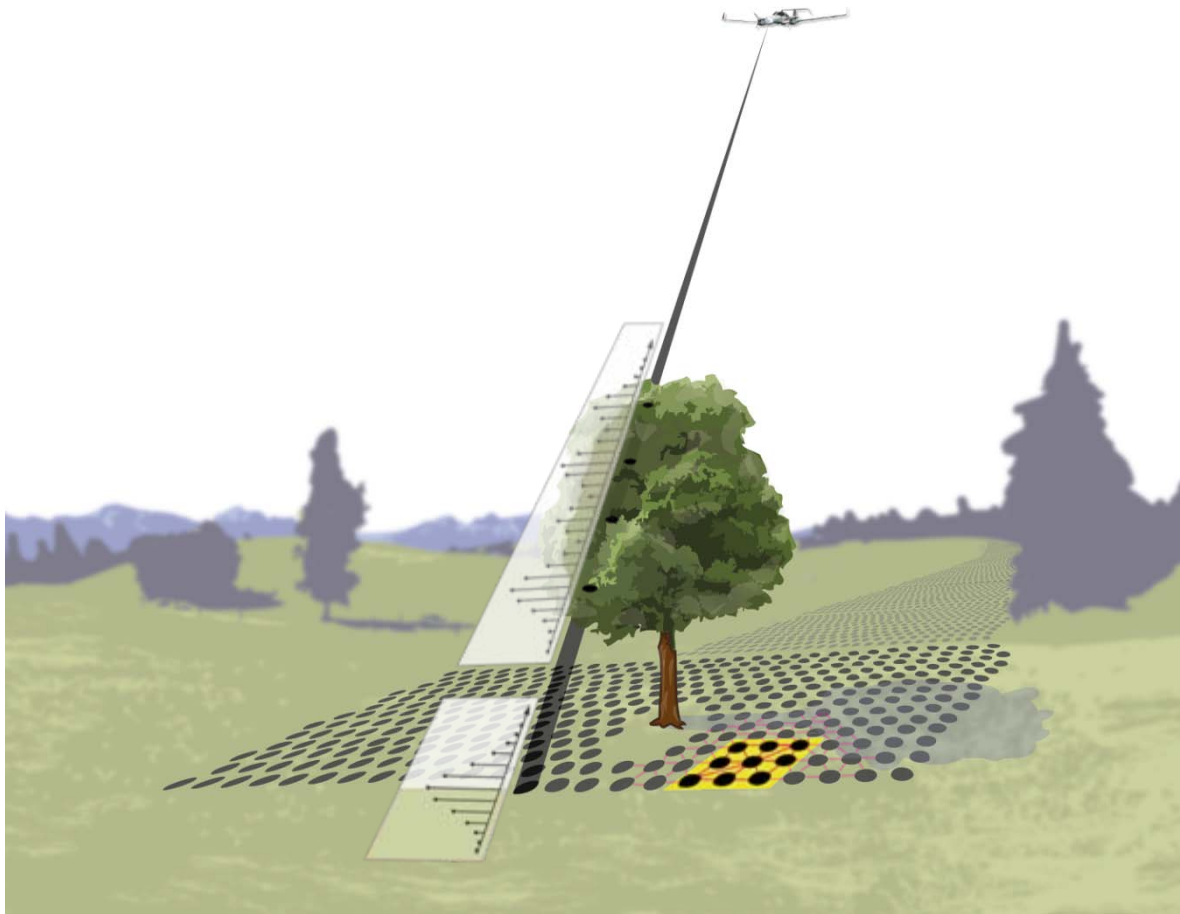


Radiometric Calibration of LIDAR instruments and LIDAR data

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- sequential data acquisition
- surface sampling at laser footprints
- “sampling” footprint $\leftarrow \rightarrow$ point(s) of point cloud
- echo-digitization with full waveform analysis \rightarrow best multi-target resolution
- for each detected target / echo \rightarrow Gaussian decomposition provides signal strength of electrical echo signal
- how to get to an estimate of the radiometric properties of the targets?

LIDAR equation:

$$P_T \cdot \frac{4}{R^2 \theta_T^2 \pi} \cdot \eta_{ATM} \cdot \sigma \cdot \frac{1}{4\pi R^2} \cdot \eta_{ATM} \cdot \frac{\pi D^2}{4} \cdot \eta_{SYS} = P_R$$

emitted power

power spread on forward path

atmospheric attenuation (single pass)

power density at target

laser radar cross section

power spread return path

power density at receiver

receiver aperture

system losses

received power

laser radar cross section

$$\sigma = A \cdot \rho \cdot d$$

actual geometric cross-section of target interacting with laser beam

reflectance

directivity of backscattered radiation

LIDAR equation for arbitrary targets

$$P_T \cdot \frac{4}{R^2 \theta_T^2 \pi} \cdot \eta_{ATM} \cdot \sigma \cdot \frac{1}{4\pi R^2} \cdot \eta_{ATM} \cdot \frac{\pi D^2}{4} \cdot \eta_{SYS} = P_R$$

Small foot print LIDAR on large Lambertian target

$$P_T \cdot \eta_{ATM} \cdot \rho \cdot \frac{\cos(\phi)}{\pi R^2} \cdot \eta_{ATM} \cdot \frac{\pi D^2}{4} \cdot \eta_{SYS} = P_R$$

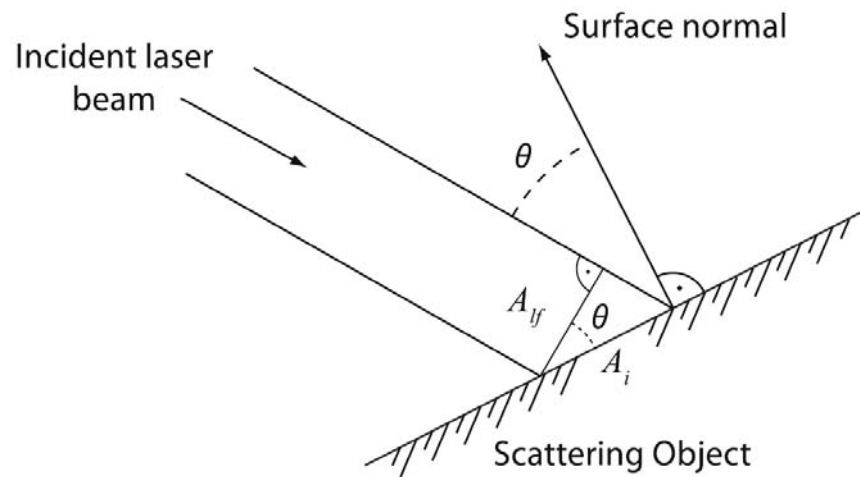
by comparison

$$\frac{4}{R^2 \theta_T^2 \pi} \sigma \frac{1}{4\pi R^2} = \rho \cos \phi \frac{1}{\pi R^2}$$

$$\frac{1}{A_{lf}} \sigma \frac{1}{4\pi R^2} = \gamma \frac{1}{4} \frac{1}{\pi R^2} = \rho \cos \phi \frac{1}{\pi R^2} \quad \gamma = 4\rho \cos \phi$$

Backscattering coefficient in γ [m^2m^{-2}]

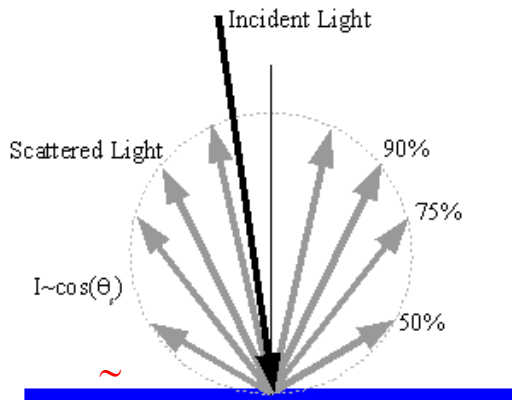
$$\gamma = \frac{\sigma}{A_{lf}}$$



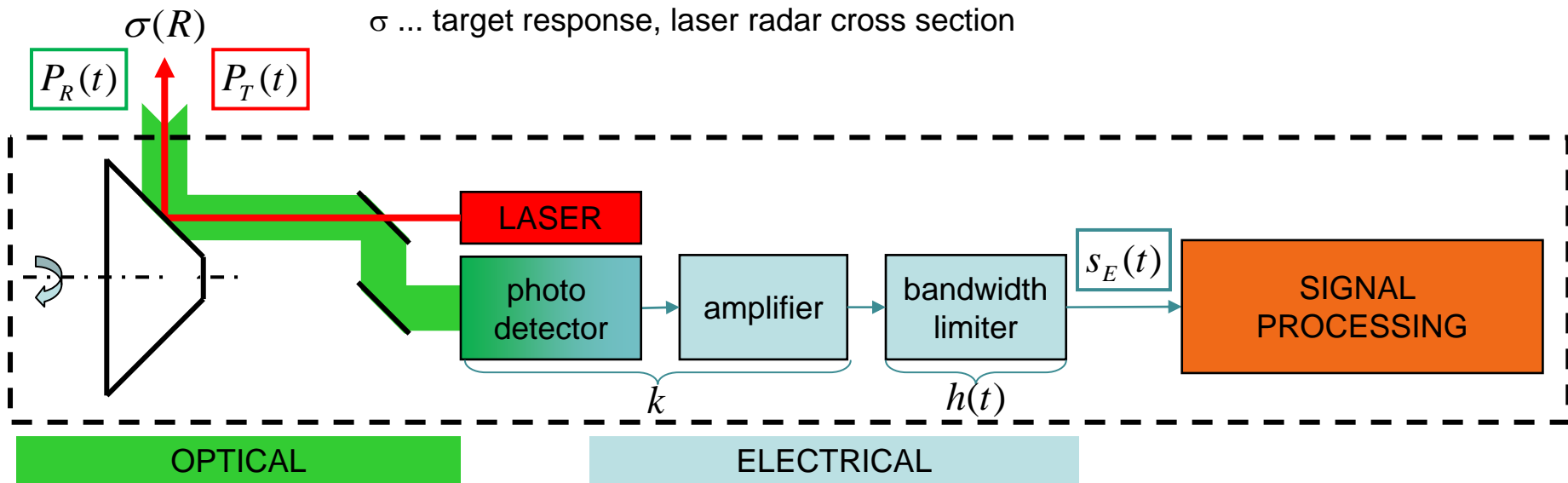
Diffuse reflectance measure ρ_d [m^2m^{-2}]

Assumption: **Lambertian reflection**

$$\tilde{\rho}_d = \frac{\gamma}{4 \cos \phi}$$



σ ... target response, laser radar cross section



— $P_T(t)$

■ $P_R(R) = K P_T(R) * \sigma(R)$

$$R = \frac{v_g}{2} t$$

■ $s_E(t) = k.K.P_E(t) * h(t)$

$s_E(t) = k.K.P_T(t) * \sigma(t) * h(t)$

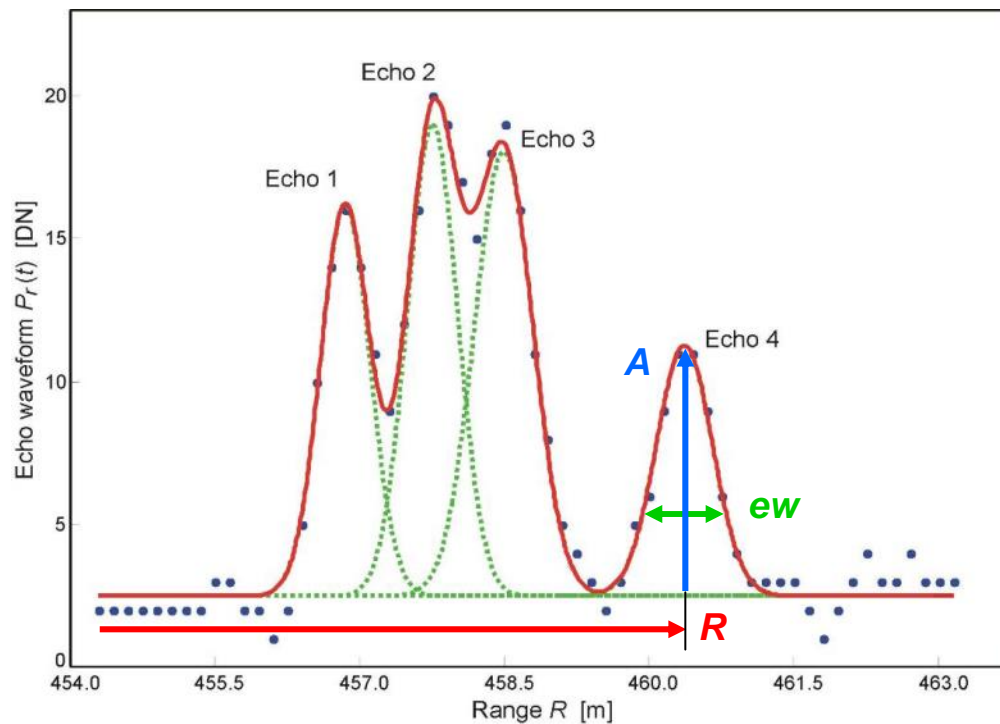
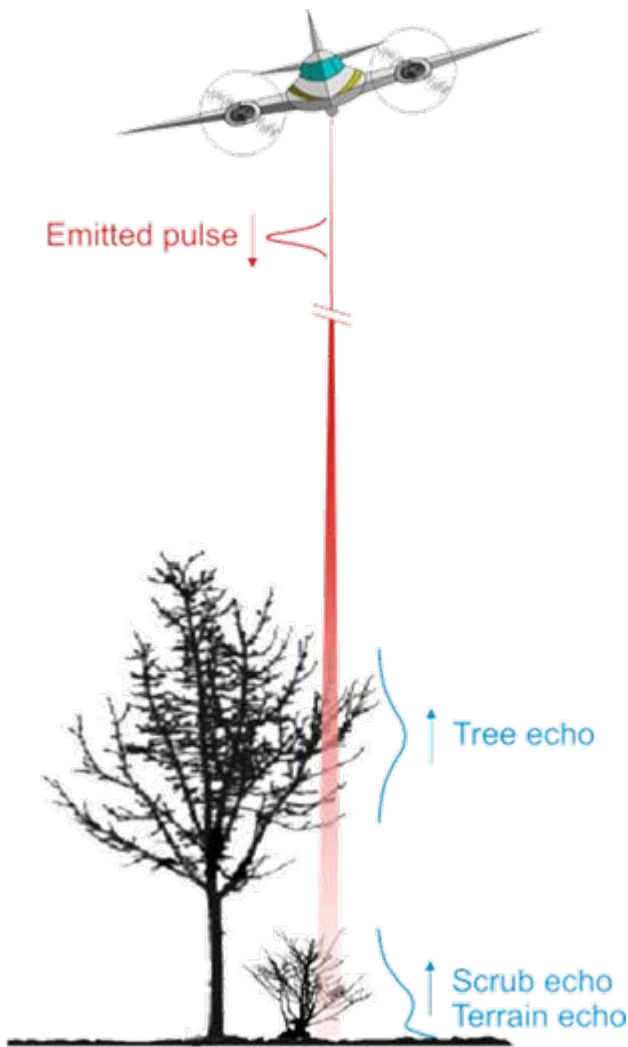
$s_E(t) = k.K.P_T(t) * h(t) * \sigma(t)$

system response

$s_E(t) = s_R(t) * \sigma(t)$

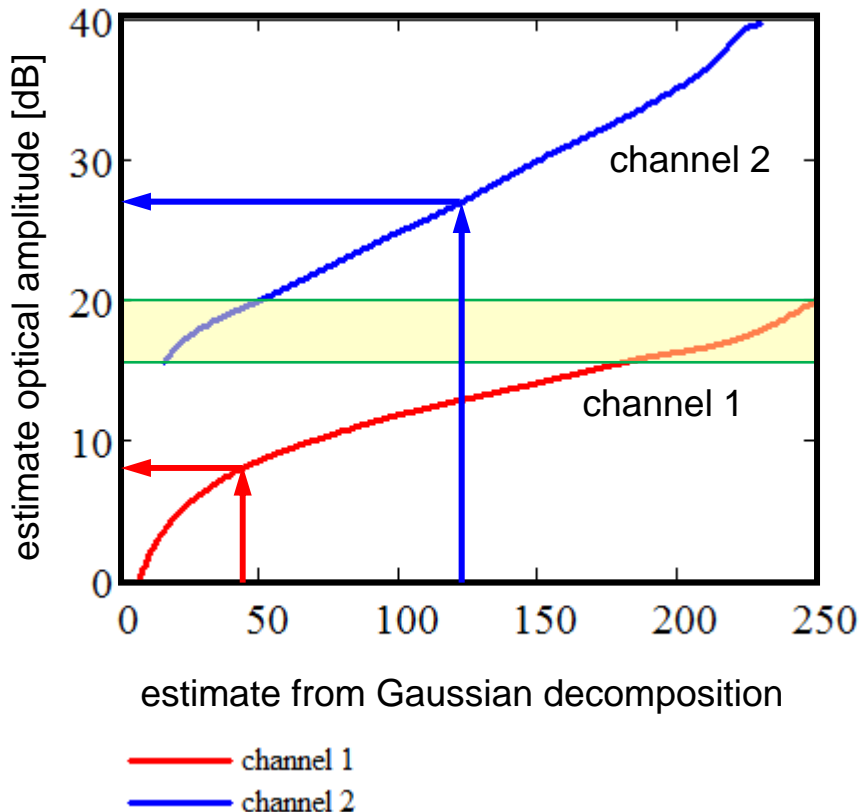
- digitization and offline analysis
- digitization and online processing

besides geometric also radiometric information



Information per Echo:
 amplitude: A [DN]
 range: R [m]
 echo width: ew [ns]

How to get from an electrical amplitude to an optical amplitude? By LUTs.



PulseWaves - Full Waveform LiDAR Specification (version 0.3 revision 9)



creators of **LAStools**, **LASzip**, and **PulseWaves**

approach for *RIEGL*'s „full waveform“ LIDAR instruments: LMS-Q560, LMS-Q680, LMS-Q780, LMS-Q1560



Encoding by calibrated amplitude

(0 dB to 50 dB above detection threshold)
 Brightness decreases from near objects to far objects.

$$A_{dB} = 10 \cdot \log \left(\frac{P_{echo}}{P_{DL}} \right)$$

A_{dB} ... calibrated amplitude [dB]
 P_{echo} ... echo signal power [W]
 P_{DL} ... detection limit [W]

Encoding by reflectance

(-20 dB to 3 dB, with respect to diffuse white target)
 Brightness independent of object distance.

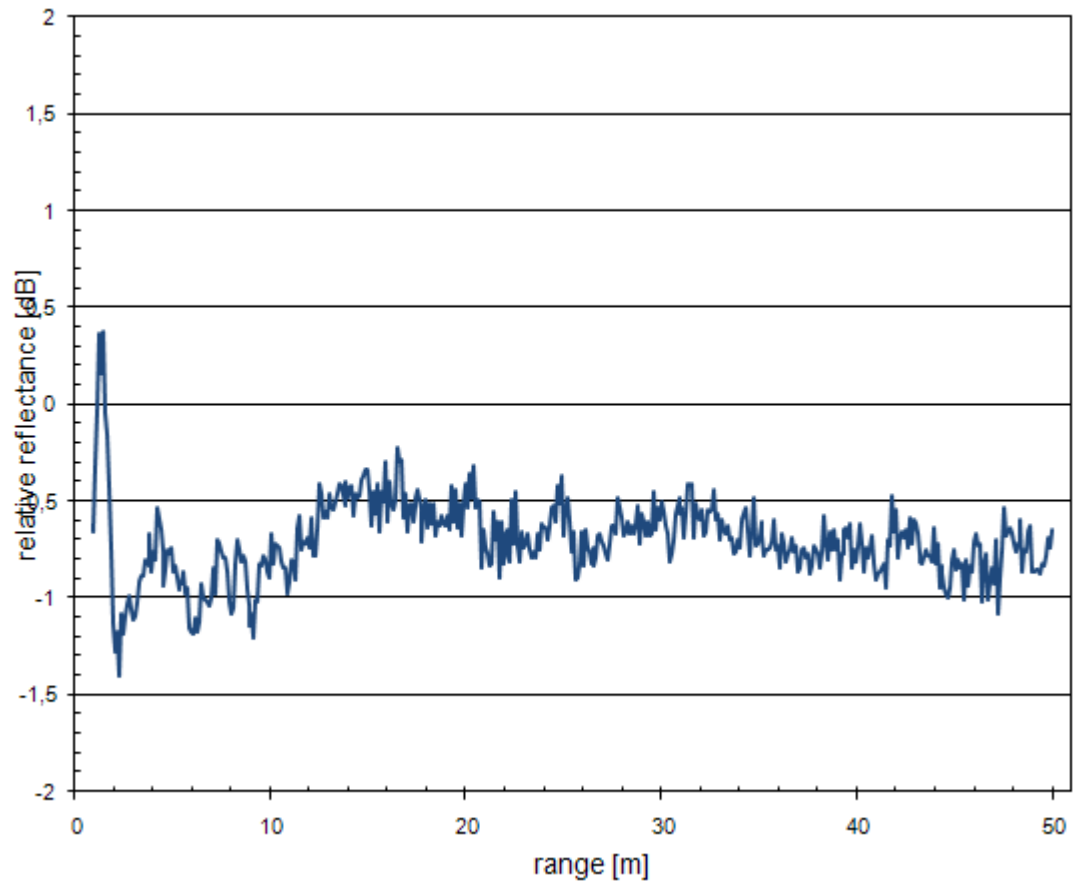
$$\rho_{rel,T} = A_{dB,T} - A_{dB,White}(R_T)$$

R_T ... target range

- Measurement of amplitude A_{dB} vs. range from 1 m to 50 m
- Interpolation of result and extrapolation assuming $1/R^2$ law to obtain $A_{dB,Ref}(R)$
- Determine relative reflectance

$$\rho_{rel,T} = A_{dB,T} - A_{dB,Ref}(R_T)$$

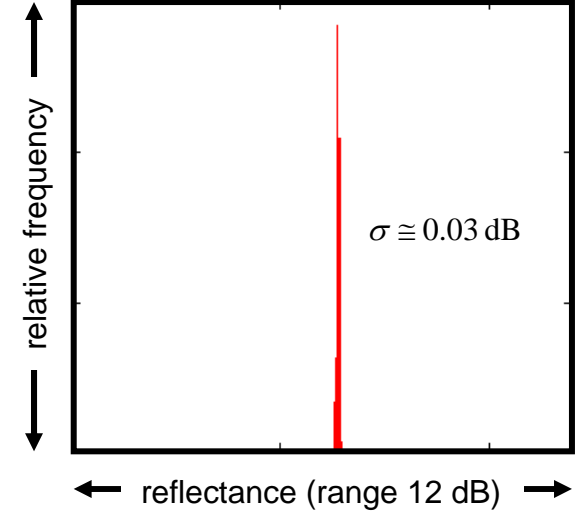
for every measurement





TARGET

Gigahertz-Optik, BN-R-SQ300,
size 0.3 m x 0.3 m, reflectance 98%



LIDAR

RIEGL VZ-400
(modified / unmodified)



LIDAR MEASUREMENTS

- target at 50 m distance
- nearly normal incidence
- angular sampling 0.001 deg
- overlapping footprints (~ x 20)

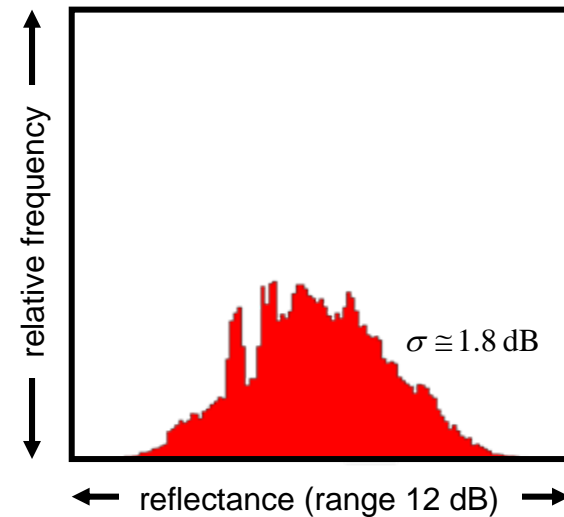
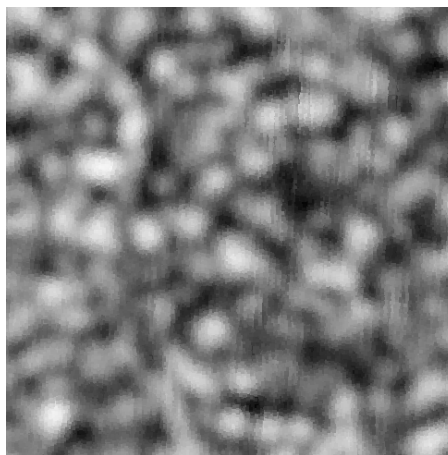
modified RIEGL VZ-400

- receiver aperture size reduced to beam diameter

$$A_R \cong A_T$$

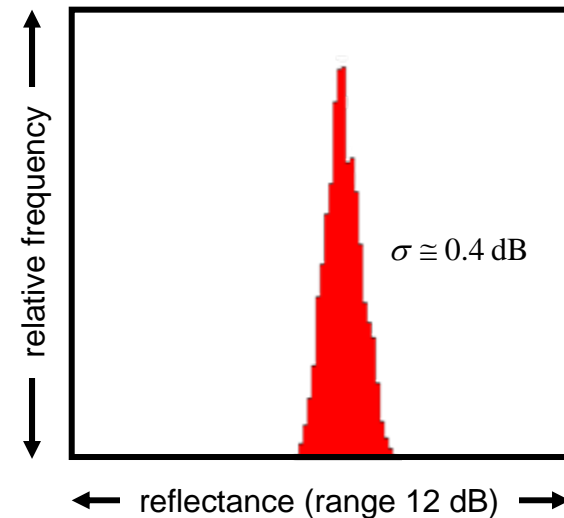
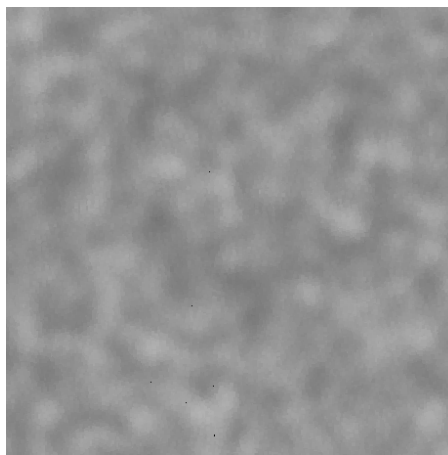
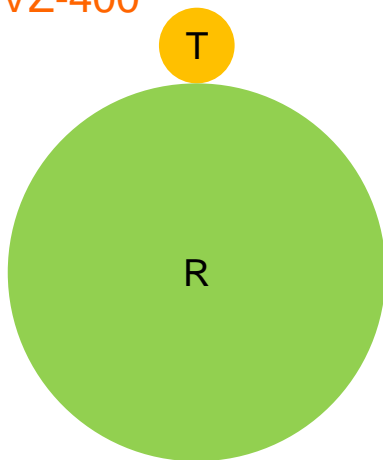


T .. transmitter aperture
R .. receiver aperture



unmodified RIEGL VZ-400

$$A_R \cong 25A_T$$

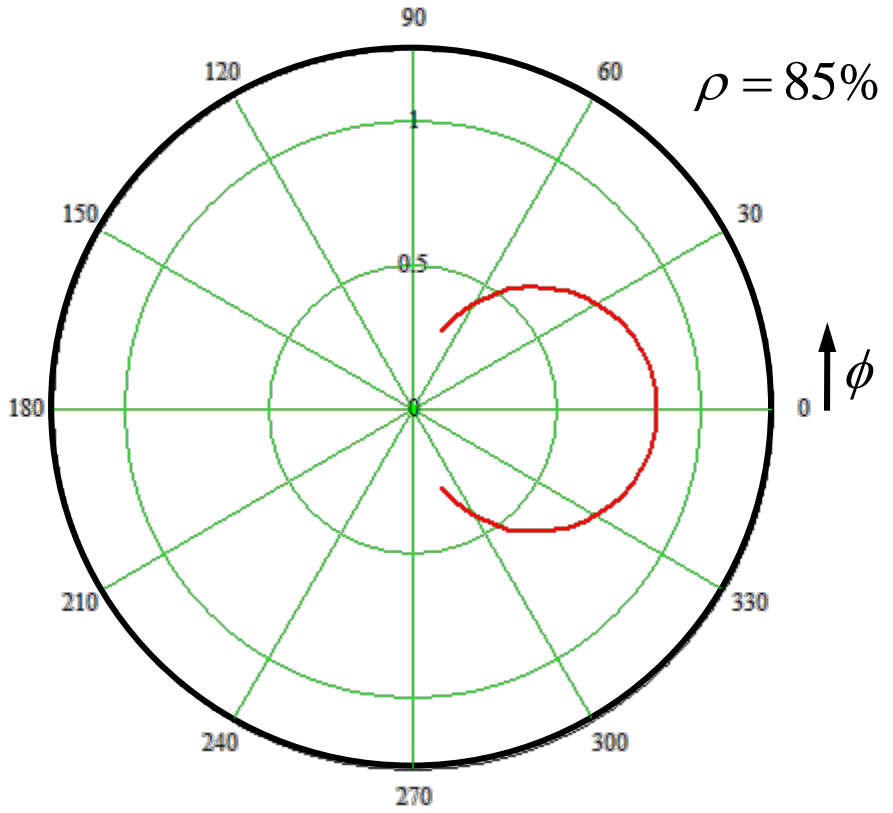
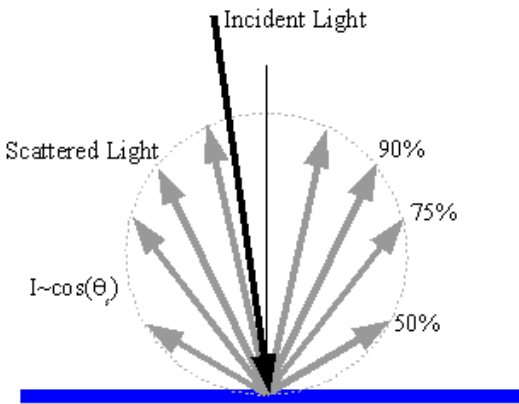




ideal Lambertian target

$$\gamma = 4\rho \cos \phi$$

$$\sigma = 4A_f \rho \cos \phi$$

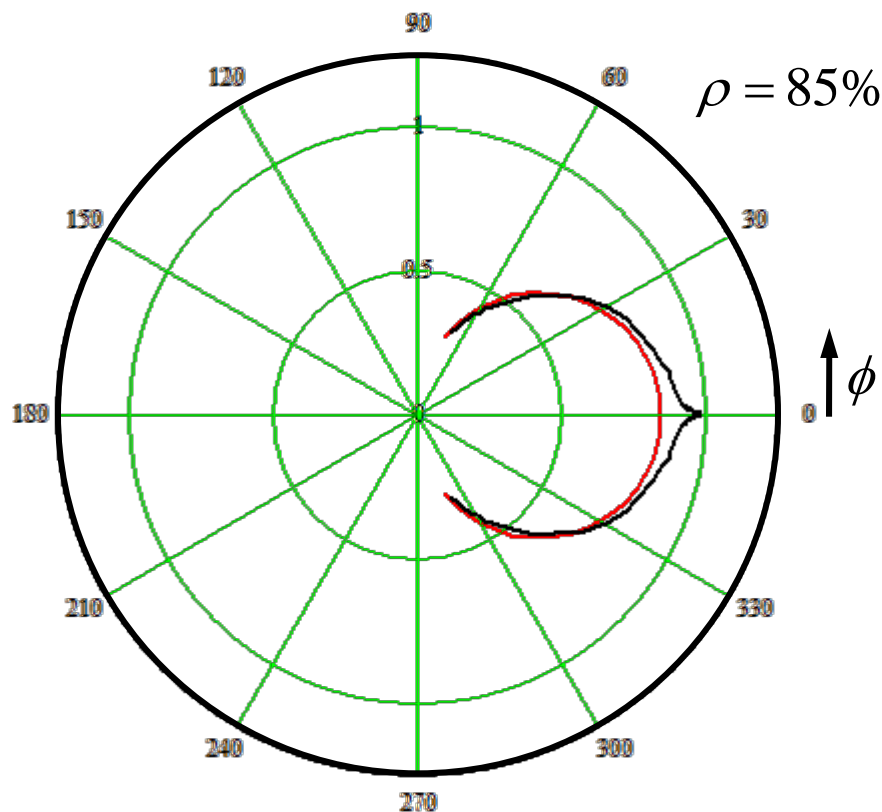


real diffusely reflecting target

$$\gamma \approx 4\rho \cos \phi$$

$$\sigma \approx 4A_f \rho \cos \phi$$

dry crown tile



glossy, diffusely reflecting target

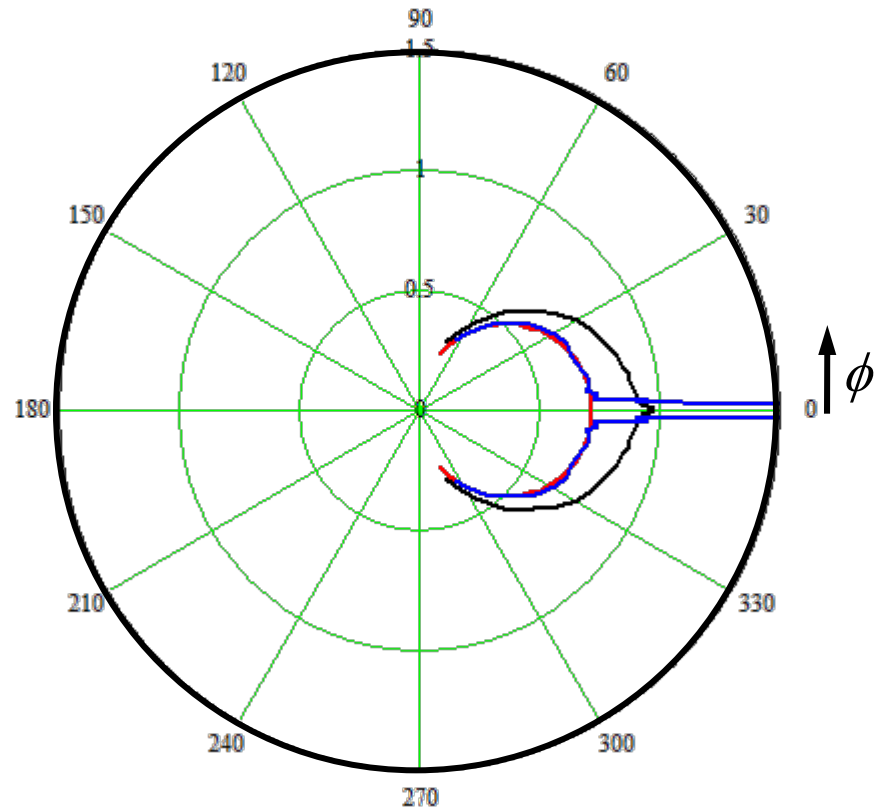
$$\gamma \neq 4\rho \cos \phi$$

$$\sigma \neq 4A_F \rho \cos \phi$$

Lambertian 72%

dry crown tile

wet crown tile



glossy, diffusely reflecting target

$$\gamma \neq 4\rho \cos \phi$$

$$\sigma \neq 4A_F \rho \cos \phi$$

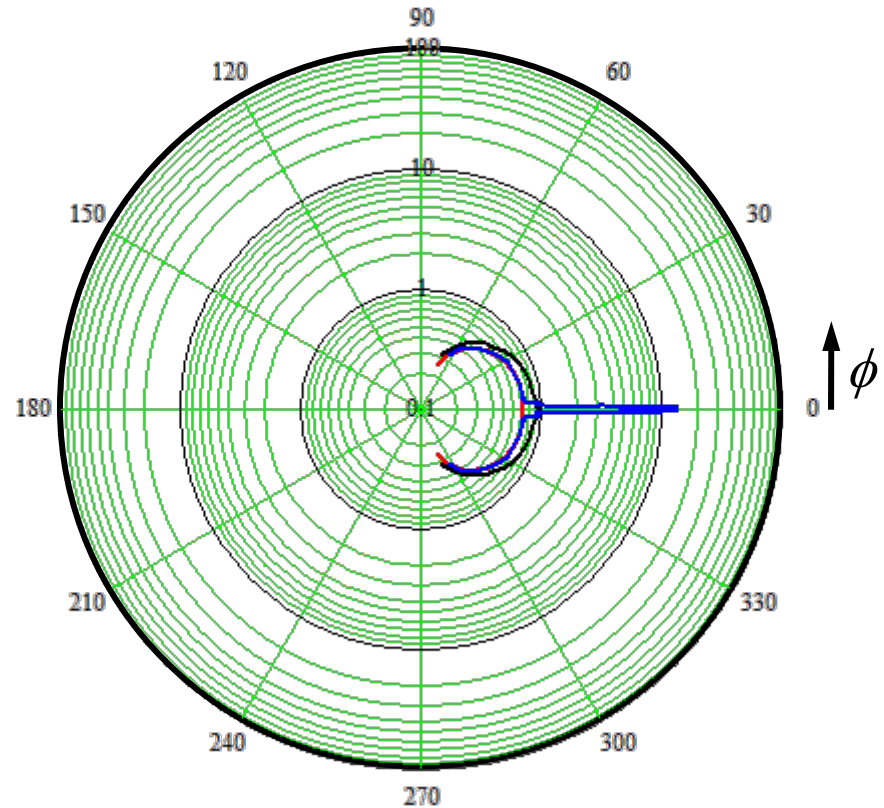
Lambertian 72%

dry crown tile

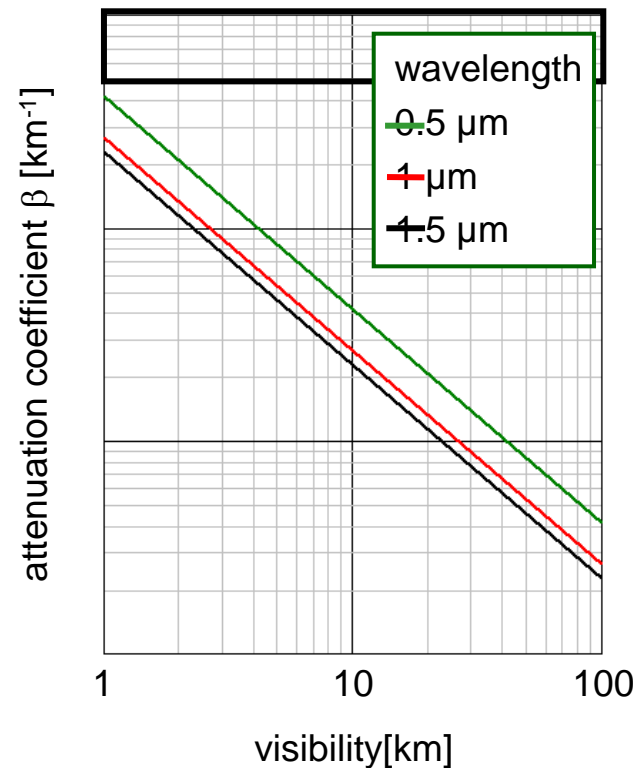
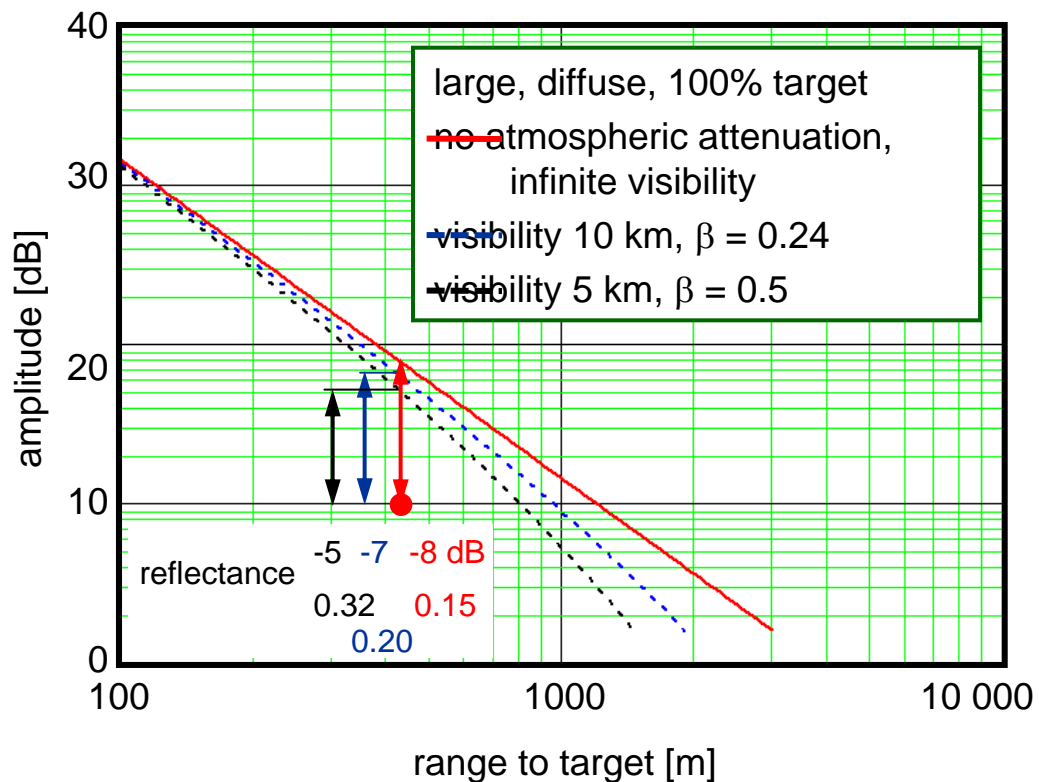
wet crown tile

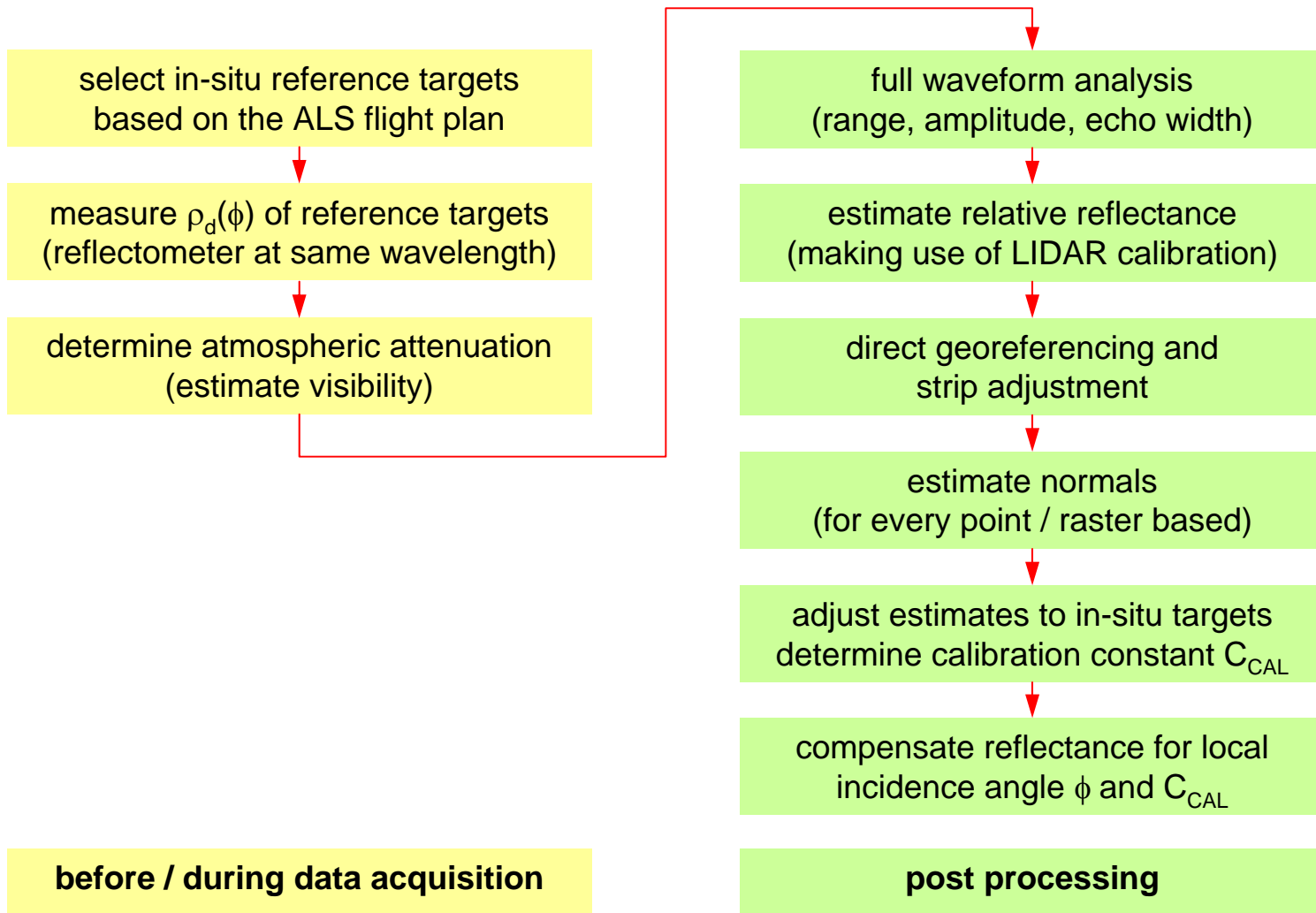
maximum at $\phi = 0$ deg:
~13, ~11.1 dB

$$\frac{\rho_{peak}}{\rho_{diffuse}} = \frac{13}{0.72} = 18$$

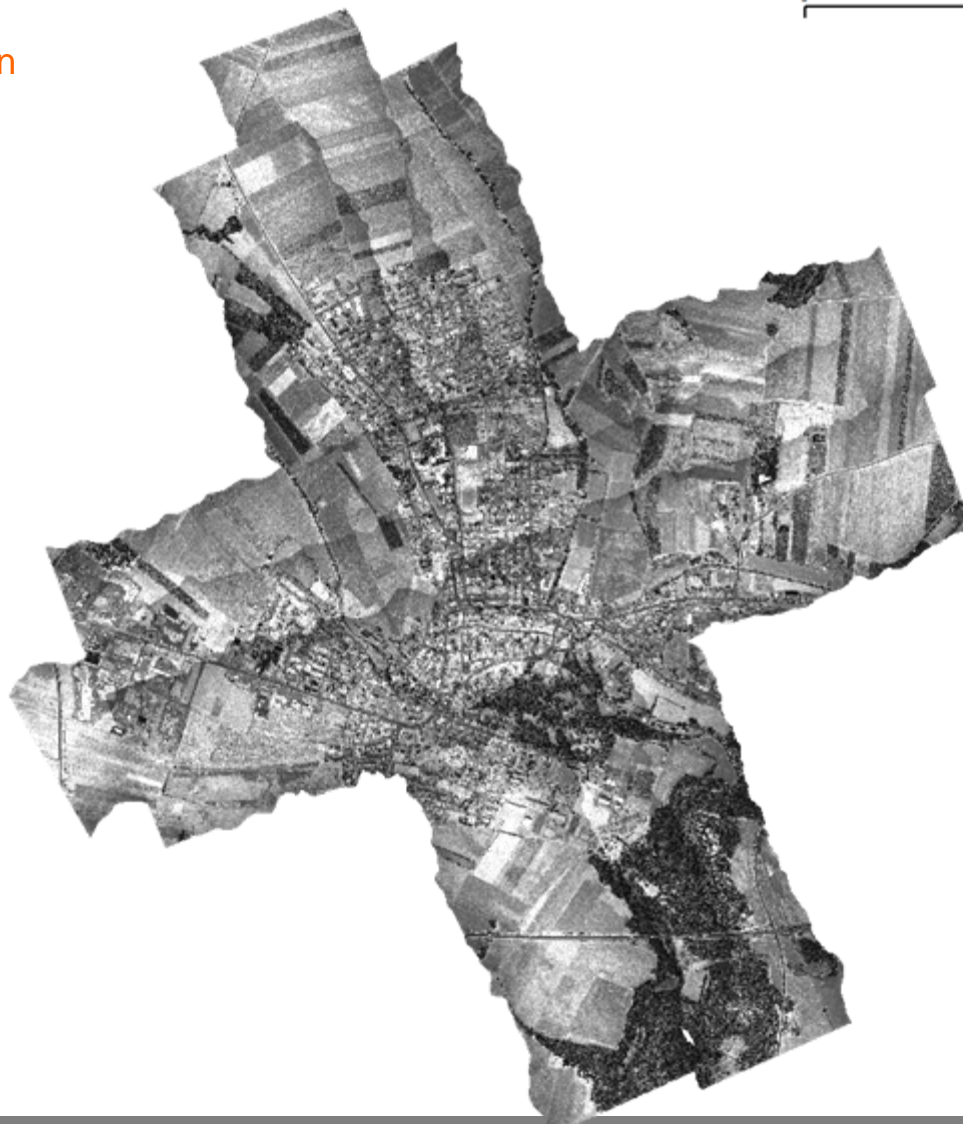


$$\eta_{\text{ATM}} \cdot \eta_{\text{ATM}} = e^{-2\beta R}$$





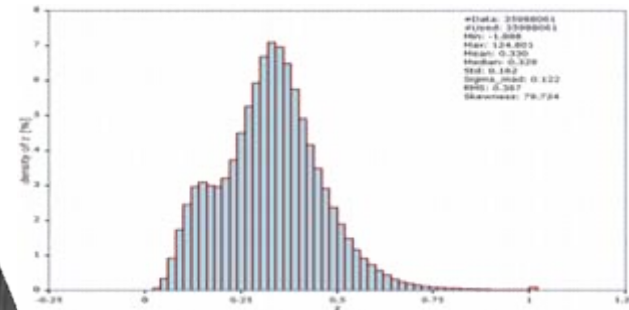
ALS – Flight Horn
 2011 09 22
 RIEGL Q680i



Black to White

| Value | Color | Comment |
|-------|---------------|----------------------------|
| BG | | background color white |
| 0 | | index_min |
| 37 | 32, 32, 32 | index_min |
| 75 | 64, 64, 64 | index_min |
| 150 | 127, 127, 127 | index_min |
| 225 | 190, 190, 190 | index_min |
| 300 | 255, 255, 255 | overflow color = index_max |

ALS – Flight Horn
 2011 09 22
 RIEGL Q680i

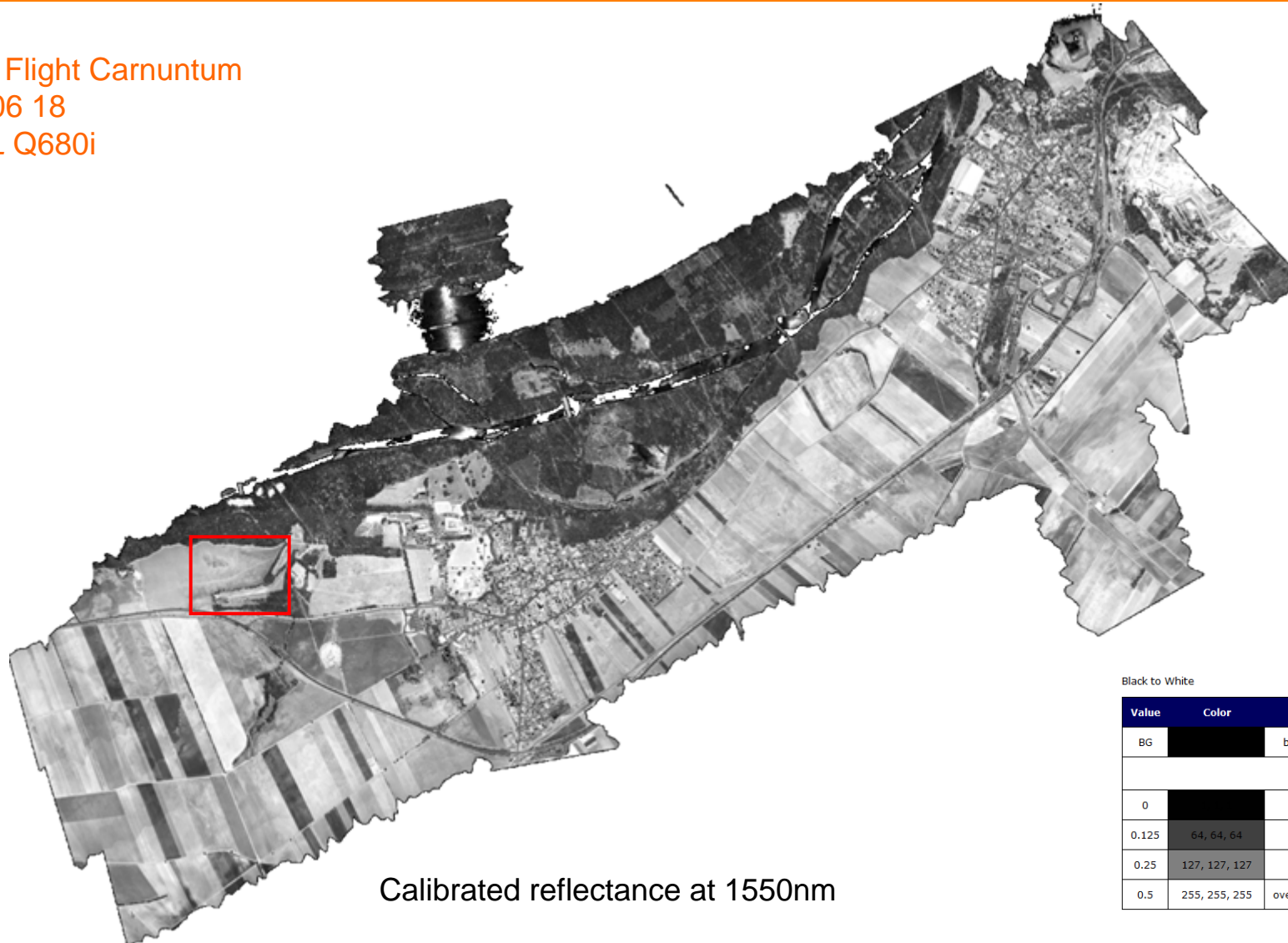


Calibrated reflectance at 1550nm

Black to White

| Value | Color | Comment |
|-------|---------------|----------------------------|
| BG | | background color white |
| 0 | | index_min |
| 0.125 | 32, 32, 32 | index_min |
| 0.25 | 64, 64, 64 | index_min |
| 0.500 | 127, 127, 127 | index_min |
| 0.75 | 190, 190, 190 | index_min |
| 1 | 255, 255, 255 | overflow color = index_max |

ALS – Flight Carnuntum
 2012 06 18
 RIEGL Q680i



Calibrated reflectance at 1550nm

Black to White

| Value | Color | Comment |
|-------|---------------|----------------------------|
| BG | | background color white |
| 0 | | index_min |
| 0.125 | 64, 64, 64 | index_min |
| 0.25 | 127, 127, 127 | index_min |
| 0.5 | 255, 255, 255 | overflow color = index_max |

detail:



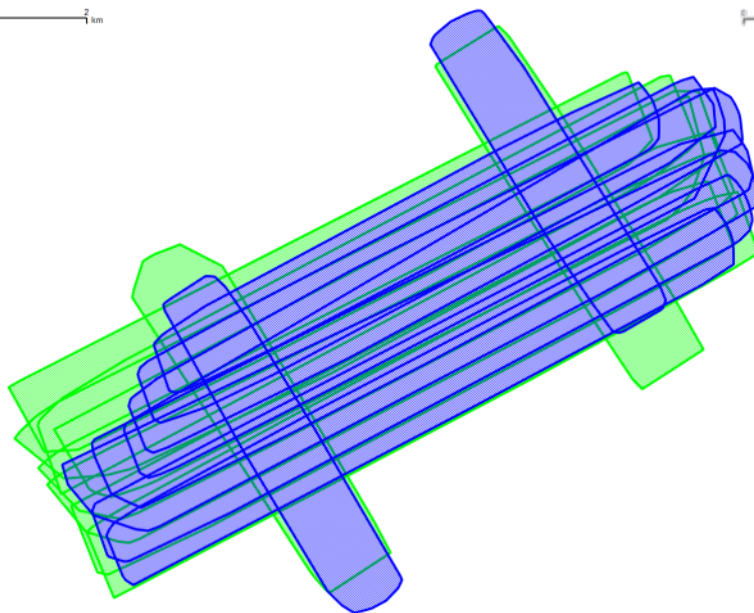
Black to White

| Value | Color | Comment |
|-------|---------------|----------------------------|
| BG | | background color white |
| 0 | | index_min |
| 0.125 | 64, 64, 64 | index_min |
| 0.25 | 127, 127, 127 | index_min |
| 0.5 | 255, 255, 255 | overflow color = index_max |

2 ALS flight missions

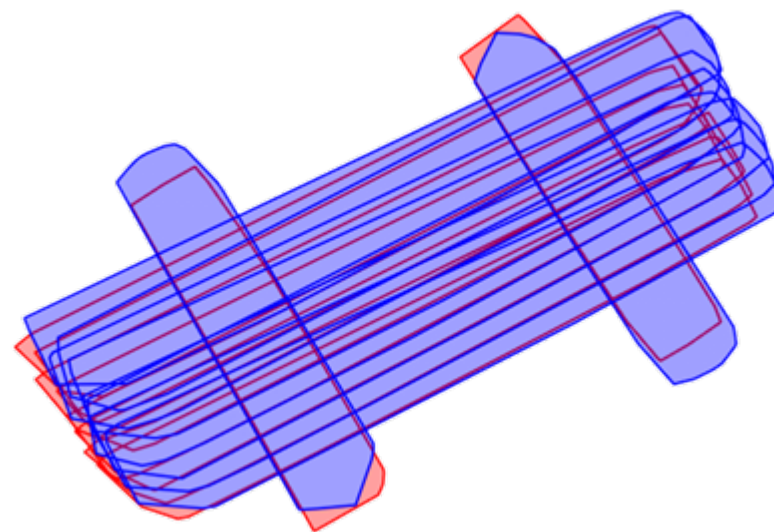
- 2013 05 24: *RIEGL VQ-580i* and *RIEGL VQ-820-G* (1064 nm and 532 nm)
- 2013 05 28: *RIEGL VQ-480i* and *RIEGL VQ-820-G* (1550 nm and 532 nm)

0 1 km



2013 05 24

0 1 km



2013 05 28

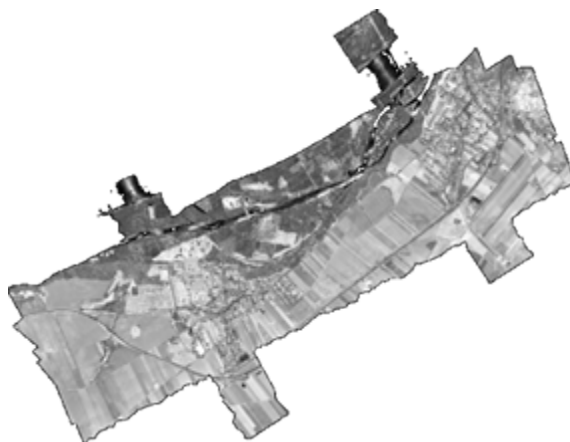
RIEGL VQ-820-G

0.5 μm



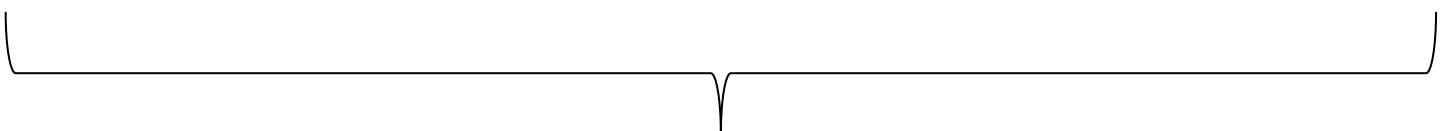
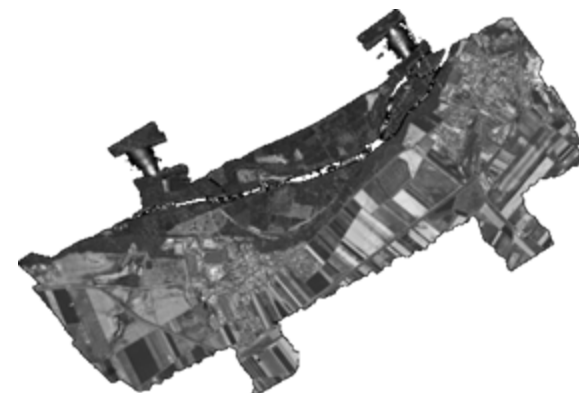
RIEGL VQ-580

1.0 μm

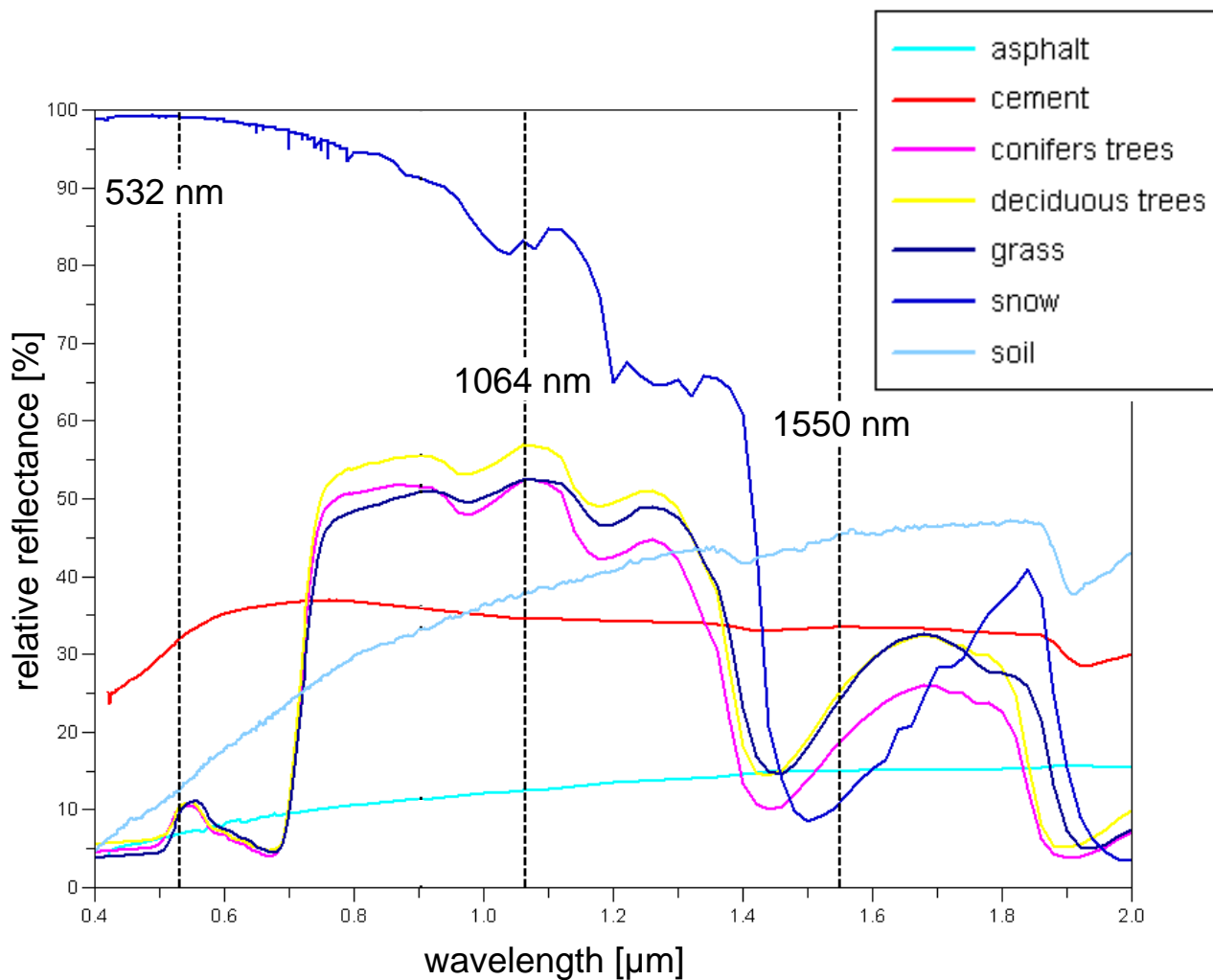


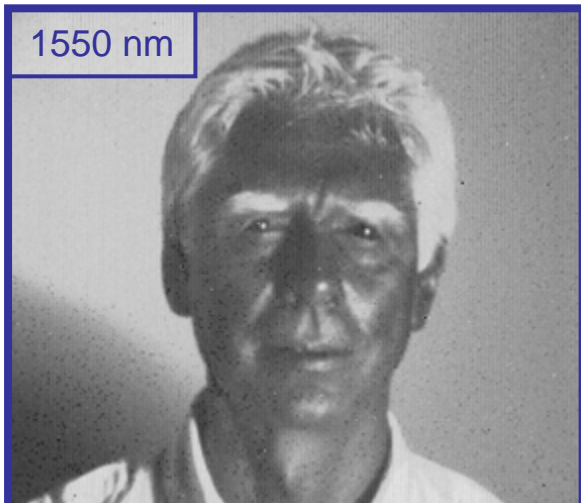
RIEGL VQ480i

1.5 μm



calibrated multi-wavelength reflectance image

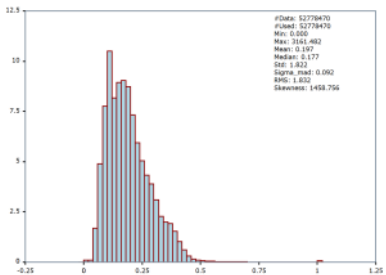




visible
532 nm
1064 nm
1550 nm

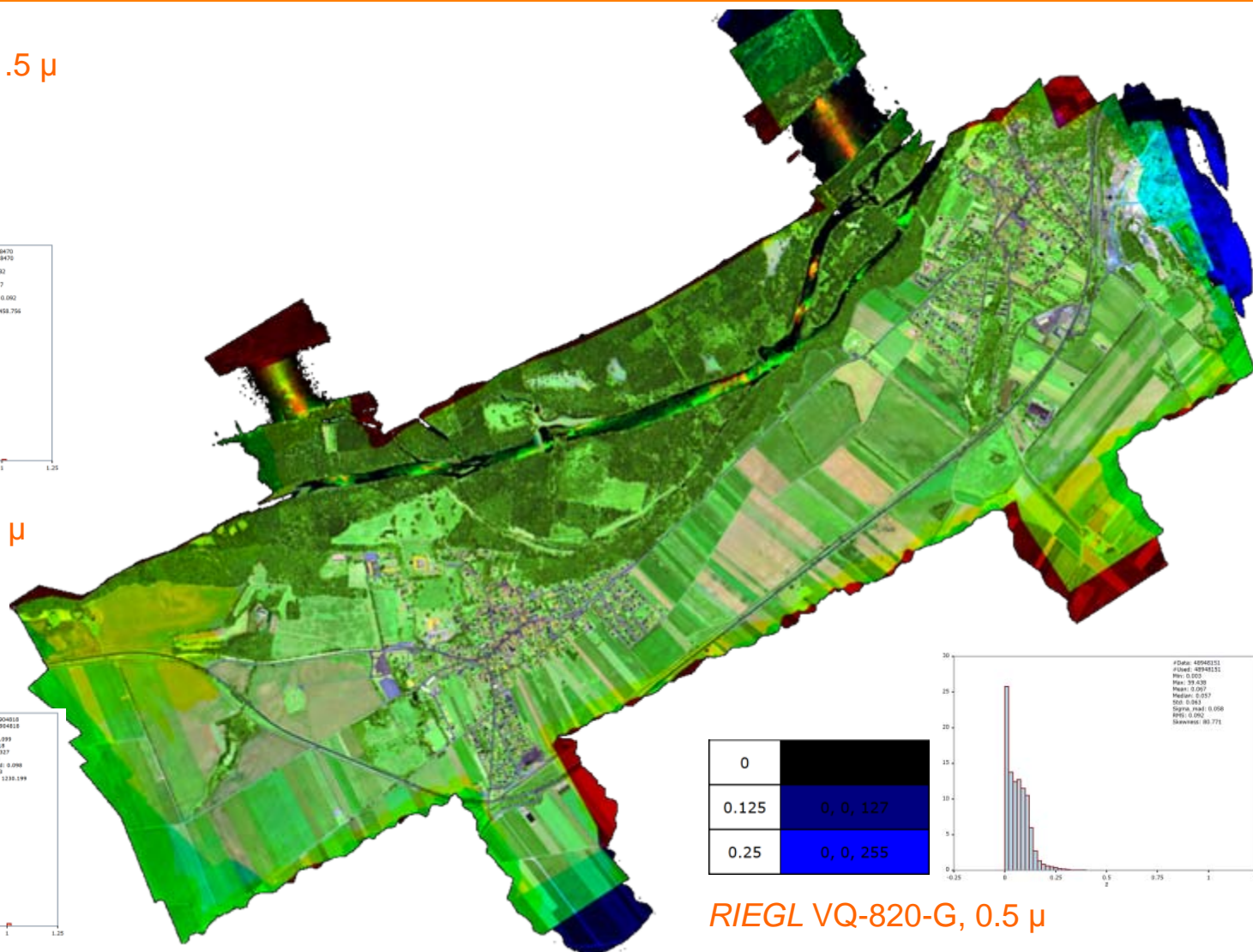
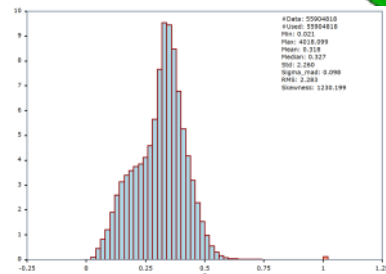
RIEGL VQ-480i, 1.5 μ

| | |
|------|-----------|
| 0 | |
| 0.25 | 128, 0, 0 |
| 0.5 | 255, 0, 0 |

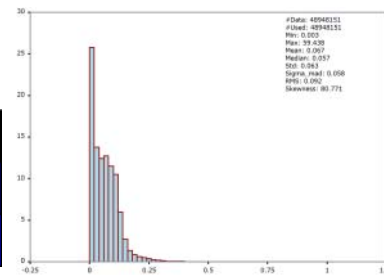


RIEGL VQ-580, 1 μ

| | |
|------|-----------|
| 0 | |
| 0.25 | 0, 127, 0 |
| 0.5 | 0, 255, 0 |



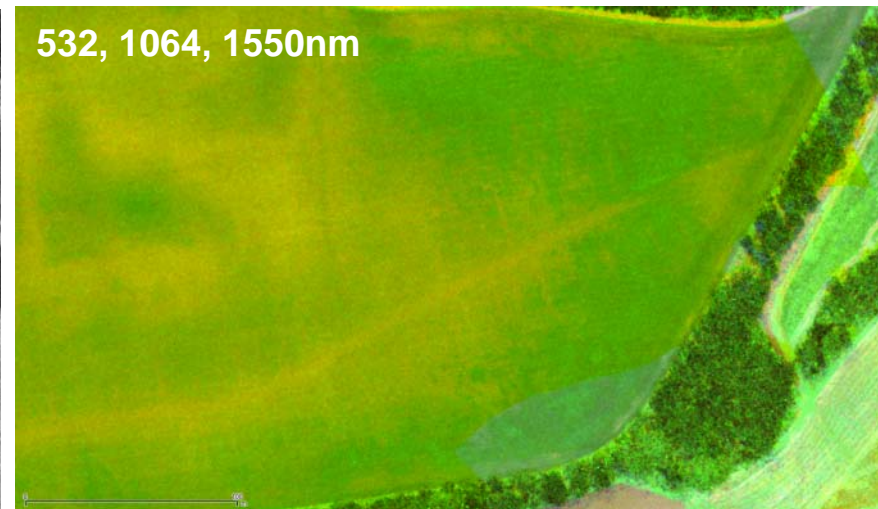
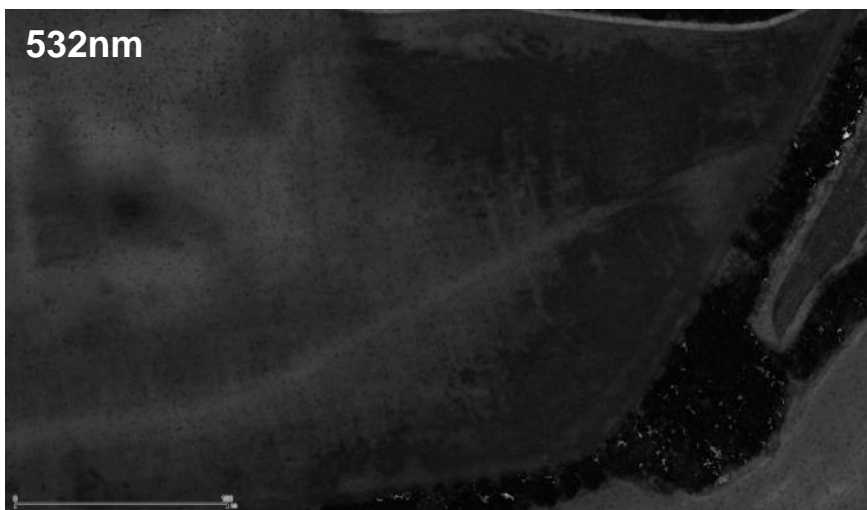
| | |
|-------|-----------|
| 0 | |
| 0.125 | 0, 0, 127 |
| 0.25 | 0, 0, 255 |




RIEGL VQ-820-G, 0.5 μ







- **radiometric calibration** is essential for the physical interpretation of the recorded full-waveform signal (physical observables)
- **physical properties** have to be considered (speckles, target reflectance)
- **practical methods** are available 
- **adds** calibrated **spectral information to the ALS point cloud**
- **LiDAR properties** compared to passive imagery:
 - active illumination → no shadows caused by sunlight
 - well defined wavelengths
 - true-orthophoto from the point cloud