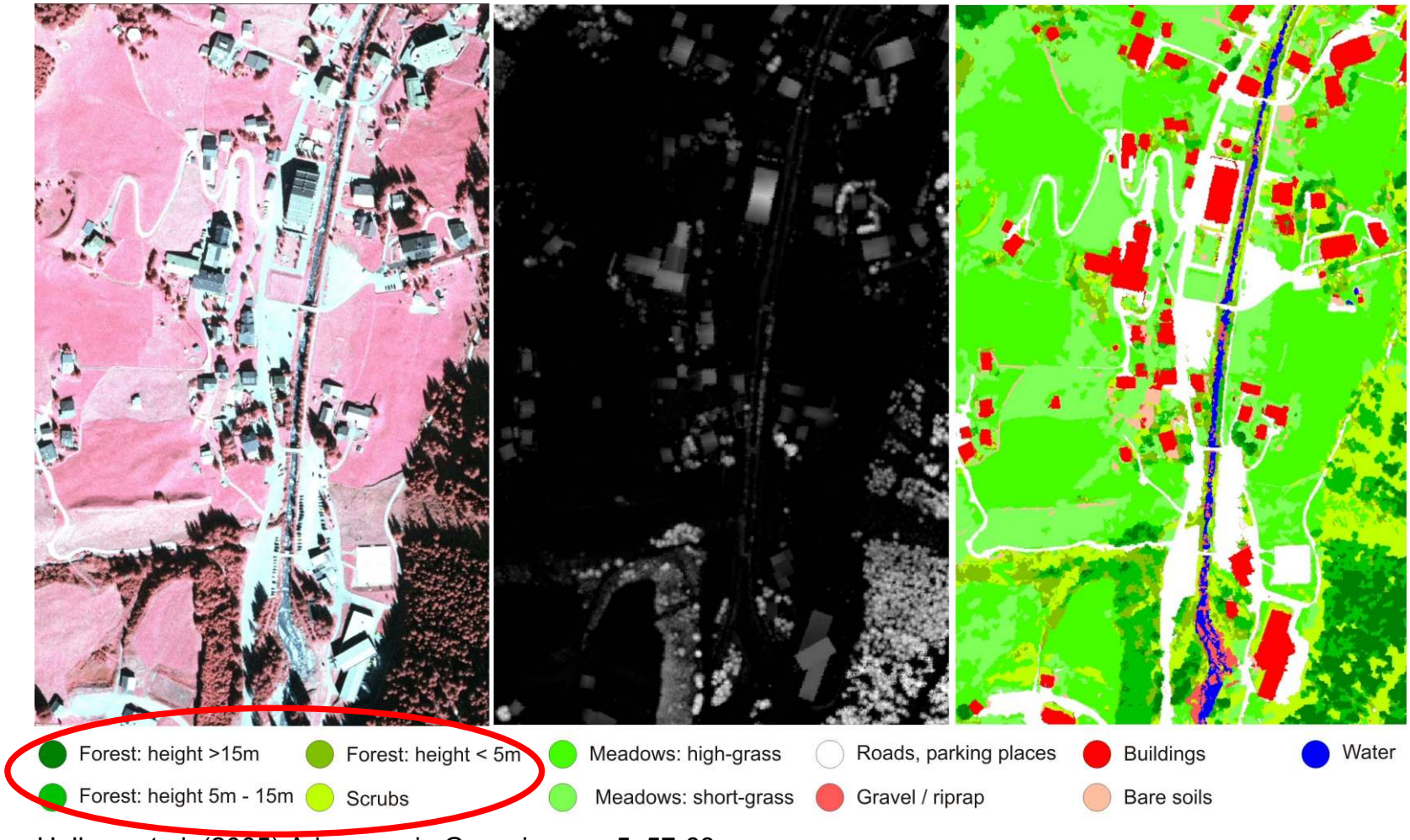
Buildings

Forest

Forest area mapping (IV)

- **Object-based land cover classification based on ALS (nDSM) and orthophotos (e.g. eCognition, …)**

CIR Orthophoto **ALS Heights (nDSM)** **Classification**



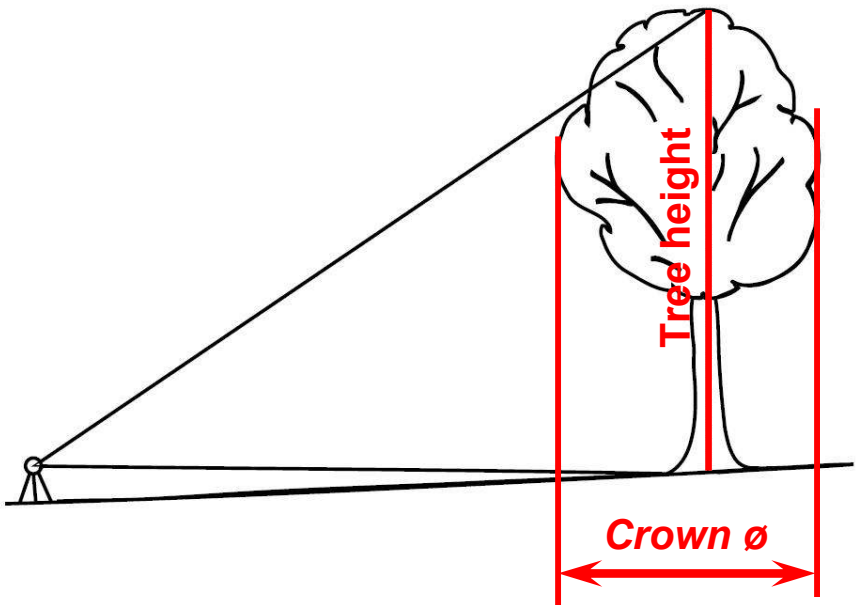
Hollaus et al. (2005) Advances in Geosciences, 5, 57-63

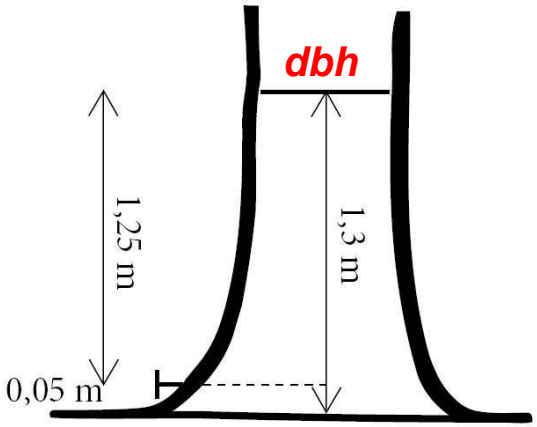
Forest parameter from ALS data

- **Two approaches**
  - Single-tree-based
    - Higher ALS point density is required (e.g. > 4 points/m²
    - Sensitive regarding differences in the point density and the acquisition time
    - Derivation of forest parameter without reference data possible
    - Time consuming computations
    - Commonly used for small study areas (e.g. urban vegetation, …)
  - Area-based (plot-/stand-level)
    - Reference data (e.g. national forest inventory data) are required to calibrate the empirical models
    - More robust than single-tree-based approaches
    - Already in use for operational applications

Forest parameters for single trees

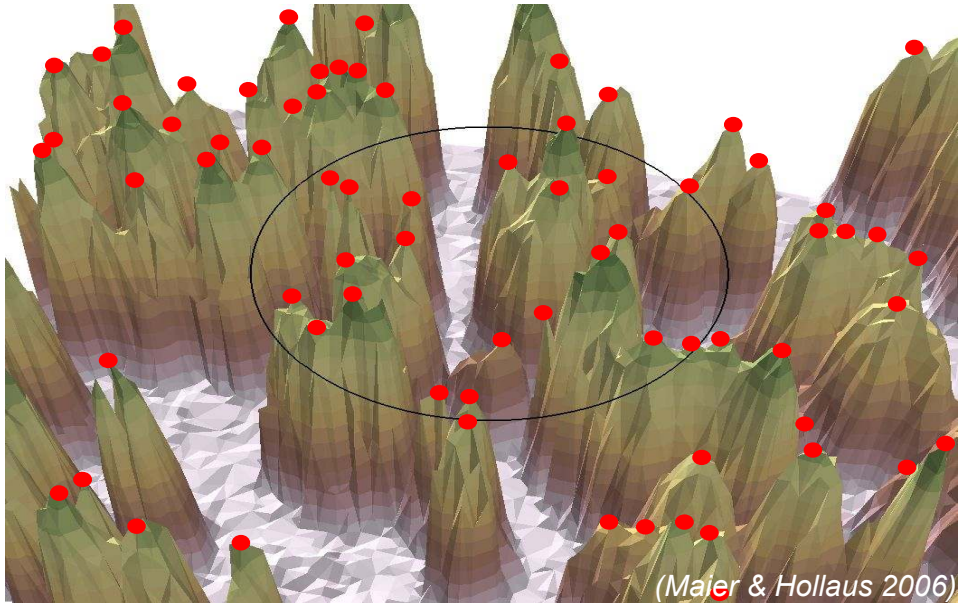
- **Detection of single trees**
- **Tree height estimation**
- **Estimation of tree crown diameter**
- **Diameter at breast height (*dbh*)**
- **Tree species**



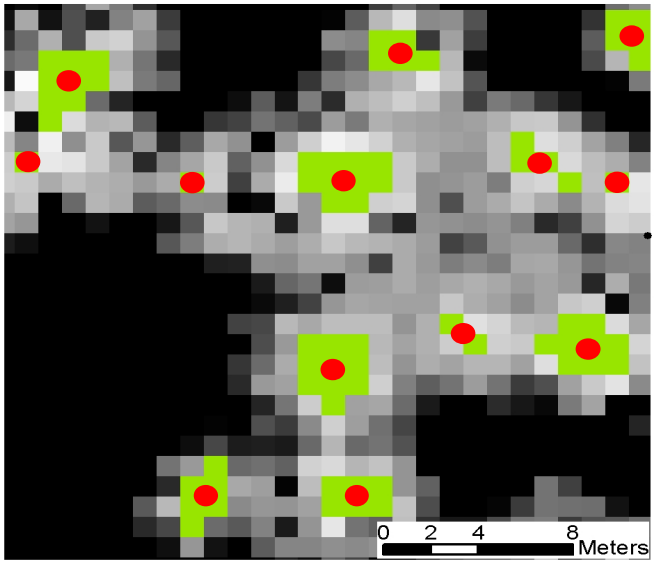


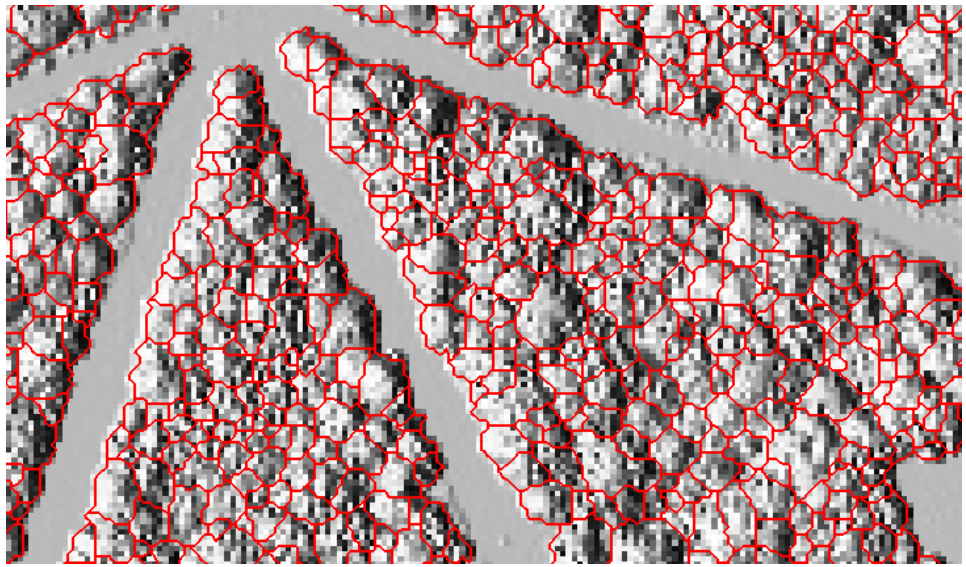
Detection of single trees

- **Local maxima filters**
  → tree tops



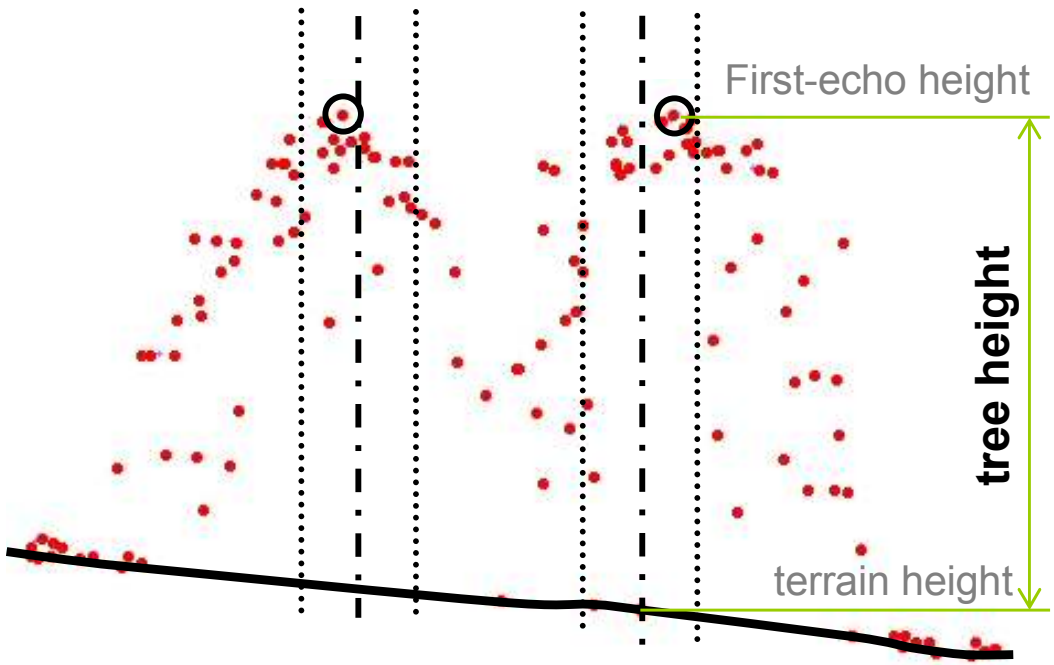
- **Tree crown segmentation**
  → tree crowns

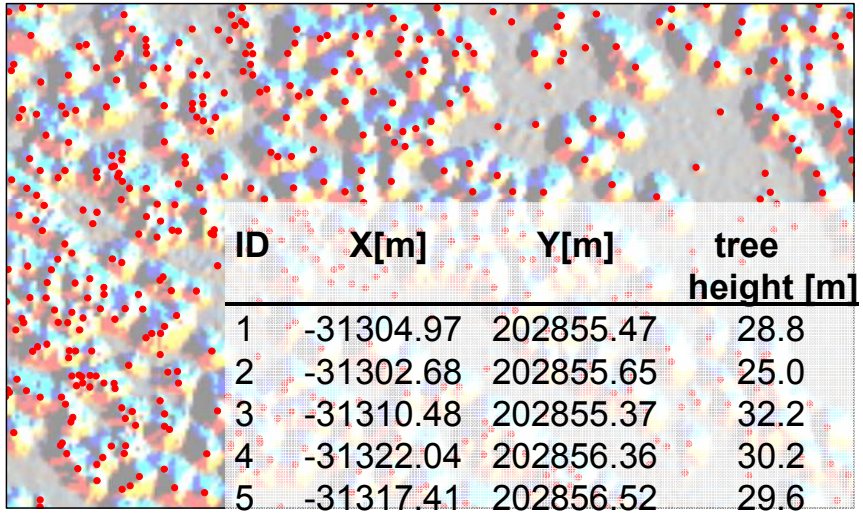




Tree heights

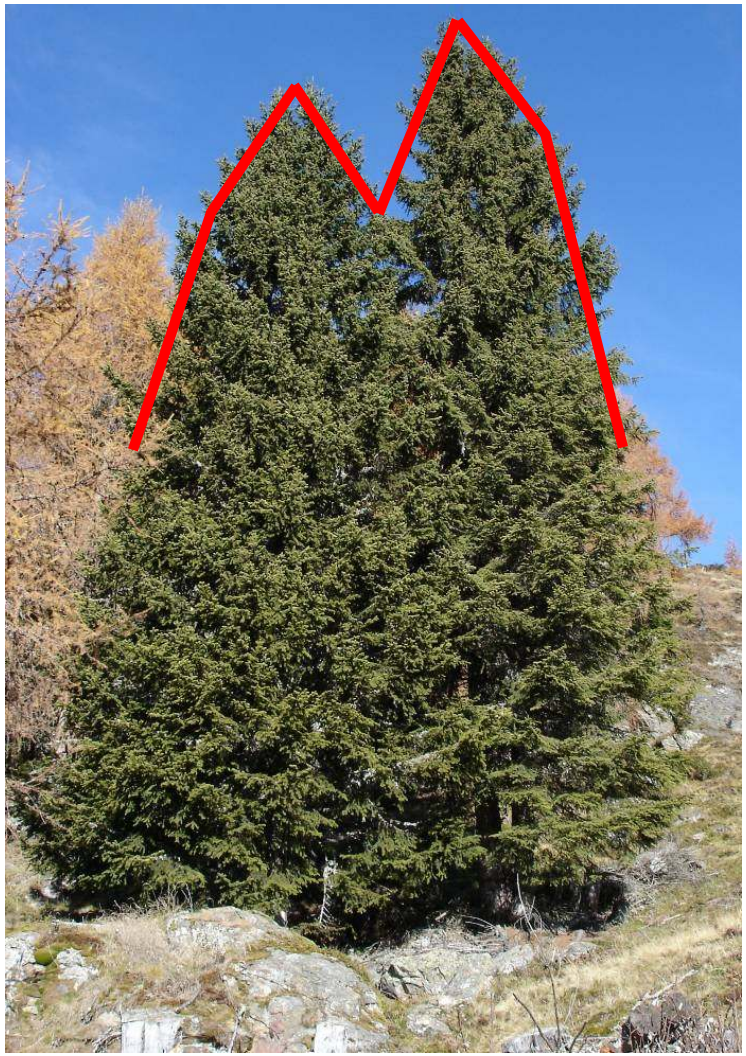
- **Extracting tree heights based on**
  - First-echo 3D-points (or the DSM) and DTM
  - Search the highest first-echo point inside a radius (depending on the tree height)
  - Subtract the terrain height from the highest first-echo point





ID	X[m]	Y[m]	tree height [m]
1	-31304.97	202855.47	28.8
2	-31302.68	202855.65	25.0
3	-31310.48	202855.37	32.2
4	-31322.04	202856.36	30.2
5	-31317.41	202856.52	29.6
6	-31318.55	202858.56	21.4
7	-31320.78	202858.52	21.1
8	-31316.92	202859.49	28.6
9	-31322.69	202859.55	31.9
10	-31314.04	202860.53	28.1
11	-31322.68	202861.40	32.6
12	-31320.38	202862.50	33.3
13	-31315.42	202863.57	31.5

Practical problems for single-tree parameter estimations

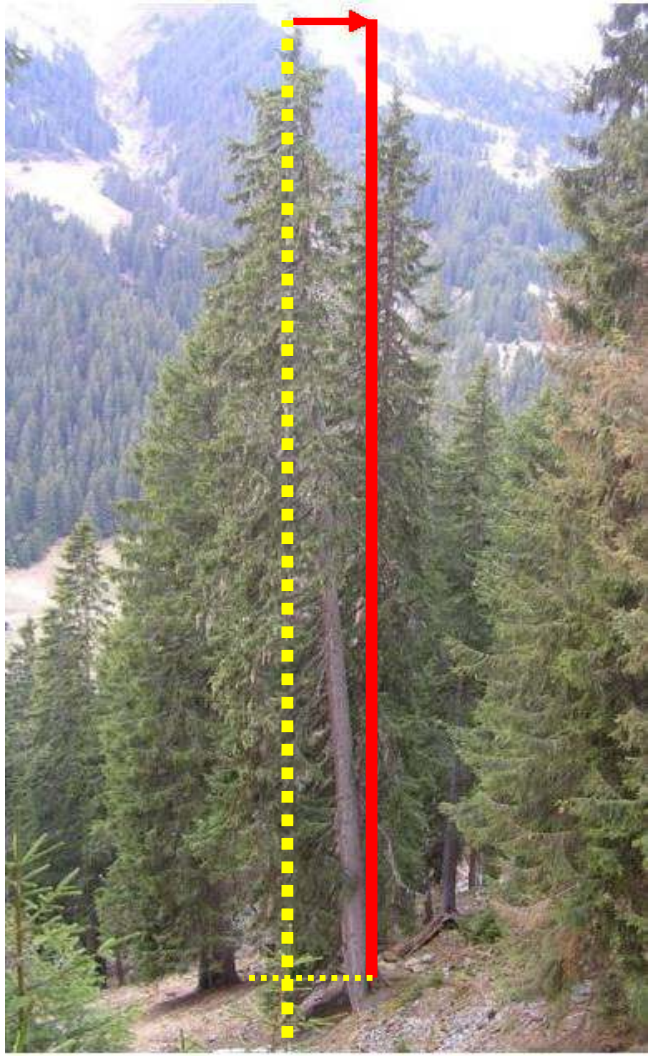


Interlocked trees

6 single trees are interlocked to 2 groups

Dense forests

If ALS data have a low point density – single trees can hardly be detected

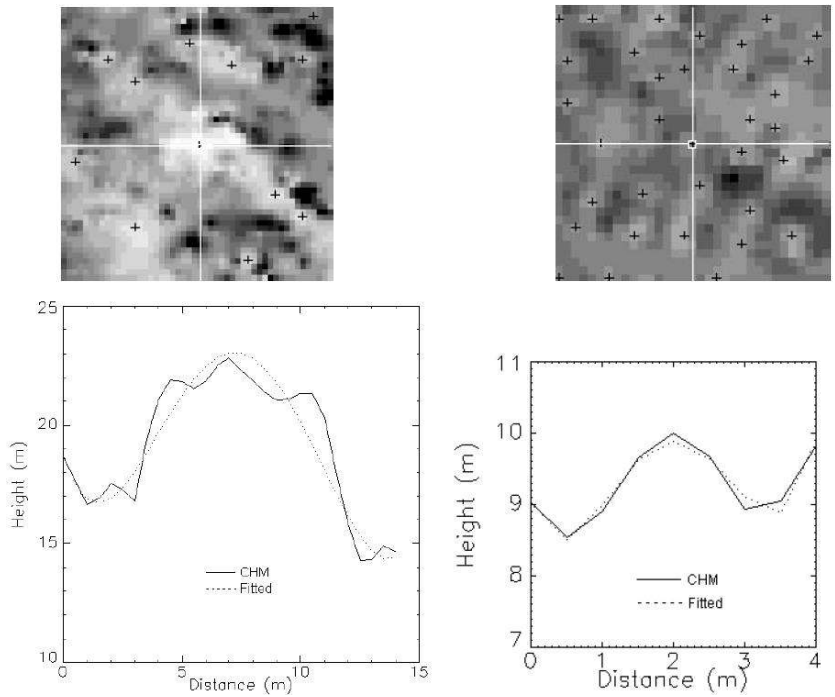


Leaning trees

An overestimation of the tree heights occurs (yellow line)

Tree crowns

- **Estimation of tree-crown diameters**
  - Calculation of the mean diameter of the derived tree-crown segments (e.g. mean diameter, smallest enclosing circle, …)
  - Based on the tree-crown area $L = \sqrt{\frac{4A}{\pi}}.$
    (Hyyppä et al., 2001)
  - Fitting rotating ellipsoids
    (Vögtle & Steinle, 2004)
  - Fitting fourth order polynomial functions *(Popescu et al., 2003)*

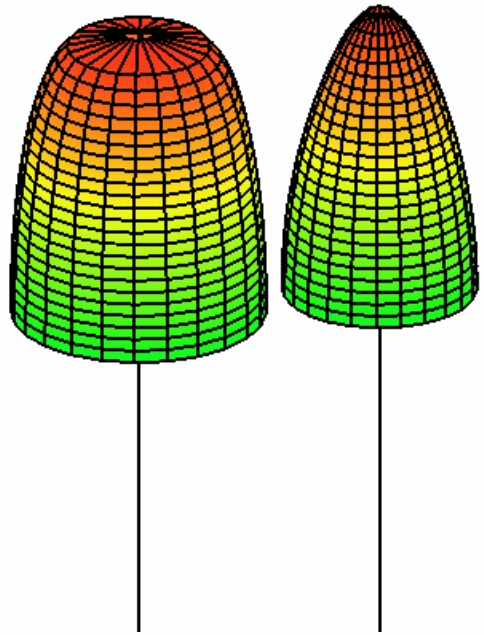


Diameter at breast height / stem volume

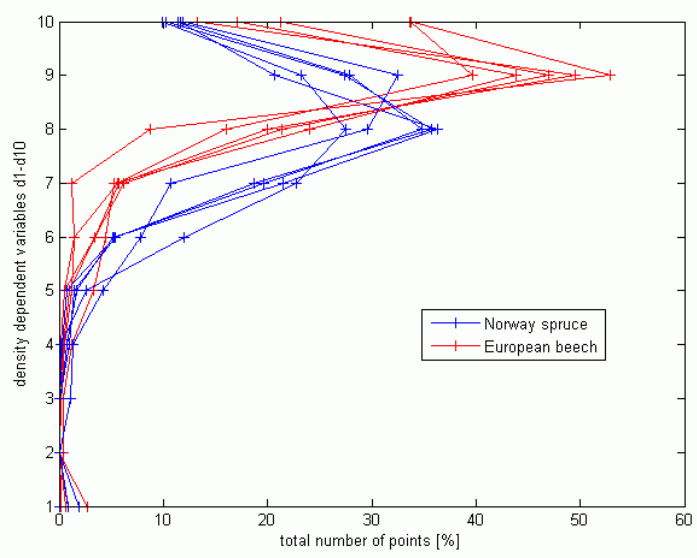
- **Assessment of diameters at breast height (1.3 m) → dbh**
  - Based on empirical functions
    - E.g.: dbh = $f_{(\text{tree height, crown diameter})}$)
    - E.g.: dbh = $f_{(\text{tree height, crown diameter, tree species})}$)
- **Stem volume**
  - Based on empirical functions
    - E.g.: Stem volume = $f_{(\text{tree height, dbh, tree species})}$)

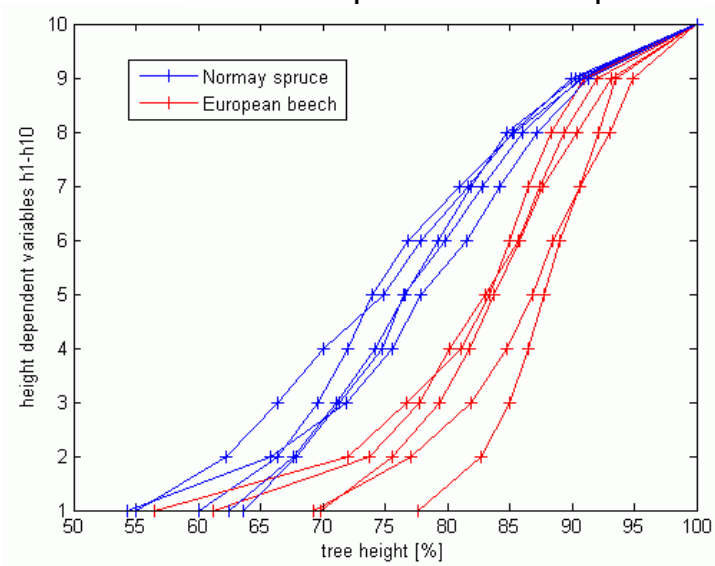
Tree species

- For different tree species typical tree crown mod can be found in the literature
- Fitting these models into the 3D-ALS point cloud → best fit → tree species



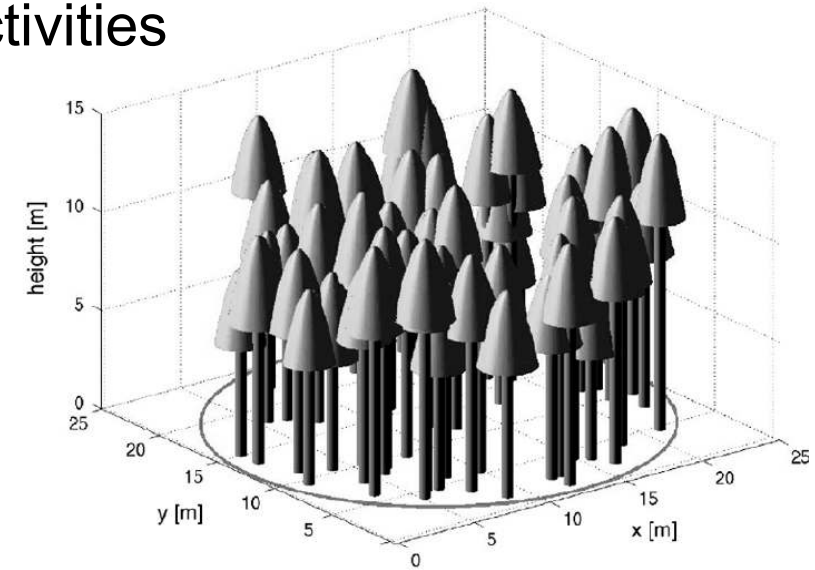
- Tree species classification based on the vertical distribution of the laser points

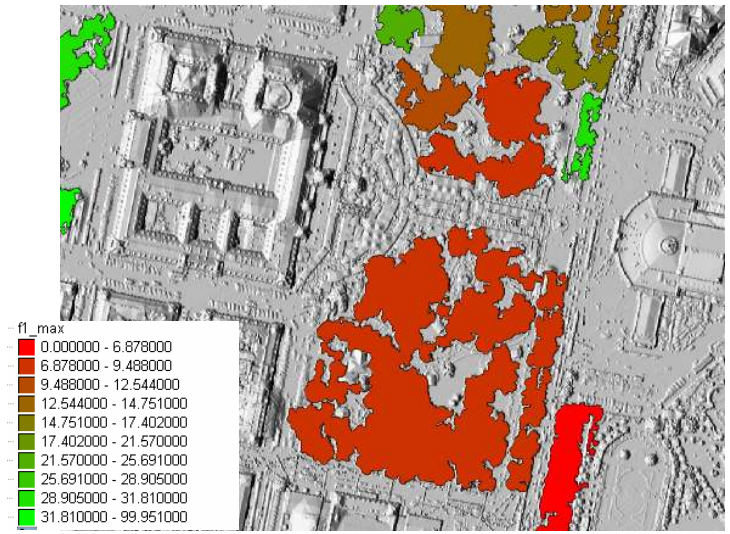


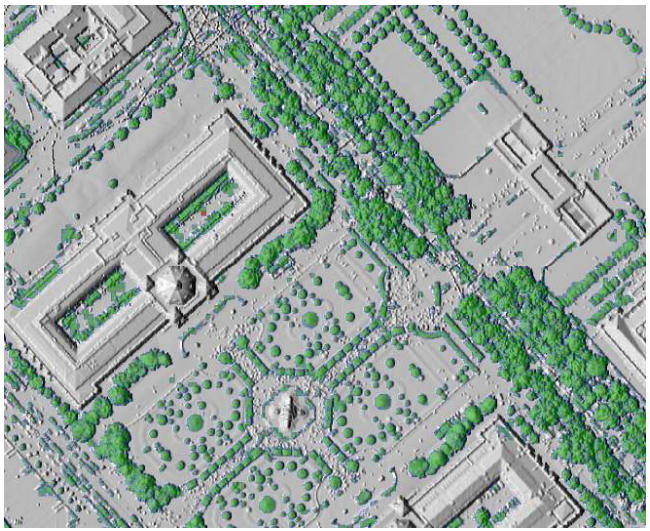


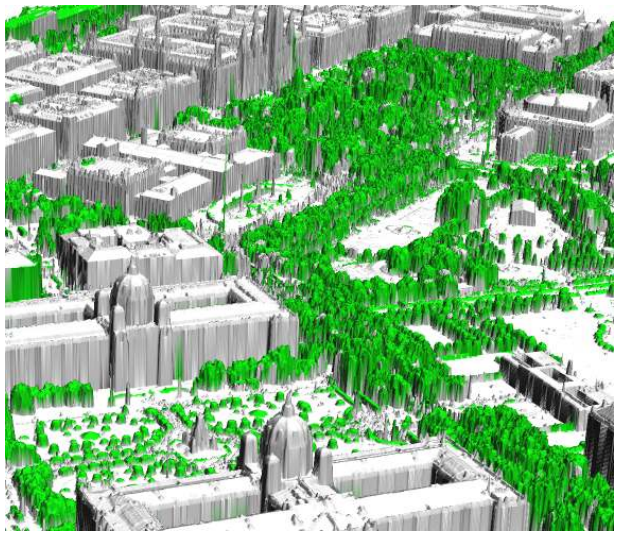
Application of single-tree specific parameters

- **A digital model of the forest derived from ALS can be used for**
  - Forest management and planning activities
  - Ecological studies
  - Fire behavior modeling
  - Basis for a urban tree cadastre
  - Visualizations
  - …







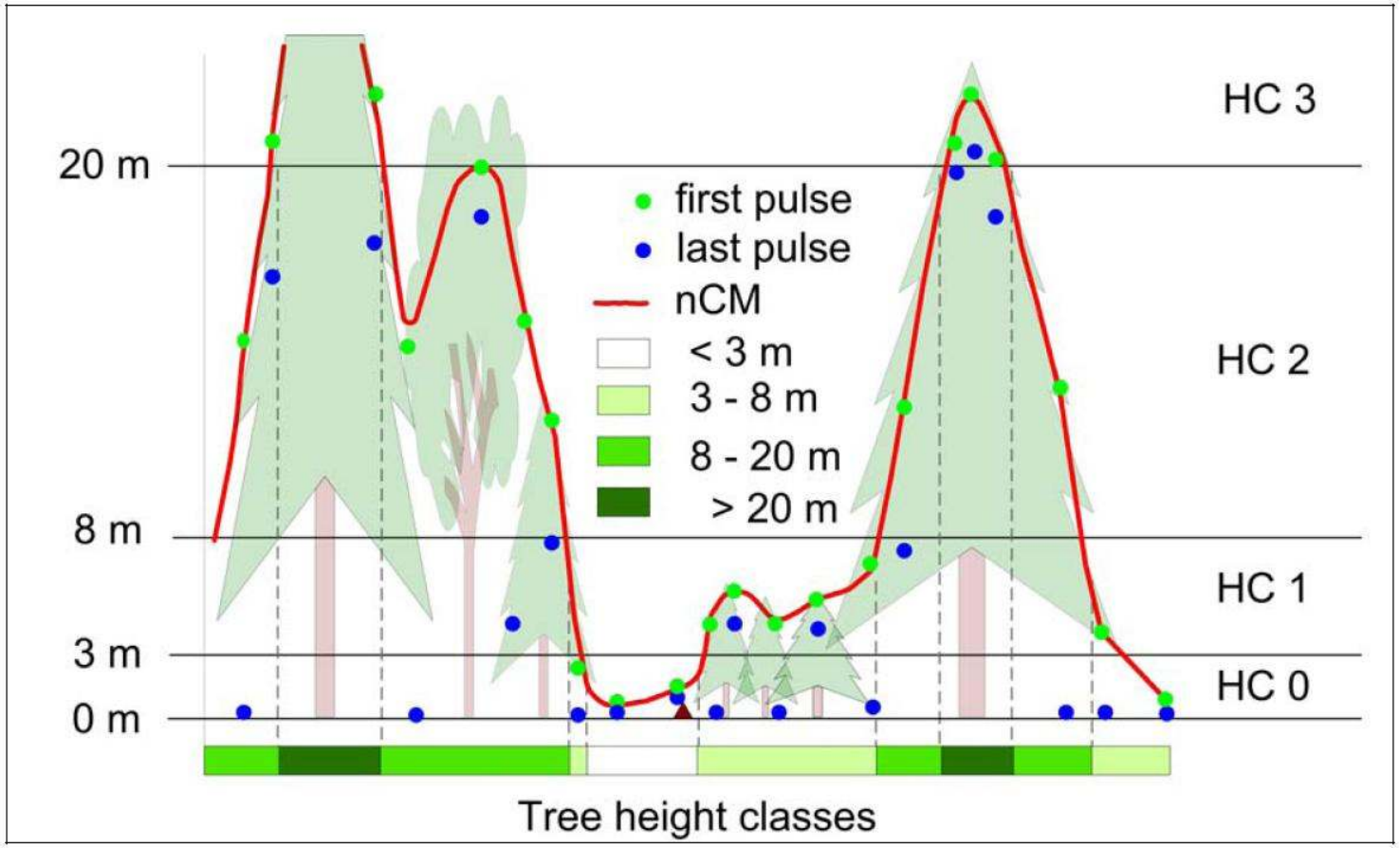


Area-based forest parameters

- Crown cover / structure types
- Stand heights
- Stem volume
- Biomass

Crown cover / structure types (I)

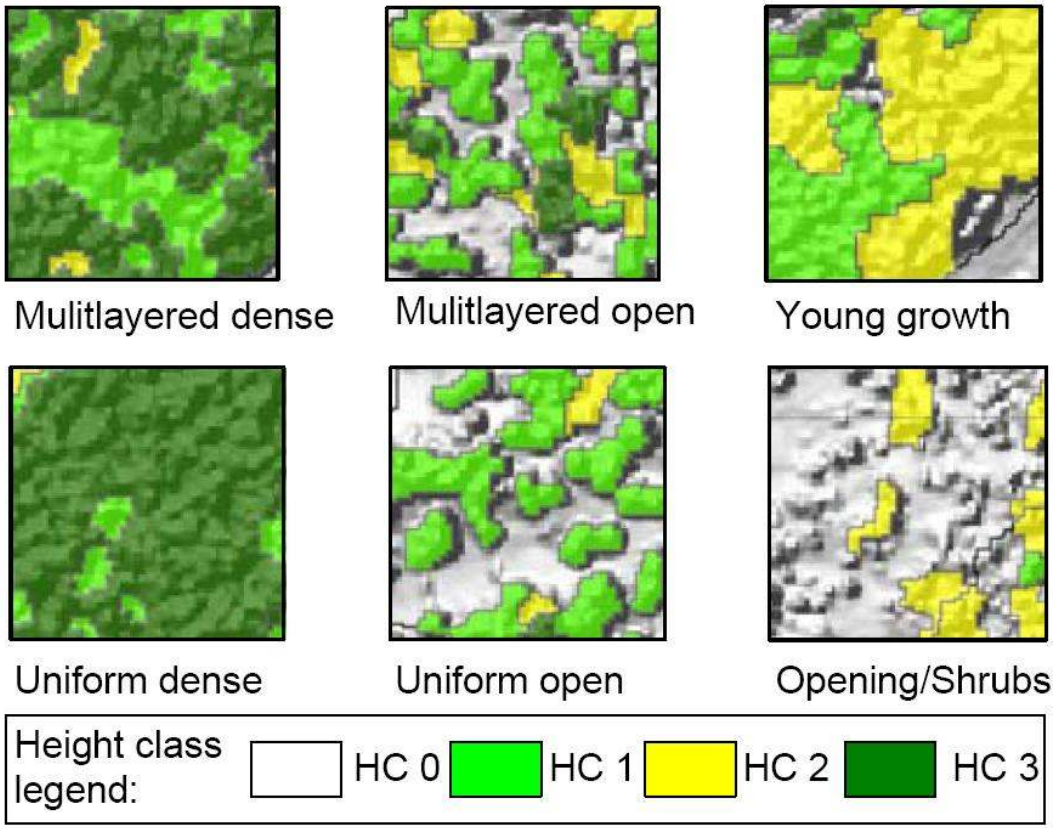
- **Segmentation of the nDSM**
  → derive areas with homogenous canopy heights
- **Classification based on canopy heights**



(Maier B. et al. 2007)

Crown cover / structure types (II)

- **Meta-segmentation**
  → forest stands
- **Classification**
  → forest structure for each forest stand



Rule set	Structure type	No. of Stands	Area in %
HC1 > 50%	Young growth	0	0
Division Index >= 0.75; HC2 or HC3 > 50% or two HC with > 30%	uniform dense	18	36
Division Index <= 0.75; HC2 or HC3 > 50% or two HC with > 30%	uniform open	11	9
Division Index >= 0.75; no HC > 50% and not two other HC with > 30% and CD > 20%	multilayered dense	14	27
Division Index <= 0.75; no HC > 50% and not two other HC with > 30% and CD > 20%	multilayered open	29	26
CD < 20%	opening	6	2
Total		**78**	**100**

(Maier B. et al. 2007)

Crown cover / structure types (III)

- **Mapping the forest structure types for large areas**

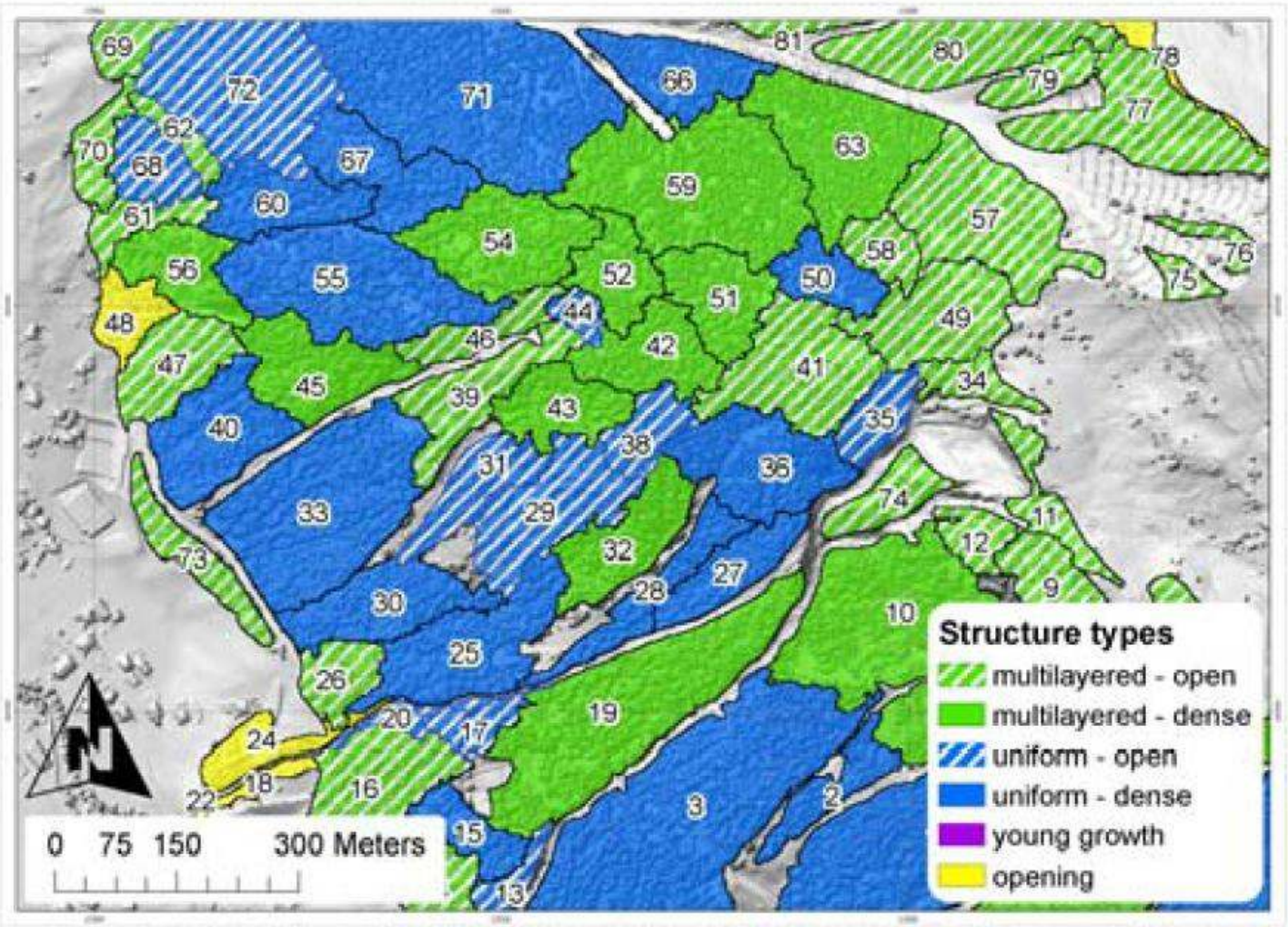
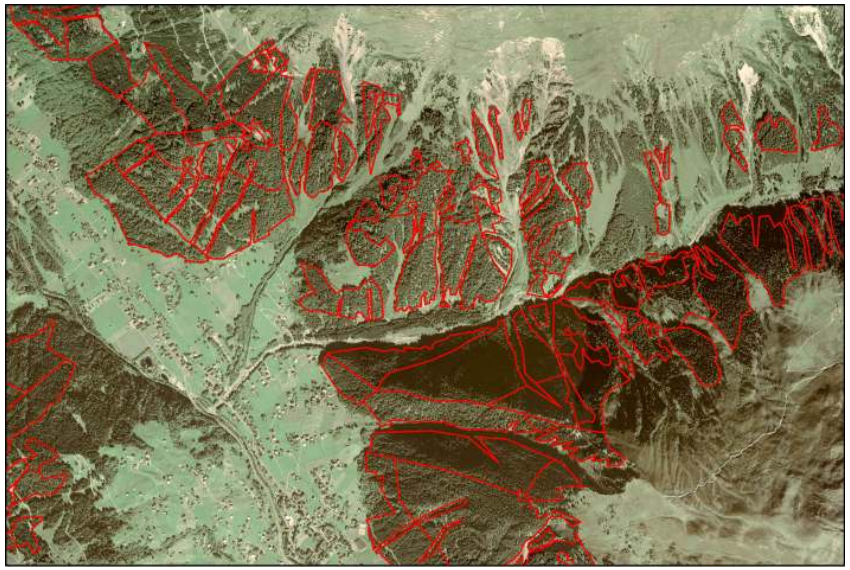
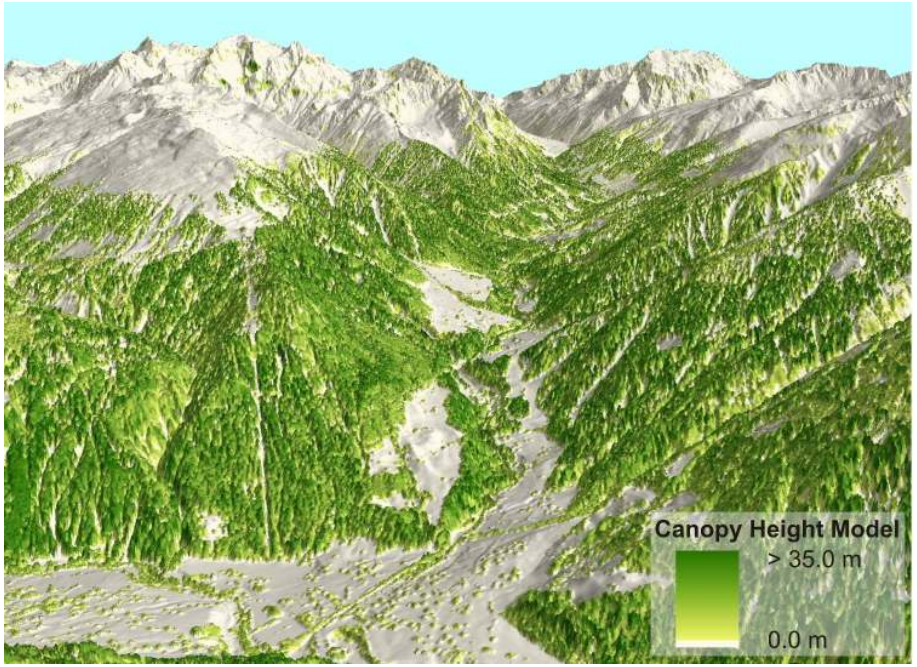


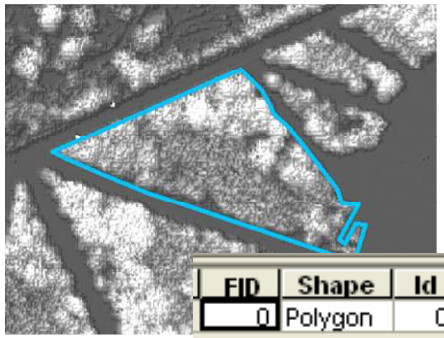
Figure 8. Distribution of discrete structure types *(Maier B. et al. 2007)*

Forest stand heights

- **Based on the nDSM**
- **The outline of the forest stands can be generated from the ALS data**
  or can be taken from a GIS
- **Mean heights, median height, …**



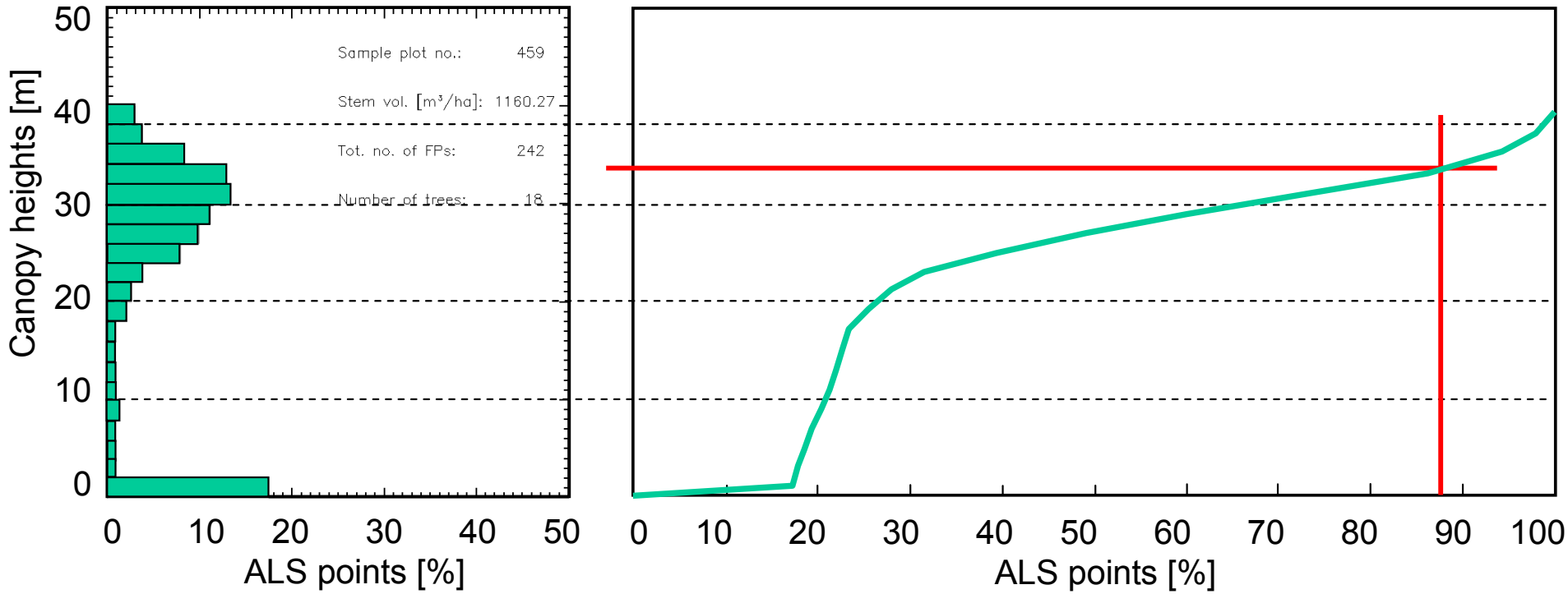




FID	Shape	Id	rdh_min	rdh_mean	rdh_max	rdh_std
0	Polygon	0	0,500087	10,263277	26,686371	4,846506

Lorey‘s mean height

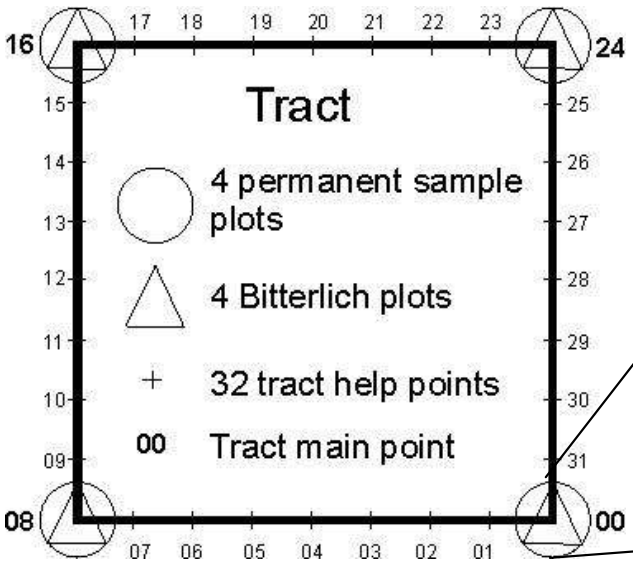
- **Lorey‘s mean height is the mean tree height weighted by the basal areas**
- **Basal area is the cross section area of a tree at breast height (1.3m above ground level).**

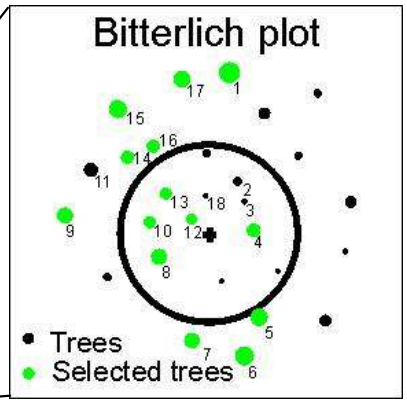


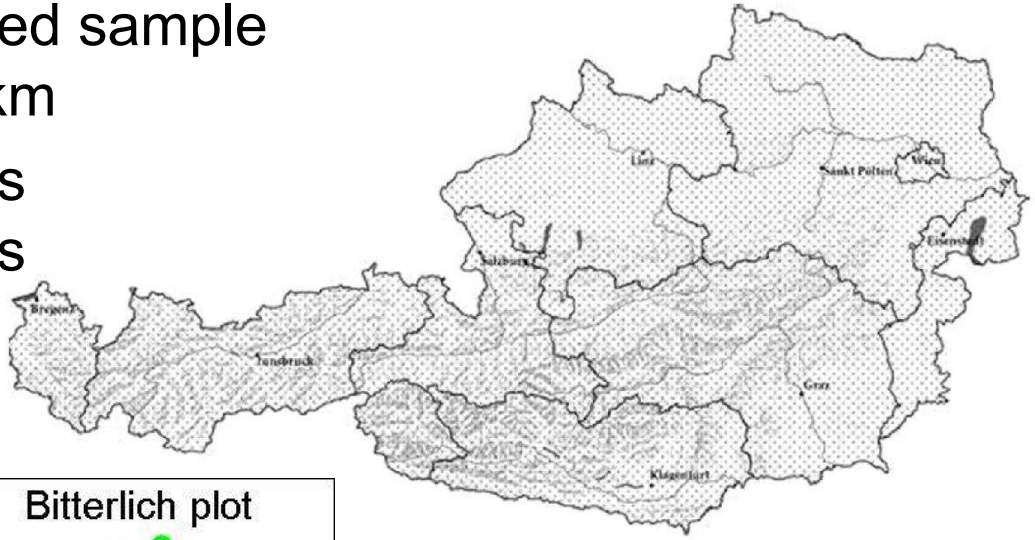
e.g. For the sample plot number 459 the canopy height at 88% corespondent to the Lorey‘s mean height

Stem volume estimation

- **The estimation of stem volume is based on empirical models**
- **For the calibration of the models reference data are required**
  - E.g. national forest inventory data
  - E.g. The National Forest Inventory (NFI) of Austria is based on permanent, regularly distributed sample plots with a distance of 3.89 km
  - Each grid point (tract) consists of 4 Angle gauge sample plots



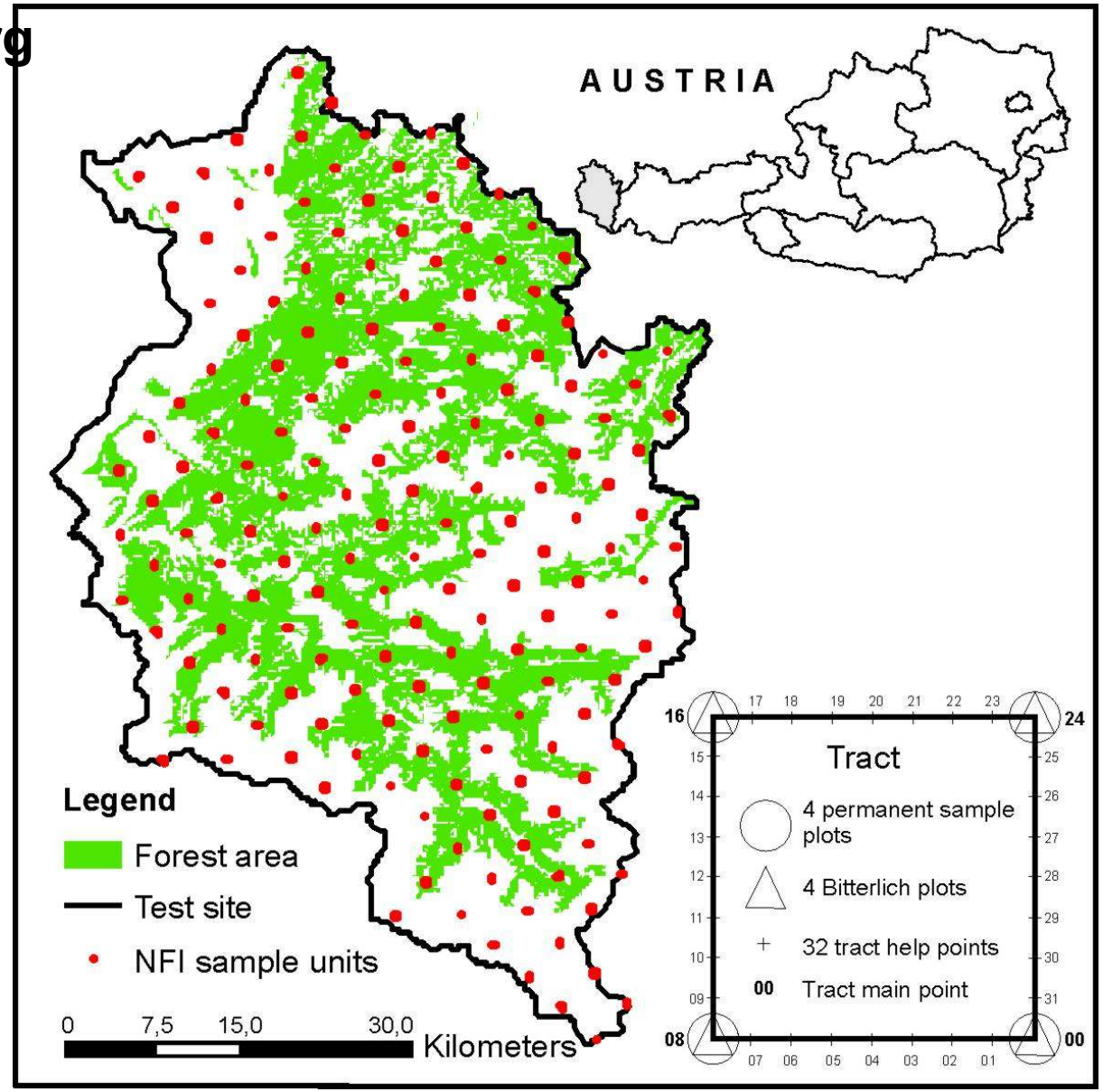




Example Vorarlberg: NFI data

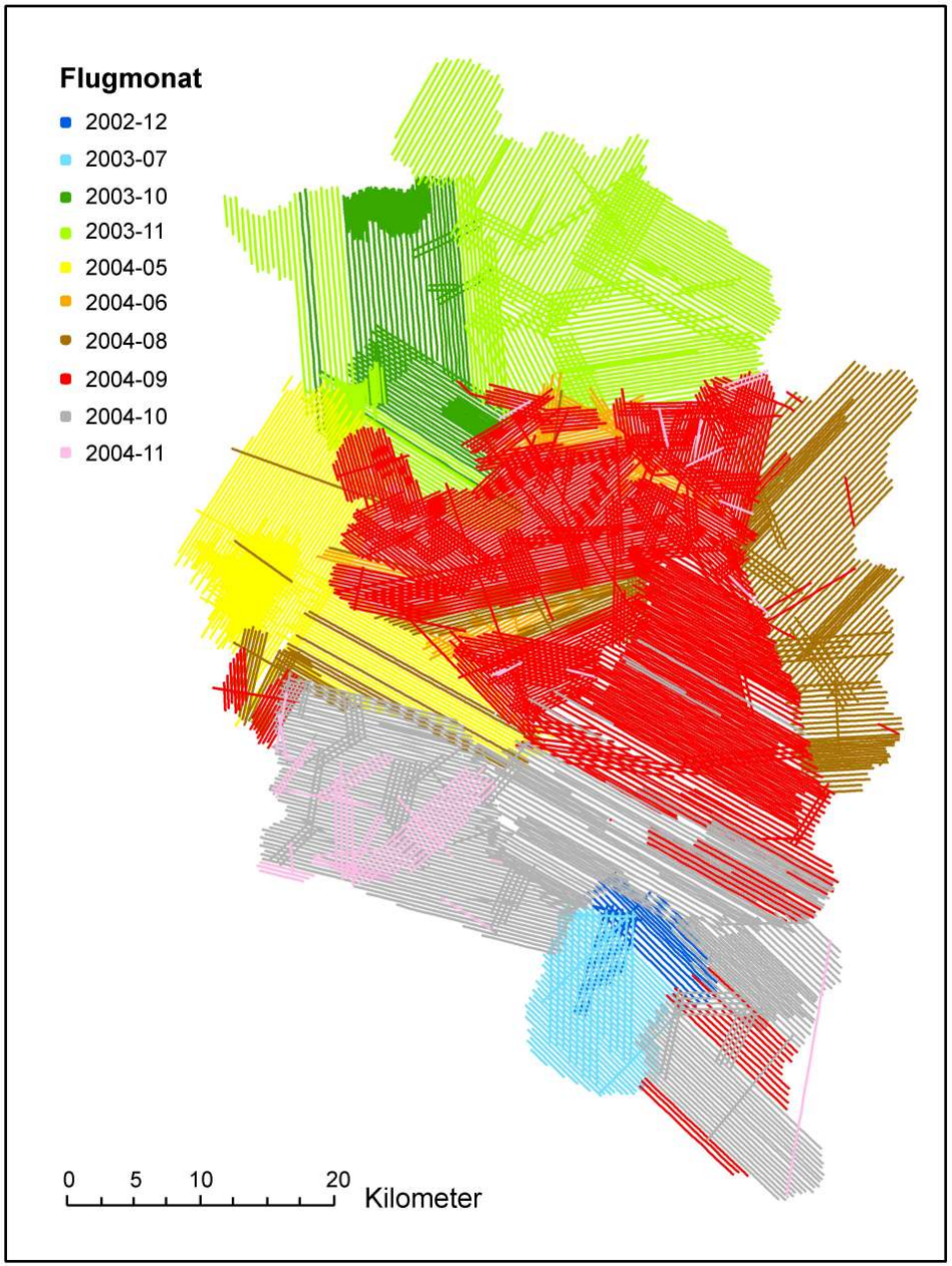
- **Entire district of Vorarlberg**
  - 2 604 km² entire area
  - 970 km² forest area
  - Altitudes: 396 - 3312 m

- **NFI data**
  - 132 Bitterlich plots
  - Tree-based parameter
    - Position, species, bhd, height
  - Area-based parameter
    - Stem volume [m³/ha]



Example Vorarlberg: ALS data

- Data acquisition within the framework of a commercial terrain mapping project
- Acquisition time: 2002-2004
- Higher altitudes in summer under snow free conditions
- Lower altitudes in autumn, winter, spring with leaf-off condition
- Point densities: 1-4 p/m²
- Flying heights: ~650 to 2000 m
- Different ALS sensors:
  Optech ALTM 1225 & 2050, Leica ALS50
- Complex flight pattern due to the difficult topography
- Exact georeferencing is required
- The derived topographic models (DTM, DSM, CHM) have a spatial resolution of 1 m



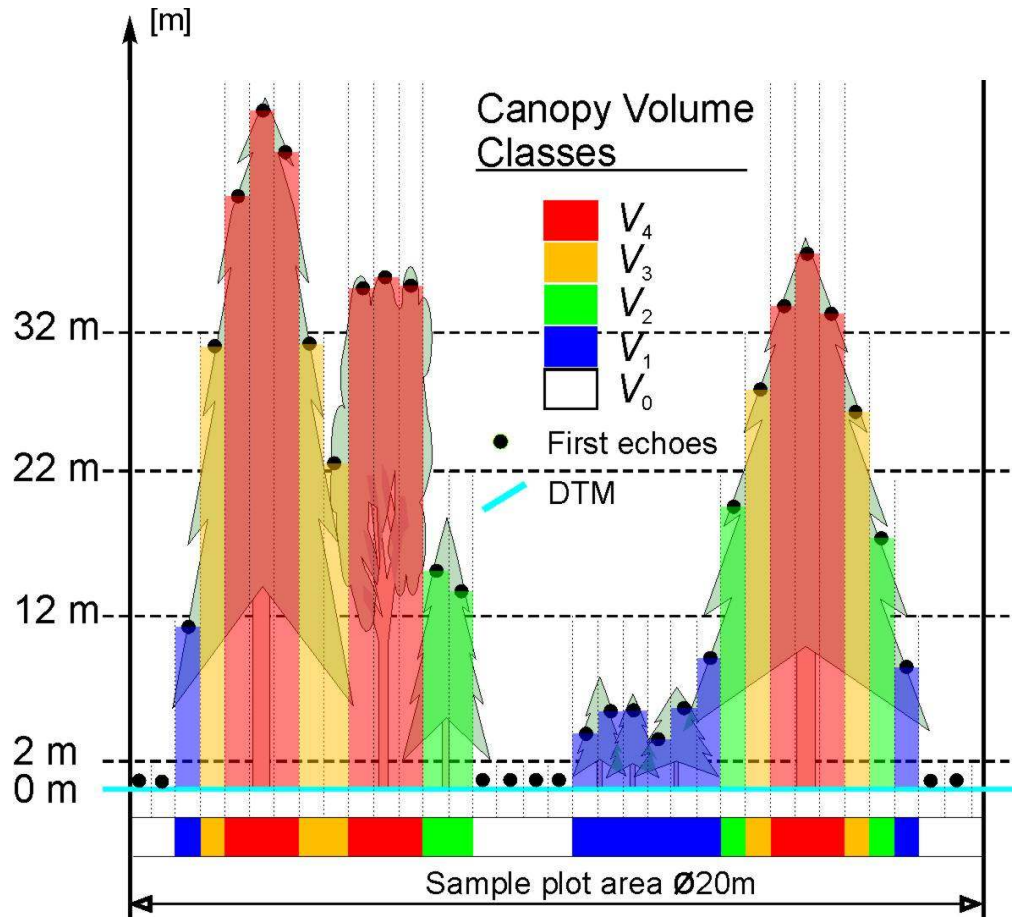
Empirical stem volume model: concept

- **Stem volume = f(canopy volume)**

$$v_{\text{stem,fi}} = \sum_{i=1}^{n} \beta_i \cdot v_{\text{can},i}$$

$$v_{\text{can},i} = f_{\text{first-echo},i} \cdot ch_{\text{mean},i}$$

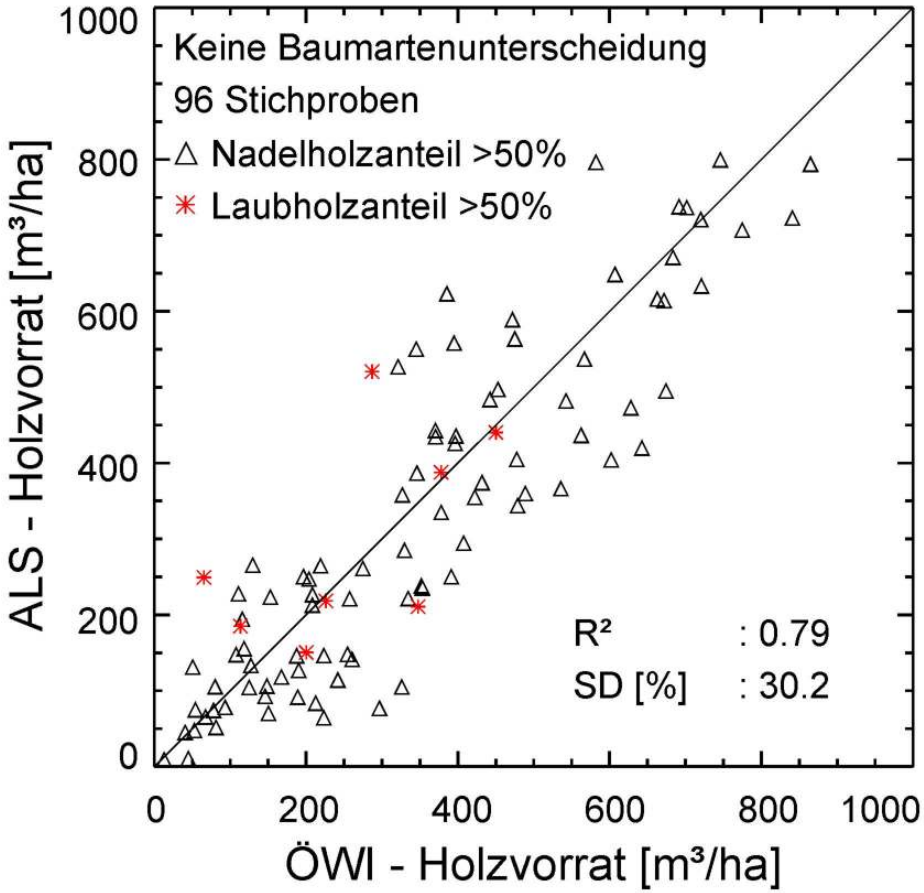
$v_{\text{stem.fi}}$	Stem volume - forest inventory data [m³/ha]
β_i	*Unknown model parameters*
n	Number of canopy height classes
$v_{\text{can},i}$	Canopy volumes for the canopy height classes *i* [m³/ha]
$ch_{\text{mean},i}$	Mean canopy height for the canopy height classes *i* [m]
$f_{\text{first-echo},i}$	Percentage of first echoes within the canopy height class *i* [-]



- **V_{can} calculated from CHM of Ø20m around center NFI plot**

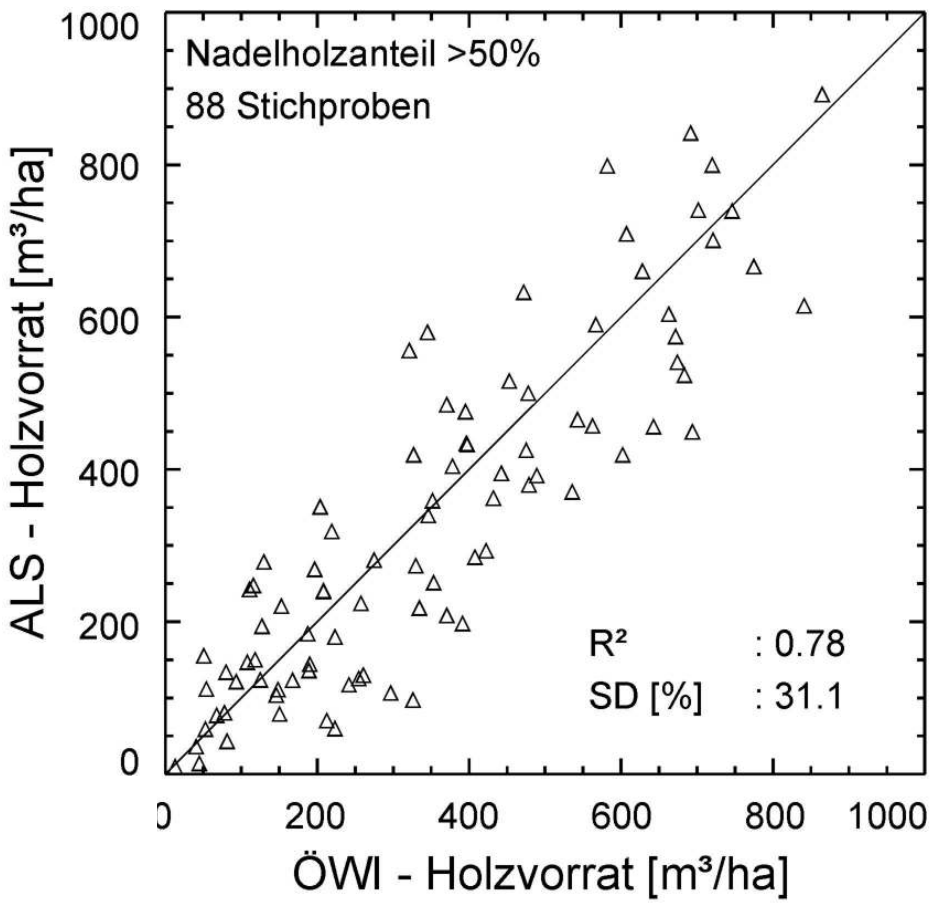
Stem volume model – calibration (I)

- **Calibration of the stem volume model with NFI sample data**
  The stem volume estimation is based on the 3D first echo laser points

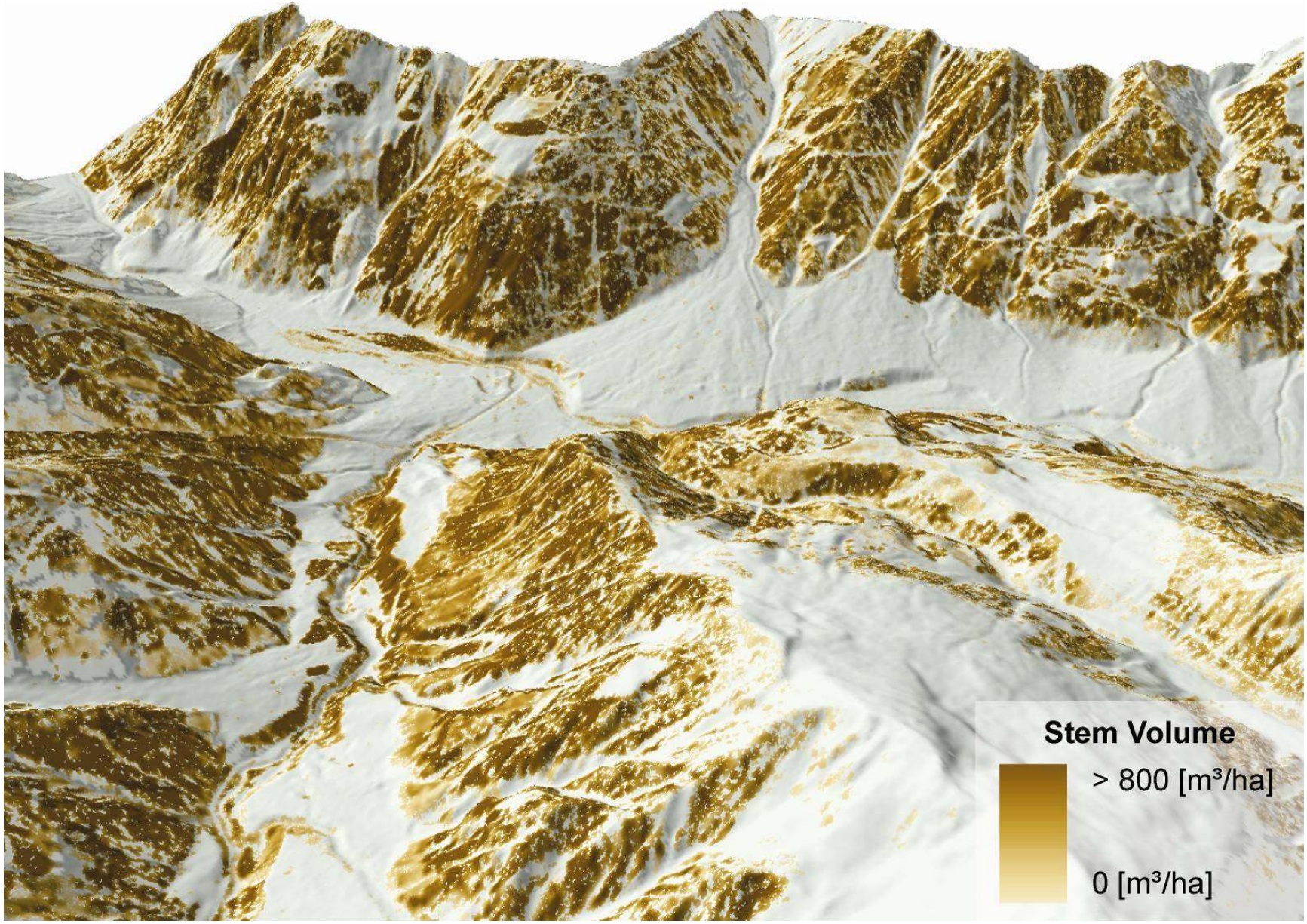


Stem volume model – calibration (II)

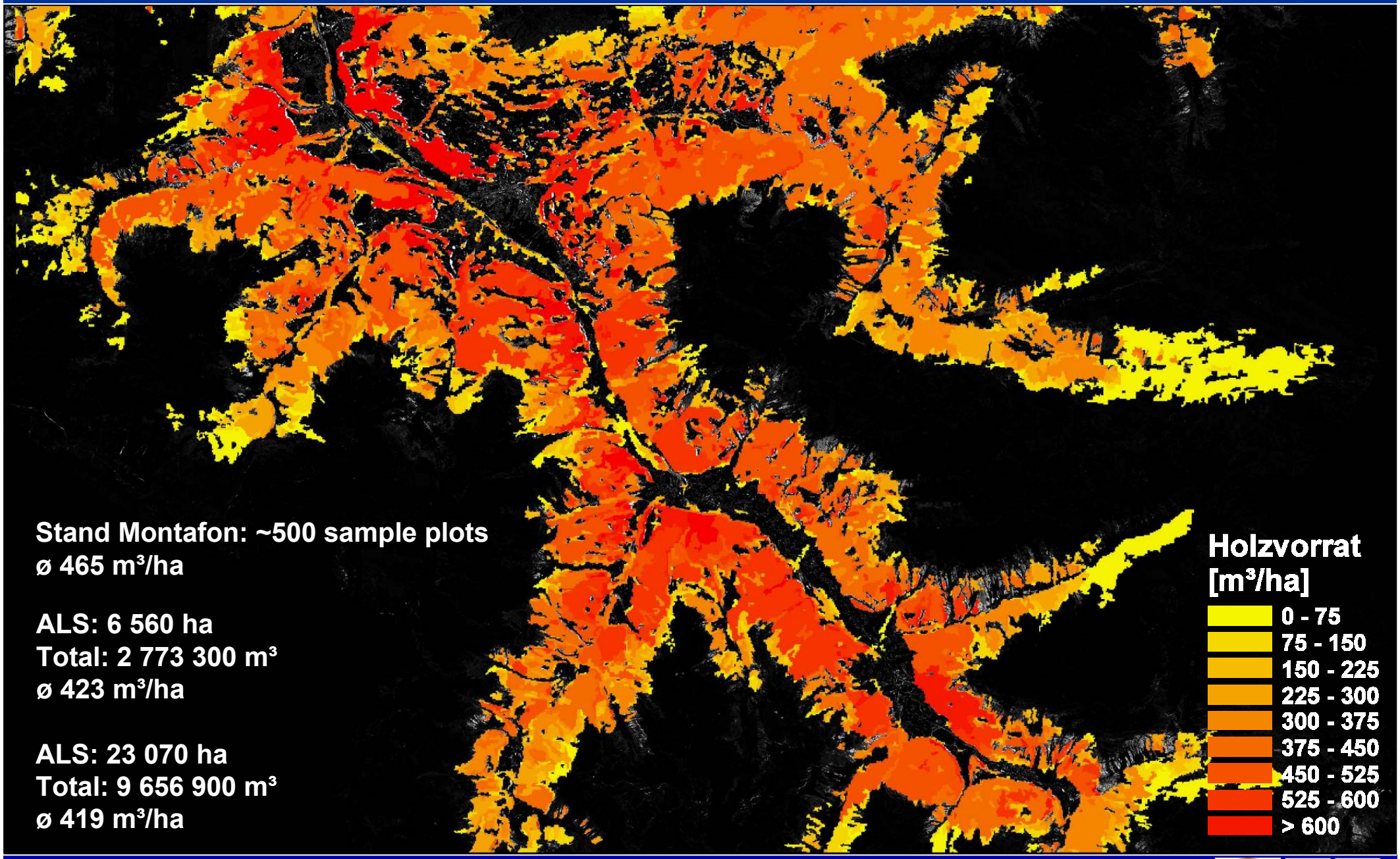
- **Calibration of the stem volume model with NFI sample data The stem volume estimation is based on the nDSM (pixel size 1m)**



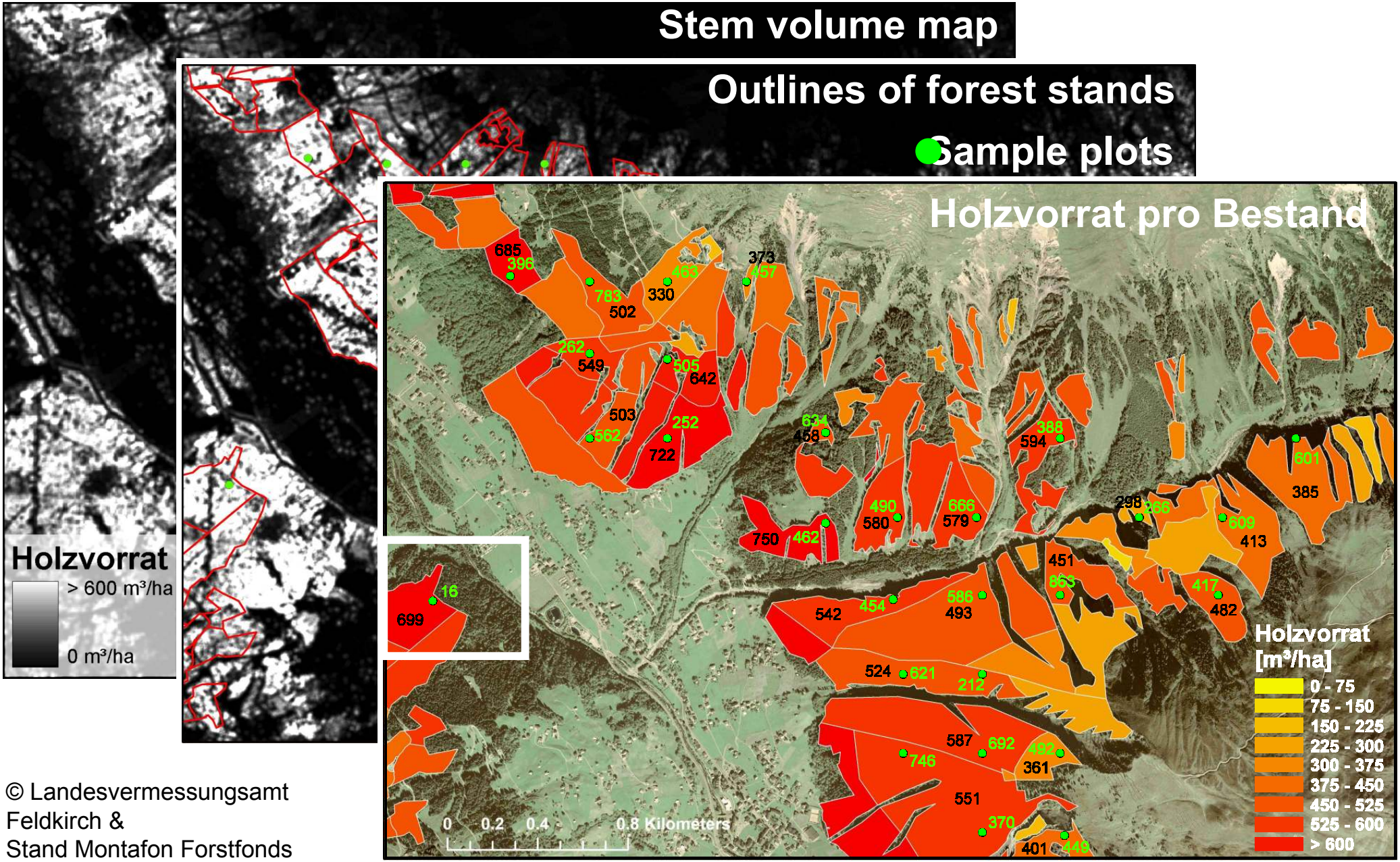
Stem volume map



Validation


Stand Montafon: ~500 sample plots
ø 465 m³/ha
ALS: 6 560 ha
Total: 2 773 300 m³
ø 423 m³/ha
ALS: 23 070 ha
Total: 9 656 900 m³
ø 419 m³/ha
Holzvorrat
[m³/ha]
0 - 75
75 - 150
150 - 225
225 - 300
300 - 375
375 - 450
450 - 525
525 - 600
> 600

Application



Summary and outlook

- **Multiple-shift usage of ALS data**
  - Topographic models (DTM, DSM), buildings, power lines, parameters for vegetation, …
  - Competition between ALS data acquisition companies → decreasing data costs → **quality!!**
- **Operational parameters from ALS**
  - Forest area mapping
  - Single tree detection – if the ALS point density is high enough (e.g. > 5 points/m² → depending on the forest types / structure)
  - Tree height estimation
  - Stand heights, crown cover, …
  - Stem volume / biomass estimation for large areas
- **Future work**
  - Transfer of the presented algorithms to deciduous forests
  - Use of new laser scanner sensors e.g. Full-Waveform laser scanner data (amplitude, echo width, backscatter cross-section, …)