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and Landscape Information Systems
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Applications of Laserscanning in Forestry

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Overview

1. **Introduction to ALS in Forestry**

2. **Applications of Laserscanning**

   2.1 Single Tree Delineation

   2.2 Forest Stand Mapping

   2.3 Estimation of Forest Characteristics

3. **Software Demonstration**

   **TreesVis - processing, analyzing and visualisation of laserscanning data**

- **Faculty of Forest and Environmental Sciences**

- **University of Freiburg i. Breisgau, Germany**

- **Teaching and Research:**

→ **Remote sensing applications in forestry and relevant neighbouring disciplines (e.g. nature conservation, landscape planning)**
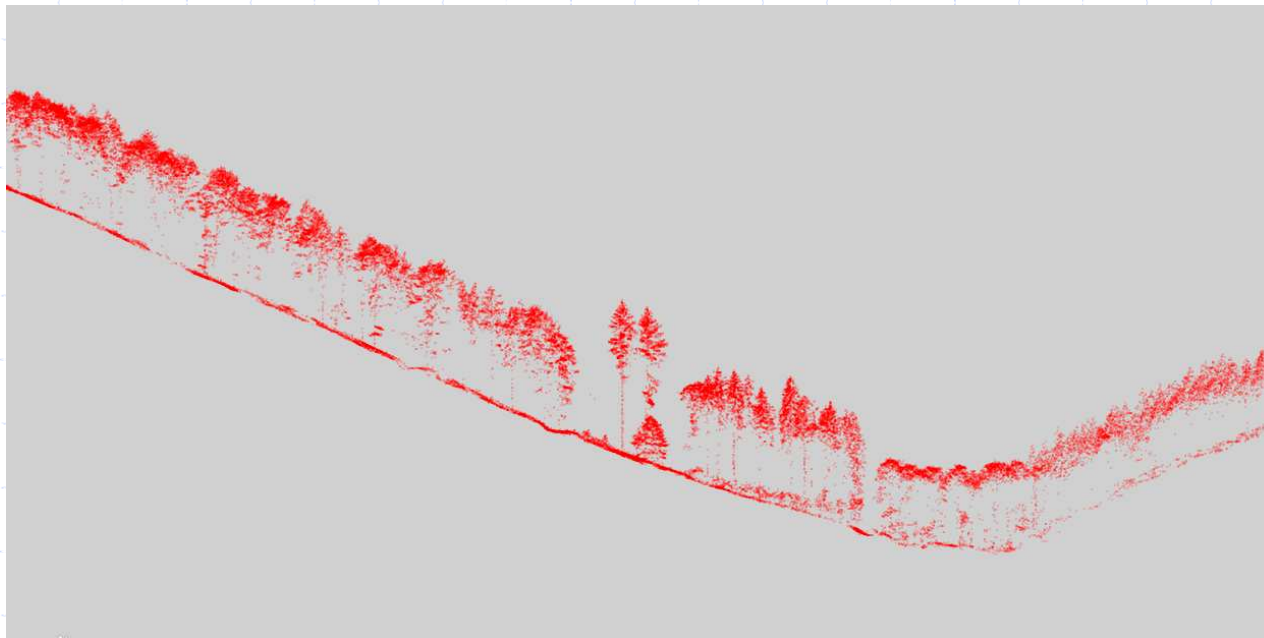
GERMANY

Freiburg

1. Introduction

Why is Airborne Laserscanning (ALS) interresting for forestry?
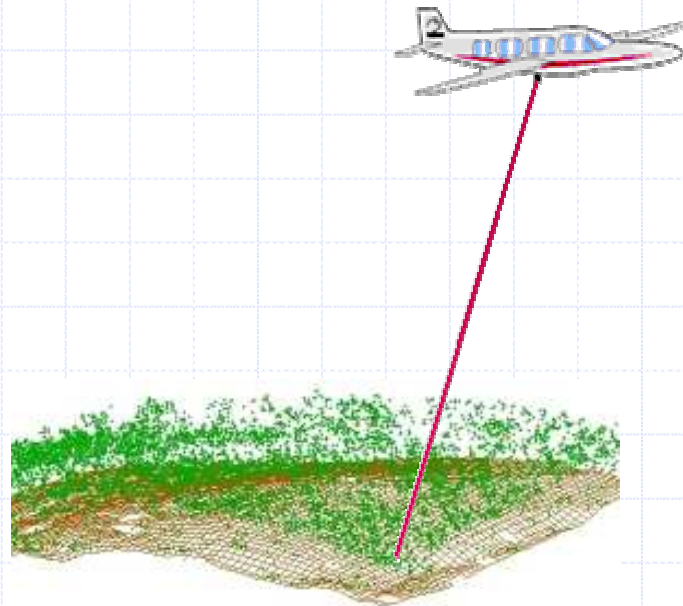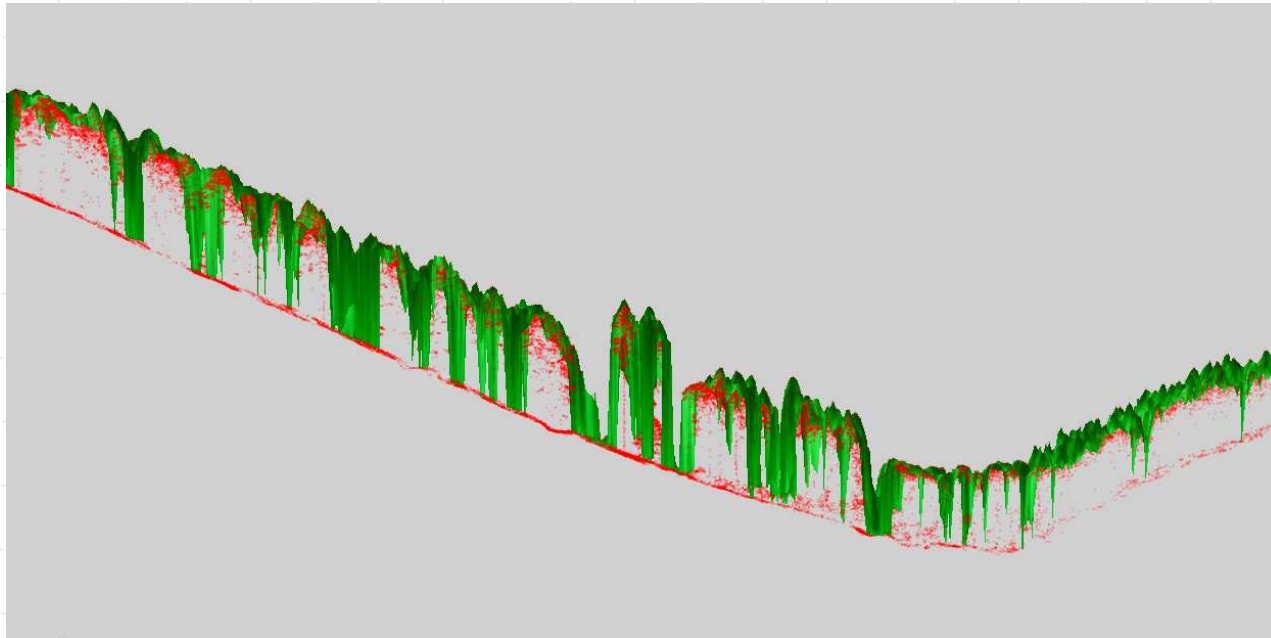
1. Introduction

Raw Data - Profile:
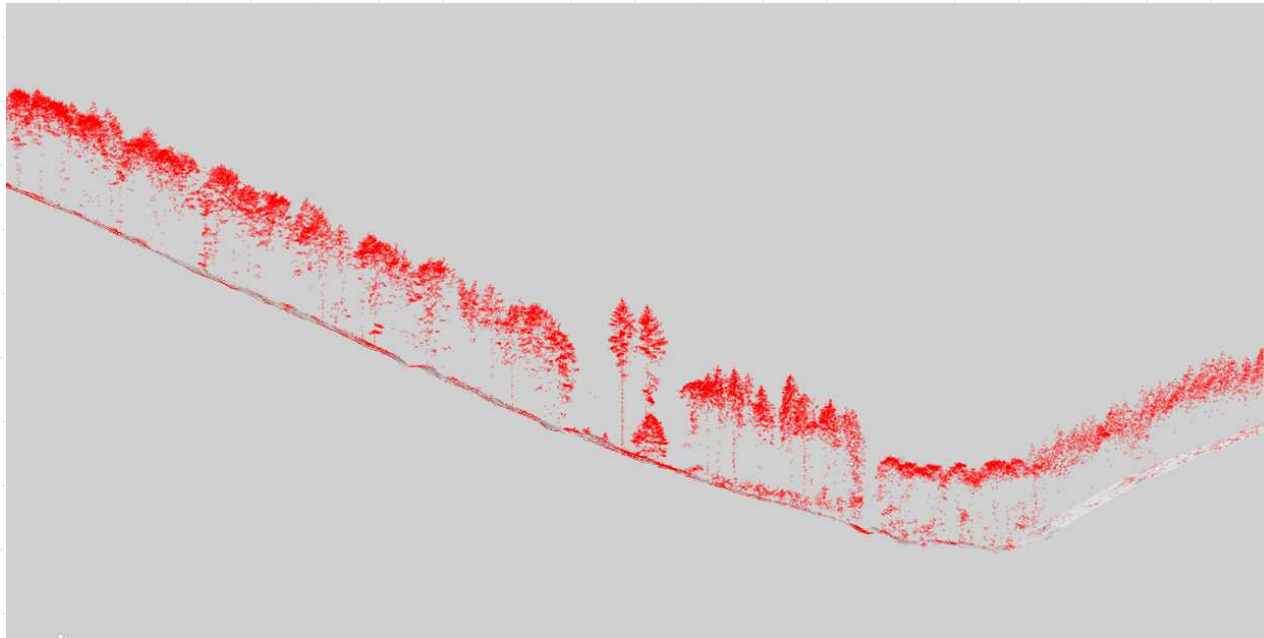

Fullwave, IGI LiteMapper 5600, Summer 2005

1. Introduction

DSM:

Active Surface Algorithm (Weinacker 2004)
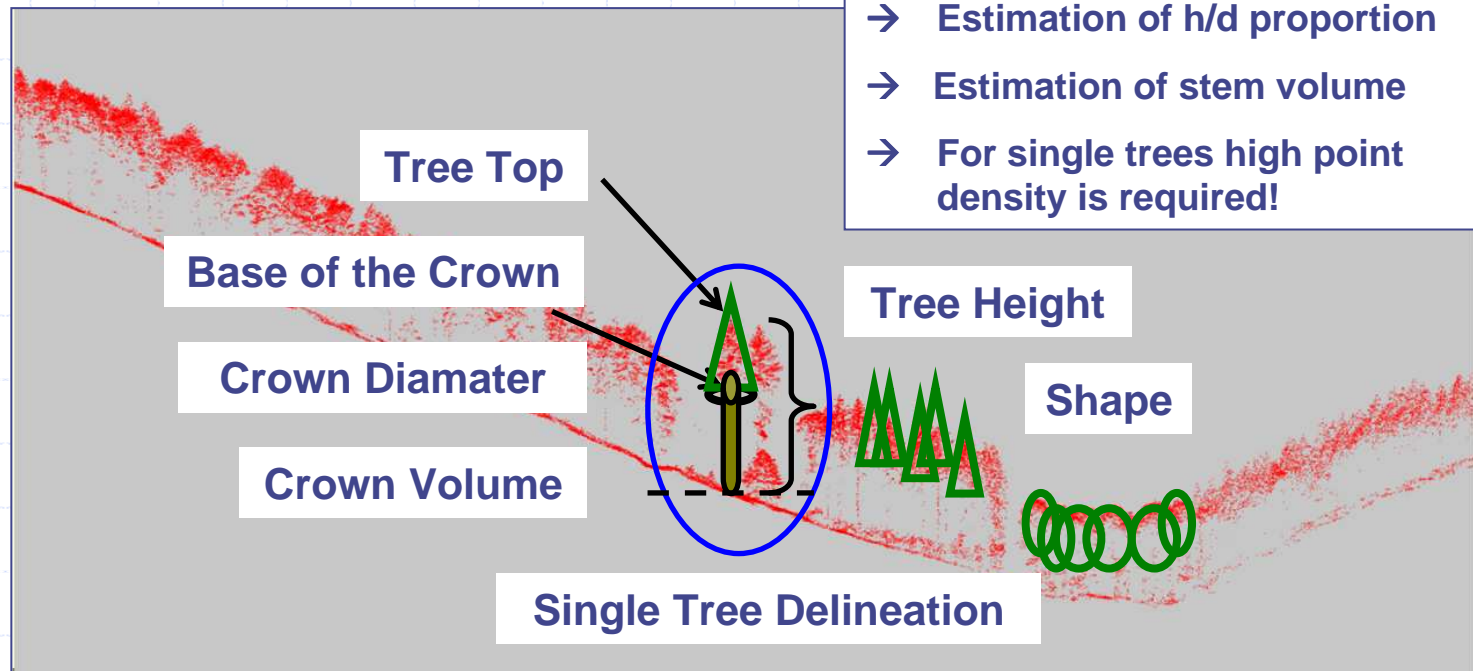
1. Introduction

DTM:

Active Surface Algorithm (Weinacker 2004)
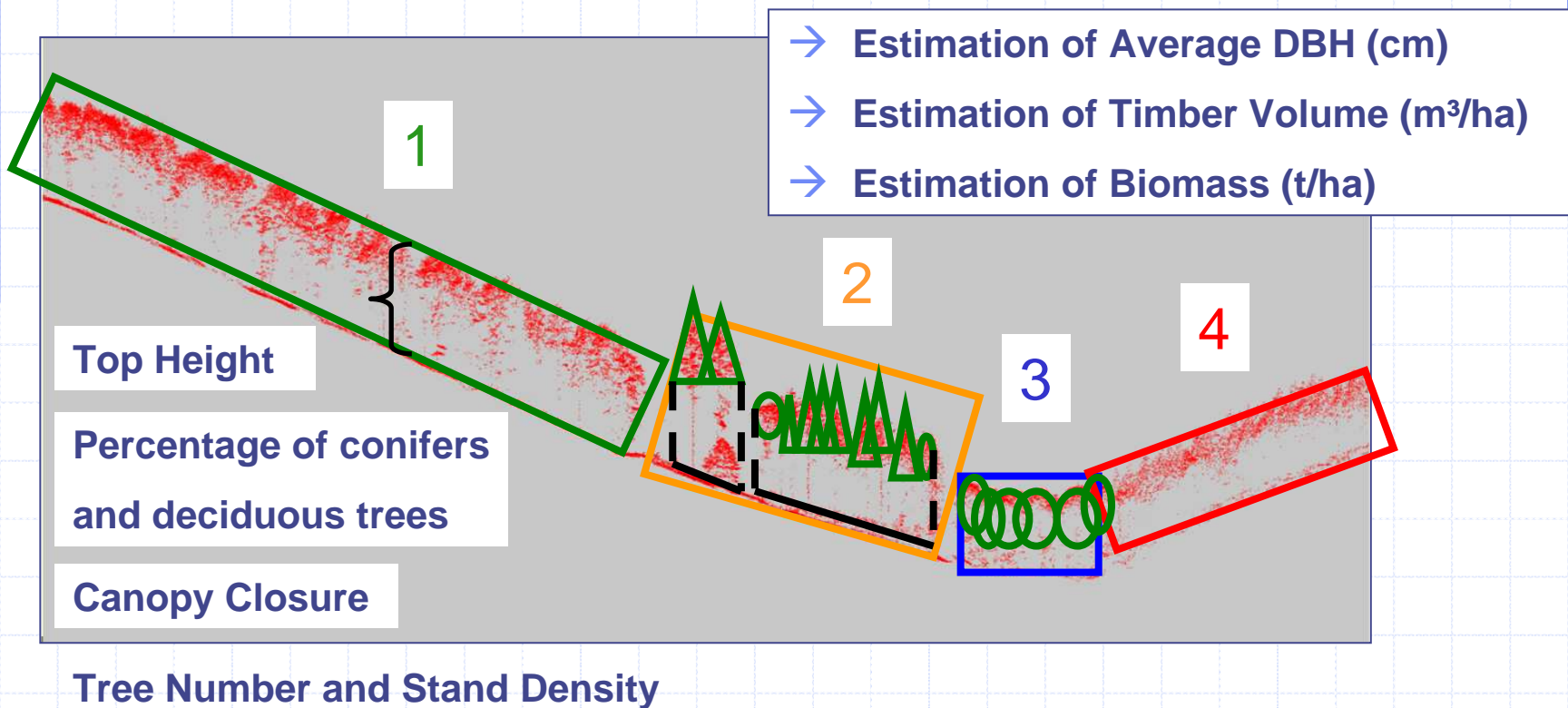
1. Introduction

Single Trees:

→ **Estimation of DBH (The stem diameter of a tree measured at breast height (1.3 meters above ground level))**

→ **Estimation of h/d proportion**

→ **Estimation of stem volume**

→ **For single trees high point density is required!**

Tree Top

Base of the Crown

Crown Diamater

Crown Volume

Tree Height

Shape

Single Tree Delineation

Fichte

Buche

→ **Classification into conifers and deciduous trees; (during winter: penetration rate);**

In boreal forest: differentiation of birch, spruce, pine
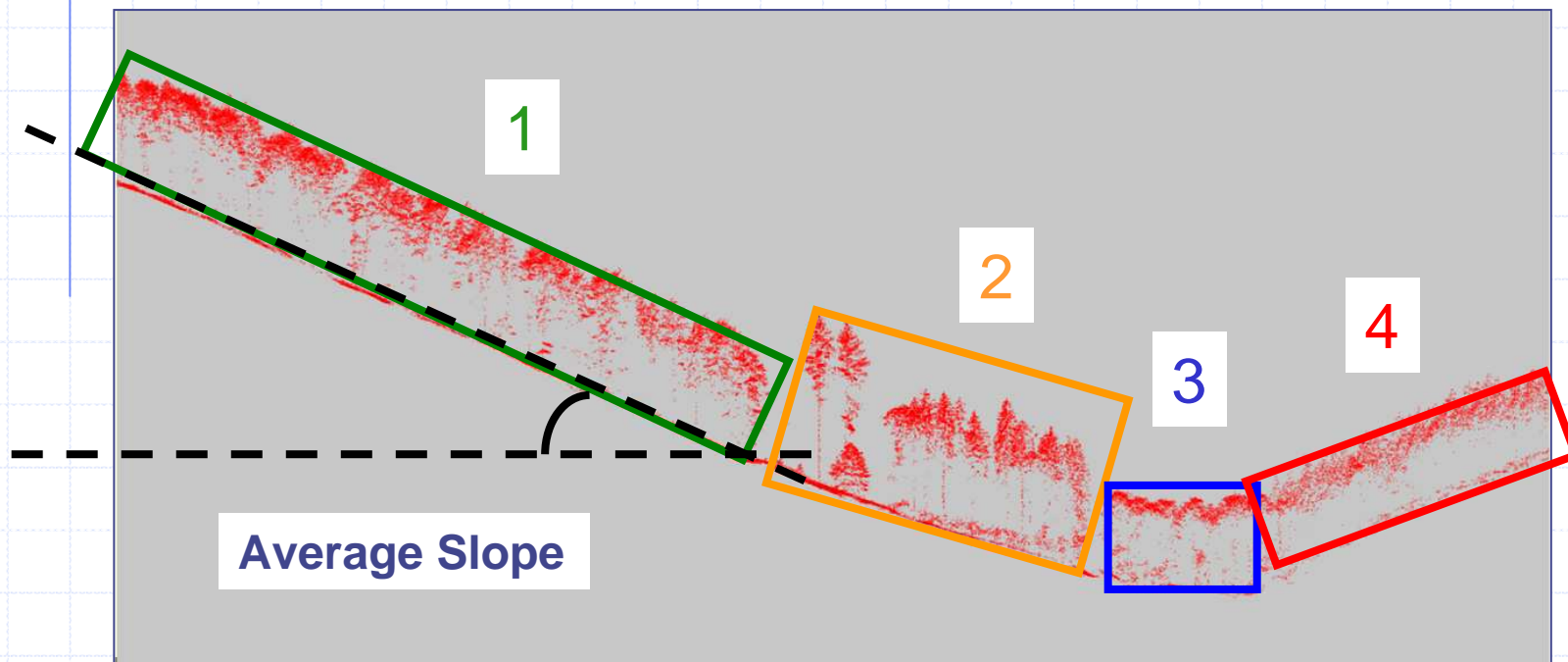
→ **Species with spectral image data (RGB and CIR)**

1. Introduction

Forest Stands (management units):

→ **Estimation of Average DBH (cm)**

→ **Estimation of Timber Volume (m³/ha)**

→ **Estimation of Biomass (t/ha)**

1

2

3

4

Top Height

Percentage of conifers and deciduous trees

Canopy Closure

Tree Number and Stand Density

1. Introduction

Forest Stands (management units):

1

2

4

3

Average Slope

1. Introduction

→ **Applicability of automated harvesting methods**

→ **Harvester (machine that fells trees, delimbs them and crosscuts**
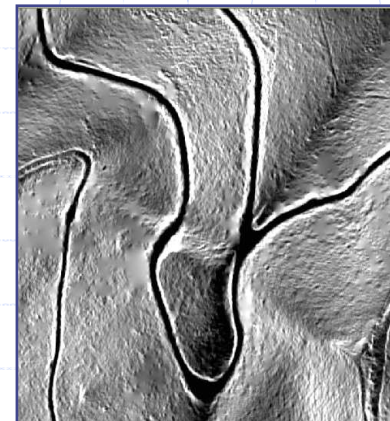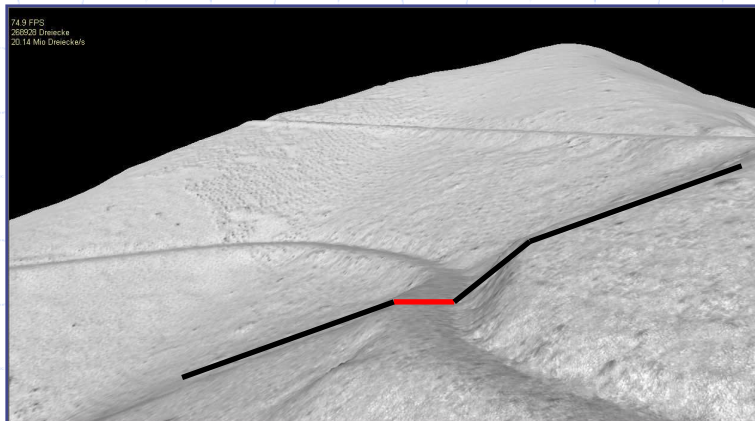
  them into logs):

→ **Steepness of terrain and DBH are limiting factors for highly automated harvesters (Heisig et al. 2005)**

1470D Rad Harvester

Forsttechnik GmbH (John Deere)

http://www.forstgmbh.at

1. Introduction

Forest Roads:

Local Slope in %:
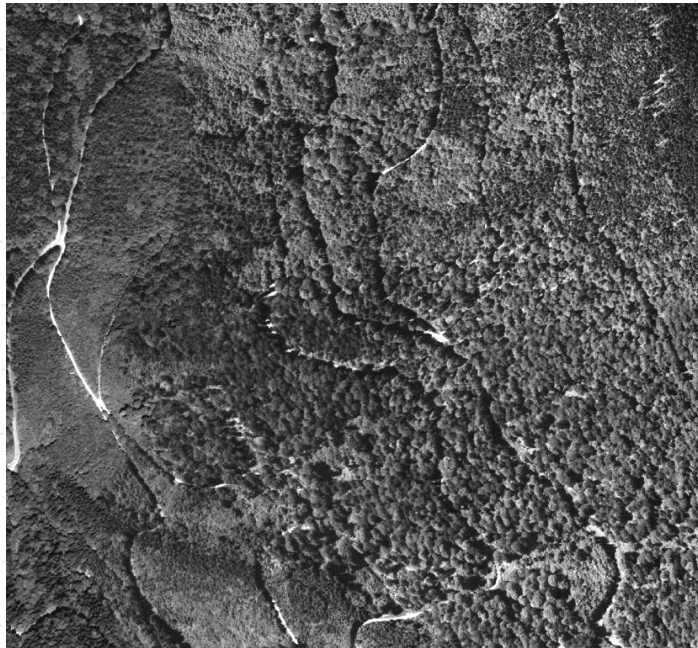
low   high

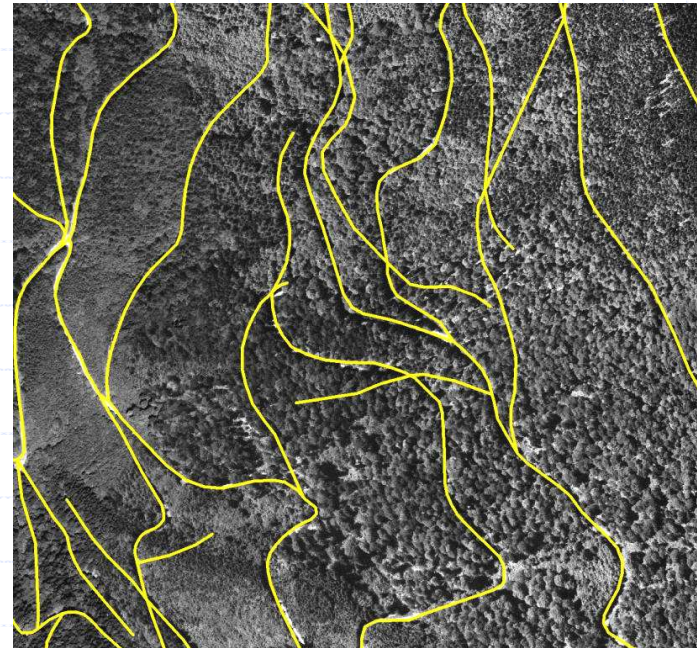**The documentation of the road and path network in the forest:**
→ precondition for an optimization of timber transport
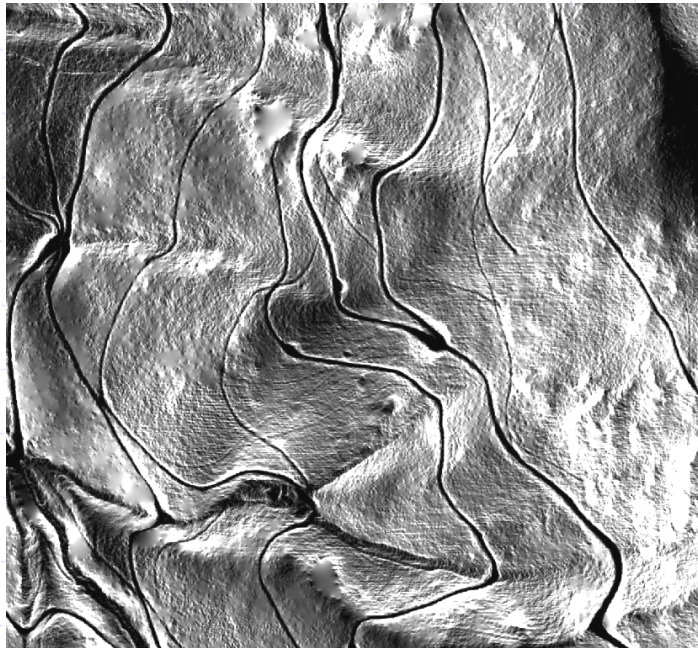**→ high importance for soil conservation**

1. Introduction

Orthoimage
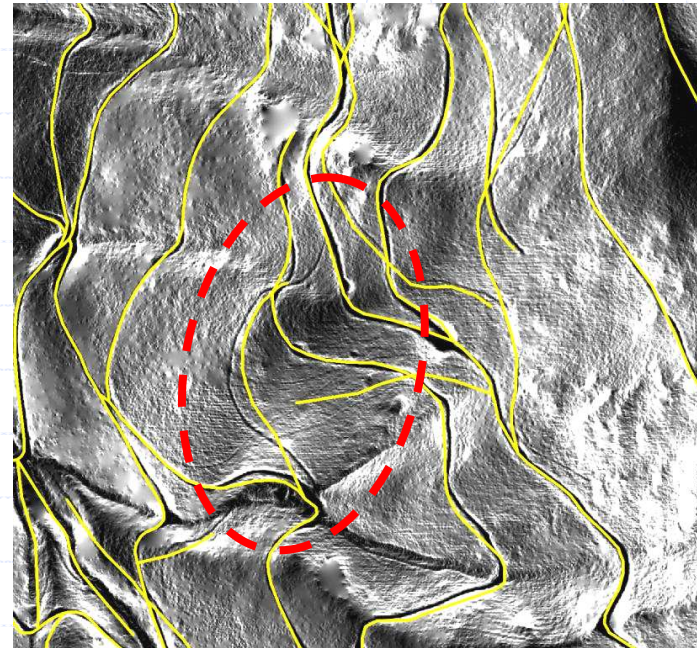

Orthoimage with roads

as digitized line features
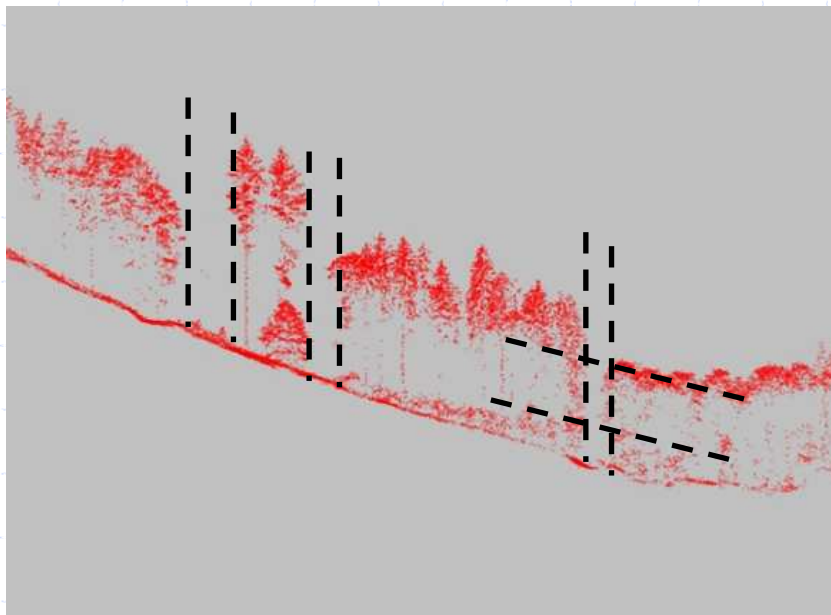
1. Introduction

Slope image from LIDAR

→ **Accuracy can be improved**

→ **With LIDAR additional attributes can be collected e.g. slope per road segment, road width ...**

1. Introduction

**Nature Conservation – Biodiversity / Stand Structure:**

→ **Gaps in forest stands are important ecological elements and can support the biodiversity of forest ecosystems**

→ **Multi-storied forest stands support high diversity and thus biodiversity**

→ **Modelling of habitat quality**

1. Introduction

→ **In Scandinavia (Norway): LIDAR is already used for forest inventories (Næsset 2002)**

→ **In Germany: LIDAR for forest inventories is still a research topic; in the moment: terrestrial surveys → expensive**
   → LIDAR as an alternative to support or even replace field measurements (?)

→ **Orthoimages are used for forest stand mapping (costs are reduced 30-40%)**

→ **Monitoring of forest damages e.g. bavarian national park (insects, fire, windstorm…)**

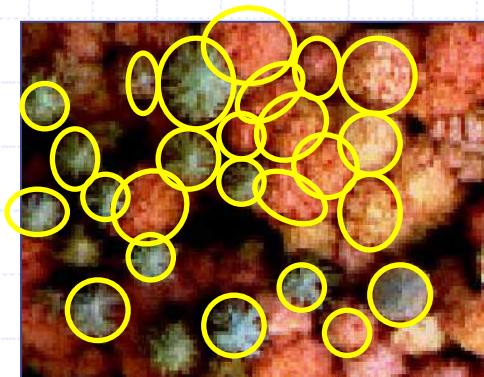# 2. Applications of Laserscanning

2.1 Automatic Single Tree Delineation
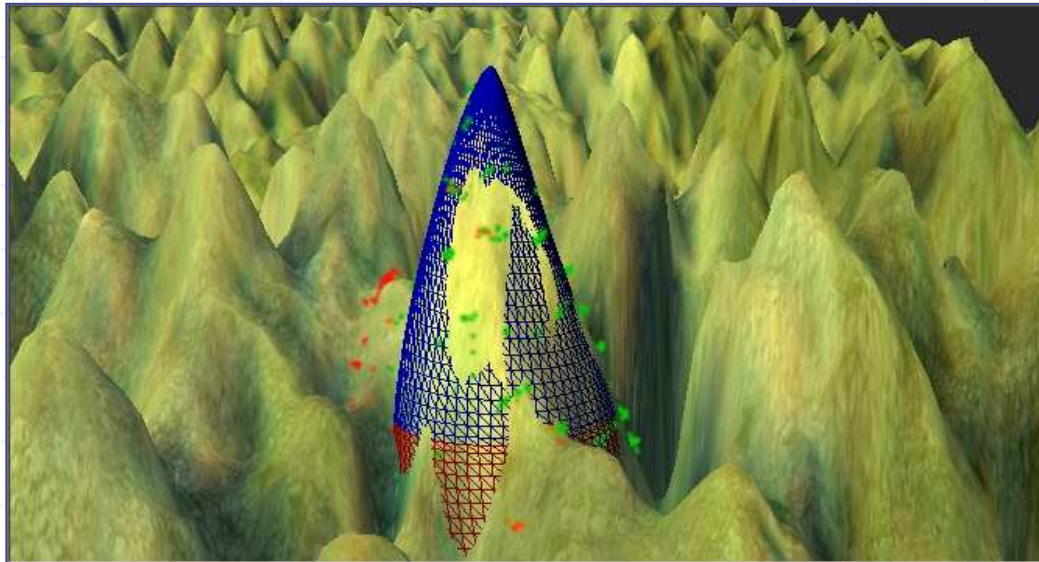
2.1 Automatic Single Tree Delineation

→ **A difficult task.**

→ **No straight lines, no right angles, no planes, overlapping crowns, many different crown shapes and sizes:**

2.1 Automatic Single Tree Delineation

Different approaches for automatic single tree delineation – some examples:

- **HIGH-SCAN Project: First European wide attempt to derive single tree information from laserscanner data (Hyyppä 2001)**
- **Swedish Defence Research Agency: Algorithm for boreal trees (Persson 2001, Persson et al. 2002)**
- **FeLIS: Algorithm developed under German conditions (Koch et al. 2006)**

→ **"Watershed Segmentation": Segmentation of an image by means of a flooding simulation (Soille 1999)**
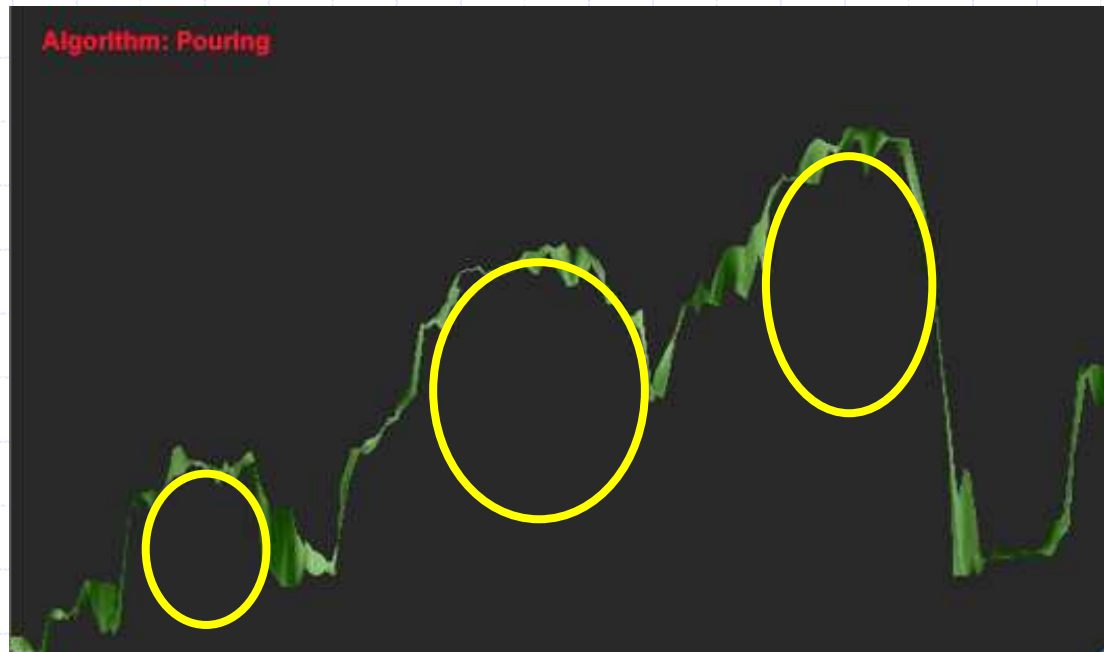
2.1 Automatic Single Tree Delineation

FeLIS - Single Tree Delineation (main processing steps):

1. **INPUT: Rasterized laser data (DSM/DTM)**

2. **DSM is smoothed (Gaussian Smoothing)**

3. **Tree tops are extracted (Local Maxima)**

4. **„Pouring Algorithm" (raindrop model)**

5. **Final detection of crown edges by searching vectors from the tree tops → „Ray Algorithm"**

6. **Knowledge-based assumptions on the shape of trees**

→ **Minimum size**

→ **Minimum distance between tree tops**

→ **Crown shape (compactness, circularity)**
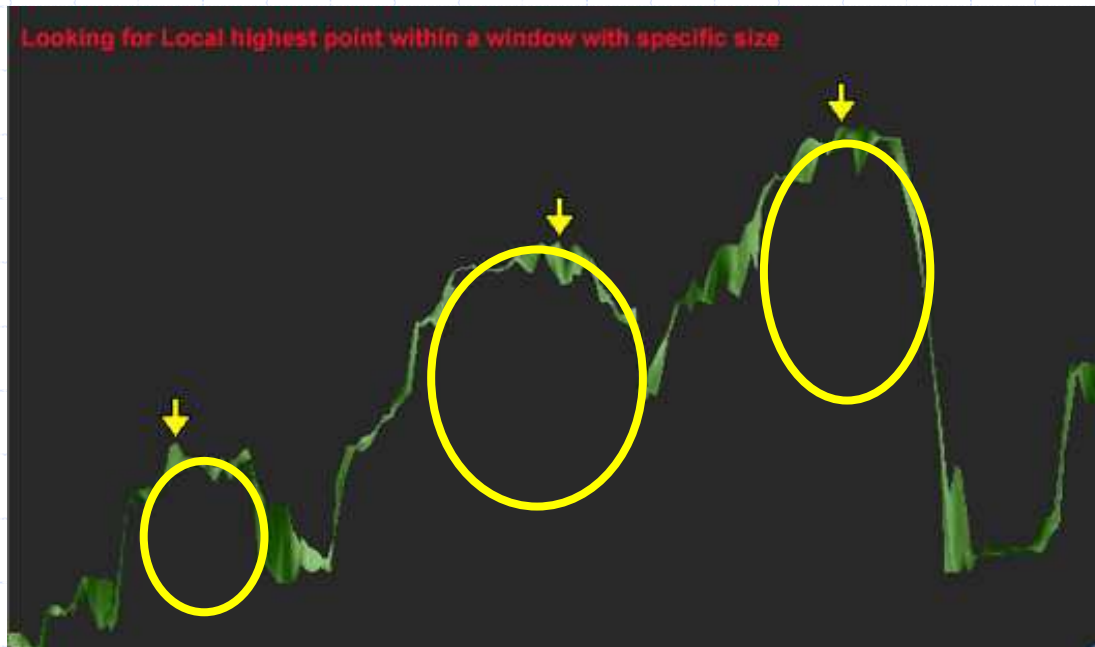
2.1 Automatic Single Tree Delineation

Profile of DSM
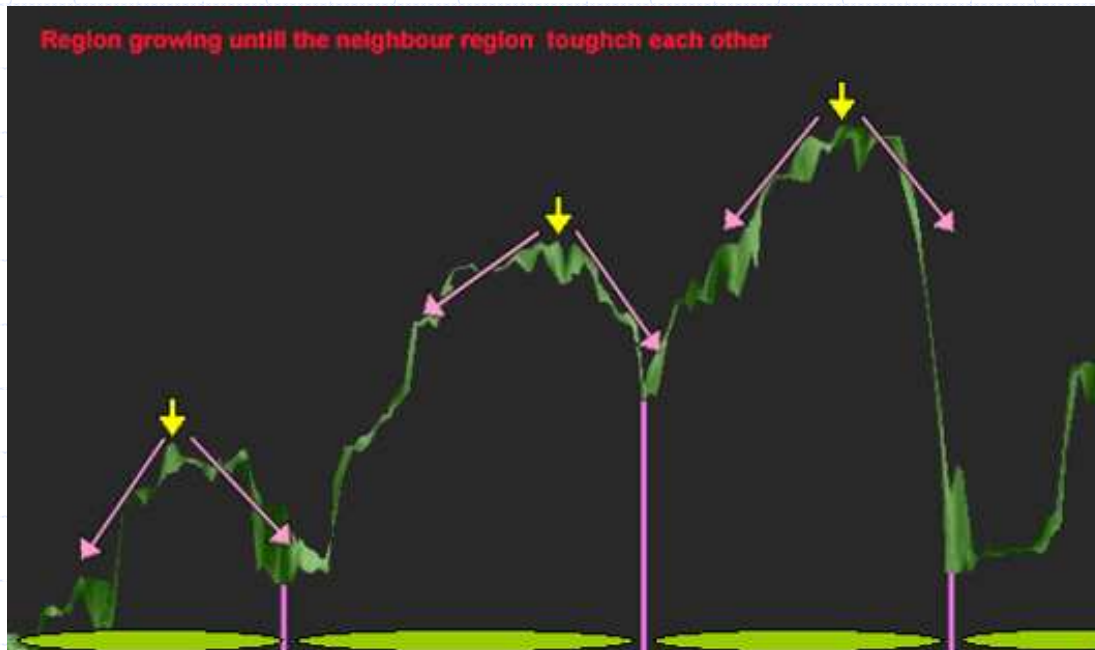
(individual trees are expected within each salient curve)

Algorithm: Pouring

2.1 Automatic Single Tree Delineation

Pouring (first step) - Local Maxima detection:

Looking for Local highest point within a window with specific size

2.1 Automatic Single Tree Delineation

Pouring (second step) – expansion:

Region growing untill the neighbour region toughch each other

1. Maxima are the starting points for an expansion until „valley bottoms" are reached.

2. The expansion is done as long as there are chains of pixels in which the gray value gets smaller (like raindrops running downhill from the maxima in all directions)
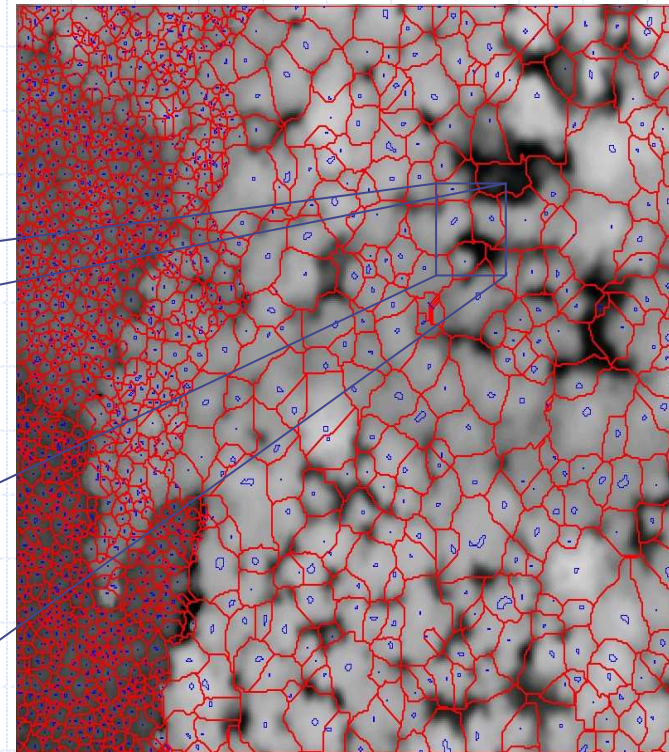
2.1 Automatic Single Tree Delineation

Local Maximum

Result after

„Pouring Operator"
(Individual crowns
can be expected within
each segment. Further
analysis are needed to
extract the exact
shape of crowns)
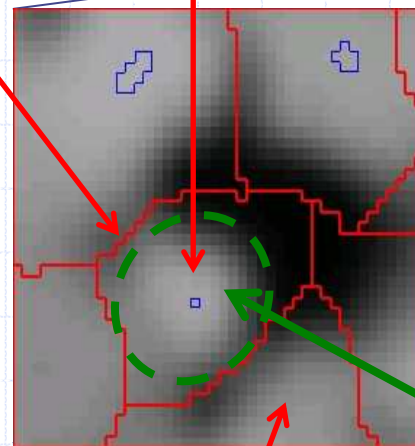
„exact shape"

Smoothed DSM

2.1 Automatic Single Tree Delineation

Extraction of individual crowns (ray algorithm)

End Point:

Border of Crown

New Point

Start Point:
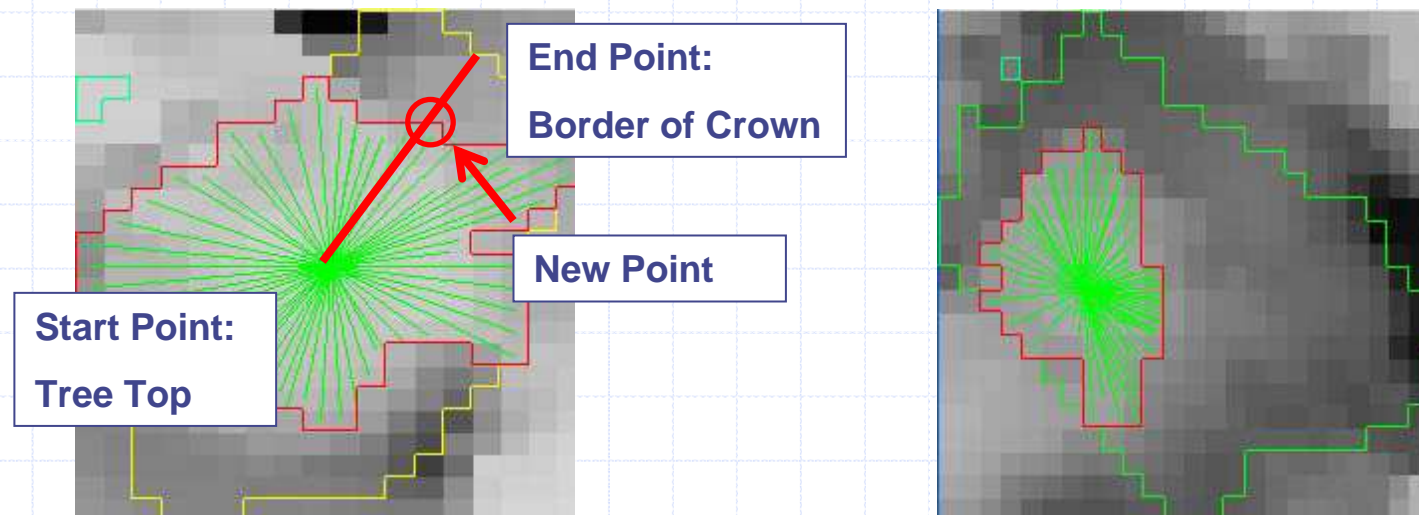
Tree Top

1. **Assumption: The height change within an individual crown must be continuous**
2. **Virtual rays between the tree tops and border points are generated**
3. **New border points of the tree crown are created if there is an interruption of the continuous height changes by pixels with high difference in elevation**

2.1 Automatic Single Tree Delineation

Verification of the algorithm (field measurements):
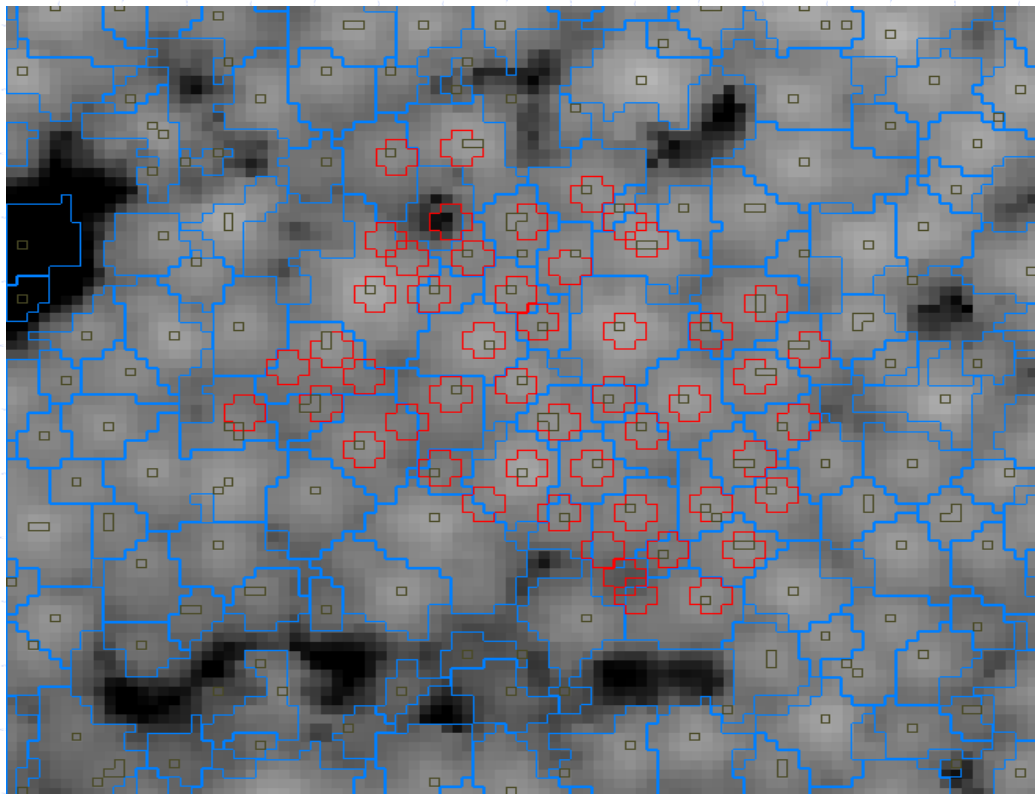
Red: Positions of trees measured with GPS during field work

Blue: Segmentation result

2.1 Automatic Single Tree Delineation

Verification with field measurements:

Coniferous trees (Pseudotsuga menziesii):

No of trees:	Identified correctly:
49	87%

Deciduous trees (Carpinus betulus, Acer pseudoplatanus, Fraxinus excelsior):

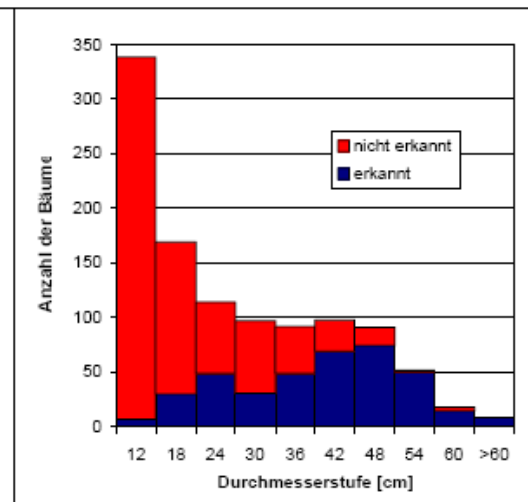| No of trees:	Identified correctly:
49	50%

(Koch et. al 2006)

2.1 Automatic Single Tree Delineation

→ **Verification with 2575 trees**

→ **998 trees were indentified (~39%)**

→ **74.7 % of timber volume**
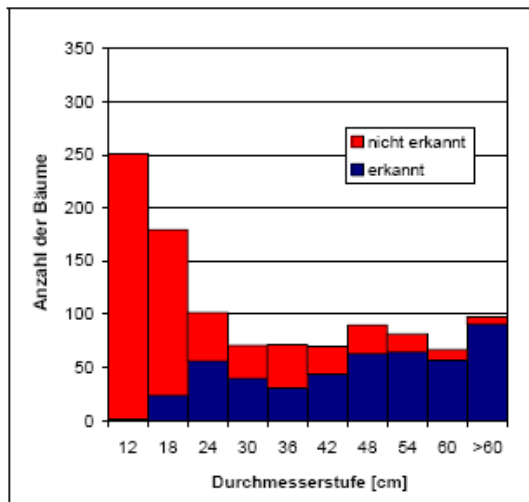
Coniferous trees: **Deciduous trees:**

(from Heurich 2006)

2.1 Automatic Single Tree Delineation

Summary of the verification:

- Good results for conifers

- Problems with small and suppressed trees

- Stem numbers are underestimated

- Most dominant trees are found ($\rightarrow$ trees with high timber volume)

- Crown areas are overestimated

Mean crown area for segmented trees:	Mean crown area for reference trees:
11m²	8.2m²

(Koch et. al 2006)

2.1 Automatic single tree delineation

"New Ideas" (Wang 2007) :

Tree structure is traced from top to bottom:
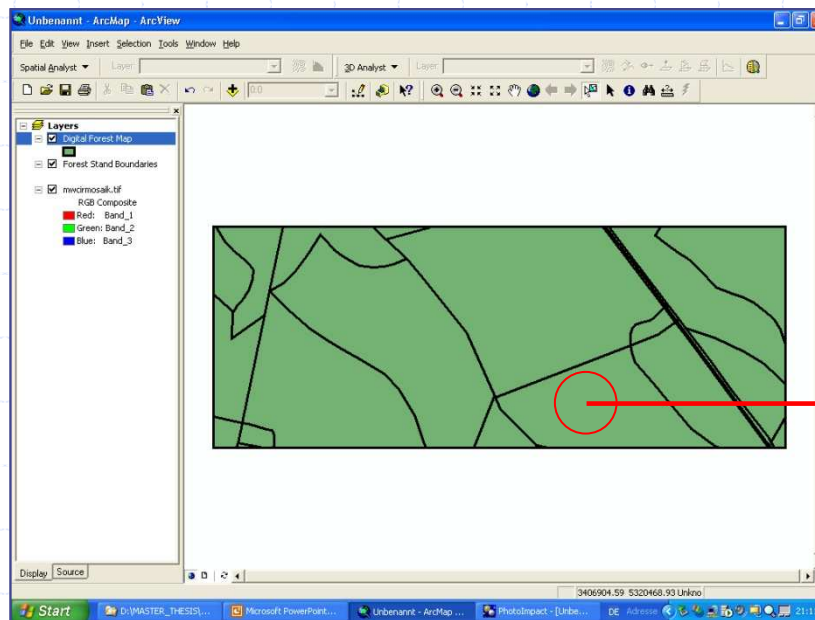
Layer 1

Layer 2

...
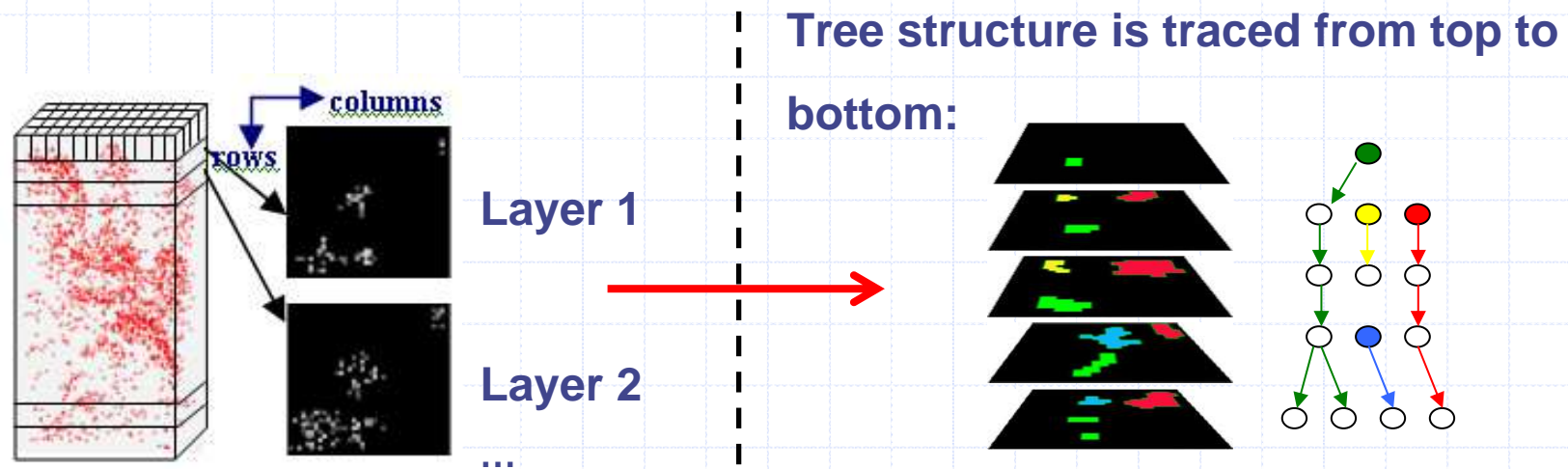
„Voxel-Model" of point cloud

(dividing the area into small three-dimensional cells).

Layers are created and number of lasercanner points is

calculated in each voxel and stored into 2d image.

2.2 Forest Stand Mapping

Digital Forest Stand Maps:

Forest Area is classified into „management units" based on:

- **species**
- **age**
- **structure**
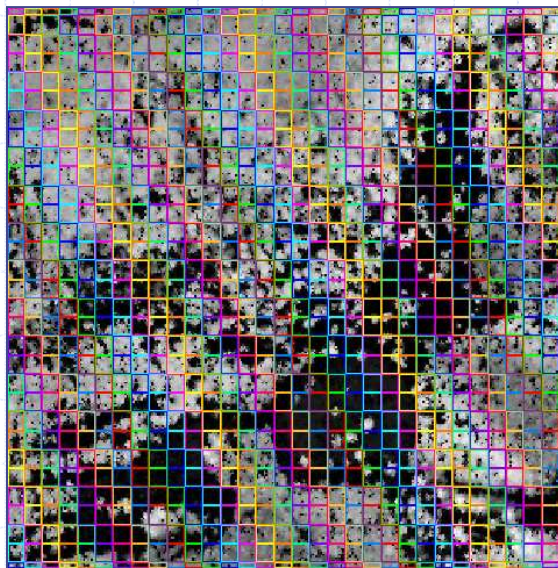- **composition**

Size
Age
Main Tree Species
…

2.2 Forest Stand Mapping

Subdivision of study area into cells (20x20m, nDSM in the background):

Classification of the cells based on:

1. **Percentage of conifers, deciduous trees and forest floor**

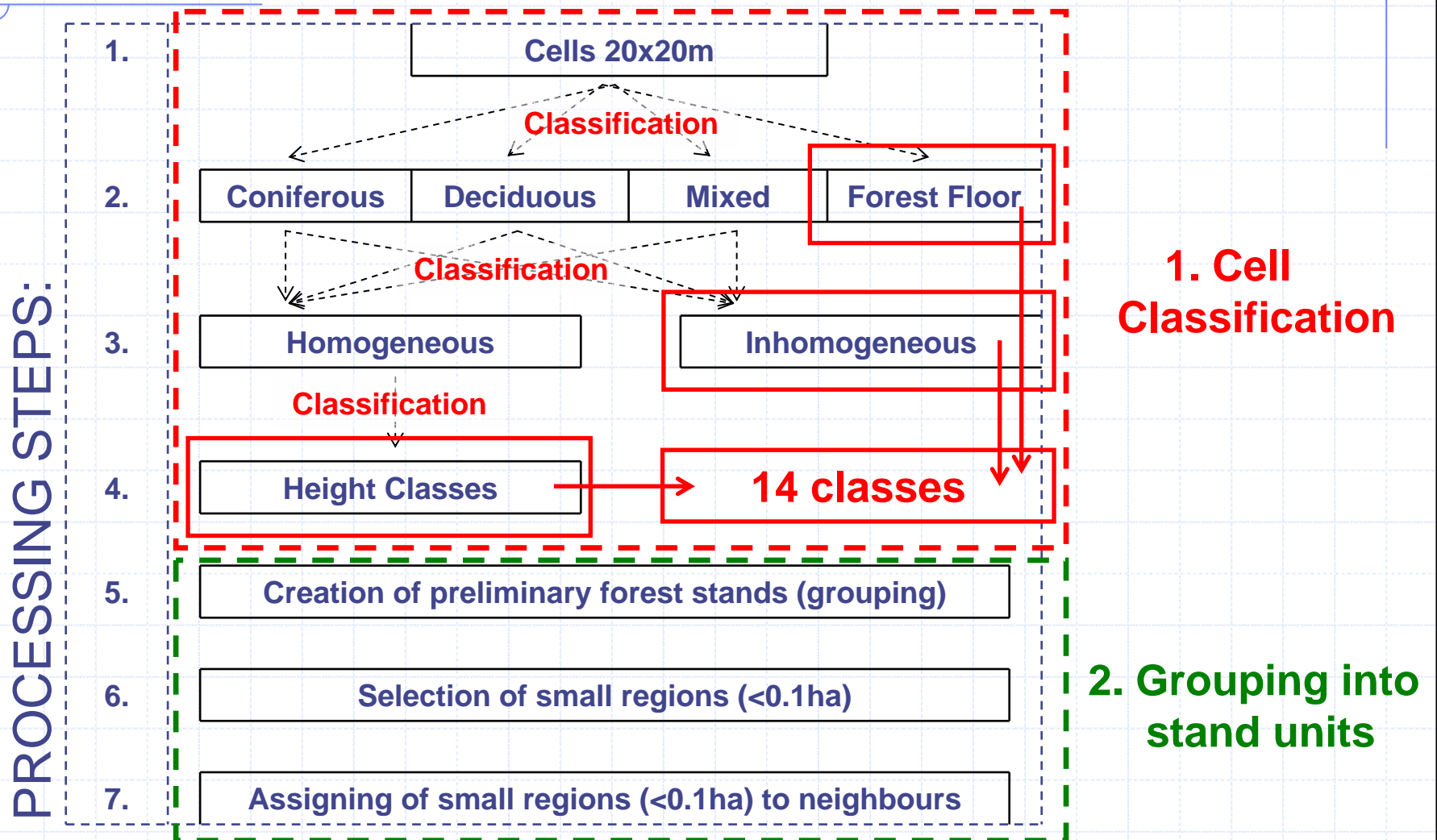→ **Classes: Conifers-, Deciduous-, Mixed, Forest Floor**

2. **Surface Roughness (variation of height values):**

→ **Classes: homogeneous, inhomogeneous**

3. **Height Classes:**

Dev. Stage	Height
Sapling	3-10 m
Pole	10-15 m
Mature Trees	15-25 m
Old Trees	> 25 m

2.2 Forest Stand Mapping

PROCESSING STEPS:

1. Cells 20x20m

Classification

2. Coniferous | Deciduous | Mixed | Forest Floor

Classification

3. Homogeneous | Inhomogeneous

Classification

4. Height Classes → **14 classes**

5. Creation of preliminary forest stands (grouping)

6. Selection of small regions (<0.1ha)

7. Assigning of small regions (<0.1ha) to neighbours

1. Cell Classification

**2. Grouping into stand units**

2.2 Forest Stand Mapping

Example for stand mapping (during winter (leaf-off) conditions):

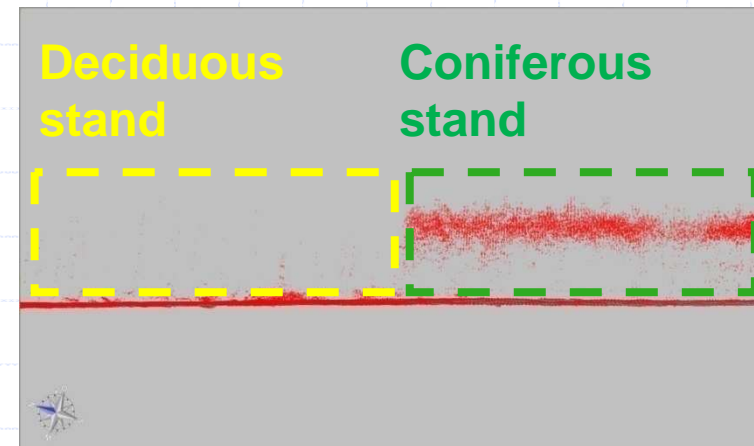**„Quellgebiet Wieslauter" in the biosphere reserve „Pfälzerwald"**
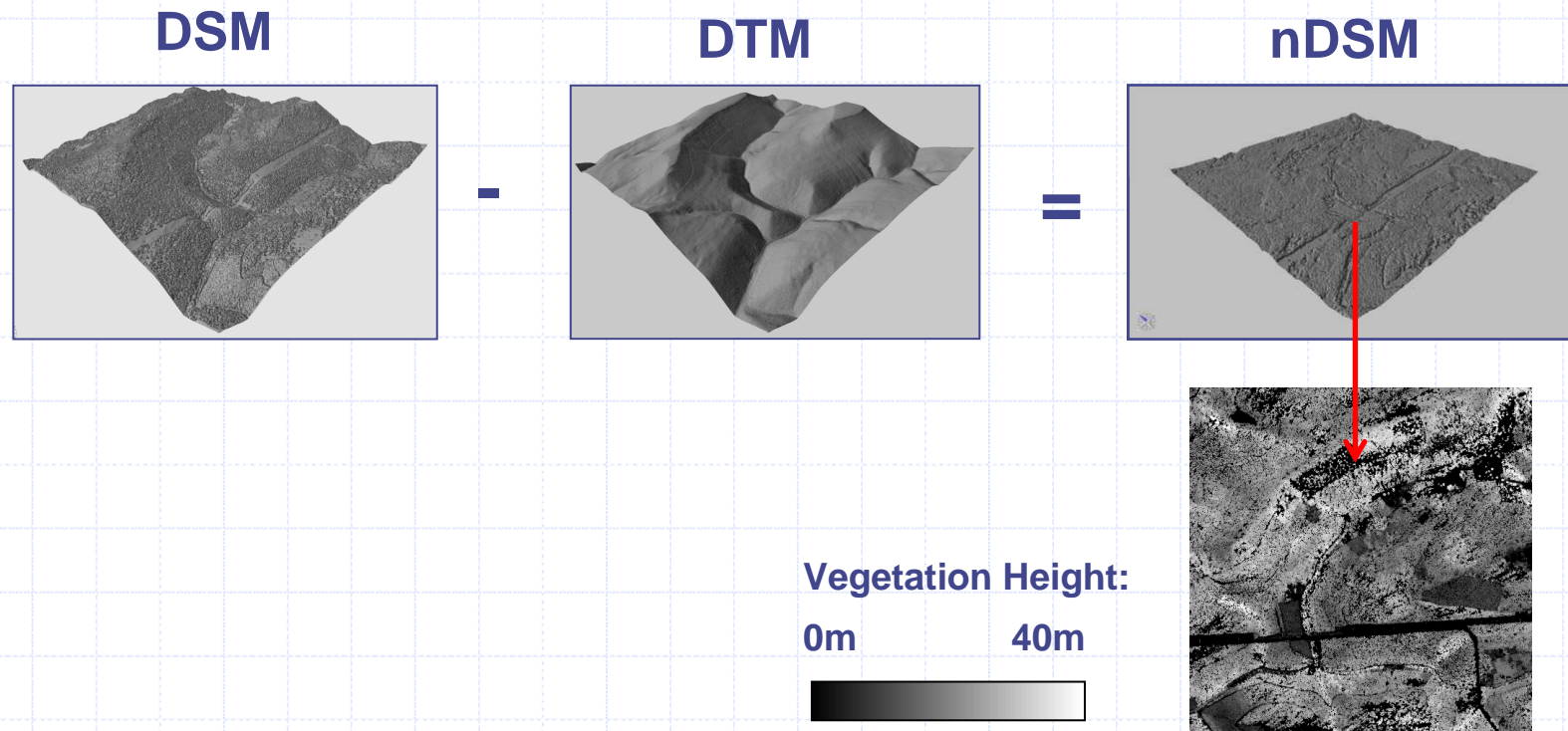
DSM   **DTM**   **nDSM**

Vegetation Height:

0m   40m

2.2 Forest Stand Mapping

STEP 1: Modelling of deciduous and coniferous stands during winter (leaf-off) conditions:

Deciduous stand Coniferous stand

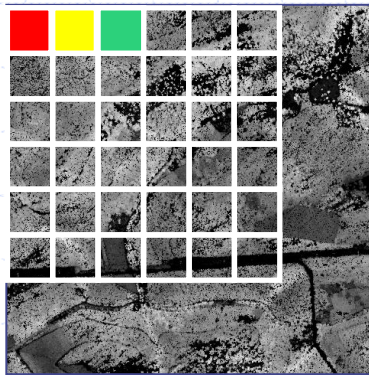Deciduous stand Coniferous stand
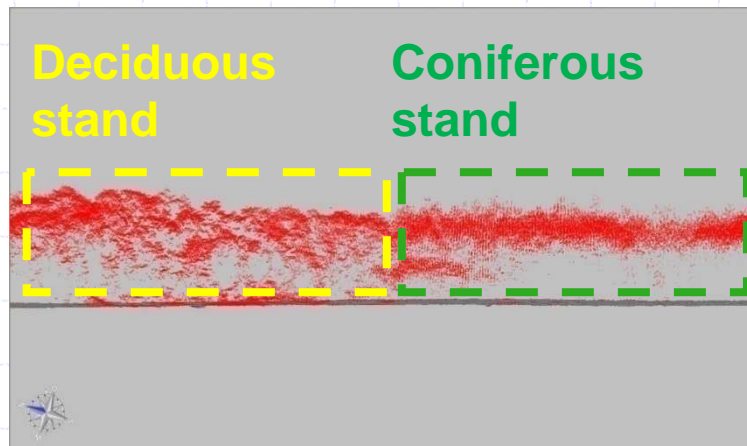
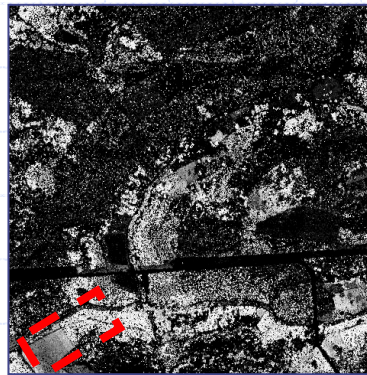**Winter: First Echo**   **Winter: Last Echo**

2.2 Forest Stand Mapping

STEP 1: Modelling of deciduous and coniferous stands during winter (leaf-off) conditions:
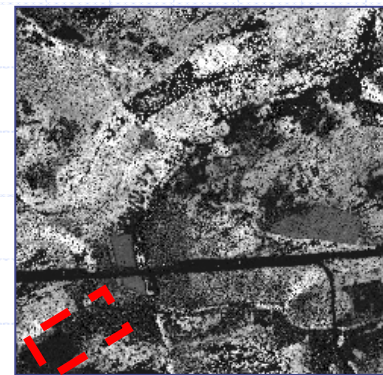
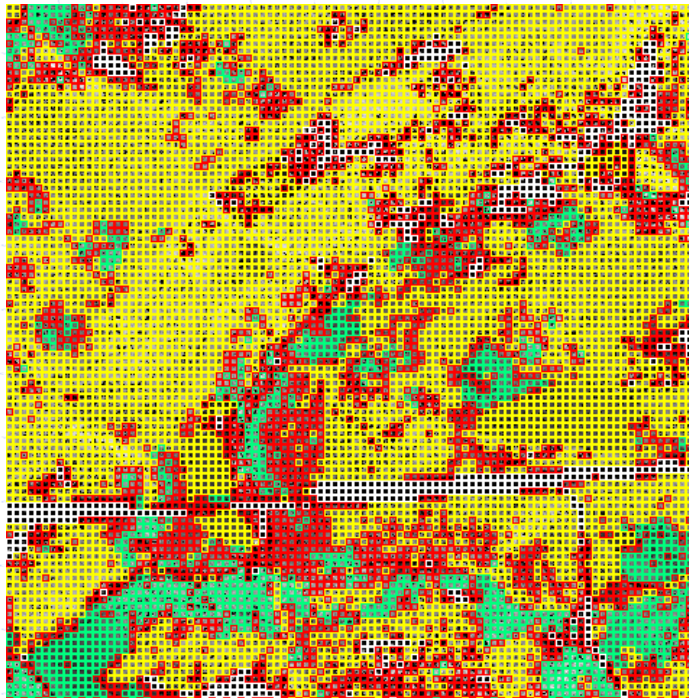**First Echo (nDSM):**   **Last Echo (nDSM):**

**All trees**   **Coniferous trees**   **Deciduous trees**

→ **Regions with forest floor**

→ **Regions with coniferous trees**

→ **Regions with deciduous trees**

…used for classification of cells

2.2 Forest Stand Mapping

Classification Result:

🟩 **Coniferous forest**

🟨 **Deciduous forest**

🟥 **Mixed forest**

⬜ **Forest floor and small vegetation**

2.2 Forest Stand Mapping
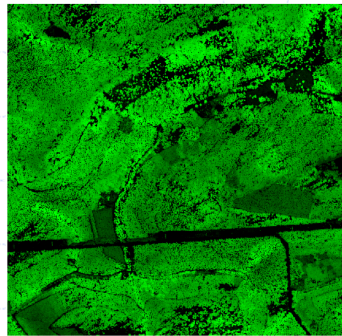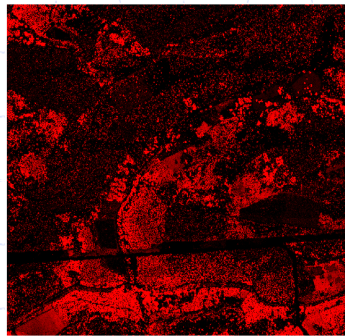
nDSM FirstPulse　　　**nDSM LastPulse**　　　**[nDSM FirstPulse - nDSM LastPulse]**
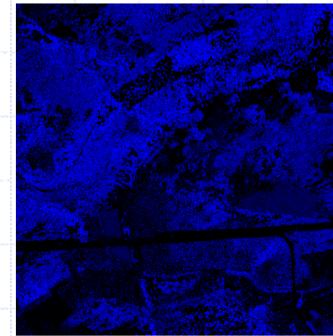
Green　　　　　**Red**　　　　　　**Blue**
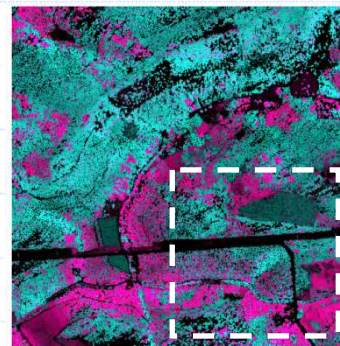
„Laserscan-RGB"

→ **for visual interpretation**

→ **combination of height and differentiation into con. and dec. trees**

2.2 Forest Stand Mapping

„Laserscan-RGB"

„CIR-Orthophoto"

Young deciduous stand

Forest floor

Mixed forest

Old coniferous stand
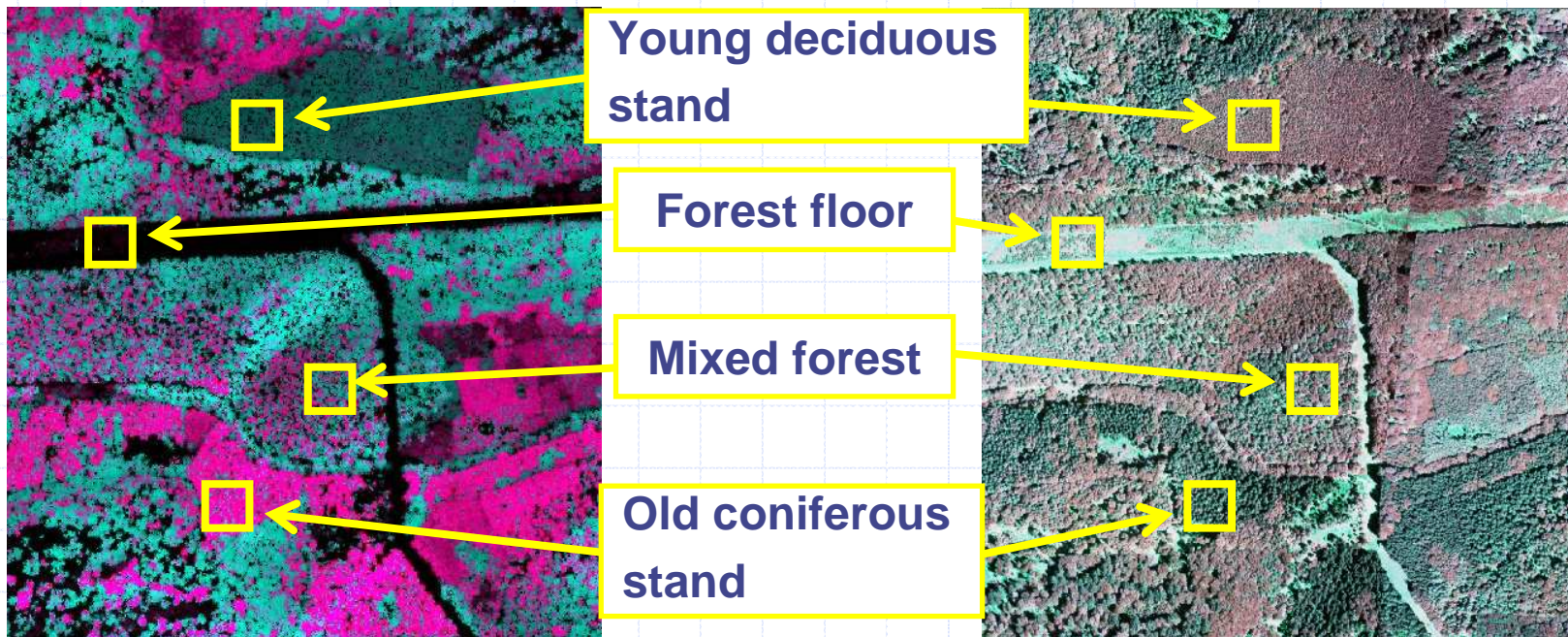
2.2 Forest Stand Mapping

STEP 2: Classification based on variation of height values:

→ **coefficient of variation (Cv) of height values in each cell as a measure for the surface roughness**

$$C_v = \frac{\sigma}{\mu}$$

σ **standard deviation**

μ **mean**

… Cv allows comparison of the variation of populations that have significantly different mean values.
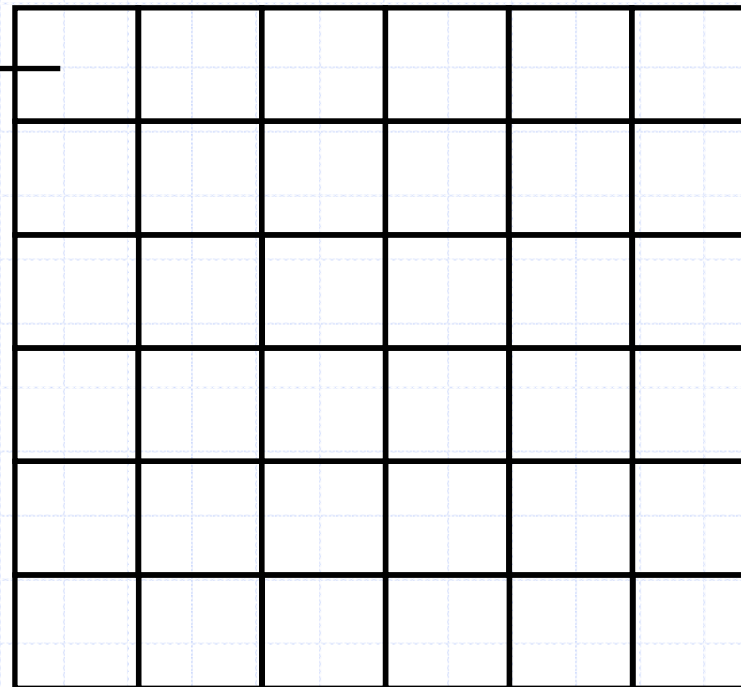
2.2 Forest Stand Mapping

Homogeneous and inhomogeneous canopy structure:
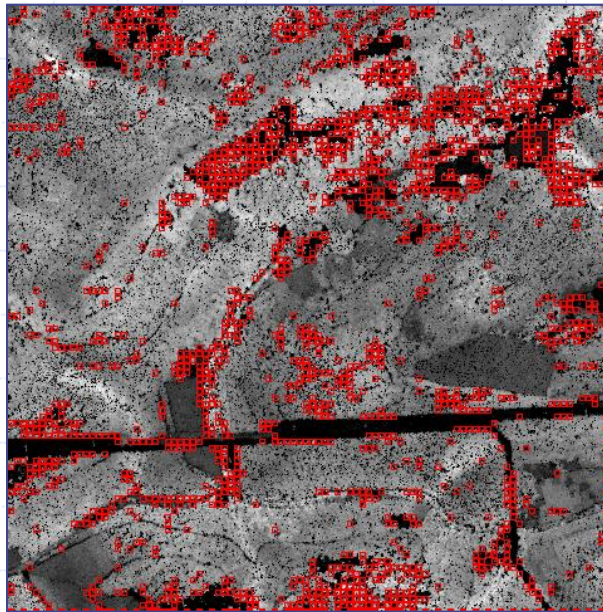
■ = Regions with „high vertical structure"

2.2 Forest Stand Mapping

STEP 3: Height classes based on Top Height:

$$Top\_Height = \frac{Max(1) + Max(2) + ... + Max(n)}{n}$$
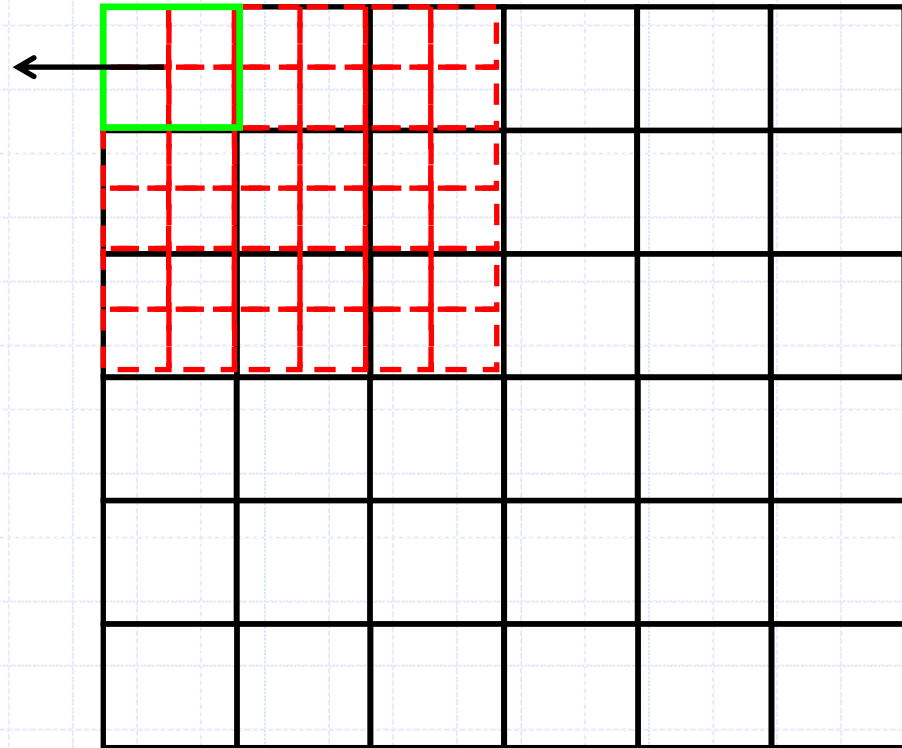
2.2 Forest Stand Mapping

„Coniferous Forest Cells" classified with height classes:
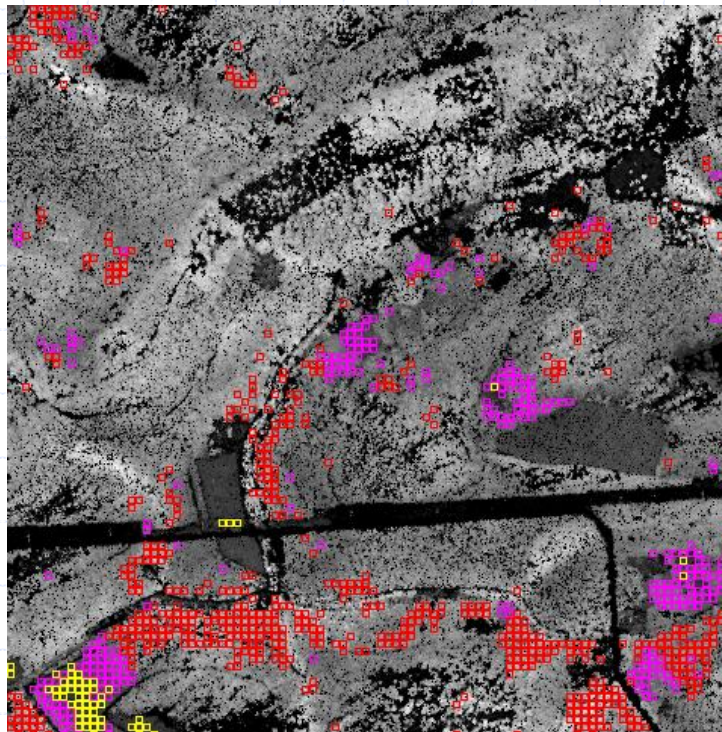
"juvenile":	h < 3m	
"sapling":	3 =< h <10m	
"pole":	10 =< h <15m	🟨
"mature trees":	15 =< h <25m	🟪
"old trees"	25m =< h	🟥

2.2 Forest Stand Mapping

Grouping of cells :
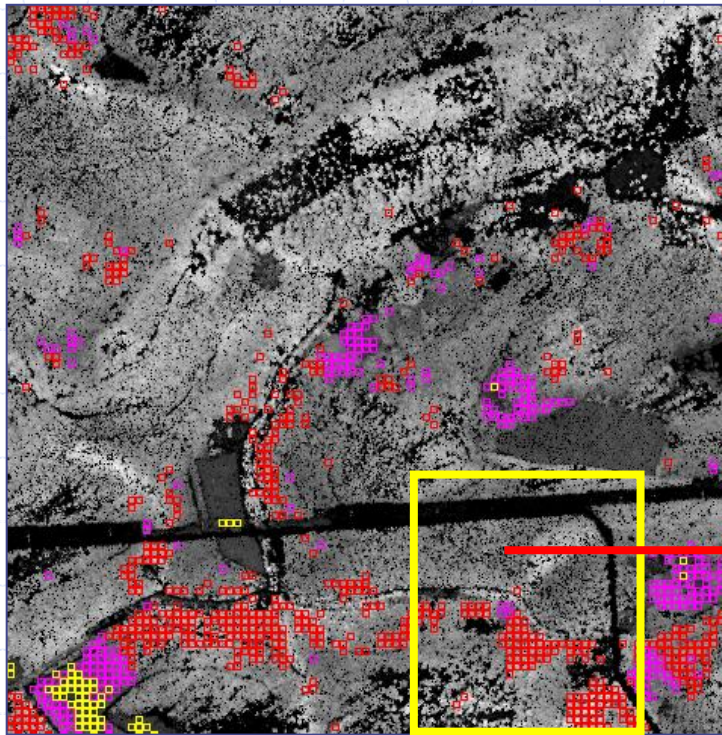
Grouping of neighbouring cells within each class into forest stands:
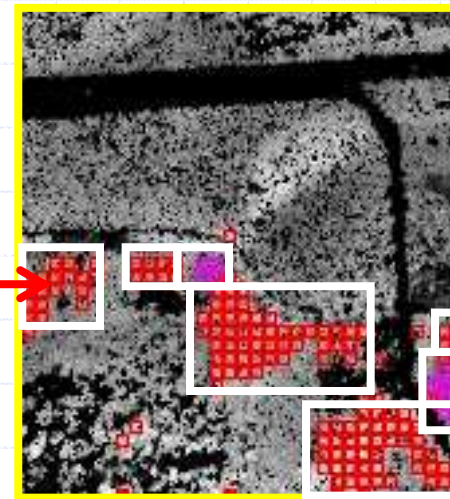
2.2 Forest Stand Mapping

Result of the automatic delineation into stand units:

Legend

Dec h > 25m	Mix h > 25m	Con h > 25m	floor & juvenile
Dec 25m > h > 15m	Mix 25m > h > 15m	Con 25m > h > 15m	h_struct
Dec 15m > h > 10m	Mix 15m > h > 10m	Con 15m > h > 10m	v_struct
Dec 10m > h > 3m	Mix 10m > h > 3m	Con 10m > h > 3m	
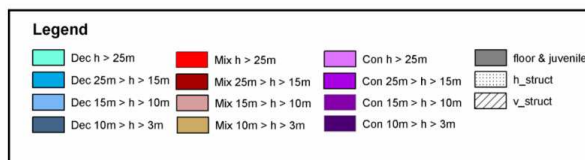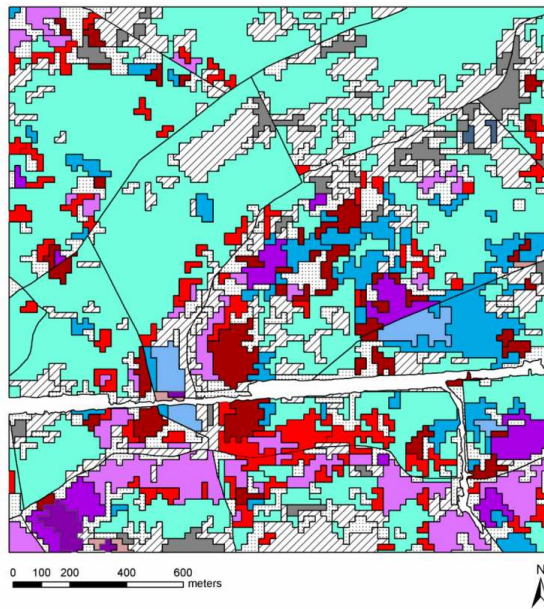
2.2 Forest Stand Mapping – vertical structure analysis

"Normalization" of Raw Data Points:

$$RawPoint(x,y).Height - DTM(x,y).Height = RawPoint(x,y).Normalized\_Height$$
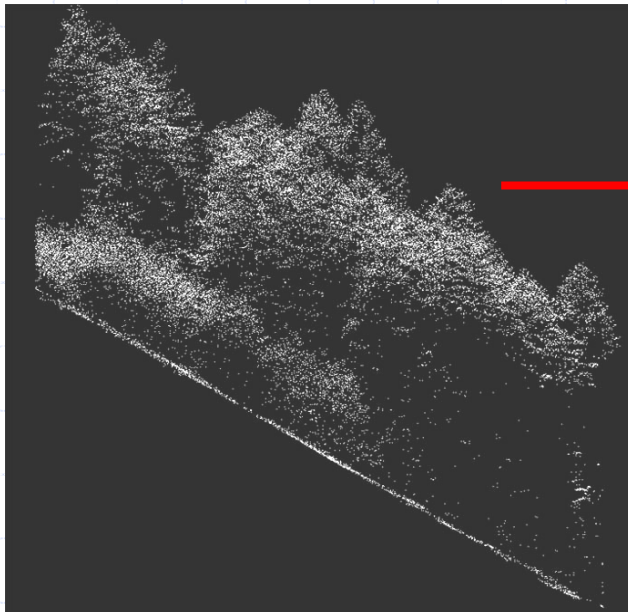
"Original" point cloud
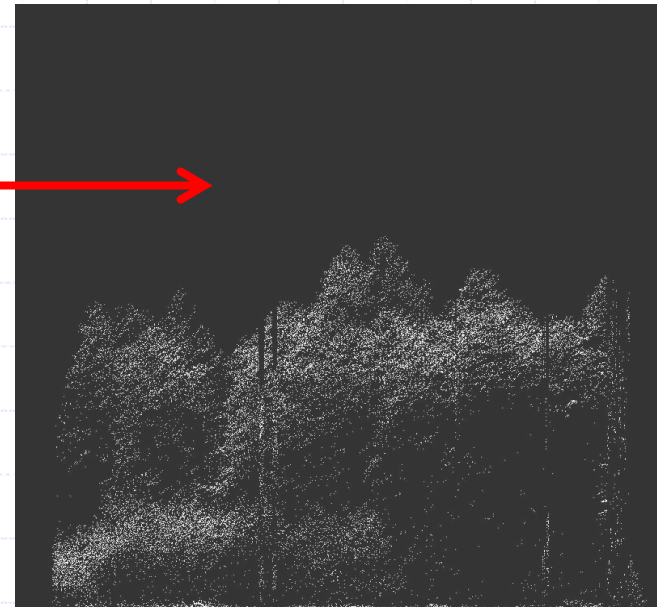
"Normalized" point cloud

2.2 Forest Stand Mapping – vertical structure analysis

Height Distribution Function:

Number of Points

— $\phi(h)$

— $S(h)$

— $S''(h)$
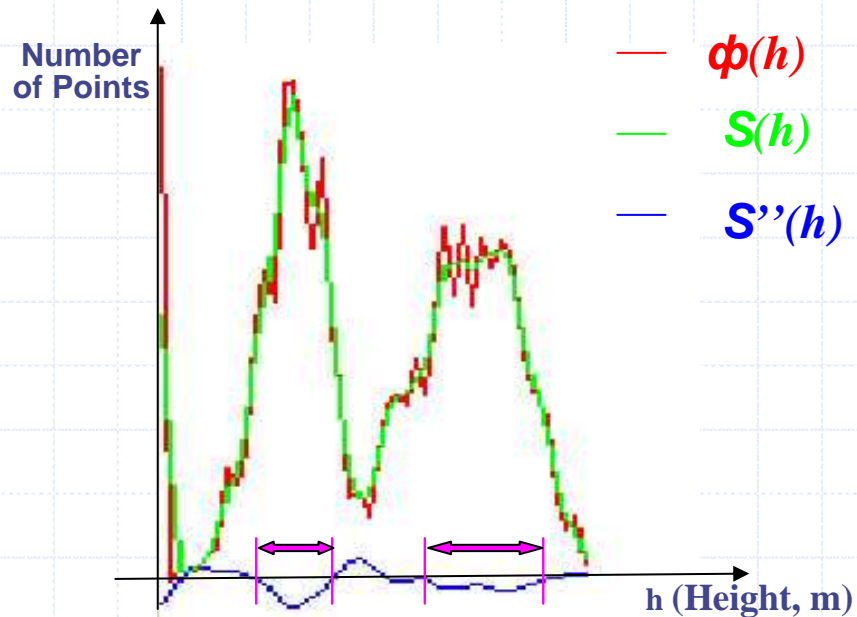
h (Height, m)

$\phi(h)$: Height distribution function

$S(h)$: Smoothed height distribution function

$S''(h)$: Second derivative of $S(h)$

At the intervals of h where S''(h)<0, there must be salient curves of function S(h);

→ The intervals of h are considered as height ranges of tree canopy layers.

2.3 Estimation of Forest Characteristics

Size:	1.84ha
Top Height:	23.4m
Developmental Stage:	Mature
Canopy Closure:	99%
Volume:	440m³
Slope:	3 %
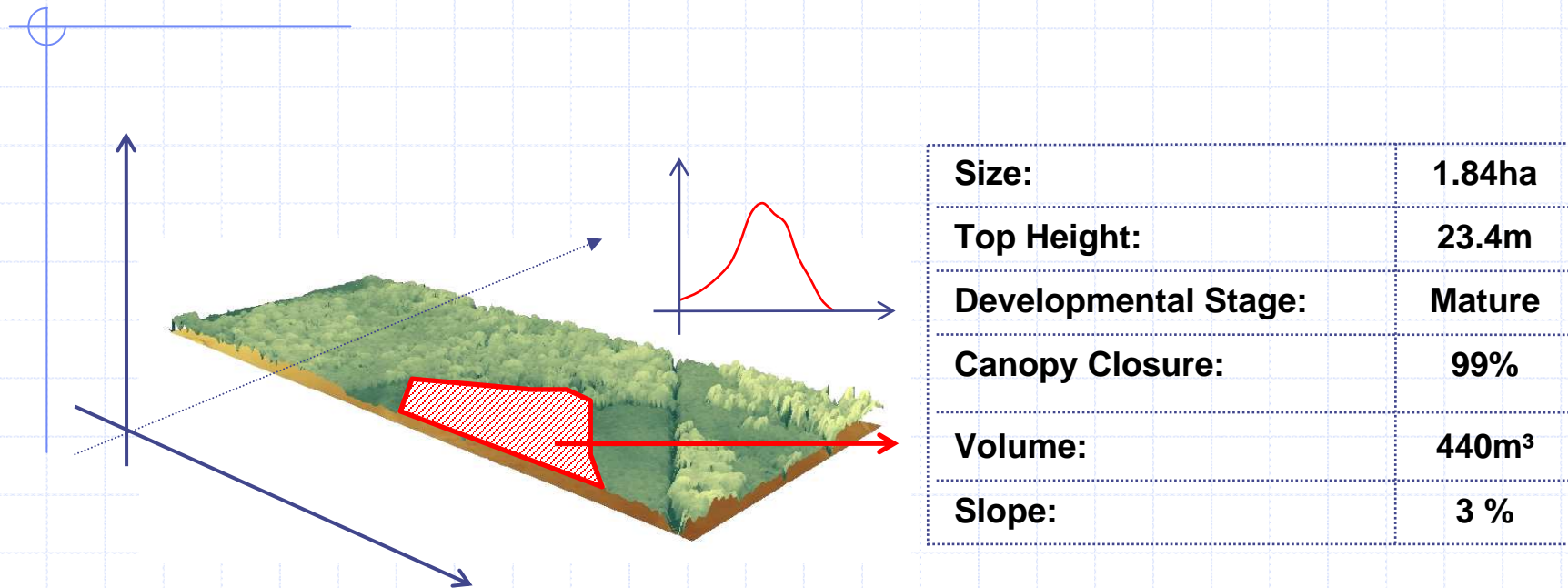
Field Measurements vs. LIDAR

2.3 Estimation of Forest Characteristics

Two possibilities to analyze the data:

1. High resolution data → single tree variables can be estimated

2. Low resolution data → plot or forest stand characteristics can be estimated

2.3 Estimation of Forest Characteristics

Tree Height (single trees):

Coniferous trees: **Deciduous trees:**
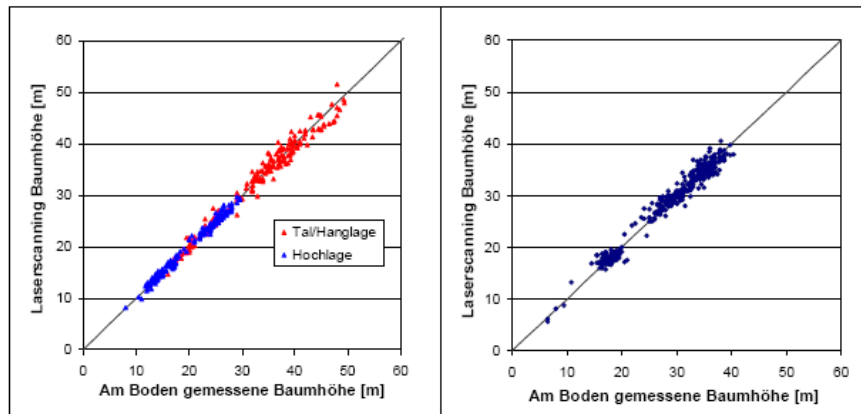
	n	ln	b_0	b_1	b_2	b_3	b_4	R^2	RMSE [m]	VK_{RMS} [%]
Laubbäume	371	nein	-1.673	1.125	0.009	0.017	-0.001	0.97	1.25	4.36
Nadelbäume (Hochlage)	169	nein	-1.439	1.268	-0.461	-0.007	0.086	0.99	0.59	2.95
Nadelbäume (Tal- und Hanglage)	281	nein	-0.687	1.081	-0.304	0.000	0.012	0.98	1.19	3.37

(From Heurich 2006)

2.3 Estimation of Forest Characteristics

Crown Radius (single trees):

Coniferous trees: **Deciduous trees:**
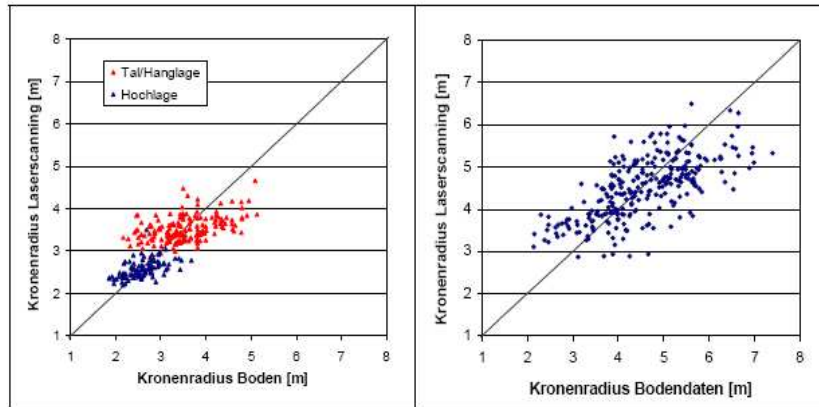
	n	ln	b_0	b_1	b_2	b_3	b_4	R^2	RMSE [m]	VK_{RMS} [%]
Laubbäume	278	ja	1.368	-0.043	0.000	0.005	0.001	0.46	0.79	17.3
Nadelbäume (Hochlage)	160	ja	1.124	-0.073	0.246	0.002	-0.027	0.31	0.32	12.5
Nadelbäume (Tal- und Hanglage)	93	nein	8.223	-0.375	0.183	0.006	-0.018	0.19	0.57	16.1

(From Heurich 2006)

2.3 Estimation of Forest Characteristics

DBH (single trees):

Coniferous trees: **Deciduous trees:**
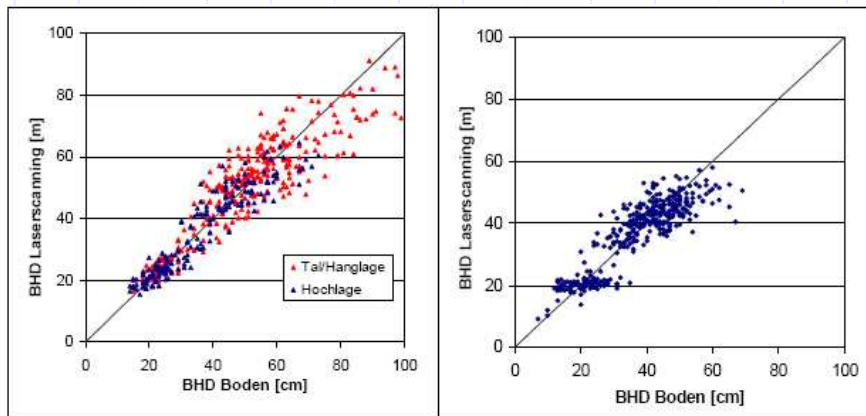
	n	ln	b$_0$	b$_1$	b$_2$	b$_3$	b$_4$	R^2	RMSE [cm]	VK$_{RMS}$ [%]
Laubbäume	368	ja	1.592	0.089	0.081	-0.003	-0.001	0.82	5.84	15.7
Nadelbäume (Hochlage)	171	ja	1.682	0.087	0.211	-0.001	-0.029	0.90	5.10	14.1
Nadelbäume (Tal- und Hanglage)	287	ja	1.684	0.074	0.075	0.000	-0.004	0.86	7.90	15.3

(From Heurich 2006)

2.3 Estimation of Forest Characteristics

Standard volume function for single trees:

$$V = \frac{\pi}{4} \cdot \left(DBHp\right)^2 \cdot Hp \cdot f$$

V = volume

$DBHp$ = diameter of tree (predicted)

Hp = height of tree (predicted)

f = form factor

2.3 Estimation of Forest Characteristics

Plotwise approach:

Field measurements
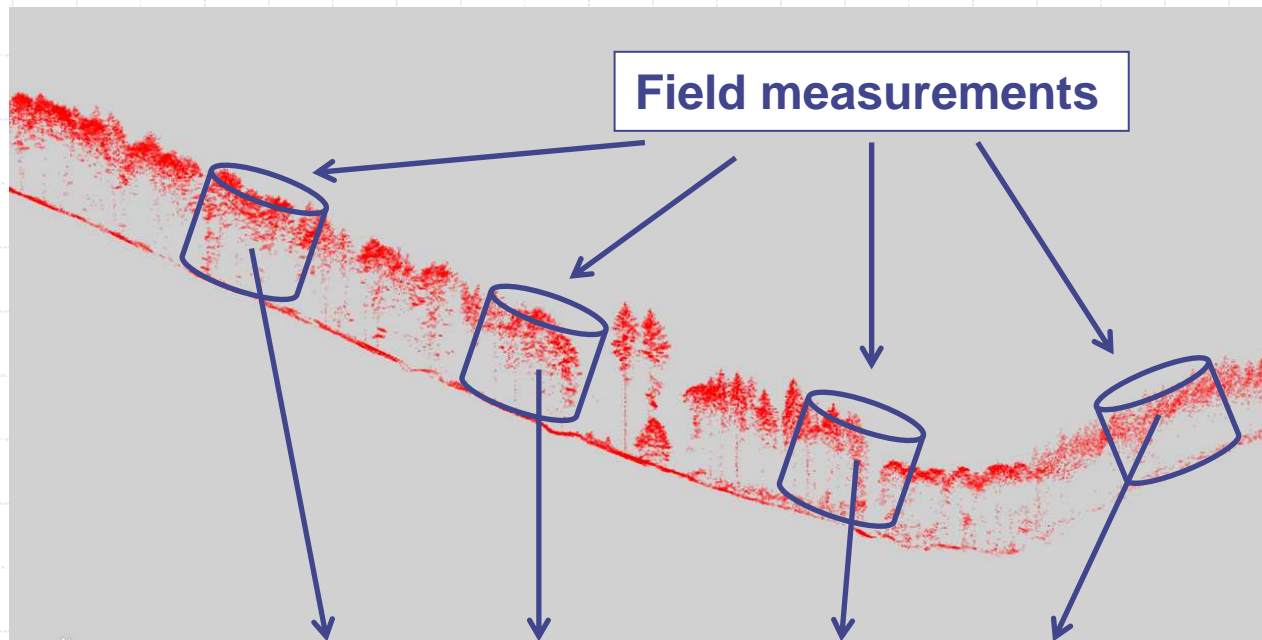
For each georeferenced plot properties from raw data points are extracted and are related to field plot data by regression analysis (→ calibration of regression models)

2.3 Estimation of Forest Characteristics

Properties which may be extracted from ALS data (Næsset 2003):

Height related variables:

Density related variables:
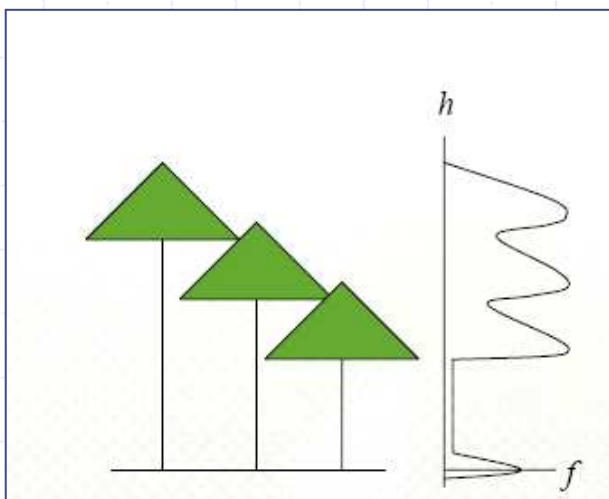
Height-related variables:

Percentiles of the heights: hp0, hp10, ….,

hp90 , hcv, hmean …
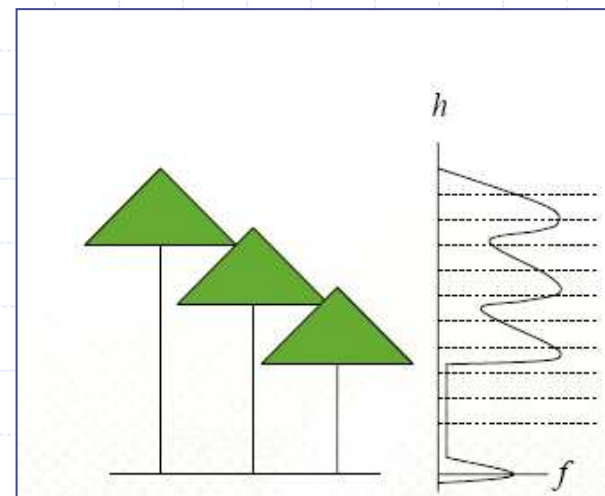
Densities of 10 vertical layers: d0, d1, …., d9
Proportions of points above percentiles of
the heights for 0%, 10%, …90% to total number
of points

2.3 Estimation of Forest Characteristics

Results of study in Norway (Næsset 2002):

Figure 1: Scatterplots of observed stand attributes as a function of attributes predicted using regression models estimated from the sample plot inventory

Stand Height: (green box)
- Field h_L (m) vs Predicted h_L (m)
- ▲ Poor site quality
- ▪ Good site quality
- R²=0.91

Timber Volume: (red box)
- Field V (m³ha⁻¹) vs Predicted V (m³ha⁻¹)
- R²=0.91
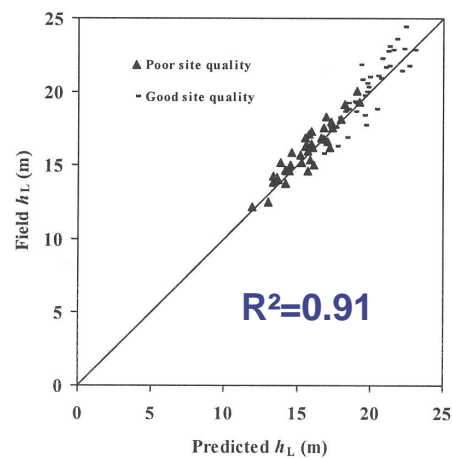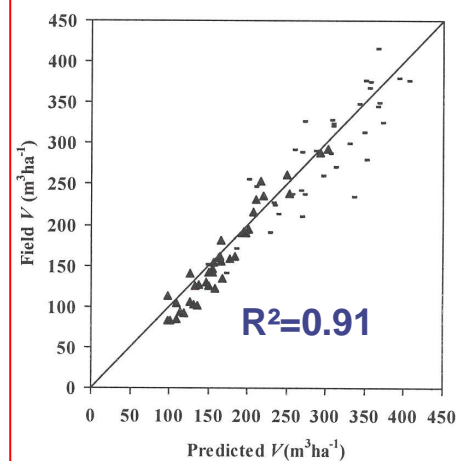
2.3 Estimation of Forest Characteristics

Forest Inventories (plotwise) proposed by (Næsset 2003), modified:

Stand boundaries

Study area subdivided into cells

Laserscanning data

Field measurements

Computing stand characteristics within grid cells

Computing stand values

$V = 2.326 * h_{90l}^{1.912} * d_{3l}^{3.14}$

$V = 82\ m^3/ha$

Relating laser data to field plot data by regression analysis

www.umb.no
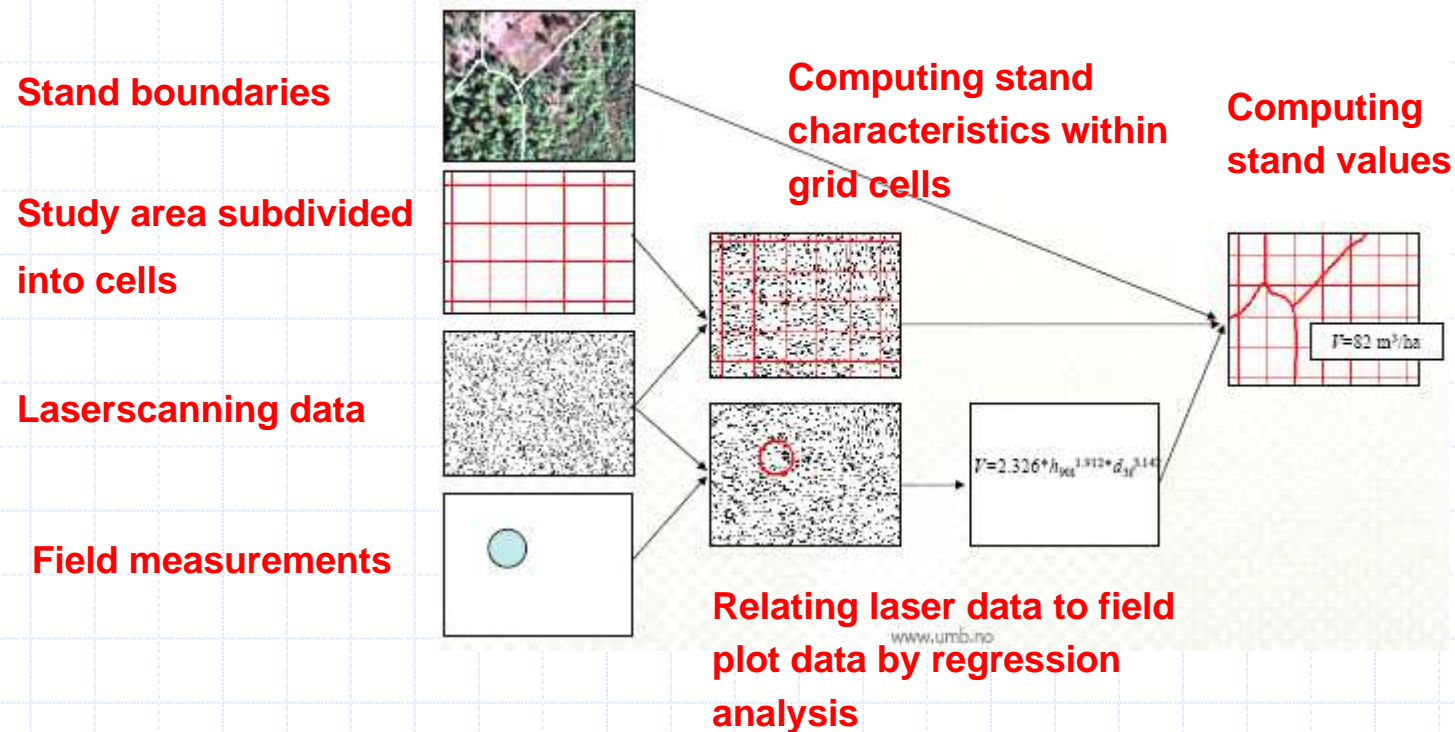
3.0 Software Demonstration

TreesVis - processing, analyzing and visualisation of laserscanning data
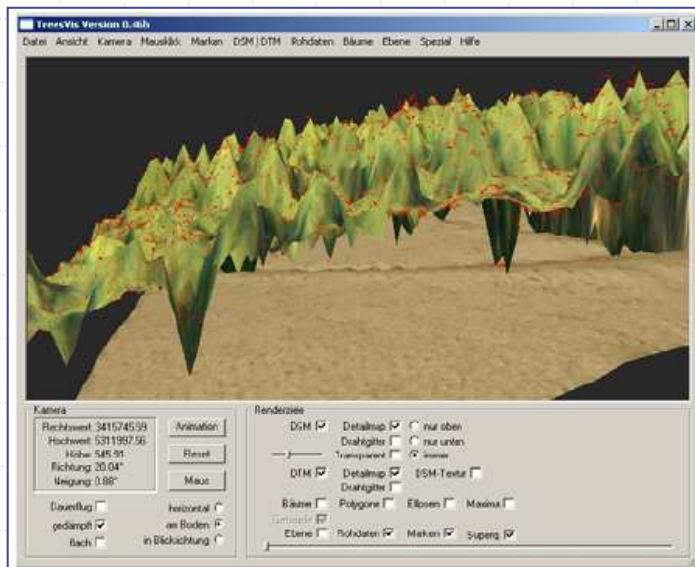
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