LIDAR

Exploiting the Versatility of a measurement principle in Photogrammetry

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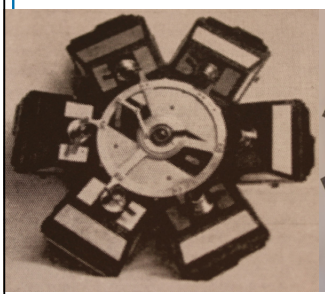
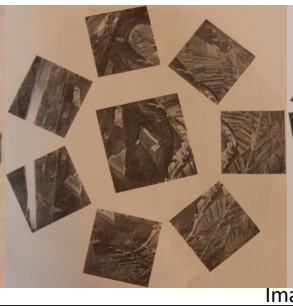
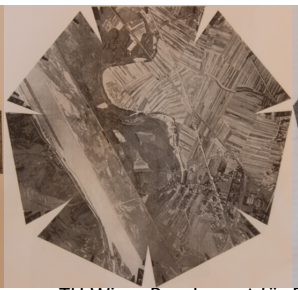
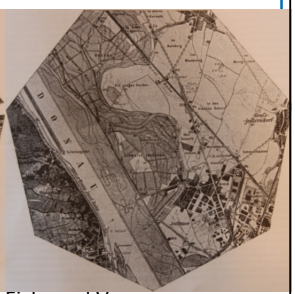
Photogrammetry and cameras

- TU Wien, 200th anniversary
  November 6, 1815: k. k. polytechnisches Institut in Wien



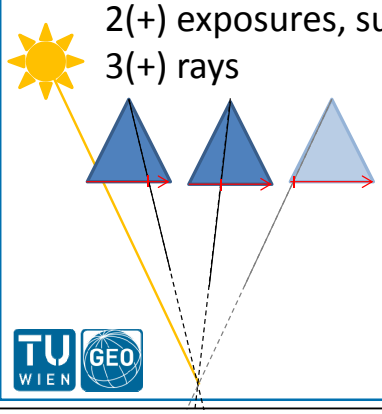
- Theodor Scheimpflug, 1865-1911: 150th anniversary

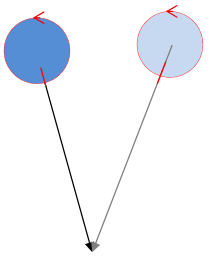
Images: TU Wien, Bundesamt für Eich- und Vermessungswesen

Cameras and Laser Scanners

- Measurement of angles/directions
- Measurements in focal plane simultaneous
- 3D point reconstruction: 2(+) exposures, sun light = 3(+) rays



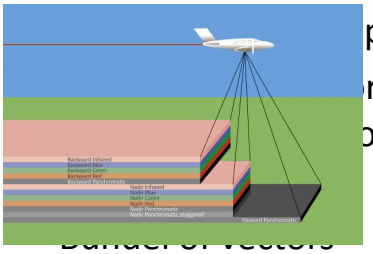
- Measurement of angles/directions and range
- Sequential measurements
- 3D point reconstruction: 1(+) scan = 1(+) vector



Cameras and Laser Scanners

Other differences and convergence

- Size of aperture & resolution limit
- Sampling (under-, contiguous, over-sampling)
- Push broom cameras and flash lidar sensors



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- Area-wise sampling of

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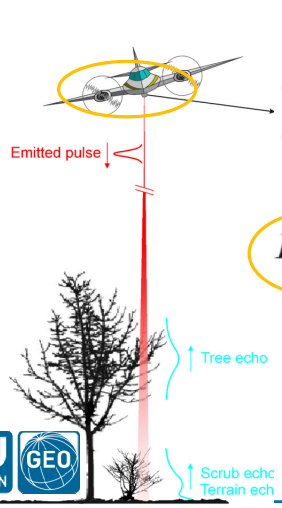
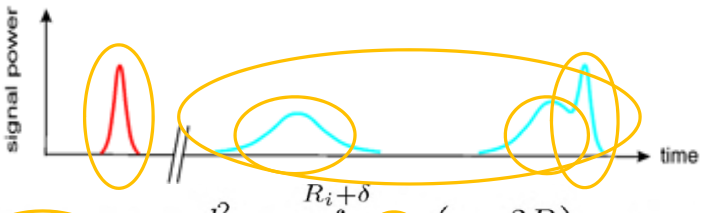
Laser scanning is the polar photogrammetry ...

Images: Leica, PMD

... beyond rays vs. vectors

- Laser Range Finder → Light Detection and Ranging
- Lidar principle
  emission of a laser pulse and
  time resolved detection and analysis of its echo
  to infer properties of the reflecting objects (targets, reflectors, ...)





$$P_{D,i}(t) \approx \frac{d_D^2}{4\pi R_i^4 \beta_E^2} \int_{R_i-\delta}^{R_i+\delta} P_E\left(t - \frac{2R}{v_g}\right) \sigma_i(R) dR$$

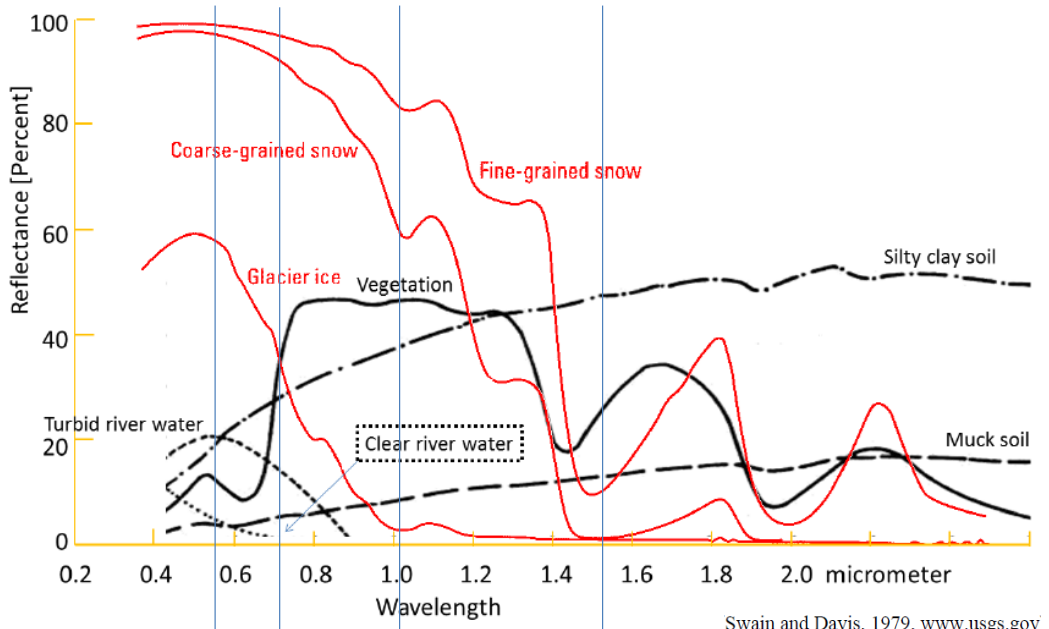
Exp[illegible] Waveform

The Versatility of Lidar

- Wavelength of the emitted pulse
  Lidar bathymetry
  Case study on river dynamic morphology
- Full waveform recording
  Waveform analysis and radiometric calibration
  Case study on bi-temporal classification of grass-land
- Single photon counting
  Towards Lidar from space
- Platform developments
  Case study on measurement of vegetation parameters

- Additionally exploited in (e.g.) atmospheric remote sensing:
  frequency shift of the backscatter, polarization, ...

Reflectance and LiDAR wavelength



532nm bathymetric | 690nm terrestrial | 1064nm airborne +terrestrial | 1550nm topographic

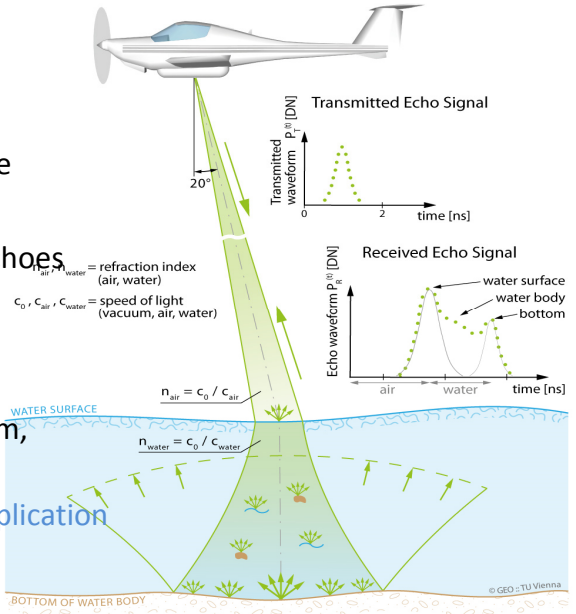
Bathymetric Lidar

Challenges to Understanding

- Backscatter from water surface , relation of water properties, effect on echo time lag and shape

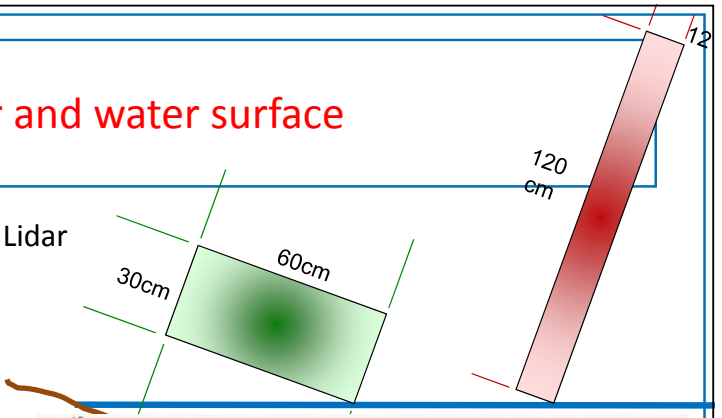
Challenges in Processing

- Identification of water surface echoes
- Modeling of water surface for application of Snell's law
- Classification of echoes Foreland, vegetation, river bottom, water column reflectors, etc.
- Suitable modeling for specific application

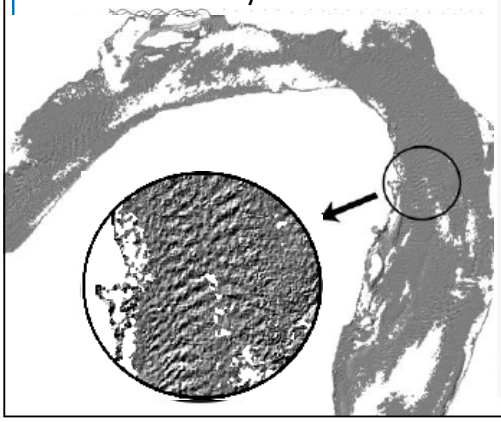


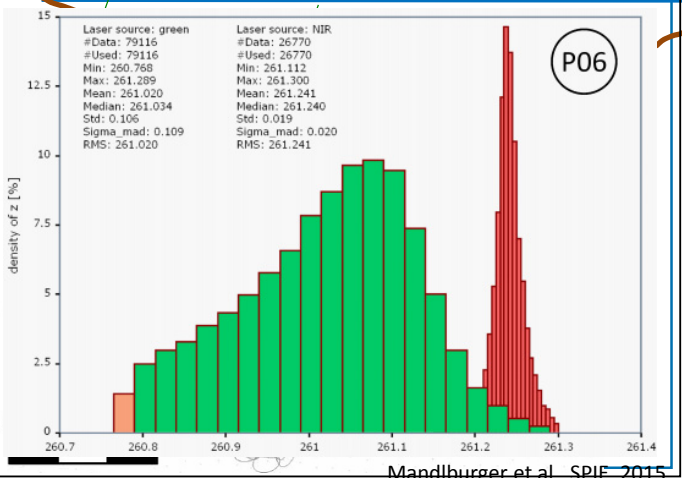
Lidar and water surface

- Difference to topographic Lidar
  shape of emitted pulse
  typical example



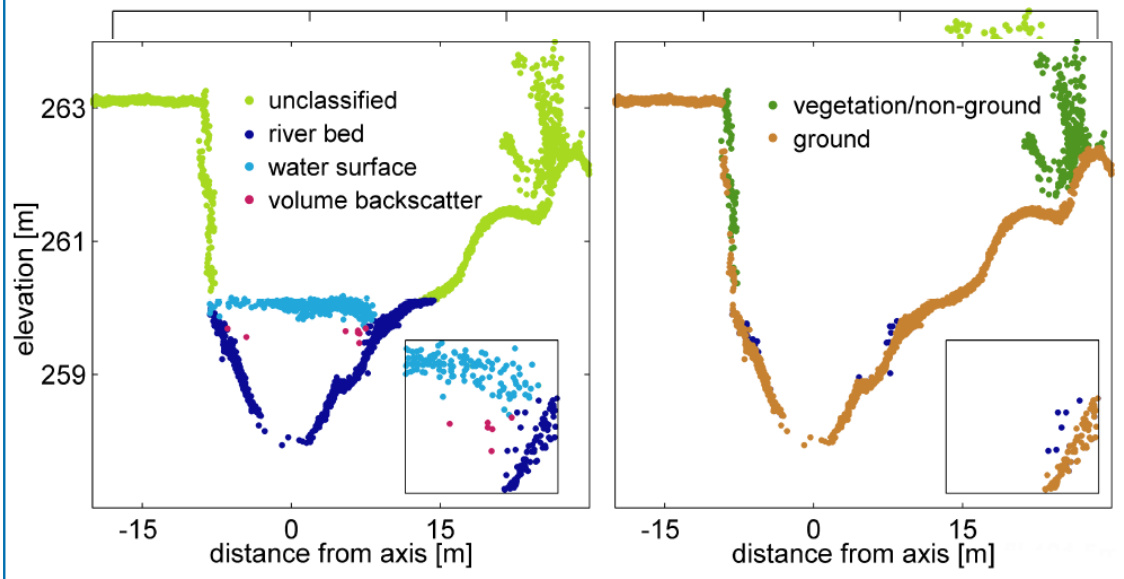
- Case study on river bank



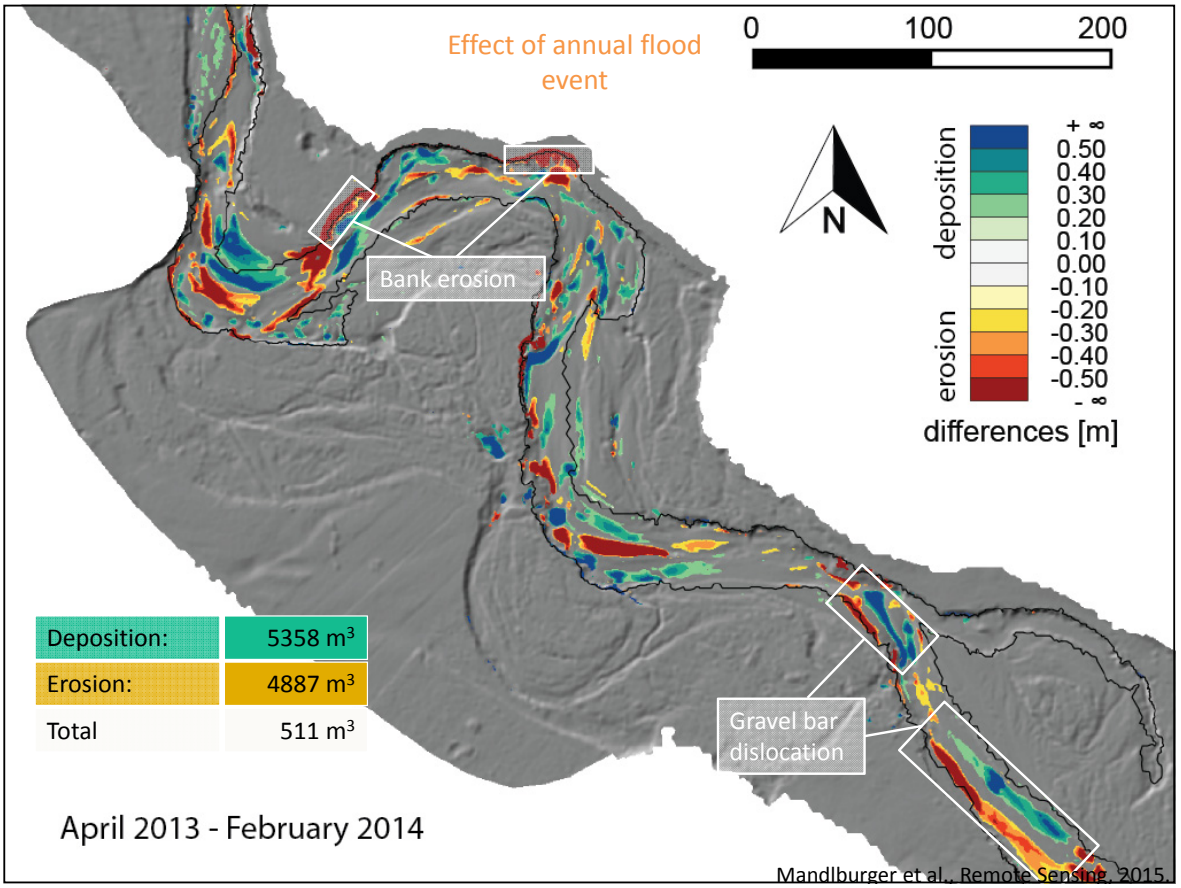


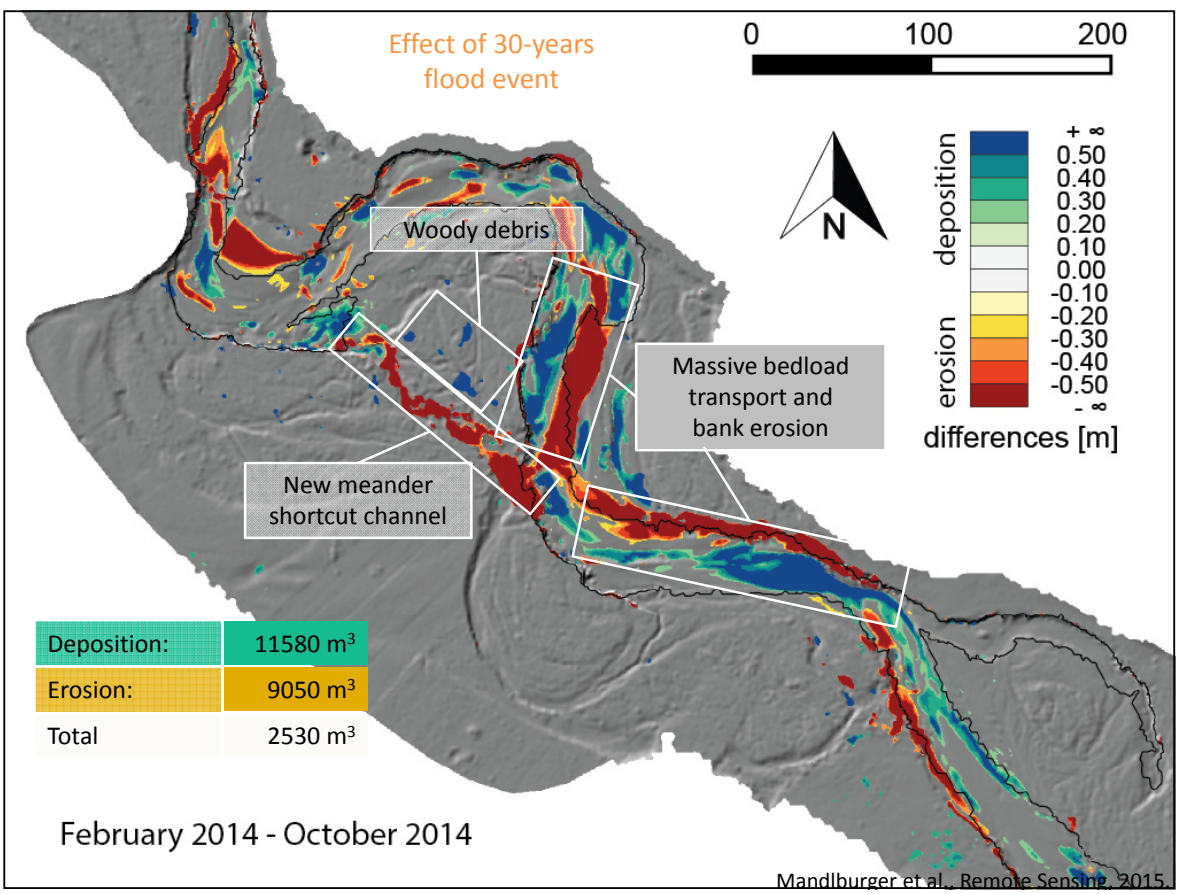
Mandlburger et al., SPIE, 2015

Processing and modeling of bathymetric point clouds

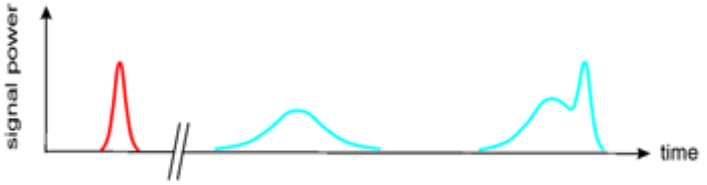


Mandlburger et al., Remote Sensing, 2015


Effect of annual flood event
0
100
200
N
deposition
erosion
+ ∞
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
- ∞
differences [m]
Bank erosion
Gravel bar dislocation
Deposition: 5358 m³
Erosion: 4887 m³
Total 511 m³
April 2013 - February 2014
Mandlburger et al., Remote Sensing, 2015.


Effect of 30-years flood event
0
100
200
N
deposition
erosion
+ ∞
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
- ∞
differences [m]
Woody debris
Massive bedload transport and bank erosion
New meander shortcut channel
Deposition: 11580 m³
Erosion: 9050 m³
Total 2530 m³
February 2014 - October 2014
Mandlburger et al., Remote Sensing, 2015.

Waveform analysis and exploitation



$$P_{D,i}(t) \approx \frac{d_D^2}{4\pi R_i^4 \beta_E^2} \int_{R_i-\delta}^{R_i+\delta} P_E\left(t - \frac{2R}{v_g}\right) \sigma_i(R) dR$$

- Amplitude of emitted pulse and backscattered echoes are sampled
  Δt = 0.5 ns – 2 ns
- Waveform recording allows radiometric calibration
  Measurement at sensor $\rightarrow$ reflection properties of objects
- Established (e.g.) to strongly support differentiation between low vegetation and ground/solid objects (terrain in forest, deadwood, ...)

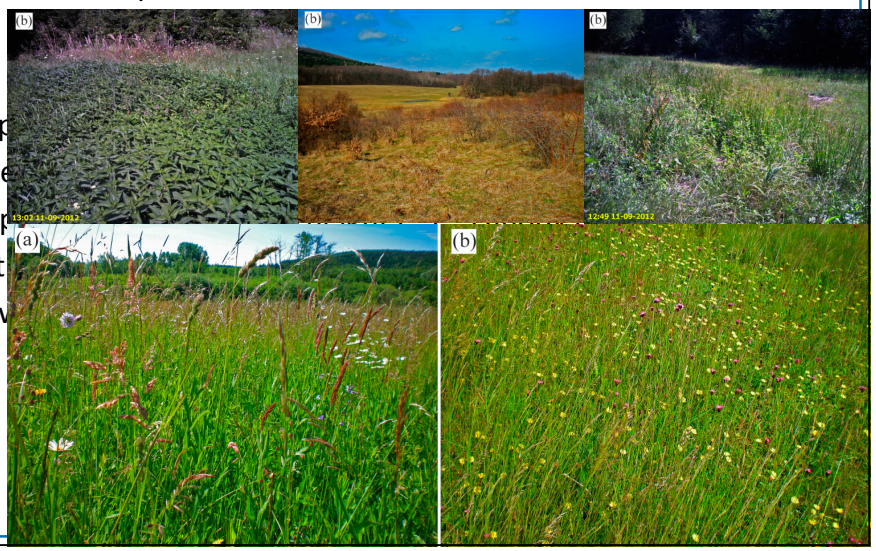
Waveform: exploitation of radiometric and geometric measurements

Study on the classification of grass land

- 10 classes, including fringe, abandoned, meadow-like, lowland hay meadow, dry meadow

Exploitation of

- waveform shap
- radiometric me
- geometric prop
- geometric text
- difference betw



Waveform: exploitation of radiometric and geometric measurements

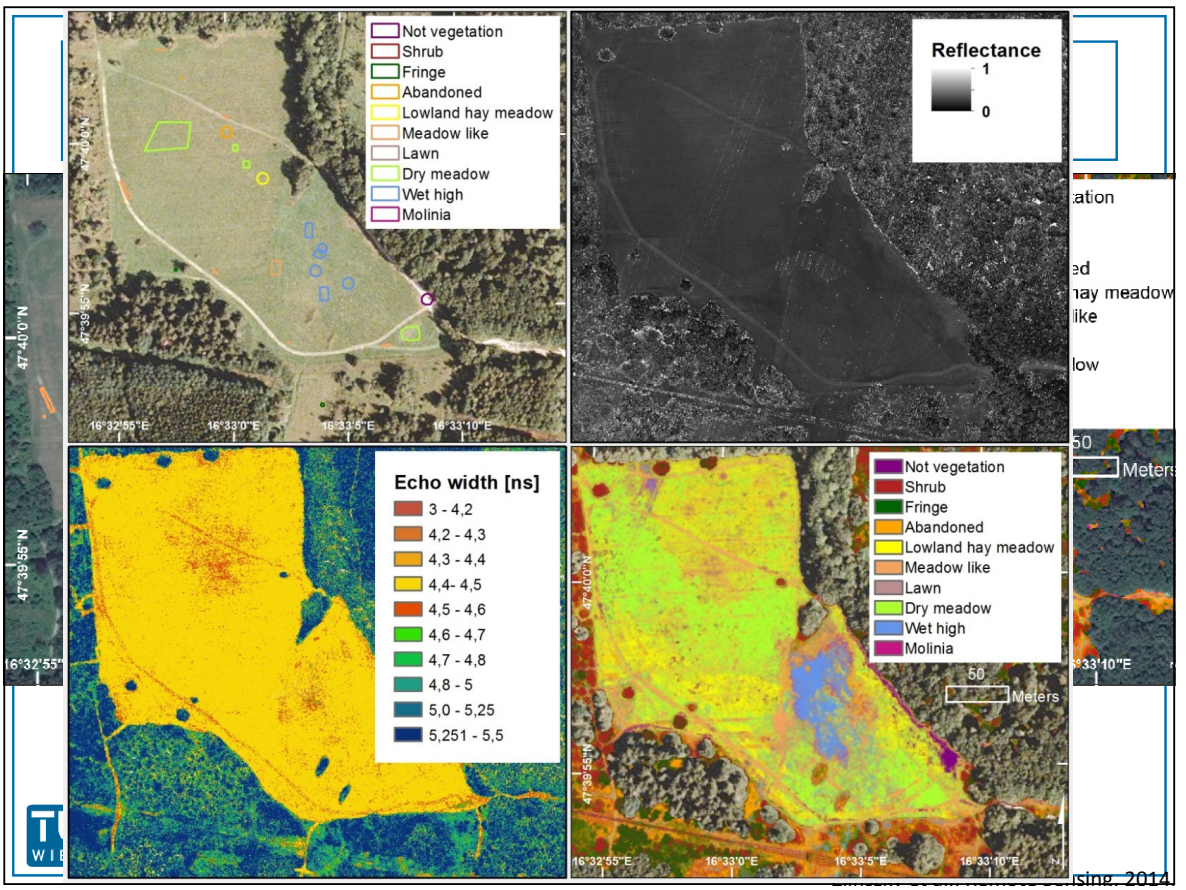
Classification

- Decision trees
- Machine learning based on ground reference data
- Determine class and probability (on pixel basis)

Most imortant bands according to classifier

- Leaf off echo width, difference between leaf on/leaf off reflectance, leaf off nDSM height

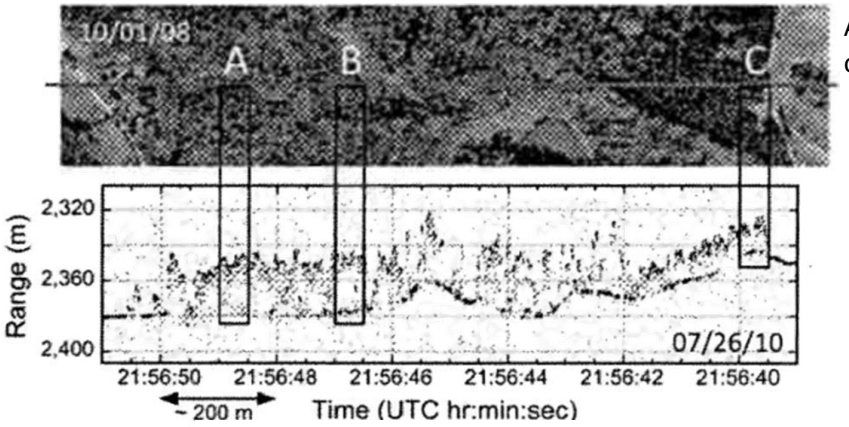
Zlinszky et al., Remote Sensing, 2014



Detection: Single Photon Counting

Large „flying“ heights, lidar on space-borne platforms

- Strong signals required for weak return signals
- Therefore, single photon detection

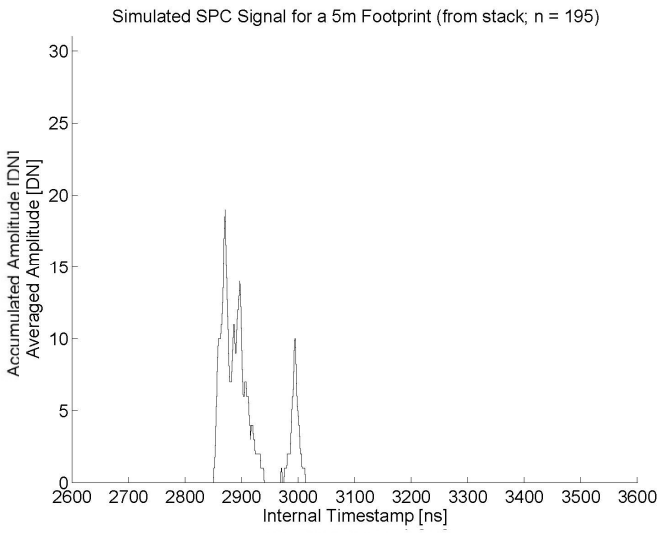


Airborne demonstration of SPC measurements

Harding et al., 2011. Polarimetric, two-color, photon-counting laser altimeter measurements of forest canopy structure. International Symposium on Lidar and Radar Mapping 2011: Technologies and Applications, 8286

Single Photon Counting / Simulation

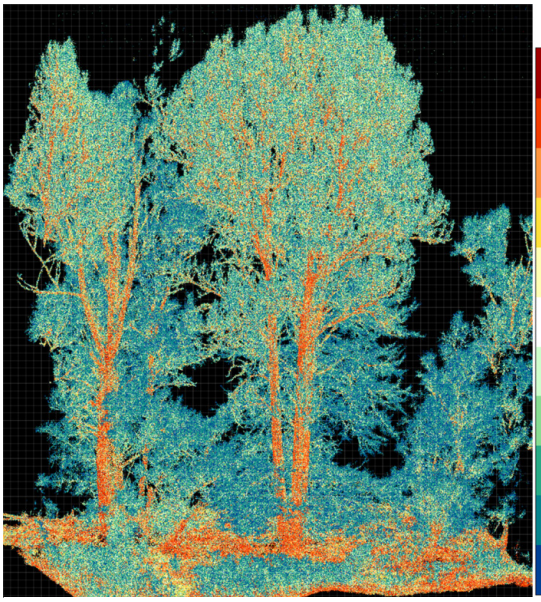
Simulated return of 5m footprint, SPC

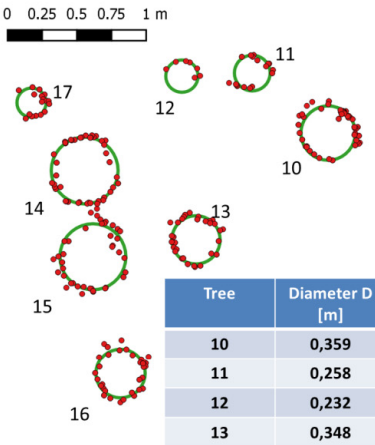


UAV as platform for Lidar

Image: Riegl

Modeling of tree diameter from UAV Lidar





Tree	Diameter D [m]	ΔD [m]
10	0,359	0,046
11	0,258	0,010
12	0,232	0,030
13	0,348	0,014
14	0,482	0,046
15	0,476	-0,004
16	0,356	0,034
17	0,210	0,064

Relative reflectance

Mandlburger et al., GIM, 2015

Data provided by Riegl

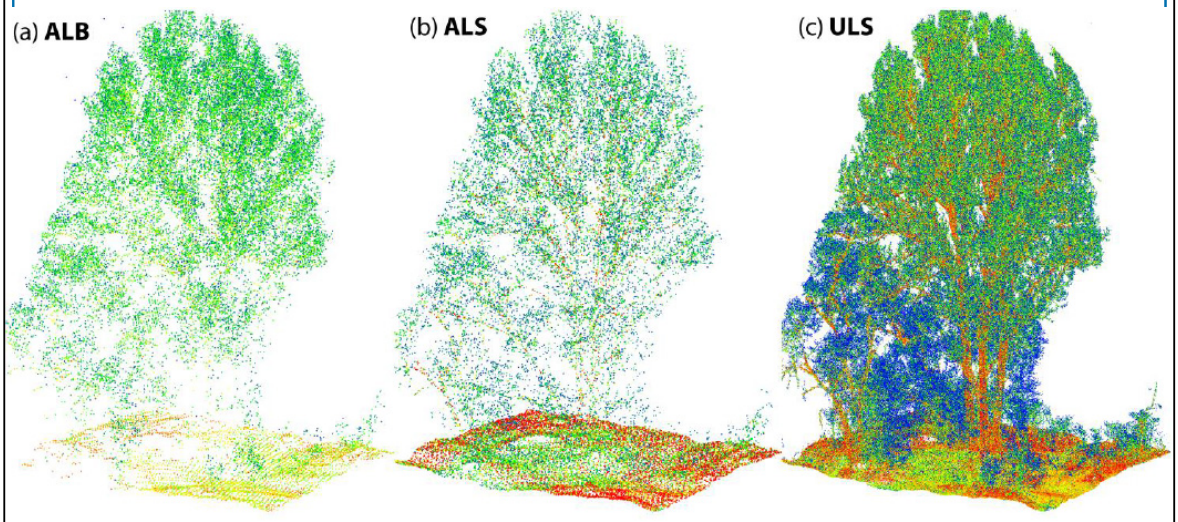
Take home message

- Lidar provides more than (multiple) ranges along the direction of imaging rays
- Additional observations (echo width, reflectance, ...)
  for land cover classification / object detection
- Wavelength choice adapted to studied phenomenon or process
  e.g. water
  will become importance for classification (multi wavelength case)
- SPC (and also beam deflection) studied by space agencies for global lidar coverage
- Correct interpretation of point clouds requires knowledge about footprint size
- Very high resolution dynamic lidar point cloud acquisition will require refined models of strip adjustment

Literature

- Mandlburger et al., SPIE, 2015:
  Mandlburger, Pfennigbauer, Riegl, Haring, Wieser, Glira, Winiwarter, 2015: Complementing airborne laser bathymetry with UAV-based lidar for capturing alluvial landscapes. SPIE (forthcoming)
- Mandlburger et al., Remote Sensing, 2015:
  Mandlburger, Hauer, Wieser, Pfeifer, 2015: Topo-Bathymetric LiDAR for Monitoring River Morphodynamics and Instream Habitats—A Case Study at the Pielach River. Remote Sensing, 2015, 7.
- Zlinszky et al., Remote Sensing, 2014:
  Categorizing Grassland Vegetation with Full-Waveform Airborne Laser Scanning: A Feasibility Study for Detecting Natura 2000 Habitat Types. Remote Sensing, 2014, 6.
- Mandlburger, Glira, Pfeifer, 2015:
  UAS-borne Lidar for Mapping Complex Terrain and Vegetation Structure. GIM International, 29.

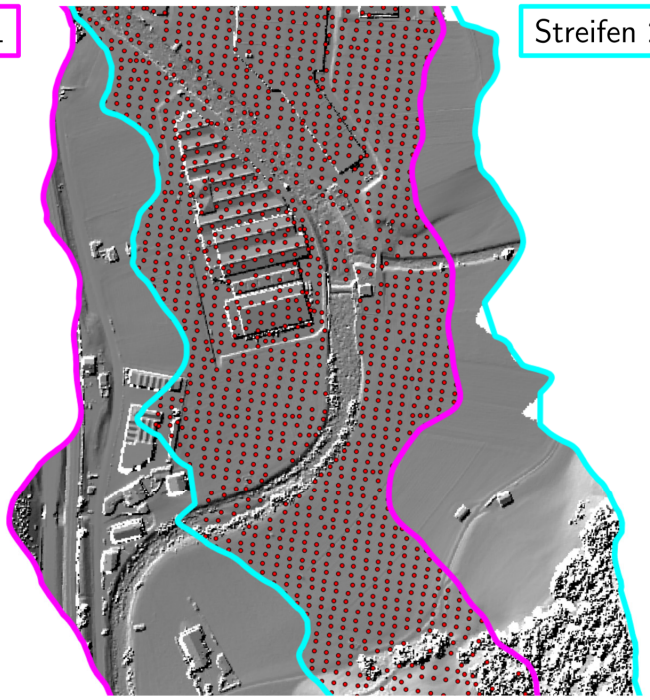
Comparison of point clouds



Mandlburger et al., SPIE, 2015.

Streifen 1

Streifen 2

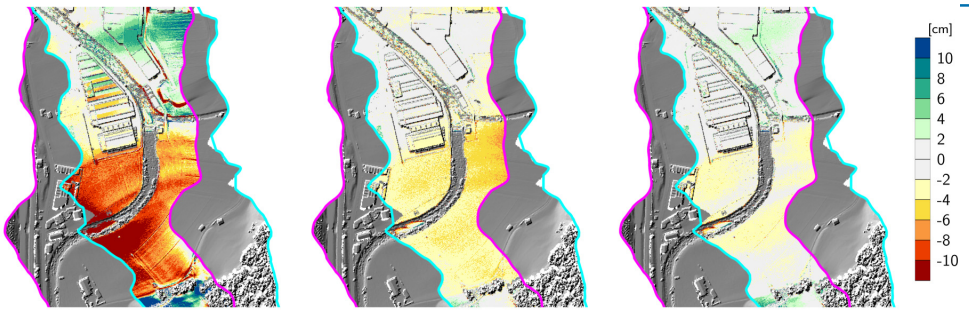


Rot = Korrespondenzen

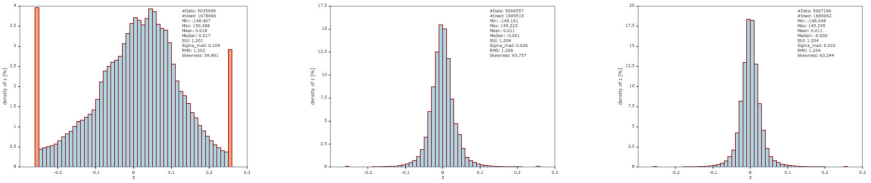
1 keine zeitabhängige Korrektur der Trajektorie

2 zeitabhängige Korrektur mit $\Delta t = 60\,\mathrm{s}$

3 zeitabhängige Korrektur mit $\Delta t = 30\,\mathrm{s}$



Histogramm mask. Streifendiff.:



median = 1.7 cm
sigma_mad = 10.9 cm

median = -0.1 cm
sigma_mad = 2.6 cm

median = 0.0 cm
sigma_mad = 2.2 cm

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Bedingungen: C1-,C2-,C3-Stetigkeit, 1. und 2. Abl. = 0 zu Start- und Endzeit

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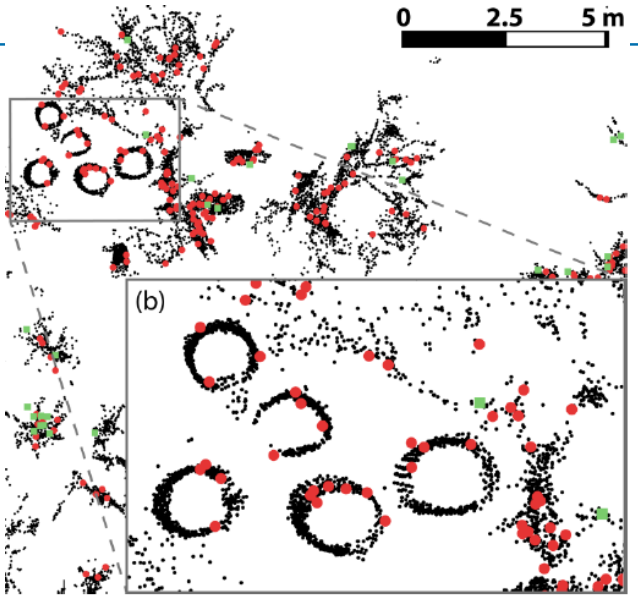
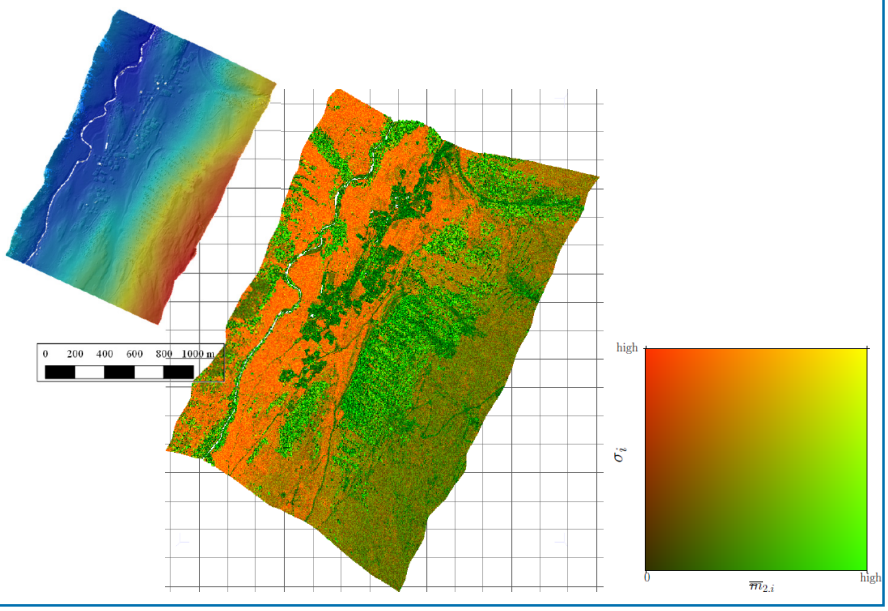
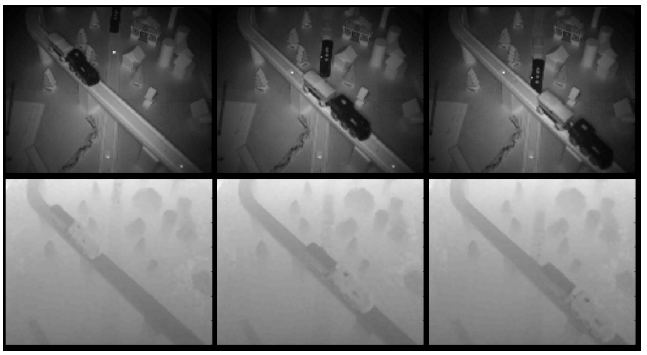
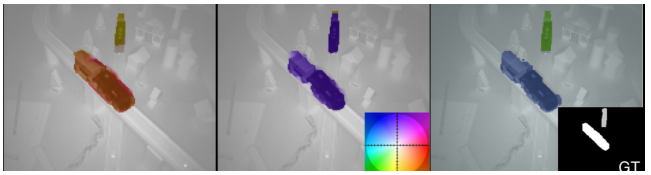


FWF-Signale rückfalten zur Objektcharakterisierung

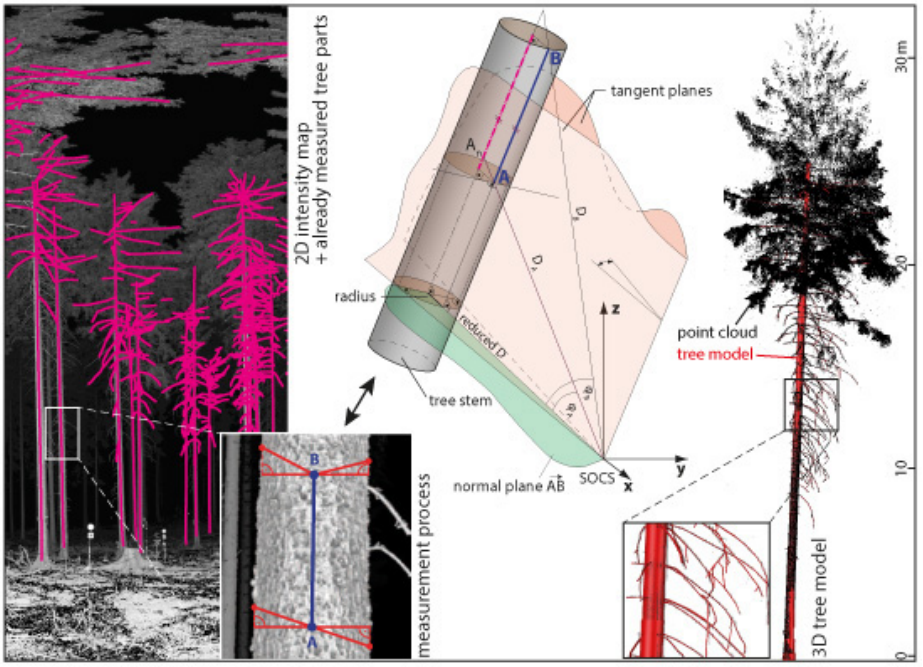


Pixel, Bewegungsrichtung, Trajektorie, Segmente in Raum und Zeit



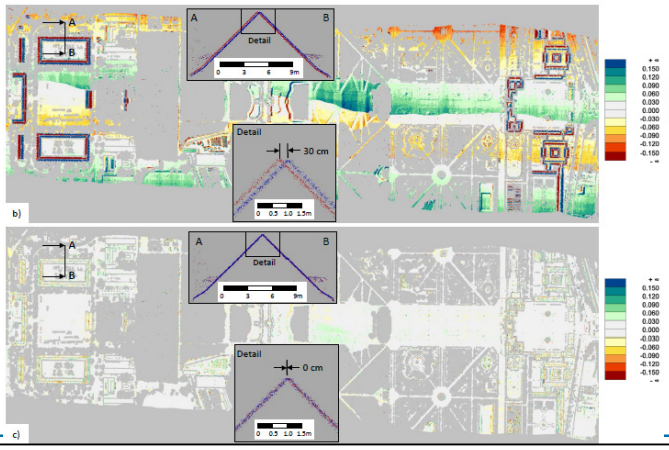


Baummodelle aus TLS Punktwolken im Wald (für RT)



Punktwolken: Review (paper) und Prozessierung (software)

(a) LiDAR data (b) Dense matching



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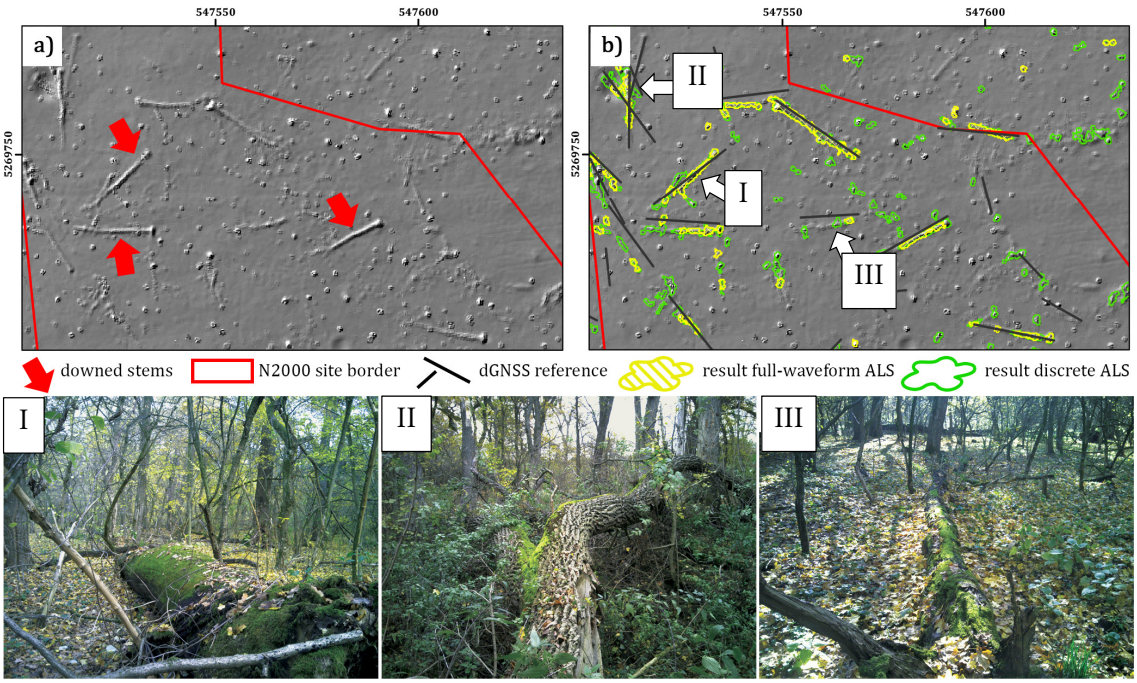
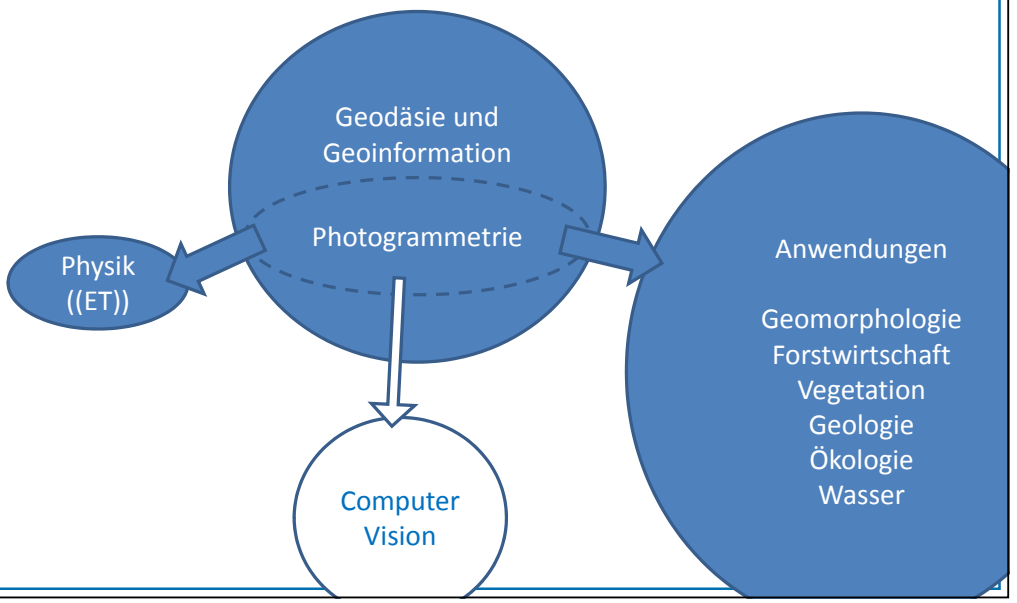
Liegendes Totholz aus FWF Airborne Laserscanning



Forschung – Konzept



Fringe (e.g. Urtica), abandoned (e.g. woody enchroachment), meadow like (e.g. timber storage and traffic), lowland hay meadow, dry meadow