ALS Sensor Development
Chances and Challanges for DTM Generation and Adminstration

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Spatial Data from Laser Scanning
and Remote Sensing

Outline

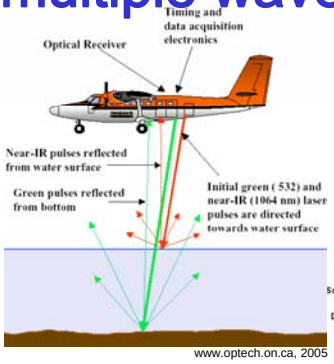
- Sensor developments
  – new data streams
- Raw data processing
  – extraction of information/data
- Adminstration of enriched data
  – setting a standard
- Exploitation of enriched data
  – improving automation, reliability, precision

Development in ALS Technology

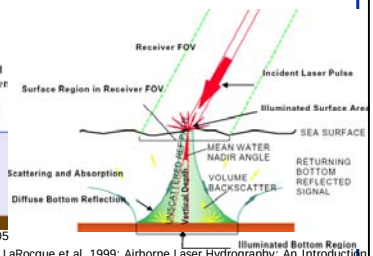
- 1996/97 – 1pt/10m^2 – one echo / shot – Vienna Woods, first project@I.P.F.
- now:
  - ~250kHz PRR (for oscillating mirrors: PRR = measurement rate)
  - Recording of first and last echo and possibly intermediate echoes
  - Recording of the intensity of the backscattered echoes
  - Flying heights up to ~6km
  - Ranging precision: ±2cm (vendor specification, 1σ, best conditions, only ranging!)
  - GPS frequency: 10Hz, IMU frequency: 2kHz
  - Multiple wavelengths …
  - Multiple emitted laser shots concurrently in the air …
  - Multiple laser scanners on one platform: downwards / sidewards …
  - Forward, nadir, and backward looking in one laser scanner …
  - Full waveform recording …
  - Integration with other sensors: moderate

ALS Sensor development – multiple wavelengths

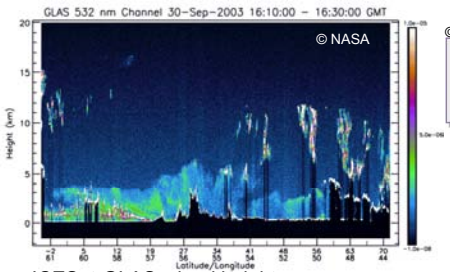
- LiDAR bathymetry
  - Green: better transmission in water
  - nIR: recording of topography and water top surface
- Satellite missions
  - nIR: ranging
  - Green: cloud studies
  - UV: atmospheric studies stronger molecular and aerosol scattering
- Terrestrial developments
  - 4 color prototype (e.g.), object studies, e.g. humidity, ranging possible (Wehr et al., 2007. Optical 3D Measurement Techniques, Zurich).



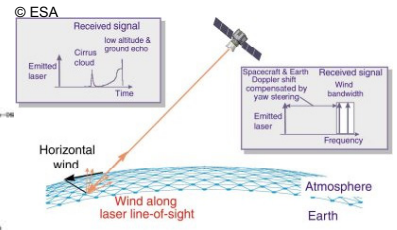
www.optech.on.ca, 2005



LaRocque et al, 1999: Airborne Laser Hydrography: An Introduction ROPME/PERSGA/IHB Workshop on Hydrographic Activities in the ROPME Sea Area and Red Sea, Kuwait City.



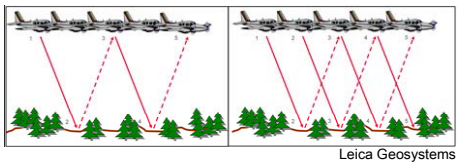
ICESat-GLAS: cloud heights



Aeolus-Aladin: wind speed (principle)

ALS sensor developments

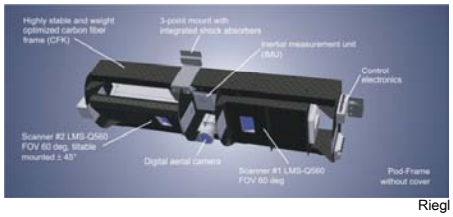
- Multiple pulse in air



Leica Geosystems

- Multiple laser scanners

Diamond



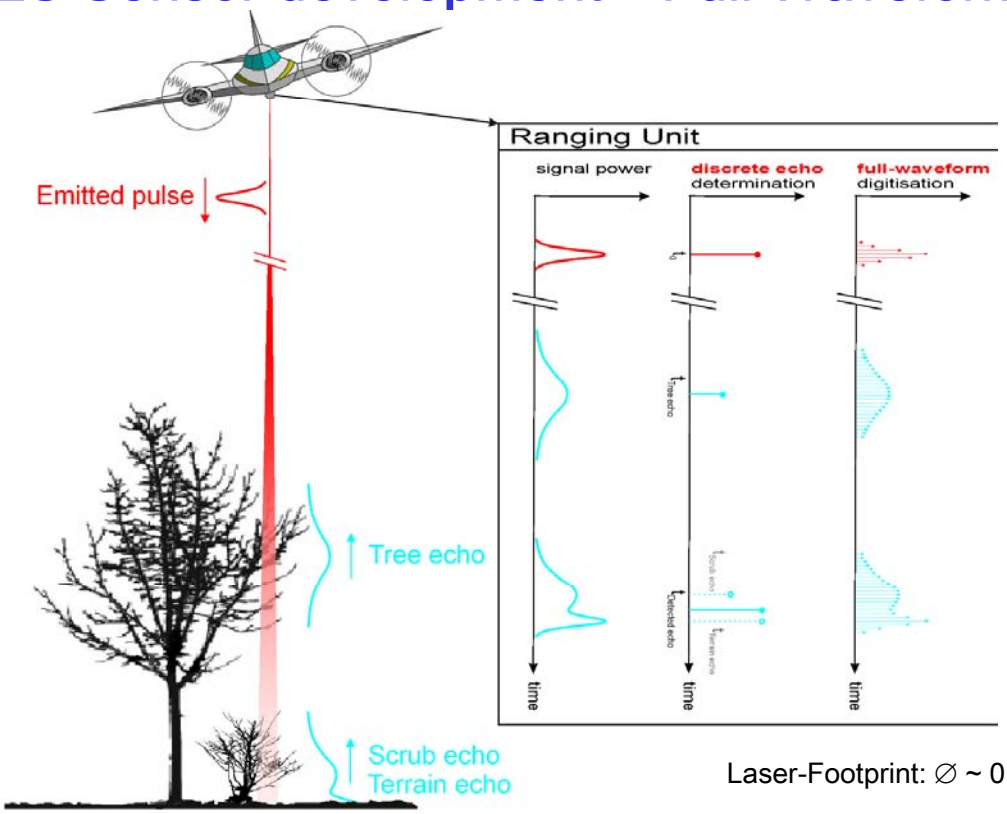
Riegl

- Multiple directions from one scanner
  multi-faceted mirror with different inclination angles

Laser Look Angles	Nadir (50% of pulses) Forward looking (7 degrees) (25% of pulses) Rear looking (7 degrees) (25% of pulses)

FLI-MAP, Fugro-Inpark

ALS Sensor development – Full Waveform



Laser-Footprint: ∅ ~ 0.2 – 3m

Capturing the **entire** echo with a digitization intervall of ~1 ns

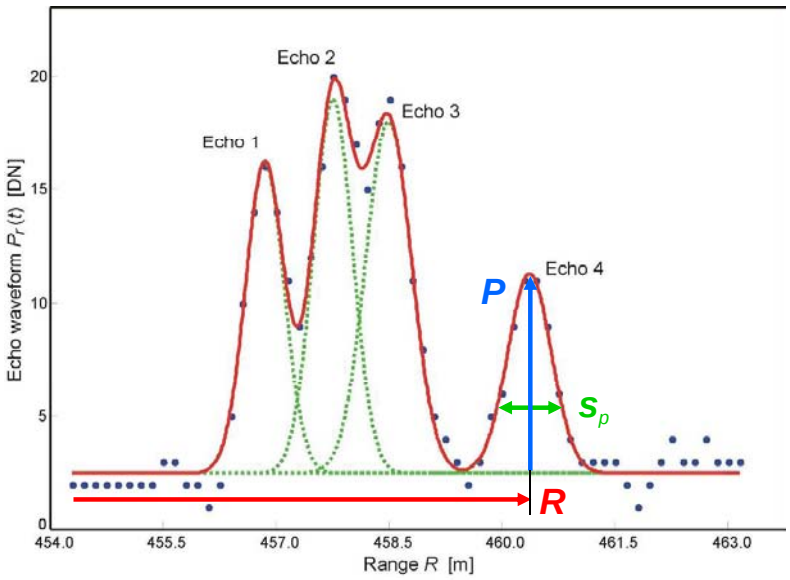
ALS Sensor development – Full Waveform

- Gaussian decomposition

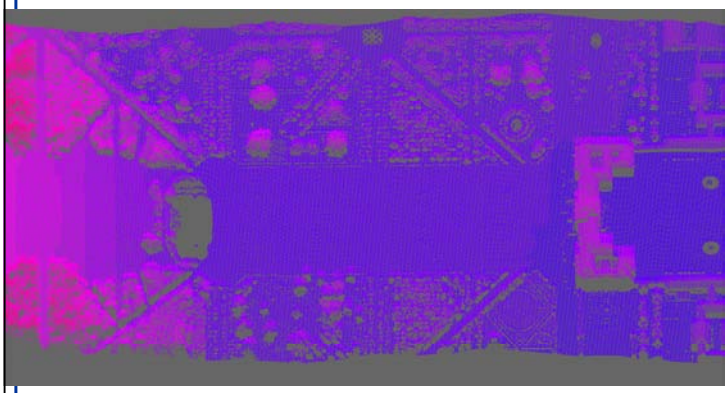
  Detection of echoes by Fitting of Gaussians

  →Information per echo:

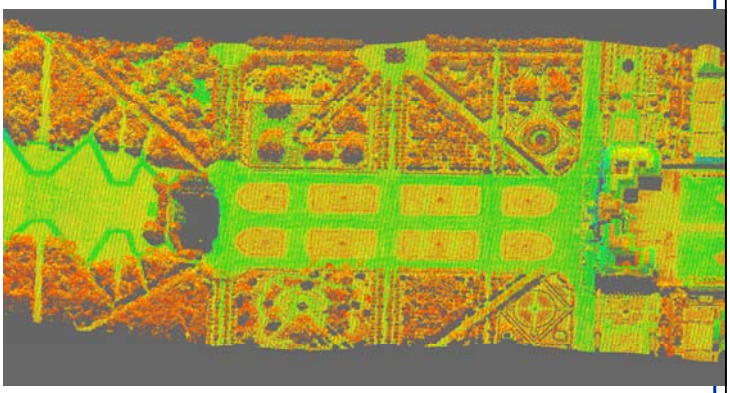
  - Amplitude (Intensity) *P* [DN]
  - Range *R* [m]
  - Echo width s_p [ns]



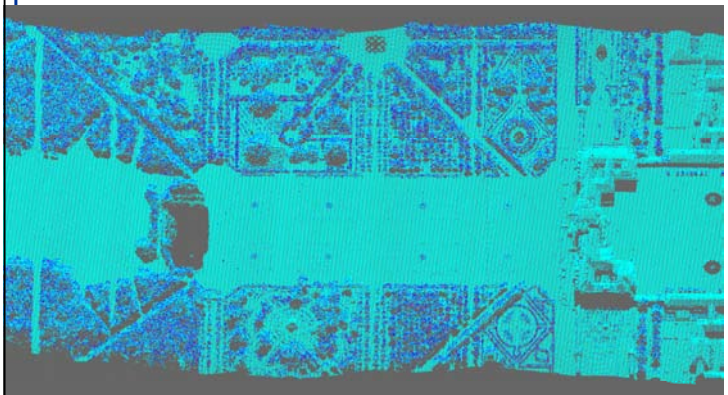
FWF Data



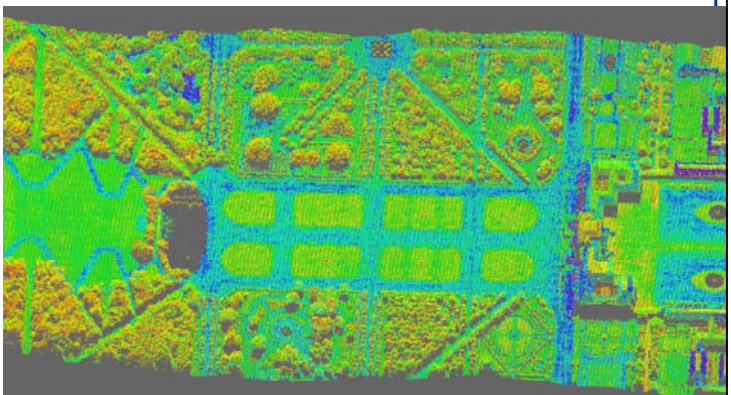
Range



Amplitude



Echo width



Cross-section

Best practice processing of ALS data with commercially available high-end sensors

- Aerial data acquisition → binary, vendor specific data
- FWF analysis → echo information: XYZ, range, echo number, echo width, amplitude, angles (not FWF) + cross section
- Strip adjustment with tie and control patches → update coordinates

  radiometric calibration → update amplitude, cross section
- Filtering / classification → class ID per point (including probability measures)
- DTM computation, building recontruction, …

Data Administration

- Current Status
  - Coordinates (point, multipoint, line, polygon, …)
  - Coding information (geometric type and semantic)
  - Metadata (owner, creator, accuracy, compilation date, …)
  - Missing: Additional point attributes
- Extended Administration Concept for Storage of LiDAR Data:
  - Storage of additional echo attributes (range, amplitude, echo width)
  - Storage of pulse emitting time for linkage with trajectory
  - Storage of return number of each echo enabling pulse-based or echo-based administration
  - Storage of cross section (object information without assumptions on the object)
  - Storage of class identifier

LAS 1.1, LAS 2.0

Table definition: Current status

```
IDOBJ         INTEGER      UNIQUE INDEX  NOT NULL  SYSNUM IDENTIFIER          ,
DATAFORMAT    CHAR(16)            INDEX  NOT NULL                             ,
AGGREGATE     CHAR(64)            INDEX  NOT NULL                             ,
COORDINATES   LINE|MULTIPOINT     INDEX  NOT NULL  PERIOD(3) RESOLUTION(2,2,2) ,
OBJECTNAME    CHAR(16)            INDEX  NOT NULL                             ,
OBJECTTYPE    CHAR(16)            INDEX  NOT NULL                             ,
FEATURECODE   CHAR(32)            INDEX       NULL                            ,
STATUS        CHAR(16)            INDEX       NULL                            ,
PROJECT       CHAR(32)            INDEX       NULL                            ,
MODEL         CHAR(32)            INDEX       NULL                            ,
XYACCURACY    NUMBER(12.2)        INDEX       NULL                            ,
ZACCURACY     NUMBER(12.2)        INDEX       NULL                            ,
CREATOR       CHAR(32)            INDEX       NULL                            ,
OWNER         CHAR(32)            INDEX       NULL  ARRAY                     ,
COMPILEMODE   CHAR(32)            INDEX       NULL                            ,
PROPERTIES    CHAR(32)            INDEX       NULL  ARRAY                     ,
COMPILEDATE   DATE                INDEX       NULL                            ,
COMPILETIME   TIME                INDEX       NULL                            ,
INSERTDATE    DATE                INDEX  NOT NULL                             ,
INSERTTIME    TIME                INDEX  NOT NULL                             ,
UPDATEDATE    DATE                INDEX       NULL                            ,
UPDATETIME    TIME                INDEX       NULL
```

Geometry

Coding information

Metadata

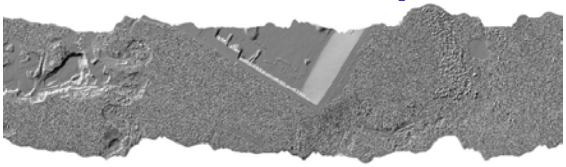
Table Definition for Full Wave Form LiDAR-Data

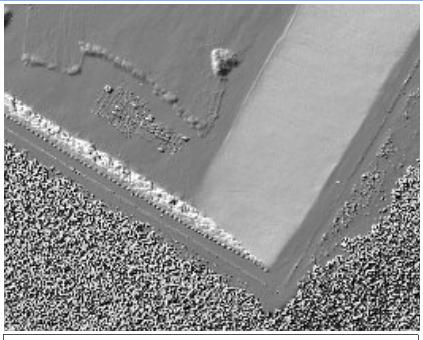
```
IDOBJ         INTEGER    UNIQUE INDEX  NOT NULL  SYSNUM IDENTIFIER
COORDINATES   MULTIPOINT        INDEX  NOT NULL  RESOLUTION(2,2,2)
PULSETIME     NUMBER(12.6)      INDEX  NOT NULL  ARRAY
RETURNNUMBER  INTEGER                  NOT NULL  ARRAY
RANGE         NUMBER(12.3)             NOT NULL  ARRAY
AZIMUTH       NUMBER(12.8)             NOT NULL  ARRAY
ZENITHANGLE   NUMBER(12.8)             NOT NULL  ARRAY
AMPLITUDE     NUMBER(12.3)             NOT NULL  ARRAY
ECHOWIDTH     NUMBER(12.3)             NOT NULL  ARRAY
CROSSSECTION  NUMBER(12.3)             NOT NULL  ARRAY
CLASSID       INTEGER                  NOT NULL  ARRAY
OBJECTNAME    CHAR(16)          INDEX  NOT NULL
OBJECTTYPE    CHAR(16)          INDEX  NOT NULL
FEATURECODE   CHAR(32)          INDEX       NULL
…
```

UTC, sequential if possible

Not rank-angle!

Selection Examples, TopDM





a: Point cloud (all echoes)

b: Selection by GPS time

```
WHERE PULSETIME > 555675.5
  AND PULSETIME < 555678.0
```

c: Selection by zenith angle

```
WHERE ZENITHANGLE >= -1.5
  AND ZENITHANGLE <= 6.5
```

d: Selection by amplitude

```
WHERE AMPLITUDE > 75
```

e: Selection by echo width

```
WHERE ECHOWIDTH >= 1.7
```

f: Selection by echo class

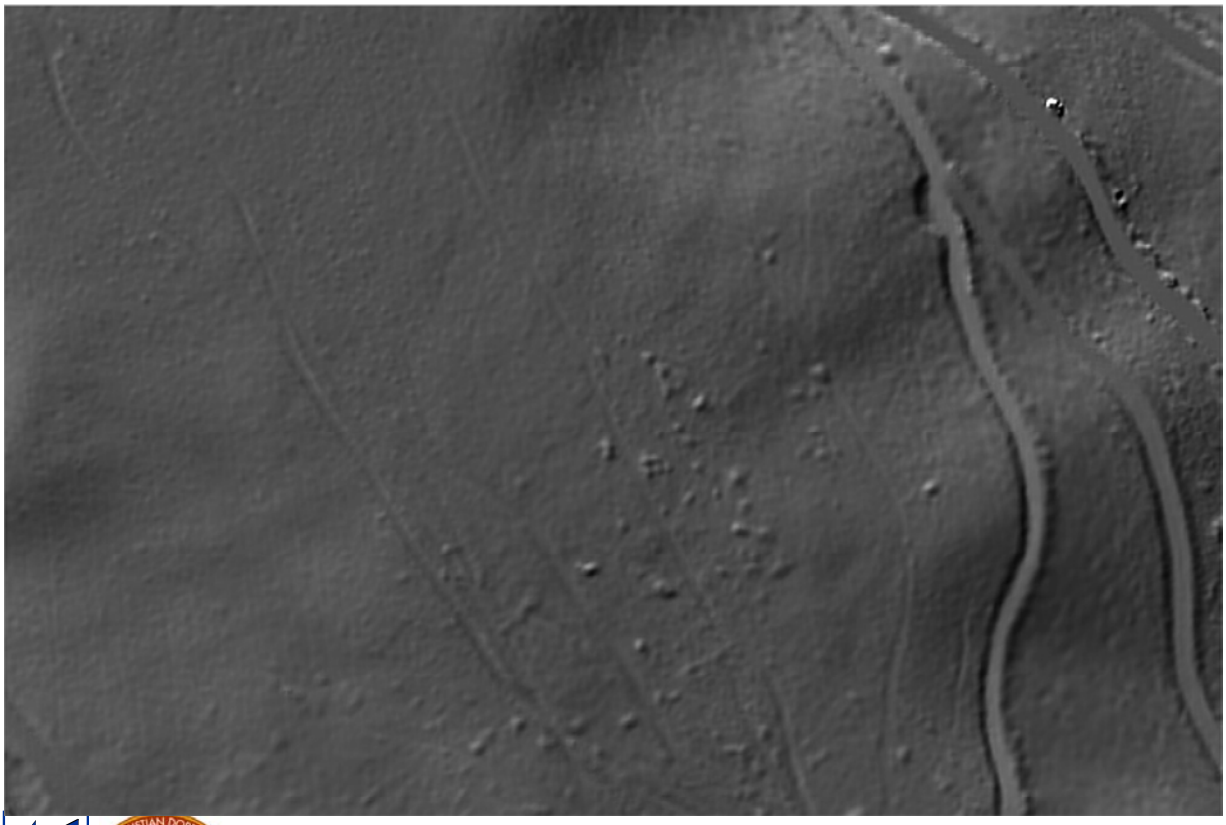
```
WHERE CLASSID = 2
```

Data: Leithagebirge, Lower Austria

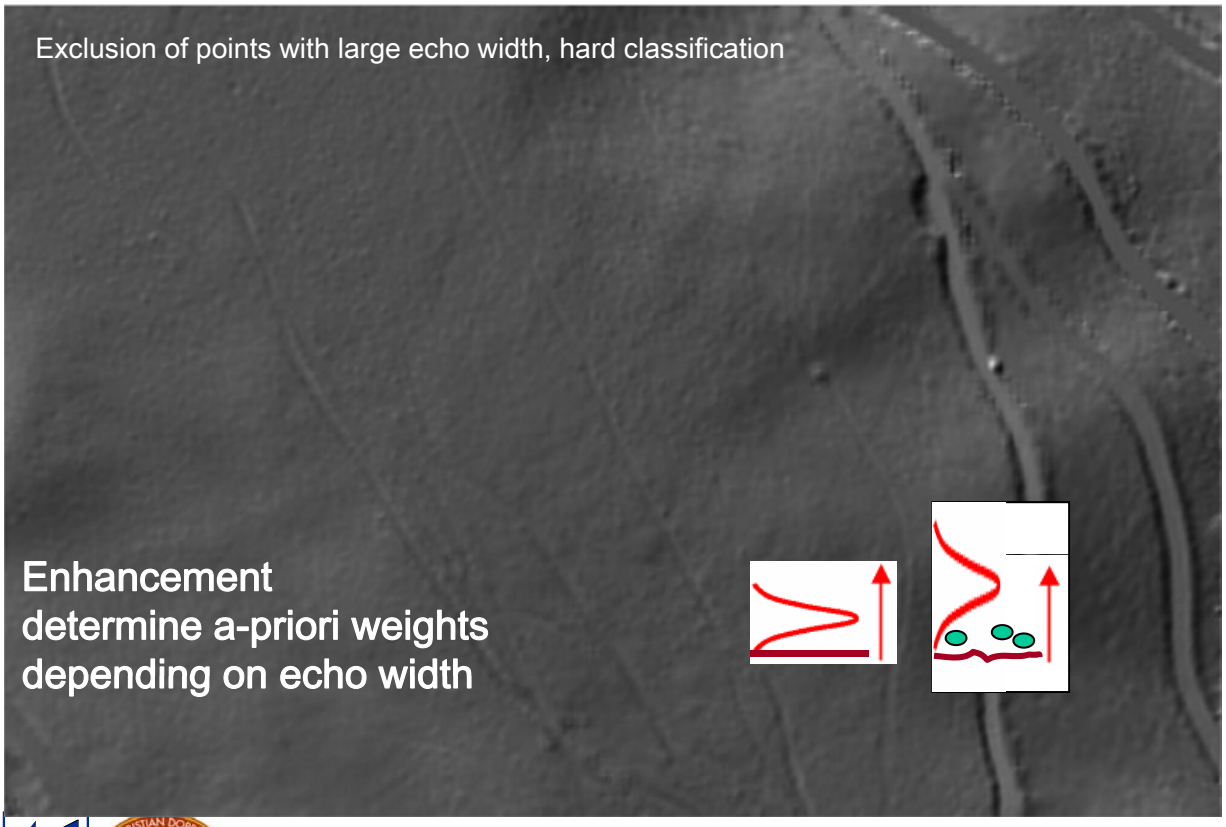
FWF ALS data: exploitation for DTM generation

Aerial image	DSM	DTM – robust interpolat.
Amplitude	Echo width	DTM, only narrow ech´s

FWF ALS data: exploitation for DTM generation

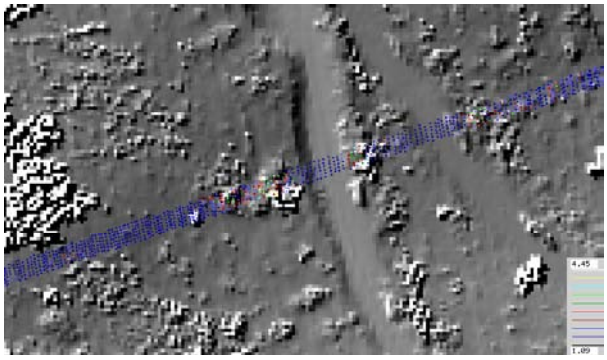


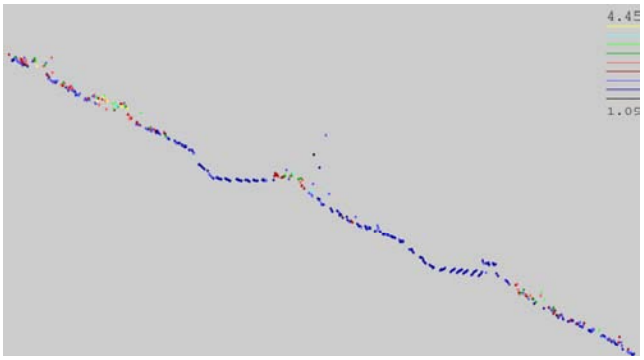
FWF ALS data: exploitation for DTM generation

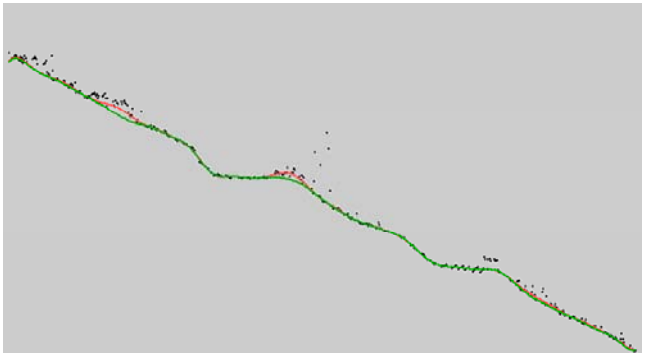


- Enhancement
  determine a-priori weights
  depending on echo width

DTM derivation from FWF ALS with robust interpol.







- Individual accuracy per point, reweighted by robust interpolation
- Enhancement in DTM computation

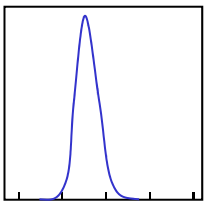
Conclusions

- FWF ALS data adminstration
  - proposal of a system
  - standardization benefitial (?)
- Expoitation of FWF
  - example: DTM
  - general information content not investigated
  - usability for standard products not investigated
  - new products …

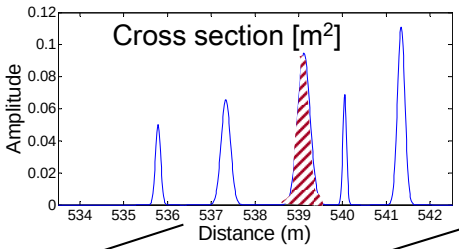
ALS Sensor development – Full Waveform

Viewing direction

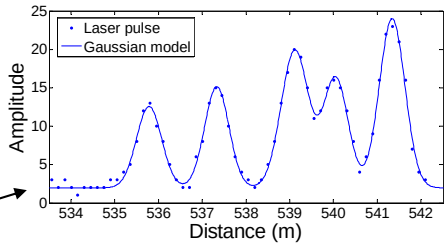
- Emitted pulse



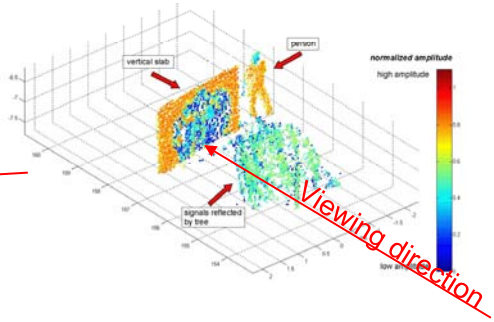
Height distribution of objects



Received echoes



⊗ Convolution



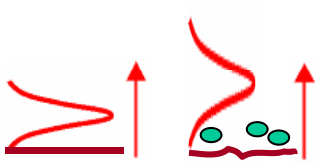
Cross section requires radiometric calibration

DTM derivation from ALS with robust interpolation

- Iteratively compute weights
  depending on distance of averaging DTM to points

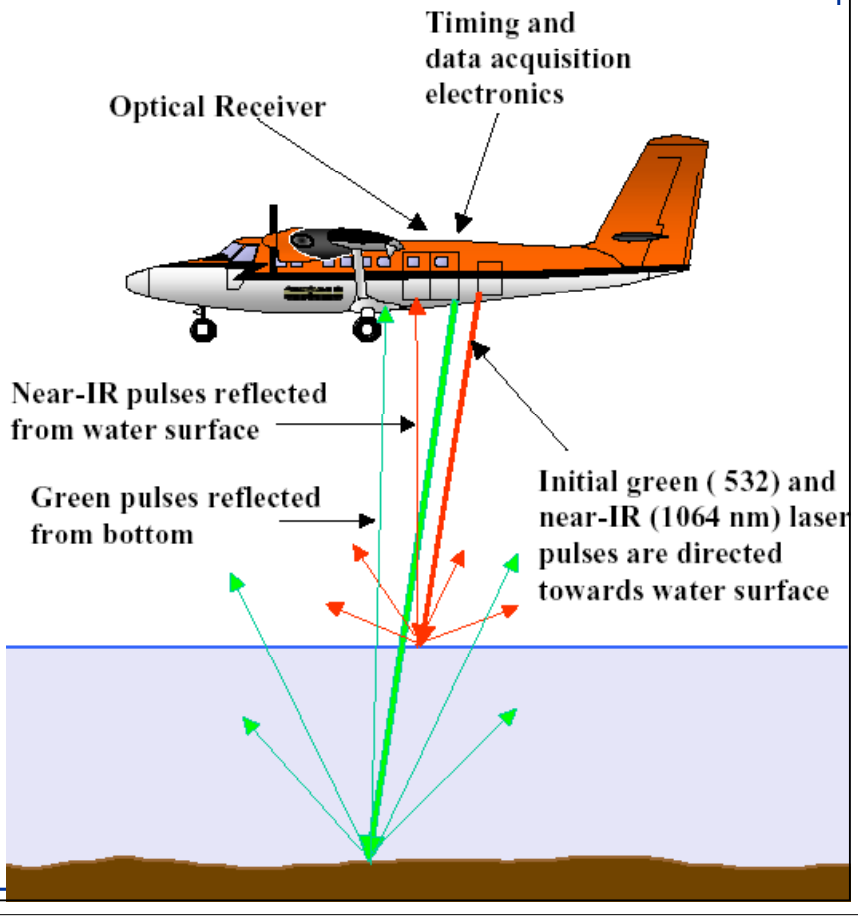
$$\begin{pmatrix} C(P_1P_1) & C(P_2P_2) & \cdots & C(P_1P_j) & \cdots & C(P_1P_n) & 1 \\ C(P_2P_1) & C(P_2P_2) & & C(P_2P_j) & & C(P_2P_n) & 1 \\ \vdots & & \ddots & & & \vdots & \\ C(P_iP_1) & C(P_iP_2) & & C(P_iP_j) & & C(P_iP_n) & 1 \\ \vdots & & & & \ddots & \vdots & \\ C(P_nP_1) & C(P_nP_2) & \cdots & C(P_nP_j) & \cdots & C(P_nP_n) & 1 \\ 1 & 1 & & 1 & & 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_i \\ \vdots \\ \lambda_n \\ -\mu \end{pmatrix} = \begin{pmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_i \\ \vdots \\ Z_n \\ 1 \end{pmatrix} \Rightarrow \quad \mathbf{K} \cdot \boldsymbol{\lambda} = \mathbf{c}$$

- Enhancement
  determine a-priori weights
  depending on echo width



LIDAR Bathymetry

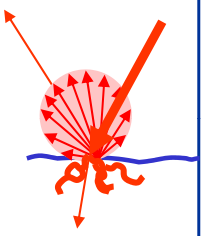
Range measurements
through different media



Source: http://www.optech.on.ca

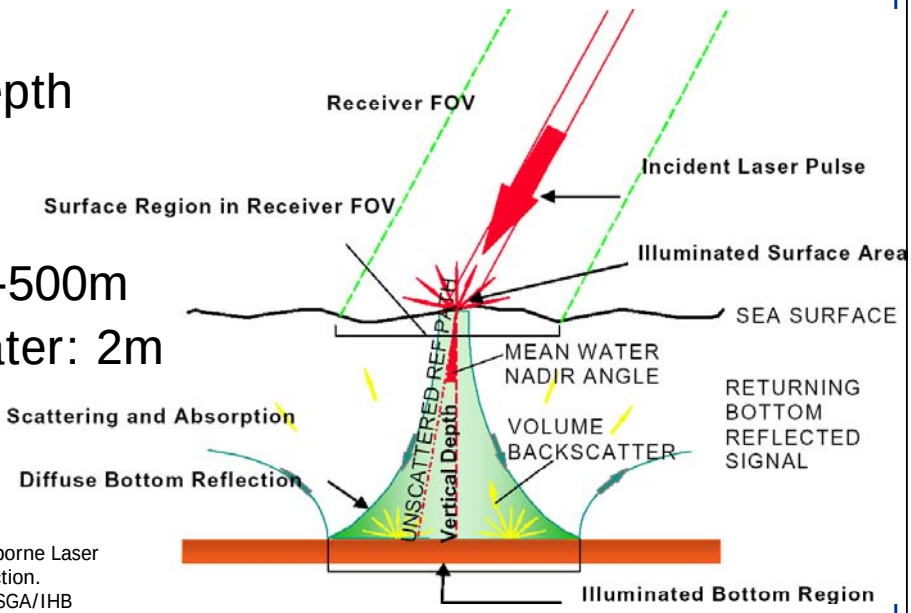
Using green lasers
(Technology extension)

- near IR: reflection on water surface
- green light: penetrates into the water



Depth: 3x Secchi depth
- attenuation (–)
- scattering (~)

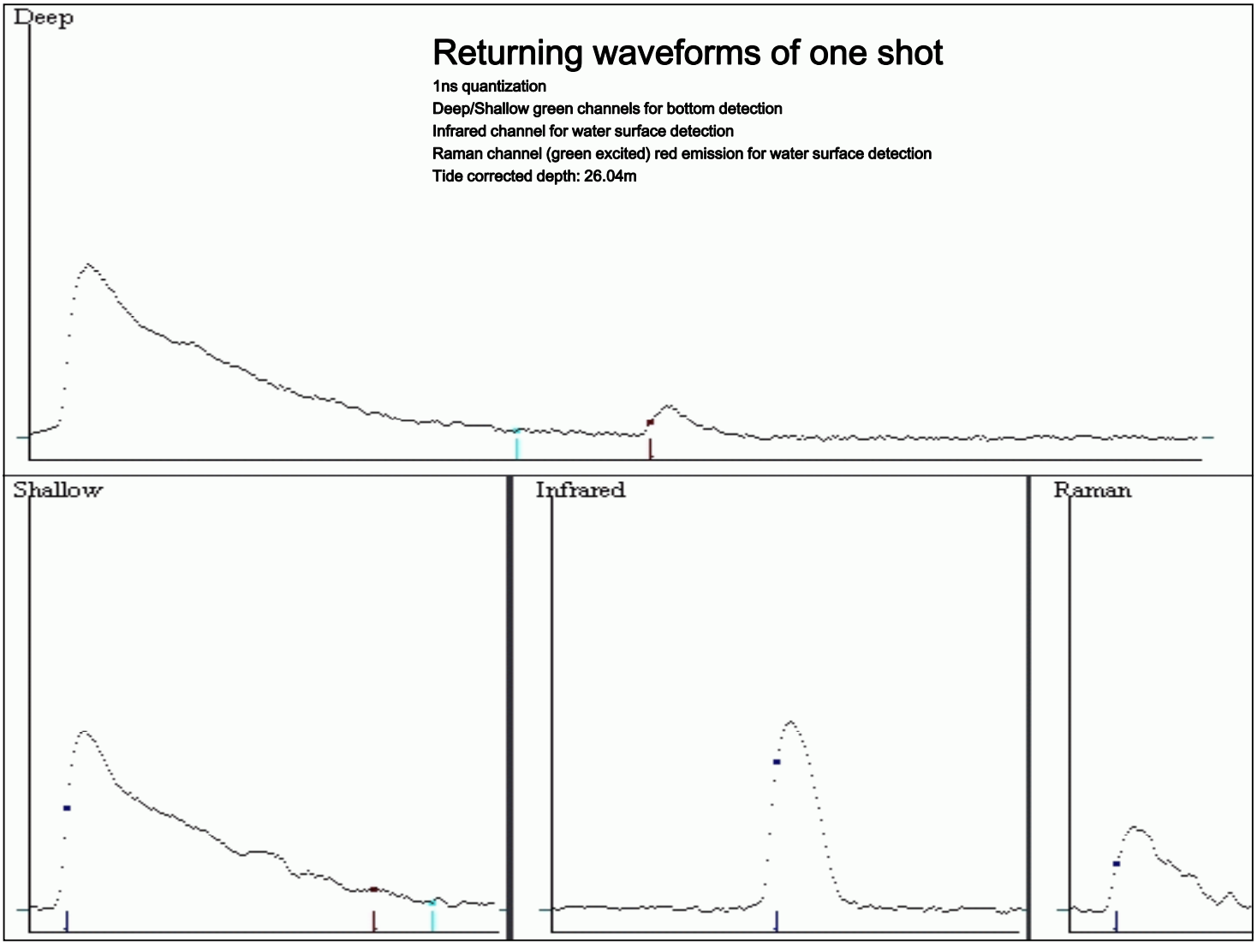
flying height: 200m-500m
green diameter@water: 2m
green FoV: 15m
1000Hz



LaRocque et al, 1999: Airborne Laser Hydrography: An Introduction. Proceedings, ROPME/PERSGA/IHB Workshop on Hydrographic Activities in the ROPME Sea Area and Red Sea, October 24-27, Kuwait City.

Returning waveforms of one shot

1ns quantization
Deep/Shallow green channels for bottom detection
Infrared channel for water surface detection
Raman channel (green excited) red emission for water surface detection
Tide corrected depth: 26.04m



Level 0,1,2,3 vs. TopDM

- **Level *i* … description for satellite data products**
  - 0: raw sensor data stream
  - 1: geo-physical quantities
  - 2: model-based derivations of level 1
  - 3: integrated with other sources
- **TopDM**
  - Data imported after
    - fine georeferencing
    - echo analysis

    … Level 1
  - augmented by
    - cross section computation with emitted pulse shape assumption
    - classification

    … Level 2

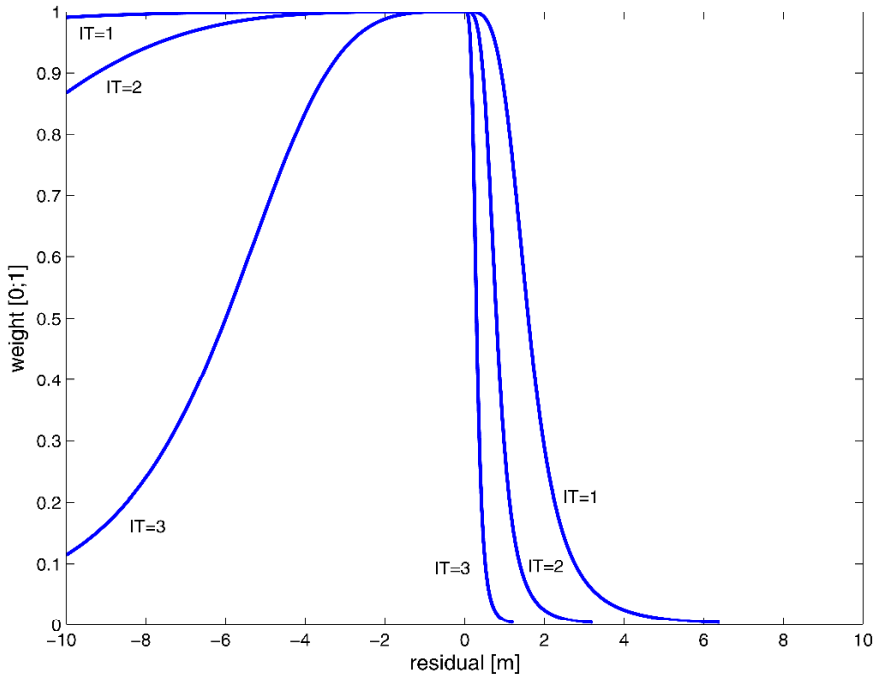
Kriging/Linear Prediction with individual a-priori weights

$$\begin{pmatrix} C(P_1P_1) & C(P_2P_2) & \cdots & C(P_1P_j) & \cdots & C(P_1P_n) & 1 \\ C(P_2P_1) & C(P_2P_2) & & C(P_2P_j) & & C(P_2P_n) & 1 \\ \vdots & & \ddots & & & \vdots & \\ C(P_iP_1) & C(P_iP_2) & & C(P_iP_j) & & C(P_iP_n) & 1 \\ \vdots & & & & \ddots & \vdots & \\ C(P_nP_1) & C(P_nP_2) & \cdots & C(P_nP_j) & \cdots & C(P_nP_n) & 1 \\ 1 & 1 & & 1 & & 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_i \\ \vdots \\ \lambda_n \\ -\mu \end{pmatrix} = \begin{pmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_i \\ \vdots \\ Z_n \\ 1 \end{pmatrix} \Rightarrow \quad \mathbf{K} \cdot \boldsymbol{\lambda} = \mathbf{c}$$

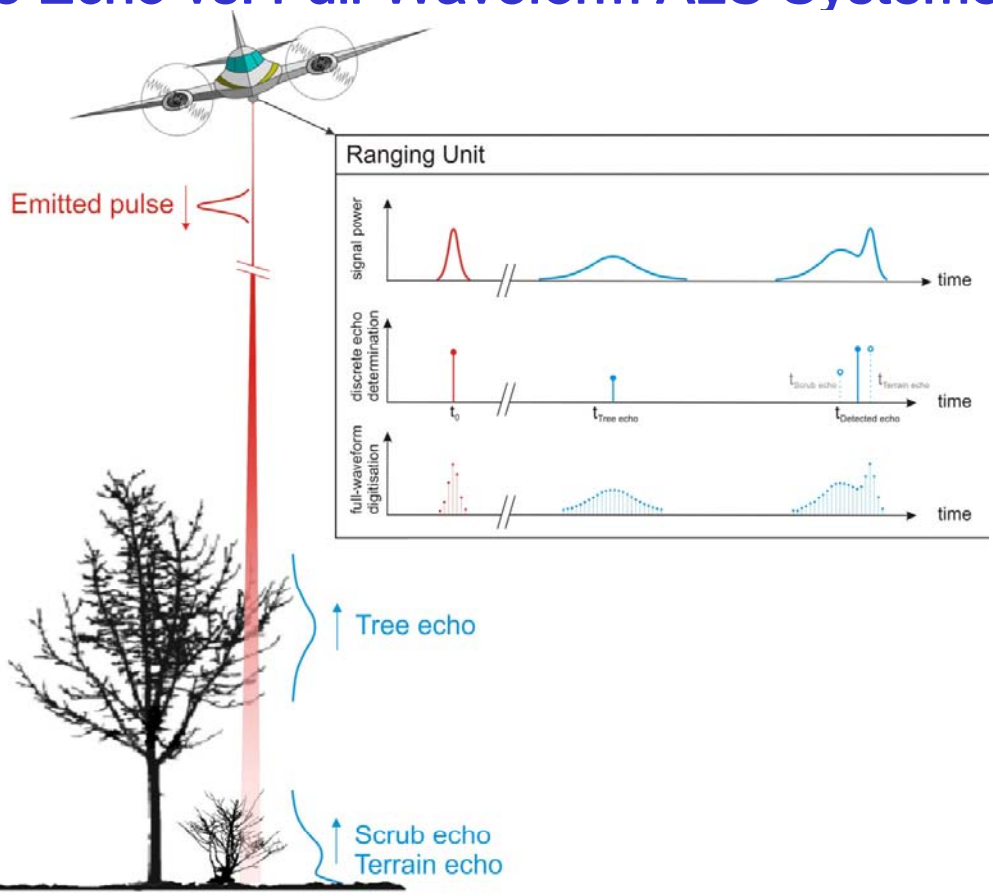
Kriging/Linear Prediction with individual a-priori weights
and additional slope observations

$$\begin{pmatrix} C_z(P_1P_1) & \cdots & C_z(P_1P_n) & C_\alpha(P_1N_1) & \cdots & C_\alpha(P_1N_m) & 1 \\ \vdots & \ddots & \vdots & \vdots & & \vdots & \vdots \\ C_z(P_nP_1) & \cdots & C_z(P_nP_n) & C_\alpha(P_nN_1) & \cdots & C_\alpha(P_nN_m) & 1 \\ \frac{\partial C_z(N_1P_1)}{\partial t_1} & \cdots & \frac{\partial C_z(N_1P_n)}{\partial t_1} & \frac{\partial C_\alpha(N_1N_1)}{\partial t_1} & \cdots & \frac{\partial C_\alpha(N_1N_m)}{\partial t_1} & 0 \\ \vdots & & \vdots & \vdots & & \vdots & \vdots \\ \frac{\partial C_z(N_mP_1)}{\partial t_m} & \cdots & \frac{\partial C_z(N_mP_n)}{\partial t_m} & \frac{\partial C_\alpha(N_mN_1)}{\partial t_m} & \cdots & \frac{\partial C_\alpha(N_mN_m)}{\partial t_m} & 0 \\ 1 & \cdots & 1 & 0 & \cdots & 0 & 0 \end{pmatrix} \cdot \boldsymbol{\lambda} = \begin{pmatrix} Z_1 \\ \vdots \\ Z_n \\ \tan\alpha_1 \\ \vdots \\ \tan\alpha_m \\ 1 \end{pmatrix}$$

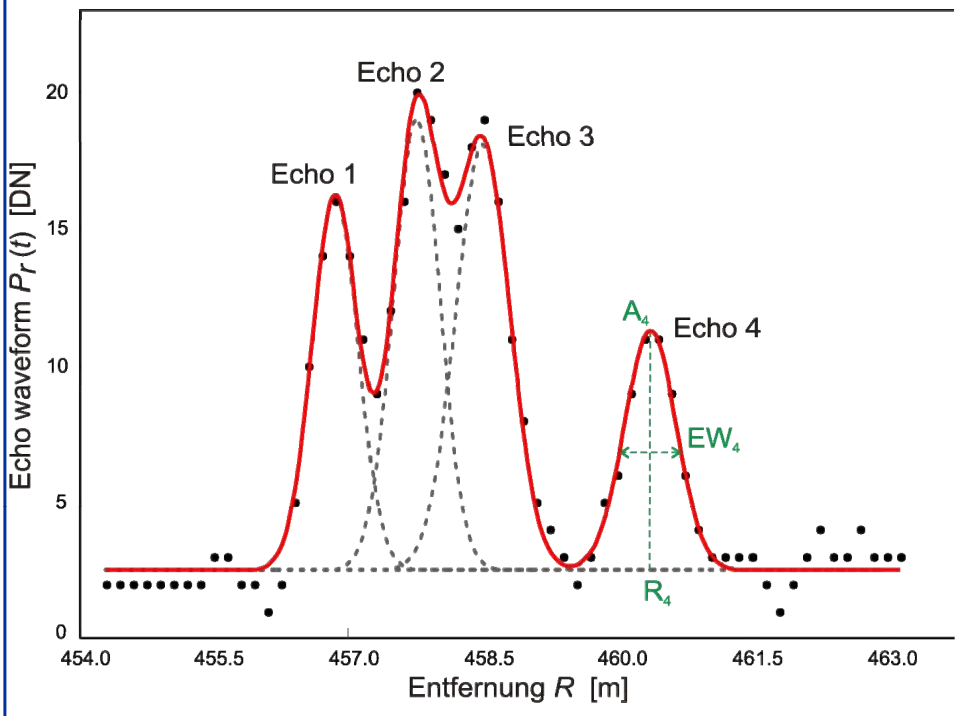
Robust Interpolation with a self adapting asymmetric weight function



Diskrete Echo vs. Full-Waveform ALS Systeme



Zusätzliche Kenngrößen pro detektiertem Echo



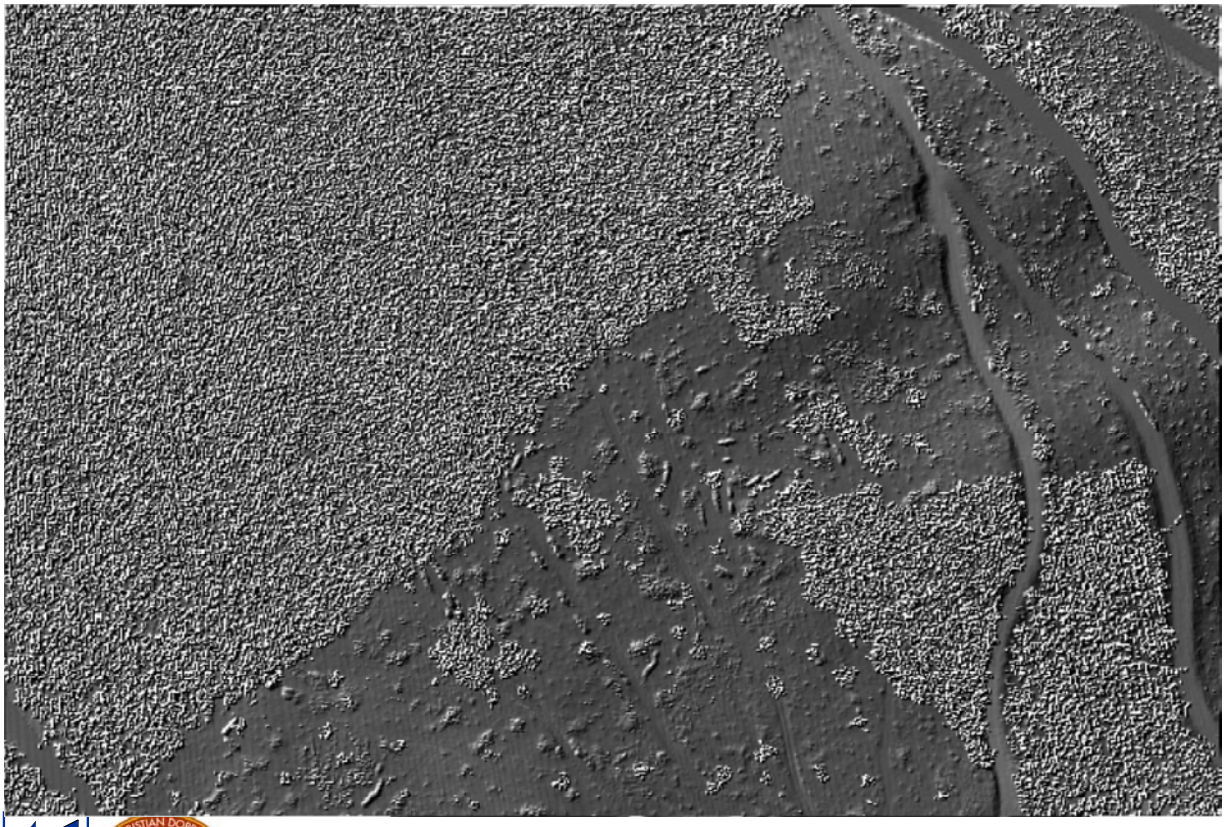
Echo Parameter:

- Distanz R_i
- Amplitude A_i
- Echo weite EW_i
- Cross section σ_i (= $C_{cal}*R_i^4*A_i*EW$
- σ_{Ri}
-… ?

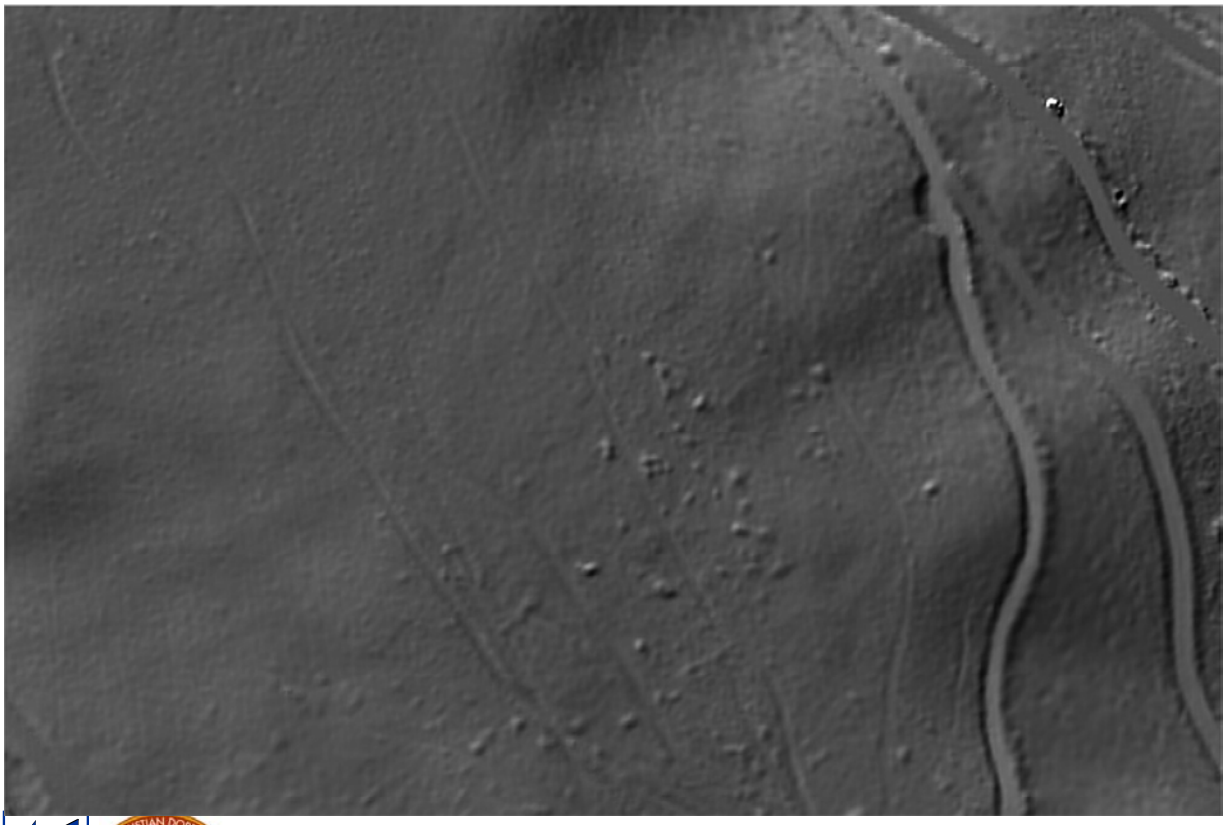
Modellierung der verspeicherten Wellenform (schwarze Punkte) mittels der Summation von Gaußschen-Glockenkurven (vgl. Wagner et al., 2006)

ALS Leithagebirge - Luftbild

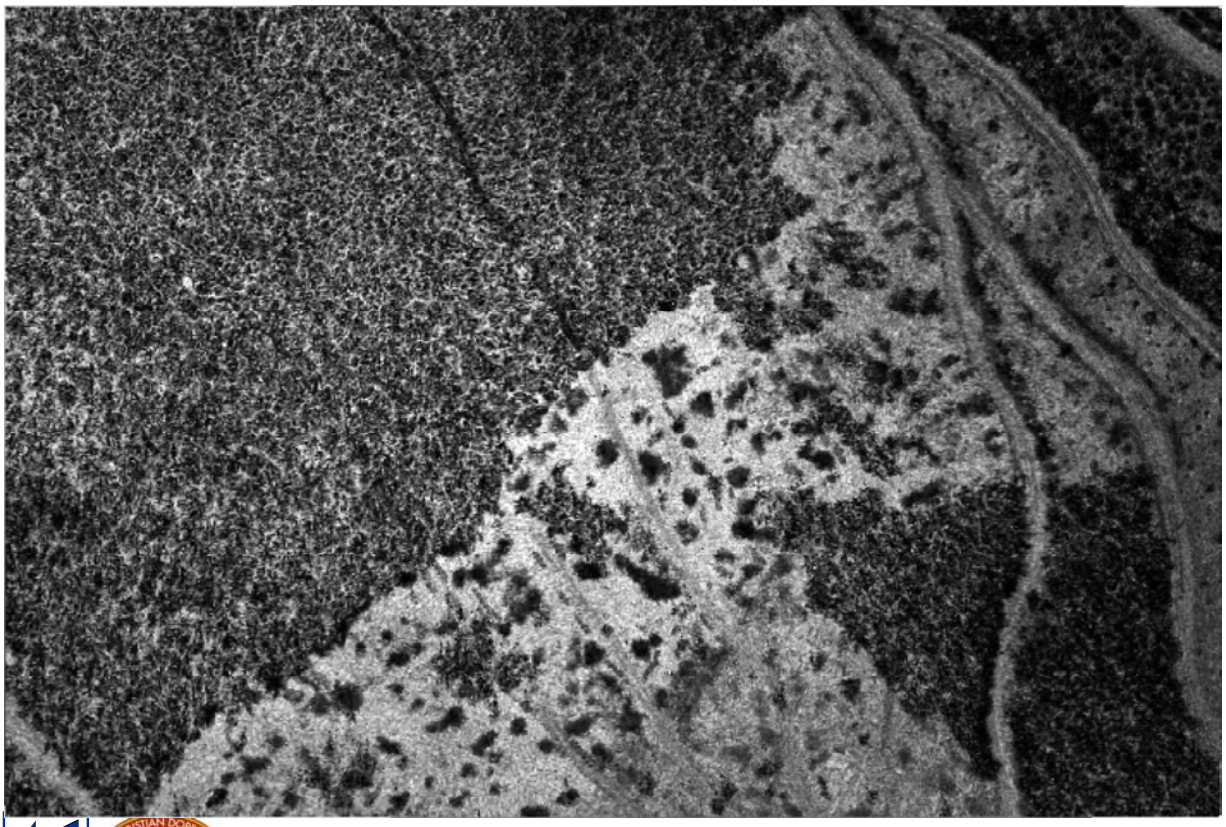
ALS Leithagebirge – DOM (first Echo)



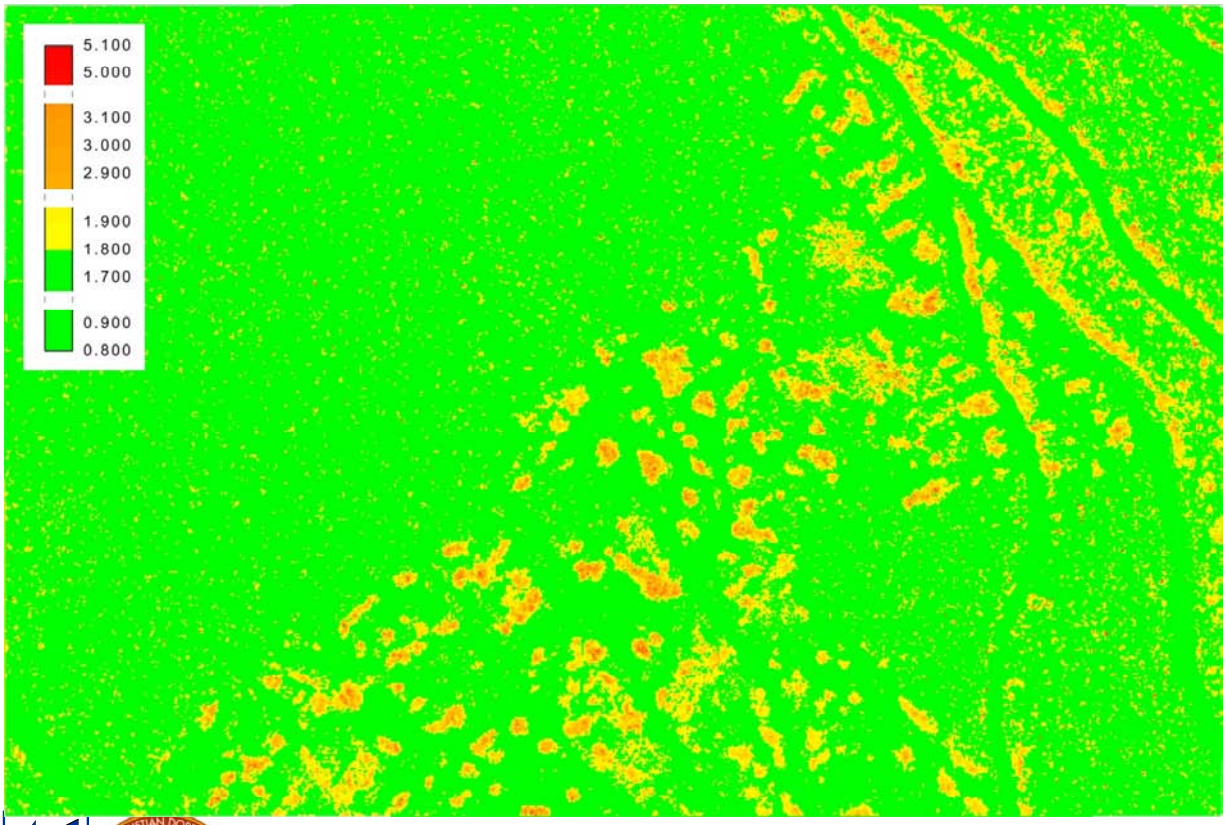
ALS Leithagebirge – DGM (SCOP++ (HRI))



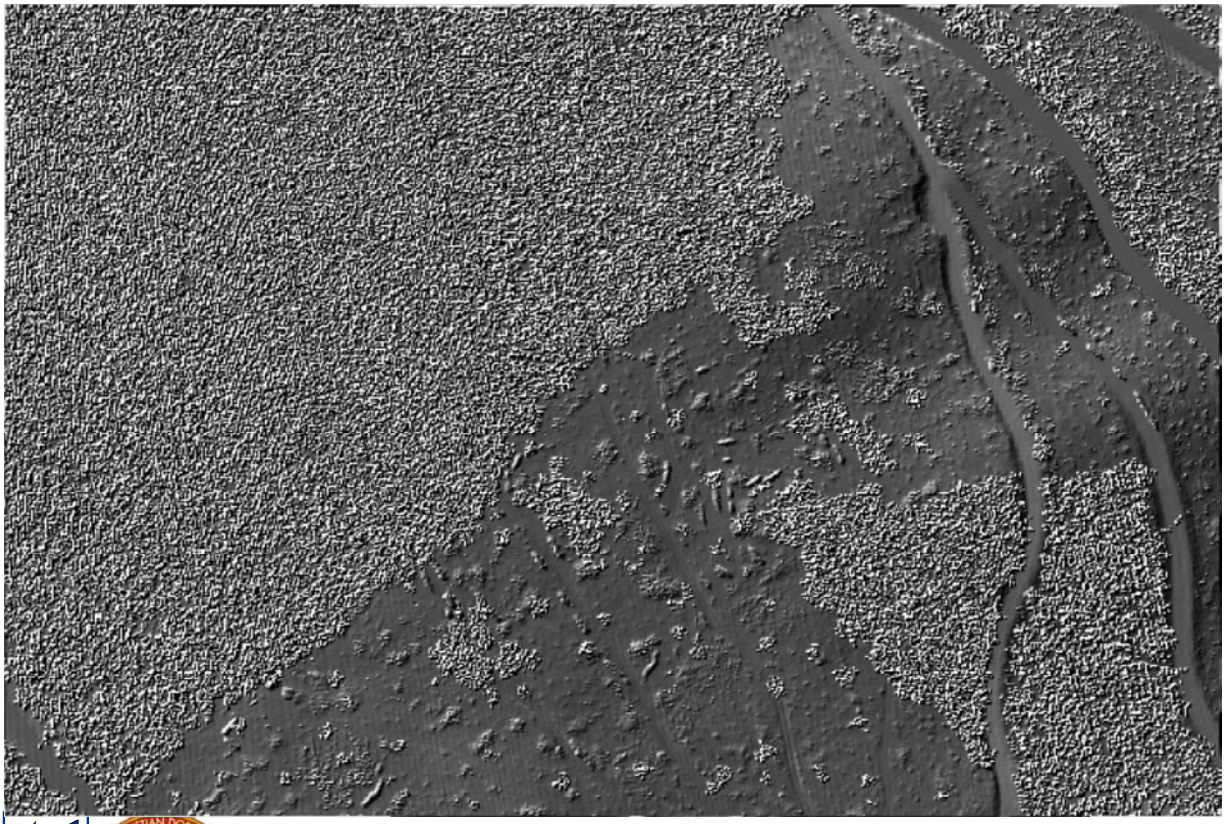
ALS Leithagebirge – Amplitude



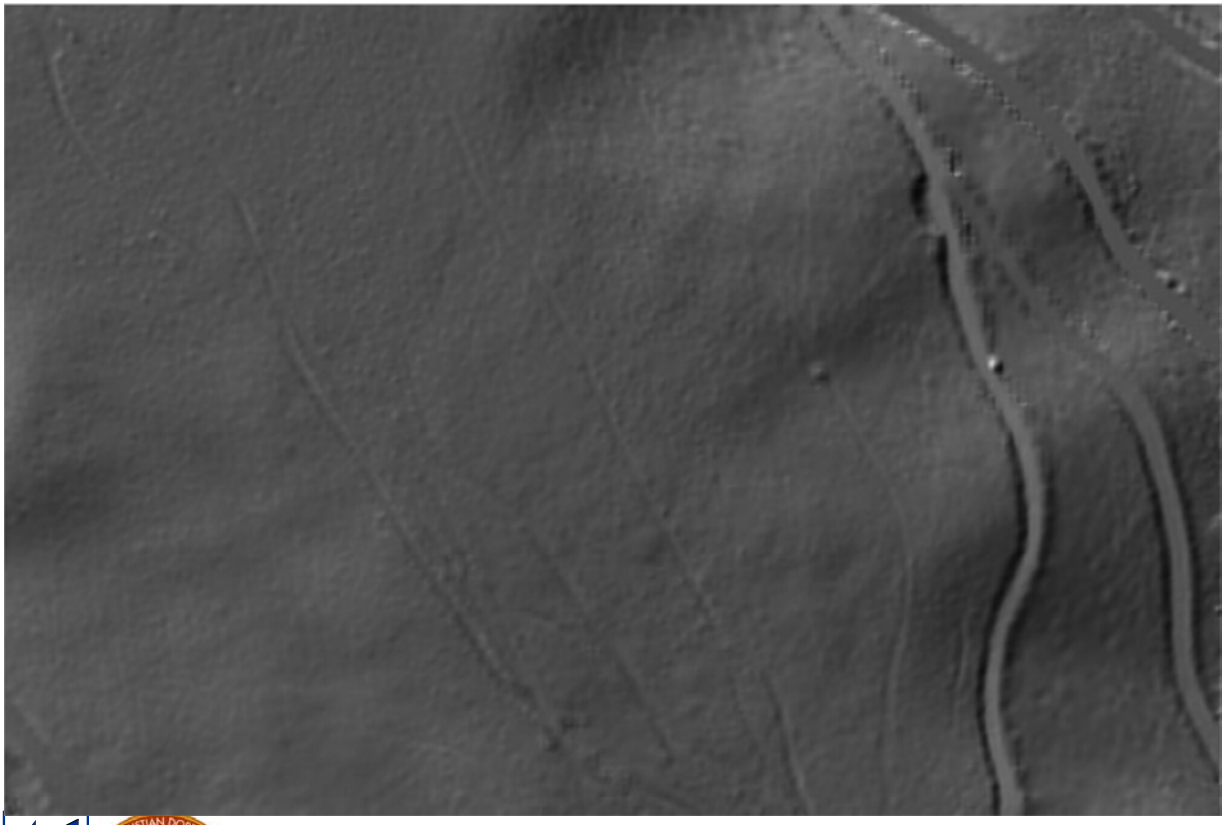
ALS Leithagebirge – Echoweite



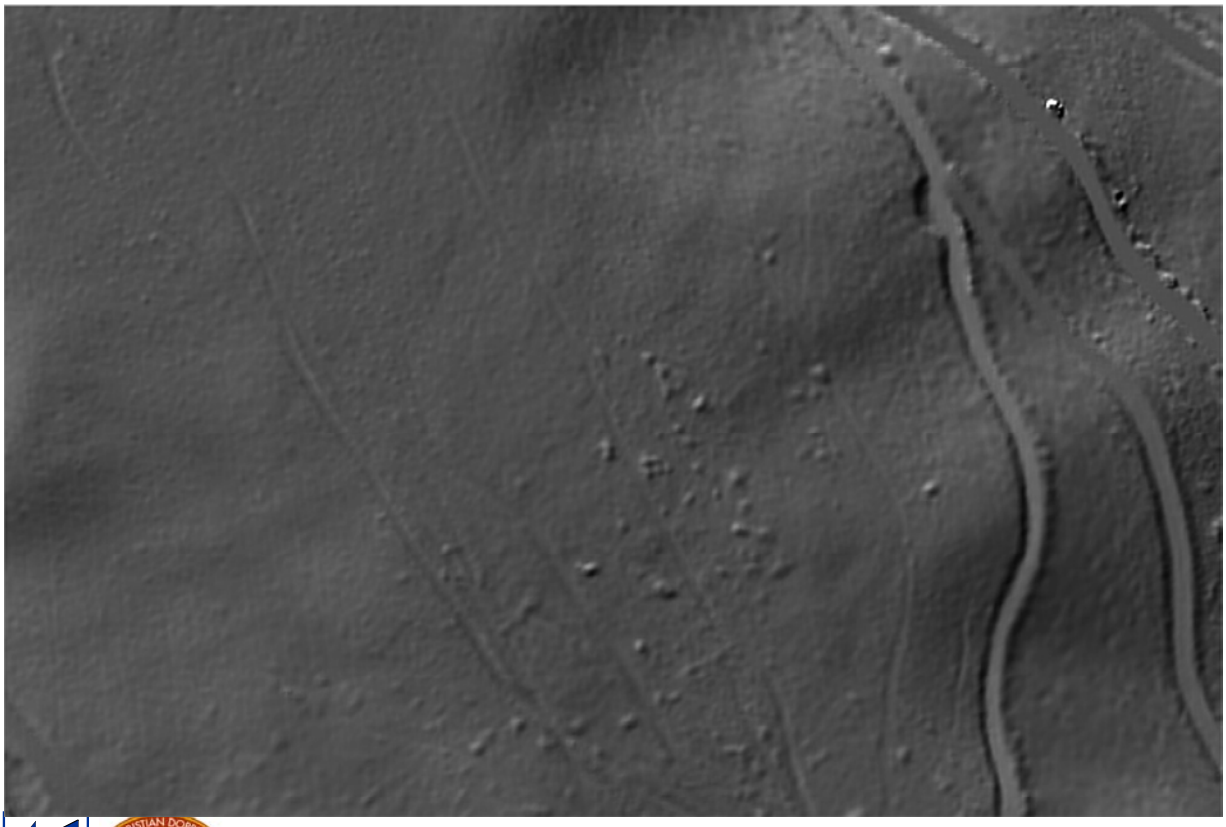
ALS Leithagebirge – DOM (first Echo)



Verbesserte DGM Erstellung unter der Berücksichtigung der Echoweite



ALS Leithagebirge – DGM (SCOP++ (HRI))



Verbesserte DGM Erstellung unter der Berücksichtigung der Echoweite