Bathymetry from active and passive airborne remote sensing – looking back and ahead

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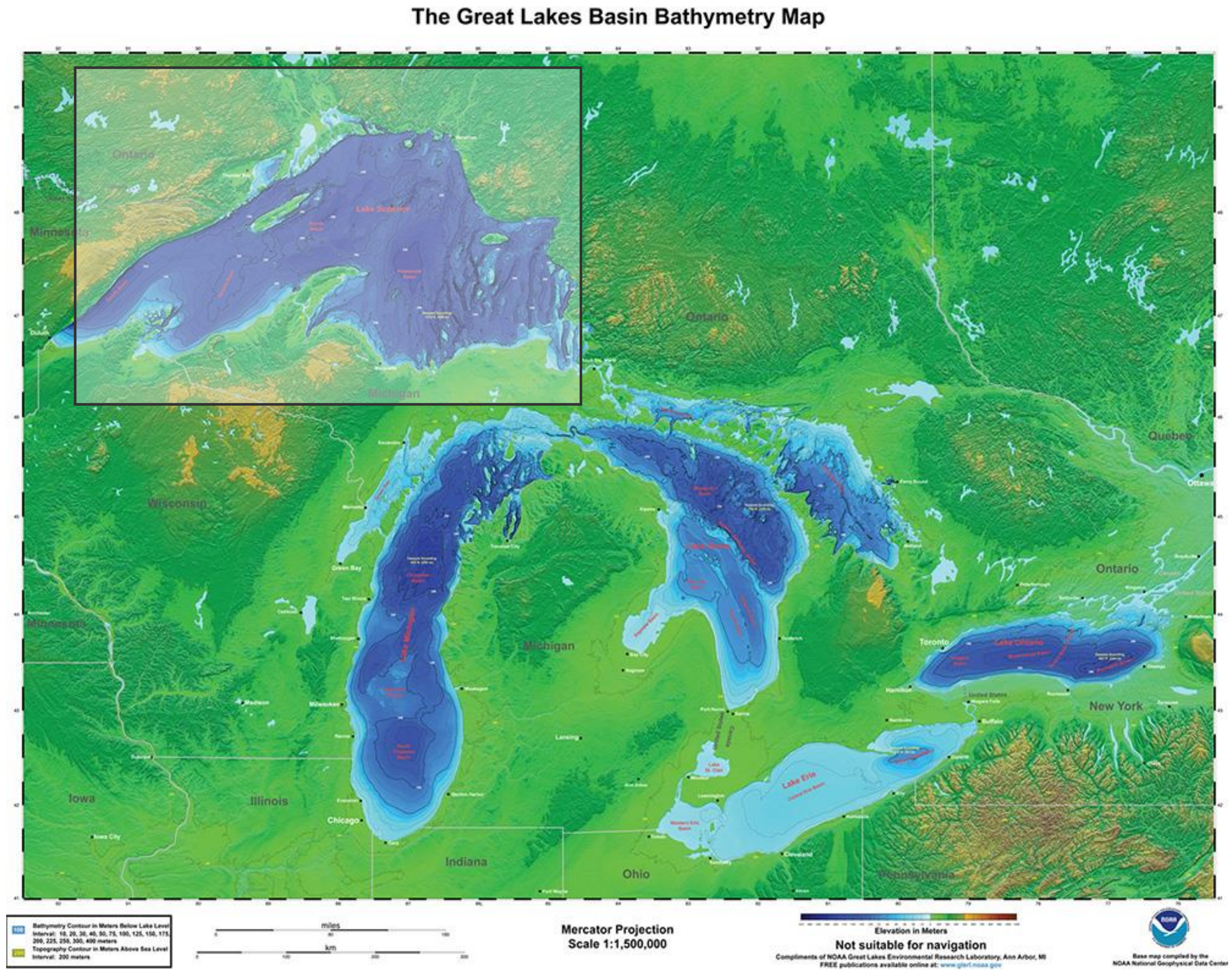
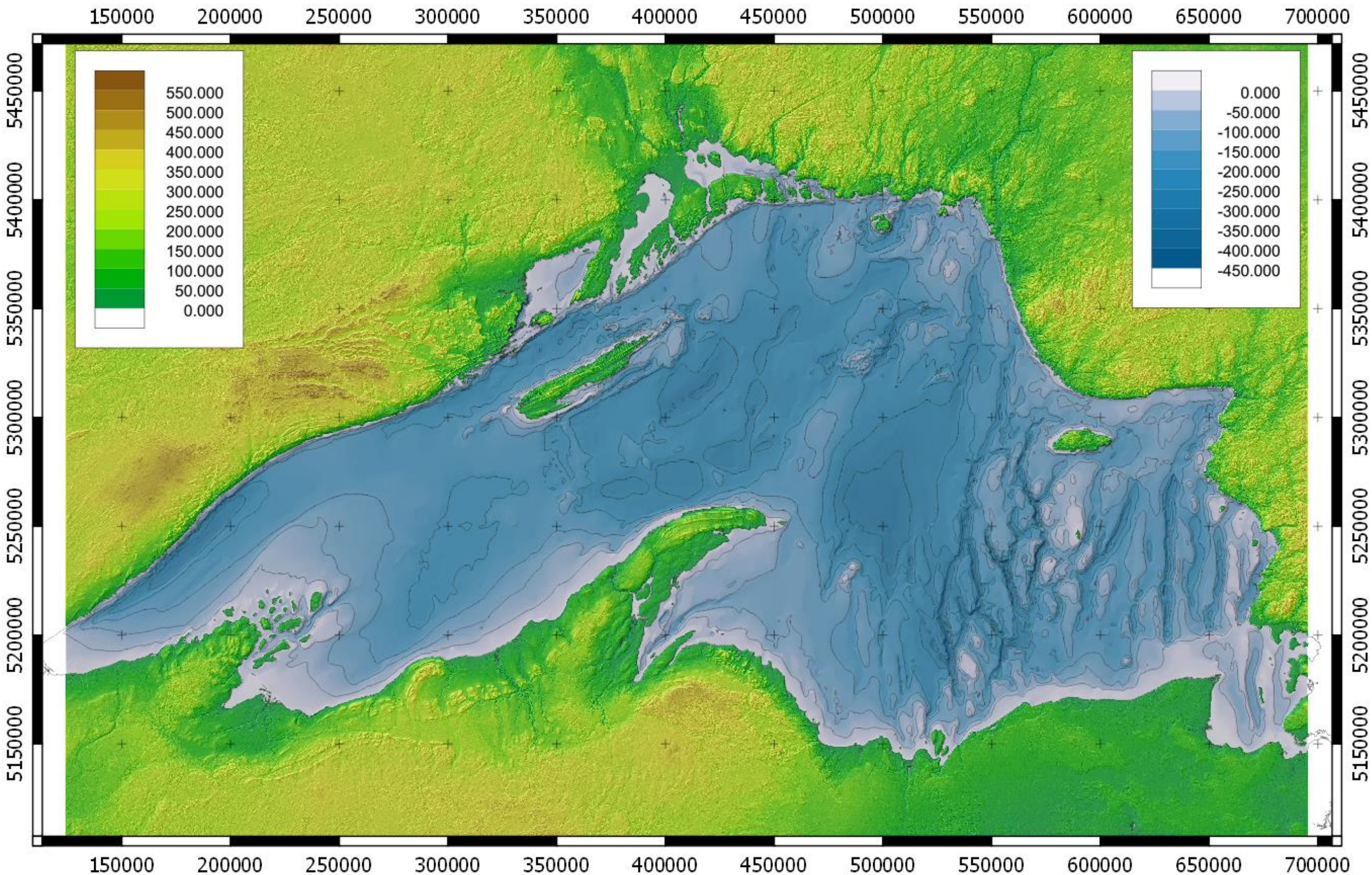
Advancement in Photogrammetry, Remote Sensing and Geoinformatics



Data: NOAA

https://www.glerl.noaa.gov/data/bathy/bathy.html

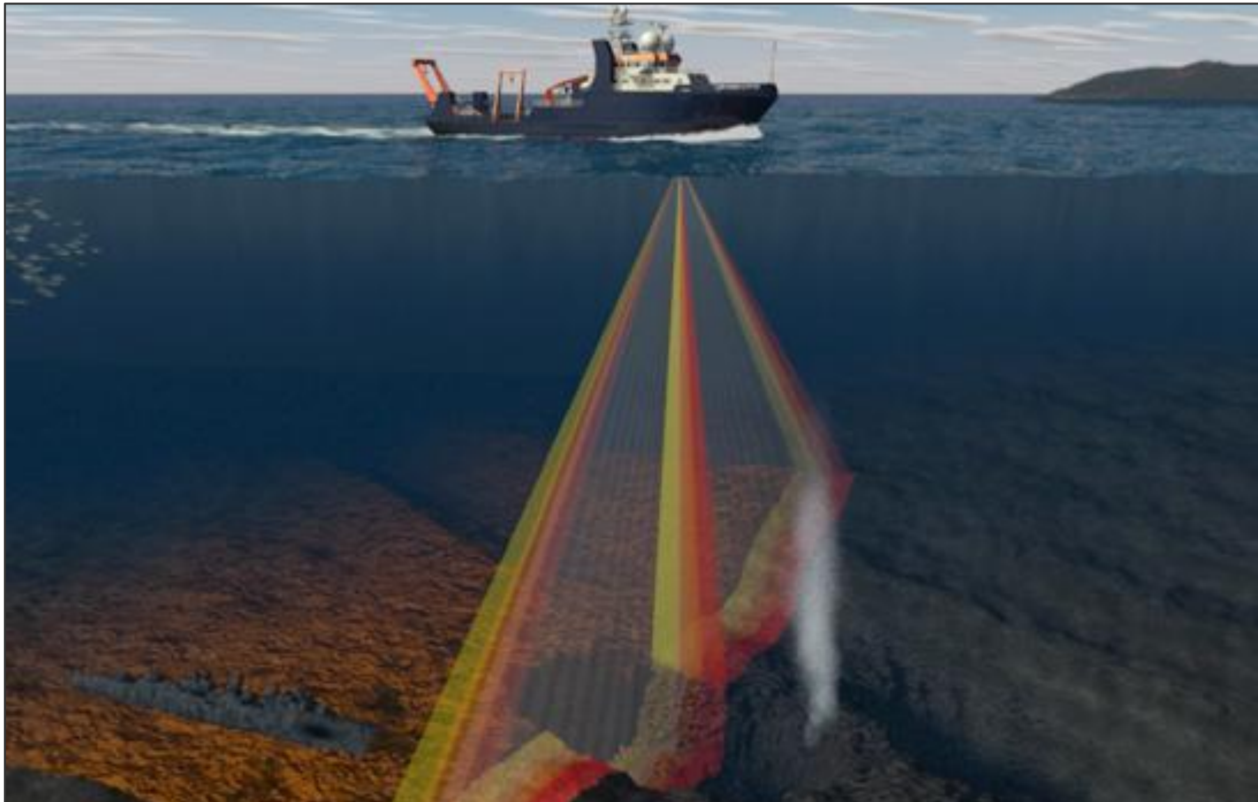
Bathymetric map of Lake Superior



Data: NOAA
https://www.glerl.noaa.gov/data/bathy/bathy.html

Mean/max water depth: 150/405m ⟹ Airborne remote sensing unfeasible ⟹ Echo sounding

Bathymetry via ship-borne echo sounding



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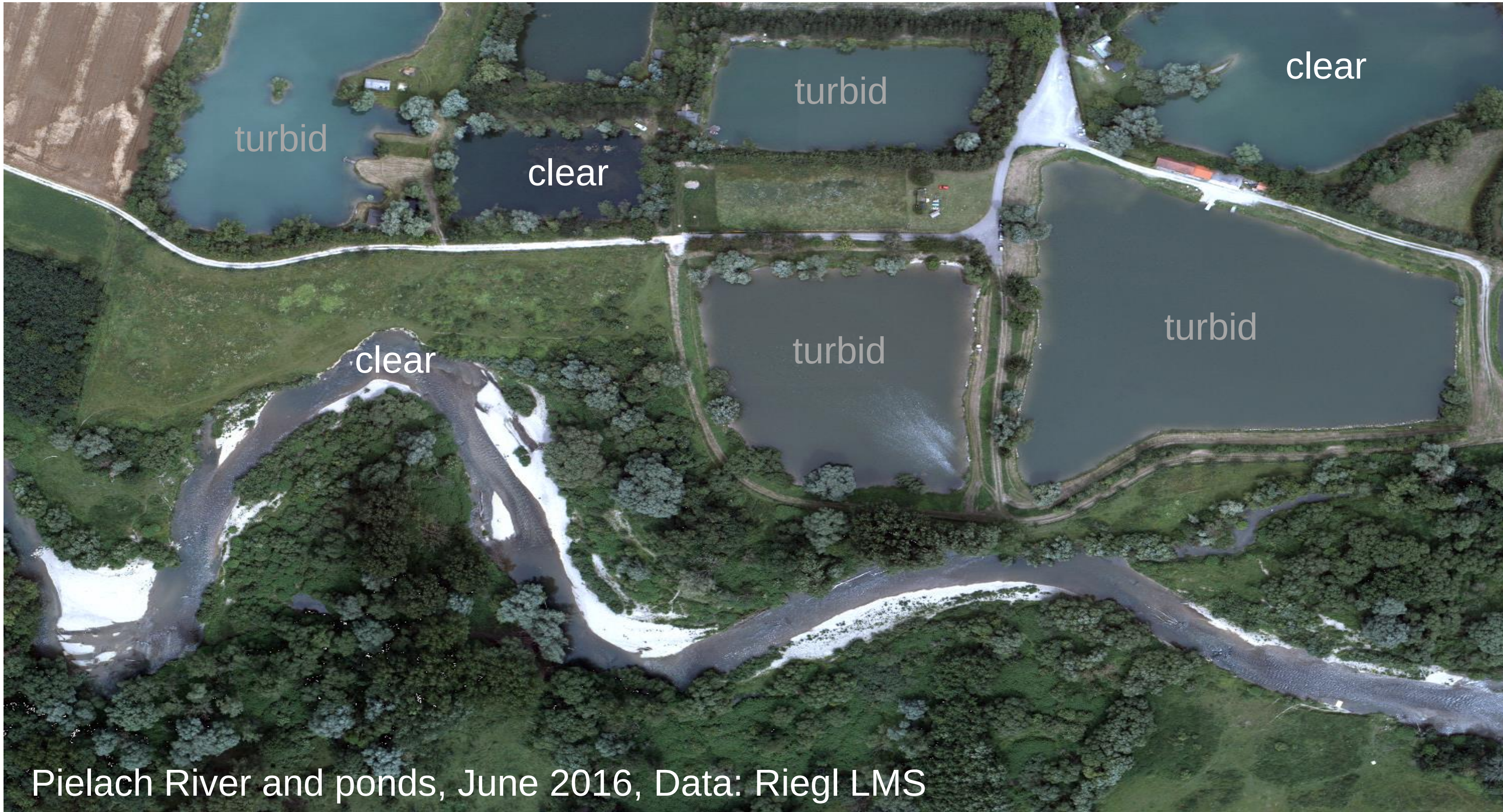
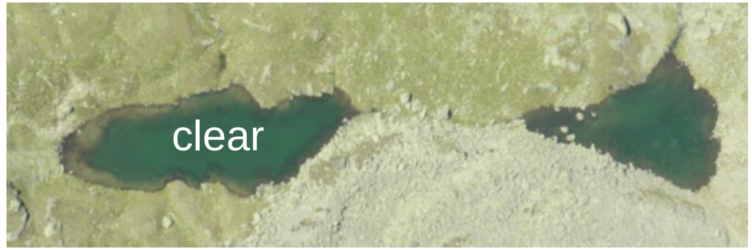
http://www.nationalgeographic.de/aktuelles/blogs/unterwegs-mit-der-polarstern/echos-vom-meeresgrund

Shallow water examples: Elbe River, Germany

Shallow water examples: Pielach River, Austria

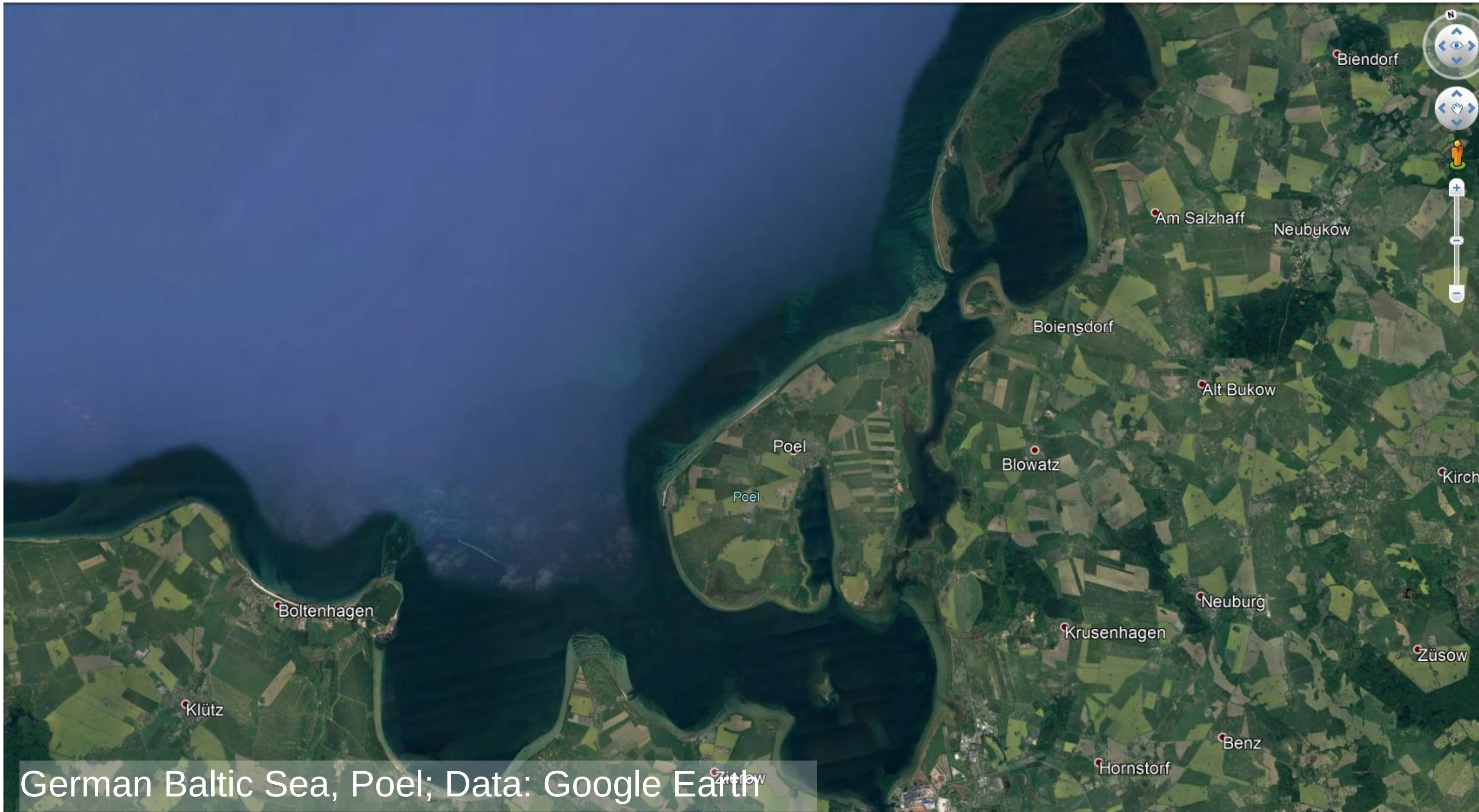


Shallow water examples: Mountain lakes, Stubai Alps, Tyrol



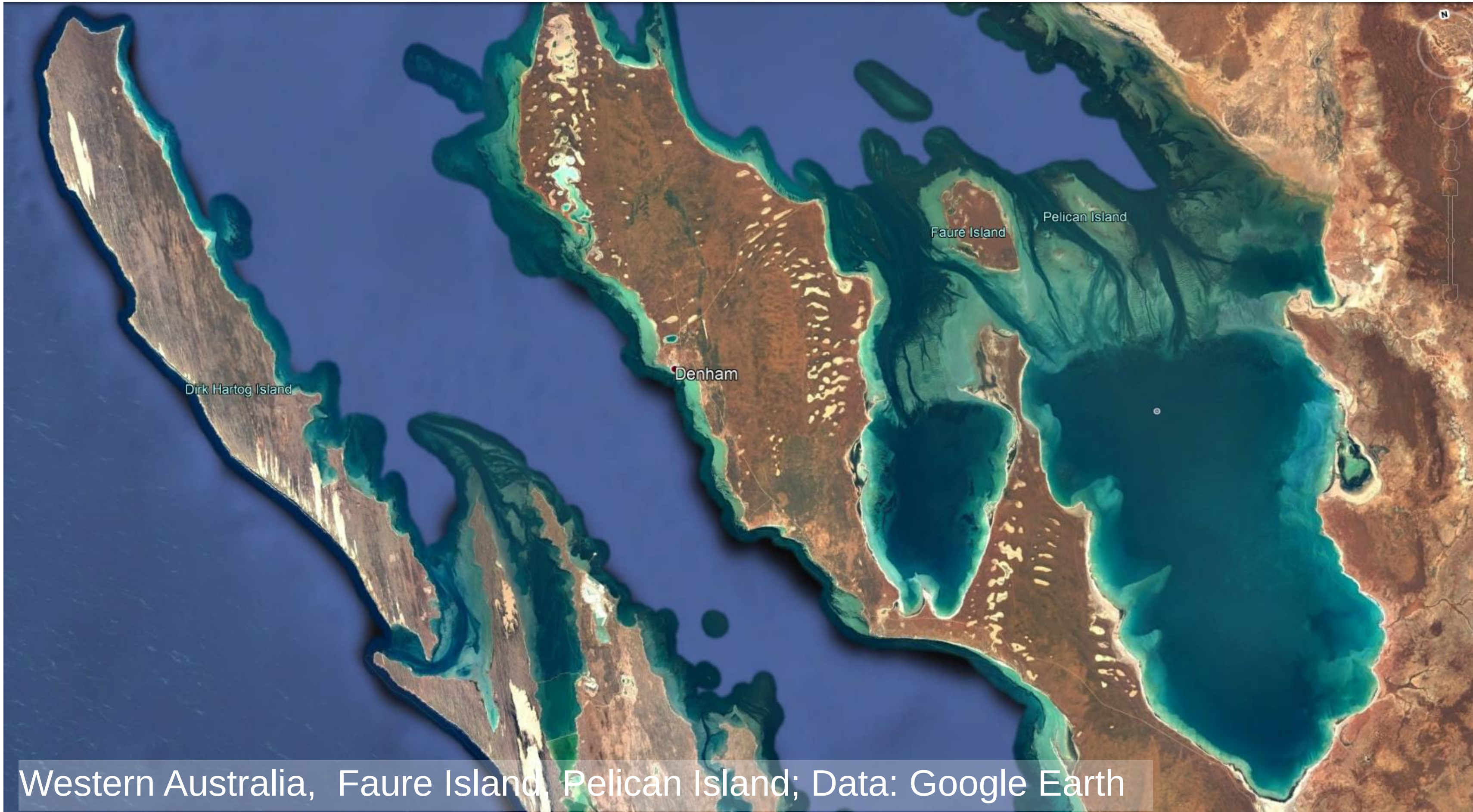
Shallow water examples: Istria/Croatia

Shallow water examples: German Baltic Sea



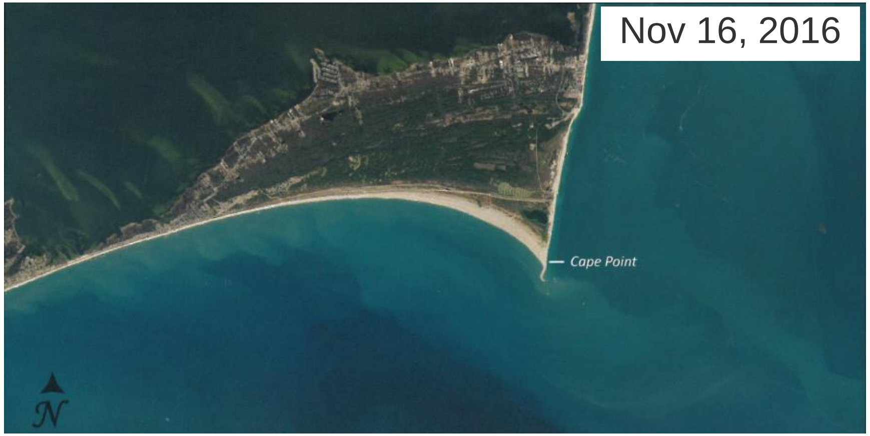
German Baltic Sea, Poel; Data: Google Earth

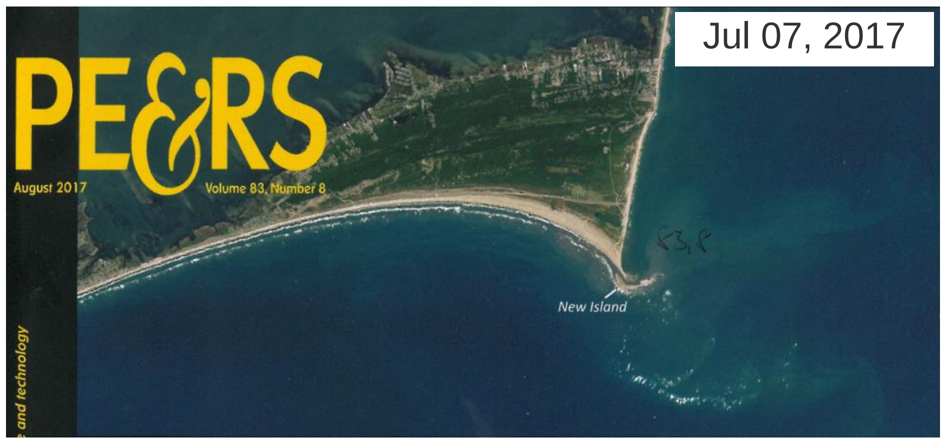
Shallow water examples: Western Australia



Western Australia, Faure Island, Pelican Island; Data: Google Earth

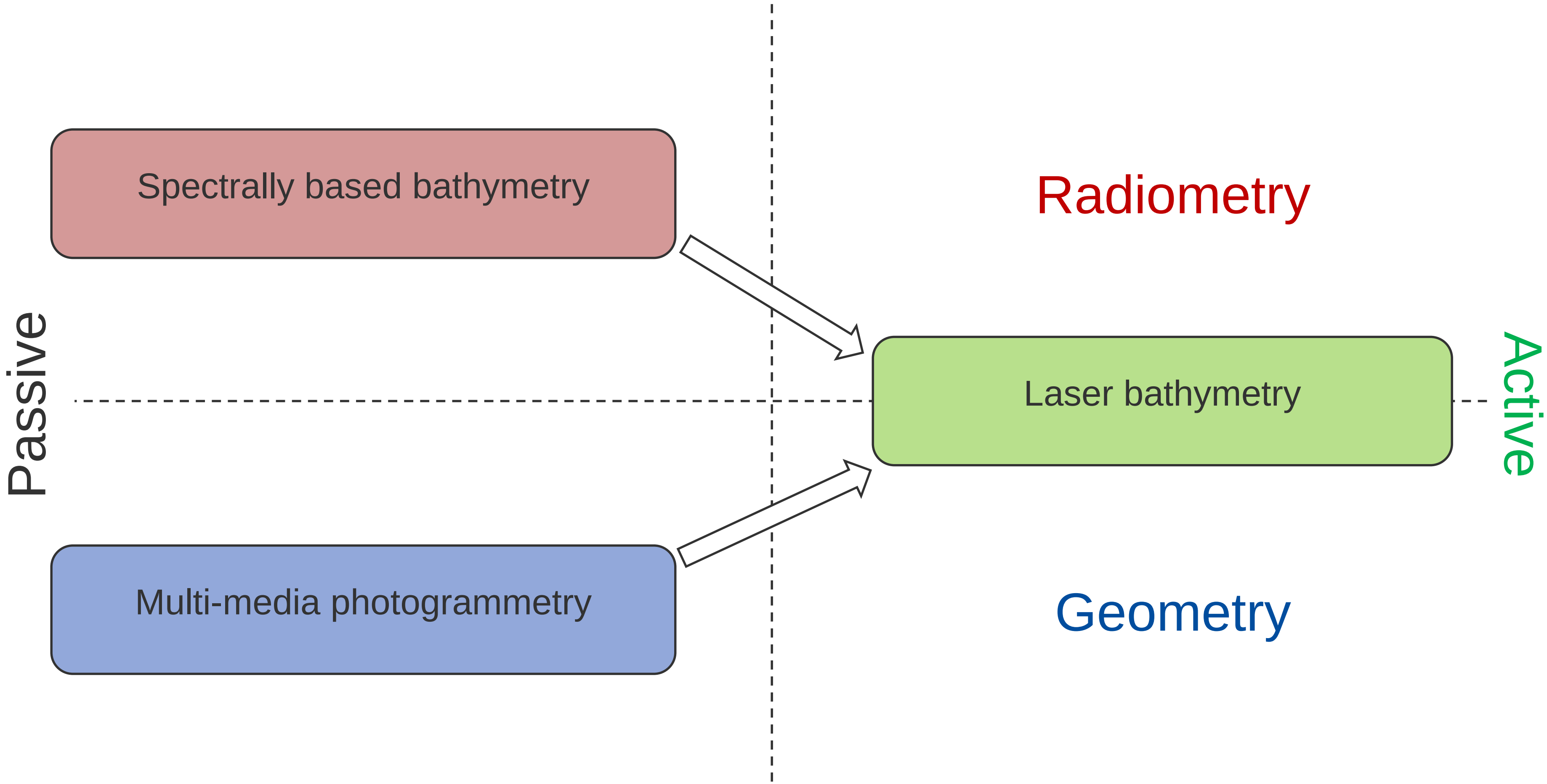
Shallow water examples, North Carolina, USA



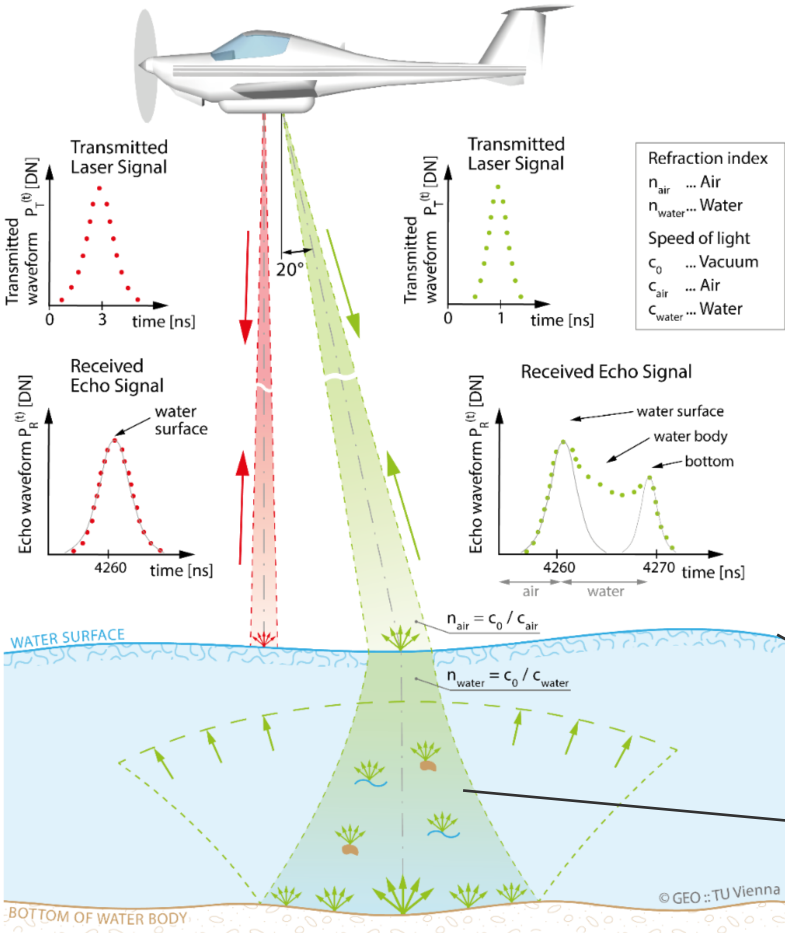


Cape Point, North Carolina, U.S.A., Cover photo, PE&RS, August 2017

Bathymetry via active and passive airborne remote sensing



Airborne Laser Bathymetry - Geometry



Snells‘ law of refraction

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

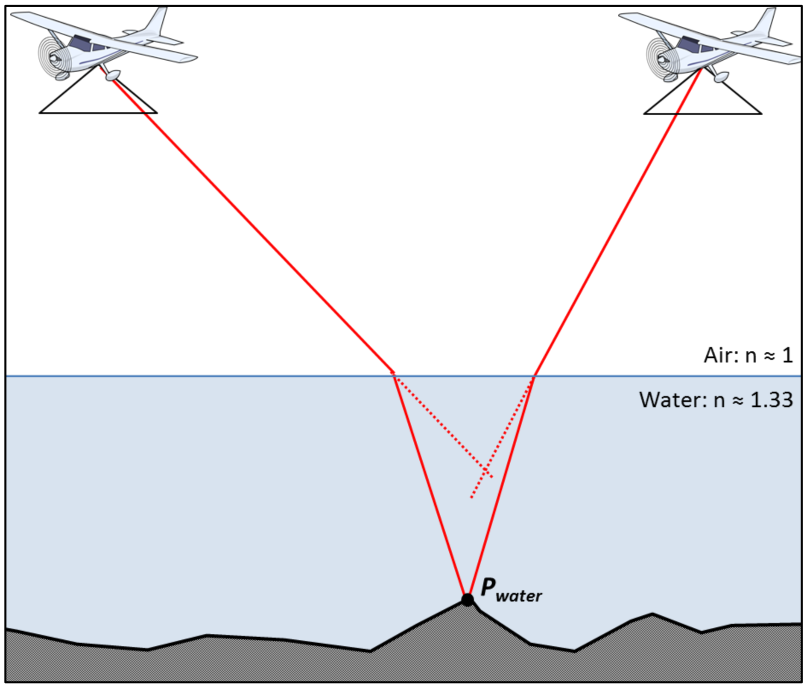
Reflection from air-water-interface

Light attenuation within water

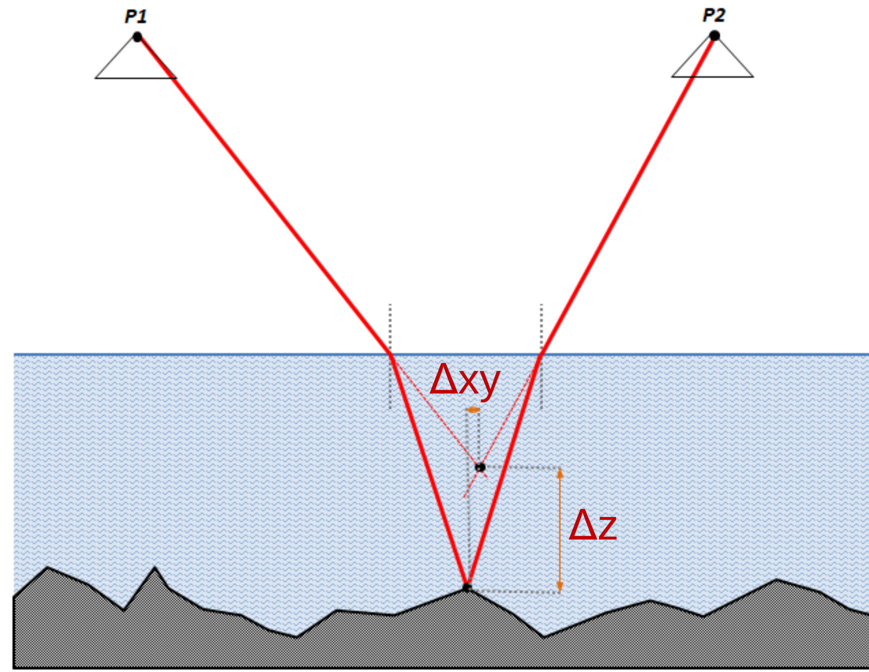
- Absorption
- Scattering

Multi-media photogrammetry

Apparent and actual beam path

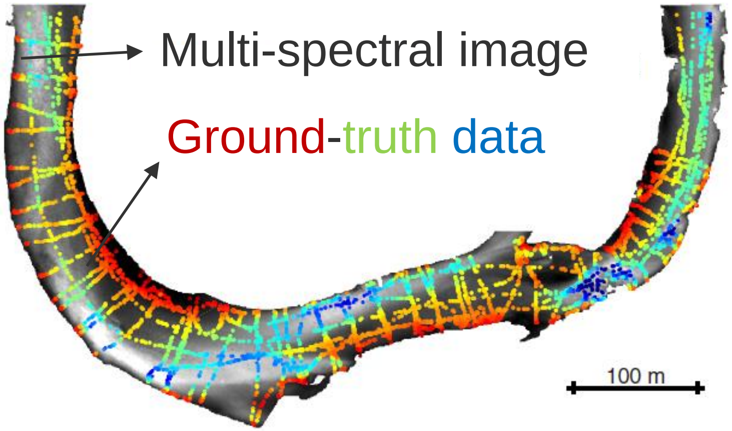


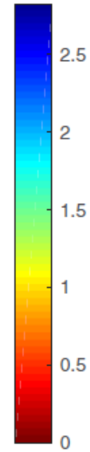
Horizontal and vertical displacement of raw ray intersection point due to refraction

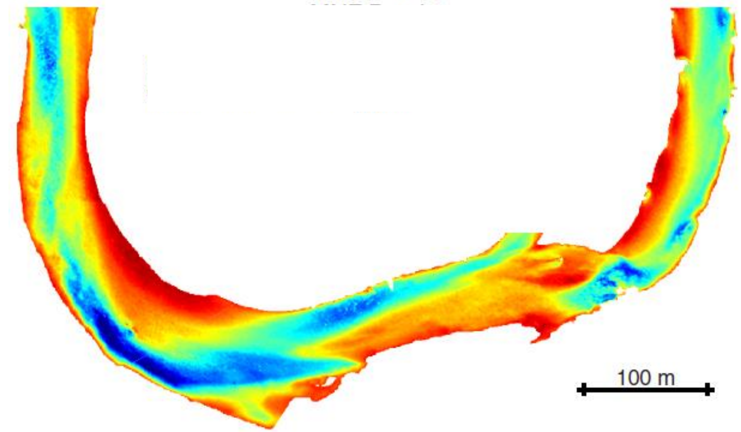


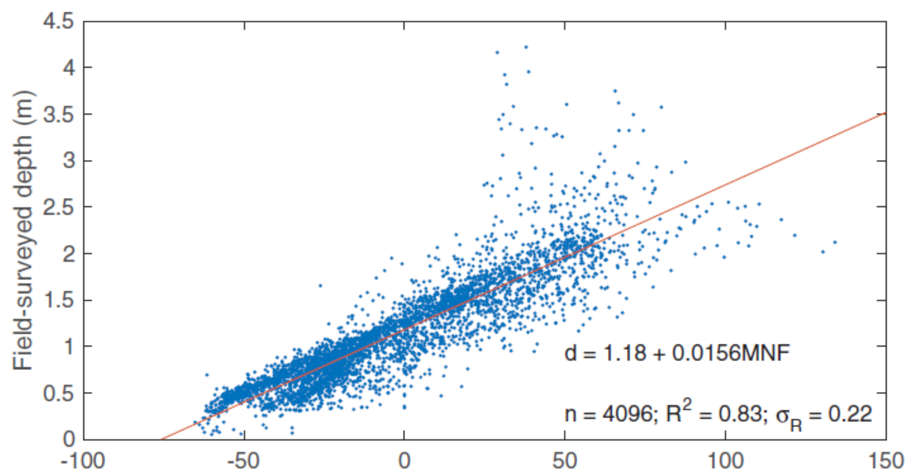
From: M. Wimmer, 2016: Comparison of active and passive optical methods for mapping river bathymetry, Master thesis @ TU Wien (Supervisor: G. Mandlburger)

Bathymetry from multi-spectral images









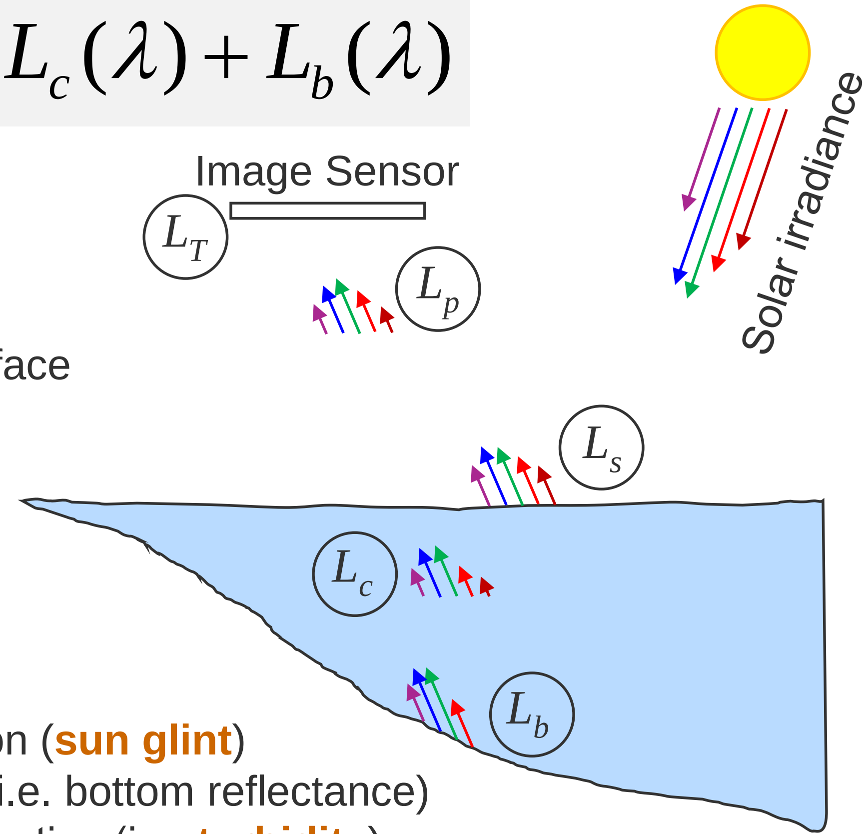
Source: Carl Legleiter, 2016:
Inferring river bathymetry via
Image-to-Depth Quantile Transformation.
Water Resour. Res., 52, 3722–3741,
doi:10.1002/2016WR018730.

Basics of spectrally based depth estimation

e.g. Legleiter et al, 2009: Spectrally based remote sensing of river bathymetry

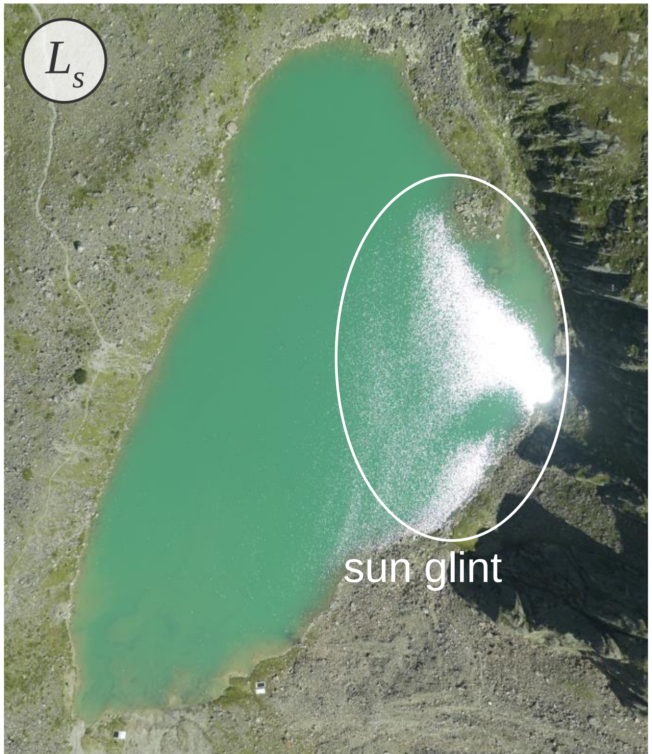
$$L_T(\lambda) = L_p(\lambda) + L_s(\lambda) + L_c(\lambda) + L_b(\lambda)$$

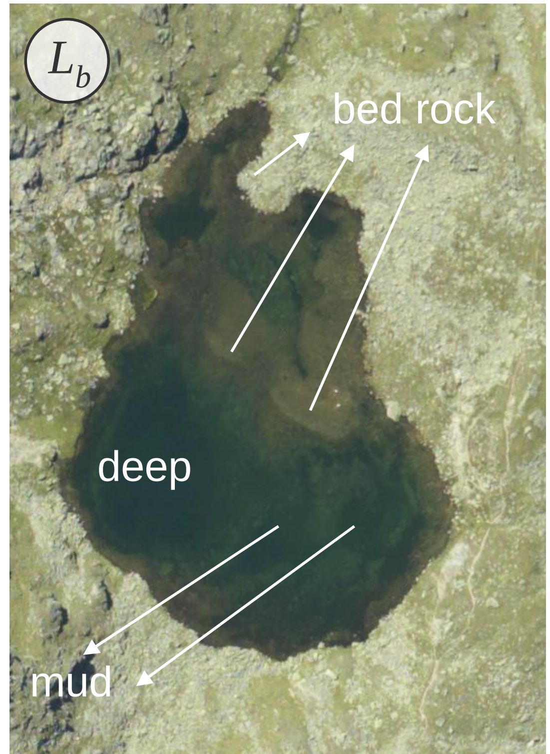
L_T .... total upwelling radiance
L_p .... contributions from the atmosphere
L_s .... radiance reflected from the water surface
L_c .... radiance from the water column
L_b .... bottom-reflected radiance



L_s .... depends on roughness and sun position (**sun glint**)
L_b .... related to **depth** and **substrate type** (i.e. bottom reflectance)
L_c .... determined by the waters' optical properties (i.e. **turbidity**)

Examples: Sun glint, bottom reflectance, depth, turbidity





Stubai Alps, Tyrol, August 2017, Camera: IGI-H39 (RGB)

Basic colour-to-depth relation

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

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

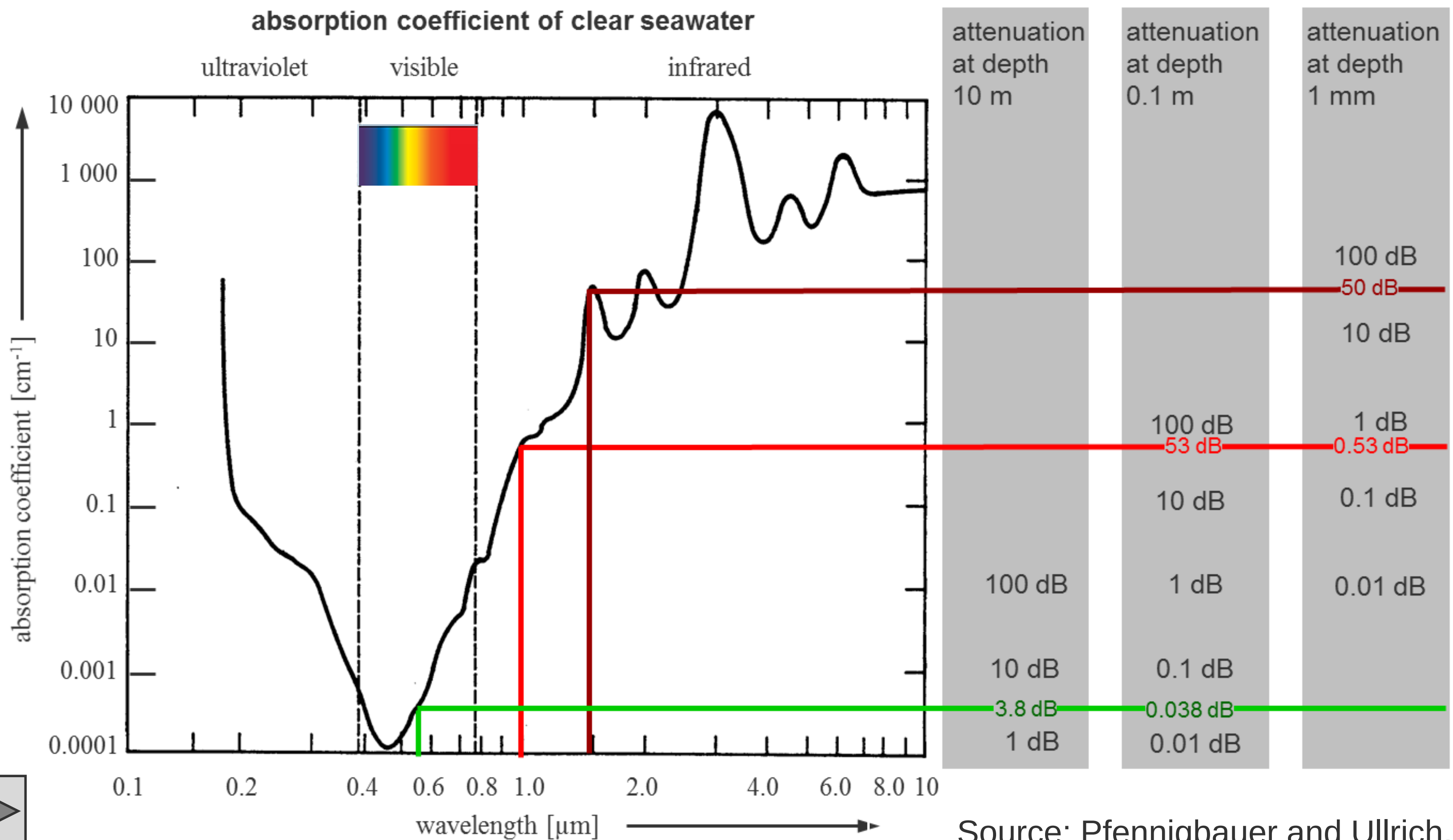
$L(h)$ .... upwelling radiance depending on the water depth *h*
L_S .... **surface** reflections and **volume scattering** from **infinitely deep** water
L_B .... transmission **losses** through **surface** + **bottom reflectance** + **volume scattering**
$\propto$ .... sum **of diffuse attenuation coefficients**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

$$h = \frac{\ln L_B - \ln(L - L_S)}{\alpha}$$

Modifications:

- Sun glint removal (often) using the NIR band or a multi-spectral image (Lyzenga et al, 2006)
- *h* from linear comb. of multiple bands to acount for different substrate types (Lyzenga, 1985)
- *h* from an optimal band ratio --||-- (Legleiter et al., 2009)
- Sophisticated calibration techniques e.g. using hydraulic parameters (Legleiter, 2016)

Absoprtion of EM-radiation in clear water



Source: Pfennigbauer and Ullrich, 2011

Airborne Laser Bathymetry – Radiometry

General Laser-Radar-Equation

$$P_R = \frac{P_T}{(\gamma R)^2\,\pi/4} \cdot \sigma \cdot \frac{D^2\,\pi/4}{4\pi R^2} \cdot \eta_{ATM}\eta_{SYS} + P_{BK}$$

Laser-Radar-Equation specialized for bathymetry

$$P_R = P_{WS} + P_{WC} + P_{WB} + P_{BK}$$

Water surface

$$P_{WS} = \frac{P_T D^2\,\pi/4\,\eta_{ATM}\eta_{SYS} L_O \cos\alpha_L}{\pi H^2}$$

Water column

$$P_{WC}(z) = \frac{P_T D^2\,\pi/4\,\eta_{ATM}\eta_{SYS} F (1-L_O)^2 \beta(\varphi) e^{\frac{-2kz}{\cos\alpha_W}}}{\left(\frac{n_W H + z}{cos\alpha_L}\right)^2}$$

Water bottom

$$P_{WB} = \frac{P_T D^2\,\pi/4\,\eta_{ATM}\eta_{SYS} F (1-L_O)^2 R_B e^{\frac{-2kZ}{\cos\alpha_W}}}{\pi\left(\frac{n_W H + Z}{cos\alpha_L}\right)^2}$$

Abdallah et al, 2012: Wa-LiD: A New LiDAR Simulator for Waters.

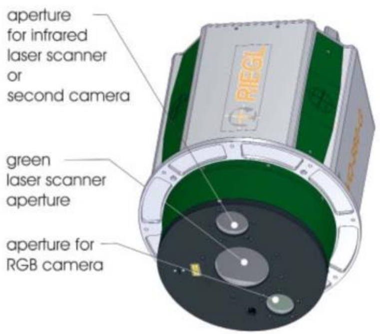
Tulldahl and Steinvall, 2004: Simulation of sea surface wave influence on small target detection with airborne laser depth sounding

Intermediate Summary

- Spectrally based depth estimation (passive, radiometric)
  - No sophisticated geometry processing necessary
  - Requires visibility of bottom features (therefore, inherent depth performance: 1 Secchi)
  - Can handle certain differences in substrate type and water clarity via multi-spectral image processing
  - Requires ground-truth for calibrating coefficients
- Through-water (multi-media) photogrammetry (passive, geometric)
  - Requires texture (therefore, inherent depth performance: 1 Secchi)
  - Delivers bathymetry but no bottom reflectance
  - Delivers high point density in shallow water areas when embedded in a Dense Matching (enough overlap required)
- Airborne Laser Bathymetry (active, geometric + radiometric)
  - Measures bathymetry via round trip time measurement
  - Delivers bottom reflectance (laser-radar equation)
  - Independent from external illumination and availability of texture
  - Spatial resolution limited by relatively large laser footprint (~50 cm → eye safety of green laser)

Examples of hybrid topo-bathymetric scanning and imaging sensor systems

Riegl VQ-880-G



- 1 laser channel (λ=532 nm)
- full waveform (fwf) recording
- max. depth: 1.5 * Secchi
- scan rate: 550 kHz
- 24 MP RGB/CIR camera

Leica SPL 100 – Single Photon Lidar

- 1 laser channel (λ=532 nm)
- detector array:
  10x10=100 beamlets /shot
- discrete echo system
- scan rate: 60 kHz = 6 MPix/sec
- max. depth: ???
- 24 MP RGBI (RCD30)

Source: http://leica-geosystems.com

Teledyne Optech Titan

- 3 laser channels
  (λ=532/1064/1550 nm)
- fwf recording opt.
- scan rate: 3x330 kHz
- 80 MP RGB/CIR camera

Leica AHAB HawkEye III

- 2 bathy channels (deep/shallow)
- 1 topo channel
- fwf recording
- scan rate: 35/10/60 kHz
- max. depth: 3.0 / 1.5 * Secchi
- 80 MP RGBI (RCD30)

DFG research project - Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery - I

Goals

- Improving the accuracy, reliability, density and completeness of DTM of the submerged topography via fusion of concurrently acquired image and laser data
- Improving the object classification using methods allowing the inclusion of contextual information. Classes of interest:
    - land
    - water surface
    - water bottom
    - under water vegetation
    - under water obstacles

DFG research project - Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery - II

Ideas and Methods (1/2)

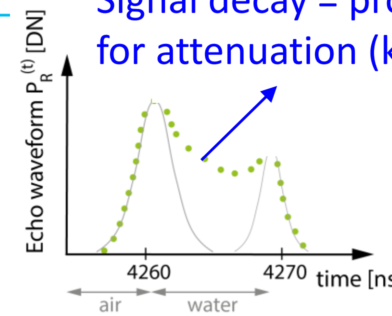
- DTM
  - density/spatial resolution: Image=**GSD** vs. Laser=**footprint diameter,** GSD<laser footprint
    - Shallow area less effected by turbidity
      → Dense Image Matching (Multi-media photogrammetry)
    - Less texture deeper areas → Spectrally based depth estimation
  - accuracy/reliability: redundant information (DIM and laser).
    - Remark: Spectrally based bathymetry does not increase redundancy
      (needs laser depths, etc. for calibration)
  - completeness: Spectrally based method always (!) delivers a depth estimate
    - Limitation: penetration depth (turbidity)
  - fusion: extension of existing approaches allowing the inclusion of spatial context
    - Conditional Random Fields (CRF)
    - Deep Learning (Conditional Neural Networks, CNN)

DFG research project - Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery - III

Ideas and Methods (2/2)

- Classification

cf. Richter et al., 2017



Signal decay = proxy for attenuation (k/α)

(Multi-spectral) Image

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

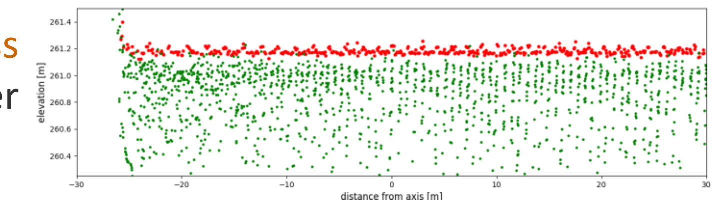
Observed variable

Auxiliary parameters

Main parameters
- Water depth
- Bottom reflectance

Laser

- Attenuation related to signal decay → full waveform
- Surface roughness visible in 3D water surface points

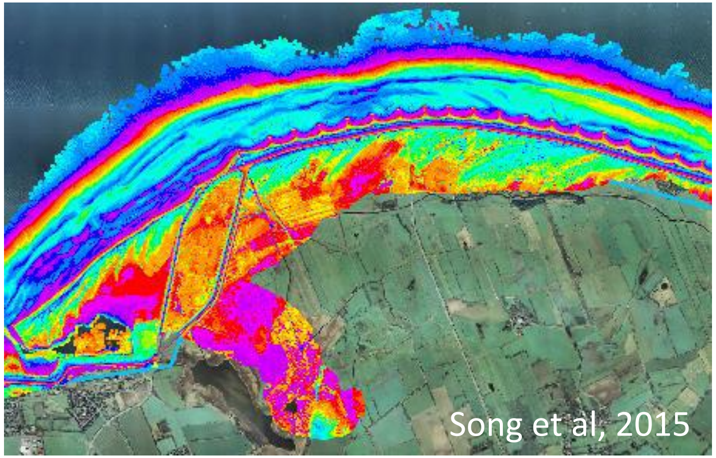


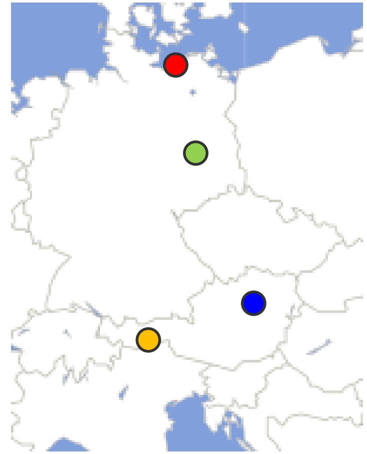
- Water depth via roundtrip time measurement (i.e. areal calibration data for spectral depth estim.)
- Bottom reflectance → via radiometric calibration of laser data (laser-radar equation)

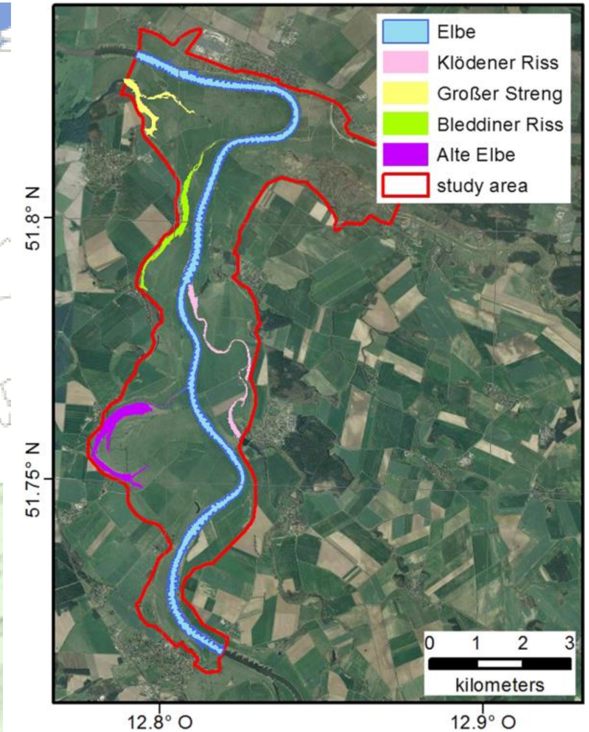
"Measure what can be measured, and make measurable what cannot be measured." (Galileo Galilei)

DFG research project - Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery – IV datasets

German Baltic Sea,
Data: BSH

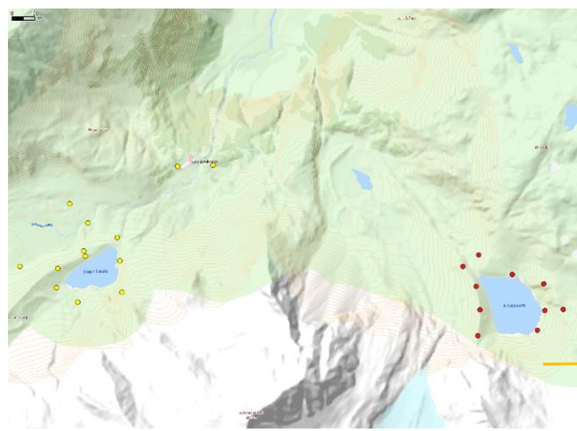






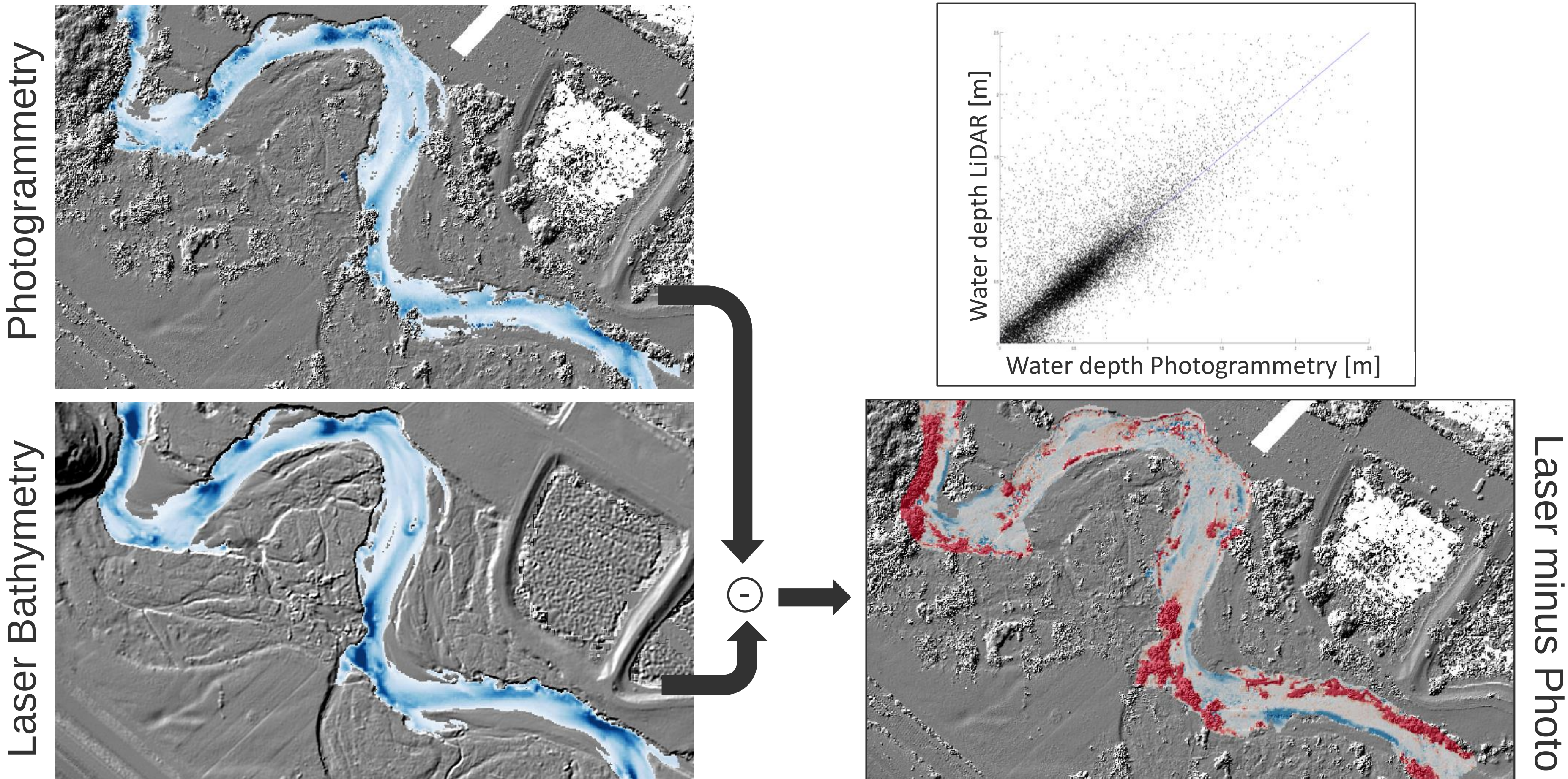
Elbe/Klöden, Data: BfG

Pielach River
Data: Riegl LMS



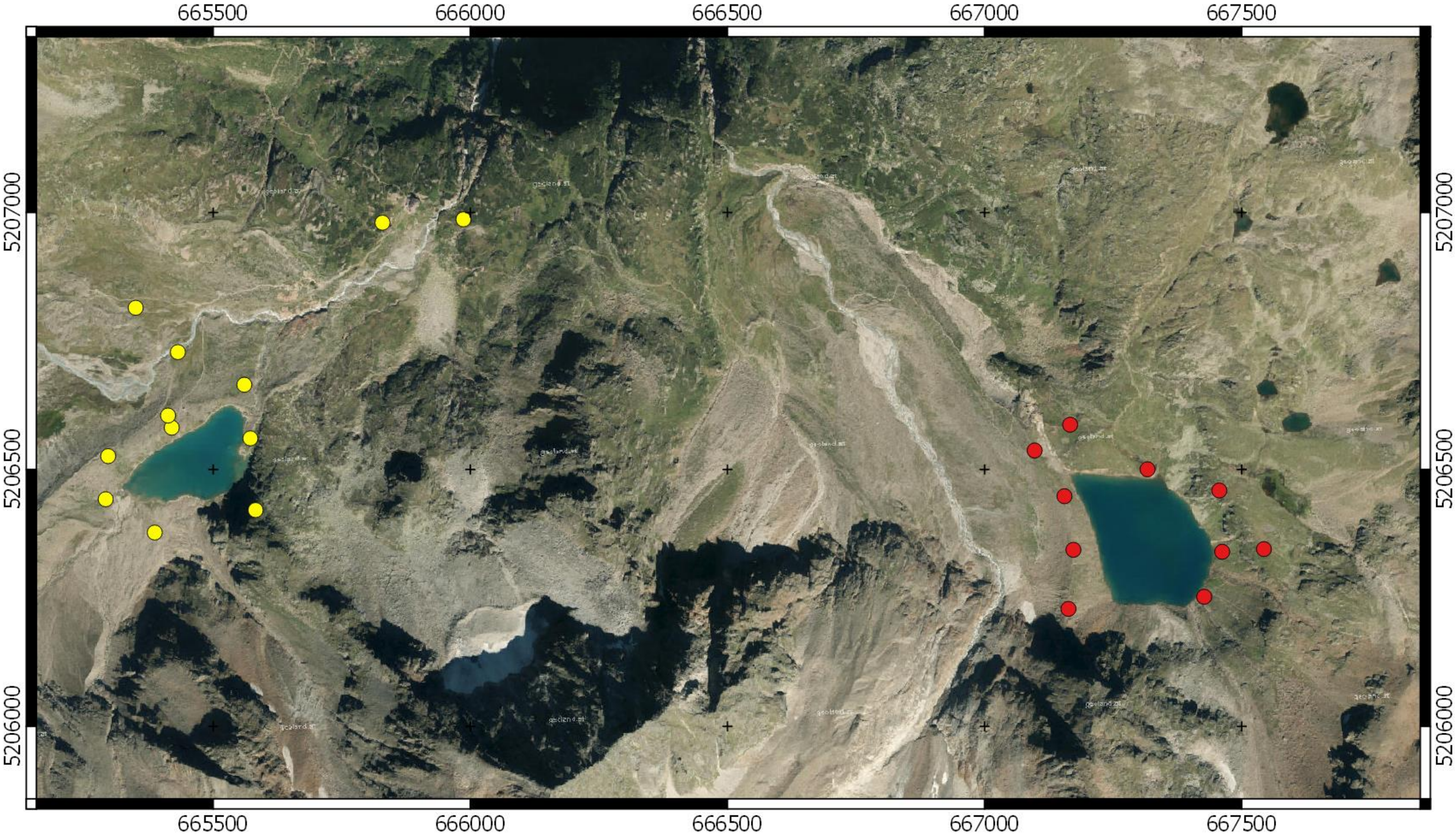
Mountain lakes, Stubai Alps
Data acquisition: 07-08/2017

Comparison: multi-media photogrammetry vs. laser bathymetry

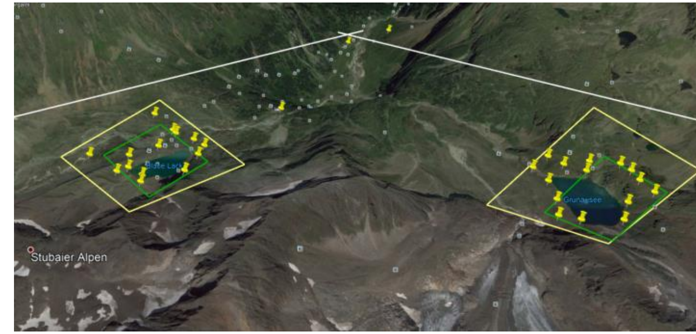


From: M. Wimmer, 2016: Comparison of active and passive optical methods for mapping river bathymetry, Master thesis @ TU Wien (Supervisor: G. Mandlburger)

Study area: Stubai Alps, mountain lakes Grünausee / Blaue Lacke I

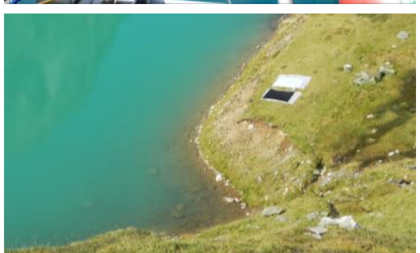


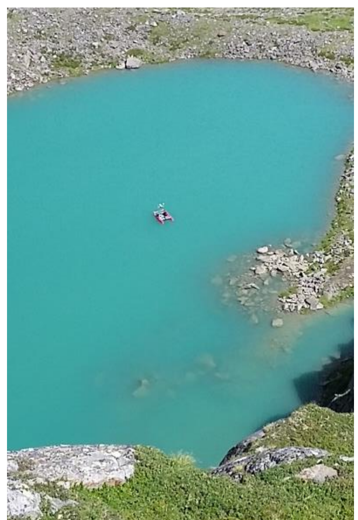
Study area: Stubai Alps, mountain lakes Grünausee / Blaue Lacke II

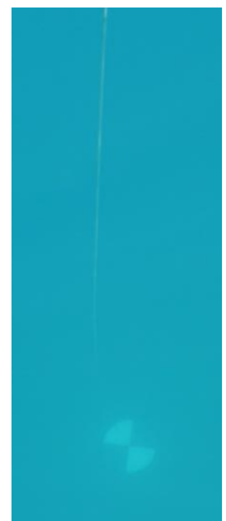


Carried out tasks:

- Flight mission planning
- GNSS surveying of control pts (07/08-2017)
- Secchi depth measurement (07+08-2017)
- Sonar data acquisition (07-2017, Univ. Innsbruck)
- Airborne data acquisition (08-2017, AHM)
- Data processing (in progress)

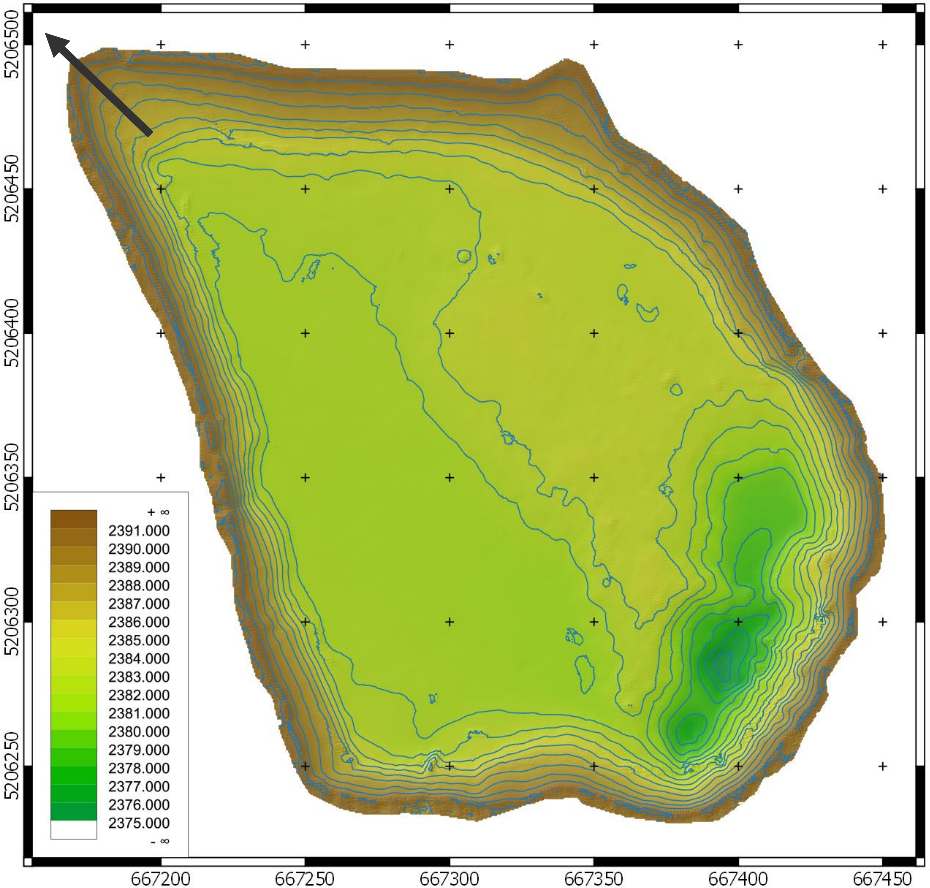




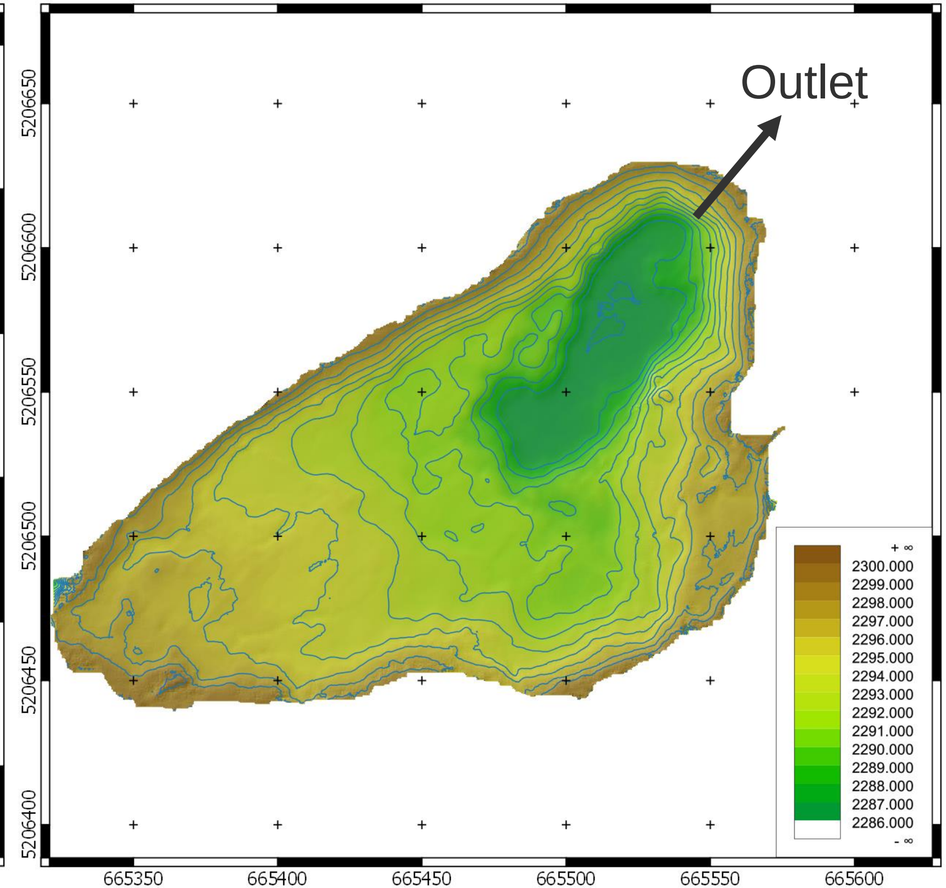


Results of reference data acquisition by echo sounding, July 2017

Grünausee



Blaue Lacke



Summary and conclusions

Airborne active and passive remote sensing suitable for capturing relatively clear and shallow water bodies

Available techniques for measuring water depth:

▪ Multi-spectral images	passive	color-to-depth relation
▪ Multi-media photogrammetry	passive	intersection of (refracted) image rays
▪ Laser scanning	active	bathymetry via round trip time measurement

Techniques are mostly used independently so far

Hybrid sensor (camera + laser scanner) are available

DFG research project: Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery

- Goal: joint data processing of concurrently captured images and laser scans to …
- … improve below-water DTM (accuracy, reliability, spatial resolution, completeness)
- … improve classification (substrate type, under water vegetation)

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