VIENNA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SENSING

Antrittsvorlesung – Inaugural Lecture

Optical Hydrography: Charting the underwater world with photos and laser scans

Univ. Prof. Dr. Gottfried Mandlburger

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TU Wien, Department of Geodesy and Geoinformation

Research Area Photogrammetry (E120.7)

with contributions by: Laure-Anne Gueguen, Jan Rhomberg-Kauert, Lucas Dammert, Michael Grömer, Markus Brezovsky, Nike Wagner, Carolina Damm, Fabian Unterasinger, Moritz Kapeller, Julian Skilich, Christian Mulsow, Hannes Sardemann, Theresa Himmelsbach

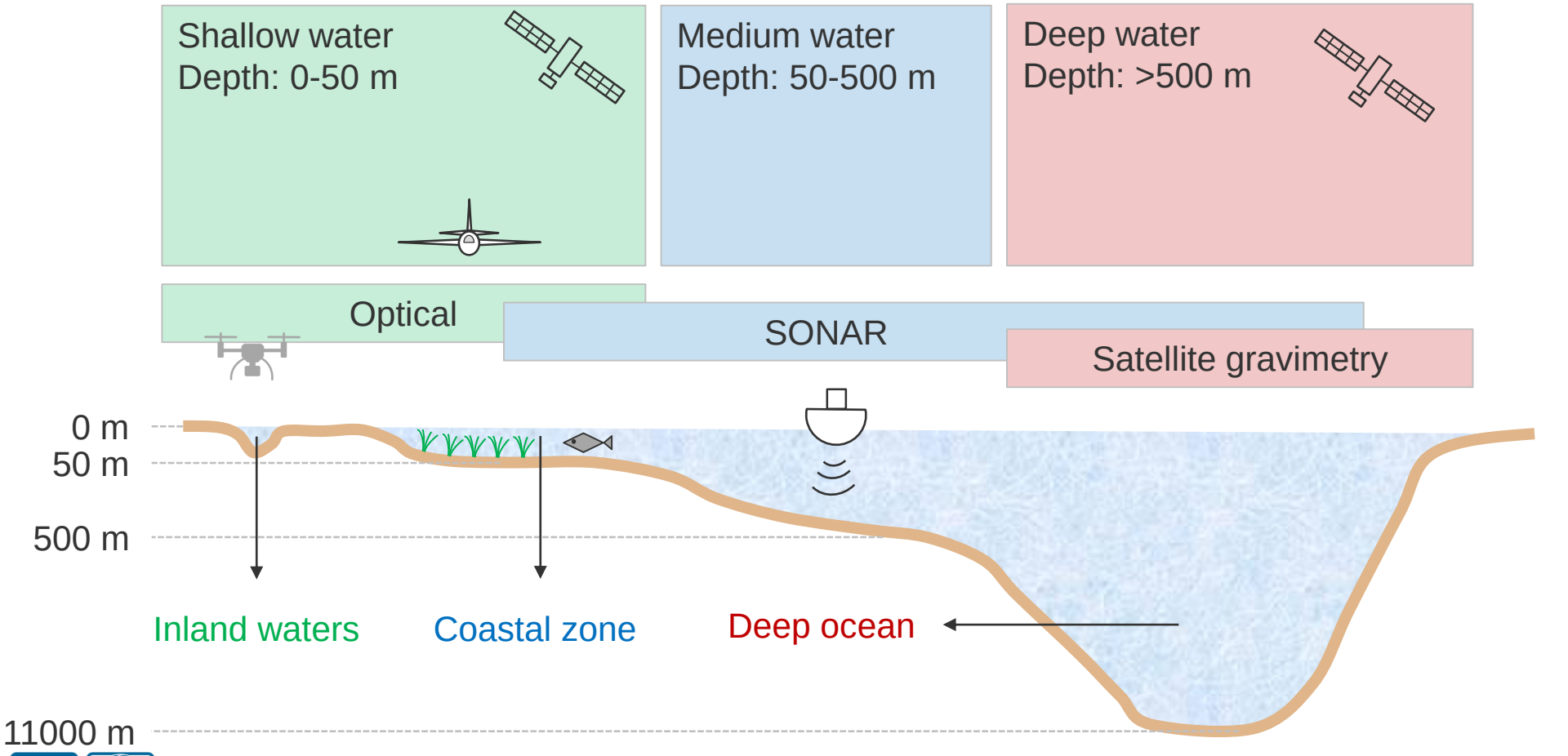
Curriculum Vitae

- 1995: Diploma study in Geodesy, TU Wien
- 1996: Engineering Company Stolitzka, Vienna (Tunnel surveying)
- 2002: Research assistant at Institute of Photogrammetry and Remote Sensing, TU Wien
- 2006: PhD at Institute of Photogrammetry and Remote Sensing (IPF), TU Wien
- 2006: PostDoc at IPF / GEO-Photo, TU Wien
- 2017: PostDoc at Institute for Photogrammetry, University of Stuttgart
- 2021: Habilitation in Photogrammetry
  Bathymetry from active and passive Photogrammetry
- 2022: Assistant Professor at GEO-Photo / TU Wien
- 2023: Associate Professor at GEO-Photo / TU Wien
- 2024: University Professor at GEO-Photo / TU Wien
  Optical Bathymetry

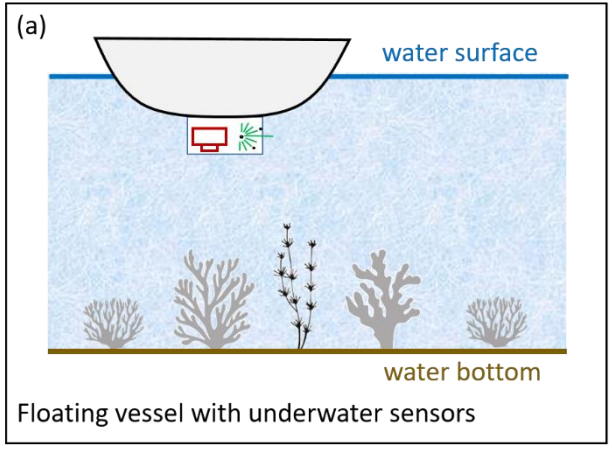
Content

- Basics
  - Research field Optical Hydrography/Bathymetry
  - Spectrally Derived Bathymertry
  - Multimedia Photogrammetry
  - Laser Bathymetry
- What we did in the past (decade)
  - Laser bathymetry sensors
  - Pielach River Test Site
  - Applications: Flood risk and protection, fluvial morphology, mapping of macrophytes
- What we do today
  - Pushing the limits of multimedia photogrammetry
  - Monitoring hydropower infrastructure with optical hydrography
  - Laser bathymetry where it gets tricky
- Where do we go and who needs all that?

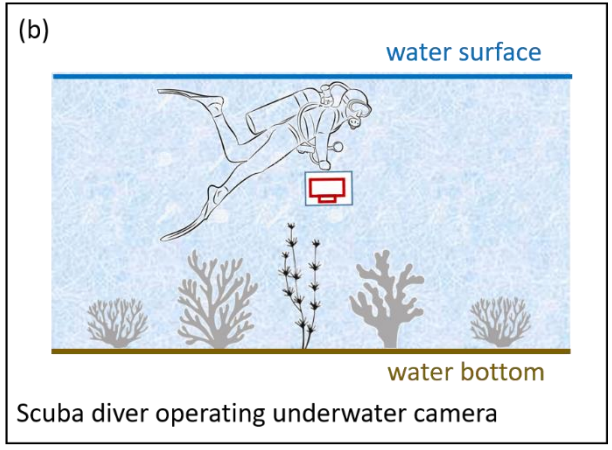
Optical Methods - SONAR - Gravimetry



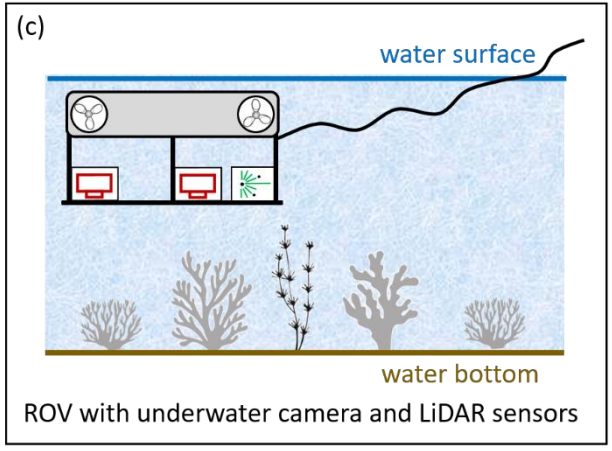
Underwater data acquisiton configurations



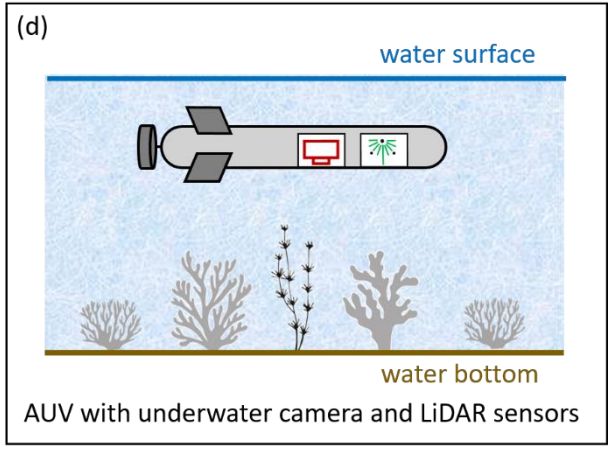
Floating vessel with underwater sensors



Scuba diver operating underwater camera



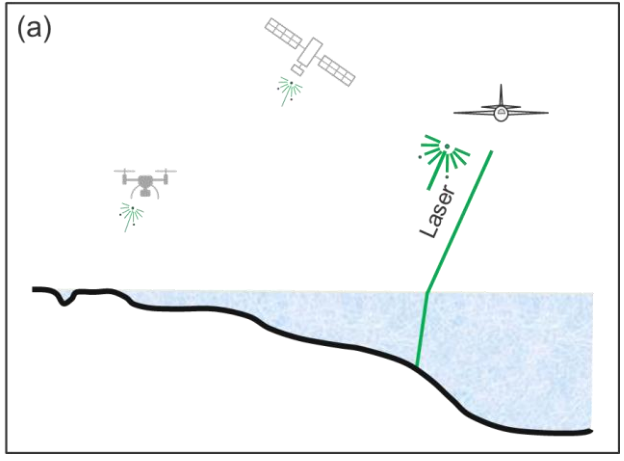
ROV with underwater camera and LiDAR sensors



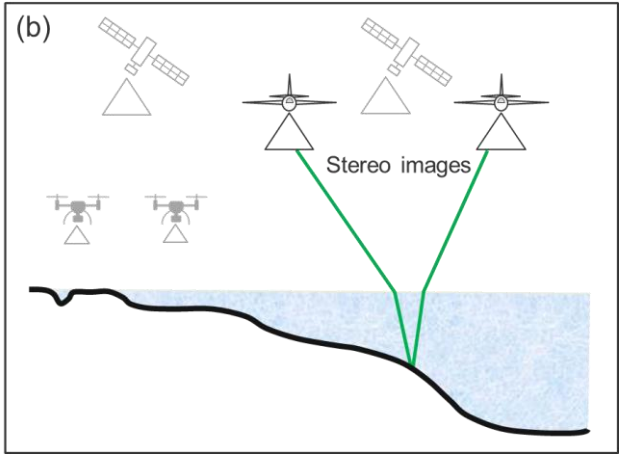
AUV with underwater camera and LiDAR sensors

Optical hydrographic methods

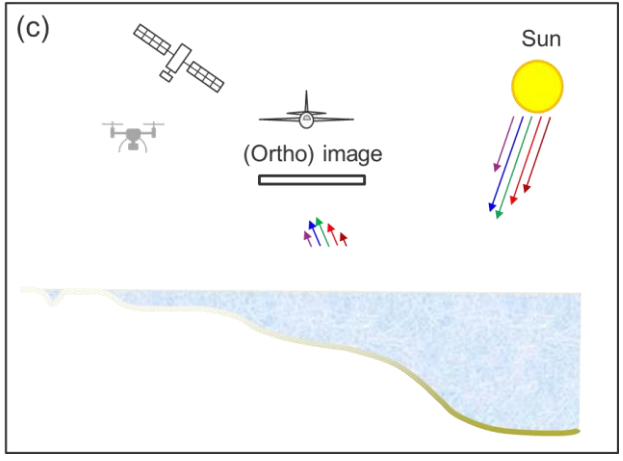
Laser bathymetry



Multimedia photogrammetry



Spectrally derived bathymetry



Basic color-to-depth relation

e.g. Lyzenga et al, 2006: Multispectral Bathymetry Using a Simple Physically Based Algorithm

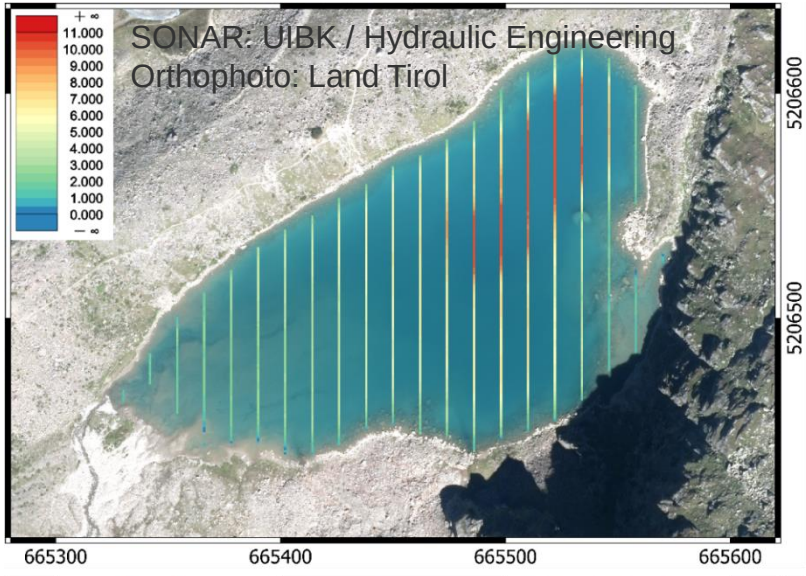
$$L(h) = L_S + L_B e^{-\propto h}$$

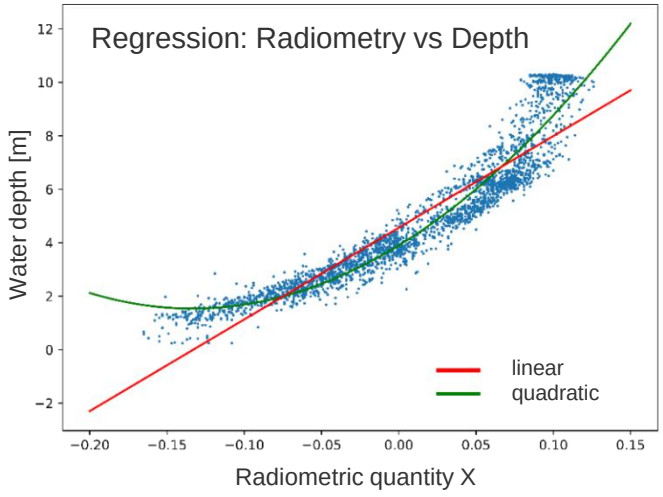
$L(h)$ ..... upwelling radiance depending on the water depth *h*
L_S ..... **surface** reflections and **volume scattering** from **infinitely deep** water
L_B ..... transmission **losses** through **surface** + **bottom reflectance** + **volume scattering**
$\propto$ ..... sum **of diffuse attenuation coefficients** for up- and down-welling light

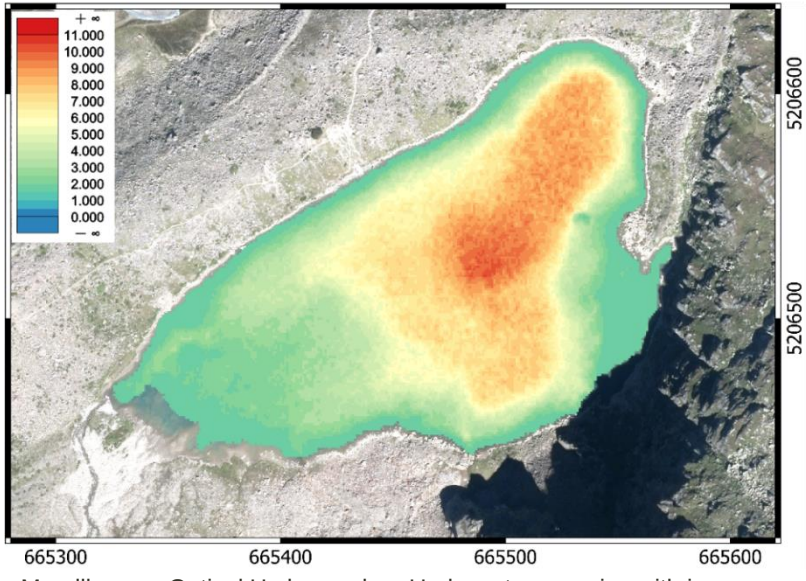
Modifications

- Sun glint
- *h* from lin
- Calibratio

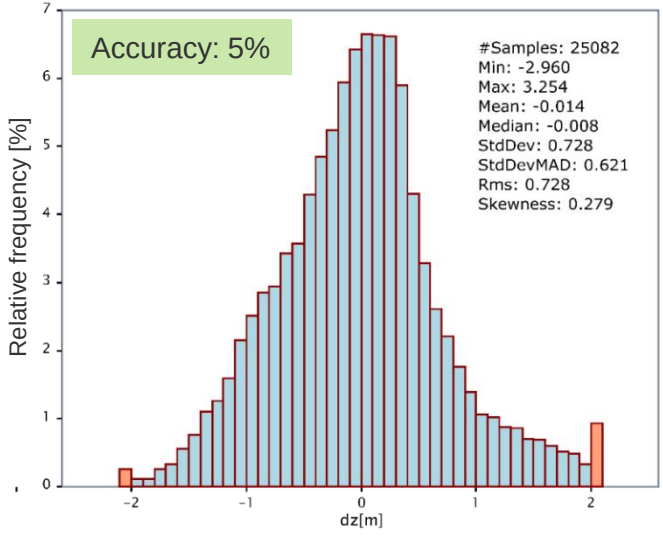
ga et al, 2006)
Lyzenga, 1985)







Height deviation: SONAR vs SDB



Multimedia photogrammetry aka Photo bathymetry


Sonderheft 5
der Österreichischen Zeitschrift
für Vermessungswesen

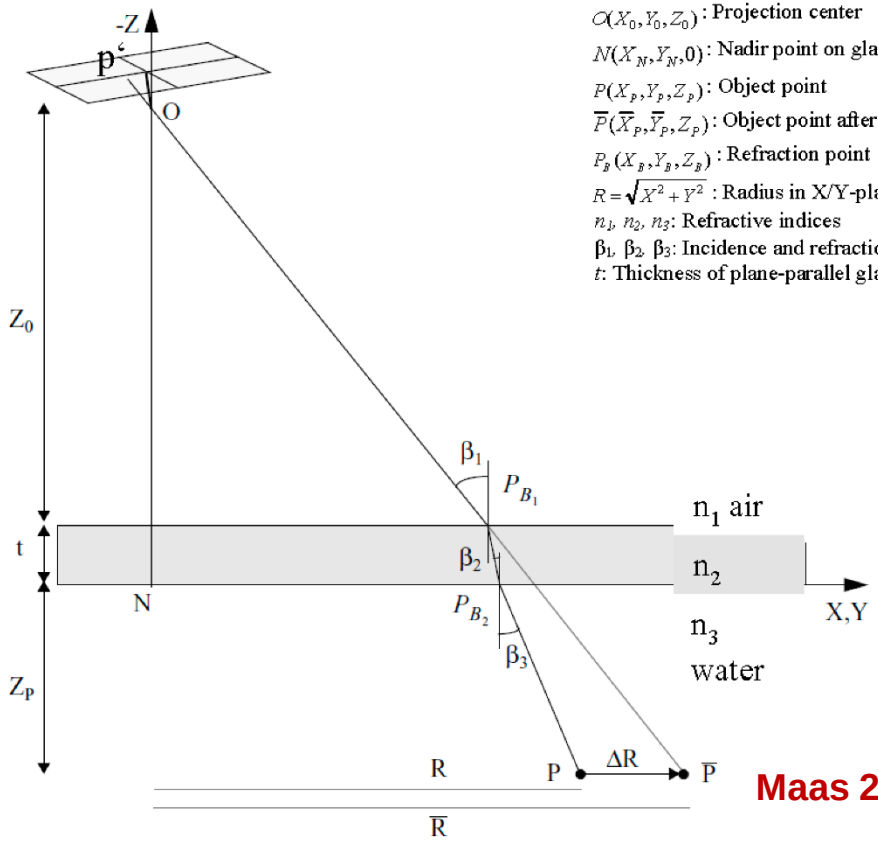
Abbildungsgesetz
und Orientierungsaufgaben in der
Zweimedienphotogrammetrie

von

Dipl. Ing. Dr. techn. Karl Rinner

WIEN 1948

Rinner 1948, VGI



$O(X_0, Y_0, Z_0)$: Projection center
$N(X_N, Y_N, 0)$: Nadir point on glass/water interface
$P(X_P, Y_P, Z_P)$: Object point
$\bar{P}(\bar{X}_P, \bar{Y}_P, Z_P)$: Object point after radially shift
$P_B(X_B, Y_B, Z_B)$: Refraction point
$R = \sqrt{X^2 + Y^2}$: Radius in X/Y-plane
n_1, n_2, n_3: Refractive indices
β_1, β_2, β_3: Incidence and refraction angles (Snellius)
t: Thickness of plane-parallel glass plate

Maas 2015, Sensors

UAV-based photo bathymetry (Pielach, Austria)

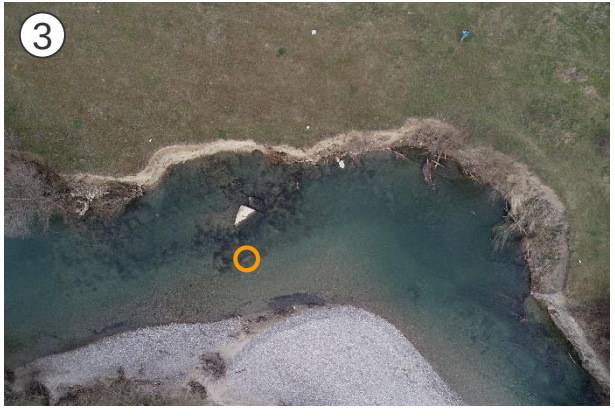


Photo bathymetry: refraction correction I

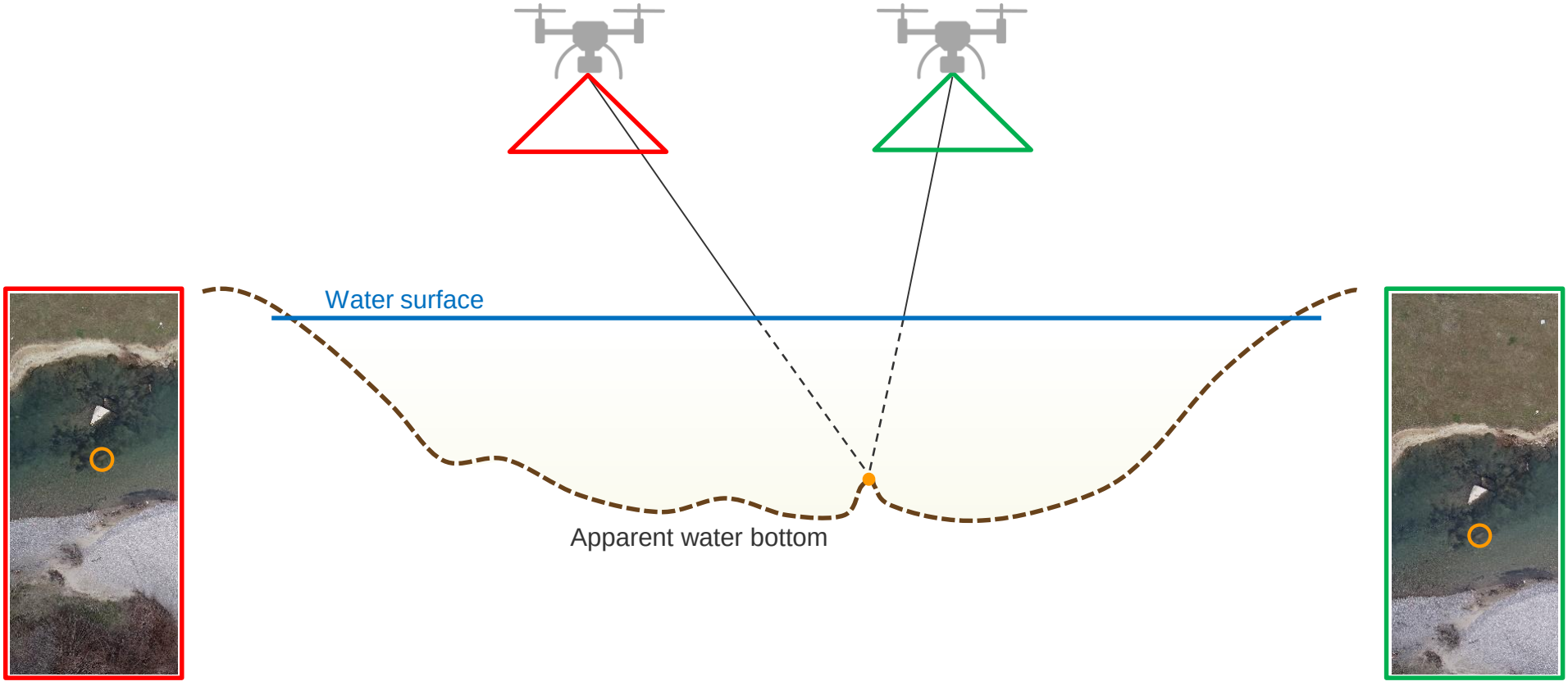
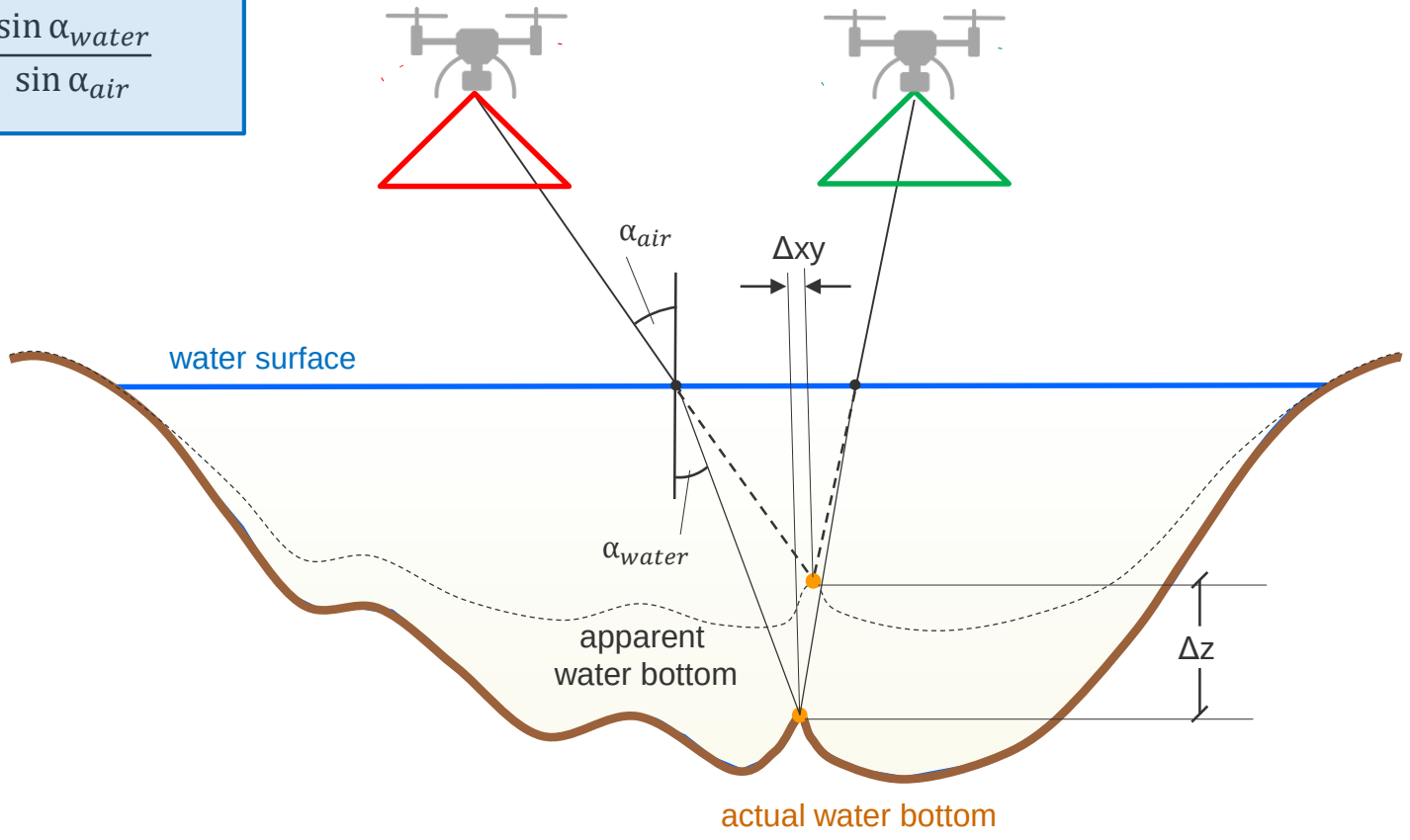
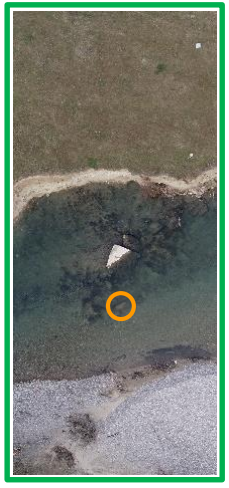


Photo bathymetry: refraction correction II

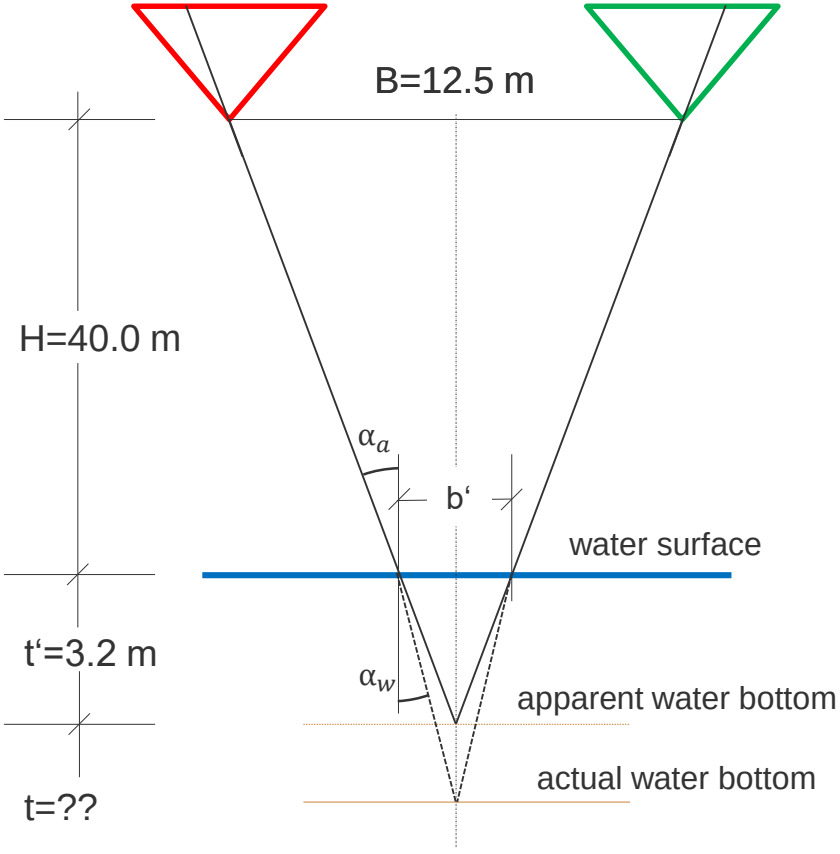
Snells‘ law of refraction

$$\frac{n_{air}}{n_{water}} = \frac{\sin \alpha_{water}}{\sin \alpha_{air}}$$





Numerical example refraction correction (UAV images)



$$\alpha_a = \sin^{-1}\frac{B}{2(H+t')} = 8.319°$$

$$\frac{\sin\alpha_a}{\sin\alpha_w} = \frac{n_w}{n_a} = \frac{1.33}{1.0}$$

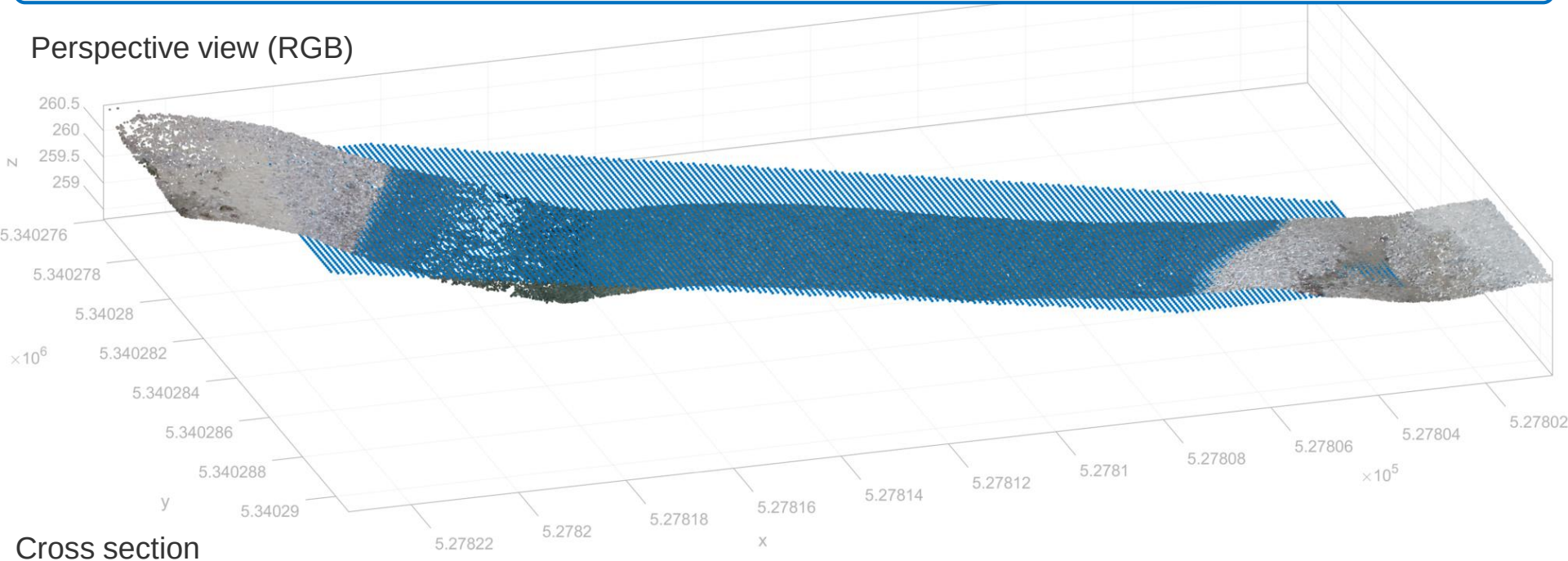
$$\alpha_w = \sin^{-1}\frac{\sin(8.319°)}{1.33} = 6.245°$$

$$\frac{B}{b} = \frac{H}{t'} \rightarrow b = \frac{12.5}{40}\,3.2 = 1.0$$

$$\mathbf{t} = \frac{b}{2\ \tan\alpha_w} = \mathbf{4.62m}$$

Photo bathymetry – raw point cloud

Perspective view (RGB)



Cross section

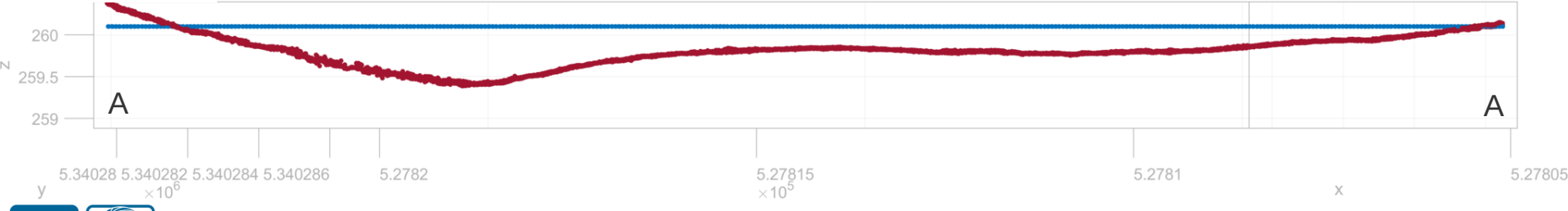
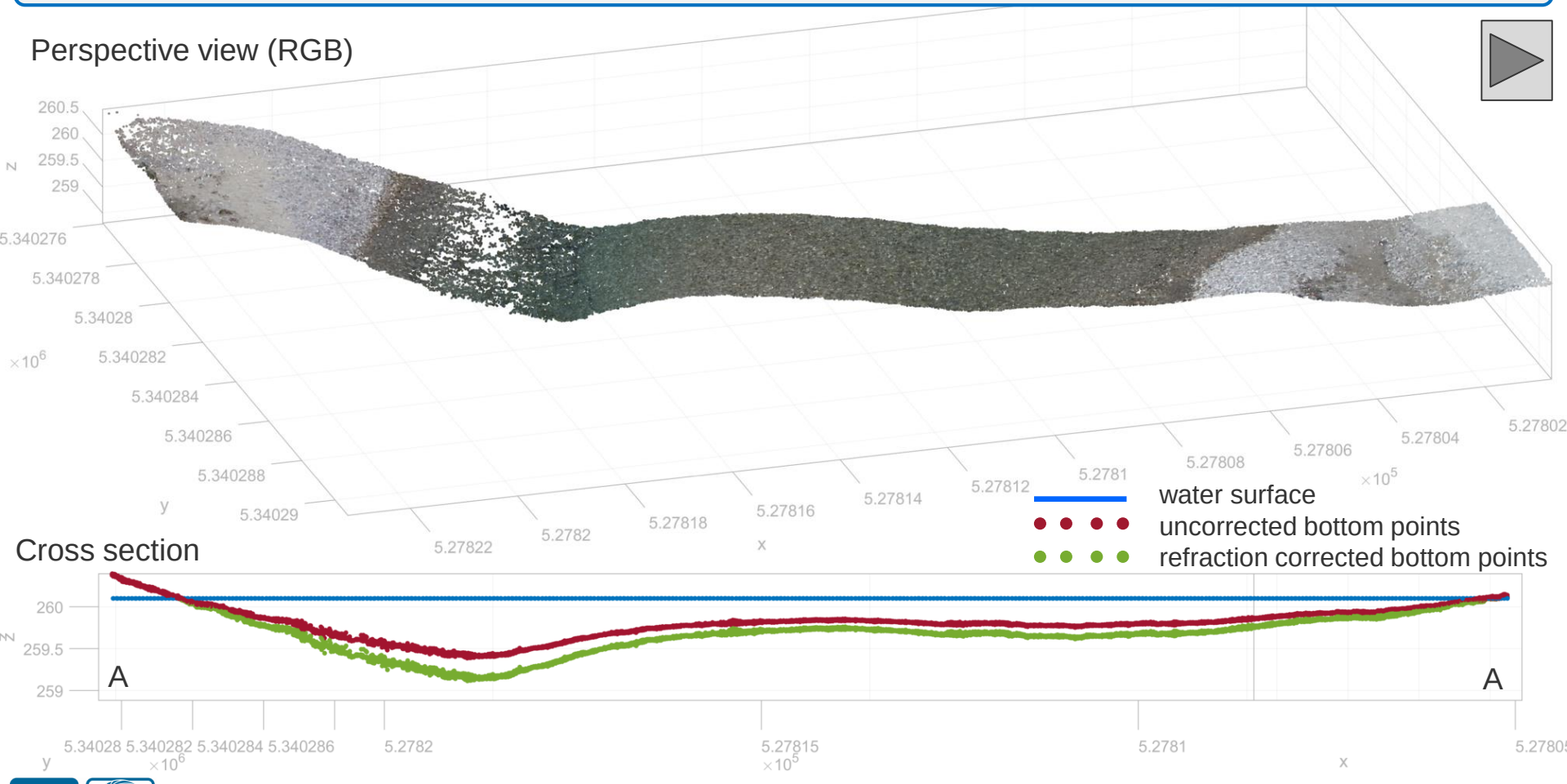
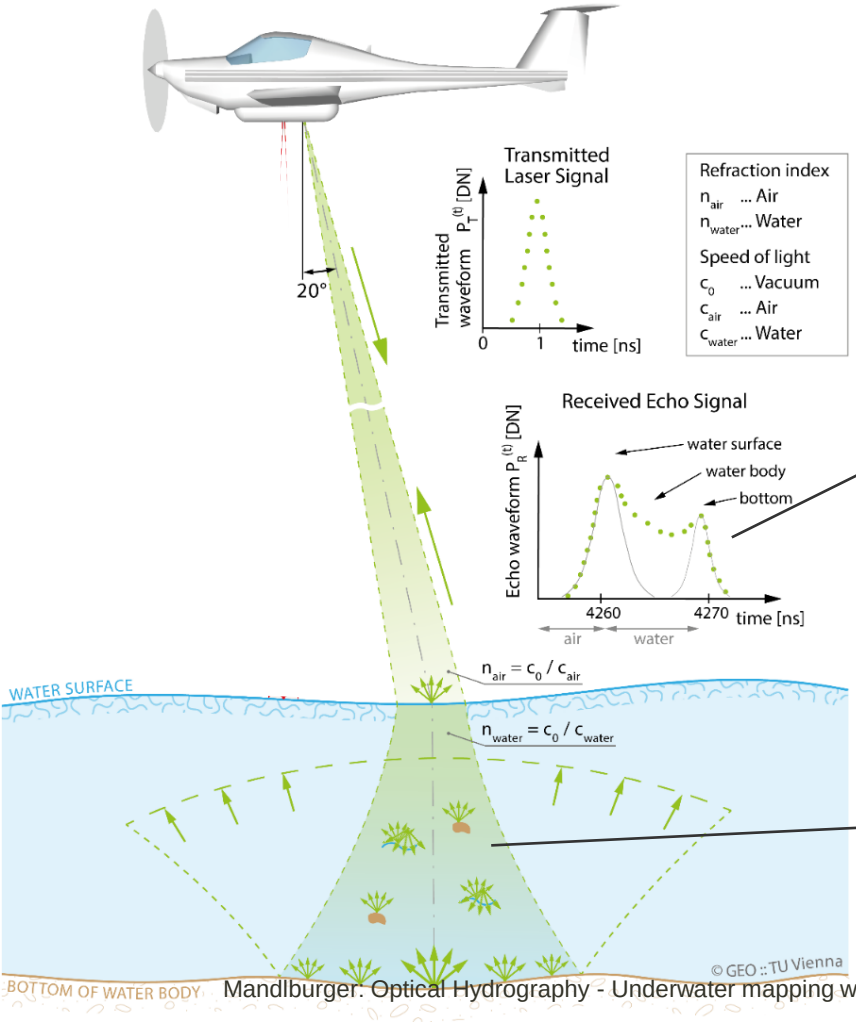
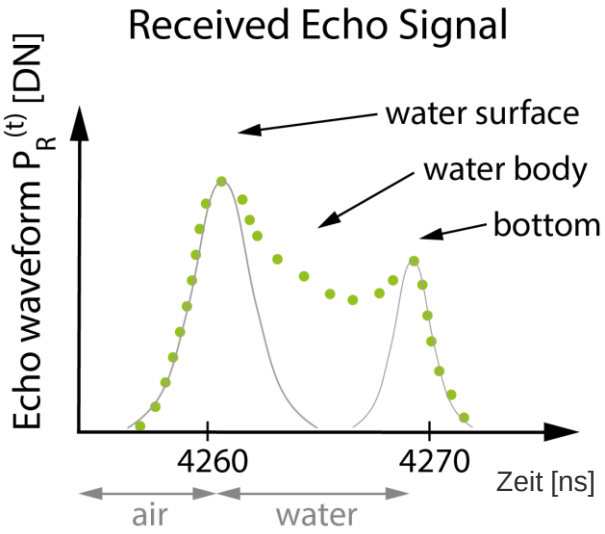


Photo bathymetry – refraction corrected point cloud



Airborne laser bathymetry





Reflection at the water surface

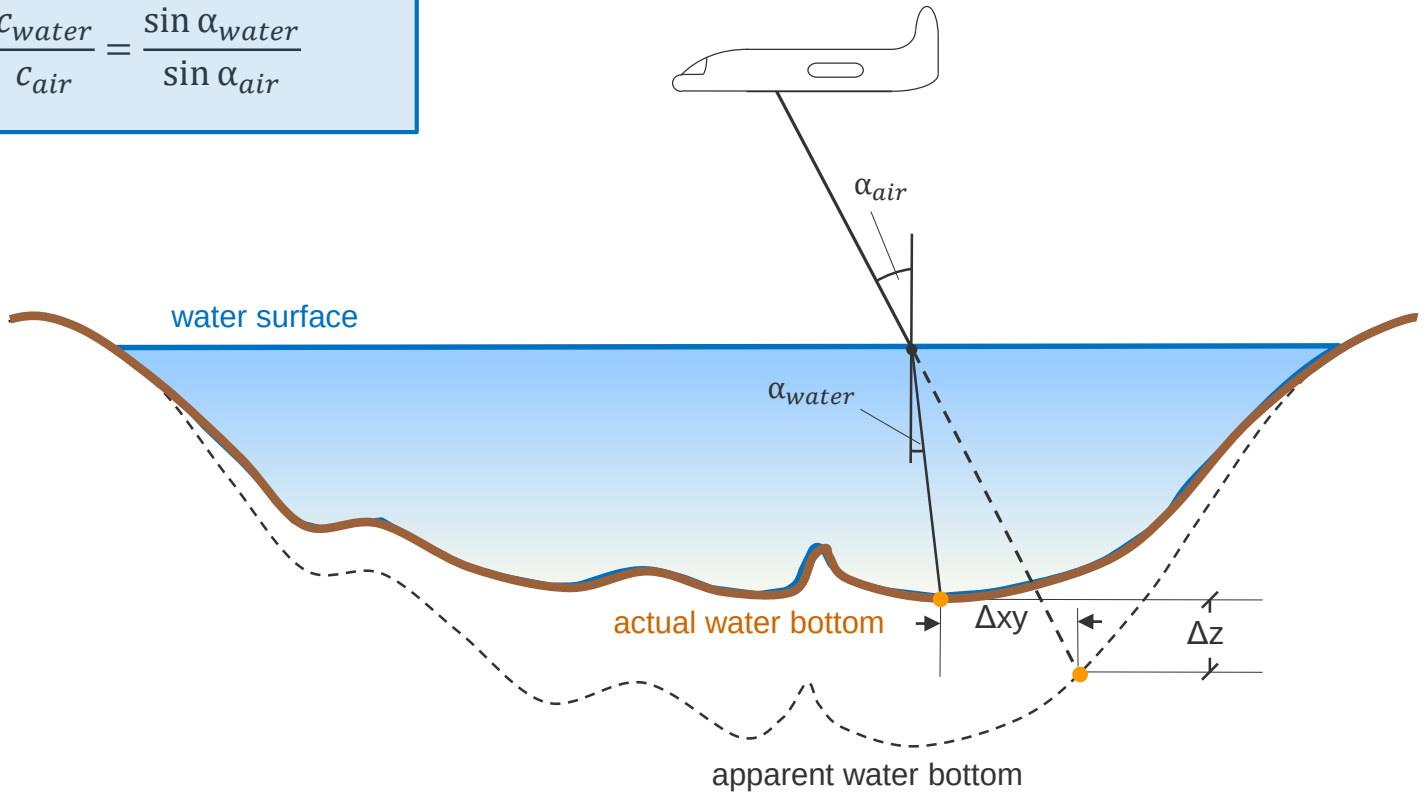
Attenuation of light in water

- Absorption
- Scattering
  - Forward
  - Backward

Refraction correction: Laser bathymetry

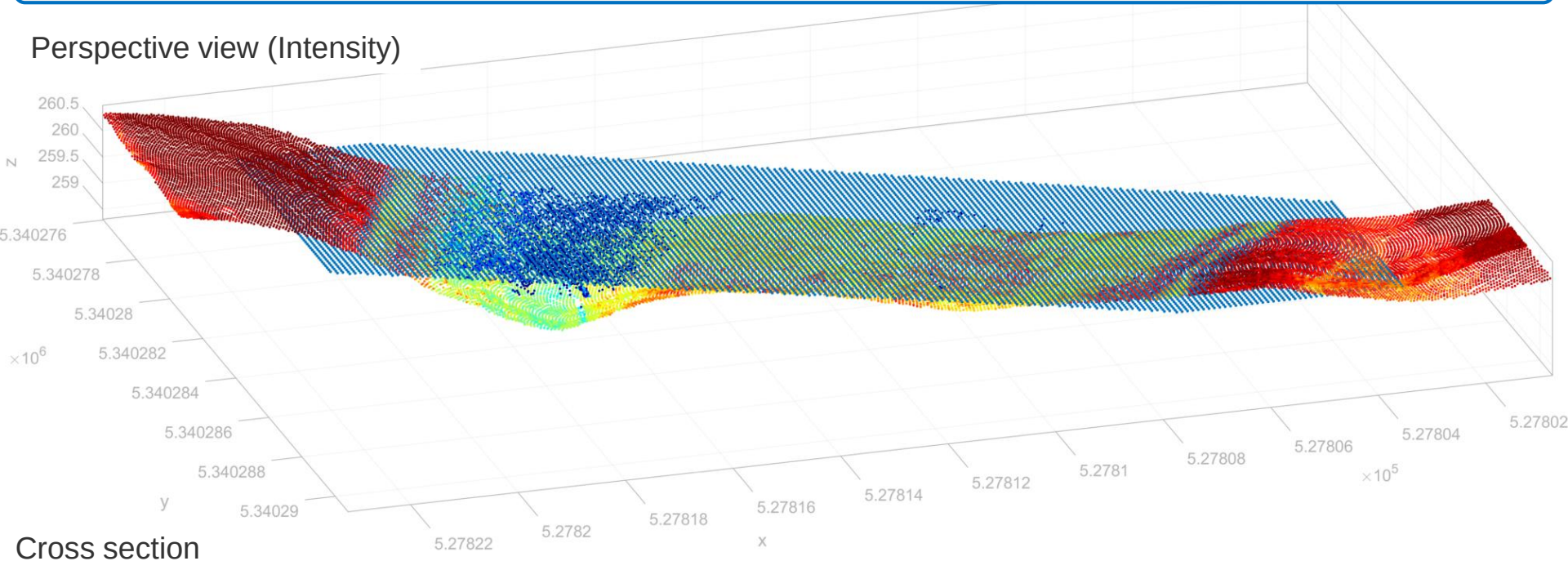
Snell's law of refraction

$$\frac{n_{air}}{n_{water}} = \frac{c_{water}}{c_{air}} = \frac{\sin \alpha_{water}}{\sin \alpha_{air}}$$

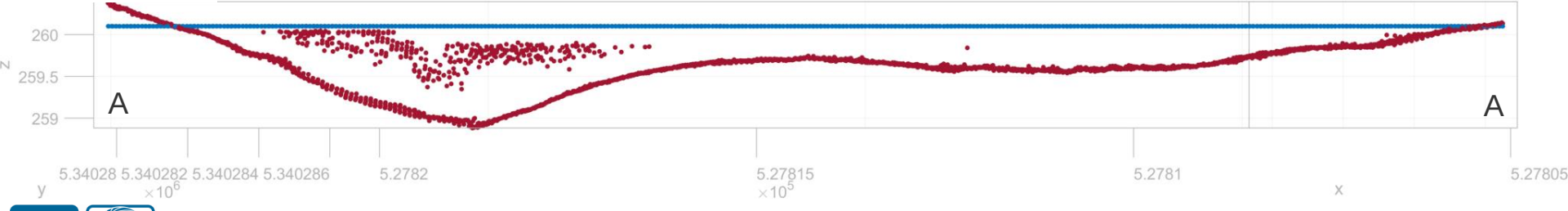


Laser bathymetry – raw point cloud

Perspective view (Intensity)

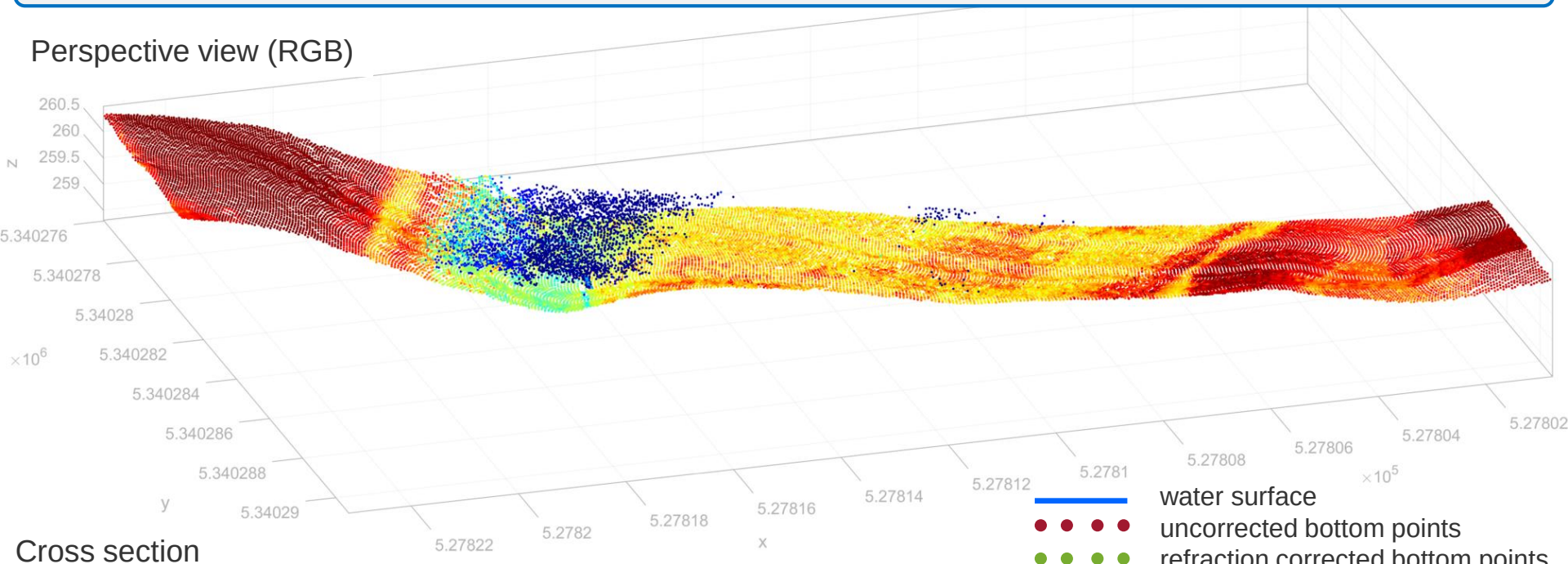


Cross section

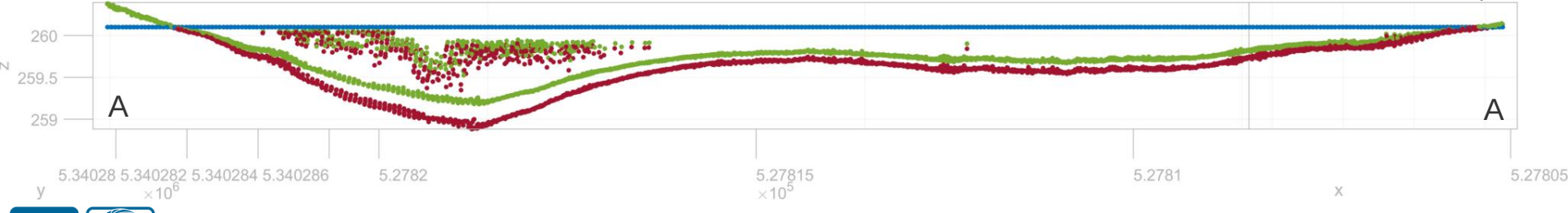


Laser bathymetry – refraction corrected point cloud

Perspective view (RGB)



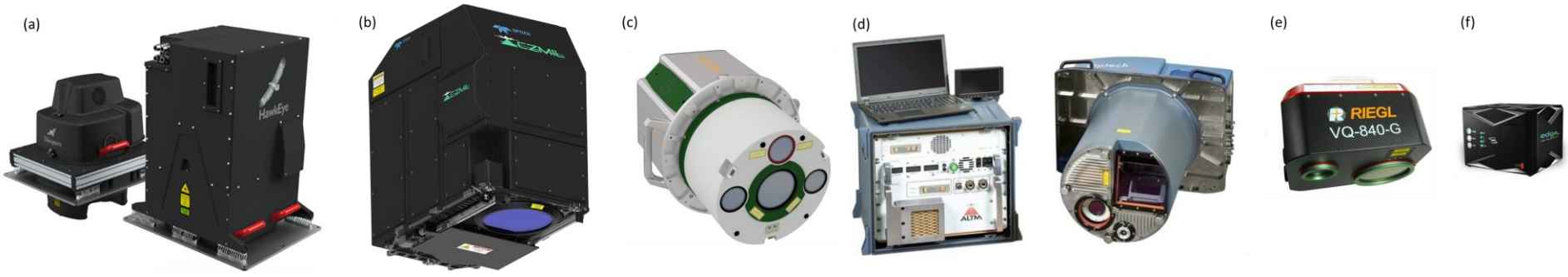
Cross section



What we did in the past (decade)

Review of Airborne Laser Bathymetry

G. Mandlburger: "*A review of airborne laser bathymetry for mapping of inland and coastal waters*"; Journal of Applied Hydrography, **116** (2020); DOI: 10.23784/HN116-01; 6 - 15.



- Thorough literature review of Airborne Laser Bathymetry (~. 90 references)
- Compact summary of basics of Airborne Laser Bathymetry including water suface modelling, full waveform analysis, refraction correction, volume backscattering
- Comprehensive LiDAR sensor overview: Deep bathy, topo-bathy, UAV-bathy
- Summary of ALB applications: object detection, submerged topography, ecology, morphology, turbidity, disaster management

Categorization of Airbore Laser Bathymetry sensors

Penetration depth

Secchi disc

Deep bathy:

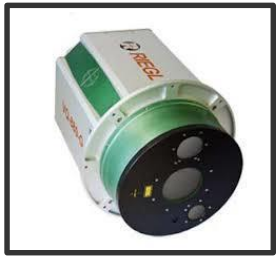
- ~3x Secchi depth (i.e. 50 m@ k=0.1)
- high pulse energy (5-7 mJ)
- low pulse repetition (3-10 kHz)
- long pulses (2-6.5 ns = 60-200 cm)
- large laser footprints (3.5m @ 500m agl)
- low spatial resolution
- focus: maximum pentration
- application: charting coastal waters, object detection

Shallow bathy:

- 1.5-2.0 x Secchi depth (i.e. 25m) @k=0.1)
- low-medium pulse energy (0.02-0.1 mJ)
- high pulse repetition rate (35-550 kHz)
- Short pulses (1.2-2 ns = 36-60 cm)
- small laser footprints (50 cm @ 500m agl)
- high spatial resolution
- focus: littoral zone, rivers, etc.
- application: flood simulation, habitat modelling, hydro-morphodynamics, etc.

deep only

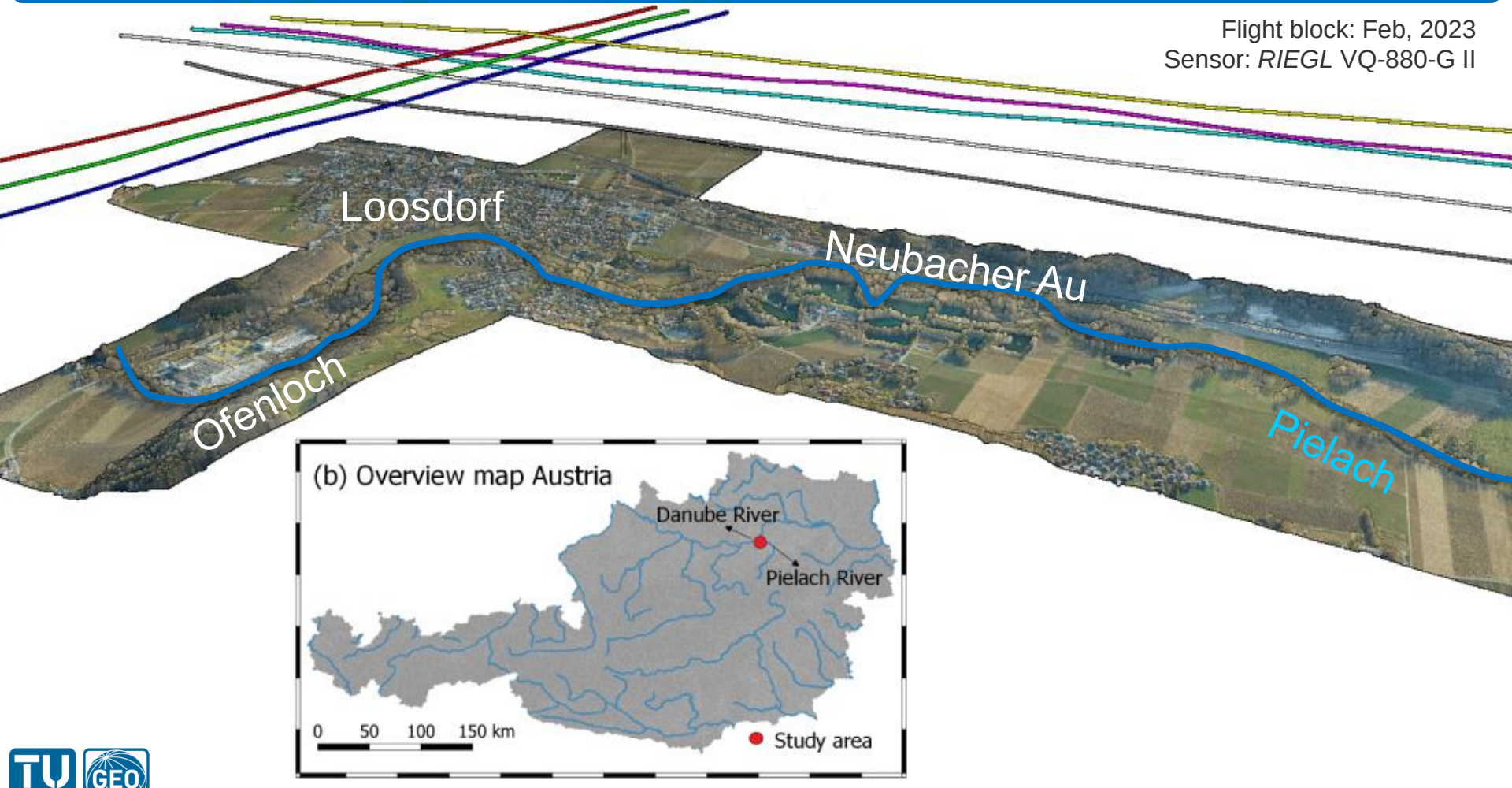
deep and shallow



shallow only

Topo-bathymetric flight block Loosdorf – Pielach I

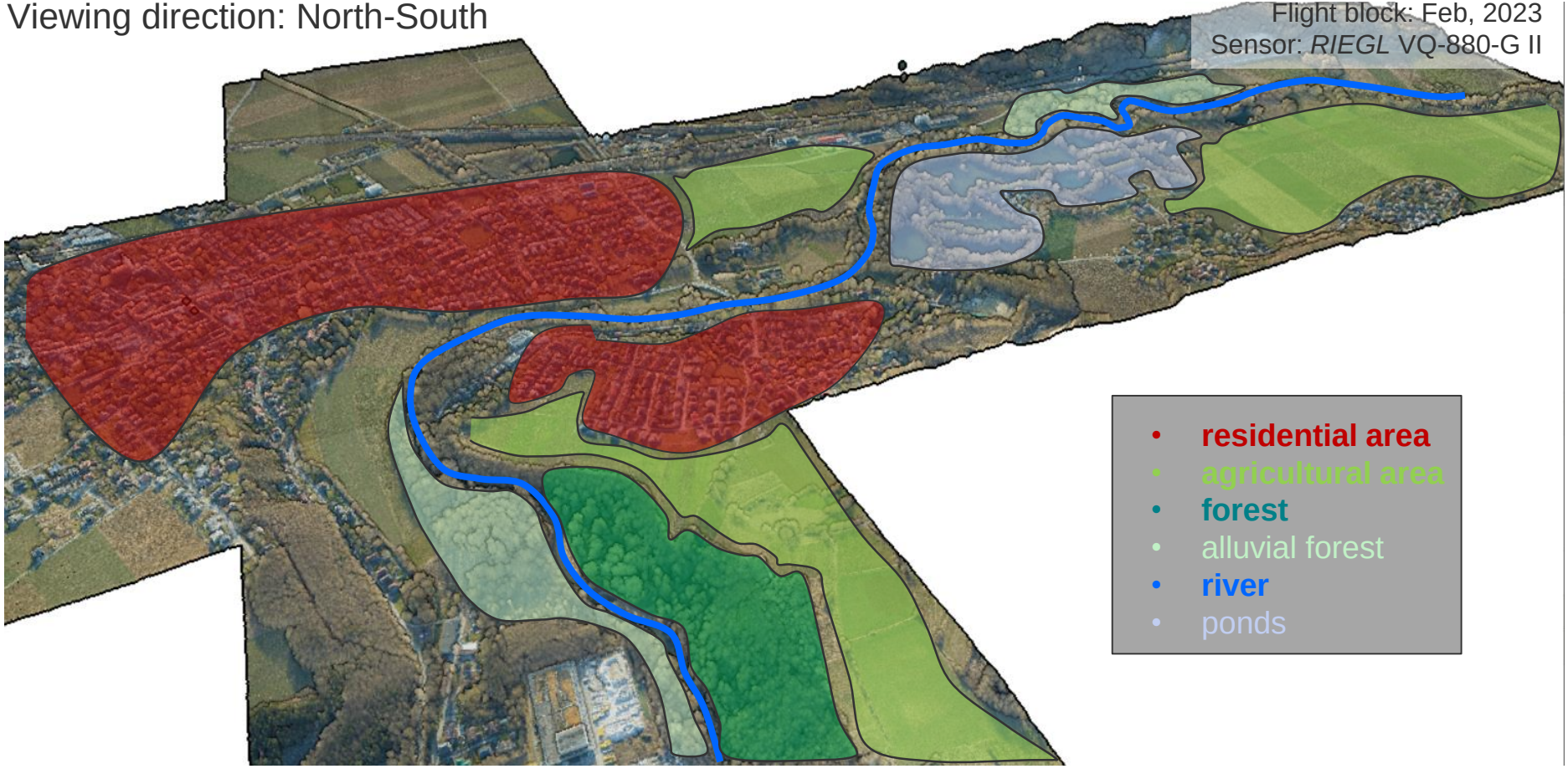
Flight block: Feb, 2023
Sensor: *RIEGL* VQ-880-G II



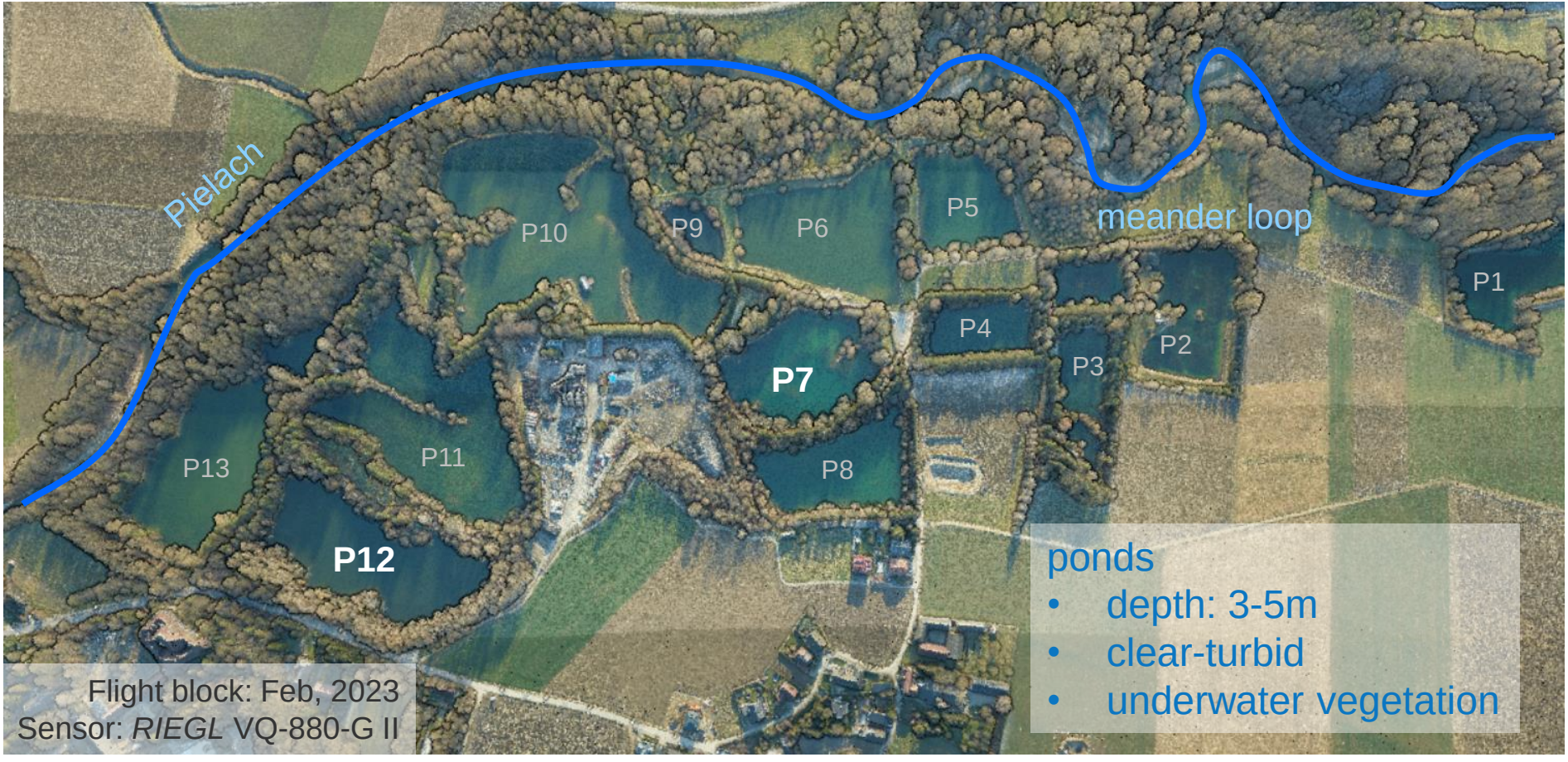
Topo-bathymetric flight block Loosdorf – Pielach II

Viewing direction: North-South

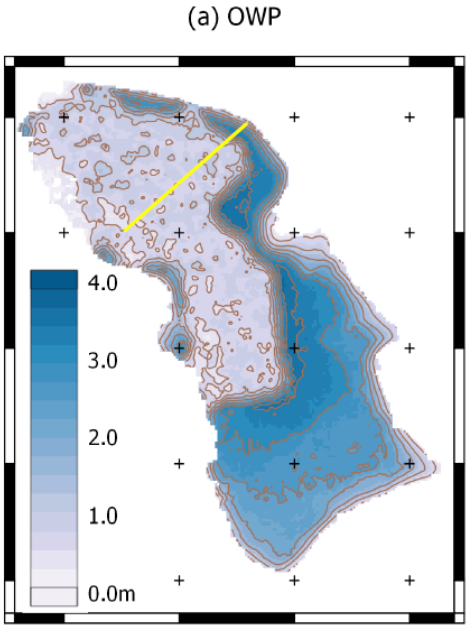
Flight block: Feb, 2023
Sensor: *RIEGL* VQ-880-G II

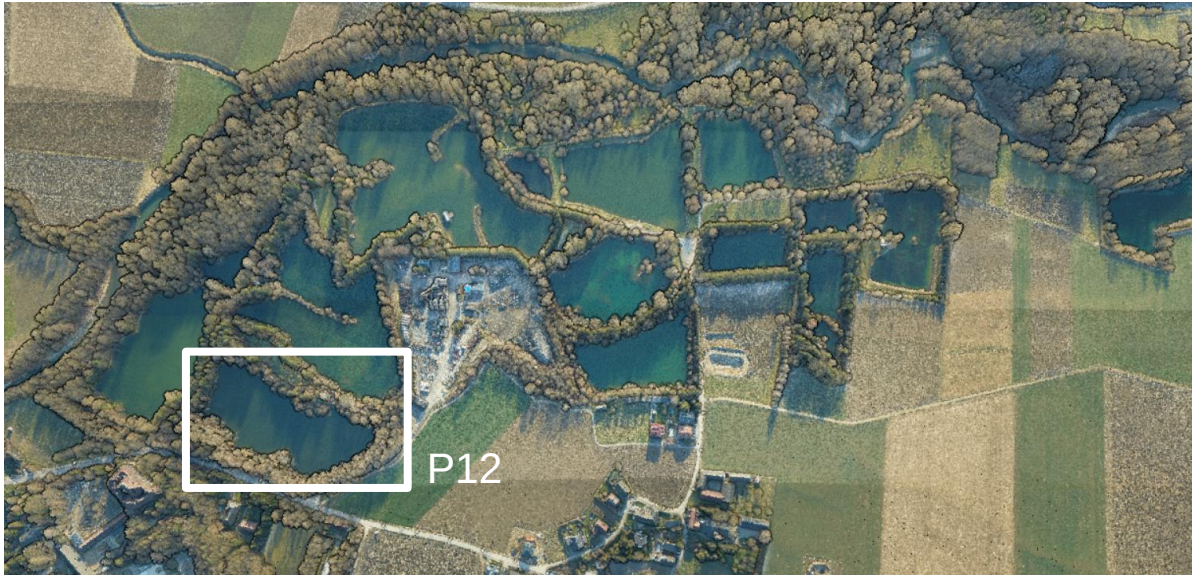


Focus point: Neubacher Au I (ponds)



A decade of progress in topo-bathy laser scanning





Depth penetration comparison for pond 12 using different full waveform processing strategies:

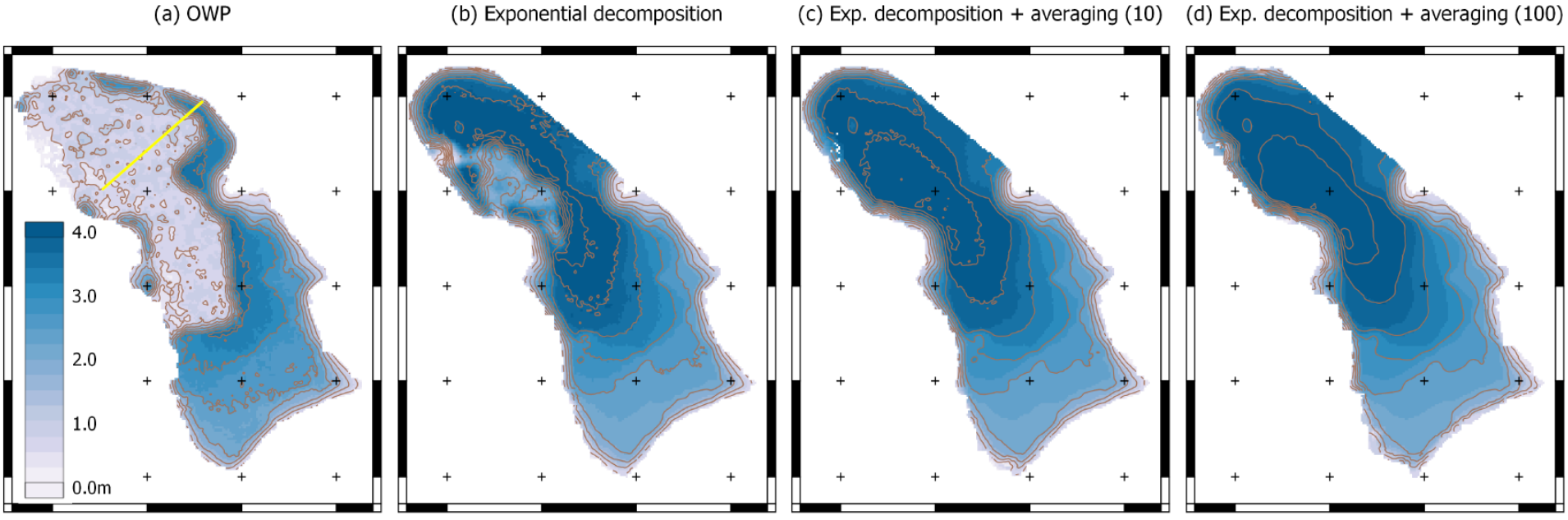
(a) Online Waveform Processing (**OWP**)

(b) Exponential Decomposition (**XDC**) **without** waveform **averaging**

(c) XDC with **10** waveforms **averaged**

(d) XDC with **100** waveforms **averaged**

A decade of progress in topo-bathy laser scanning



Depth penetration comparison for pond 12 using different full waveform processing strategies:

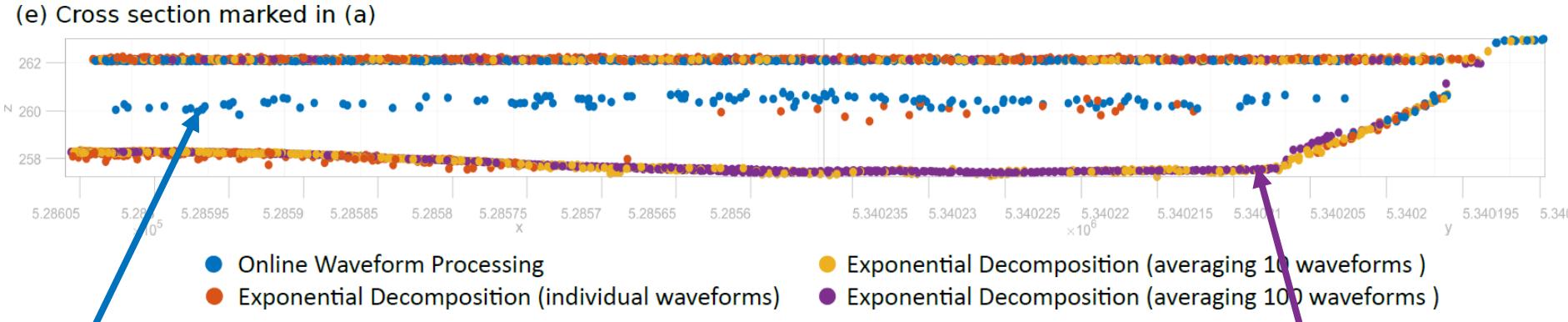
(a) Online Waveform Processing (**OWP**)

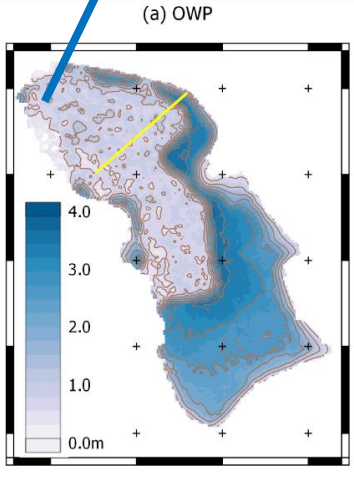
(b) Exponential Decomposition (**XDC**) **without** waveform **averaging**

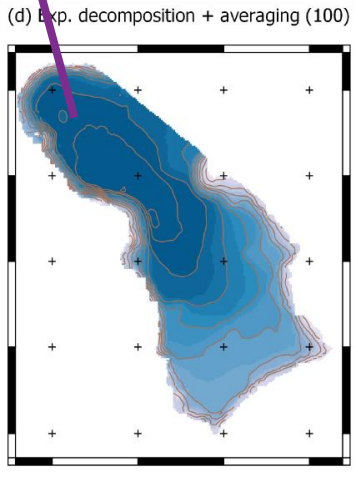
(c) XDC with **10** waveforms **averaged**

(d) XDC with **100** waveforms **averaged**

Cross secion comparison: OWP – XDC – XDC + avg.

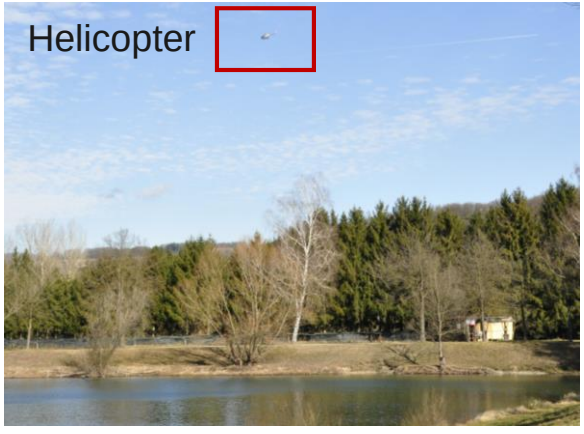




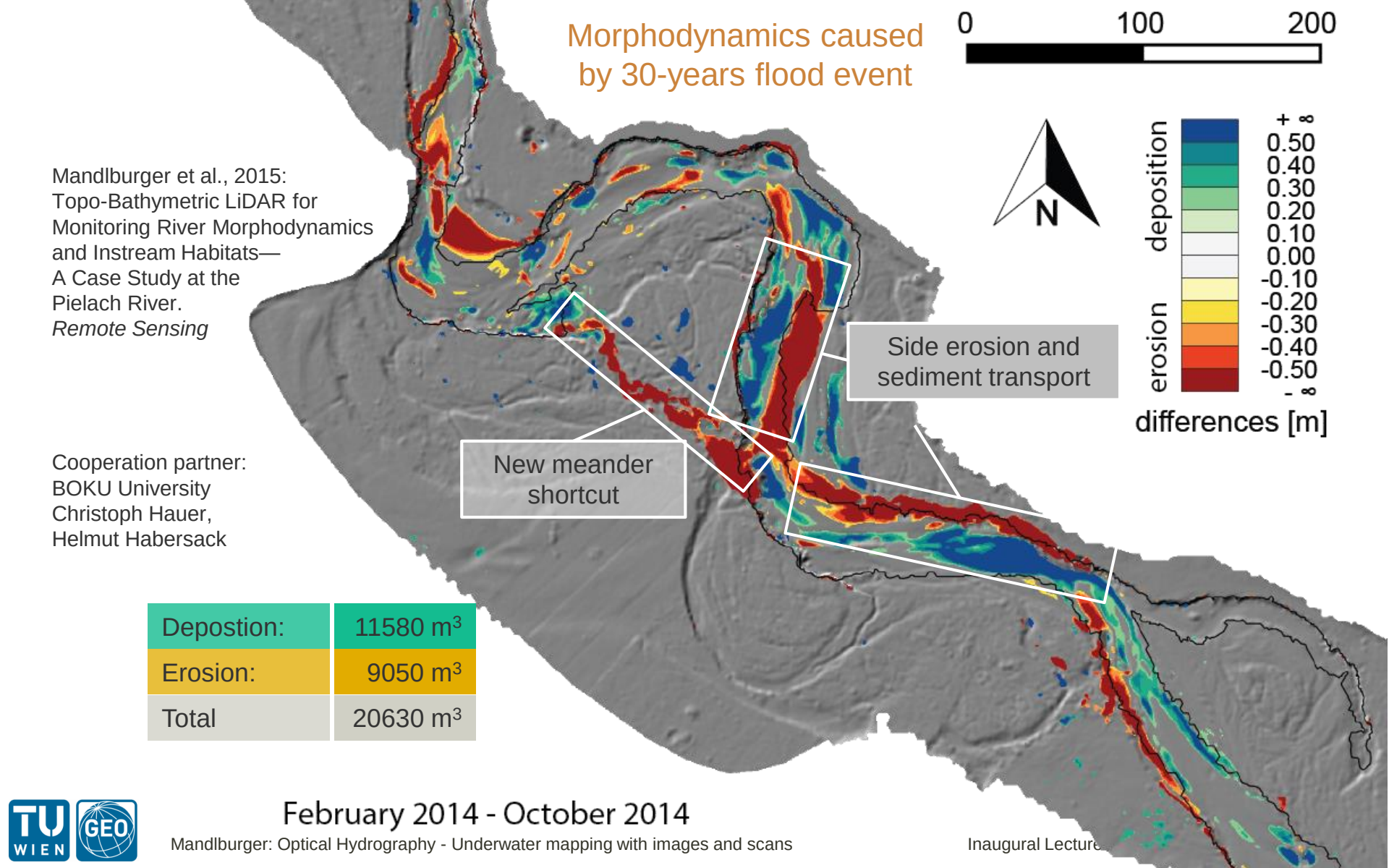


Focus point: Neubacher Au II (meander loop)

Carrier platforms: aircraft, helicopter, multi-copter UAV



Morphodynamics caused by 30-years flood event



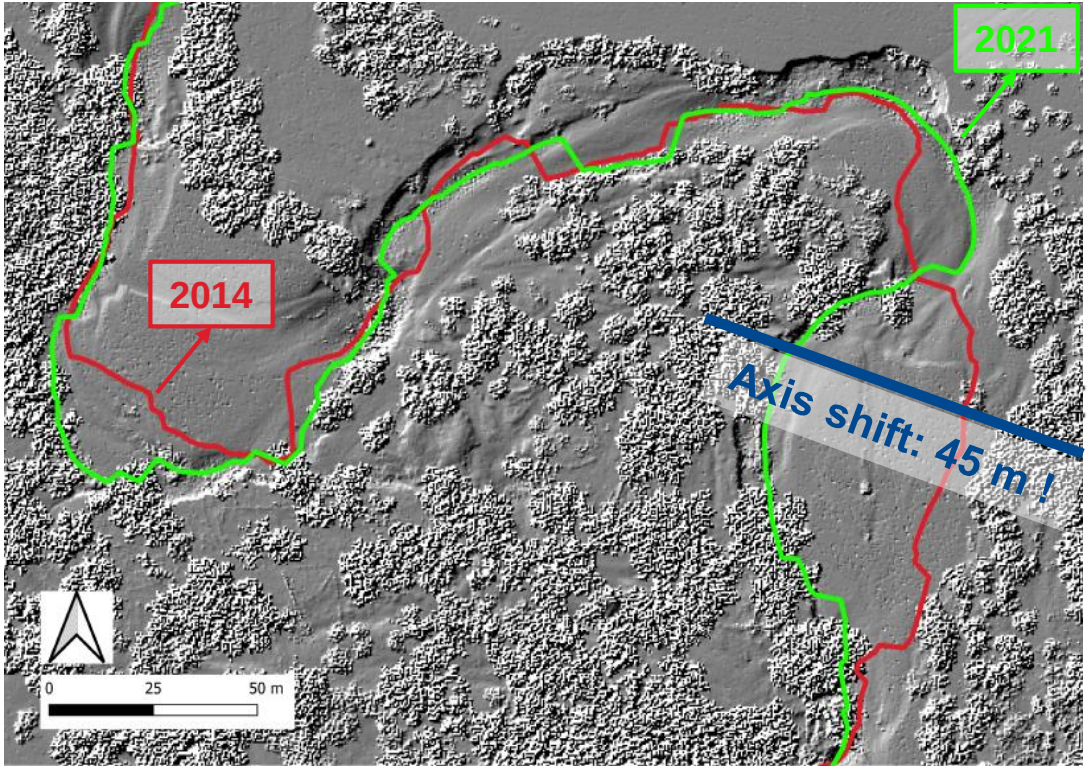
Mandlburger et al., 2015: Topo-Bathymetric LiDAR for Monitoring River Morphodynamics and Instream Habitats—A Case Study at the Pielach River. *Remote Sensing*

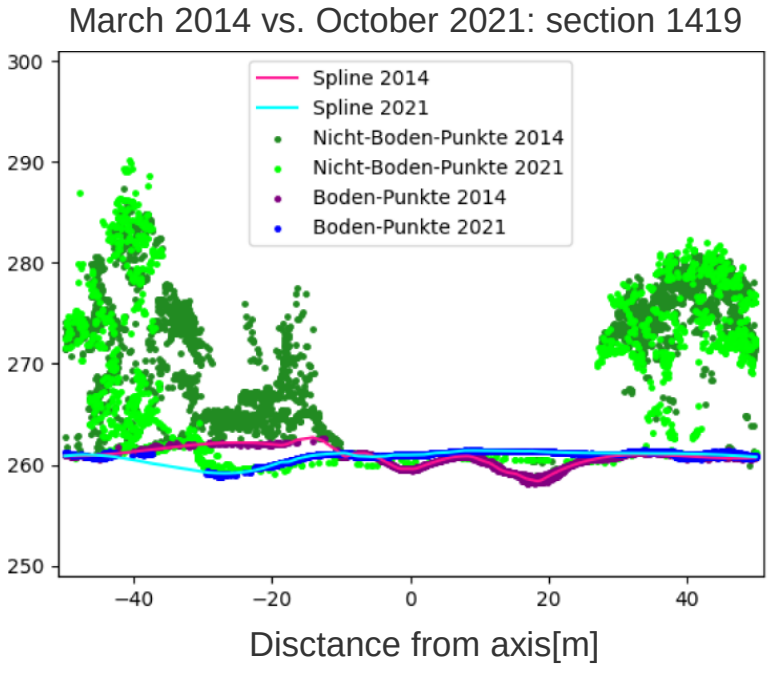
Cooperation partner:
BOKU University
Christoph Hauer,
Helmut Habersack

Depostion:	11580 m^3
Erosion:	9050 m^3
Total	20630 m^3

February 2014 - October 2014

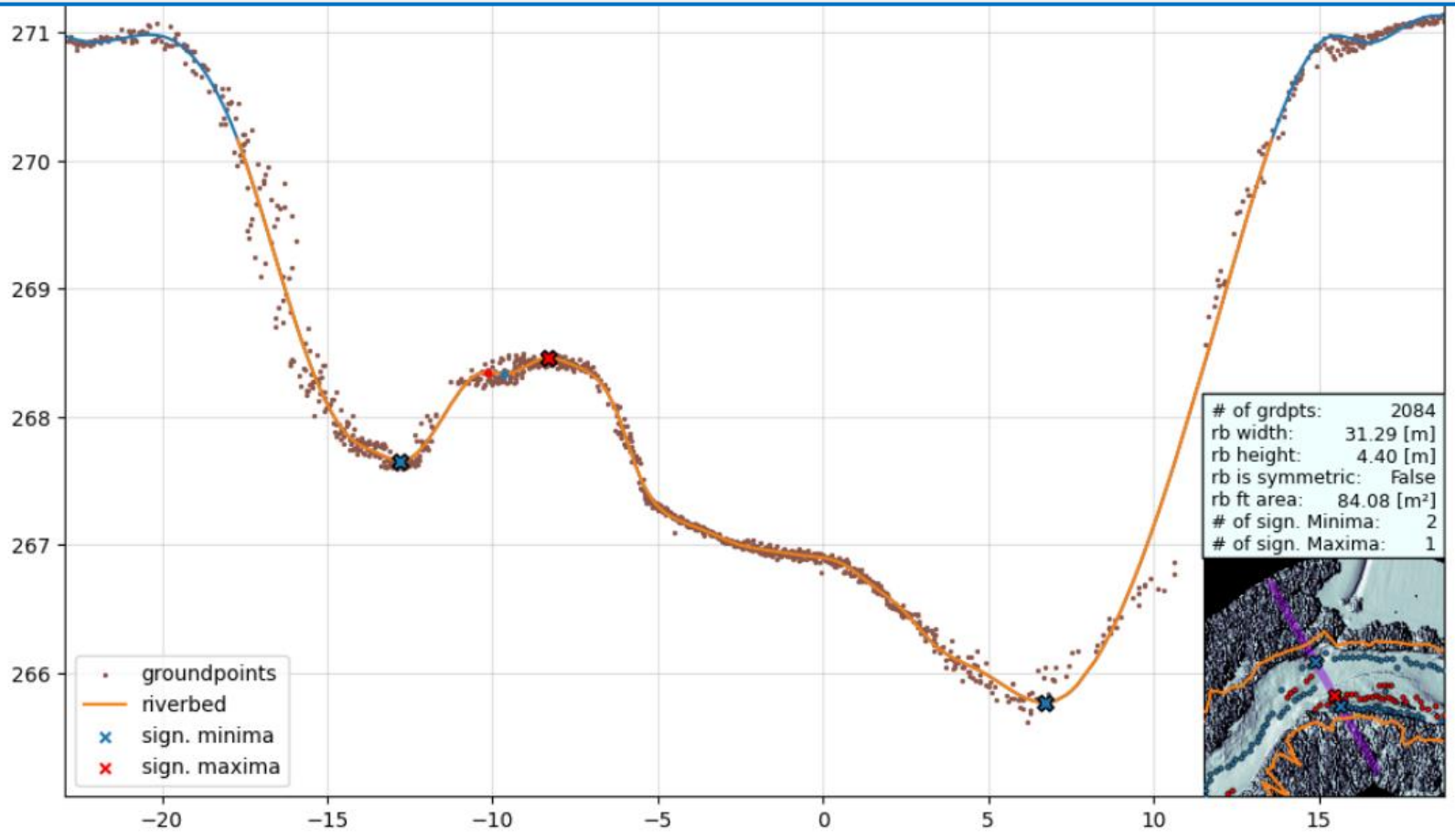
BSc Thesis Carolina Damm: Thalweg monitoring





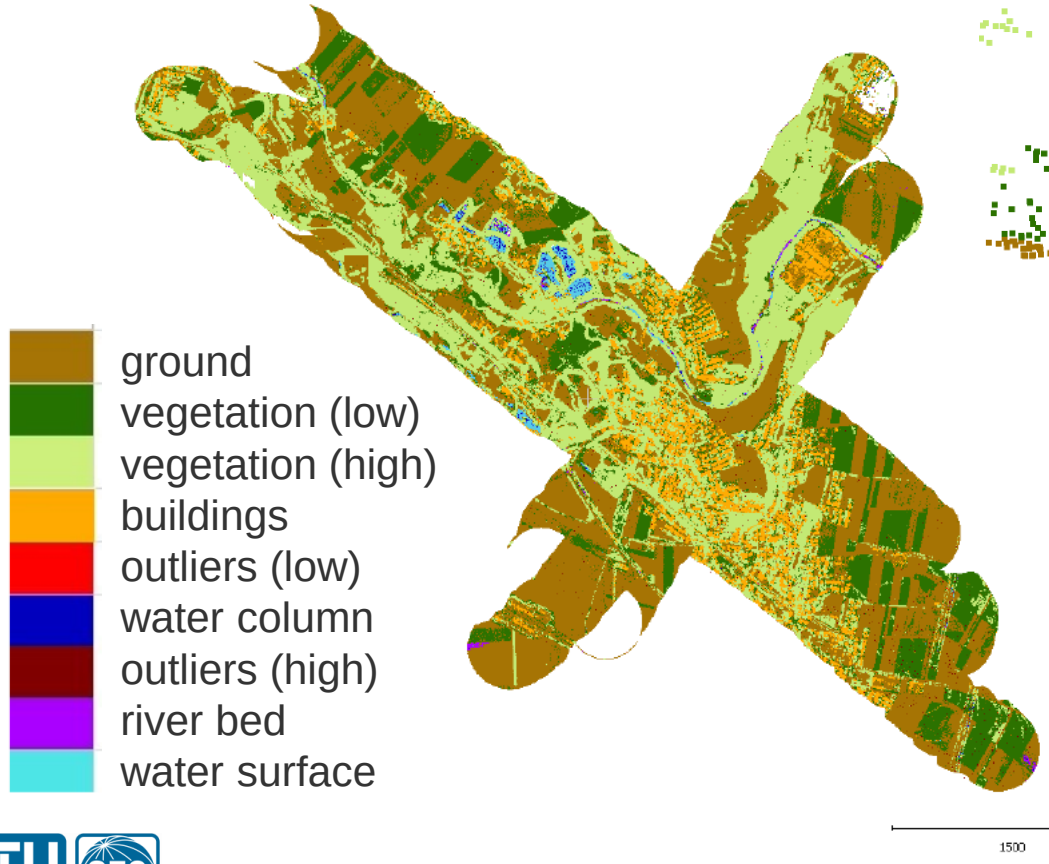
Co-supervised by Koen Blanckart (Prof. of Hydraulic Engineering @ TU Wien)

BSc Thesis Fabian Unterasinger: Fluvial morphology

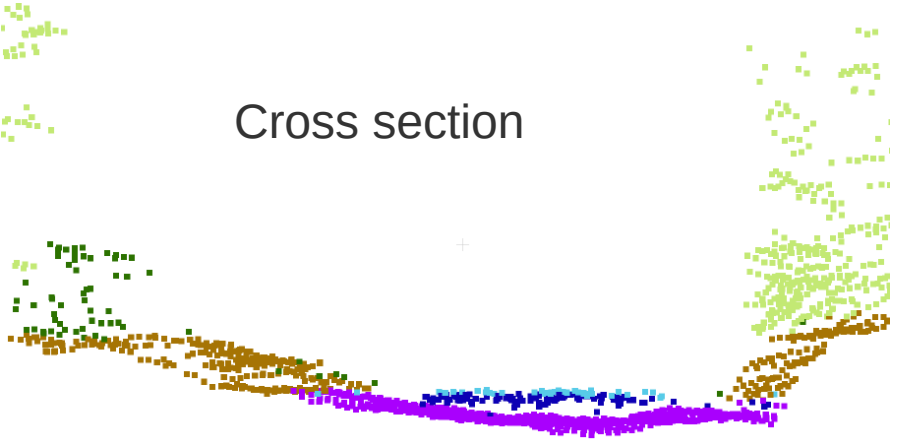


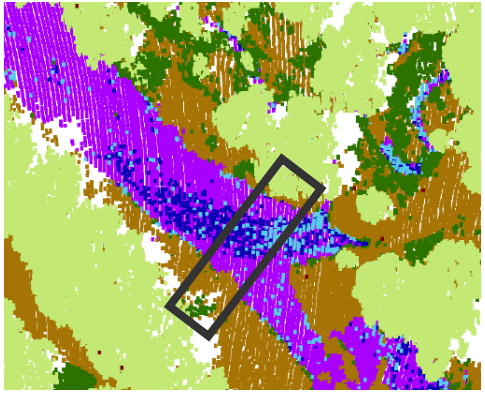
BSc Kapeller/Skilich: AI-based semantic labelling

Flight block Loosdorf/Piealch 2014



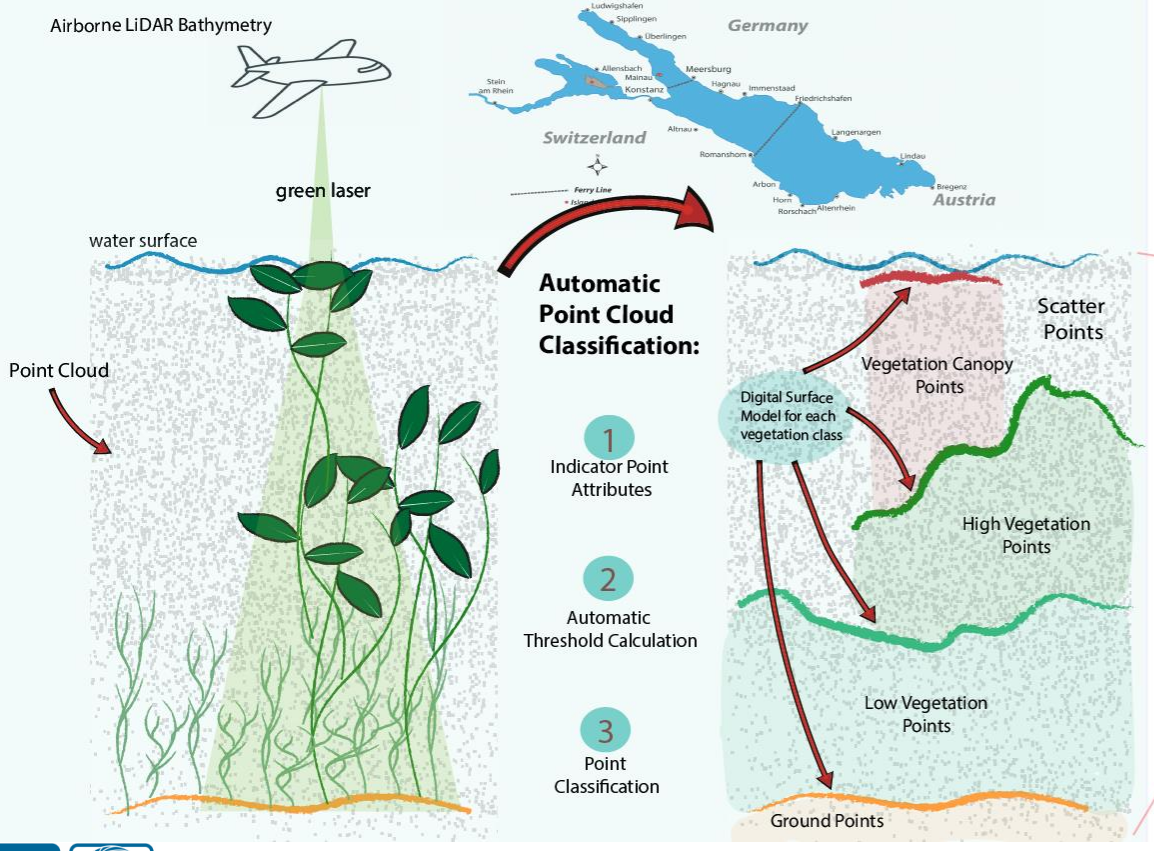
Cross section



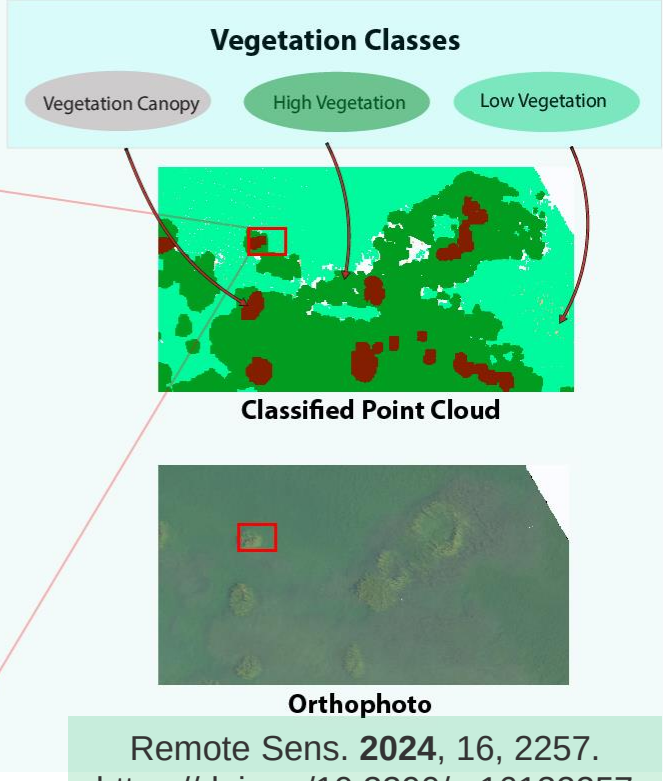


BSc thesis Nike Wagner: Classification of Submerged Macrophytes at Lake Constance based on Laser Bathymetry

Classification Concept and Study Area

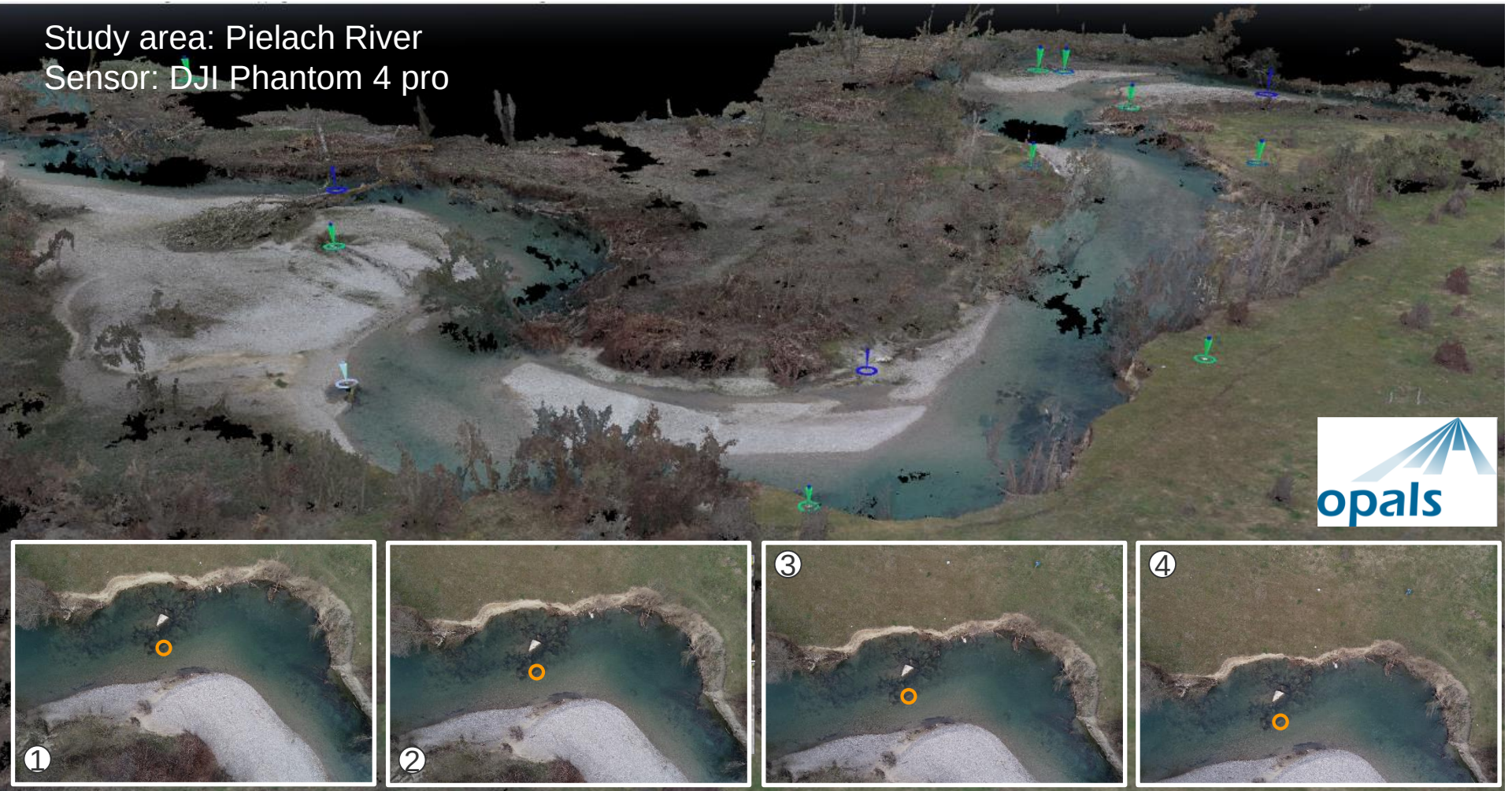


Classification Results



Remote Sens. **2024**, 16, 2257.
https://doi.org/10.3390/rs16132257

UAV images: dense point cloud + oriented images

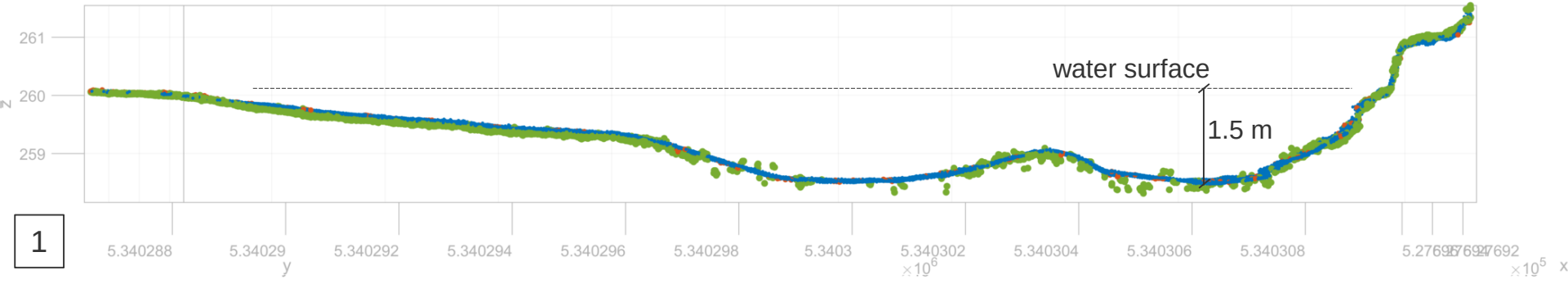


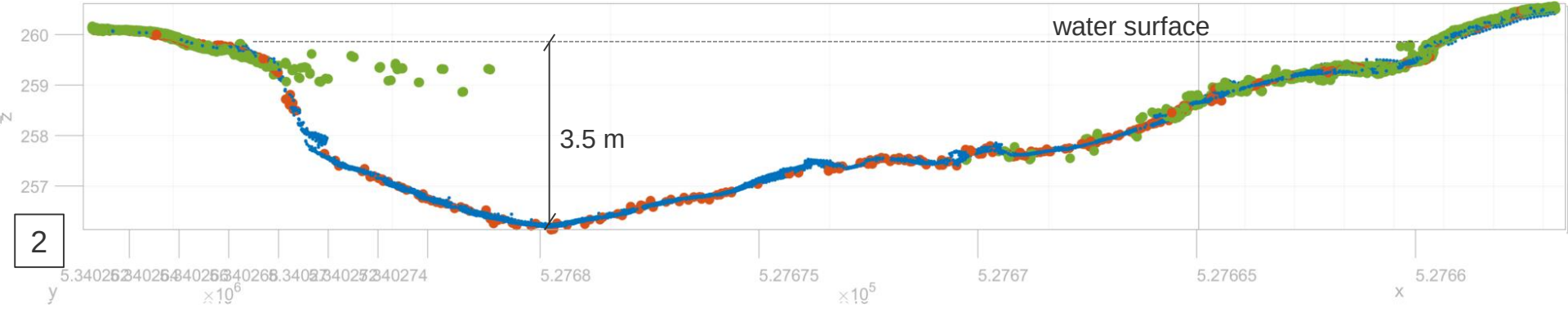
Comparison laser vs photo bathymetry (II)

RIEGL VQ-840-G (UAV)
Flying altitude: 60 m agl

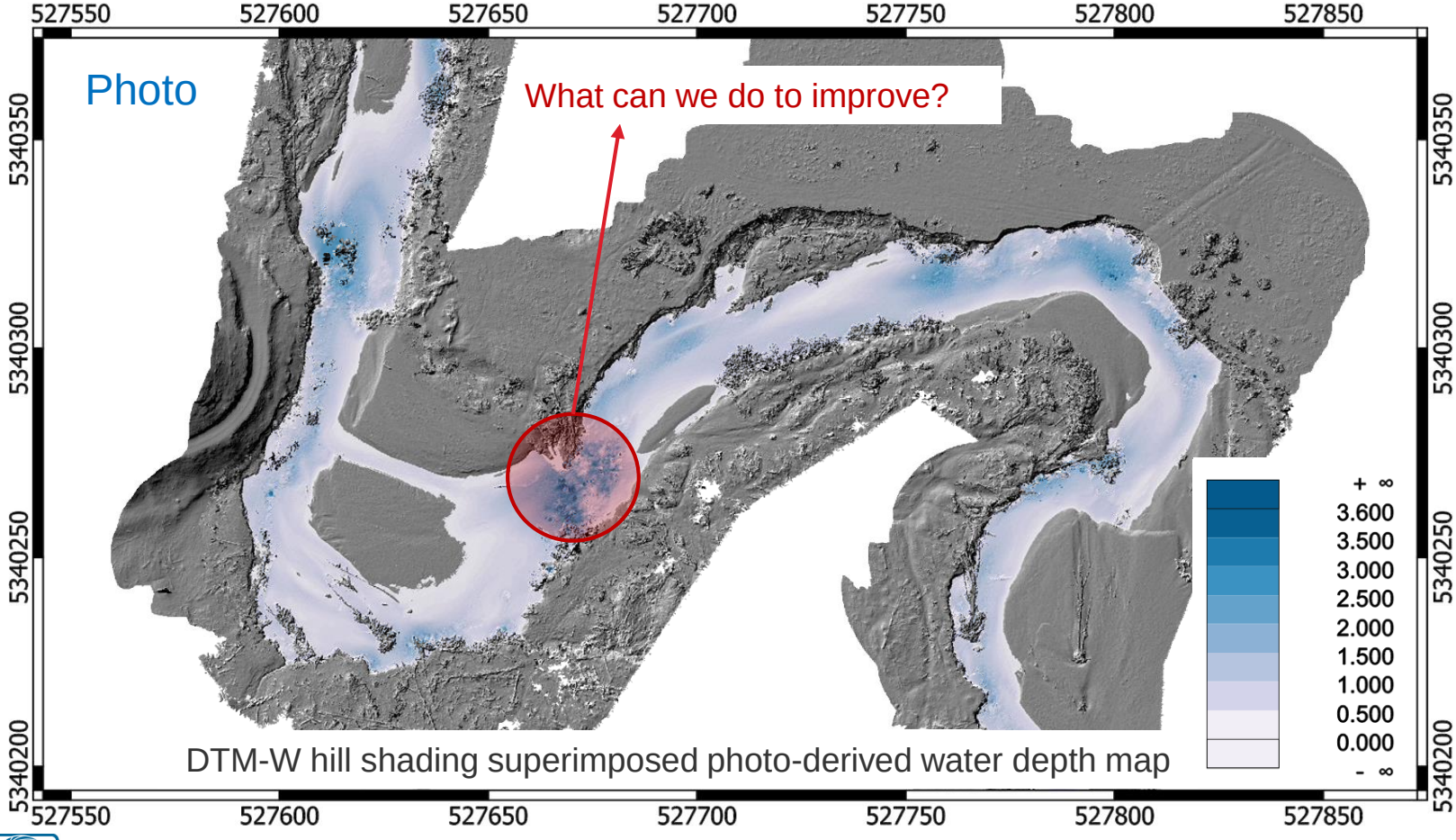
RIEGL VQ-880-GH (aircraft)
Flying altitude : 700 m agl

DJI Phantom 4 (UAV)
Flying altitude: 40 m agl





Digital Watercourse DTM: UAV-laser/photo bathymetry



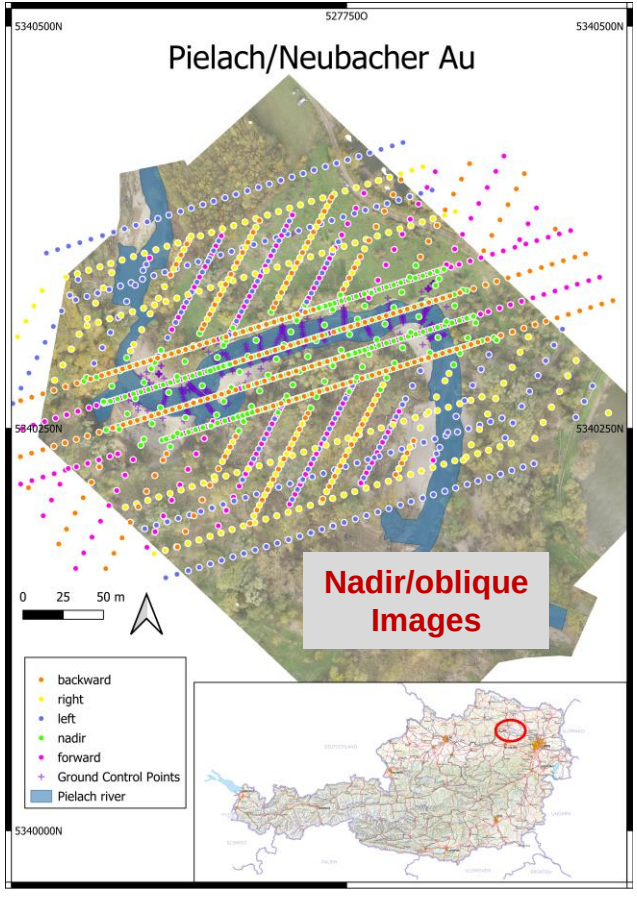
DTM-W hill shading superimposed photo-derived water depth map

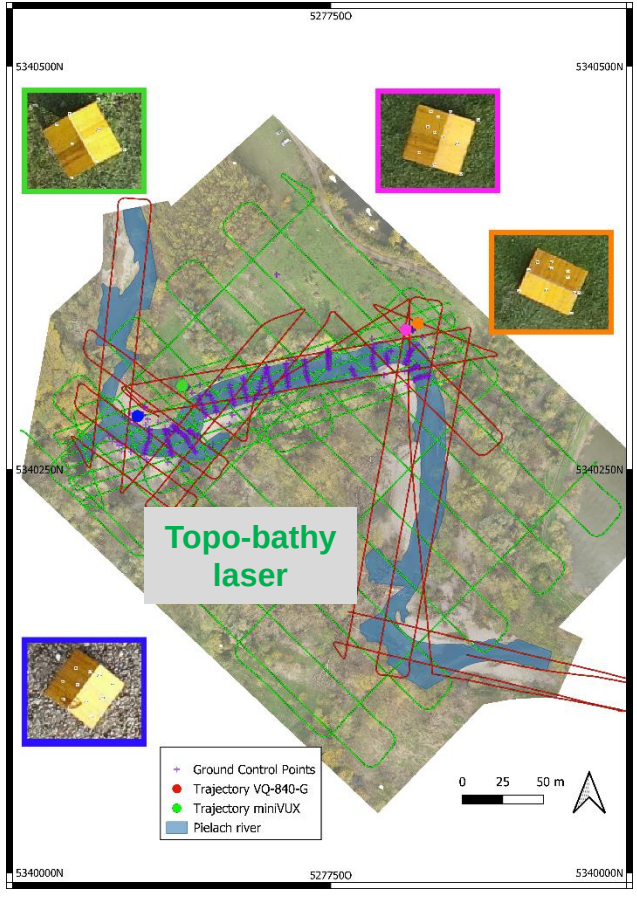
What we do today

Running PhD projects @GEO/Photo

- PhotoBathyWave (FWF): **Laure-Anne Gueguen**
  - Improving photo bathymetry via (strict) consideration of dynamic water surface
  - Approach 1: Freeze scene → Synchronous capture of nadir and oblique images
  - Approach 2: Spatio-temporal modelling of water surface → Holistic Bundle Block Adjustment
  - Approach 3: Mitigation of wave effects via image sequences
  - Project partner: TU Dresden (Hannes Sardemann, Christian Mulsow, Hans-Gerd Maas)
- BathyNeRF (FWF): **Markus Brezovsky**
  - Neural Radiance Fields (NeRFs) for estimating shallow water bathymetry
  - NeRF: AI-based view synthesis and 3D scene reconstruction
  - BathyNeRF: Consideration of image ray refraction at water surface
  - Project partners: UIBK (Frederik Schulte, Lukas Winiwarter), KIT (Anatol Günthner, Boris Jutzi)
- UnterWasserKraft (VERBUND): **Michael Grömer**
  - Mapping and monitoring underwater hydropower infrastructure
  - Robotly Operated Vehicles (ROV), underwater photogrammetry with (stereo) cameras
- LaserBathy (RIEGL): **Jan Rhomberg Kauert**
  - Mapping and modeling submersed macrophytes
  - Fostering (bathymetric) laser waveforms: white water, incidence angles, reflectance
- TrackDrone (FFG): **Lucas Dammert**

Pielach River research dataset October 2024





TU Wien research data:

Pielach River research dataset October 2024 - Mapping shallow inland running waters with UAV-borne photo and laser bathymetry

Mandlburger et al., 2025

DOI: 10.48436/5xwsn-7qb10.

Related article:

Mapping shallow inland running waters with UAV-borne photo and laser bathymetry – The Pielach River showcase

Mandlburger et al., 2025

Journal of Applied Hydrography

DOI: 10.23784/HN130-06

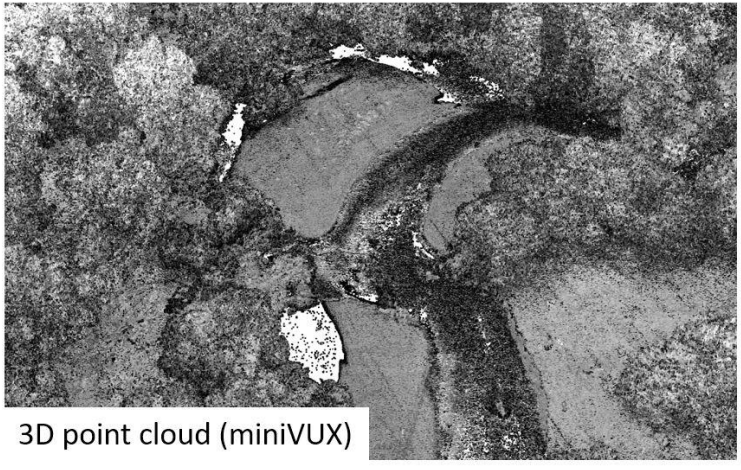
Impressions from the October 2024 field campaign

From left to right: Me, Laure-Anne Gueguen (TUW) and Silvia Glas (UIBK) with the 2 DJI M350/P1 drones taking synchronized images

The 4 drones used: from left to right: DJI Mavic3E, Acecor Nova with topo-bathy scanner (RIEGL VQ-840-G) 2x DJI M350 with Zenmuse P1 cameras (48MPix, RGB)

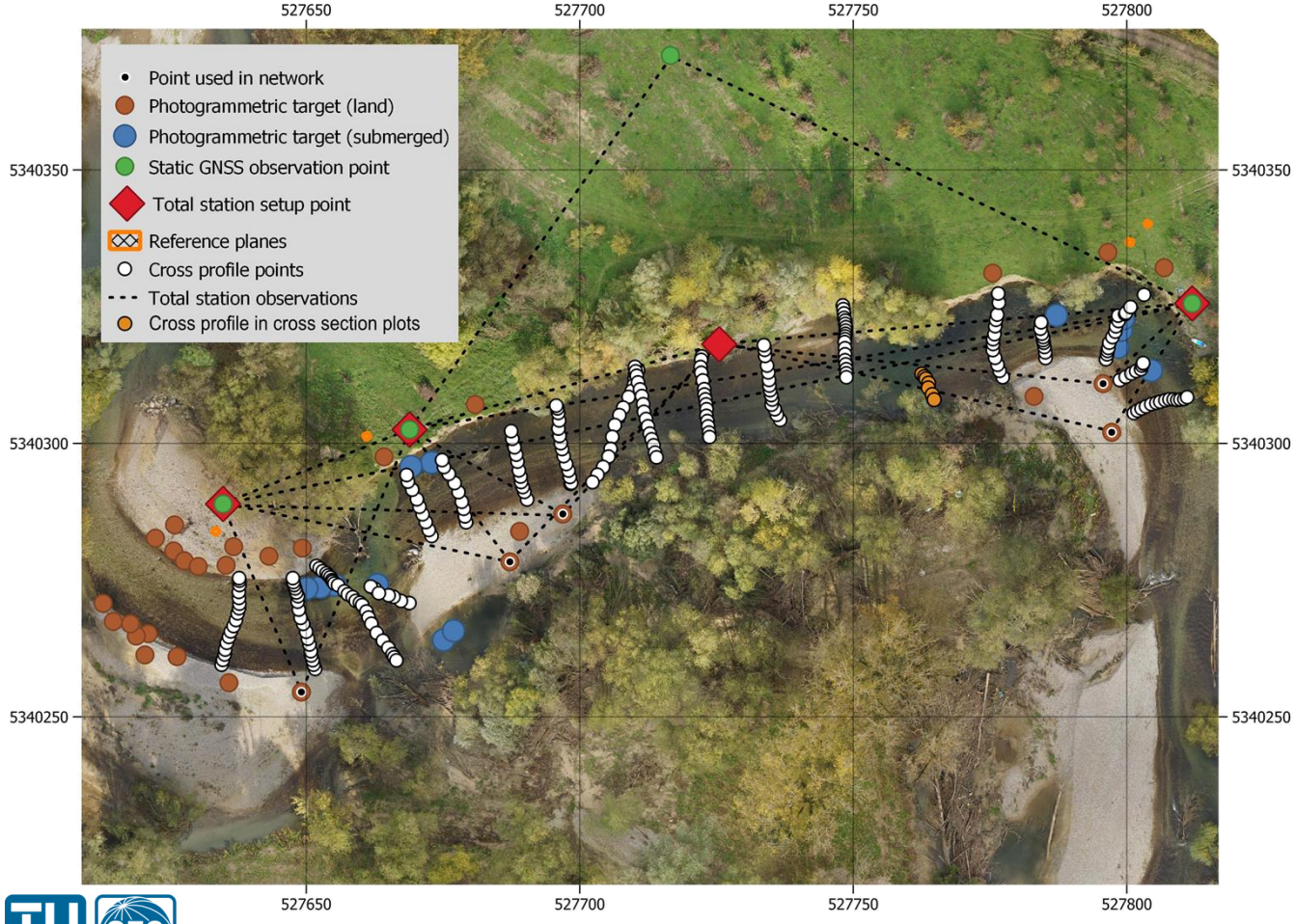
Study area at Pielach/Neubacher Au)

Oblique aerial image (P1)



3D point cloud (miniVUX)

Reference data for photo/laser bathymetry



Reference measurements:

- GNSS network
- Totalstation network
- Ground Control Points
- Reference points for bathymetry

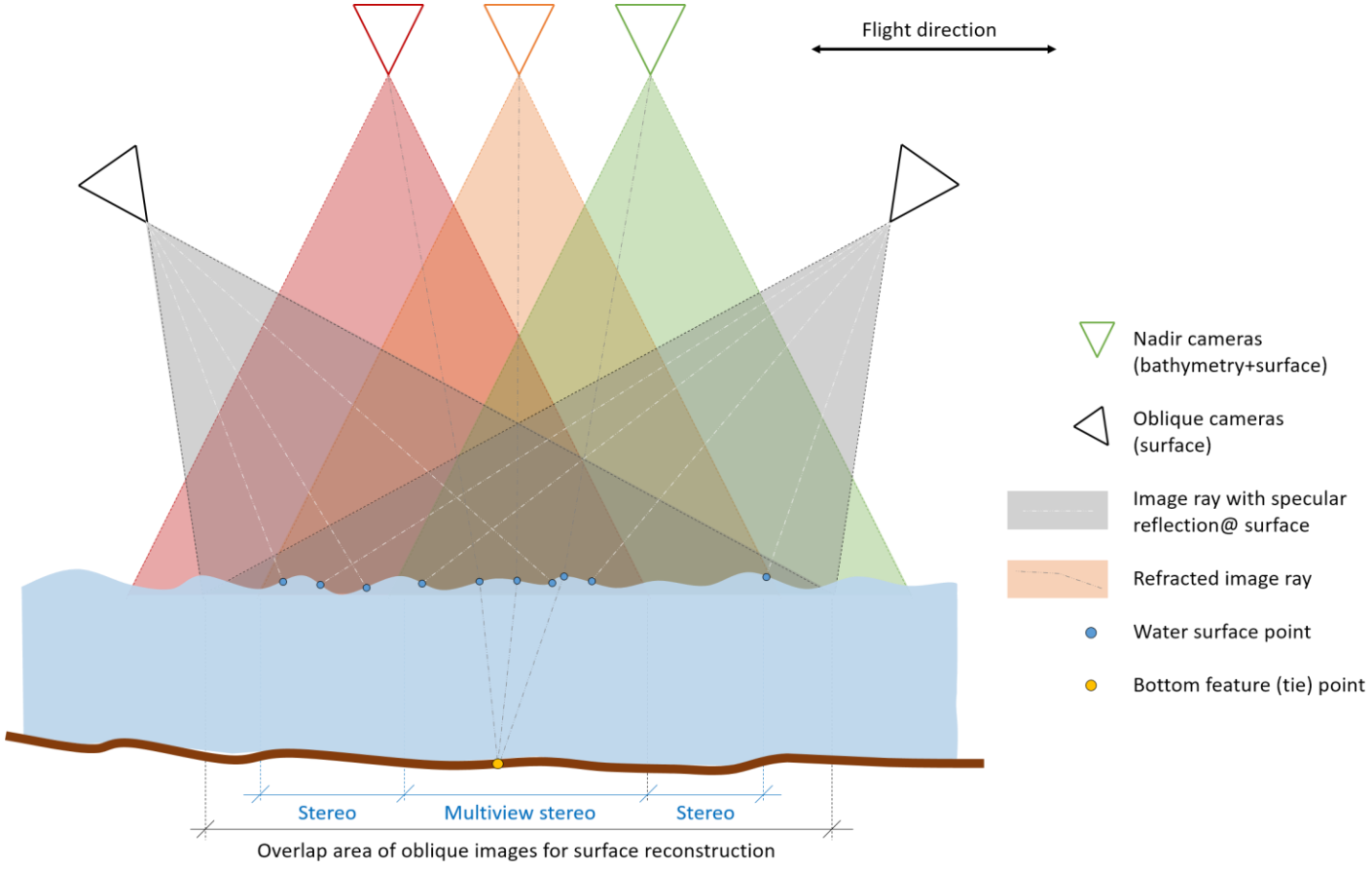
TU Wien research data:

Pielach River research dataset October 2024 - Mapping shallow inland running waters with UAV-borne photo and laser bathymetry

Mandlburger et al., 2025

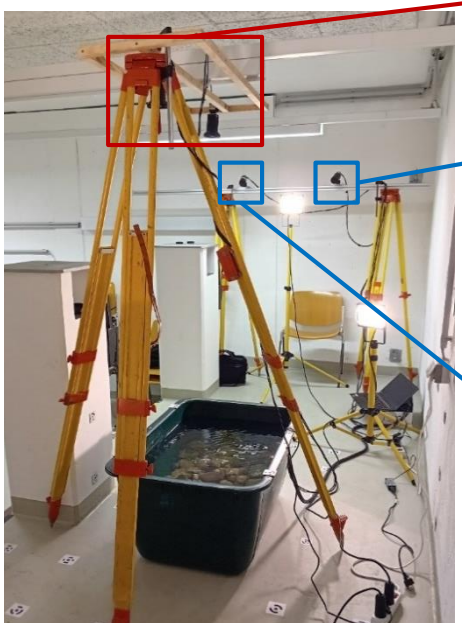
DOI: 10.48436/5xwsn-7qb10.

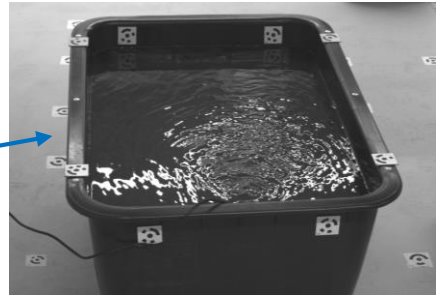
PhotoBathyWave project idea: Simultan. surface and bottom



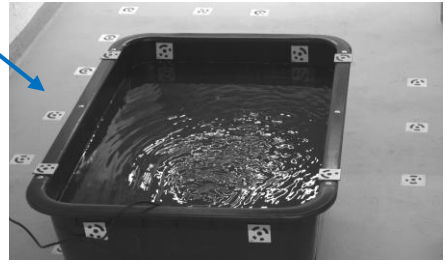
PhotoBathyWave lab experiment: Simultan. surface and bottom

- multi-camera setup simultaneously triggered by an Arduino
- 2 oblique and 2 nadir looking cameras
- water tank filled with 2 layers of stone

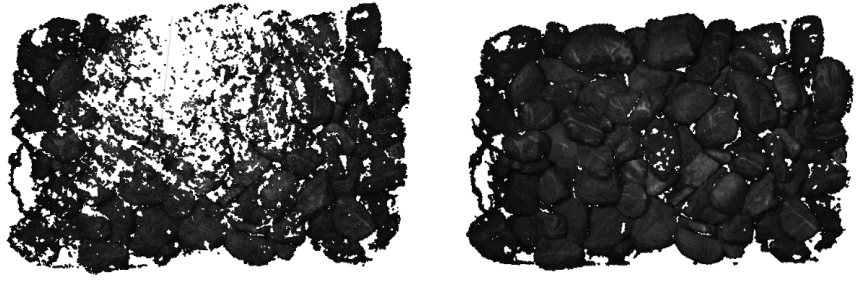




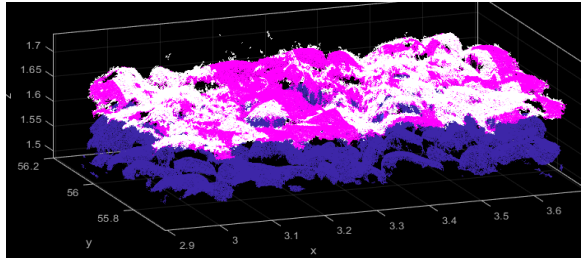
Oblique stereo pair

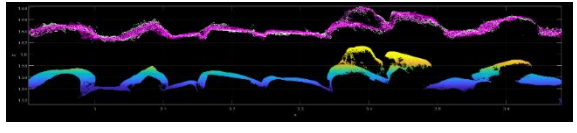


Provided by cand. PhD Laure-Anne Gueguen, TU Wien 4D meas. lab



Dense point cloud of topography from nadir images with dynamic surface (left) and flat surface (right)

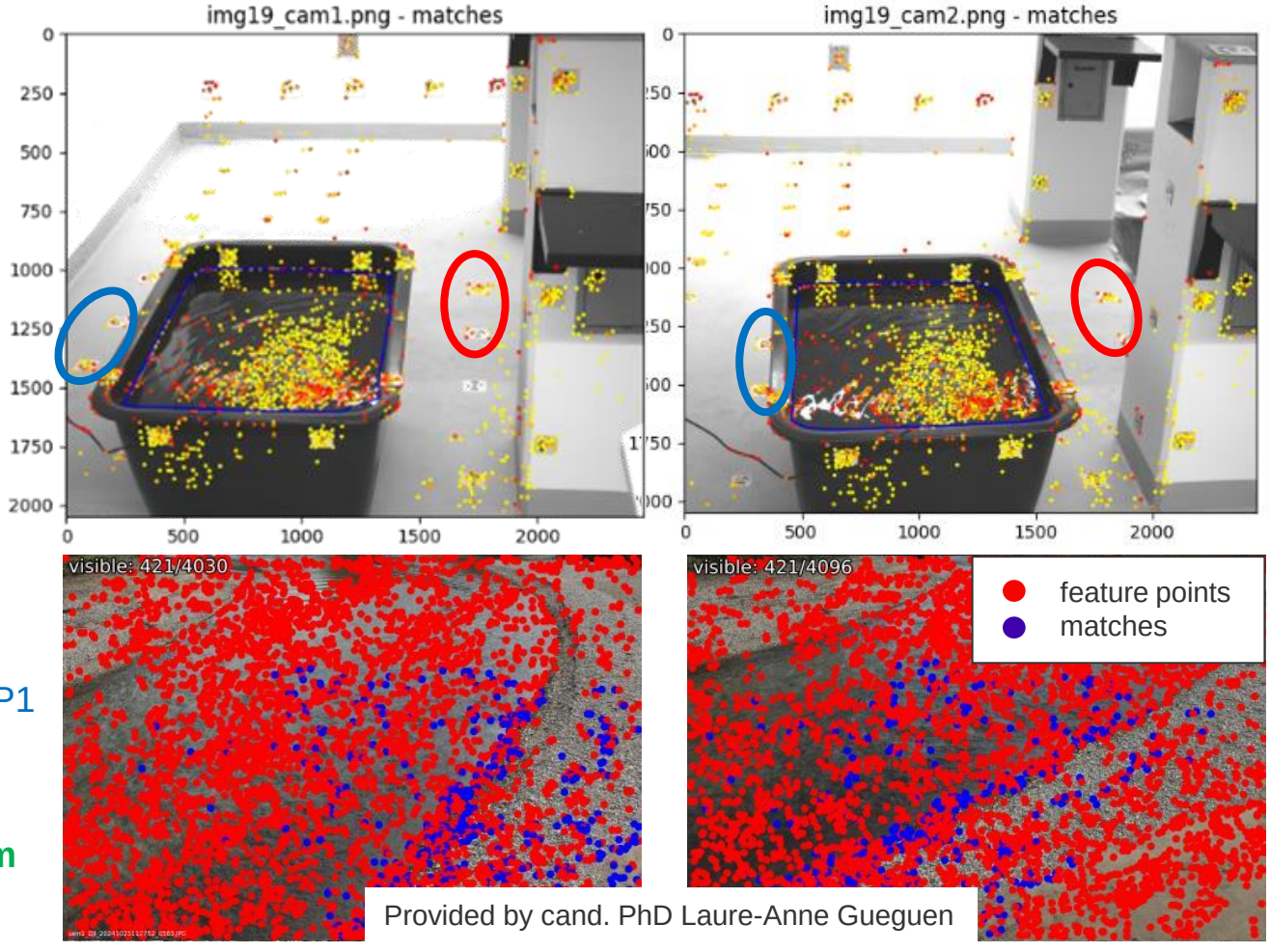




Observation of the effect of refraction from the water surface on the topography reconstruction (purple is ground truth)

Water surface extraction from synch. oblique images

- Classic Feature Matching
  - poor results
  - very few matches
  - → AI
- hloc - hierarchical localization toolbox
  - Superpoint (descriptor)
  - Superglue (matcher)
  - Lightglue (matcher)
- Real-world test @ Pielach River (10/24)
  - 2 DJI M350 / Zenmuse P1
  - manually triggered
  - **71 tie points** found
  - height **deviation < 10cm**



Provided by cand. PhD Laure-Anne Gueguen

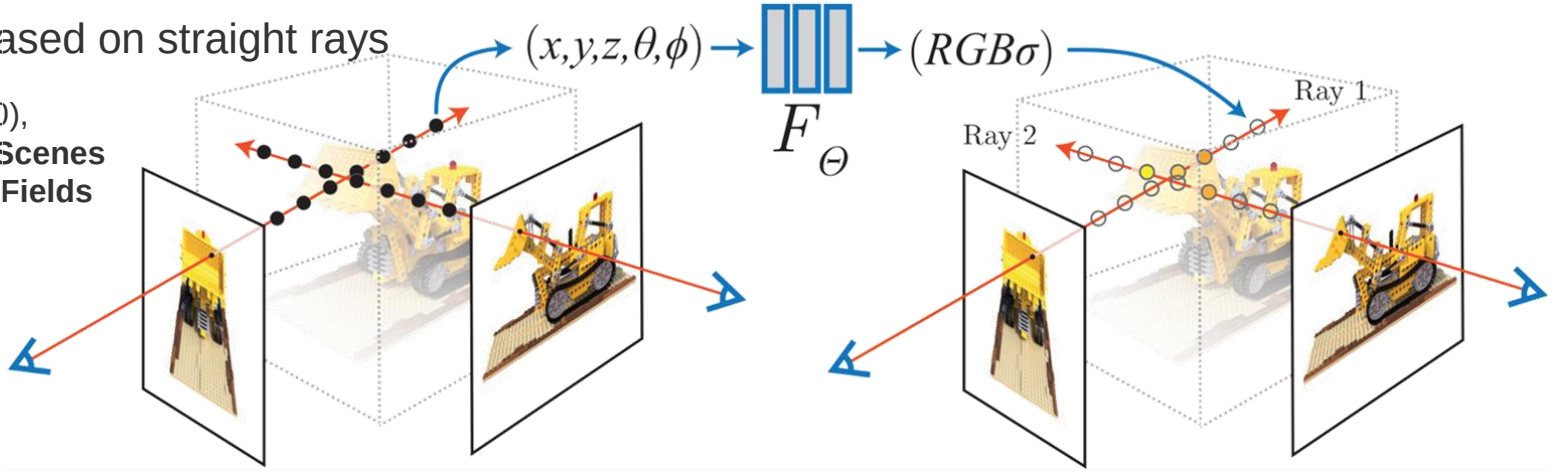
Bathymetry from image sequences

Christian Mulsow (TU Dresden): in **Mapping shallow inland running waters with UAV-borne photo and laser bathymetry – The Pielach River showcase,** Journal of Applied Hydrography, DOI: 10.23784/HN130-06

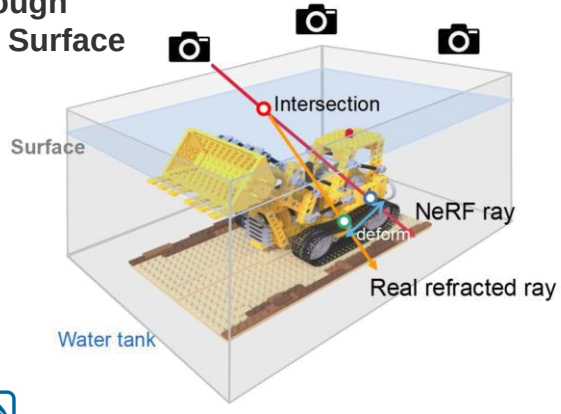
Neural Radiance Fields (NeRFs)

- NeRFs are based on straight rays

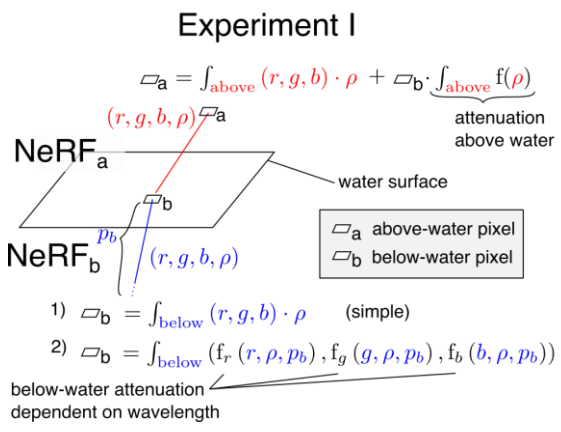
Mildenhall et al. (2020),
Nerf: Representing Scenes as Neural Radiance Fields for View Synthesis.

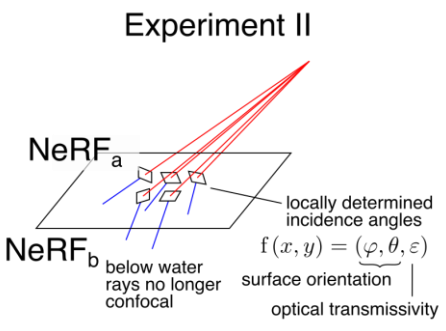


Zhan et al. (2023)
NeRFrac: Neural Radiance Fields through Refractive Surface



Winiwarter, Mandlburger, Jutzi (2023)**: BathyNeRF: project idea**





First results from Pielach October 2024 images

Provided by cand. PhD Markus Brezovsky

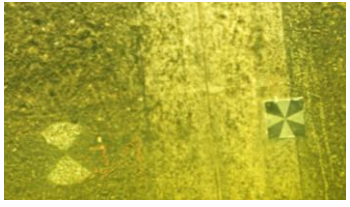
Monitoring of hydroelectric power dam – Pack/Styria

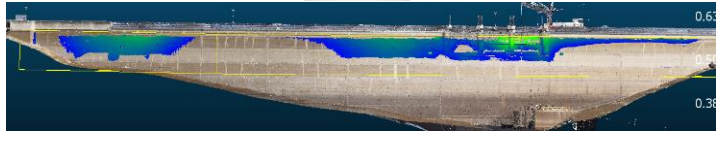
- **Use of the emptying 03/2023**

- Markings applied and measured with high precision using a total station
- Water side recorded with terrestrial laser scanner
- Reference model for comparisons / further development of underwater photogrammetry

Results of underwater photogrammetry

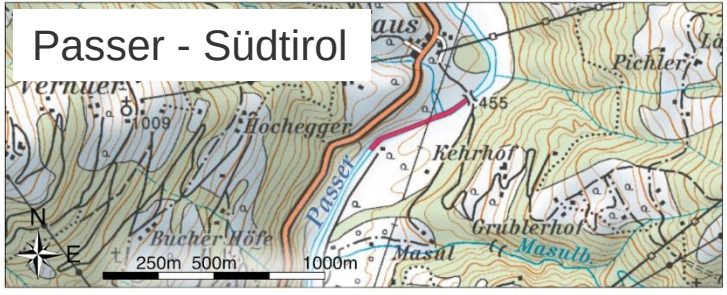
- Around 1000m^2 area based on ROV images
- High resolution (details recognizable)
- Difference to the reference model calculated
- Navigation to detailed photos located on the dam

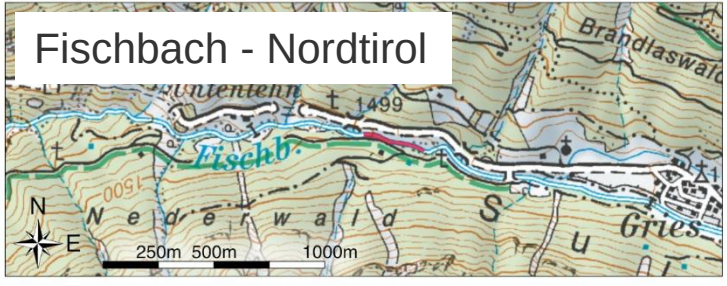




Grömer et. al., 2024: High-detail and low-cost underwater inspection of large-scale hydropower dams, ISPRS Archives

Riverbed mapping in white-water rapids with full-waveform bathymetric LiDAR

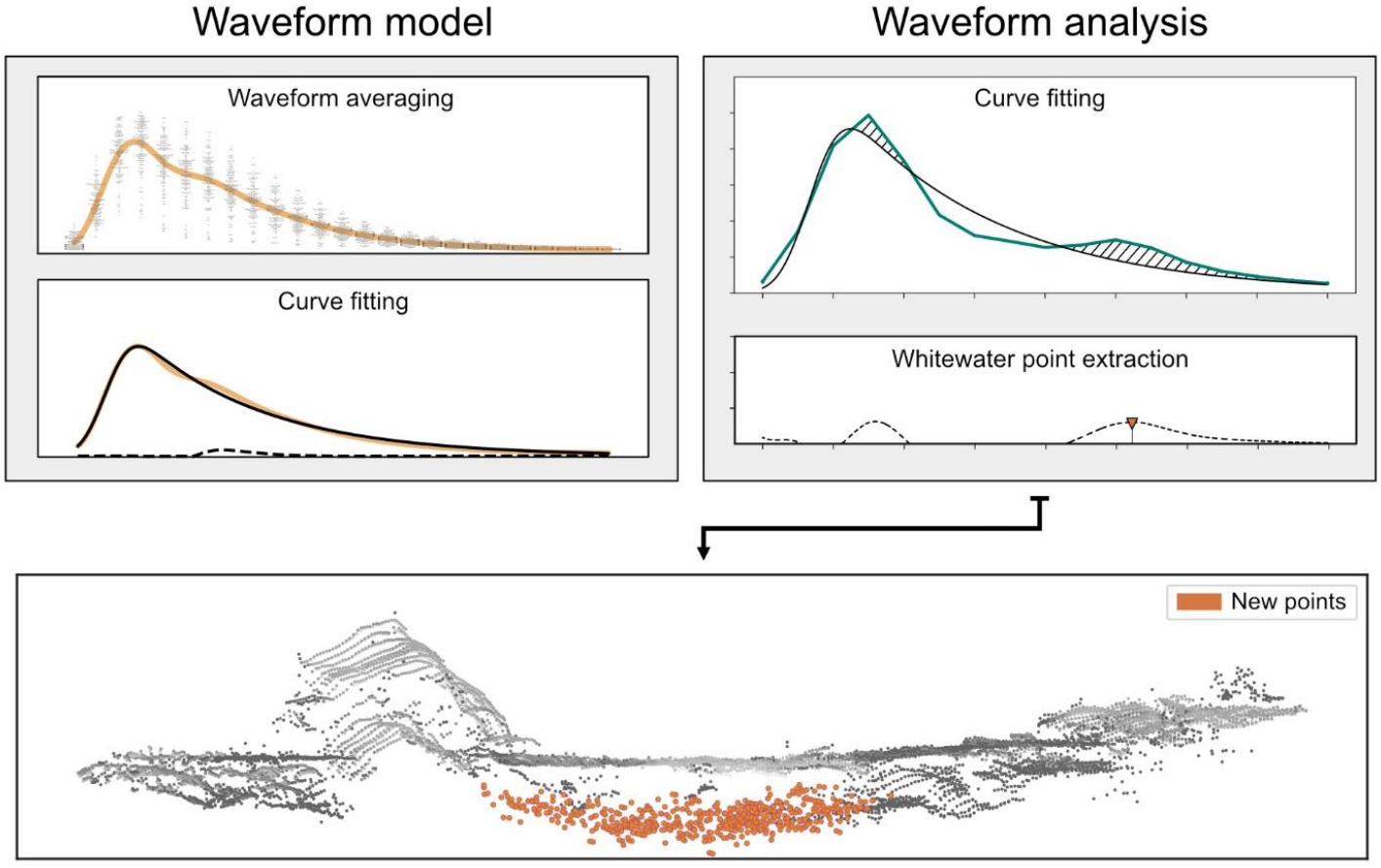




Jan Rhomberg-Kauert @ Pielach River

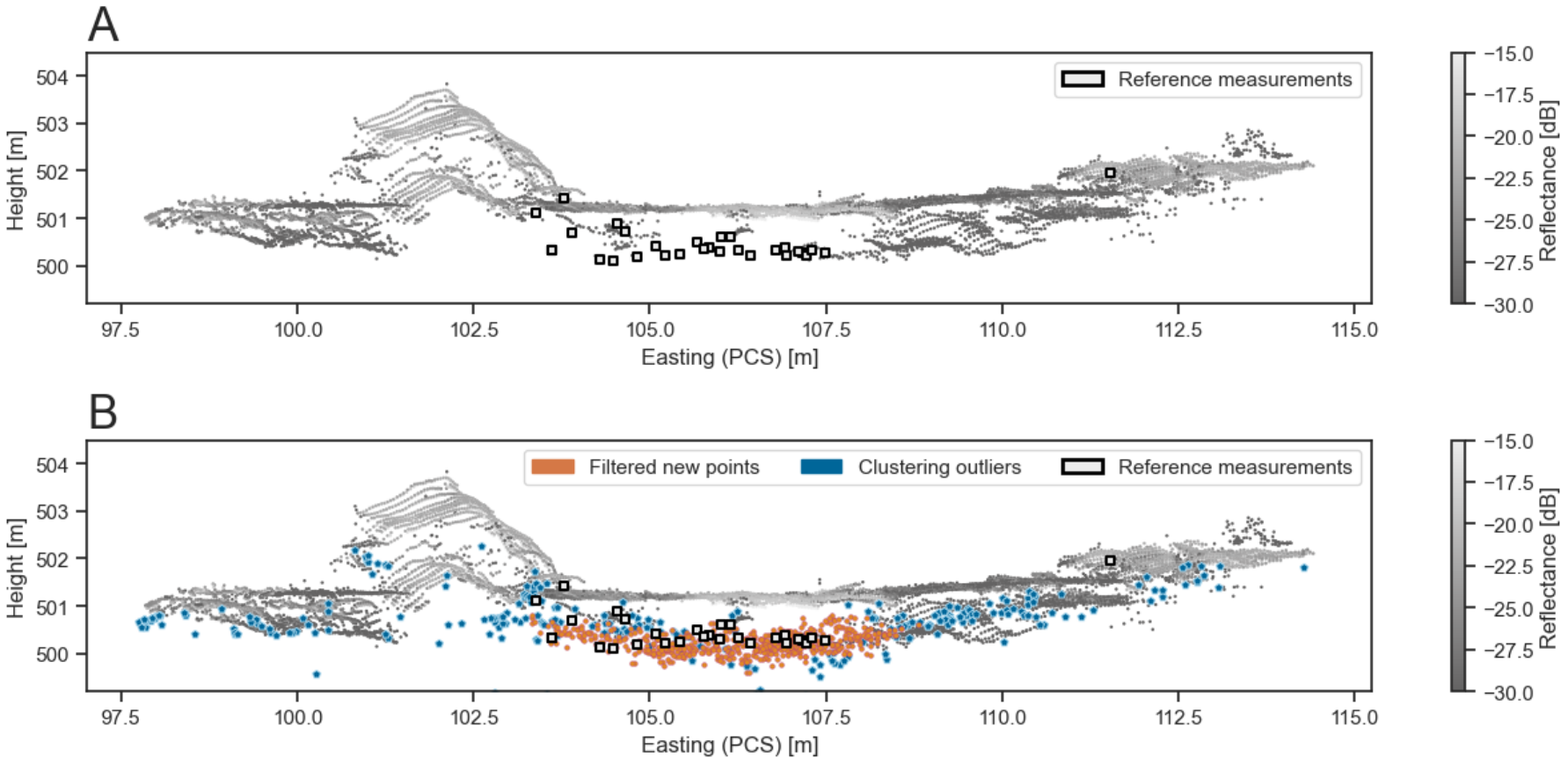
Riverbed mapping in white-water rapids with full-waveform bathymetric LiDAR

Rhomber-Kauert, Himmelsbach, Pöppl, Dammert, Pfennigbauer, Mandlburger(2025): **Mapping river topography in whitewater rapids using full-waveform bathymetric LiDAR** (paper in preparation)



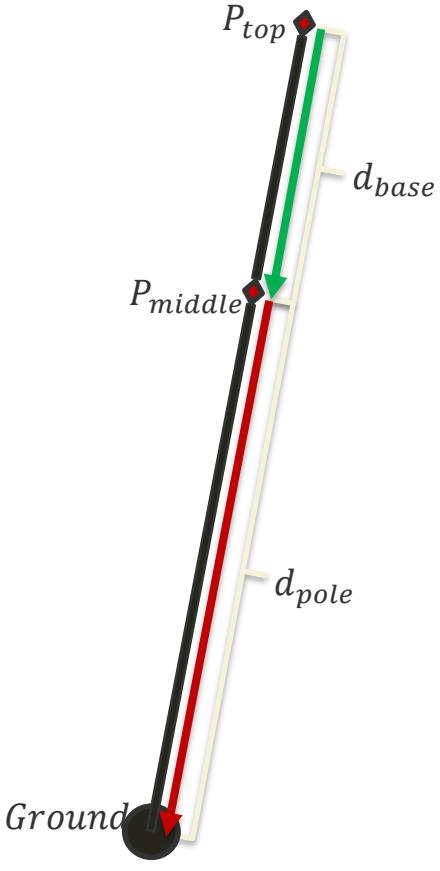
Provided by cand. PhD Jan Rhomberg-Kauert

Riverbed mapping in white-water rapids – first results



Ground truth for optical hydrographic measurements

Tilt-compensating dual-prism pole tracked by two Robotic Total Stations



Provided by cand. PhD Lucas Dammert

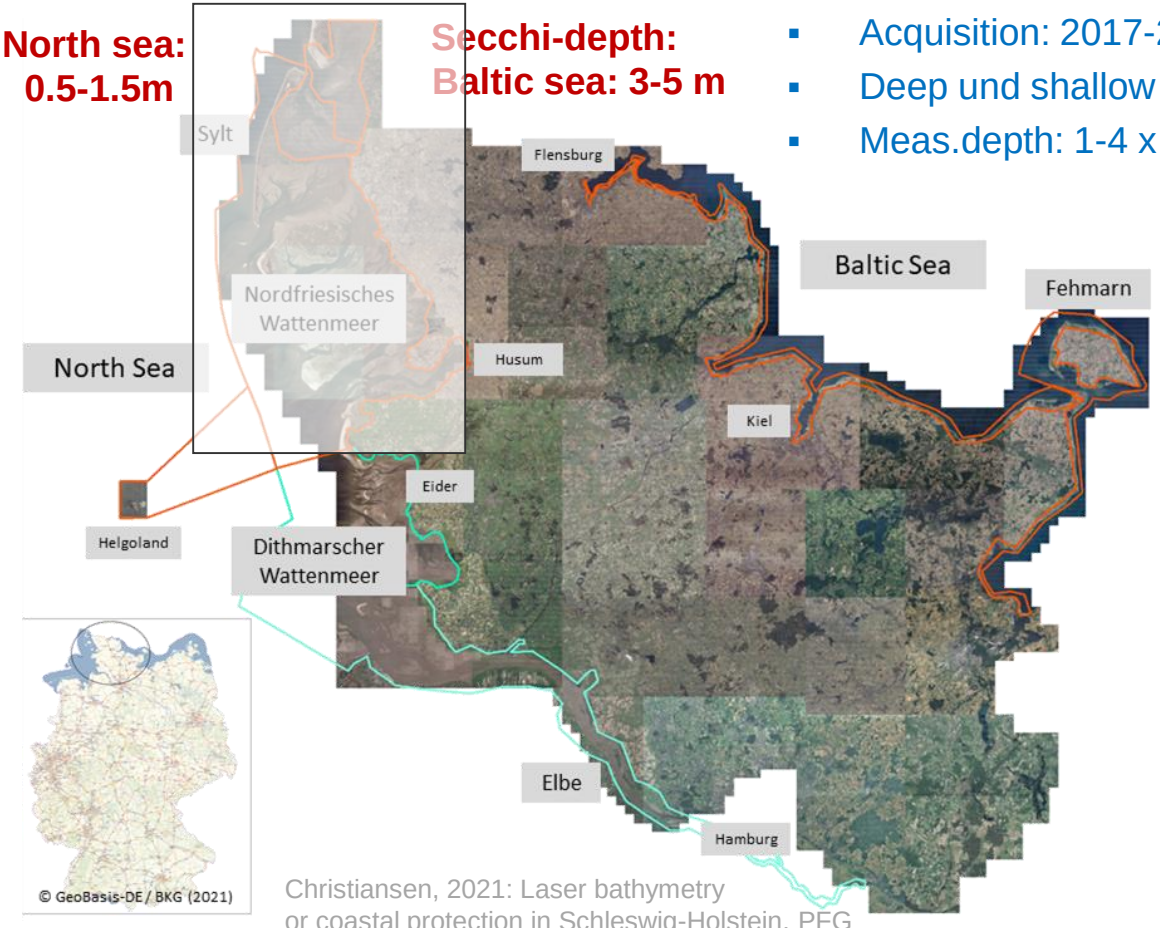
Where do we go and who needs all that?

Laser bathymetry for coastal protection @ LKN.SH

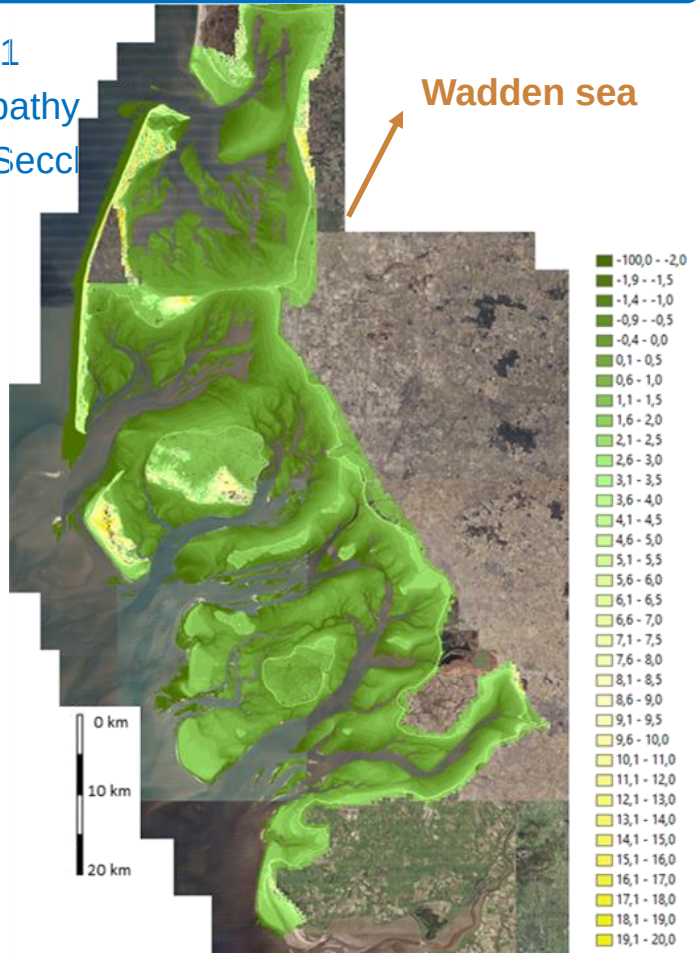
North sea: 0.5-1.5m

Secchi-depth: Baltic sea: 3-5 m

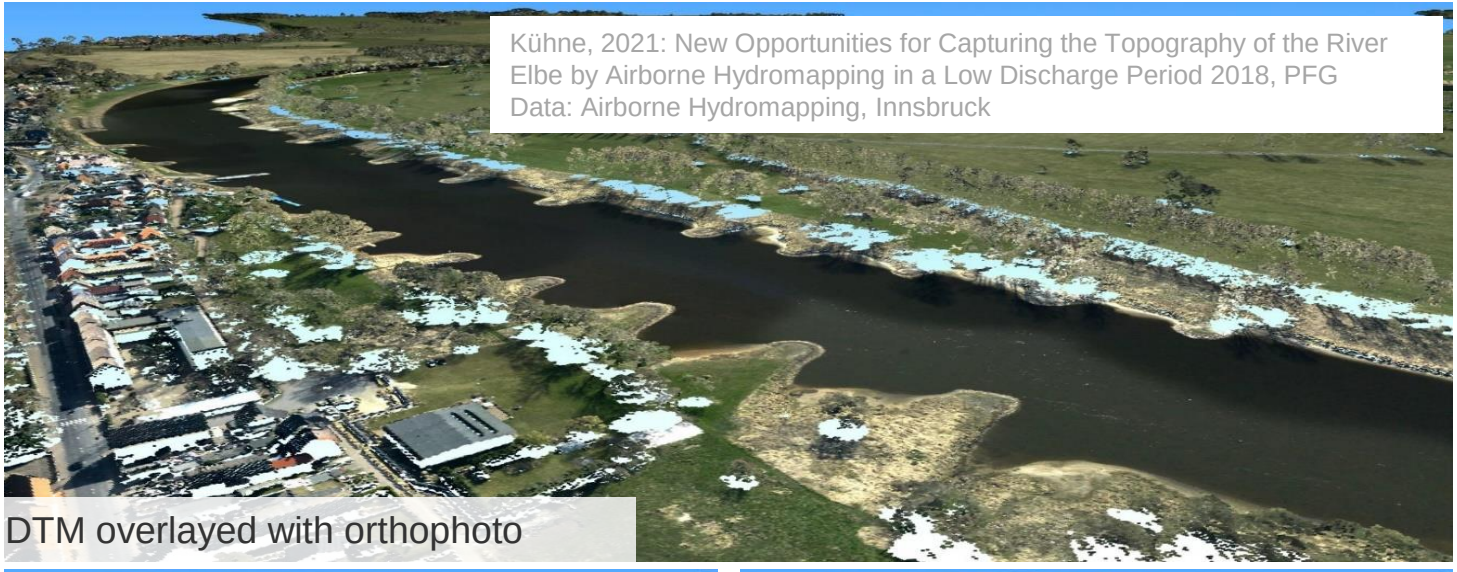
- Acquisition: 2017-21
- Deep und shallow bathy
- Meas.depth: 1-4 x Secchi



Christiansen, 2021: Laser bathymetry or coastal protection in Schleswig-Holstein, PFG

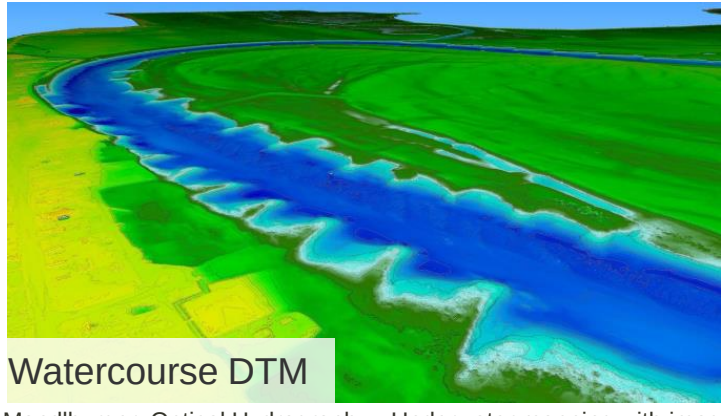


Laser bathymetry@Elbe: DTM for hydraulic modelling

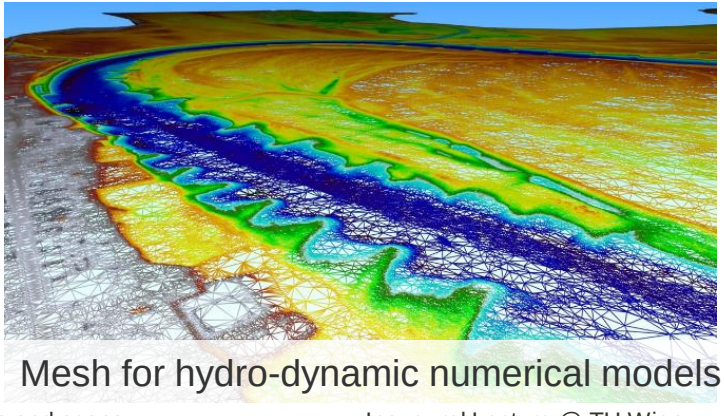


Kühne, 2021: New Opportunities for Capturing the Topography of the River Elbe by Airborne Hydromapping in a Low Discharge Period 2018, PFG
Data: Airborne Hydromapping, Innsbruck

DTM overlayed with orthophoto

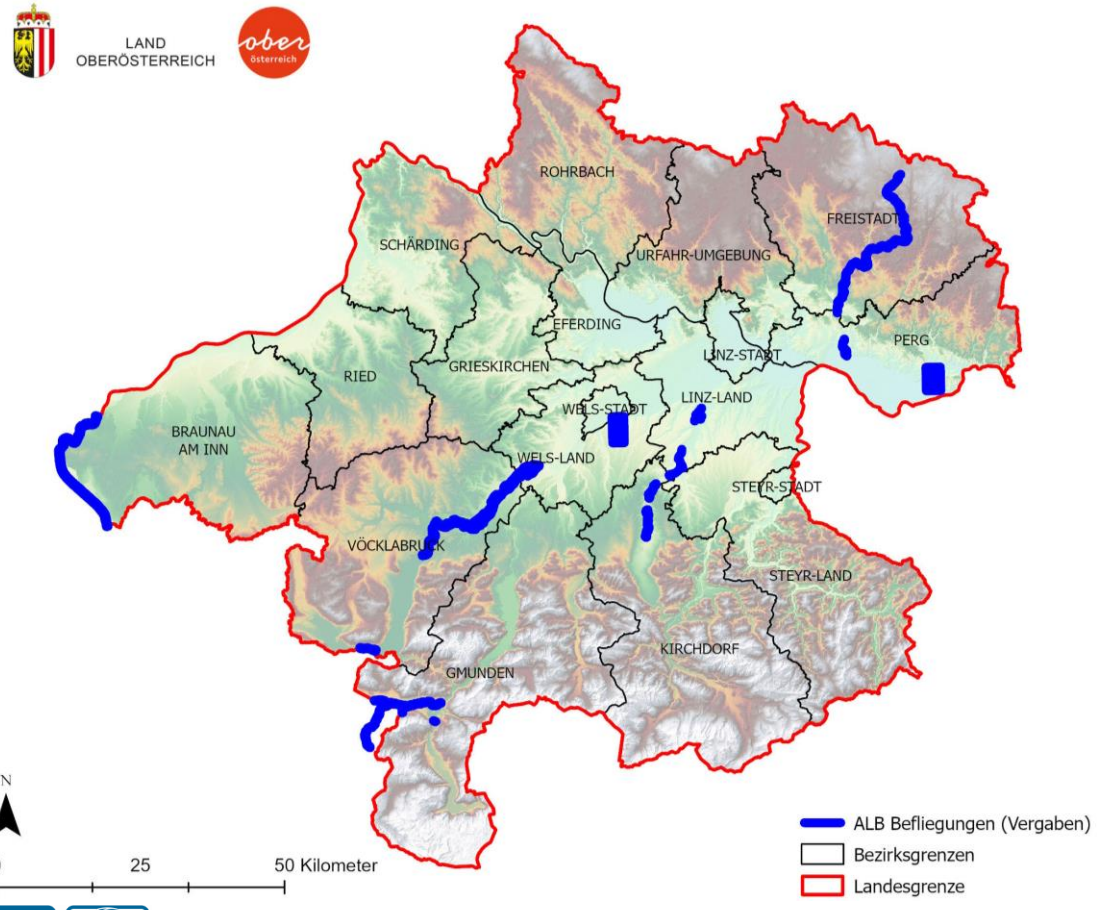


Watercourse DTM



Mesh for hydro-dynamic numerical models

Airborne Laserbathymetry (ALB) @ Land Oö.



Aircraft

- ✓ ALB Klambach (2011)
- ✓ ALB Thalbach (2011)
- ✓ ALB Salzach (2016)

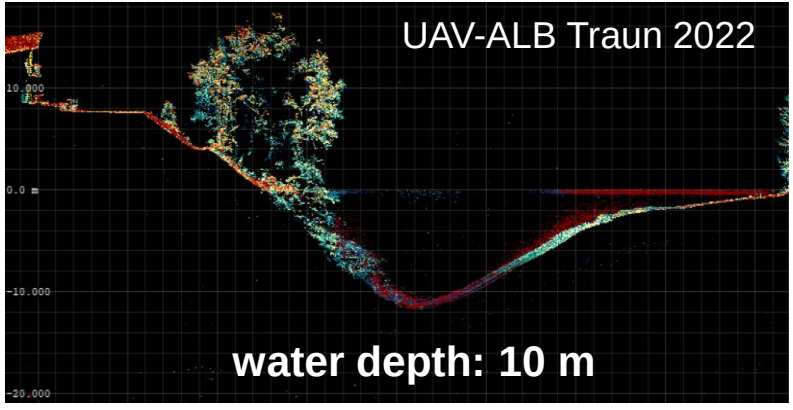
UAV

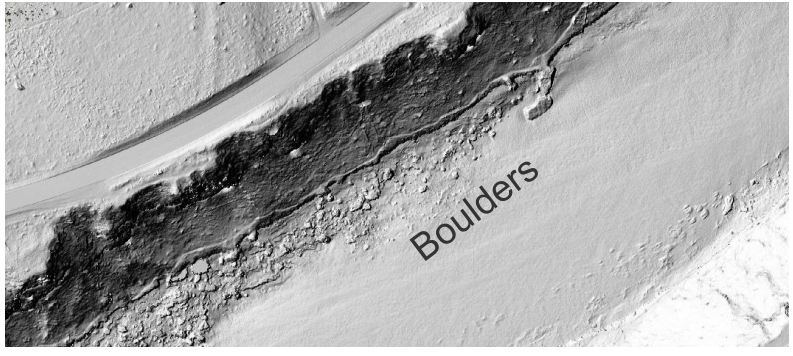
- ✓ UAV-ALB Waldaist (2021)
- ✓ UAV-ALB Ager (2021, 2022)
- ✓ UAV-ALB Abschnitt Traun (2022)
- ✓ UAV-ALB Mondseeache (2022)
- ✓ ALB Abschnitt Salzach (2023/2024)
- ✓ ALB Abschnitte Krems (2023/2024)

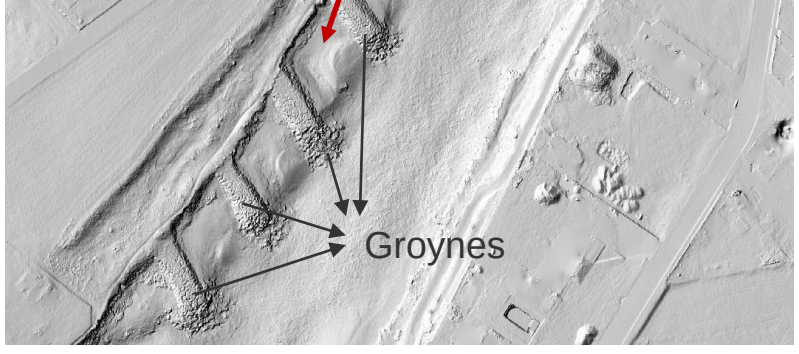
Helicopter

- ✓ ALB Abschnitt Aist (2024)
- ✓ ALB Abschnitt Traun (2024)
- ✓ ALB Ischl (2024)

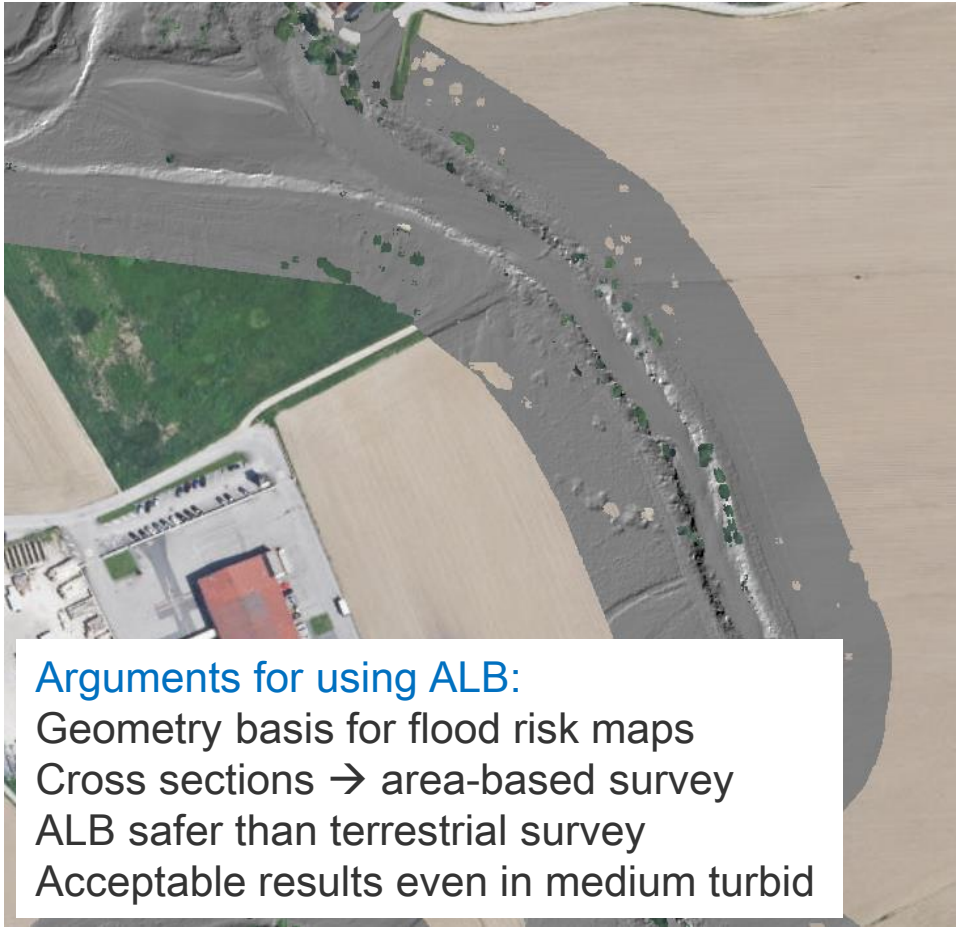
Airborne Laserbathymetrie (ALB) – Land Oö.







ALB Aist – post 2024 flood event documentation

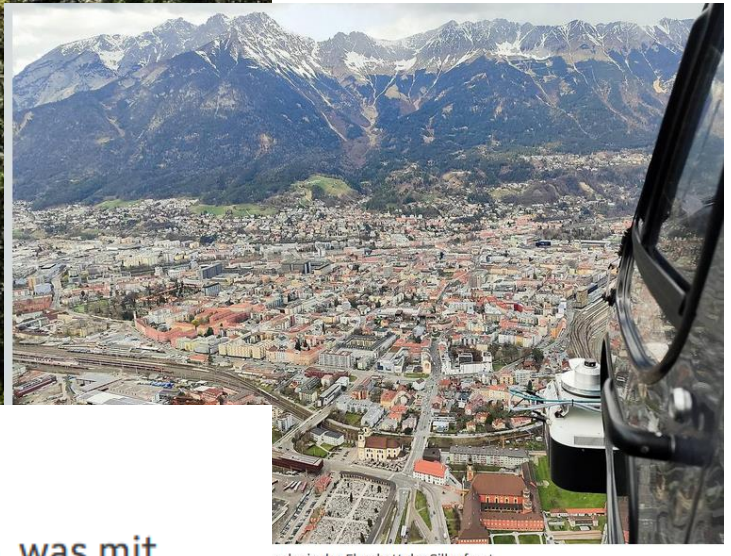


Arguments for using ALB:
Geometry basis for flood risk maps
Cross sections → area-based survey
ALB safer than terrestrial survey
Acceptable results even in medium turbid

ORF news – Landesstudio Tirol – Di, 24.03.2025

Tirol-News | Radio Tirol | Fernsehen | Landesstudio | Ganz Österreich

The pilot project is part of the flood protection strategy of Tyrol



nologie das Flussbett der Sill erfasst

Erfassung der Flusssohle

Dies ermögliche eine genaue Erfassung der Flusssohle, was mit herkömmlichen Methoden nur mit großem Aufwand möglich wäre, heißt es beim Land. Das Pilotprojekt ist Teil einer Hochwasserschutzstrategie des Landes.

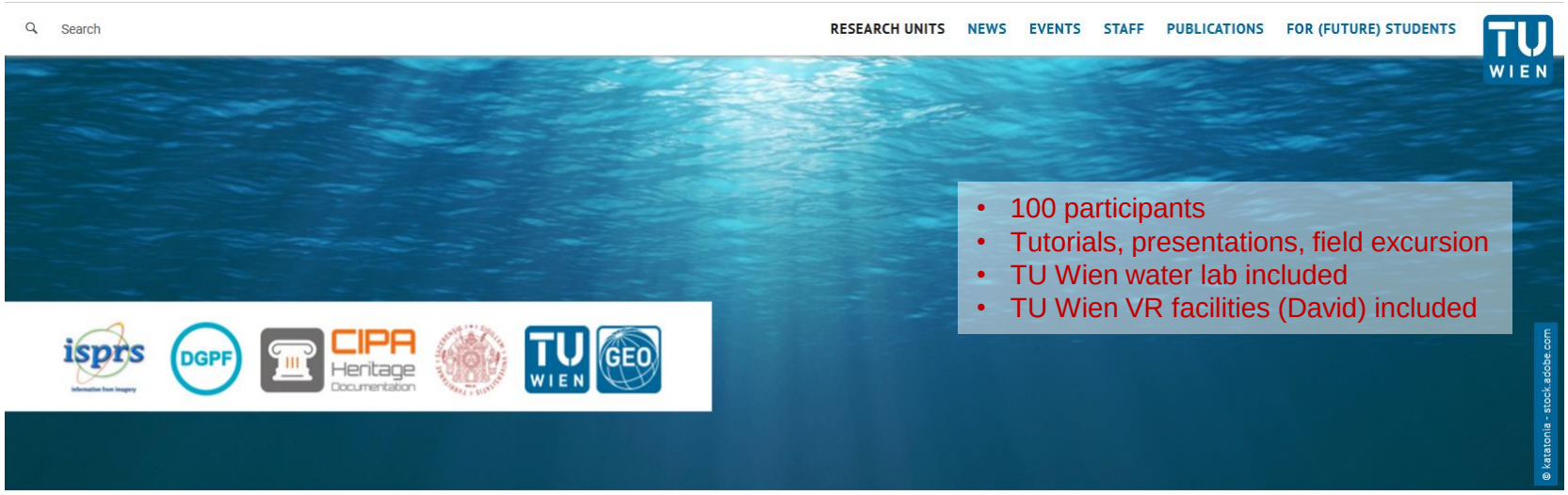
Data acquisition:
AltoDrones (IT)

Sensor:
RIEGL VQ-860-G

Thanks

- TU Wien
  - Rectors Jens Schneider and Sabine Seidler
  - Dean Wolfgang Wagner, Head of Senate Norbert Pfeifer
- Department of Geodesy and Geoinformation
  - Research Area Photogrammetry (E120.7)
- Students
  - Classroom
  - BSc and MSc candidates
  - PhD candidates
- Partners
  - RIEGL LMS, skyability, AHM, BfG, NMCAs, Photogrammetric companies
- OVG
  - DGPF, ISPRS, EuroSDR, …
- Family, friends, and all of you

Next milestone: ISPRS workshop @TU Wien, July 8-11



- 100 participants
- Tutorials, presentations, field excursion
- TU Wien water lab included
- TU Wien VR facilities (David) included

PHOTO / Events / 3D Underwater

3D Underwater Mapping from Above and Below

8-11 July 2025, TU Wien, Vienna, Austria

3rd International Workshop

On behalf of the International Society of Photogrammetry and Remote Sensing (ISPRS, WG II/7) 7), CIPA Heritage Documentation, and the German Society for Photogrammetry, Remote Sensing and Geoinformation **(DGPF)**, the 3rd underwater workshop edition is held at the TU Wien. After Piano di Sorrento, Italy (2015) and Limassol, Cyprus (2019), we are happy to welcome you in Vienna, Austria, in July 2025. Vienna, the most livable city in the world, offers outstanding culture, environment and infrastructure. Its technical university (TU Wien) is the home of leading research in both Geodesy and Geoinformation as well as Hydrology and Hydraulic engineering.

We are looking forward to welcome researchers, practitioners and companies in the field of laser bathymetry, multimedia photogrammetry, spectrally derived bathymetry, computer vision, image processing, VR and AR as well as archaeologists, hydrogeologists, hydrobiologists and ecologists, and hydropower scientists and engineers to present and discuss their results and activities.

The event is aiming to bring together researchers, users and interested persons in the field of **underwater 3D imaging** with (photogrammetry, bathymetry, etc.)

Kontakt

Email:
3d-underwater@geo.tuwien.ac.at

Call for Papers

First announcement and call for papers (PDF)

Data protection declaration for conference participants (PDF)

VIENNA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SENSING

Antrittsvorlesung – Inaugural Lecture

Optical Hydrography: Charting the underwater world with photos and laser scans

Univ. Prof. Dr. Gottfried Mandlburger

gottfried.mandlburger@geo.tuwien.ac.at

TU Wien, Department of Geodesy and Geoinformation

Research Area Photogrammetry (E120.7)

with contributions by: Laure-Anne Gueguen, Jan Rhomberg-Kauert, Lucas Dammert, Michael Grömer, Markus Brezovsky, Nike Wagner, Carolina Damm, Fabian Unterasinger, Moritz Kapeller, Julian Skilich, Christian Mulsow, Hannes Sardemann, Theresa Himmelsbach