Education & Training

# LIDAR
# Projects, Quality and Vegetation Mapping

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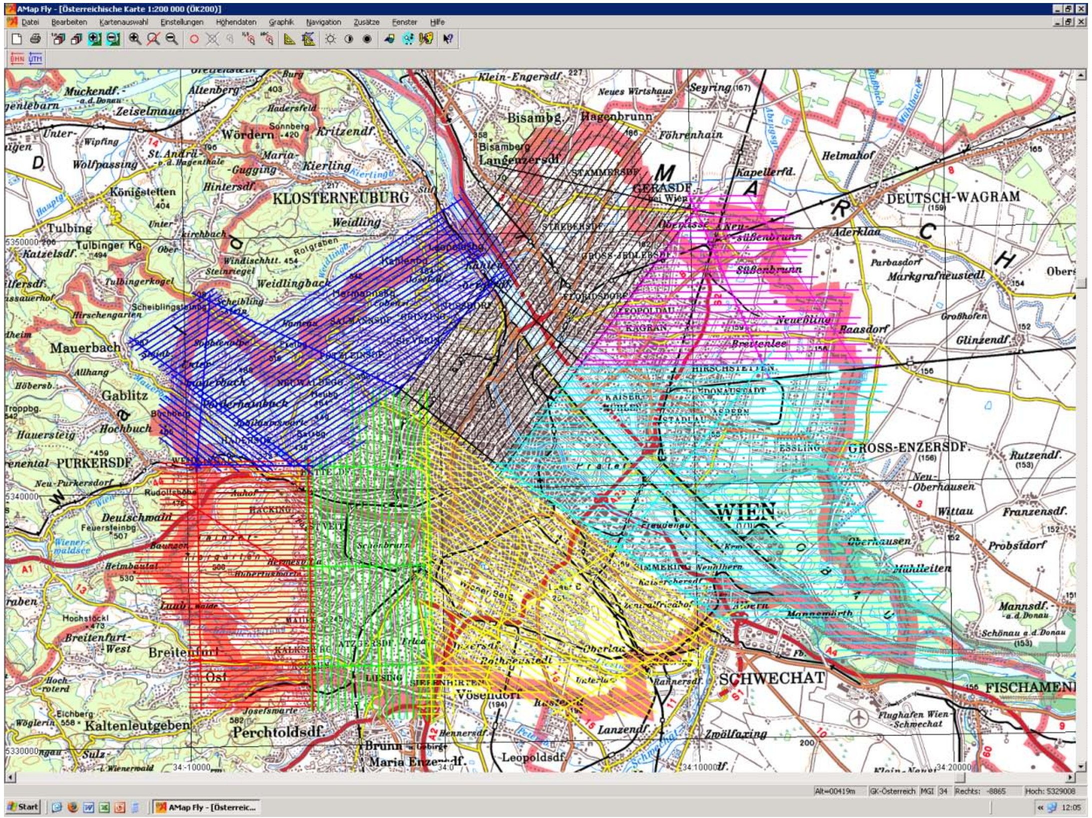
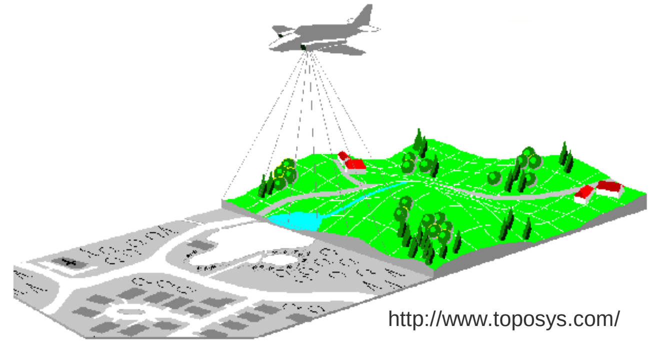
*ADDRESSS training course, 19-28 August 2010, Balaton Limnological Research Institute , Hungary*

# Content

- Remarks: ALS Projects
  - Flight planning
  - Flight date
  - Point density
- Quality Control
  - Point density
  - Relative Georeferencing
    - Strip differences
  - Absolute Georeferencing
    - Control patches
- Vegetation mapping

# Flight Planning (I)



http://www.toposys.com/

**Range Measurement Performance**

| | |
|---|---|
| Maximum Measurement Range [1] | |
| @ Laser PRR 50 kHz: | |
| natural target, $\rho \geq 20\%$ | 1200 m |
| natural target, $\rho \geq 60\%$ | 1800 m |
| @ Laser PRR 100 kHz: | |
| natural target, $\rho \geq 20\%$ | 1000 m |
| natural target, $\rho \geq 60\%$ | 1200 m |
| @ Laser PRR 200 kHz: | |
| natural target, $\rho \geq 20\%$ | 700 m |
| natural target, $\rho \geq 60\%$ | 700 m |
| Minimum Range | 30 m |
| Accuracy [2] | 20 mm |
| Precision [2] | 10 mm |
| Laser Pulse Repetition Rate [3] | up to 200 000 Hz |
| Effective Measurement Rate | up to 100 kHz @ 45 deg scan angle<br>up to 133 kHz @ 60 deg scan angle |
| Laser Wavelength | near infrared |
| Laser Beam Divergence [4] | ≤ 0.5 mrad |
| Number of targets per pulse | unlimited for digitized waveform [5]<br>first pulse or last pulse in online monitoring data |
| Eye Safety Class<br>according to IEC60825-1:1993+A1:1997+A2:2001<br>The following clause applies for instruments delivered into the United States:<br>Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated July 26, 2001. | CLASS 1 LASER PRODUCT |

**Scanner Performance**

| | |
|---|---|
| Scanning Mechanism | rotating polygon mirror |
| Scan Pattern | parallel scanning lines |
| Scan Angle Range [6] | ± 22.5 deg = 45 deg total |
| Scan Speed | 10 - 160 scans/sec |
| Angle Step Width $\Delta \vartheta$ [3] between consecutive laser shots | $\Delta \vartheta \geq 0.004$ deg (@ PRR 100.000 HZ [7]) |
| Angle Readout Resolution | 0.001 deg |

**Intensity Measurement**

For each echo signal, high-resolution 16-bit intensity information is provided which can be used for target discrimination and/or identification/classification.

**Maximum Operating Altitude AGL** [8]

| | |
|---|---|
| Laser PRR 50 kHz | approx. 1000 m (3280 ft.) |
| Laser PRR 100 kHz | approx. 800 m (2630 ft.) |
| Laser PRR 200 kHz | approx. 550 m (1800 ft.) |

Technical Data

**Input:**

- **Planned ALS-strips**
- **Scanner parameter**
- **Rough DTM**

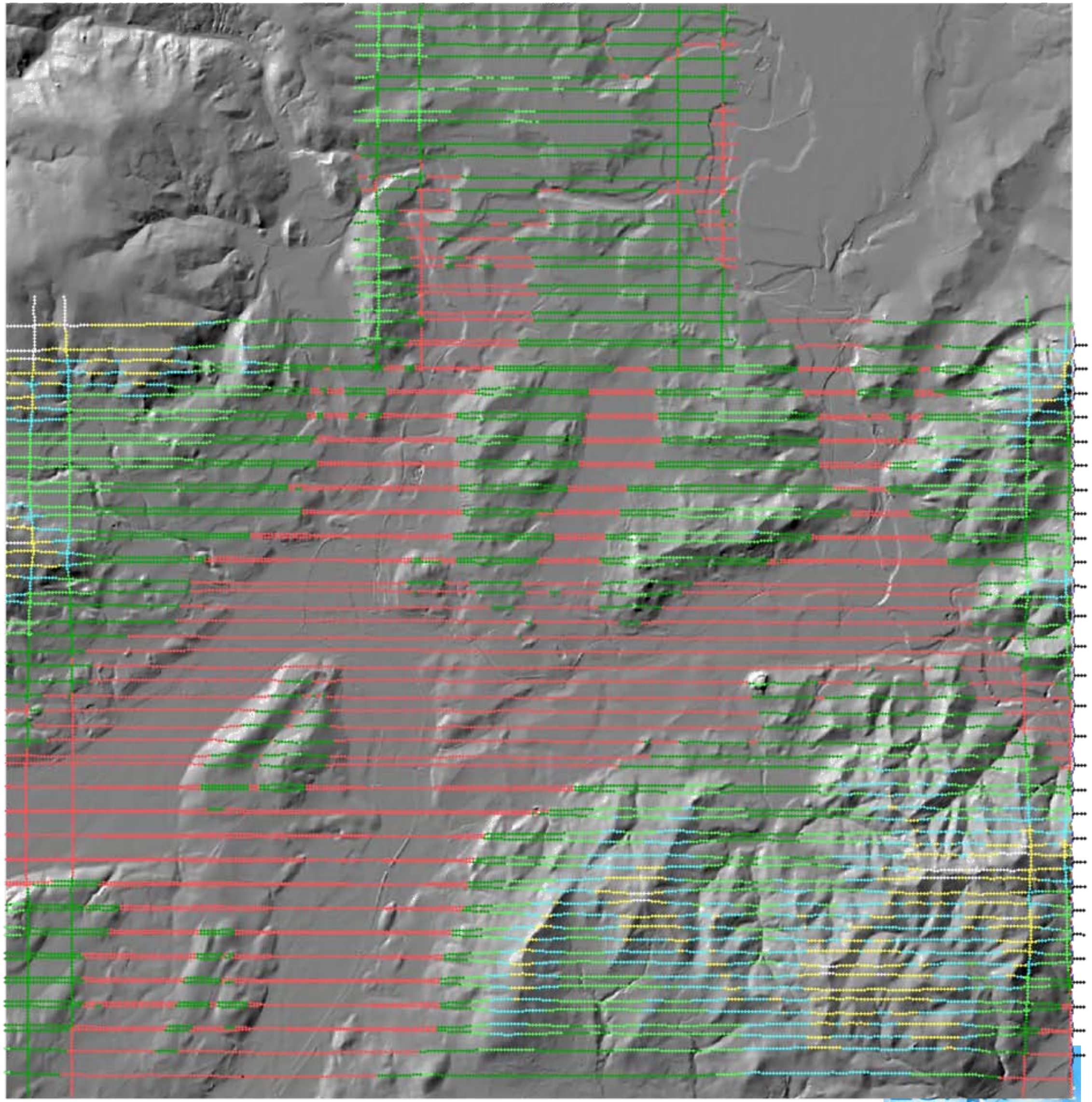
# Flight Planning (II)

Input:

1. Current (rough) DGM
2. Planned layout of the flight strips

→ Prediction of:

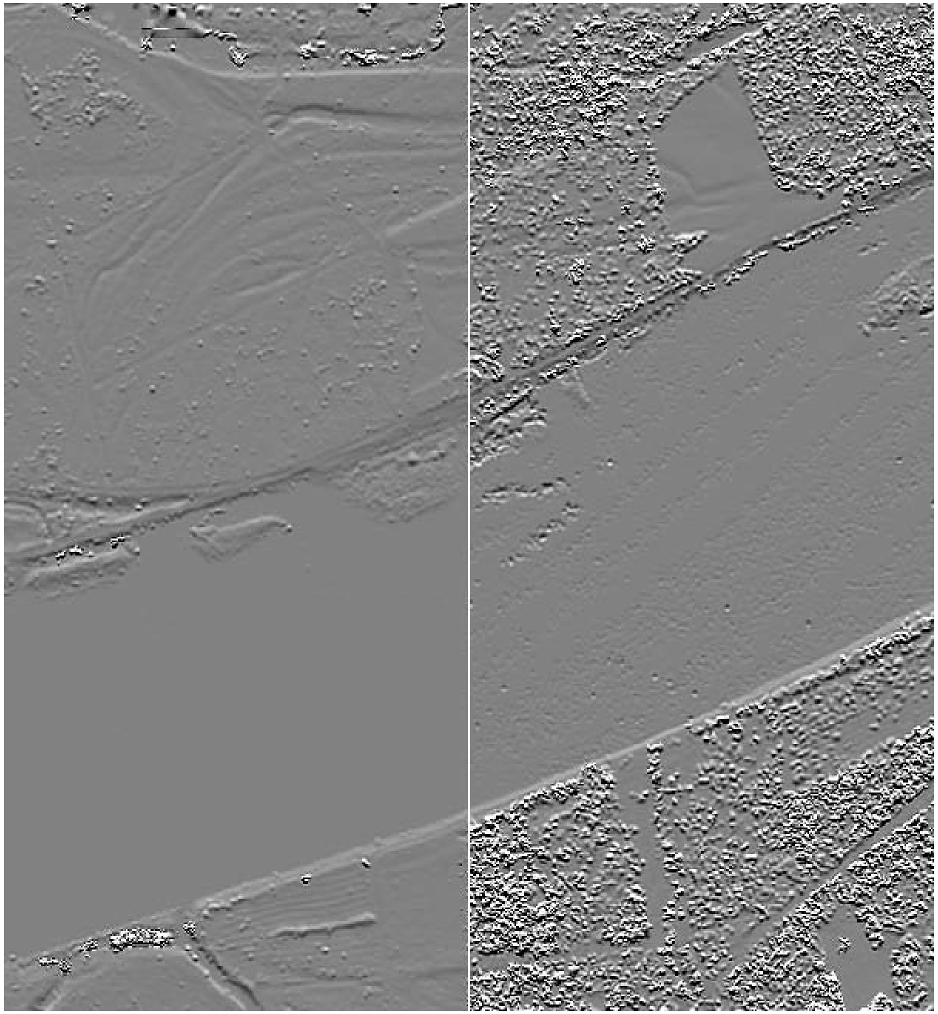
- Coverage on the ground
- Strip overlap
- Point density
- Laser footprint ∅



ALS Kärnten, Glantal

# Project Parameters: Flight Date (I)

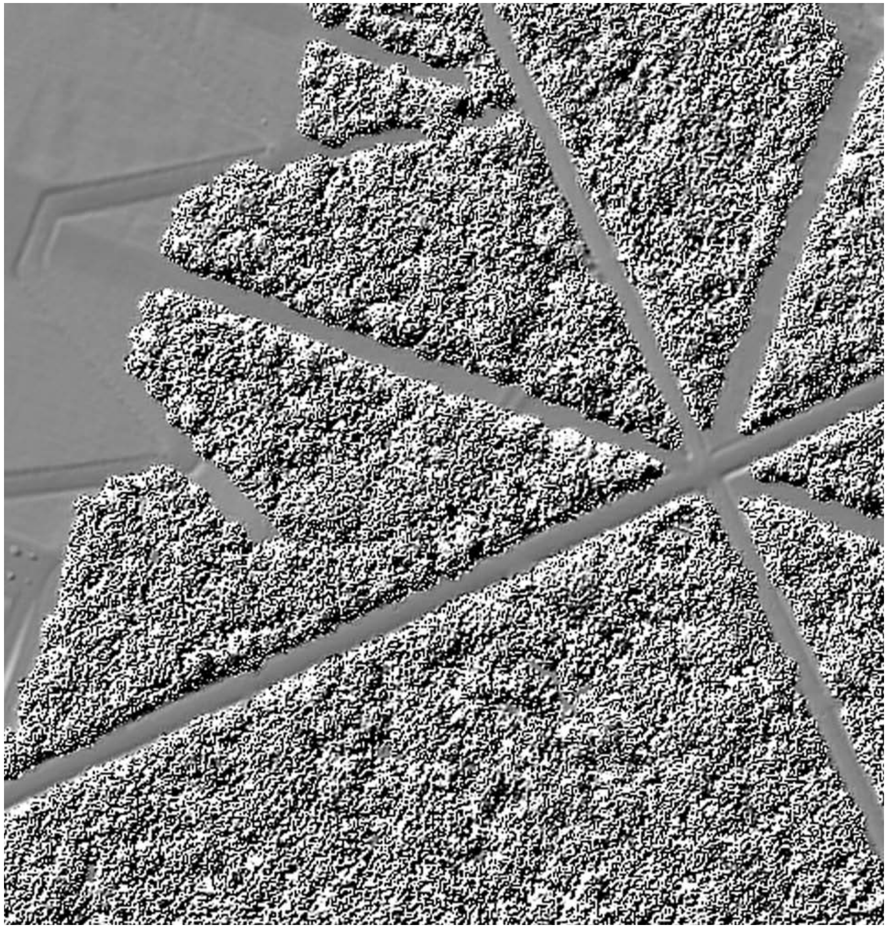
DSM (detail):



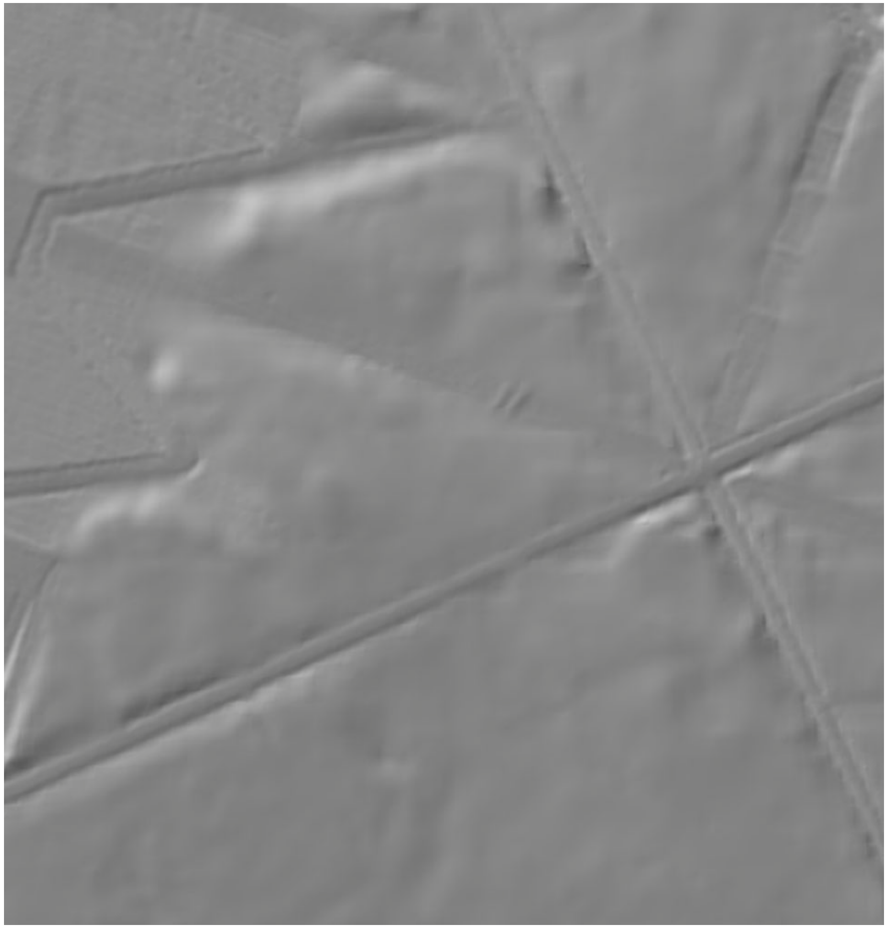
26./27. March　　23. April

# Project Parameters: Flight Date (IIa)

- airplane borne, 4 pts. / m², September



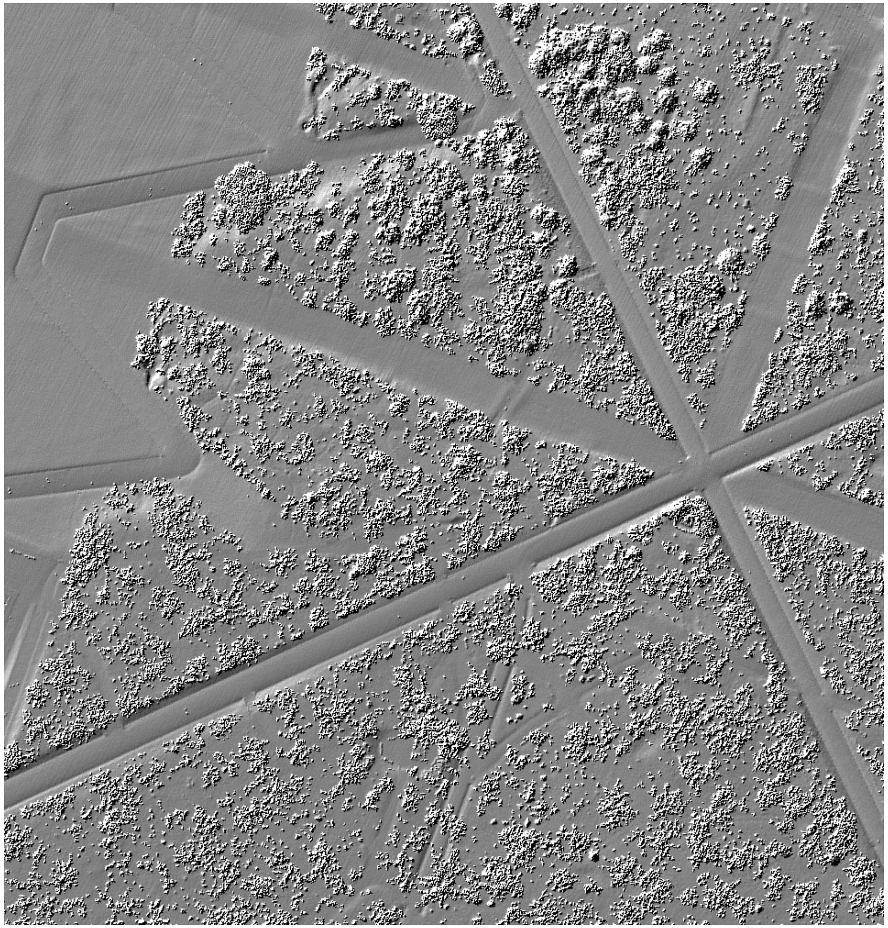
*Digital Surface Model (DSM)*



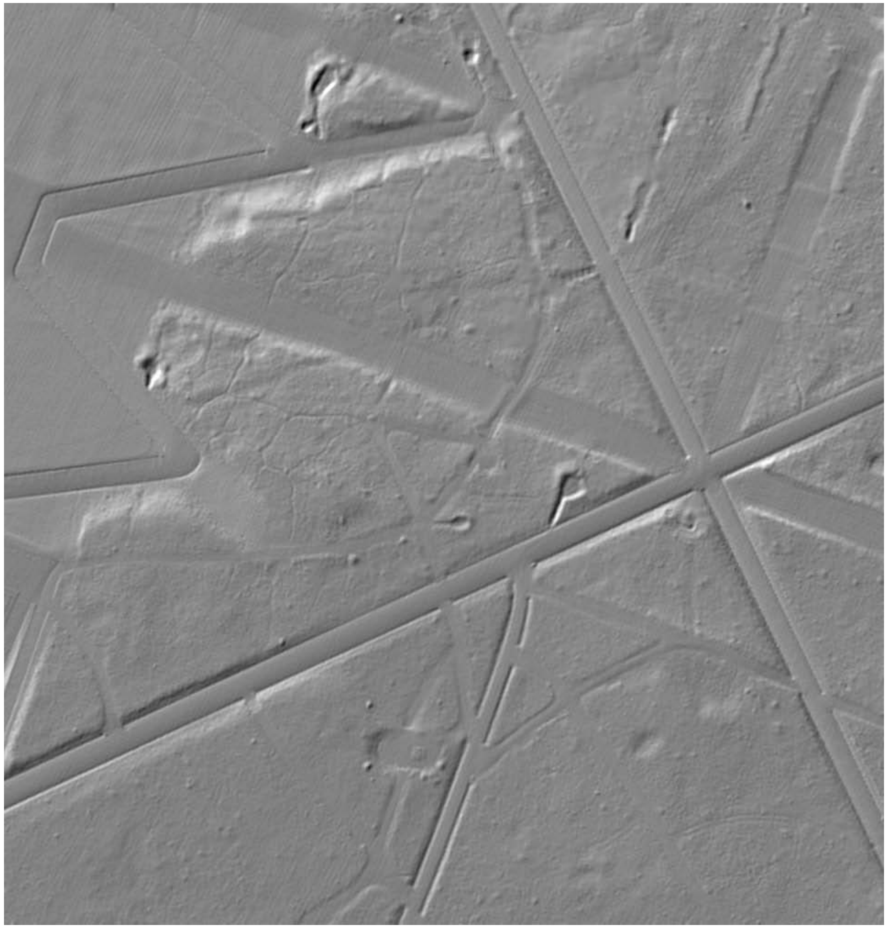
*Digital Terrain Model (DTM)*

# Project Parameters: Flight Date (IIb)

- helicopter borne, 8 pts. / m², March

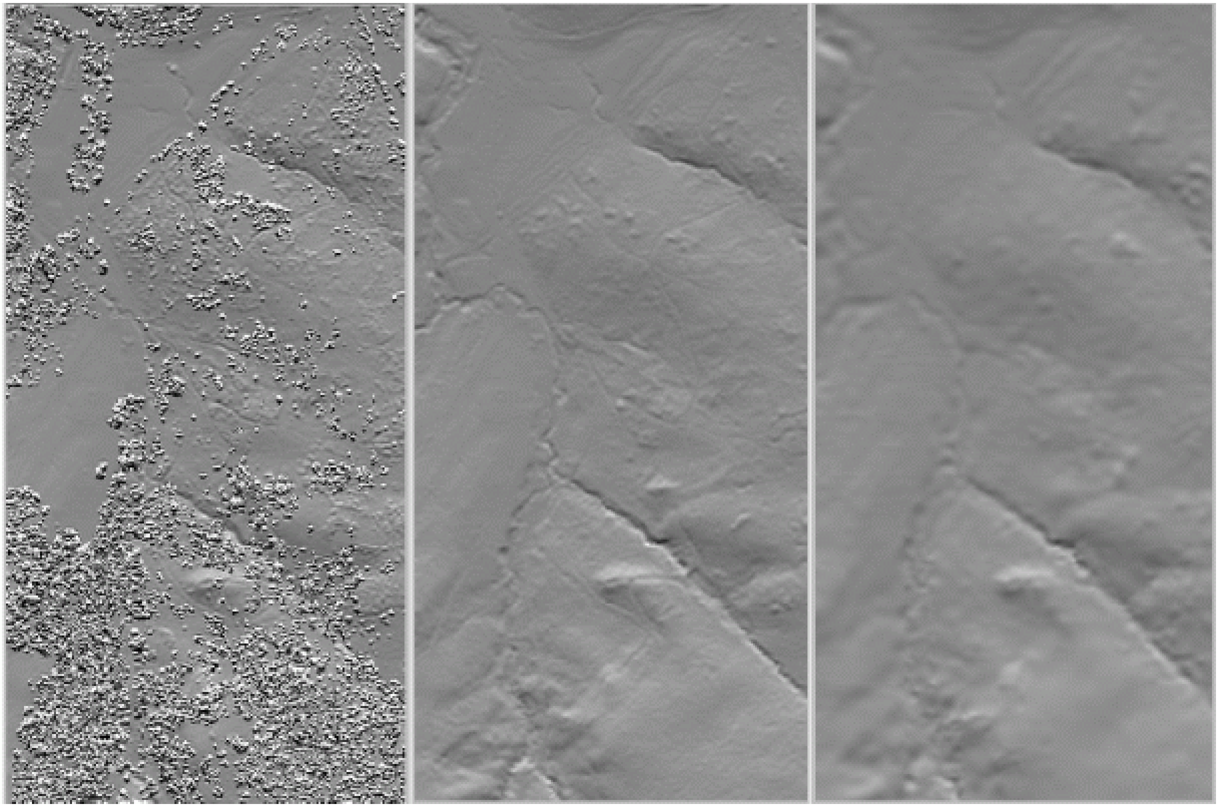


*Digital Surface Model (DSM)*



*Digital Terrain Model (DTM)*

# Project Parameters: Point Density



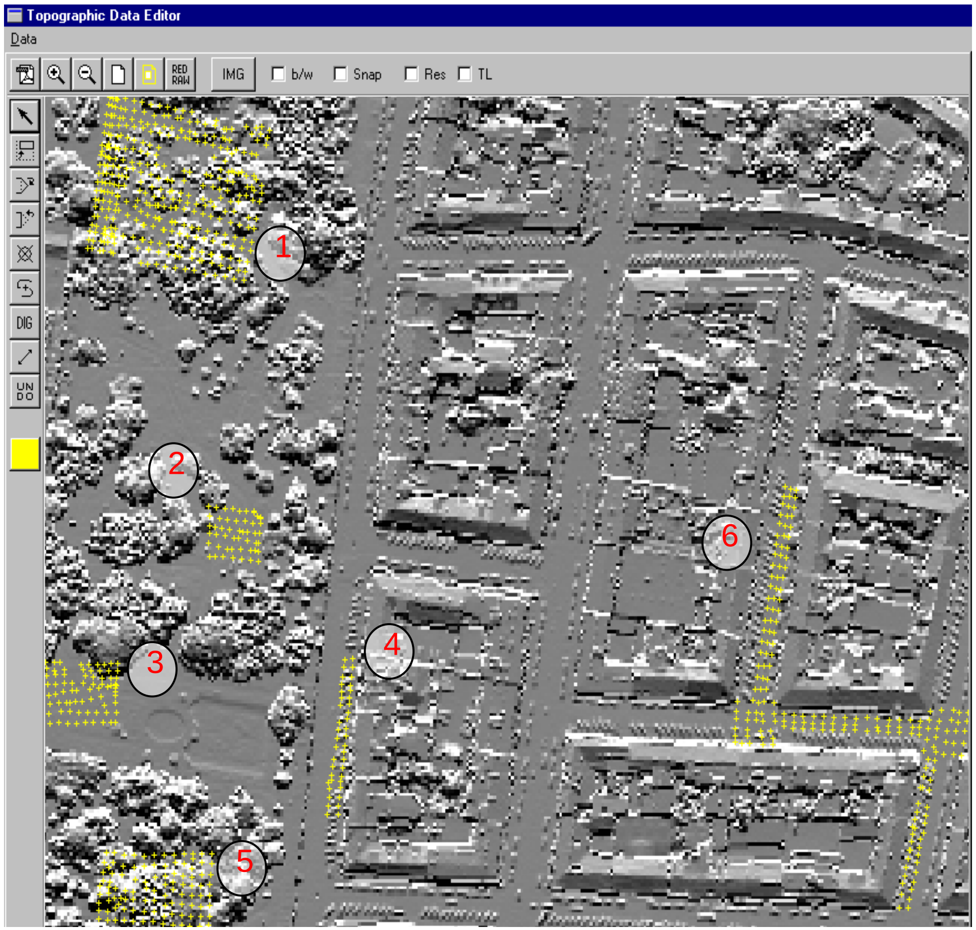
271 control points: | point distance: ~1m | point distance : ~3.1m
| | $\sigma = \pm 18$cm | $\sigma = \pm 29$cm

→ **Point density** is the **most important parameter** regarding **accuracy** and **level of detail** (e.g. building reconstruction)

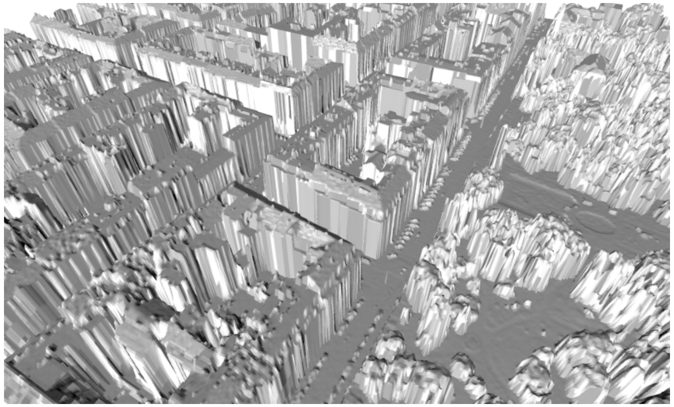
# Accuracy Potential

Accuracy Control of an ALS DTM by 816 **check points:**

ALS Vienna 1999, 500m AGL, 0.5m grid




| Region | RMS [cm] | б [cm] |
|---|---|---|
| All points | ± 10.5 | ± 7.1 |
| Park, dense vegetation | ± 14.5 | ± 11.1 |
| Park, low vegetation | ± 11.4 | ± 7.8 |
| Park, open area | ± 8.6 | ± 4.5 |
| Street with parking cars | ± 9.2 | ± 3.7 |
| Street without cars | ± 2.4 | ± 1.0 |



MA 41, Vienna

# Quality Parameters

The geometric accuracy of the ALS points is strongly influenced by 2 main parameters:

- Point density
  - Defines the level of detail of the subsequently derived products (e.g. DSM, DTM and building modells)

  → Corresponds the delivered point density to the planned/requested point density?
- Georeferencing
  - Defines the geometric accuracy of the ALS points and subsequently limits the accuracy of the derived modells
  - 2 types:
    relative Georef.: → How well fit overlapping strips together?
    absolute Georef.: → How well fits the data into the final co-ordinate frame?
  - Both are affected by the quality of the inner orientation (calibration of the multi sensor system)

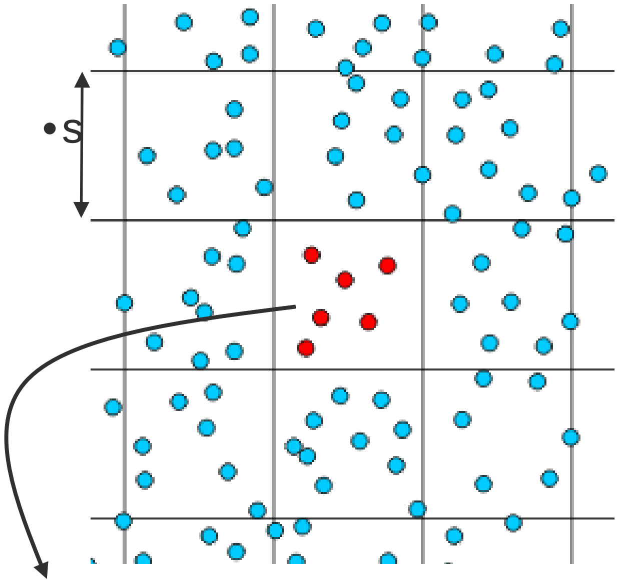
# Point density

**Point density**:

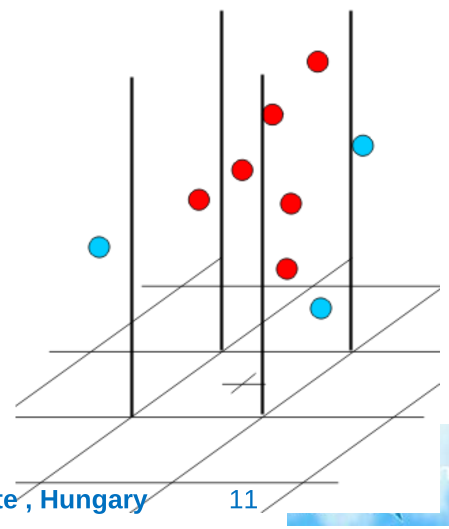
Average number of recorded points per square meter within an analysis unit (in the case of multiple echoes per pulse only the points defined by the last echo have to be considered).

If the strip overlap is smaller than 50% or in the case of crosswise strips that do not cover the whole analysis unit, the point density has to be estimated with the help of the points of the singular cover.

Areas with data holes have to be excluded from the computation and have to be considered in a different way.




point density= $6/s^2$

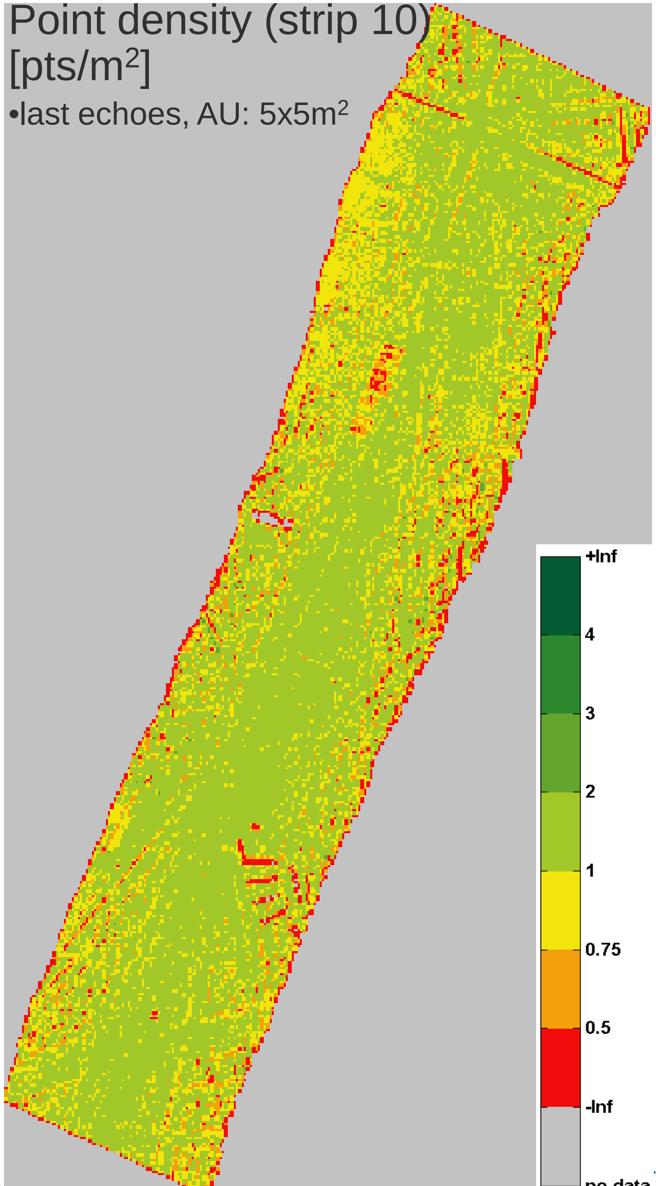


Quadratic analysis unit with the length l; z.B. l=5m

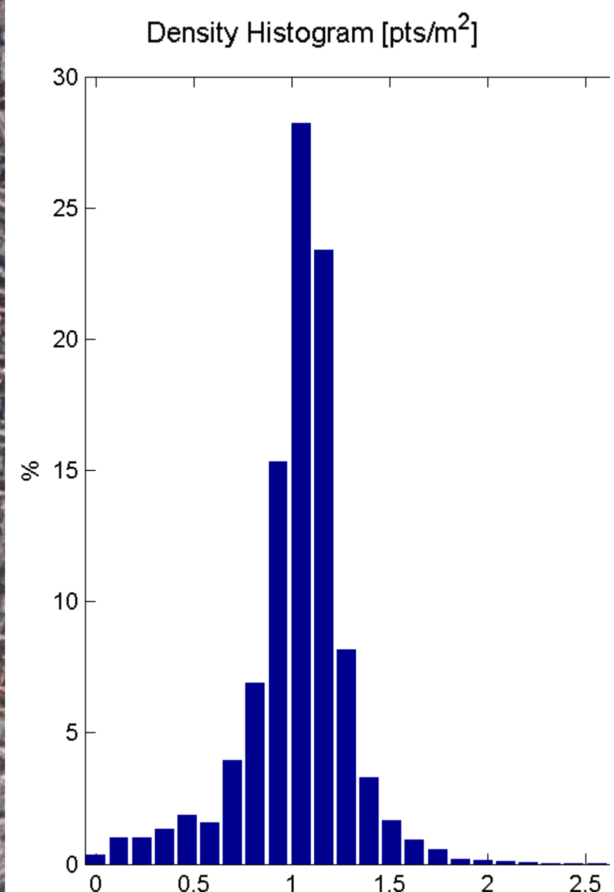
# Example 1: Schönbrunn 2004

- Location:
  Schönbrunn, Vienna
- Acquisition date:
  30.08.2004
- Scanner:
  Riegl LMS-Q560 Fullwave Scanner
- Flight lines:
  11 strips, 1 Punkt/m², strip overlap >60%,

# Schönbrunn 2004 – Point density (single strip)







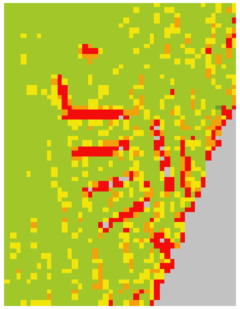

$n_{used}/n_{data}$: 35394/= RMS: 1.0593

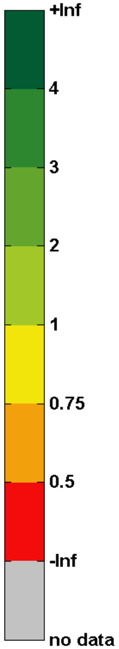
median: 1.0400 $sig_{MAD}$: 0.1779

mean: 1.0253 sig: 0.2662

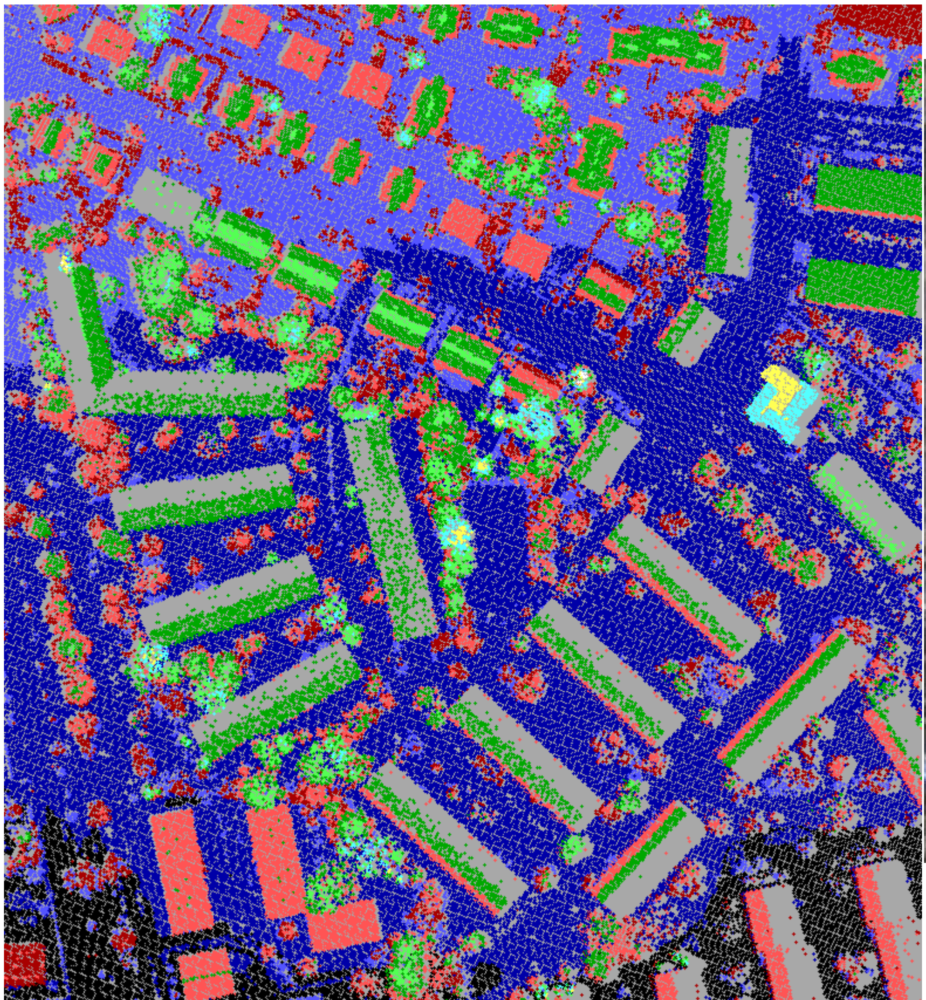
# Schönbrunn 2004 – Point density (single strip)

Point density (strip 11) [pts/m$^2$] last echoes, AU: 5x5m$^2$



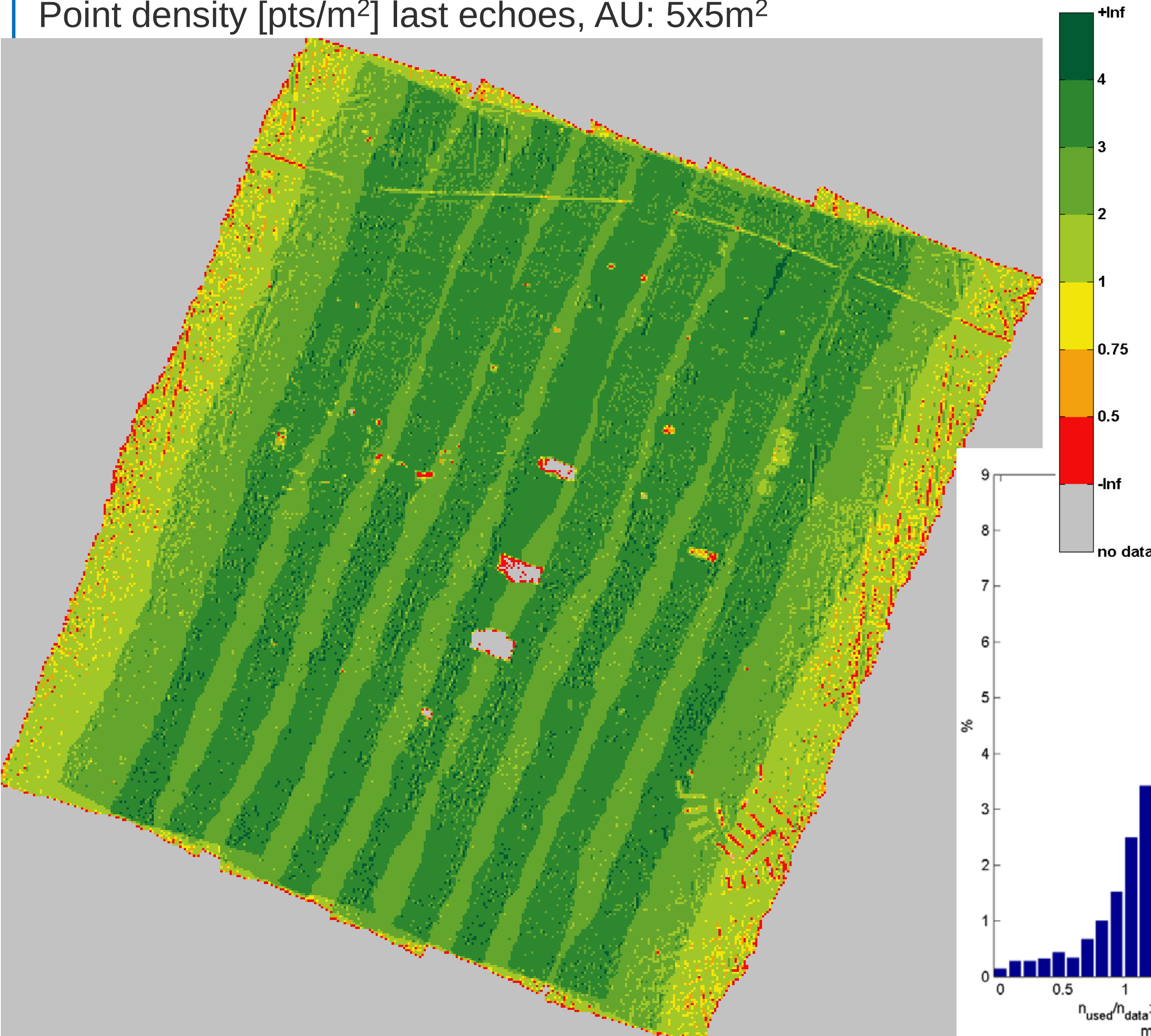



AoI of the point cloud strip (height coded) 11

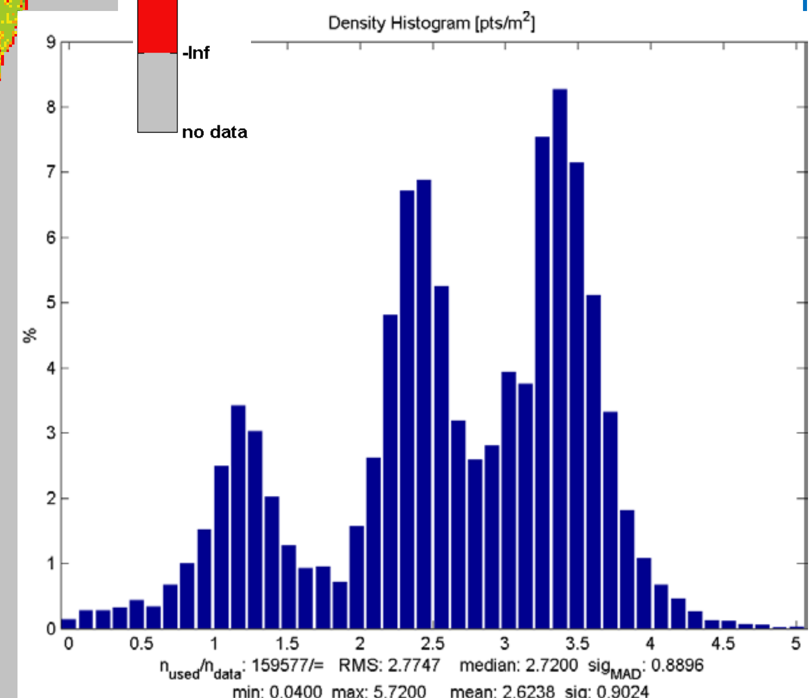


# Schönbrunn 2004 – Point density (all strips)

Point density [pts/m$^2$] last echoes, AU: 5x5m$^2$




- area with strip overlap clearly visible
- areas without points (water)



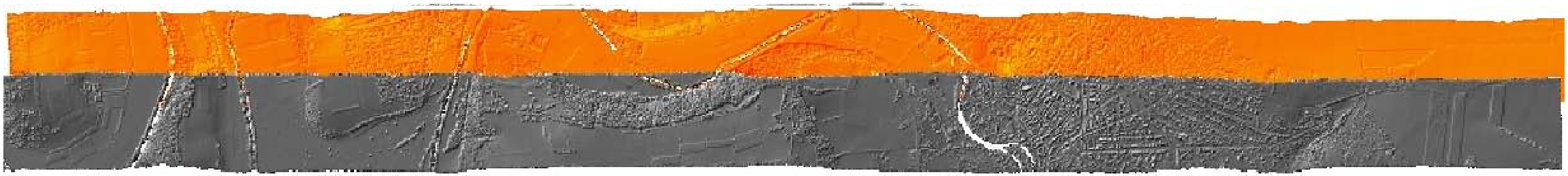
# Relative Georeferencing

- **Relative Georeferencing** describes the relative alignment between two strips.

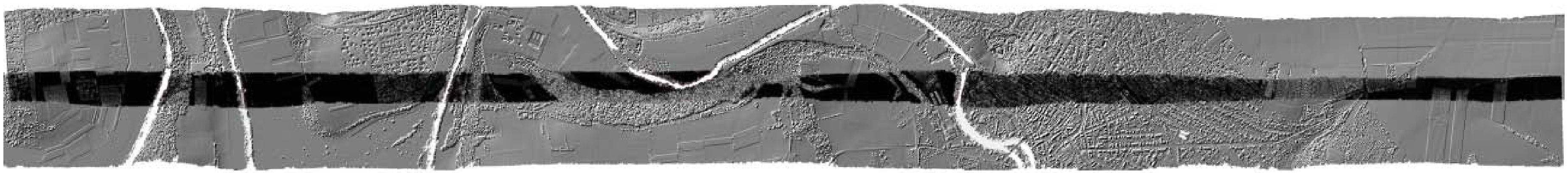
Relative Quality Control by:
→ **height difference of overlapping strip pairs**

# Strip difference

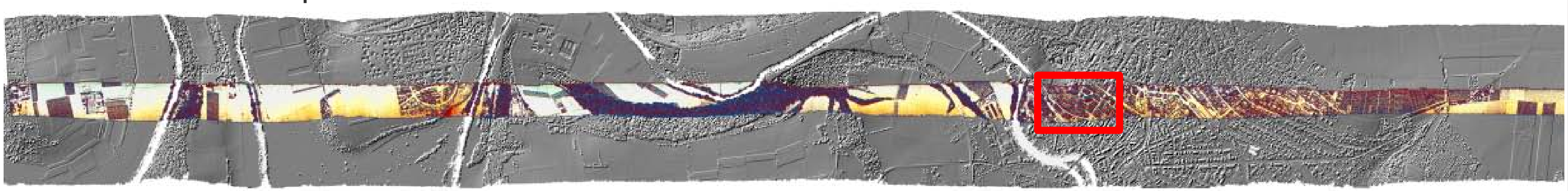
2 overlapping strips:

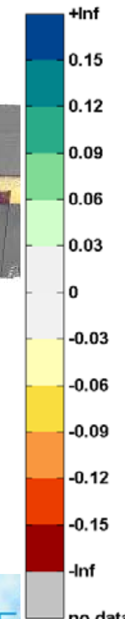


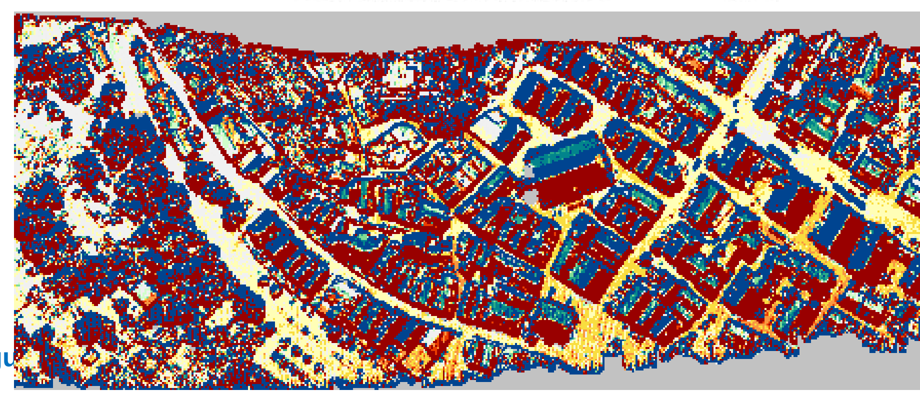
Overlapping zone:



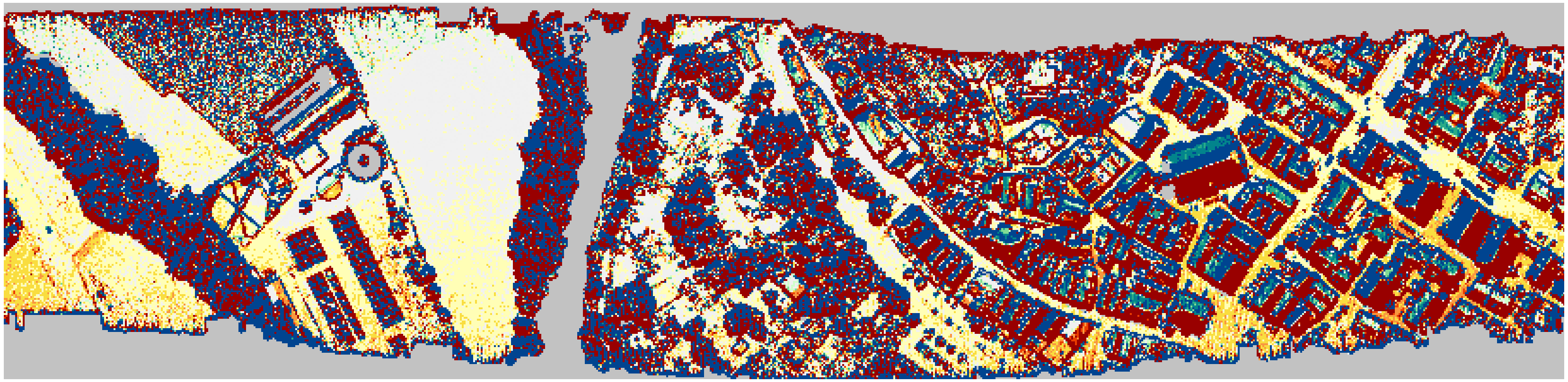
Colour coded strip difference model:

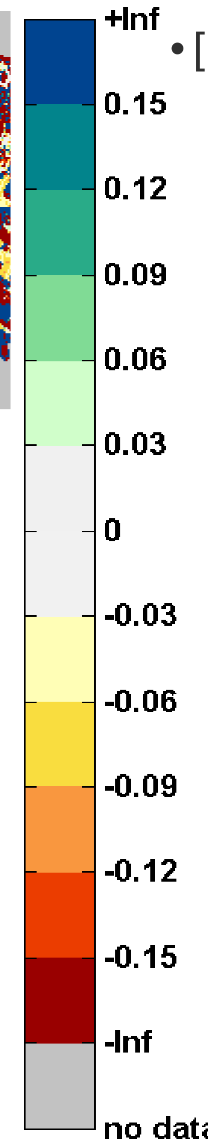




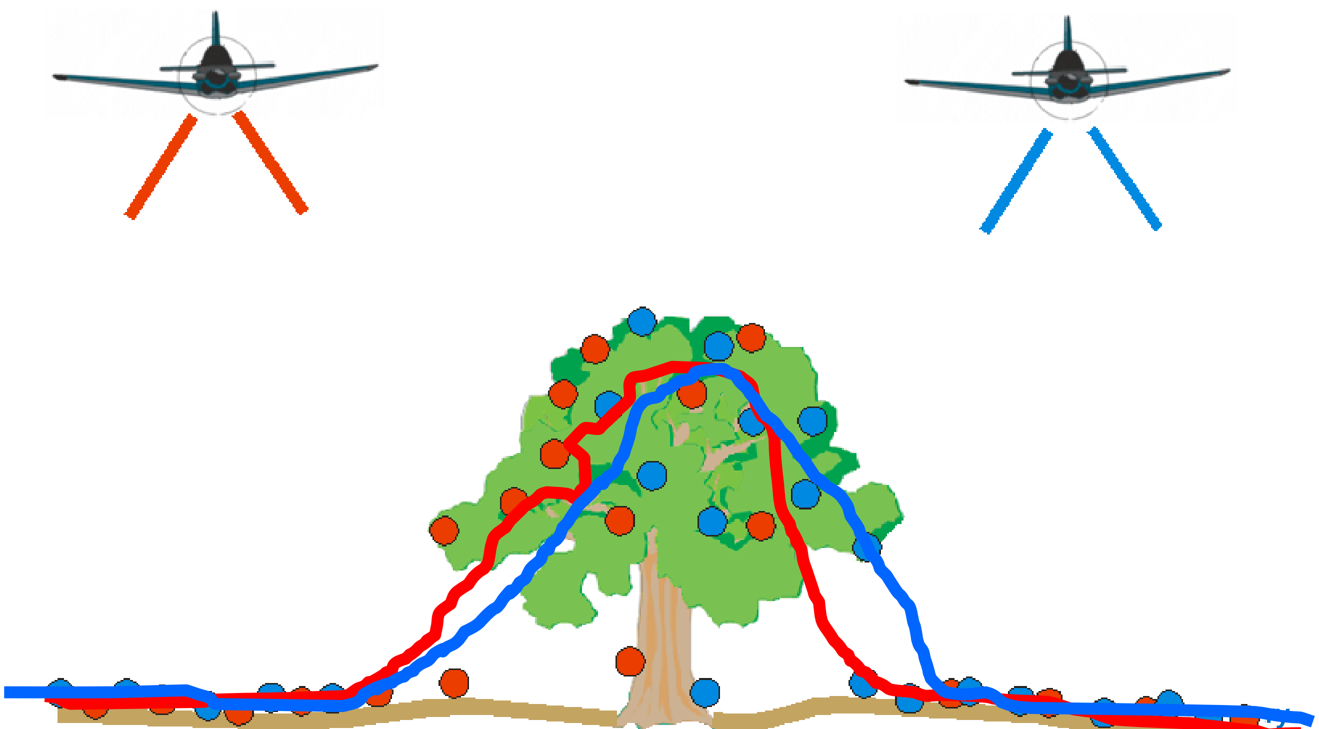



# Strip difference - example



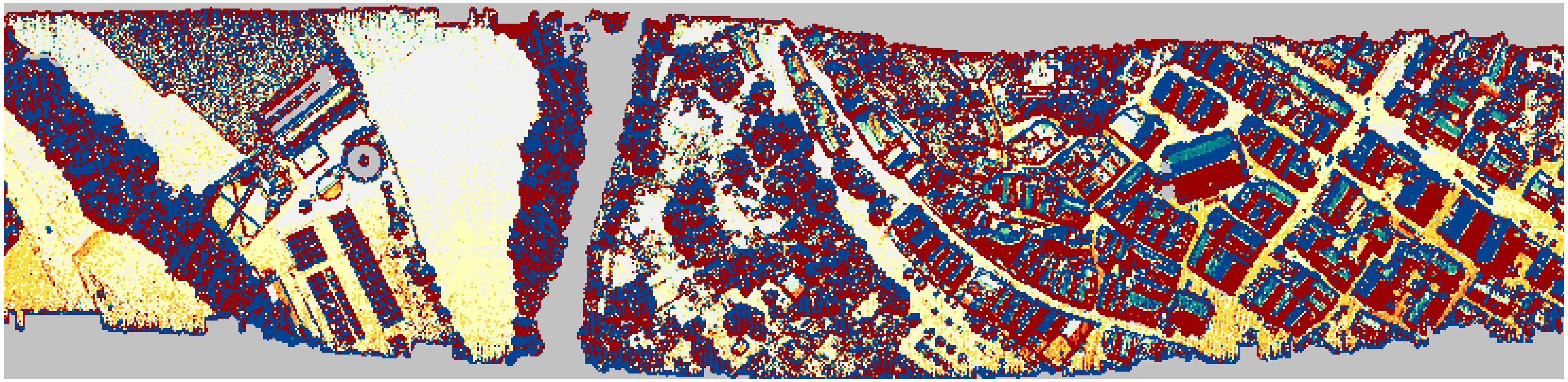



• [m

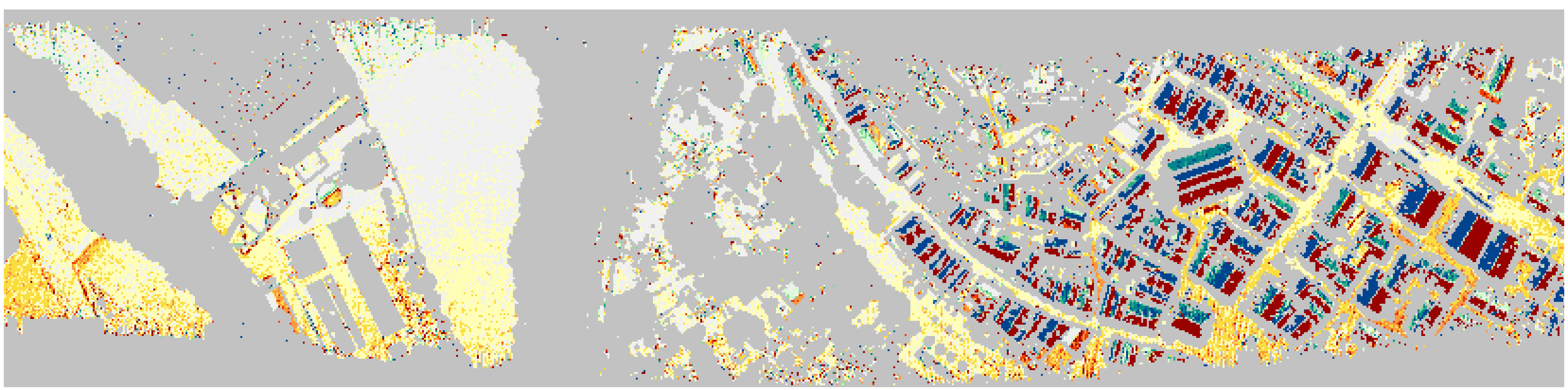


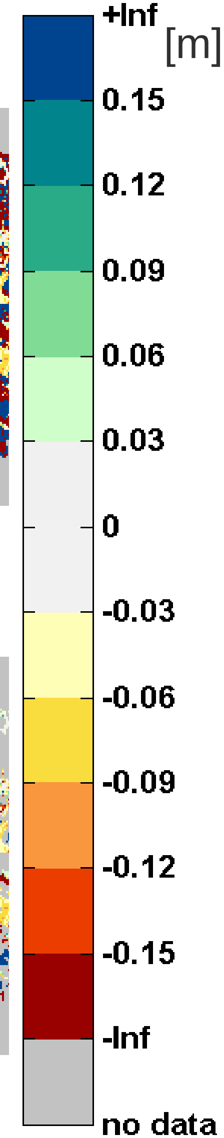
# Strip differences with and without a mask

Unmasked strip difference



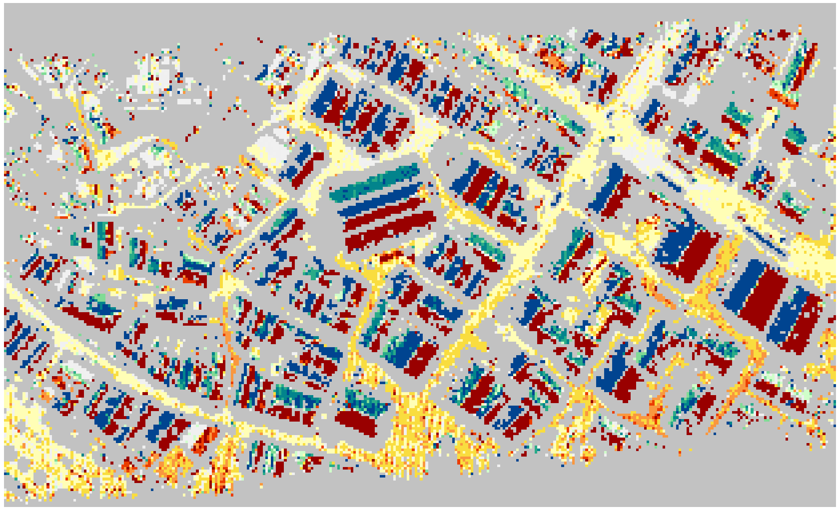
Masked strip difference

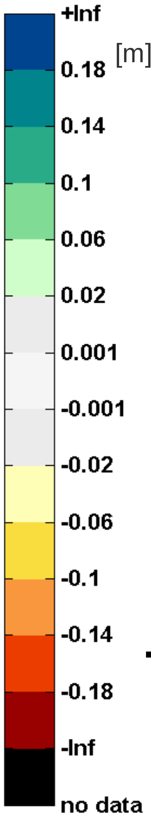




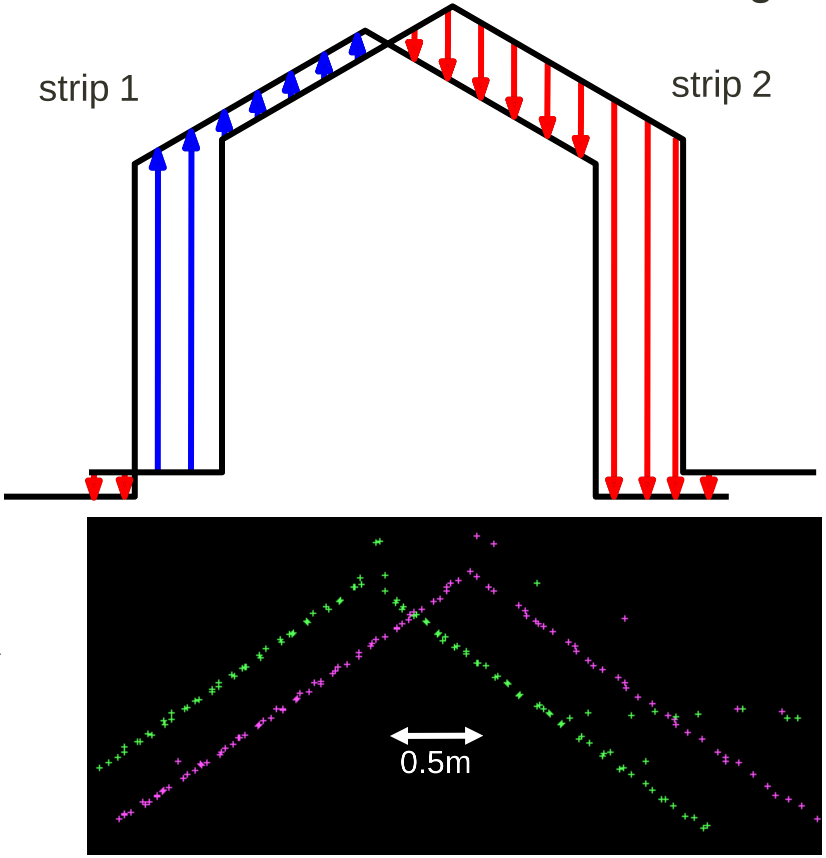
# Strip differences: buildings

Colour coded strip difference:






Error effect in an area with buildings:



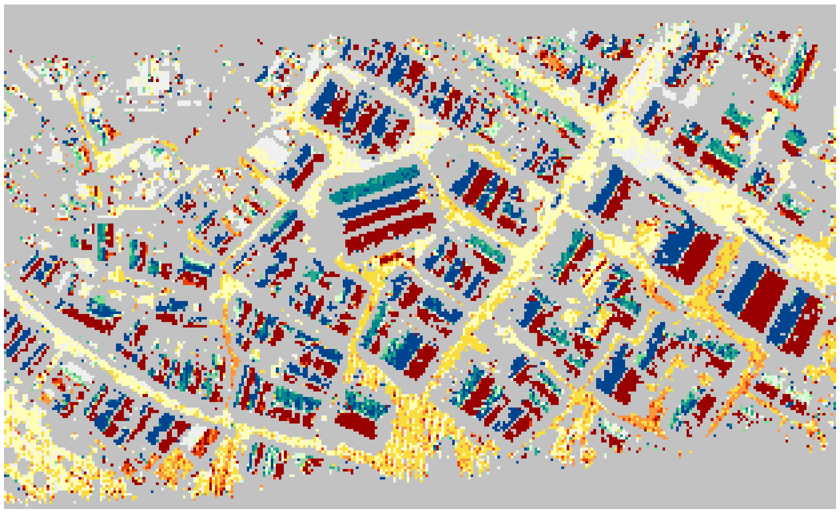

Schönbrunn 2004 strip 8/9

Mainly planar errors

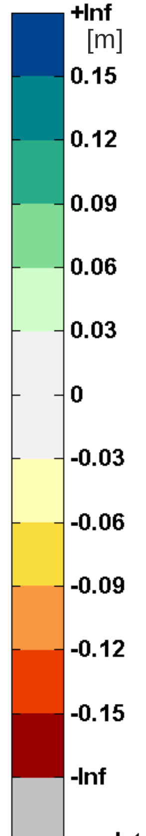
(typically due to an inadequate mounting calibration)

# Strip difference improvement due to strip adjustment

Original Georeferencing:

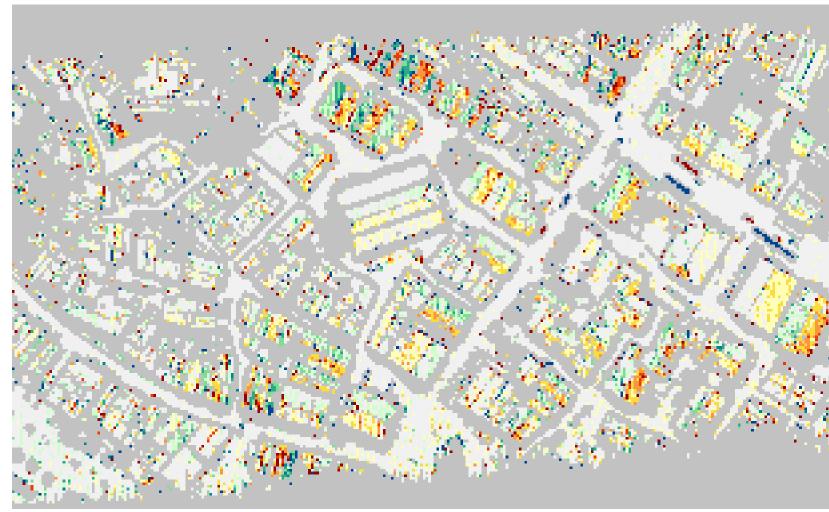


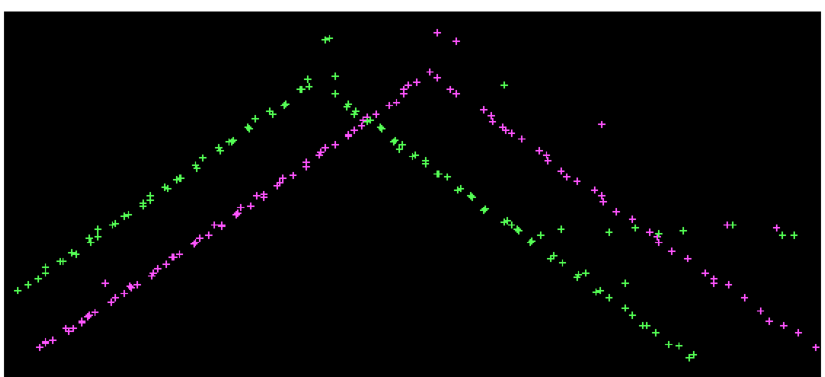
DGPF,Strips: 9-10

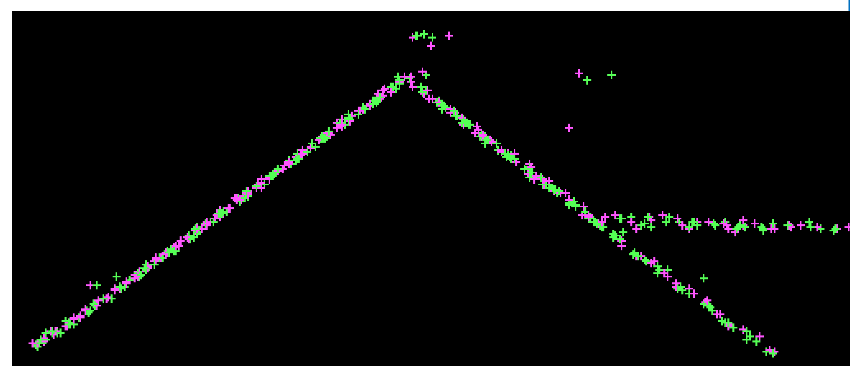



Improved Georeferencing:

→ ALS strip adjustment

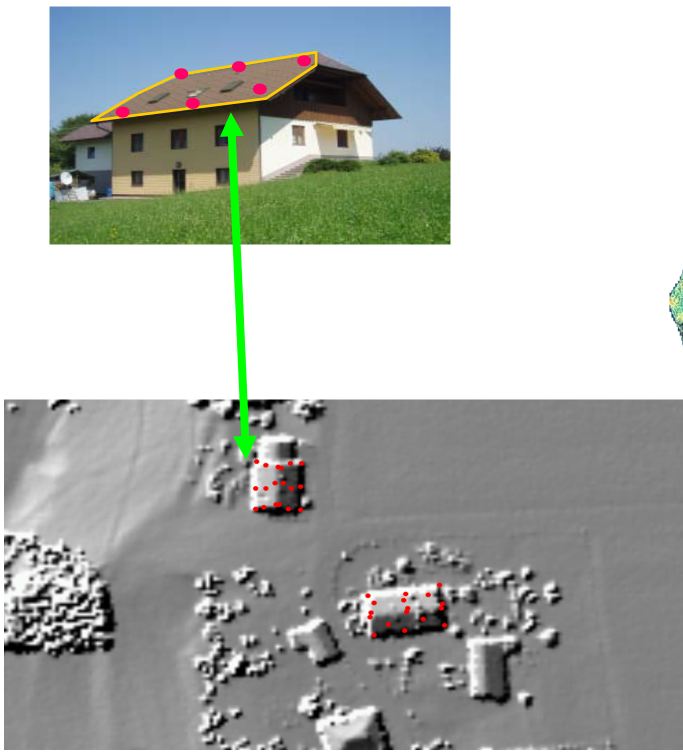


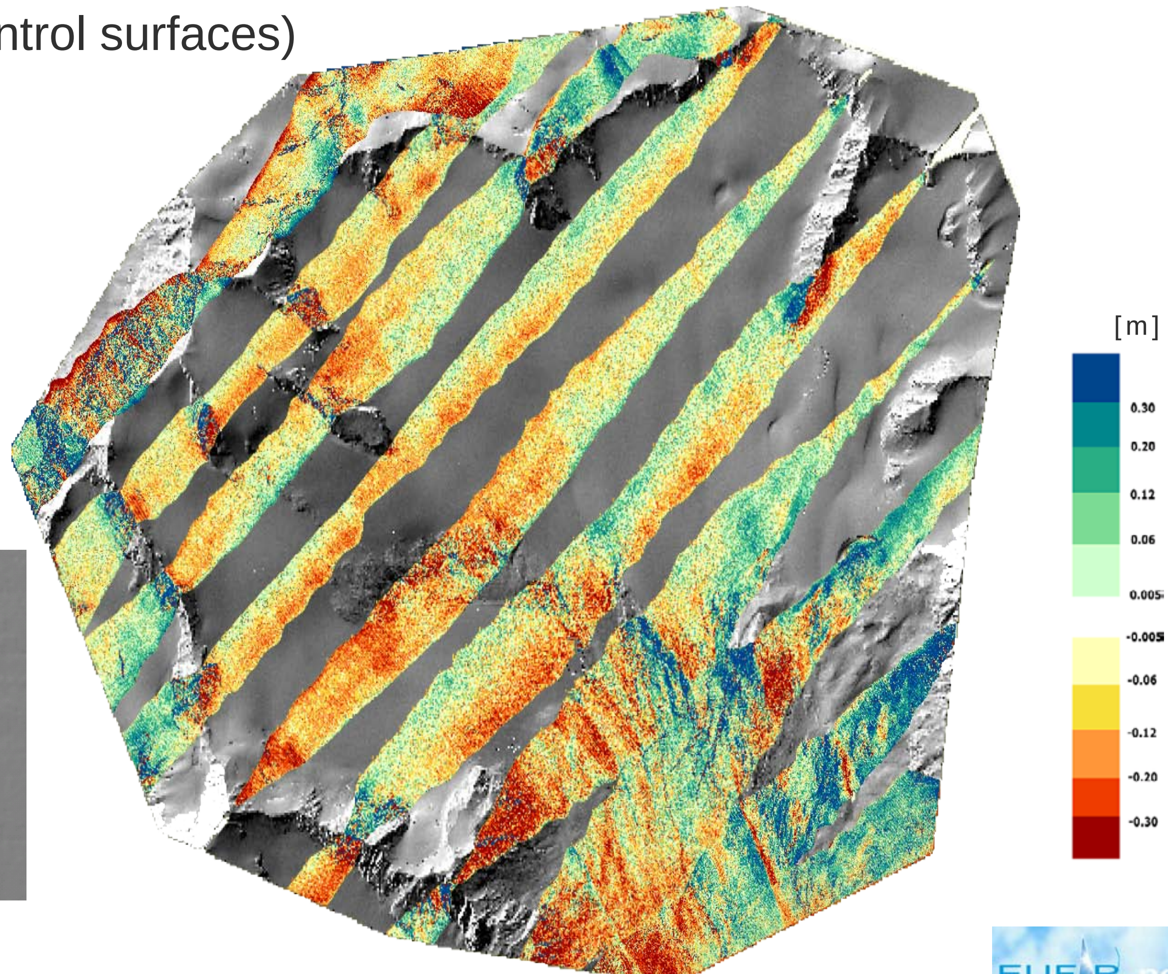




# Quality Control (II)

- Accuracy
  - Relative accuracy (strip differences)
  - Absolute accuracy (control surfaces)

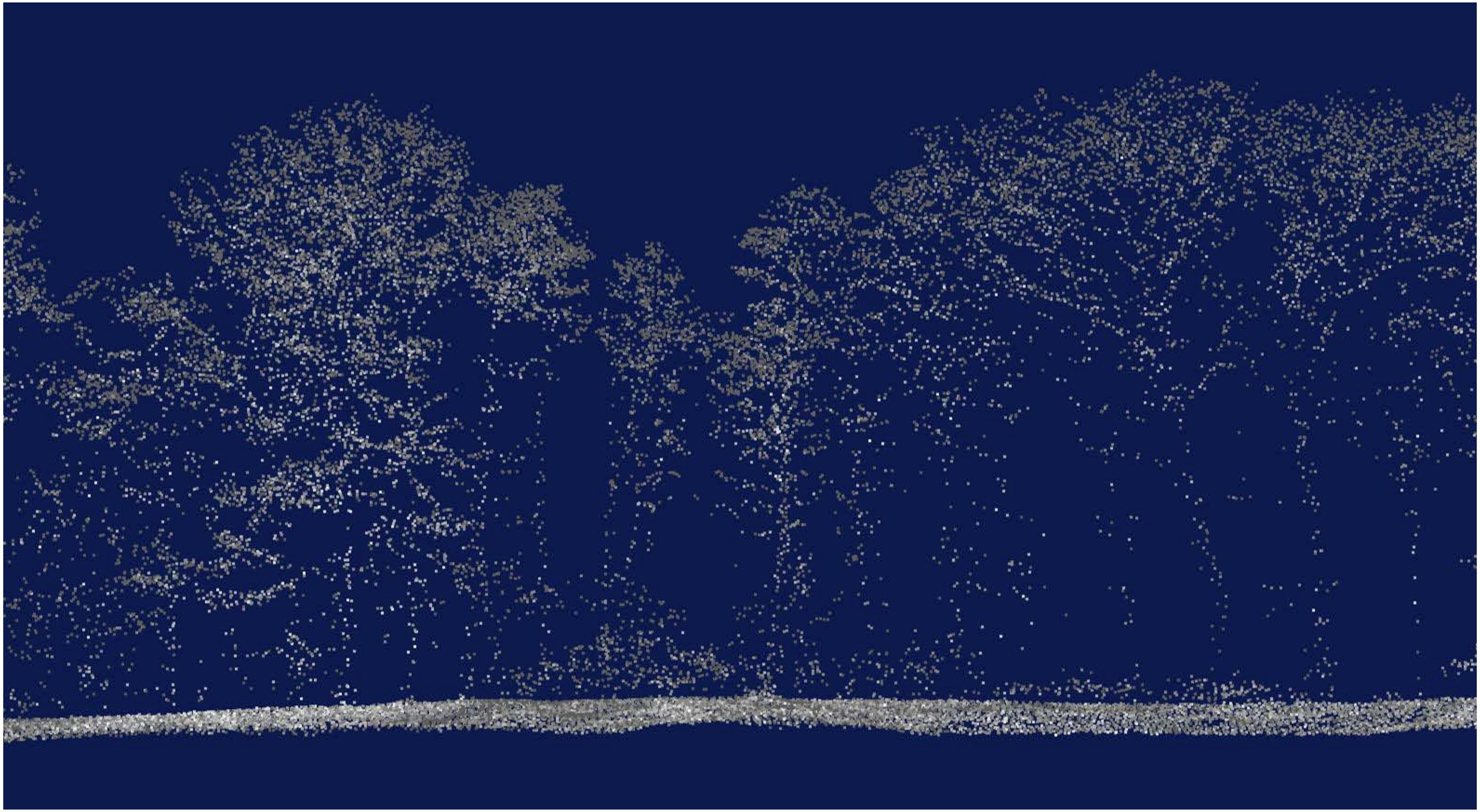




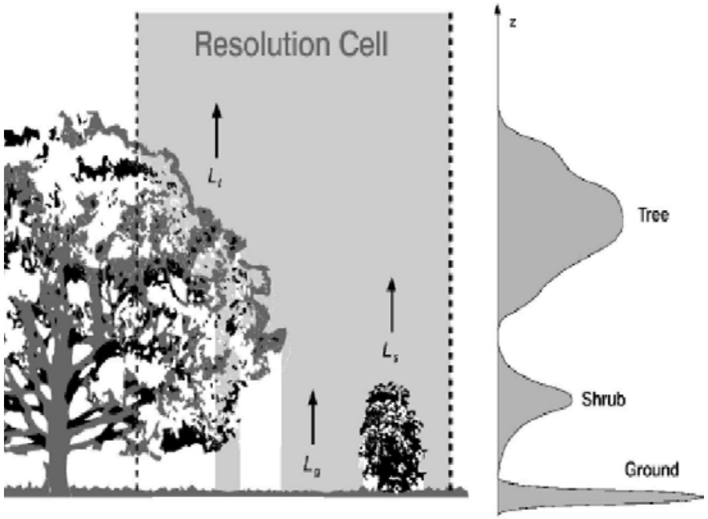
# Summary QC

- Point density
  - Analysis Unit
- Relative Georeferencing
  - Strip difference – quality in overlapping areas
- Absolute Georeferencing
  - Pass areas and check areas

# Vegetation mapping

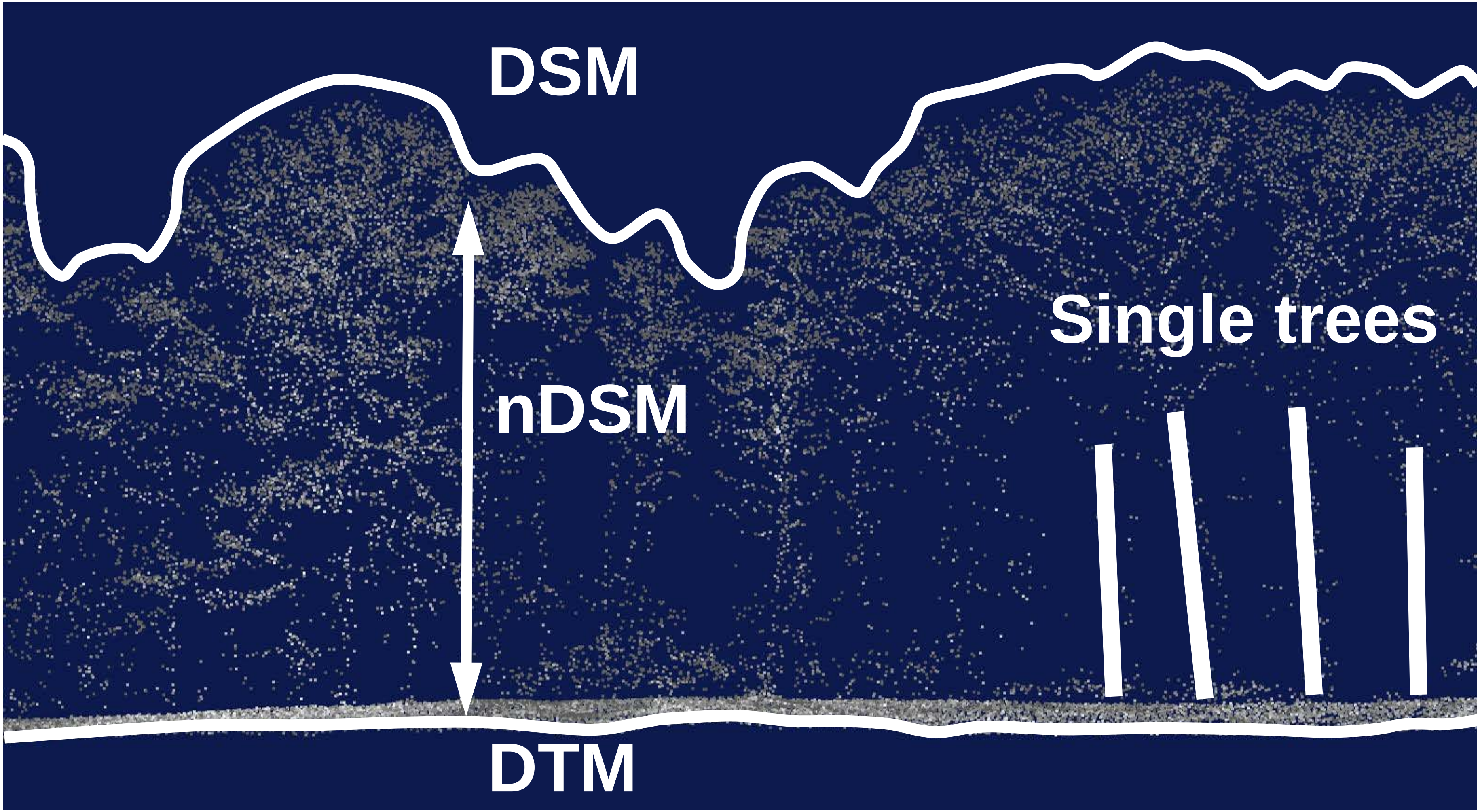


# Vegetation mapping

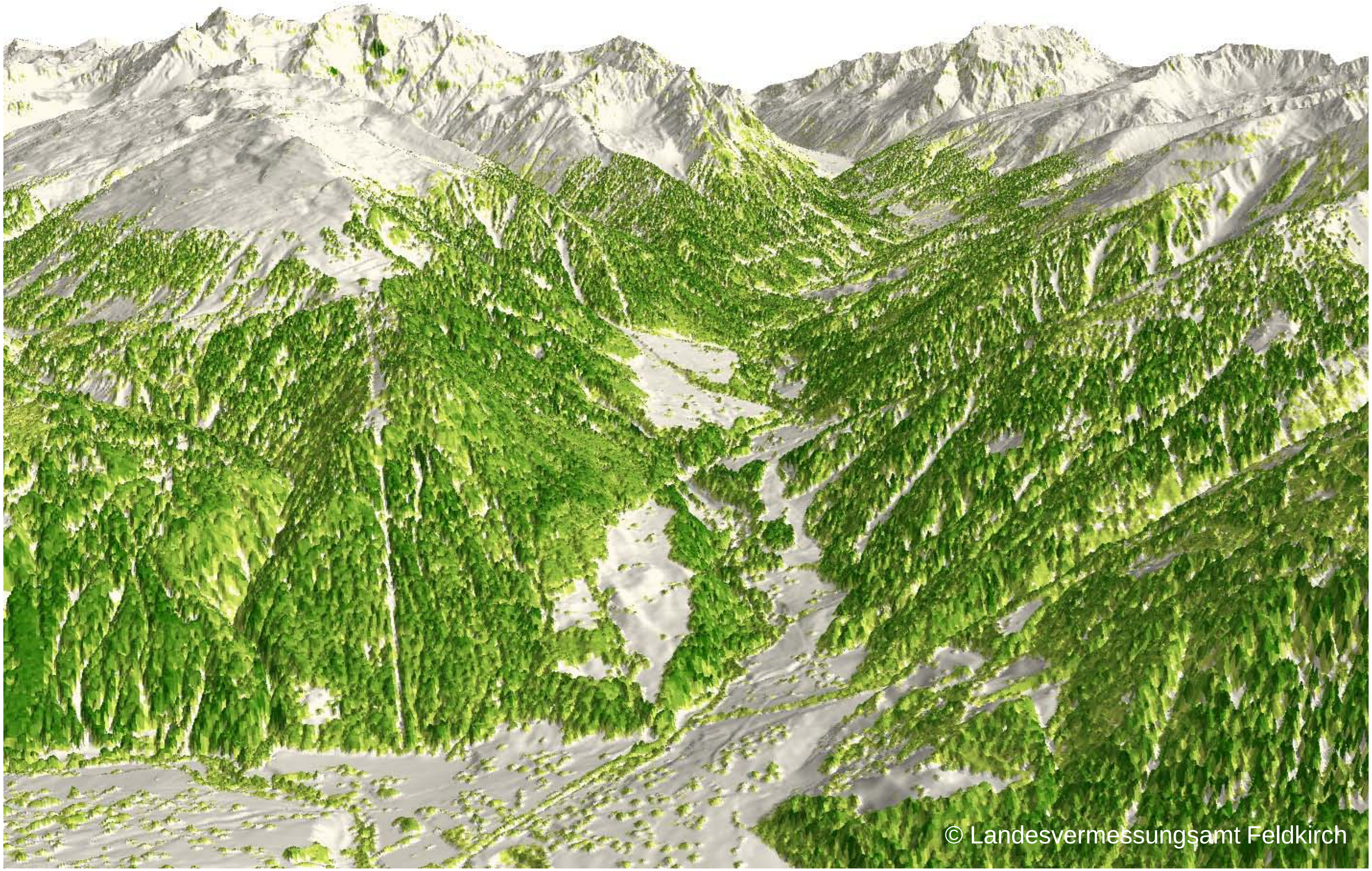



- ALS advantages
  - Vertical vegetation structure
  - Penetration trough small gaps in the canopy
  - Backscatter within and below the crown
  - Backscatter of the terrain
  - Measurement process is based on geometric optics, in contrast to sensors that utilise longer wavelength (radar)
  - High sampling density, therefore ALS is a good detector for single trees

# Vegetation mapping



# nDSM → Object heights



# Landcover from ALS data: DSM

# Landcover from ALS data: “Echo Ratio”

**Echo ratio: ratio of the number of echoes in a 3D neighbourhood compared to a 2D neighbourhood [%]**


Mücke et al. 2009: Detection of building regions using airborne LiDAR – A new combination of raster and point cloud based GIS methods . GI-Forum ’09, Salzburg.

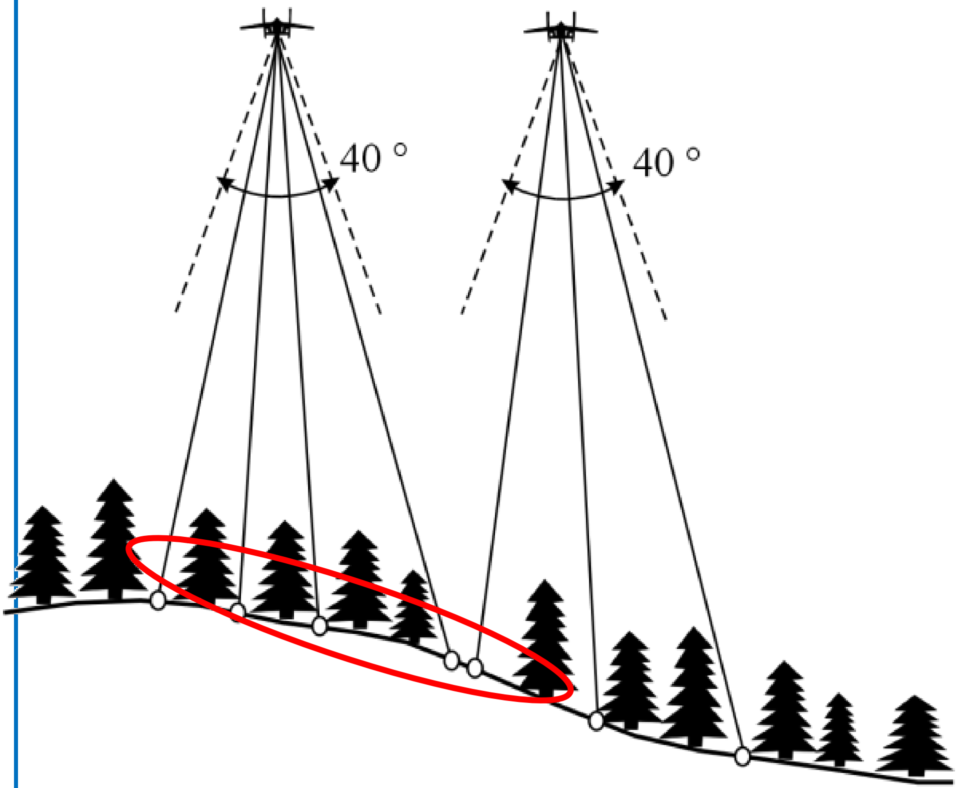
# Landcover from ALS data: Building and Vegetation Layer

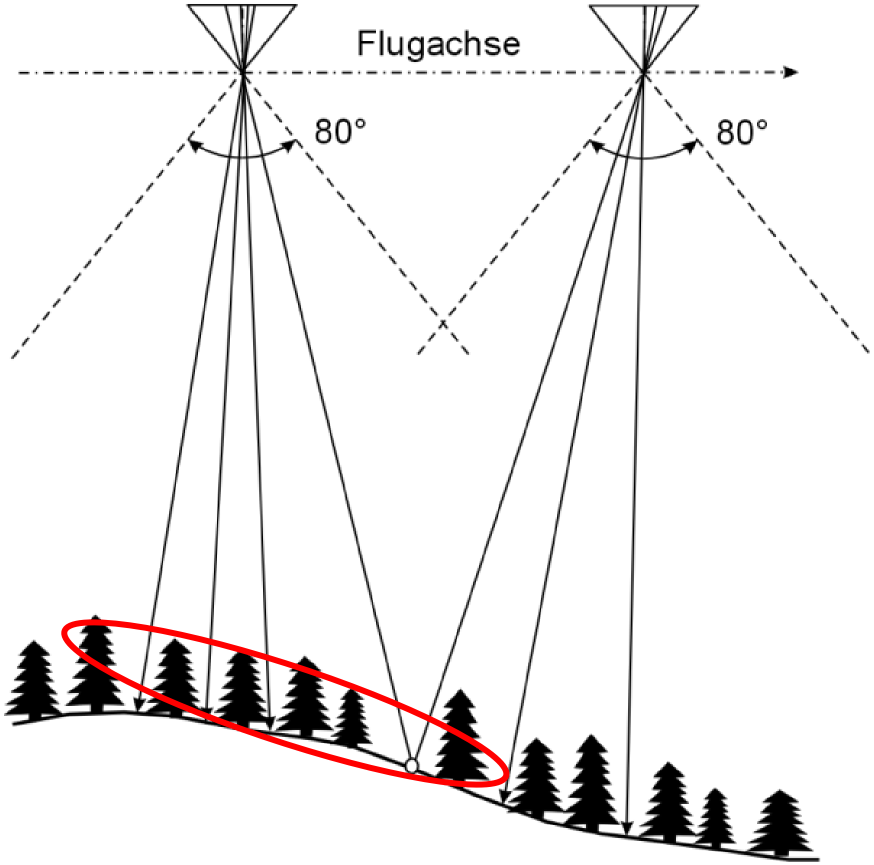
# Photogrammetry versus Laserscanning I

**A C T I V E**
**Airborne Laserscanning**

**versus**

**P A S S I V E**
**Photogrammetry**

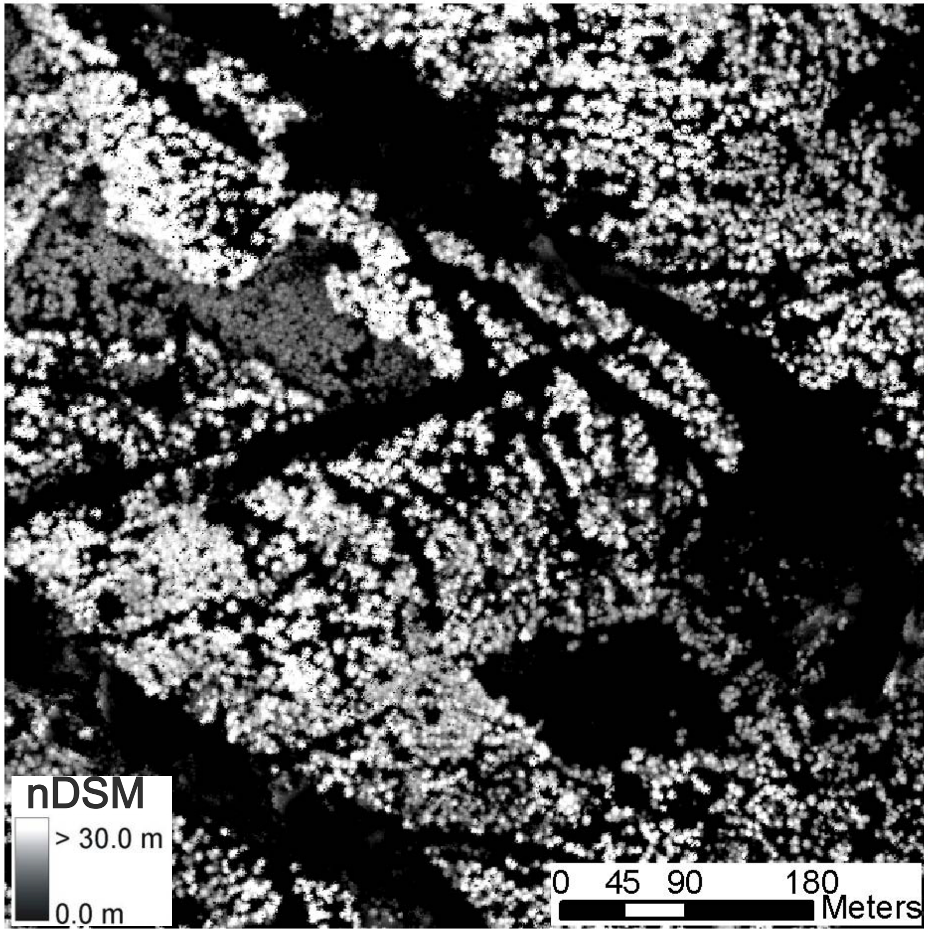


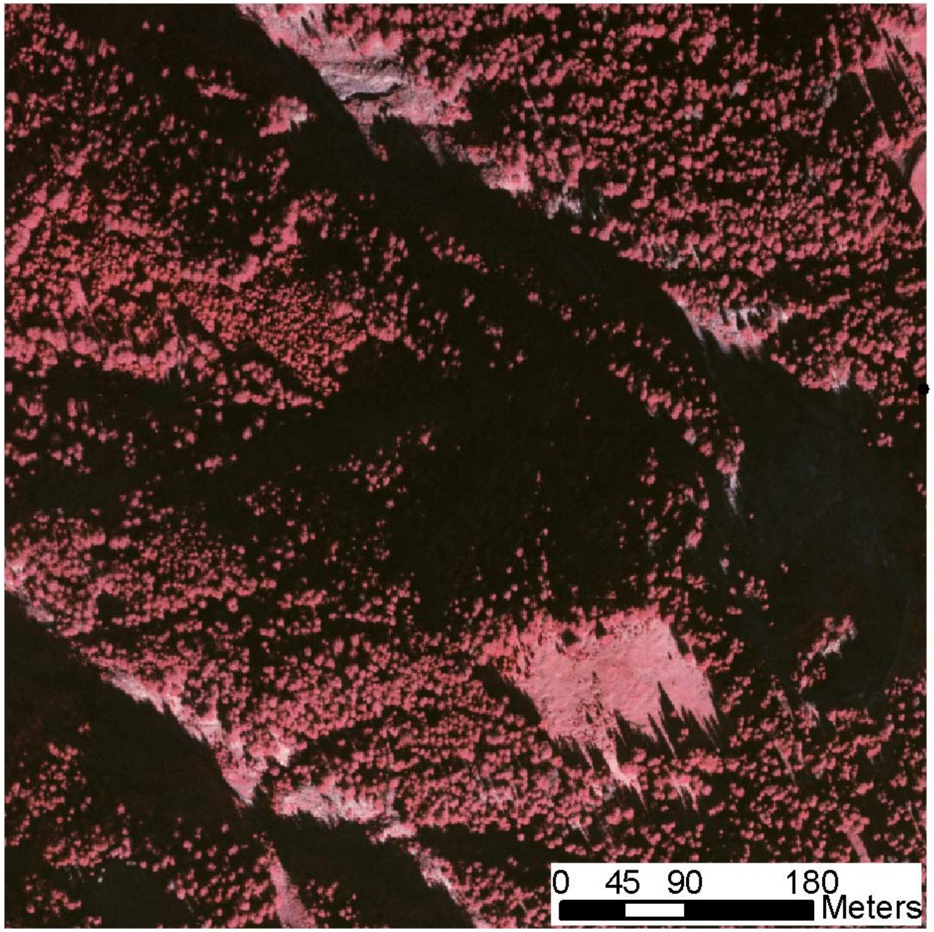

**→ Advantage for the derivation of the terrain within forested areas!**

# Photogrammetry versus Laserscanning II

nDSM




Orthophoto



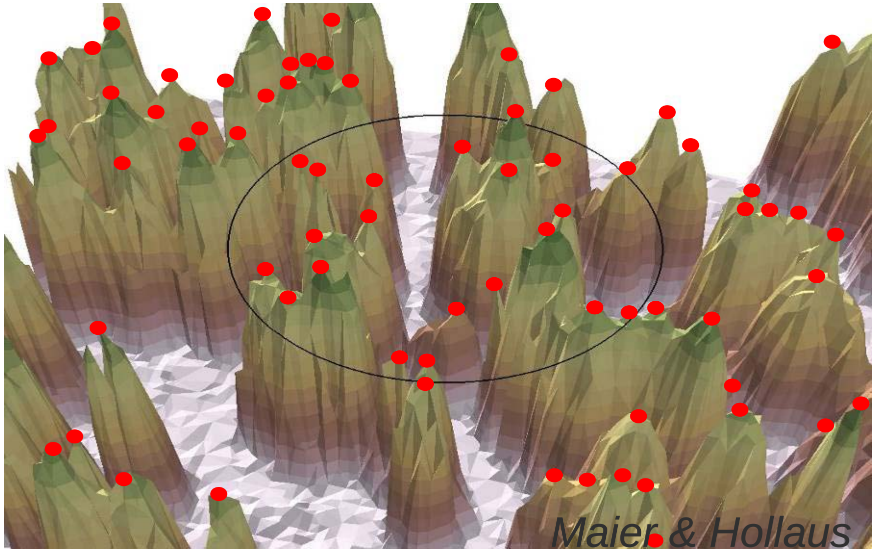
# Forest parameter from ALS data

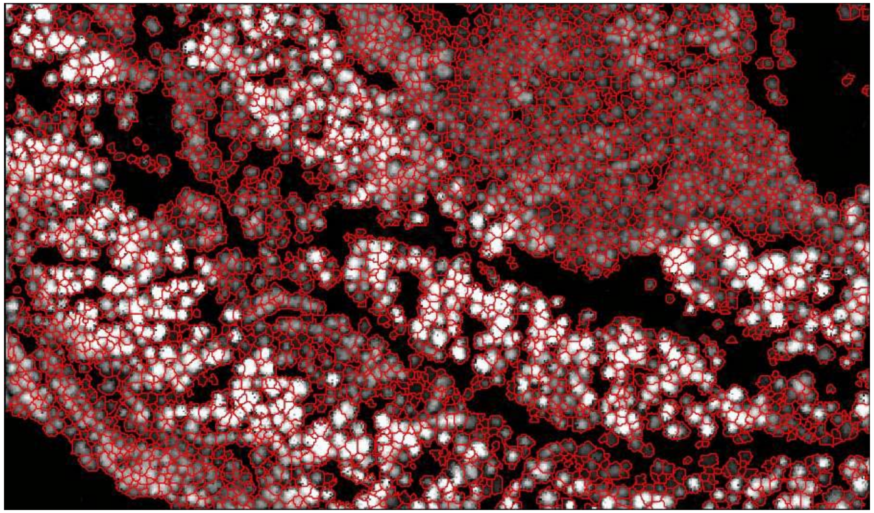
Two approaches

- Single-tree-based
  - High ALS point density is required (e.g. > 4-5 points/$m^2$)
  - 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

- Position of single trees
  - Local maxima filters
- Tree crown determination
  - Region growing
  - Edge-based segmentation
- Tree height estimation
  - Highest echo inside the tree crown
- Tree species
  - Fitting tree crown models
  - Classifying vertical point distributions
- Assessment of *dbh*
  - Based on empirical functions
    E.g.: dbh = $f_{(\text{height, crown ø})}$
    E.g.: dbh = $f_{(\text{height, crown ø, species})}$
- Stem volume
  - Based on empirical functions
    E.g.: Stem volume = $f_{(\text{height, dbh, species})}$

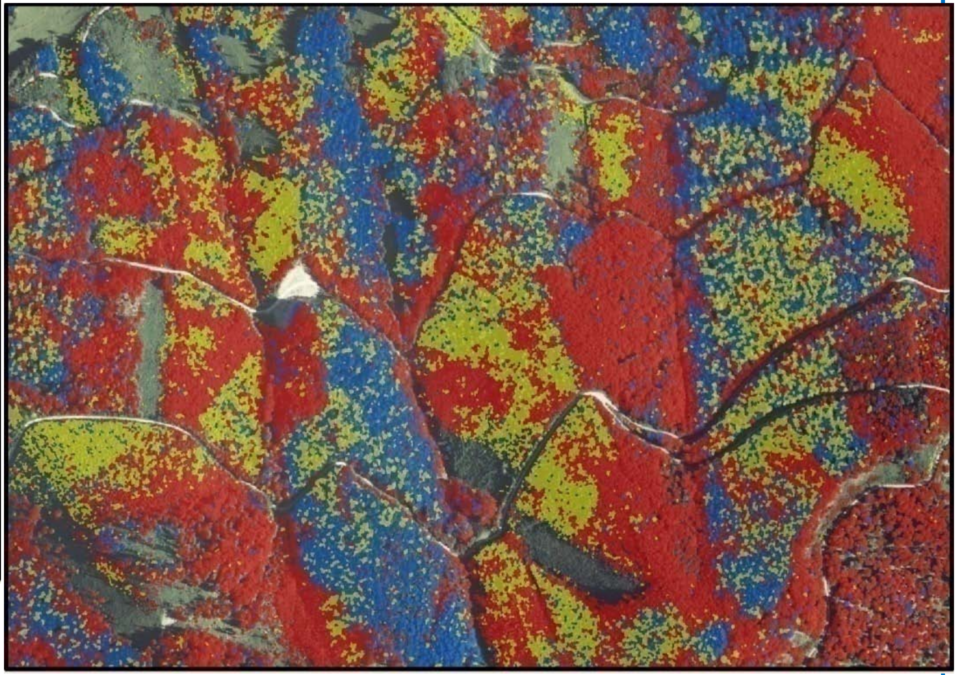


# Classification of tree species using FWF-ALS

© maps.live.com

beech spruce larch



Hollaus, M., Mücke, W., Höfle, B., Dorigo, W., Pfeifer, N., Wagner, W., Bauerhansl, C. and Regner, B., 2009b: Tree species classification based on full-waveform airborne laser scanning data. Silvilaser 2009, October 14-16, 2009 - College Station, Texas, USA.

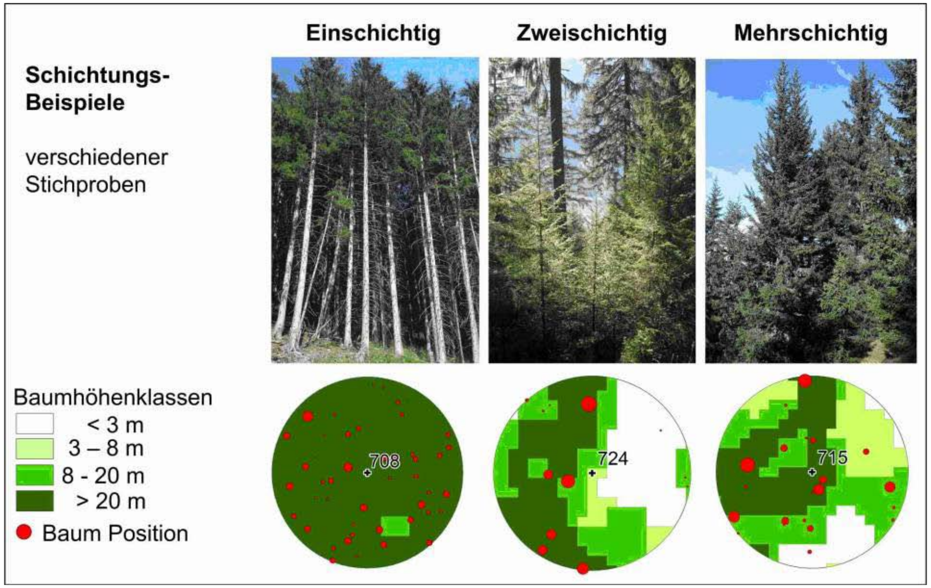
**Overall accuracy for classifying:**

- Beech, spruce and larch: 75%
- Deciduous and coniferous: 83%

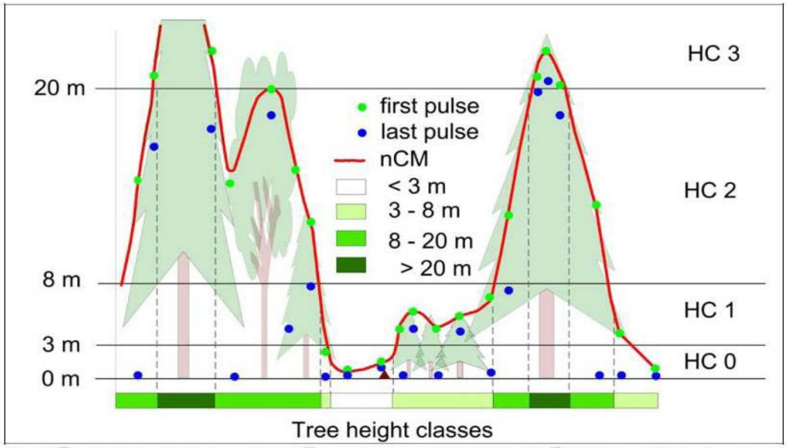
ALS data provided by the government of Lower Austria

# Crown cover / structure types

- **Segmentation of the nDSM**
  → Canopy height classes
- **Meta-segmentation based on available forest stands**
- **Classification**
  → forest structure type for each forest stand




(© Maier, B. & Hollaus, M., 2008: Waldstrukturerfassung mittels Laserscanning im Schutzwald. Kleine Waldzeitung des Vorarlberger Waldvereines 3:9-11)



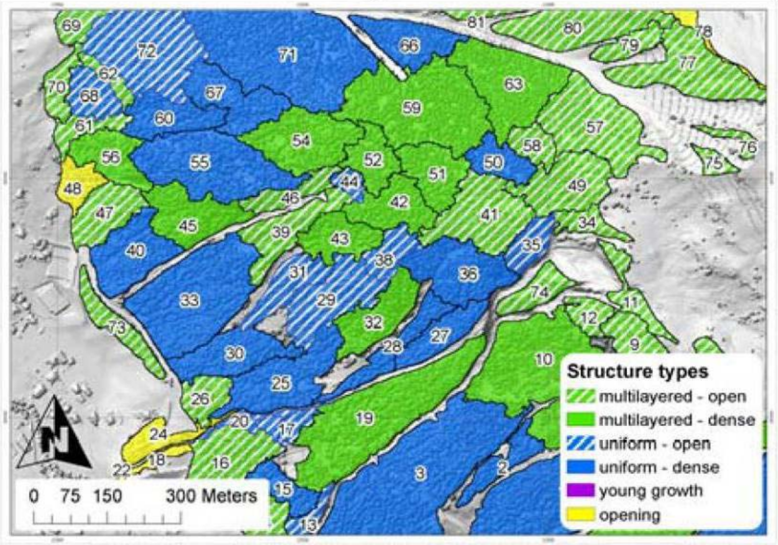
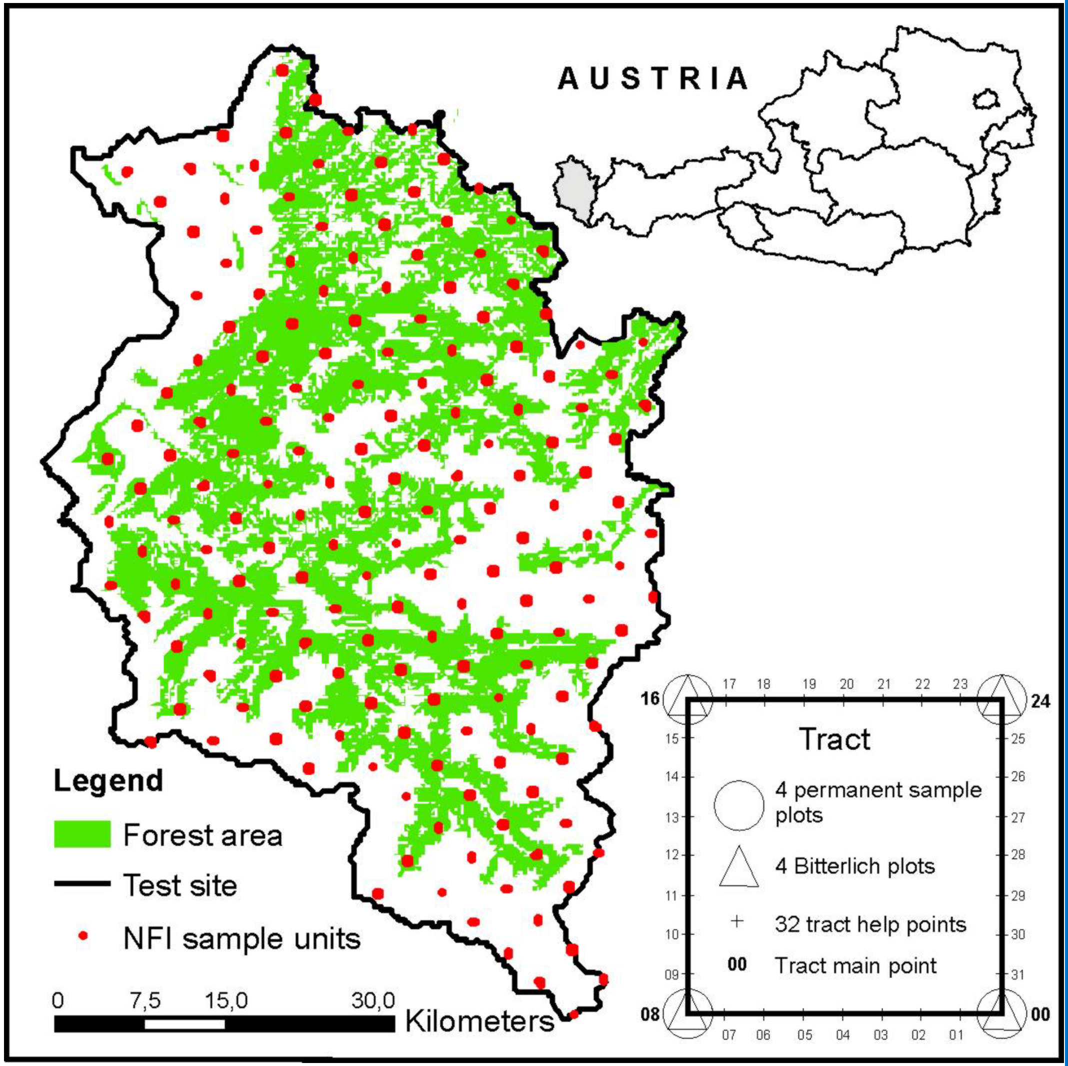




Figure 8. Distribution of discrete structure types

(© Maier B. 2007: Characterising Mountain Forest Structure using ALS. Master thesis)

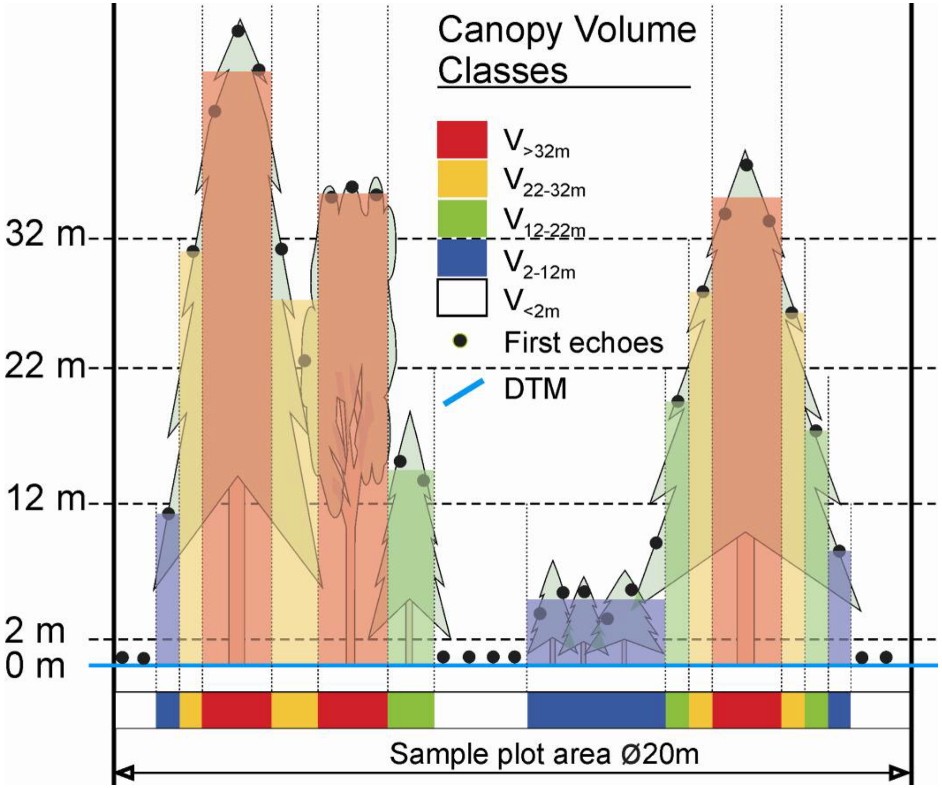
# Downscaling NFI data: Study area & data

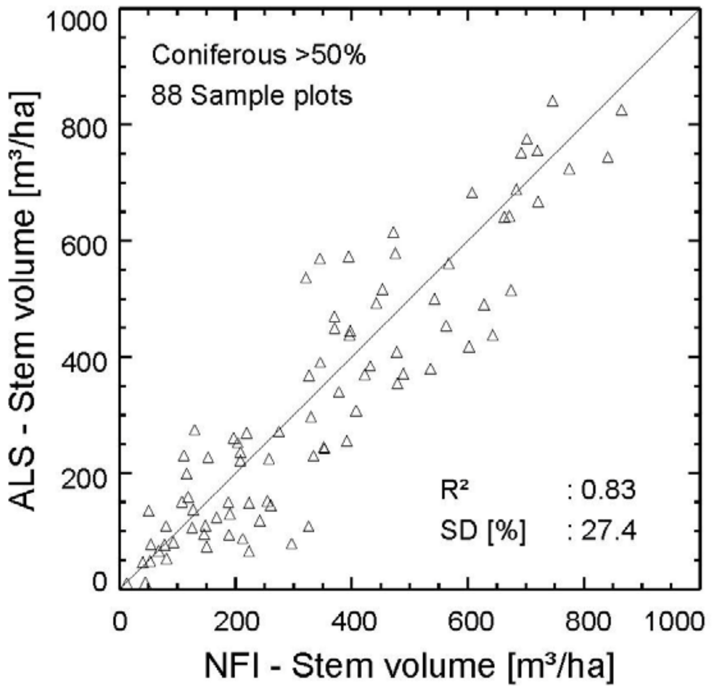
- **Entire district of Vorarlberg**
  - 2 604 km² entire area
  - 970 km² forest area
  - Altitudes: 396 - 3312 m
- **NFI data**
  - 132 Bitterlich plots
  - Tree-based parameter
    - Position, species, bhd, height
  - Area-based parameter
    - Stem volume [m³/ha]
- **Stand Montafon Forstfonds forest inventory data**
  - ~500 Bitterlich plots distributed in a 350 m grid
  - Used for external validation




*Hollaus, M., 2009*

# Downscaling NFI data: Stem volume model




$$v_{stem,fi} = 10^4 \cdot \sum_{i=1}^{n} \beta_i \cdot v_{can,i}$$

Parameter from ALS Data

Forest parameter from field measurements

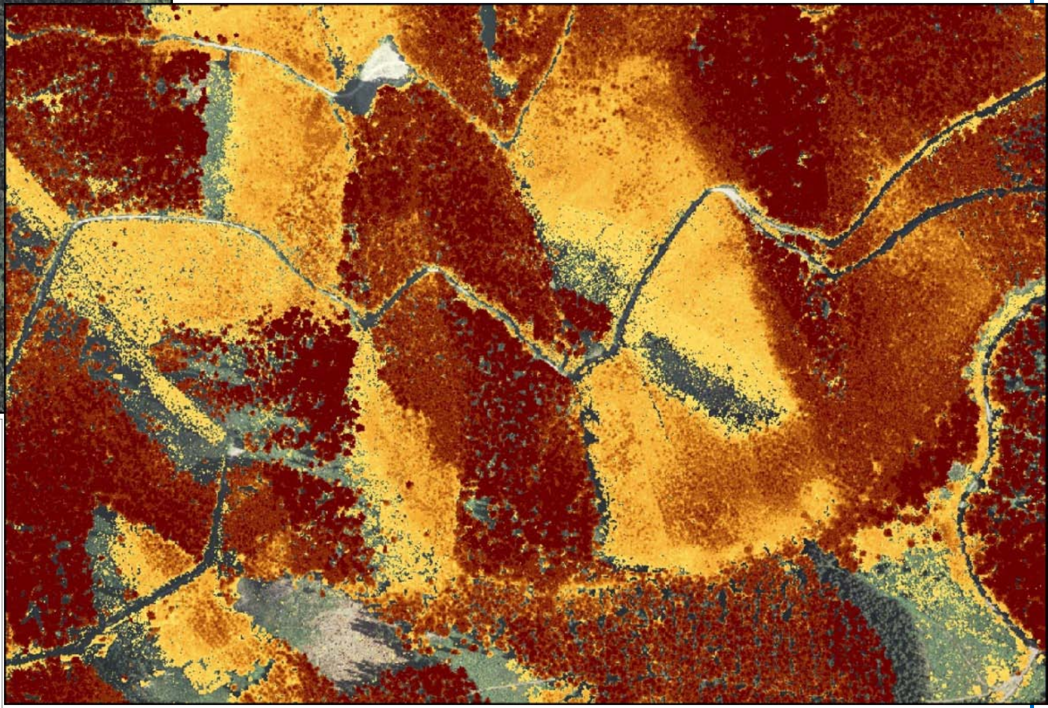
Model coefficients
← reference data are used for calibration

*Hollaus, M., 2009*

# Downscaling NFI data: Stem volume result

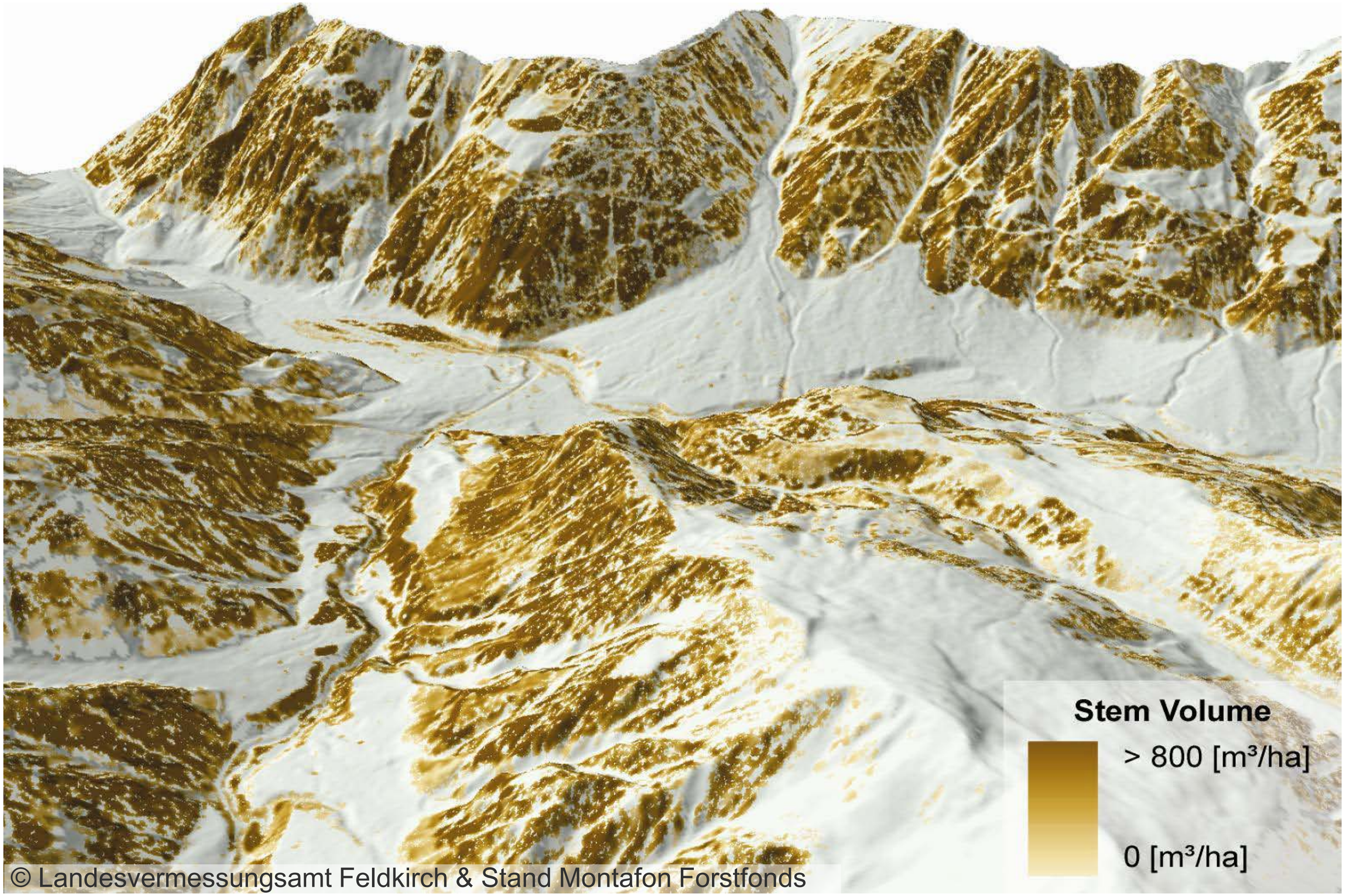
- Stem volume estimation of coniferous and deciduous trees



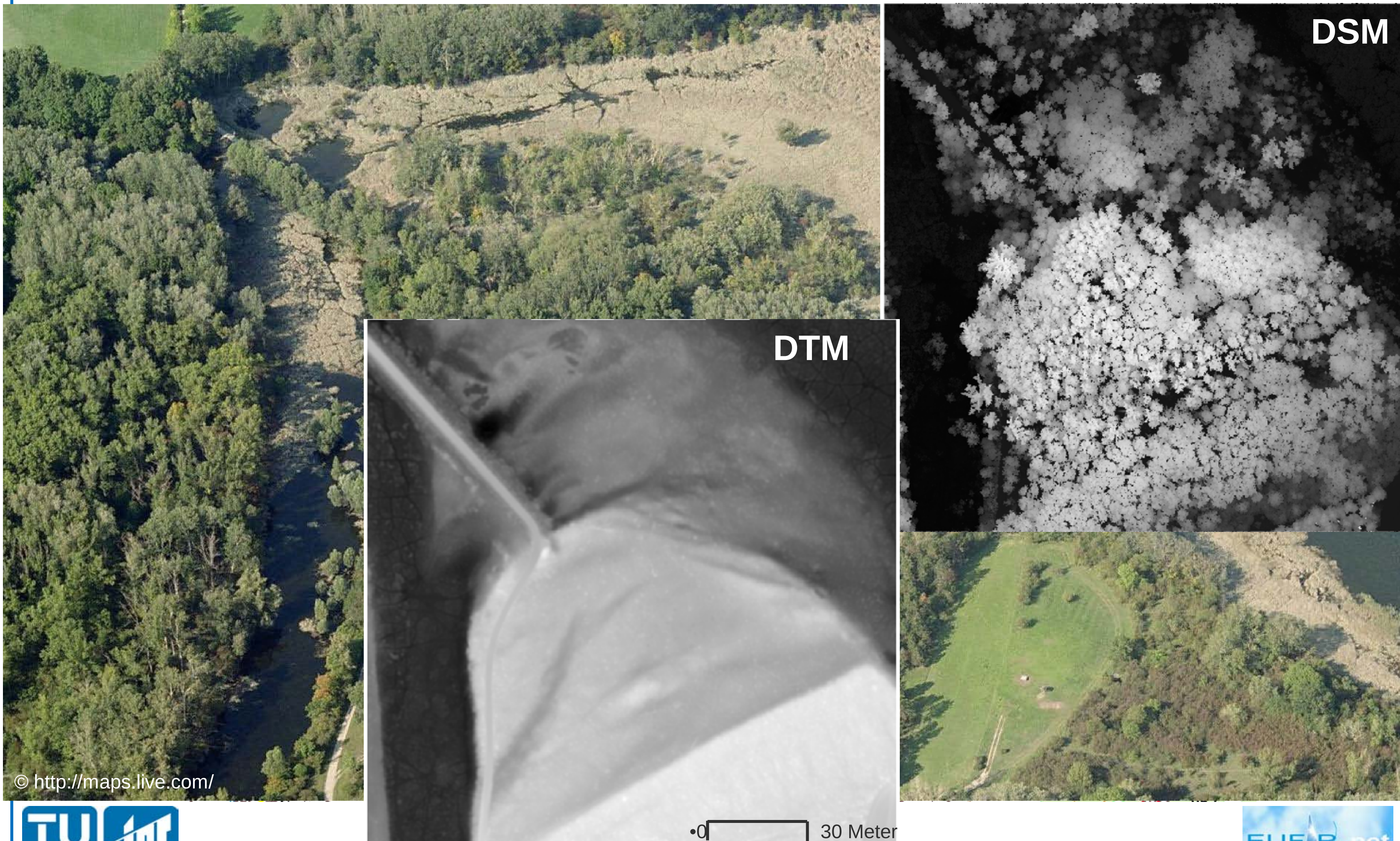



Hollaus, M., Mücke, W., Höfle, B., Dorigo, W., Pfeifer, N., Wagner, W., Bauerhansl, C. and Regner, B., 2009b: Tree species classification based on full-waveform airborne laser scanning data. Silvilaser 2009, October 14-16, 2009 - College Station, Texas, USA.

# Downscaling NFI data: Large area stem volume mapping



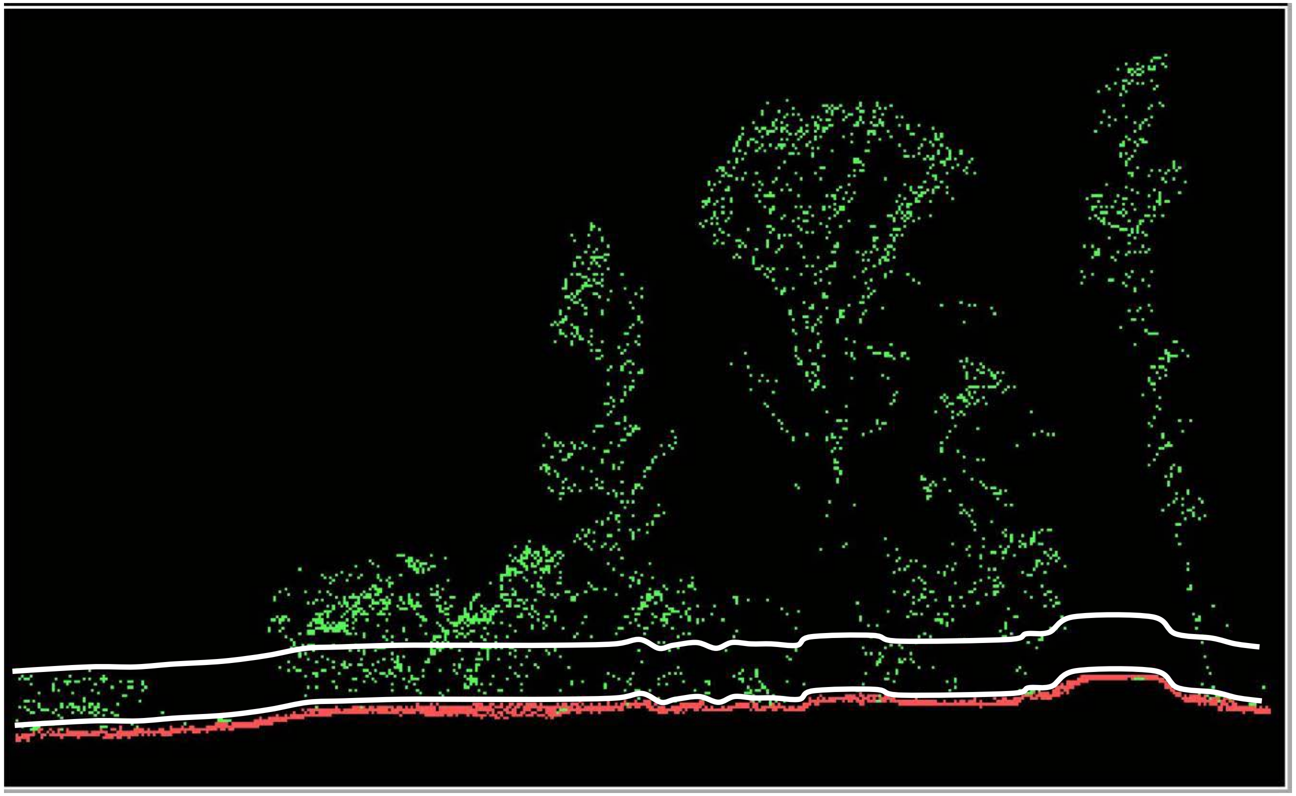
# Vegetation near the ground level



# Vegetation near the ground level

Analyses of the point density in different height levels

$$\frac{\#\,\text{ALS points h} < 2.0\,\text{m}}{\#\,\text{ALS points h} < 0.2\,\text{m}} \Rightarrow \text{penetrability of the vegetation near the ground}$$



H < 2.0 m

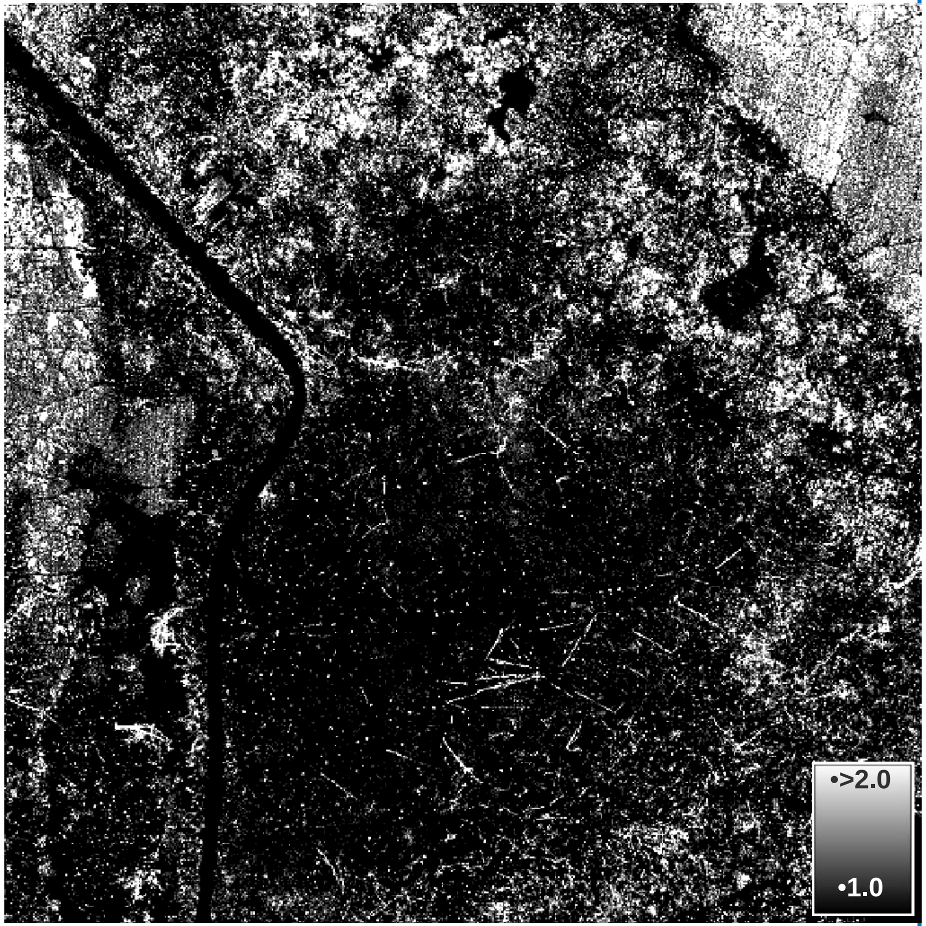
H < 0.2 m

Hollaus, 2008: Vegetationsinformation aus Laserscanning. "Fernerkundung in der Hydrologie und Wasserwirtschaft", ISBN: 978-3-902084-29-3;

# Vegetation near the ground level: Echo Ratio

**Orthophoto**


$$\frac{\#\,\text{ALS points } h < 2.0\,\text{m}}{\#\,\text{ALS points } h < 0.2\,\text{m}}$$



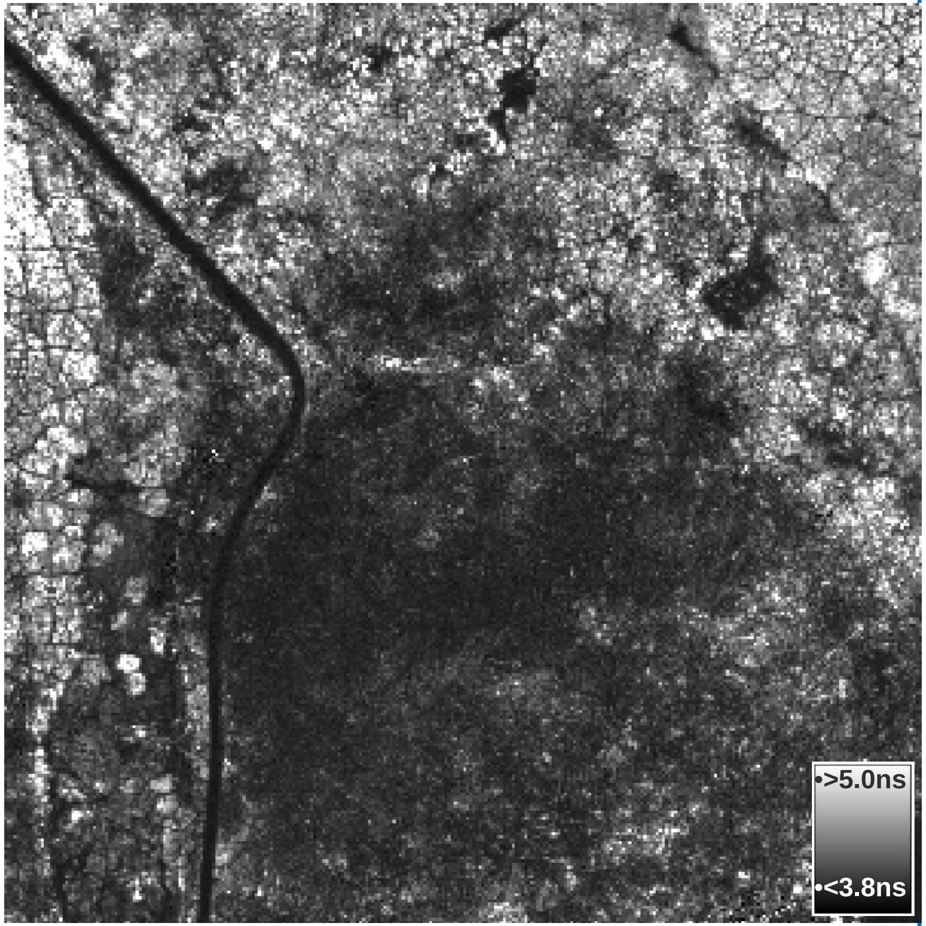

Hollaus, 2008: Vegetationsinformation aus Laserscanning. "Fernerkundung in der Hydrologie und Wasserwirtschaft", ISBN: 978-3-902084-29-3;

© ALS Daten zur Verfügung gestellt von der MA41, Wien

# Vegetation near the ground level: Echo width

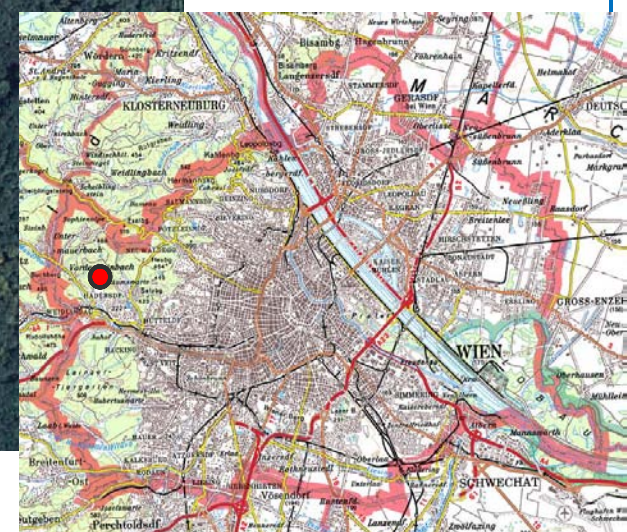
**Orthophoto**

**Echo width of the echoes near the ground $\Delta z<0.2m$**



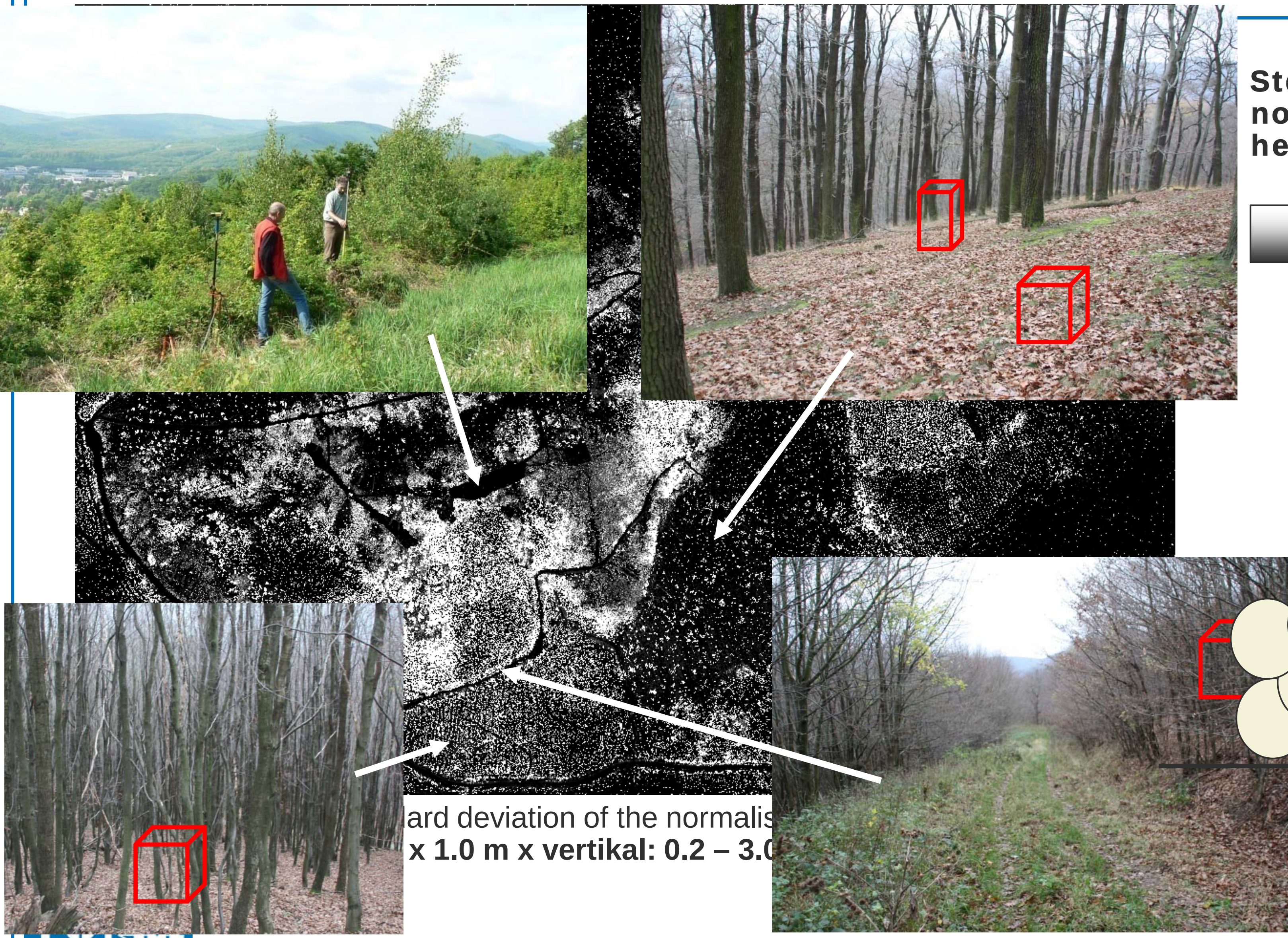

Hollaus, 2008: Vegetationsinformation aus Laserscanning. "Fernerkundung in der Hydrologie und Wasserwirtschaft", ISBN: 978-3-902084-29-3;

# Vegetation near the ground level


Orthophoto. Study area: Kolbeterberg, Wienerwald, Wien.

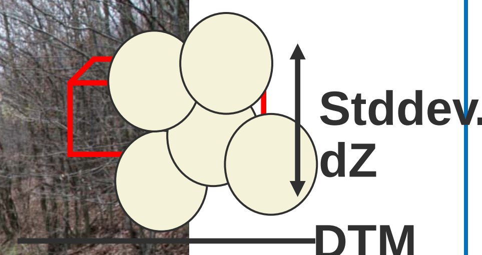
# Standard deviation of echoes (0.2–3.0m)



**Stddev. Of the normalised heights [m]**

> 0.5 m

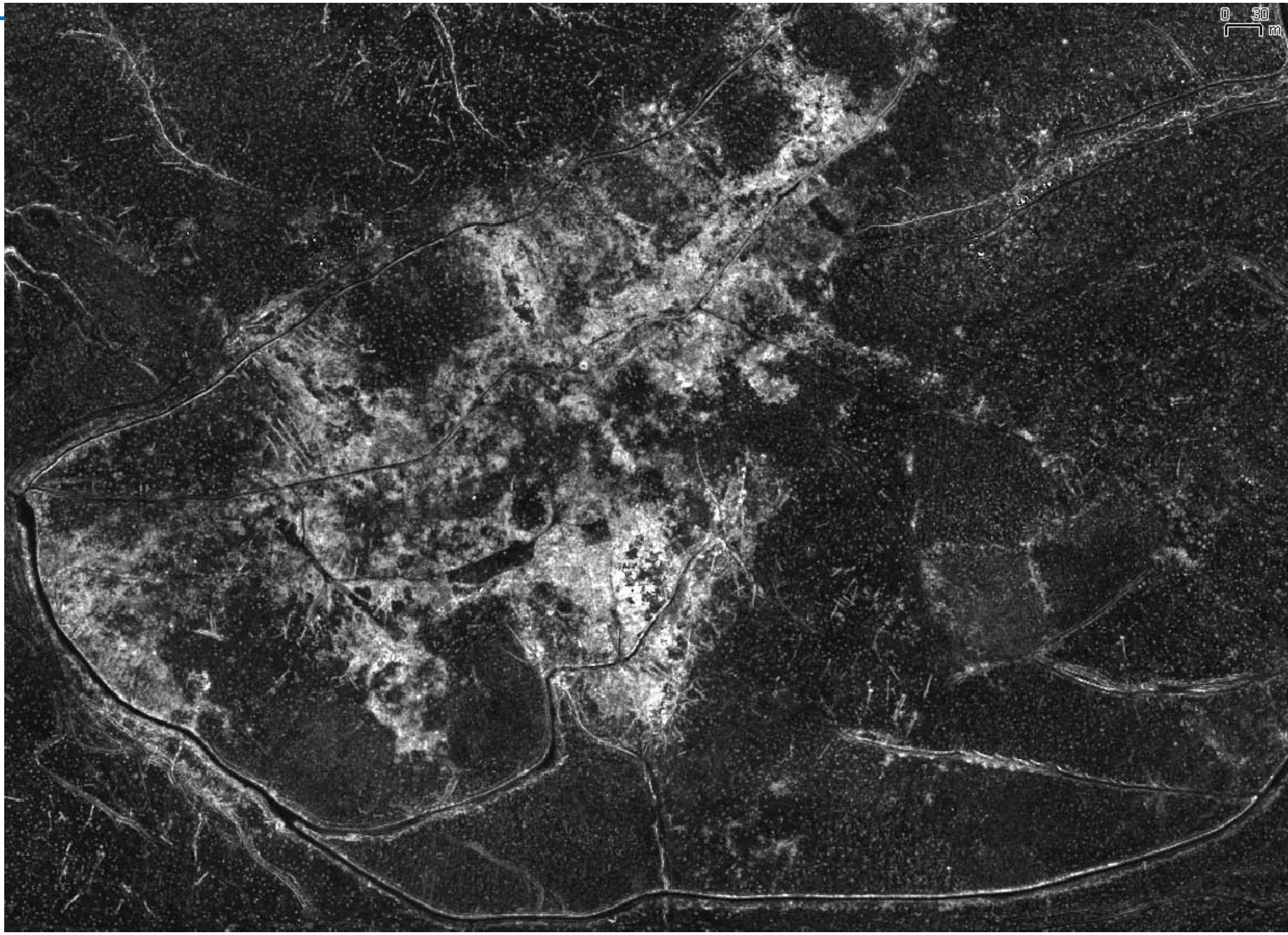
0.0 m




ard deviation of the normalis … etermined in

**x 1.0 m x vertikal: 0.2 – 3.0**

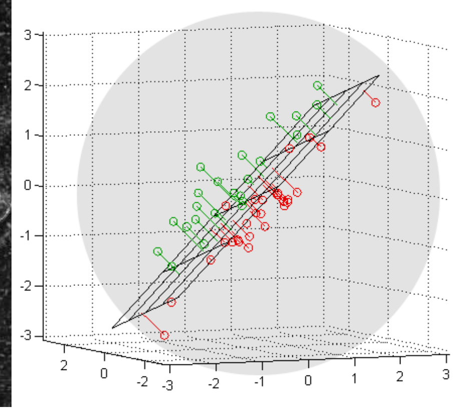
# Standard deviation of echoes (<0.5m)




**Stddev. of the normalised heights [m]**

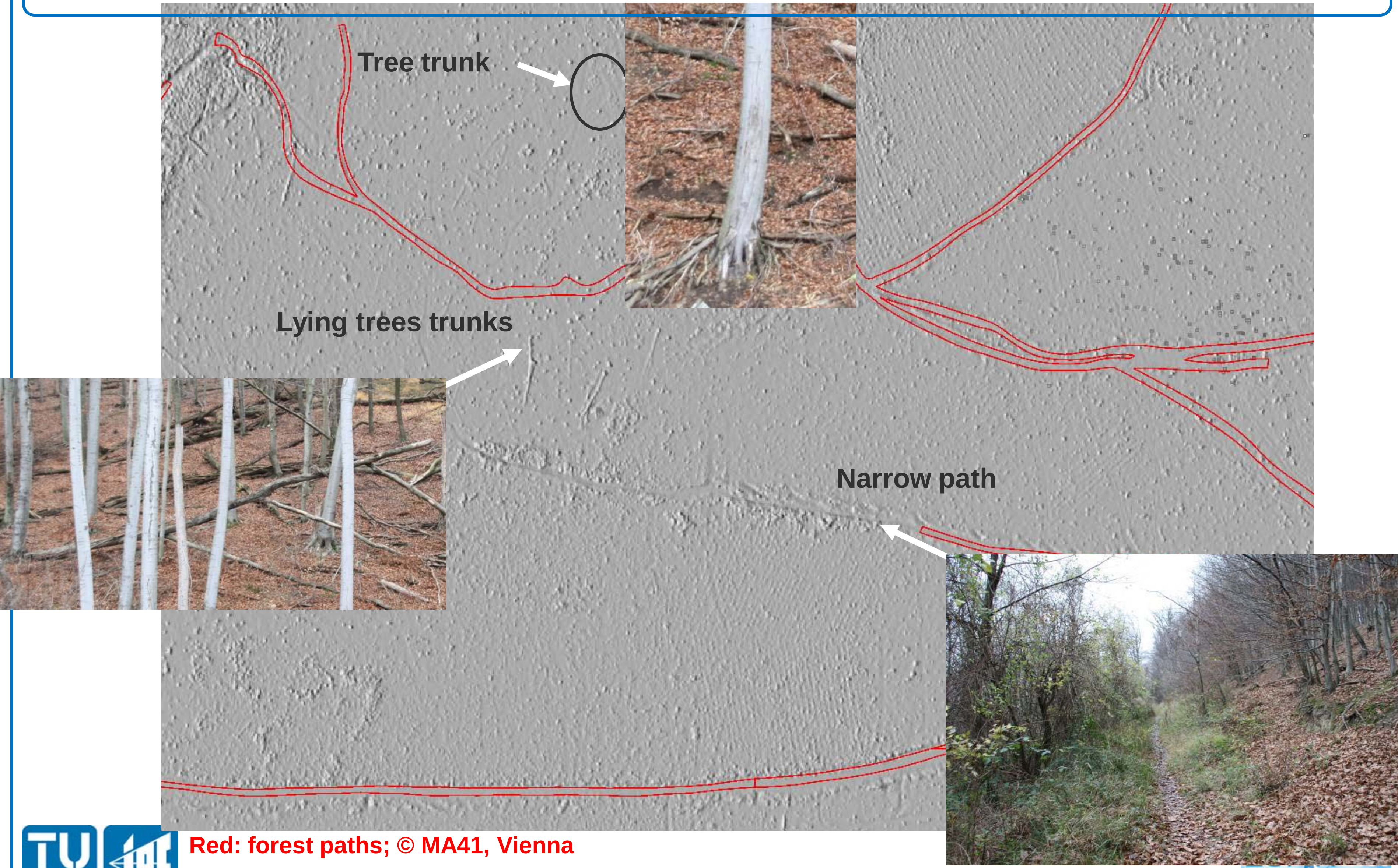
> 0.2 m

0.0 m



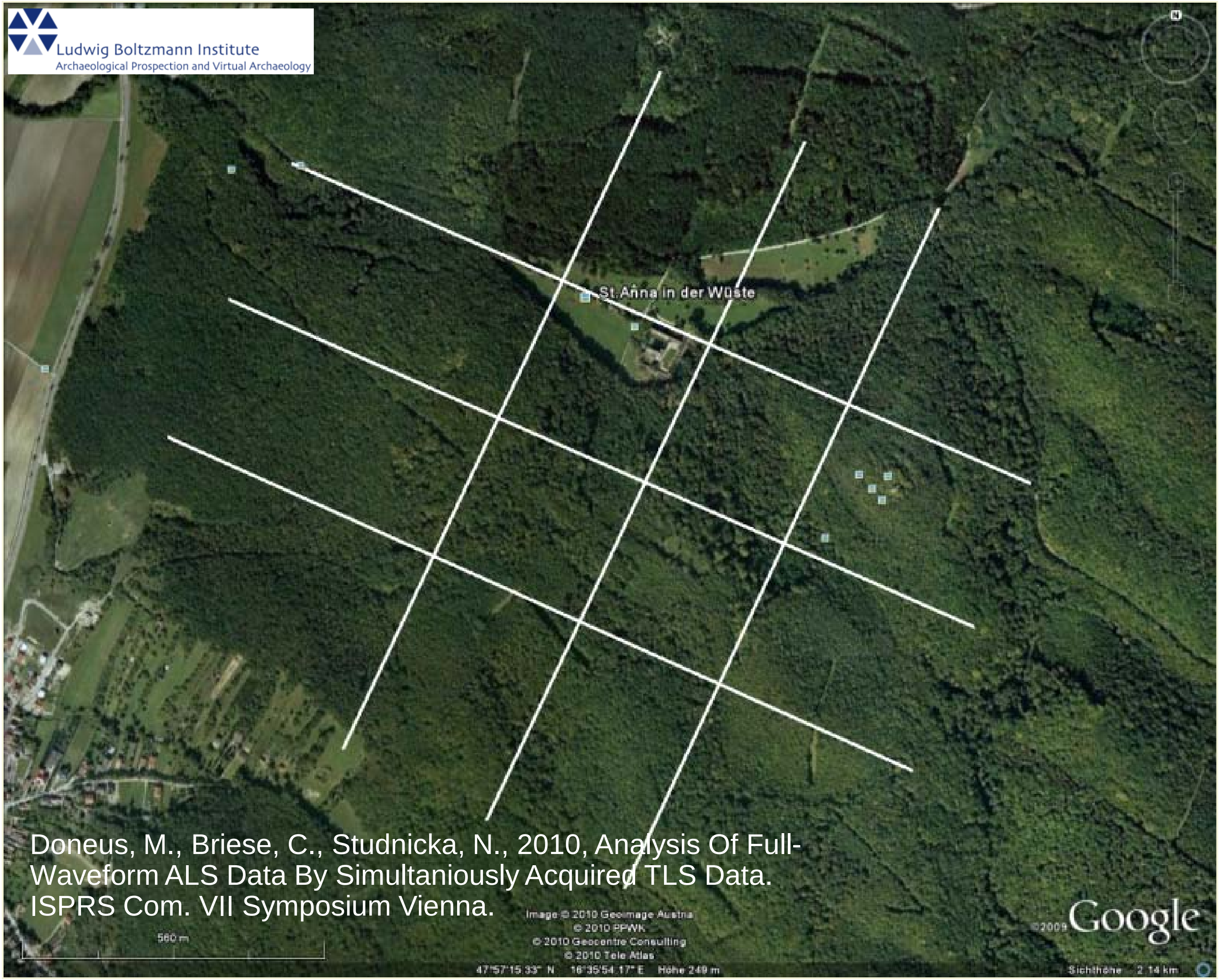
DTM shading overlayed with the standard deviation of the normalised heights of the near ground echoesdetermined in cells with **horizontal: 1.0 x 1.0 m x vertikal: 0.0 – 0.5 m** above the DTM.

# DSM shading with echoes <0.5m above the DTM




Red: forest paths; © MA41, Vienna

# Analysis Of Full-Waveform ALS data by simultaneously acquired TLS Data




Doneus, M., Briese, C., Studnicka, N., 2010, Analysis Of Full-Waveform ALS Data By Simultaniously Acquired TLS Data. ISPRS Com. VII Symposium Vienna.

# Analysis Of Full-Waveform ALS data by simultaneously acquired TLS Data

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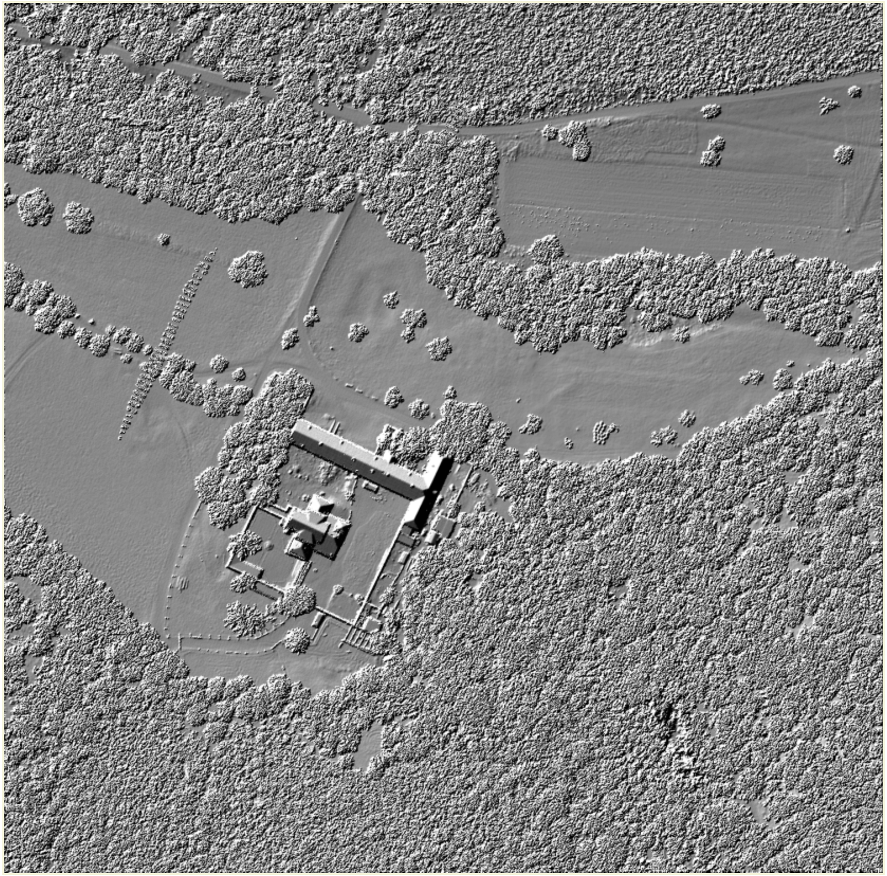
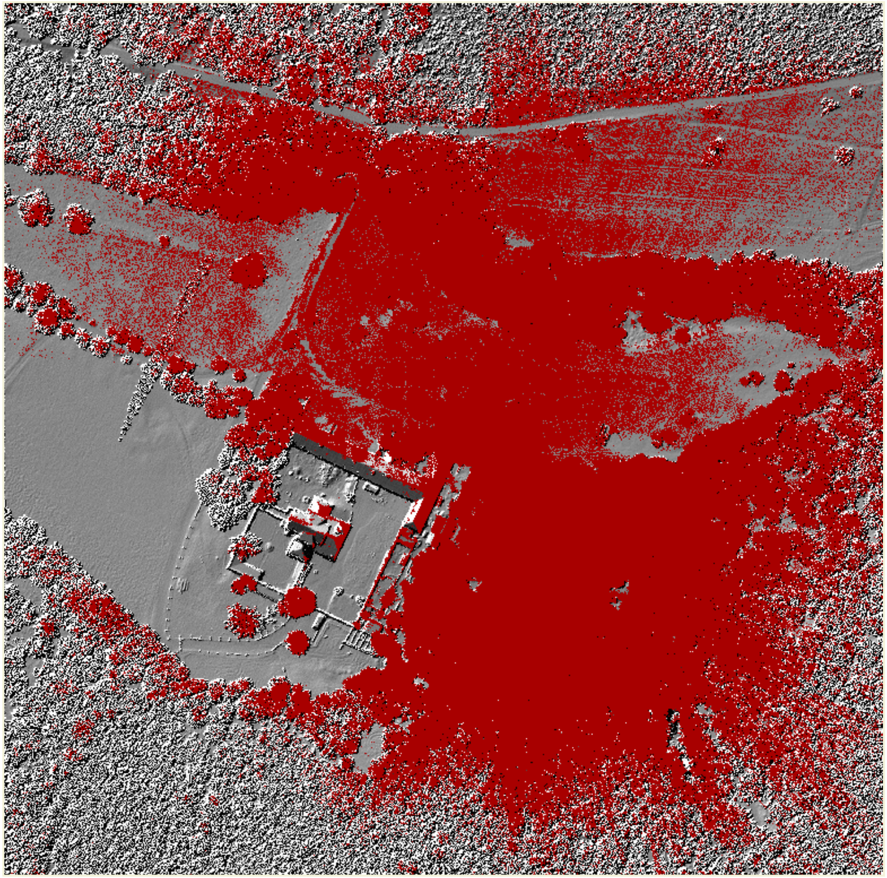
**ALS:**
- Riegl LMS-Q680
- 500 m flying height
- 20 pt /$m^2$

**TLS:**
- Riegl VZ400
- online waveform processing
- attached camera
- 16 stations

# Analysis Of Full-Waveform ALS data by simultaneously acquired TLS Data





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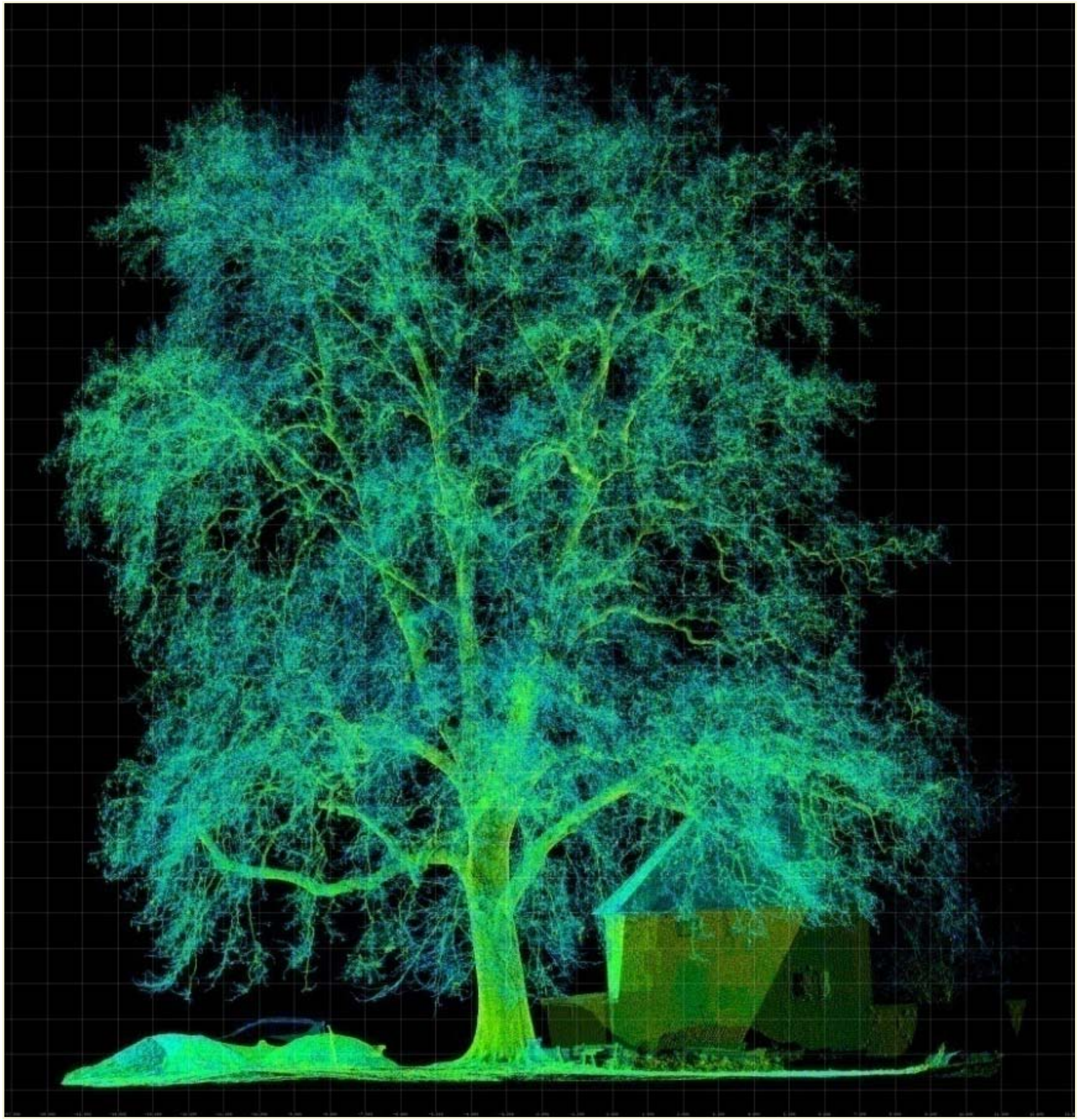
# Analysis Of Full-Waveform ALS data by simultaneously acquired TLS Data

# TLS Data



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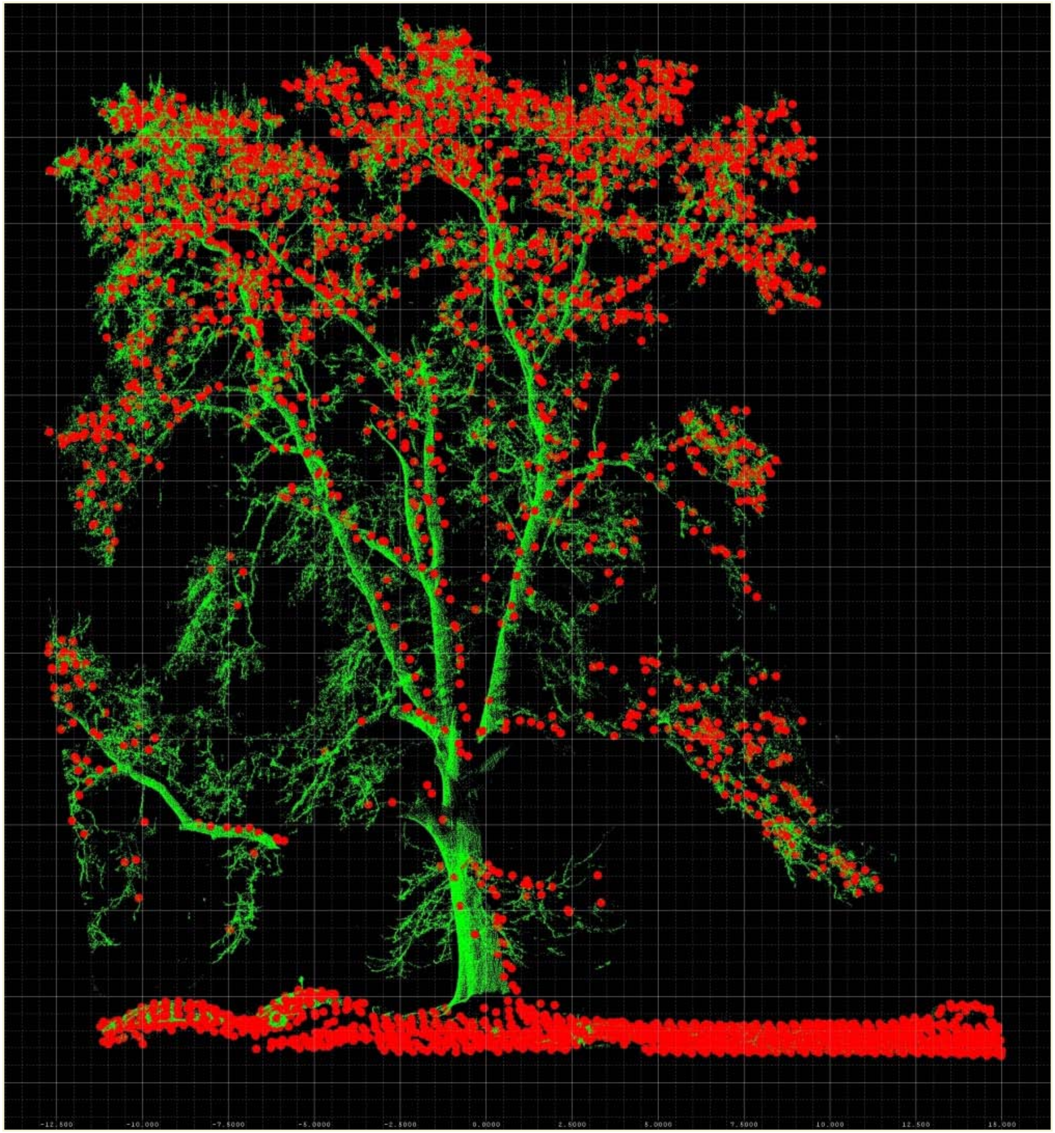
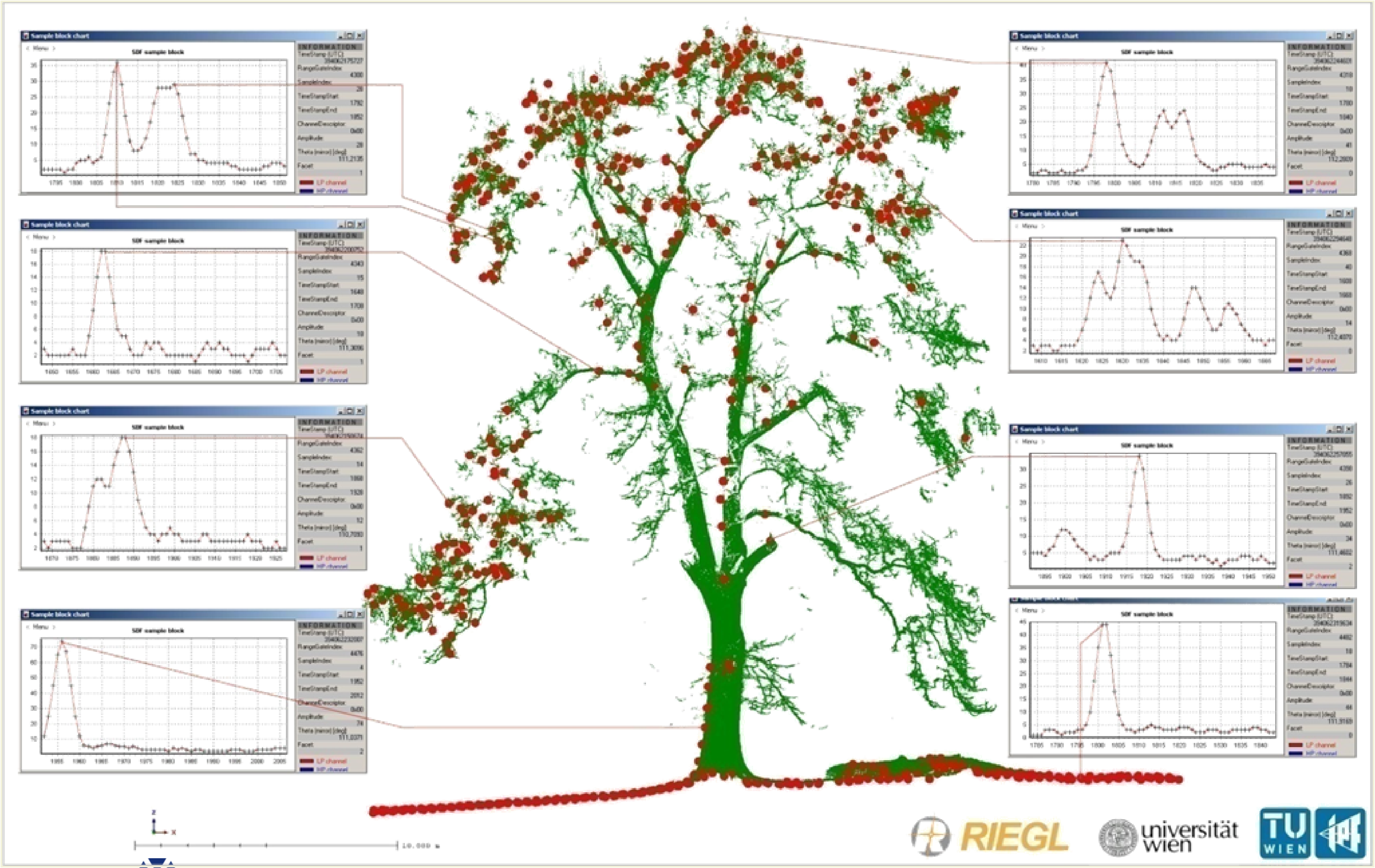
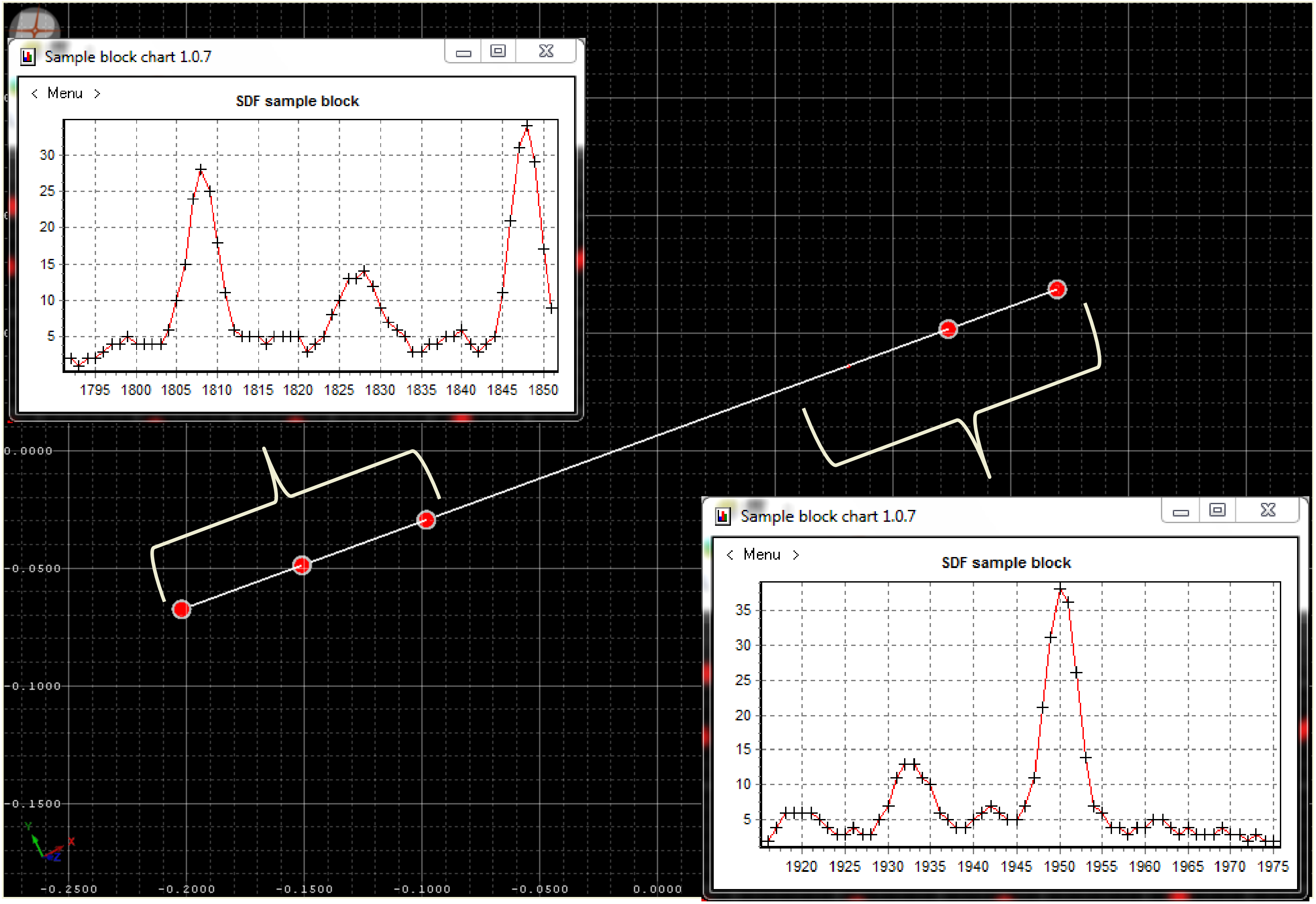
# ALS and TLS point cloud



# ALS and TLS point cloud + FWF information



# Echoes from one line of sight + waveform

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# Summary

- Multiple usage of ALS data
  - Topographic models (DTM, DSM), buildings, power lines, parameters for vegetation, …
- 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, forest structure, …
  - Stem volume / biomass estimation for large areas
- Future work
  - Transfer of the algorithms to different forest types
  - Further study of FWF-ALS
  - Combination with optical data