VIENNA UNIVERSITY OF TECHNOL
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SE

3D Punktwolken sind mehr wert…

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www.geo.tuwien.ac.at/photo

Digital Earth

Al Gore, 1998

[…]

I believe we need a "Digital Earth".
A **multi-resolution, three-dimensional** representation of the **planet**, into which we can **embed vast quantities** of **geo-referenced data**.

[…]

The Digital Earth: Understanding our planet in the 21st Century.

http://portal.opengeospatial.org/files/?artifact_id=6210

Fragen zu 2D

- **Ist das Orthophoto 2D?**
  - Als Produkt: **Ja**
  - In seiner Entstehung: **Nein**
- **Ist der Kataster 2D?**
  - Als Produkt: **Ja**
  - In seiner Weiterverwendung: Nein (Berghöfe-Kataster): **Nein**
- **Ist der Stadtplan 2D?**
  - Als Produkt: **Ja**
  - In seiner Weiterverwendung: Nein (Geschoßplan/Gebäudehöhe): **Nein**
- **Ist das Gewässernetz 2D?**
  - Als Produkt: **Ja**
  - In seiner Entstehung: **Nein**
- **Flächenwidmungsplan/Bebaungsplan/Leitungskataster/… 2D?**
  - **…**

Fragen zu 2D

- **Ist unsere Welt 2D?**

Ungarische Tiefebene, www.fotocommunity.de

Himmalaya, K2, www.alpenverein-freistadt.at

Fragen zu 2D

Und sicher nicht in Vorarlberg !
http://www.panograf.at/galerie-luftaufnahmen.html
Panograf
Die Welt ist eine Kugel

Inhalt

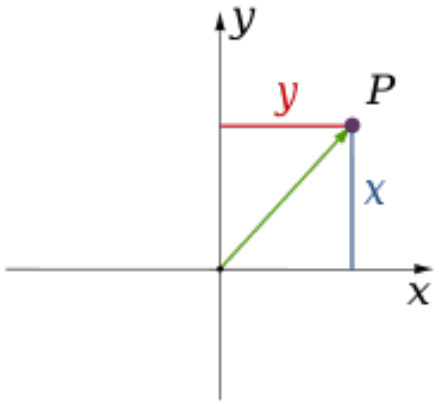
- Dimensionen:
  - 2D / 2.5D / 3D
- Datenstrukturen:
  - Raster / Vektor / Punktwolke
- 3D Sensoren
  - Spaceborne – Airborne – Terrestrisch
  - Passiv – aktiv
- Anwendungen
  - Gebäudemodellierung
  - Forstwirtschaft
  - Ökologie
  - Hydrologie/Hydraulik
- Zusammenfassung und Ausblick

Dimensionen

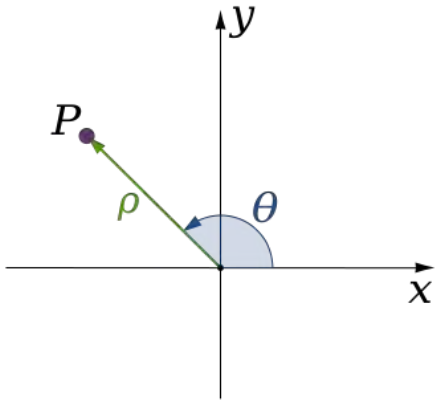
- Aus Wikipedia:
  - In der Mathematik wird mit der **Dimension** ein Konzept bezeichnet, das im Wesentlichen die Anzahl der Freiheitsgrade einer Bewegung in einem bestimmten Raum bezeichnet.
  - Der Begriff der Dimension tritt **in einer Vielzahl von Zusammenhängen** auf. **Kein einzelnes mathematisches Konzept** vermag es, die Dimension für alle Situationen **zufriedenstellend zu definieren**, darum existieren für verschiedene Räume auch unterschiedliche Dimensionsbegriffe.

Dimensionen

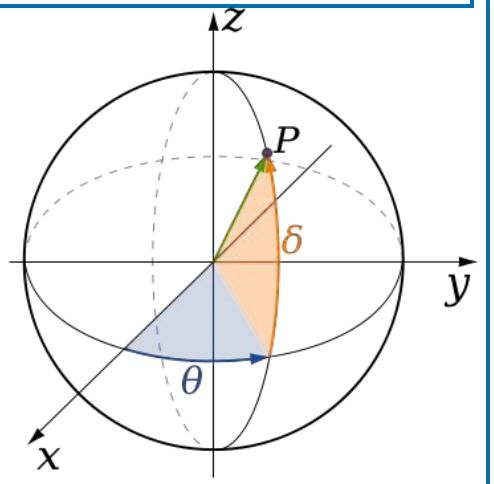
- **2D**



2D-Kartesisch (x,y)

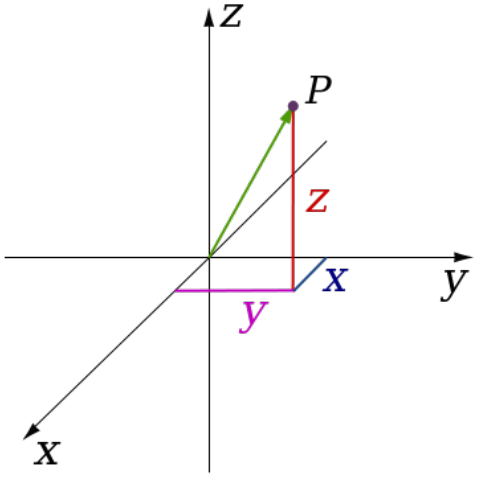


2D-Polar (Winkel,Dist)

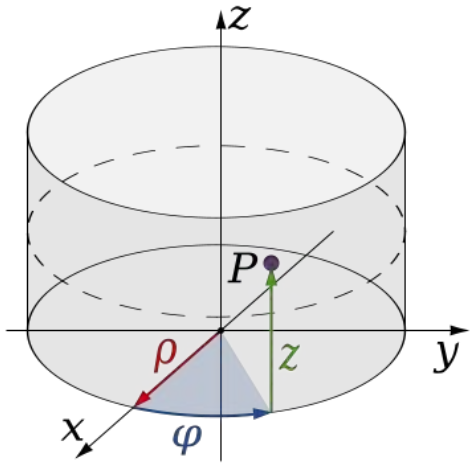


2D-Sphärisch (Lat,Lon)

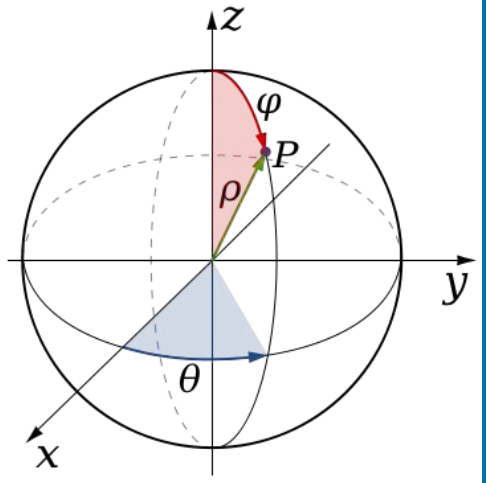
- **3D**



3D-Kartesisch (x,y,z)



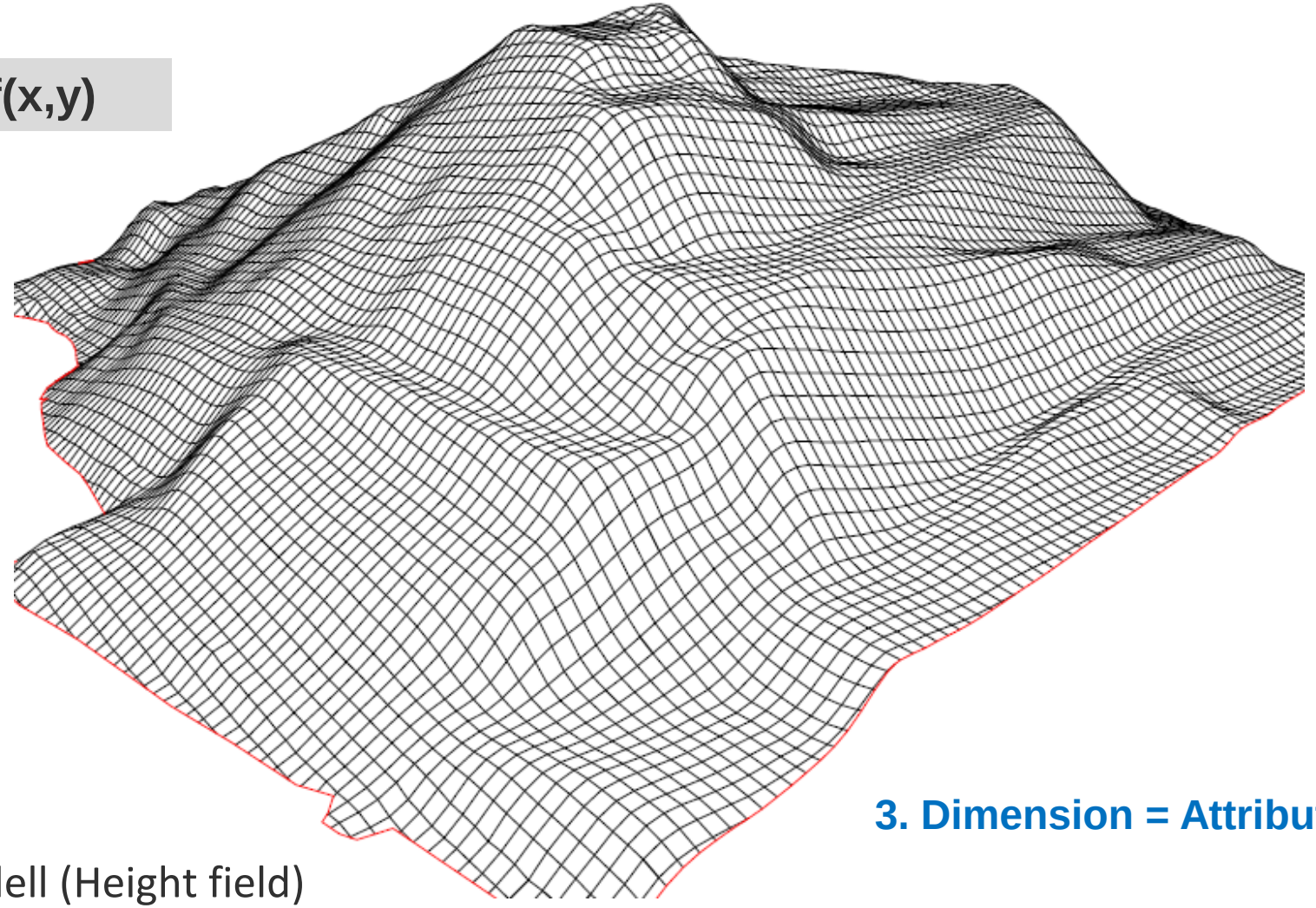
3D-Polar (zylindrisch)



3D-Sphärisch (Lat,Lon,Dist)

2.5D

z= f(x,y)

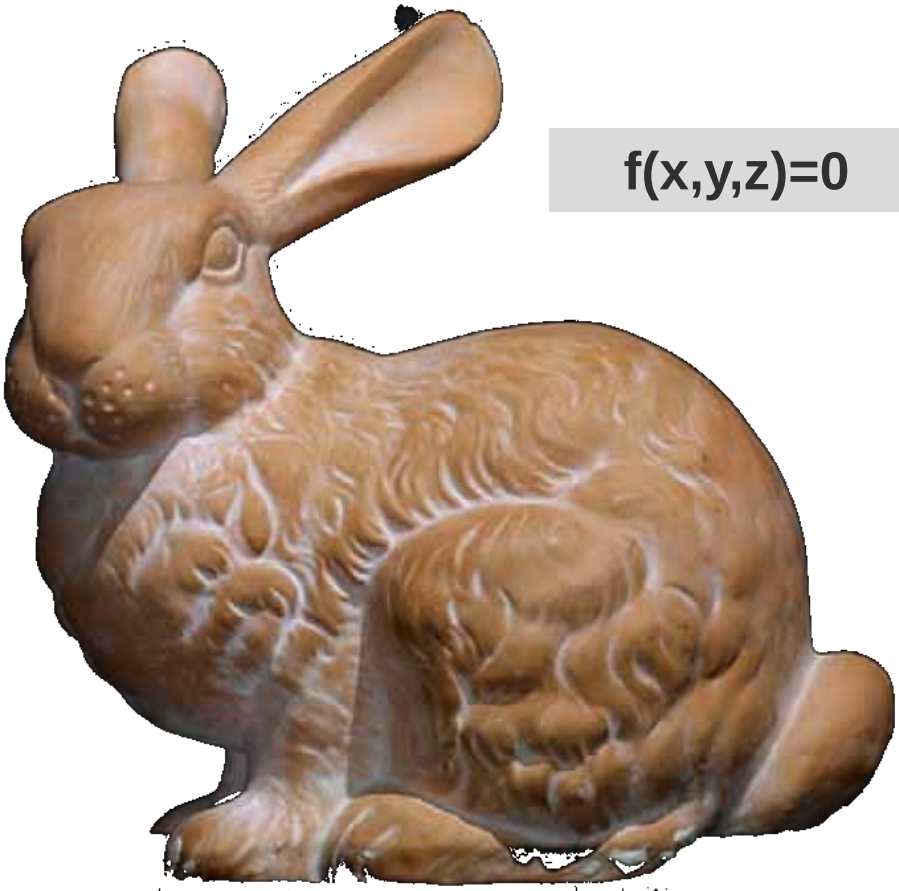


3. Dimension = Attribut

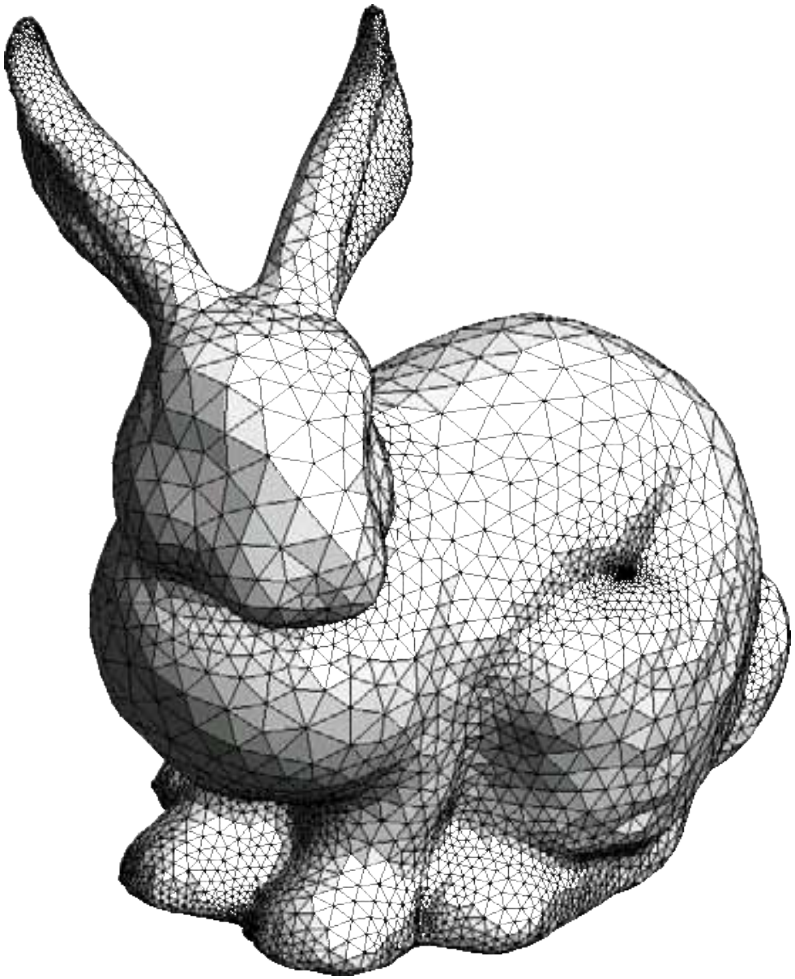
Gittermodell (Height field)

3D

Stanford Bunny



$$f(x,y,z)=0$$



Beispiel 3D: Gebäudemodell

http://www.exchange3d.com/gastank/prod_9058html

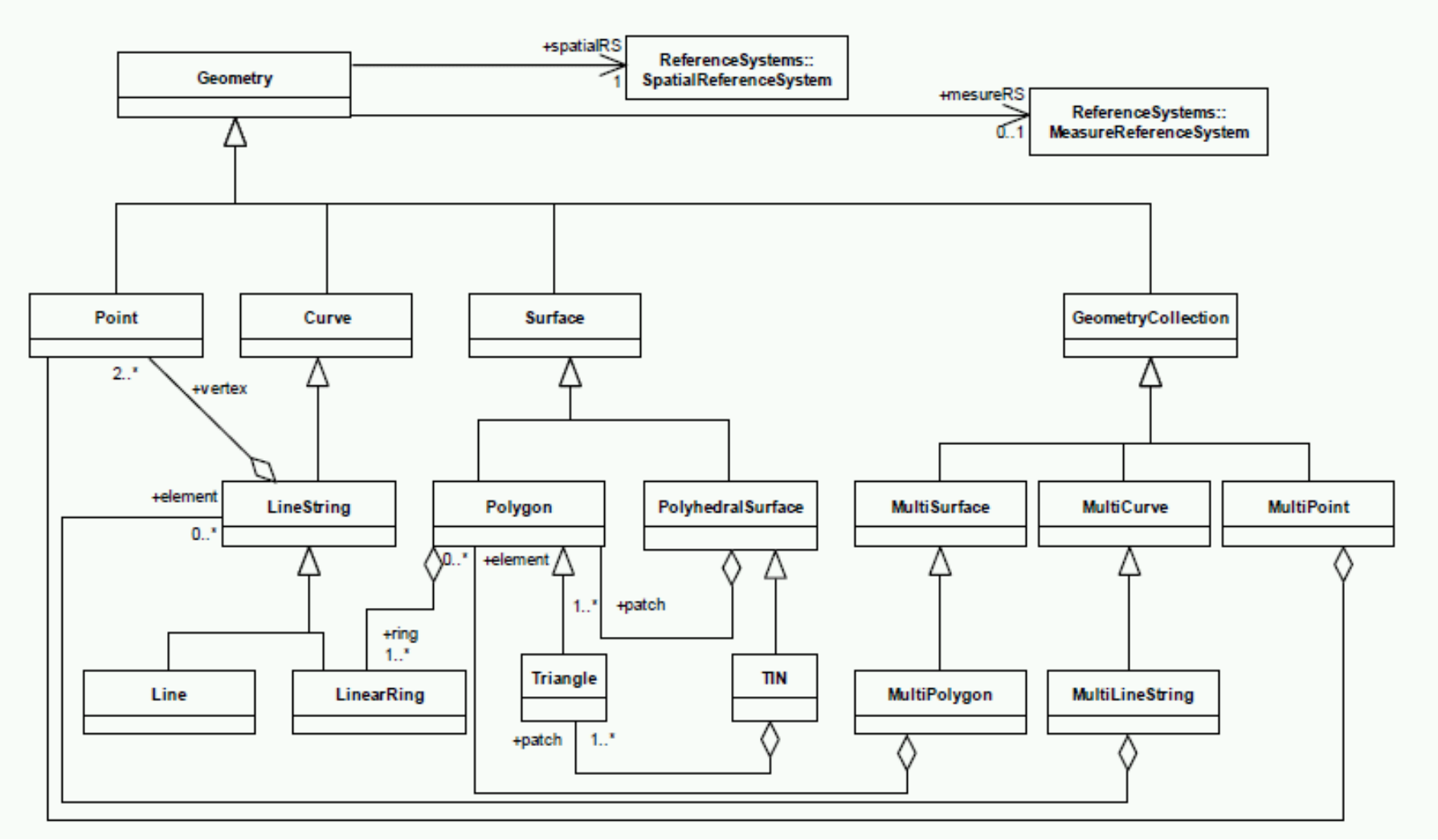
Beispiel 3D: Baummodell

Mandlburger - 3D Punktwolken
sind mehr wert...

Datenstrukturen

- 2D/3D Vektor
  - Punkte (2D+3D)
  - Linien (2D+3D)
  - Polygone (2D)
  - Polygonale Flächen (2D/2.5D/3D)
- 2.5D Gitter/Raster
- 3D Objekte
  - Boundary representation (BREP → 3D-TIN)
  - Constructive Solid Geometry (CSG → aufgebaut aus Primitiven)
- 3D Punktwolken

OGC Simple Features Specification



Geometry class hierarchy, Quelle: http://www.opengeospatial.org/standards/sfa

OGC: Simple Features Specification
Well-Known-Text - Repräsentation

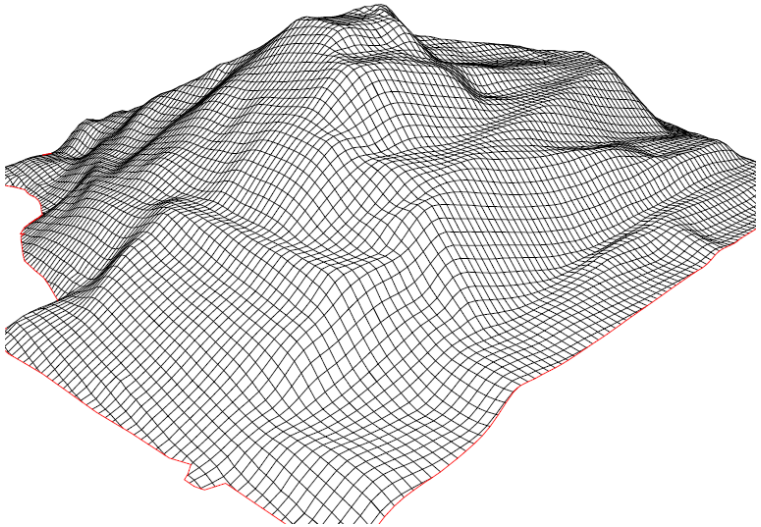
Table 2 — Example Well-known Text Representation of Geometry

Geometry Type	Text Literal Representation	Comment
Point	`'POINT (10 10)'`	a `Point`
LineString	`'LINESTRING ( 10 10, 20 20, 30 40)'`	a `LineString` with 3 points
Polygon	`'POLYGON ((10 10, 10 20, 20 20, 20 15, 10 10))'`	a `Polygon` with 1 exteriorRing and 0 interiorRings
Multipoint	`'MULTIPOINT (10 10, 20 20)'`	a `MultiPoint` with 2 points
MultiLineString	`'MULTILINESTRING ((10 10, 20 20), (15 15, 30 15))'`	a `MultiLineString` with 2 linestrings
MultiPolygon	`'MULTIPOLYGON ( ((10 10, 10 20, 20 20, 20 15, 10 10)), ((60 60, 70 70, 80 60, 60 60 ) ))'`	a `MultiPolygon` with 2 polygons
GeomCollection	`'GEOMETRYCOLLECTION (POINT (10 10), POINT (30 30), LINESTRING (15 15, 20 20))'`	a `GeometryCollection` consisting of 2 `Point` values and a `LineString` value

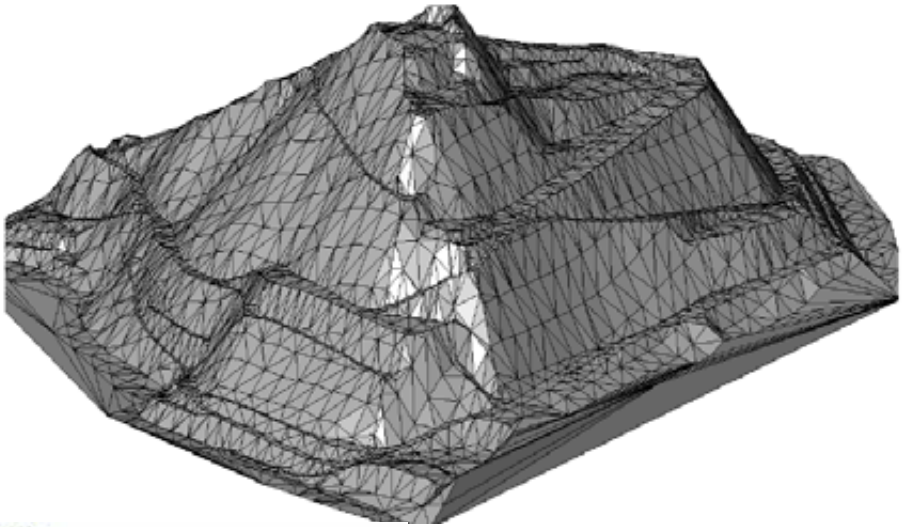
Quelle: http://www.opengeospatial.org/standards/sfa

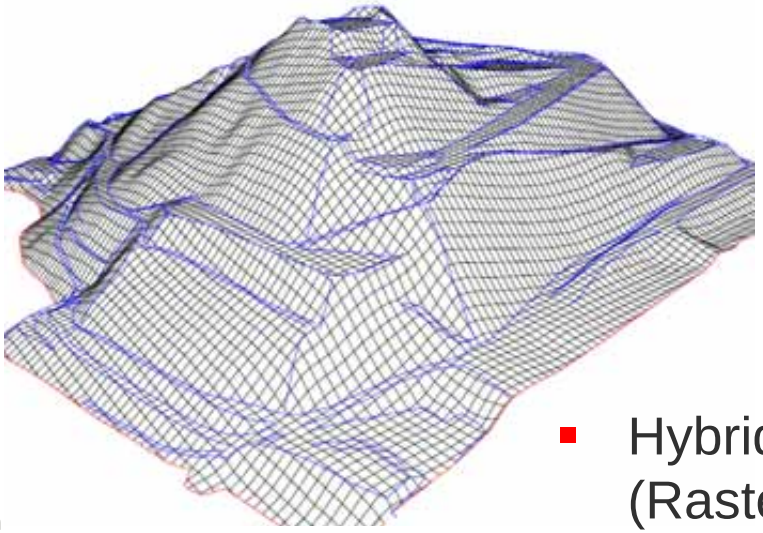
Beispiel 2.5D Raster/Vektor: Digitale Geländemodelle

- Gittermodell



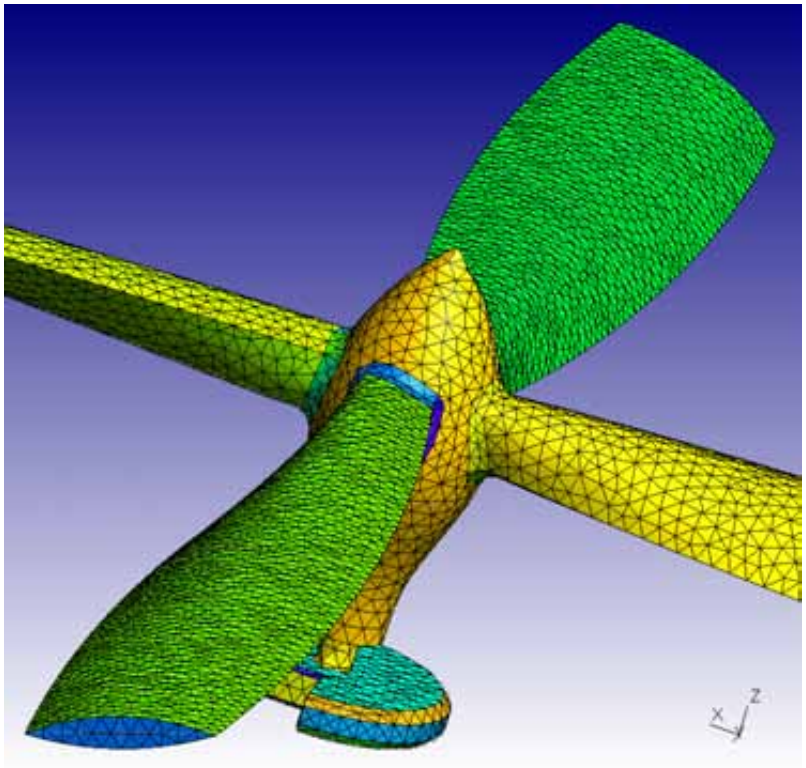
- Dreiecksvermaschung (2D-TIN+Attribut)

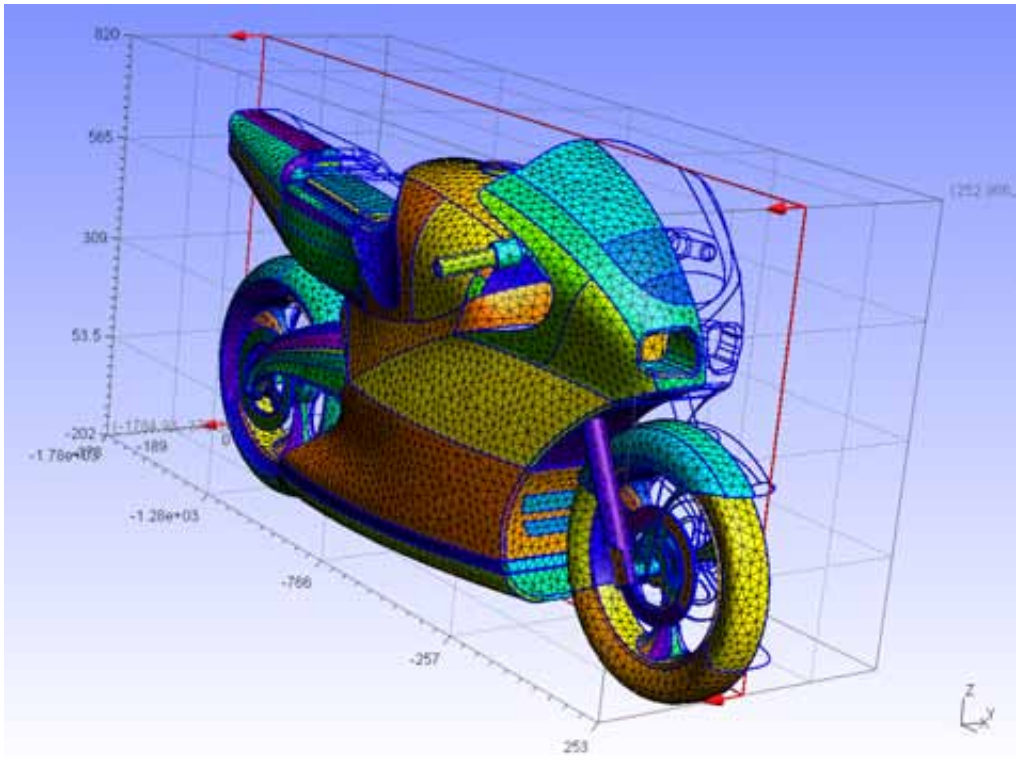




- Hybrides Modell (Raster+Linien)

Beispiel 3D boundary representation

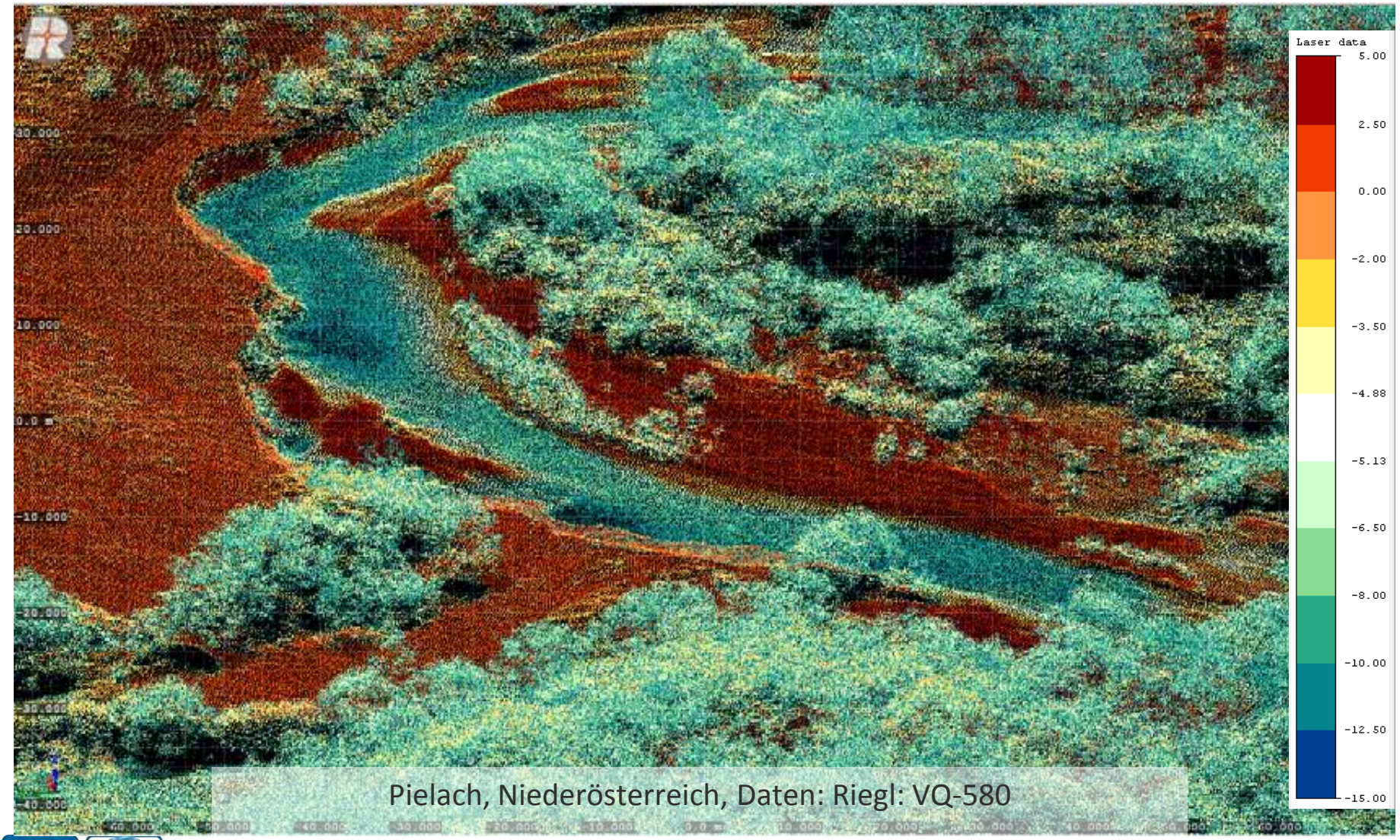




Boundary Representation: 3D-TIN

Quelle: http://geuz.org/gmsh/

Beispiel 3D Punktwolke

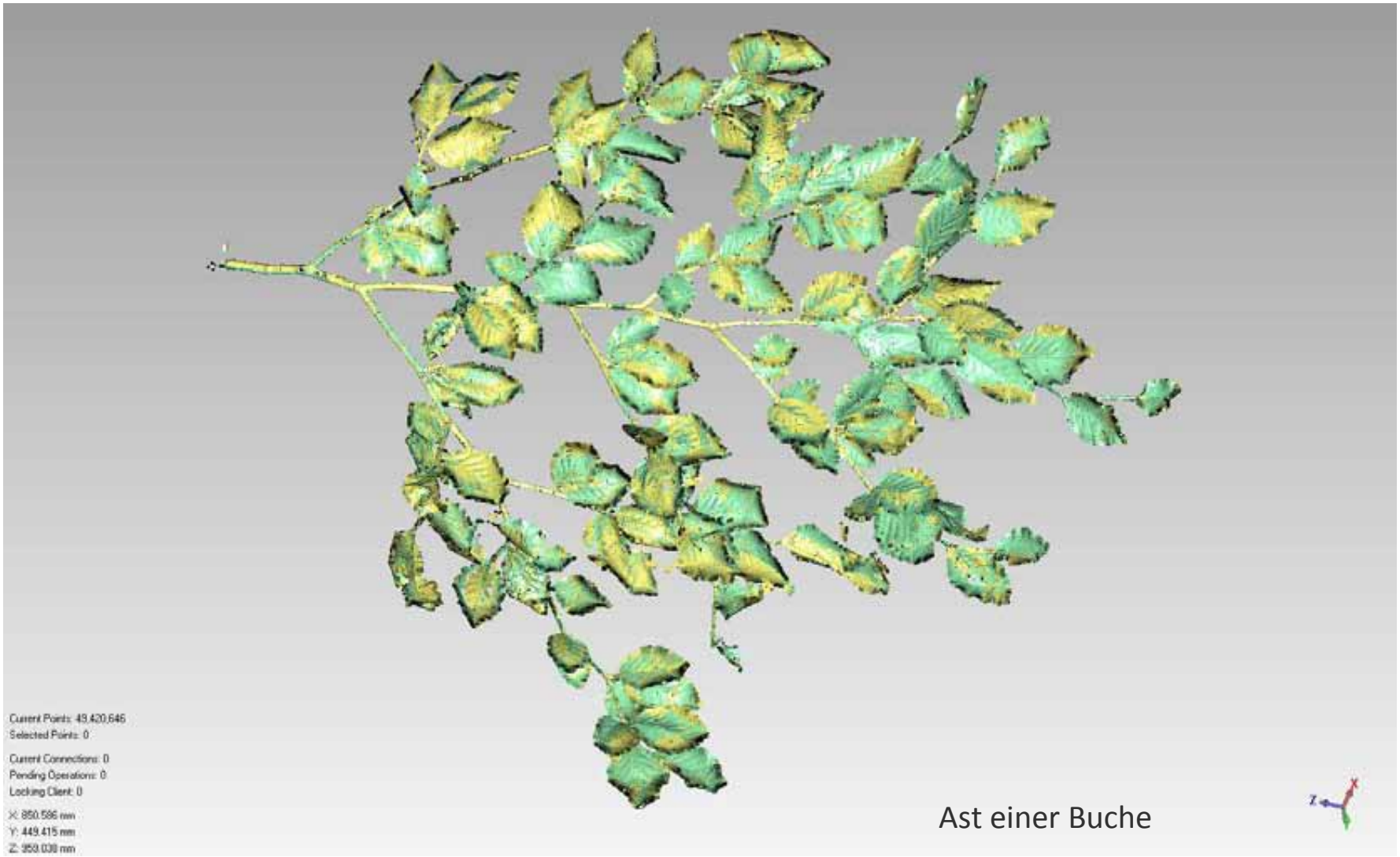


Pielach, Niederösterreich, Daten: Riegl: VQ-580

Beispiel 3D Punktwolke

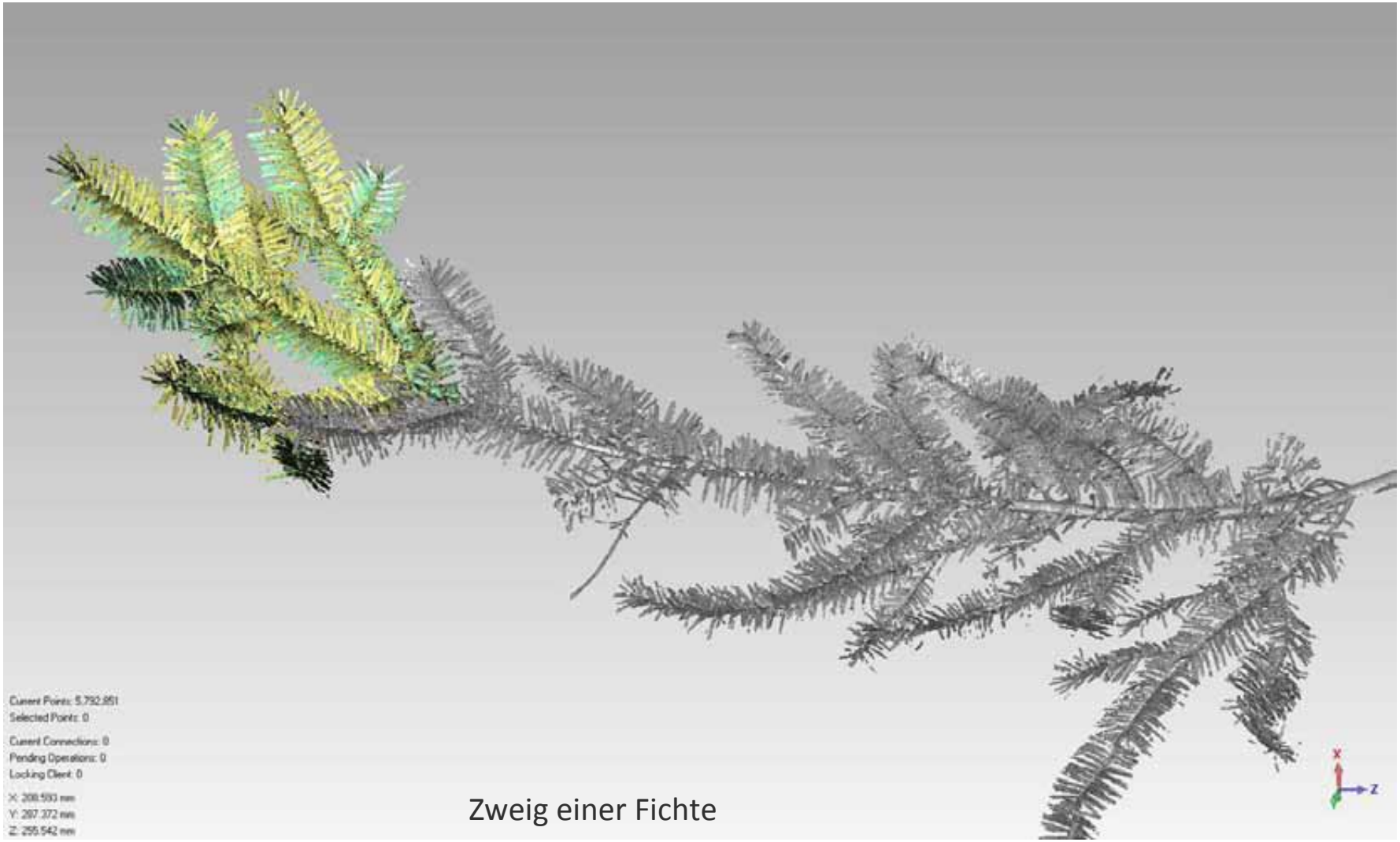
Pielach, Niederösterreich, Daten: Riegl: VQ-580

Beispiel 3D Punktwolke



Ast einer Buche

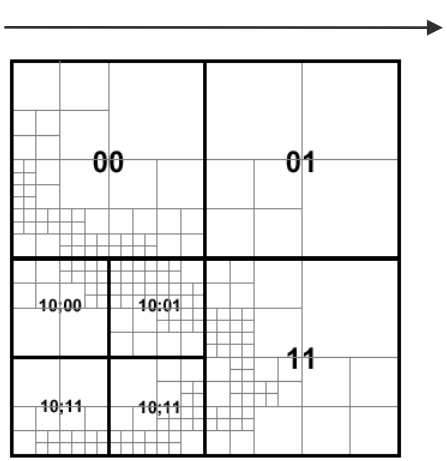
Beispiel 3D Punktwolke

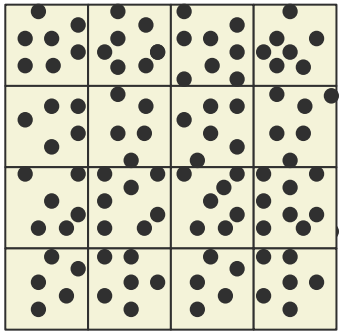


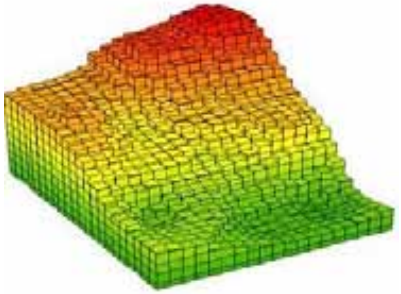
Zweig einer Fichte

Räumliche Datenstrukturen 2D/3D

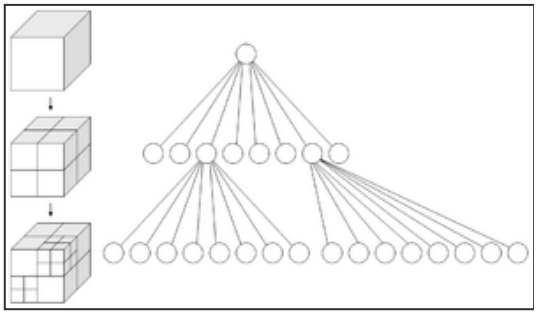
- Gridding/Voxelization

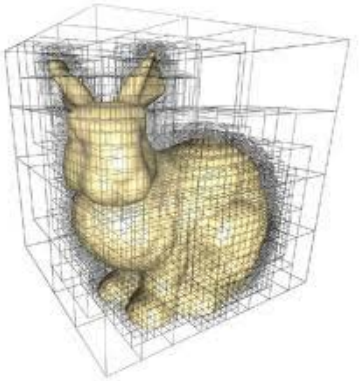




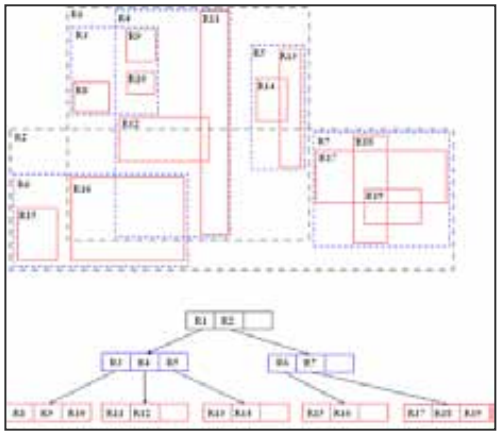


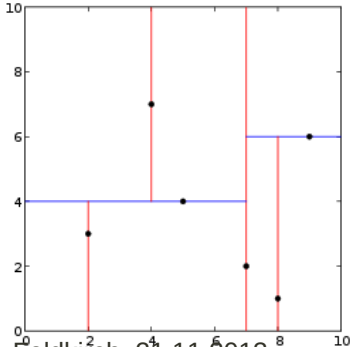
- Quad-Tree (2D)
- Oct-Tree (3D)

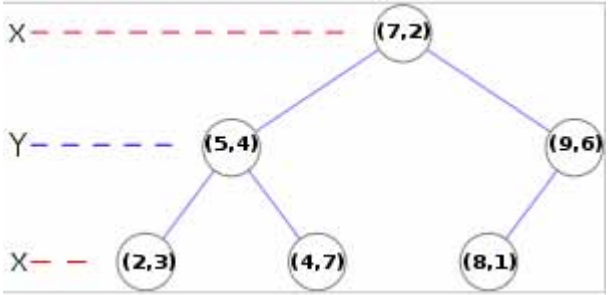




- R*-Tree





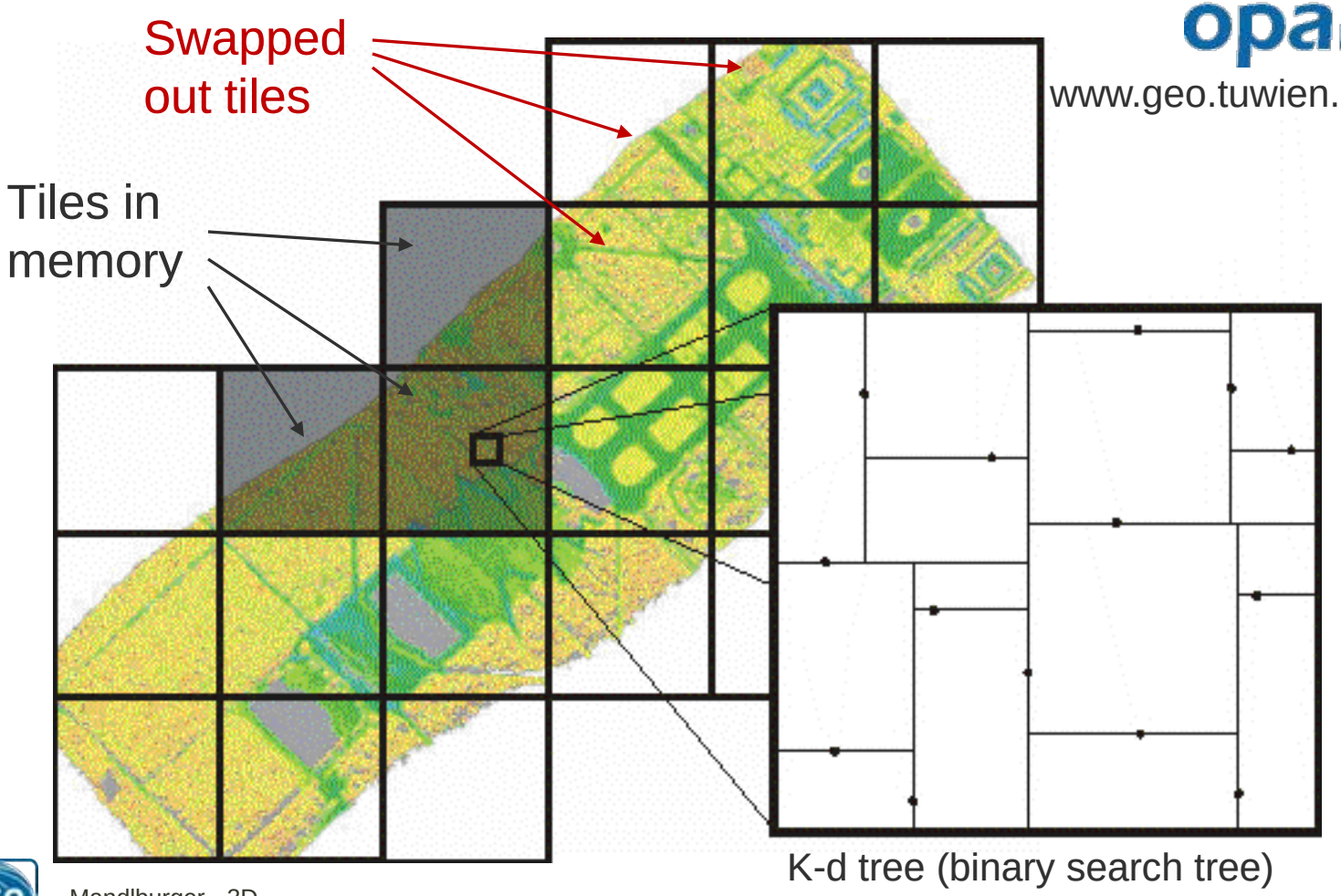


- K-dimensional (Kd) Tree

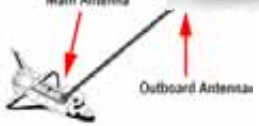
OPALS Data Manager: Extended K-d tree

K-d tree stores point clouds in a binary (k-dimensional) search tree
Extended K-d tree supports tiling and tile swapping

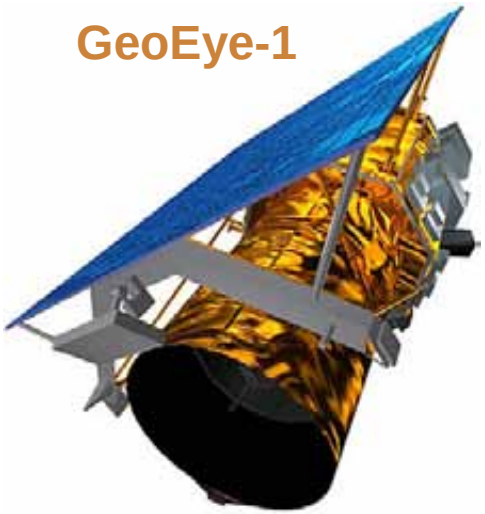
www.geo.tuwien.ac.at/opals

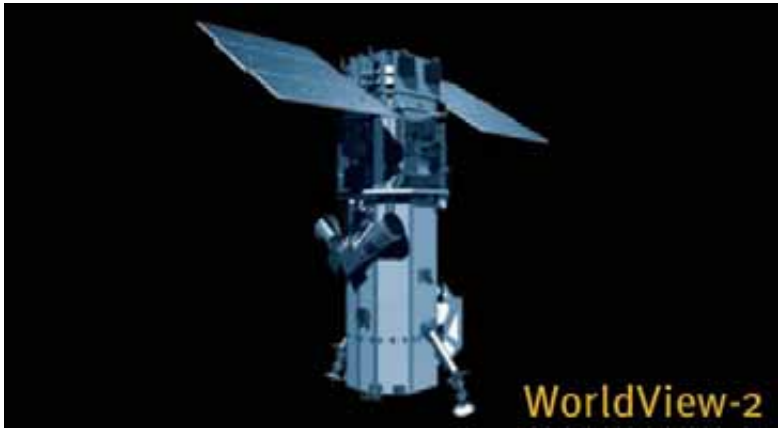


Imaging Sensors



Optical Satellite Sensors

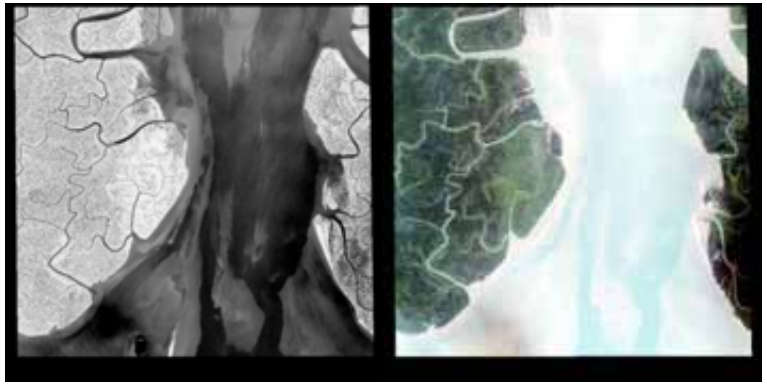


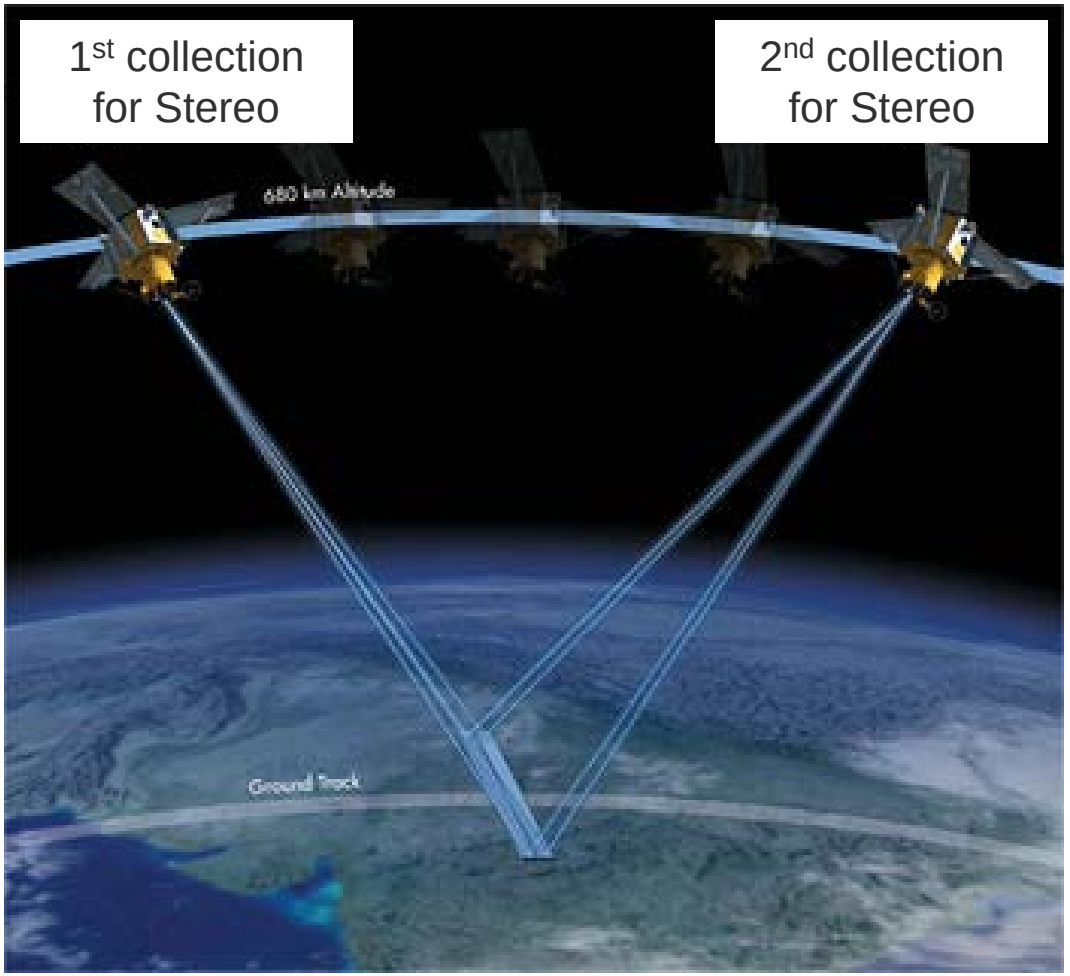


3D Mapping with along-track convergent stereo image pairs

- Passive Optical Sensors (Pan+R+G+B+NIR)
- GSD: ~ 1m
- Along-track stereo pairs → photogrammetric principle
- Stereo images enable DSM/DEM creation

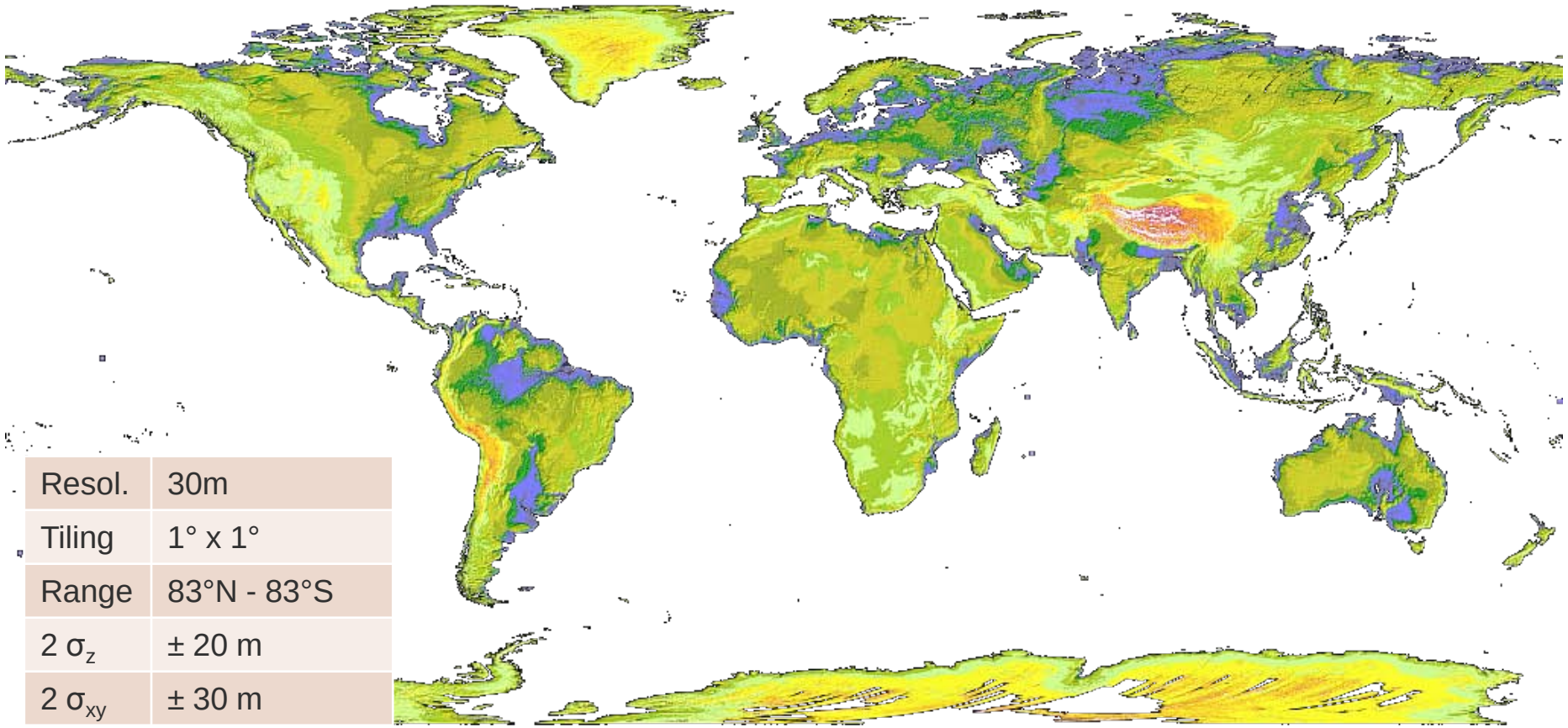
QuickBird Scene: The Sundabarns (Bangladesh), 16.5 km x 16.5 km)





along-track stereo principle (IKONOS)

ASTER GDEM (Global Digital Elevation Model)

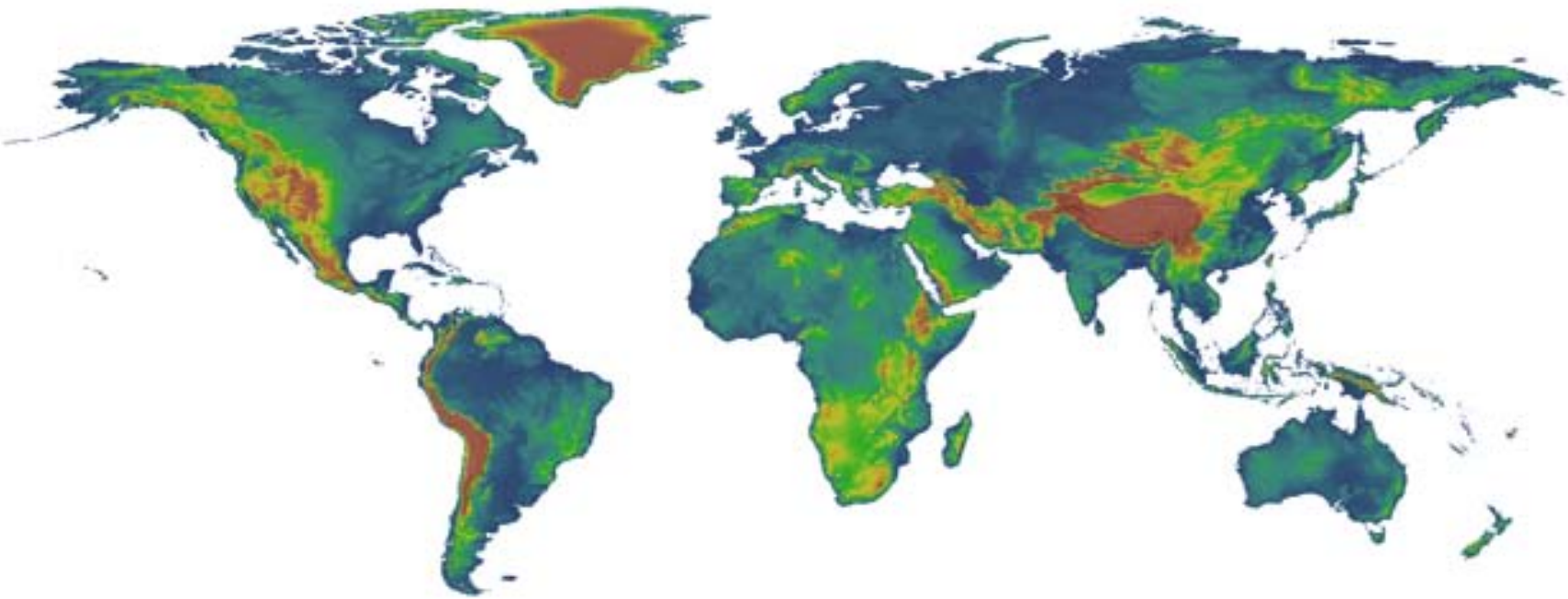


Resol.	30m
Tiling	1° x 1°
Range	83°N - 83°S
$2\,\sigma_z$	± 20 m
$2\,\sigma_{xy}$	± 30 m

SRTM (Shuttle Topographic RADAR Mission)

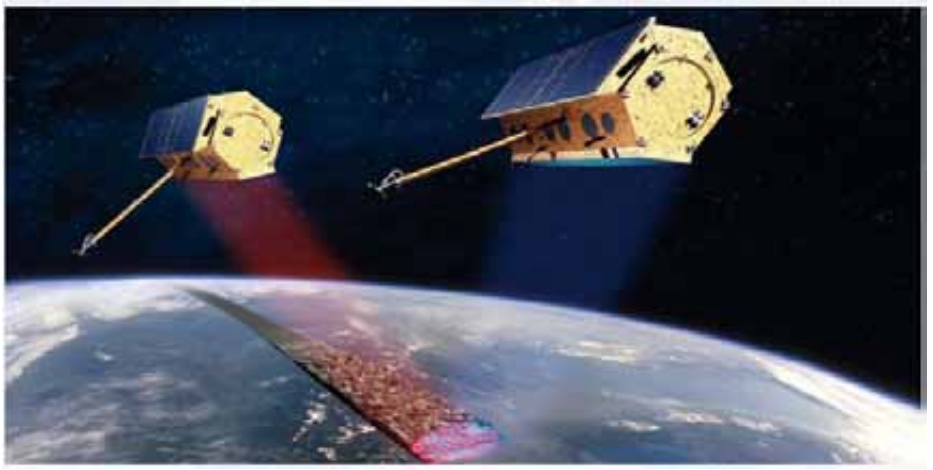
- Global DEM (1/3 arc sec ≈ 30/90m)
- Interferometric Synthetic Aperture Radar (InSAR, C/X-Band)
- Space Shuttle „Endeavour“ Mission (2000)
- Range: 60°N - 60°S (remaining parts filled up)
- Absolute Height Error: ~ ±10m (90% confidence)

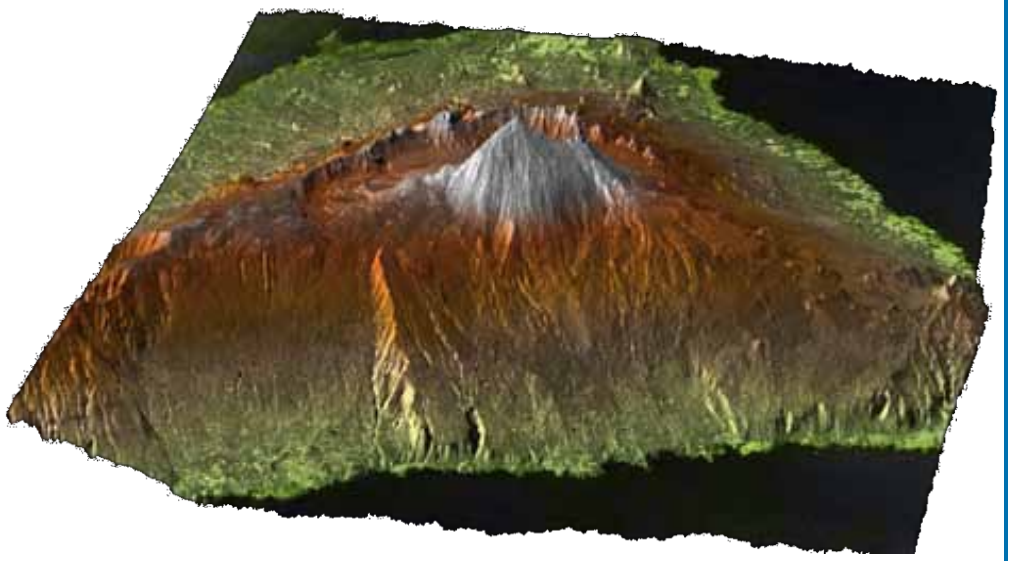
!!! Active Sensor !!!



TerraSAR-X / TanDEM-X

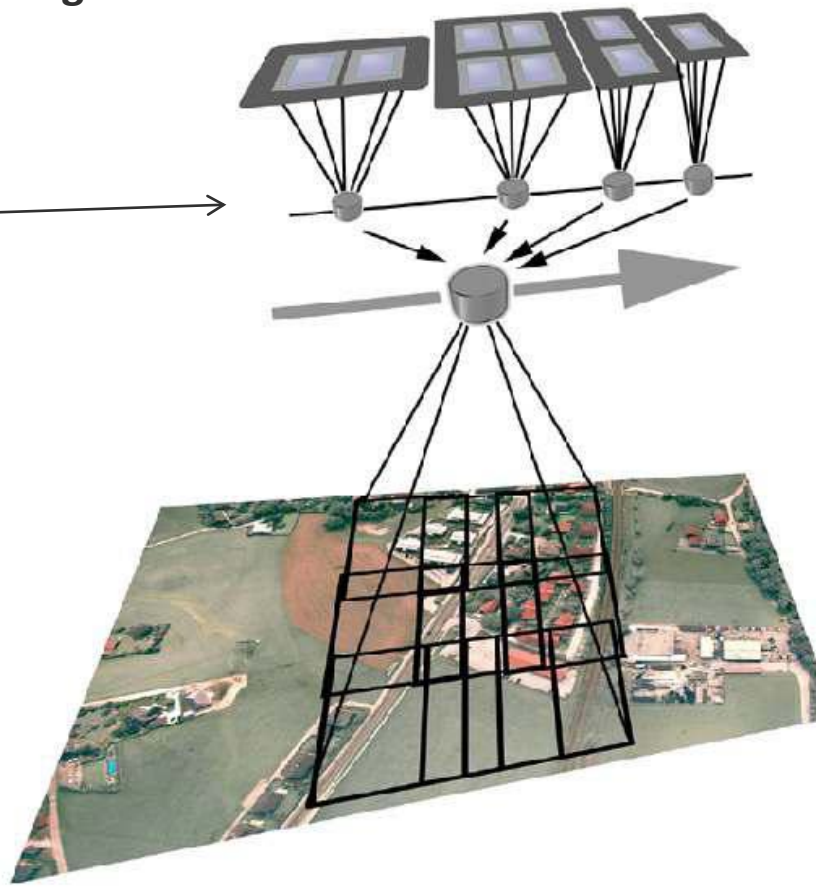
- European joint project: DLR/Astrium
- 2 satelltes in a formation flight (StripMap mode)
- DEM grid size: 12 x 12 m
- Height accuracy:
  - 2 m (relative)
  - 10 m (absolute)
- available by 2014



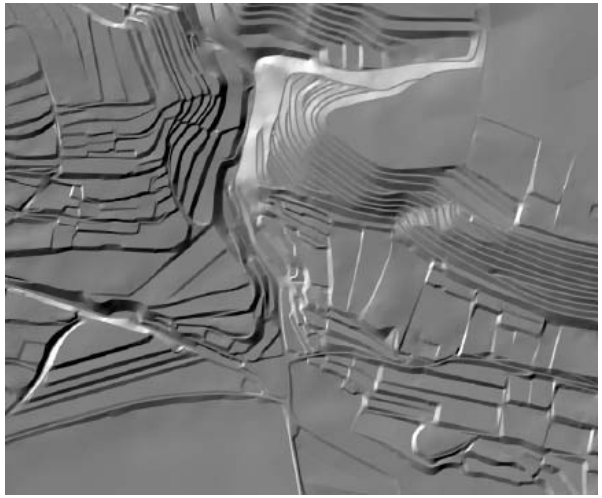


Digital cameras with multiple CCD frame sensors

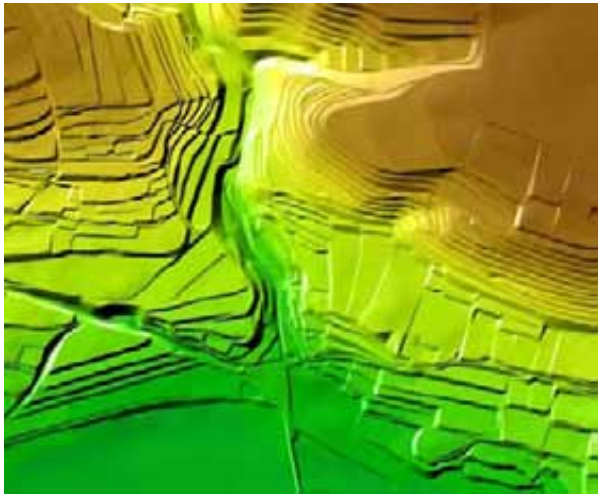
- **Vexcel Imaging Austria (Microsoft) - UltraCam-Eagle:**
  - 13 CCD's: 6.670 x 4.360 pixels each
  - 4 optical cameras (RGB + NIR)
  - 4 panchromatic cameras
  - Focal length: 80 mm (panchromatic)
  - Pixel size: 5.2 µm
  - Field of view: 66° x 46°
  - Total image size: 20.010 x 13.080 pixels



Photogrammetry products – Digital Terrain Model

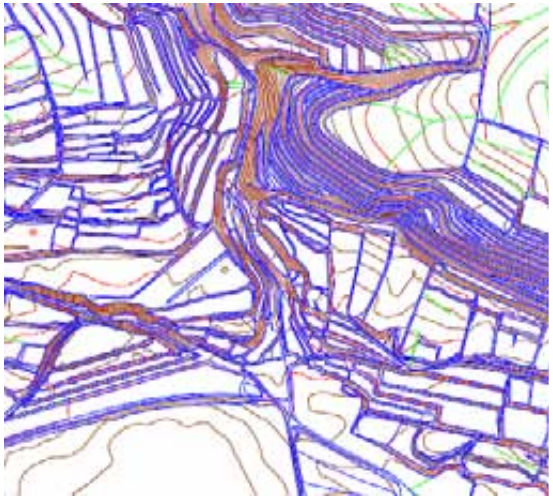


Hill shading

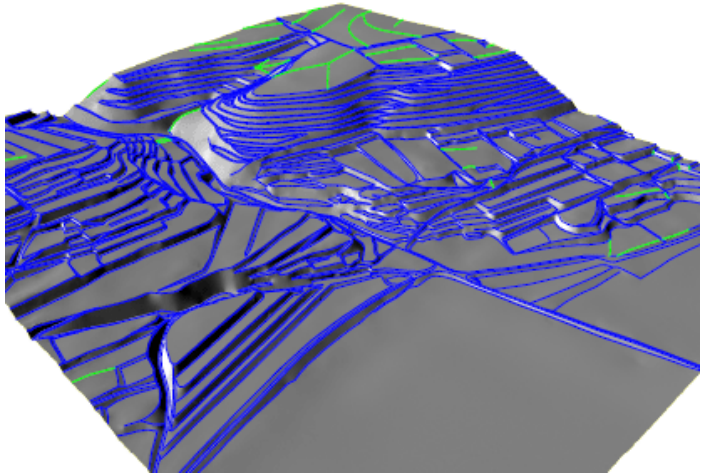


Colour coded raster map

Slope map



Break lines + contours



Perspective view of hybrid DTM

Note:
DTM only obtained by human-operated, manual 3D-digitazation based on stereo images

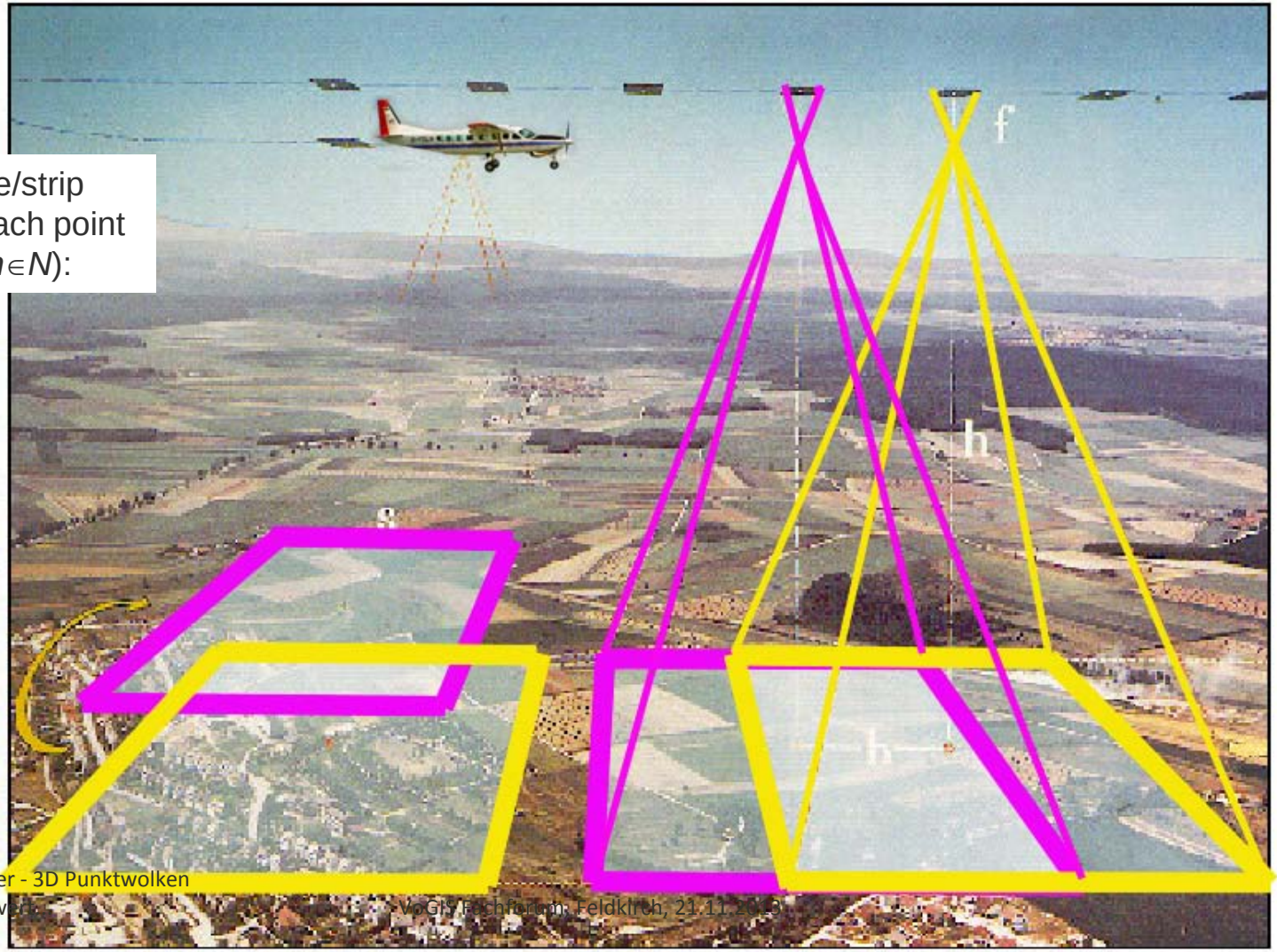
Acquisition of aerial images

Block of aerial images:

overlap in strip direction (e.g. 80%), overlap of strips (e.g. 50%)

Recommended image/strip overlap *u*, such that each point is in *n* images/strips ($n \in N$):

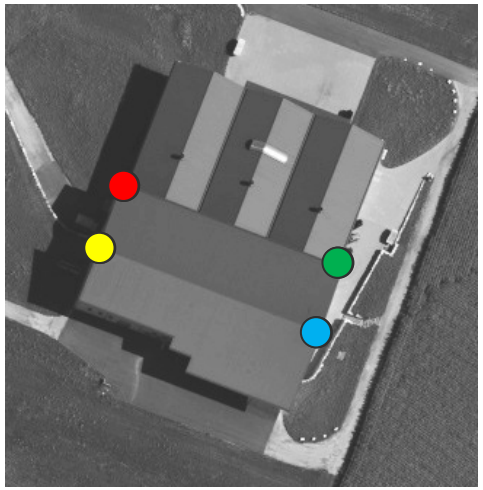
n	u [%]
2	50
3	66
4	75
5	80
6	83
7	86
8	88
9	89
10	90



Aim of Matching: Digital Surface Model

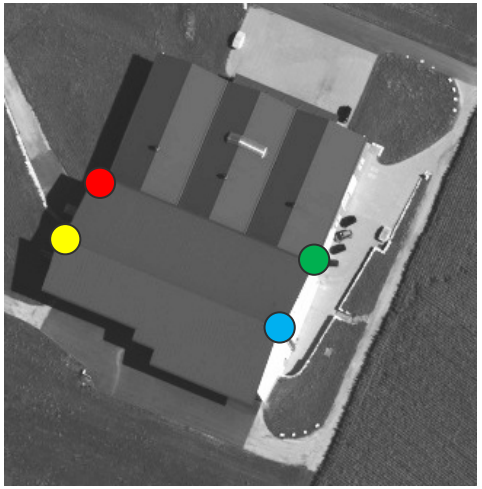
- Following steps are required:
  - Selection of image points
  - Finding corresponding points across 2 or more images (= Matching)
  - (Spatial intersection)
  - Interpolation of reconstructed points (not covered in this presentation)

Image 1



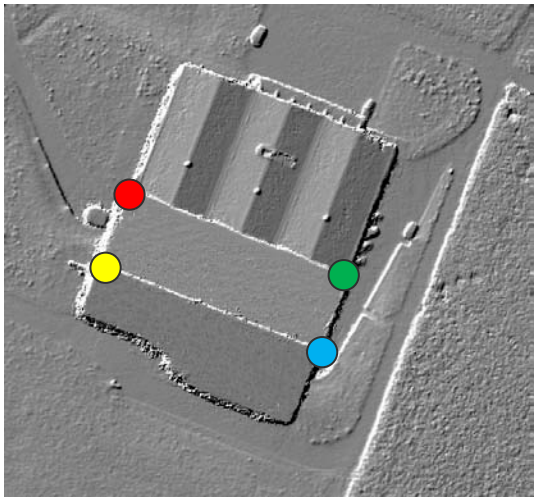
Vaihingen, DMC, 8cm, #71+73

Image 2



spatial intersection

DSM



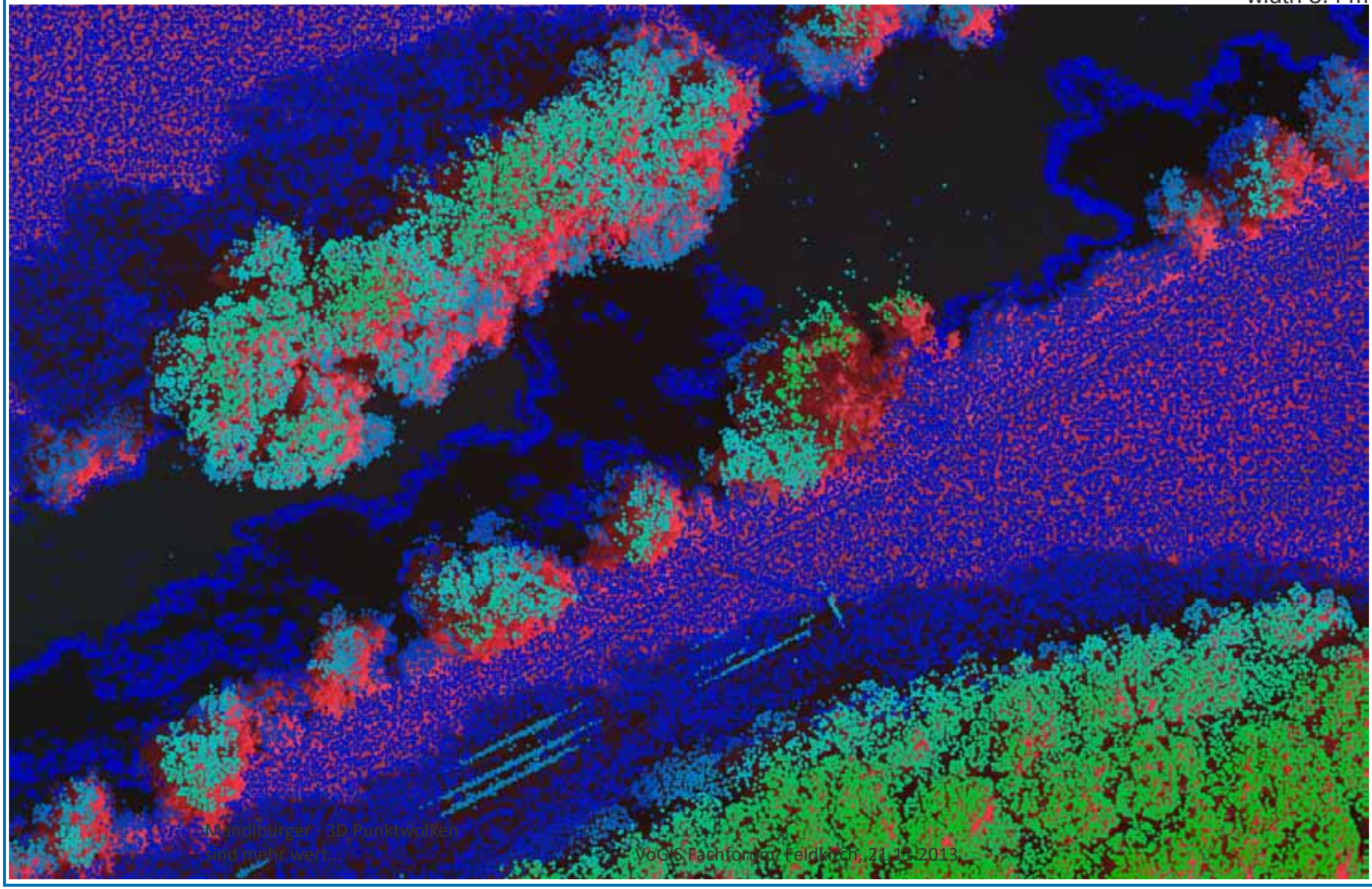
- Steps can be done separately or in combination (→ image pyramids)

Example: Vaihingen/Enz

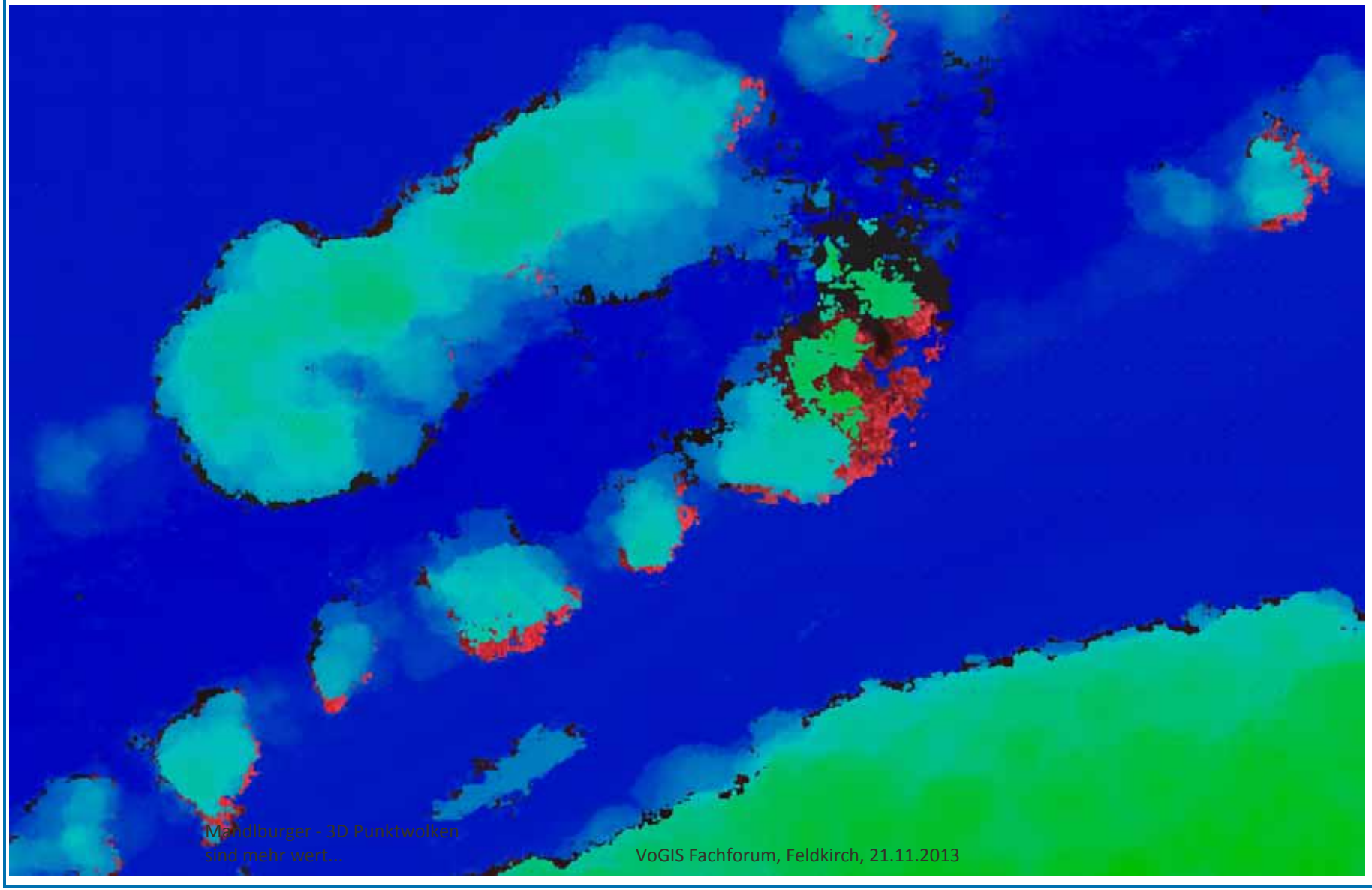
- CIR Orthophoto

Detail: Feature Based Matching

width 3.4 m



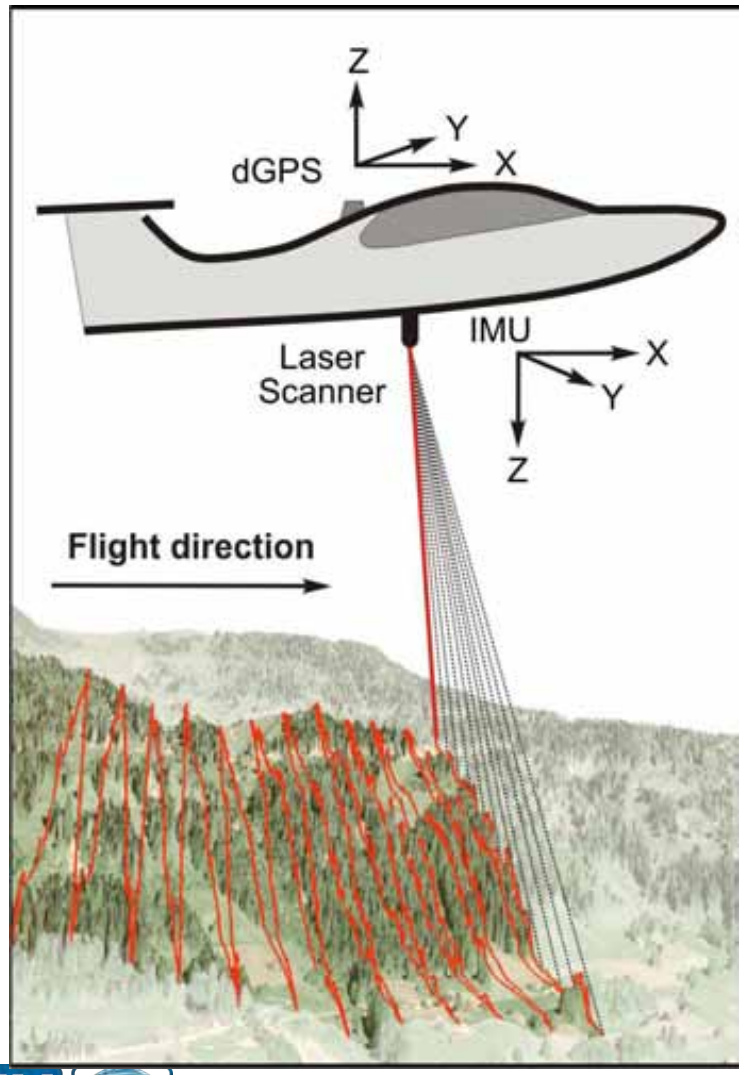
Detail: Semi Global Matching (STD of fusion < 5m)



Laser Scanning - Platforms

- Platforms:
  - Terrestrial Laser Scanning: Tripod, 3D-Scanner
  - Mobile Laser Scanning: 2D-Scanner mounted on cars, boats, ...
  - Airborne Laser Scanning: 2D-Scanner on helicopter, fixed-wing aircraft, Unmanned Airborne Vehicles (UAV)
  - Spaceborne Laser Profiler: ICESAT (1D laser profiler, no scanning)

ALS - System



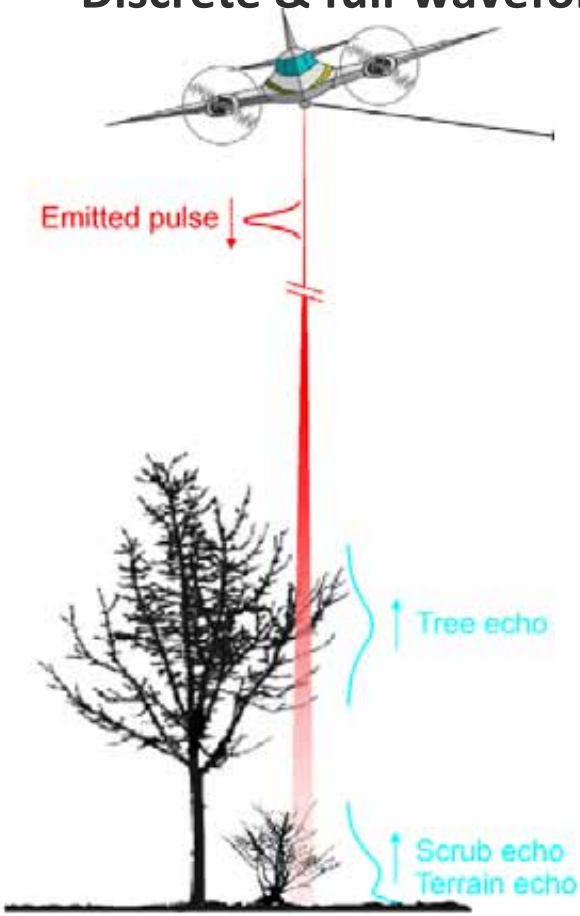
Direct measurement of a terrain point via run time measurement of an emitted pulse

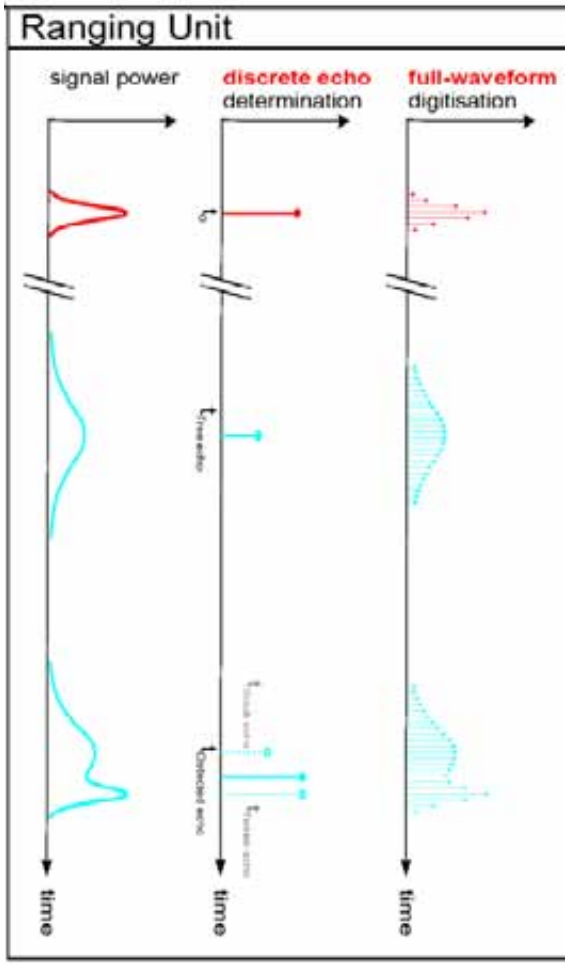
- Permanent determination of exterior orientation (sensor position and attitude) with dGPS and IMU necessary
- Earth surface is scanned point by point

Laser pulse rate:	> 200 kHz
Scan rate:	≤ 400 Hz
Flying height:	0,5 – 6km, typ. 0,5 – 1,5km
Height precision:	~ 5 – 15cm
Planimetric prec.:	~ 20 – 50cm

Common LiDAR systems

- **Discrete & full-waveform systems**

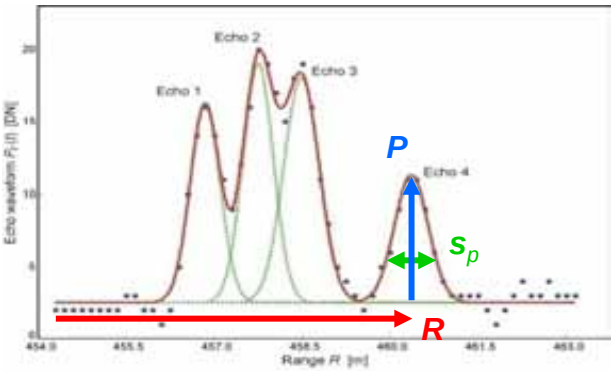




M. Doneus, C. Briese, M. Fera, M. Janner: *Archaeological prospection of forested areas using full-waveform airborne laser scanning*"; Journal of Archaeological Science, **35** (2008), 4; 882 - 893.

Gaussian decomposition

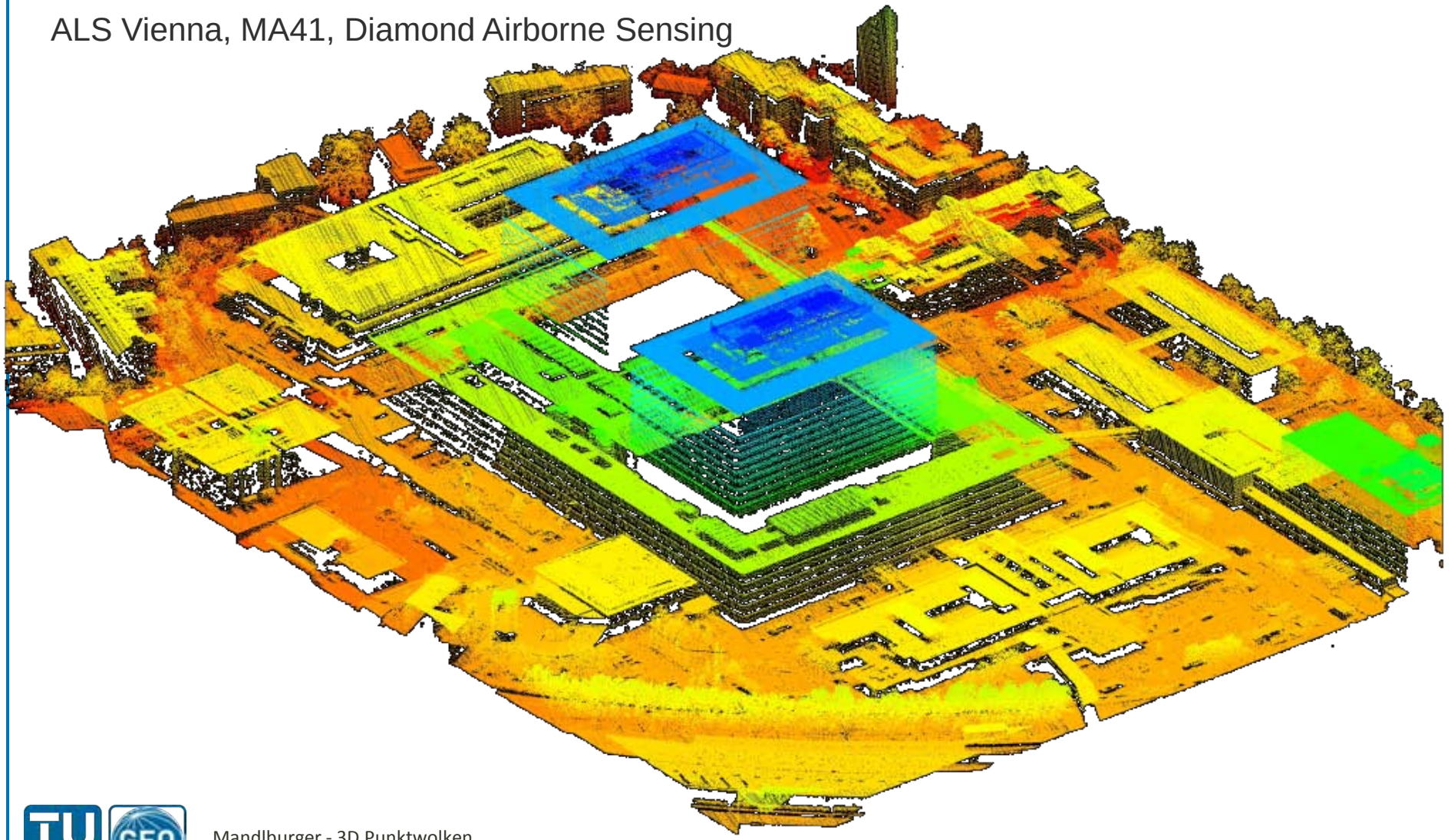
- Detection of echoes by fitting of Gaussians
- Information per echo:
  - **Range *R*** [m]
  - **Echo width s_p** [ns]
  - **Amplitude (Intensity) *P*** [DN]
  - **Backscatter cross-section (computed)**



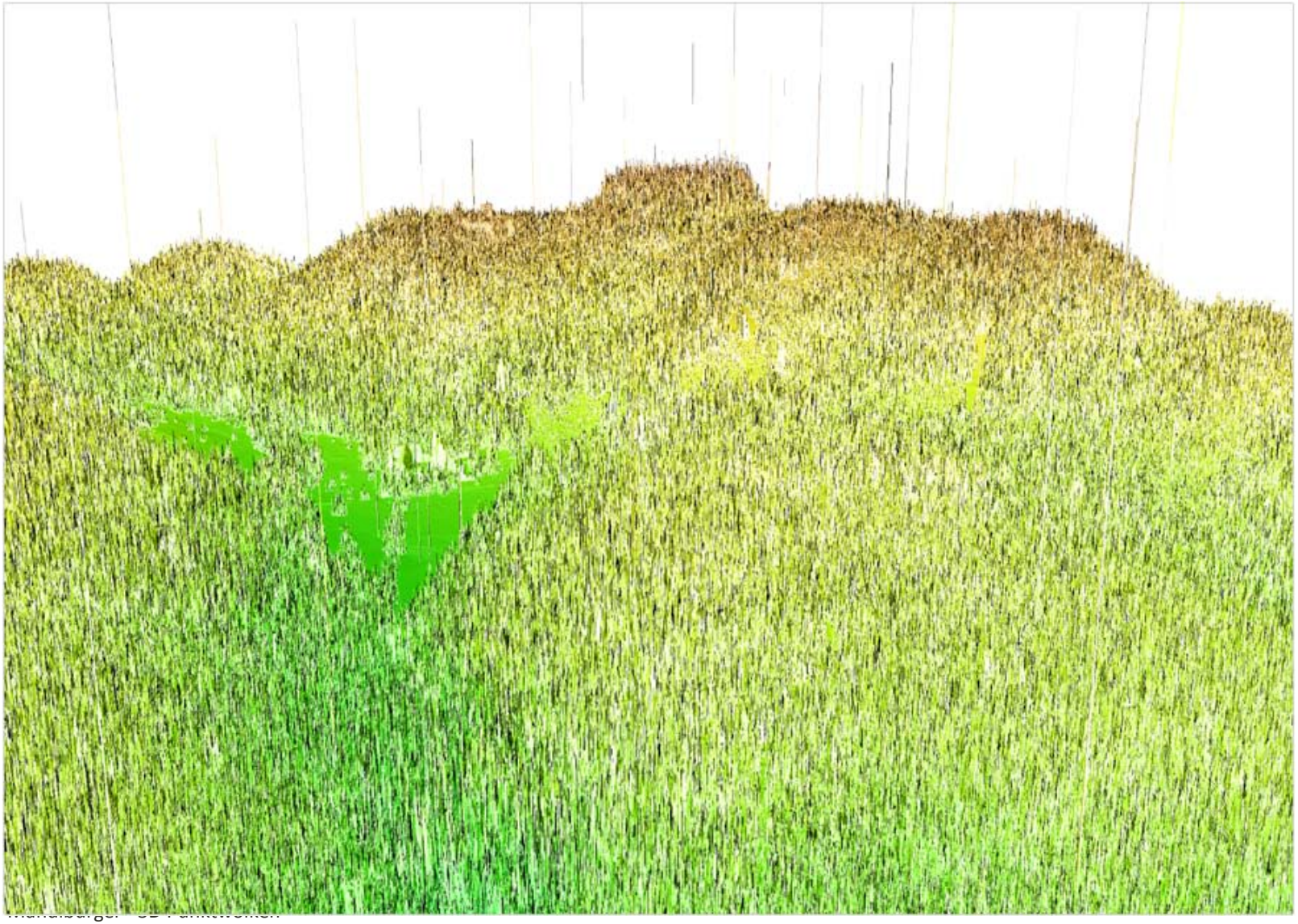
Wagner, W., et al. (2006). "Gaussian decomposition and calibration of a novel small-footprint full-waveform digitising airborne laser scanner." ISPRS Journal of Photogrammetry & Remote Sensing 60(2): 100-112.

3D point cloud

ALS Vienna, MA41, Diamond Airborne Sensing

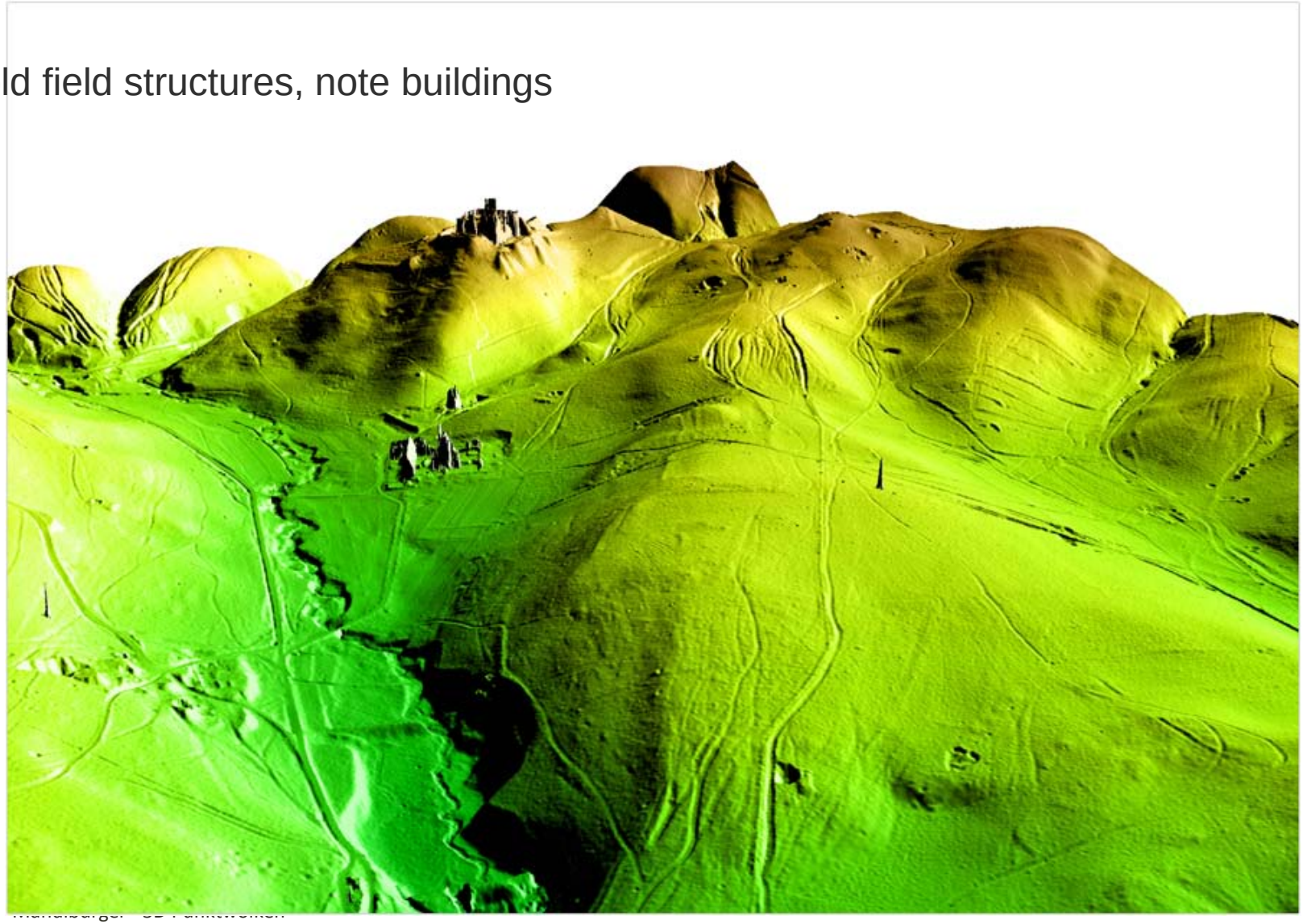


From Digital Surface Model ...



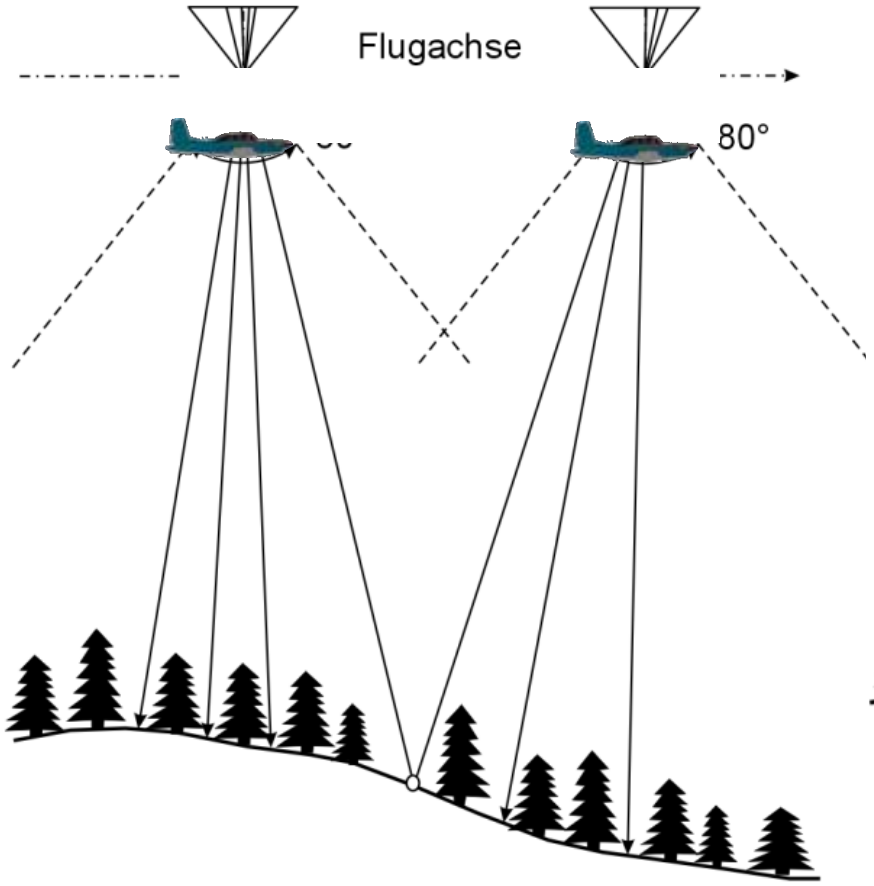
... to Digital Terrain Model

Note old field structures, note buildings

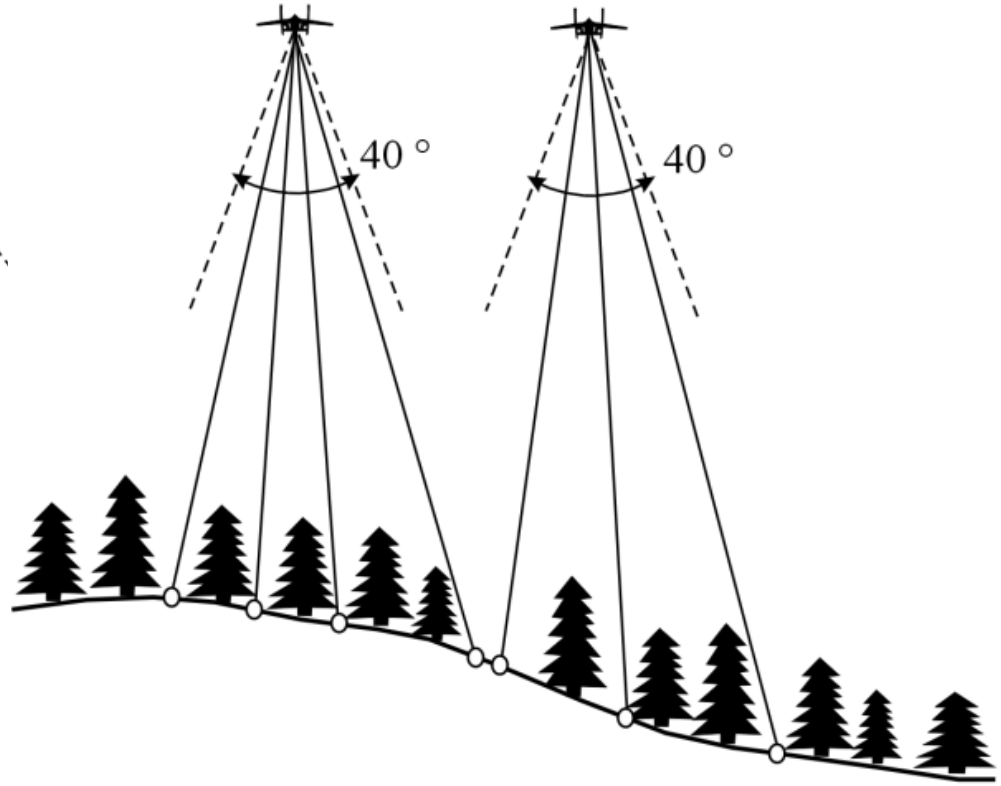


Photogrammetry vs. Laser Scanning

Airborne Photogrammetry



Airborne Laser Scanning

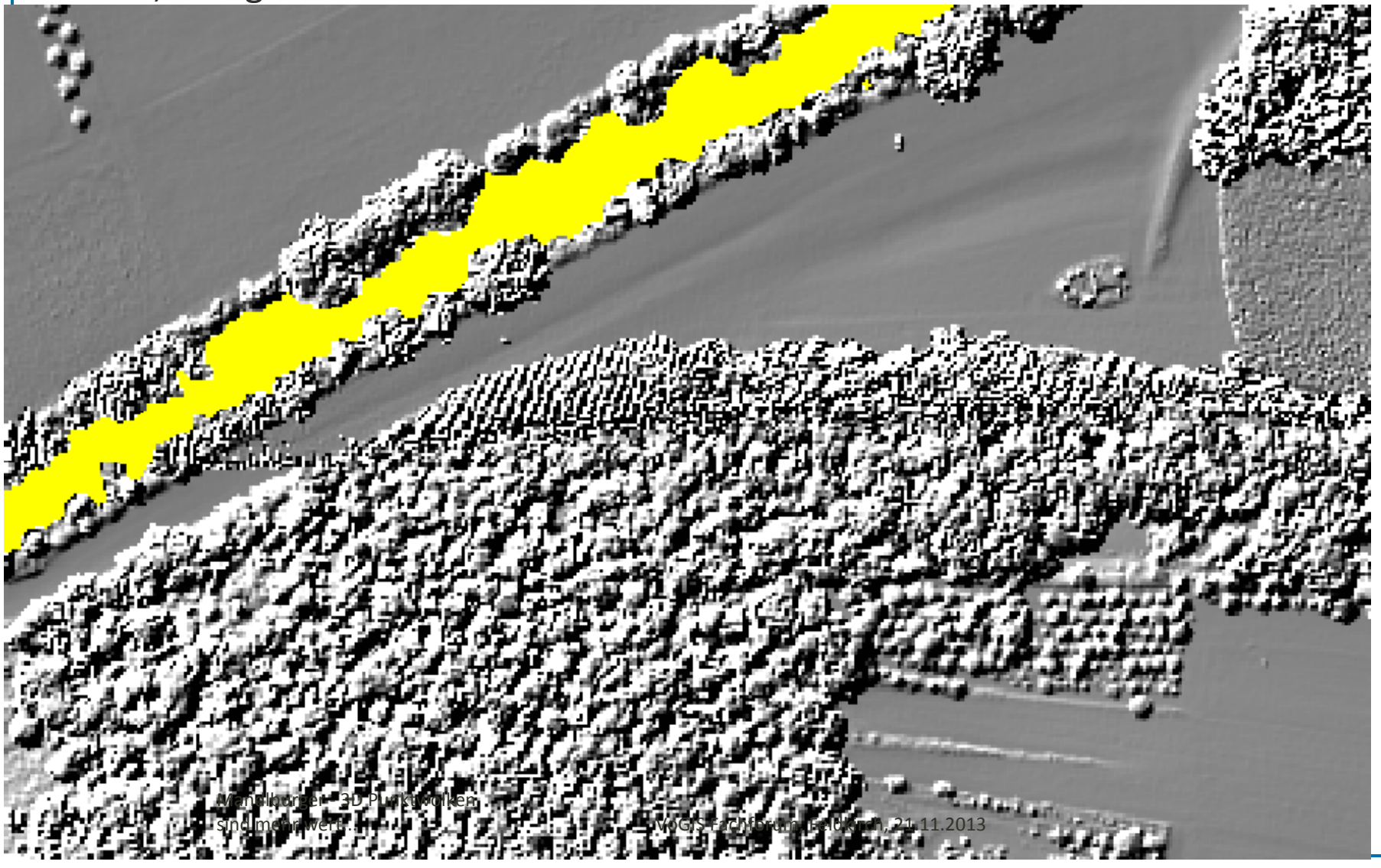


Photogrammetry: Forest ground must be seen in at least 2 images → 2x "direct visibility" required
→ not possible in general because of trees

Laserscanning: 1x "direct visibility" is sufficient (even partly visible → Last-Echo)

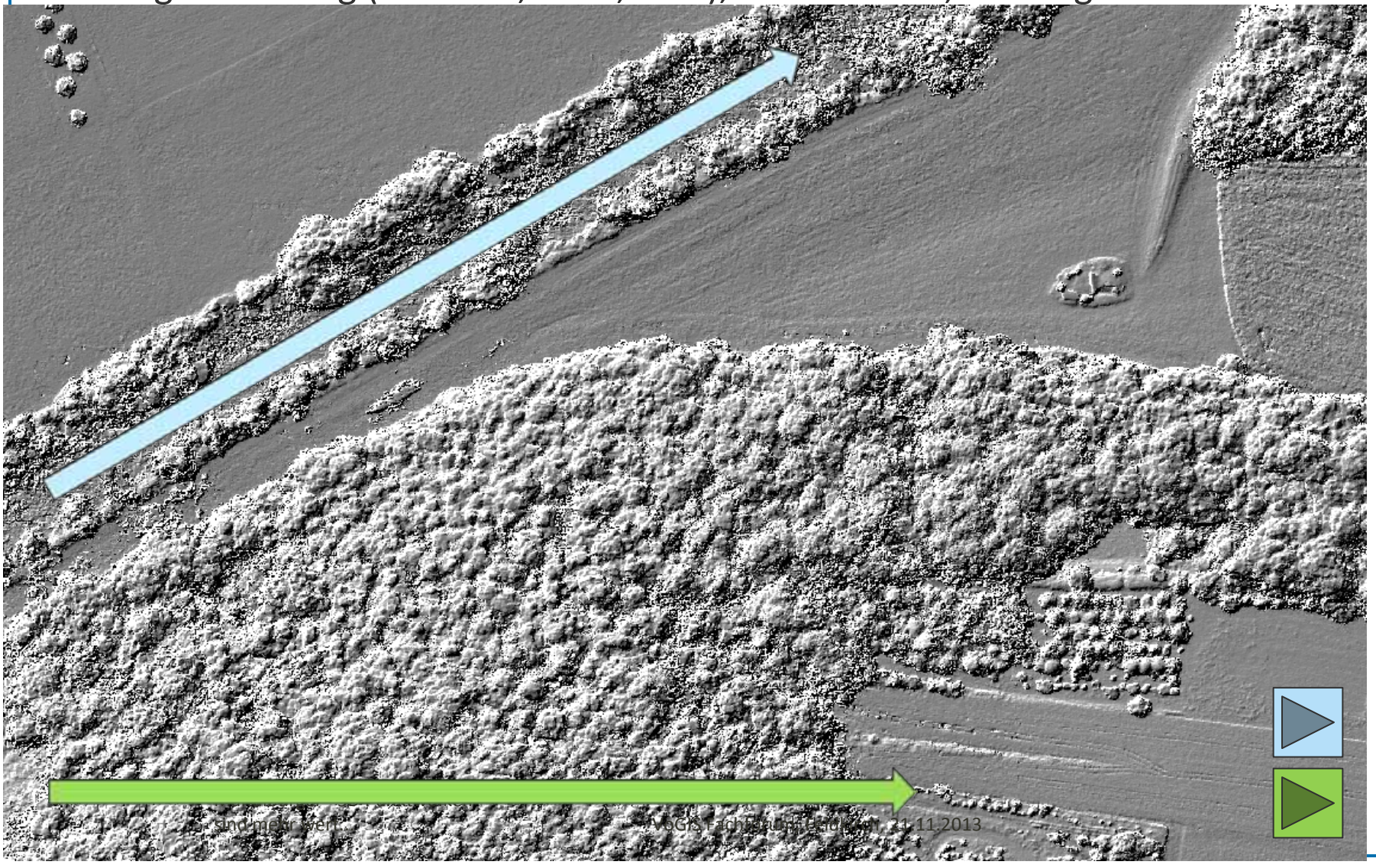
Example: Vaihingen/Enz

- ALS, 1m grid

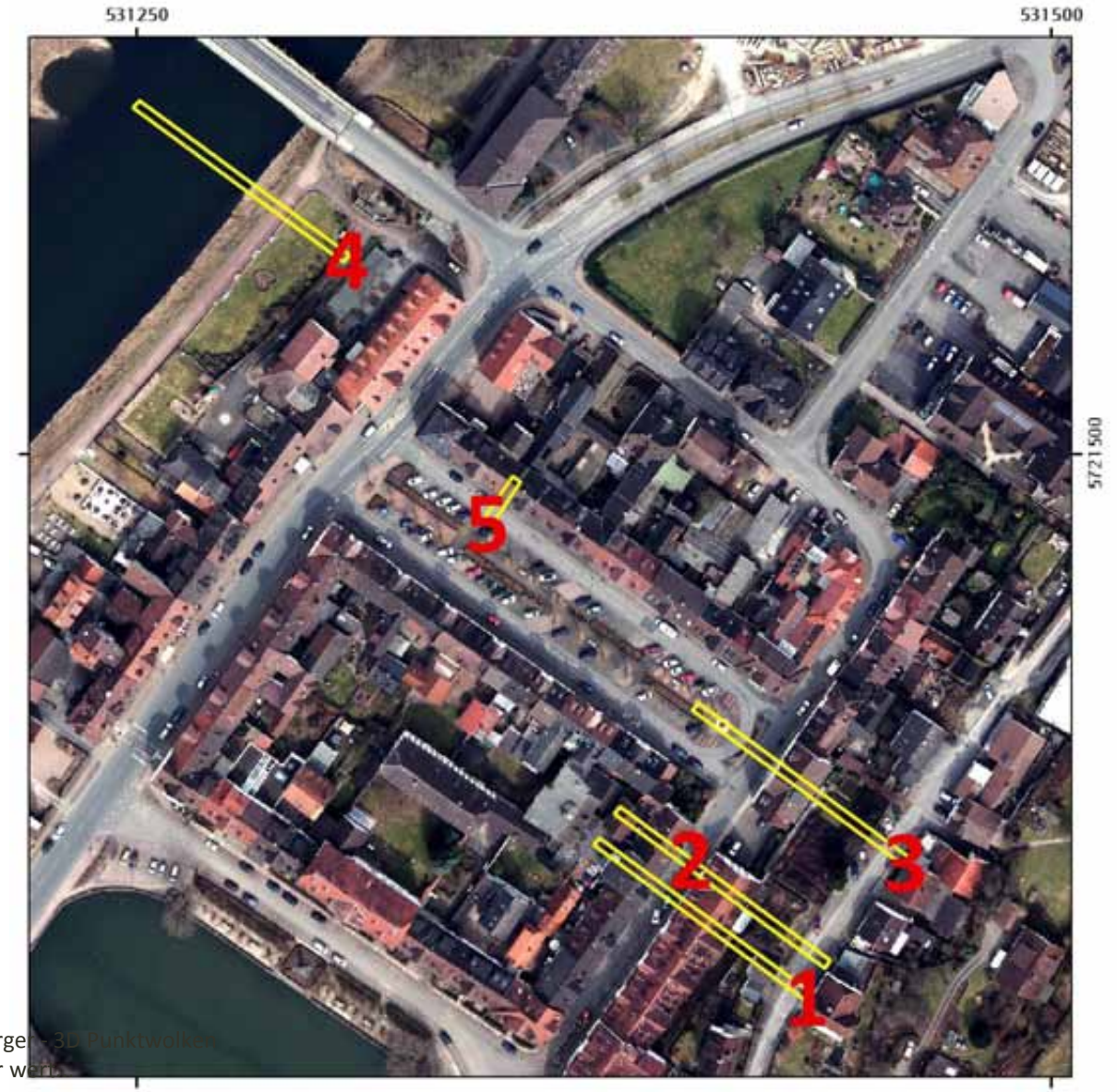


Example: Vaihingen/Enz

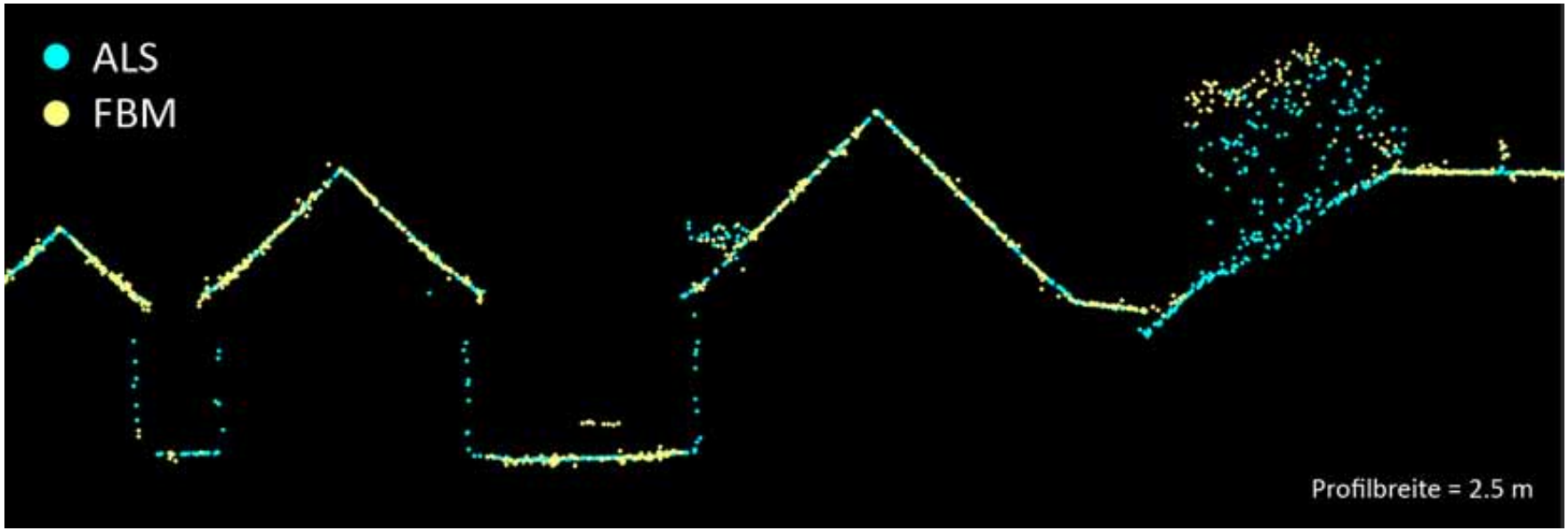
- Image matching (Match-T, SGM, PAN), fusion result, 20cm grid

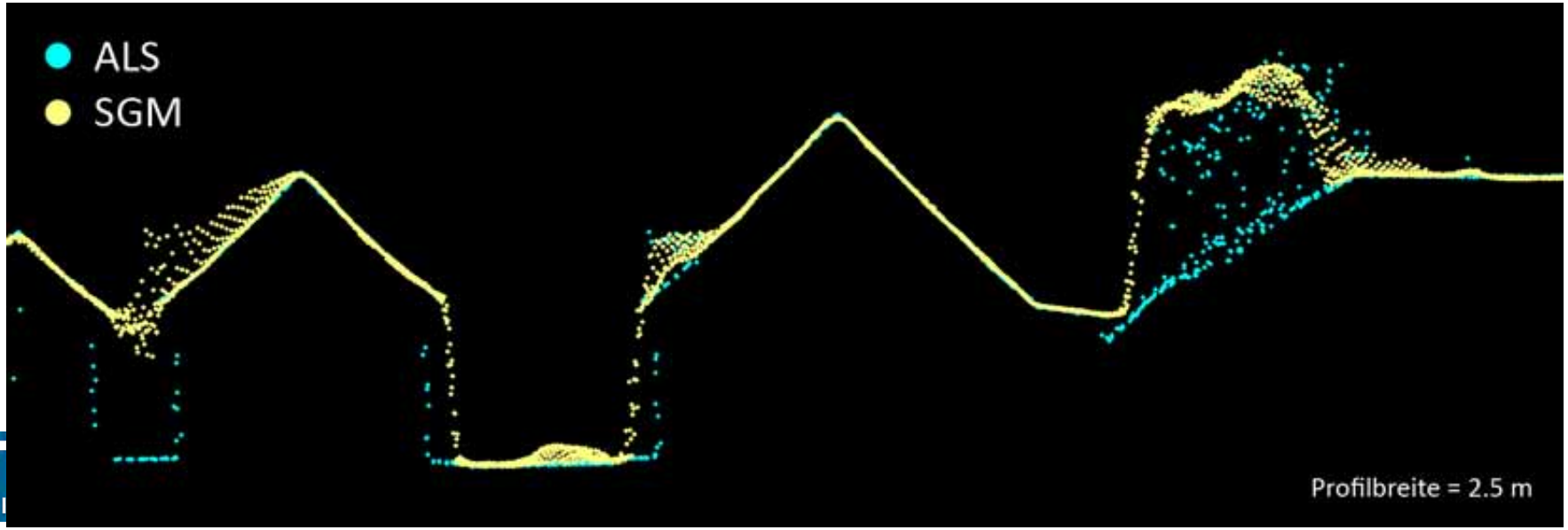


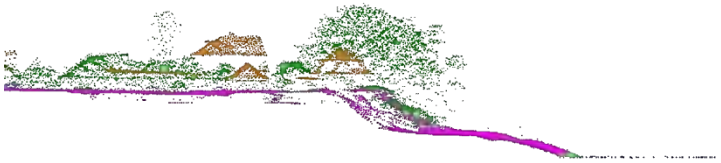
Profilvergleich: Punktwolke aus Bildmatching vs ALS

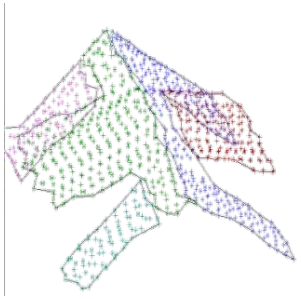


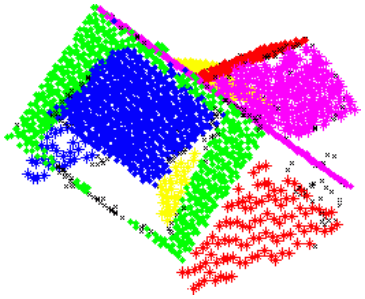
Profil 2: FBM/SGM (Match-T) vs ALS







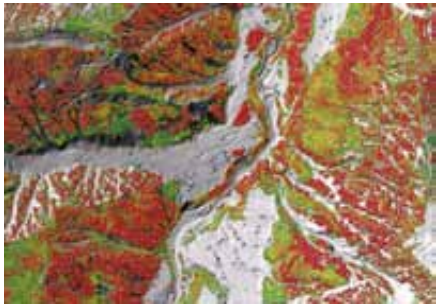


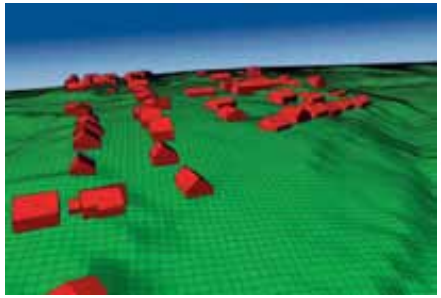


Dorninger

Anwendungen

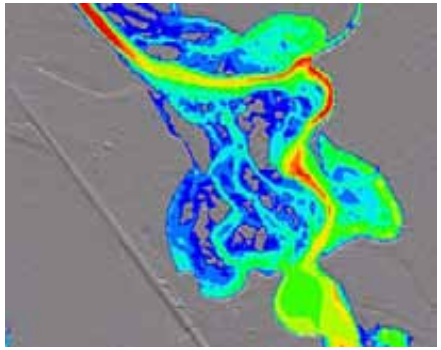
Hollaus, Eysn

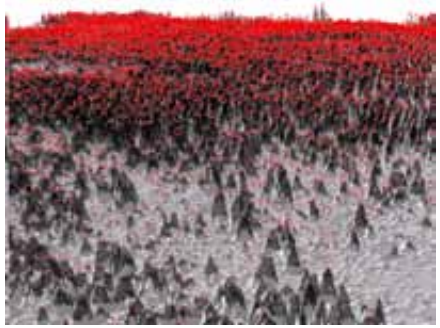




Trimble (Inpho)

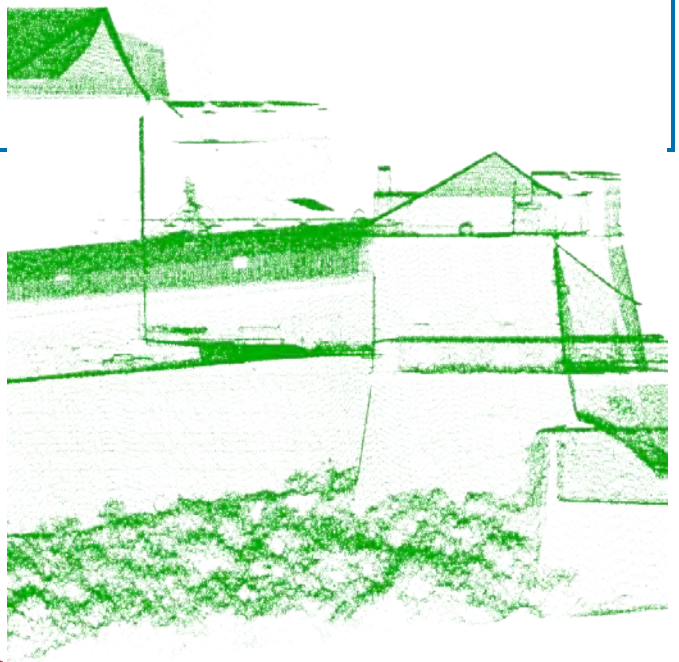
Mandlburger

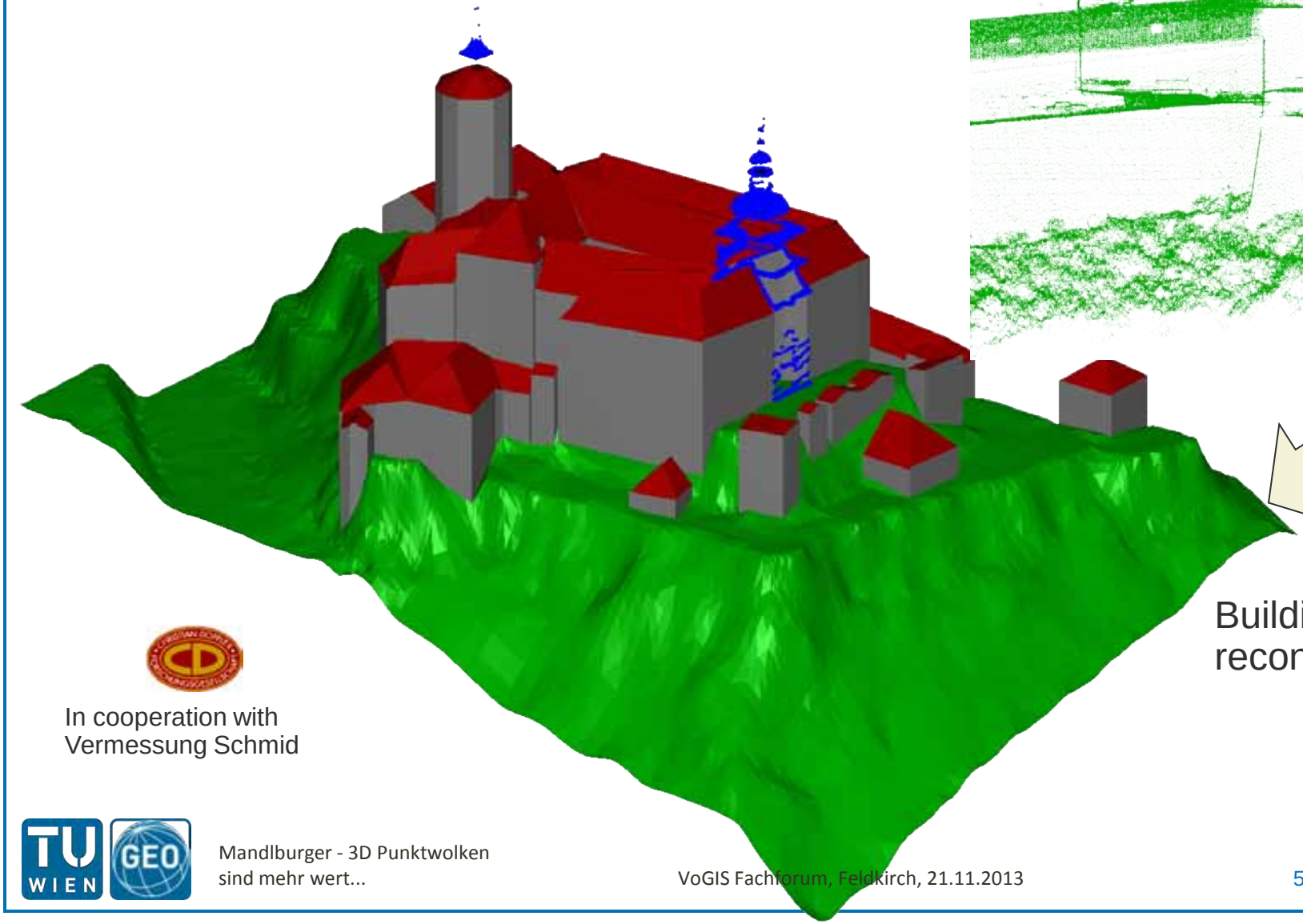




Eysn

From point cloud ... models



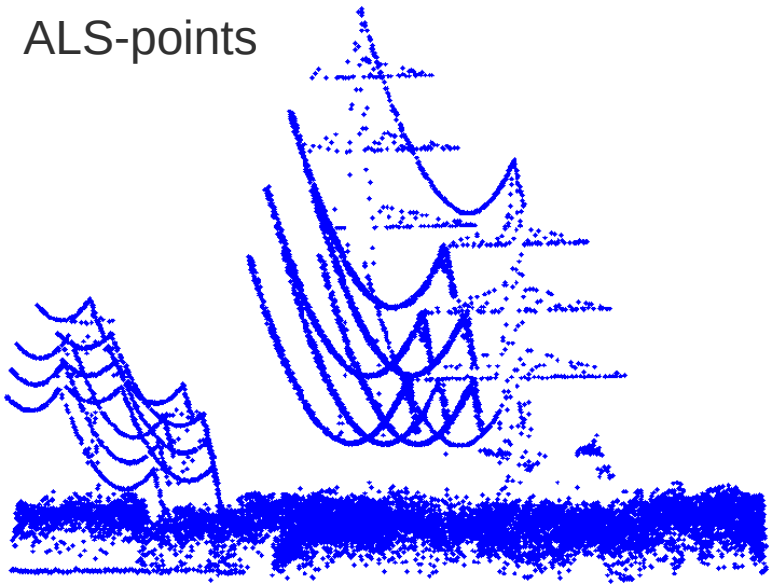


Building model reconstruction

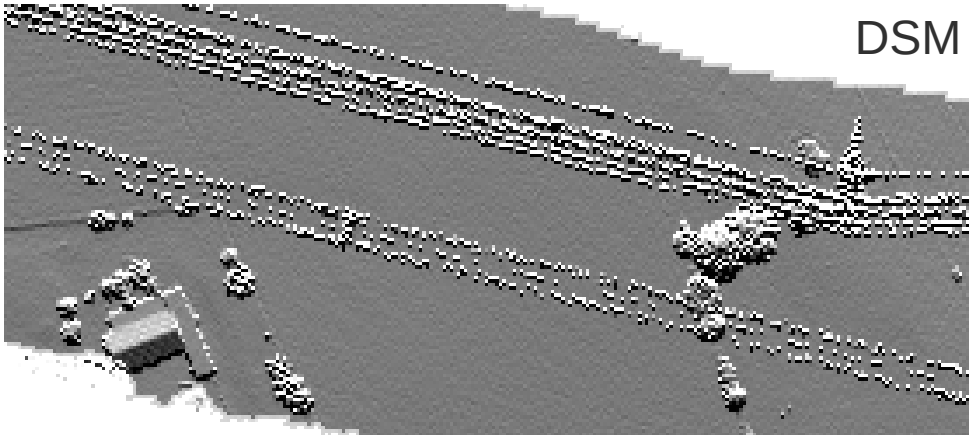
In cooperation with Vermessung Schmid

From point clouds …models

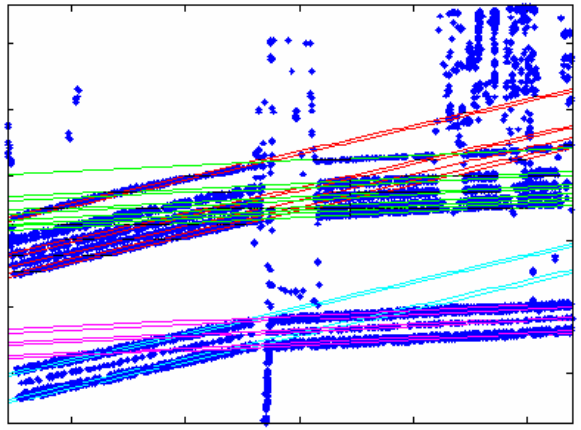
ALS-points



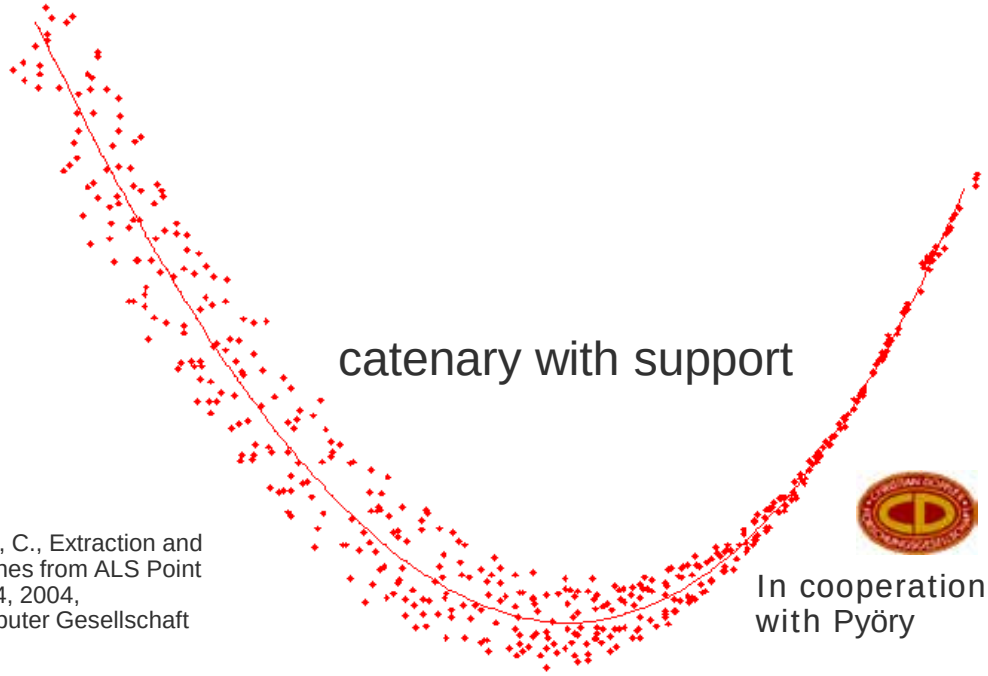
DSM



Lines via Hough transformation



Melzer, T. and Briese, C., Extraction and Modeling of Power Lines from ALS Point Clouds, OAGM, 47-54, 2004, Österreichische Computer Gesellschaft



catenary with support

In cooperation with Pyöry

Forest delineation

Forest Definition

- Worldwide different forest definitions exist (2 examples listed below)

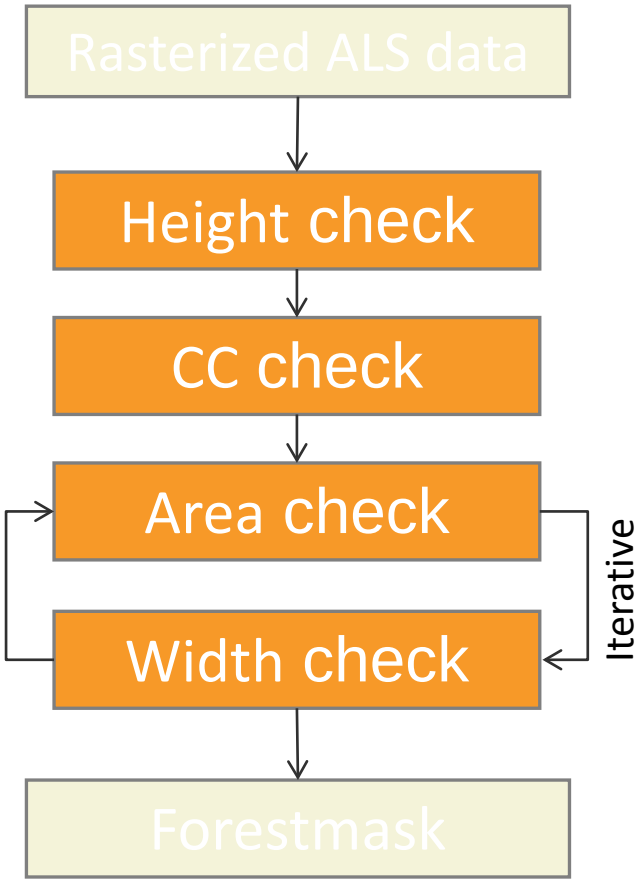
	Austrian national FI	FAO
Type	National	International
Criterions		
Min. tree height	> 2-7m	> 5m
Min. forest area	> 500m²	> 1000m²
Min. crown cover	> 30%	> 10%
Min forest width	> 10m	-
Land use	yes	yes

Criterions used in this study

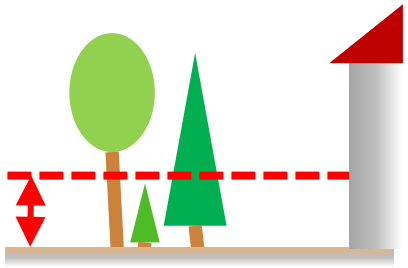
Crown Cover?

„crown coverage is the proportion of forest floor covered by the vertical projection of the tree crowns“

Workflow

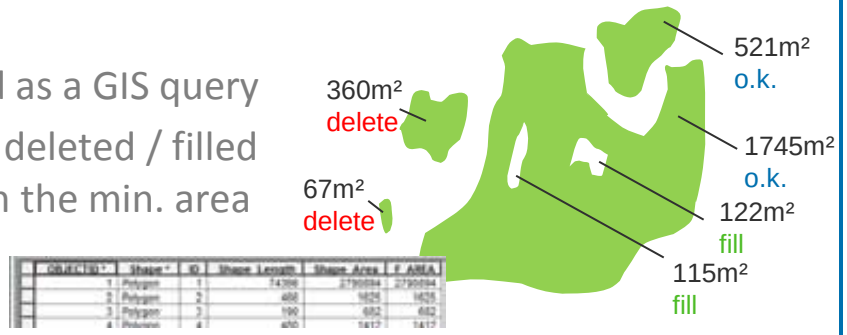


- Implemented as a height threshold on the nDSM

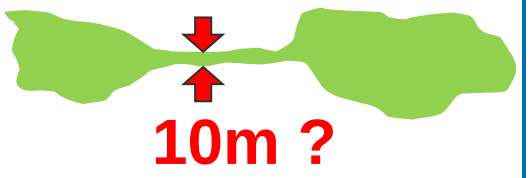


- Will be presented on the next slides

- Implemented as a GIS query
- Polygons are deleted / filled depending on the min. area criterion



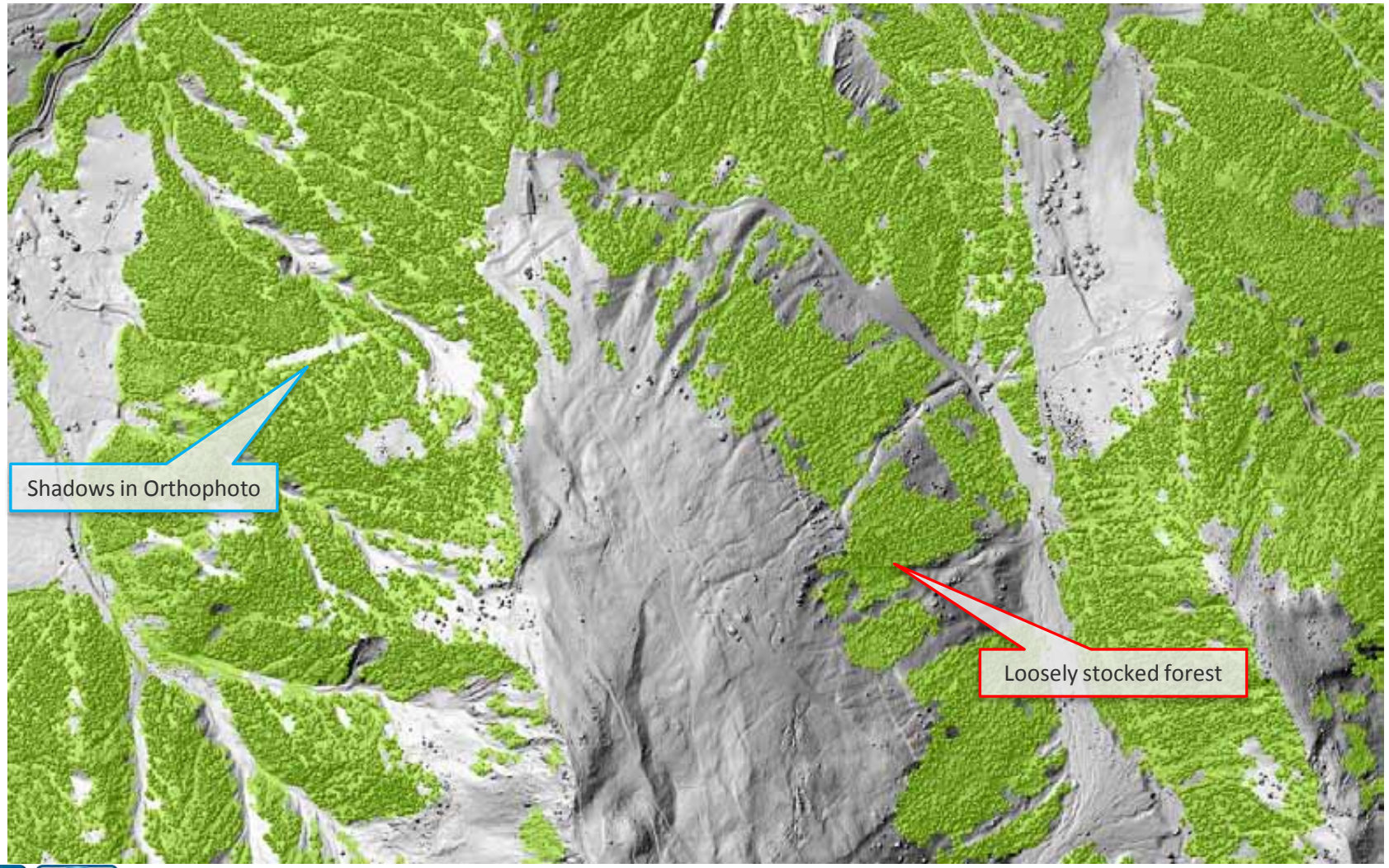
- Based on image morphology (dilation, erosion)



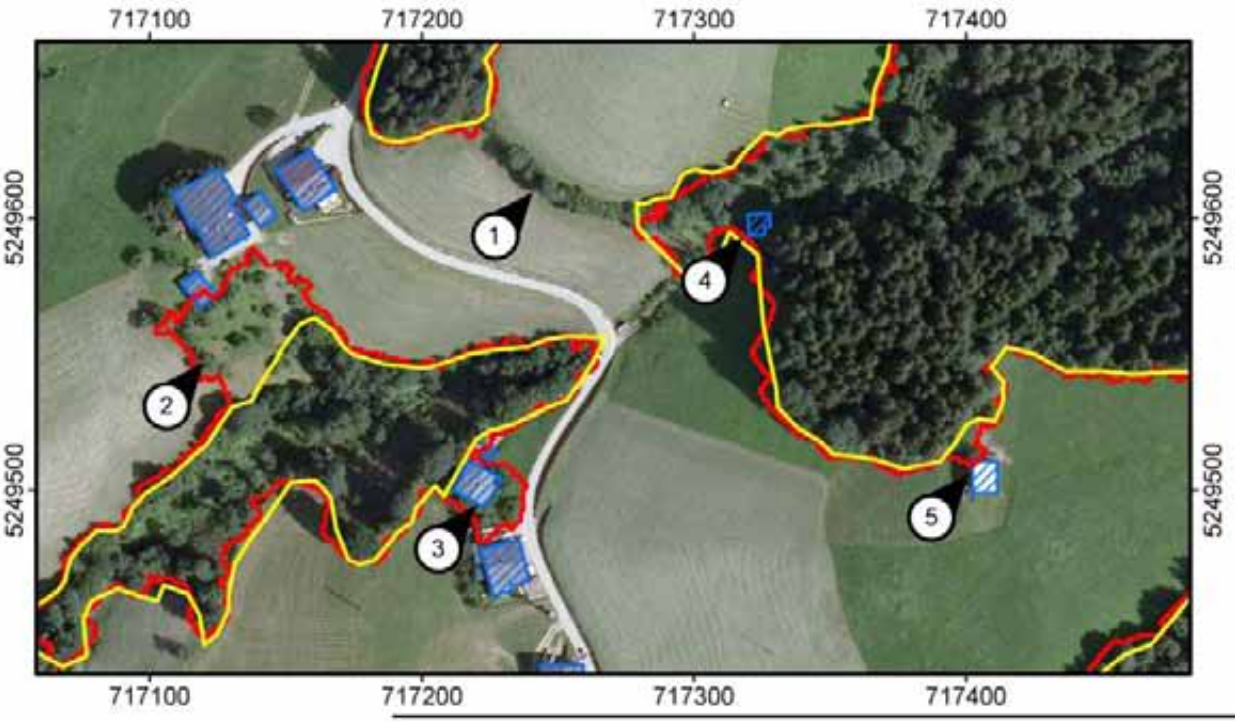
Forestmask Vorarlberg

Forestmask Vorarlberg

Forestmask Vorarlberg



Validation



Sample Area 2,5 x 2,5 km

validation of buildings and forest mask

1. minimum width criterion not fulfilled
2. fruit trees - classified as forest in red forest mask
3. building 100% inside red forest mask
4. building 100% inside both forest masks
5. building 5% inside red forest mask

- automatically delineated forest mask
- manually delineated forest mask
- manually delineated buildings

	Reference - Manually Delineated Forest Mask			
Classified Data	non-forest (ha)	forest (ha)	*Totals (ha)*	User's accuracy (%)
non-forest (ha)	345	7	*352*	98
forest (ha)	17	248	*265*	94
Totals (ha)	*362*	*255*	*617*	
Producer's accuracy (%)	95	97		
Overall accuracy: 96%		**Kappa: 0.92**		

Forestmask Vorarlberg

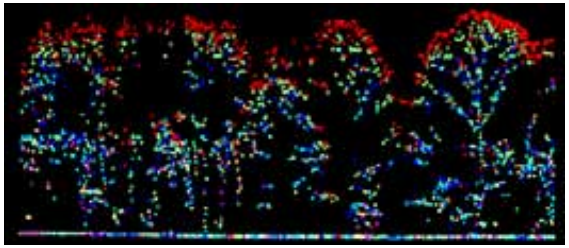
- Forestmask derived for Vorarlberg
- Fully automatic
  - Based on 4 criterions
  - Landuse not investigated!
- Processed in ~30h (Core i7-Q, 32GB RAM)
- Software: OPALS
- Total Forest Area: 1072 km²
  - ~1/3 of Vorarlberg
- Reproducible Result

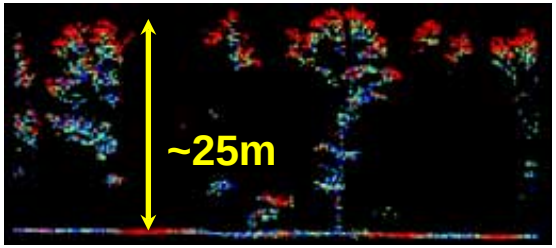
opals

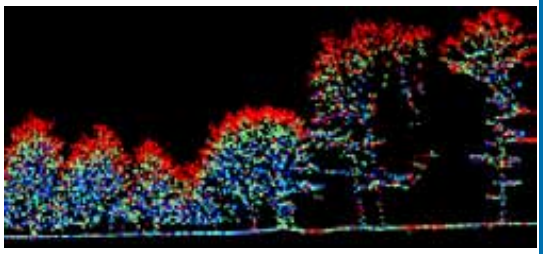
Mandlburger: 3D Punktwolken sind mehr wert...

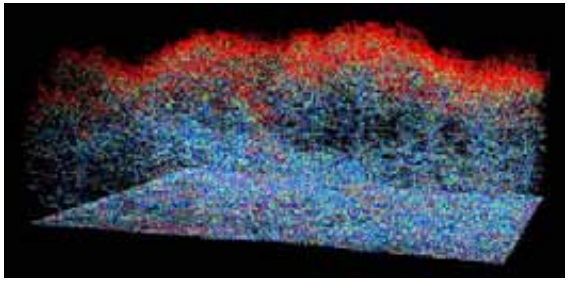
Burgenland Data: ALS vs. Forest Structure

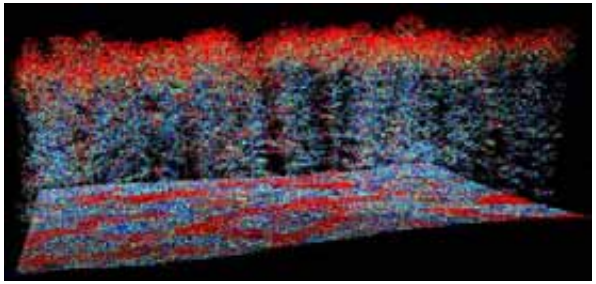
Color == Echo #

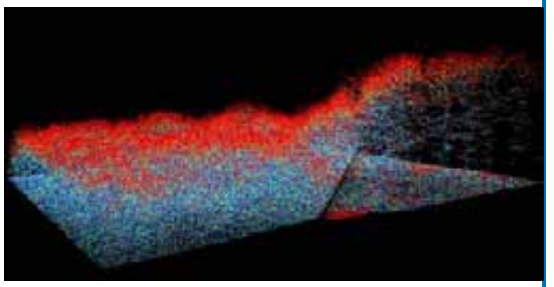




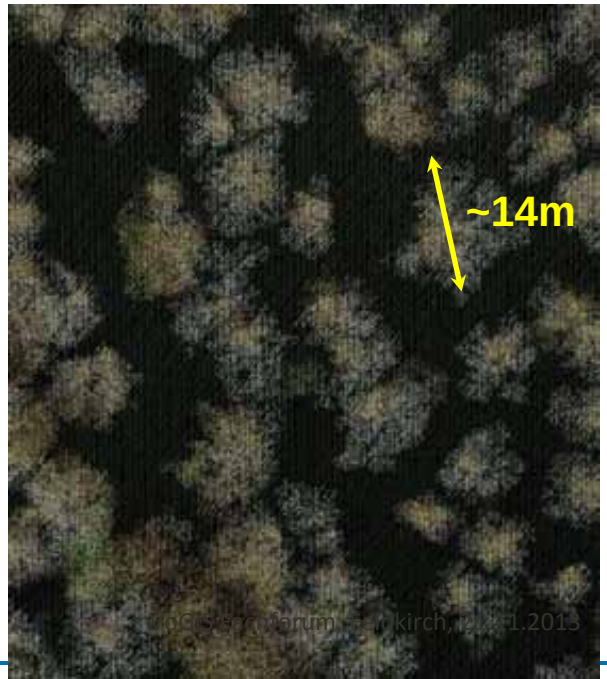








Color == Z coordinate

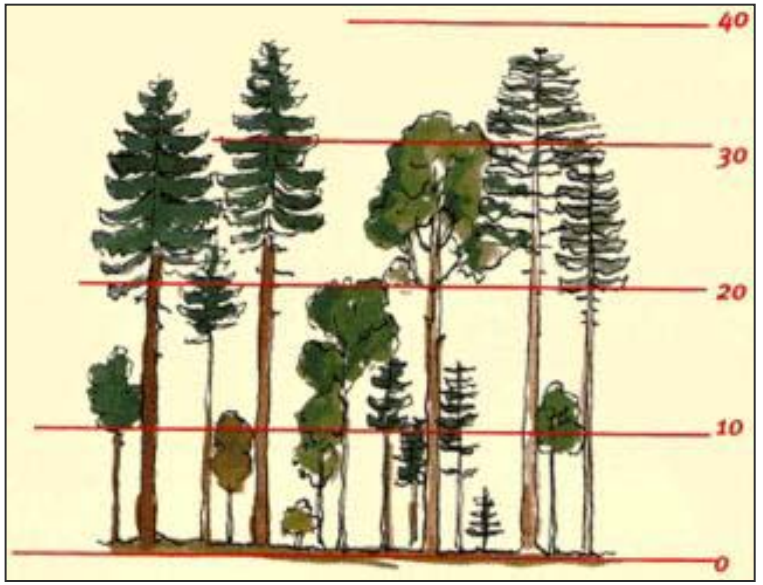


Information on **forest structure** is needed for estimation of …

- … **habitat quality**
  - 3 main criteria (with (a lot of) Subcriteria) to assess the habitat quality
    - Habitat typical **Structure**
    - Habitat typical (Plant-) **Species**
    - Anthropogenic **Disturbances & Interferences**

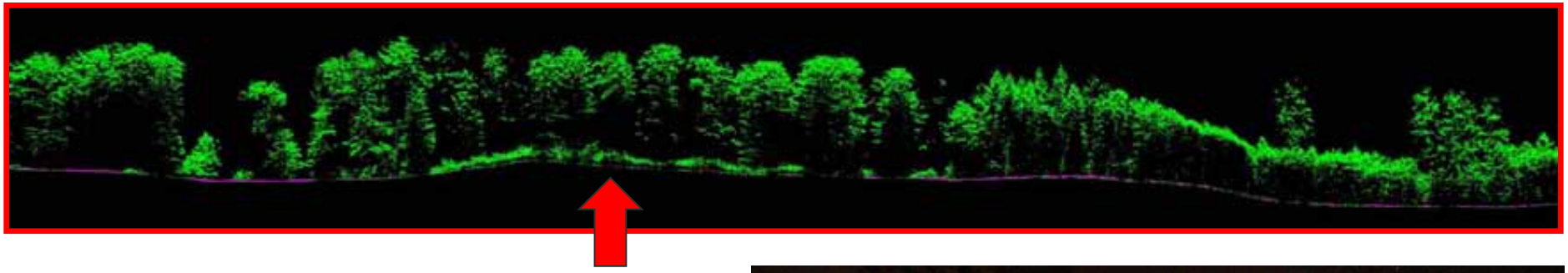
  → **total Assessment**

Graphics © Prof. Heilmeier



Information on **forest structure** is needed for estimation of …

- …**biomass**
  - Understory can be considered

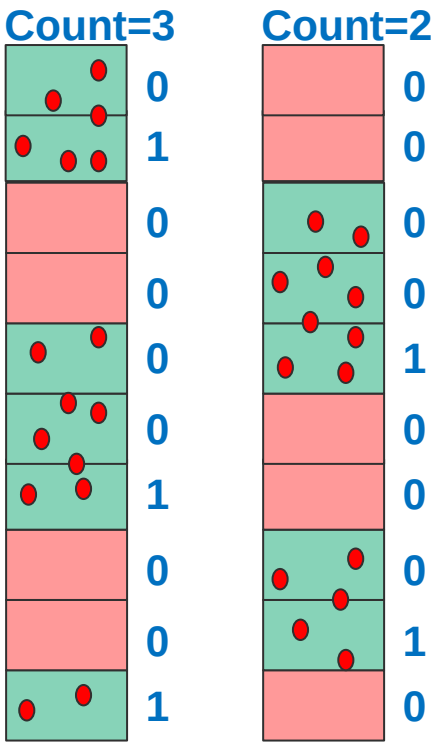


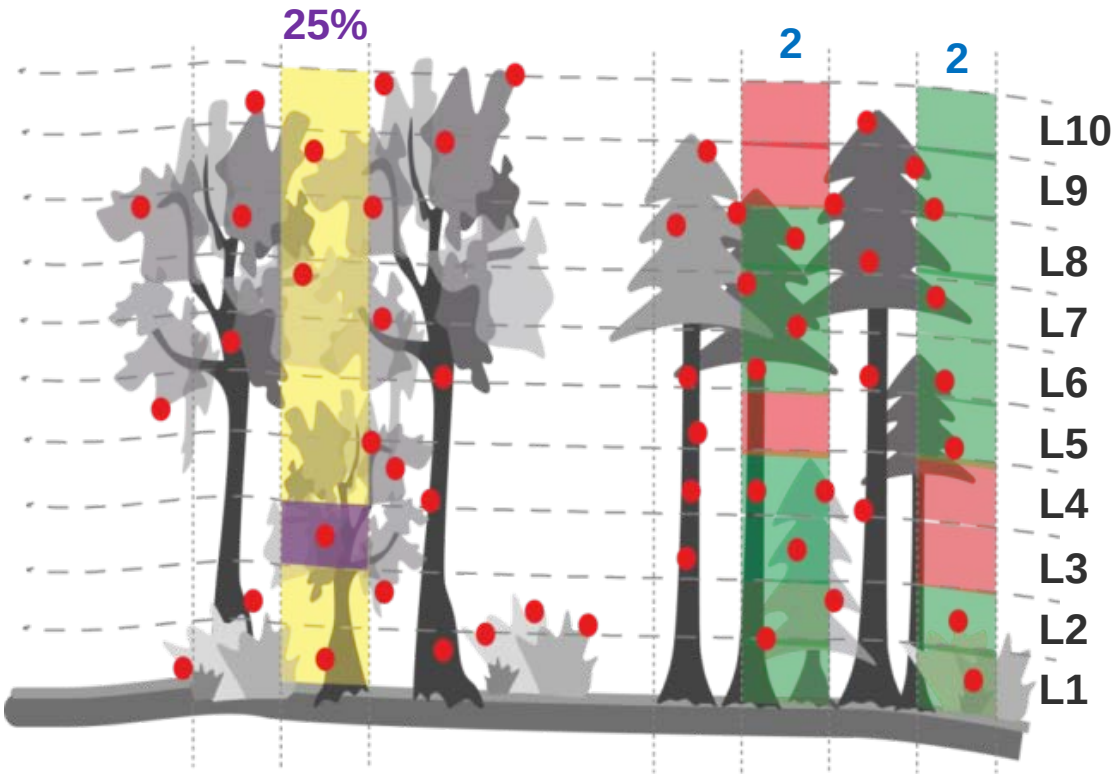
- **…fuel for forest fires**
  - E.g. ground fires spread faster

    if understory is present

Layer structure model

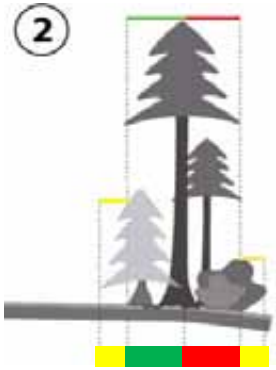
- Layer structure model based on the 3D point cloud
  - **Penetration index [%]** based on grid:
    Number of points in certain height level (purple) compared to all points in the column (yellow)
  - **Count number of vertical layers (= connected/„stacked“ cells)**



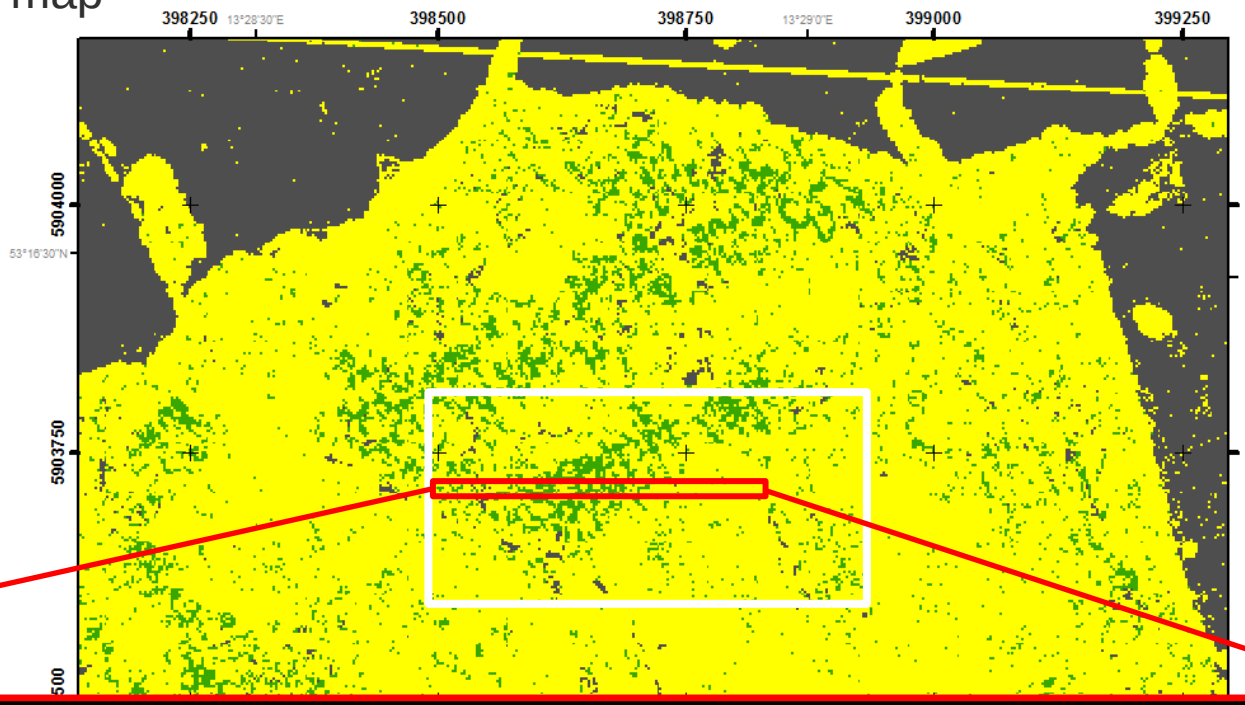


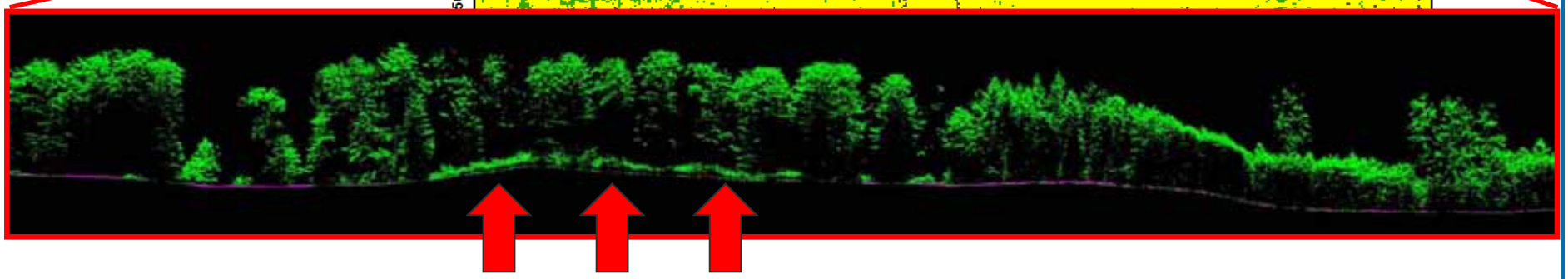
Example: forest layer structure

Color coded structure map



1 layer
2 layers
3 layers





Multi-layered forest (shrubs ~5m and high trees ~30m)

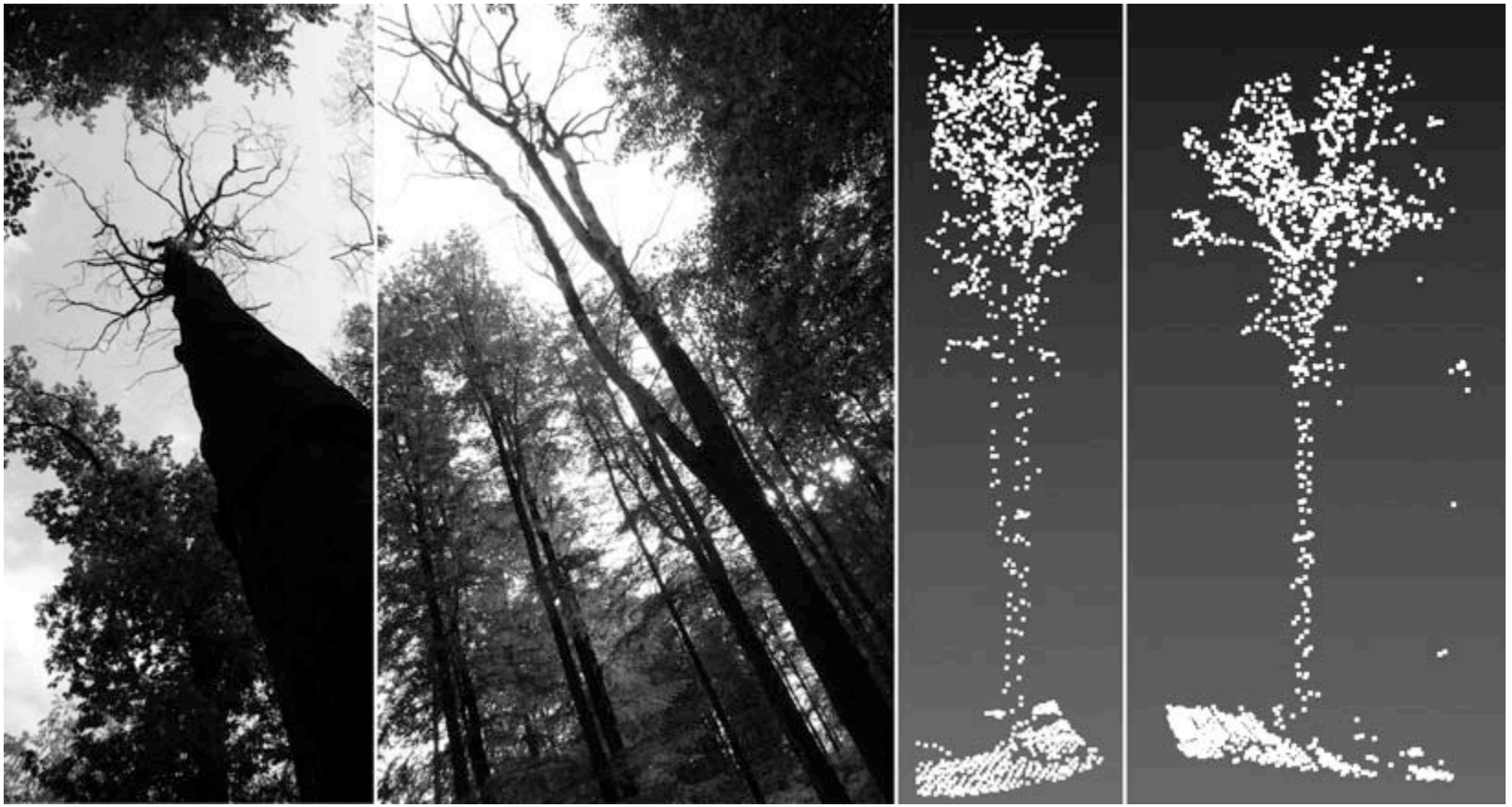
Examples: Downed dead wood (or CWD)

- Map locations of fallen stems and coarse woody debris (=CWD)
- Based on ALS data: high point density allows **direct identification of stems**
- **70.4 %** of the downed stems detected automatically (intermediate result)

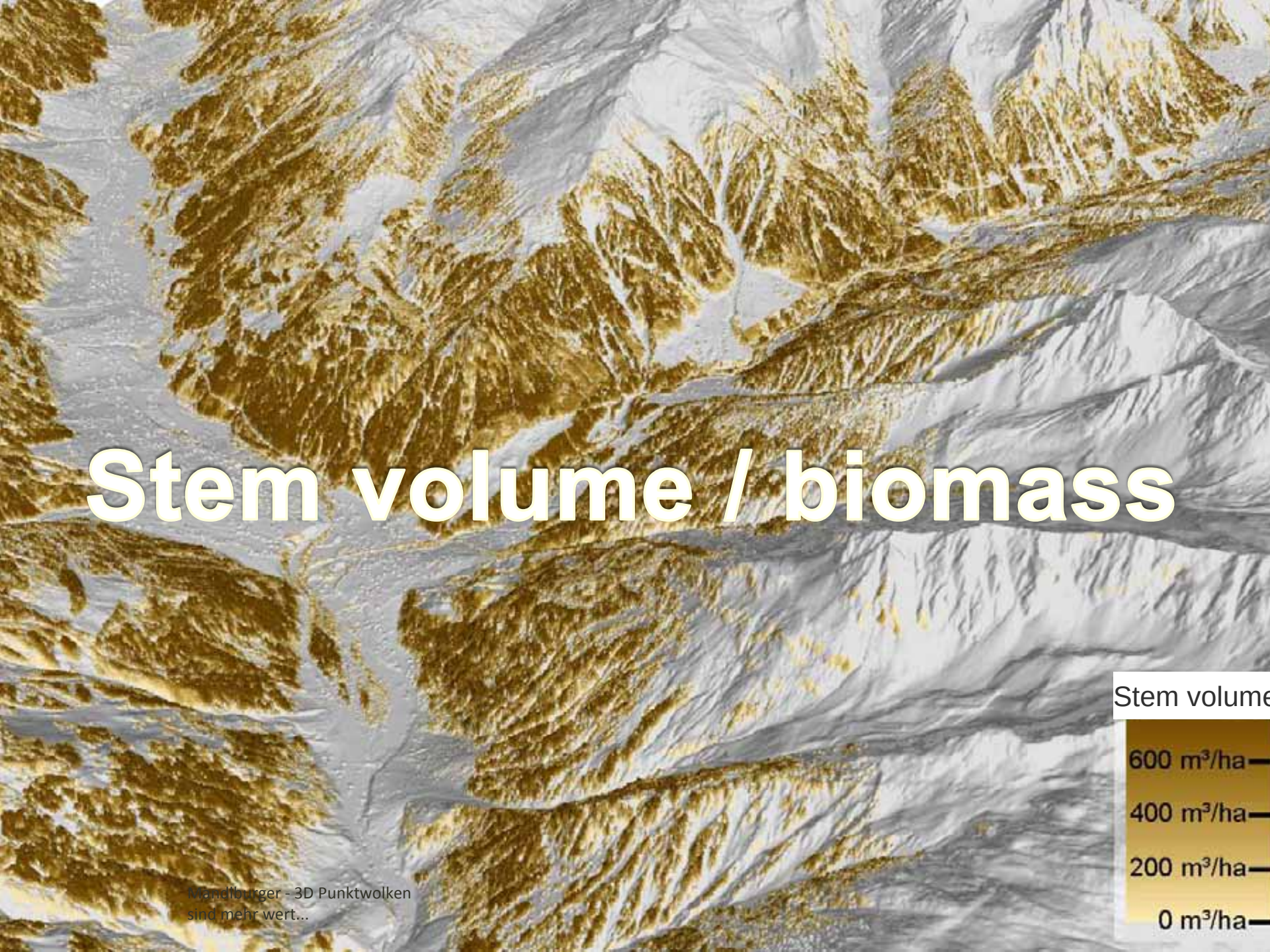
(Mücke, Hollaus & Pfeifer, 2012)

Examples: Dead wood

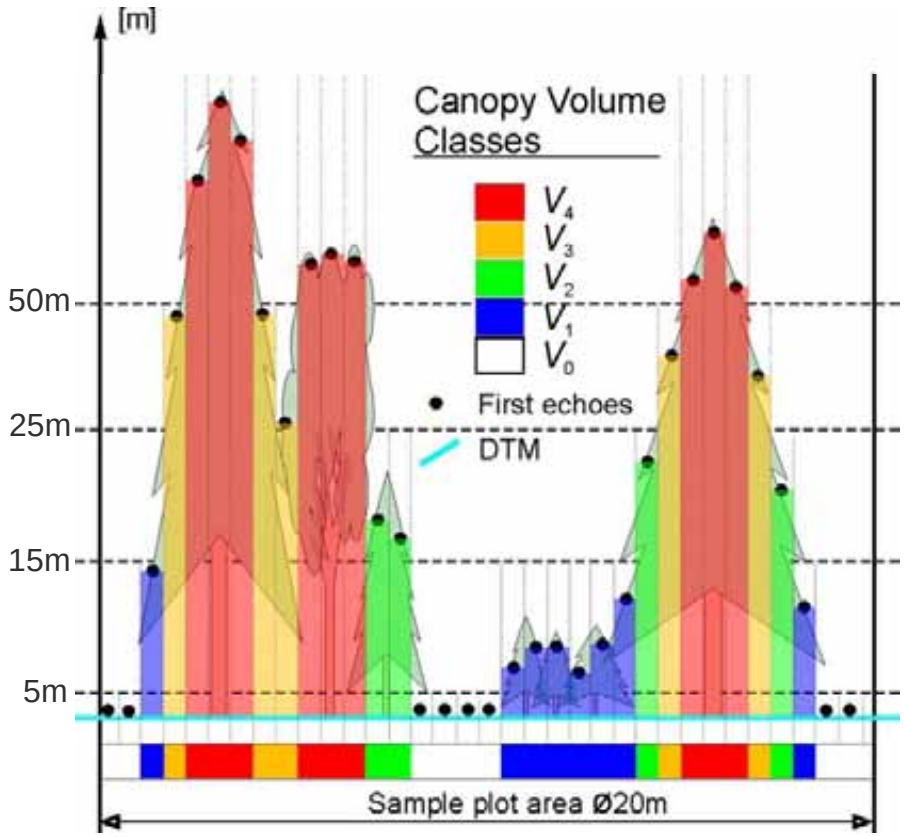
- Example from the point cloud



Stem volume / biomass



Stem Volume Model



M. Hollaus, W. Wagner, K. Schadauer, B. Maier, K. Gabler:
"Growing stock estimation for alpine forests in Austria:
a robust lidar-based approach";
Canadian Journal of Forest Research, 39 (2009), 7; 1387 - 1400.

Stem volume = $f_{(\text{Canopy volume})}$

Information from forest inventory (FI) data

Information from ALS-Data

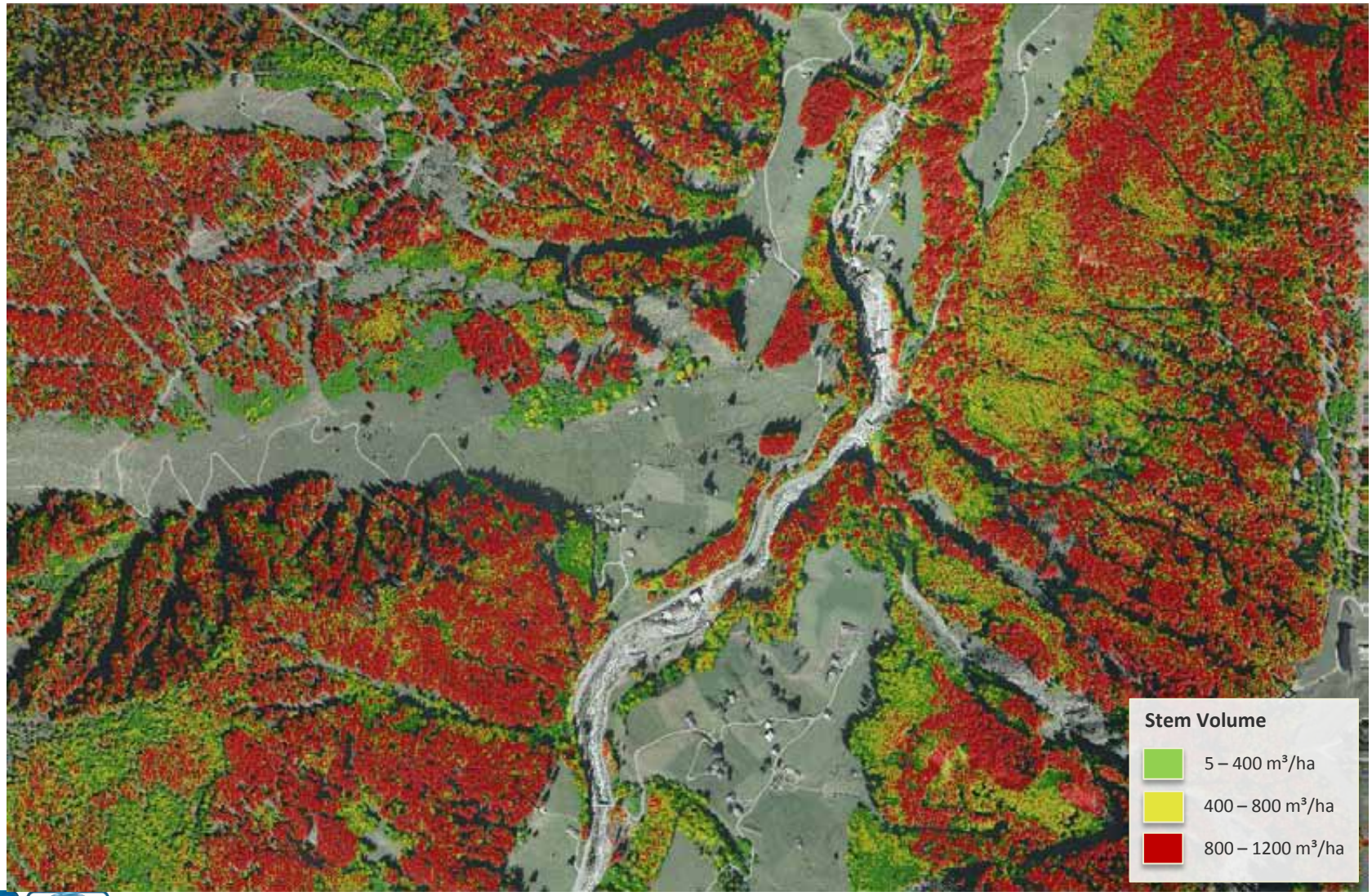
$$v_{\text{stem,fi}} = \sum_{i=1}^{n} \beta_i \cdot v_{\text{can},i}$$

Calibrated model coefficients

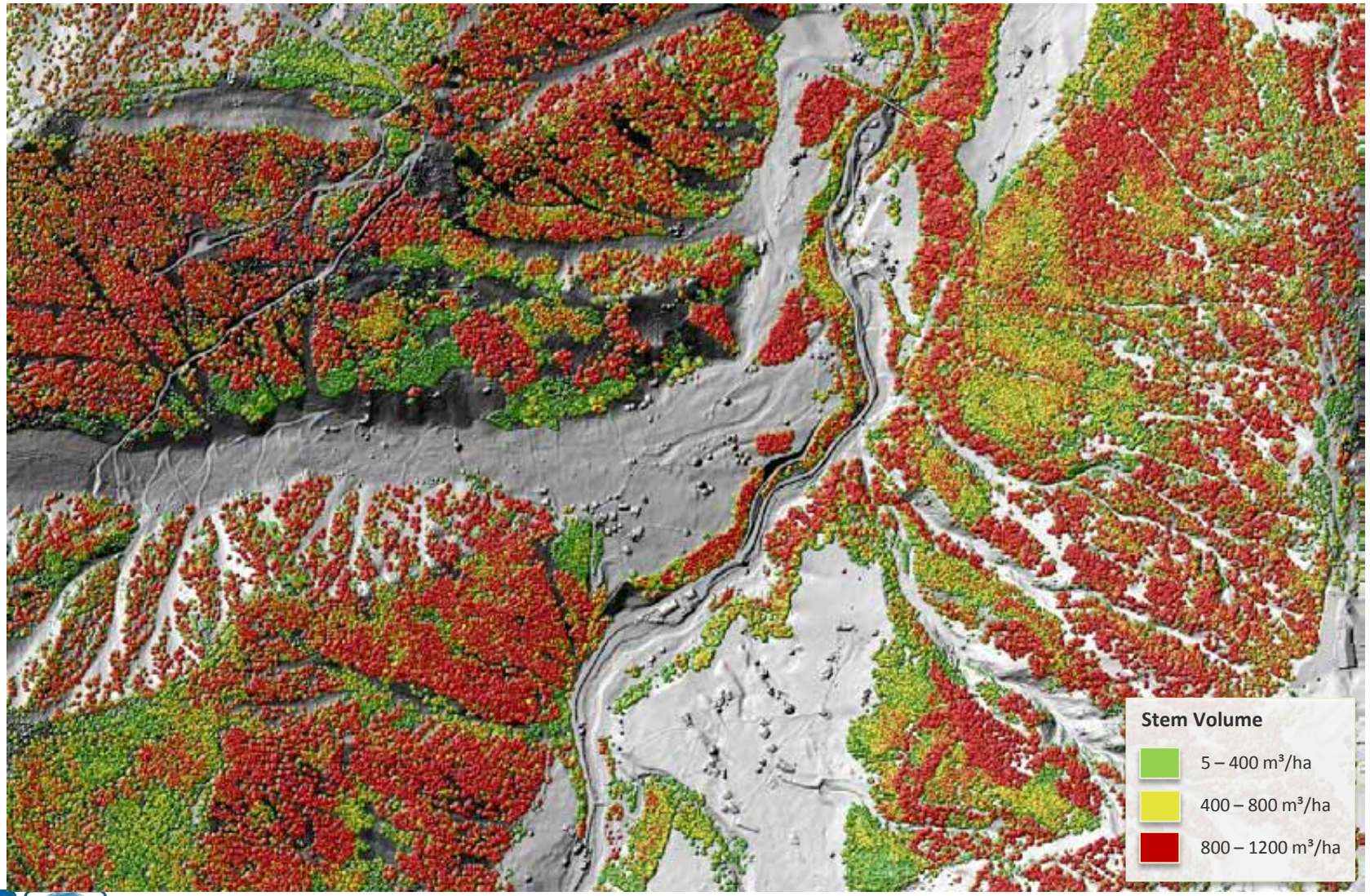
$v_{\text{can},i}$	Canopy volume for the height layer *i*
n	Number of height layers
$v_{\text{stem.fi}}$	Stem volume from forest inventory

Results – Sample Area Montafon

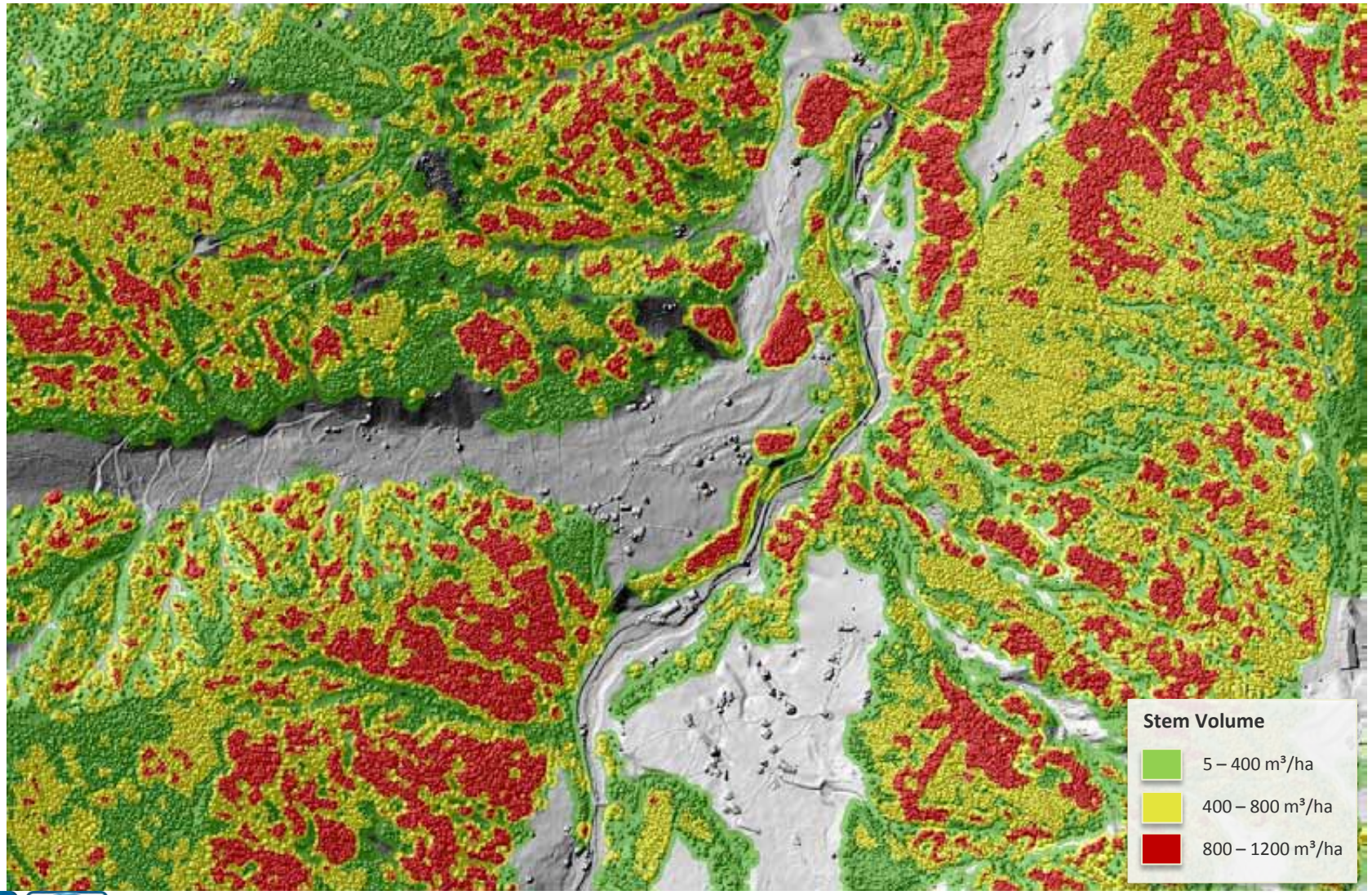
Stemvolume Map (1 x 1m Resolution)



Stemvolume Map (1 x 1m Resolution)

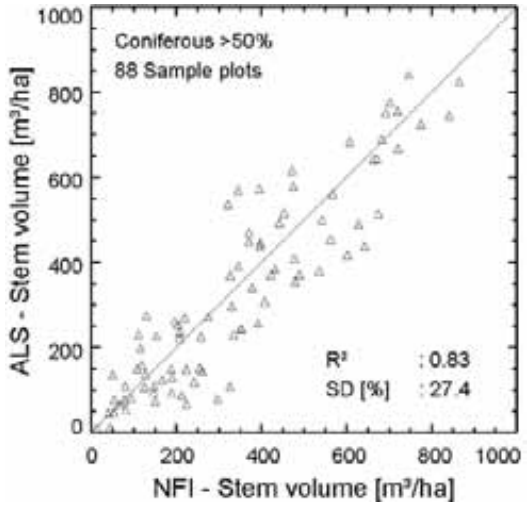


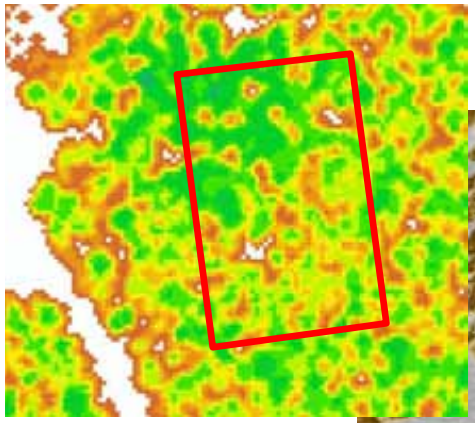
Results (Aggregated Map)



Output of the stem volume estimation

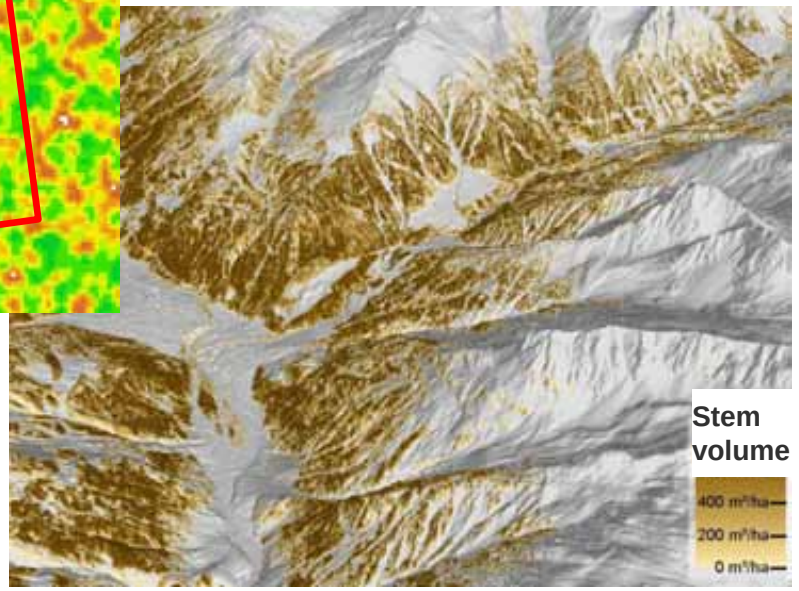
- Statistical quantities of the calibrated model
  - E.g. scatterplots
  - Coefficient of determination R^2
  - Standard deviations
  - Cross validation
  - …
- Accuracy assessment
  e.g. with external
  in-situ data





NFI: 425 m³/ha

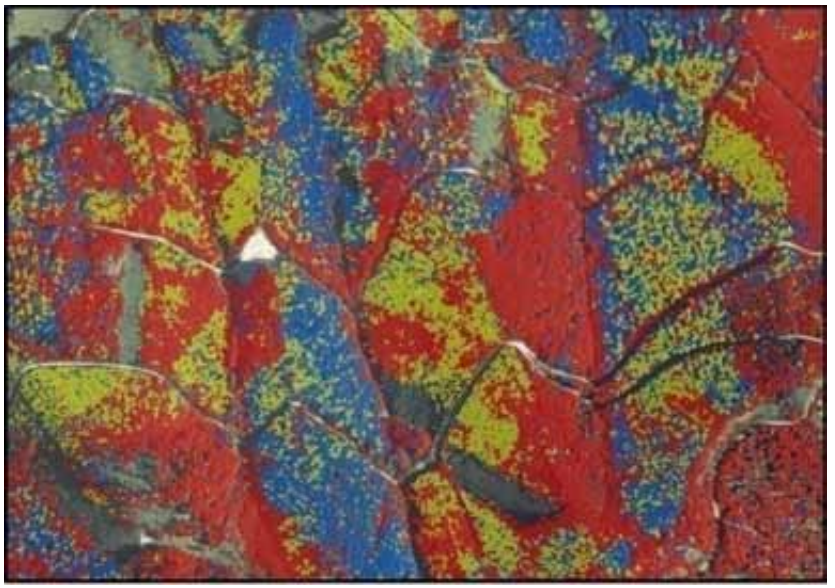
LiDAR: 428 m³/ha

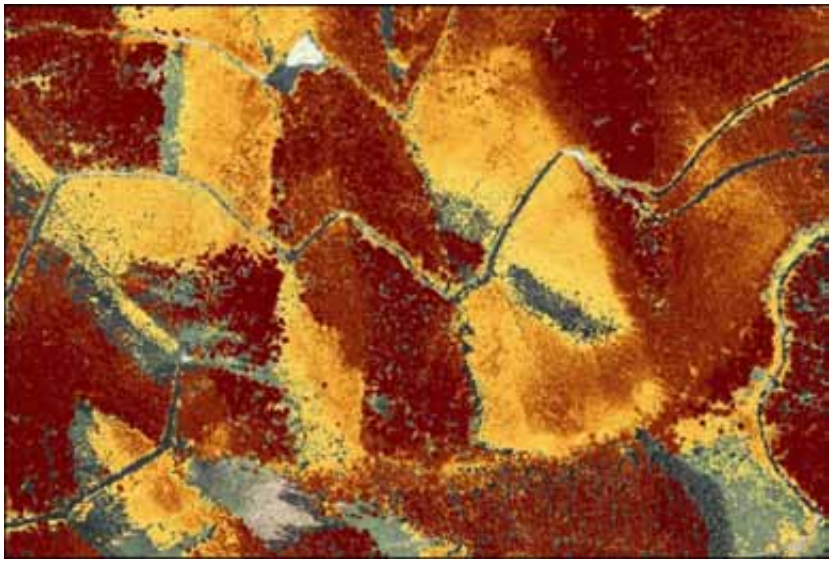


- Area-wide stem volume map

Improved stem volume estimation

… based on tree species specific models





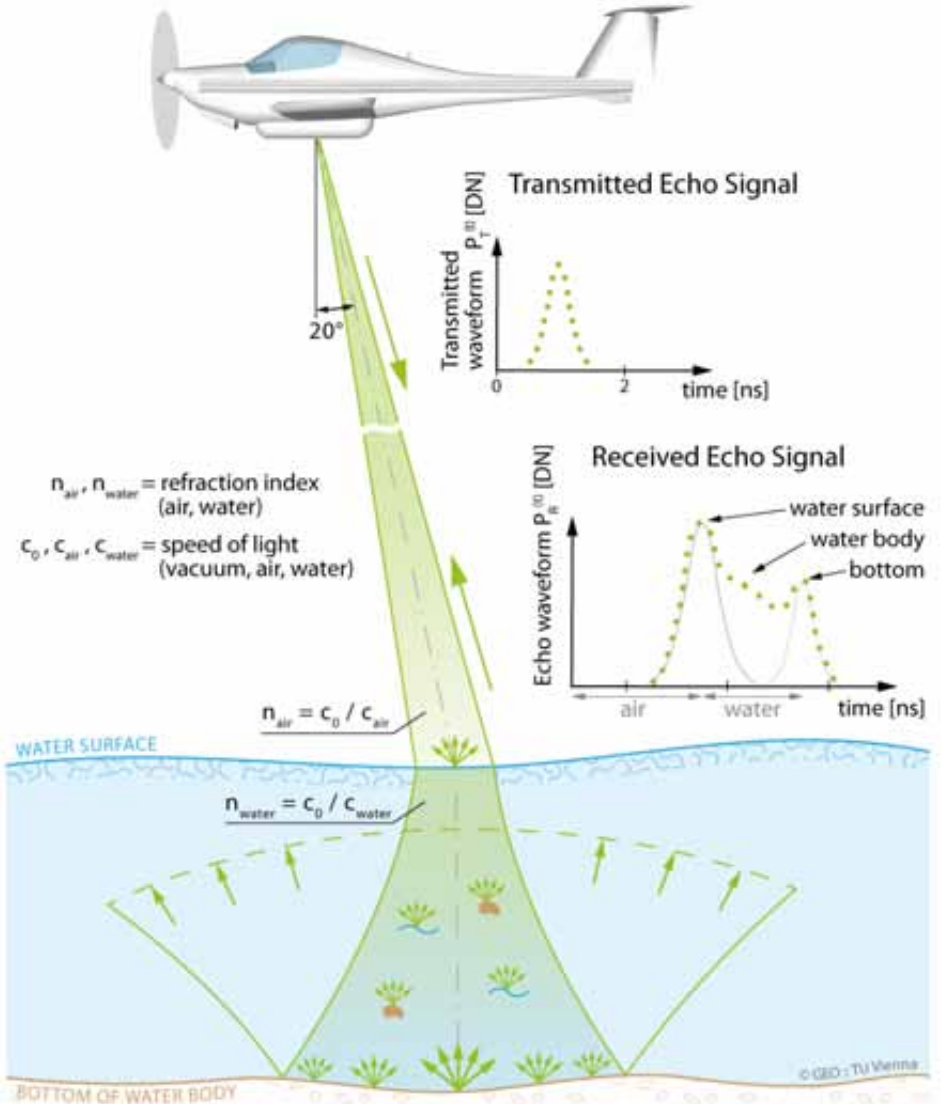
- Tree species classification based on e.g. full-waveform LiDAR data or aerial images

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.

© ALS data: *Niederösterreichischen Landesregierung, Gruppe Baudirektion, Abteilung Vermessung und Geoinformation*

Airborne Laser Bathymetry (ALB)

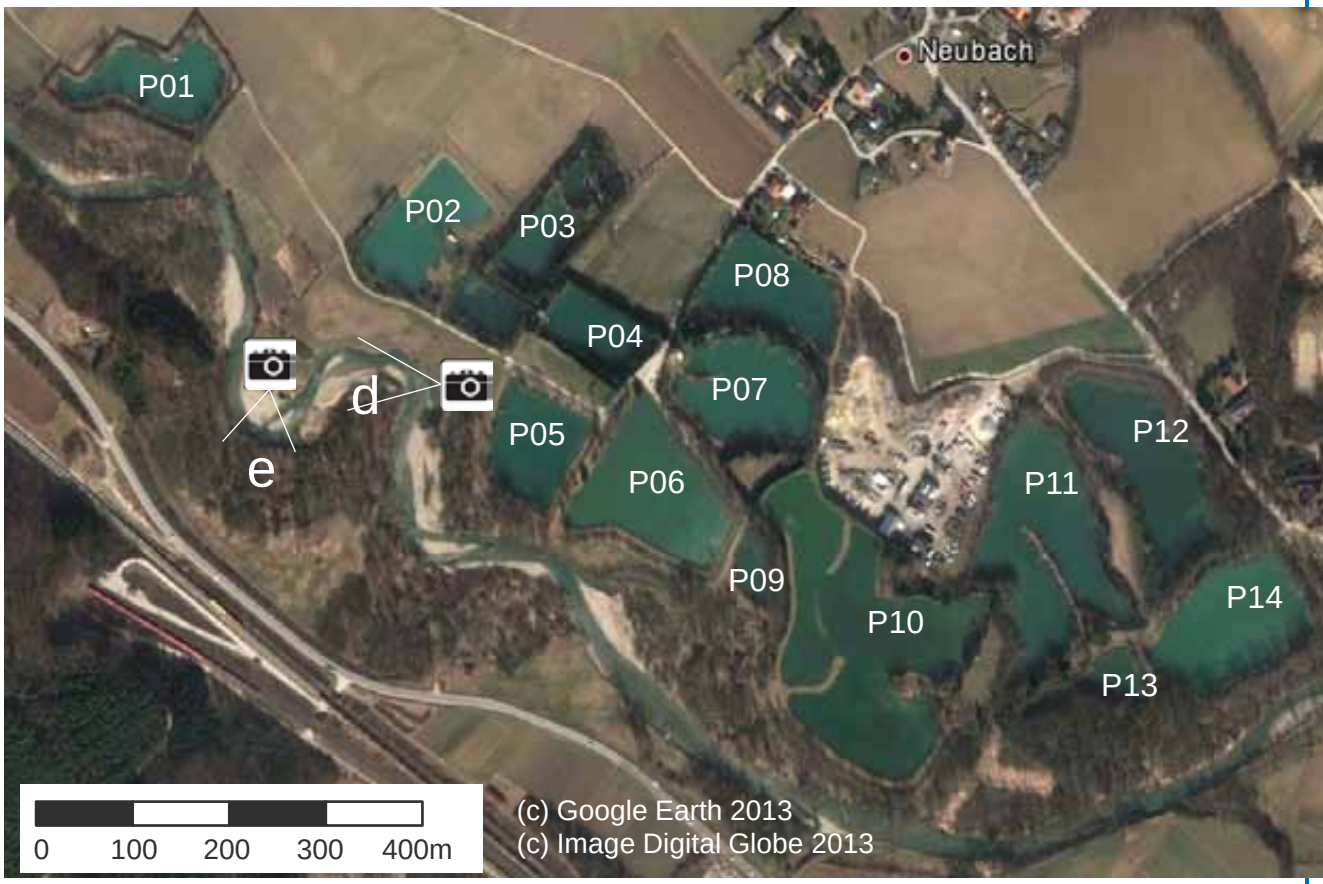
Airborne Laser (or LiDAR) Bathymetry (**ALB**) is a technique for **measuring** the **depths** of **relatively shallow**, **coastal waters** from the **air** using a **scanning**, **pulsed laser** beam. It is also known as Airborne Laser Hydrography (**ALH**) […]. *)



*) C. Guenther et. al: **MEETING THE ACCURACY CHALLENGE IN AIRBORNE LIDAR BATHYMETRY,** EARSeL-SIG-Workshop LIDAR, Dresden, 2000

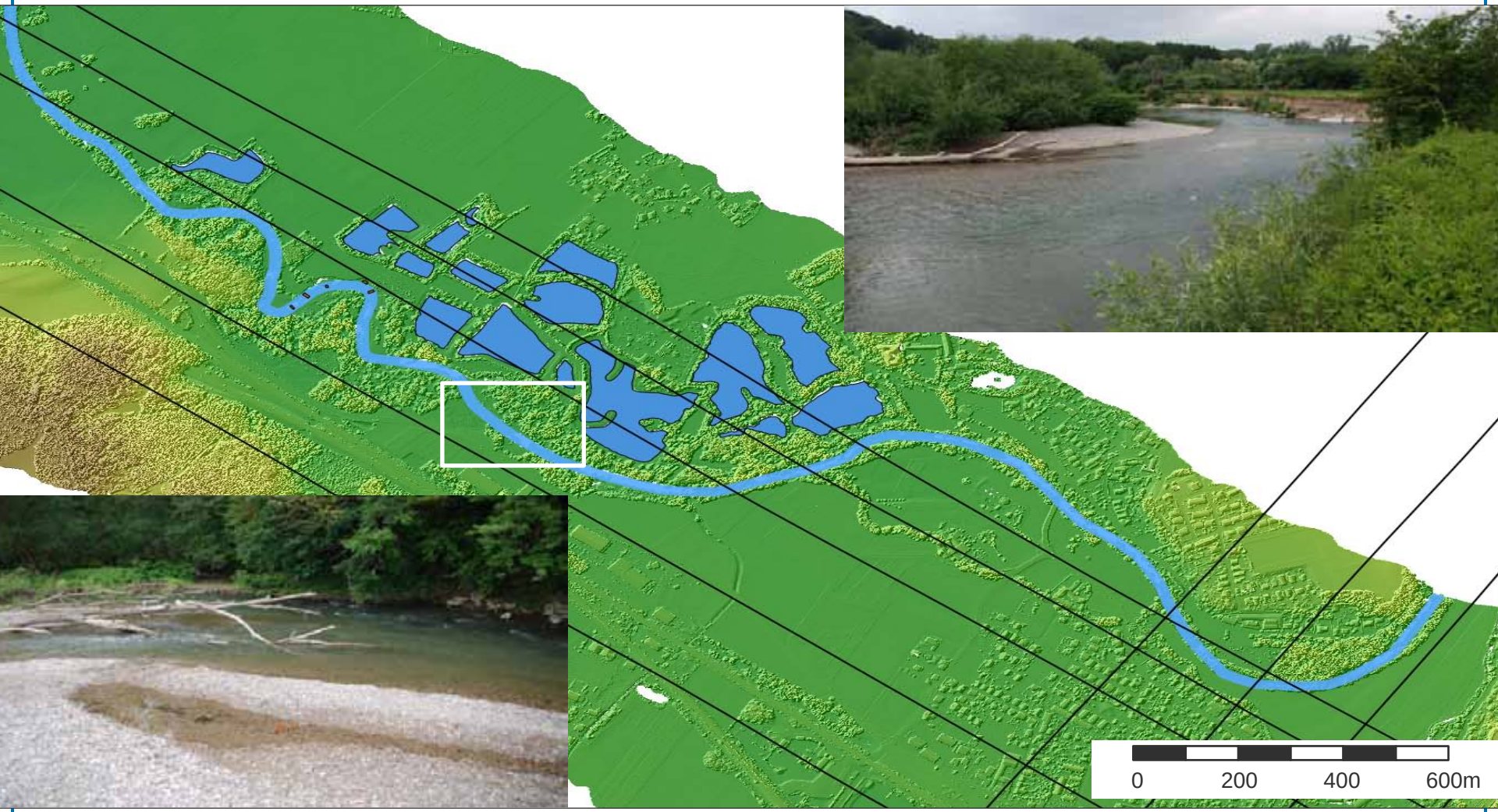
Laser source: λ=532nm, (Nd:Yag with frequency doubling)

Study area: Pielach – Neubacher Au I

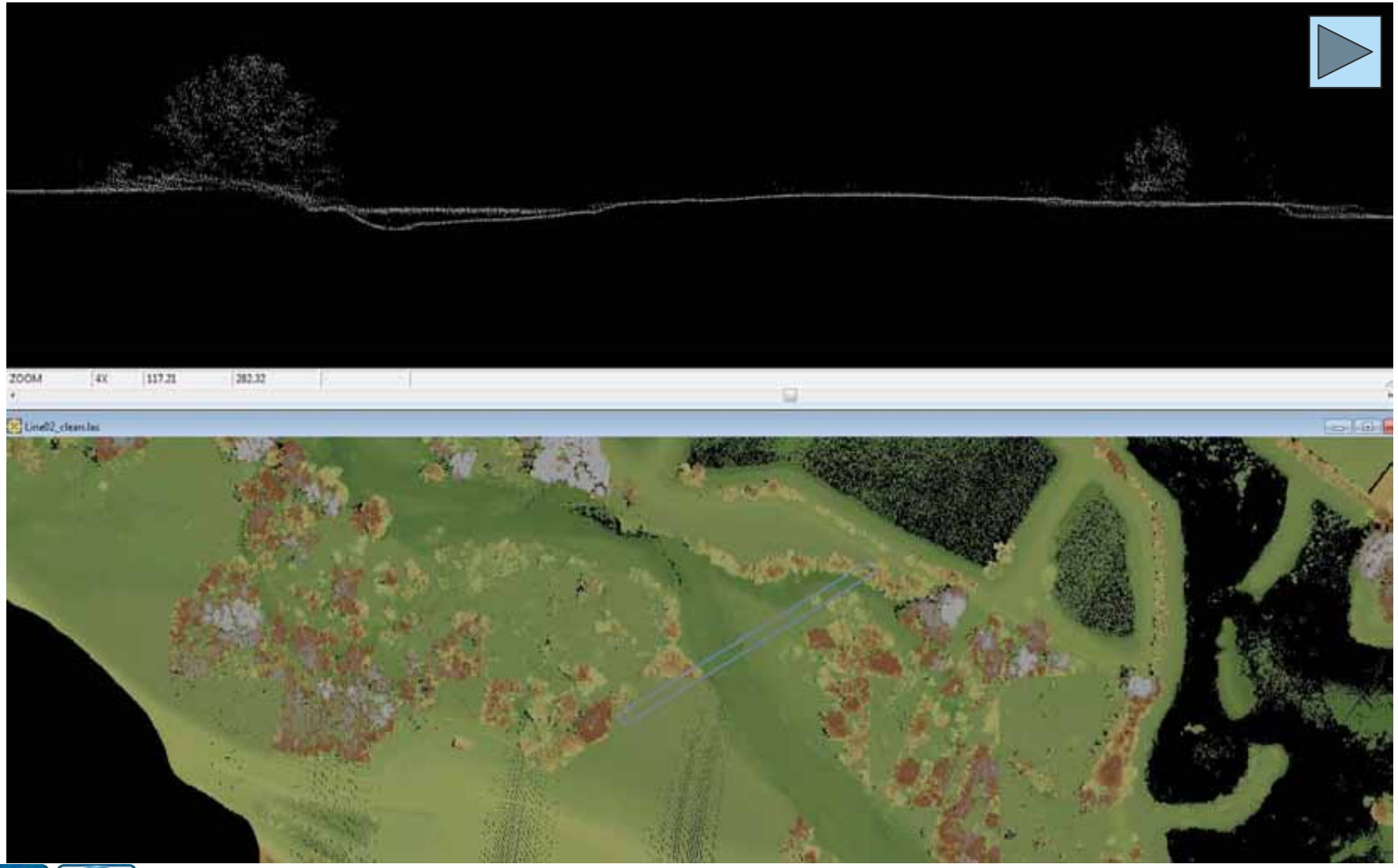


Left: River Pielach, Right; Study area Neubacher Au

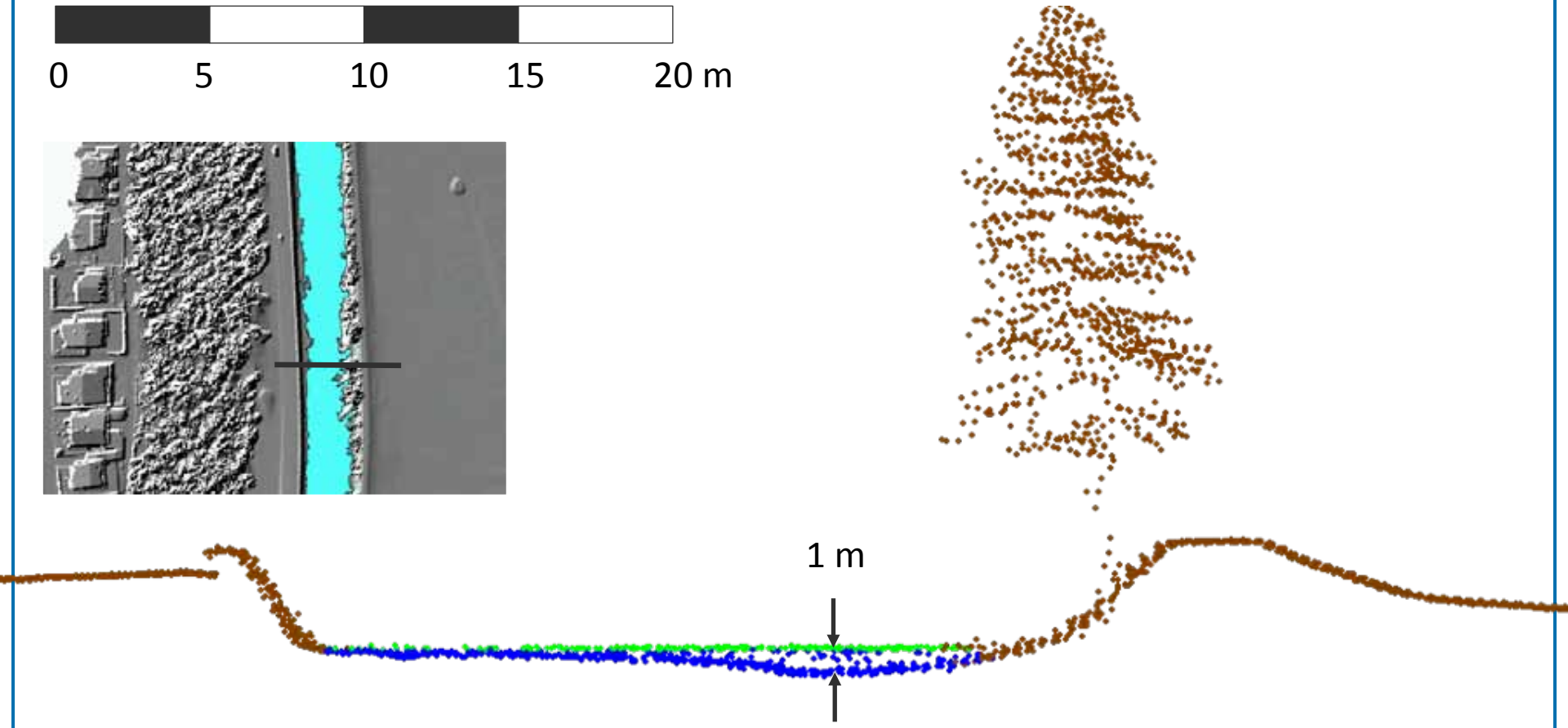
Study area: Pielach – Neubacher Au II



Bathymetric point cloud – River Pielach

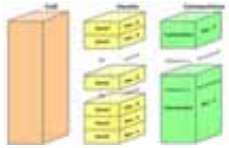


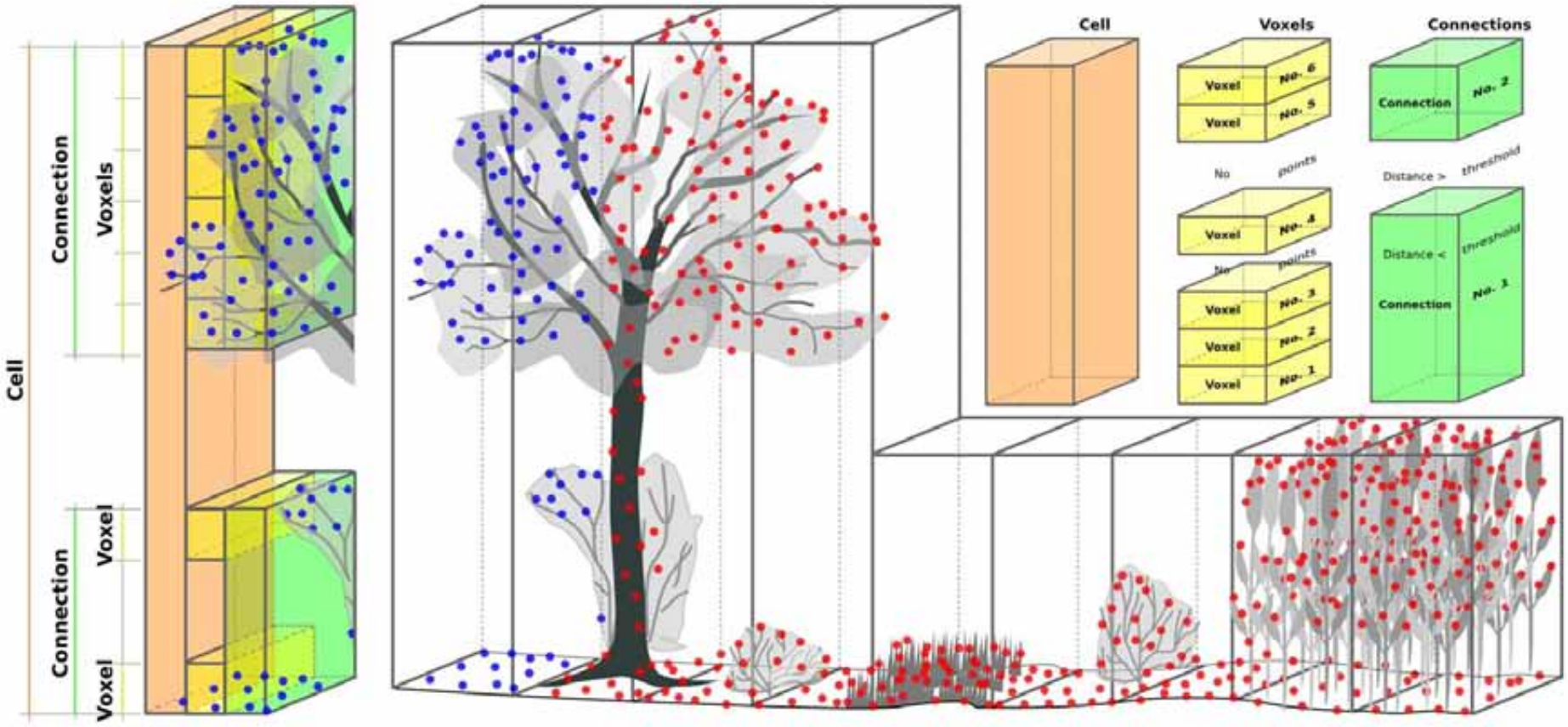
Classified point cloud (cross section)



Brown (terrain and vegetation), Blue (water bottom), Green (water surface)

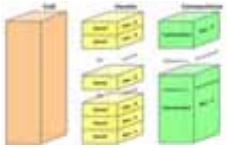
Hydraulic roughness from ALS I

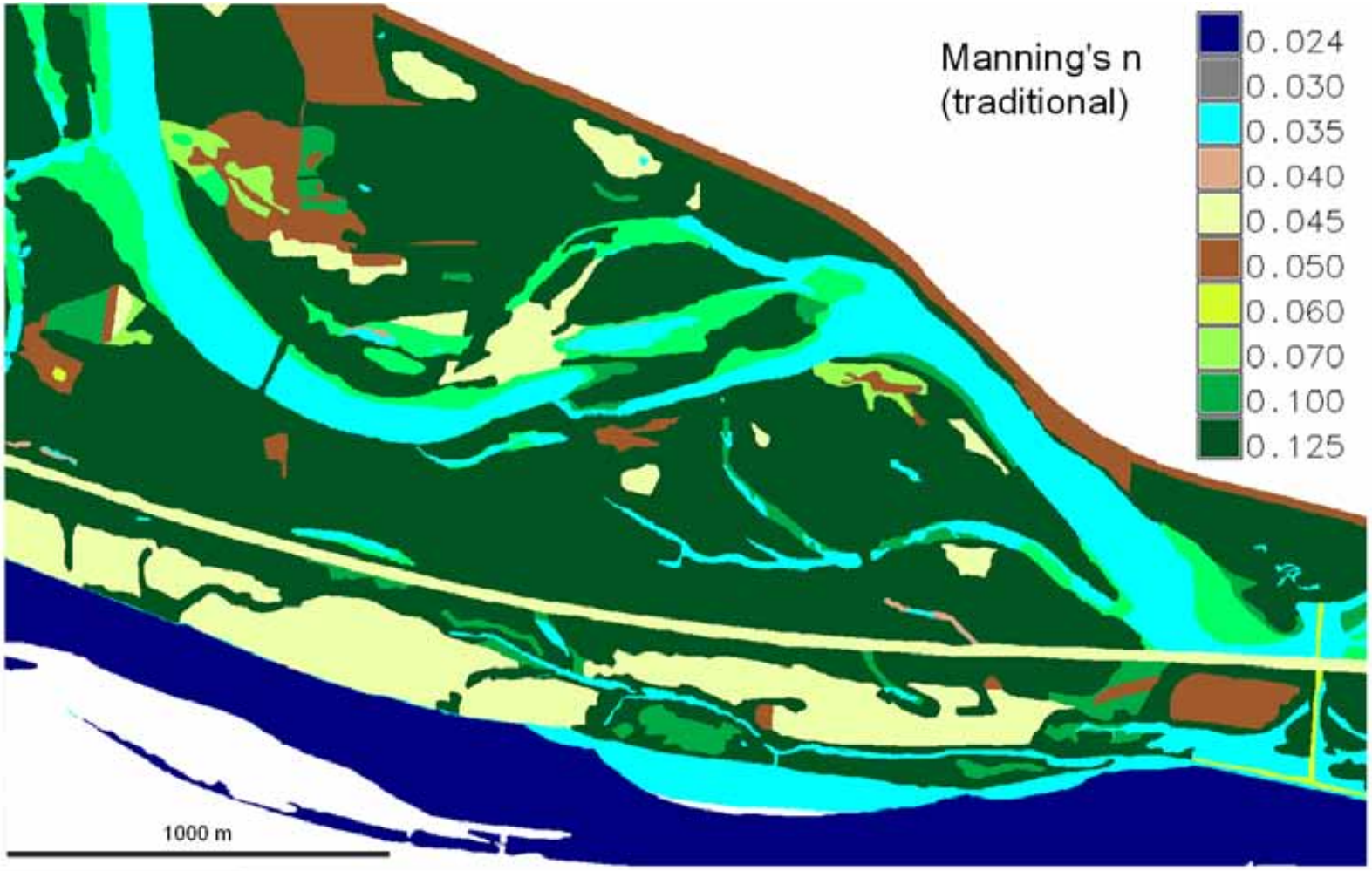




From: Vetter et. al, 2011; ISPRS Laser scanning Workshop, Calgary

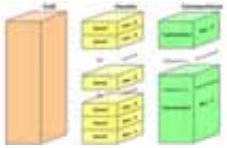
Reference data (land use mapping)

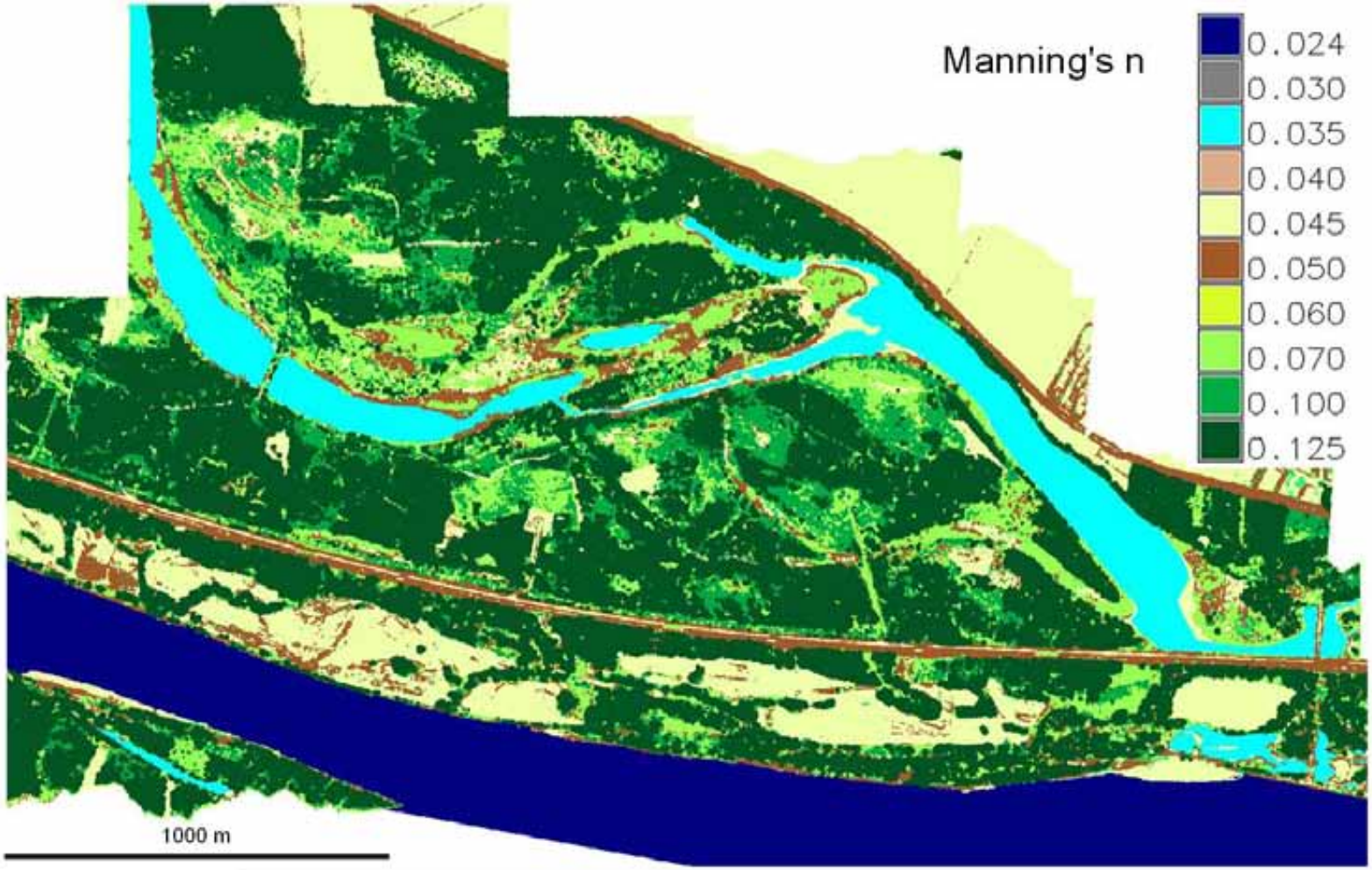




From: Vetter et. al, 2011; ISPRS Laserscanning Workshop, Calgary

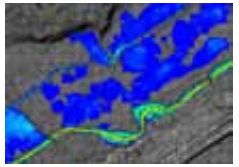
Hydraulic roughness from ALS II





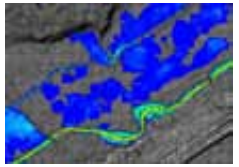
From: Vetter et. al, 2011; ISPRS Laser scanning Workshop, Calgary

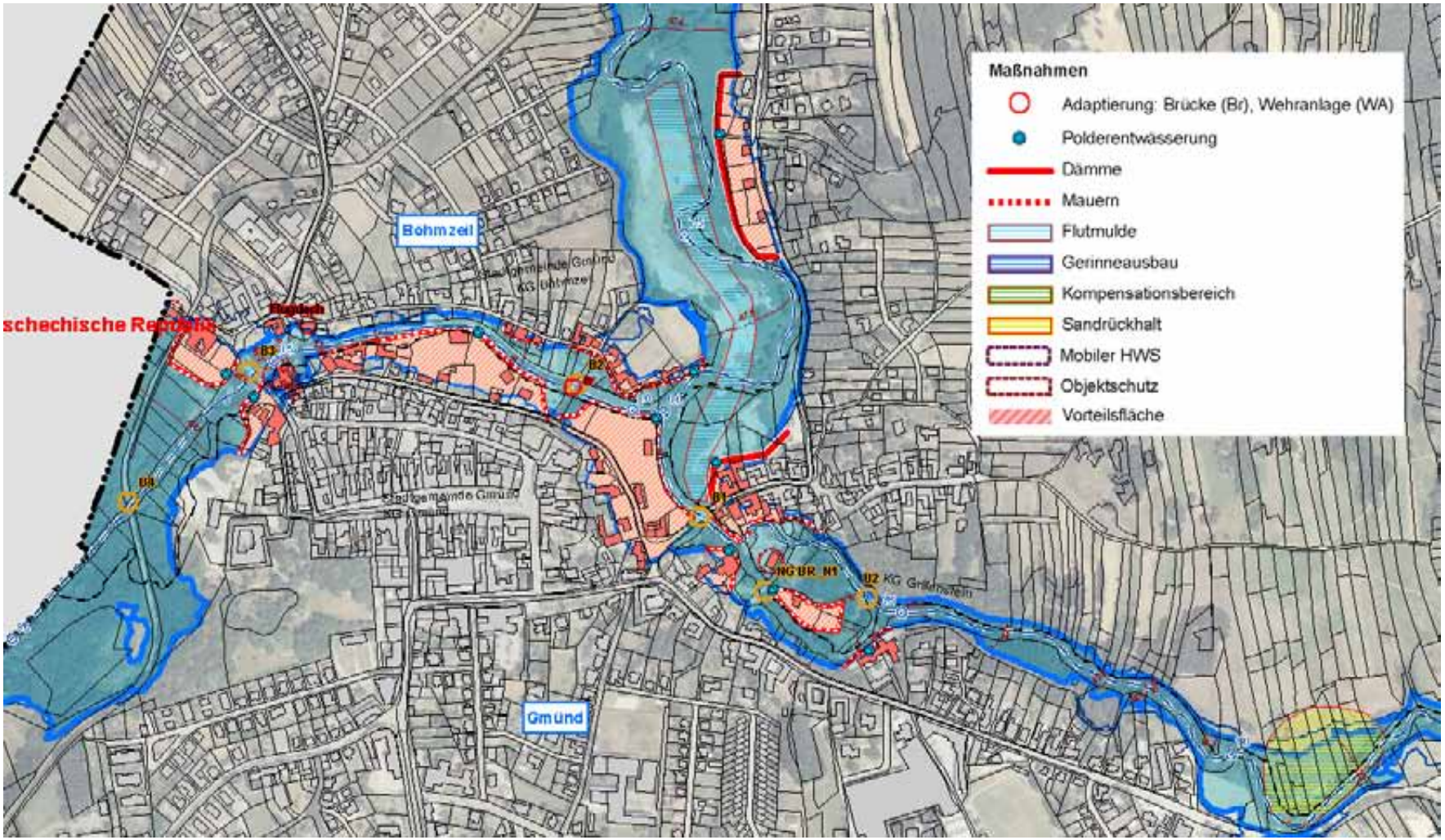
Überschwemmungskarte Lainsitz



Digitale Überschwemmungskarte von Gmünd (HQ100), Daten: Fa. GeoConsult

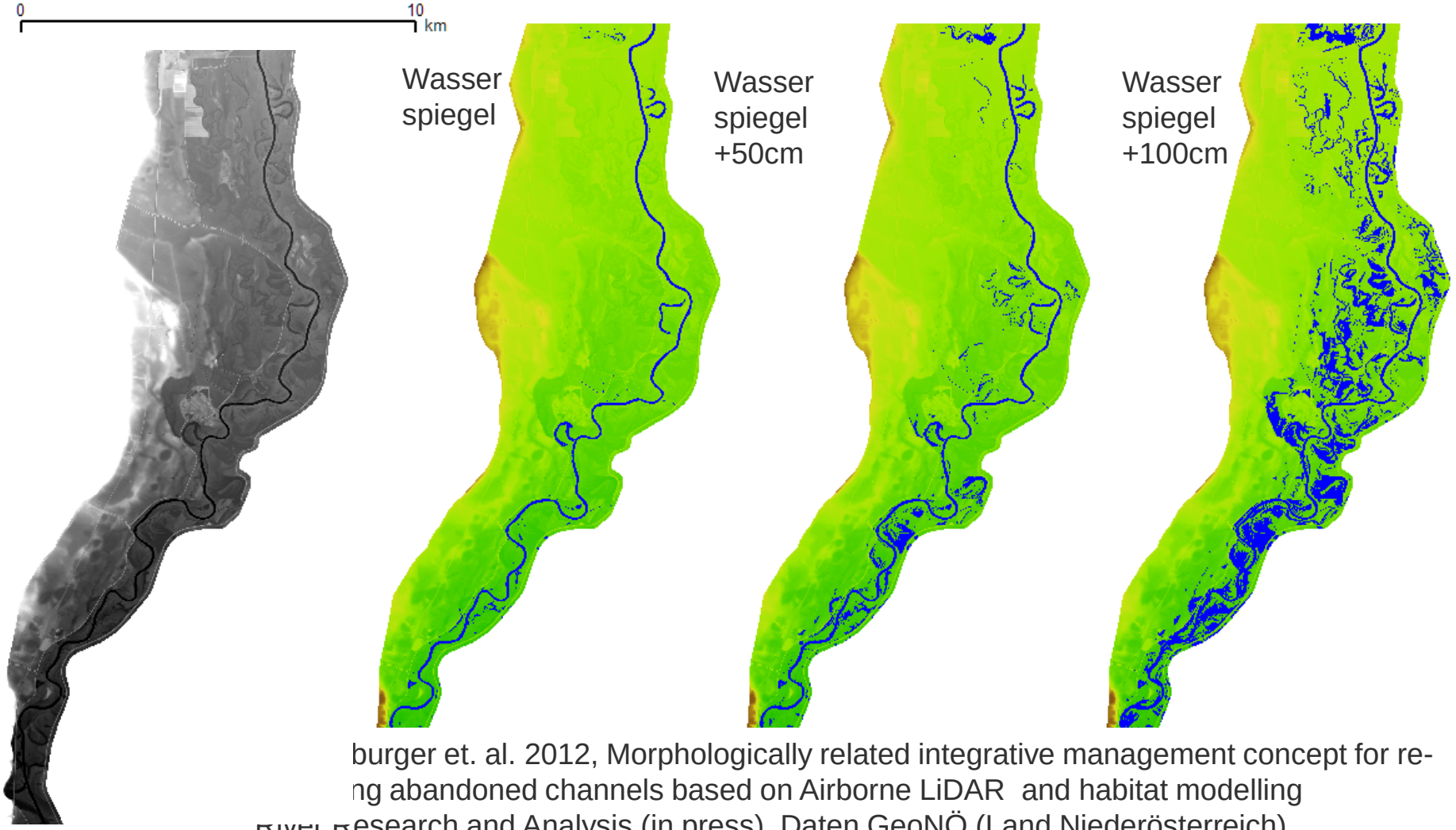
Überschwemmungskarte + Maßnahmen





Maßnahmenkatalog zum für den Objektschutz, Daten: Fa. GeoConsult

Flussrückbau: Beispiel March (NÖ)



burger et. al. 2012, Morphologically related integrative management concept for re-
ng abandoned channels based on Airborne LiDAR and habitat modelling
River Research and Analysis (in press), Daten GeoNÖ (Land Niederösterreich)

Habitatmodellierung March

Mesohabitat classes

- riffle
- fast run
- run
- pool
- backwater
- shallow water

Mesohabitat suitability

- preferred
- useable
- avoided

mesohabitat suitability for indifferent/stagnophilic adult fish guilds

Aus: Hauer, Mandlburger et. al. 2012, Morphologically related integrative management concept for re-connecting abandoned channels based on Airborne LiDAR and habitat modelling River Research and Analysis (in press), Daten GeoNÖ (Land Niederösterreich)

Zusammenfassung I

- Unsere Welt ist 3D → 3D Datenerfassung, -modellierung und –aufbereitung notwendig
- 3D Punktwolken
  - Basisprodukt einer 3D Datenerfassung
  - Ungefiltert → alle Details erhalten
  - Unstrukturiert → effiziente Ordnungskriterien erforderlich (Nchbarschaft)
  - Uninterpretiert → ermöglicht unvoreingenommene Analyse in der Zukunft
  - Mehr als Geometrie → 3D-Position und Attribute
- 2.5 / 3D Modelle
  - Abgeleitetes Produkt
  - Gefiltert → zB Digitales Geländemodell, Digitales Gebäudemodell
  - Strukturiert → Raster, TIN, /
  - Iinterpretiert → Gefährungskarte, Solarpotenzial, Waldmaske

Zusammenfassung und Ausblick

- Mehrwert 3D
  - 3D Datenerfassung heute state-of-the art
  - Ableitung von (Fach) Modellen aus Basisdaten huete:
    - automatisierter
    - schneller
    - objektiver
    - Nachvollziehbarer
  - Mehrwert durch Verfügbarkeit von Daten
    - Internet Portale, Geodata-Warehouses
    - z.B. Open Topography (Punktwolke)
    - INSPIRE (EU-weite Daten-Standards)
    - Open Government Data (Sach- und Geometrie)
  - Verfügbarkeit von 3D-Daten erhöht Anwwendungspotenzial/felder
    - Gebäude, Forst, Wasser, Naturgefahren, Ökologie, Tourismus, Infrastruktur, ...
  - Mehrwert durch Kombination von Daten
    - LiDAR + Bilddaten + Fachdaten + ...

Vielen Dank für die Aufmerksamkeit