# Topo-bathymetrische Punktwolken: Analyse und Konsequenzen für die Datenprozessierung

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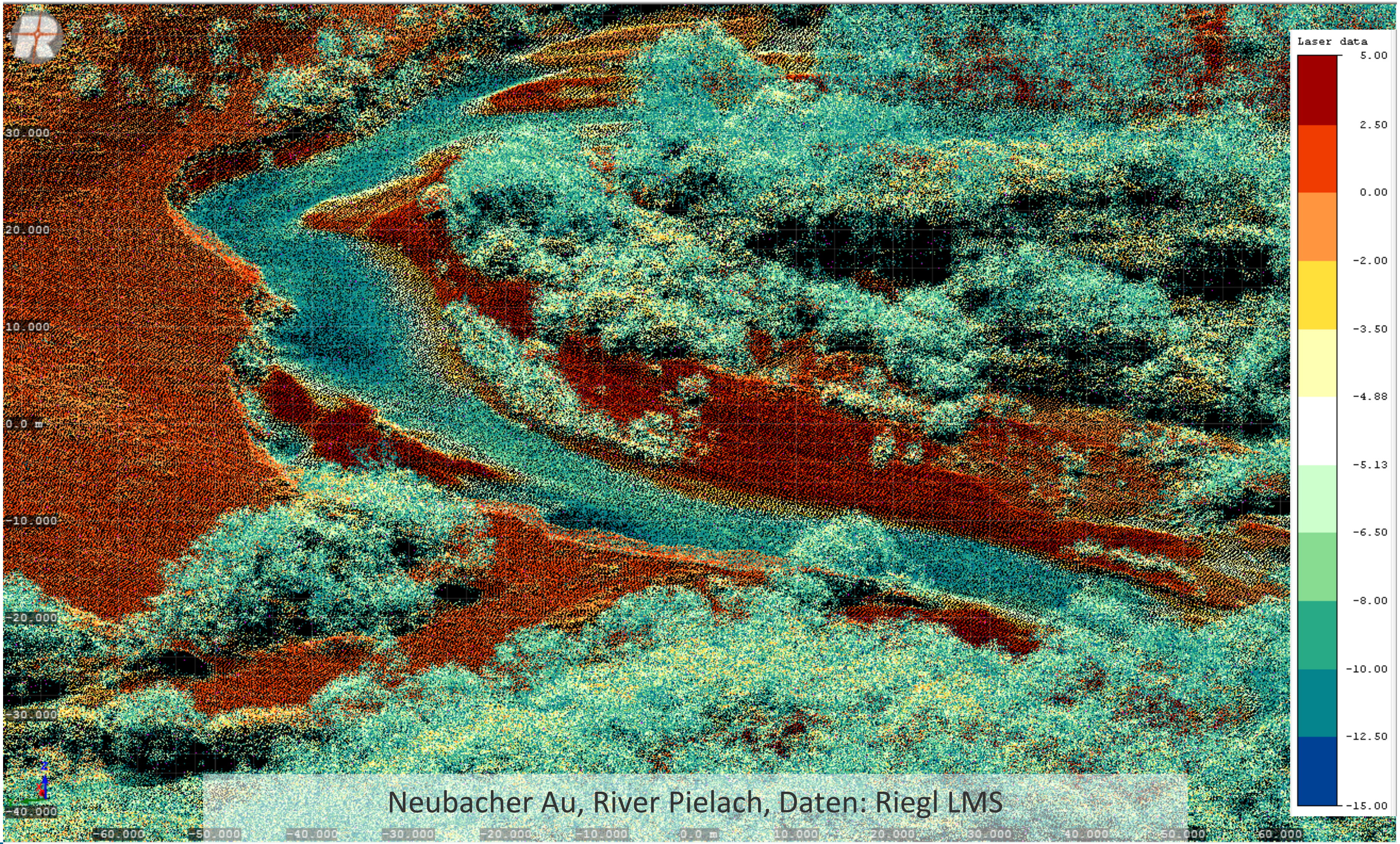
# Topo-bathymetrische 3D-Punktwolke
# Riegl VQ-820-G



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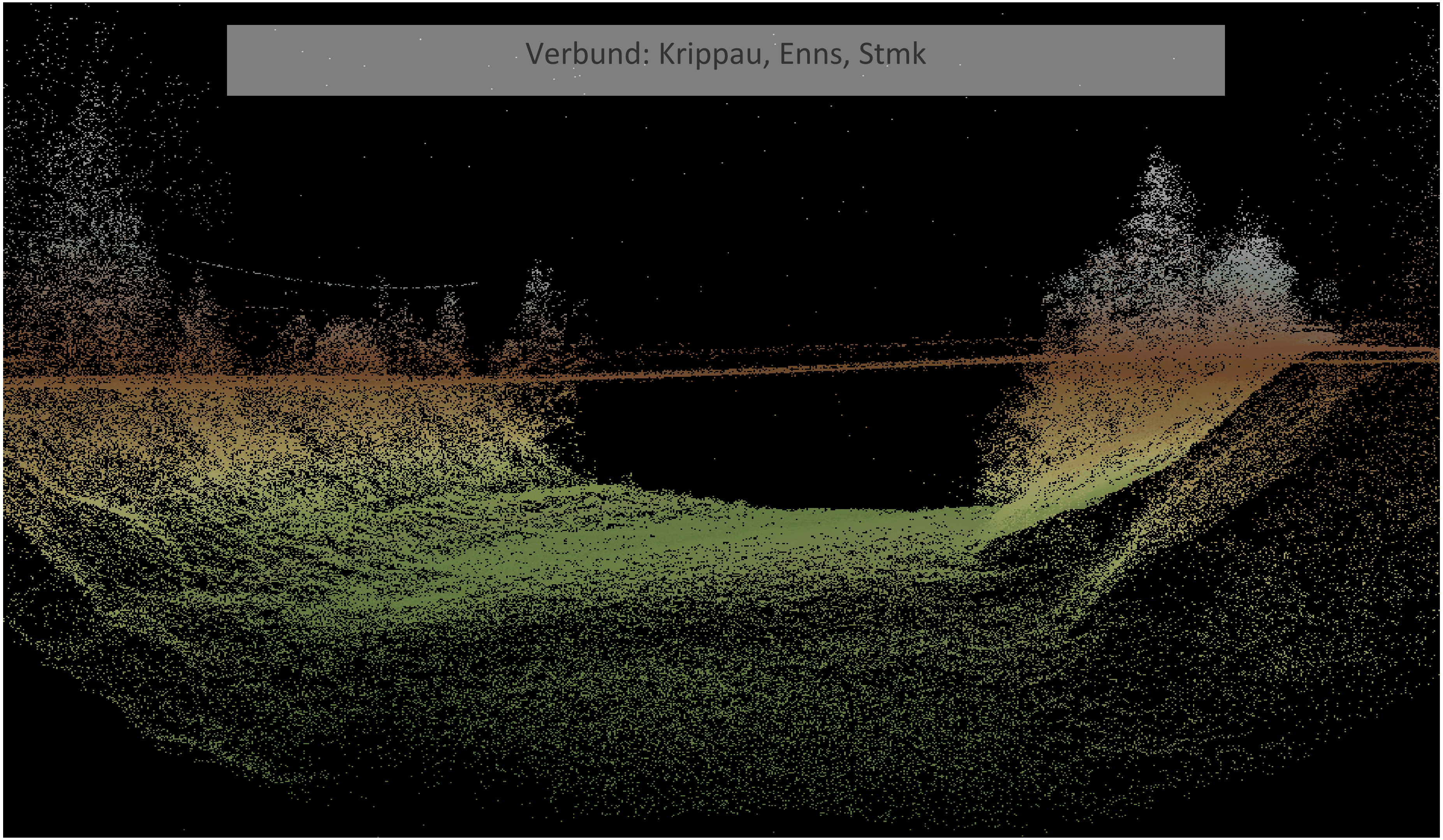

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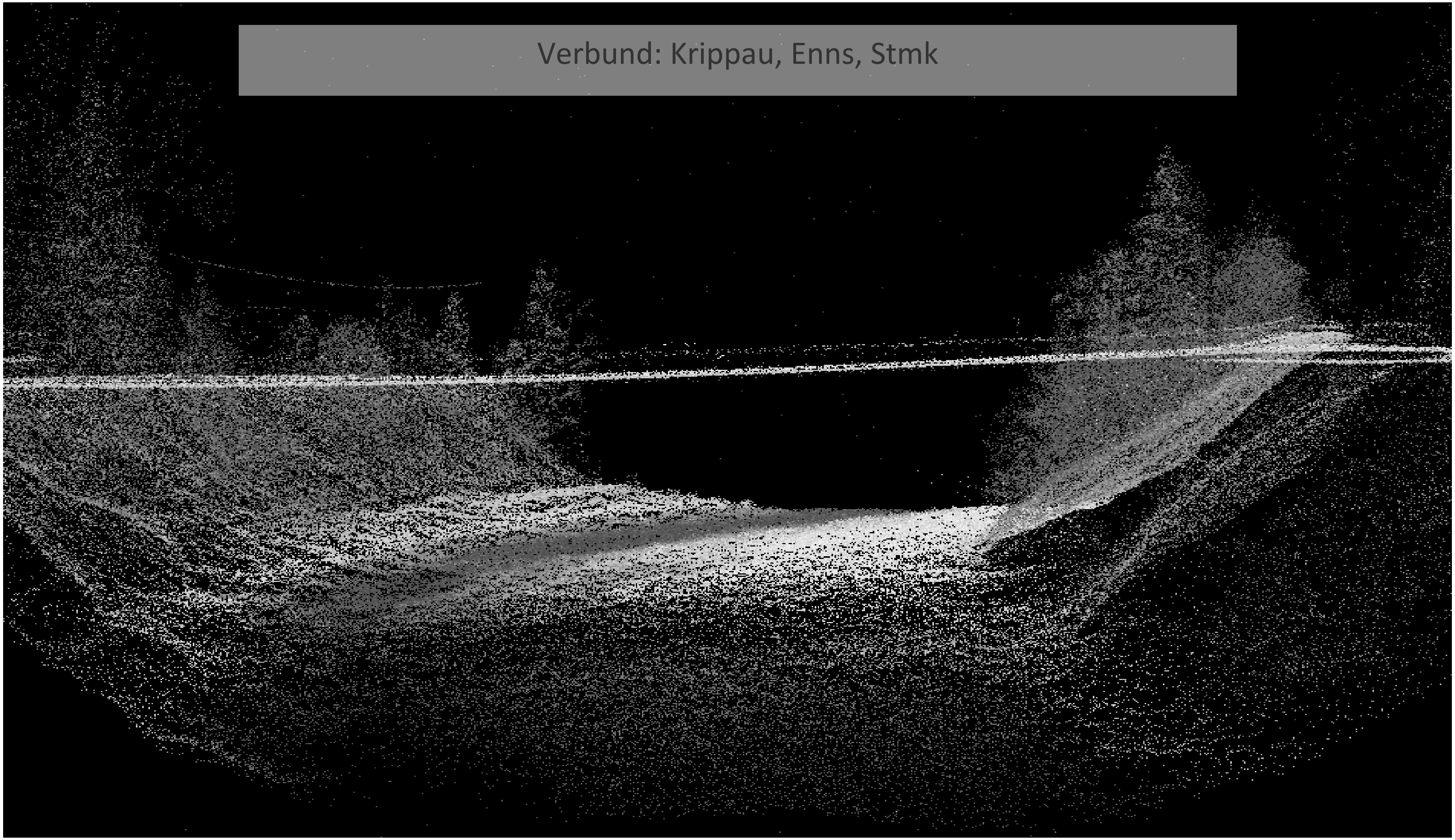

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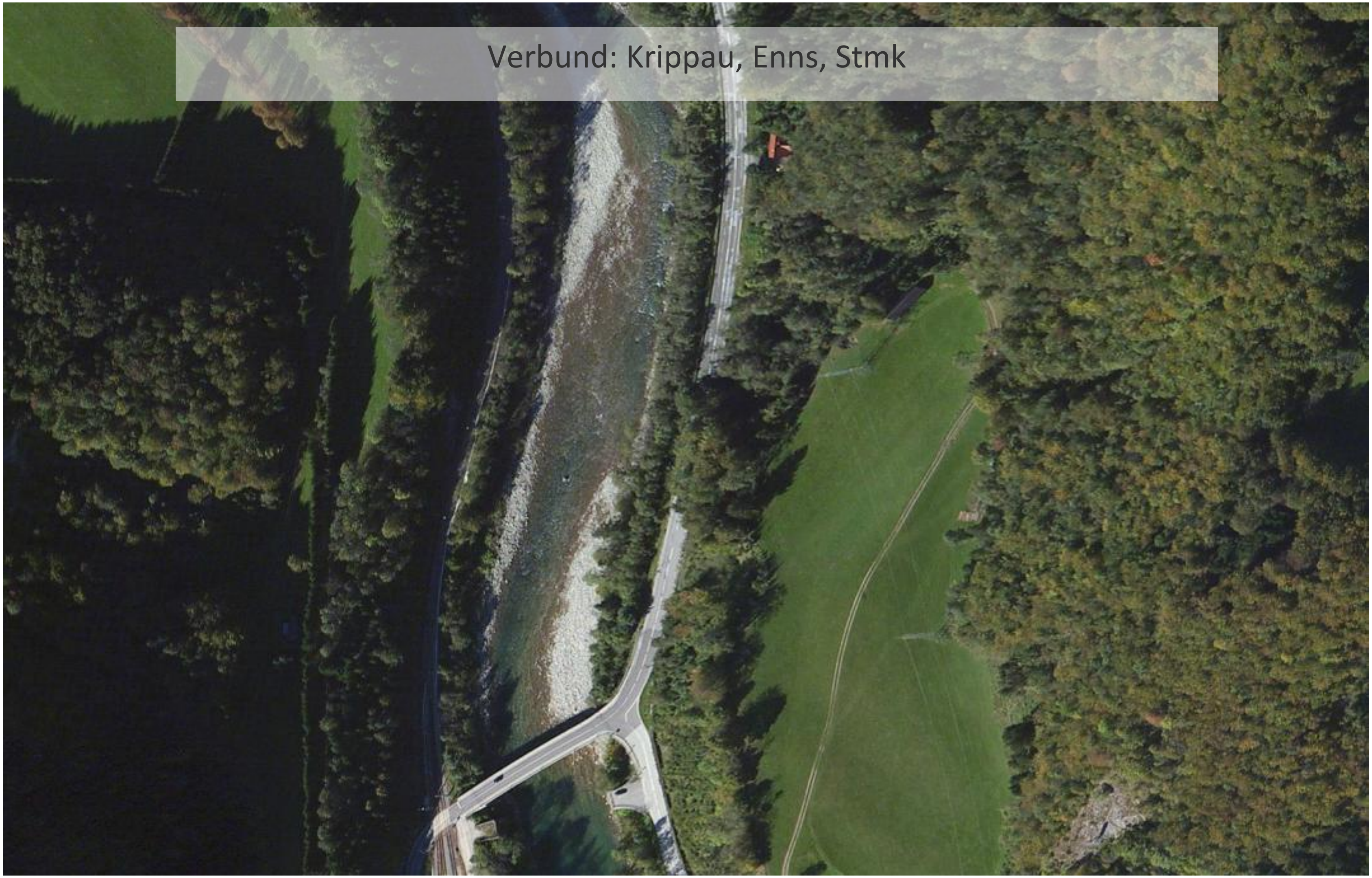
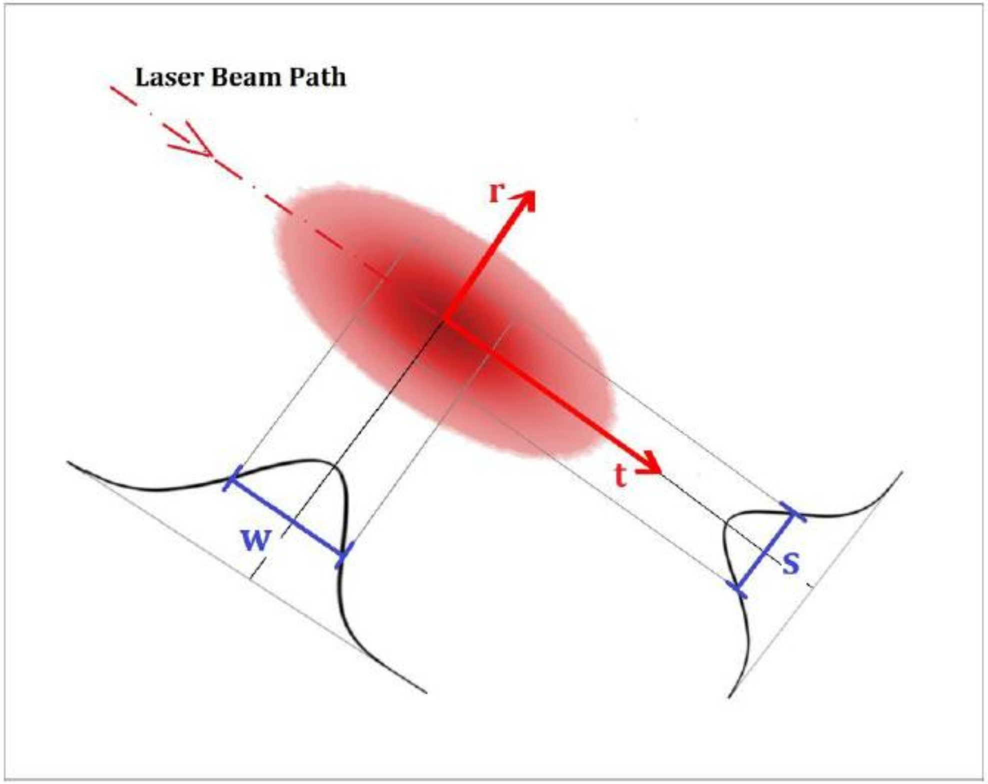


# Outline

- Laser beam
  - Pulse model
  - Pulse width
  - Beam divergence and footprint
- Reflectance
  - Comparison: NiR (1064nm) – green(532nm)
  - Incidence angle dependency
- "Green laser" in/at water
  - Penetration
  - Reflection
- Conclusions and outlook

# Laser pulse model




$$I(t,r) = I_0 \cdot exp\left[-\frac{1}{2}\cdot\left(\frac{t^2}{\sigma_{long}^2} + \frac{r^2}{\sigma_{cross}^2}\right)\right]$$

$$w = 2 \cdot \sqrt{2 \cdot ln2} \cdot \sigma_{long}$$

$$s = 2 \cdot \sqrt{2 \cdot ln2} \cdot \sigma_{cross} = \gamma \cdot R$$

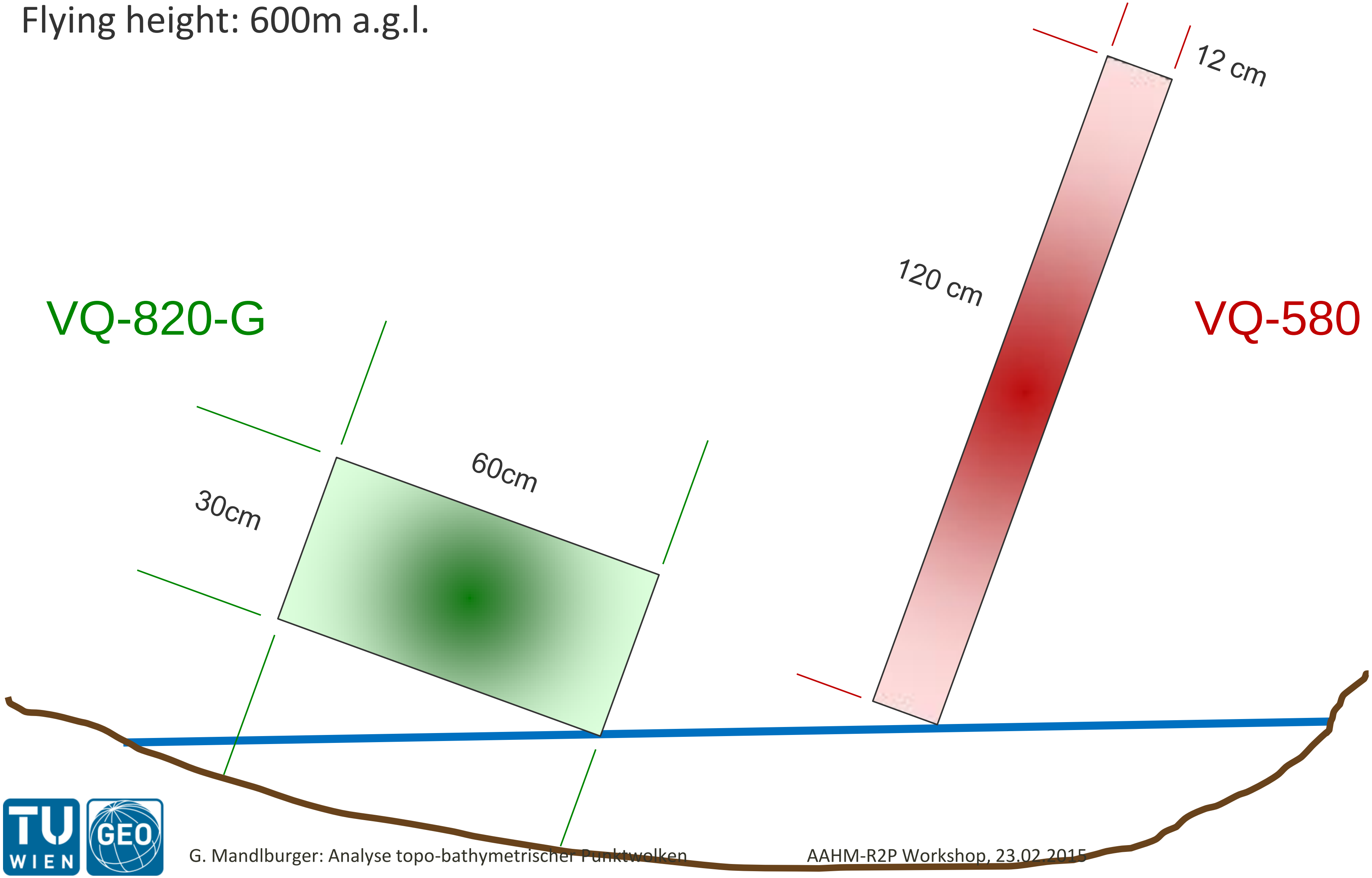
$\gamma$ – beam divergence in radians,
$R$ – range value in meters.

Source: Małgorzata SŁOTA*, Full-waveform data for building roof step edge localization:
ISPRS Journal, PHOTO-D-14-00616

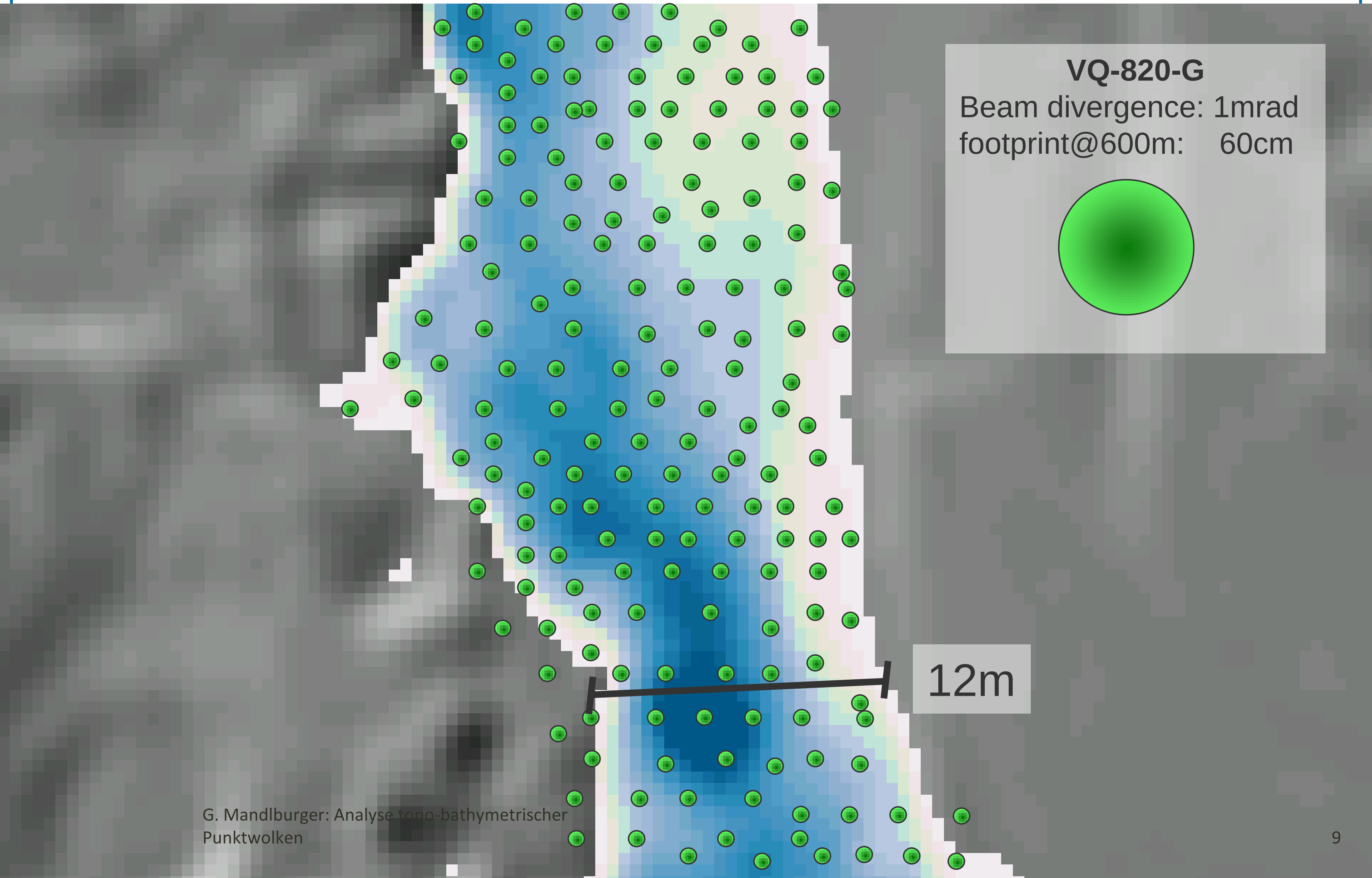
Based on:Jutzi, B and Stilla, U. 2007. Simulation and analysis of full-waveform laser data of urban objects. In Proc. of 2007 Urban Remote Sensing Joint Event. IEEE. 2007.

# Laser pulse width

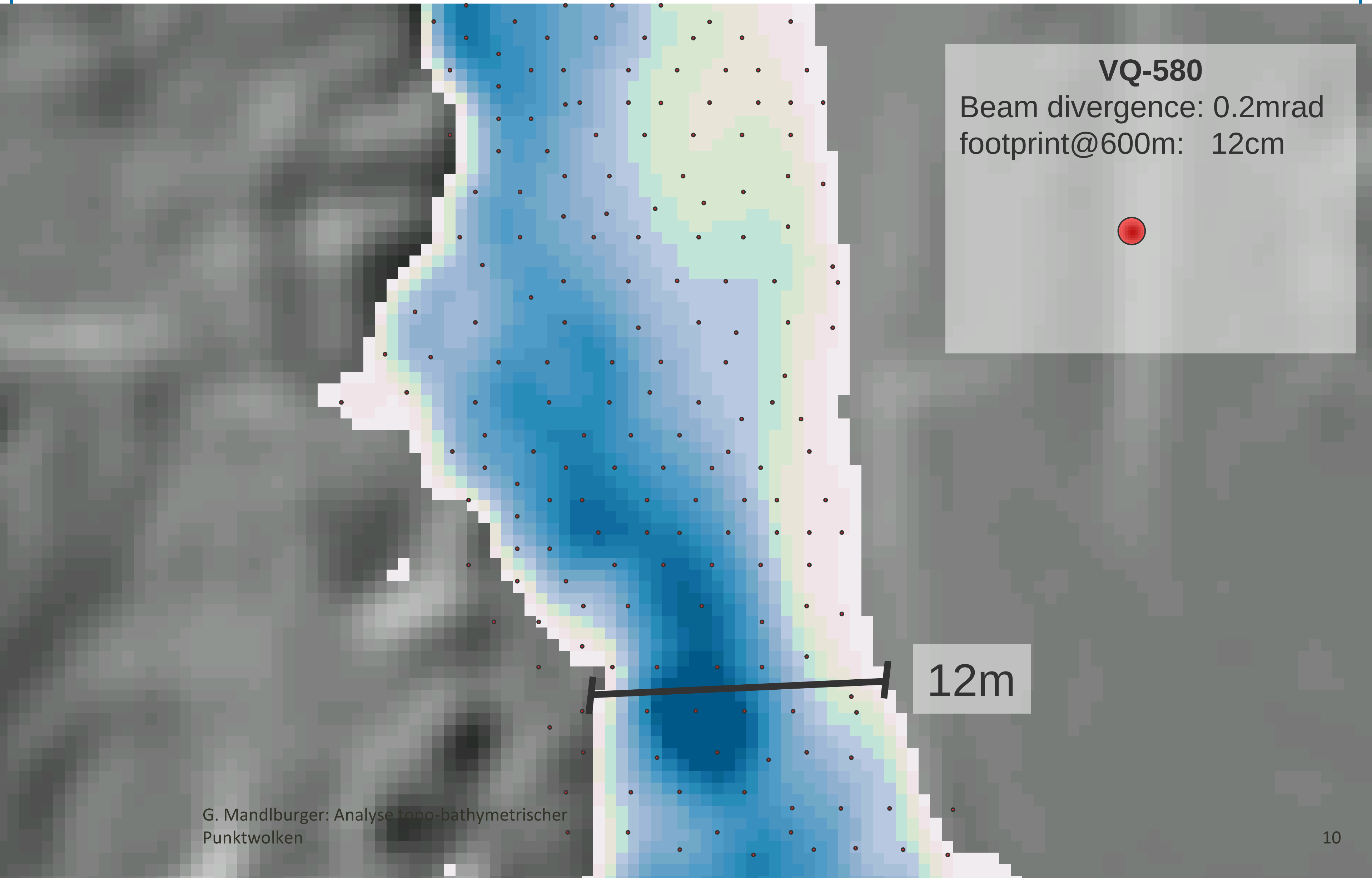
Flying height: 600m a.g.l.



# Laser footprint VQ-820-G

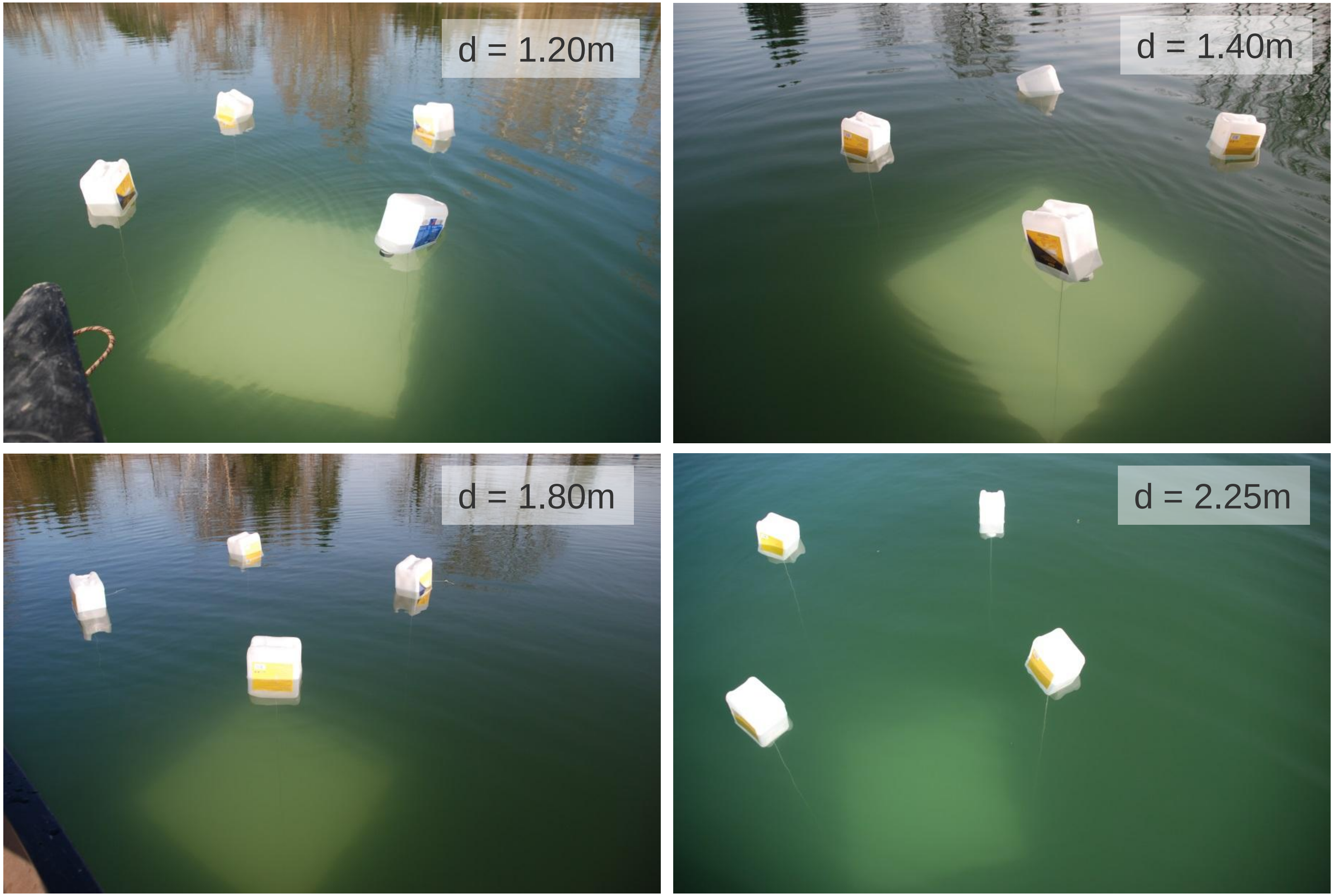


# Laser footprint VQ-580

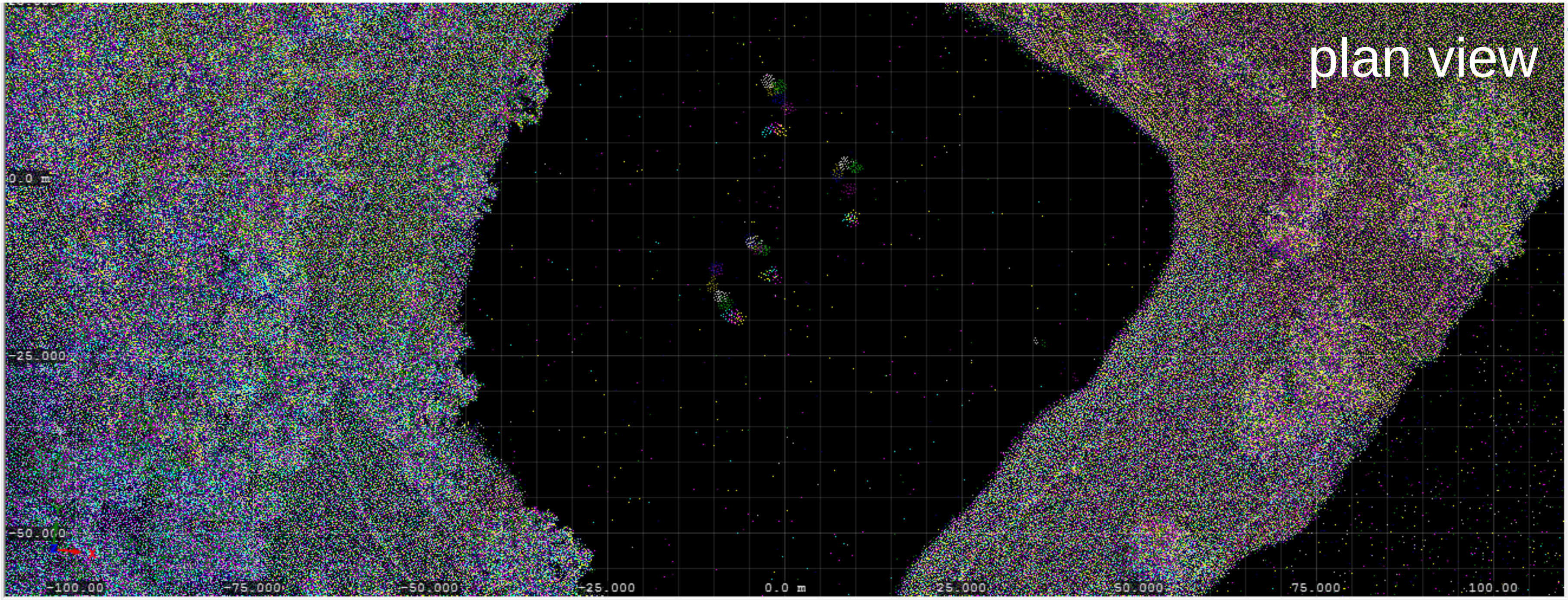


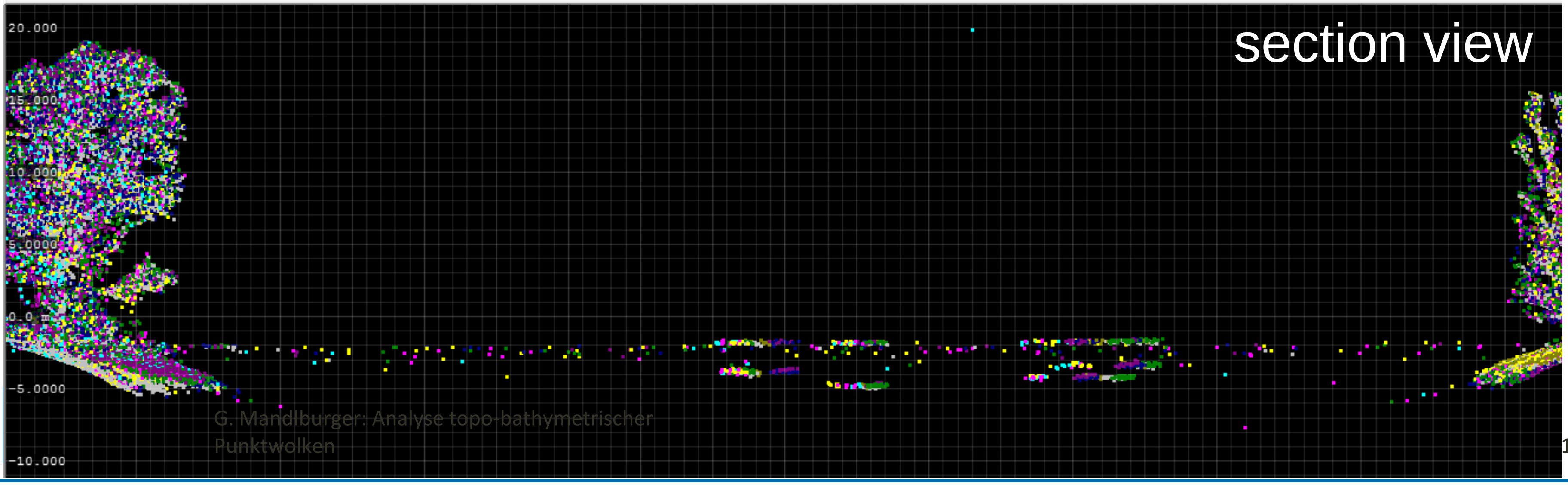
# Plate experiment- areal photo

# Plate experiment- terrestrial photos

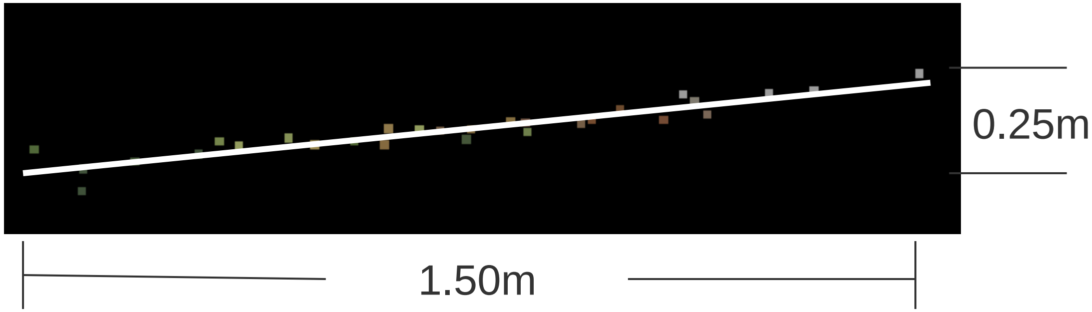


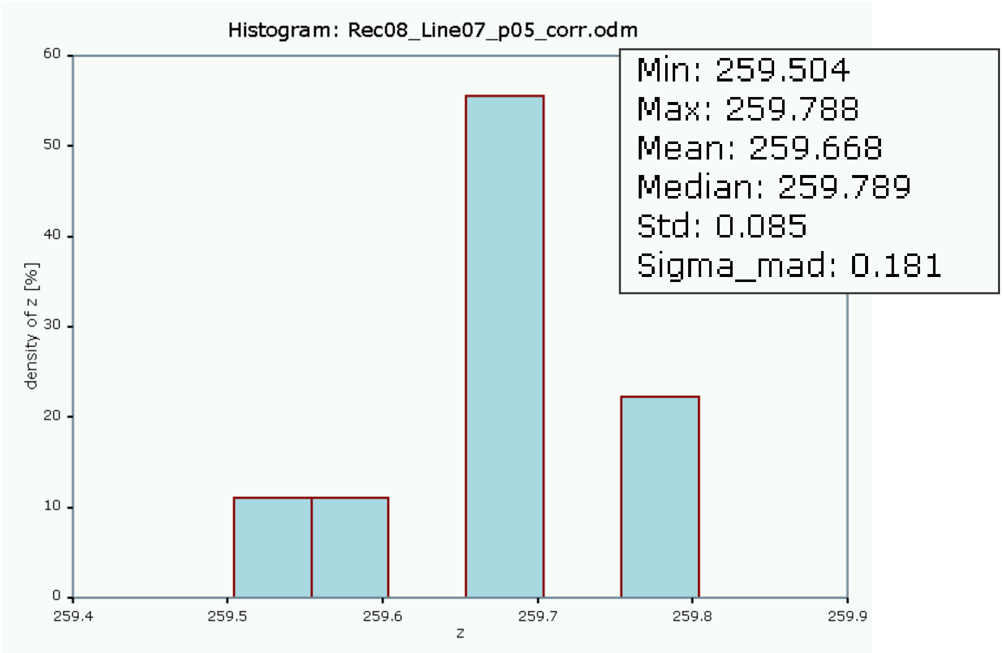
# Plate experiment- point cloud

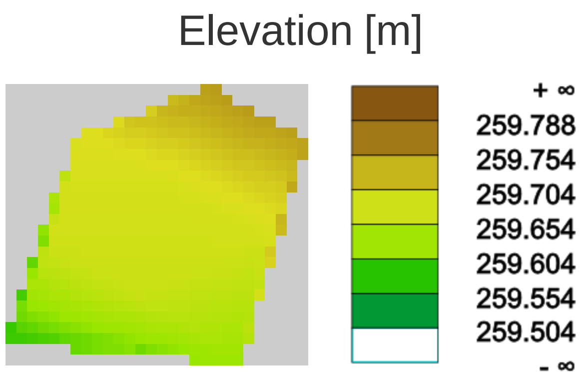


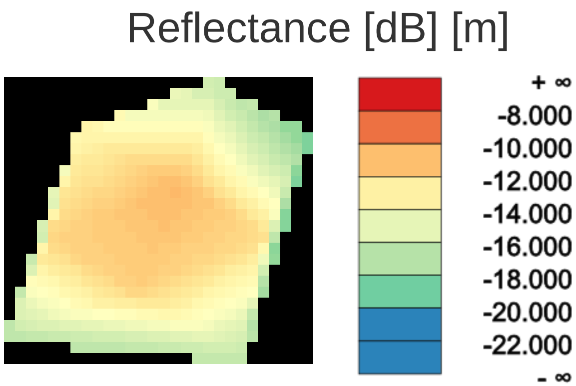



# Plate experiment – Point cloud

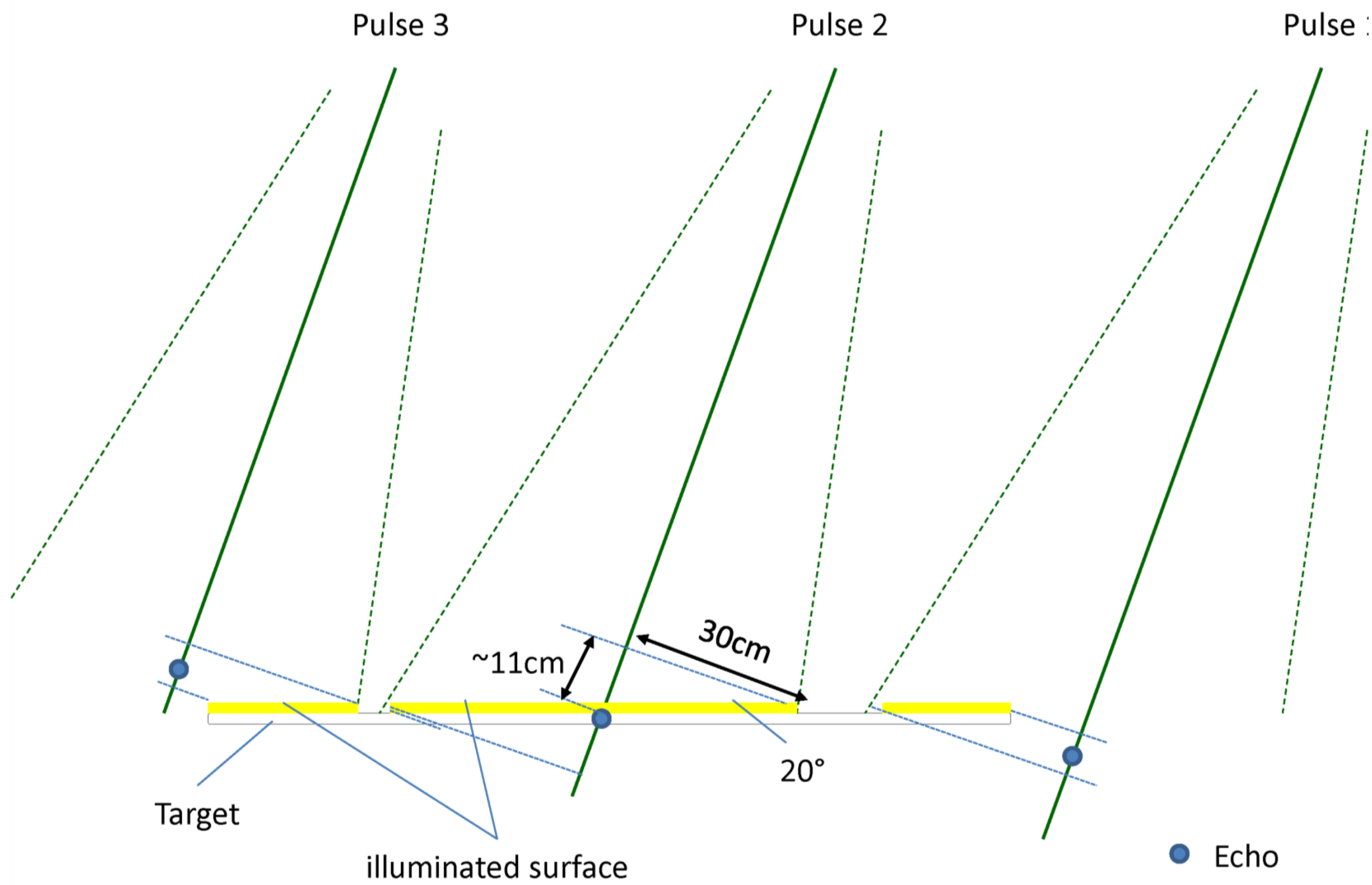


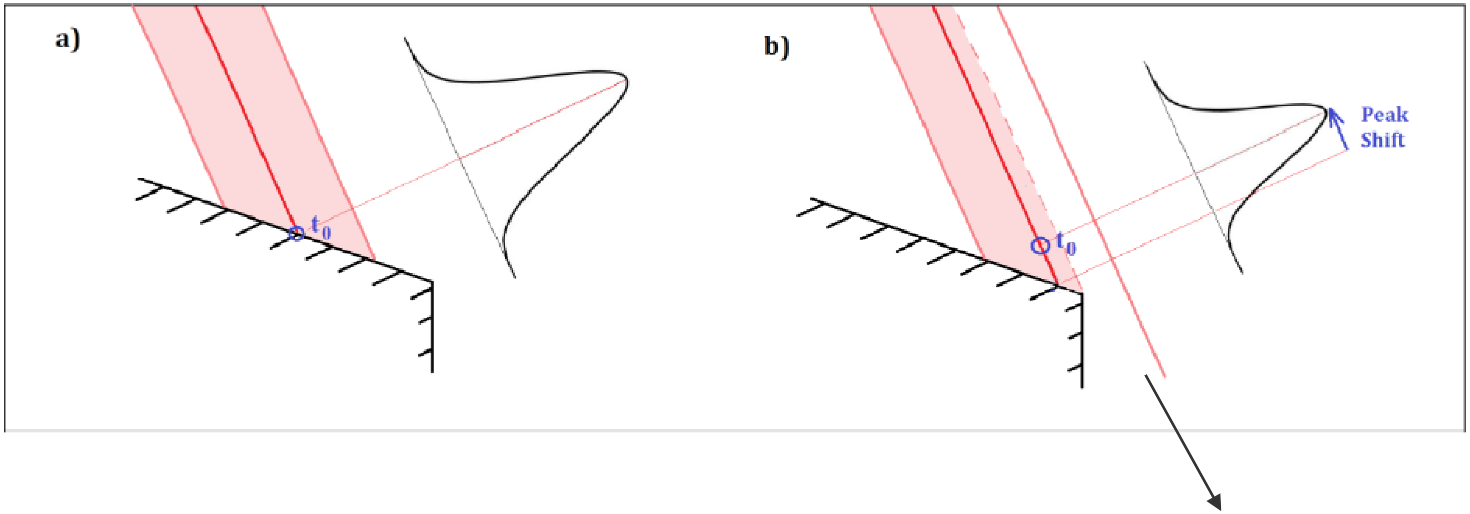



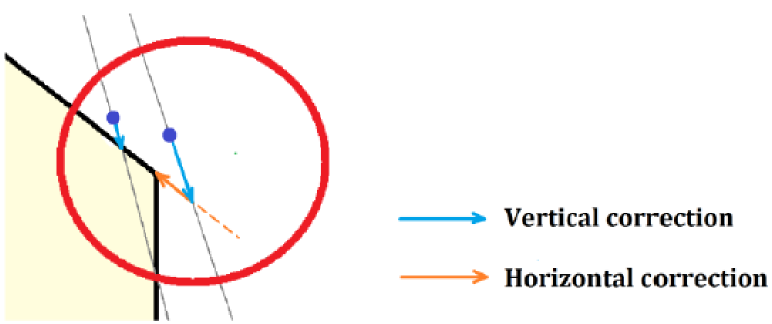



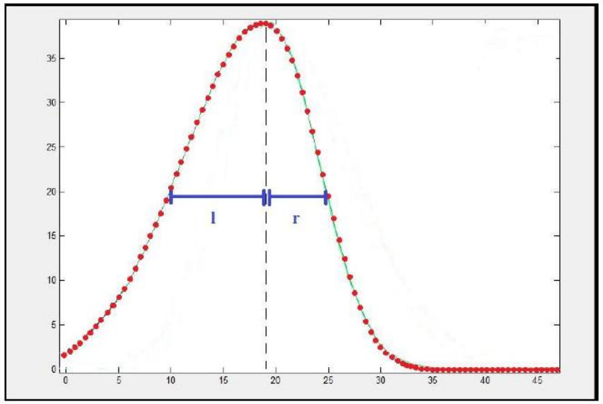
# Plate experiment- laser beam @ step edges



# Correction of step edge echoes

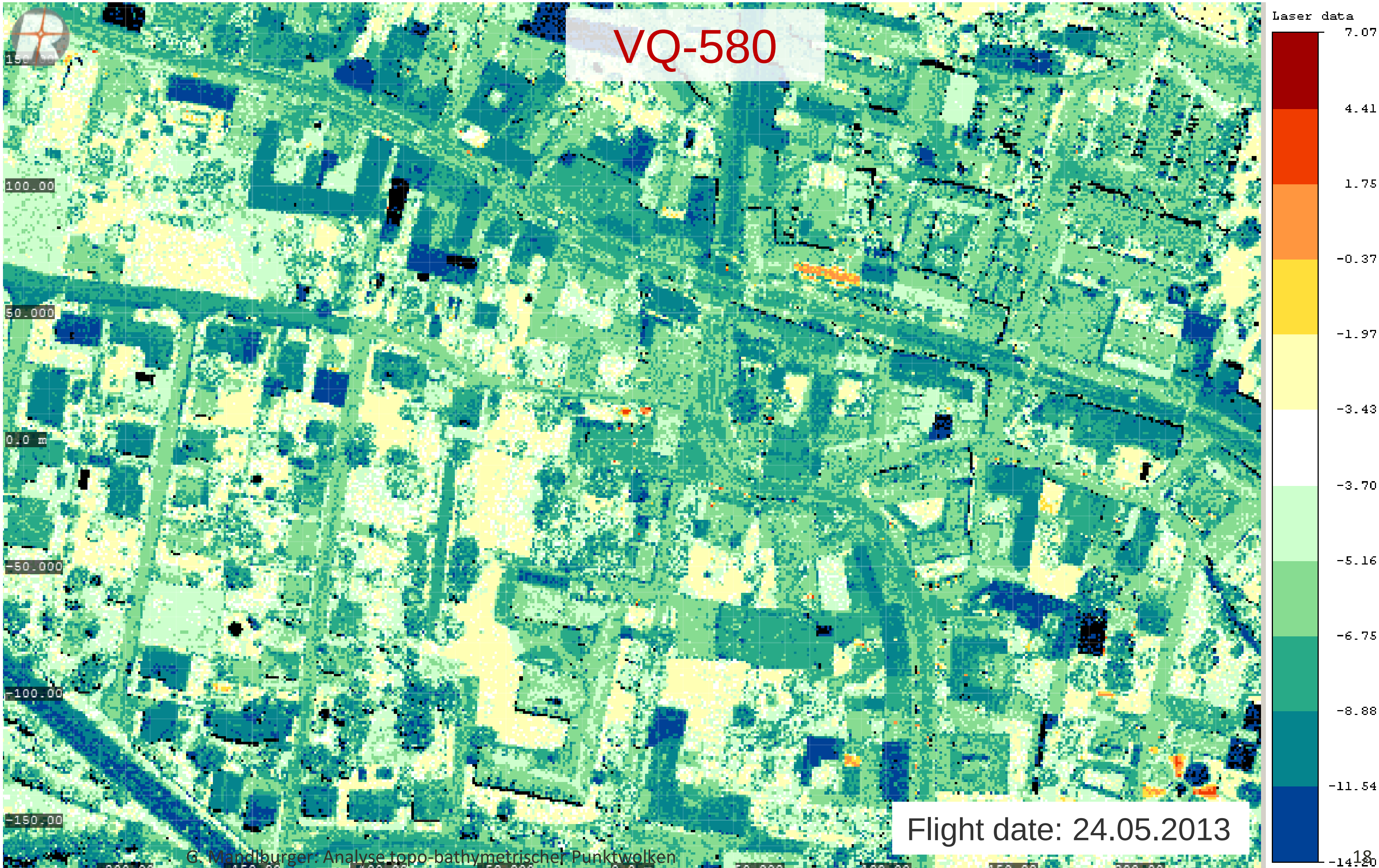


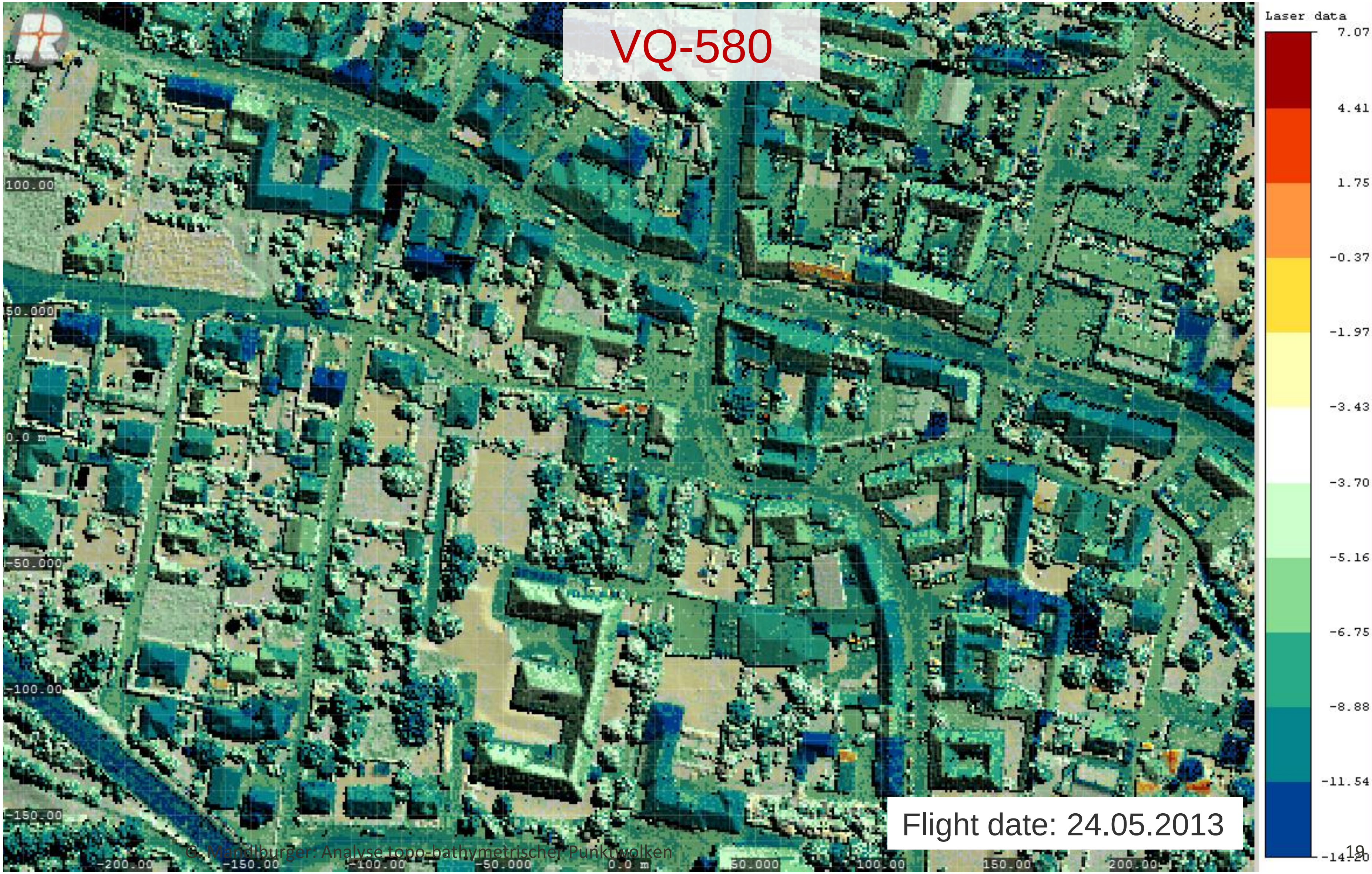




Source: Małgorzata SŁOTA*, Full-waveform data for building roof step edge localization: ISPRS Journal Manuscript (accepted), PHOTO-D-14-00616

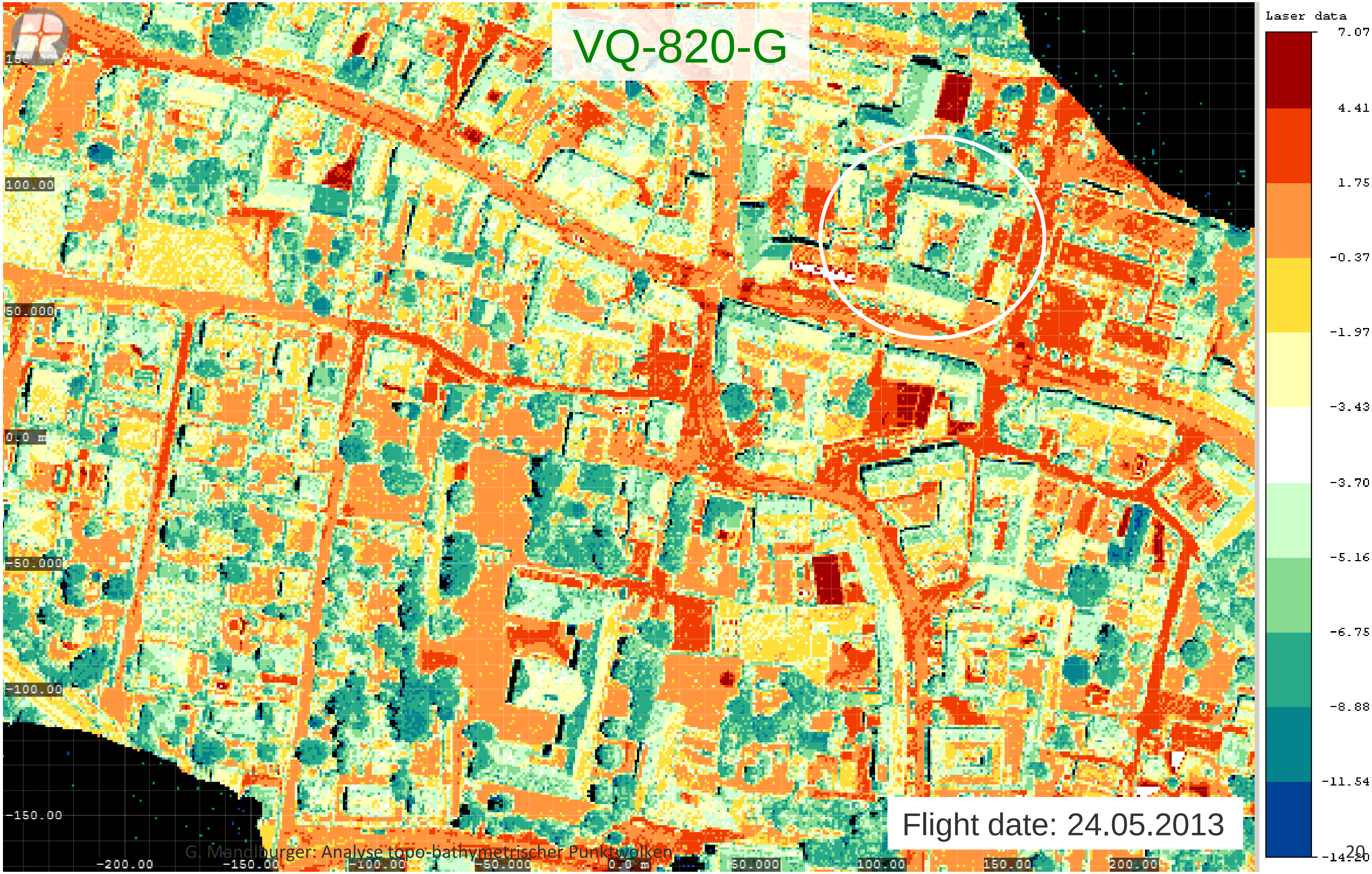
# Reflectance [dB]



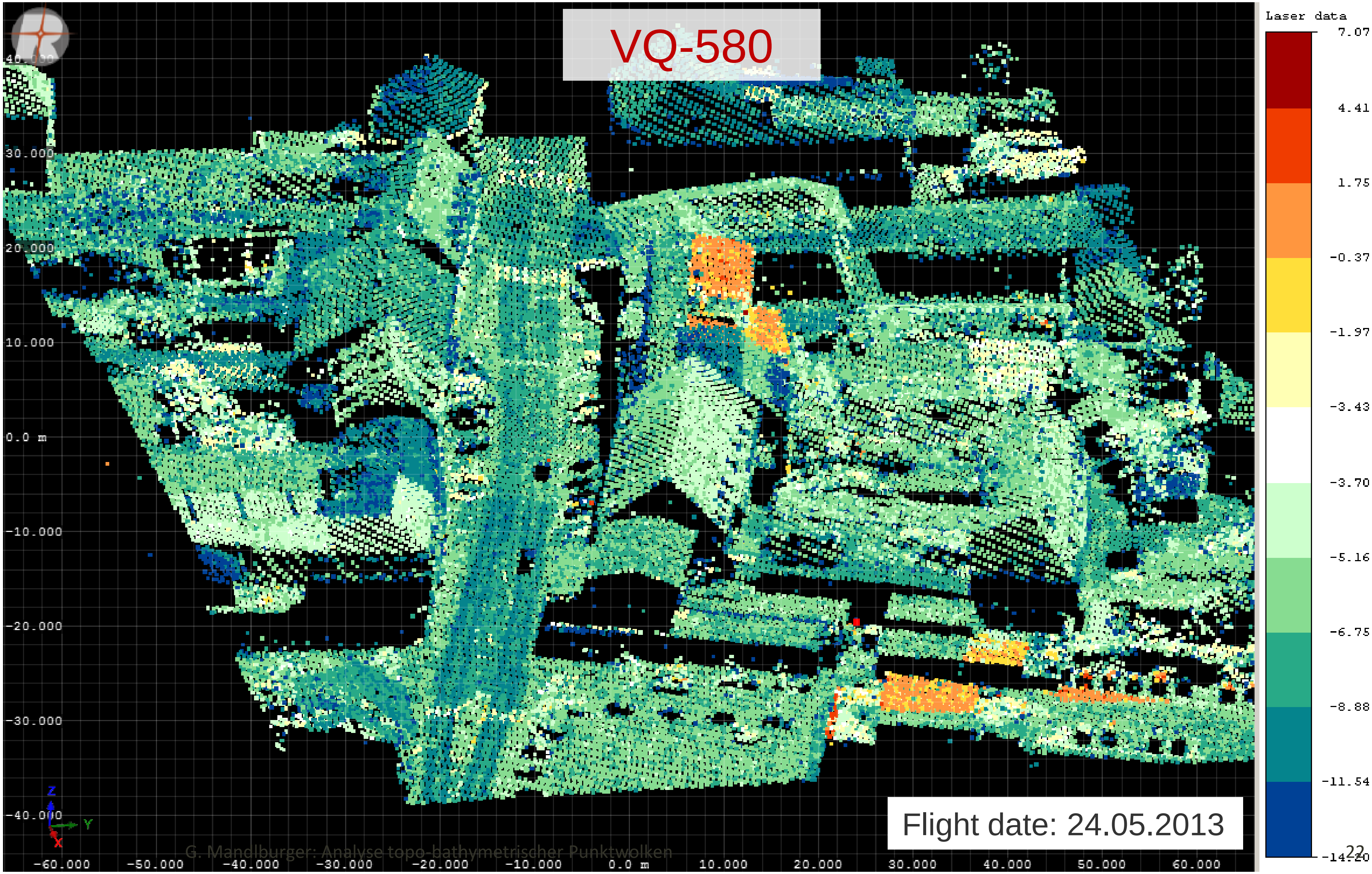
# Reflectance [dB]



# Reflectance [dB]



# Reflectance [dB]



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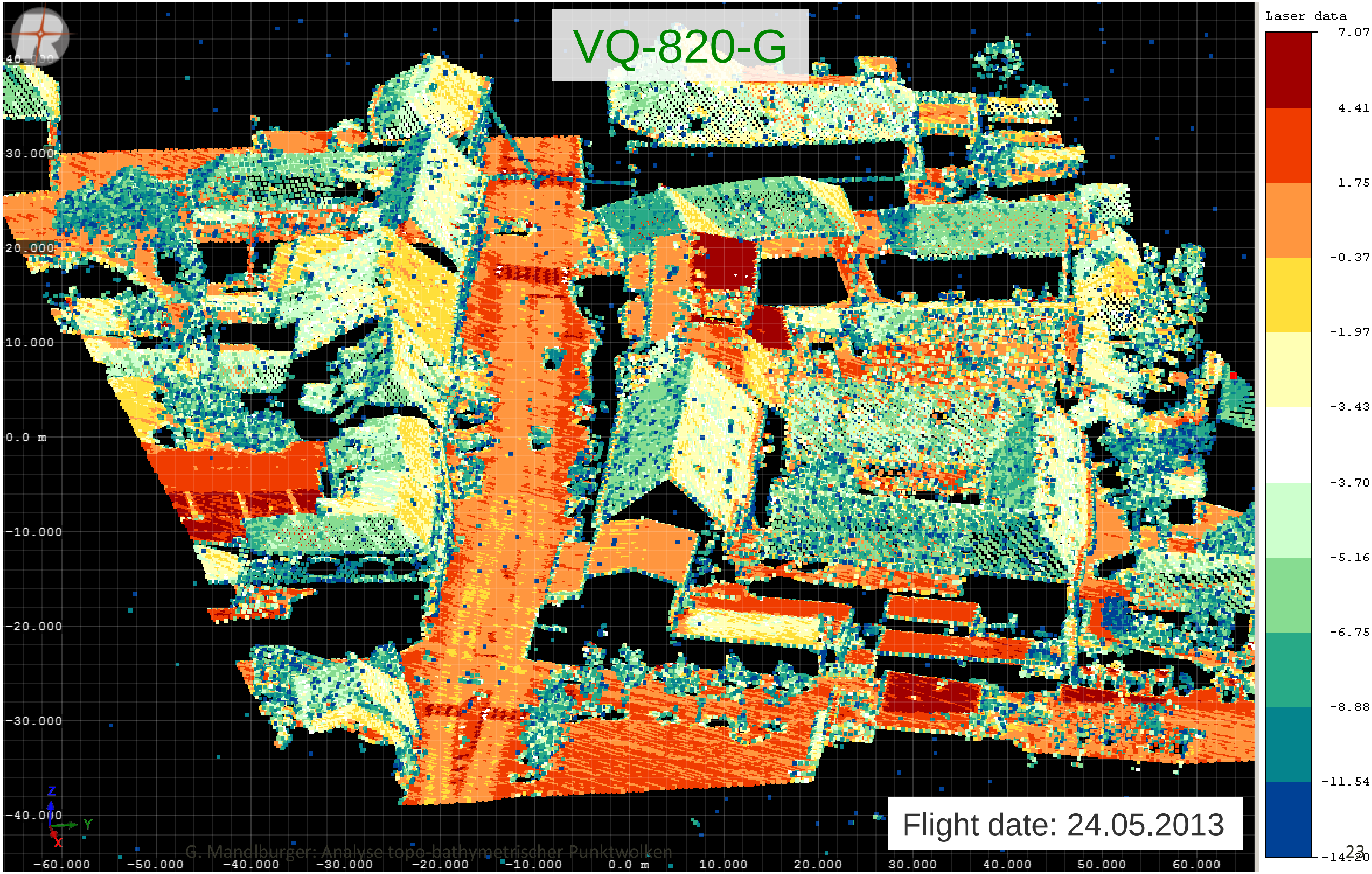

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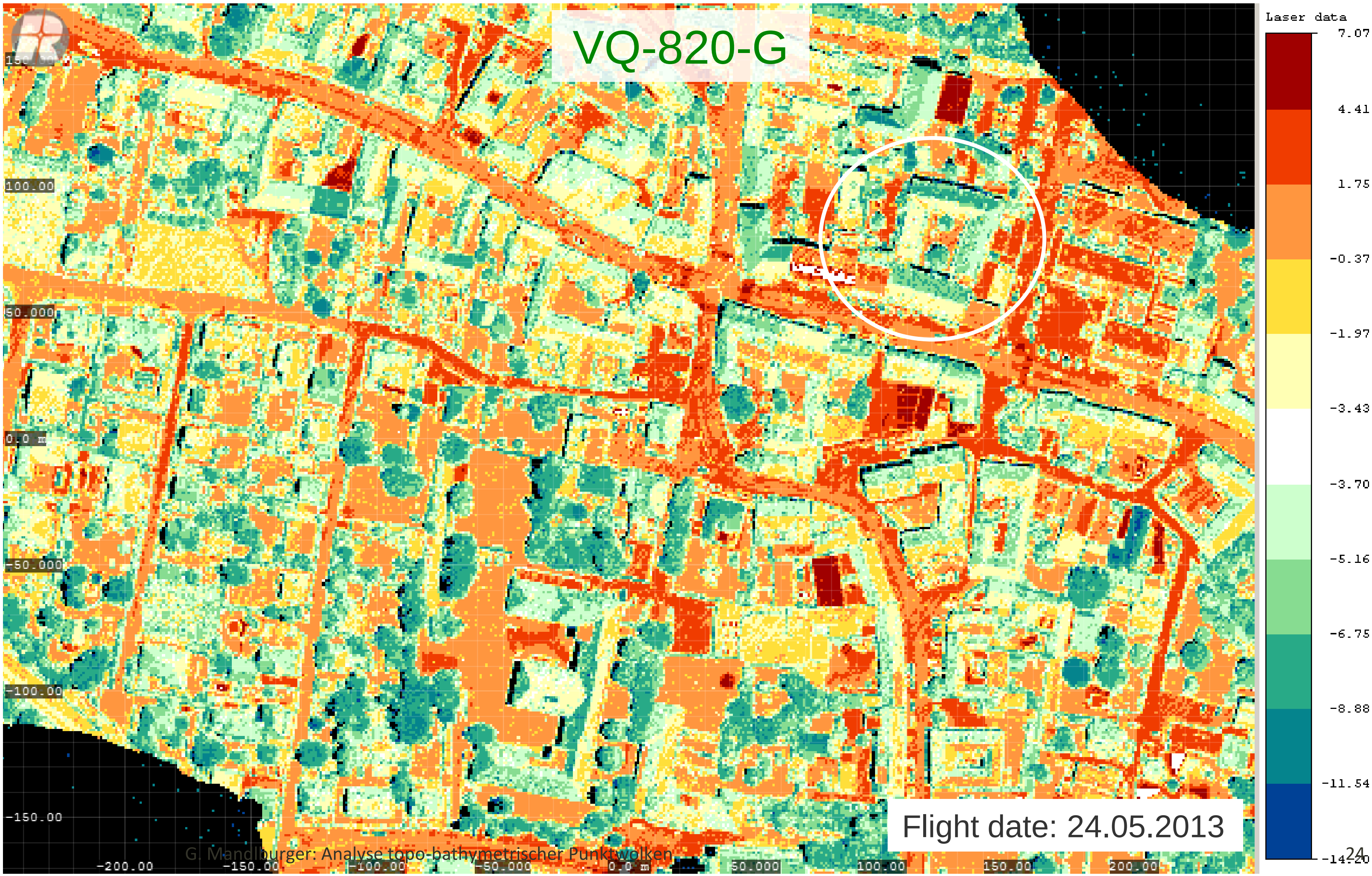

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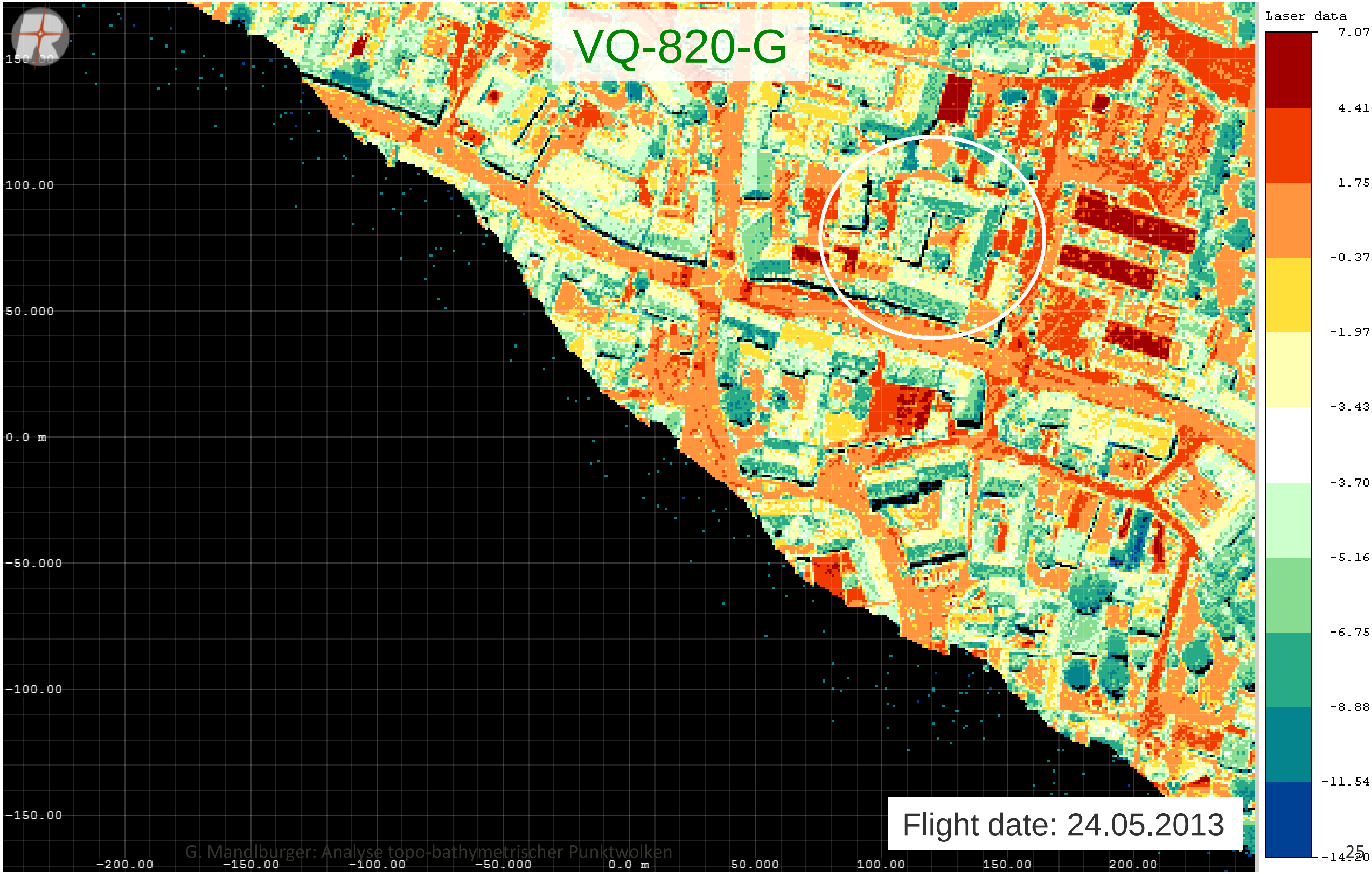
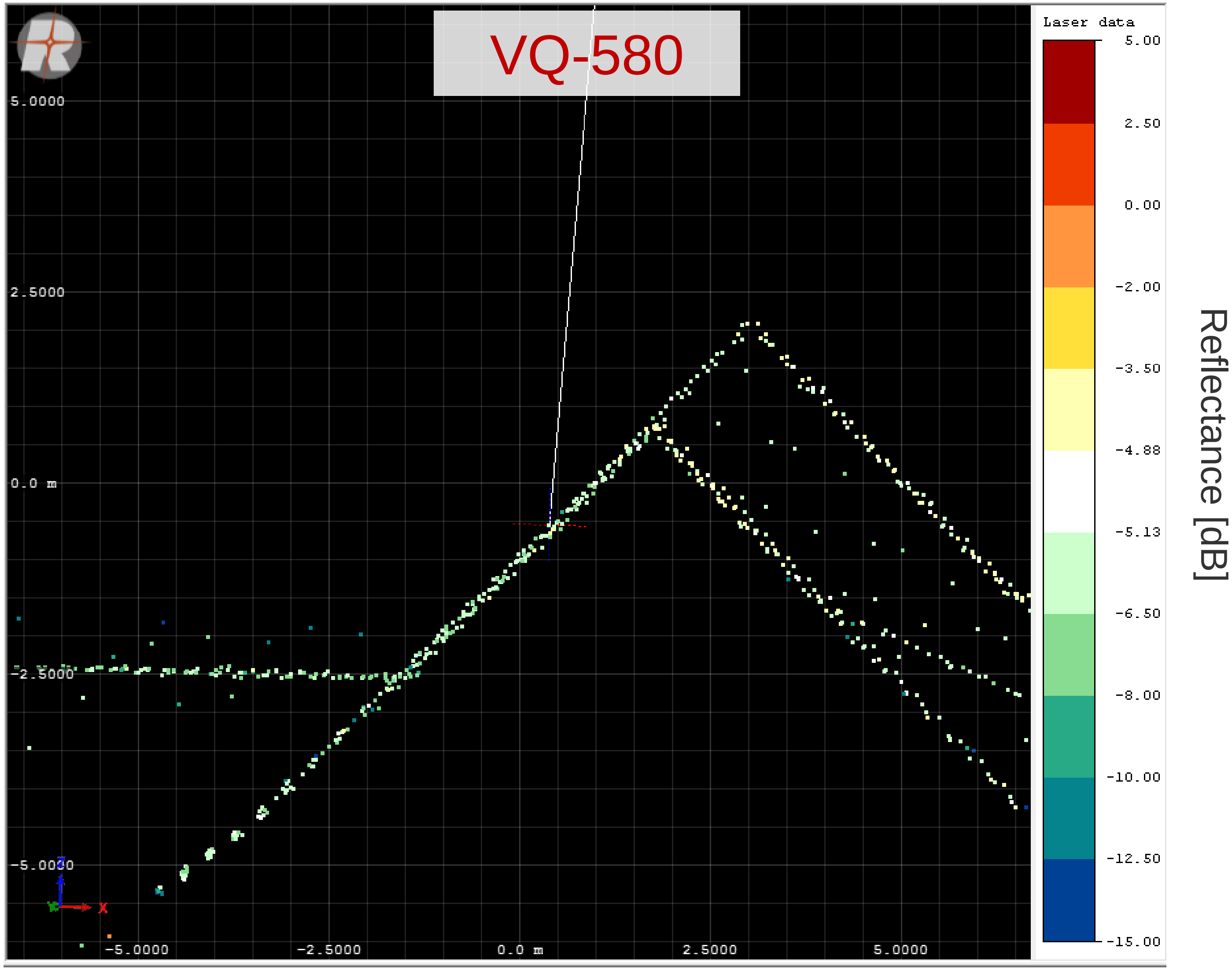
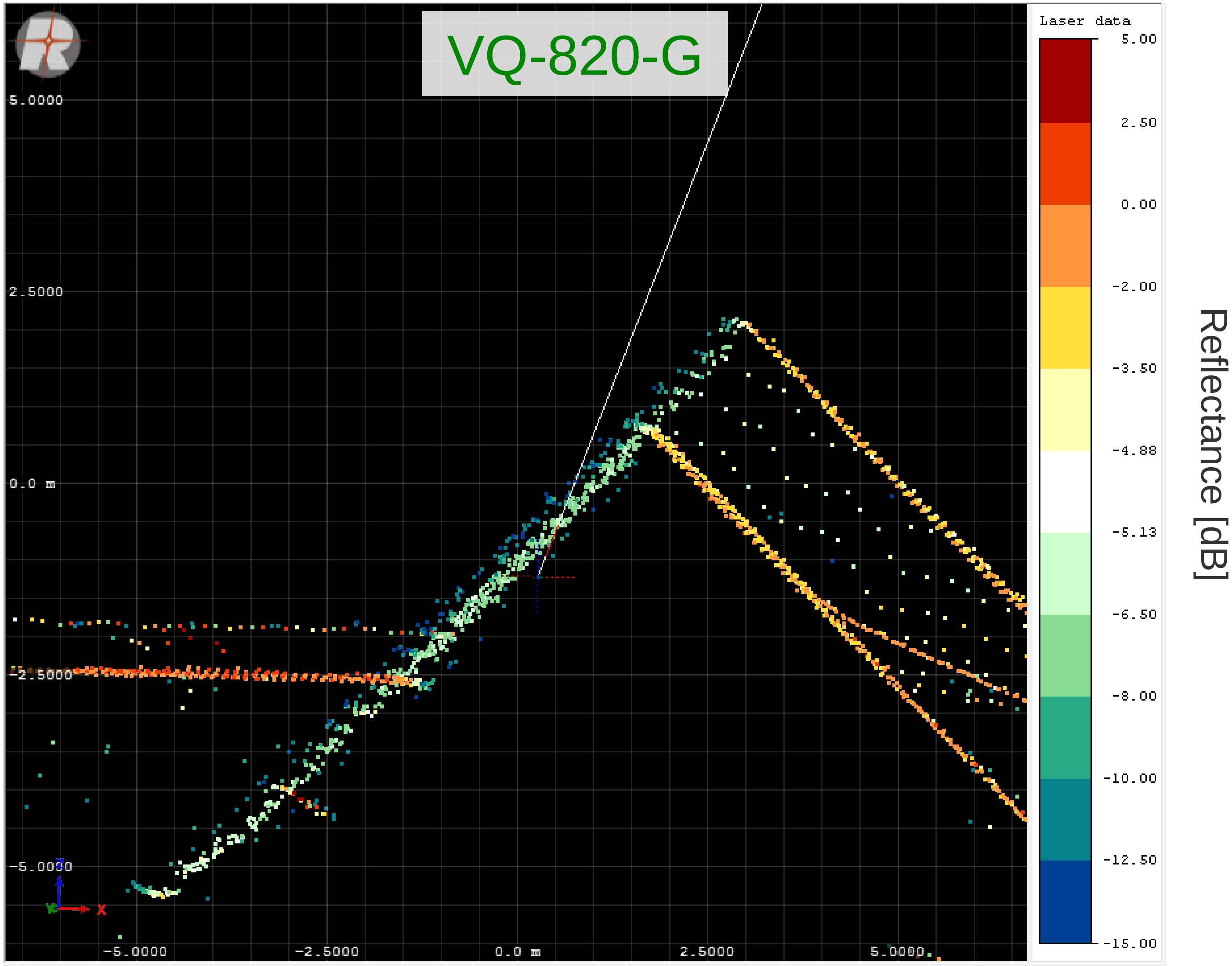


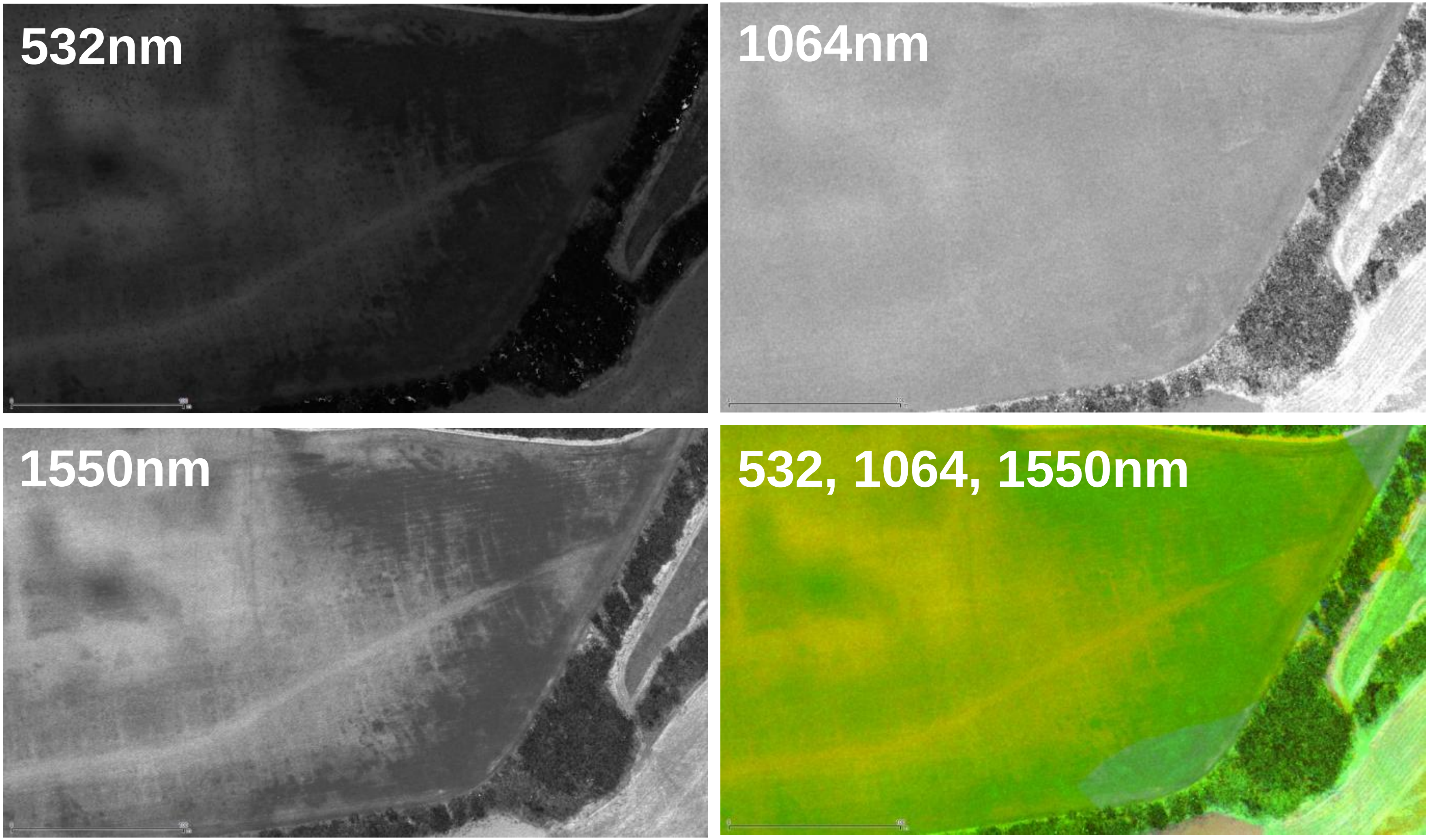
# Incidence angle dependency I



# Incidence angle dependency II

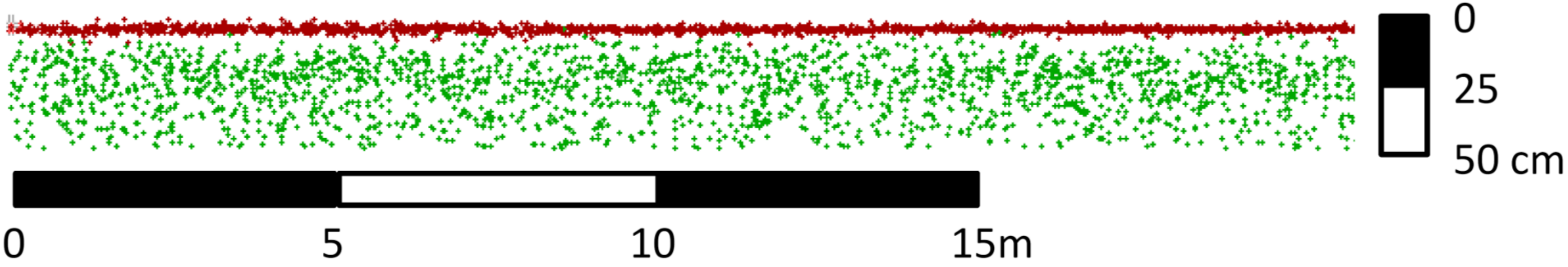


# Archaeological features observed with different wavelengths

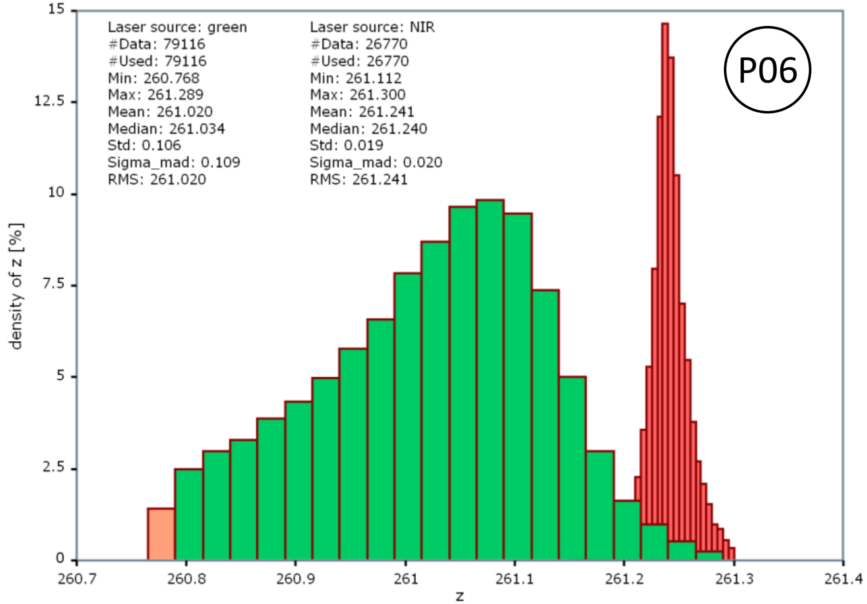


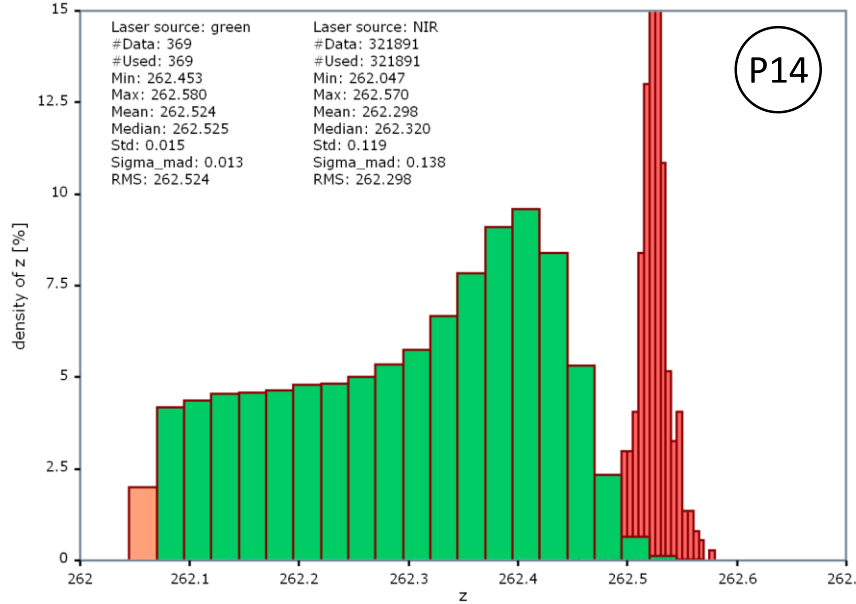
# Interaction of laser signal with medium water

- For obtaining **correct water depths** accurate knowledge of the **water surface** (air-water-interface) is mandatory.
- Modern topo-bathymetric small foot print laser scanners do **no longer** use the primary near infrared (**NI**R) signal (λ=1064nm) but only emit and receive the frequency doubled **green signal** (λ=532nm).
- The **point of reflection** of the **green pulse** on the **water surface** is **not well known** but penetration into the top layer of the water column is possible. It is, thus, not guaranteed that the first echo is from the air-water-interface.



# Statistical Analysis: NIR - Green



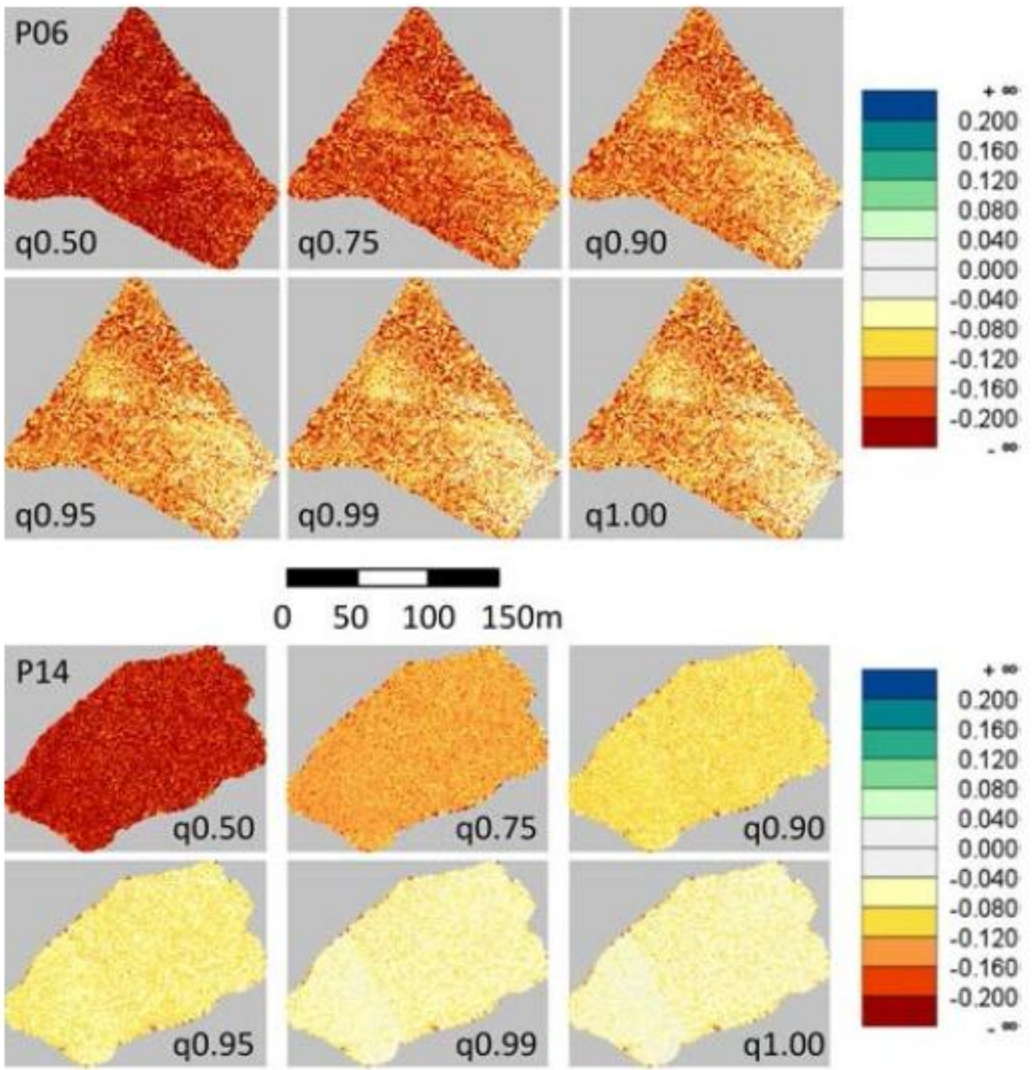




| | NIR | PID02 | PID04 | PID06 | PID07 | PID10 | PID14 | RID02 | RID04 |
|---|---|---|---|---|---|---|---|---|---|
| mean [m] | NIR | 260.13 | 260.91 | 261.24 | 261.29 | 262.00 | 262.52 | 259.96 | 260.21 |
| $\sigma_{mad}$ [m] | NIR | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02 |
| density [pts/m$^2$] | NIR | 1.20 | 0.75 | 1.73 | 1.01 | 2.25 | 0.03 | 0.90 | 2.25 |
| mean [m] | green | 259.89 | 260.67 | 261.02 | 261.05 | 261.87 | 262.30 | 259.82 | 260.06 |
| median [m] | green | 259.90 | 260.68 | 261.03 | 261.06 | 261.94 | 262.32 | 259.83 | 260.06 |
| $\sigma_{mad}$ [m] | green | 0.12 | 0.12 | 0.11 | 0.11 | 0.09 | 0.14 | 0.09 | 0.10 |
| density [pts/m$^2$] | green | 12.83 | 8.00 | 5.12 | 7.46 | 8.16 | 22.74 | 20.55 | 19.00 |

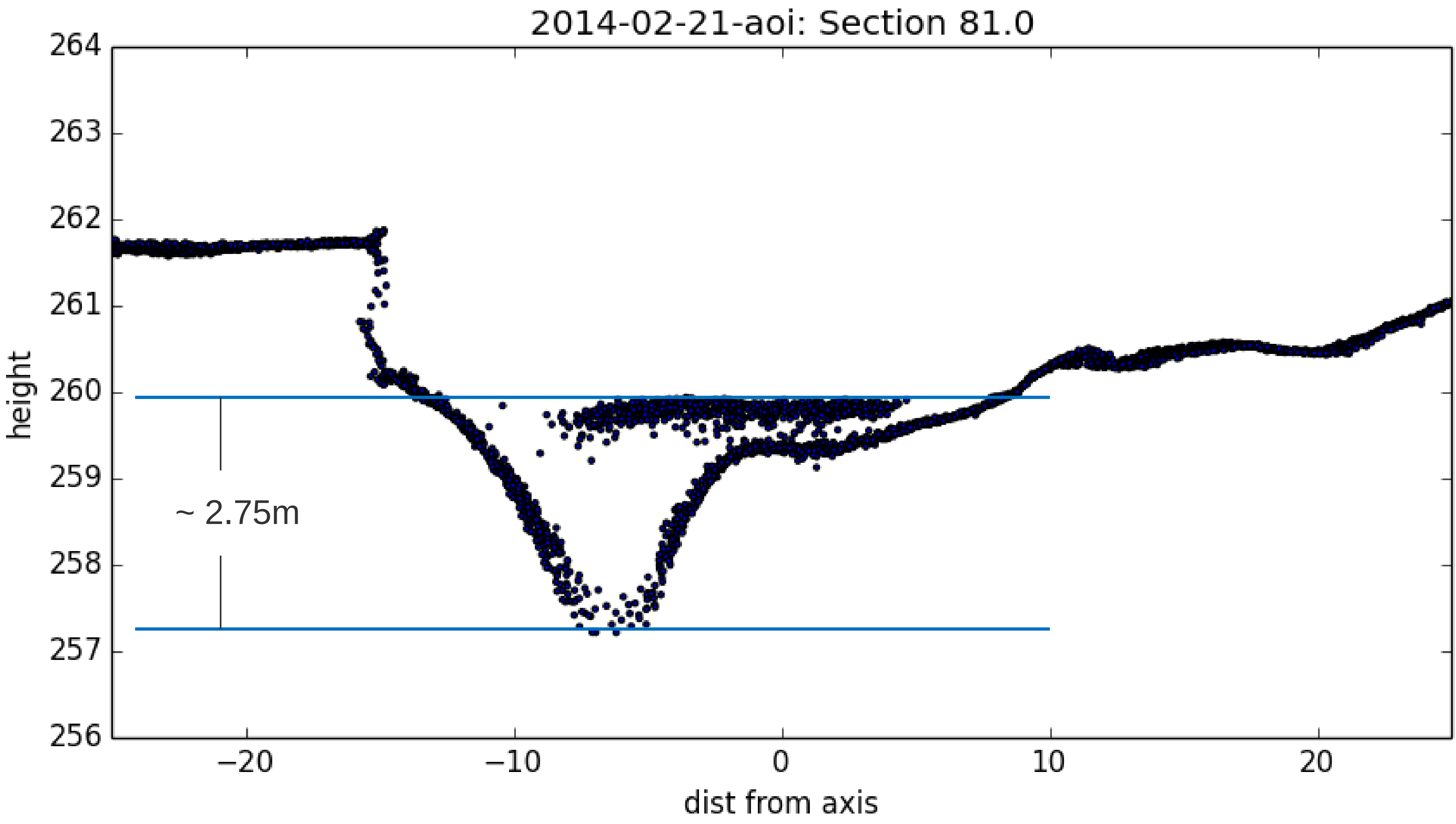
Table 1: Statistical analysis of z-distribution of nir and green water surface echoes

# Statistical Analysis: Green Signal w.r.t. NIR as reference

| | 0.5 m | 1.0 m | 2.0 m | 5.0 m | 10.0 m |
|---|---|---|---|---|---|
| **P06** | | | | | |
| q0.50 | -0.22 | -0.22 | -0.21 | -0.21 | -0.21 |
| q0.75 | -0.18 | -0.17 | -0.15 | -0.15 | -0.15 |
| q0.90 | -0.16 | -0.14 | -0.11 | -0.10 | -0.10 |
| q0.95 | -0.15 | -0.13 | -0.09 | -0.08 | -0.08 |
| q0.99 | -0.15 | -0.12 | -0.07 | -0.04 | -0.03 |
| q1.00 | -0.15 | -0.12 | -0.07 | -0.02 | 0.00 |
| **P14** | | | | | |
| q0.50 | -0.21 | -0.21 | -0.20 | -0.20 | -0.20 |
| q0.75 | -0.15 | -0.13 | -0.13 | -0.12 | -0.13 |
| q0.90 | -0.11 | -0.09 | -0.09 | -0.08 | -0.09 |
| q0.95 | -0.10 | -0.08 | -0.07 | -0.07 | -0.07 |
| q0.99 | -0.09 | -0.06 | -0.04 | -0.04 | -0.04 |
| q1.00 | -0.09 | -0.05 | -0.03 | -0.00 | 0.01 |
| **R02** | | | | | |
| q0.50 | -0.13 | -0.13 | -0.13 | -0.13 | -0.13 |
| q0.75 | -0.10 | -0.09 | -0.09 | -0.09 | -0.09 |
| q0.90 | -0.08 | -0.06 | -0.06 | -0.05 | -0.06 |
| q0.95 | -0.07 | -0.05 | -0.05 | -0.03 | -0.05 |
| q0.99 | -0.06 | -0.04 | -0.03 | -0.01 | -0.03 |
| q1.00 | -0.06 | -0.03 | -0.02 | 0.01 | -0.00 |



# Interaction of green laser with medium water



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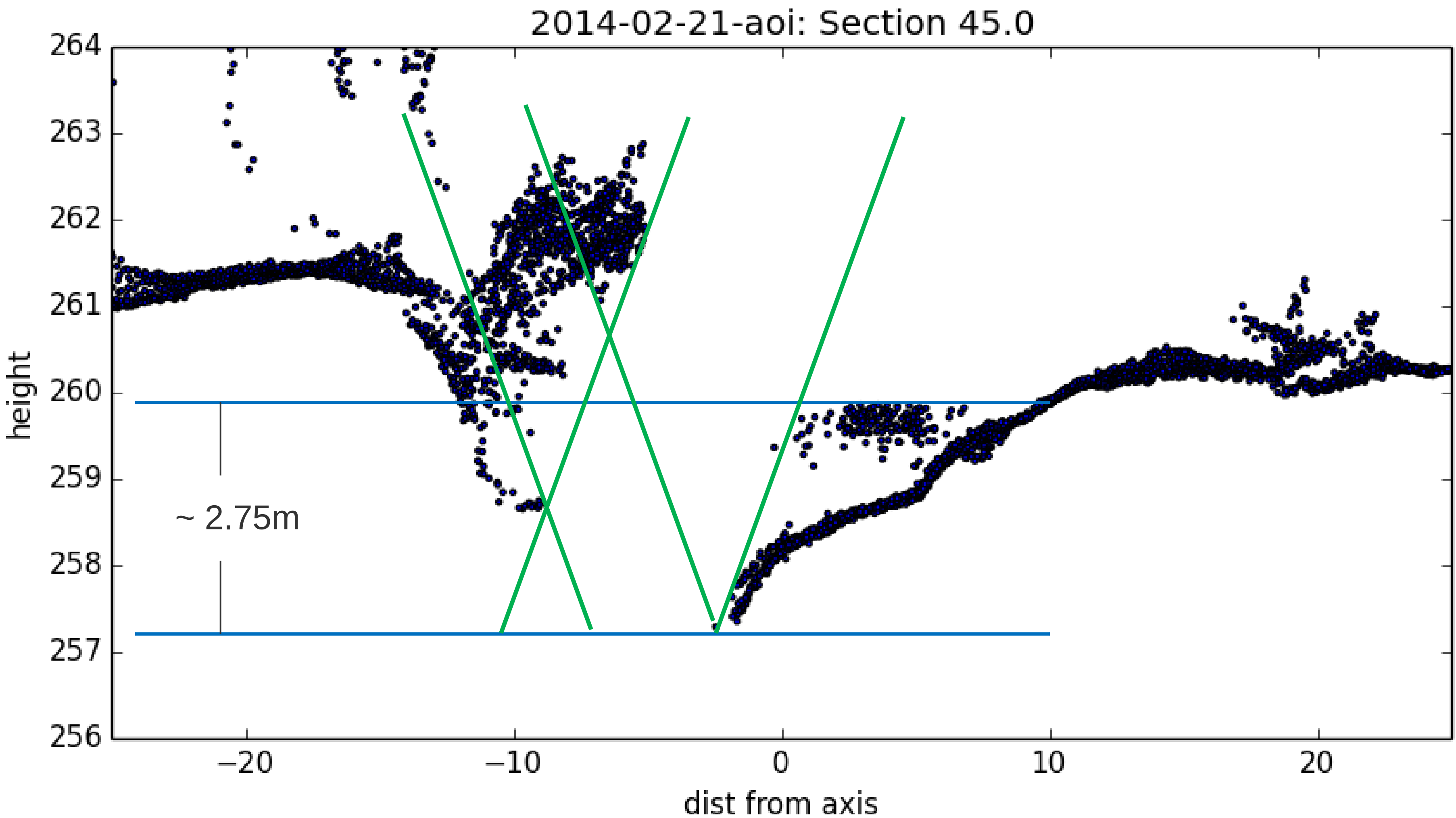

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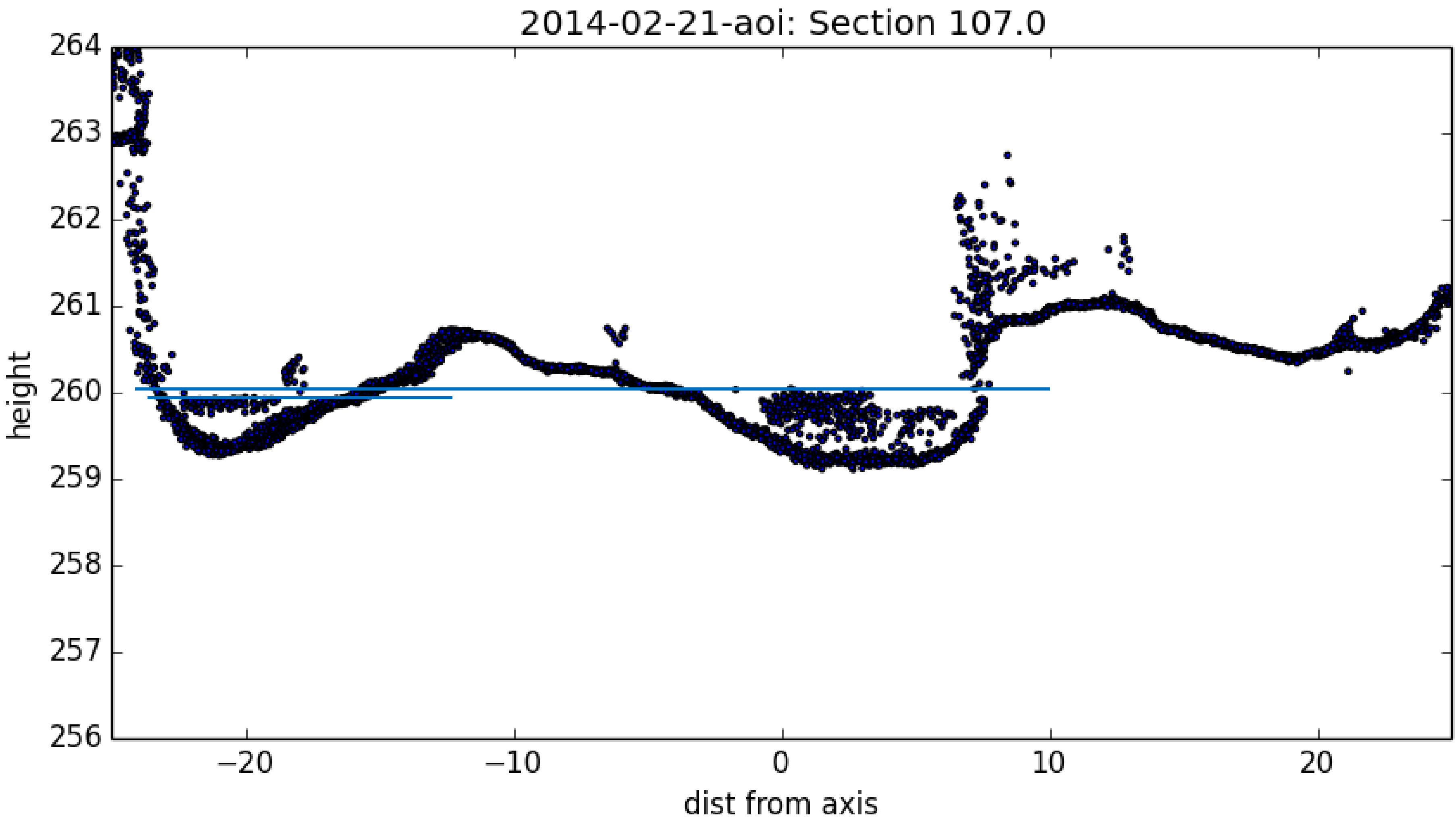
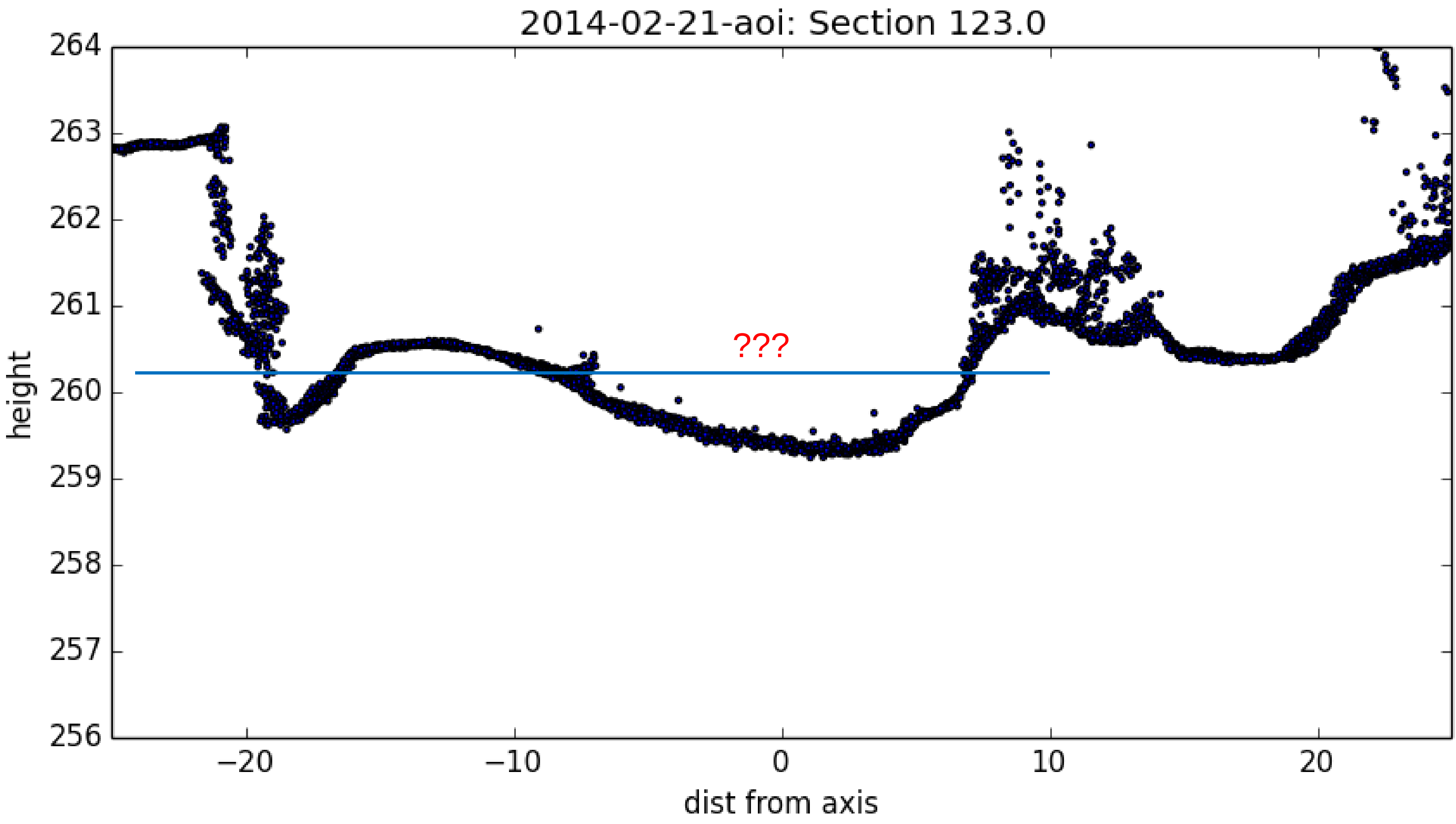
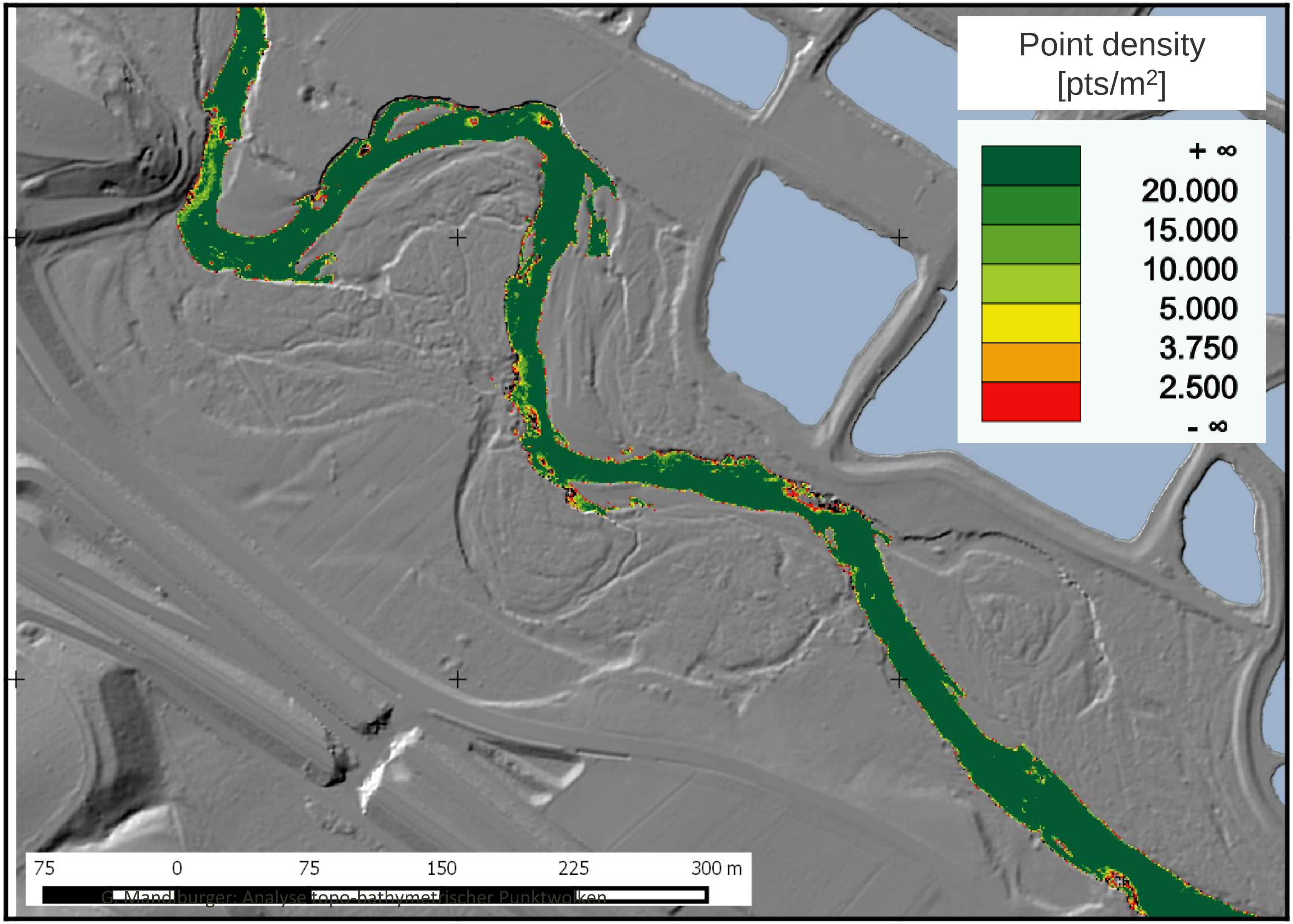


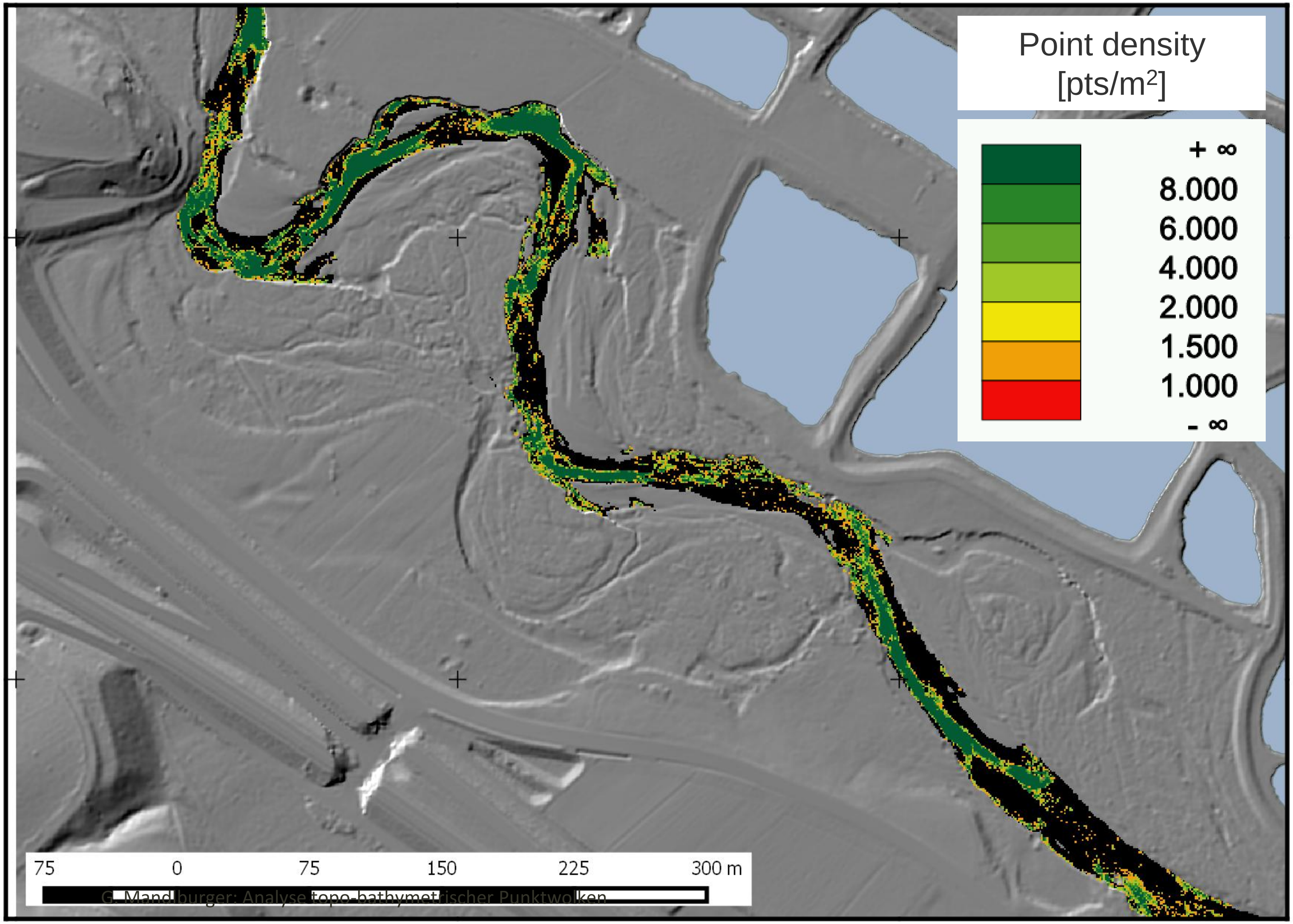
# Interaction of green laser with medium water



# Point density of river bed points – February 2014



# Point density of water surface points – February 2014



# Comparison: Coverage of water bottom/surface returns

| | Total area | Bottom return area | | Surface return area | |
|---|---|---|---|---|---|
| | [$m^2$] | [$m^2$] | [%] | [$m^2$] | [%] |
| **Apr-13** | 37.235 | 35.452 | **95,2** | 29.055 | **78,0** |
| **Oct-13** | 30.742 | 29.390 | **95,6** | 16.860 | **54,8** |
| **Feb-14** | 32.168 | 31.643 | **98,4** | 13.587 | **42,2** |
| **Jun-14** | 32.483 | 31.619 | **97,3** | 21.800 | **67,1** |

- River bottom returns: constantly over 95% → close to full river bed coverage
- Water surface coverage: 40-80% (the clearer the water, the less water surface echoes, VQ-880-G more sensitive → more water surface echoes)

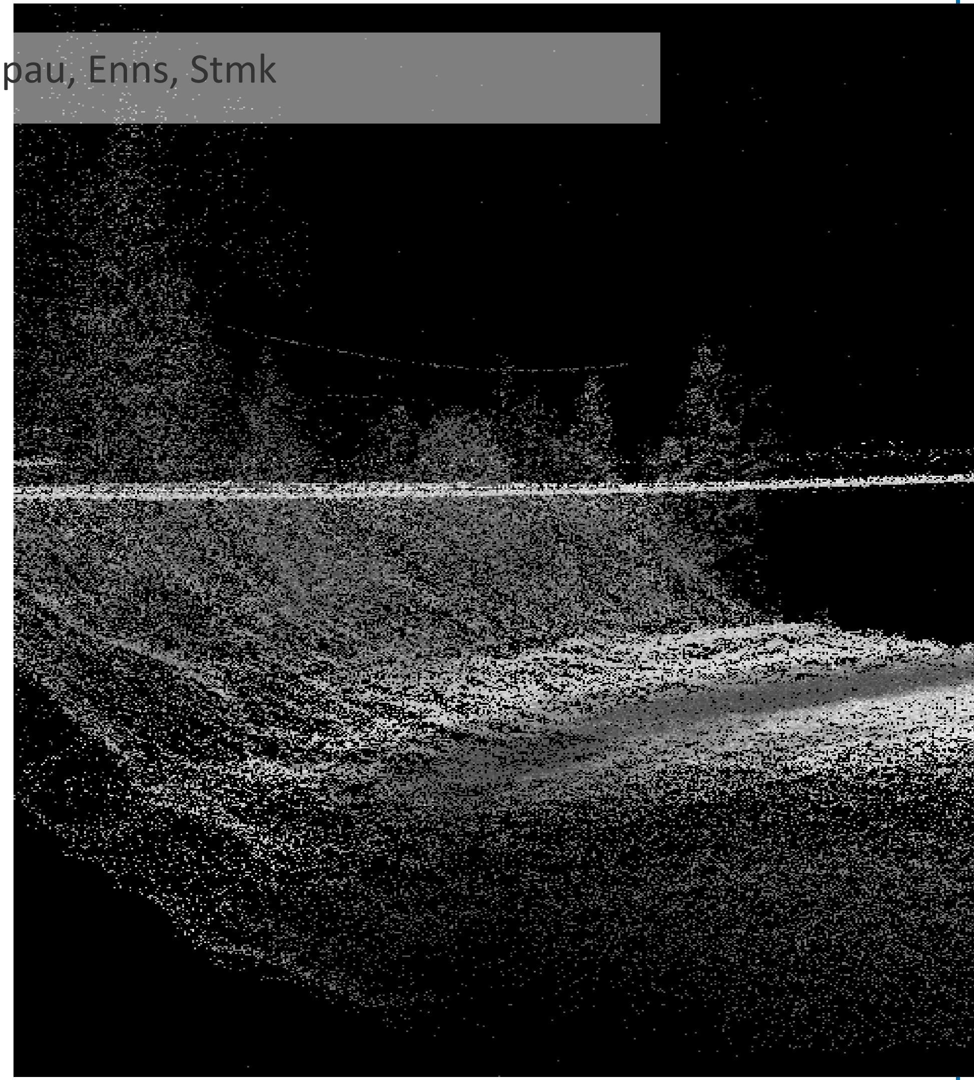
# Conclusions and outlook

- **Green laser** pulse is **short** and (relatively) **broad** (eye safety)
- Pronounced **dependency** from **incidence angle**
- Consequences for **data capturing**:
  - Flight planning considering forward/backward/left/right viewing angles
  - VQ-820-G: 50% overlap
  - VQ-880-G: forward/backward look within flight line (circular pattern)
- Consequences for **data processing**:
  - Incidence angle: requires laser beam direction + surface normal direction
  - Local point weighting based on incidence angle
  - (Step) edge problem: → Segmentation of homogeneous surface parts
- **Interaction** of laser beam with **medium water**
  - Reliable detection of water surface echoes
  - Reliable separation of water surface / volume backscatter / river bed
  - Specific analysis of full echo waveforms required

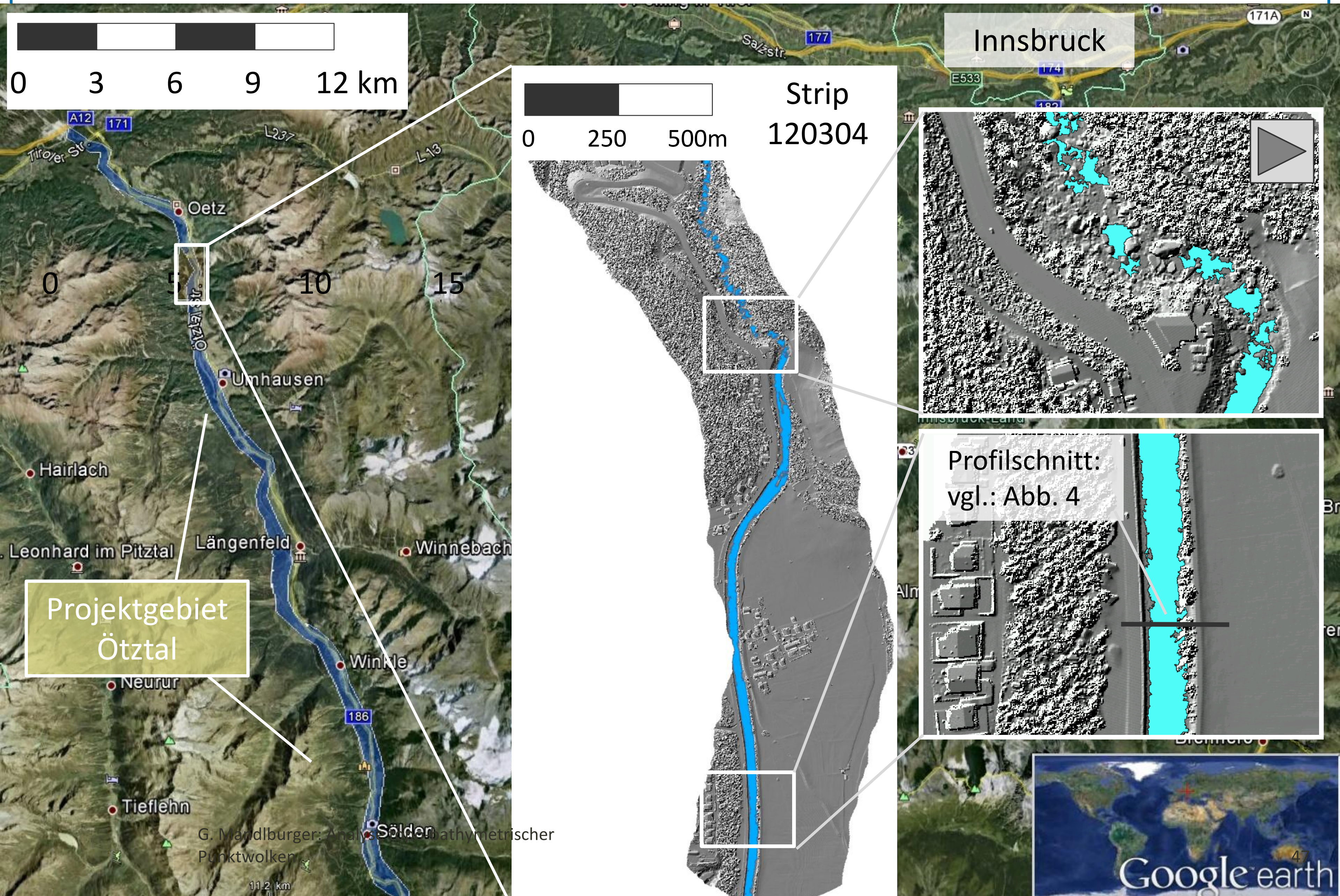
# Danke für ihre Aufmerksamkeit

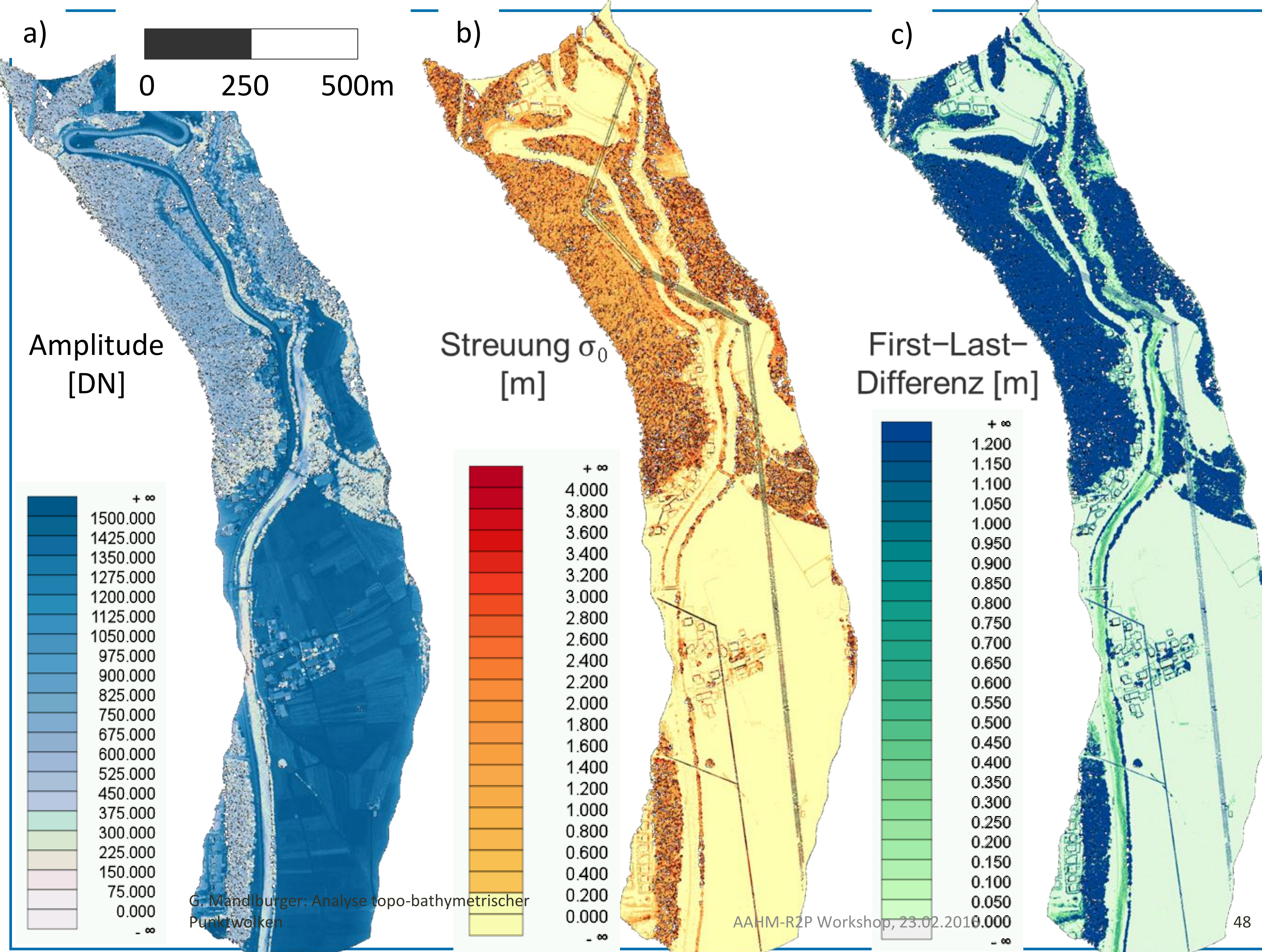
# Topo-bathymetrische 3D-Punktwolke
# Riegl VQ-820-G

Verbund: Krippau, Enns, Stmk



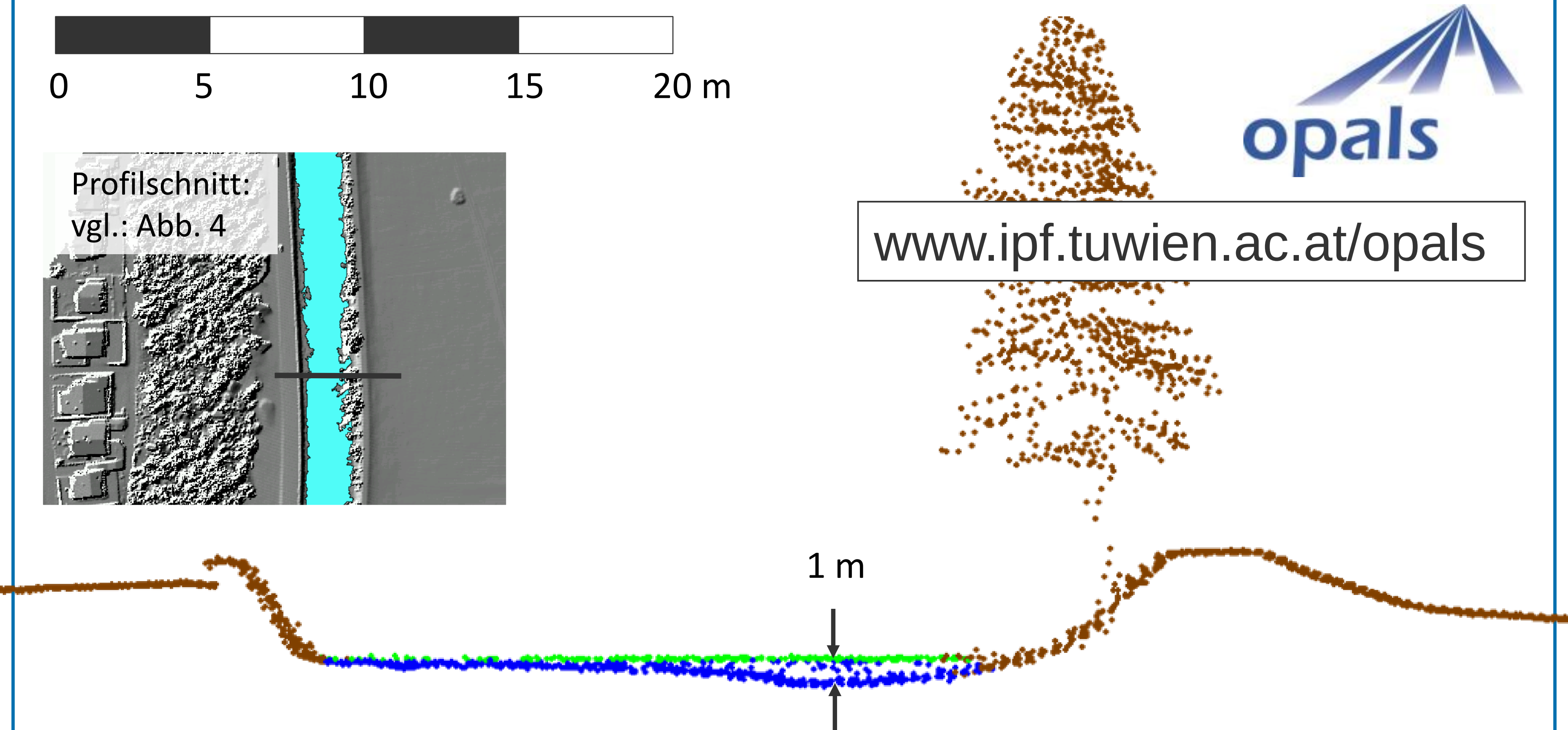
# Test area: Ötztaler Ache





a)
0
250
500m
Amplitude
[DN]
+ ∞
1500.000
1425.000
1350.000
1275.000
1200.000
1125.000
1050.000
975.000
900.000
825.000
750.000
675.000
600.000
525.000
450.000
375.000
300.000
225.000
150.000
75.000
0.000
- ∞
b)
Streuung $\sigma_0$
[m]
+ ∞
4.000
3.800
3.600
3.400
3.200
3.000
2.800
2.600
2.400
2.200
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
- ∞
c)
First-Last-
Differenz [m]
+ ∞
1.200
1.150
1.100
1.050
1.000
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
- ∞

# Classified point cloud (cross section)




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

# Inhalt

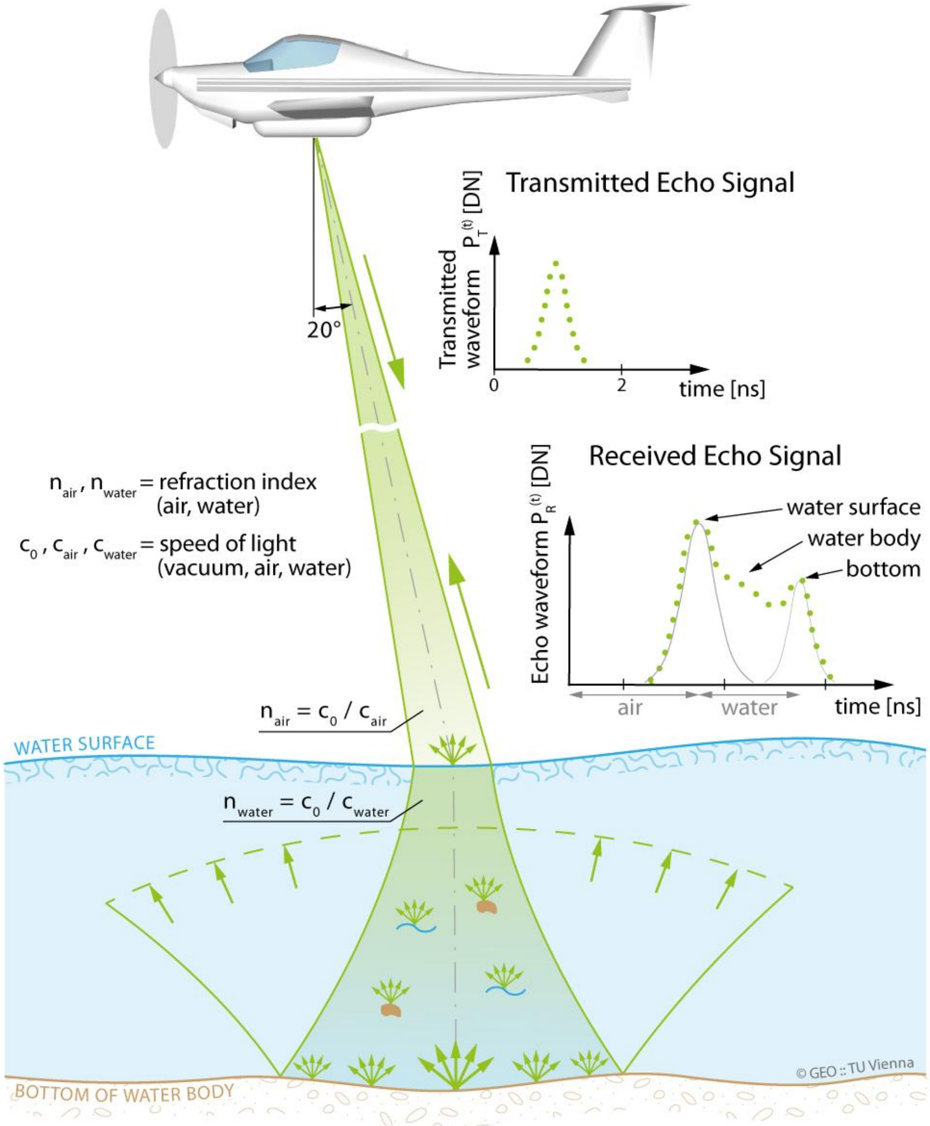
- **Überblick Airborne Laser Bathymetry (ALB)**
  - Messprinzip
  - Sensoren (Riegl VQ-820-G, VQ-880-G)
- **Untersuchungsgebiet Pielach / Neubacher Au**
- **Dokumentation der Morphodynamik** basierend auf:
  - Vergleich von Querschnitten
  - Differenzmodellen (Quantifizierung von Änderungen)
- **Zusammenfassung und Ausblick**

# 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**) [...]. *)

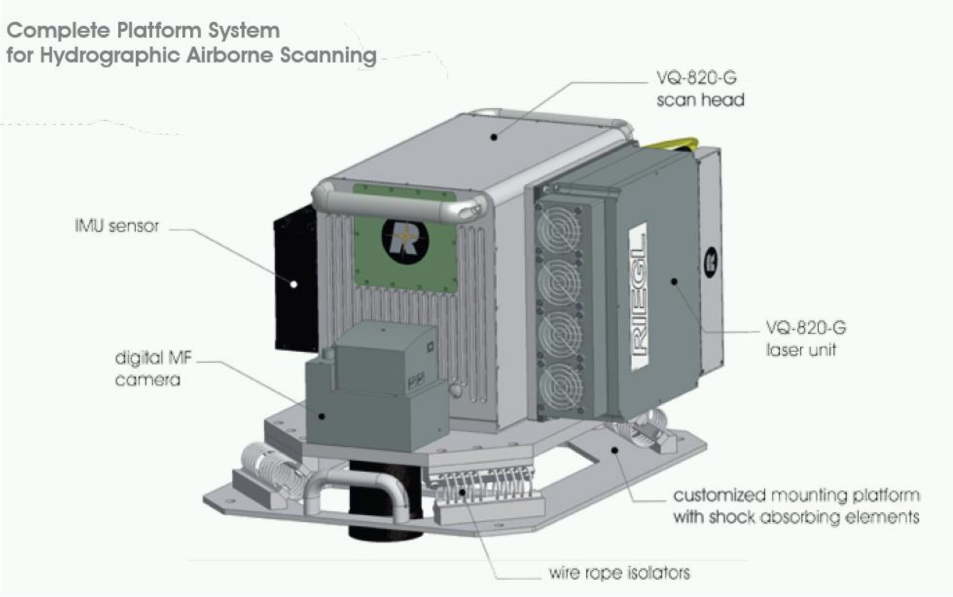
*) C. Guenther et. al: **MEETING THE ACCURACY CHALLENGE IN AIRBORNE LIDAR BATHYMETRY,** EARSeL-SIG-Workshop LIDAR, Dresden, 2000

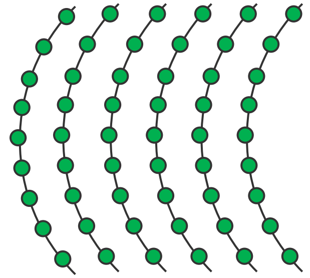
Laser source: λ=532nm, (Nd:Yag with frequency doubling)



# Riegl VQ-820-G topo-bathymetric laser scanner

| **Wavelength λ** | **532 nm** |
|---|---|
| Ranging accuracy | 25 mm |
| Min/max depth | **0-10 m (1 Secchi)** |
| Pulse repetition rate | **520 kHz (net: 200)** |
| Footprint @ 600 m | 60 cm |
| Pt dens. @ 600 m | **~15 pts/m²** |
| Full waveform | Online wfm proc |
| Scan pattern | Elliptic arcs |
| Laser Class | 3B |
| NOHD/ENOHD | 100 m / 600 m |
| Weight | **28 kg** |

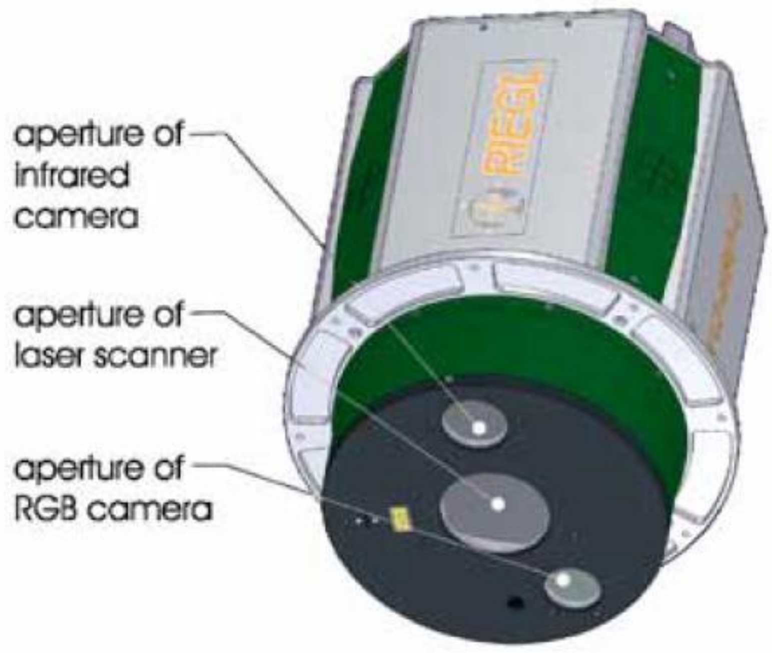


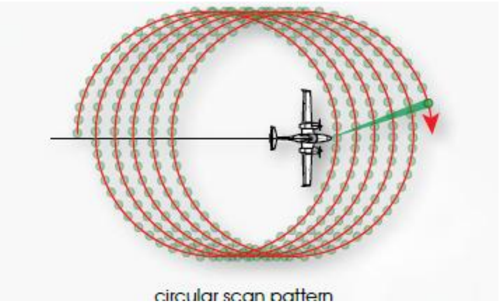



Source: www.riegl.com/nc/products/airborne-scanning/produktdetail/product/scanner/32/

# Riegl VQ-880-G topo-bathymetric laser scanner

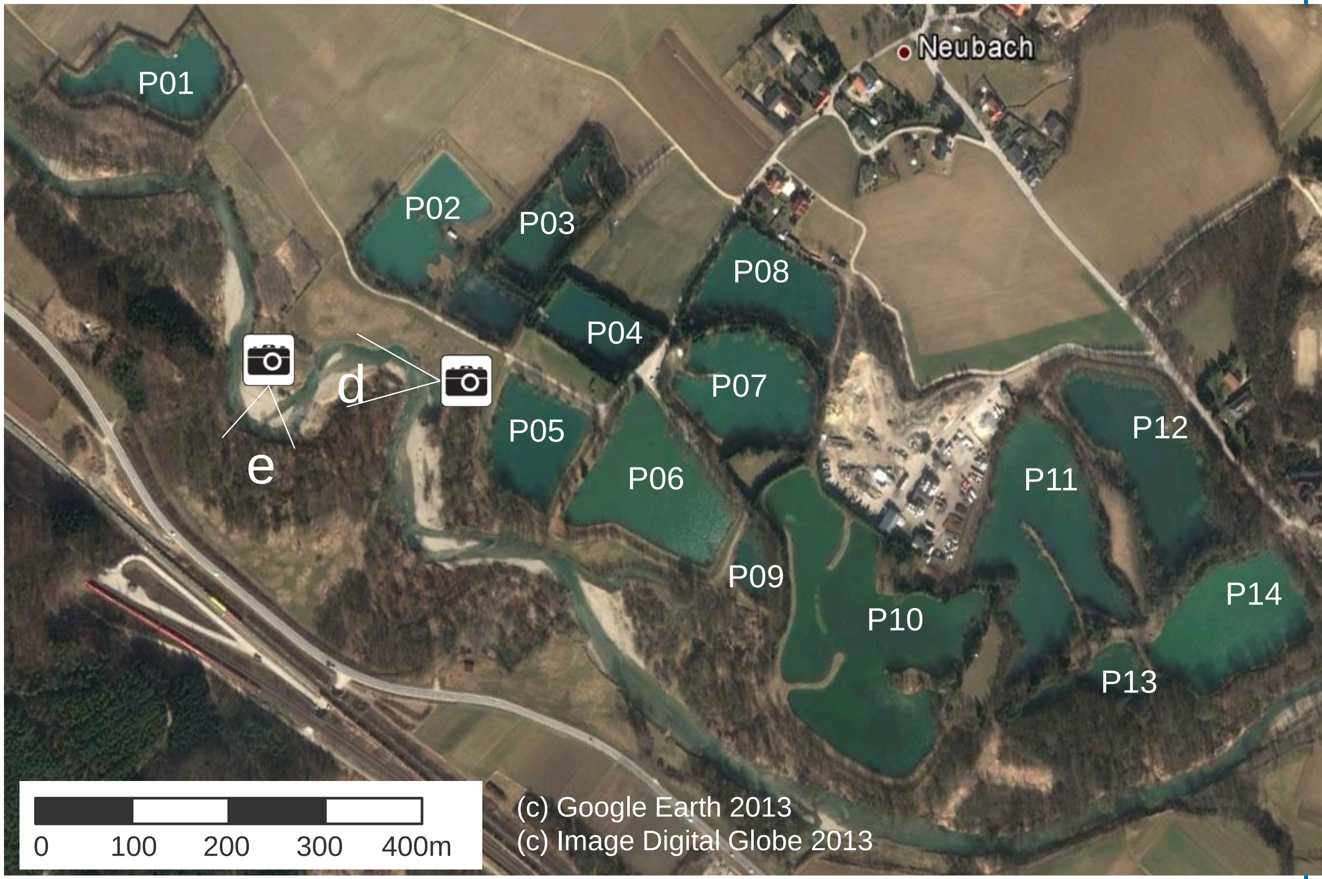
| **Wavelength λ** | **532 nm** |
|---|---|
| Ranging accuracy | 25 mm |
| Min/max depth | **0->15 m (1.5 Secchi)** |
| PRR=scan rate | **550 kHz** |
| Footprint @ 600 m | 42-120 cm (adjustable) |
| Pt dens. @ 600 m | **~50 pts/m²** |
| Full waveform | Online + post proc. |
| Scan pattern | Circles, 20° tilted |
| Laser Class | 4 |
| Laser energy | adjustable |
| Weight | **60 kg** |



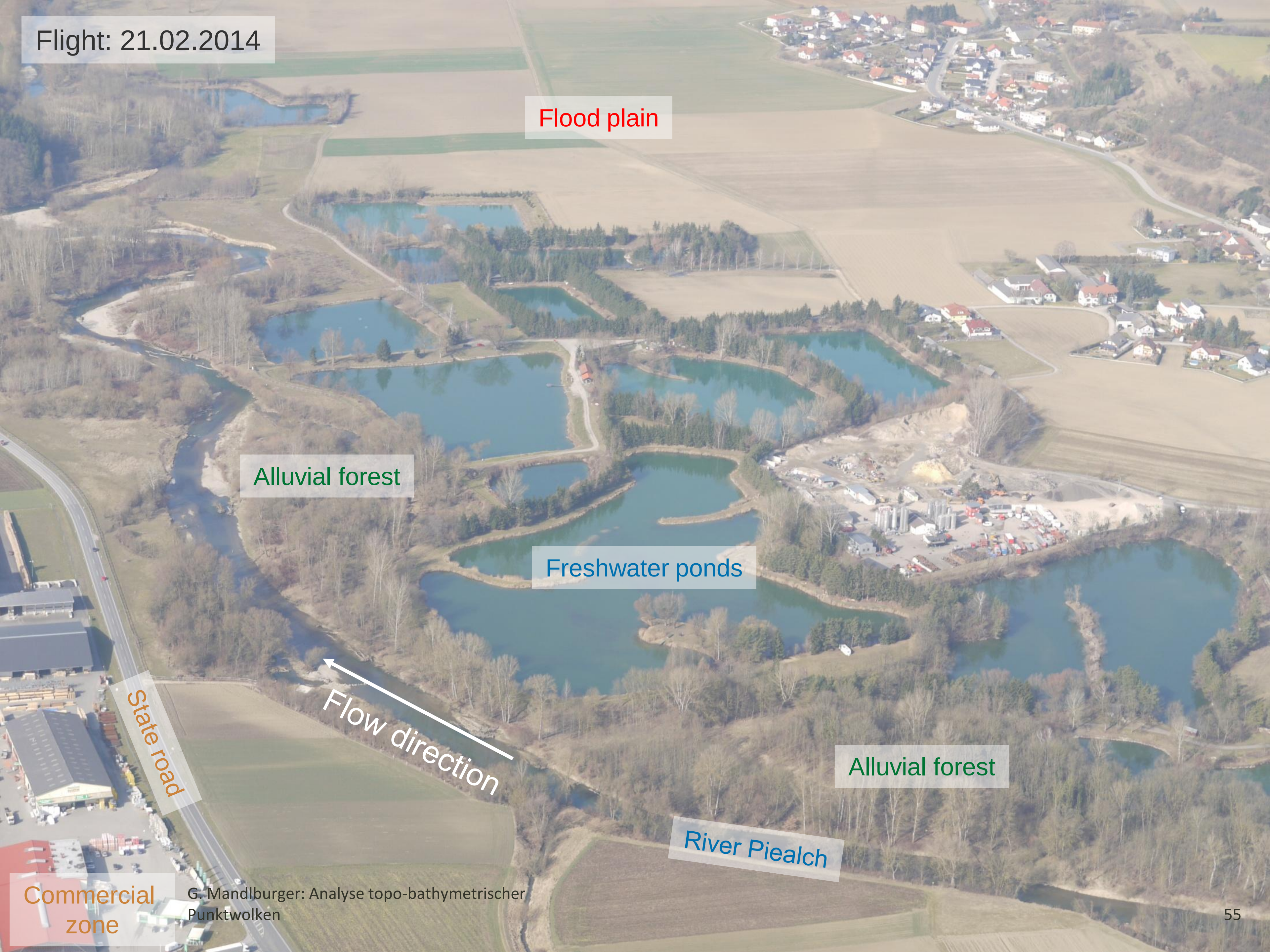




Source:
http://www.riegl.com/uploads/tx_pxpriegldownloads/DataSheet_VQ-880-G_2014-09-25_PRELIMINARY.pdf

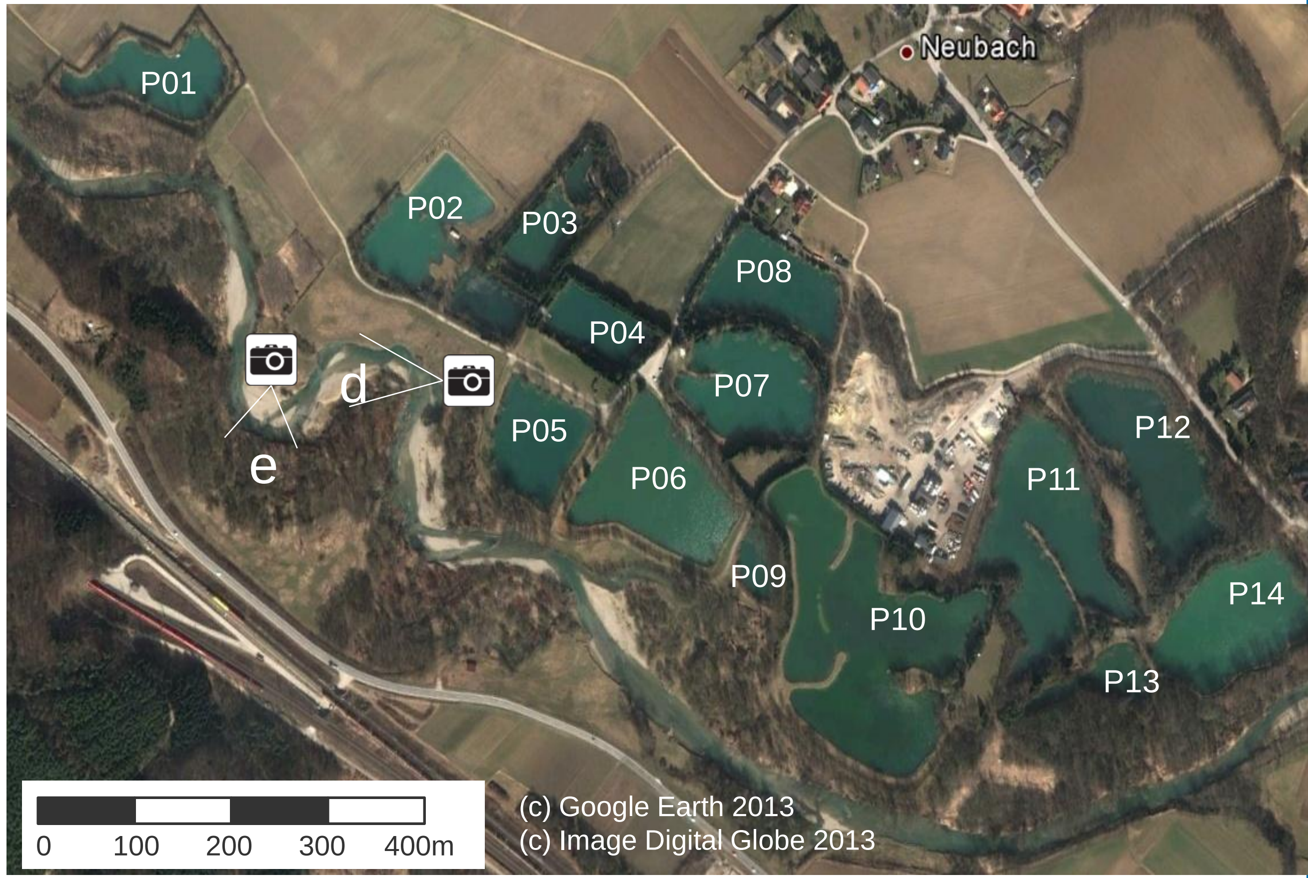
# Study area: Pielach – Neubacher Au I


Left: River Pielach, Right; Study area Neubacher Au

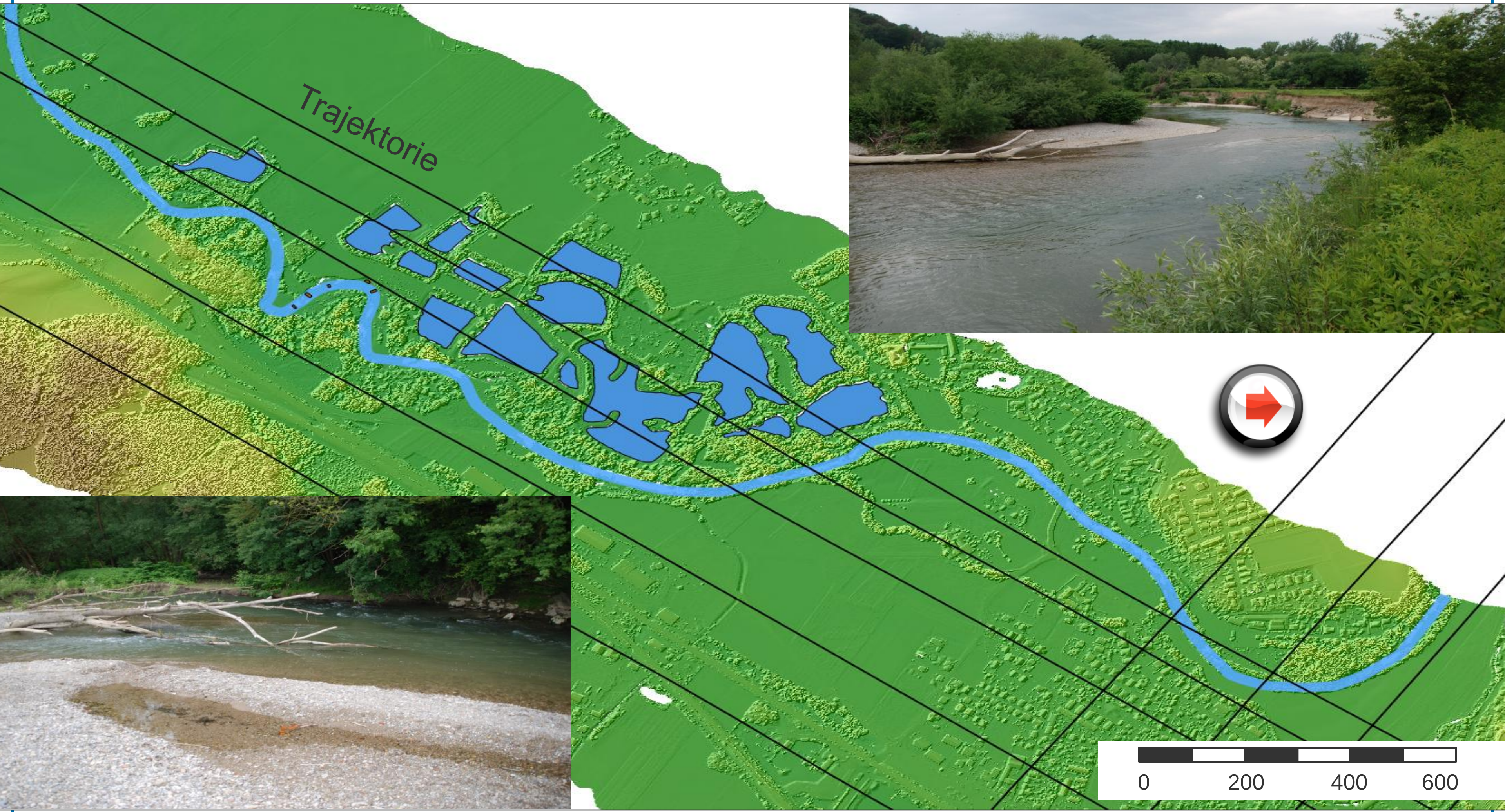

Flight: 21.02.2014
Flood plain
Alluvial forest
Freshwater ponds
State road
Flow direction
Alluvial forest
River Pielach
Commercial zone

# Untersuchungsgebiet: Pielach – Neubacher Au I

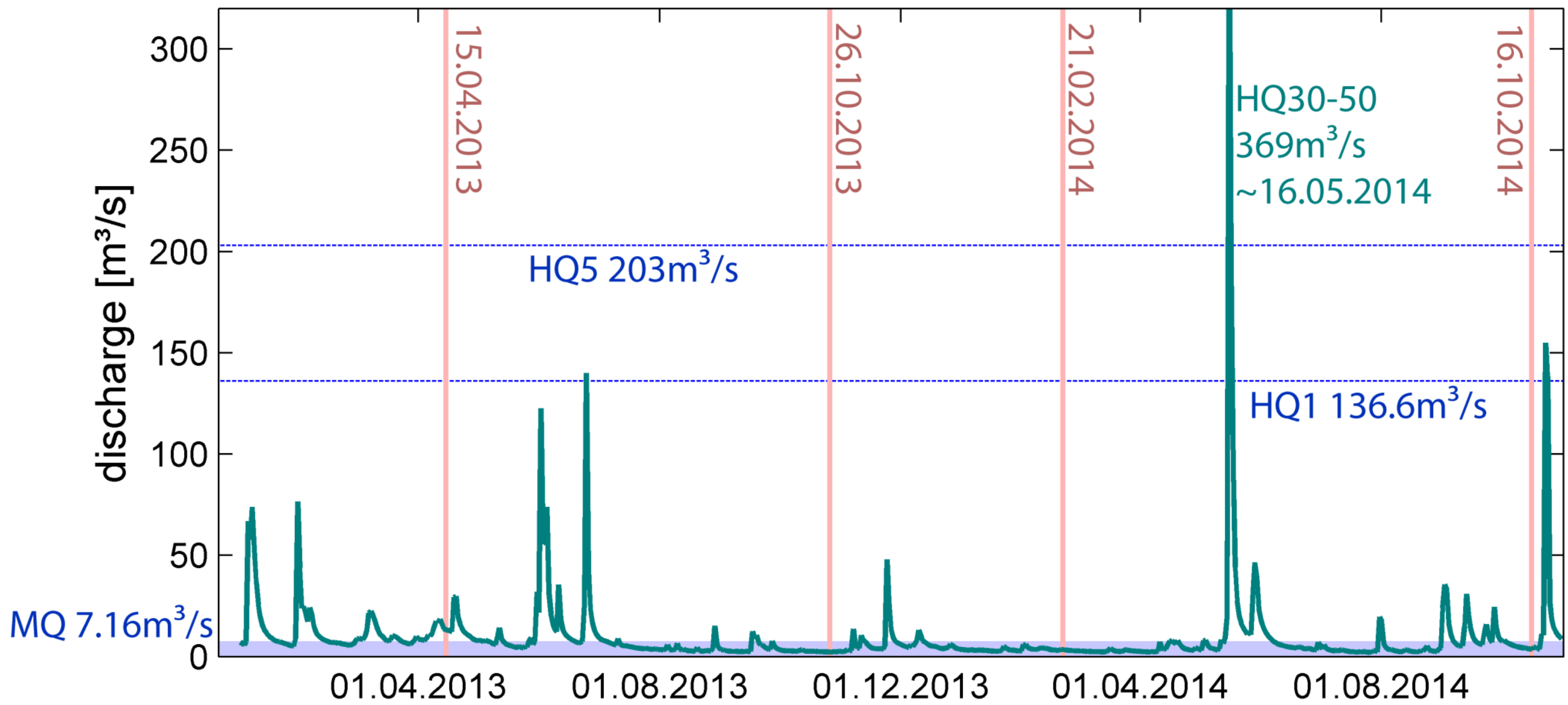




Links: Einzugsgebiet Pielach, Rechts; Untersuchungsgebiet Neubacher Au

# Untersuchungsgebiet: Pielach – Neubacher Au II



# Pielach – Abfluss: 2013-2014




**VQ-820-G** **VQ-820-G** **VQ-820-G** **VQ-880-G**

# Datenprozessierung

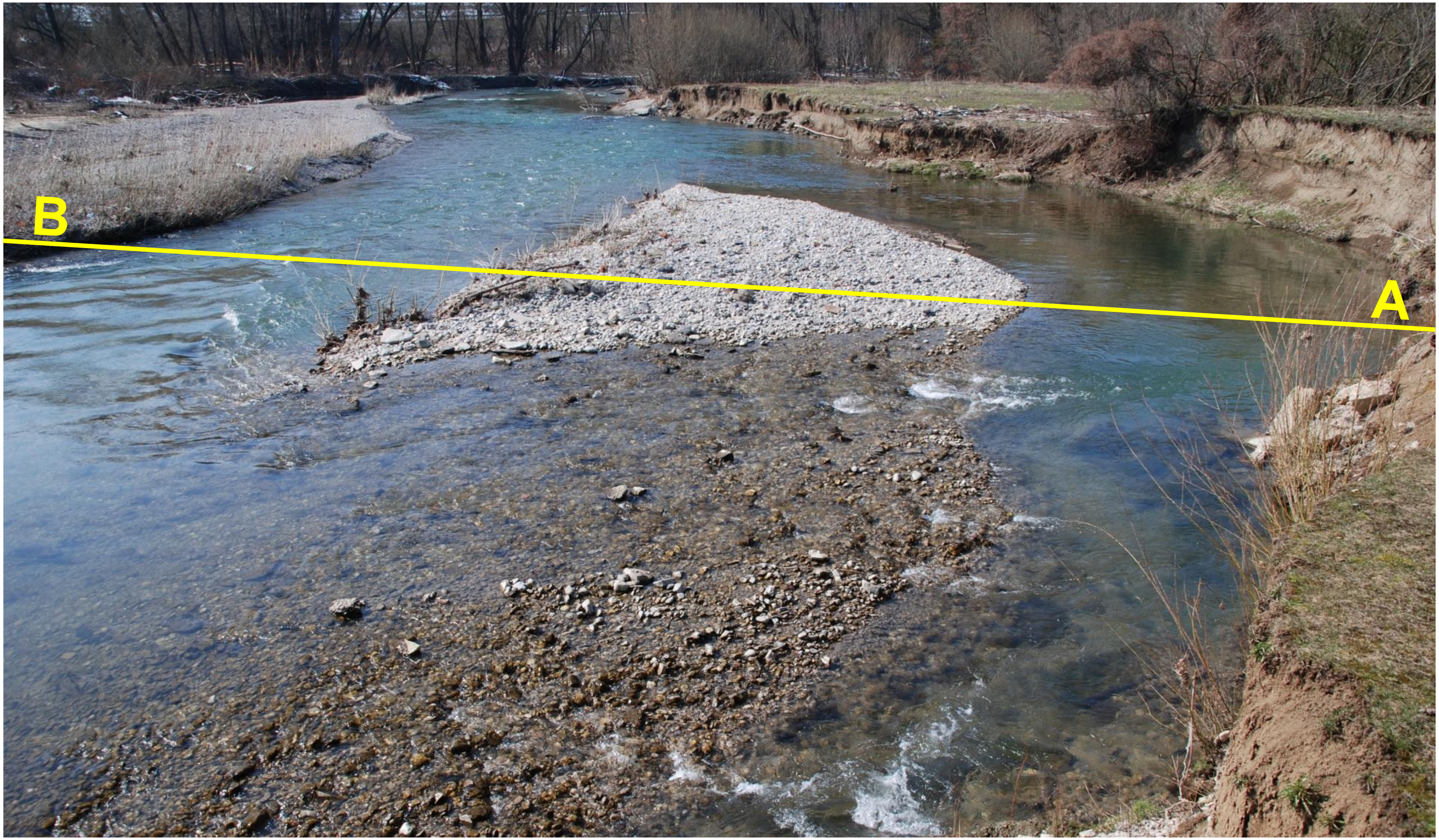
- **Typischer Laser Bathymetrie Workflow:**
  - Ableitung der 3D Punktwolke aus Scanner/GNSS/IMU Daten
  - Streifenausgleichung und Qualitätskontrolle
  - **Ableitung des Wasseroberflächen-Modells (semi-automatisch)**
  - **Entfernungs- und Refraktionskorrektur der Wasserechos**
  - Klassifizierung in Boden (inkl. Gewässerbett) und Nicht-Boden-Punkte
  - DGM Interpolation (regelmäßiges Gitter, TIN)
  - Postprocessing (Visualisierungen, Querschnitte, Statistische Analyse, Flächenvereinfachung und Export)
  - Datenaufbereitung für Folgeanwendungen (GIS, HN-Modelle, etc.)
- **Unterschied zu konventionellem topografischen LS:**
  - Modellierung der **Luft-Wasser-Grenzfläche**
  - **Entfernungs- und Refraktionskorrektur**

opals

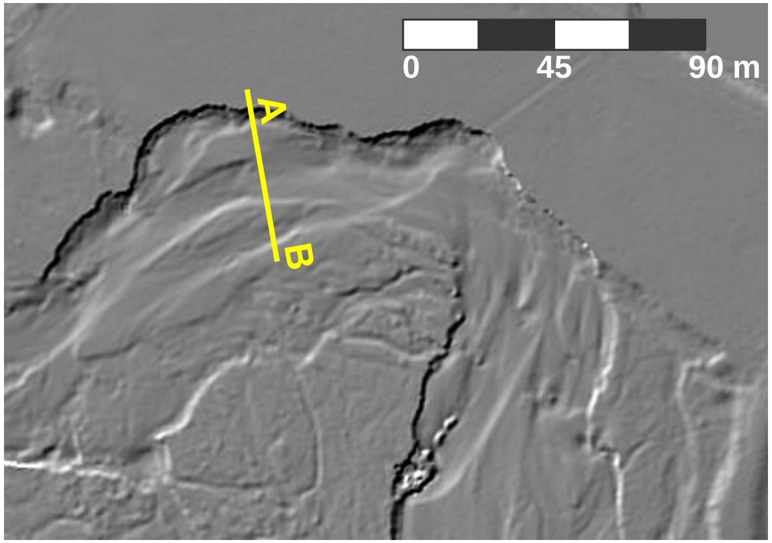
http://www.geo.tuwien.ac.at/opals

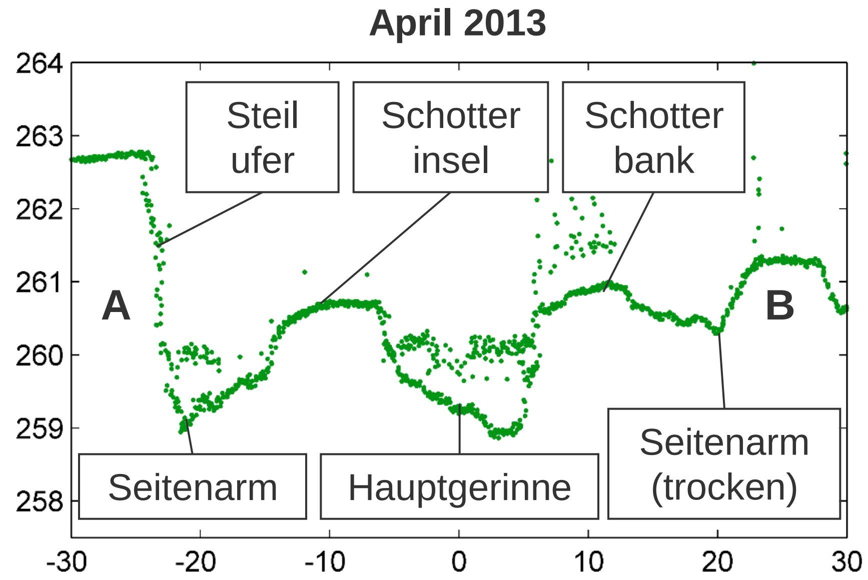
# Querschnittvergleich

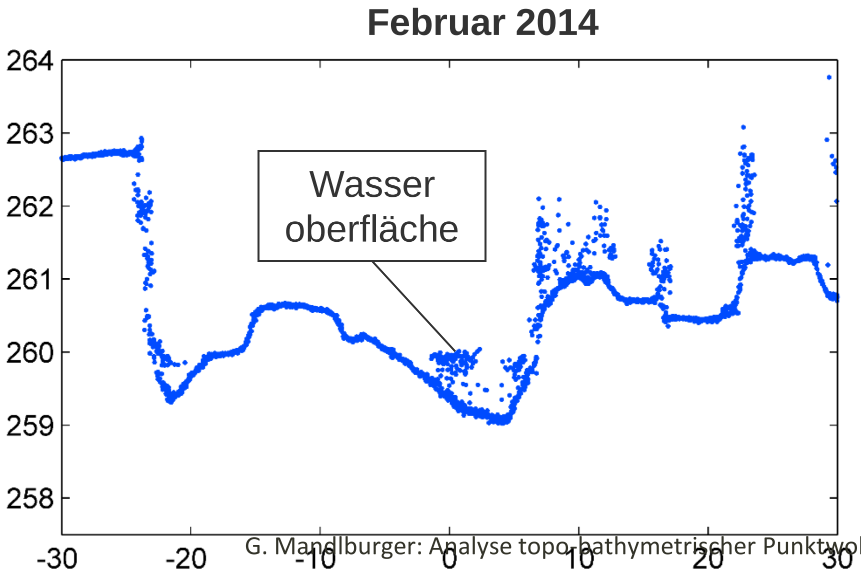
# Querschnittvergleich Apr13-Feb14-Oct14 I

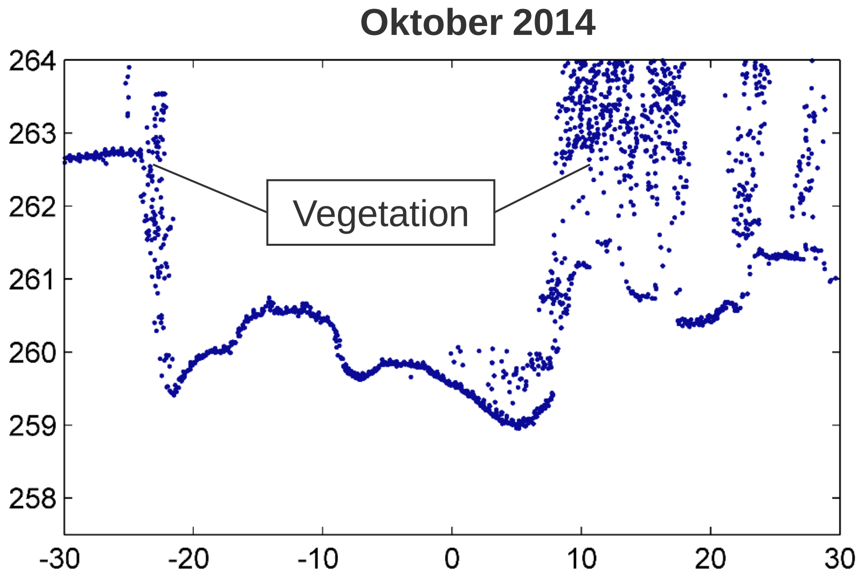


# Querschnittvergleich Apr13-Feb14-Oct14 II

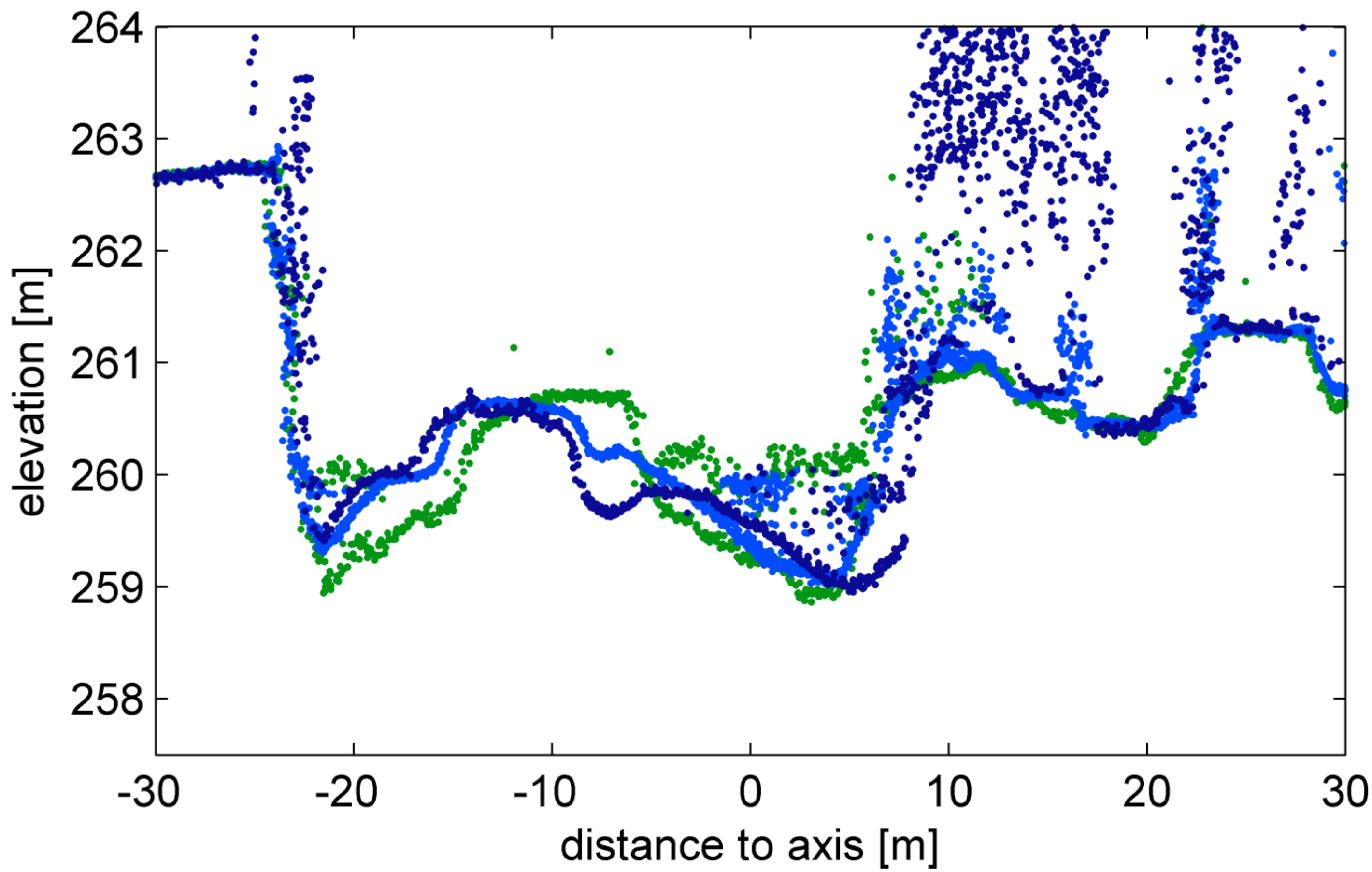


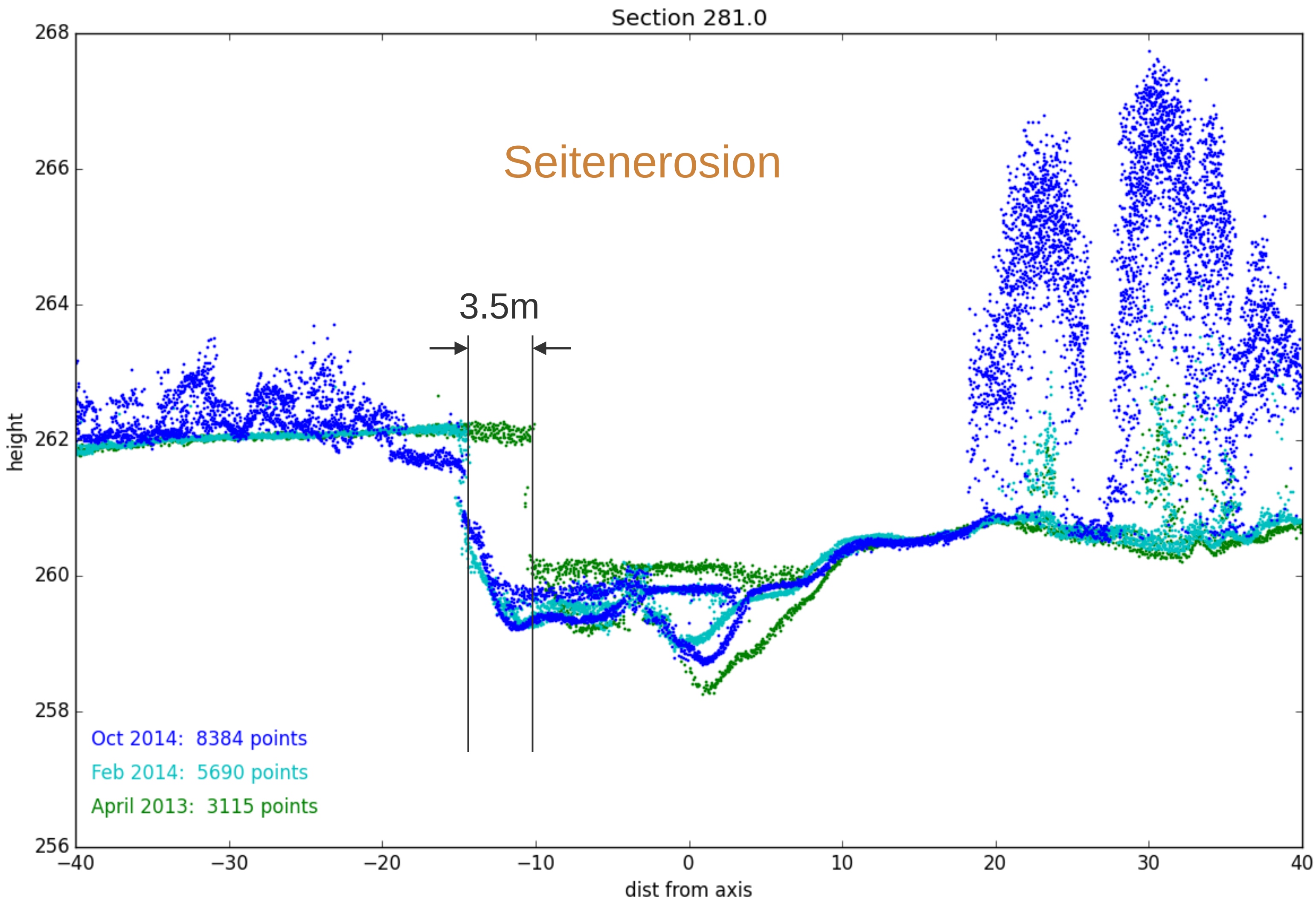



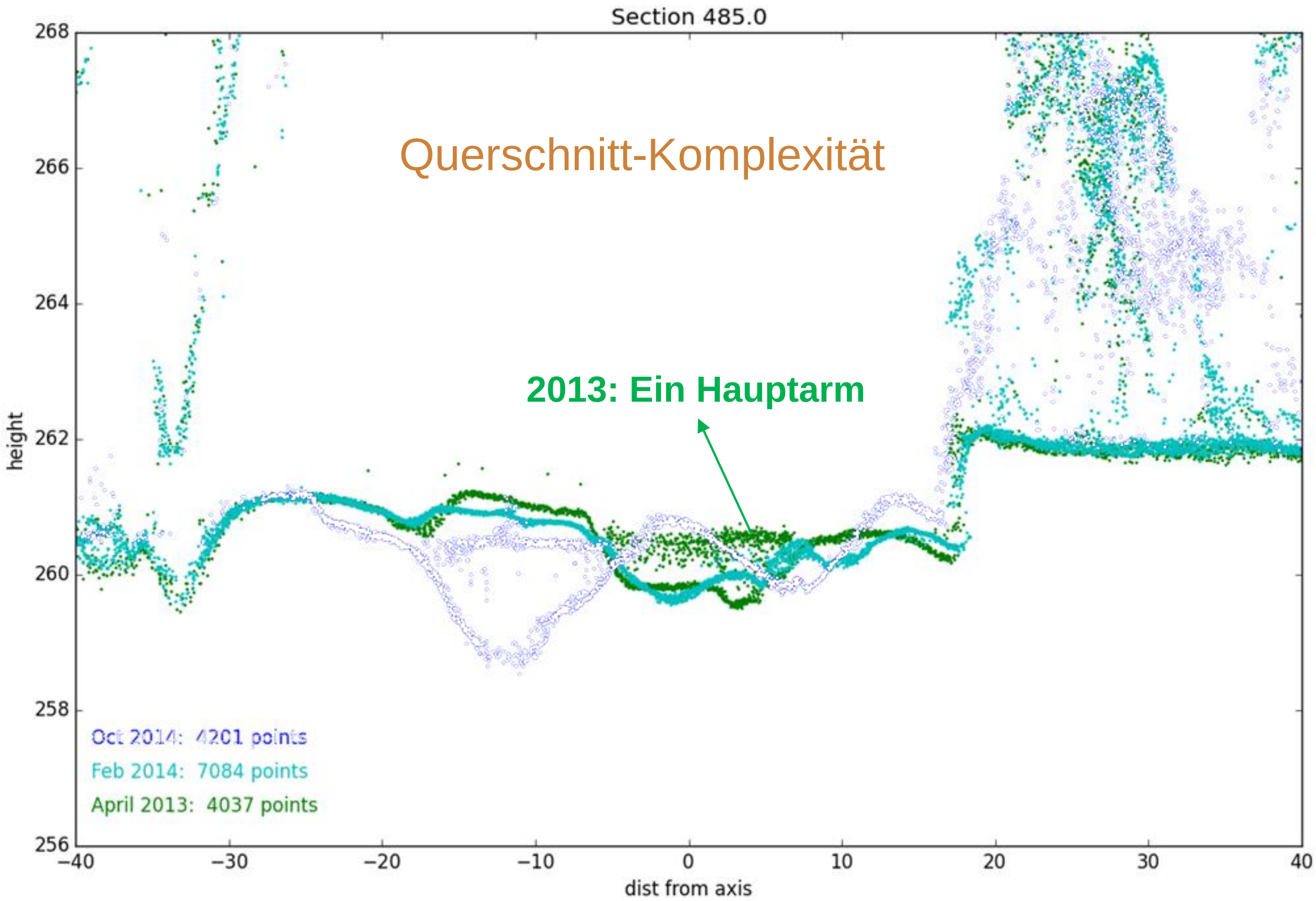
# Querschnittvergleich Apr13-Feb14-Oct14 III



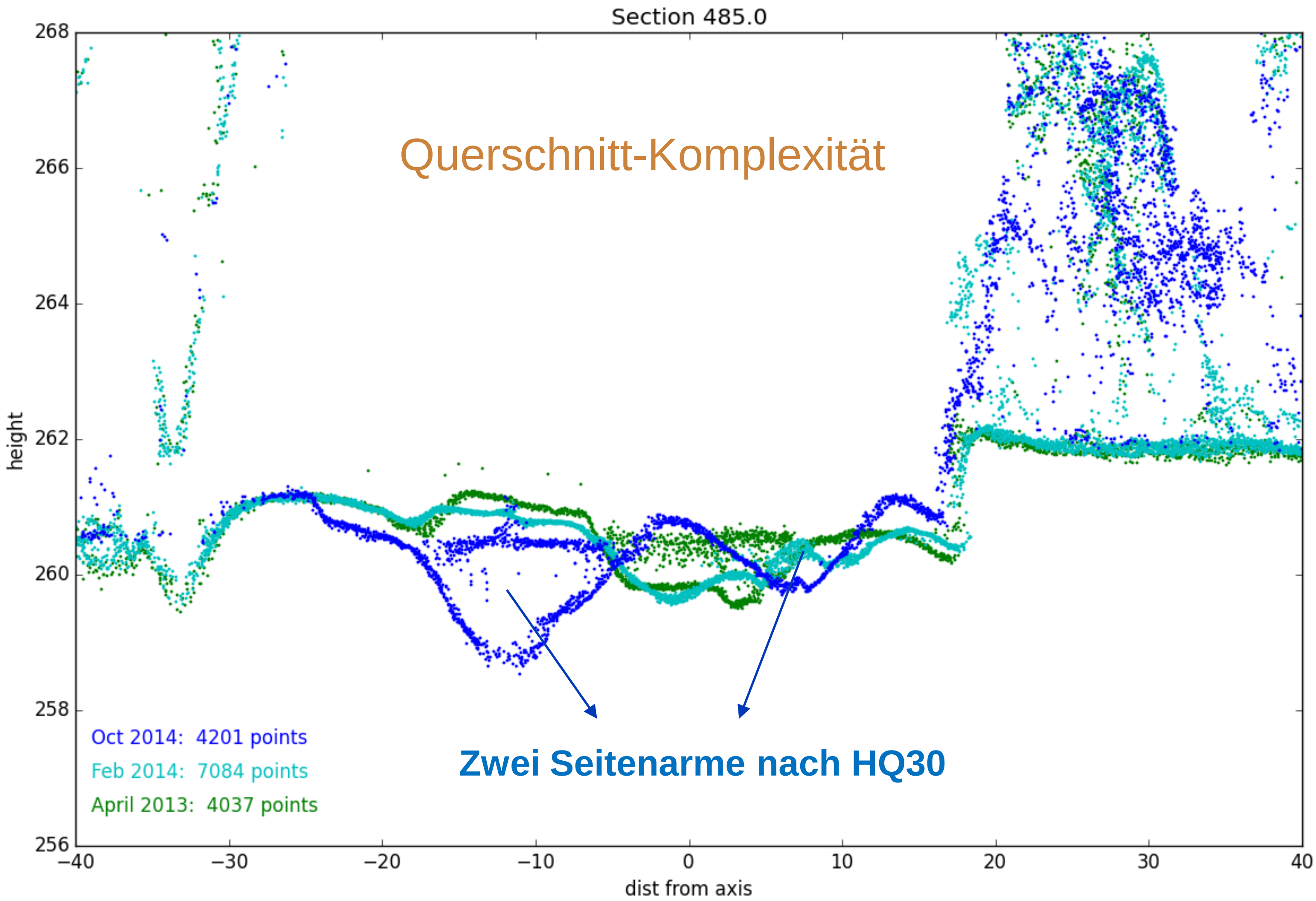
# Querschnittvergleich Apr13-Feb14-Oct14 IV



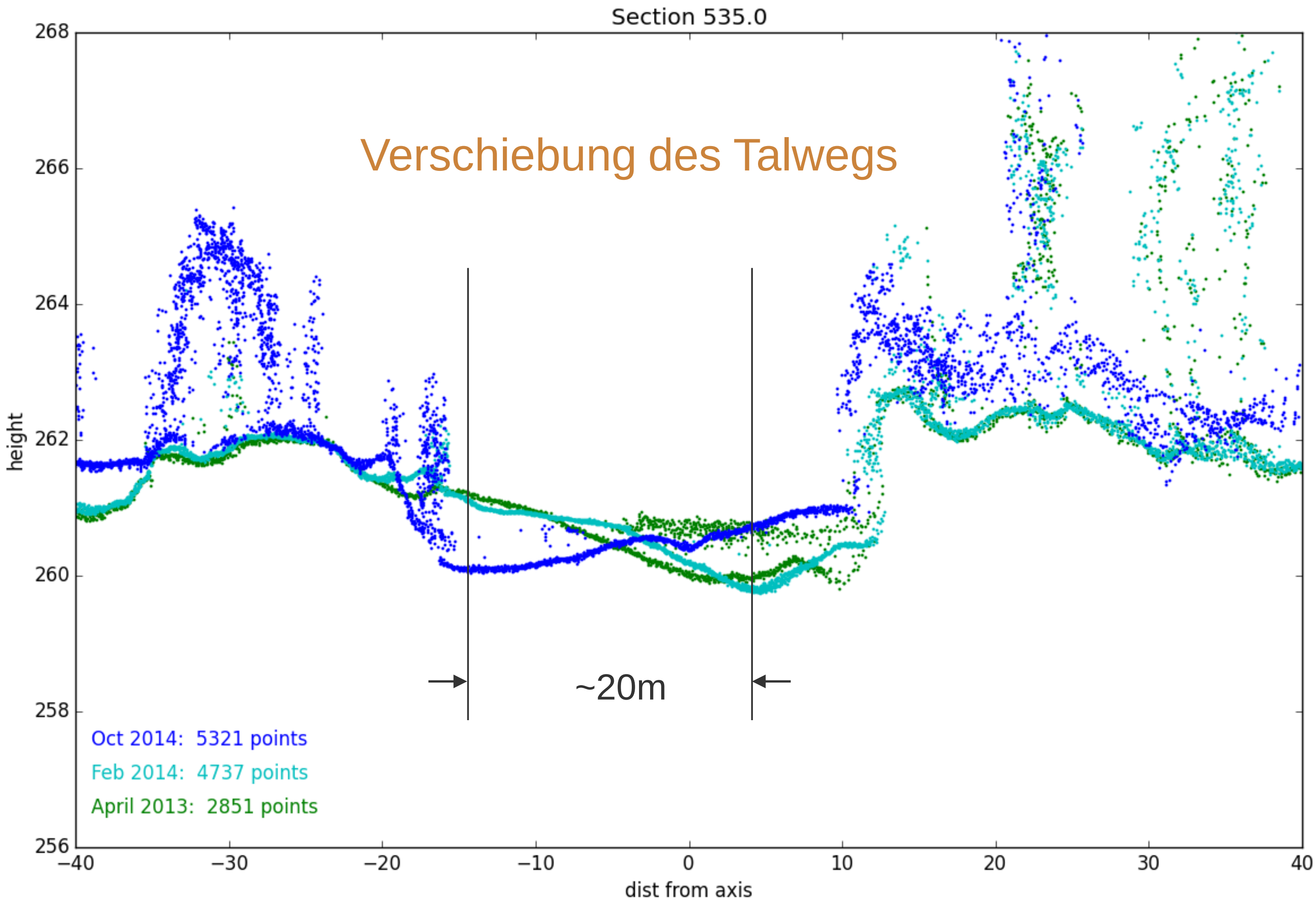
# Querschnittvergleich Apr13-Feb14-Oct14 V



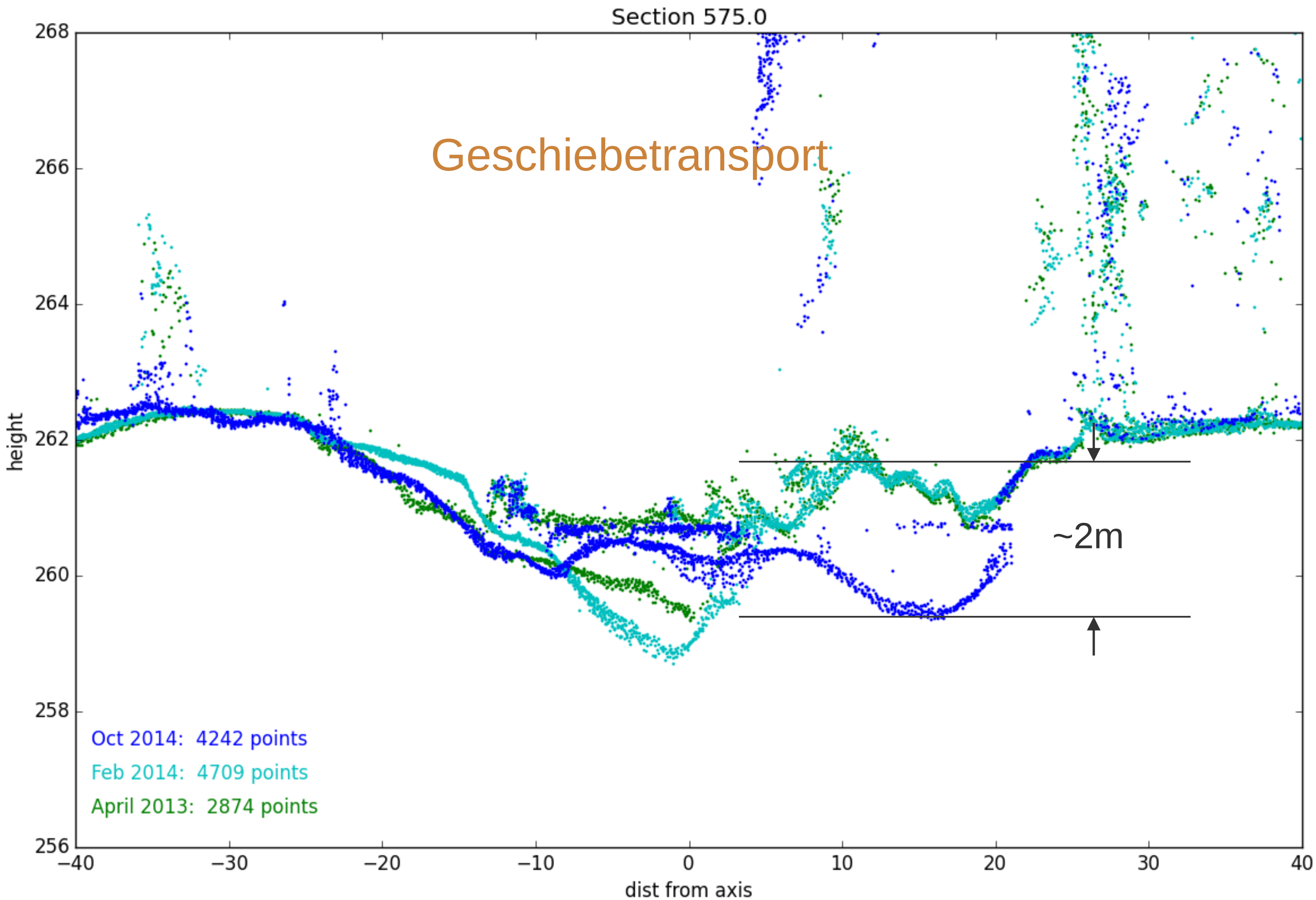
# Cross-sectional comparison Apr13-Feb14-Oct14 V

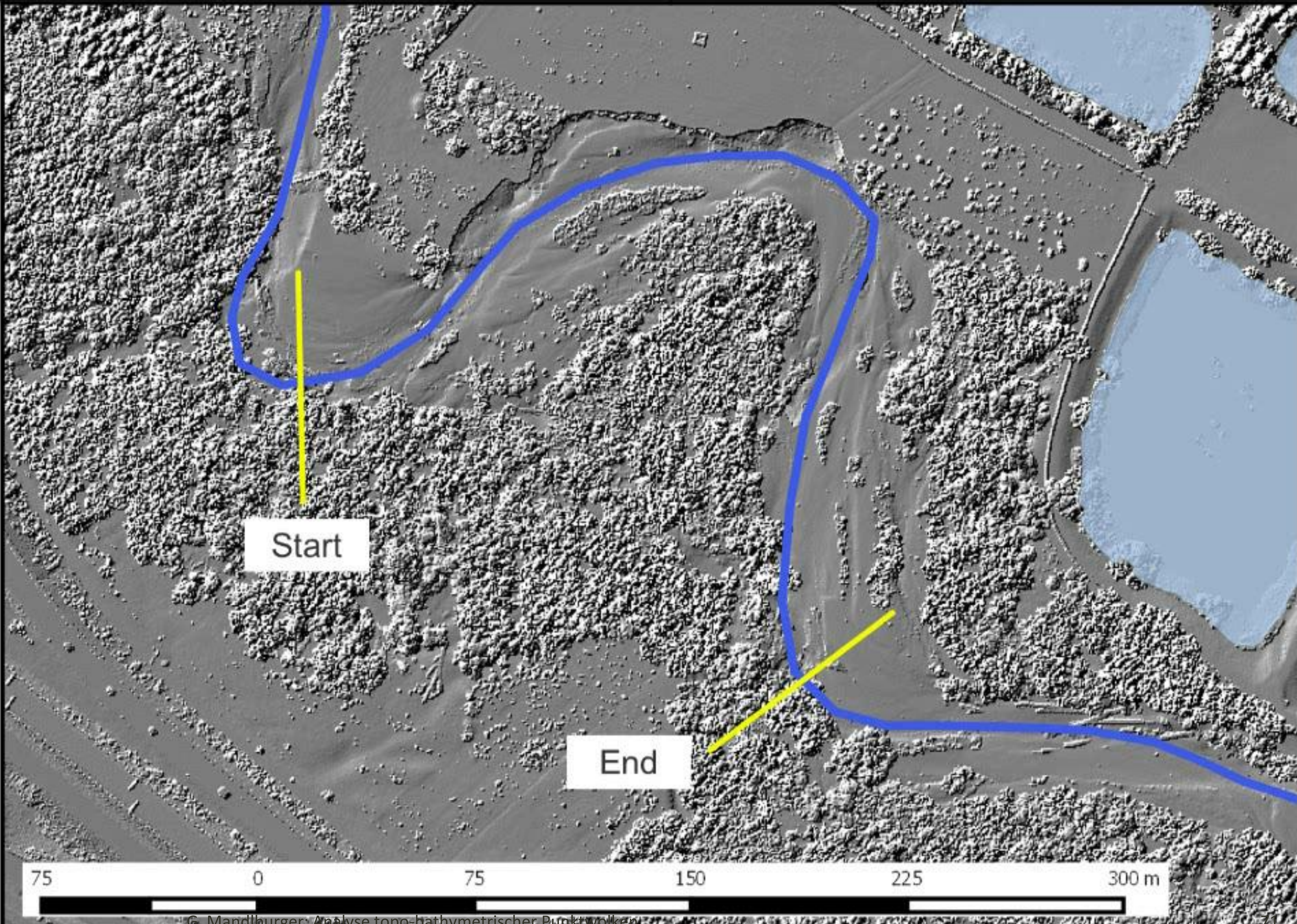


# Querschnittvergleich Apr13-Feb14-Oct14 VI



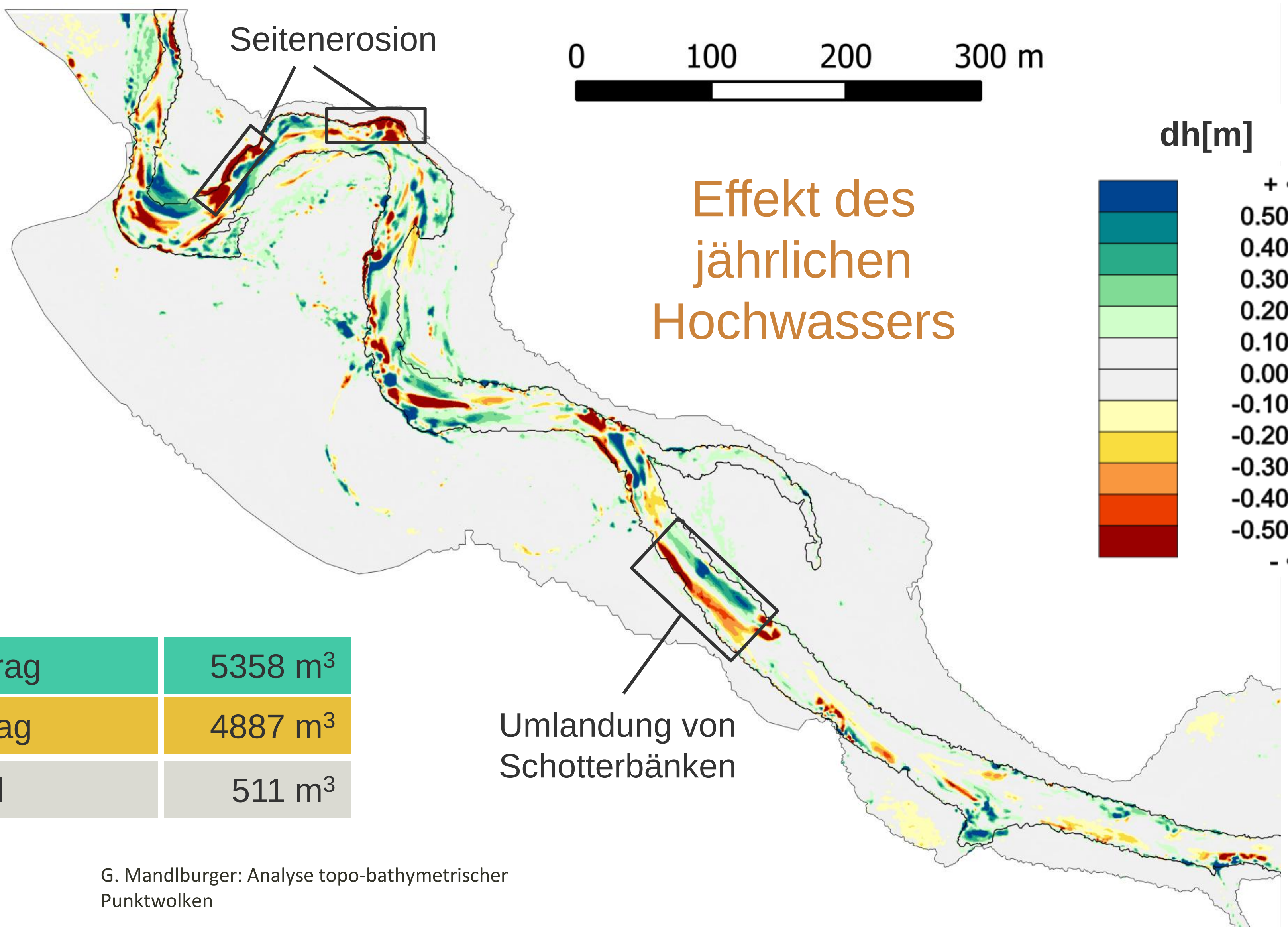
# Querschnittvergleich Apr13-Feb14-Oct14 VII




Start
End
75
0
75
150
225
300 m

# Dokumentation der Morphodynamik auf Basis von DTM Differenzmodellen

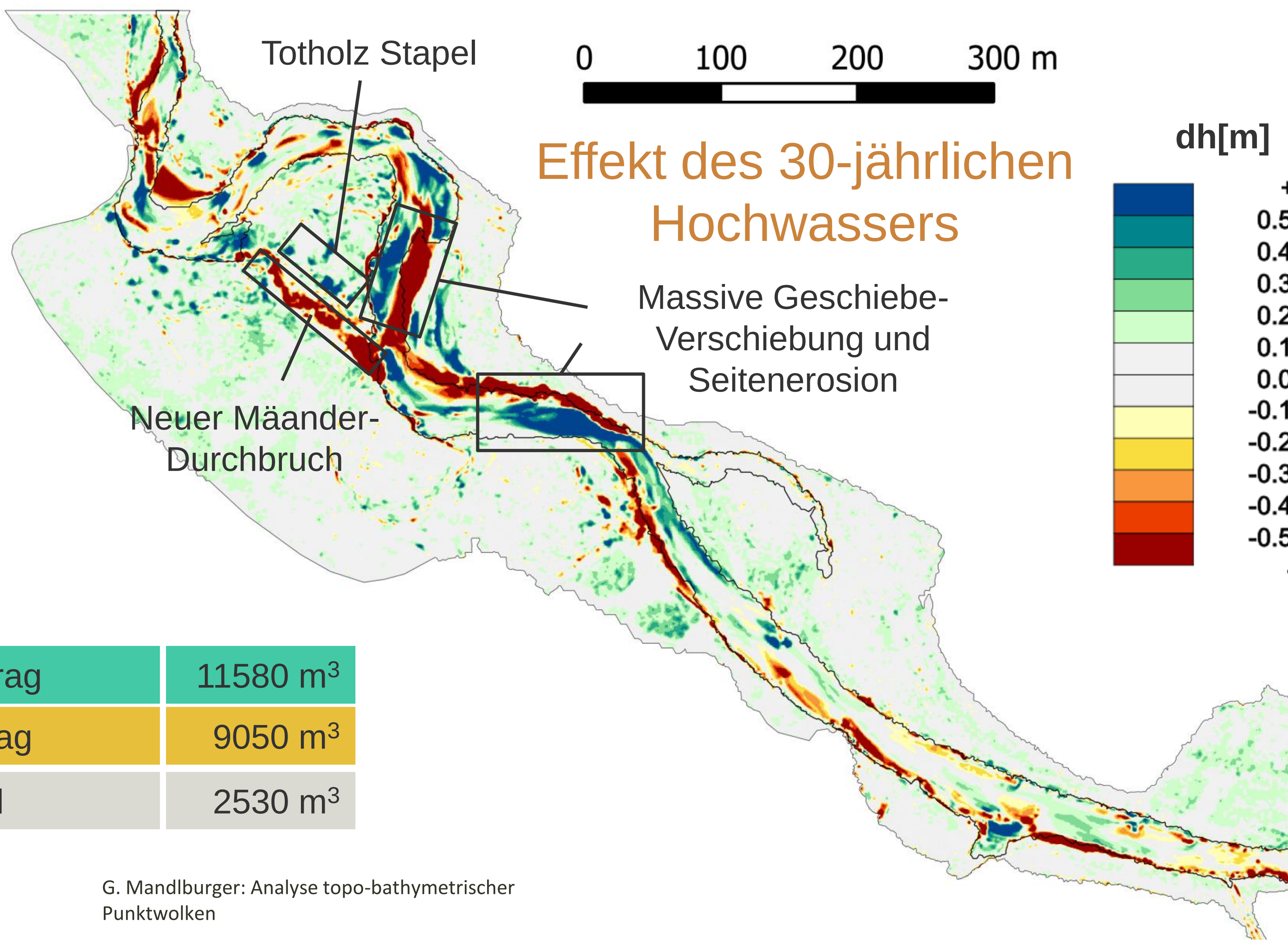
# Morphodynamik: April 2013 – Februar 2014




Effekt des jährlichen Hochwassers

| | |
|---|---|
| Auftrag | 5358 $m^3$ |
| Abtrag | 4887 $m^3$ |
| Total | 511 $m^3$ |

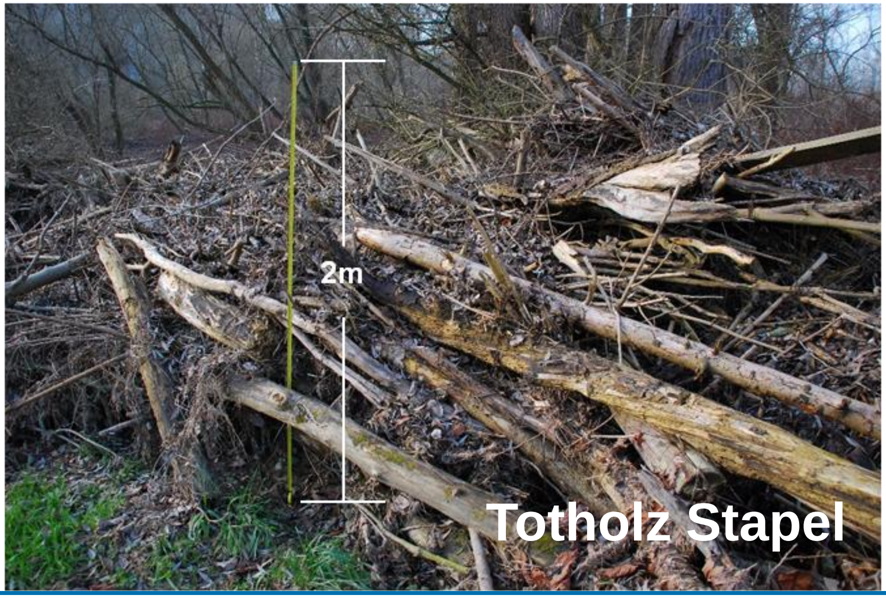
# Morphodynamik: Feb 2014 – Oct 2014



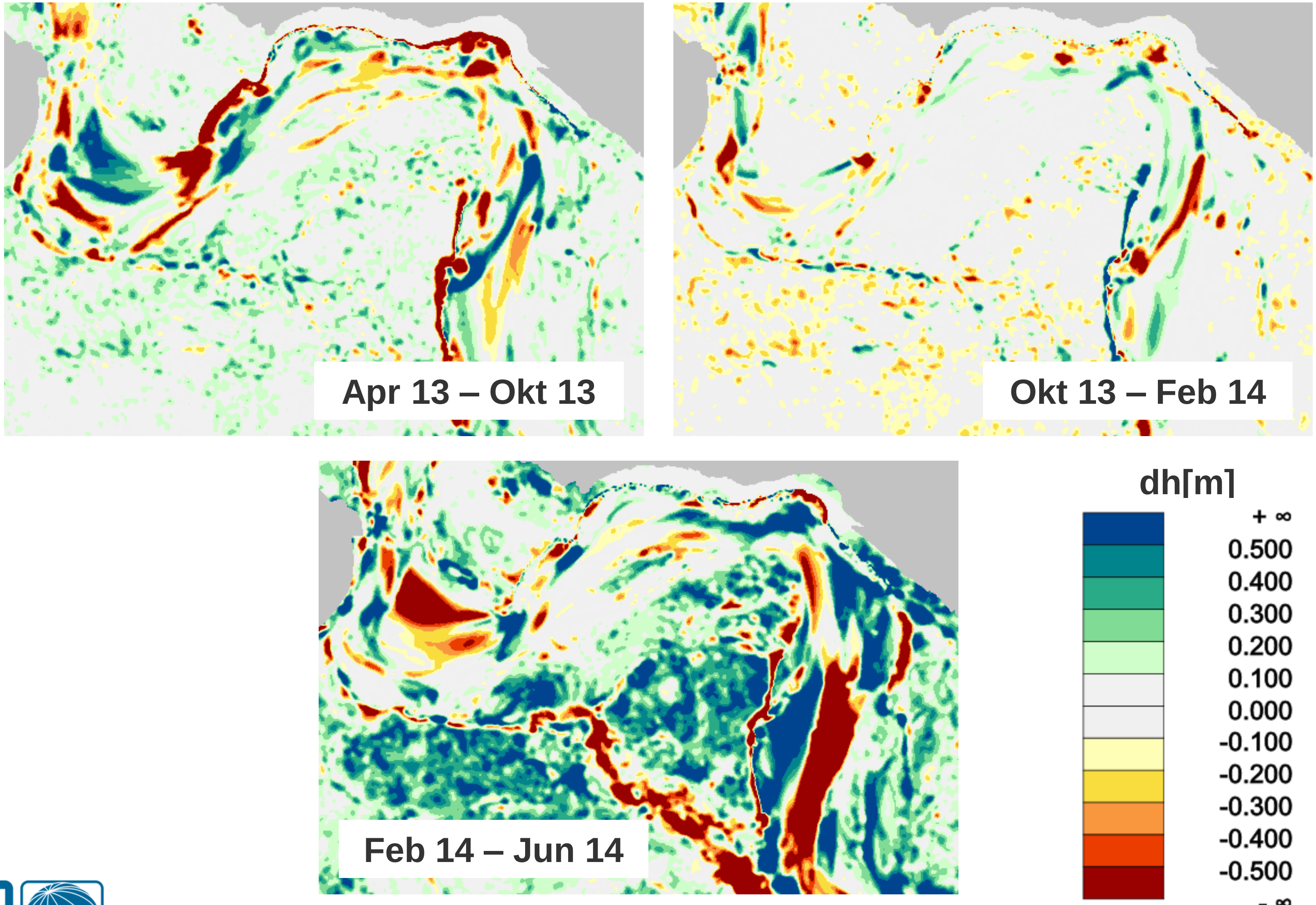

| | |
|---|---|
| Auftrag | 11580 m$^3$ |
| Abtrag | 9050 m$^3$ |
| Total | 2530 m$^3$ |

# Fotos von Feldbegehung



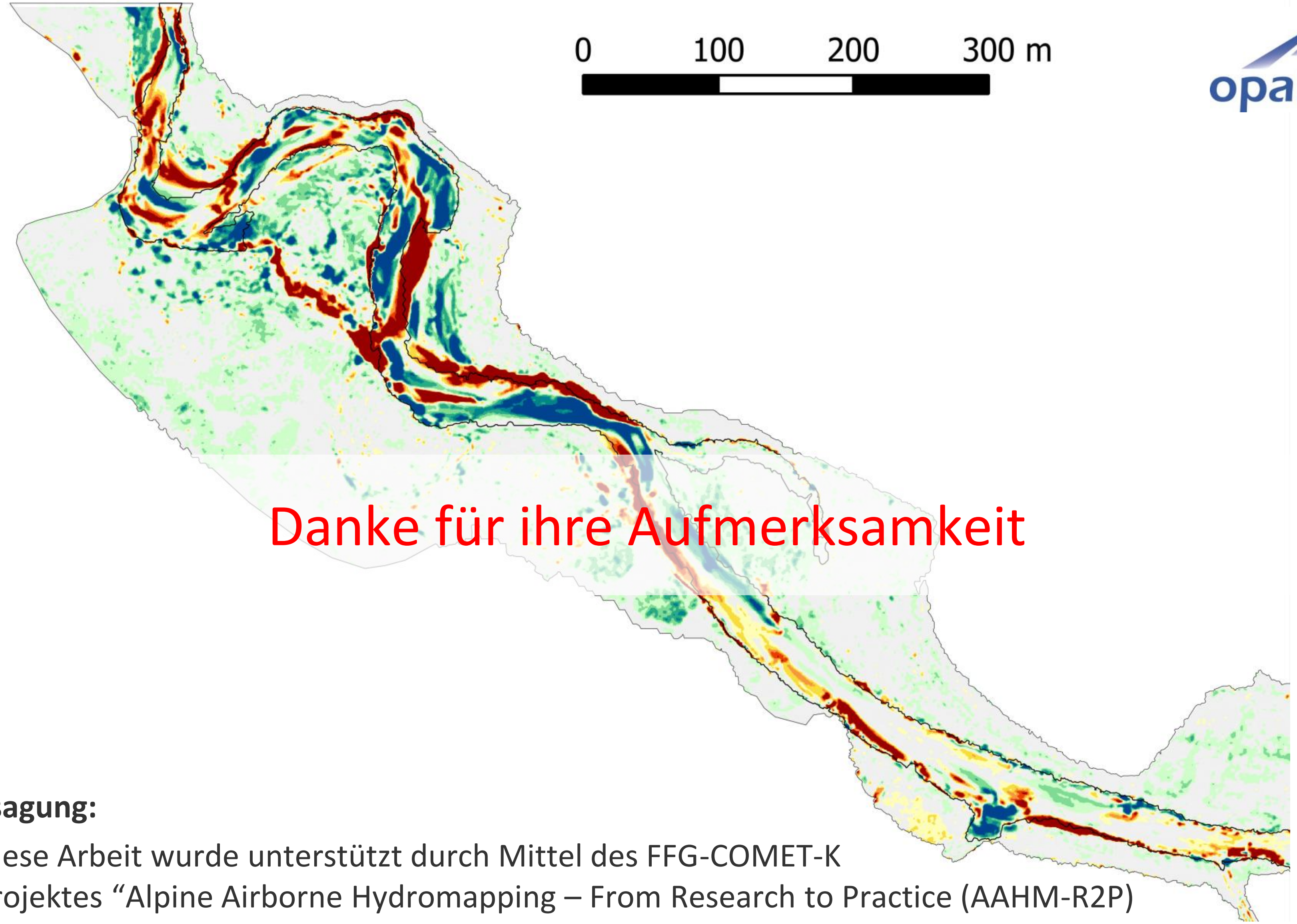



# Problematik: Erfassungszeitpunkt



# Zusammenfassung

- Multi-temporale Datenerfassung Neubacher Au (Riegl VQ-820-G/VQ-880-G)
  - **Homogene und hohe Punktdichte** im Gewässerbett und Flussvorland (**>20 pts/m²**)
  - **Gute Höhengenauigkeit <10cm** (Fehlerquellen: Entfernungsmessung, GNSS/IMU, Wasseroberfläche, Refraktionskoeffizient)
  - **Erfassung von sehr seichten** Bereichen (Tiefe < 30cm) and **tiefen Becken** (Tiefe ca. 3m) möglich
- Dokumentation Hochwasser bedingter Veränderungen
  - Hochwasserereignisse: 2013 (**HQ1**), 2014 (**HQ30**)
  - HQ1/2013: Veränderungen hauptsächlich **im Bereich des Flussbetts** (Geschiebetransport, Seitenerosion)
  - HQ30/2014: Große **Änderungen im Auwald** (neuer Seitenarm, Totholzanhäufungen)
  - **Detaillierte Erfassung der Änderungen** in Folge von **Geschiebetransport** und **Seitenerosion** möglich (Auftrag/Abtrag: HQ1: ca. **5.000 m³**, HQ30: **10.000 m³**)
- Anwendungsgebiete
  - Simulation von **Hochwasser** (Gefährdung und Prävention), **Gewässerökologie**
  - **EU-Rechtislinien:** Wasserrahmen-, Hochwasser, Fauna-Flora-Habitat Rechtslinien

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**Danksagung:**

- Diese Arbeit wurde unterstützt durch Mittel des FFG-COMET-K Projektes “Alpine Airborne Hydromapping – From Research to Practice (AAHM-R2P)
- Dank an Fa. Riegl LMS für die Bereitstellung der multi-temporalen LiDAR-Bathymetrie Daten