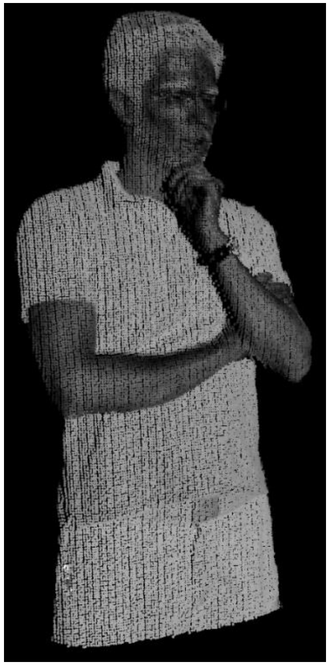
Interdisciplinary Center for Scientific Computing

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

HEIDELBERG CENTER FOR THE ENVIRONMENT

3D Laser Scanning

Beyond Geometry: Radiometric information



Prof. Bernhard Höfle

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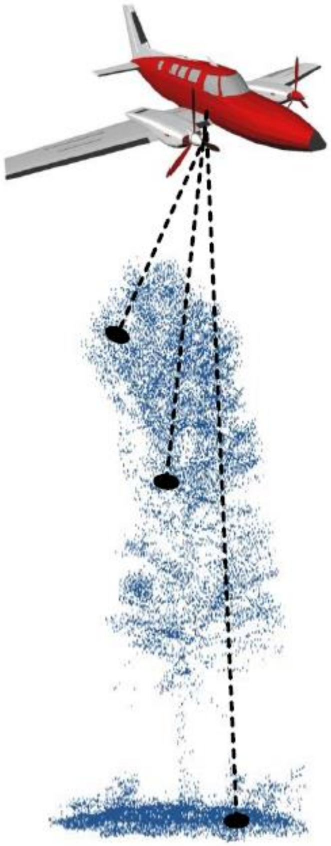
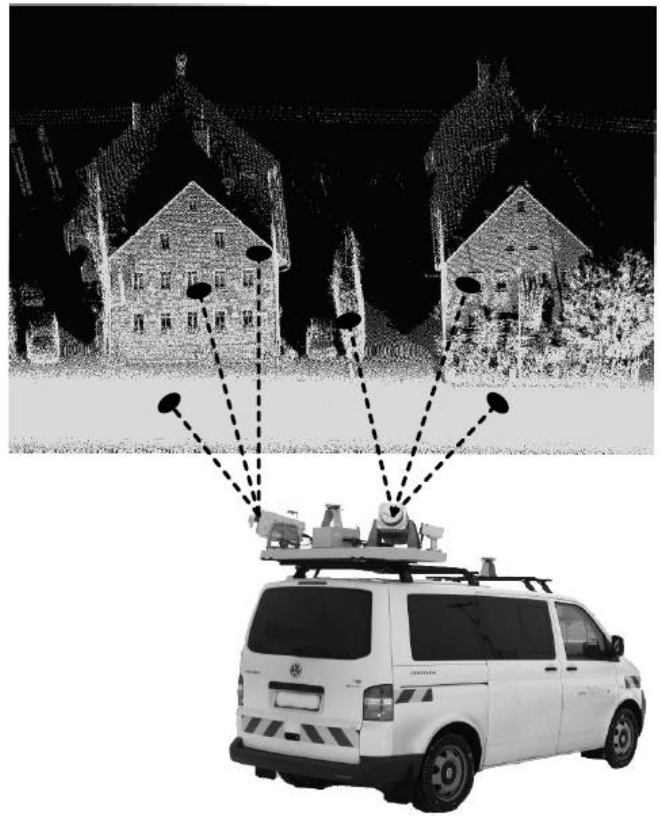
Department of Geography
Heidelberg University
Germany

LiDAR/Laser Scanning - Platforms

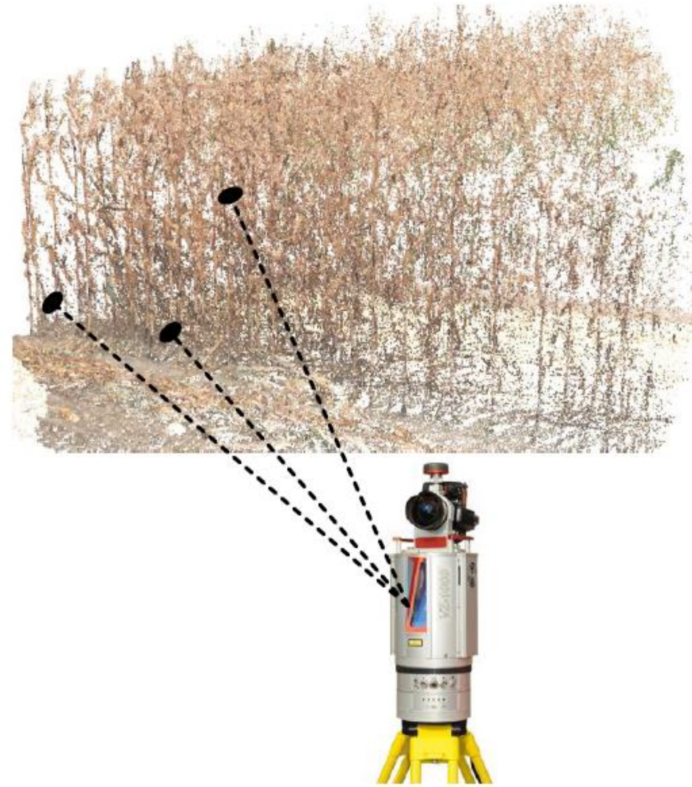
a) Airborne



b) Ground-based
Mobile

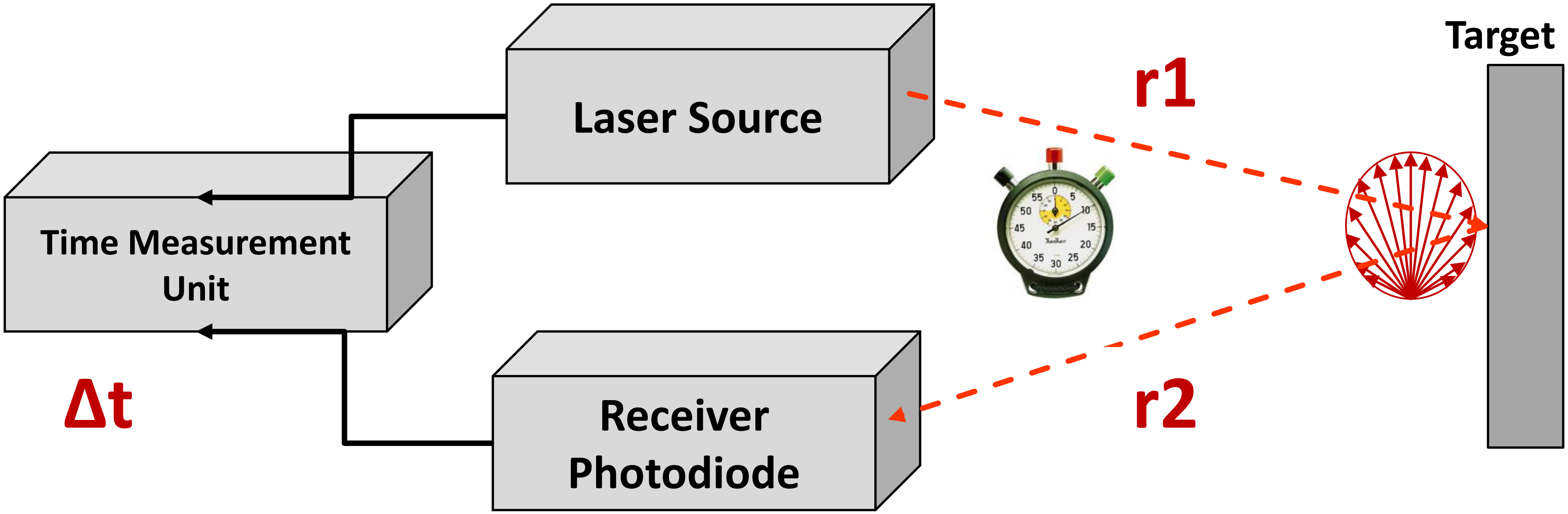


c) Ground-based
Static



LiDAR Technology

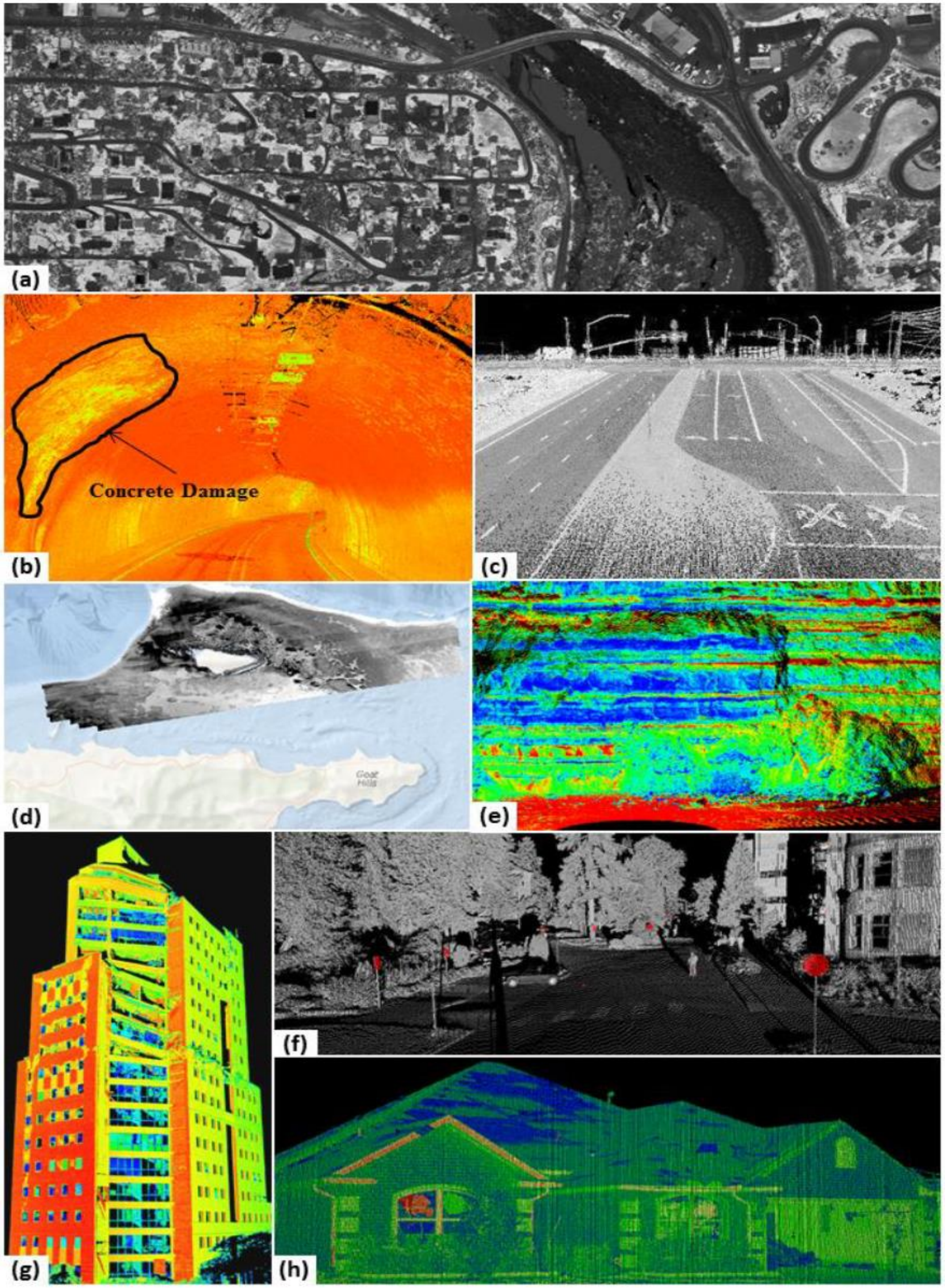
- LiDAR = Light Detection And Ranging
- Travel time of the laser beam



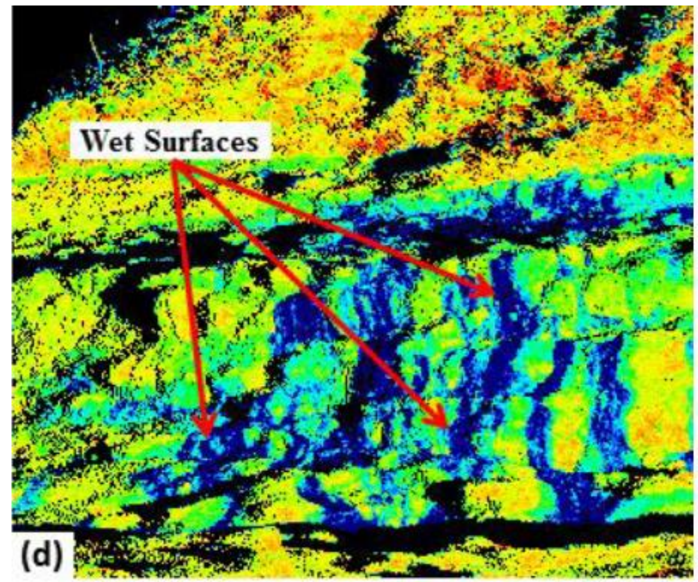
$$r = c \cdot \Delta t/2$$

r ... range (i.e. distance)
c ... group velocity of laser light

LiDAR Backscatter



Kashani et al. (2015)



Radiometric Information

- Additional information:
  - **signal intensity**, signal amplitude, backscatter, etc.
- Is stored as additional attribut (x y z r ***i***)
- Information about reflectivity of surfaces in a certain wavelength is derived (e.g. 900-1550nm)

X	Y	Z	I
33450006.57	7395000.19	1163.95	44
33450008.58	7395000.25	1163.90	40
33450011.39	7395000.07	1164.30	11
33450011.92	7395000.04	1164.65	14
33450016.60	7395000.12	1164.85	22
33450020.26	7395000.30	1165.08	54
33450028.01	7395000.08	1165.25	28
33450038.28	7395000.16	1166.02	22
33450045.23	7395000.07	1166.48	28
33450045.42	7395000.11	1166.16	52
33450052.69	7395000.21	1166.80	29
…			

Radiometric Information

- **Complementary to geometric information** (independent)
- Active system → sun shadowing effects and illumination **do not** influence the results

Reflectivity (900 nm)

White paper	up to 100%
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
Beer foam	88%
White masonry	85%
Limestone, clay	up to 75%
Newspaper with print	69%
Tissue paper, two ply	60%
Deciduous trees	typ. 60%
Coniferous trees	typ. 30%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, bare areas in dessert	typ. 50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black neoprene	5%
Black rubber tire wall	2%

Source: Riegl

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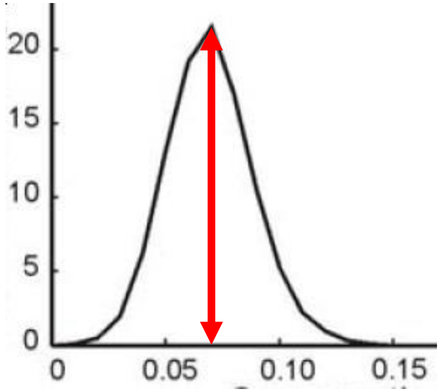
Radiometric Information

$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2} \eta_{sys} \eta_{atm} \sigma_{cross}$$

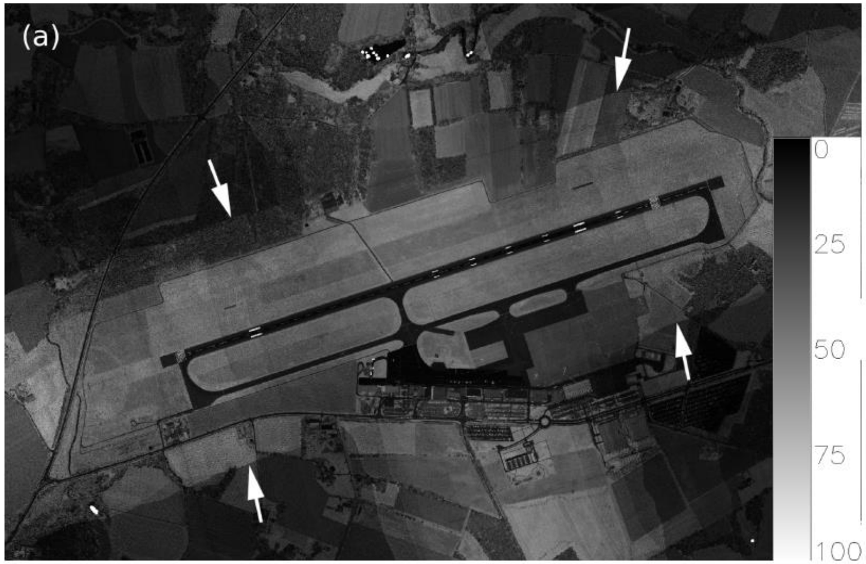


- **Amplitude** of the recorded signal
- depends on:
  - strength of transmitted pulse
  - **distance (*Range*)**
  - atmospheric conditions
  - **topography (incidence angle)**
  - surface relectivity i.e. Type, size

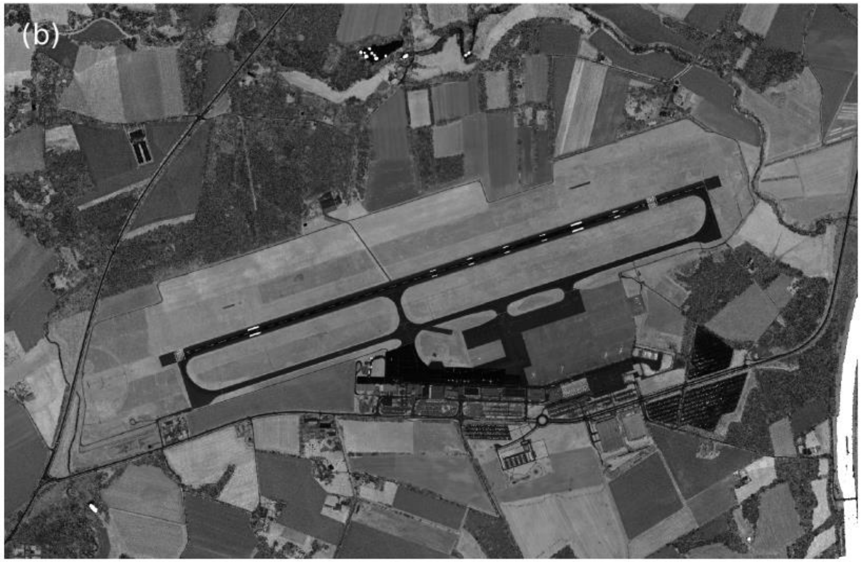
Höfle & Pfeifer (2007)

Range/Distance Effect (Airborne LiDAR)

uncorrected intensity image

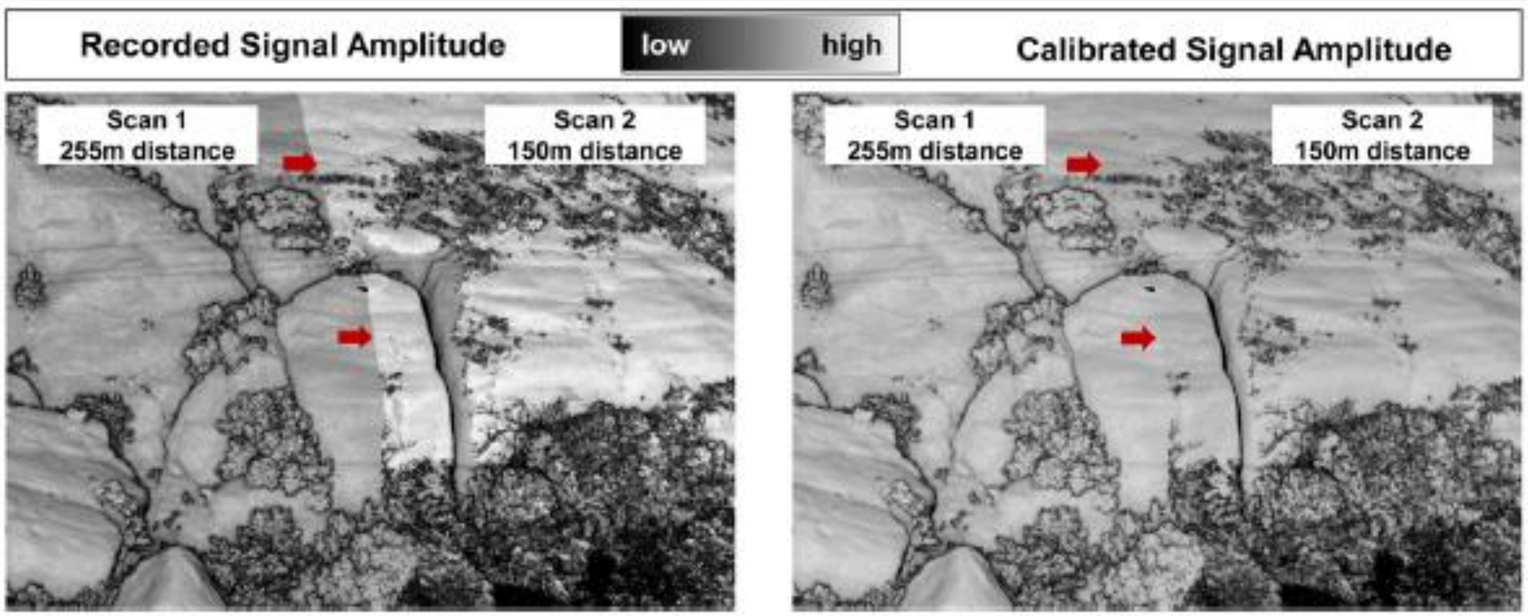


corrected intensity image



Höfle & Pfeifer (2007)

Range/Distance Effect (Terrestrial LiDAR)



lidar signal amplitude before (left) and after (right) the removal of the range-dependent effects

Eitel et al. (2016)

Theoretical Effects on Intensity

Range (Sensor)

Incidence Angle (Target)

$$I_c = I \cdot \frac{{R_i}^2}{{R_{ref}}^2} \cdot \frac{1}{\cos \alpha} \qquad (5)$$

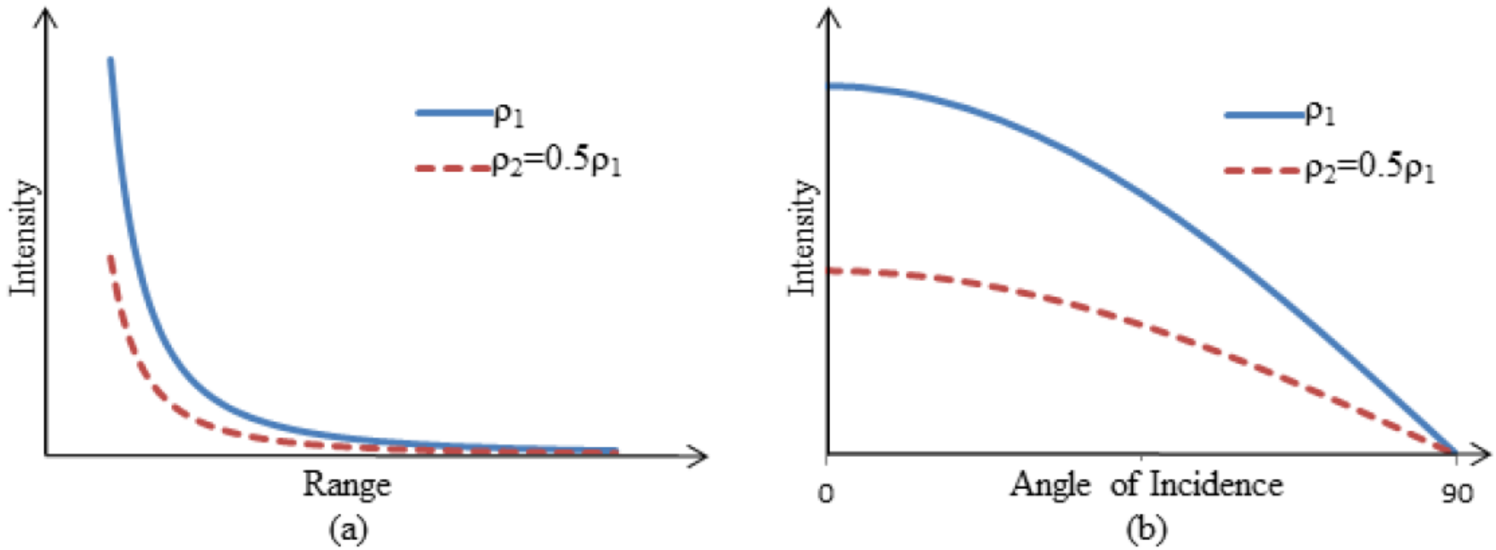


Figure 6. (**a**) Theoretical relationship of intensity measurements *vs*. range shown for two materials with different reflectance (ρ); and (**b**) theoretical relationship of intensity measurements *vs*. angle of incidence shown for two materials with different reflectance (ρ).

Kashani et al. (2015)

Incidence Angle Effect

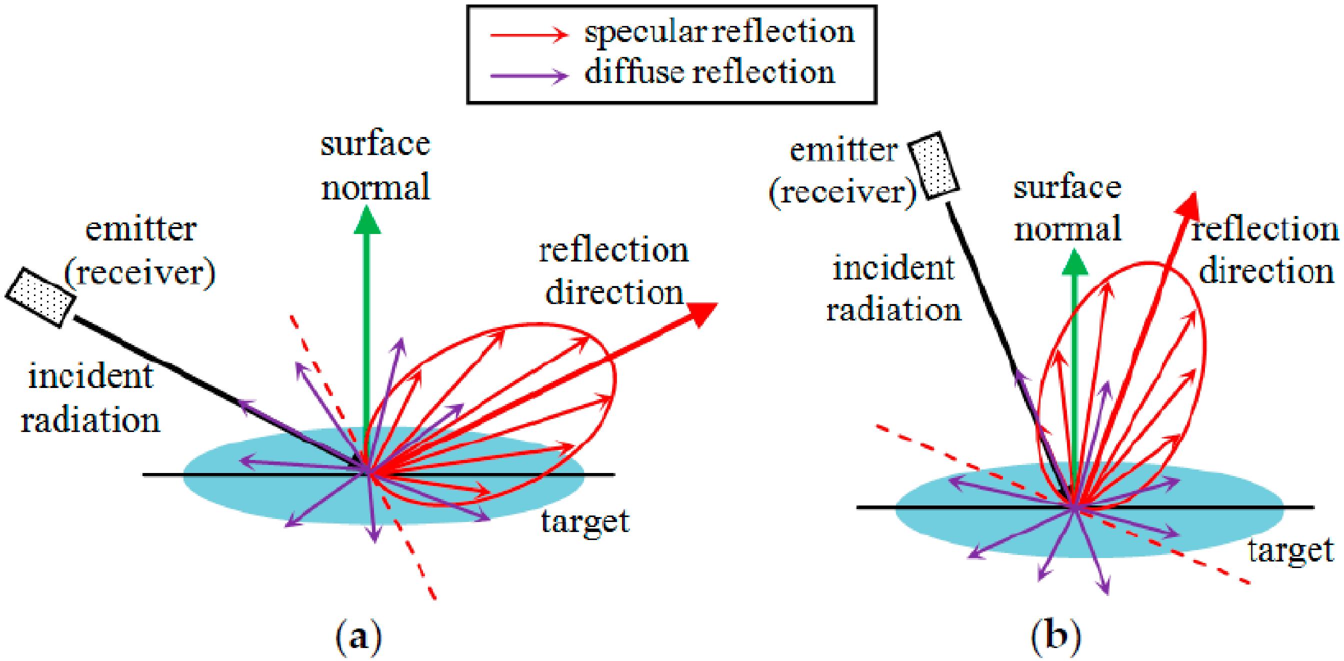
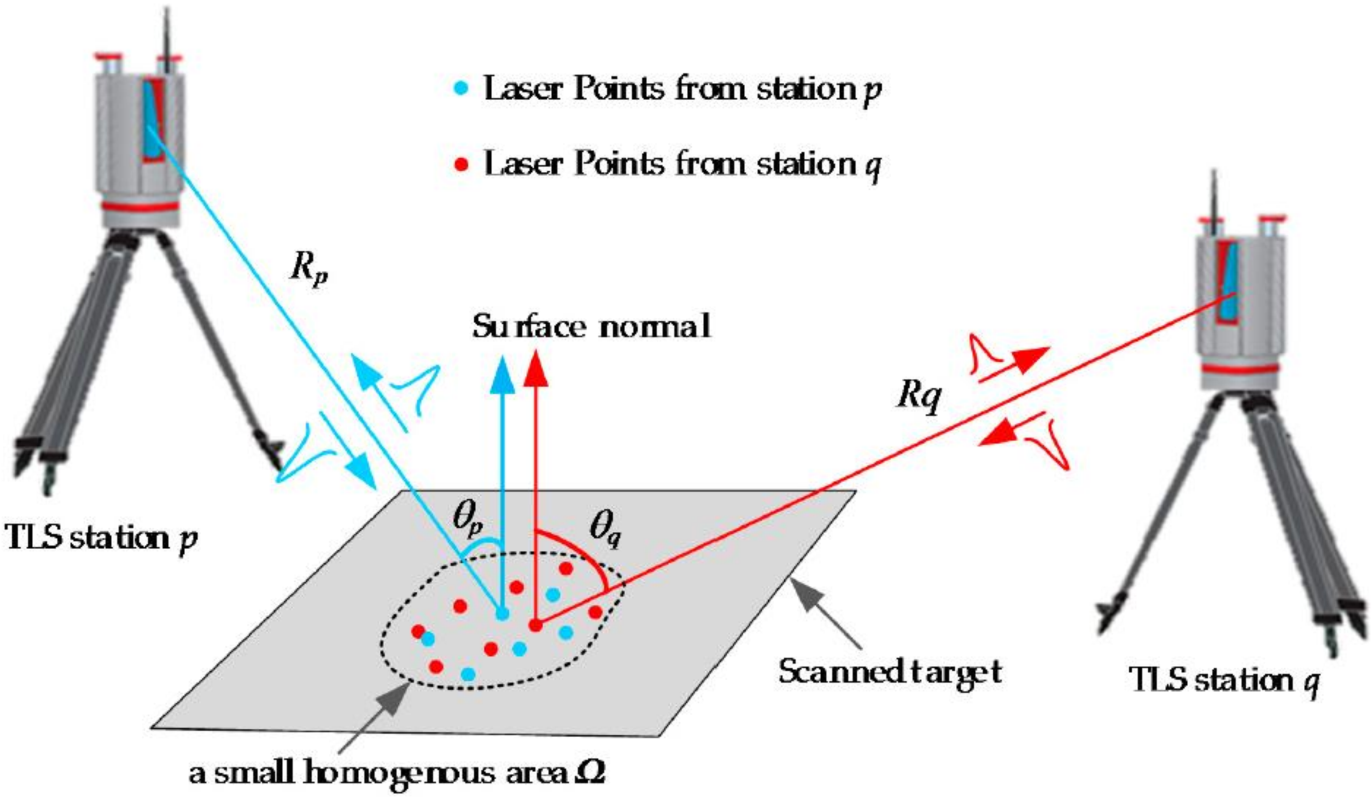


Figure 1. (**a**) At incidence angles larger than 45°, only diffuse reflections reach the receiver. (**b**) At incidence angles smaller than 45°, both diffuse and specular reflections can be received. The red dotted lines are perpendicular to the reflection directions.

Tan & Cheng (2017)

Combined Range/Incidence Angle Effects



Xu et al. (2017)

Radiometric Correction/Calibration

- **Radiometric Correction**
  - Correction of known dependencies: e.g. via empirical model of range/angle effects

- **Radiometric Calibration** needs in situ measurements
  - Spectrophotometer measurements of surfaces (e.g. roads)
  - Areas with known reflectivity
  - Calibration constant can be determined to transform the recorded intensity signal into physical units

- **→Position of sensors (range) and scan angle is required!!!**

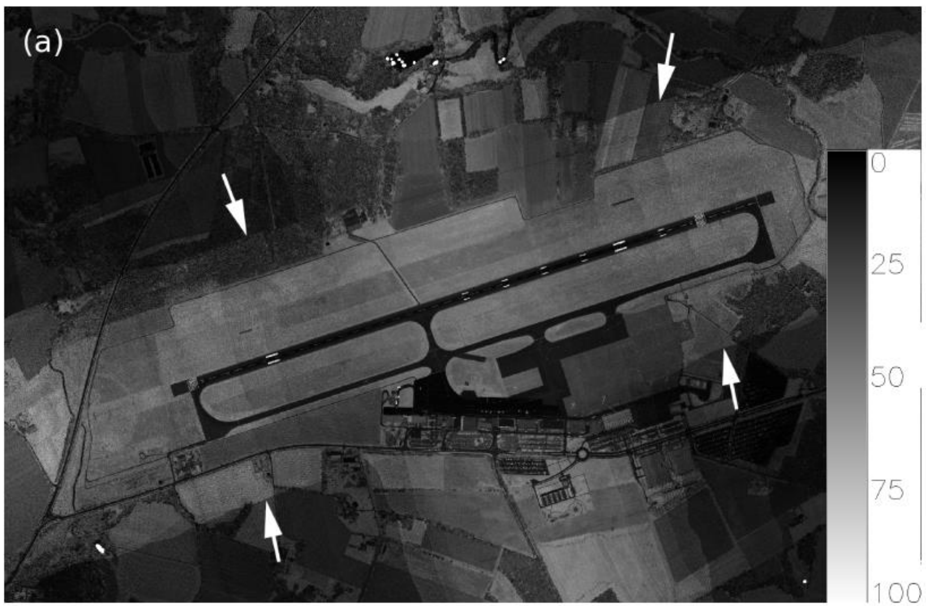
Radiometric calibration - signal amplitude

→ Transform the recorded quantities into physical units using the **radar equation**

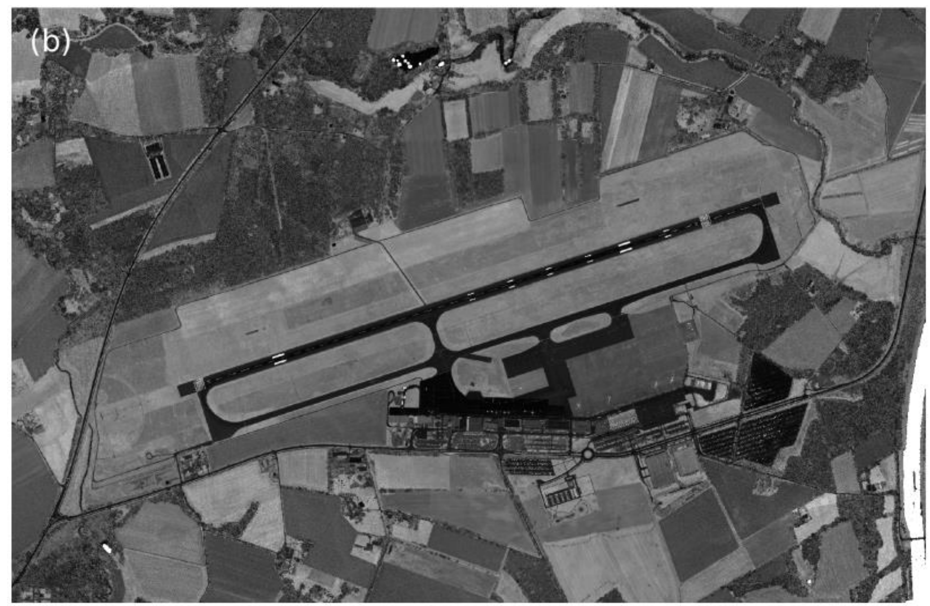
$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2} \eta_{sys} \eta_{atm} \sigma \,.$$

$$\sigma = \frac{4\pi}{\Omega} \rho A_s$$

Original image



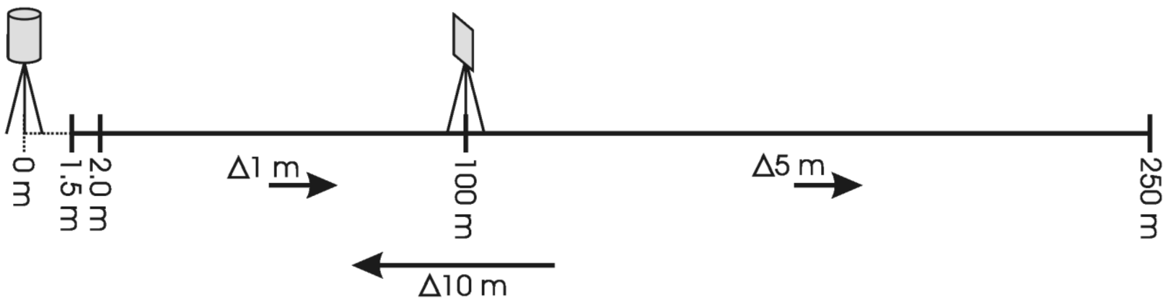
Corrected image

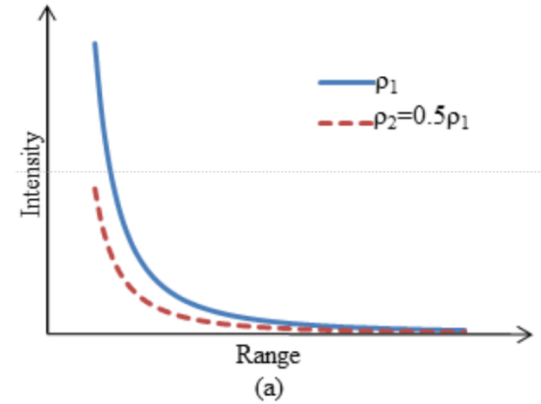


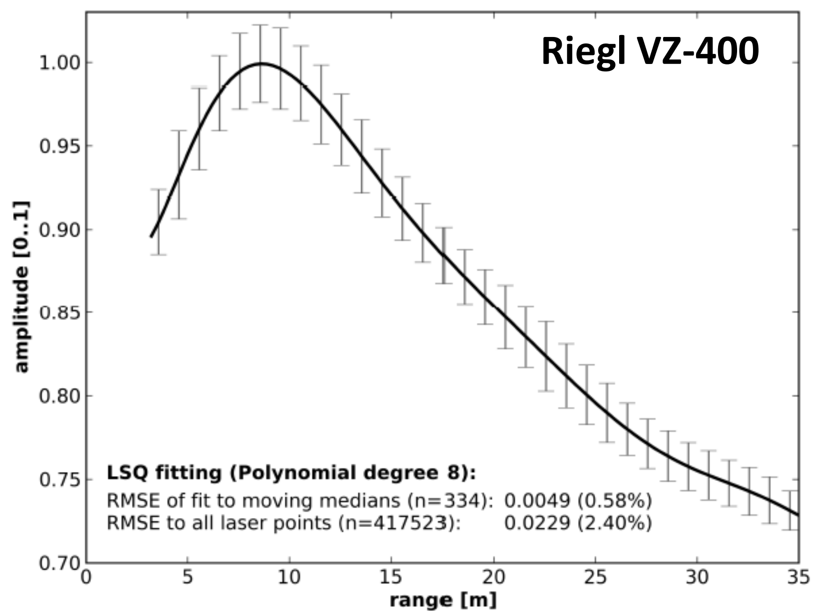
Höfle & Pfeifer (2007)

Radiometric calibration TLS

Recorded amplitude vs. range for **reference target**







Range-Intensity Relationship for TLS

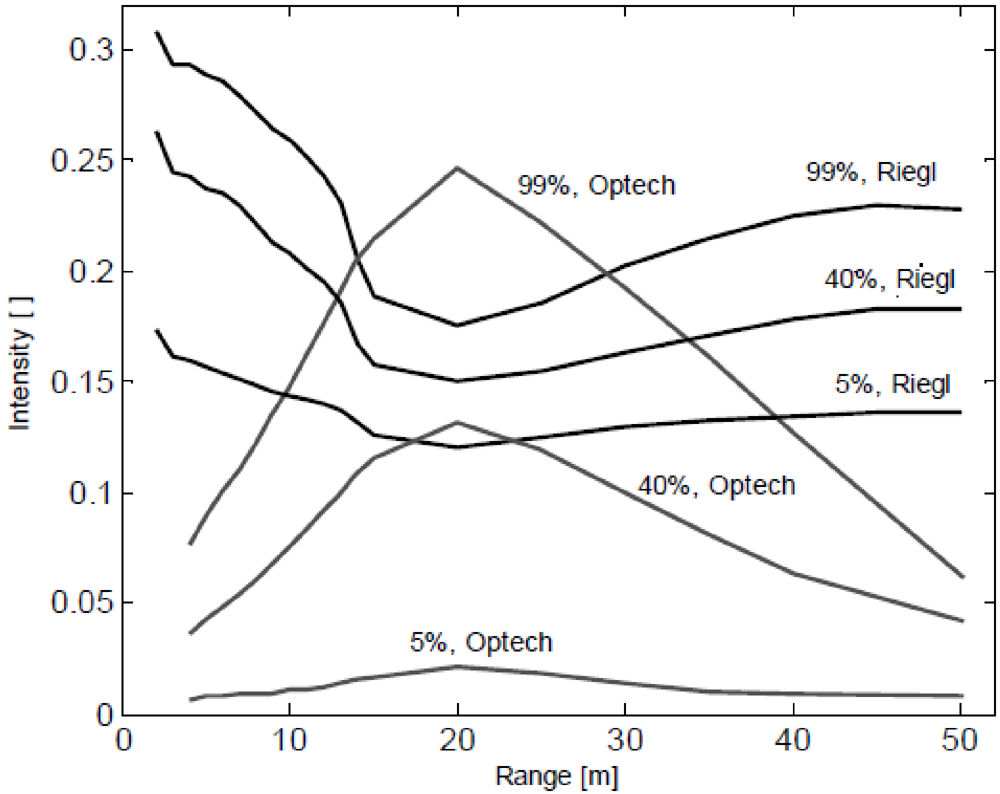
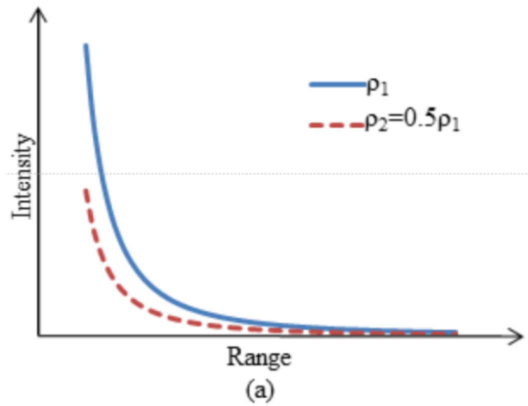


Figure 3. Mean intensities for the Riegl and the Optech laser scanner for three targets (99%, 40%, and 5% reflectivity) at different distances.



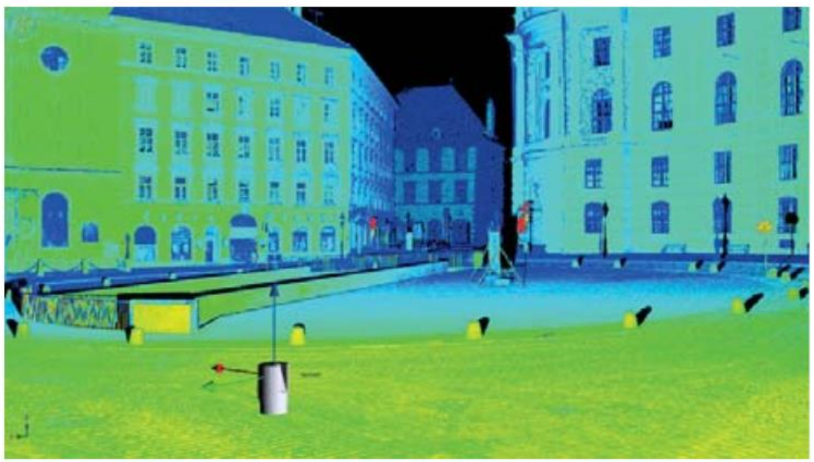
Pfeifer et al. (2008)

Online Calibration: Automatic Removal of Range Effect

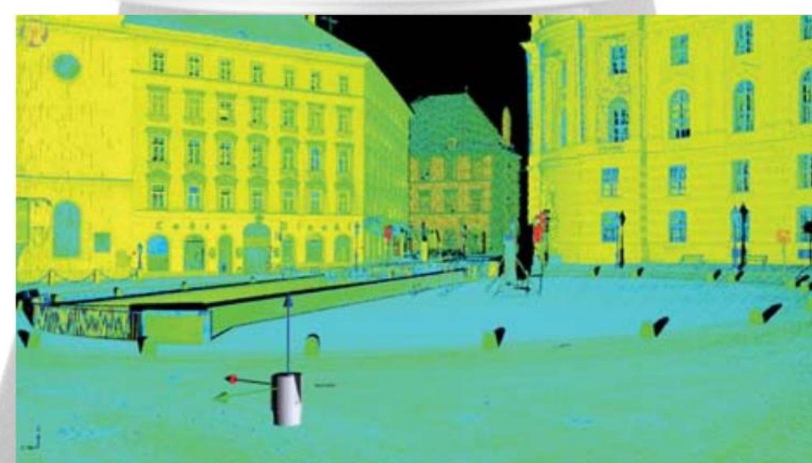
- Riegl VZ-line

Calibrated Reflectance Output

This feature allows displaying the scan data colored by range-independent reflectance of the scanned object for better data classification.



point cloud colored by the range-depending amplitude



point cloud colored by the range-independent reflectance

Riegl VZ-400i Datasheet

Radiometric Calibration TLS

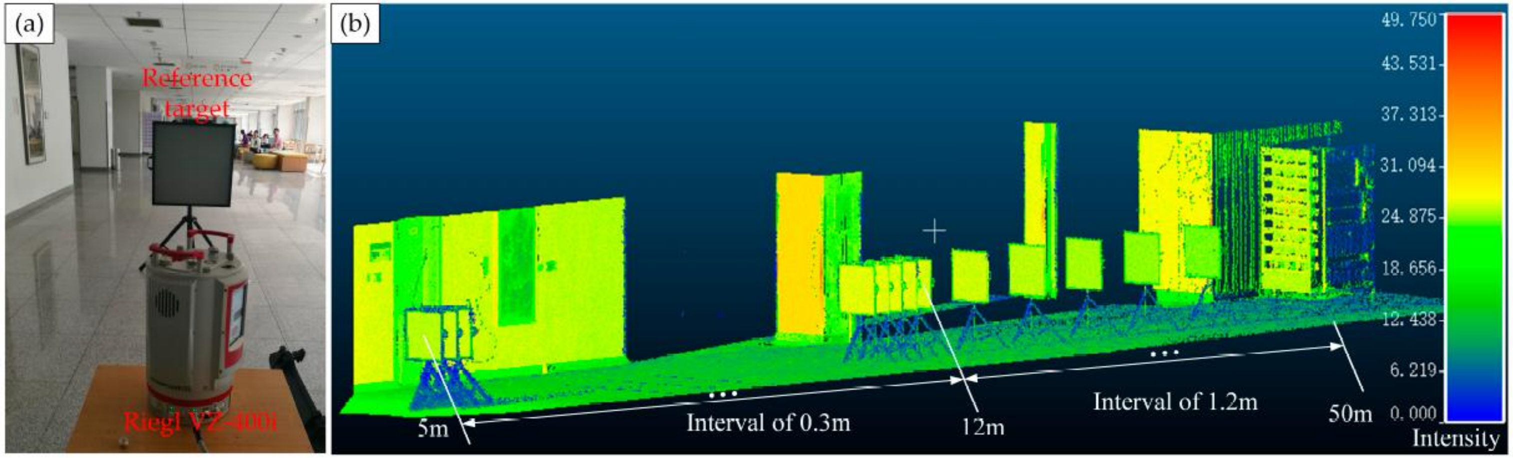
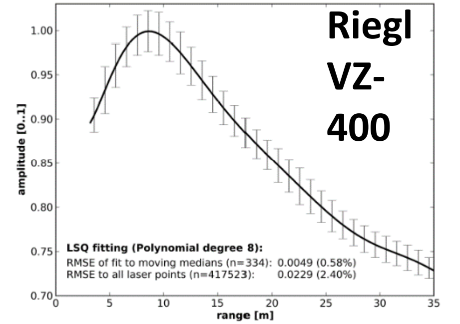


Figure 4. Experimental setup and scene of the distance experiment. (**a**) experimental setup including Riegl VZ-400i and three reference targets with reflectance of 15%, 30% and 60%, respectively; (**b**) scene of the distance experiment with distance from 5 m to 50 m, and a step interval of 0.3 m from 5 m to 12 m, and 1.2 m from 12 m to 50 m, respectively.

Xu et al. (2017)

Radiometric calibration TLS



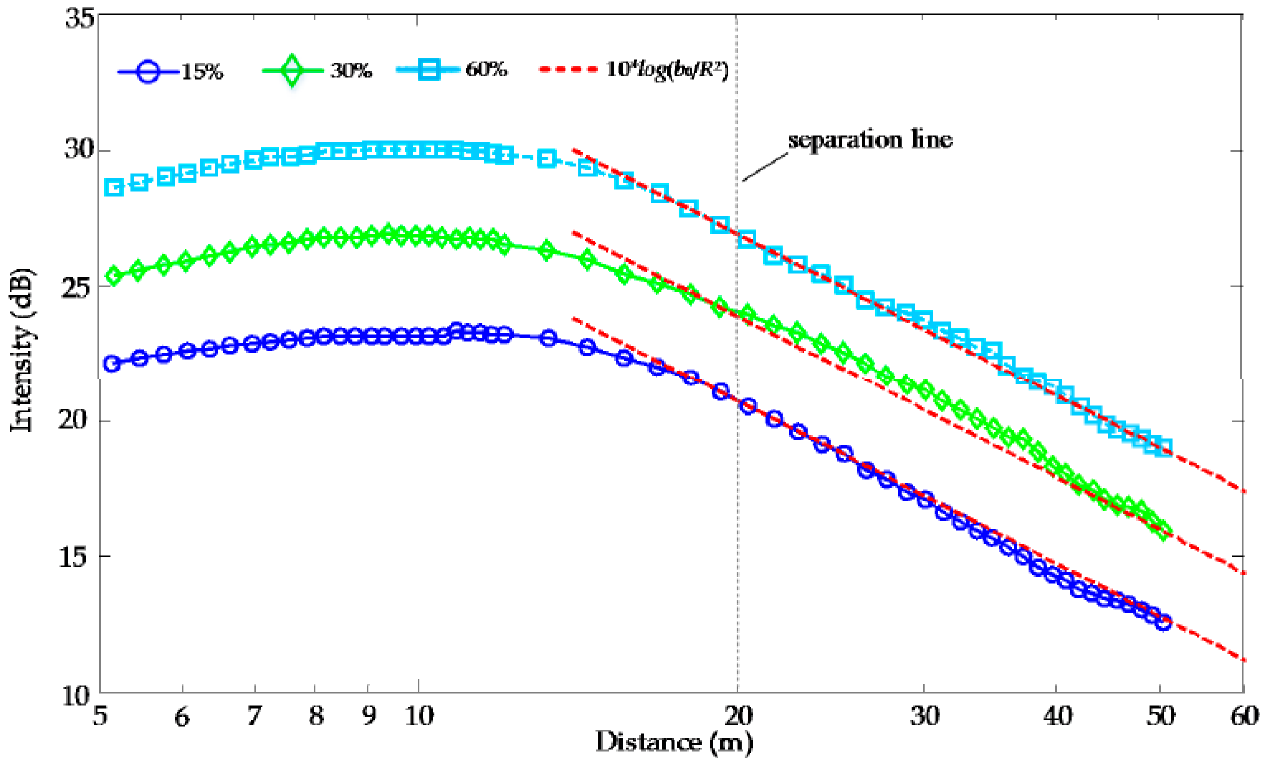


Figure 6. Variation of raw intensity data with distance for all of the three reference targets with the reflectance of 15%, 30% and 60% at the incident angle of 0°.

Xu et al. (2017)

Modeling Angle Effects

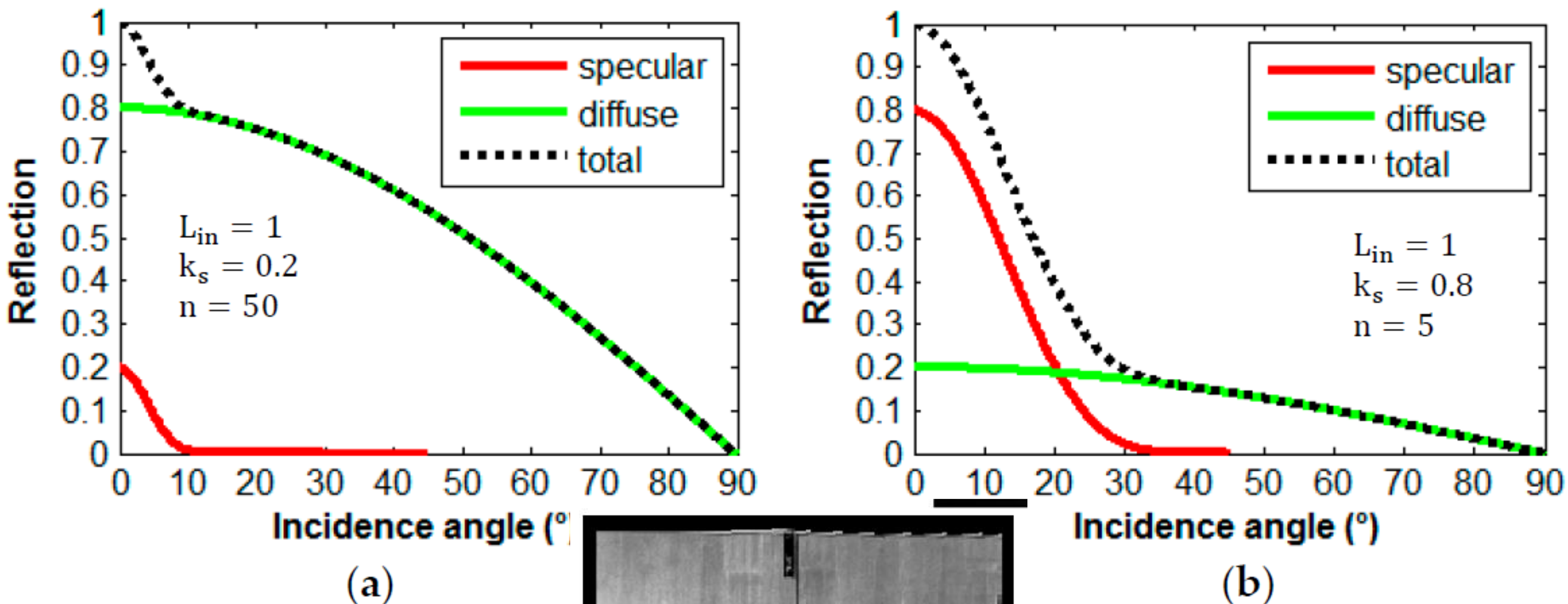


Figure 2. Phong model with different ... eflections are dominant at incidence angles smaller than 45° and must be c ... s). (**b**) Specular reflections are subtle (rough surfaces).

Tan & Cheng (2017)

Modeling Angle Effects - State-of the-Art

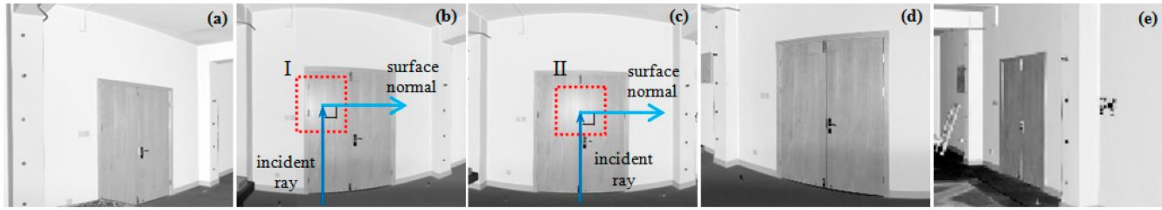
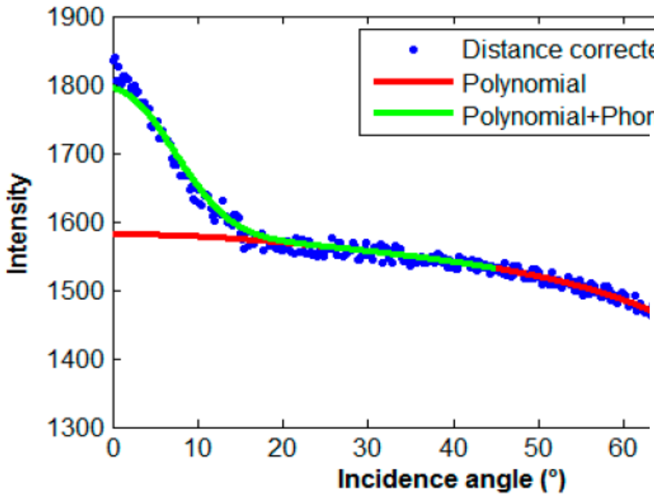
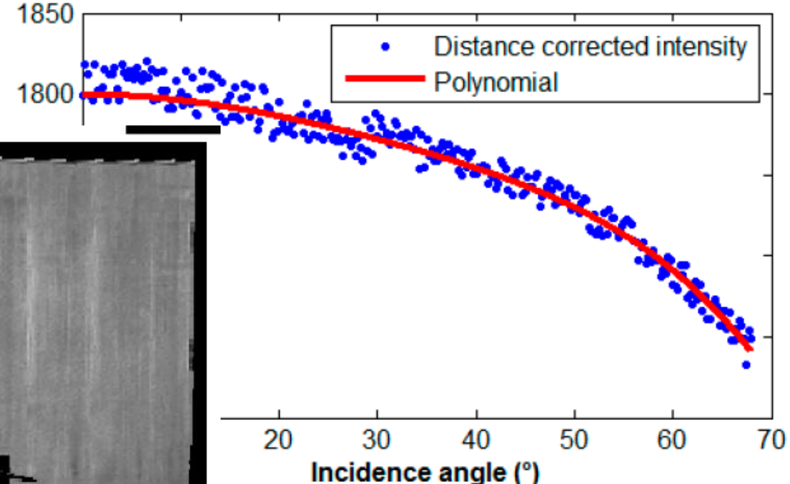


Figure 3. Original intensity images created by Faro SCENE. (**a**) Scan 1. (**b**) Scan 2. (**c**) Scan 3. (**d**) Scan 4. (**e**) Scan 5. Highlights exist in Scans 2 and 3 because the surface of the door is smooth. Scans 1, 4, and 5 do not have highlight regions as the surface of the wall is relatively rough.



(a)

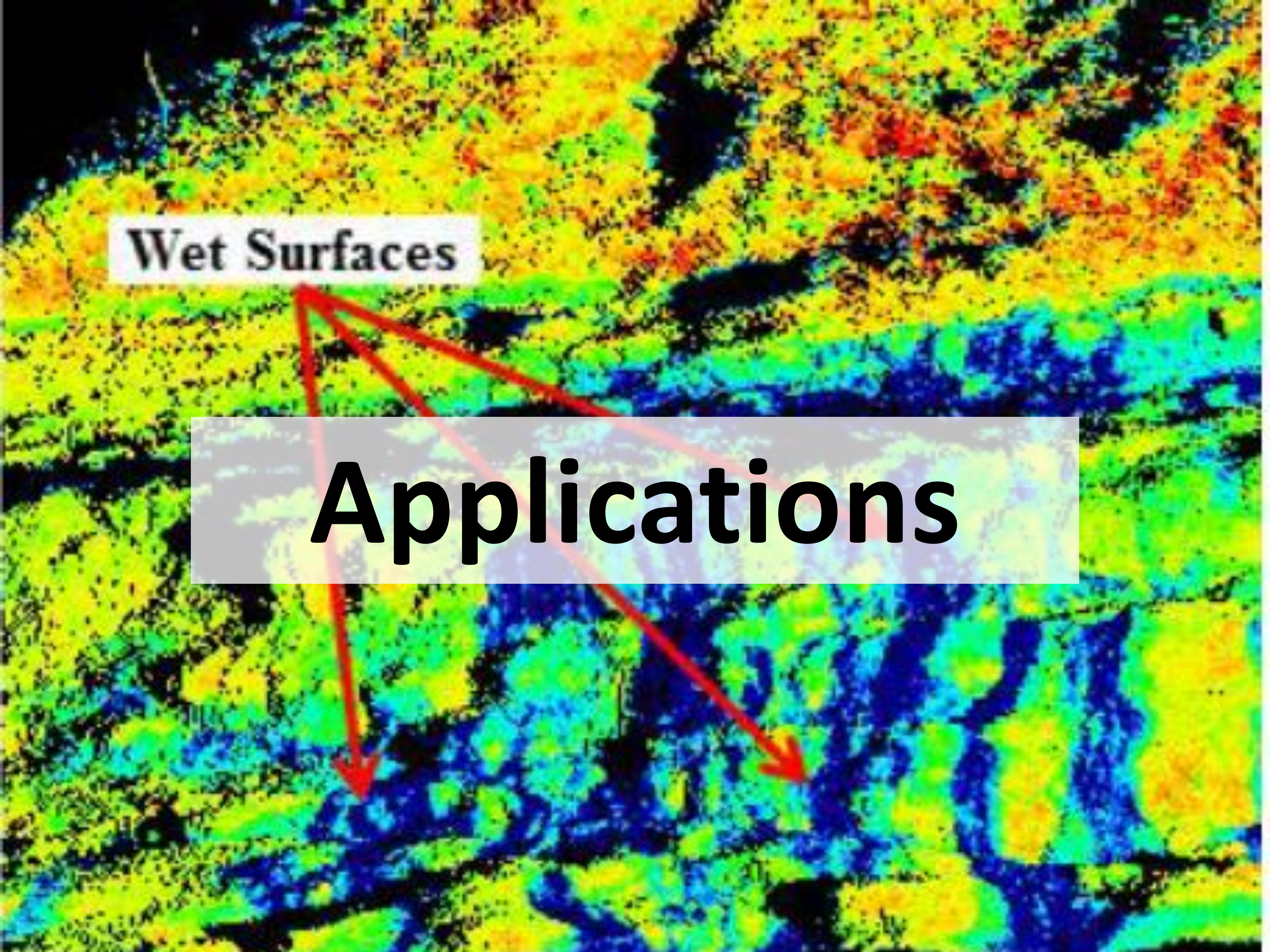


(b)

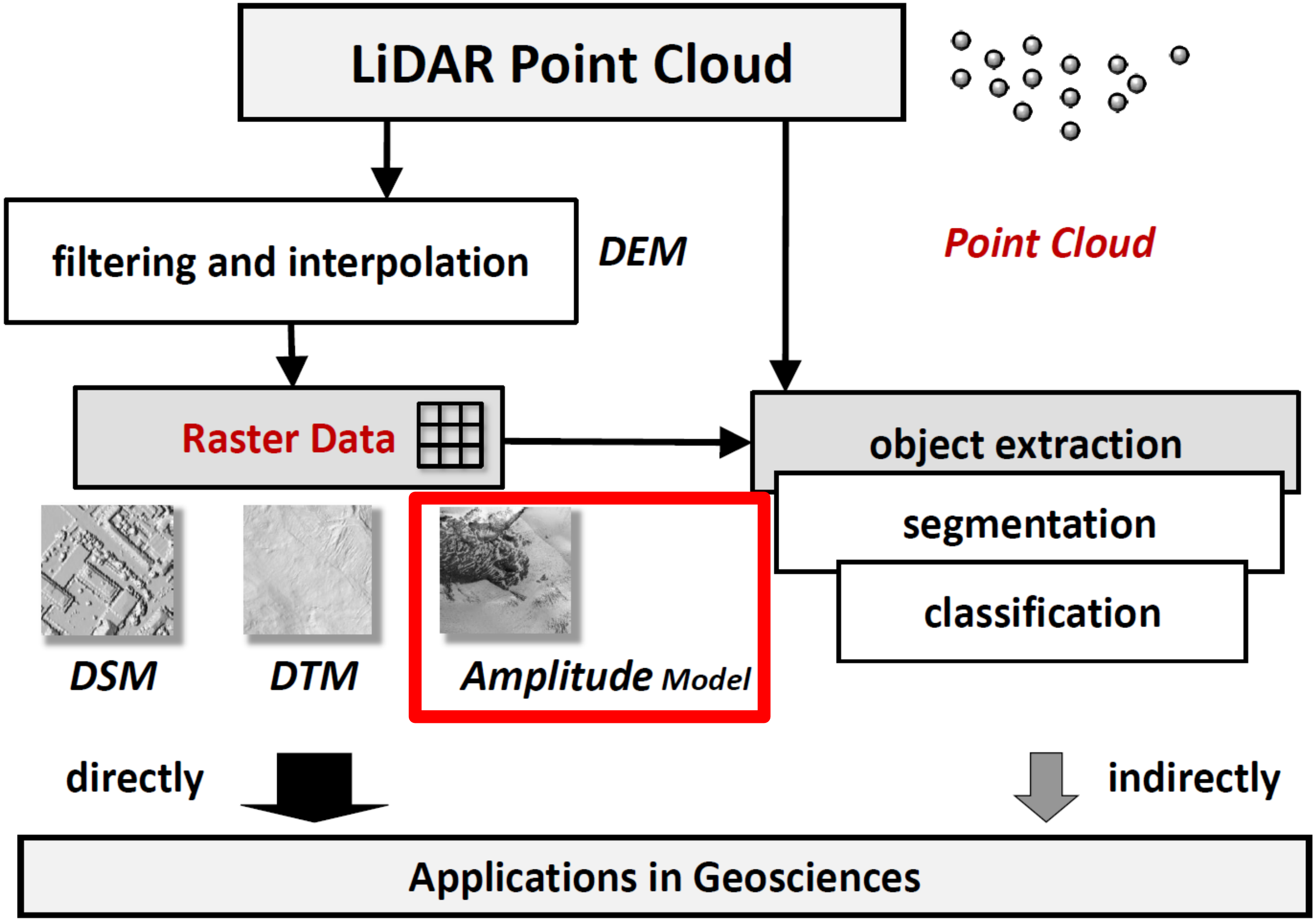
Figure 4. (**a**) Distance-corrected intens curves of the fitting polynomial and Phong model. (**b**) Distance-correc ite lime wall and the curve of the fitting polynomial.

Tan & Cheng (2017)

Applications



Geoinformation Extraction Workflow



Höfle & Rutzinger (2011)

Remote Sensor of Rock Properties

Burton et al. (2011)

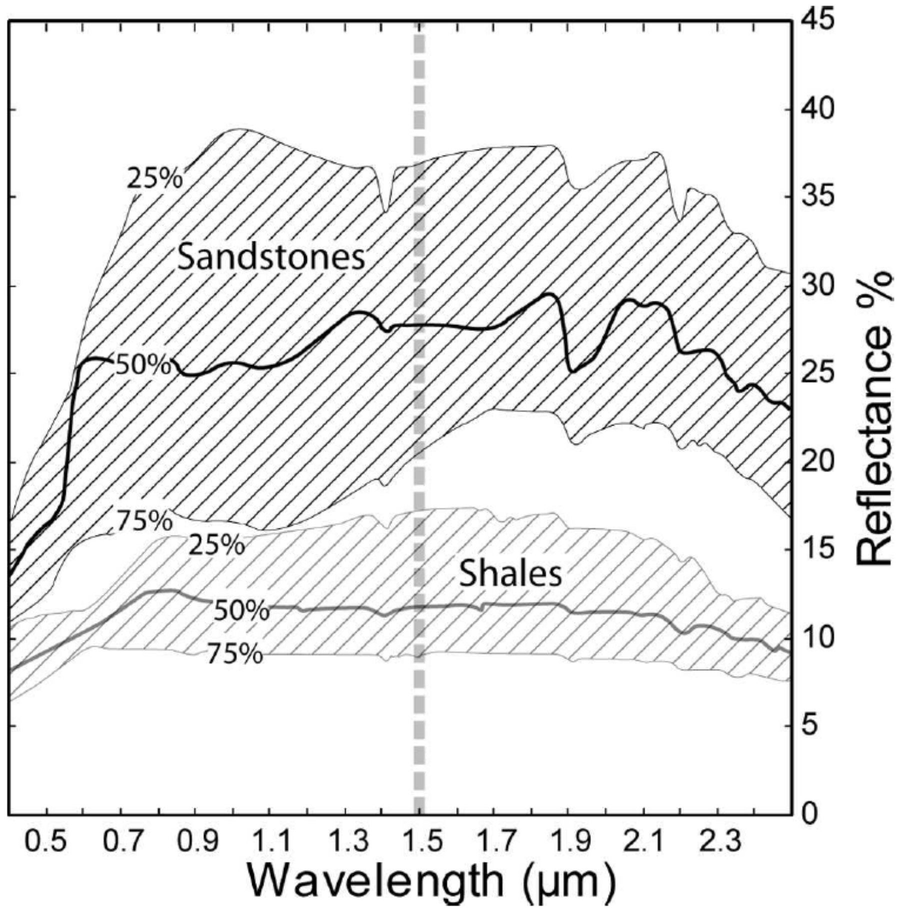
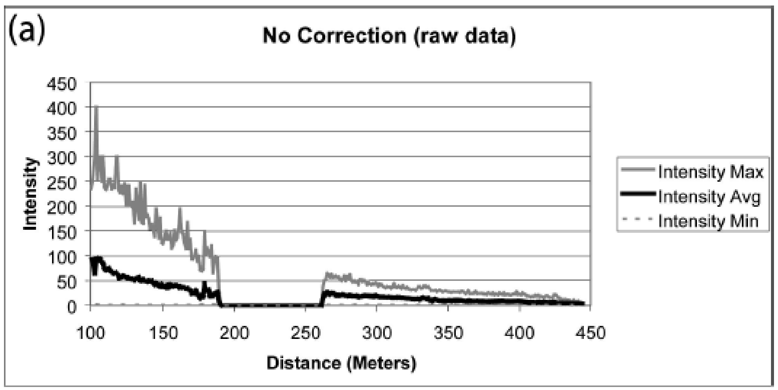


FIG. 1.—NASA JPL library spectroscopy (from Baldridge et al. 2008), solid sample data showing median (solid line) and quartiles (dashed lines) for shale (gray) and sandstone (black). The central dashed line is approximates the wavelength of terrestrial lidar. Note the spectral separability between sandstones and shale at lidar wavelengths.



Remote Sensor of Rock Properties

Burton et al. (2011)

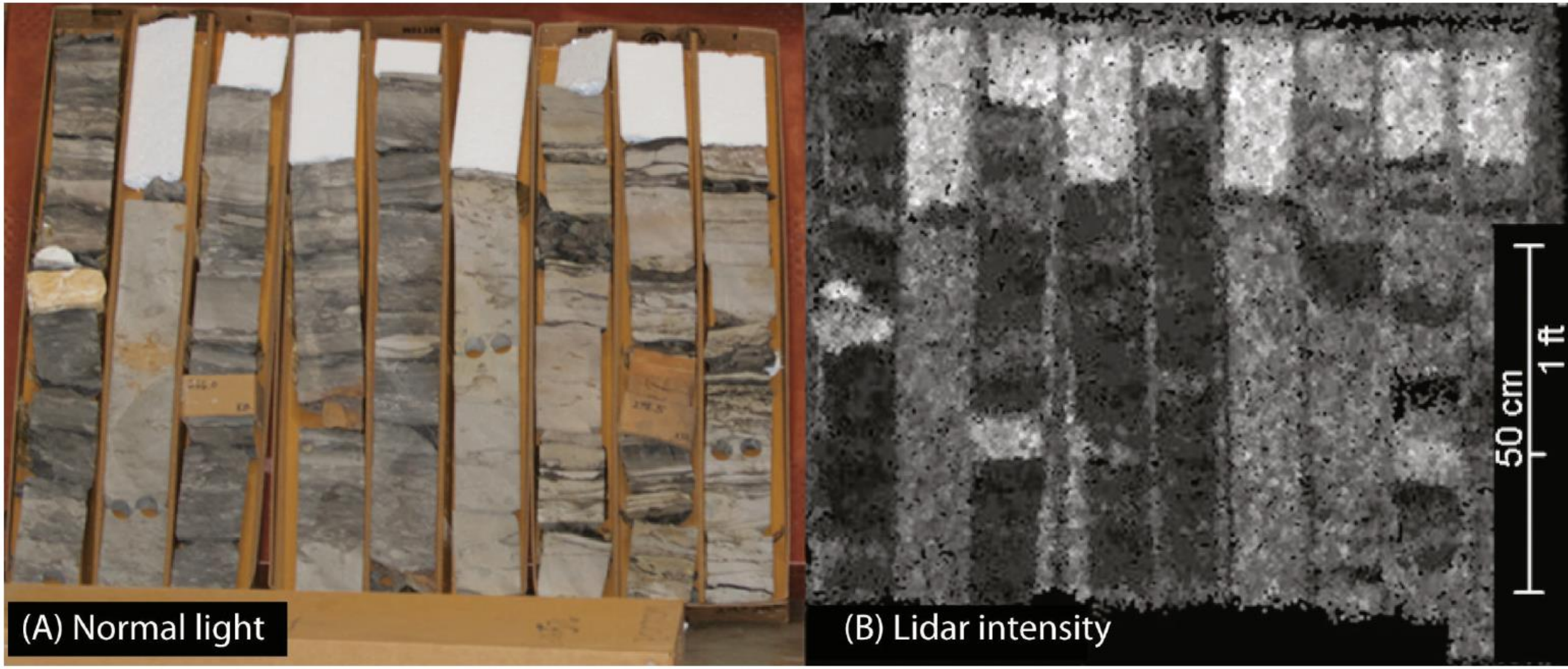
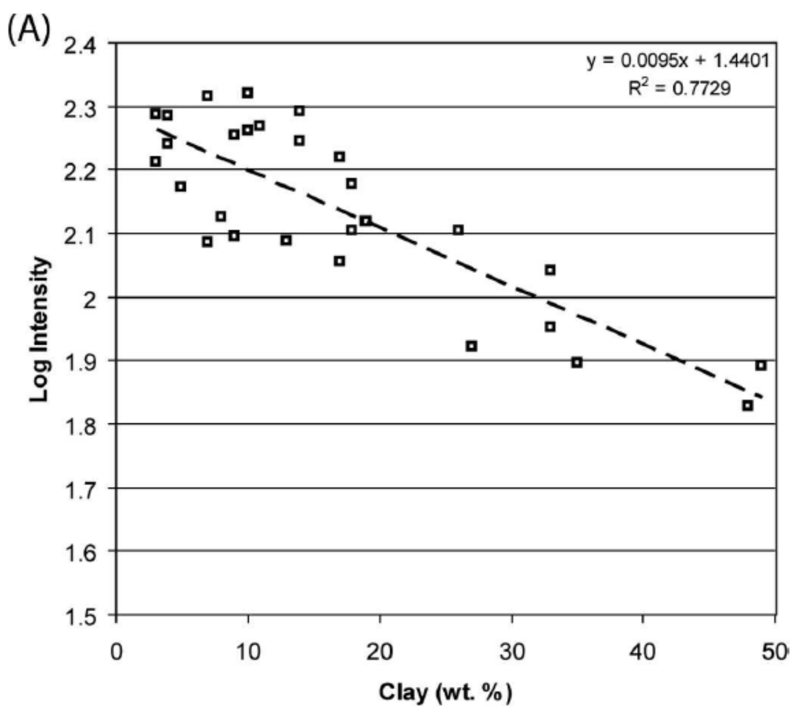


FIG. 3.—Boxes of core were used in experiment 1. **A)** Shale in the core corresponds to low intensities **B)** The intensity grayscale is 0 (black) to 255 (white).

Remote Sensor of Rock Properties

Burton et al. (2011)



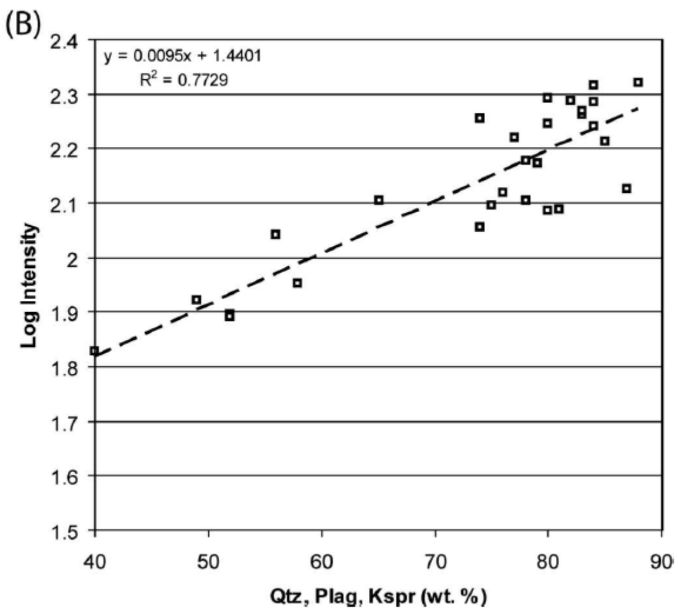


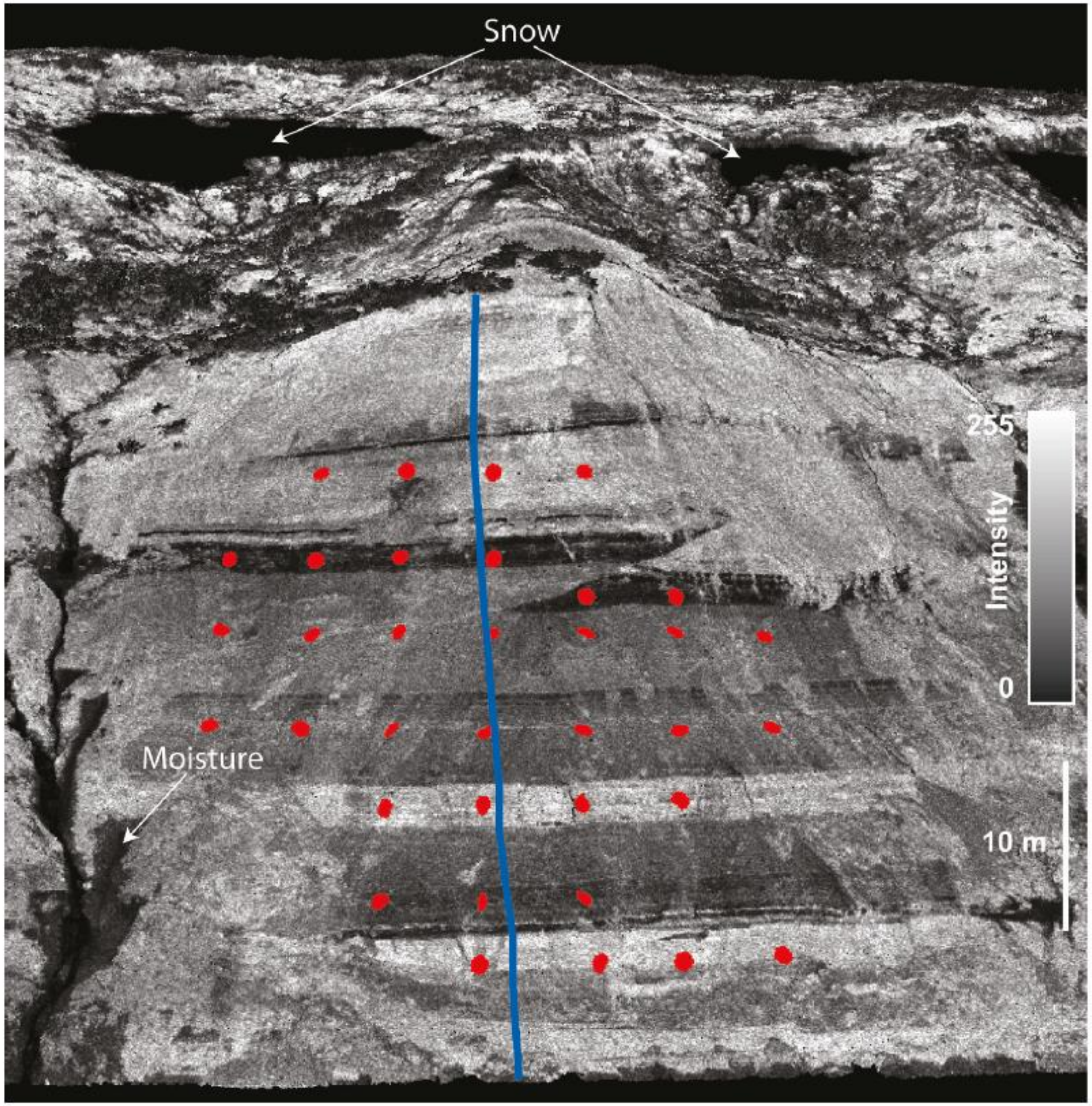
FIG. 5.—Mineralogy A) wt. % clay and B) wt % combined quartz, plagioclase, and K-feldspar (from Wendlandt and Bhuyan, 1990) compared with lidar intensity of the Sego Canyon 2 core.

Shale

Sand

Remote Sensor of Rock Properties

Burton et al. (2011)



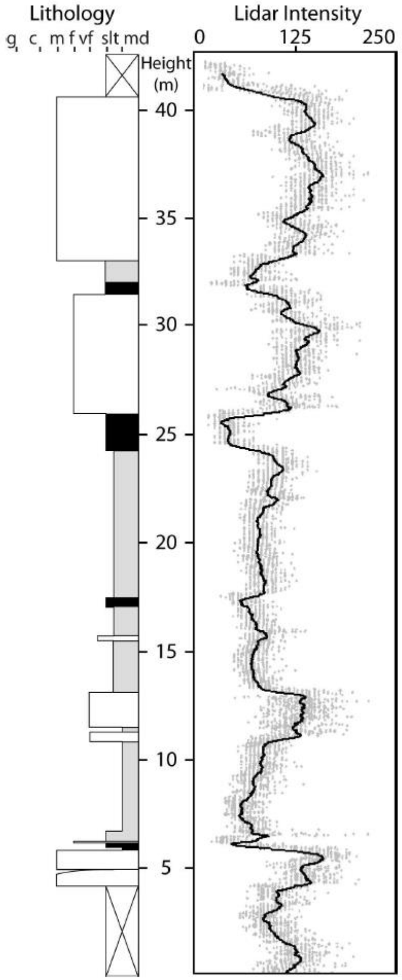
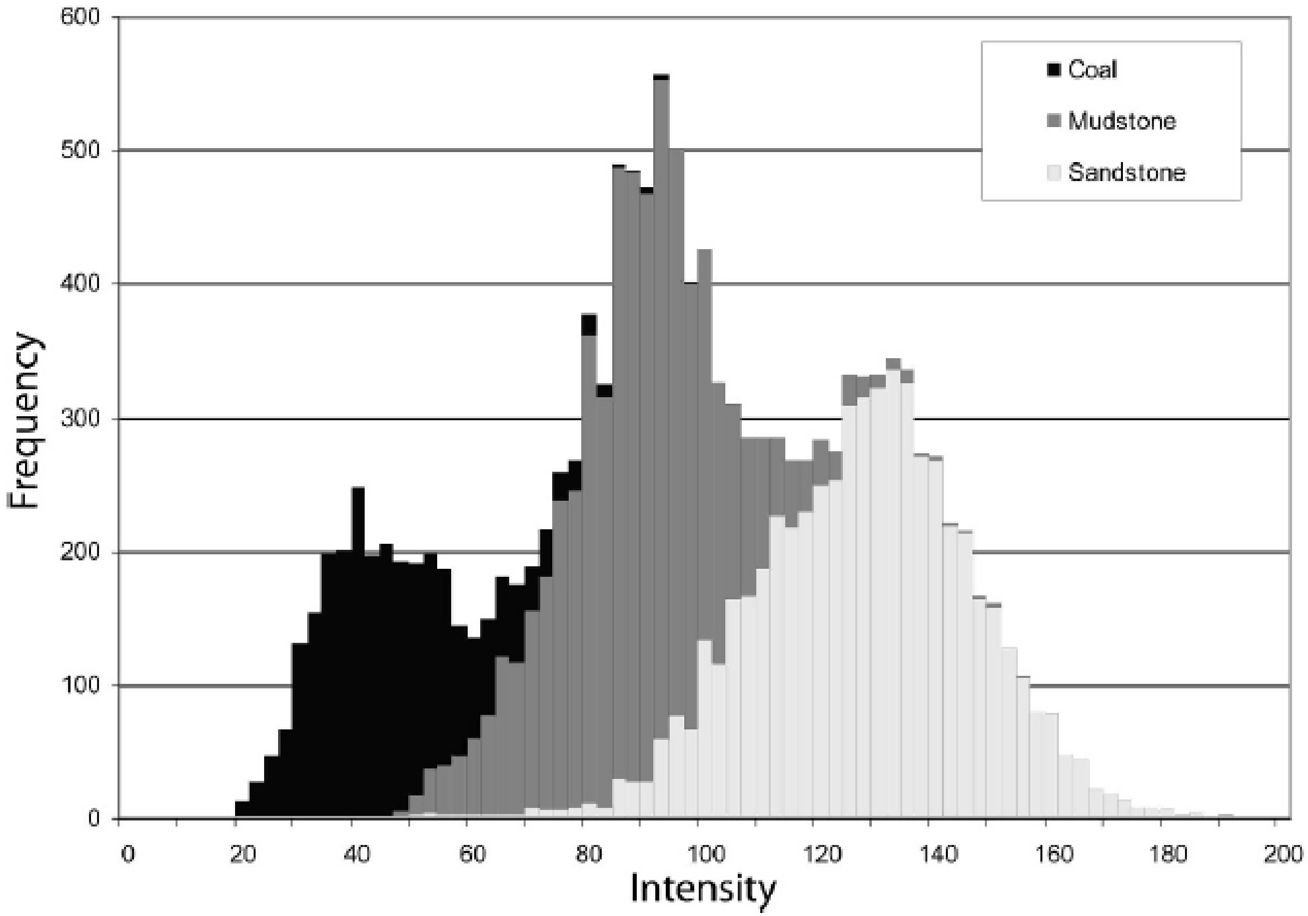


FIG. 7.—Lithology log (from measured section) and lidar intensity log of the Prince Creek Formation.

Remote Sensor of Rock Properties

Burton et al. (2011)



Mapping of Chert in Outcrops

Penasa et al. (2014)

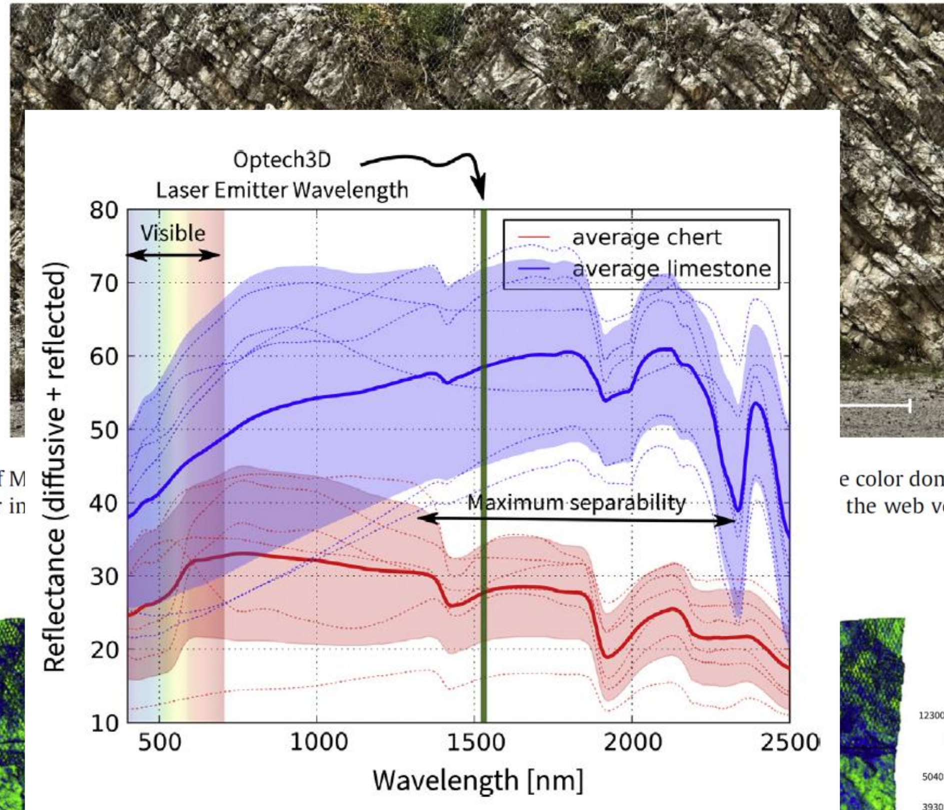


Fig. 2. Photograph of the outcrop of M … e color domain. Rock color goes from pale pink to dark gray, chert is not evident. (For in … the web version of this article.)

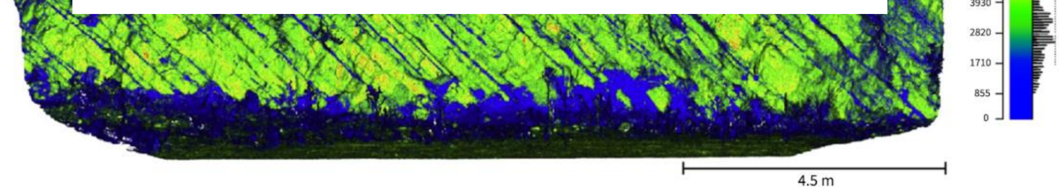
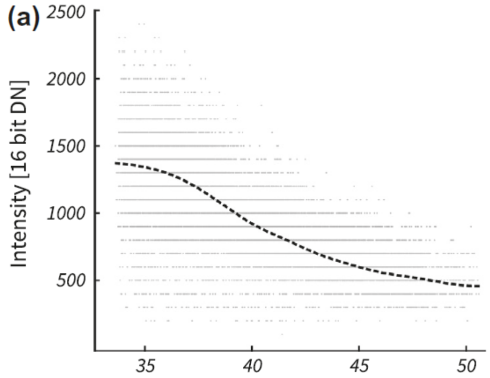


Fig. 3. The scan, colored by intensity, and histogram of intensity distribution (right). Chert, vegetation and debris are highlighted by their low intensity values. CloudCompare software (Girardeau-Montaut, 2014) used for visualization.

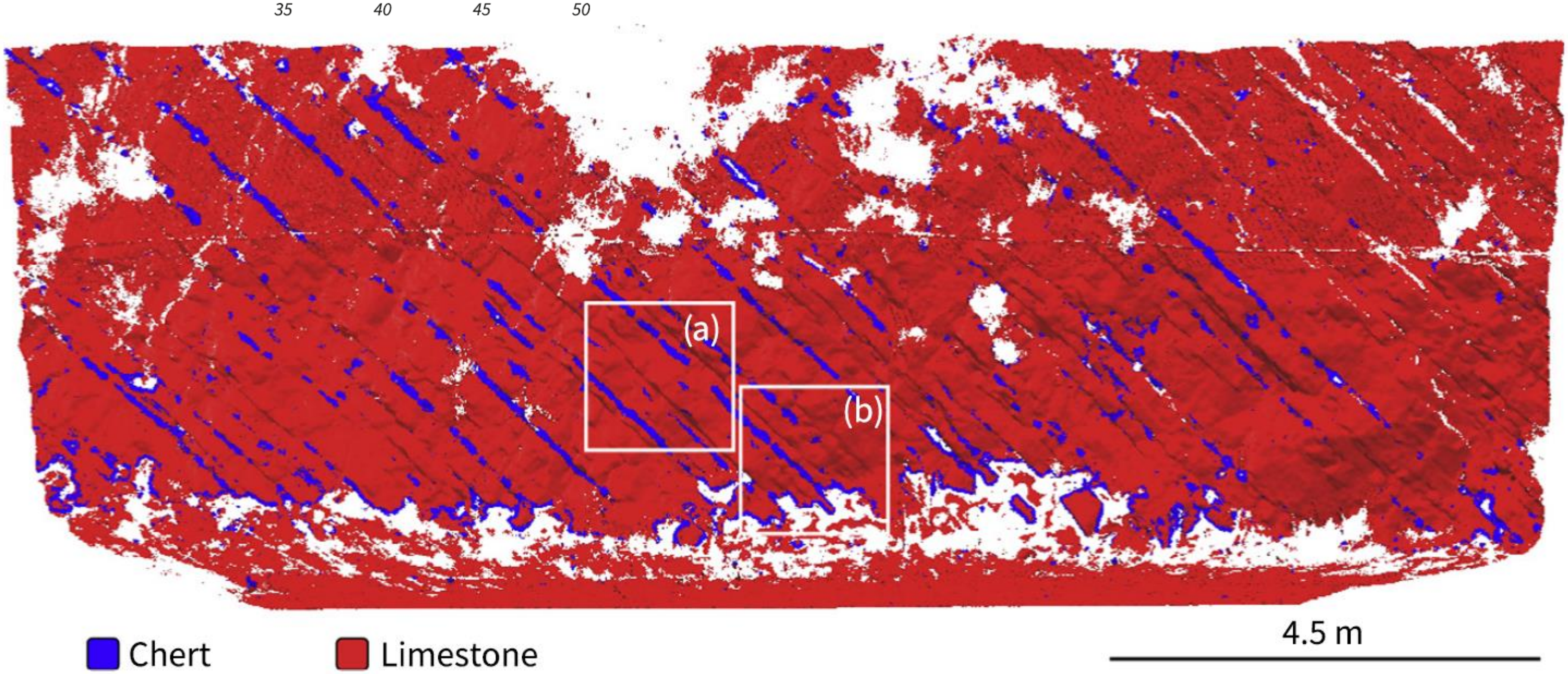
Mapping of Chert in Outcrops

Penasa et al. (2014)

- Empirical distance correction

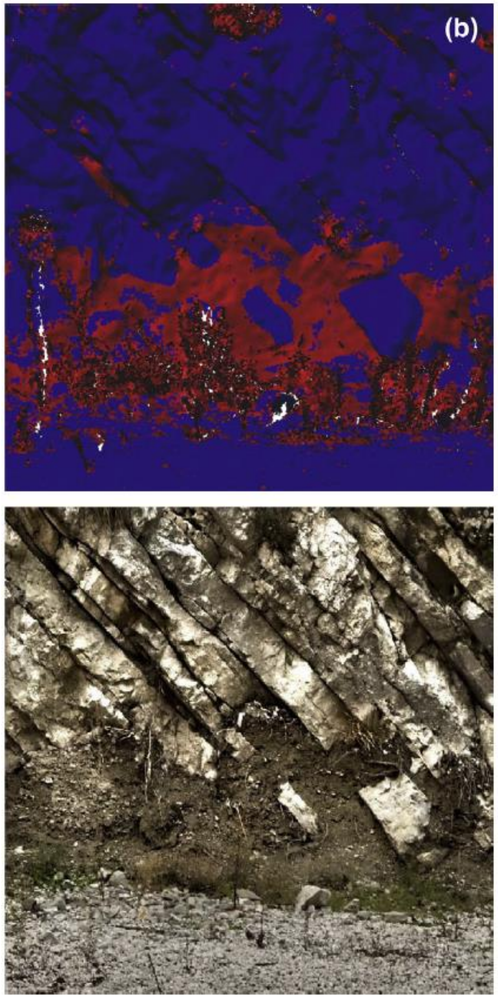


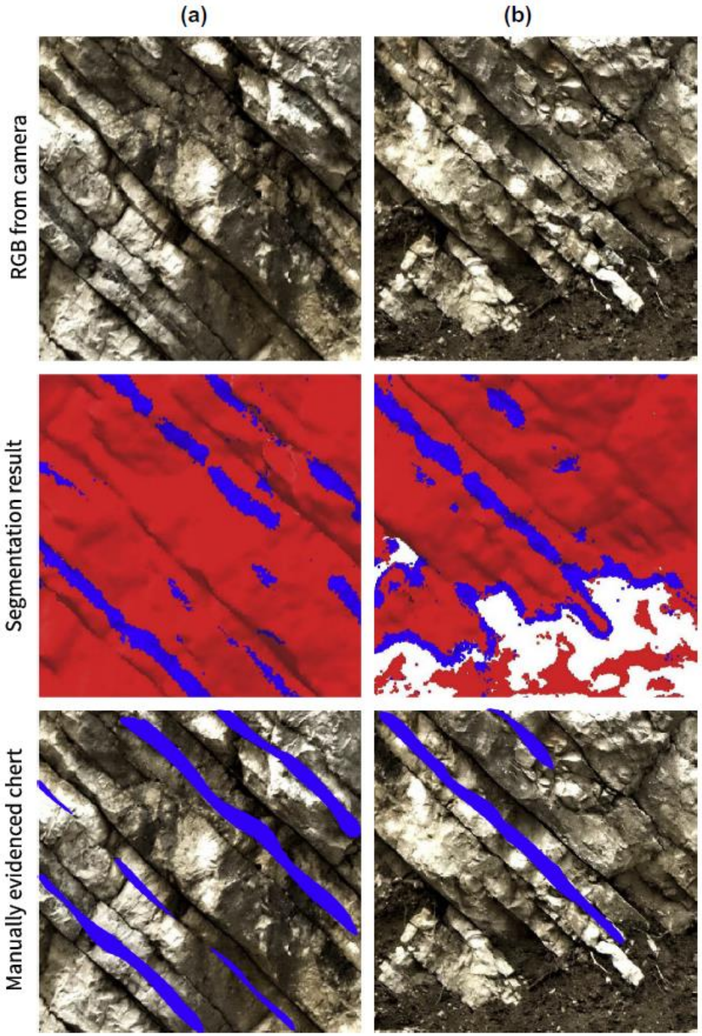
$$\widehat{I}_h(d) = \frac{\sum_{i=1}^{n} K\left(\frac{|d-d_i|}{h}\right) I_i}{\sum_{i=1}^{n} K\left(\frac{|d-d_i|}{h}\right)}, \quad \text{with} \quad K(t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2}$$



Mapping of Chert in Outcrops

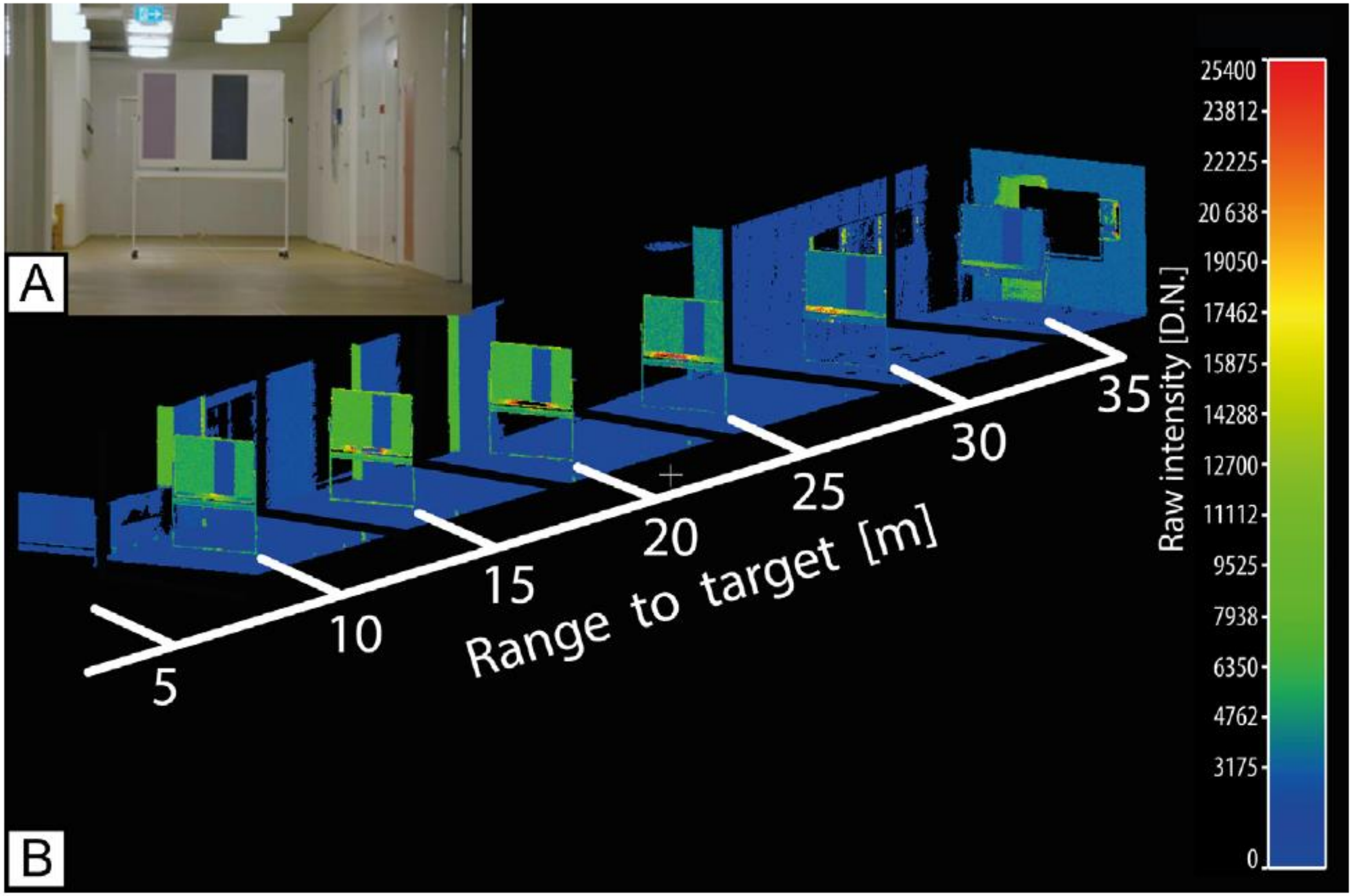
Penasa et al. (2014)





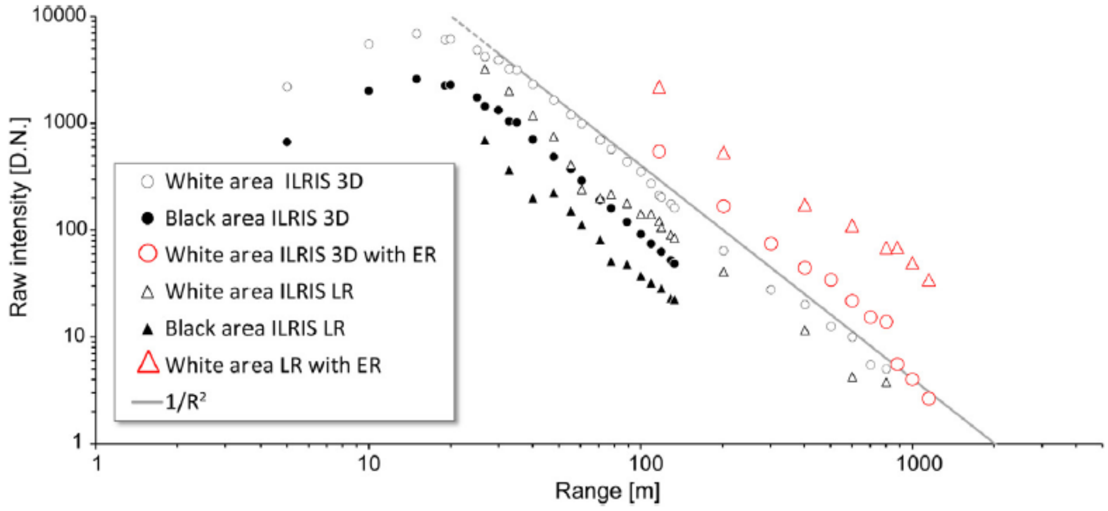
Correction of terrestrial LiDAR intensity : An application to lithological differentiation

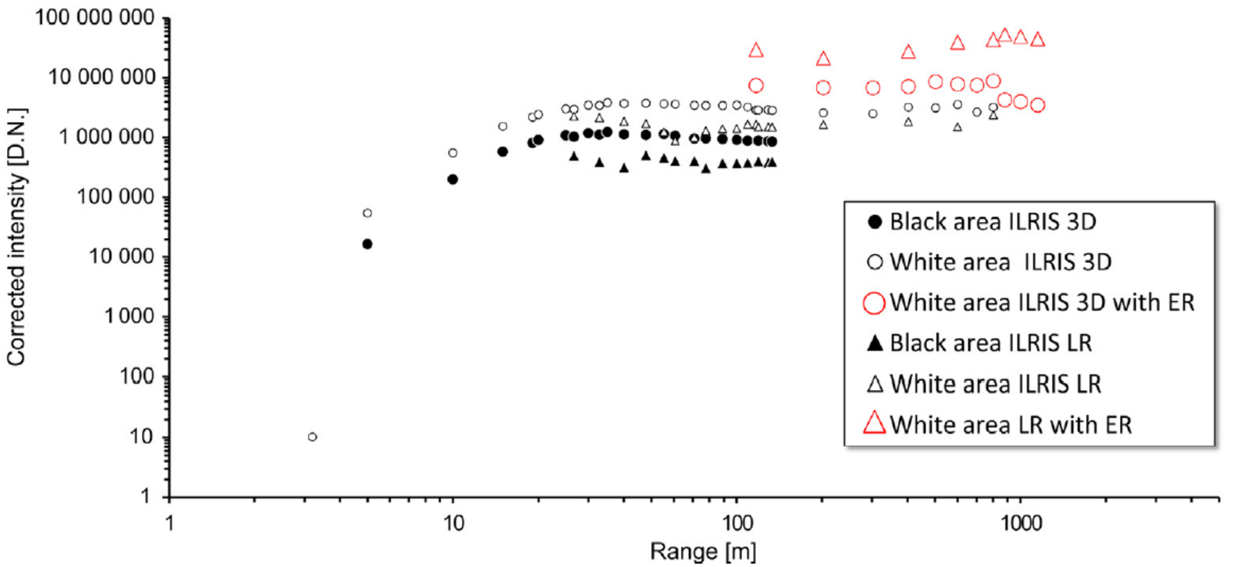
Carrea et al. (2016)



Correction of terrestrial LiDAR intensity : An application to lithological differentiation

Carrea et al. (2016)





Correction of terrestrial LiDAR intensity : An application to lithological differentiation

Carrea et al. (2016)

This intensity correction is for perfect diffuse scattering and it has already been applied with TLS data on natural surfaces by Franceschi et al. (2009). However, as mentioned earlier, rock surfaces deviate significantly from perfect diffuse reflectors. Thus, we propose to use the faceted surface reflectance model of Oren–Nayar Eq. (7) to improve the intensity correction equation (10):

$$I_{corr} = \frac{I_{raw} R^2}{\cos\alpha (A + B \sin\alpha \tan\alpha)} \tag{11.1}$$

$$A = 1 - 0.5 \frac{\sigma^2_{slope}}{\sigma^2_{slope} + 0.33} \tag{11.2}$$

$$B = 0.45 \frac{\sigma^2_{slope}}{\sigma^2_{slope} + 0.09} \tag{11.3}$$

Correction of terrestrial LiDAR intensity : An application to lithological differentiation

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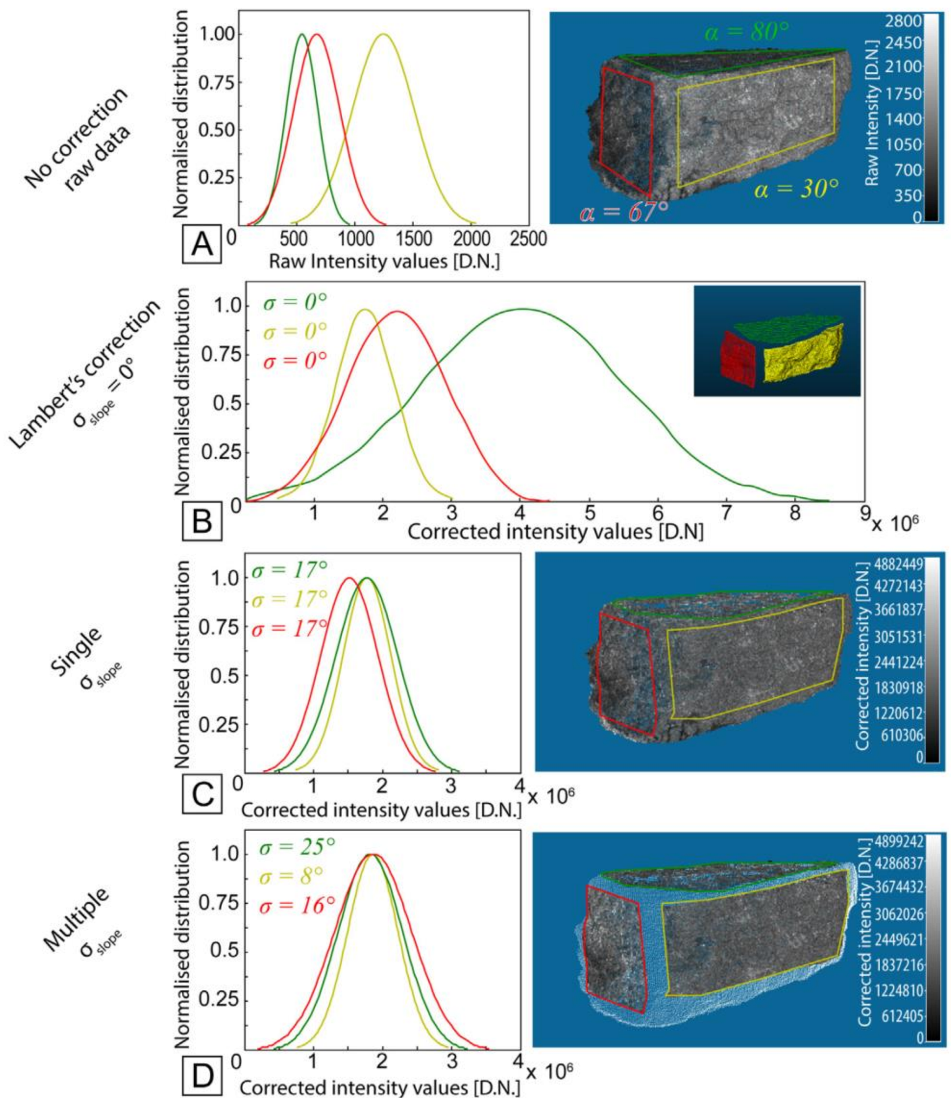


Correction of terrestrial LiDAR intensity : An application to lithological differentiation

Carrea et al. (2016)

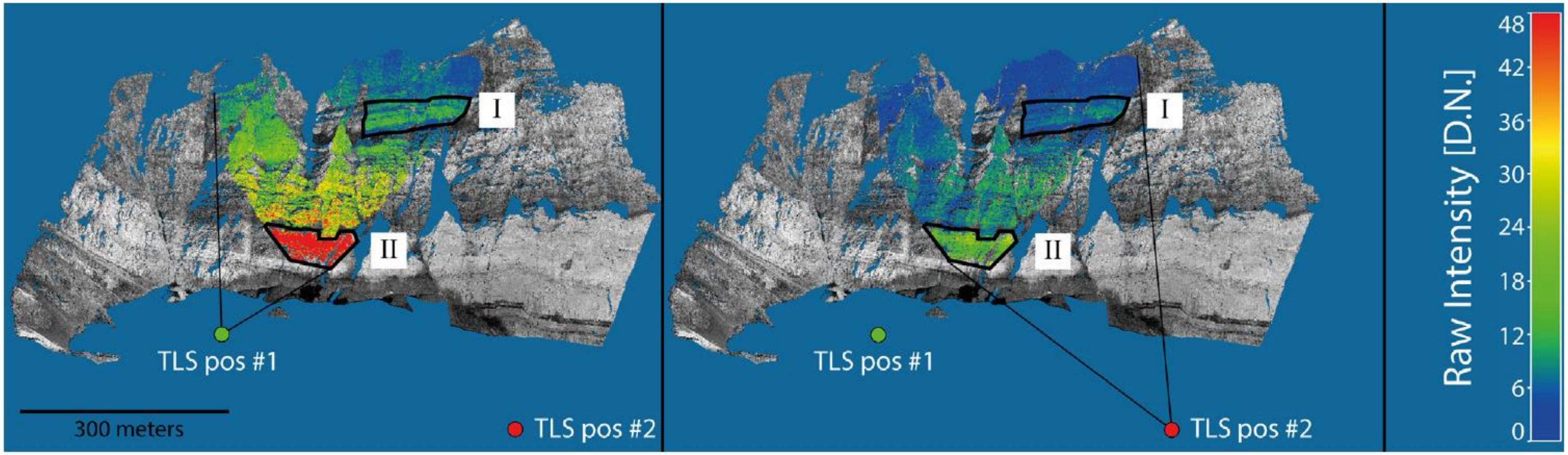
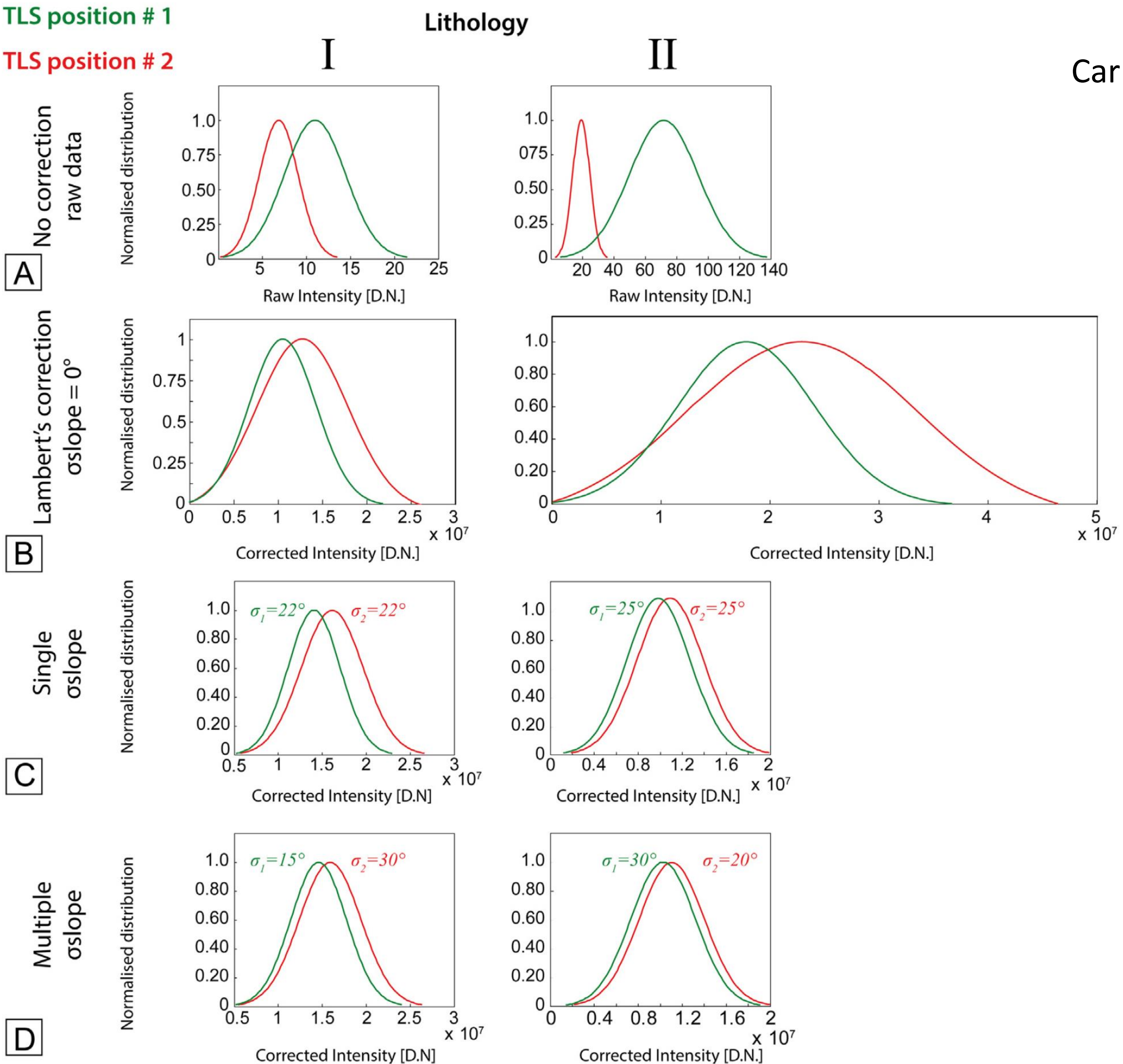


Fig. 9. Illustration of the same scanned surface with raw intensities of the Dents-du-Midi acquired from two different points of view (TLS position #1 and #2) overlaying corrected intensity scans. The comparison of the same areas between scan positions #1 and #2 shows different raw intensity values which are related to range, incidence angle and surface geometry differences.

Carrea et al. (2016)



Summary

Radiometric calibration - Signal amplitude

→ transform the recorded quantities into physical units using the **radar equation**

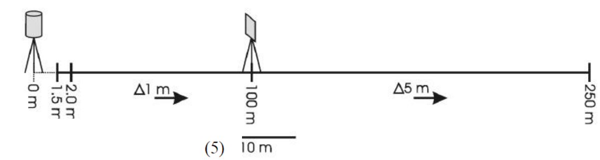
$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2} \eta_{sys} \eta_{atm} \sigma . \qquad \sigma = \frac{4\pi}{\Omega} \rho A_s$$

Original image | **Corrected image**

Höfle & Pfeifer (2007)

Radiometric calibration TLS

Recorded amplitude vs. range for **reference target**



$$I_c = I \cdot \frac{{R_i}^2}{{R_{ref}}^2} \cdot \frac{1}{\cos \alpha}$$

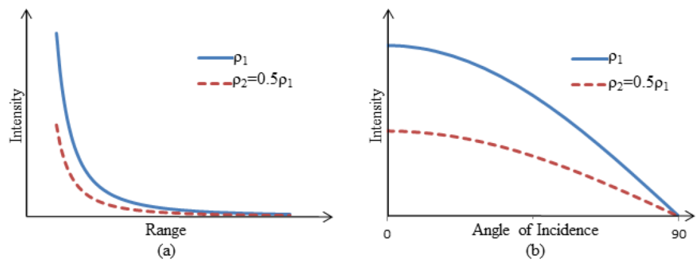
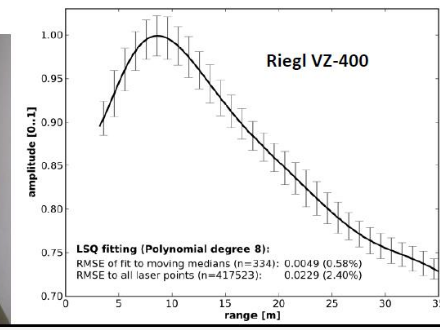
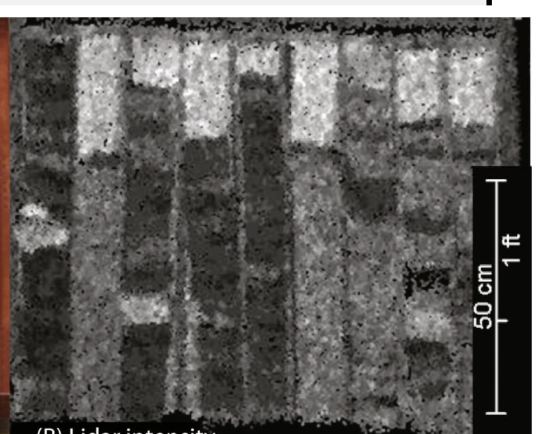
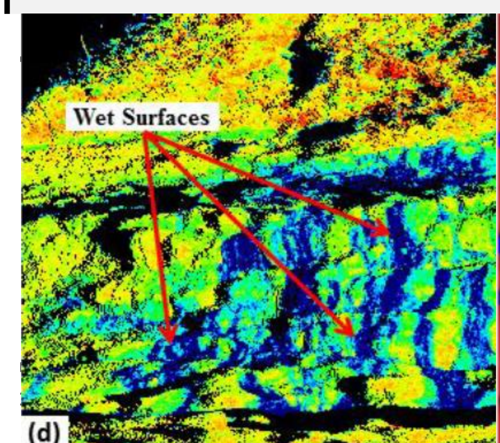
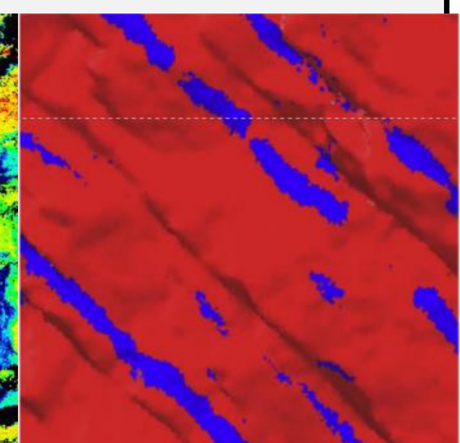


Figure 6. (**a**) Theoretical relationship of intensity measurements *vs.* range shown for two materials with different reflectance (ρ); and (**b**) theoretical relationship of intensity measurements *vs.* angle of incidence shown for two materials with different reflectance (ρ).









References

- Burton et al. (2011): http://dx.doi.org/10.2110/jsr.2011.31
- Carrea et al. (2016): http://dx.doi.org/10.1016/j.isprsjprs.2015.12.004
- Eitel et al. (2016): http://dx.doi.org/10.1016/j.rse.2016.08.018
- Höfle & Pfeifer (2007): https://doi.org/10.1016/j.isprsjprs.2007.05.008
- Höfle & Rutzinger (2011): http://dx.doi.org/10.1127/0372-8854/2011/0055S2-0043
- Kashani et al. (2015): https://doi.org/10.3390/s151128099
- Penasa et al. (2014): http://dx.doi.org/10.1016/j.isprsjprs.2014.04.003
- Pfeifer et al. (2008): http://lvisa.geog.uni-heidelberg.de/papers/2008/Pfeifer_IAPRS_2008.pdf
- Riegl VZ-400i Datasheet: http://www.riegl.com/uploads/tx_pxpriegldownloads/RIEGL_VZ-400i_Datasheet_2017-12-18.pdf
- Tan & Cheng (2017): http://dx.doi.org/10.3390/rs9080853
- Xu et al. (2017): http://dx.doi.org/10.3390/rs9111090

Interdisciplinary Center for Scientific Computing

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

HEIDELBERG CENTER FOR THE ENVIRONMENT

Range Correction

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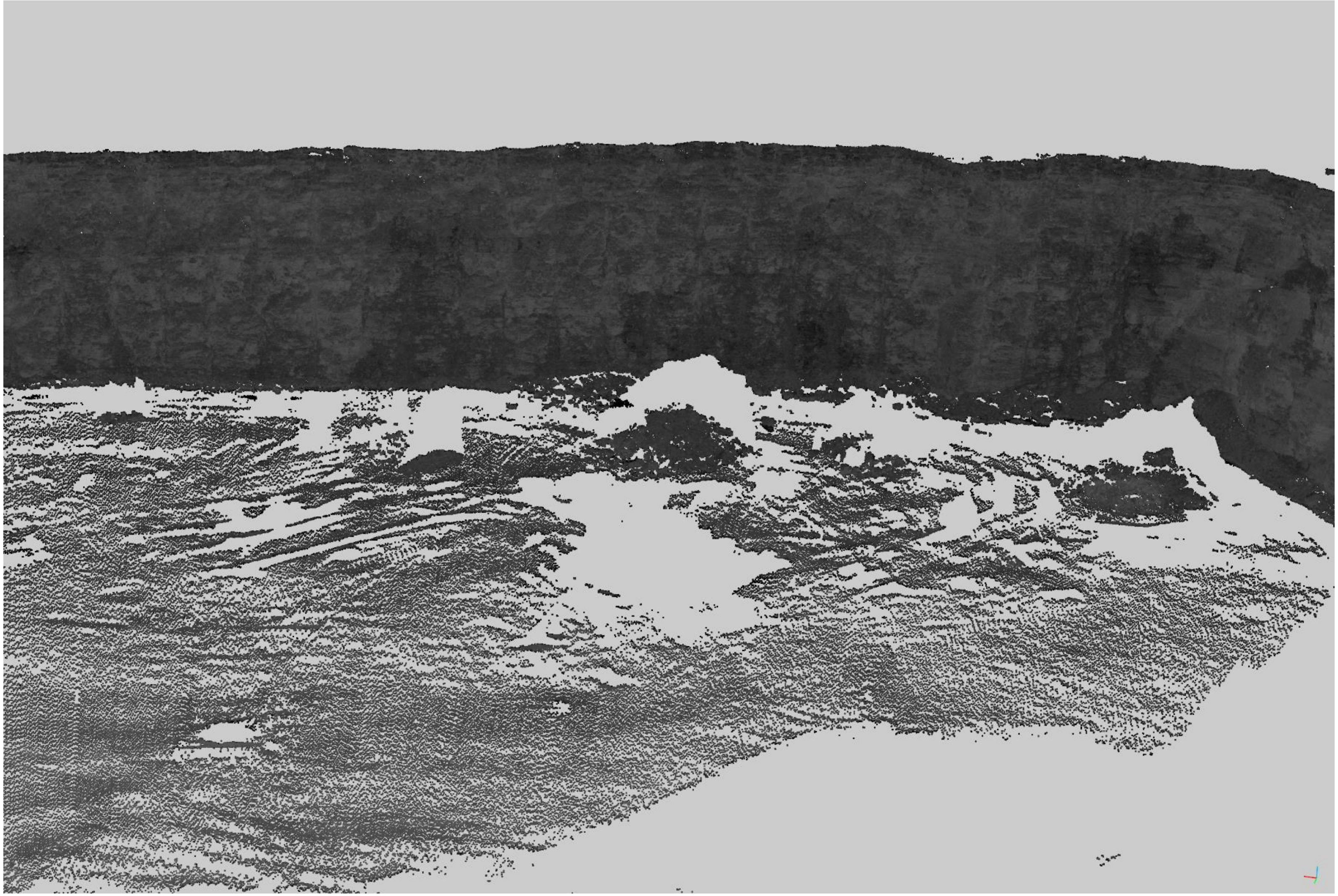
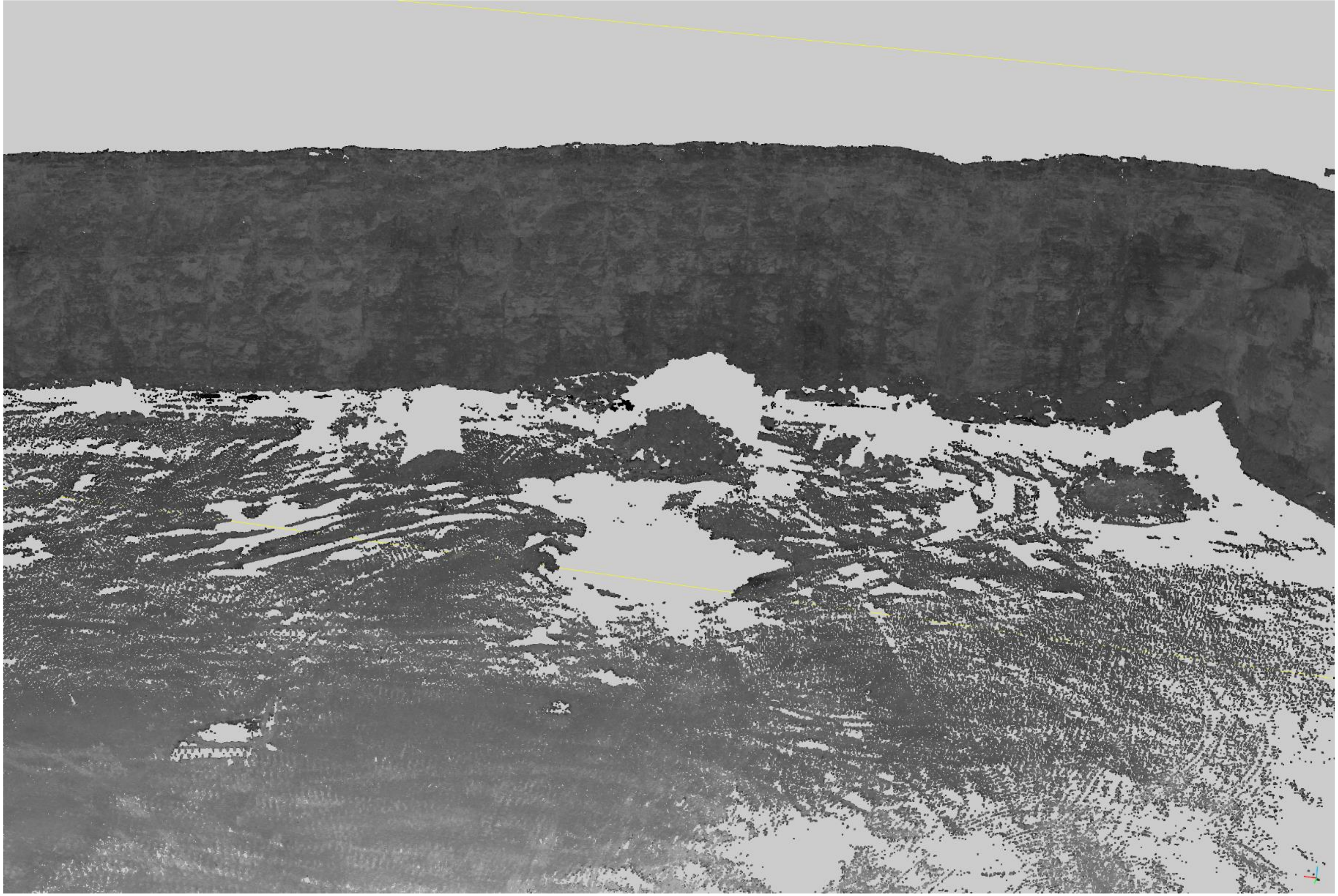
Geographisches Institut
Universität Heidelberg

GIScience LiDAR Research Group

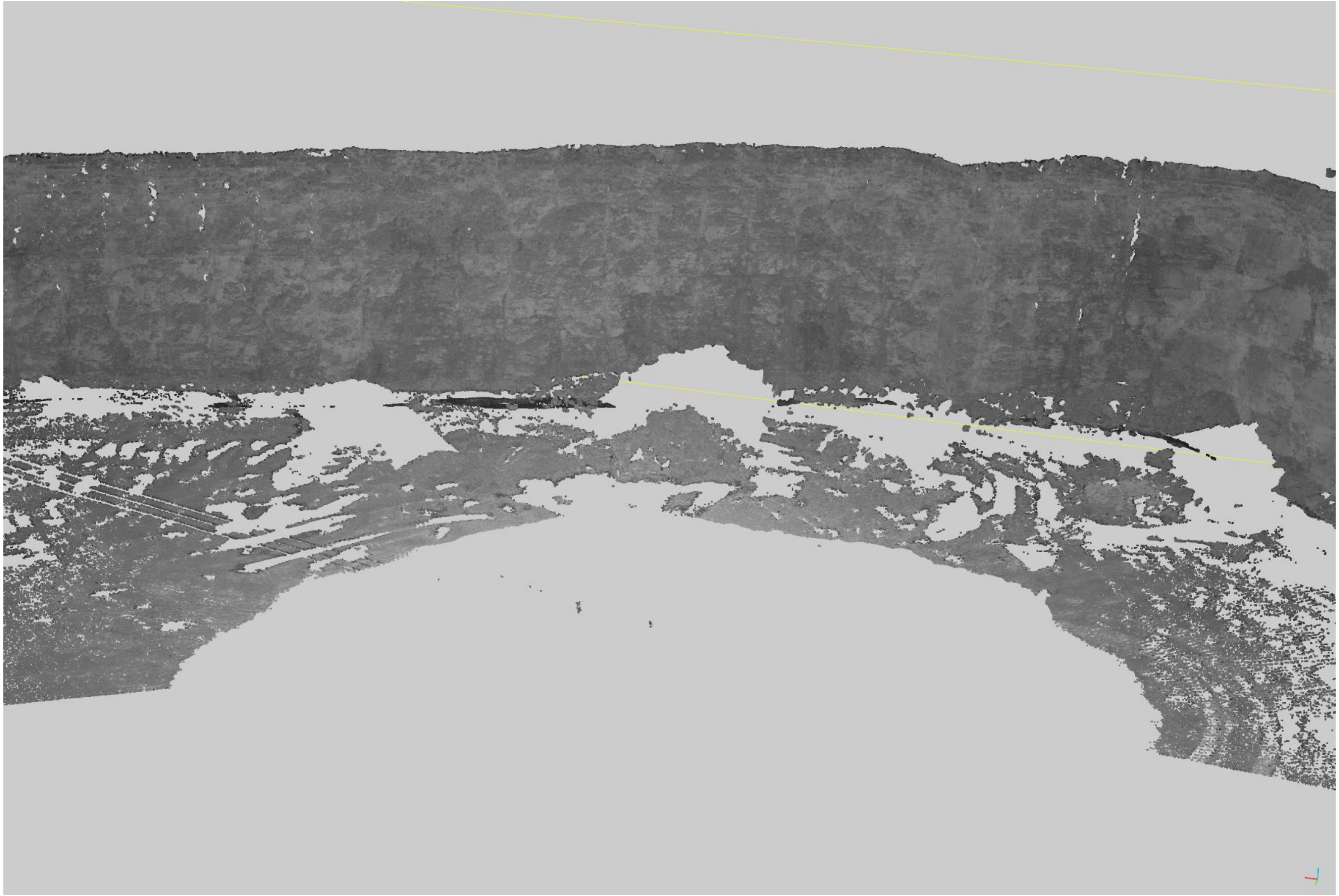
Scan 1 (Before)



Scan 2 (Before)



Scan 3 (Before)



Two steps

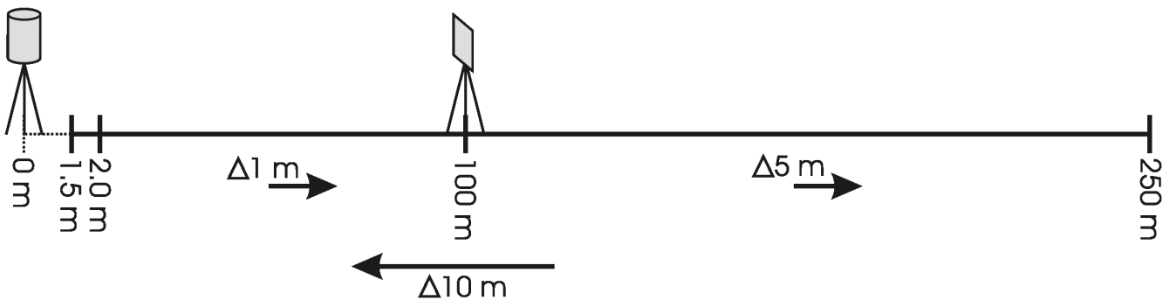
1. Determine correction function (range-intensity)
   `calib_range_ampl_TLS.py`

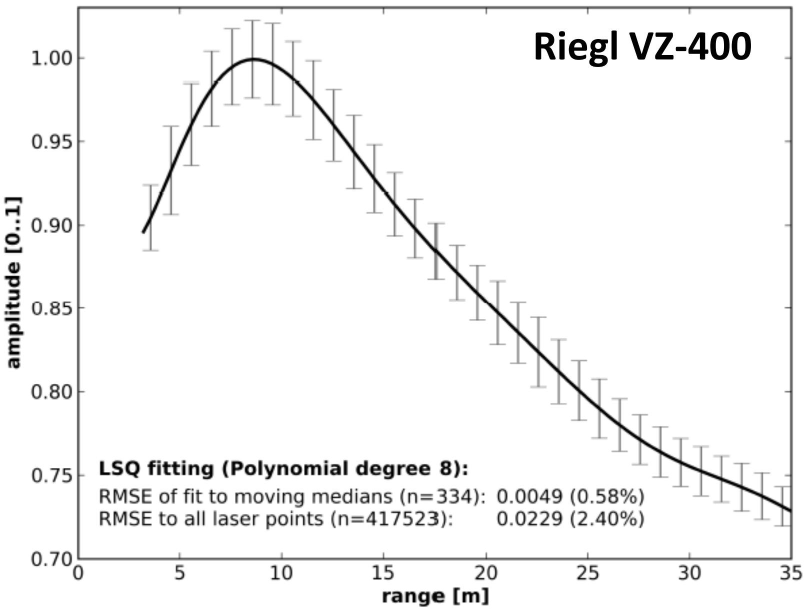
2. Apply correction function to remove range effects
   `calibrate_amplitudes.py`

Python tools (< version 3) require: Numpy, Scipy, Matplotlib

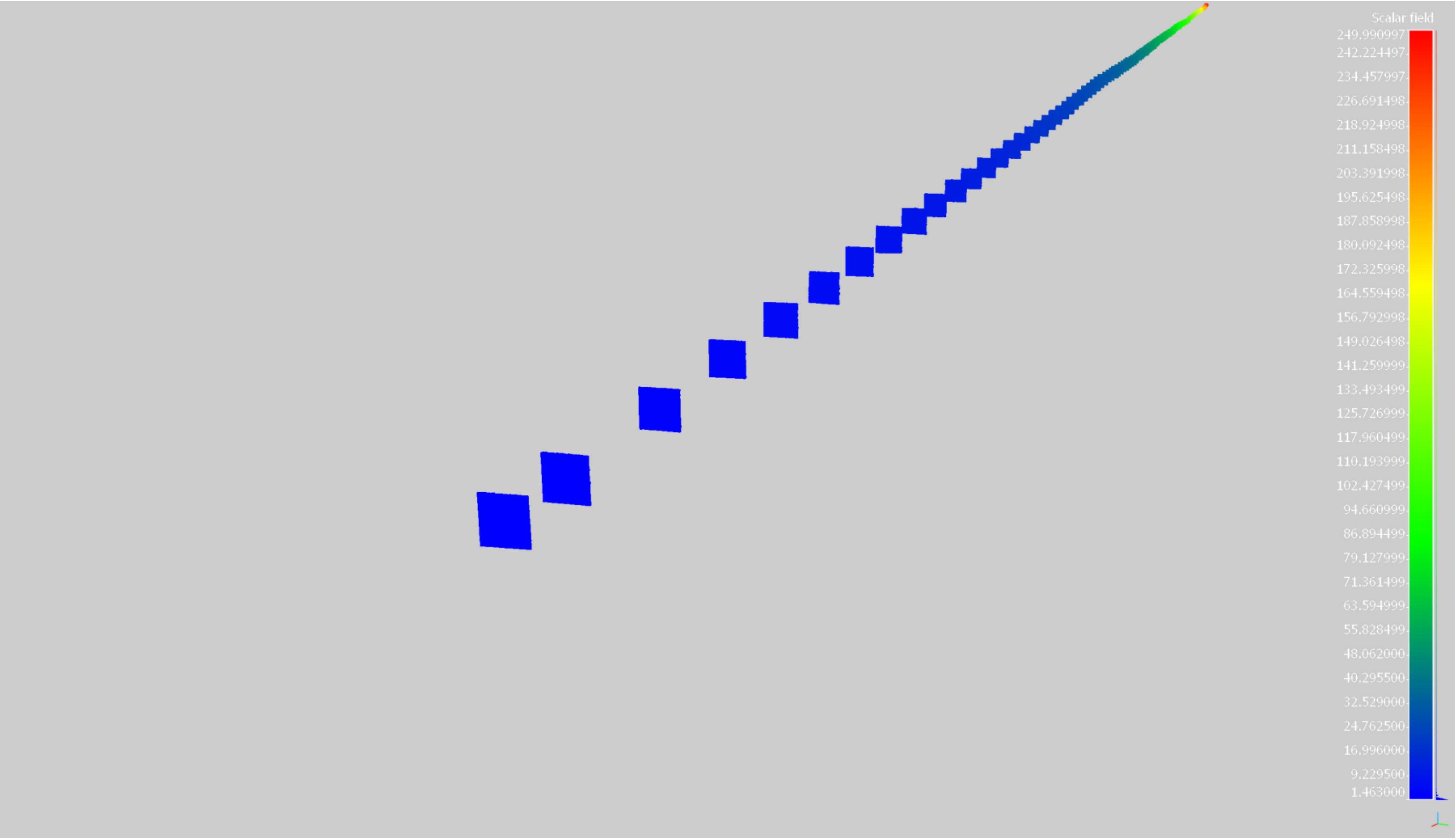
Radiometric calibration TLS

Recorded amplitude vs. range for **reference target**

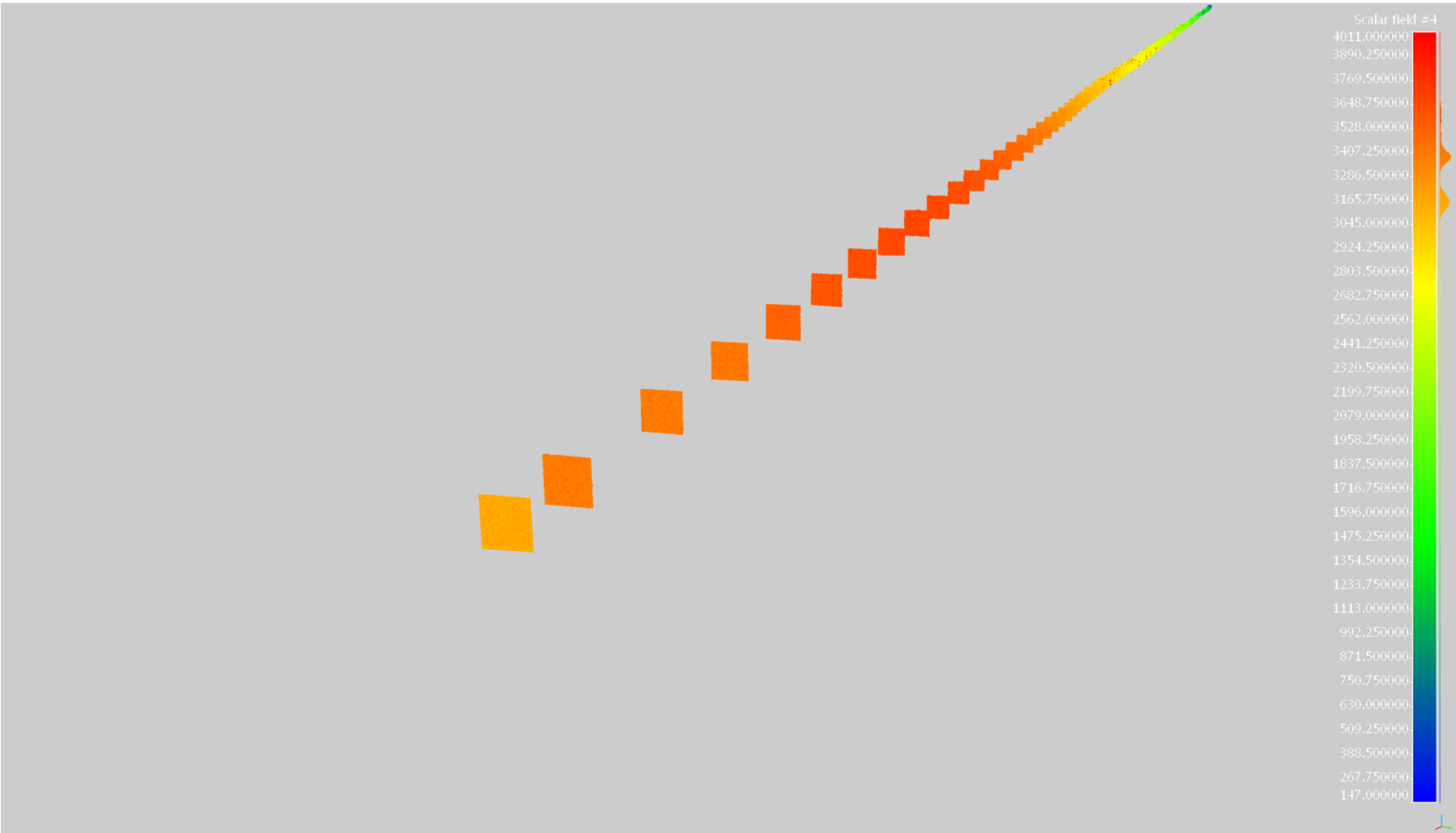




Lab Measurements (Range)



Lab Measurements (Amplitude)



1) Determine Range-Intensity-Function

```
python calib_range_ampl_TLS.py settings_calib_VZ400.txt
```

settings_calib_VZ400.txt

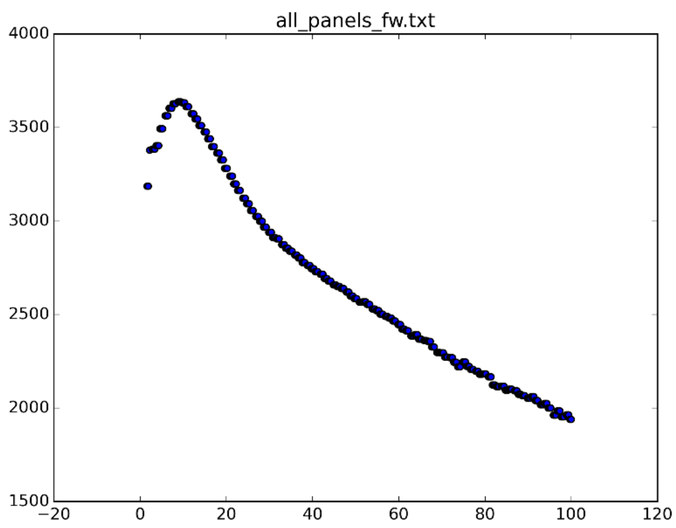
```
list_degree = [8] # polynomial degrees to test fitting
list_color = ['b', 'g', 'c', 'm', 'y', 'k'] # colors for plotting
min_range=0.0         # min. range value to be used
max_range=100.0       # max. range value to be used (e.g. filter outliers)
normalize=True        # normalize intensity values for plotting between [0..1]
degcorr=8             # polynomial degree to be selected
PLOTFINAL=1           # Plot final result (1=yes, 0=no)
SKIPHEADER=False      # skip first line in input (True / False)
FIELDSEPARATOR=";"    # field column separator in input files
COL_RANGE=3           # id/no. of column with range values (column numbering starting from 0)
COL_INT = 6           # id/no. of column with intensity values (column starting from 0)
path = r"testdata\Riegl_VZ-400_Lab"     #Open all input files with file extenstion .txt
```

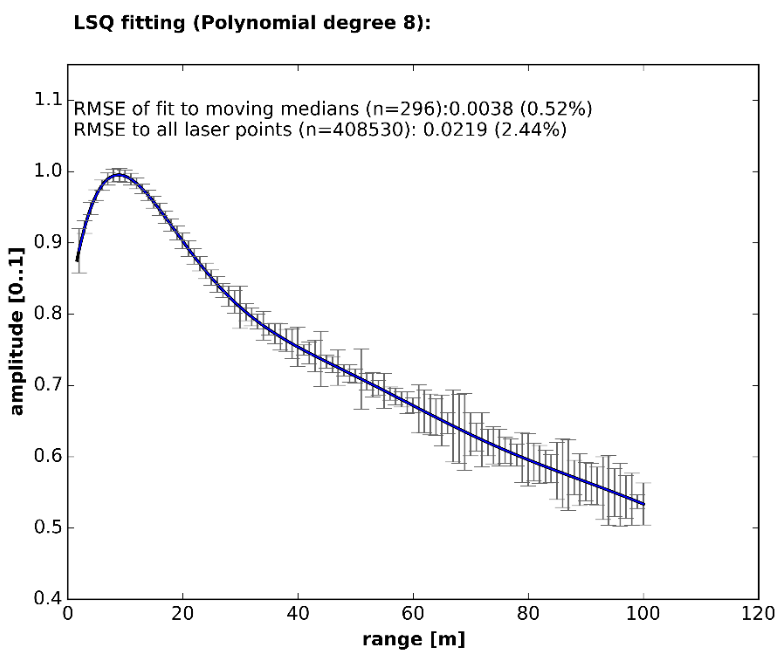
1) Determine Range-Intensity-Function

python calib_range_ampl_TLS.py settings_calib_VZ400.txt

```
C:\bh\docs\HD\Vortraege\2018-03-15_3D_Workshop_Intensity\Hands-on\scripts>python calib_range_ampl_TL
S.py settings_calib_VZ400.txt
Input file:  all_panels_fw.txt
C:\Python27_64bit\lib\site-packages\matplotlib\collections.py:571: FutureWarning: elementwise compar
ison failed; returning scalar instead, but in the future will perform elementwise comparison
  if self._edgecolors == str('face'):
----------------------------------------------------------------------------
RMS of fitting to medians with deg 8:   0.00380  - maximum value (0.995)
RMS_cv of fitting:                      0.51791%
n=296

RMSE to all data points:                0.02189
RMSE_cv to all data points:             2.43951%
n=408530
```





Example Faro

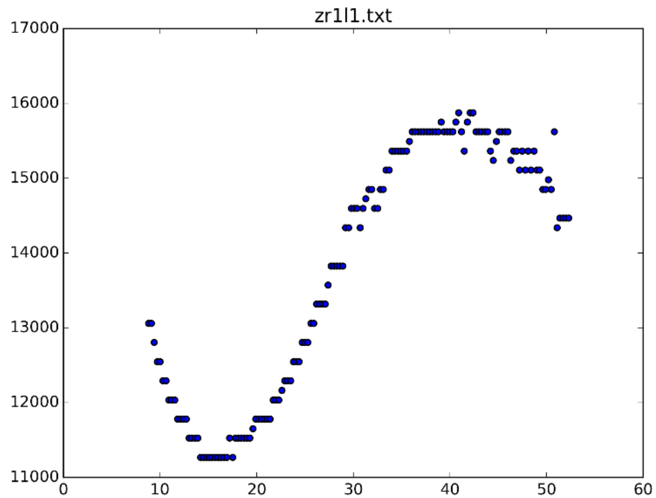
```
python calib_range_ampl_TLS.py
settings_calib_Faro.txt
```

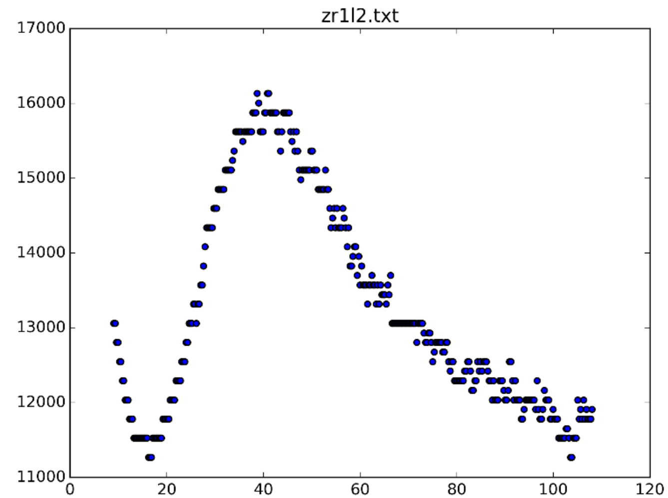
```
list_degree = [8] # polynomial degrees to test fitting
list_color = ['b', 'g', 'c', 'm', 'y', 'k'] # colors for plotting
min_range=0.0        # min. range value to be used
max_range=150.0      # max. range value to be used (e.g. filter outliers)
normalize=True       # normalize intensity values for plotting between [0..1]
degcorr=8            # polynomial degree to be selected
PLOTFINAL=1          # Plot final result (1=yes, 0=no)
SKIPHEADER=True # skip first line in input (True / False)
FIELDSEPARATOR=","   # field column separator in input files
COL_RANGE=3          # id/no. of column with range values (column numbering starting from 0)
COL_INT = 4          # id/no. of column with intensity values (column starting from 0)
path = r"testdata\Faro"     #Open all input files with file extenstion .txt
```

Example Faro

```
python calib_range_ampl_TLS.py
settings_calib_Faro.txt
```

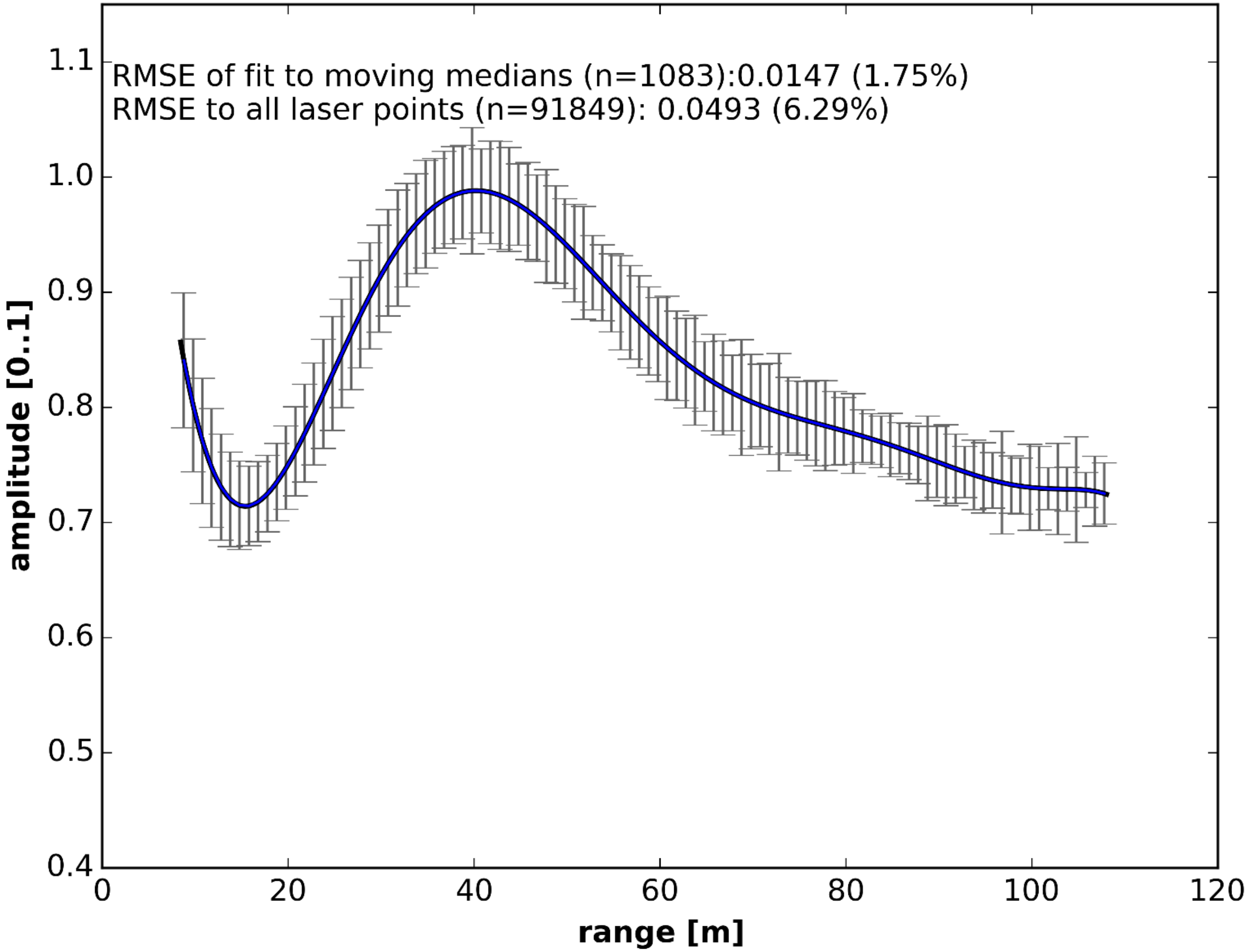
```
Input file:  zr1l2.txt
Input file:  zr2l1.txt
Input file:  zr2l2.txt
Input file:  zr4l1.txt
Input file:  zr4l2.txt
```



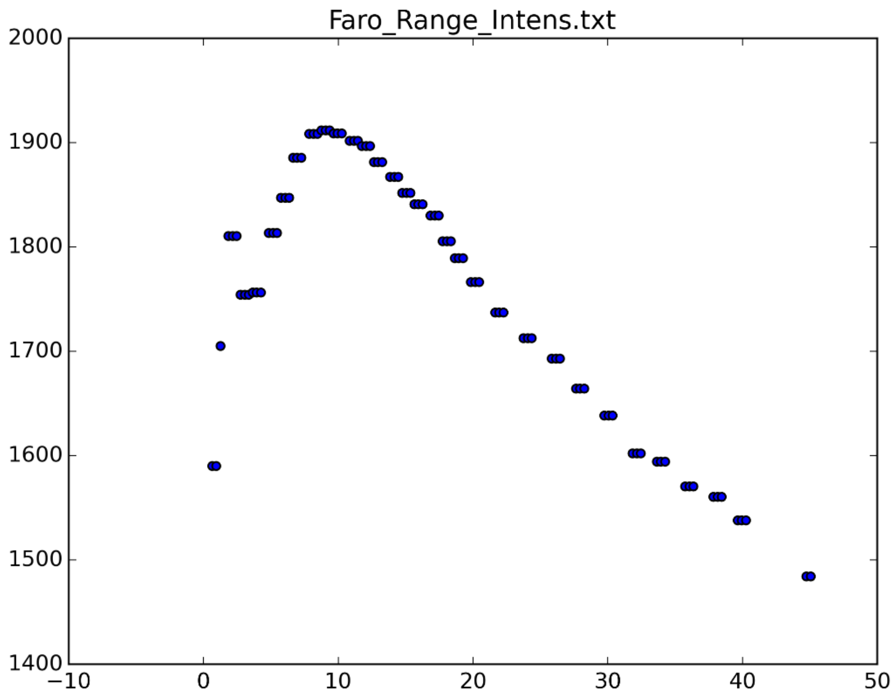


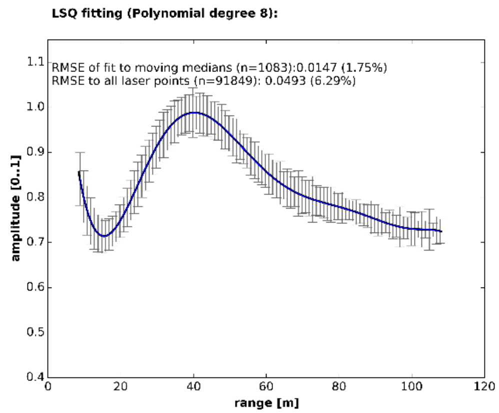
Example Faro Köln

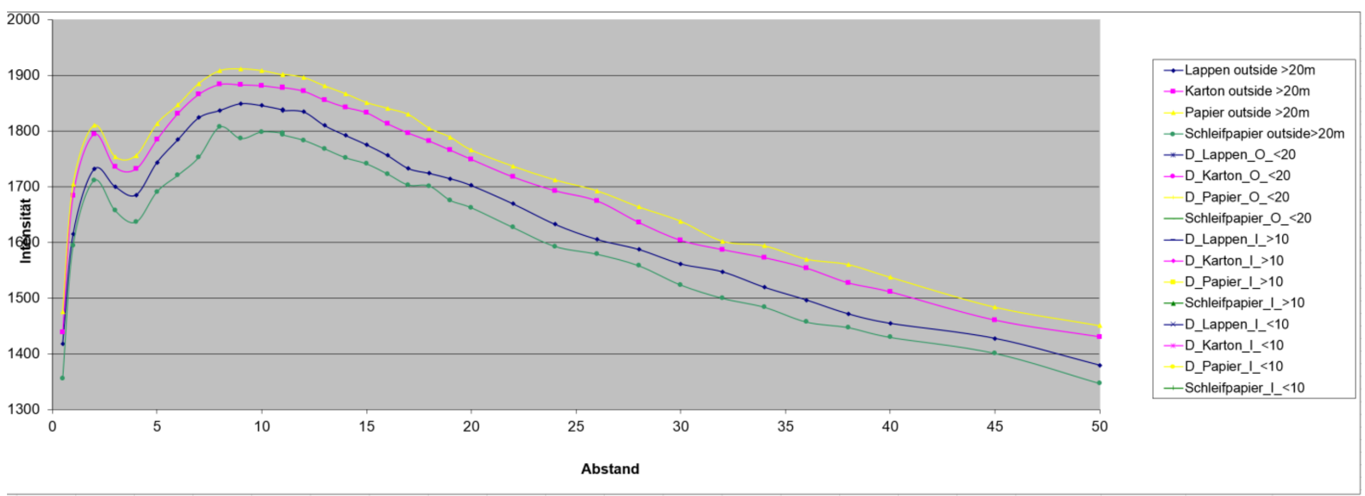
LSQ fitting (Polynomial degree 8):



Example Faro Mathias







2) Apply correction function to remove range effects

```
python calibrate_amplitudes.py settings_correct_VZ400.txt
ScanPos1_KIP.xyz ScanPos1_KIP_corr.xyz
```

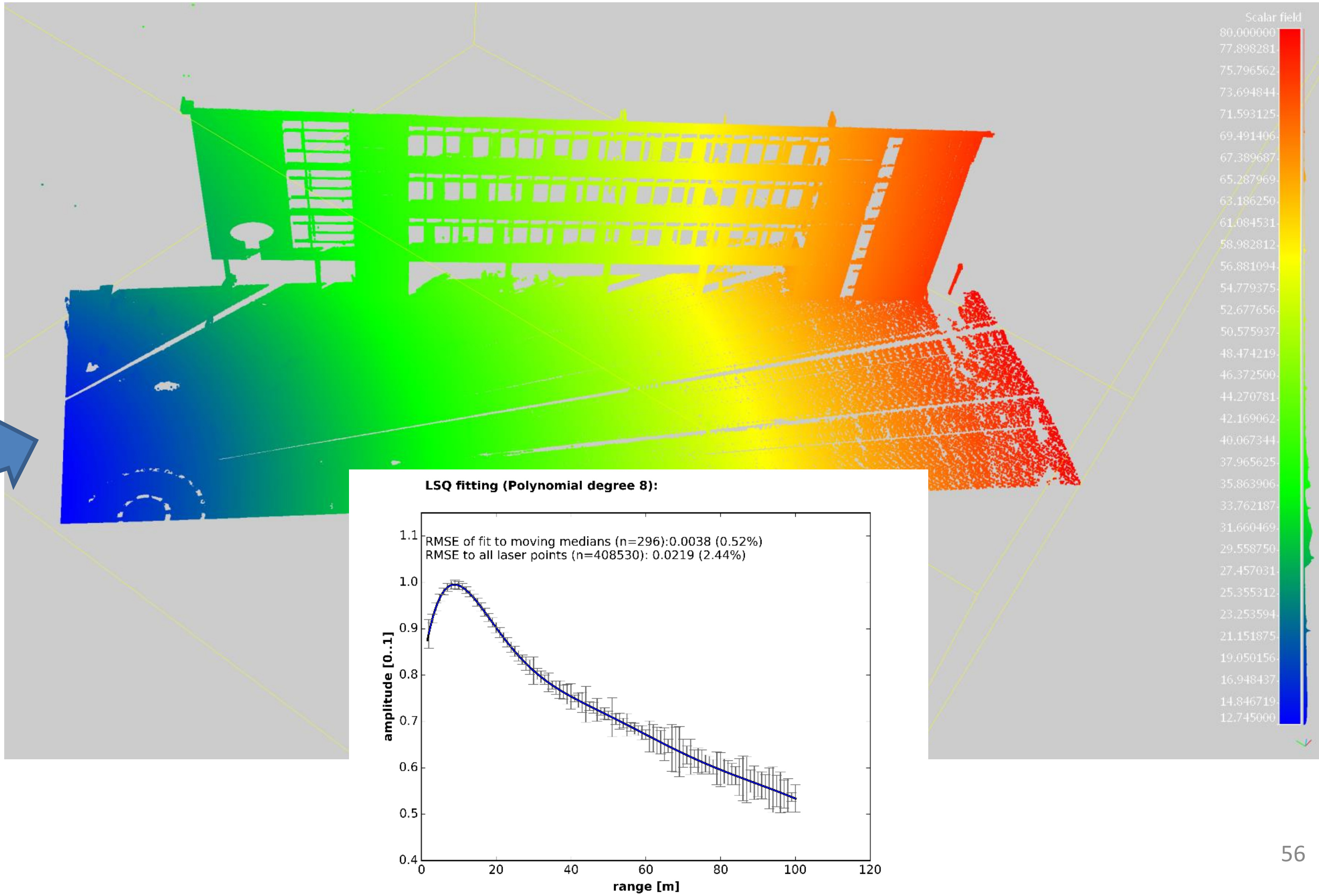
```
-17.36666489 7.58563423 -2.12658334 13.007000 23.540001 -11.939000
-17.38164520 7.60319901 -2.12670541 12.985000 25.280001 -10.209000
-17.39910126 7.62407017 -2.12585020 12.958000 23.350000 -12.149000
-17.41447067 7.64256191 -2.12497854 12.934000 24.000000 -11.519000
-17.42605972 7.65721035 -2.12607956 12.916000 23.219999 -12.299000
-17.44273758 7.67623711 -2.12521219 12.891000 22.840000 -12.699000
-17.36743927 7.58747768 -2.12659550 13.005000 23.379999 -12.099000
-17.38072395 7.60358715 -2.12670708 12.985000 25.379999 -10.109000
-17.39740372 7.62261486 -2.12583971 12.960000 24.700001 -10.799000
```

settings_correct_VZ400.txt

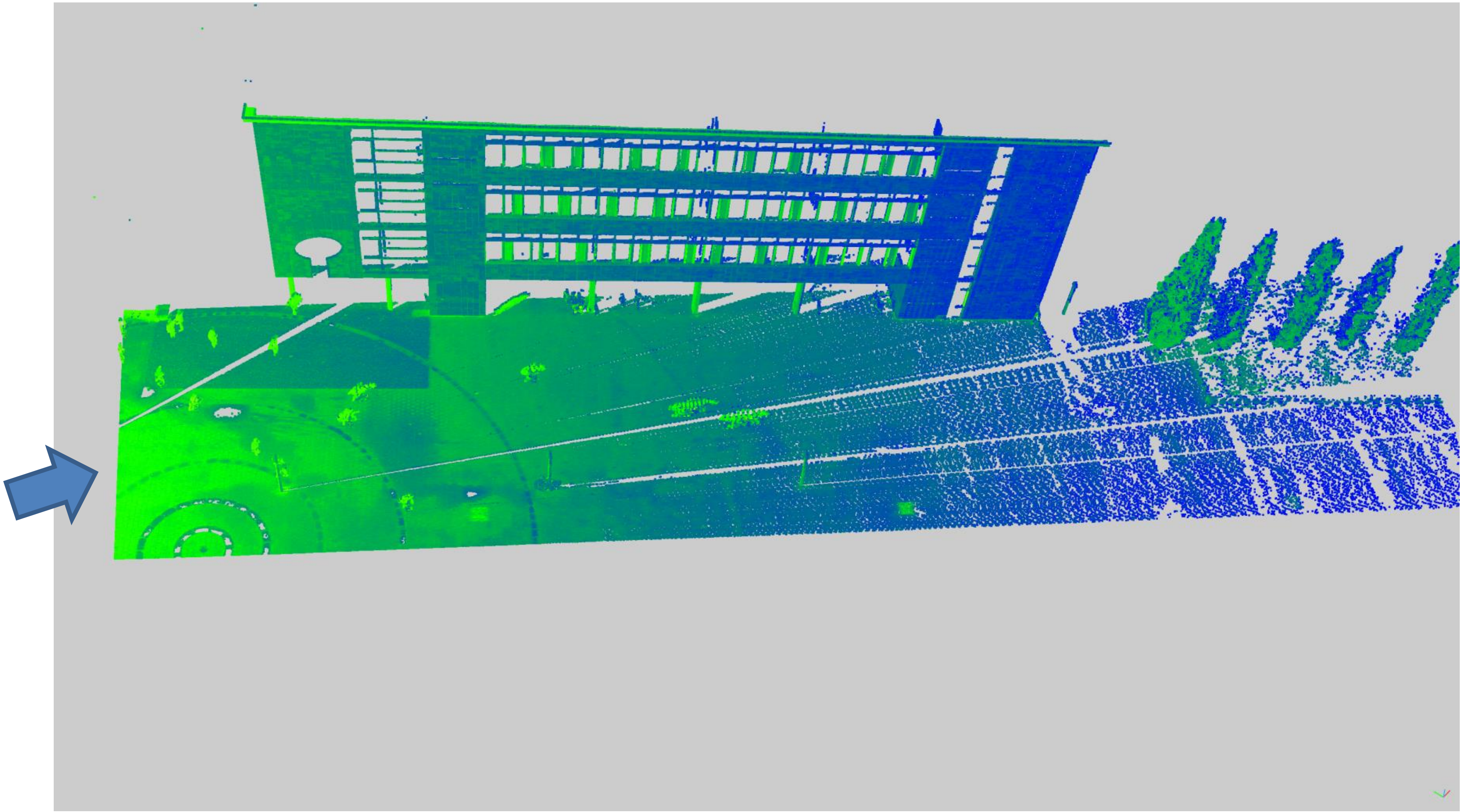
```
############### SETTINGS ###############
polyfile = r"polycoeffs_deg8.pkl"    #Calibration function file
col_ampl=4                           #column number for amplitude [starting with 0]
col_range=3                          #column number for range value [starting with 0]

rescale=0                            #rescale values 0...No, 1...Yes
rescale_min=418.0                    #Rescale limits for values after calibration: values a
rescale_max=3747.0
max_range = 80.0                     #Max. range value
########################################
```

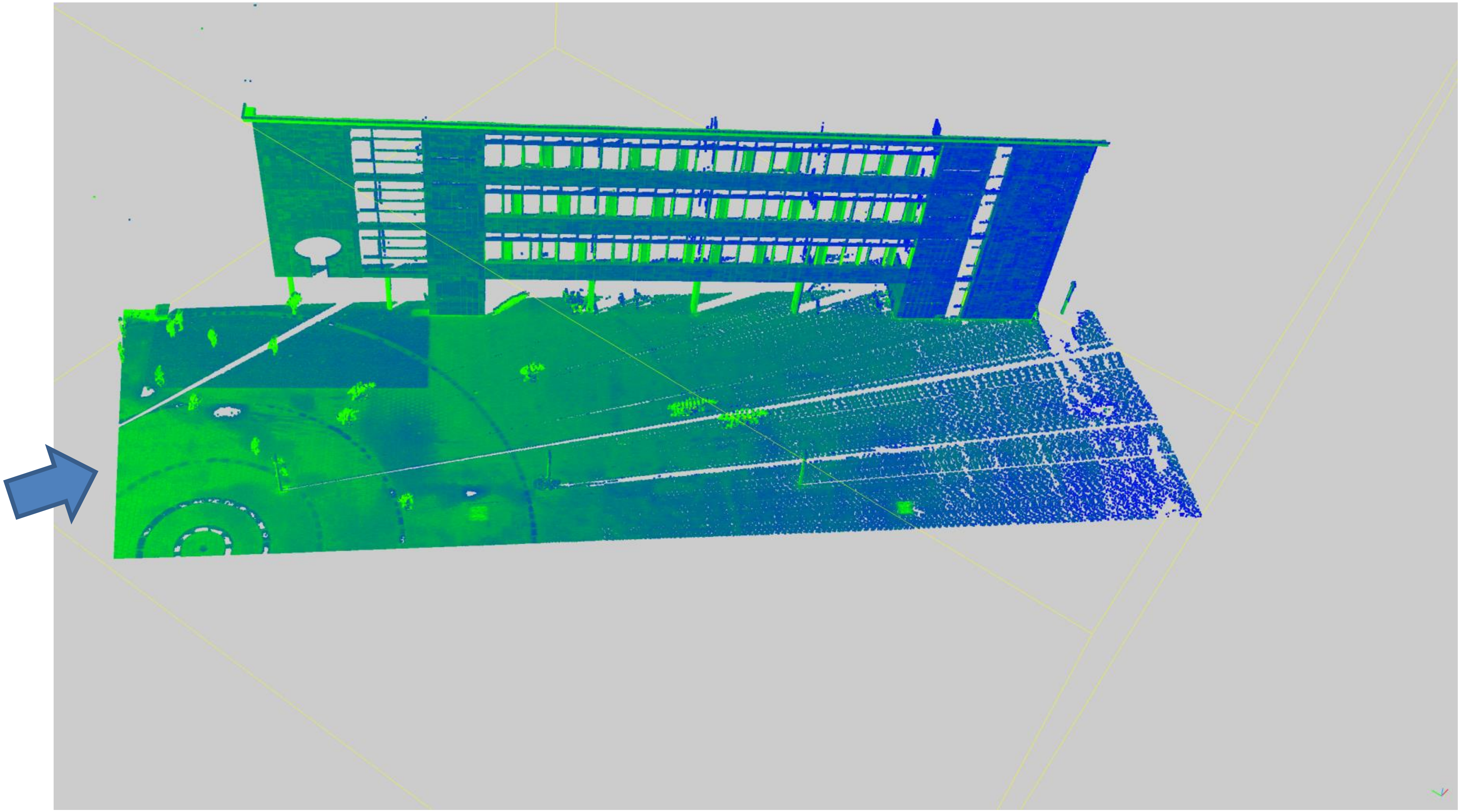
Range


Scalar field
80.000000
77.898281
75.796562
73.694844
71.593125
69.491406
67.389687
65.287969
63.186250
61.084531
58.982812
56.881094
54.779375
52.677656
50.575937
48.474219
46.372500
44.270781
42.169062
40.067344
37.965625
35.863906
33.762187
31.660469
29.558750
27.457031
25.355312
23.253594
21.151875
19.050156
16.948437
14.846719
12.745000
LSQ fitting (Polynomial degree 8):
RMSE of fit to moving medians (n=296):0.0038 (0.52%)
RMSE to all laser points (n=408530): 0.0219 (2.44%)
amplitude [0..1]
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
20
40
60
80
100
120
range [m]

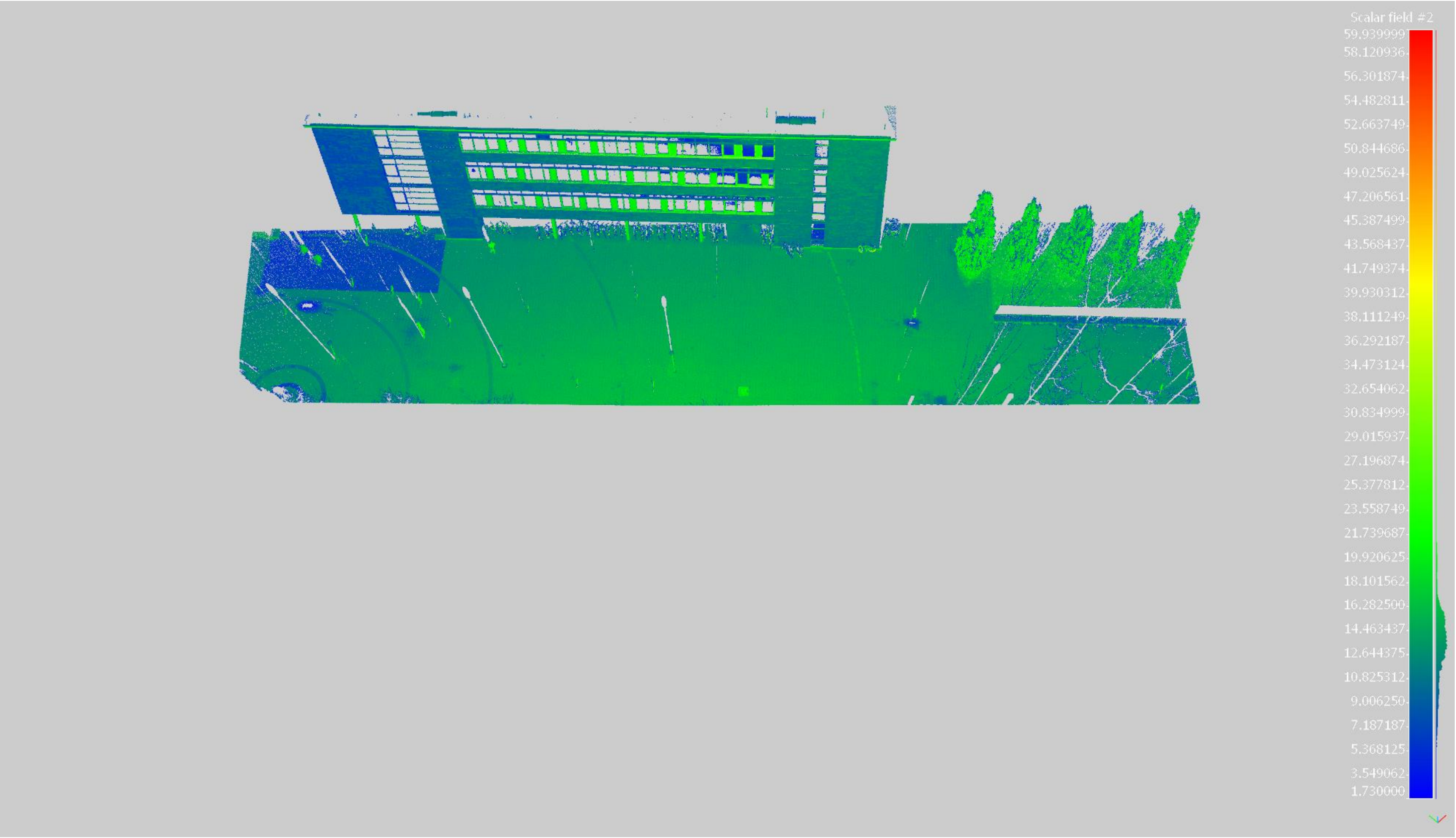
Before Correction



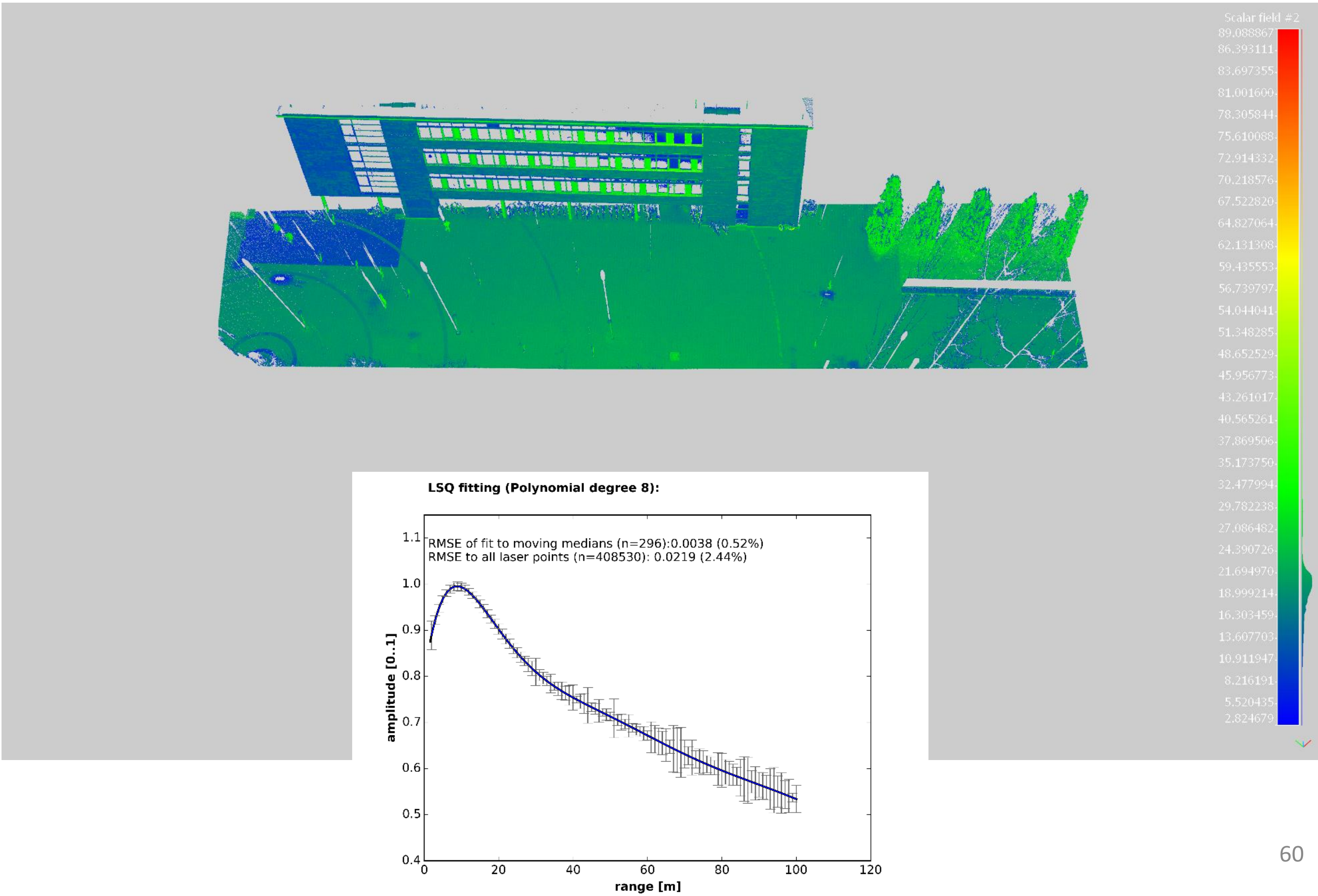
After Correction



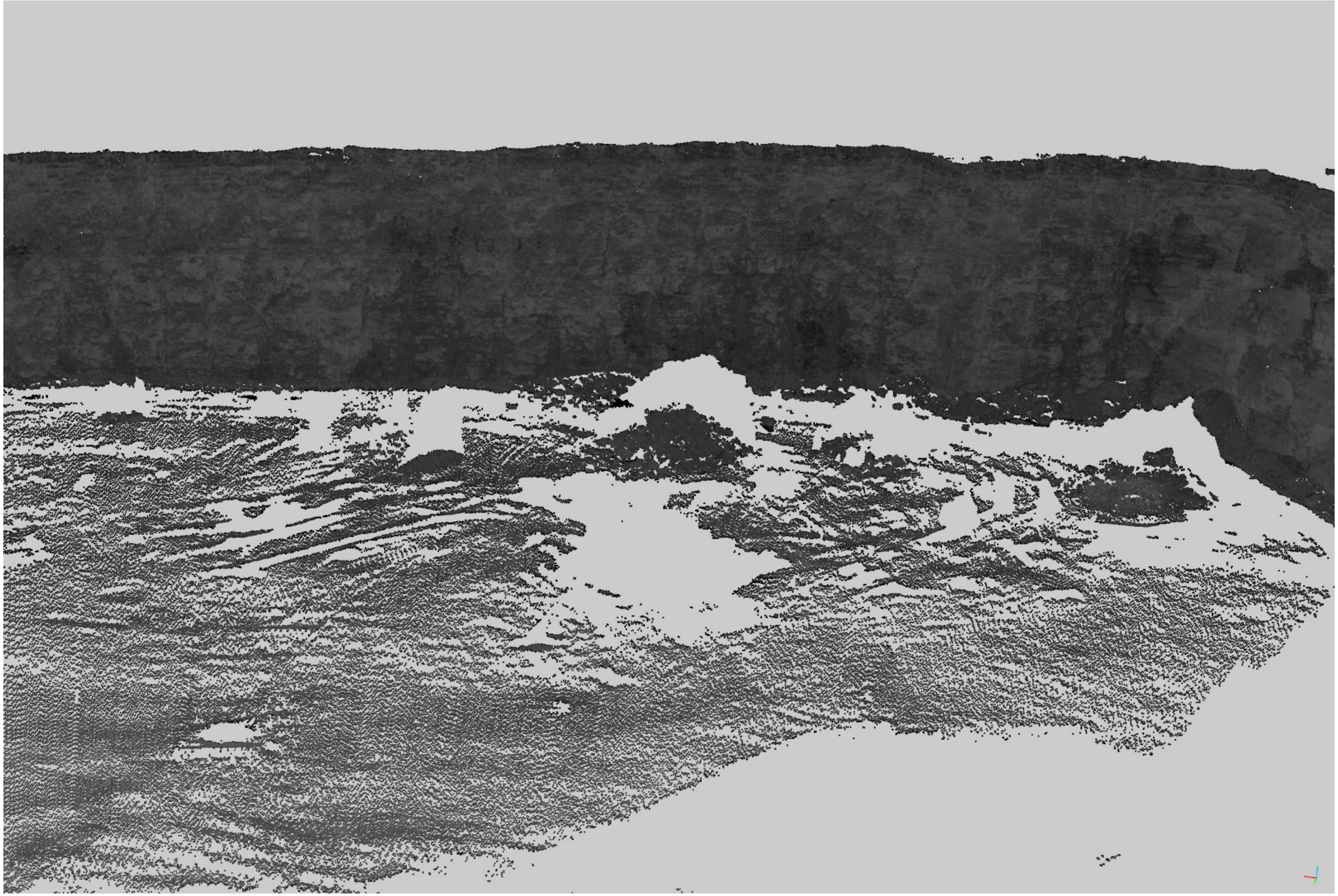
Before Correction



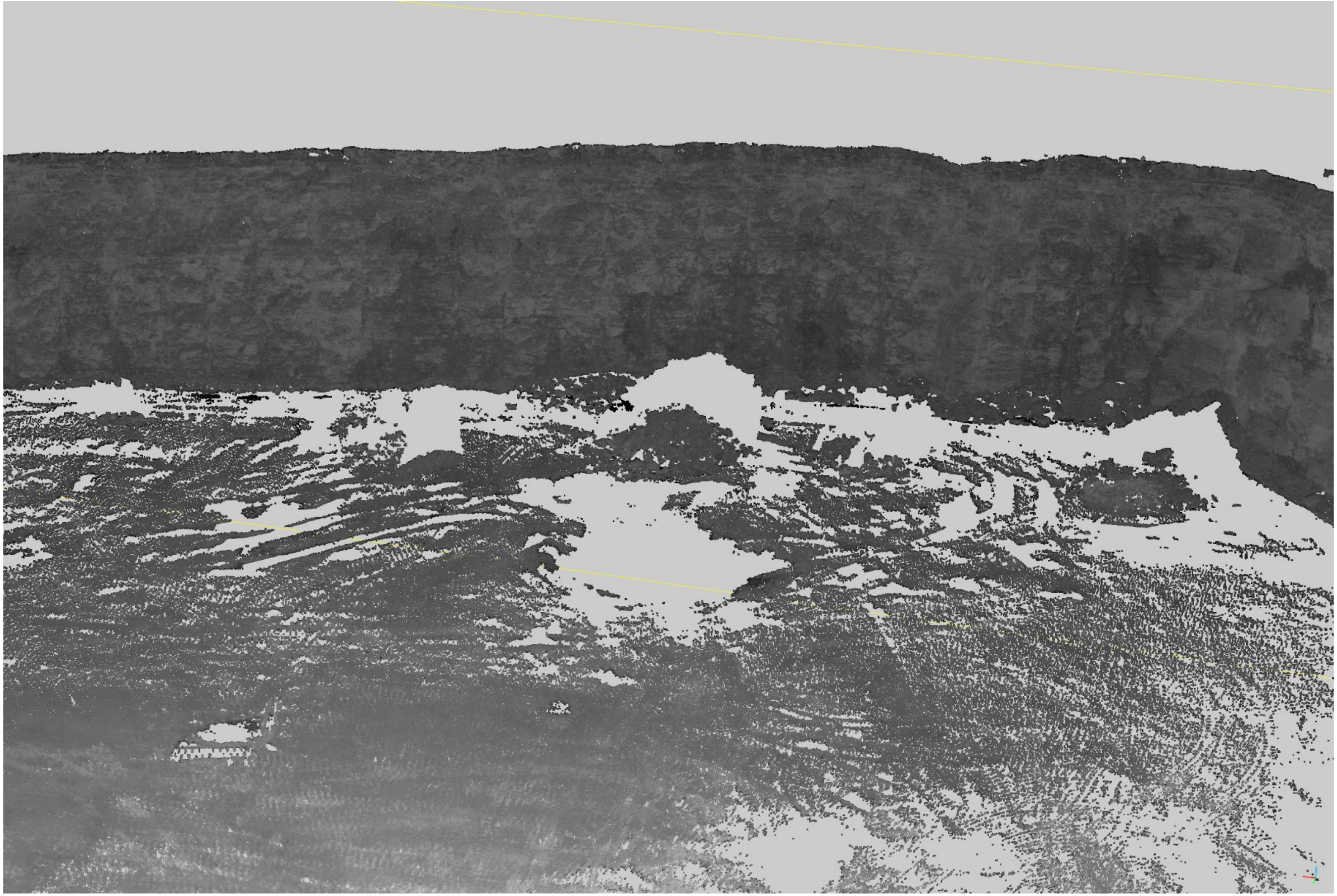
After Correction



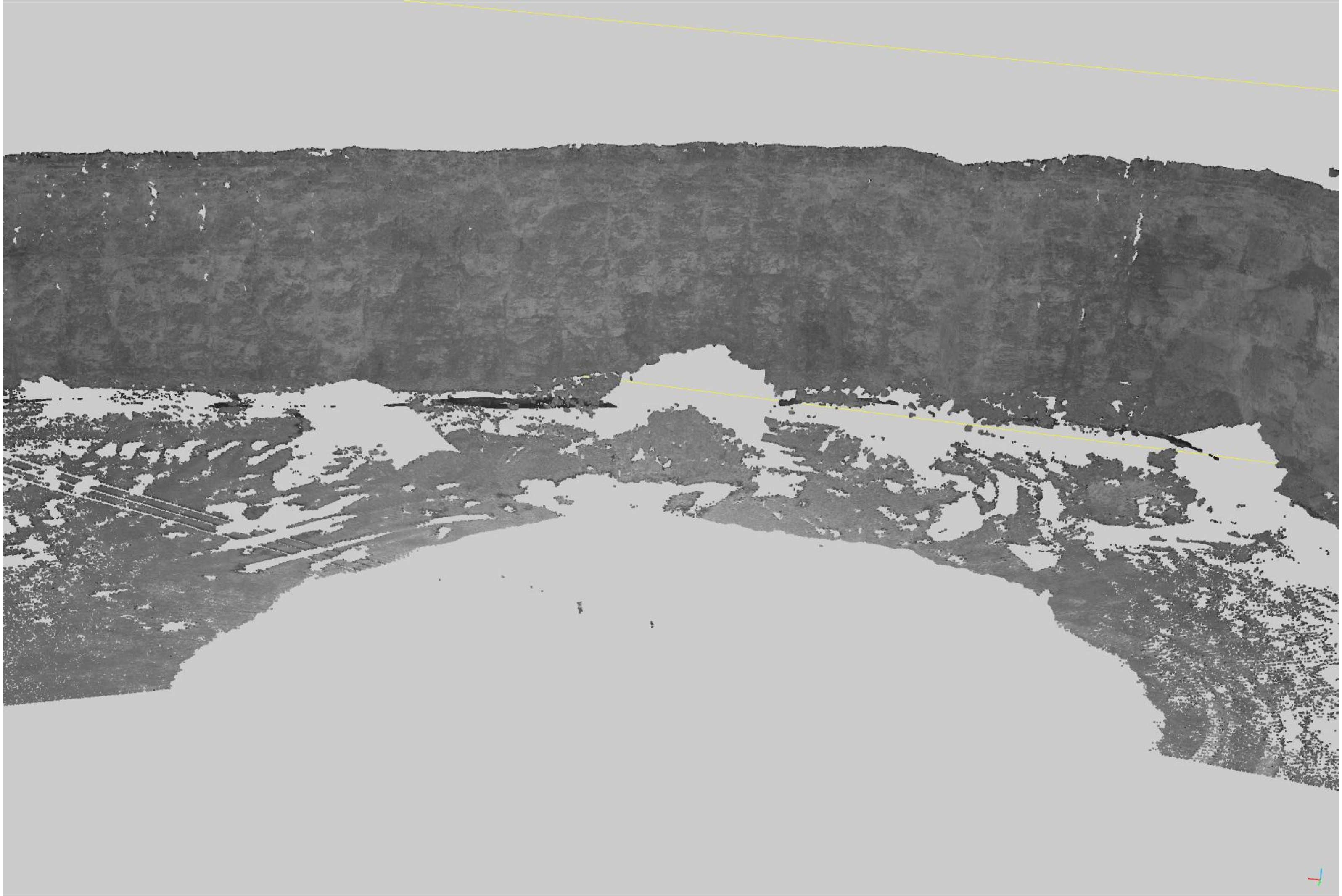
Scan 1 (Before)



Scan 2 (Before)



Scan 3 (Before)



Corrected (Scan 1 + 2)