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Airborne laser bathymetry
Grundlagen der LiDAR-Hydrographie

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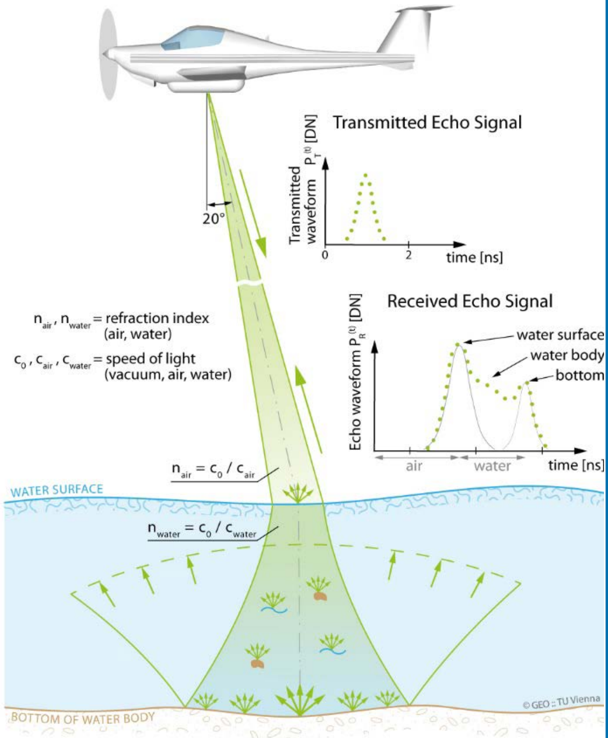


Contents - Lidar Bathymetry Principles

Bathymetric Laser Scanner

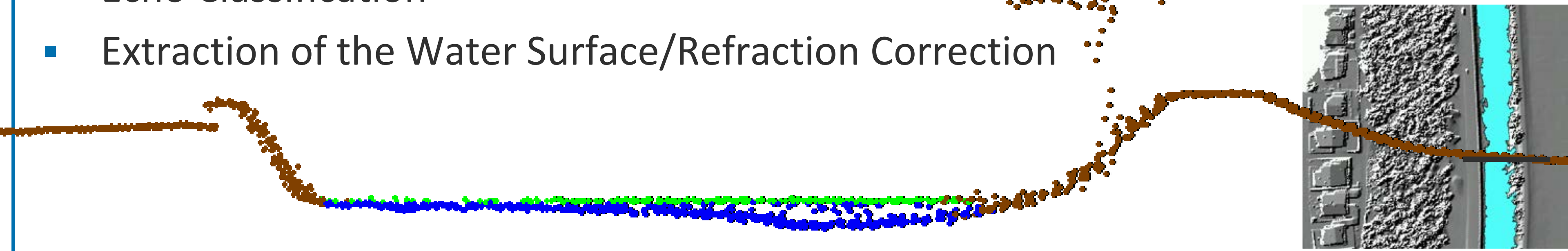
- Range detection with a laser
- Scanning
- 2 Media: Air and Water
- Absorption and Scattering

Airborne operation

- Direct georeferencing
- (QC / QA)

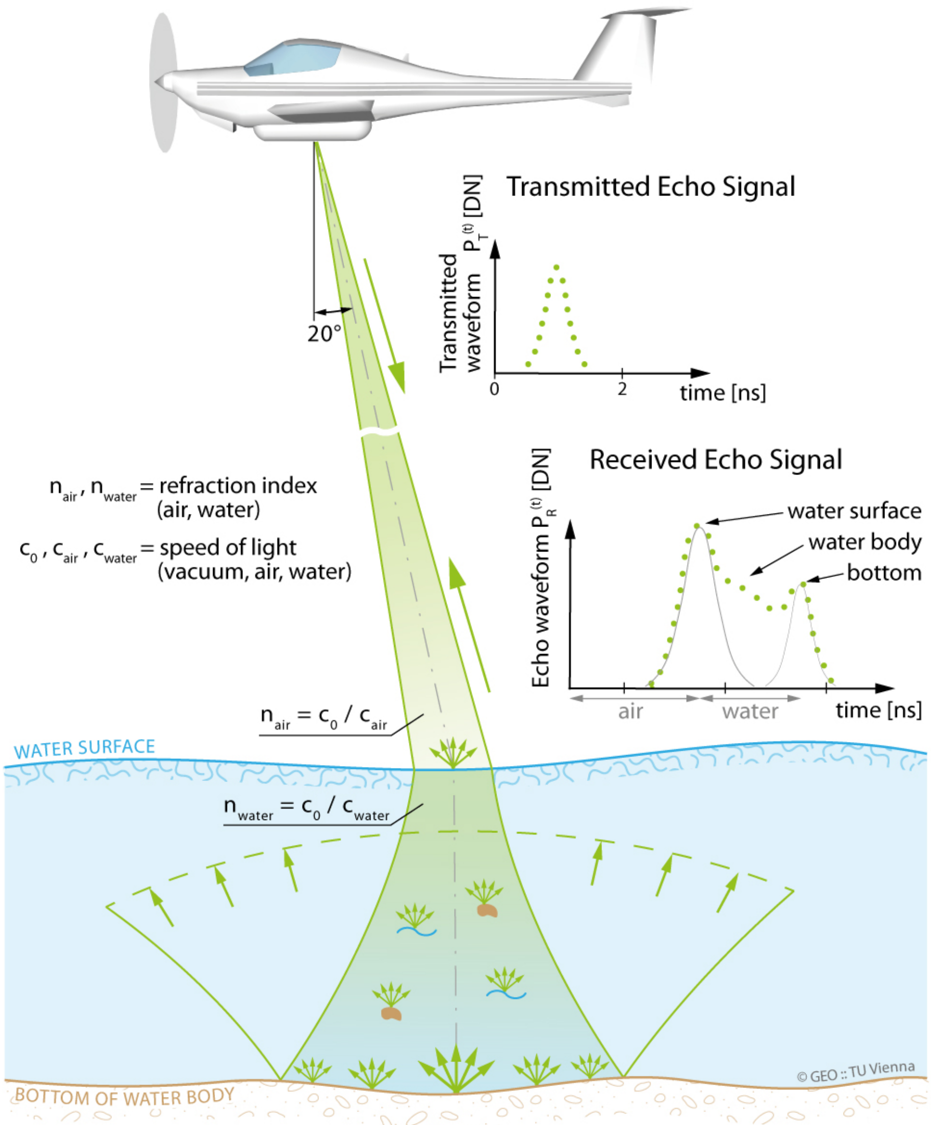
Bathymetric Point Clouds

- Echo Classification
- Extraction of the Water Surface/Refraction Correction



Definition: Airborne Laser Bathymetry (ALB)

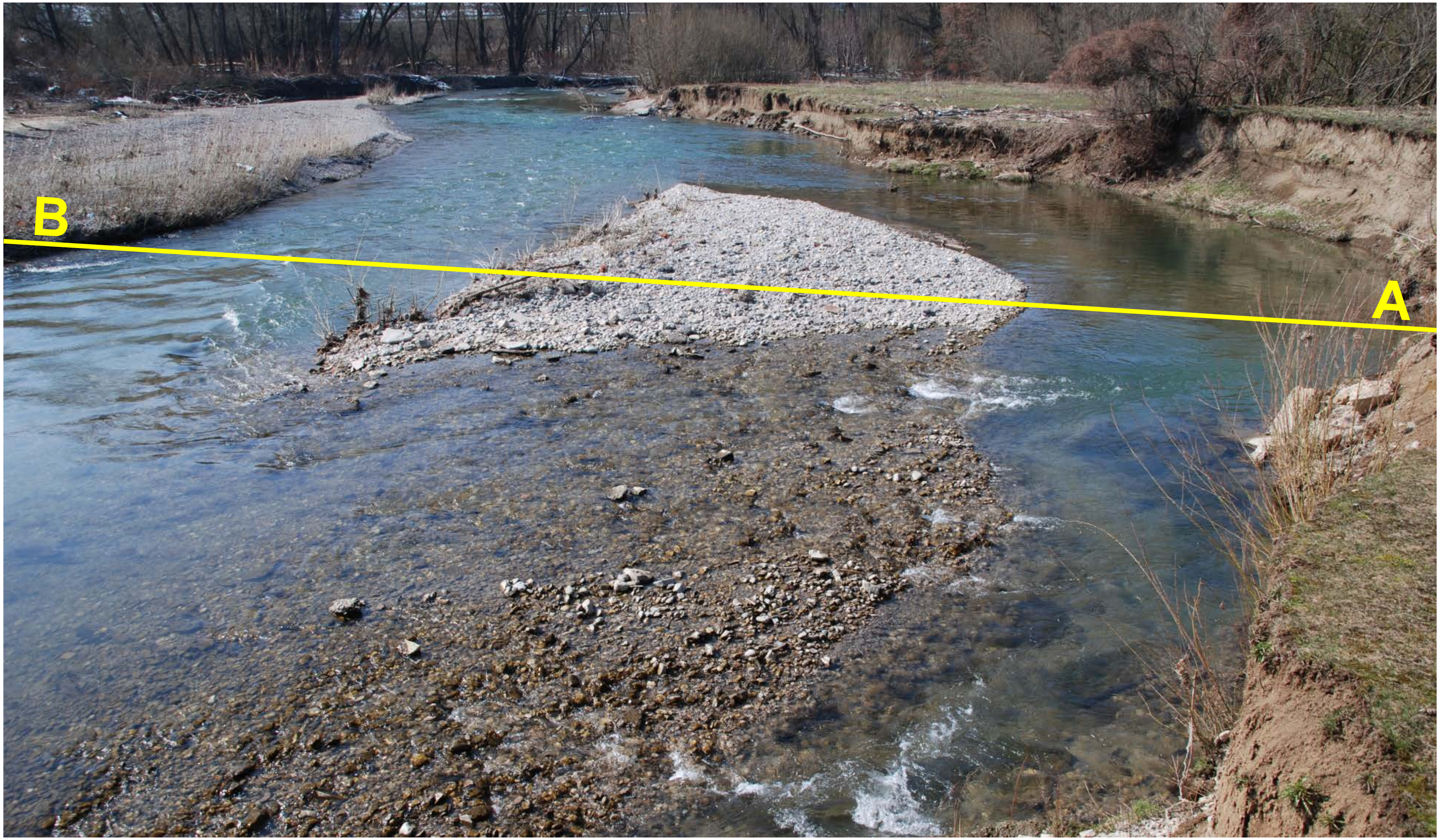
Airborne Laser (or LiDAR) Bathymetry (**ALB**) is a technique for **measuring** the **depths** of **relatively shallow**, **coastal waters** from the **air** using a **scanning**, **pulsed laser** beam. It is also known as Airborne Laser Hydrography (**ALH**) […]. *)



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

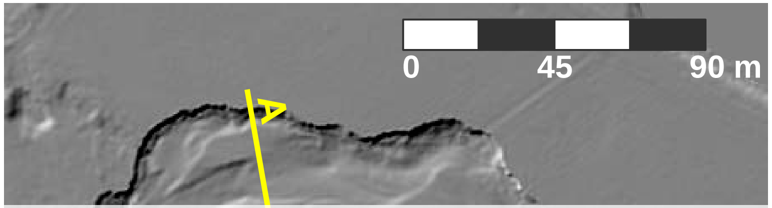
Laser source: green wavelength typically λ=532nm

River cross section

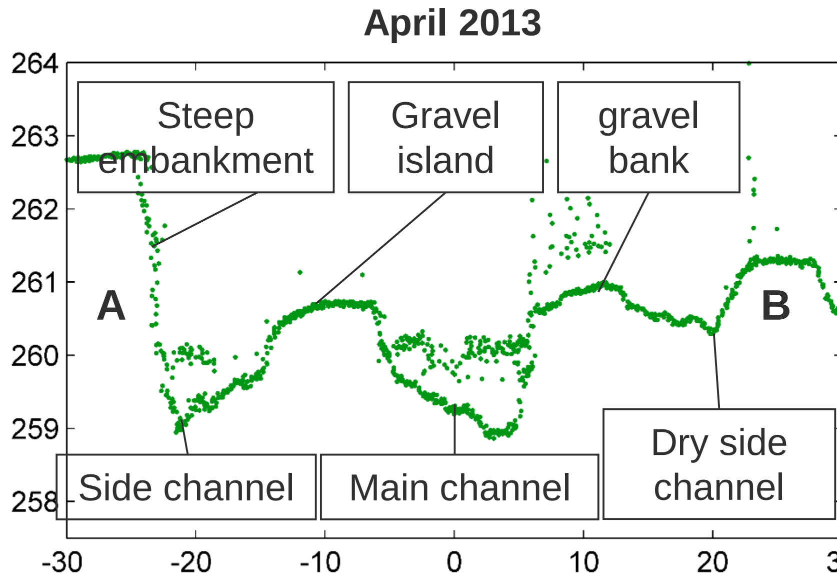


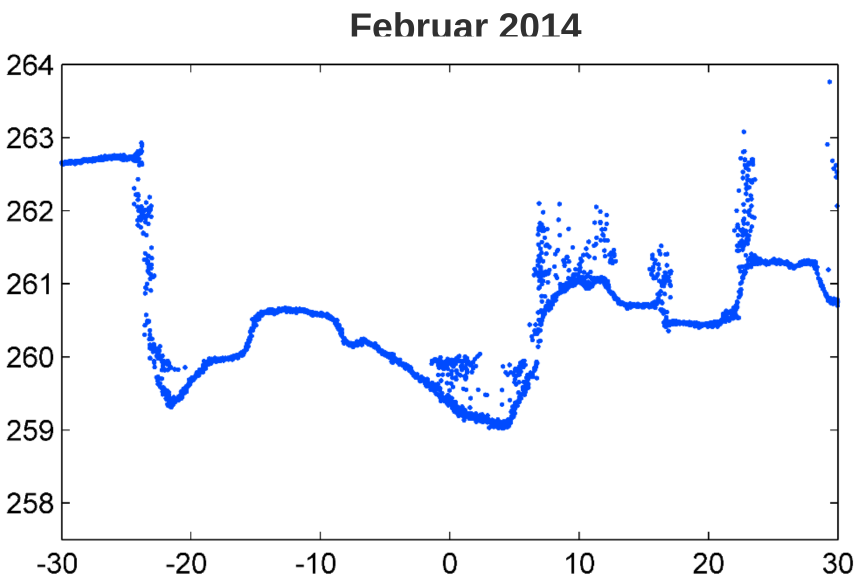
pre alpine river / Fluss im Alpenvorland

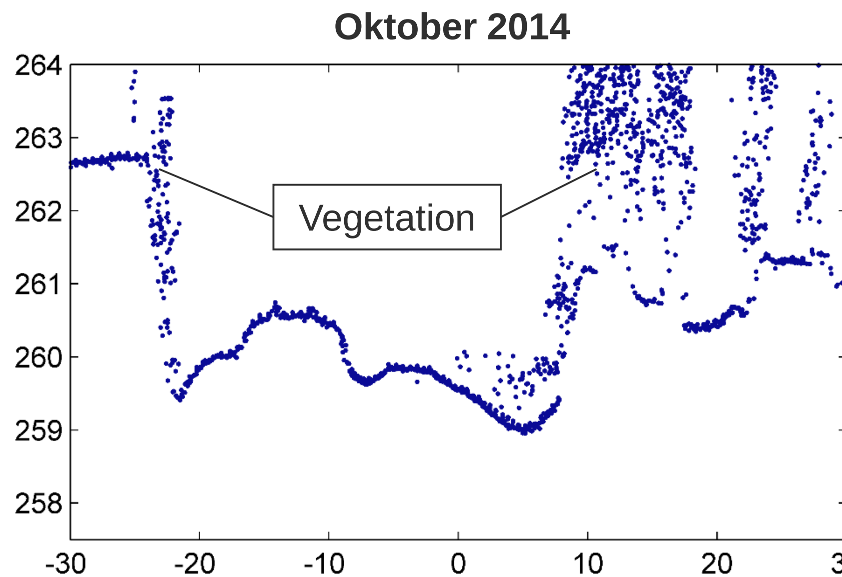
Cross sections Apr13-Feb14-Oct14



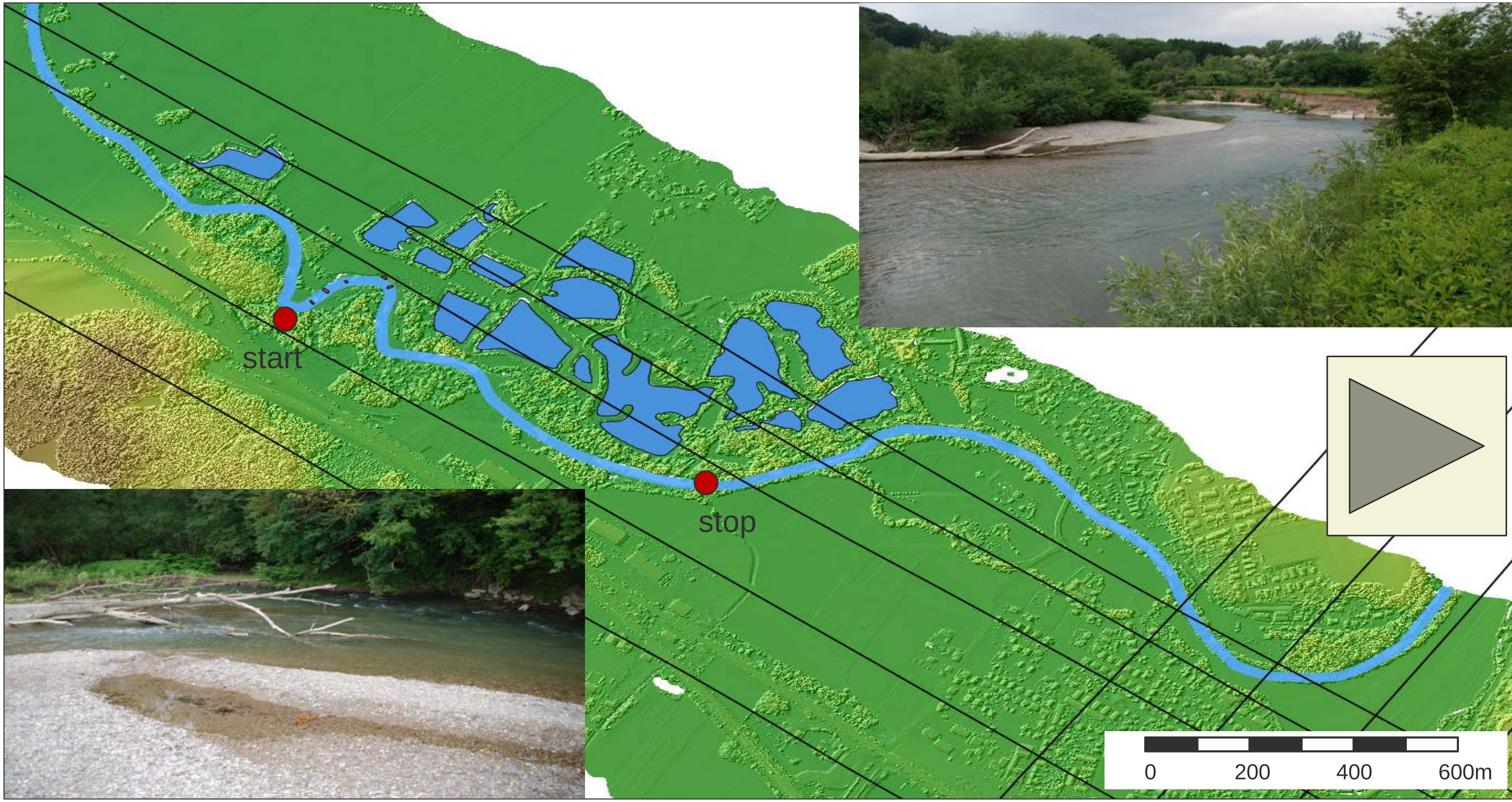
ALB + Fluvial geomorphology: Characterize, understand & simulate fluvial states and processes by monitoring shape (changes) of the river channels







Pielach – Neubacher Au (Niederösterreich)



European Directives

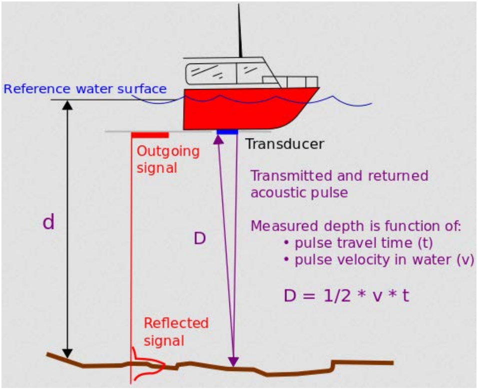
- FFH (Fauna Flora Habitat), Habitats Directive: Directive 92/43/EEC
  - The Habitats Directive ensures the conservation of a wide range of rare, threatened or endemic animal and plant species.
  - In Natura 2000 sites record species, <u>structure</u>, and human influence.
- WFD (Water Framework Directive): Directive 2000/60/EC
  - Addresses surface and ground water
  - Water quality in focus
- Flood directive: Directive 2007/60/EC
  - Understand risk of flooding for all water courses and coast lines
  - Requires flood risk assessment, hazard maps, risk maps, and flood risk plans

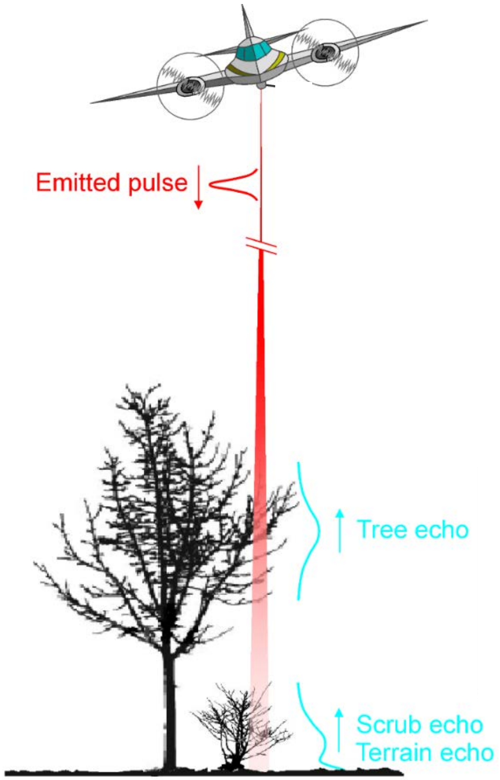


Images: http://ec.europa.eu

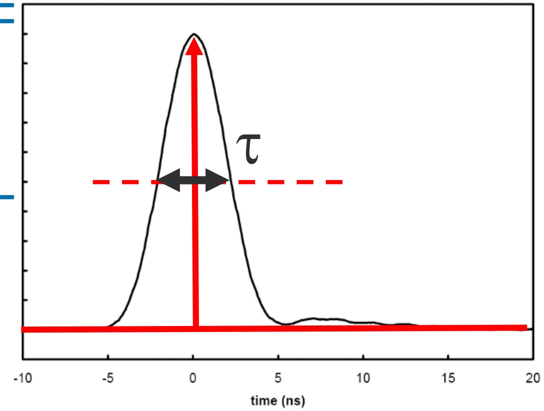
Range Finding

- Sound
  $c \approx 340ms^{-1}$ in air, $c \approx 1480ms^{-1}$ in water
  Maximum depth in water 100m up to 10km, depending on echo sounder frequency
- Light
  $c \approx 299702550ms^{-1}$ in air, $c \approx 230610000ms^{-1}$ in water
  propagation of medium strongly depends on the wavelength ($\lambda = c/f$)
- Ranging principle
  Measure run time Δt of the two way travel time of a signal from emmission to detection of its back-scatter (= echo)
- $d = \Delta t * c / 2$

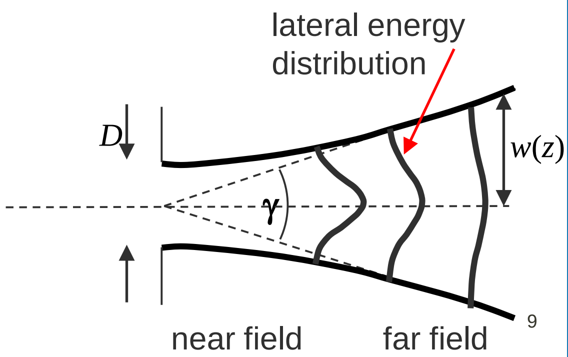




Laser Range Finding

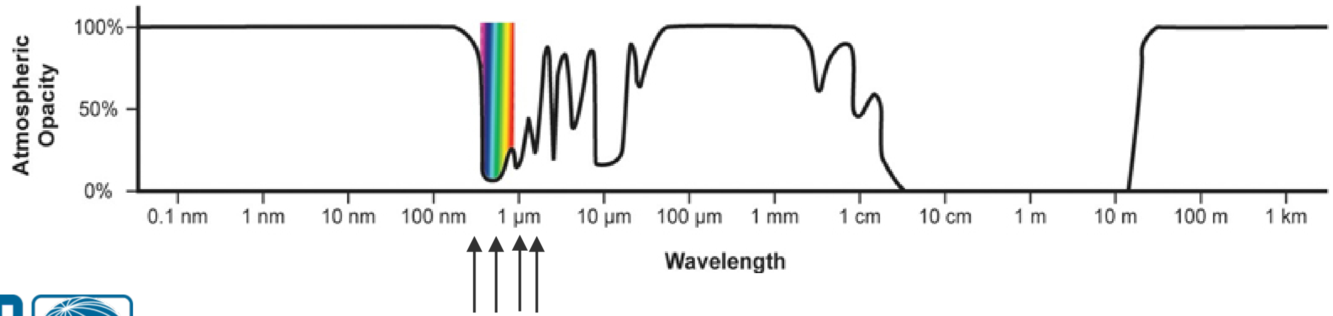


- Short laser pulse as signal
  τ = 2ns ~ signal length of 0.6m
  τ = 5ns ~ signal length of 1.5m
  shorter signals allow a better range resolution



- Collimated laser pulse (narrow bundle)
  γ = 1mrad ~ footprint of 0.5m @ 500m (distance)
  γ = 0.3mrad ~ footprint of 15cm @ 500m (distance)
  narrower beams allow a better lateral resolution

- Efficient detectors and variety of laser sources available



sources: 355nm, 532nm, 690nm, 1064nm, 1540nm, …

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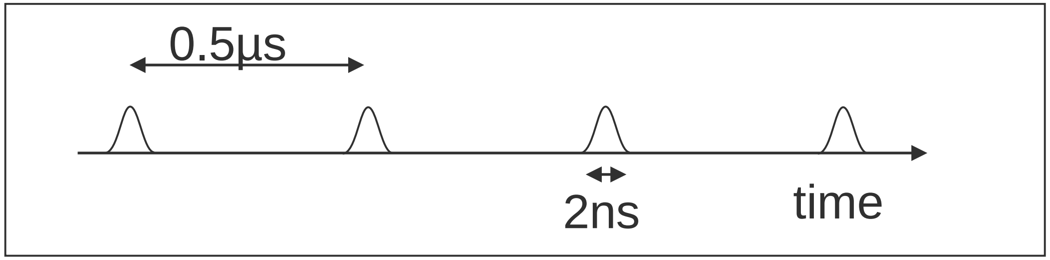
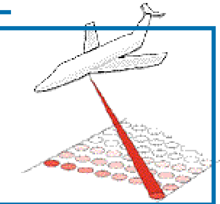
Laser Range Finding

- … accurate in range
  time measurement @ 0.1ns ~ 1.5cm
- … accurate in planimetry
  footprint diameter @ 500m ~ 15-50cm
- … feasible
- At high frequency (measurement repetition rate, *pulse repetition frequency* PRF)
  d = Δt * c / 2
  750m = 5µs * $3*10^8 ms^{-1}$ / 2
  e.g.: uniquness range (only one pulse travelling) PRF = 200kHZ: d = 750m

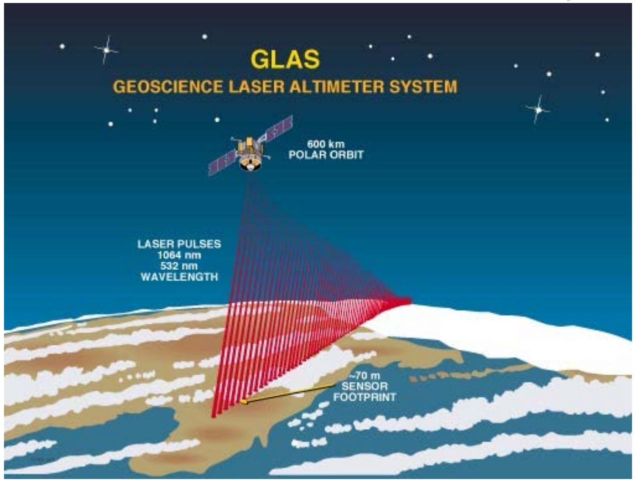


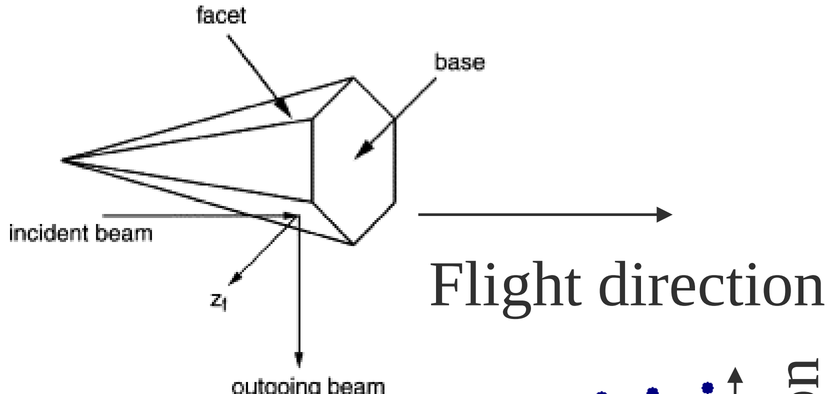


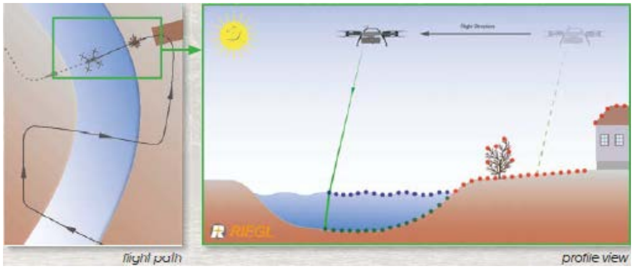
Scanning

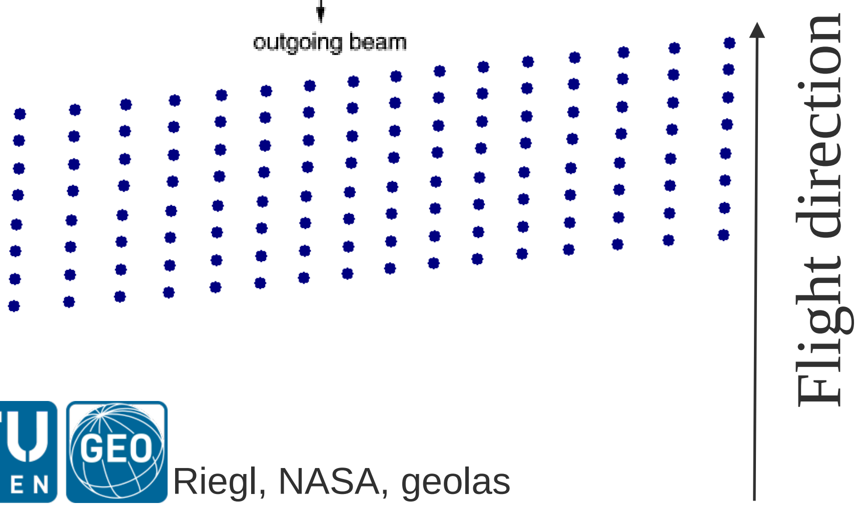
Scan beam across the field of view (FoV)

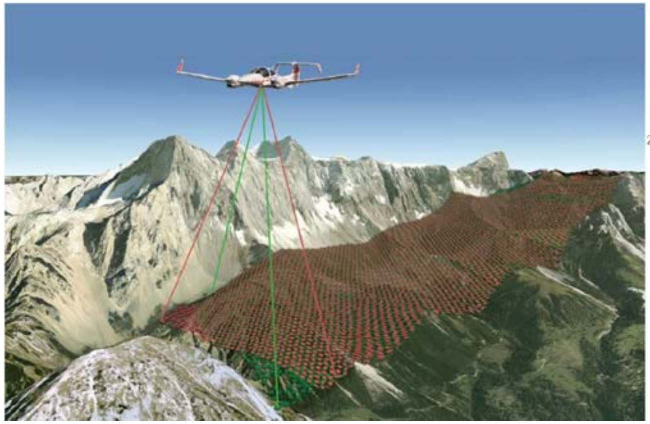
- Static laser scanning – fixed platform: 2d FoV
- Dynamic laser scanning – moving platform: 1d FoV
- Laser profiling – moving platform, no scanning

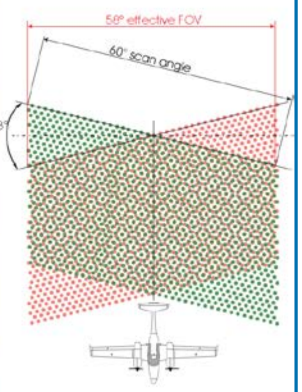








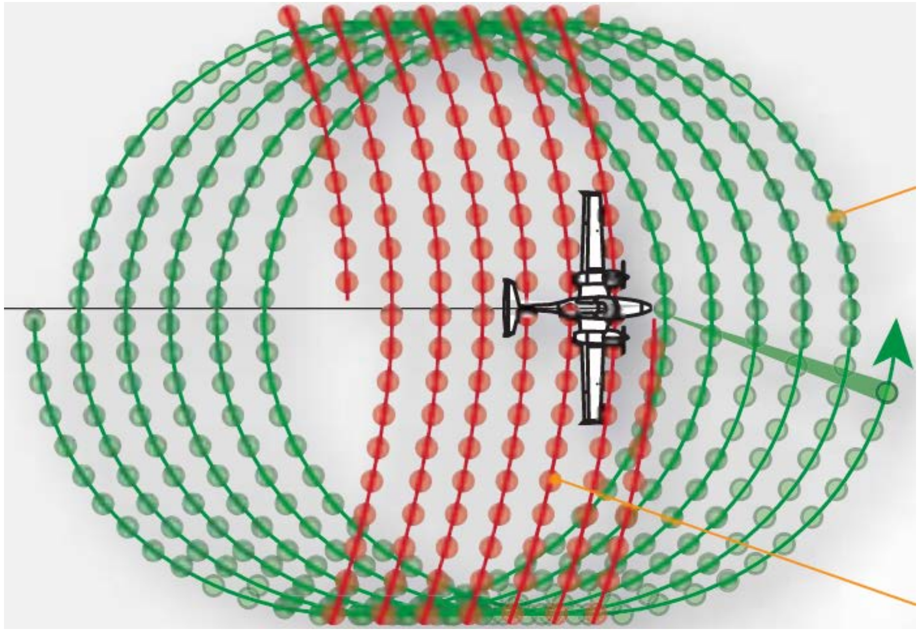


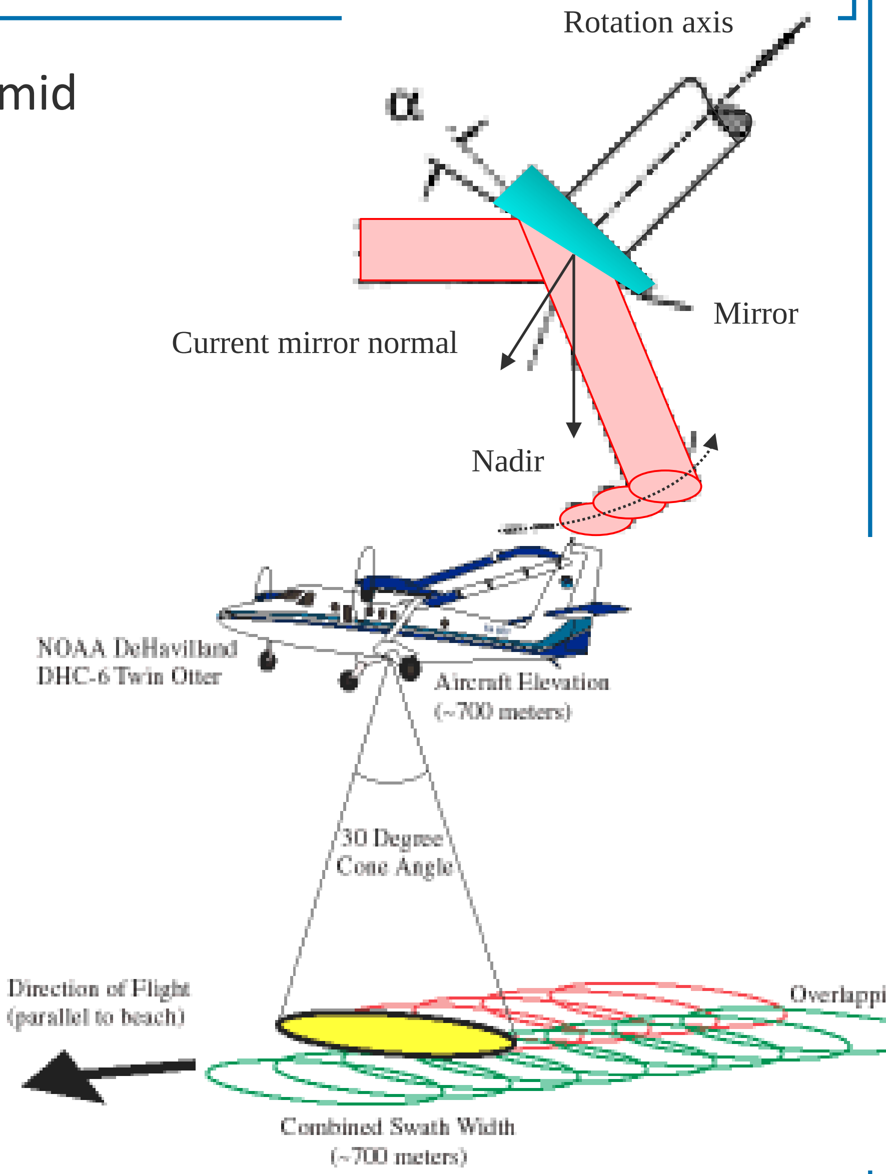


Riegl, NASA, geolas

Scanning

- Palmer scanner and inclined rotating pyramid circular or bow-shaped scan pattern



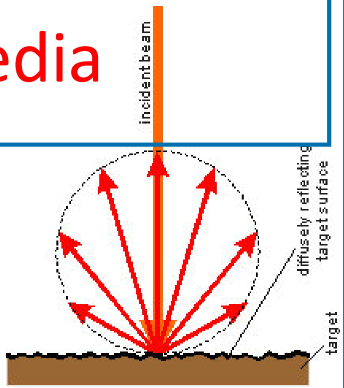


Riegl, NOAA, Wehr et al. (ISPRS-J)

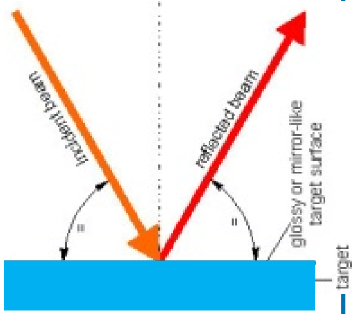
Scattering and Absorption and Multiple Media

Important modes of interaction of laser signals with surfaces

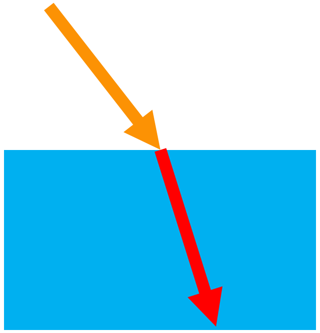
- Diffuse scattering
  ligth scattered back into all directions … also to sender/detector
  typical for solid surfaces: soil, gravel, roofs, …



- Specular reflection
  light mirrored into one direction … typically not to detector
  typical for smooth surfaces: still water, polished metals, …



- Refraction
  light refracted at boundary between 2 media
  typical for water-air-interface (Snell‘s law)



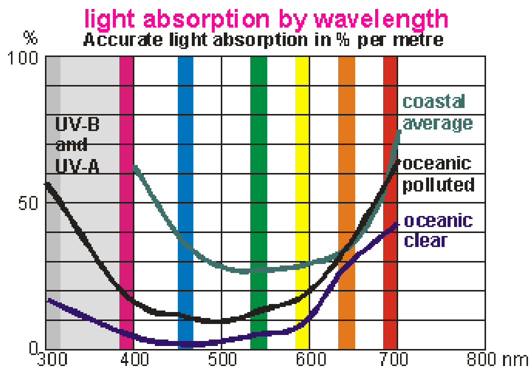
- Absorption
  light absorbed … no return to detector
  typical for „black“ surfaces: tar, rubber, dark mud, …

… but this depends on the laser wavelength
… and interaction modes occur together

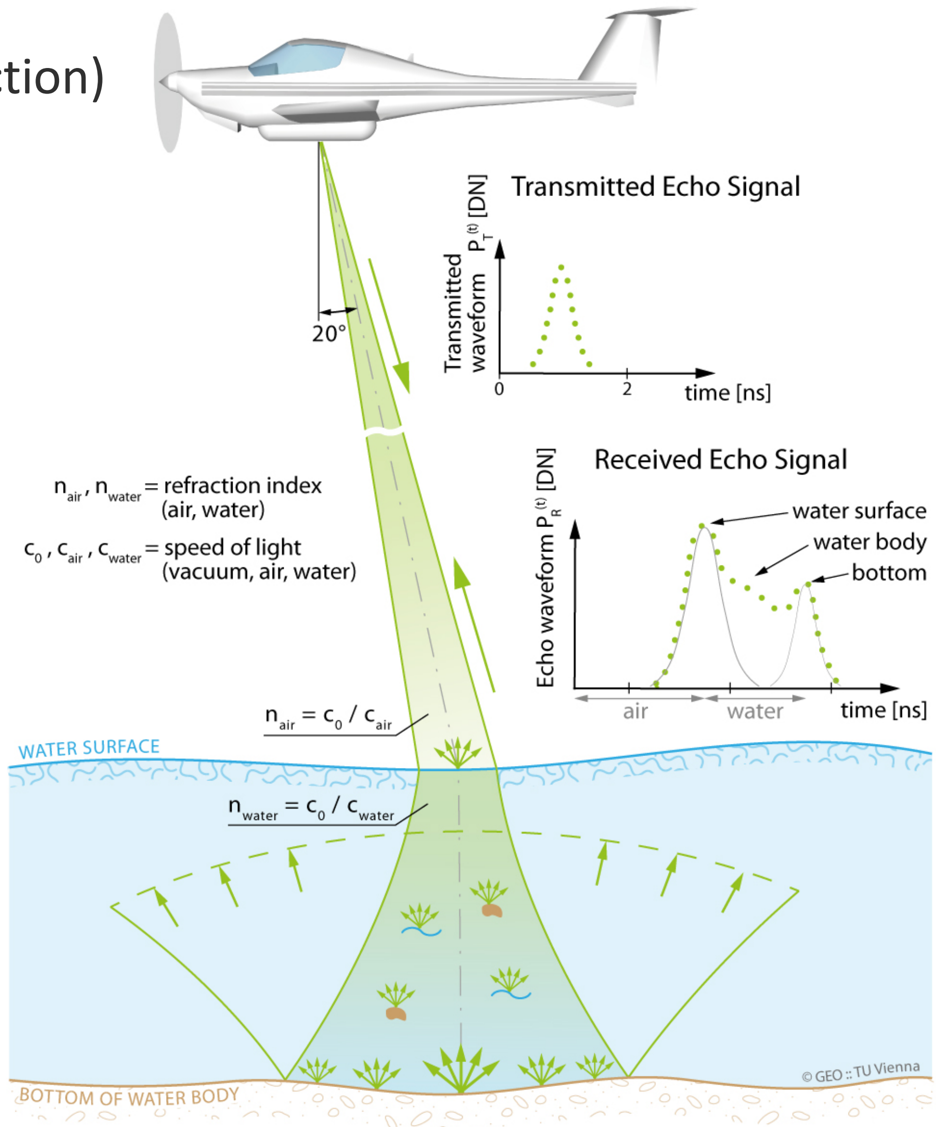
Lidar bathymetry

Green light (532nm)

- Best transmittance into water (refraction)



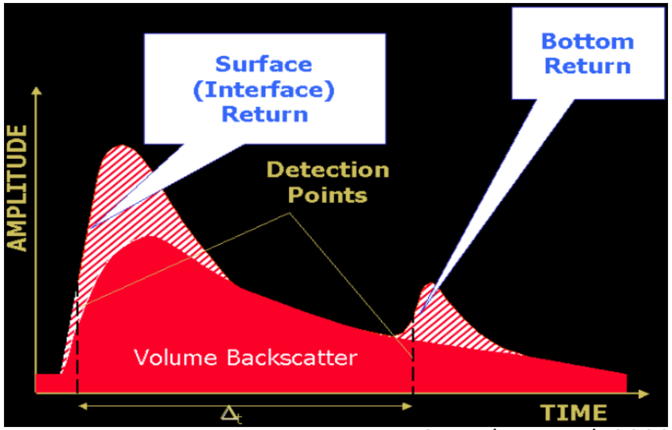
- Portion of diffuse and specular reflectance at water surface
- (Forward) scattering leads to beam widening
- Reflection at suspended sediments (air bubbles, …) in the water column



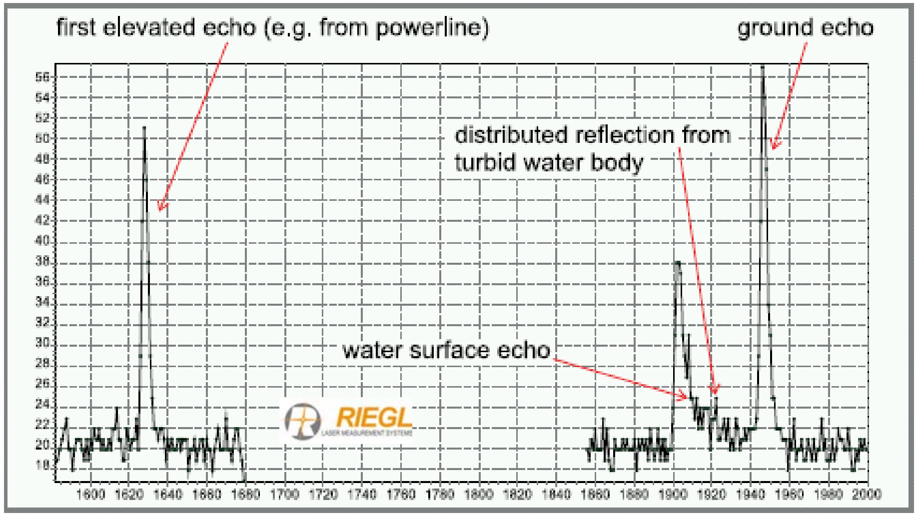
http://www.seafriends.org.nz

Lidar bathymetry signal

- Echo (model)
- 3 components
  - Backscatter from air-water interface
  - Volumetric backscatter in water column (exponential decay)
  - Backscatter from ground return

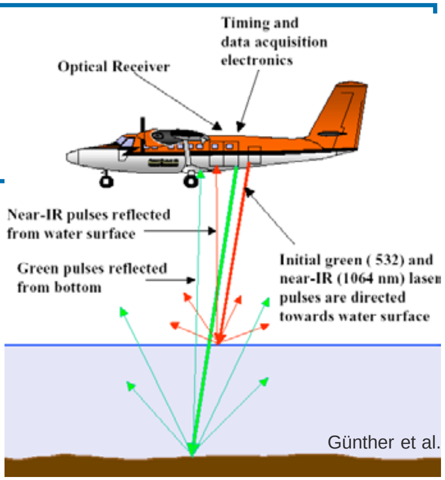


Guenther et. al, 2000



Waveform of the backscattered signal needs to be analyzed

Lidar bathymetry

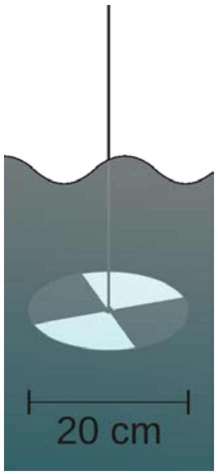


Infra red light

- Infra red ~1µm: absorption and reflection
- Longer wavelengths: absorption gets more and more dominant
- Surface returns can be used to model water surface
  (if spatio-tempolally sufficiently close to green beam)

Green light

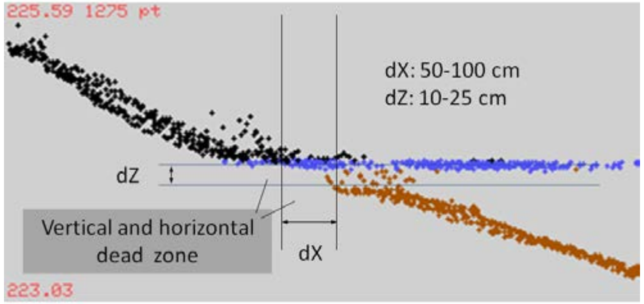
- Penetration depends on visibility (turbidity, sediment load, ...)
- Visibility measured with Secchi disk
  Secchi depth: depth at which disk is no longer visible
- Performance of bathymetric lidar specified in multiples of Secchi depth
  typical 1x – 3x Secchi depth (maximum reported around 70m for clear sea)
- <u>Stronger returns from bright bottom surface</u> (gravel vs. mud)



Wikipedia, www.aslo.org

Lidar bathymetry

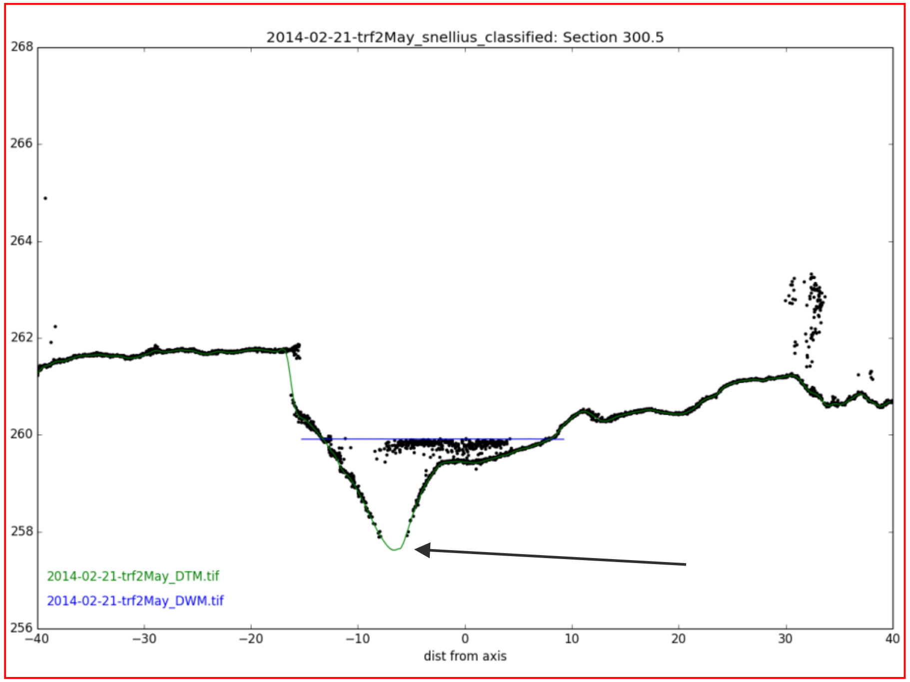
- Performace limit in shallow water: discrimination of water and bottom return



Depends on pulse duration
and bottom reflectivity

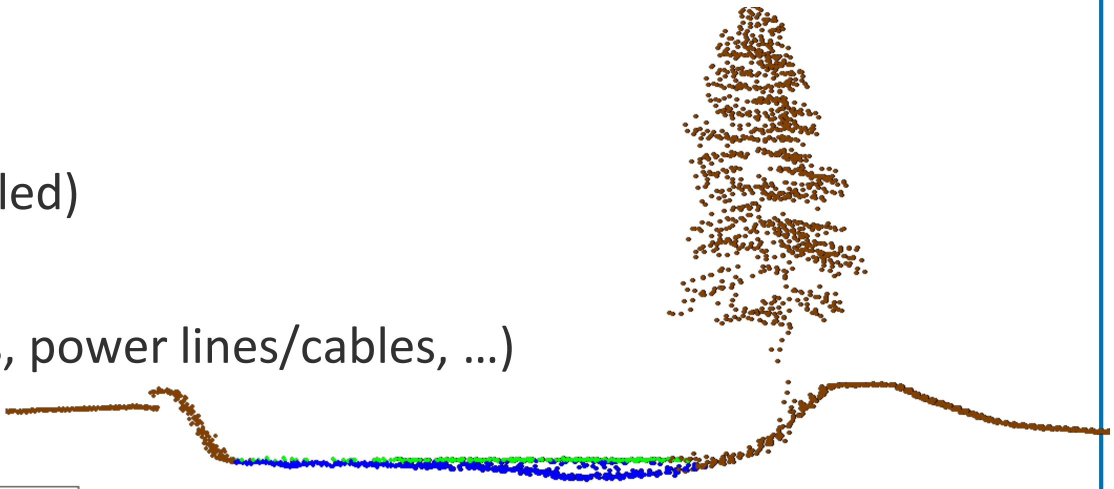
- Performace limit in deep water: no return due to scattering and absoption

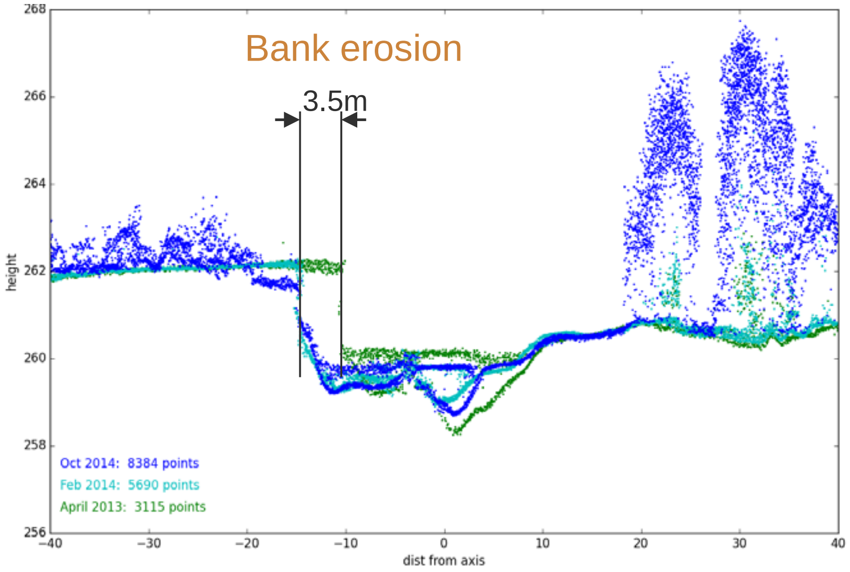
Depends on visibility
and bottom reflectivity

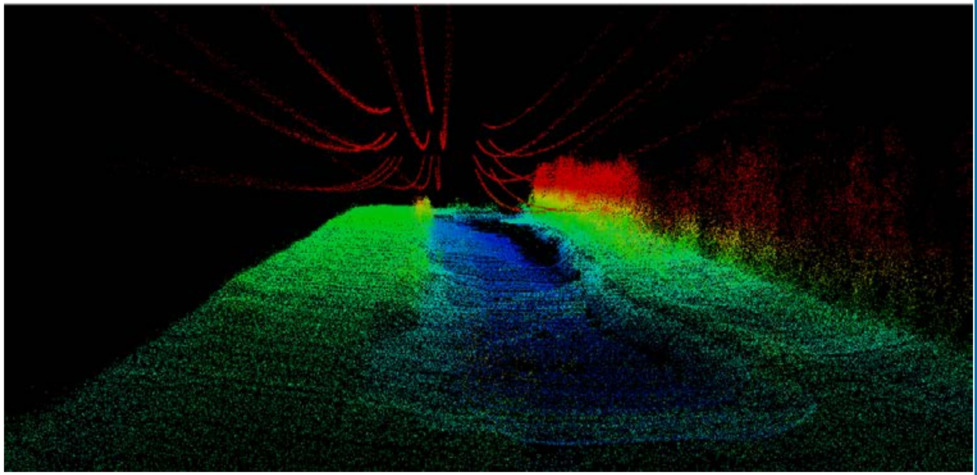


Measurements over wet and dry areas

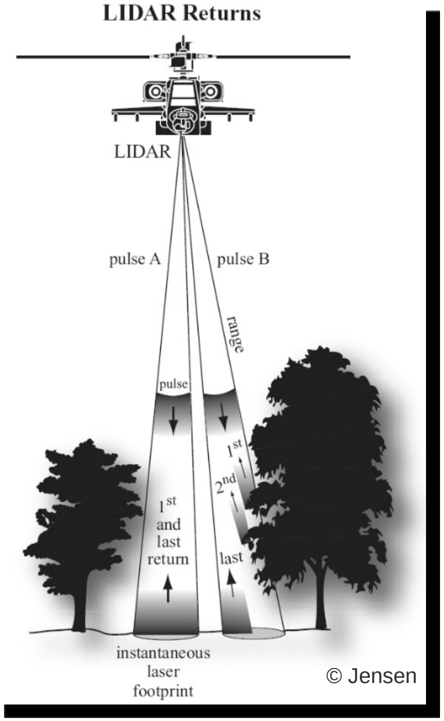
- Water air interface
- River ground (sea bottom)
- Solid ground (sealed and unsealed)
- Low and tall vegetation
- Elevated objects (building roofs, power lines/cables, …)







Scattering and Absorption and Multiple Media
… and multiple returns from not extended targets

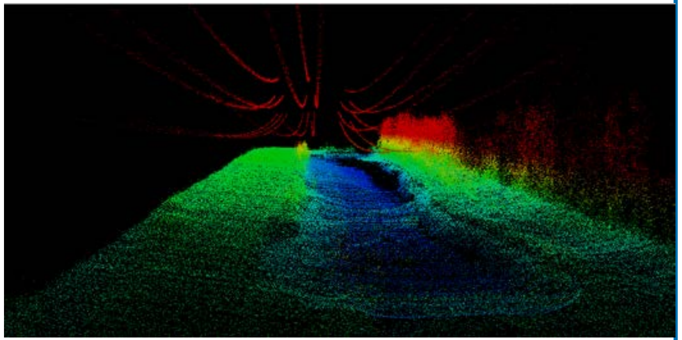


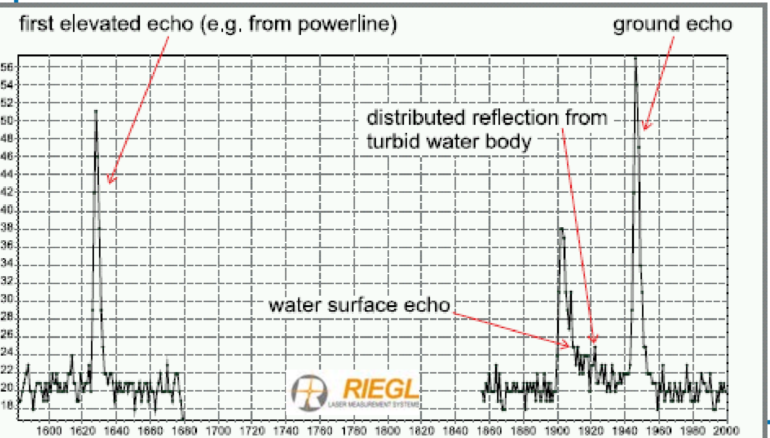
… therefore

- Return signals are complex
- Inidivual echos within one compound return

may consist of

- Water surface only
- Dry soil only
- Water surface + bottom
- Vegetation + dry soil
- Water surface + water column + bottom
- Vegetation + water surface + …

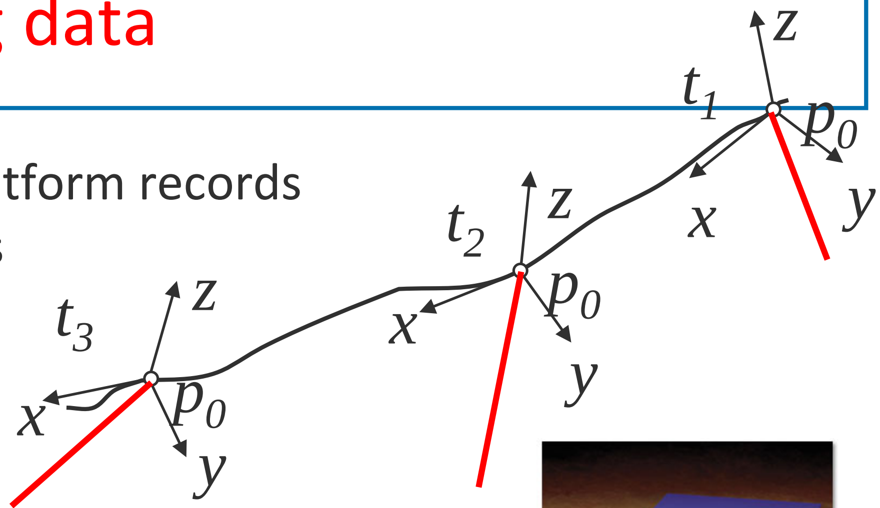


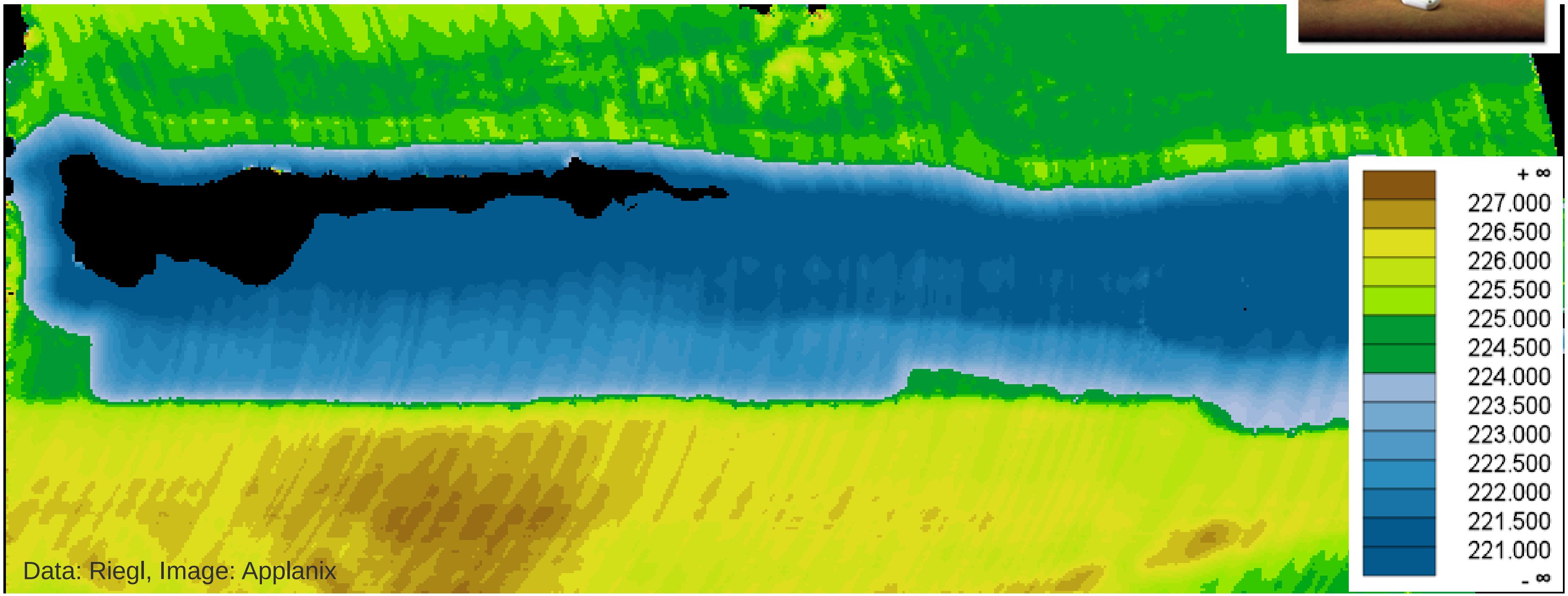


- Record shape of returning waveform
- Analyse waveform + classify individual echoes

Acquiring data

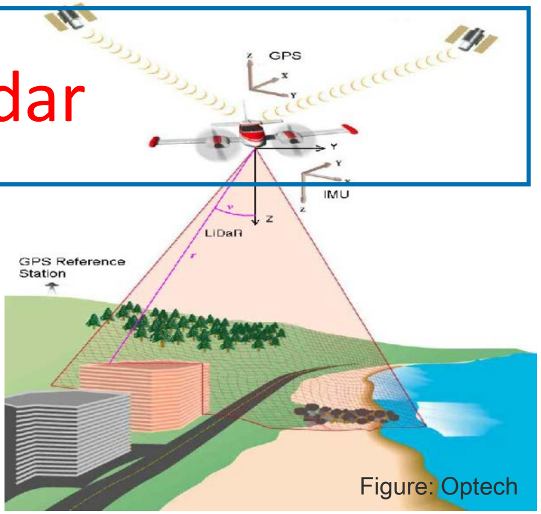
- Bathymetric lidar scanner on airborne platform records directions of rays (angles) and waveforms
- Acquire data strip wise
- Record positition of platform by satellite and intertial navigation
- Direct georeferencing of scanner measurements





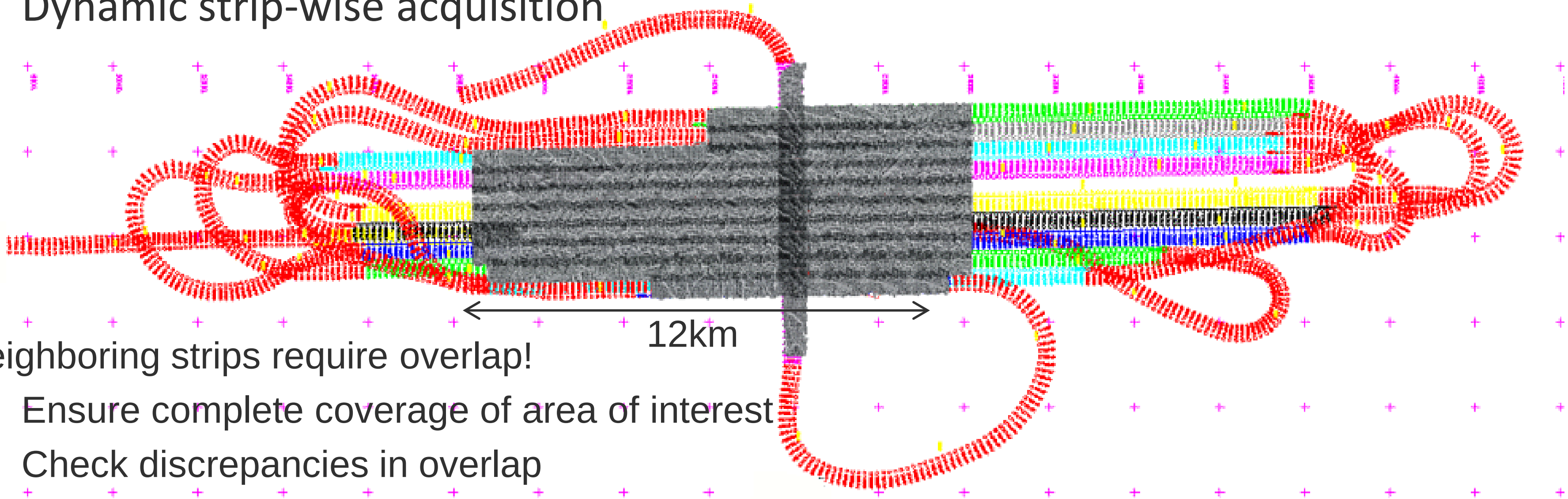
Data: Riegl, Image: Applanix

Data capturing in Airborne Lidar



- Position recorded by GPS/GNSS
  Accuracy in post-processing
  - Reference station (virtual or actual)
  - Integration of INS and GPS in Kalman filter

  ~5cm under good conditions in X, Y, worse (factor 1.5) in Z
- Orientation depends primarily on INS: accuracy around 0.01° (8cm@500m)
- Dynamic strip-wise acquisition



Neighboring strips require overlap!

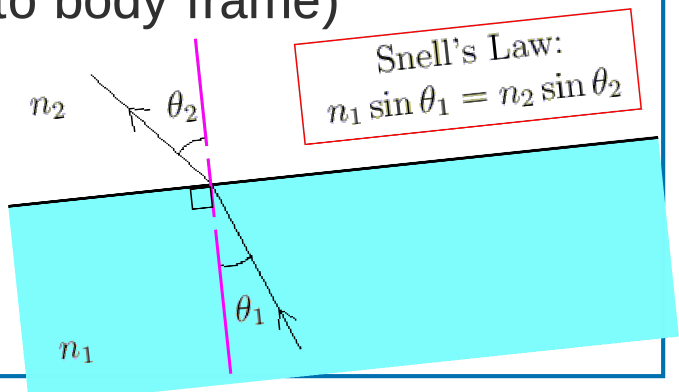
→ Ensure complete coverage of area of interest

→ Check discrepancies in overlap

Mathematical model

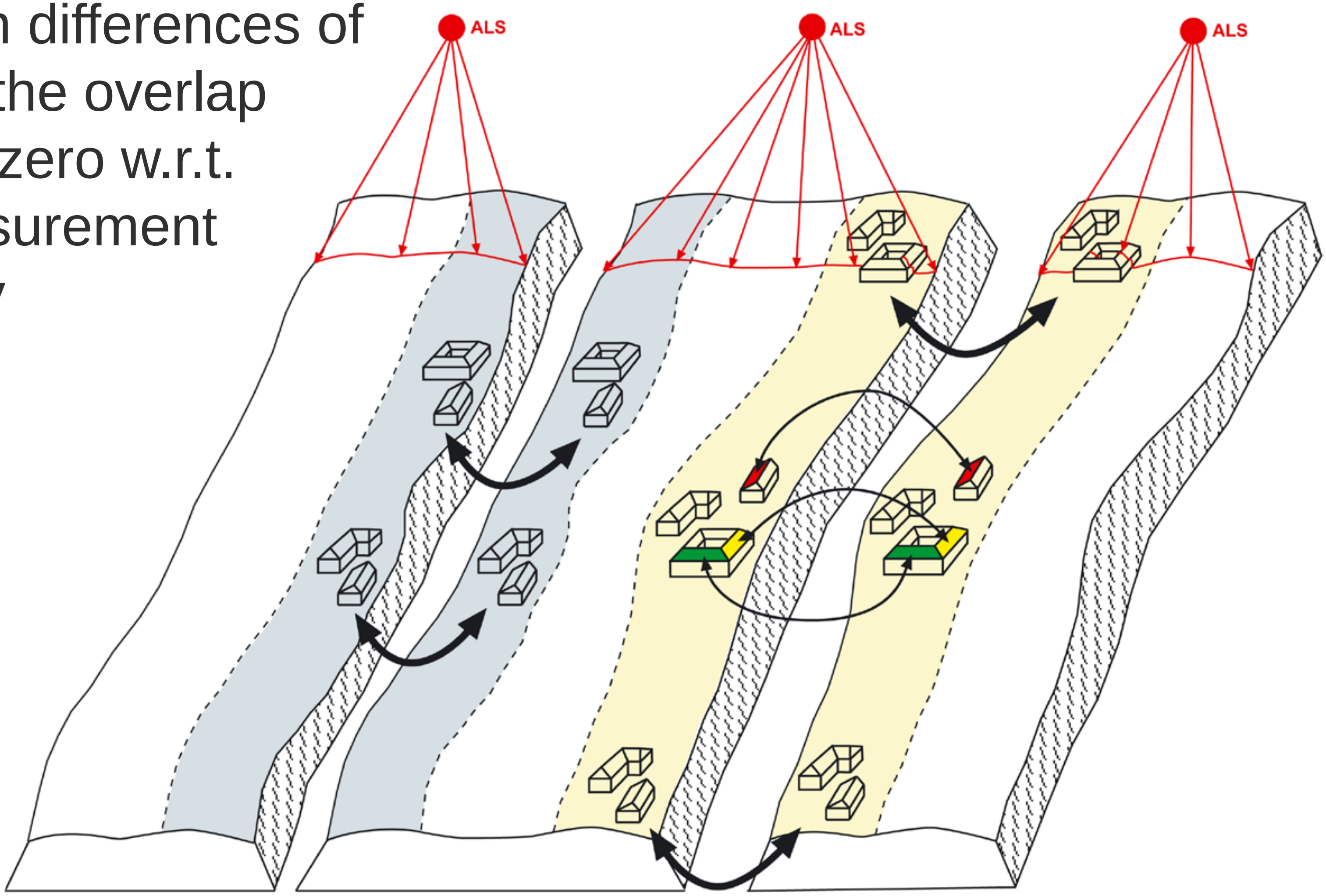
$$p = (x, y, z)^\top = p_0 + R_{\mathrm{b2g}} \left(t + R_{\mathrm{m}} R_\alpha \begin{pmatrix} 0 \\ 0 \\ -r \end{pmatrix} \right)$$

p	Ground point
$p_0 = (x_0, y_0, z_0)^\top$	GPS-Antenna: Phase center
R_{b2g}	Rotation from “sensor body frame” into global system
$t = (t_x, t_y, t_z)^\top$	Offset vector (GPS to body frame)
R_{m}	Mounting bias (IMU to body frame)
R_α	Scan angle α
r	Range

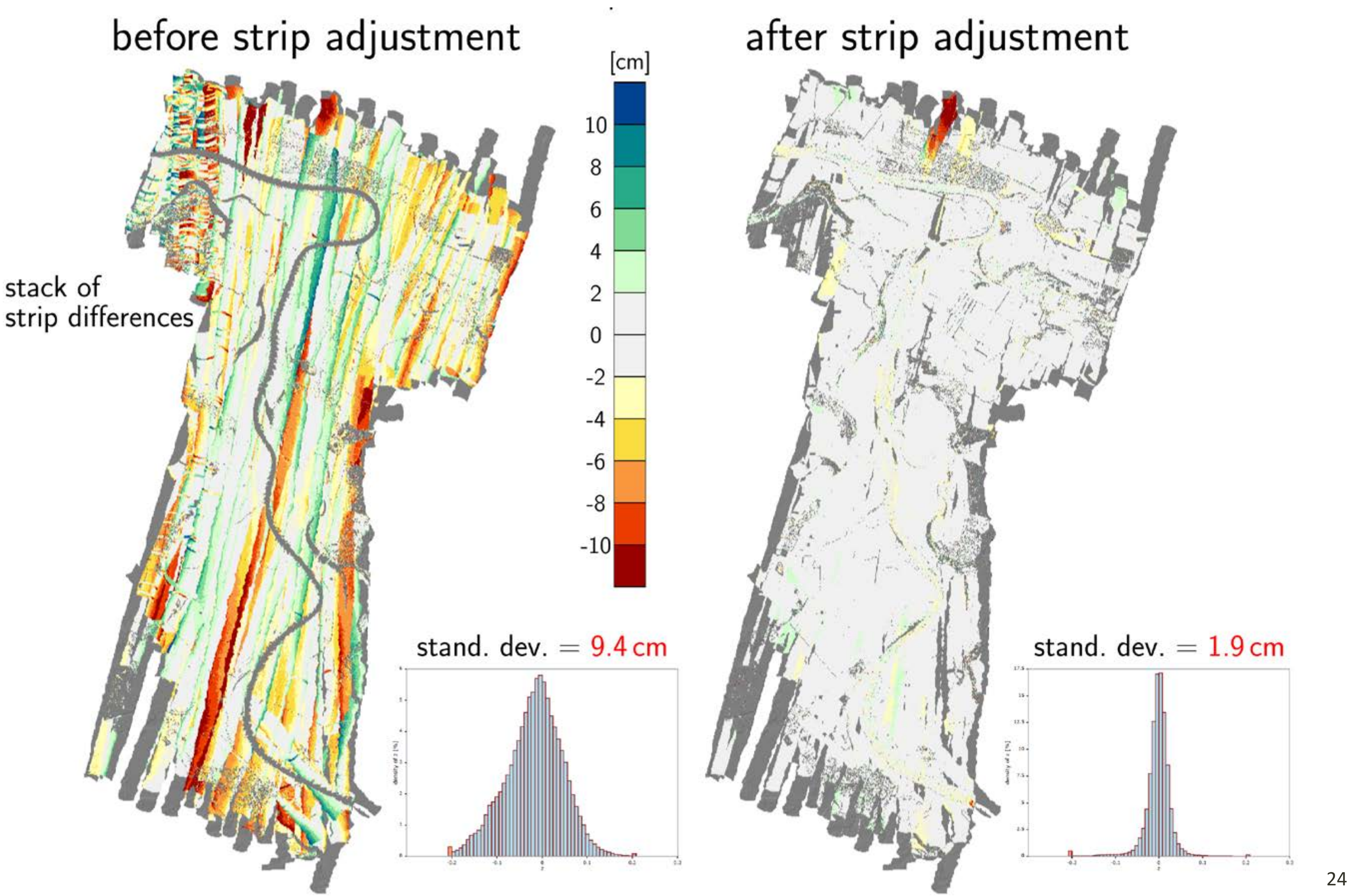


Strip differences for QC

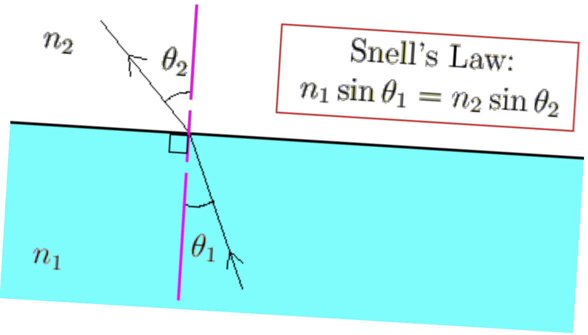
Elevation differences of strips in the overlap must be zero w.r.t. the measurement accuracy



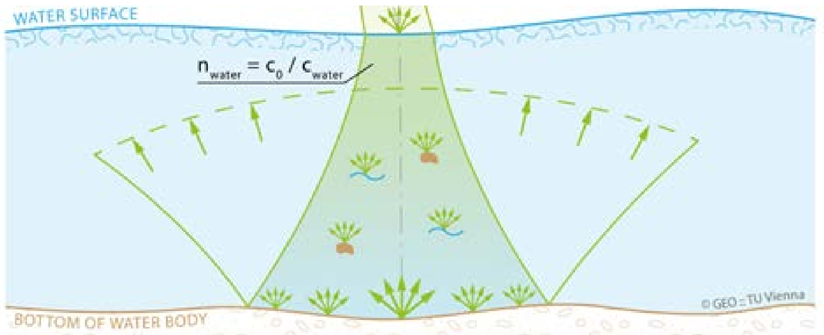
Strip differences and QC

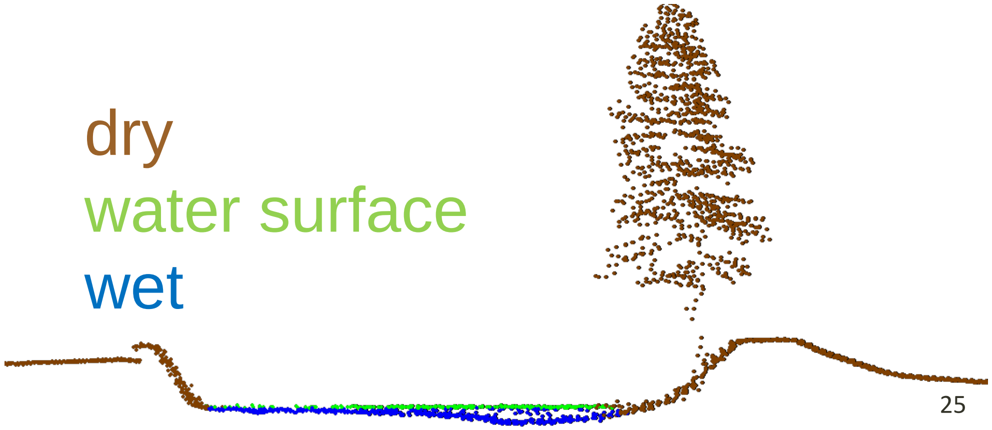


Processing ALB point clouds



1. Direct georeferencing
2. (refined georeferencing)
3. Determination of water area
4. Application of refraction correction
   requires water surface elevation and normal vector
5. Classification of each point/echo into
   - Ground return (wet)
   - Ground return (dry)
   - Water surface return
   - Water column return
   - Land vegetation retrun
   - Buildings, infra-structures, etc.





Geschichtliche Entwicklung

- Mitte 1960'er: Finden von **U-Booten** (speziell auch in Schweden)
- Frühe 1970'er: **Erste Generation** Airborne Lidar Systeme (US Navy, NASA, Canada, Australia)
- Ende 1970'er: **Zweite Generatio**n NASA Airborne Oceanographic Lidar (**AOL**) für **Hydrographie** (weitere Systems in Kanada, UdSSR, Australien, China)
- 1980'er: **Übergang von experimentellen zu operationellen Instrumenten**
  - **Larsen-500** weltweit erster operationelles ALH (Kanada)
  - **LADS** (Royal Australian Navy)
  - Weitere Systeme: **HALS** (US navy), **FLASH** (Sweden), **SHOALS** (USACE)
- 1990'er: **Operationelle Systeme**
  - **SHOALS** (US/Canada)
  - **LADS** (Australia)
  - **HawkEye** (Sweden)
- 2000'er: Kartierung von (flachen) Inland-Gewässern, **Riegl, AHAB, Optech**

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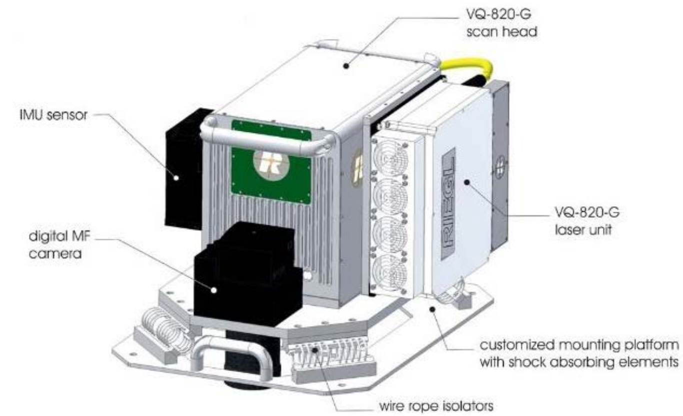
Topo-bathymetric Sensors

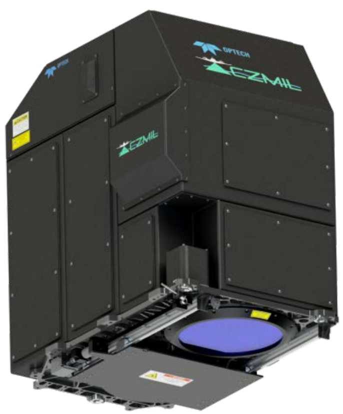
Optech Titan

Leica/AHAB Chiroptera II

Riegl LMS VQ-820-G



Optech CZMIL



Leica/AHAB HawkEye III

Riegl LMS VQ 880-G