

Single Photon vs Full Waveform LiDAR - technological differences and point cloud properties

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Overview

■ Basics/Theory

- (Conventional) Full Waverform Airborne Laser Scanning (ALS) – Linear mode LiDAR
- Geiger-mode LiDAR (GmLiDAR)
- Single Photon LiDAR (SPL)

■ Pilot study „City of Vienna“

- Single Photon LiDAR acquisition (Leica Geosystems SPL100), **end July 2018**
- Full waveform (FWF) LiDAR acquisition (*RIEGL* VQ-1560i), **mid Sept 2018**
- Additional dataset: Lake Constance 2018 (Data: LUBW)

■ Results of data evaluation

- Visual comparison of 3D point cloud
- Multi-target and penetration capability, point density
- Strip fitting precision
- Measurement precision

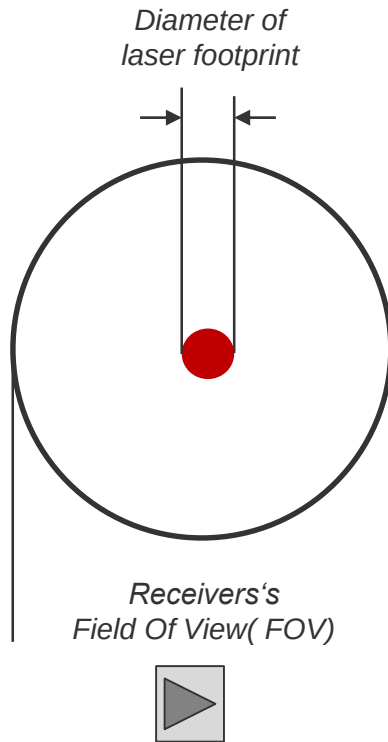


Orientation and Processing of
Airborne Laser Scanning data

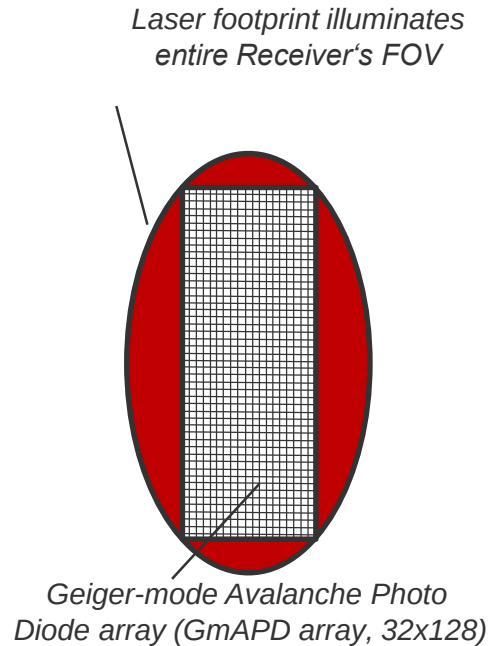


Conventional vs Single Photon LiDAR

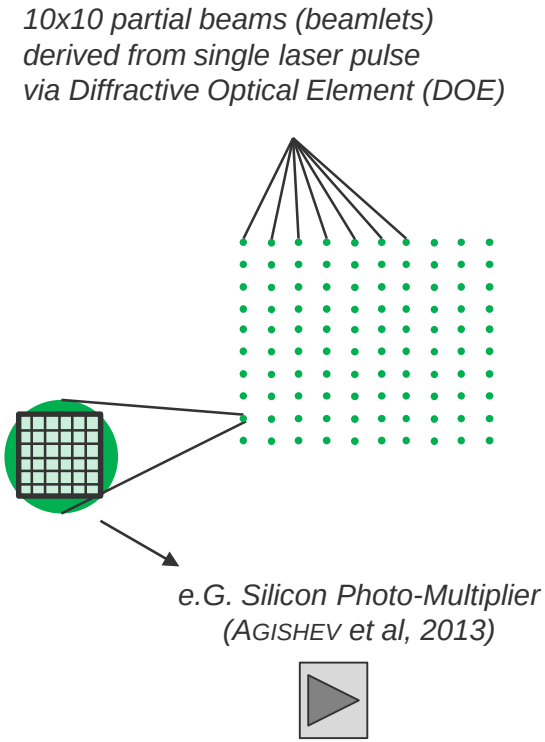
Conventional LiDAR Linear-mode LiDAR



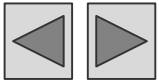
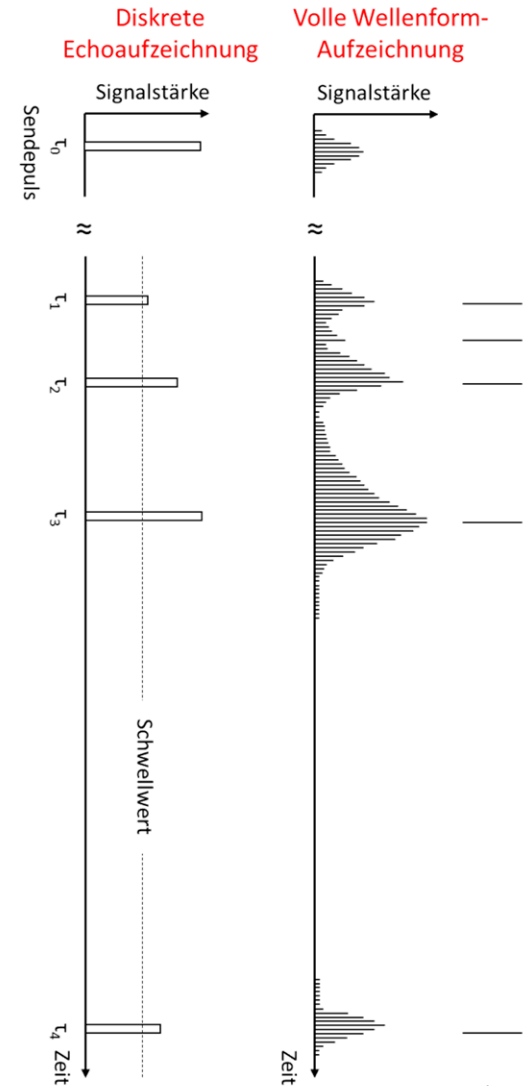
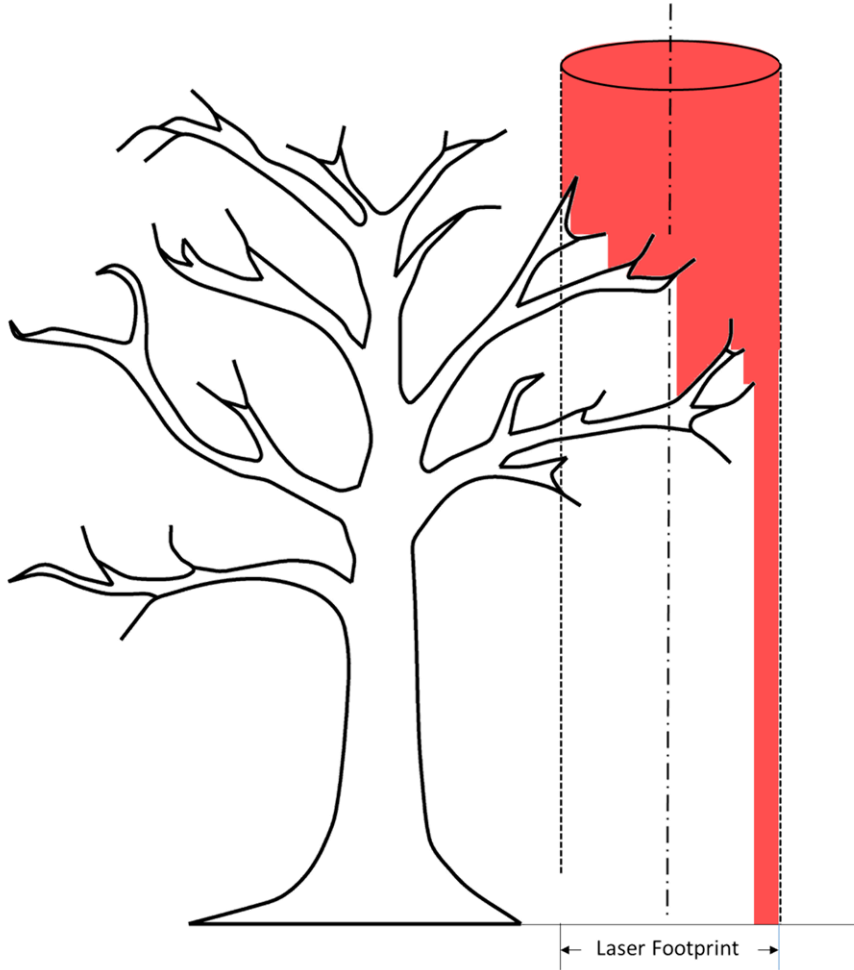
Geiger-mode LiDAR



Single Photon LiDAR



Discrete echoes vs. Full Waveform



Full Waveform Analysis



- **Gaussian decomposition:**
(Wagner et al, 2004)
 - **Echo detection** by fitting of Gaussian curves

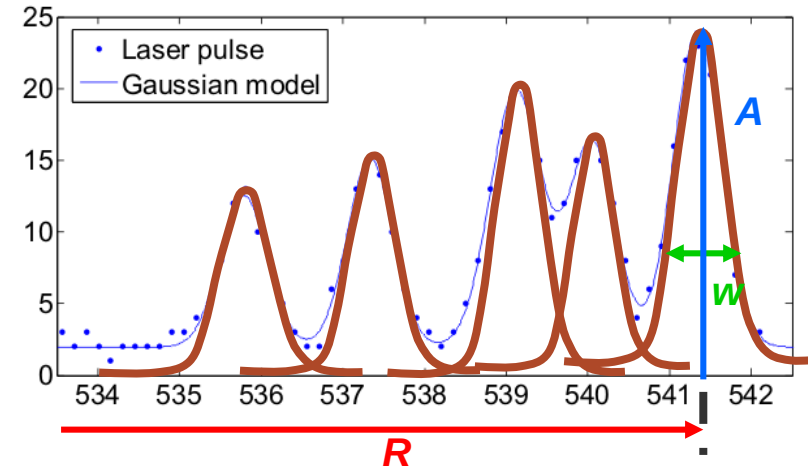
$$wf(t) = c + \sum_{i=1}^m A_i e^{-(t-\mu_i)^2 / \sigma_i^2}$$

→ Parameters per echo:

Amplitude A_i

Range R (μ_i)

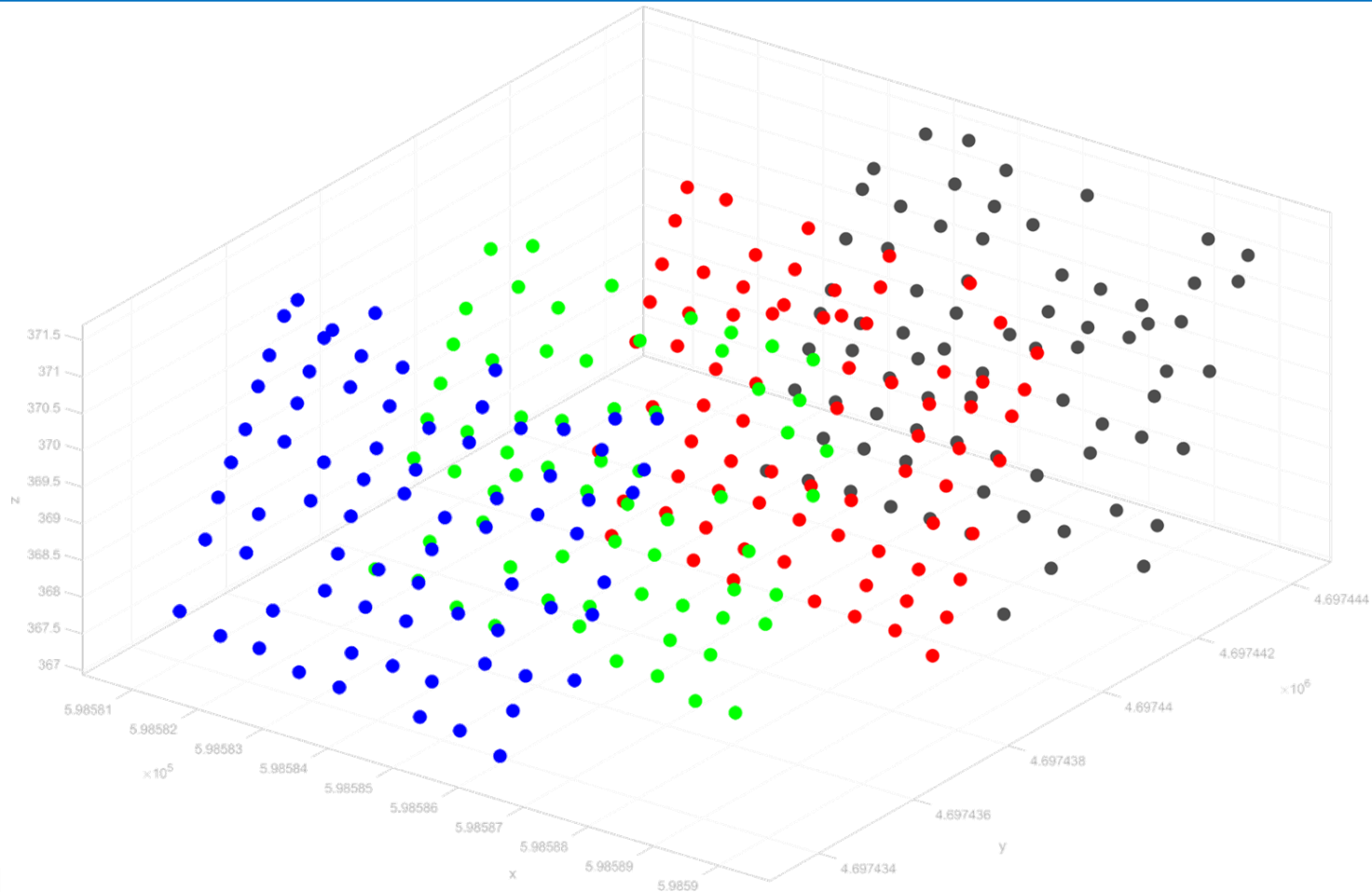
Echo width w (σ_i)



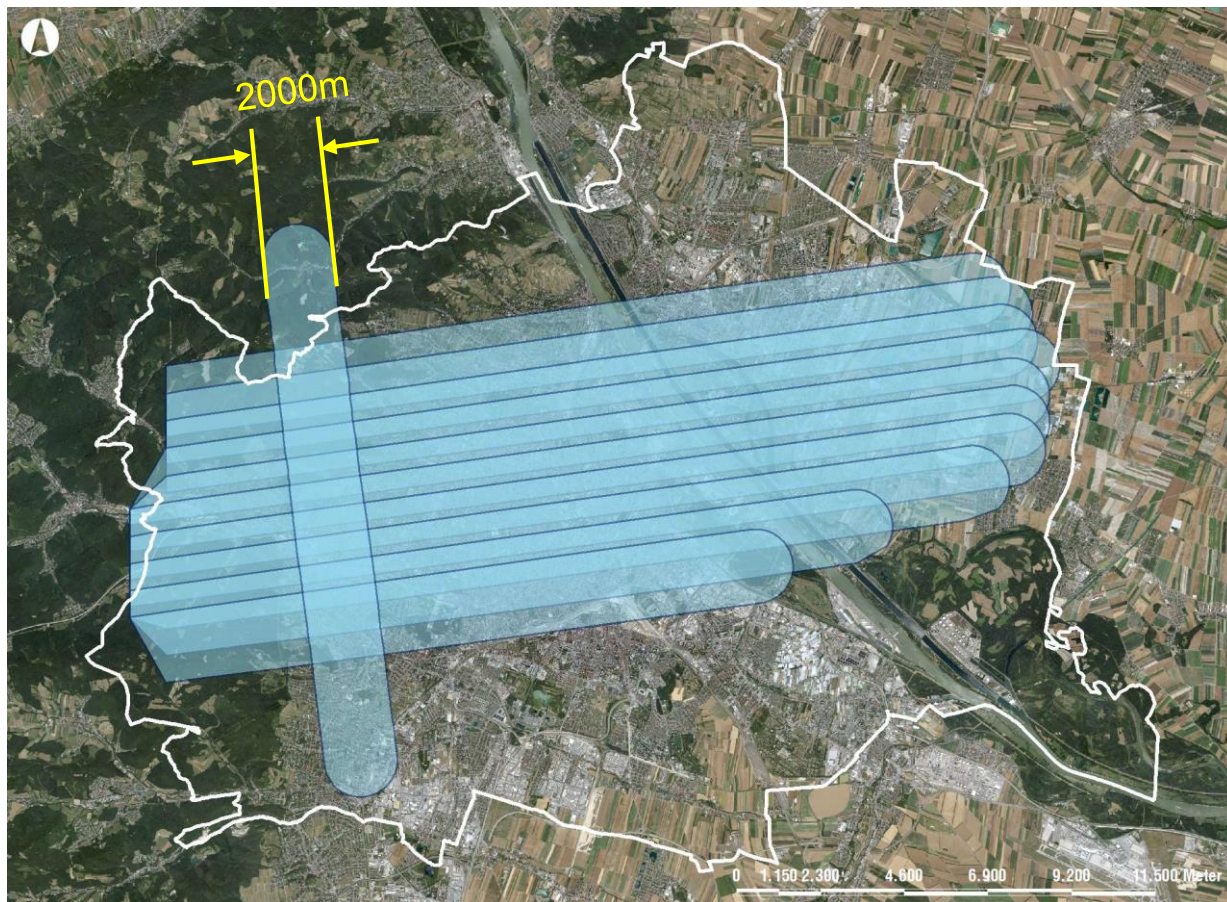
$$P_E = \frac{P_s D^2}{4\pi \gamma^2 R^4} \times \underbrace{\frac{4\pi A \rho}{\Omega}}_{\sigma} \times \eta_{\text{ATM}} \eta_{\text{SYS}} + P_{\text{BK}}$$

σ → characterizes scattering object

SPL100 – scan pattern

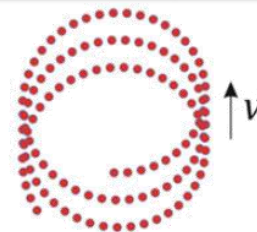


Data acquisition Single Photon LiDAR (SPL 100)

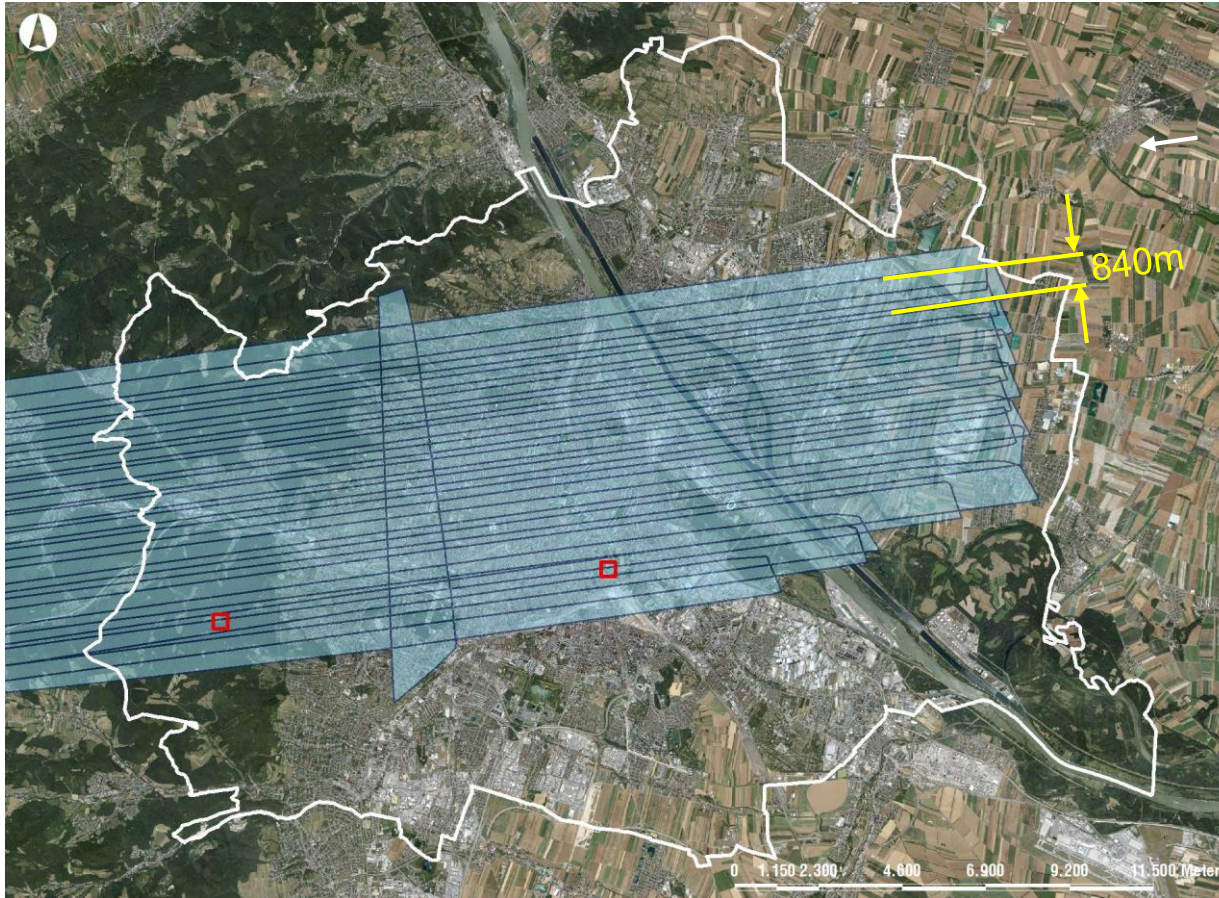


Flight mission parameters

Flight date	29.07.2018
Scan rate	5 MHz
Flying altitude	4000m
Swath width	2000m
Scan pattern	circular (Palmer)
Field-of-View	30°
Overlap	>50%
Nom. pt. density	20 Pkt/m ²
Nr. of strips	10

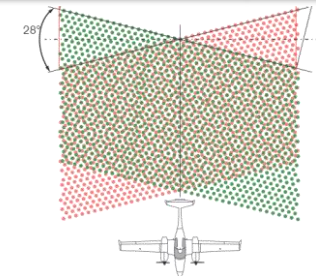


Datenerfassung Full Waveform LiDAR (VQ-1560i)

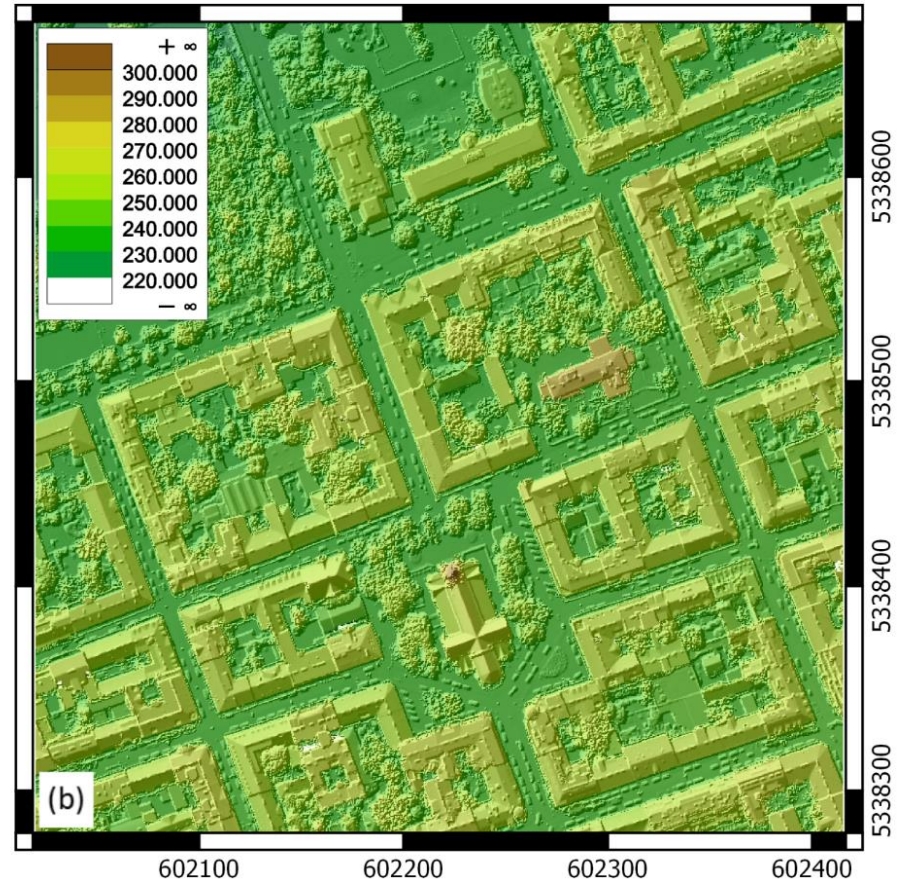
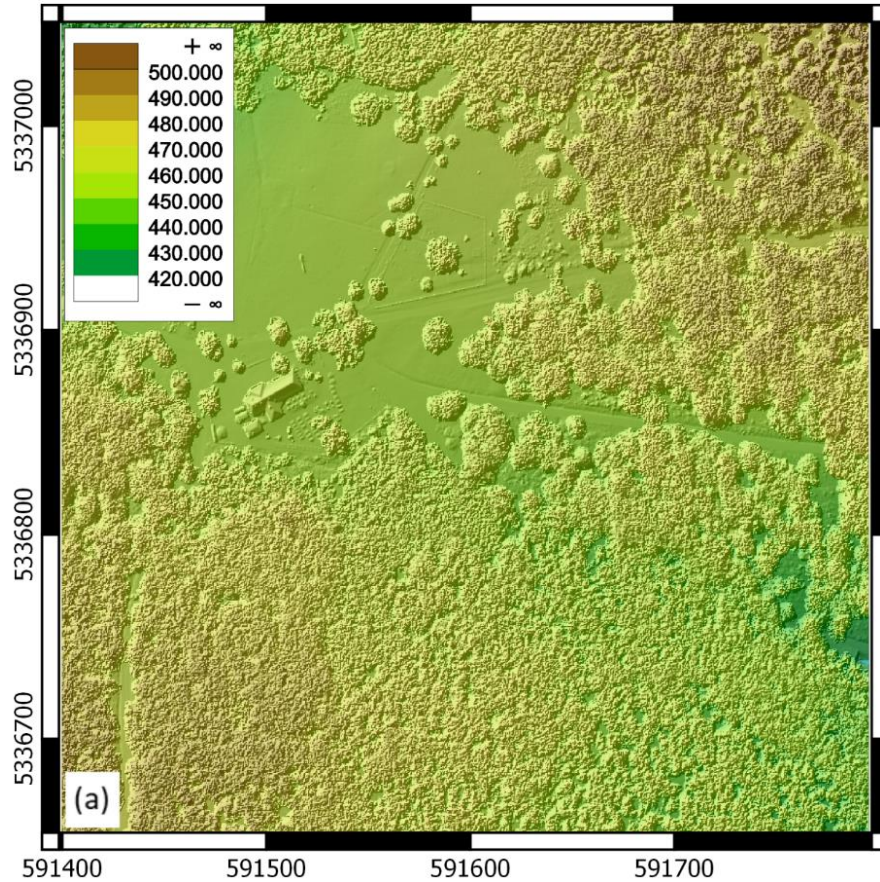


Flight mission parameters

Flight date	20.09.2018
Scan rate	1,33 MHz
Flying altitude	750m
Swath width	840m
Scan pattern	x-shaped scan lines
Field-of-View	58°
Overlap	>50%
Nom. pt. density	20 Pkt/m ²
Nr. of strips	18



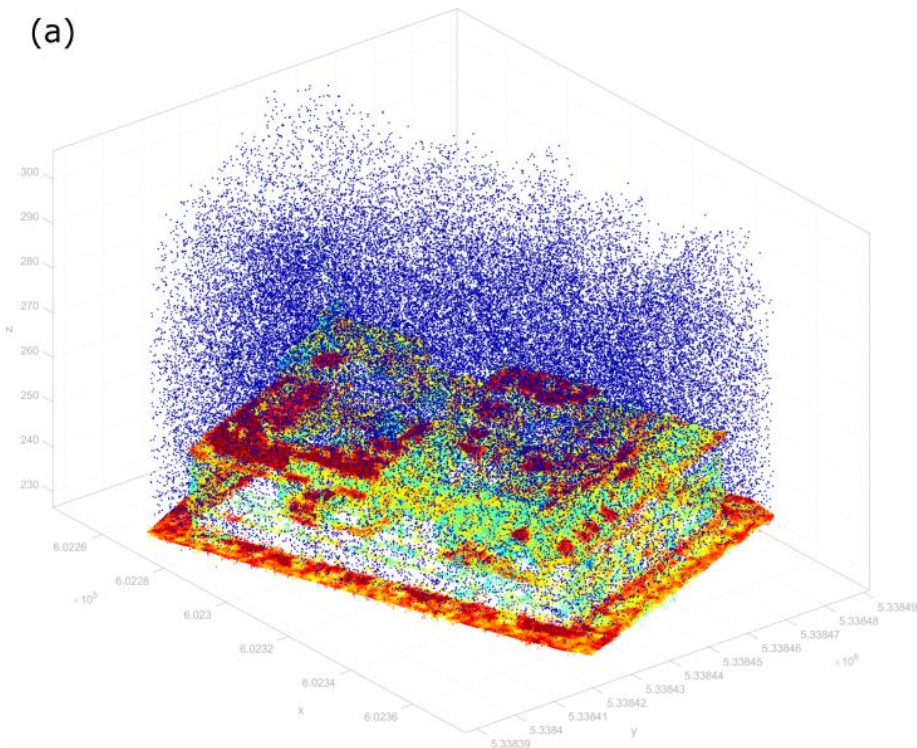
Detailed study areas: Forest + City



Single Photon LiDAR: Unfiltered 3D point cloud

Perspective view

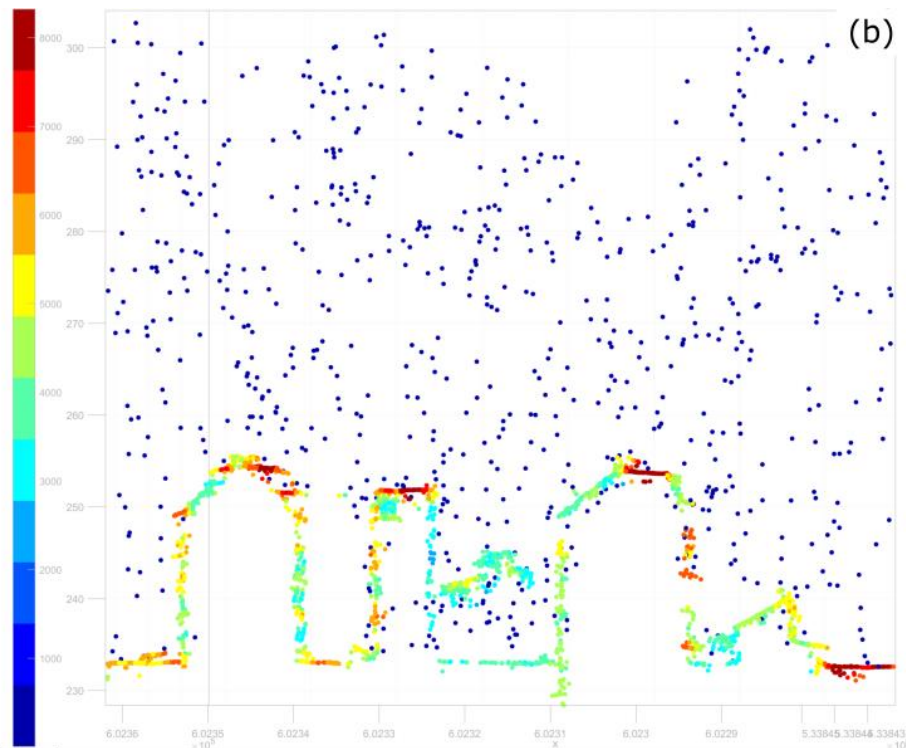
(a)



City test area

Section view

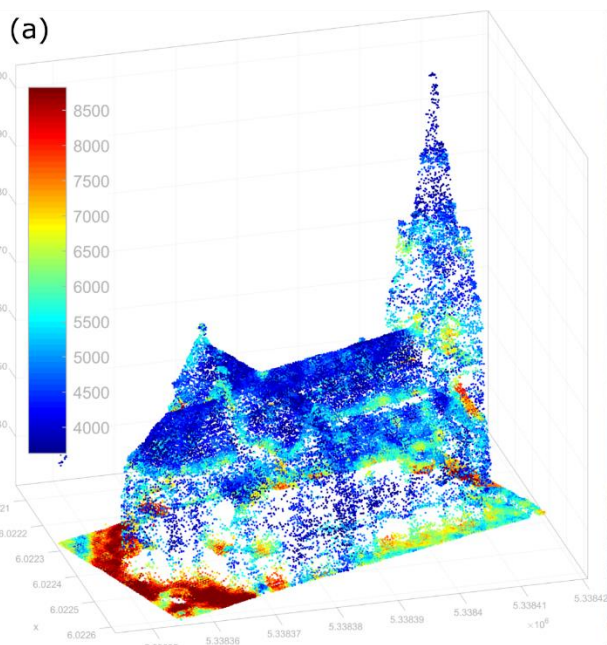
(b)



Signal intensity [DN]

Visual comparison of 3D point clouds

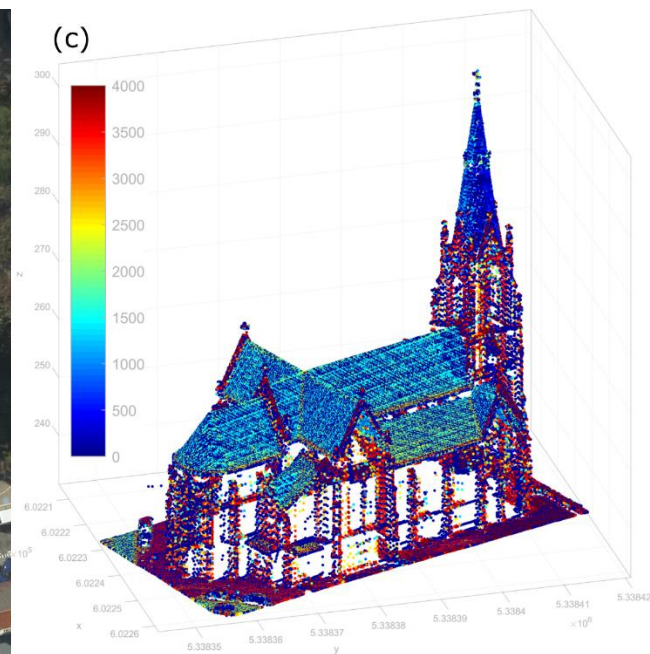
SPL



Aerial image (RGB)



Waveform LiDAR



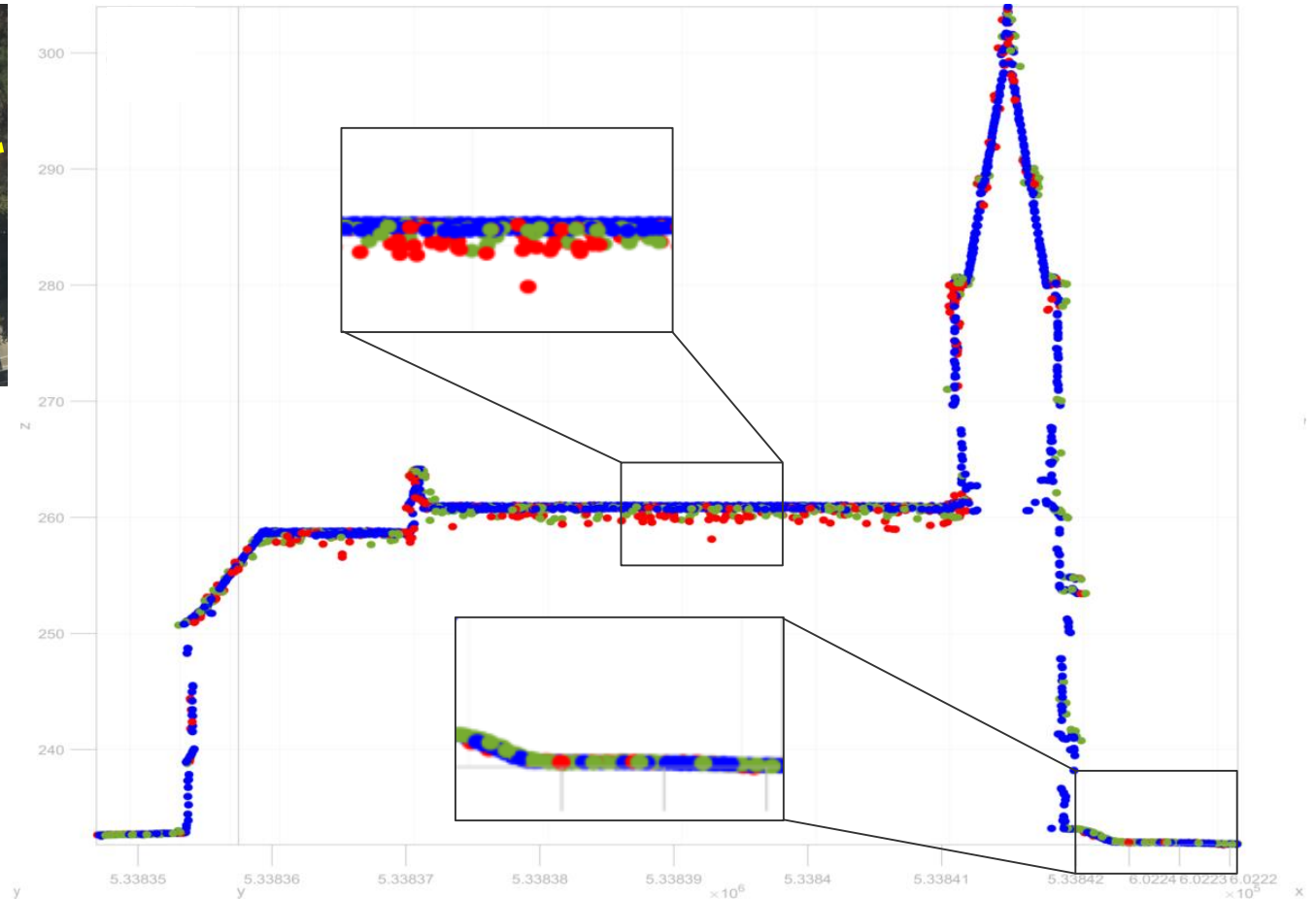
Signal intensity [DN]

Comparison: longitudinal section



Legend:

- SPL unfiltert
- SPL postprocessed
- Waveform LiDAR

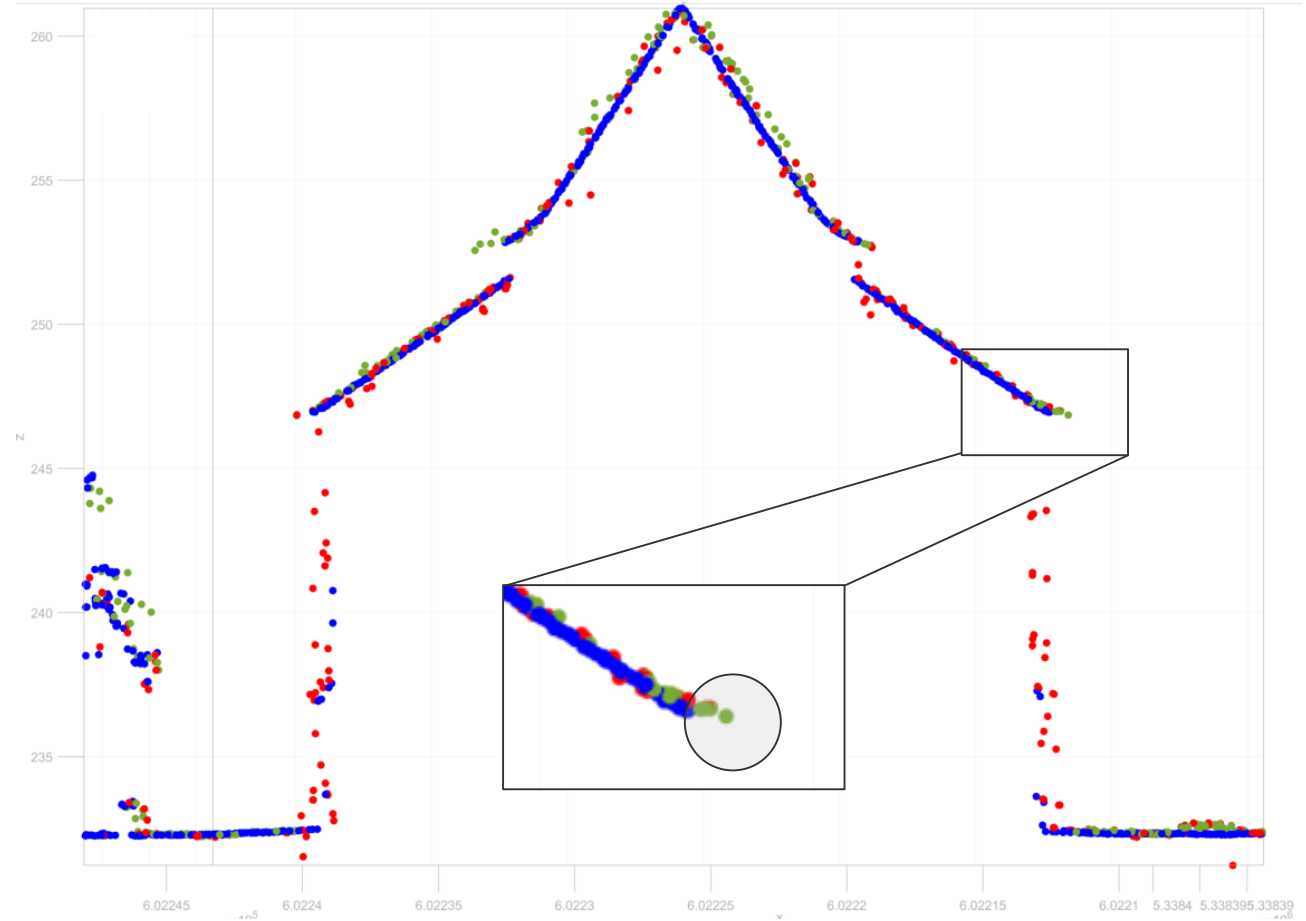


Comparison: cross section

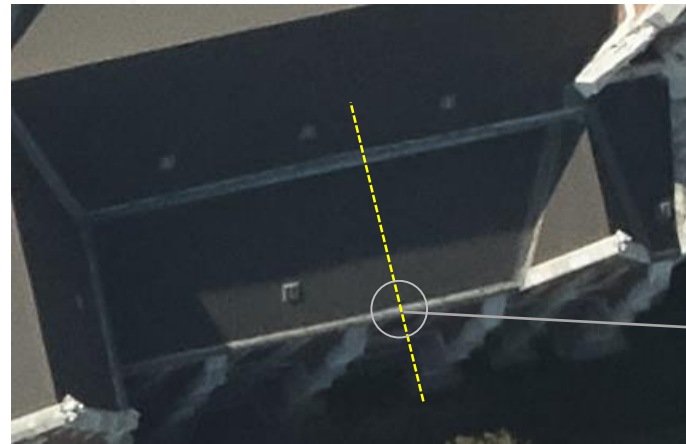
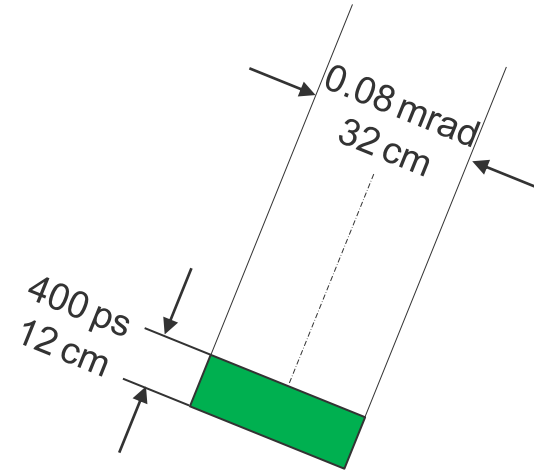
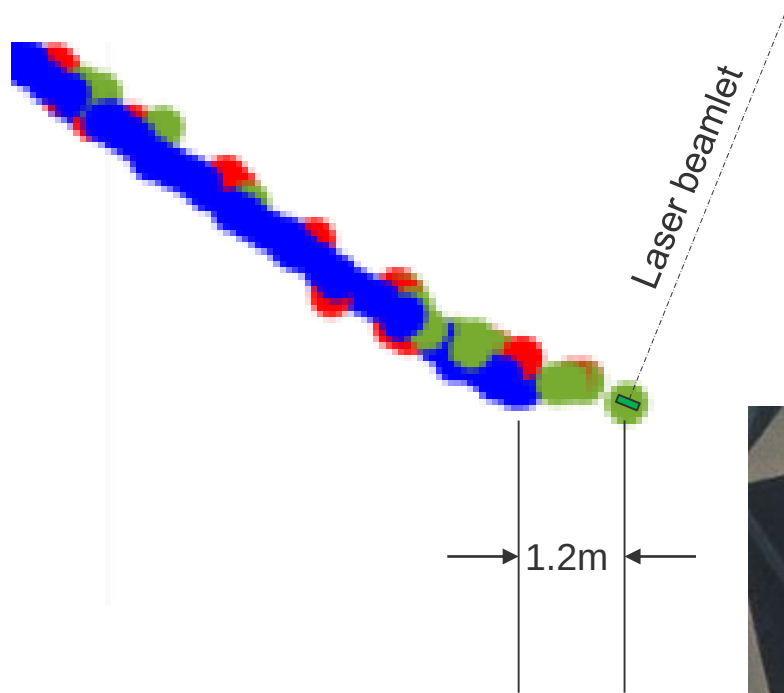


Legend:

- SPL unfiltert
- SPL postprocessed
- Waveform LiDAR



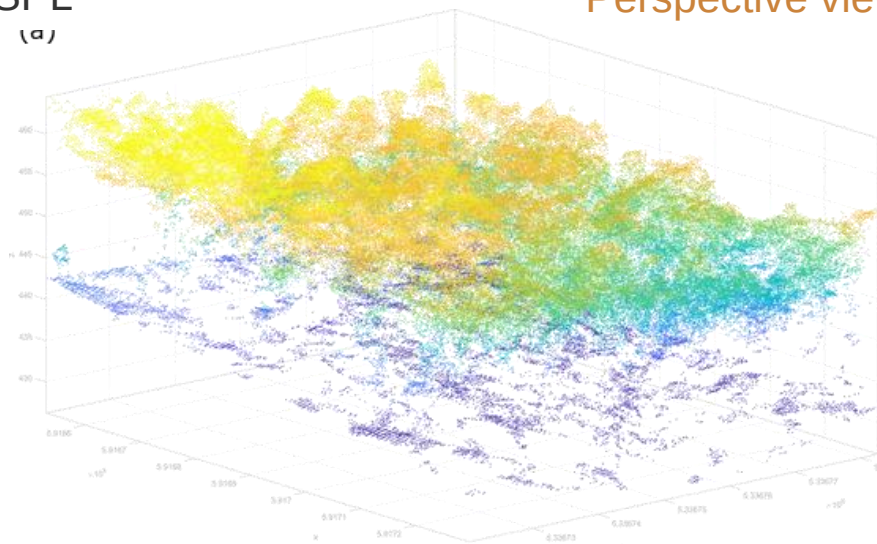
SPL: pulse duration / beam divergence



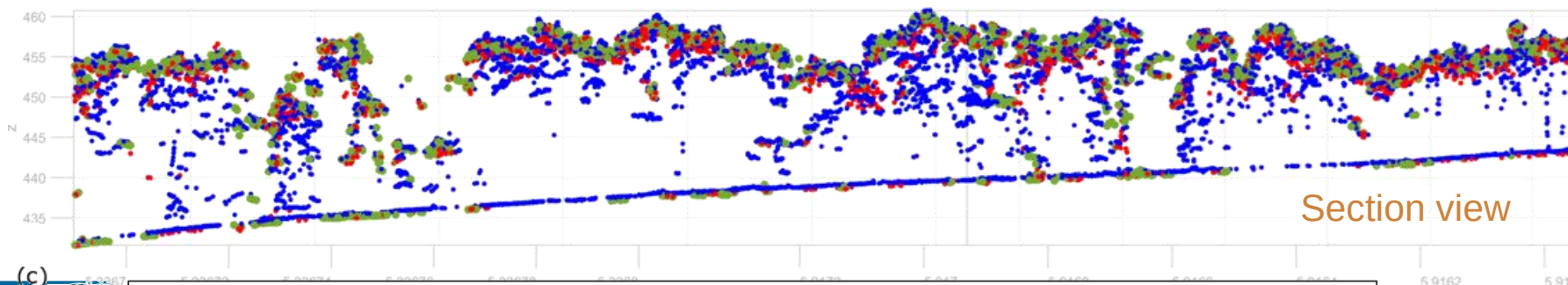
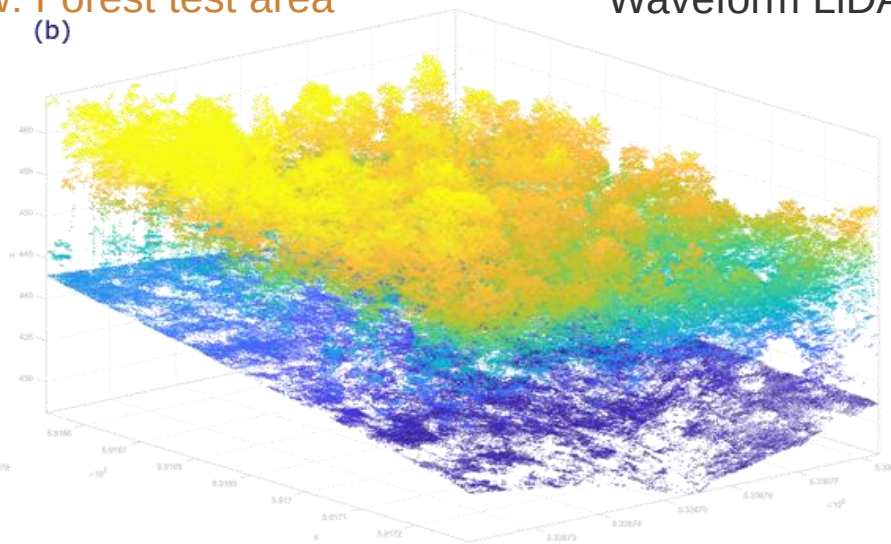
Bright scatterer

Penetration capability (leaf-on)

SPL (a) Perspective view: Forest test area



Waveform LiDAR (b)



Section view

(c)

● SPL unfiltered

● SPL postprocessed

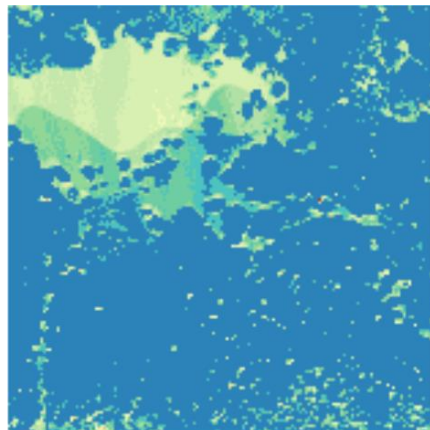
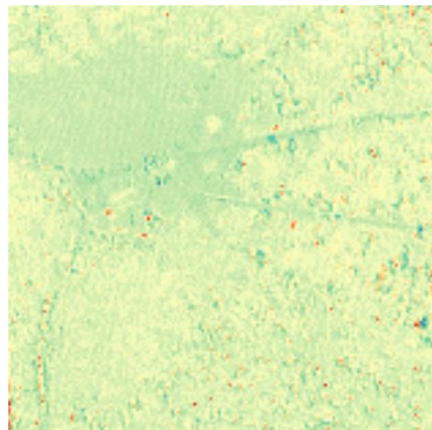
● Waveform LiDAR

Point density maps (all echoes)

SPL post processed

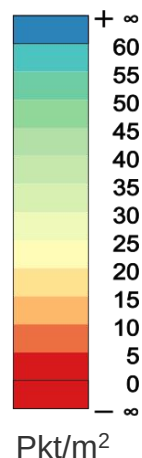
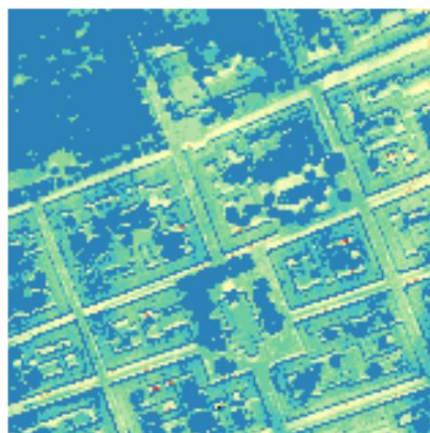
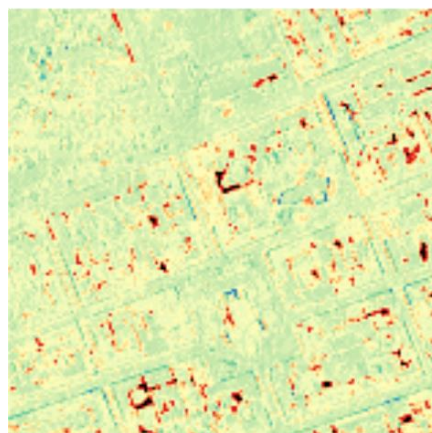
Waveform LiDAR

Forest



Waveform: **1.84** echoes/puls
SPL: **1.06** echoes/puls

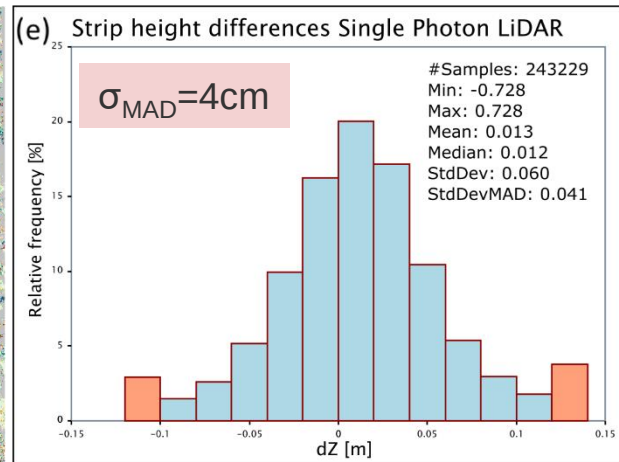
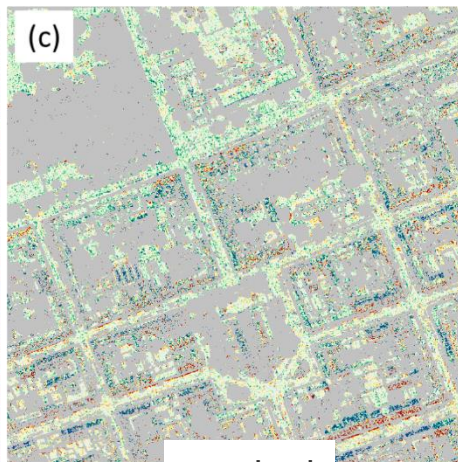
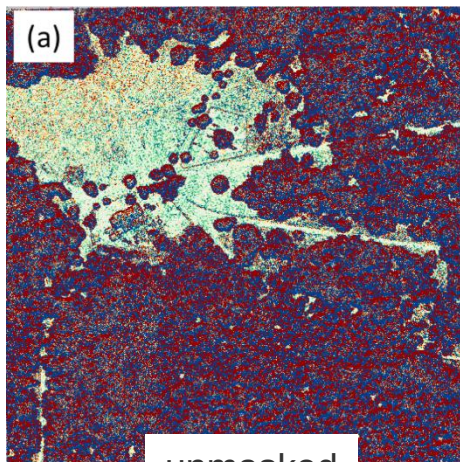
City



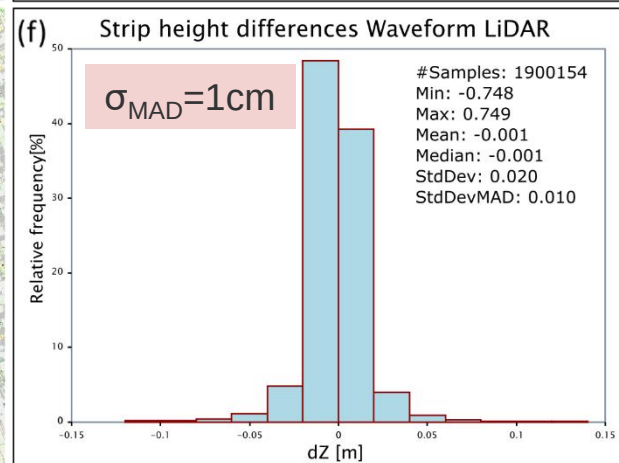
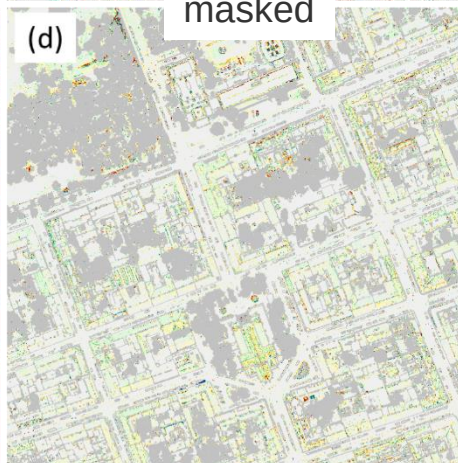
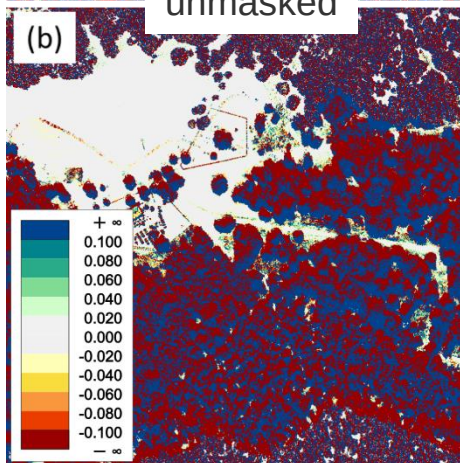
SPL: **lower** point density in
vegetation und at **facades**
→ **Elimination of useful points**
by **post processing**

Comparison strip differences

SPL
post processed

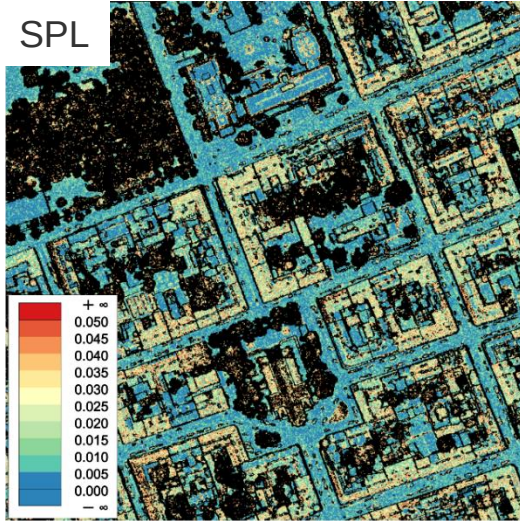


Waveform
LiDAR

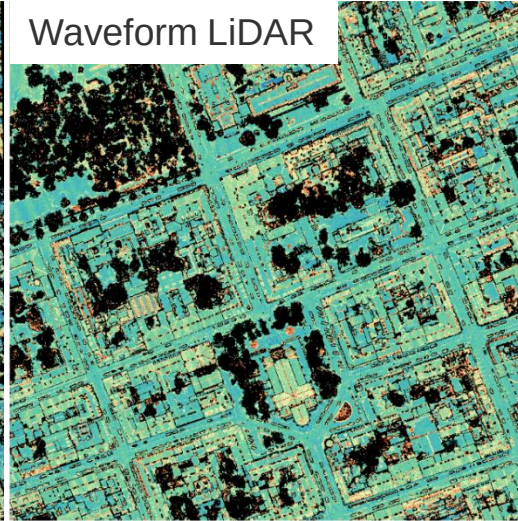


Neighborhood/measurement precision I

SPL

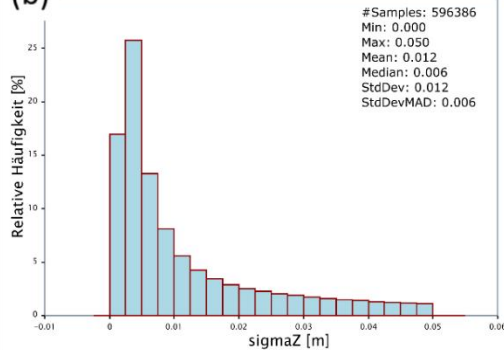


Waveform LiDAR



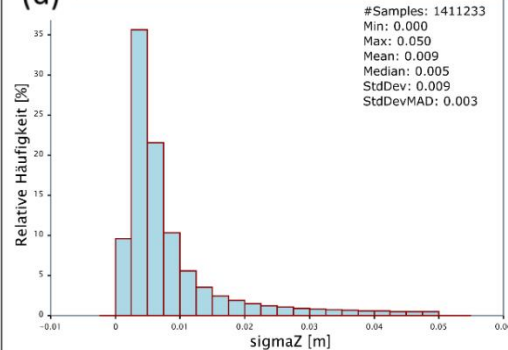
(b)

Histogramm: Nachbarschaftsgenauigkeit



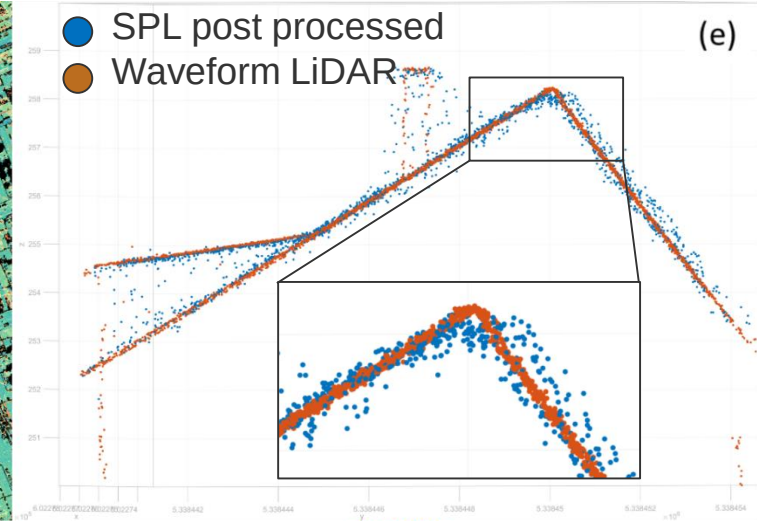
(d)

Histogramm: Nachbarschaftsgenauigkeit

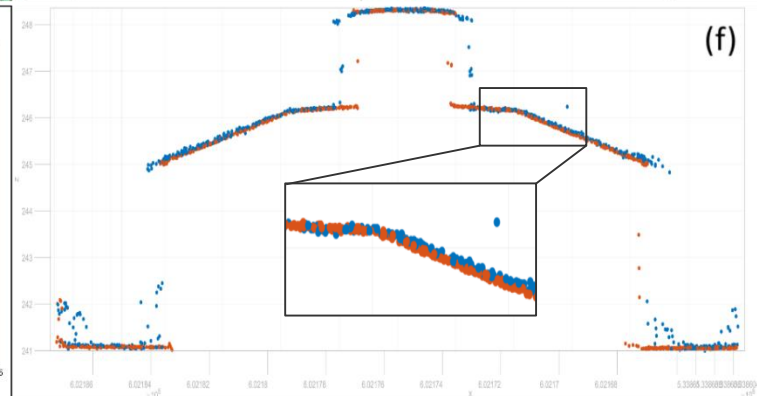


- SPL post processed
- Waveform LiDAR

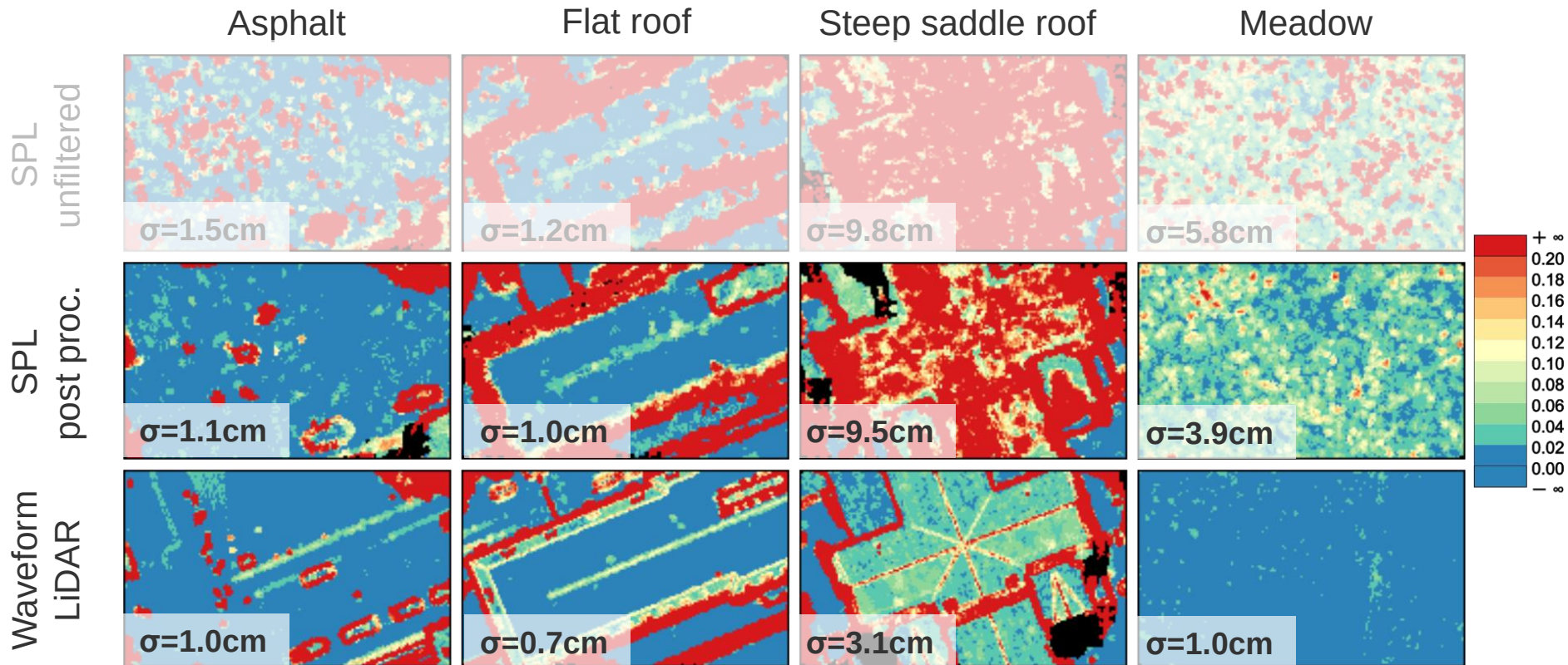
(e)



(f)



Neighborhood/measurement precision II



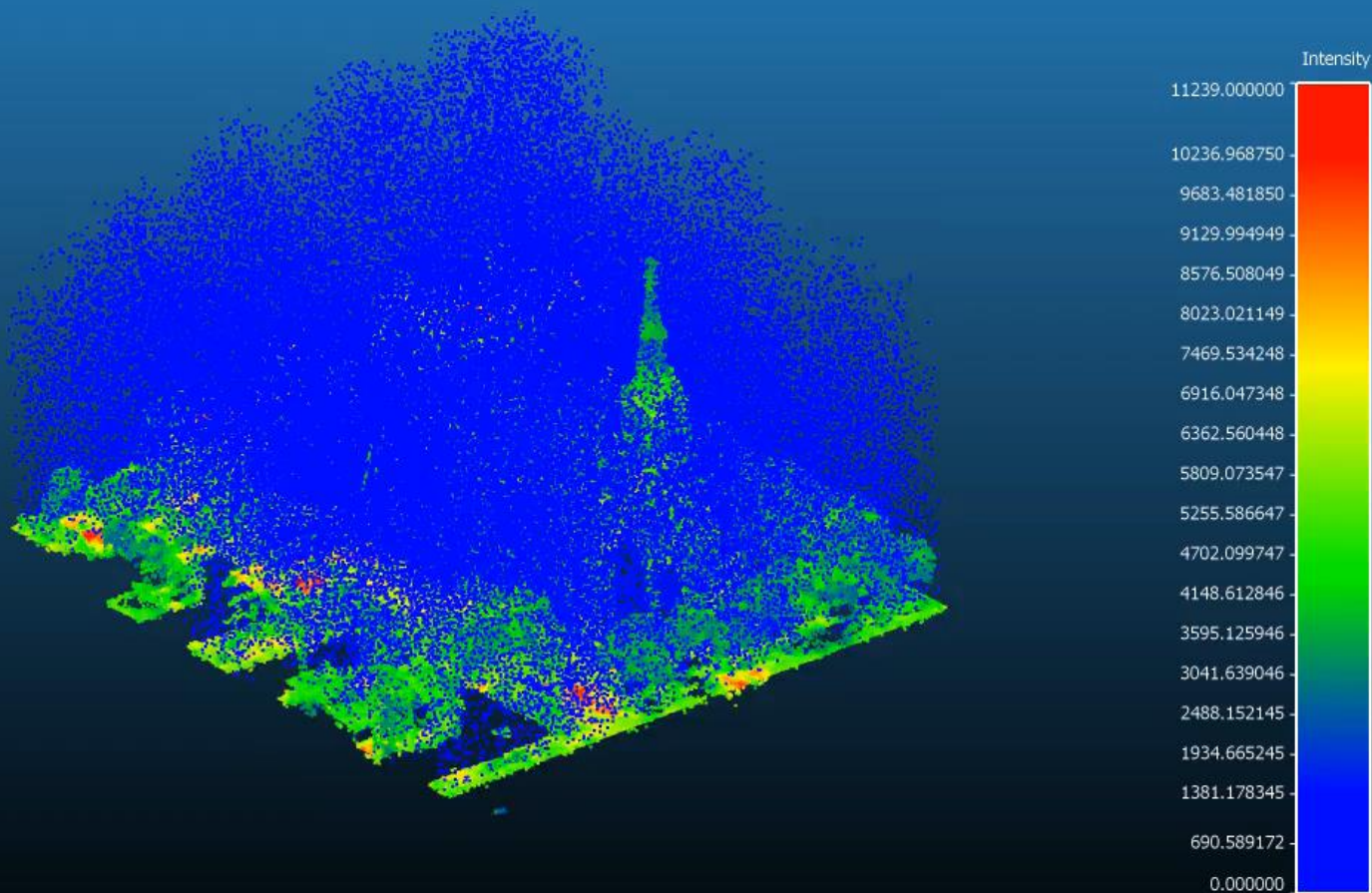
Summary and conclusions

- **Single Photon LiDAR**
 - Higher flying altitude → larger swath width → **less flight strips**
 - → **potentially higher area performance** while maintaining the same point density
- **Full Waveform LiDAR**
 - **Sharp capture** of topography and buildings
 - Reliable **measurement** of **signal strength** and **reflectance** (via radiometric calibration)
- **Penetration of vegetation under leaf-on conditions**
 - **SPL**: penetration **possible** but **moderate**
 - **Full waveform LiDAR**: **pronounced penetrations capabilities**
- **Measurement precision**
 - **SPL**: **high prec.** @smooth, **horizontal** surfaces (~1-2 cm), **Decreasing** precision @ **tilted**, poorly reflecting surfaces (~10 cm)
 - **Full waveform LiDAR**: **Advantages** @ **complex target situations** (tilted and rough surface, vegetation; ~1-3 cm)

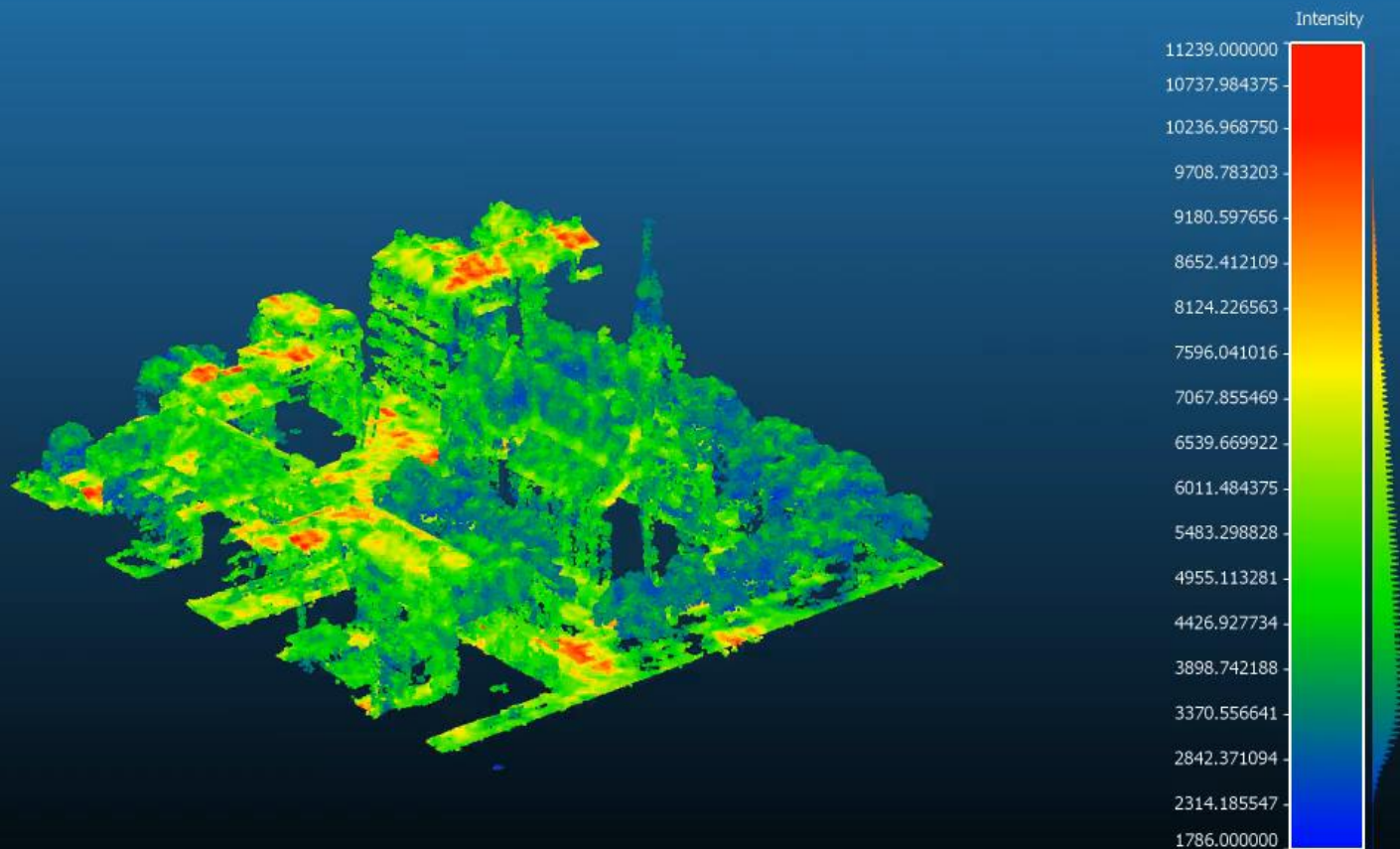
Addendum

Screenshots from animations of
City of Vienna dataset

Single Photon LiDAR (SPL): Unfiltered 3D point cloud

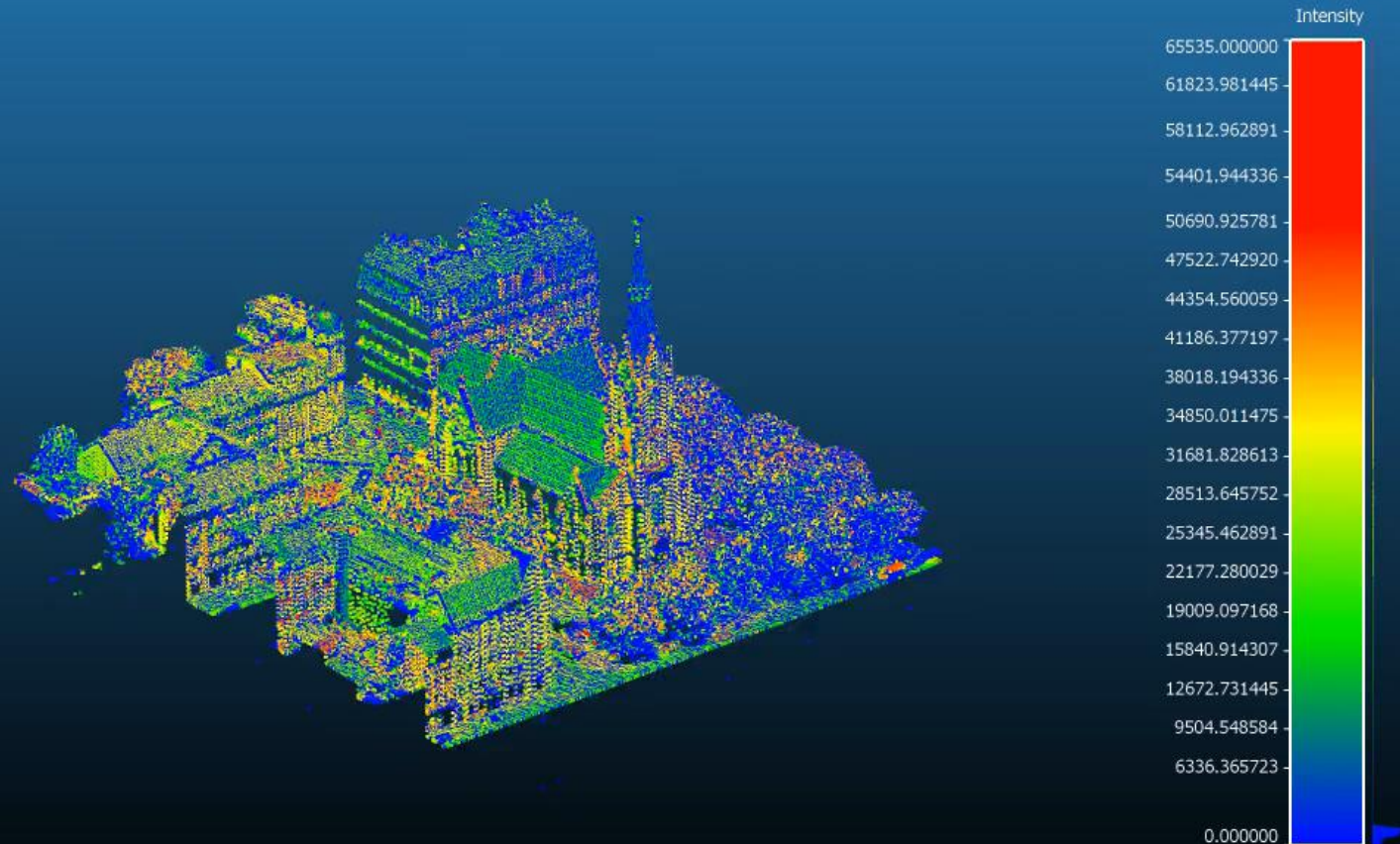


Single Photon LiDAR (SPL): Postproc. 3D point cloud



City of Vienna, 3rd district, Scanner: Leica SPL100

Full Waveform LiDAR: 3D point cloud



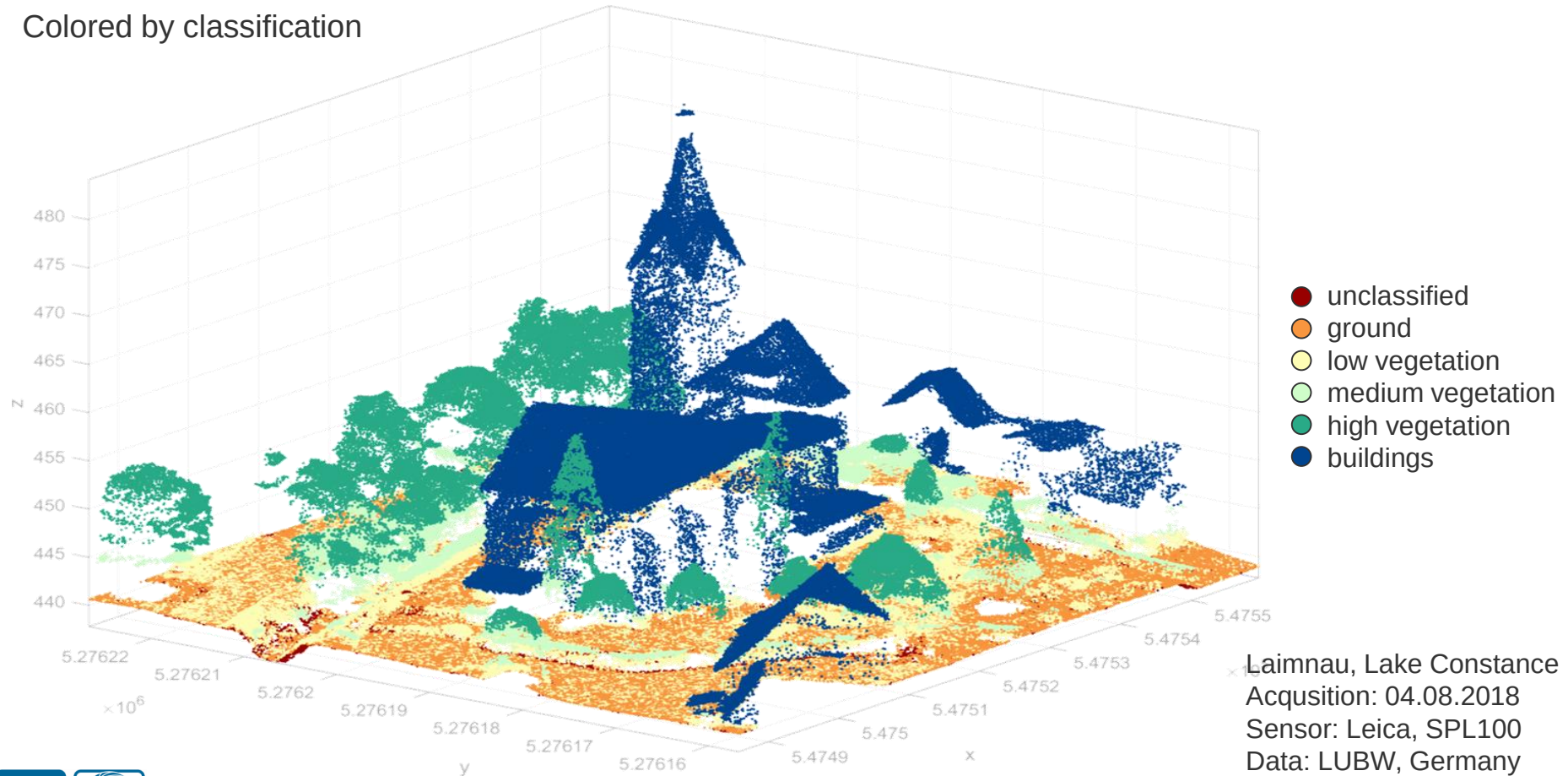
City of Vienna, 3rd district, Scanner: *RIEGL* VQ-1560i

Addendum

Dataset: Argen, Schussen, Lake Constance
Landesamt für Umwelt, Baden-Württemberg (LUBW)

Single Photon LiDAR 3D point cloud

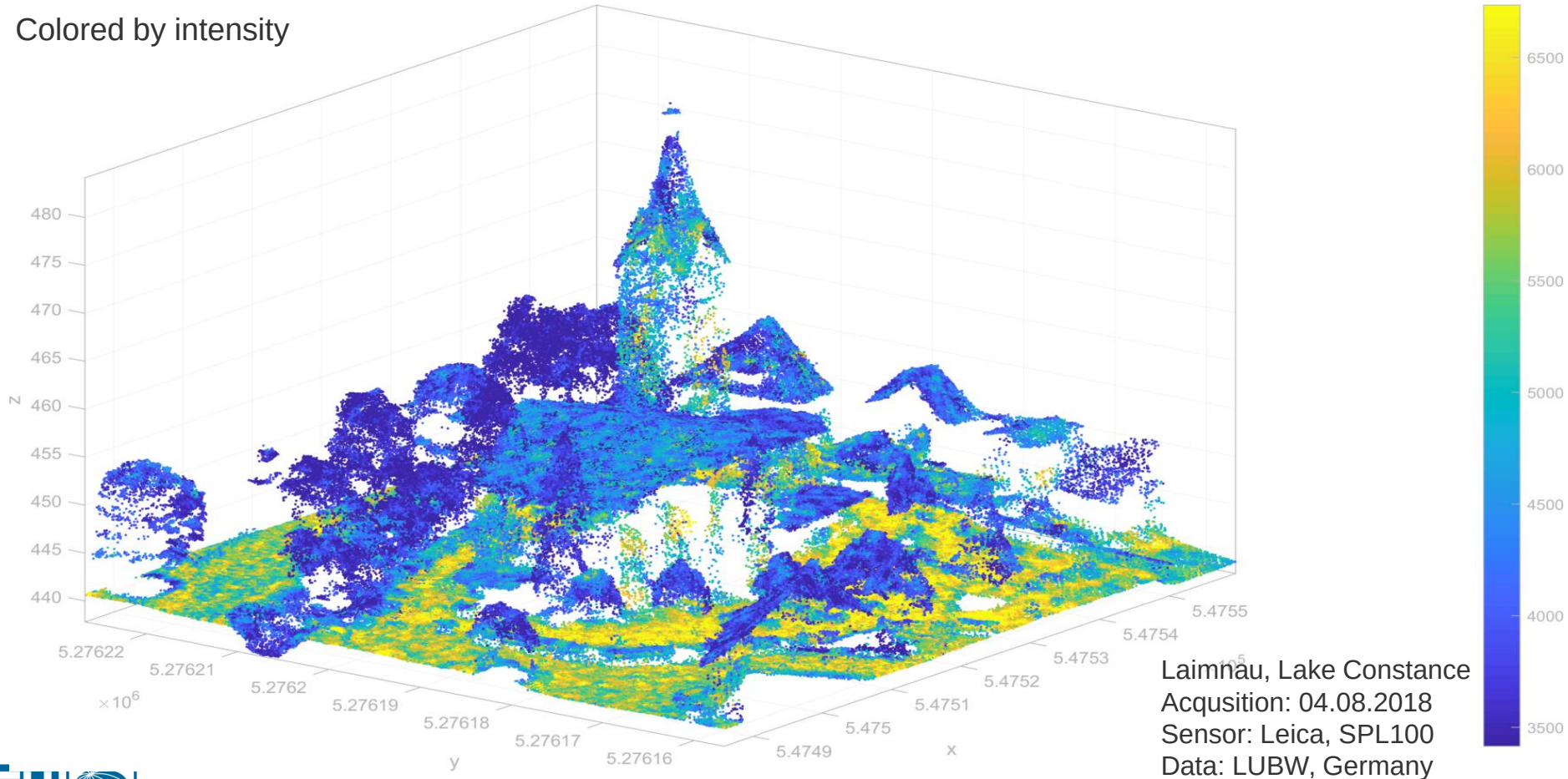
Colored by classification



Laimnau, Lake Constance
Acquisition: 04.08.2018
Sensor: Leica, SPL100
Data: LUBW, Germany

Single Photon LiDAR 3D point cloud

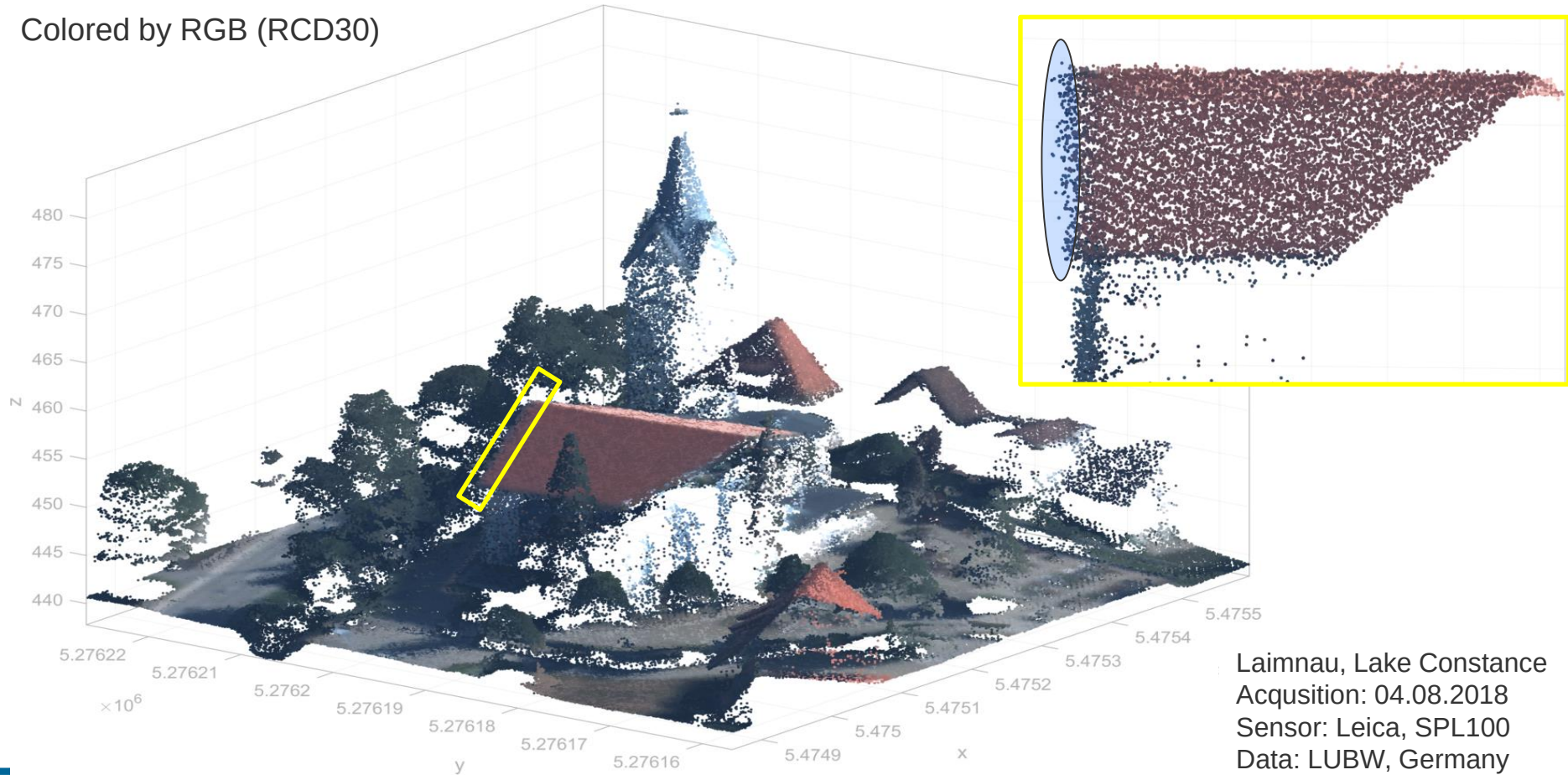
Colored by intensity



Laimnau, Lake Constance
Acquisition: 04.08.2018
Sensor: Leica, SPL100
Data: LUBW, Germany

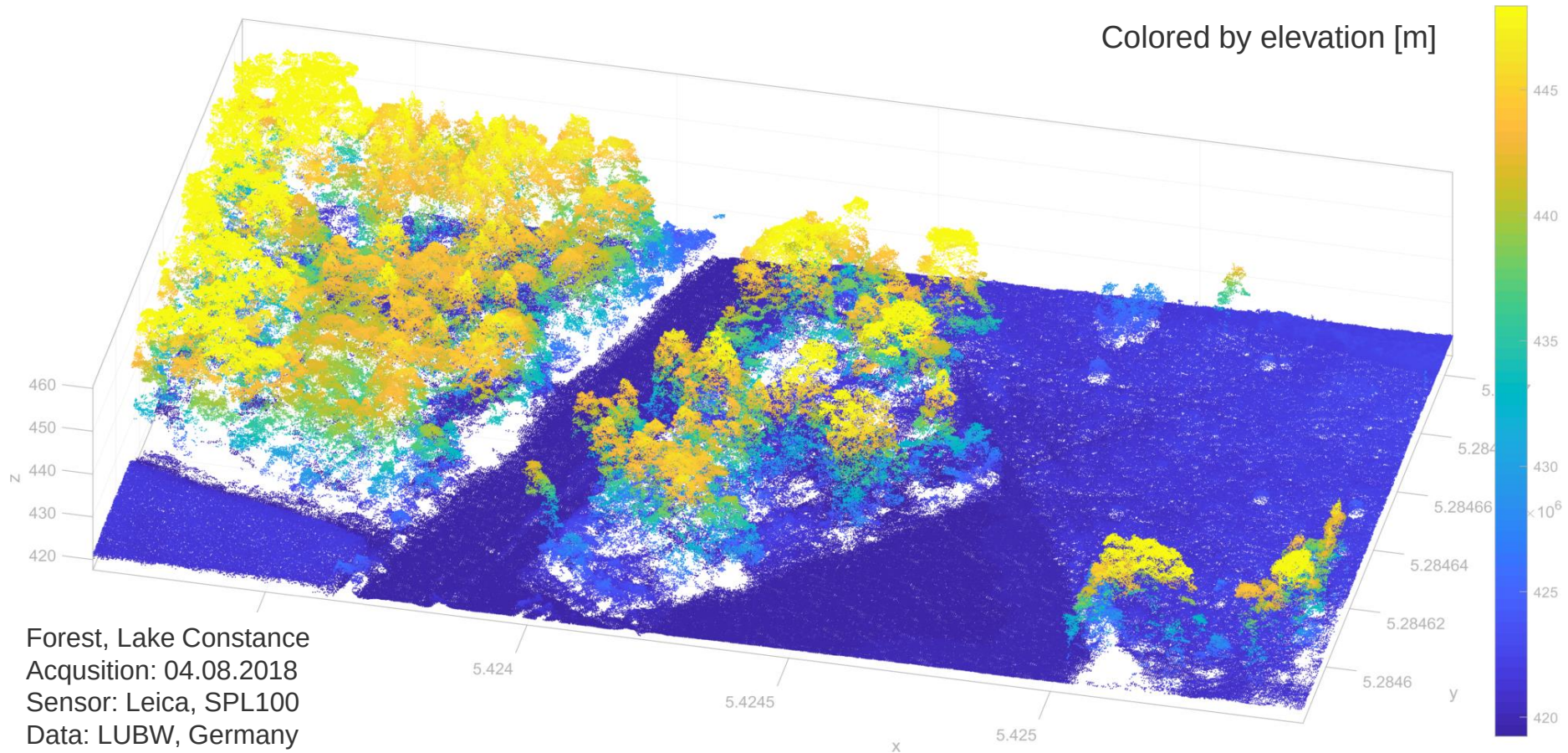
Single Photon LiDAR 3D point cloud

Colored by RGB (RCD30)

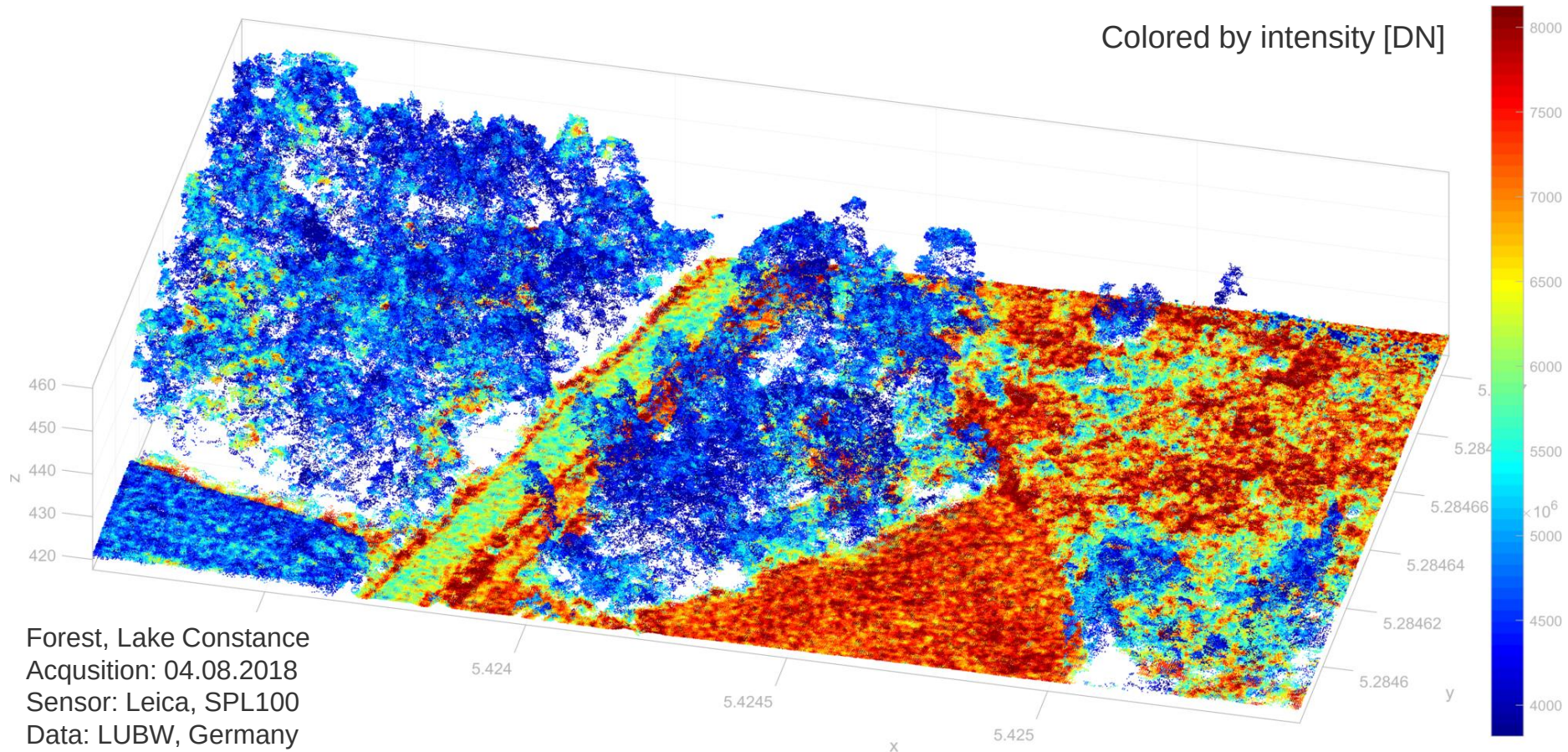


Laimnau, Lake Constance
Acquisition: 04.08.2018
Sensor: Leica, SPL100
Data: LUBW, Germany

Single Photon LiDAR 3D point cloud

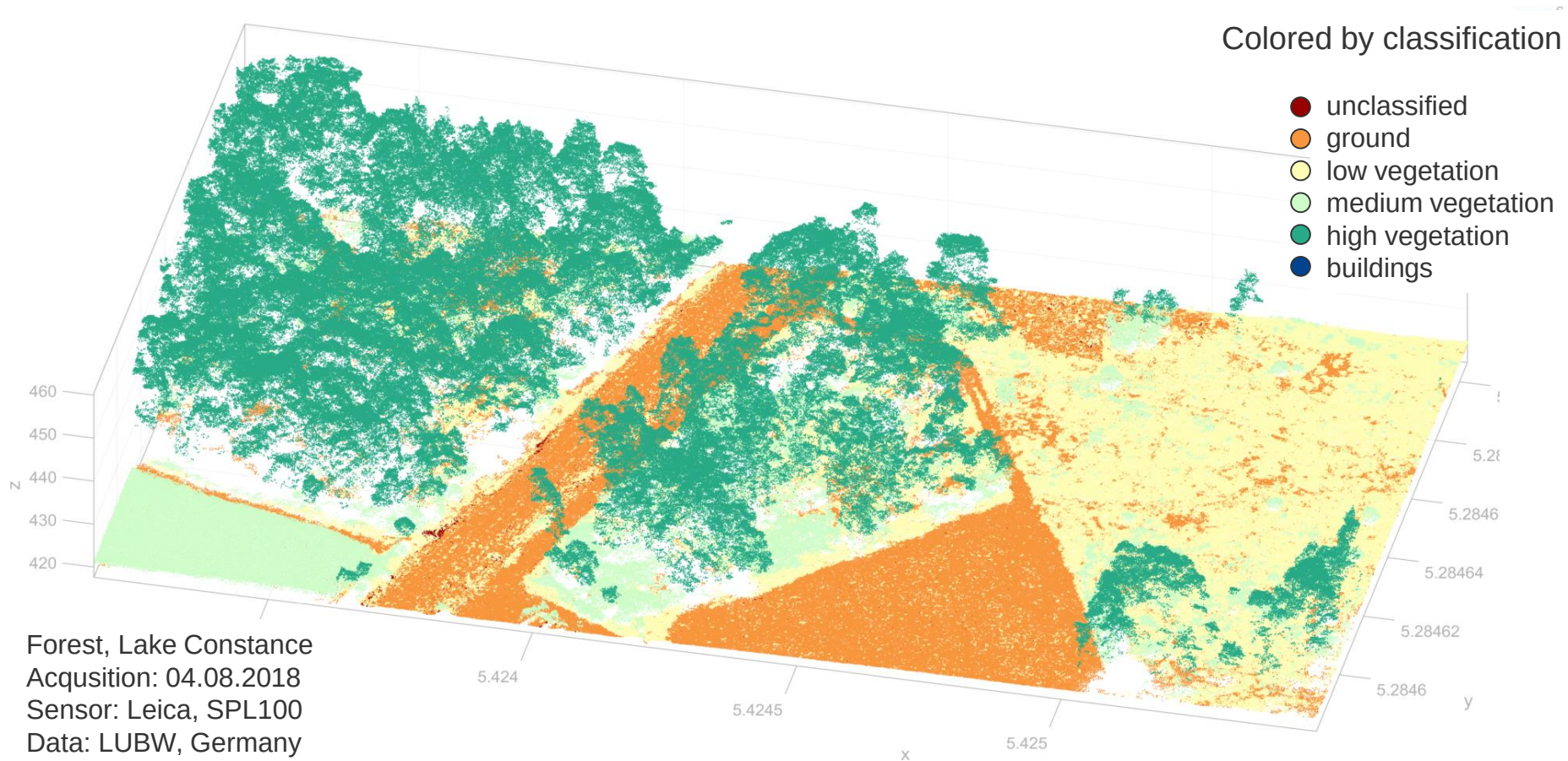


Single Photon LiDAR 3D point cloud



Forest, Lake Constance
Acquisition: 04.08.2018
Sensor: Leica, SPL100
Data: LUBW, Germany

Single Photon LiDAR 3D point cloud

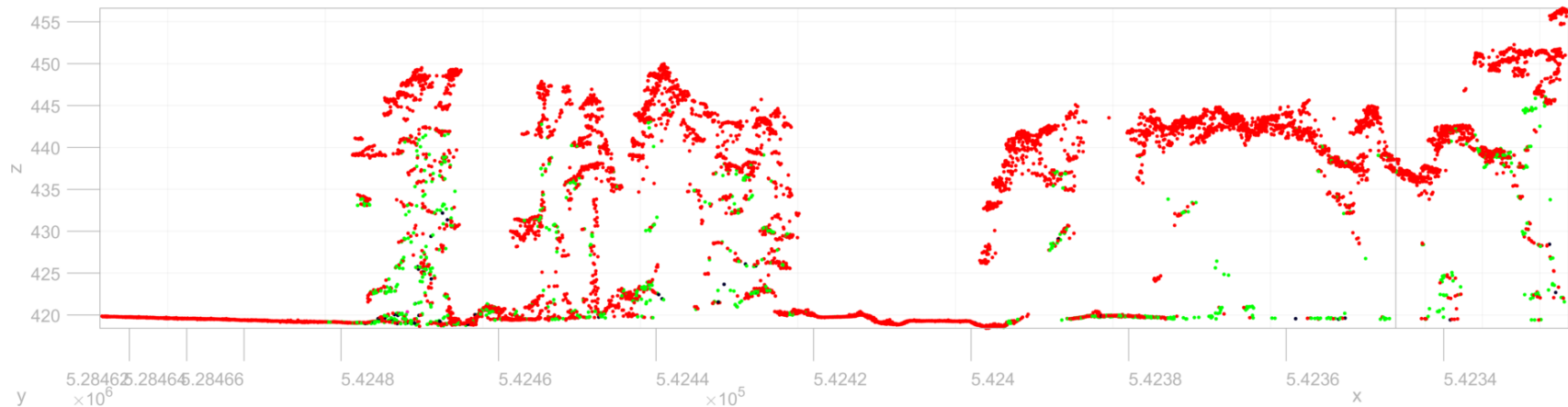


Single Photon LiDAR 3D point cloud (section view)

Colored by classification

Forest, Lake Constance
Acquisition: 04.08.2018
Sensor: Leica, SPL100
Data: LUBW, Germany

● 1st echo
● 2nd echo



SPL: 1.12 echoes/puls