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Close-range sensing and object-based analysis of shallow landslides and erosion in grasslands of the Alps

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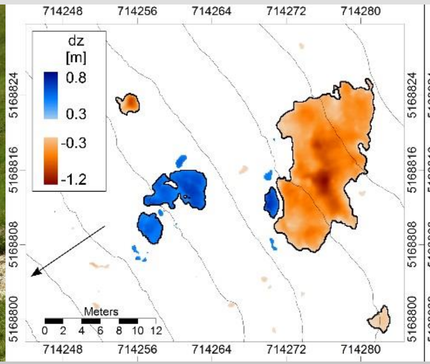
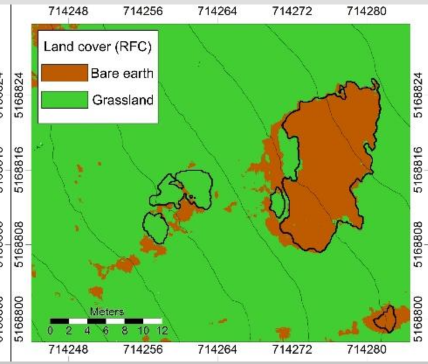




08 May 2020

Introduction

Shallow erosion in grassland of the Alps

- Mechanical erosion of grass cover and soil
- Depth approx. 0.2 – 2 m
- Eroded areas of c. 10 – 100 m²
(individual patches)
- Often large number of eroded areas at a particular slope
- Processes:
    - Shallow landslides
    - Abrasion by snow gliding and avalanches

Investigation of shallow erosion in grassland of the Alps

1. Mapping and quantification of eroded areas and their dynamics
2. Process understanding and possibilities for mitigation

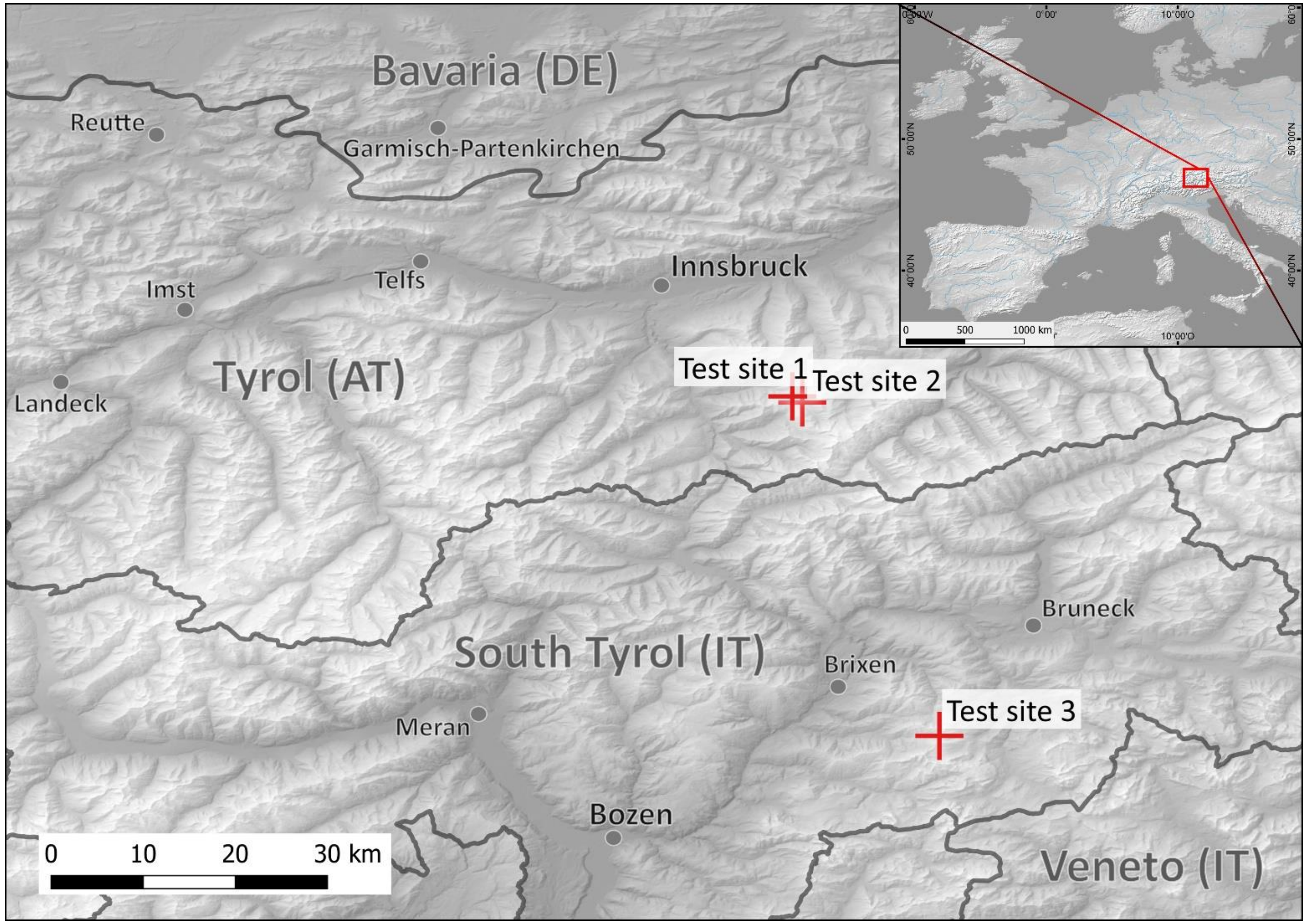
Outline

1. Mapping eroded areas using ground-based photography

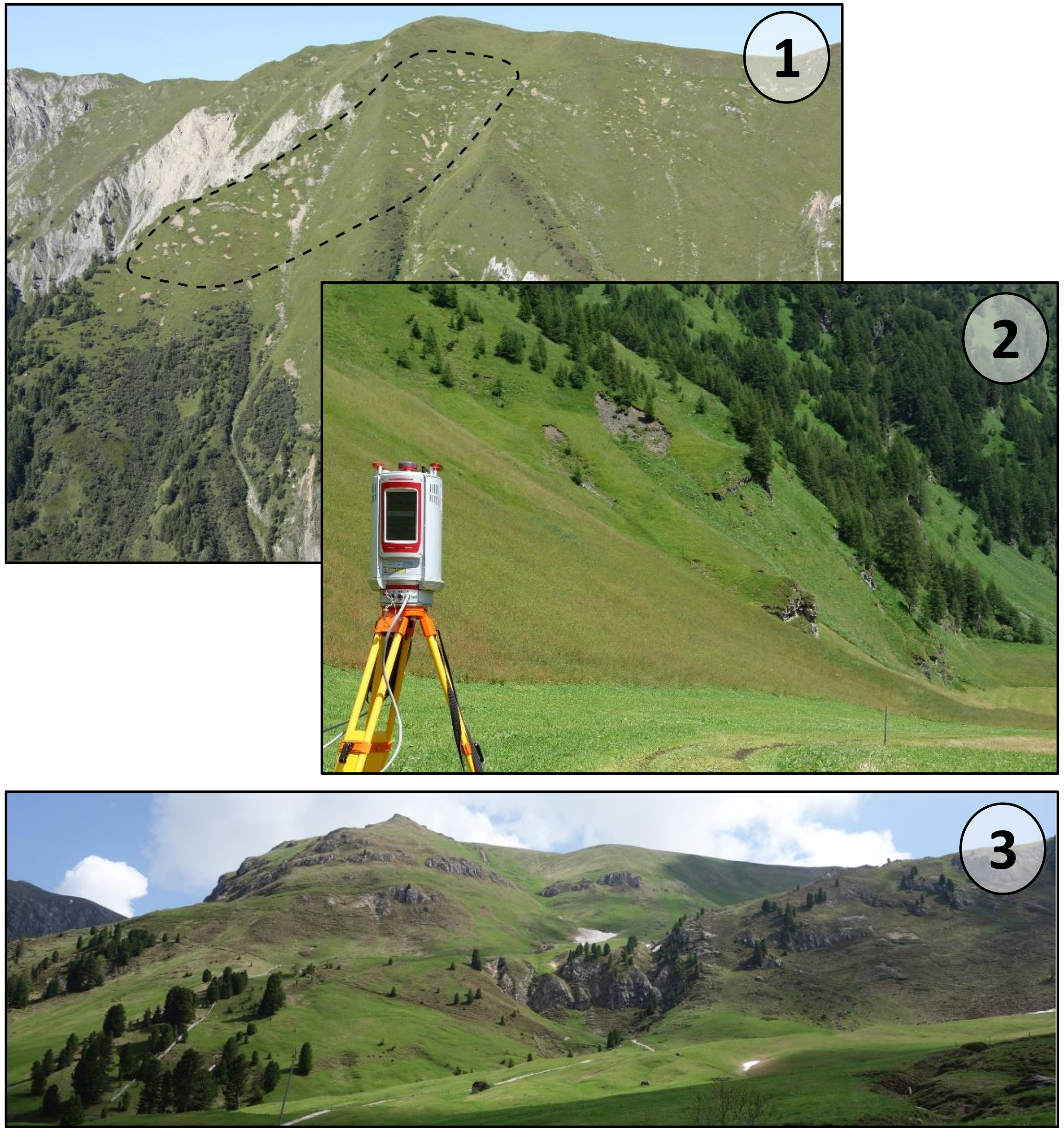
2. 3D landslide monitoring with terrestrial laser scanning

3. Unmanned aerial vehicle laser scanning for erosion monitoring

Test sites



Map data sources: Elevation model: Copernicus Land Monitoring Service 2020; small shaded relief map: Natural Earth 2020; administrative region boundaries: Autonomous Province of Bozen - South Tyrol 2017.



1. Mapping eroded areas using ground-based photography

Mayr et al. 2016. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, III-5, 137 – 144.*

Data acquisition

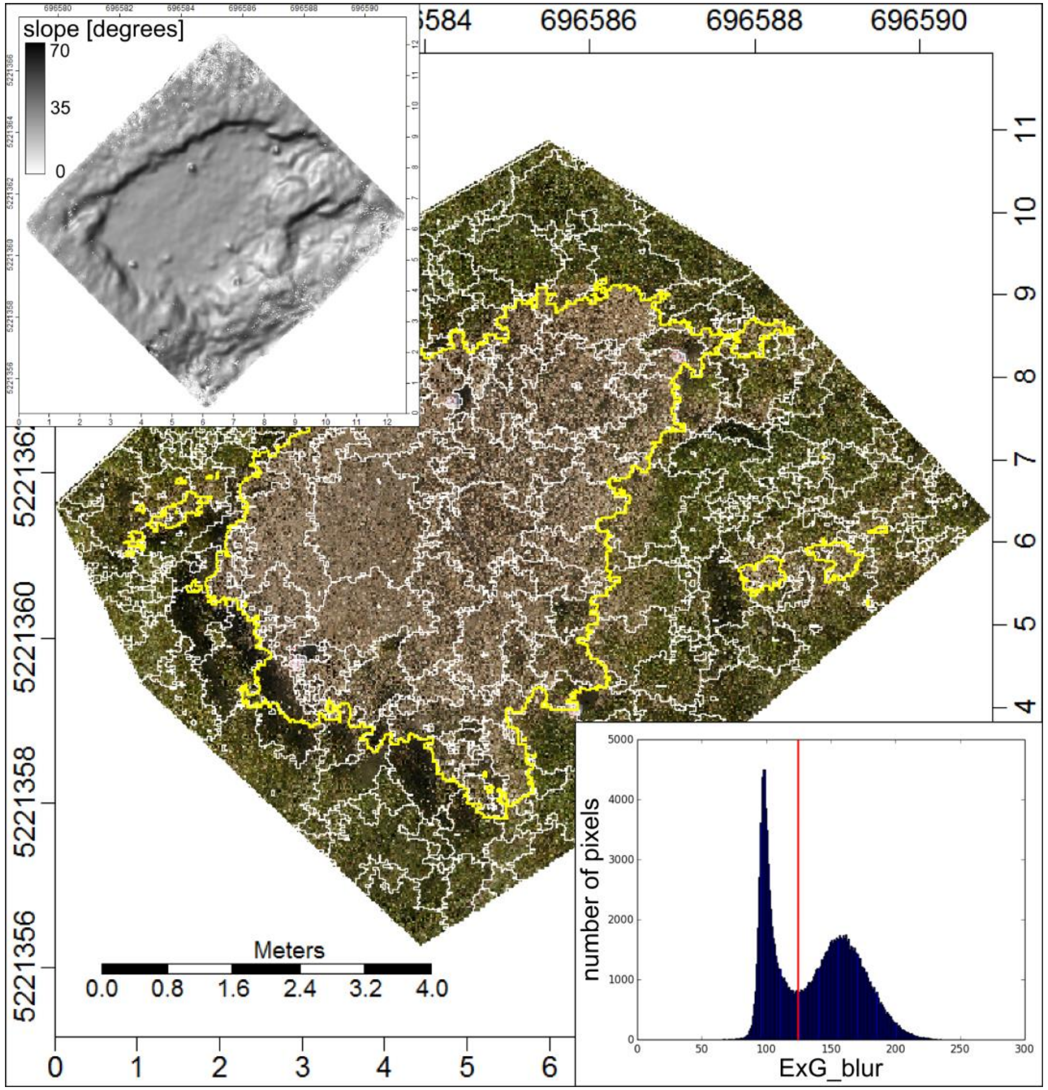
- 10 scenes with one eroded area each
- Pole-mounted DSLR camera
- 4 ground control points (measured with DGNSS)
- > 100 oblique images per scene shot from around the eroded area

Image matching

- SfM-MVS
- Point cloud and orthophoto generation (2 cm GSD)

1. Mapping eroded areas using ground-based photography

Mayr et al. 2016. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, III-5, 137 – 144.*



Orthophoto classification (OBIA)

- Classes *eroded* and *grass*
- Segmentation by seeded region growing
- ExG vegetation index calculated from RGB bands
- Unsupervised classification by histogram-based thresholding of ExG_{mean}
- Validation with manual boundary delineation

Results

→ Classification accuracy > 90% (OA)

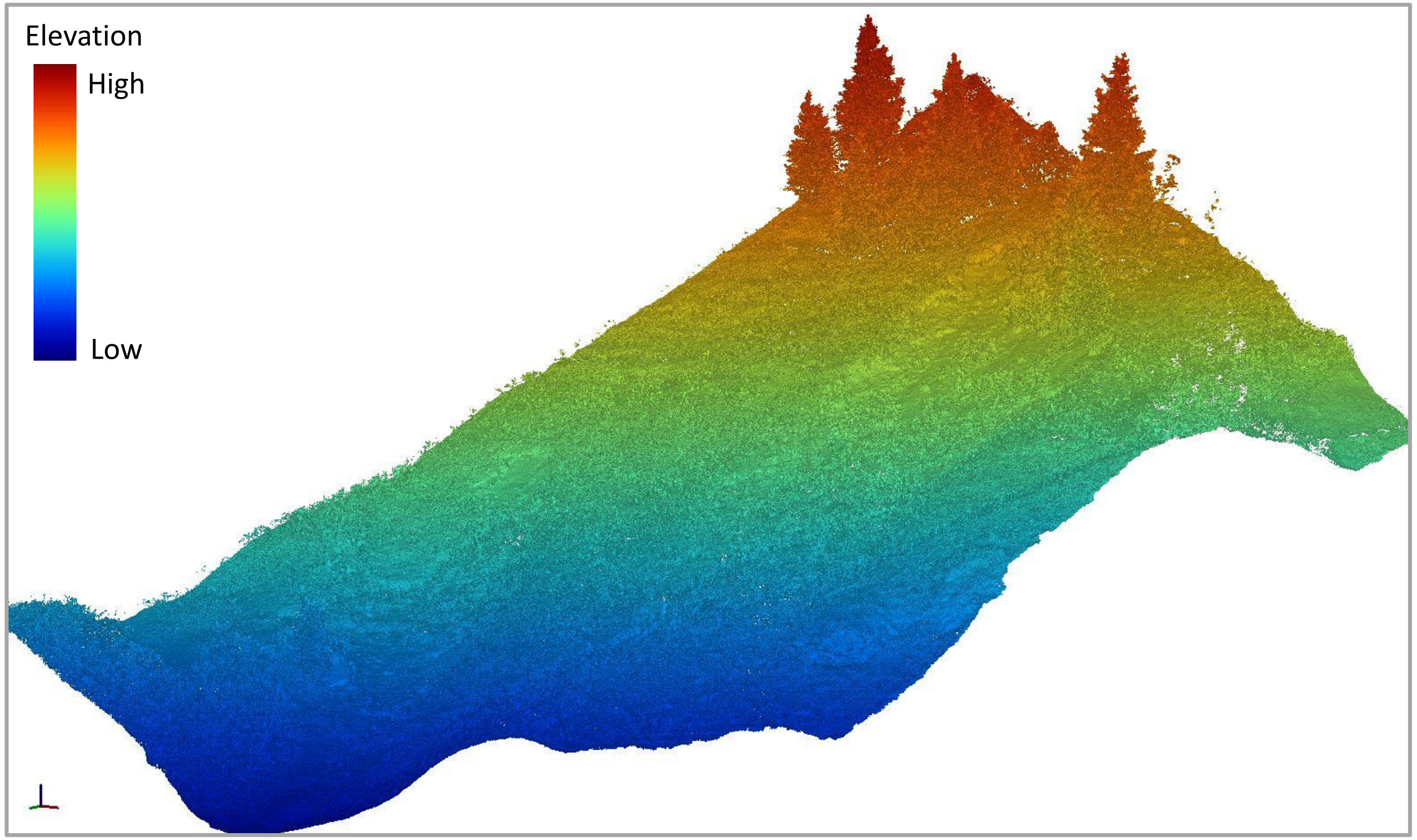
→ Main uncertainties:

Gradual transitions at eroded area boundaries

→ Useful for validation of eroded area mapping in aerial orthophotos

2. 3D landslide monitoring with terrestrial laser scanning

Interpretability of data?

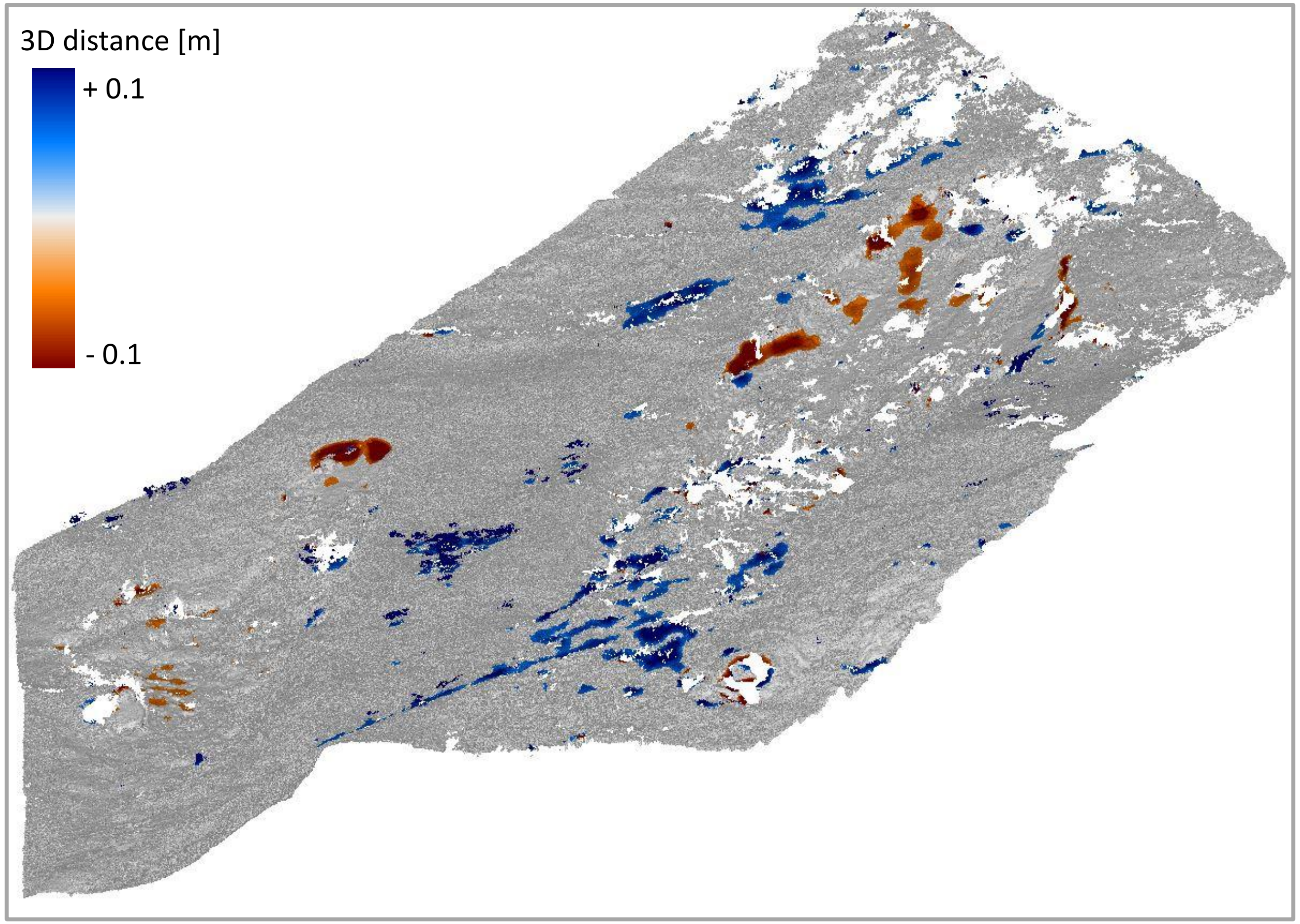


Point cloud with shading and colored by elevation (*z*).

3D landslide monitoring with TLS

Interpretability of data?

Type of changes? What kind of objects are affected?
(Reasons for change?)
→ **Lack of semantic information**



Point cloud with shading and colored by 3D distance to previous epoch (calculated with M3C2 algorithm; Lague et al., 2013).

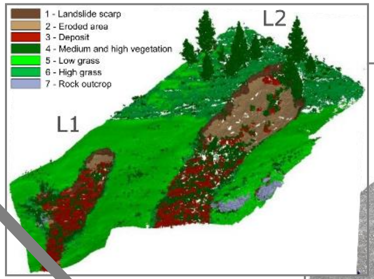
Lague et al., 2013. *ISPRS Journal of Photogrammetry and Remote Sensing, 82*, 10-26.

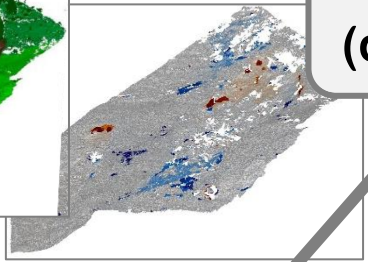
3D landslide monitoring with TLS

Approach for automated extraction of geomorphological information

Laser scanning and point cloud preprocessing

Classification
Object recognition



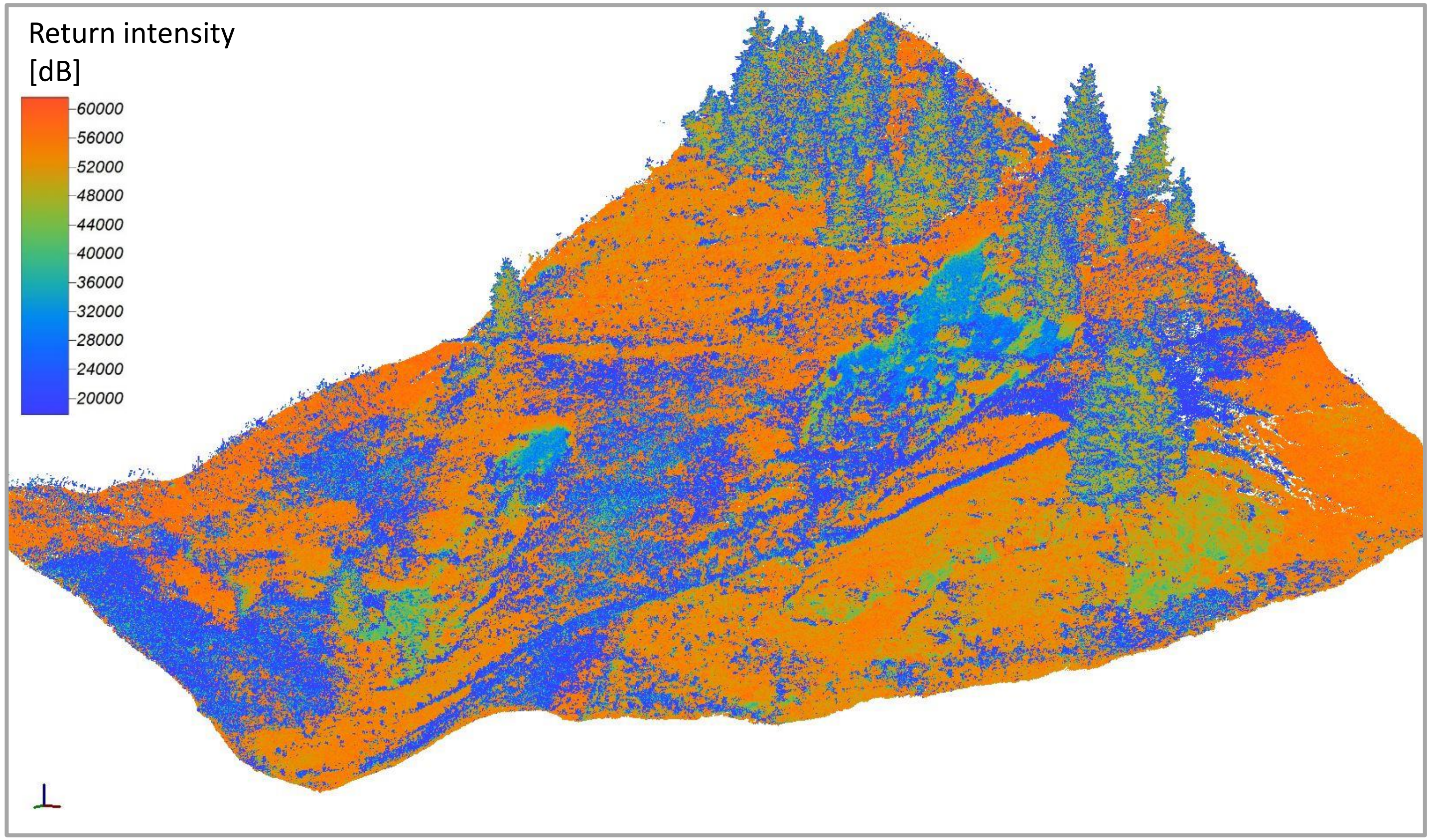


Change analysis
(deformation measurement)

Change of objects in the landslide

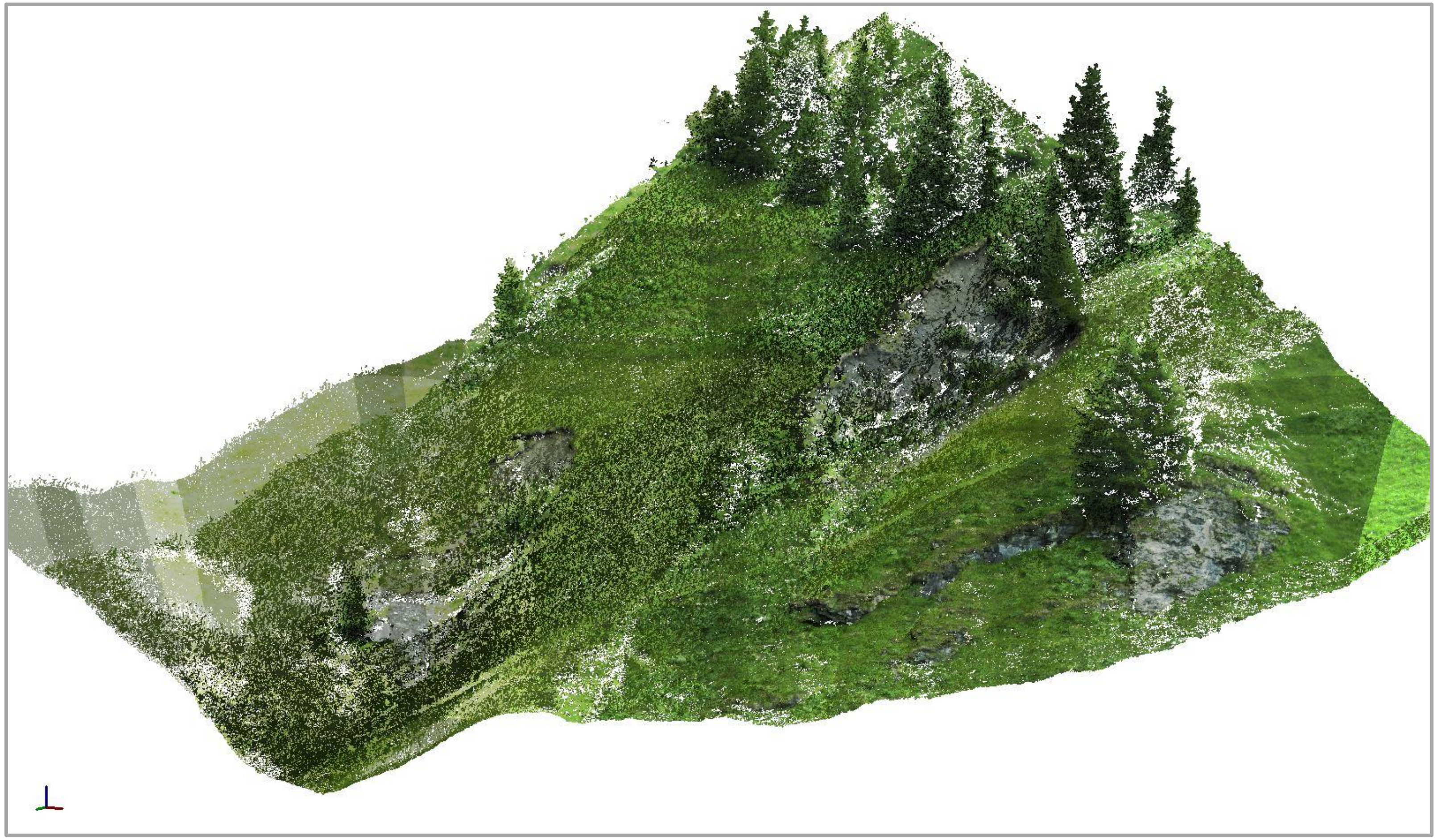
Geomorphological interpretation

3D landslide monitoring with terrestrial laser scanning



Point cloud colored by laser return intensity (1064 nm wavelength).

3D landslide monitoring with terrestrial laser scanning



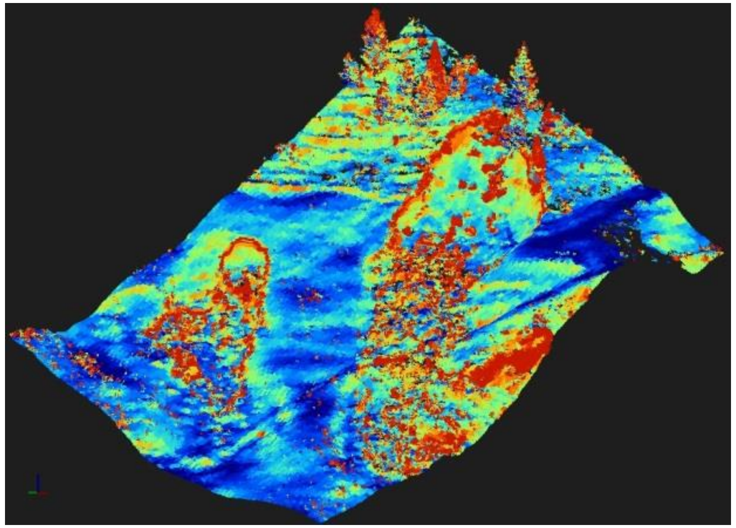
Point cloud colorized with RGB photos (04 July 2018)

Object-based point cloud classification
Geometric point cloud features

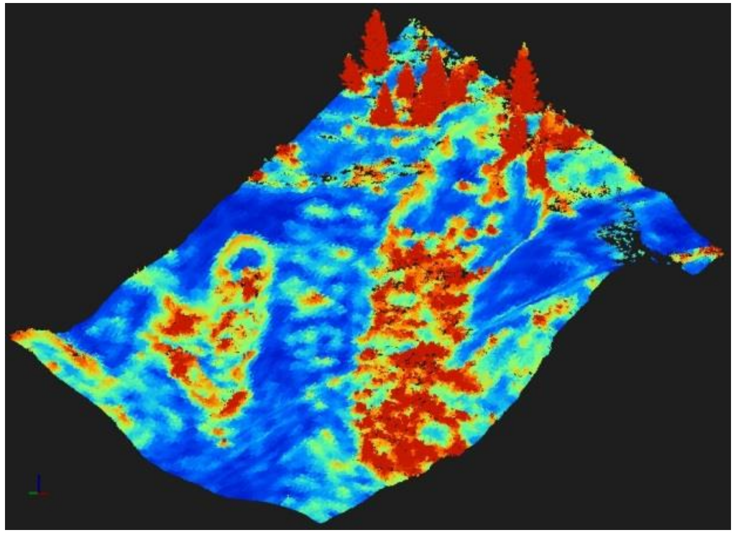
Mayr, A., Rutzinger, M., Bremer, M., Oude Elberink, S., Stumpf, F., Geitner, C. (2017). Object-based classification of terrestrial laser scanning point clouds for landslide monitoring. *The Photogrammetric Record*, *32*(160), 377-397.

- Planarity measures
- Slope
- Curvature
- Vertical distribution of points
- At three different scales
  (varying neighbourhood radius: 0.2, 0.4 and 1.0 m)

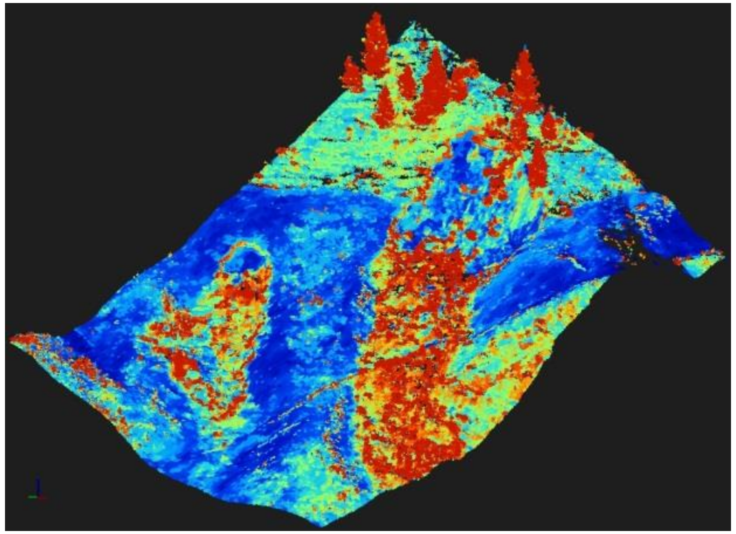
- Aggregation to segments (mean, standard dev.)



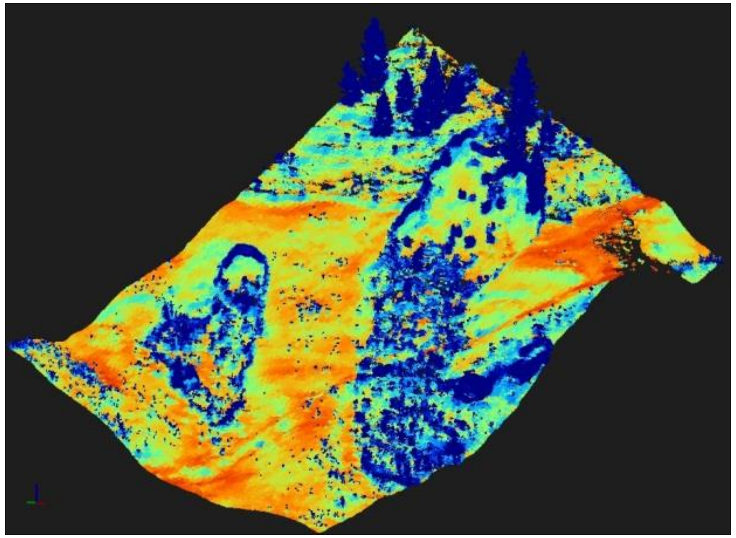
Slope (r = 0.2 m)



sd from plane (r = 1.0 m)



sd from plane (r = 0.2 m)

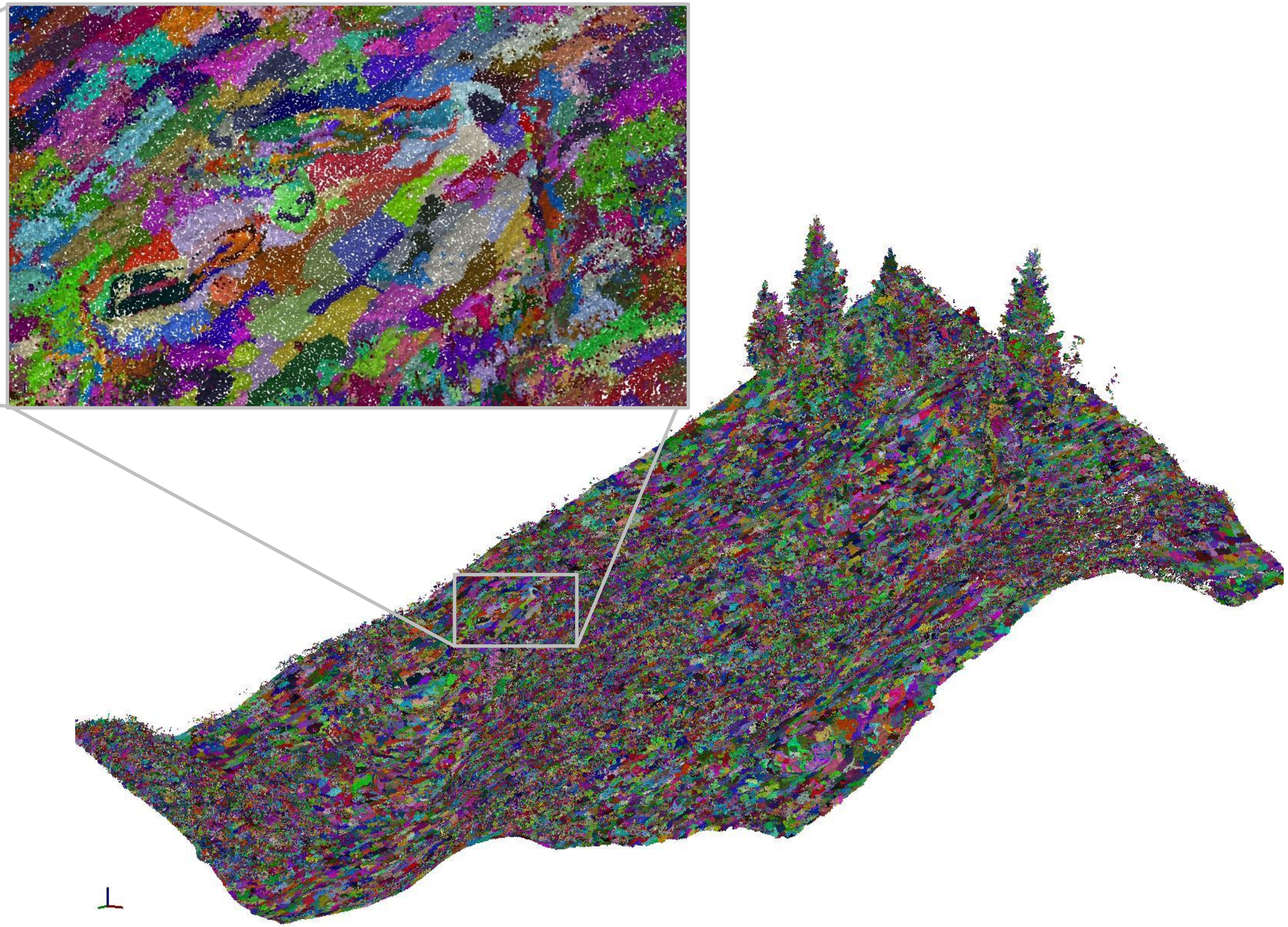


3D/2D density ratio (r = 0.2 m)

Object-based point cloud classification

Segmentation

Mayr et al. 2017. *The Photogrammetric Record*, *32*(160), 377-397.



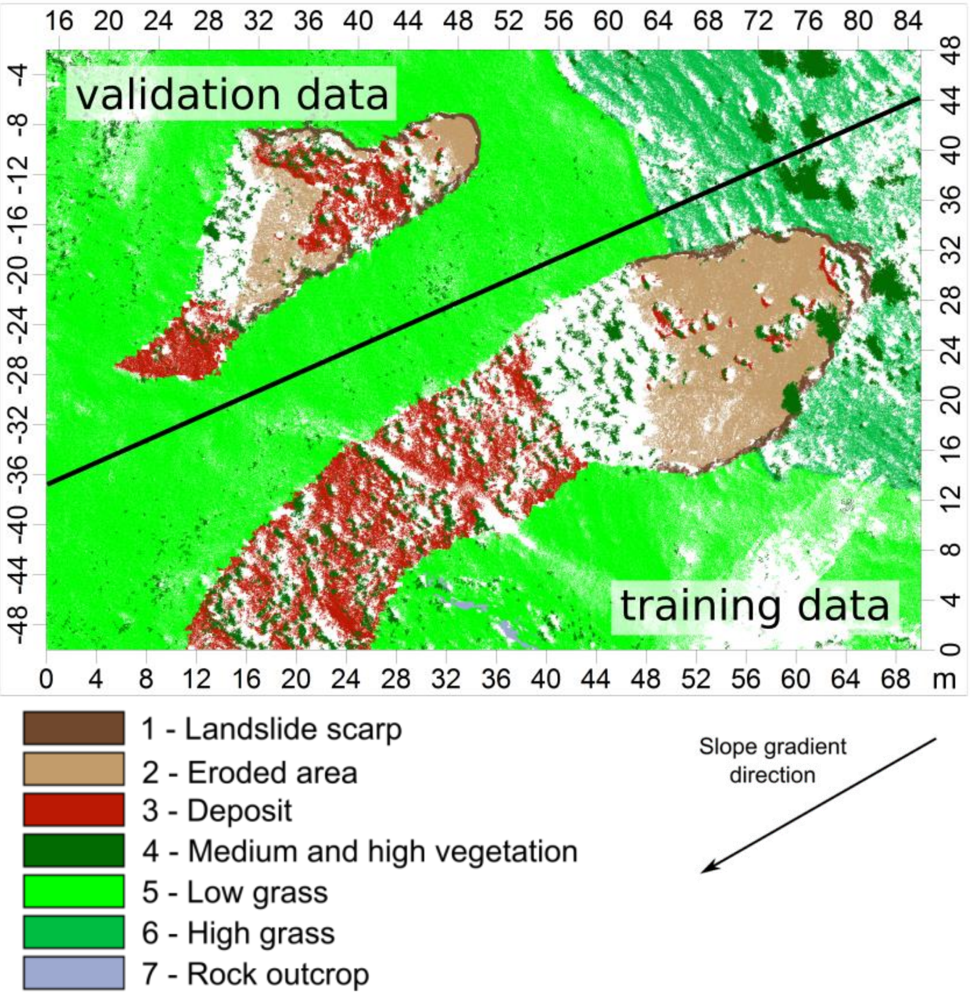
Point cloud colored by segment ID.

Object-based point cloud classification

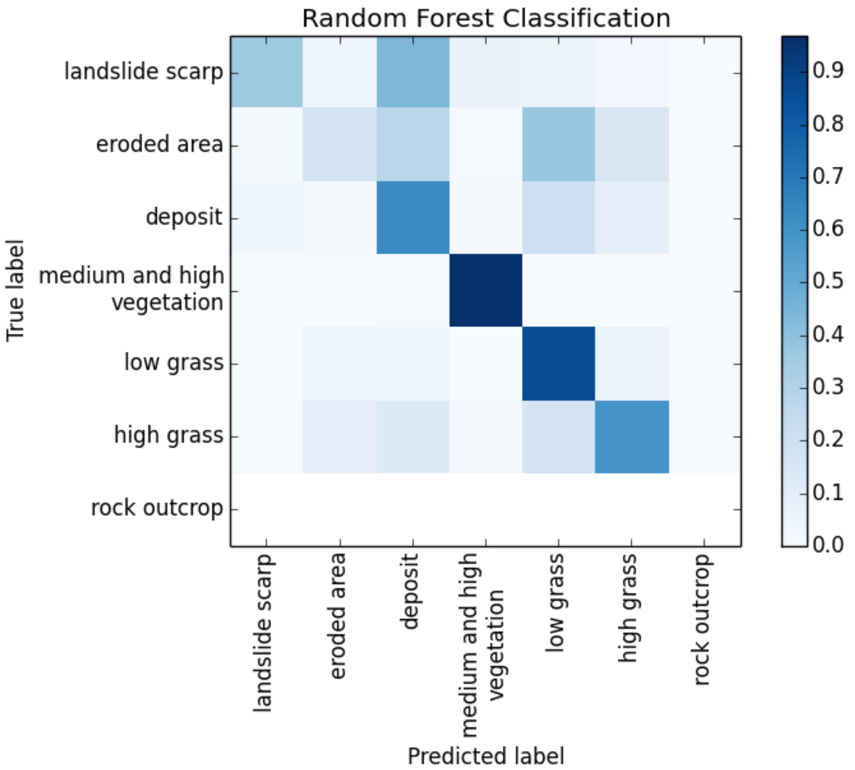
Random forest classification based on geometric features

Mayr et al. 2017. *The Photogrammetric Record*, *32*(160), 377-397.

Manually labelled reference data (one epoch (#7))



Validation



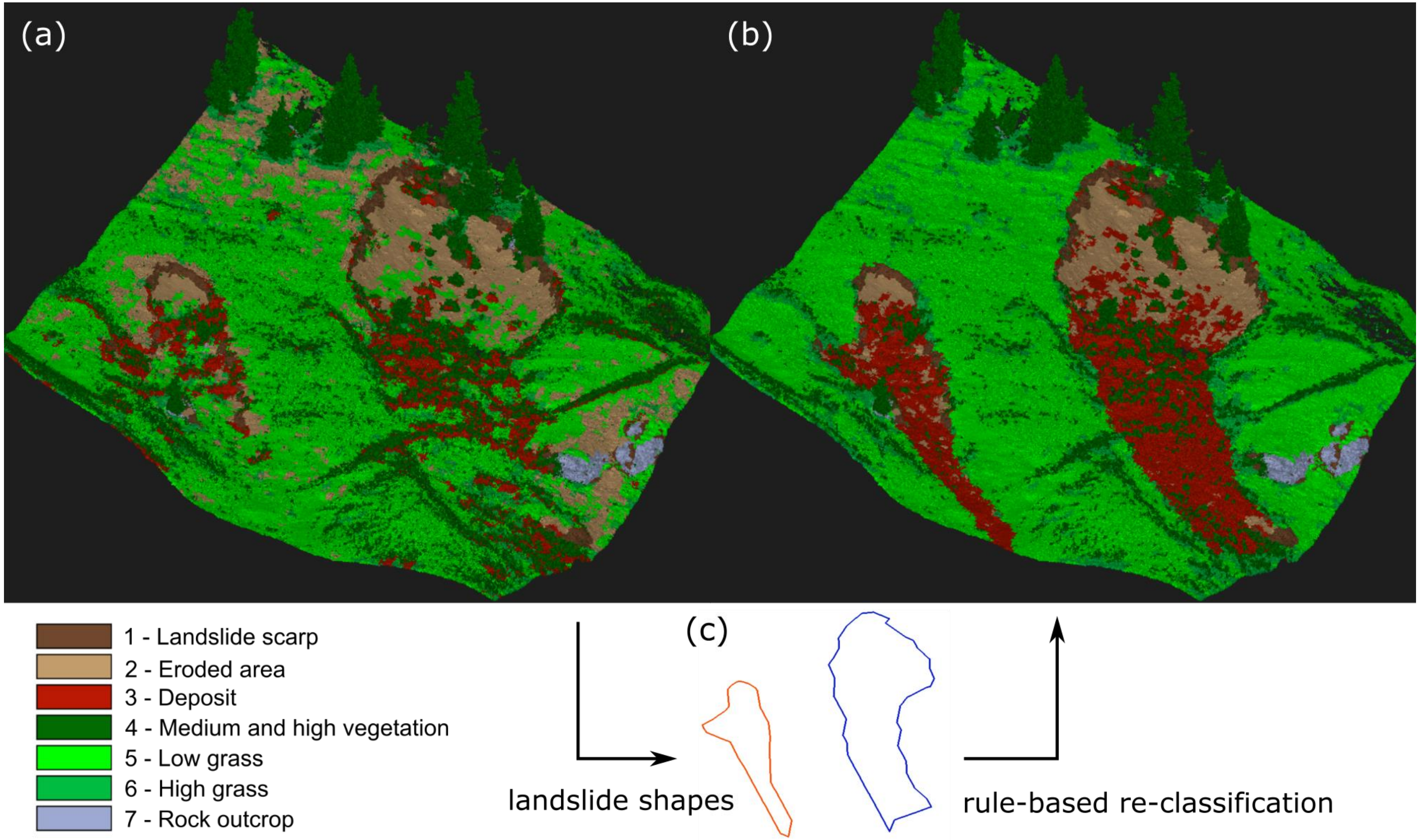
Application

→ The RF classifier labelled all point cloud epochs.

Object-based point cloud classification

Topological rules corrected the initial classification

Mayr et al. 2017. *The Photogrammetric Record*, *32*(160), 377-397.



Effect of the correction step.

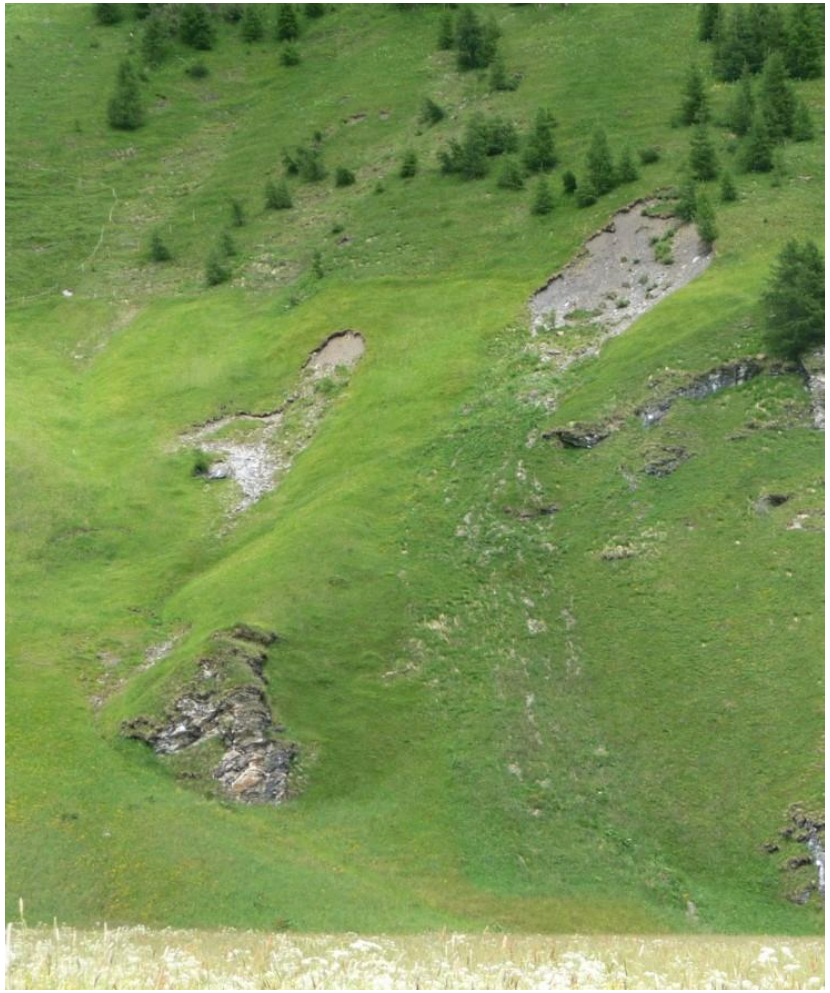
Point cloud epoch #8

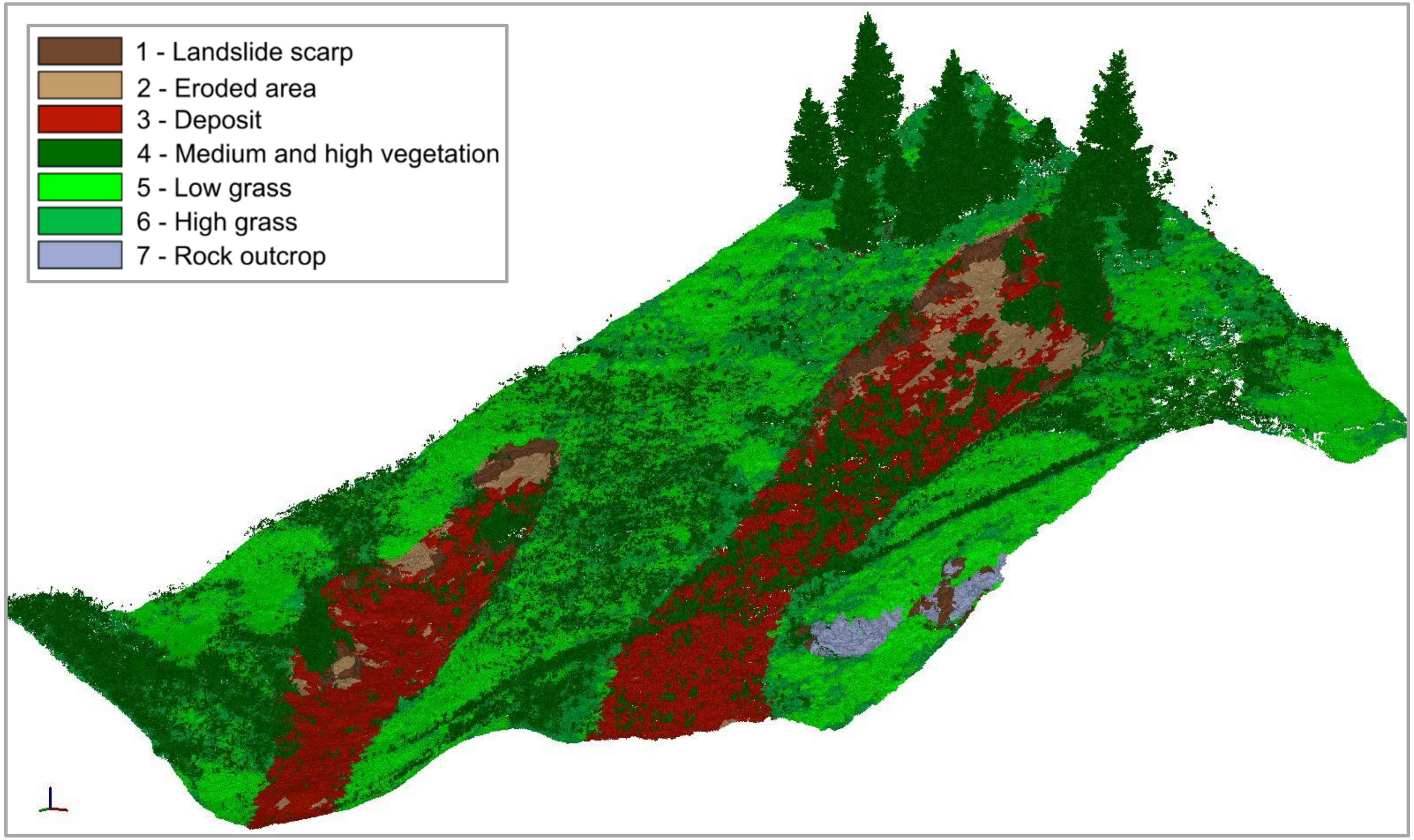
(a) as classified by the random forest classifier,

(b) after rule-based re-classifiction.

Object-based point cloud classification

Results



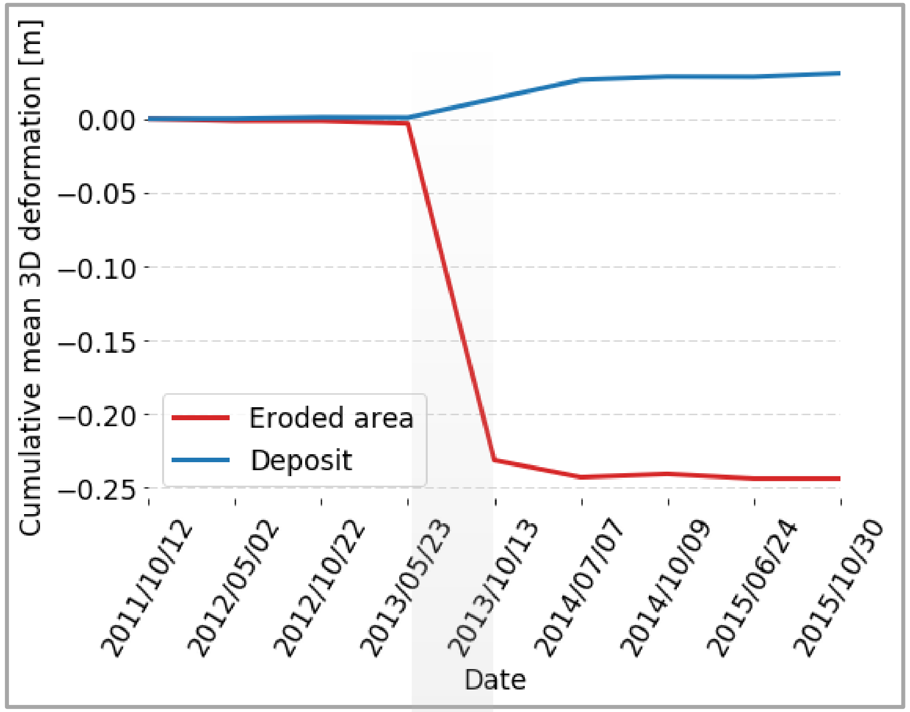


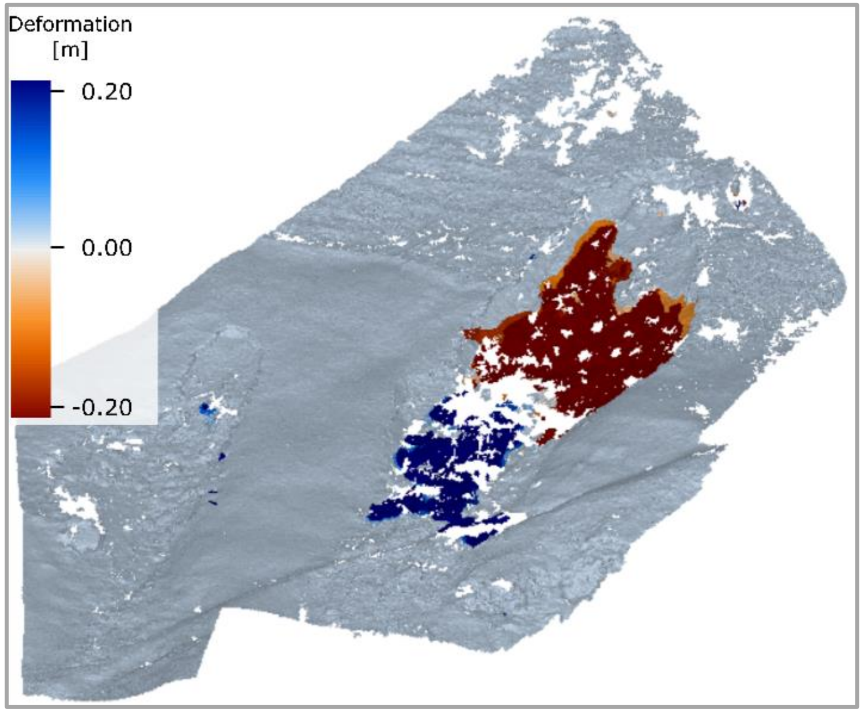
Classified point cloud epoch #13.

3D landslide monitoring with TLS

Mayr et al. 2018. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII*(2), 691-697.

Landslide reactivation



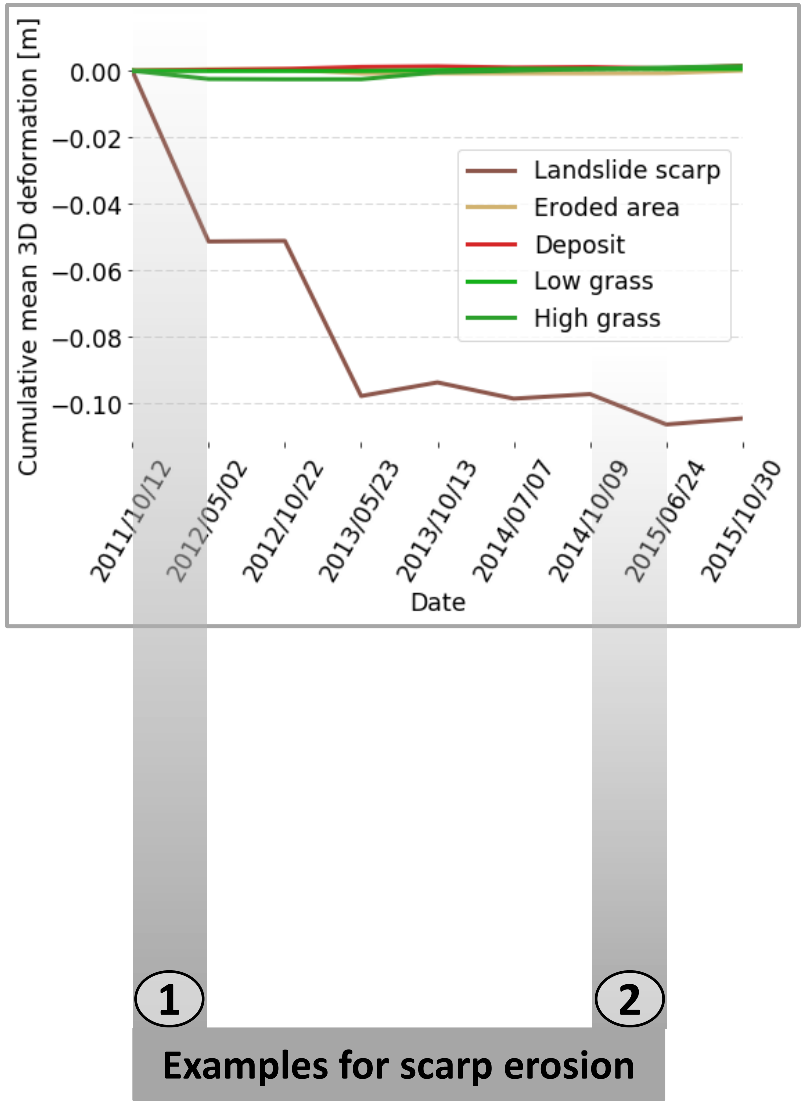


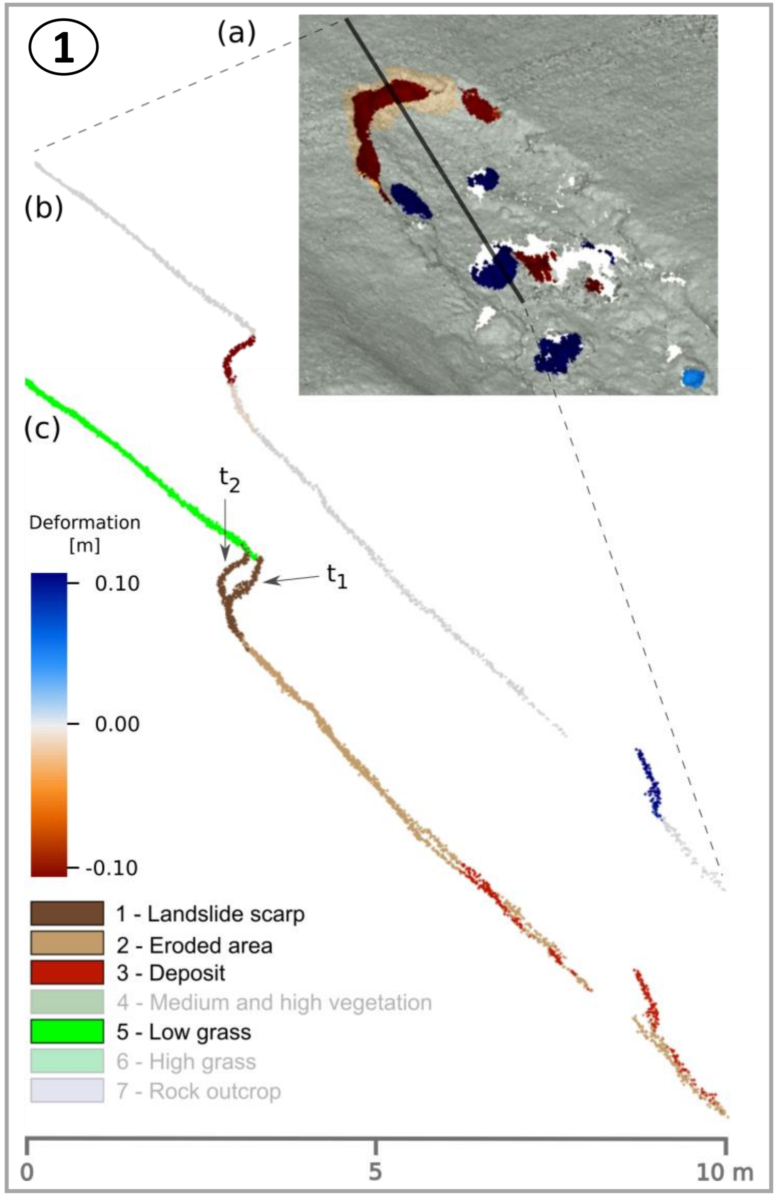
… triggered by strong rainfall
in June 2013 (110 mm over 3 days)

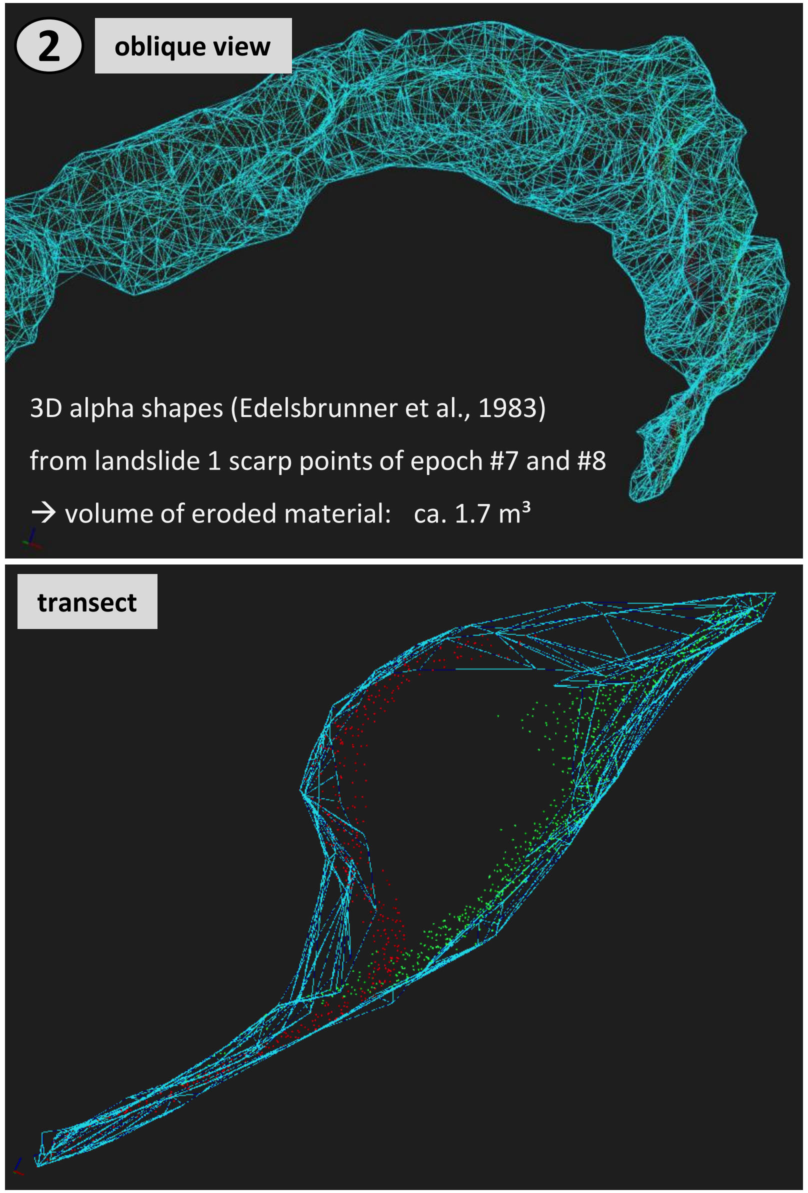
3D landslide monitoring with TLS

Mayr et al. 2017. *The Photogrammetric Record*, *32*(160), 377-397.
Mayr et al. 2018. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, *XLII*(2), 691-697.

Scarp erosion





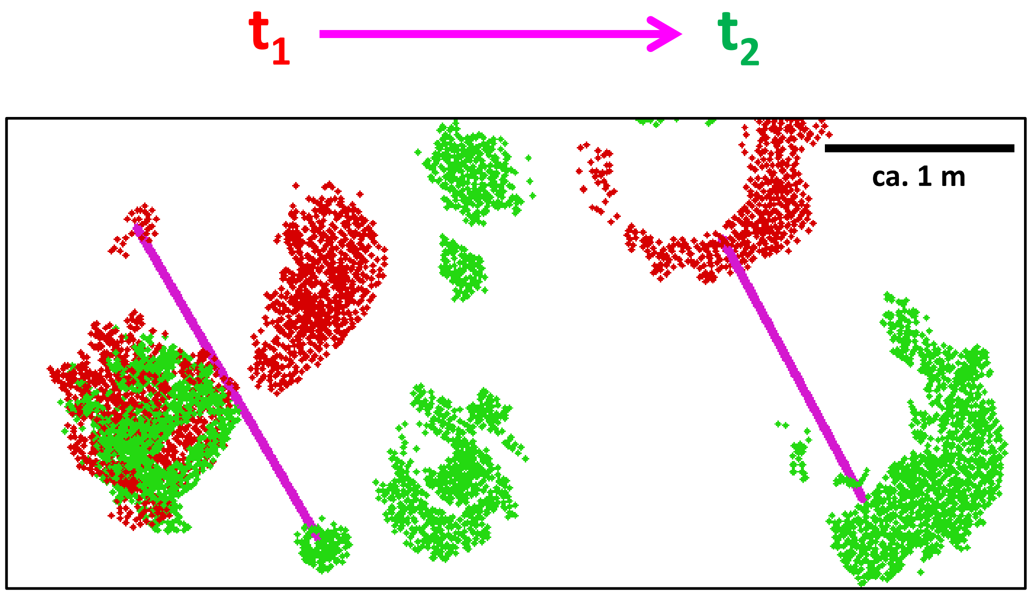


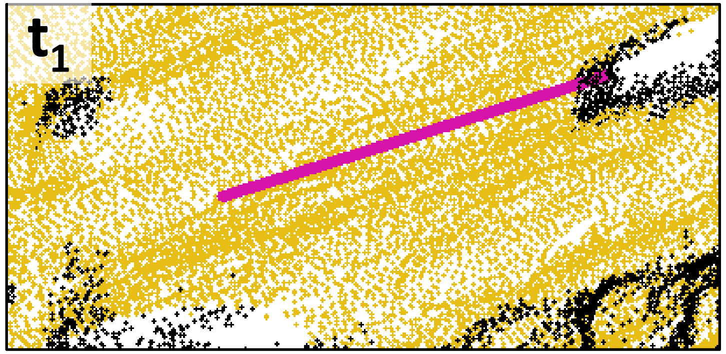
3D landslide monitoring with terrestrial laser scanning

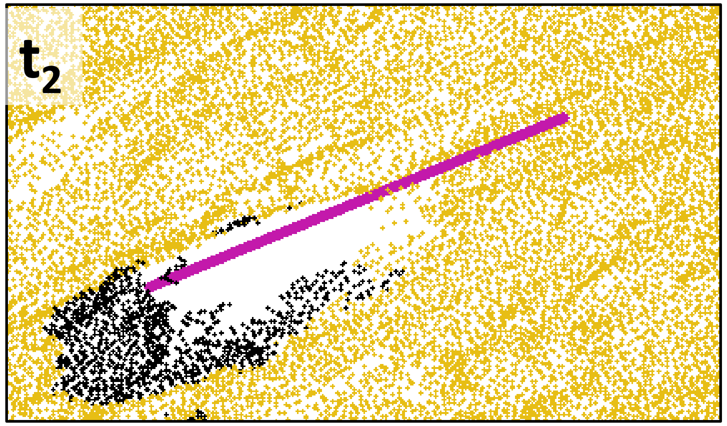
Object tracking

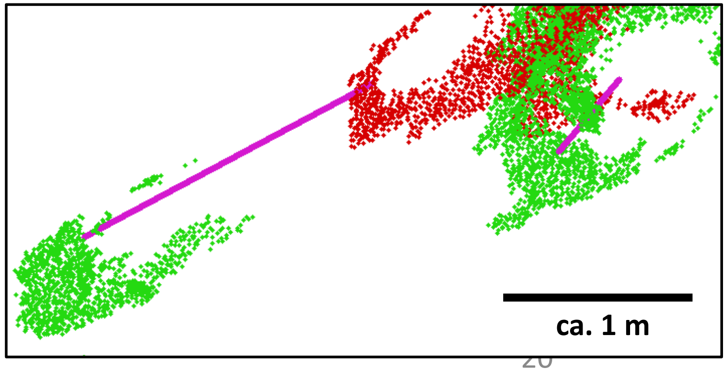
Movement of clods of turf and soil in the landslide scar:

- Object matching
- Displacement vectors
- Some preliminary results …









3. Unmanned aerial vehicle laser scanning (ULS) for erosion monitoring

System configuration and data acquisition

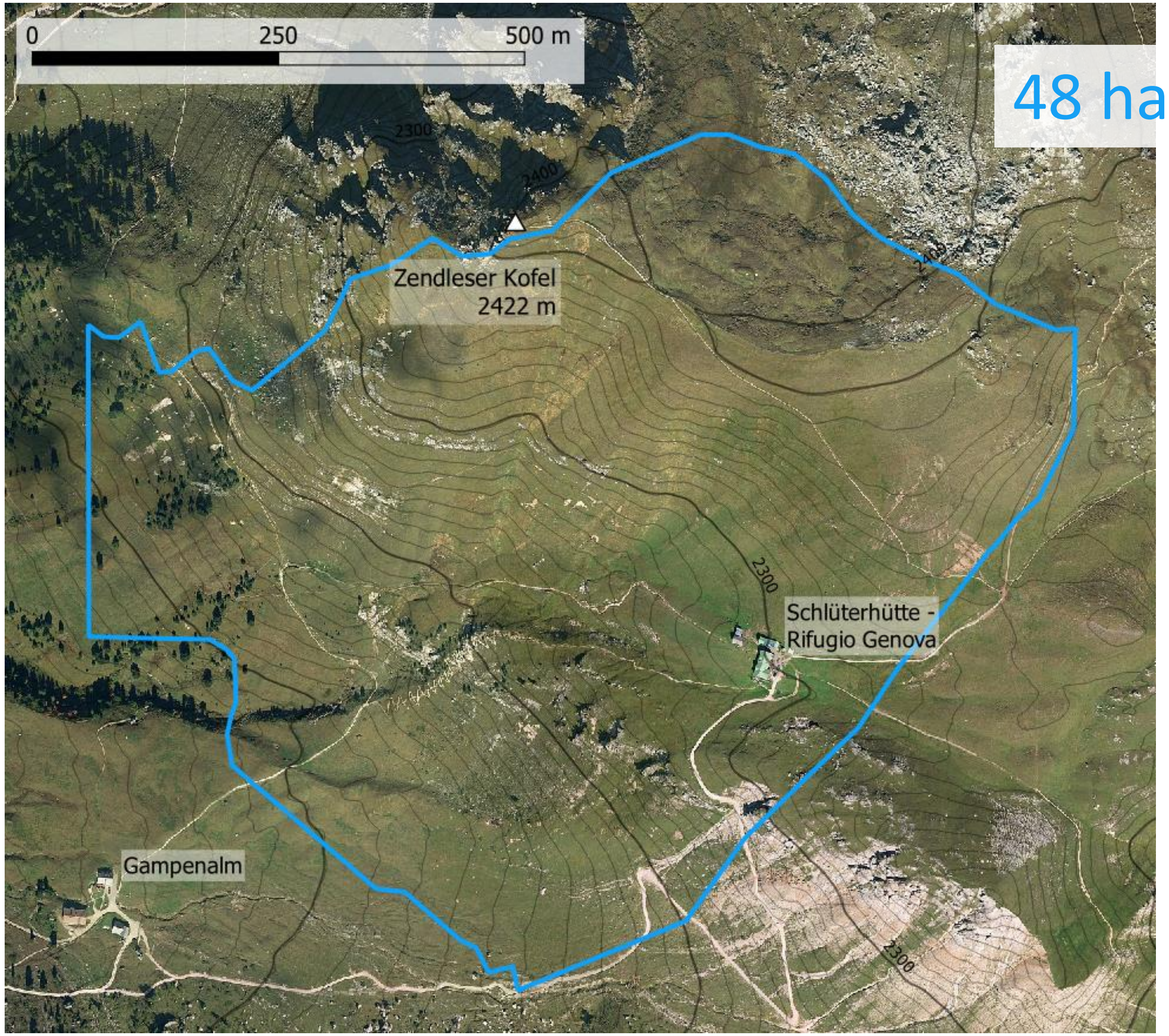
- RiCOPTER
  - octocopter
  - 24.9 kg maximum take-off mass
- Riegl VUX-1LR laser scanner:
  - 1550 nm wavelength
  - 330° FOV

- 2 oblique Sony Alpha 6000 cameras (RGB)
- Applanix AP20 IMU and DGNSS receiver recording sensor position and orientation

ULS for erosion monitoring

System configuration and data acquisition

Mayr et al. 2019. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-2/W5.

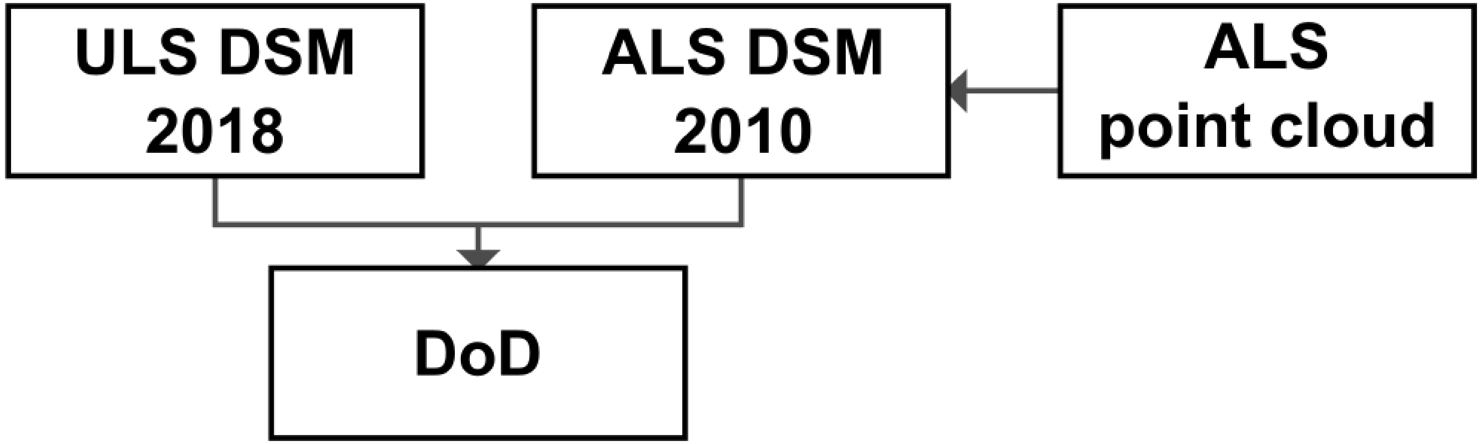


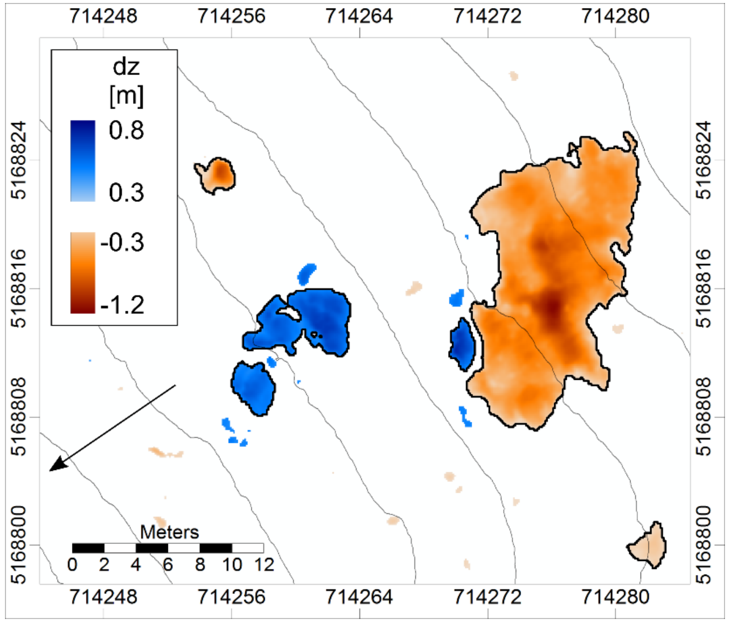
- Detailed flight planning
- Strips in different elevation levels to compensate the terrain (Δz = 300 m)
- 70 m average flying altitude
- 8 m/s flight speed
- 760 (± 374) pts/m²

ULS-based mapping and quantification of erosion

DSM-of-Difference (DoD)

Mayr et al. 2019. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-2/W5.



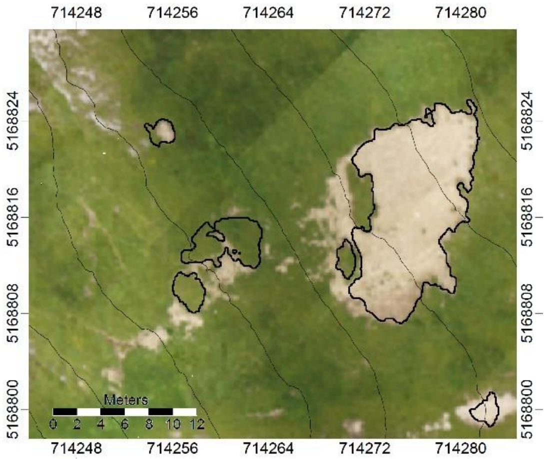


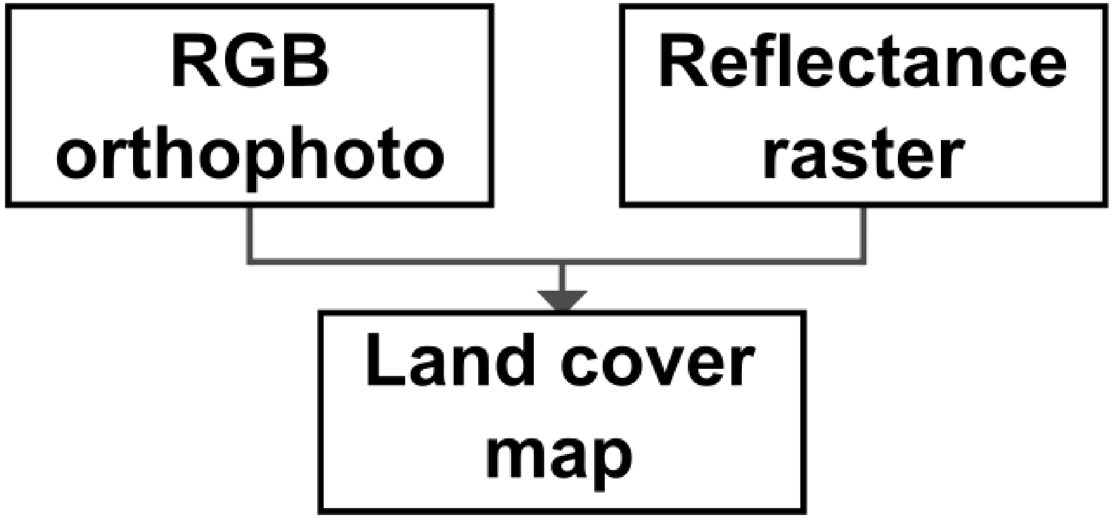
- DSM-of-Difference (DoD)
- Slope mask
- Consider only dz > 0.3 m

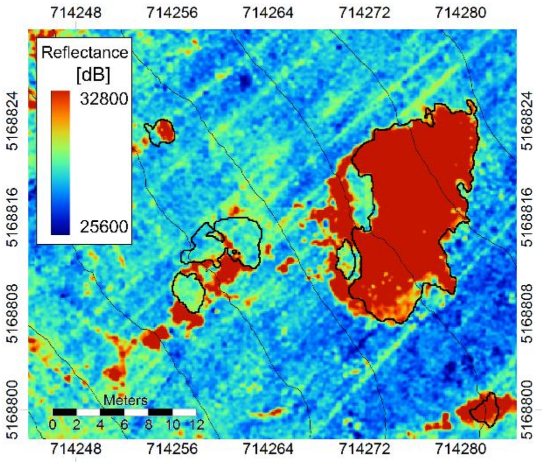
ULS-based mapping and quantification of erosion

Supervised land cover classification

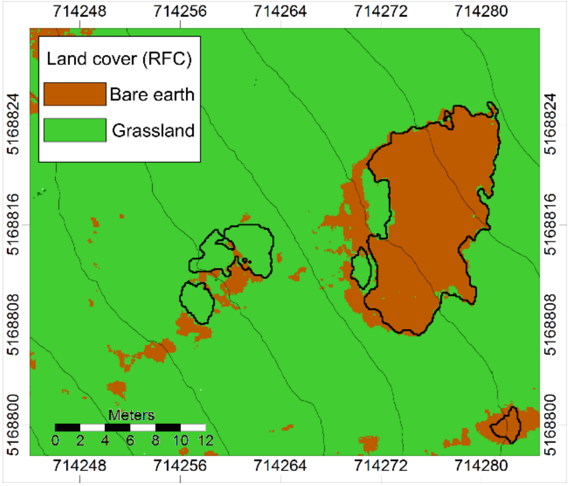
Mayr et al. 2019. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-2/W5.







- Random Forest classification
- Classes:
    - Bare earth
    - Grassland
    - Trees



ULS-based mapping and quantification of erosion
Level of detection (LOD)

Mayr et al. 2020. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, forthcoming.

Accuracy assessment of multitemporal ULS point clouds:

- mean 3D distance at validation patches:
  - 0.043 m (± 0.023 m) with direct georeferencing
  - 0.002 m (± 0.016 m) after global ICP adjustment → *registration error*
- Estimation of a spatially varying LOD (Lague et al. 2013, Fey and Wichmann 2017), including:
  - *Registration error*
  - *Plane-fitting variance* (surface roughness, noise)
  - *Point error* (3D positional uncertainties due to footprint effects)

ULS-based mapping and quantification of erosion

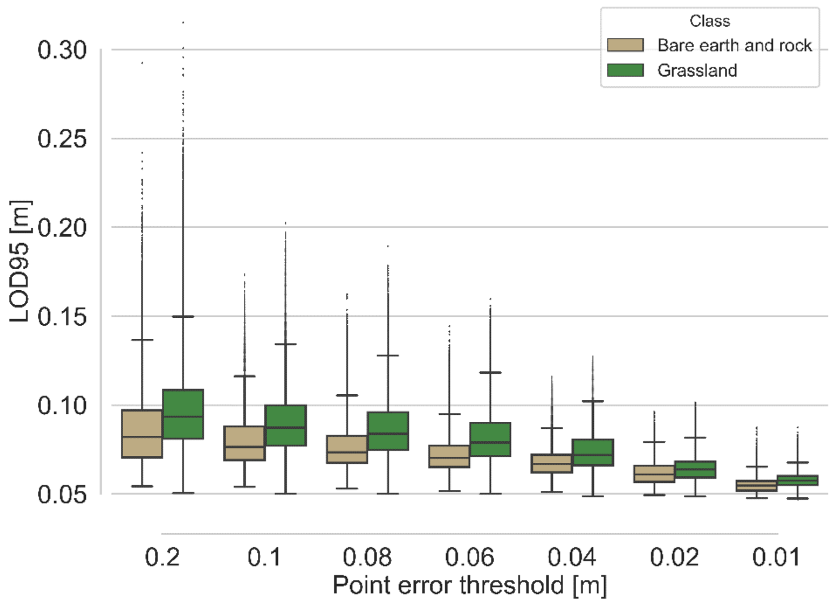
Level of detection (LOD)

Mayr et al. 2020. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, forthcoming.

Impact of scanning geometry on the LOD (via footprint effects):

Point error modelled for a subset (cf. Schär et al. 2007)

- High variability
- Compromises the LOD
- Quality-based point cloud filtering (point error threshold t_{pe}) improves the LOD
- t_{pe} must be chosen carefully (adaptively?) to maintain consistently dense point clouds



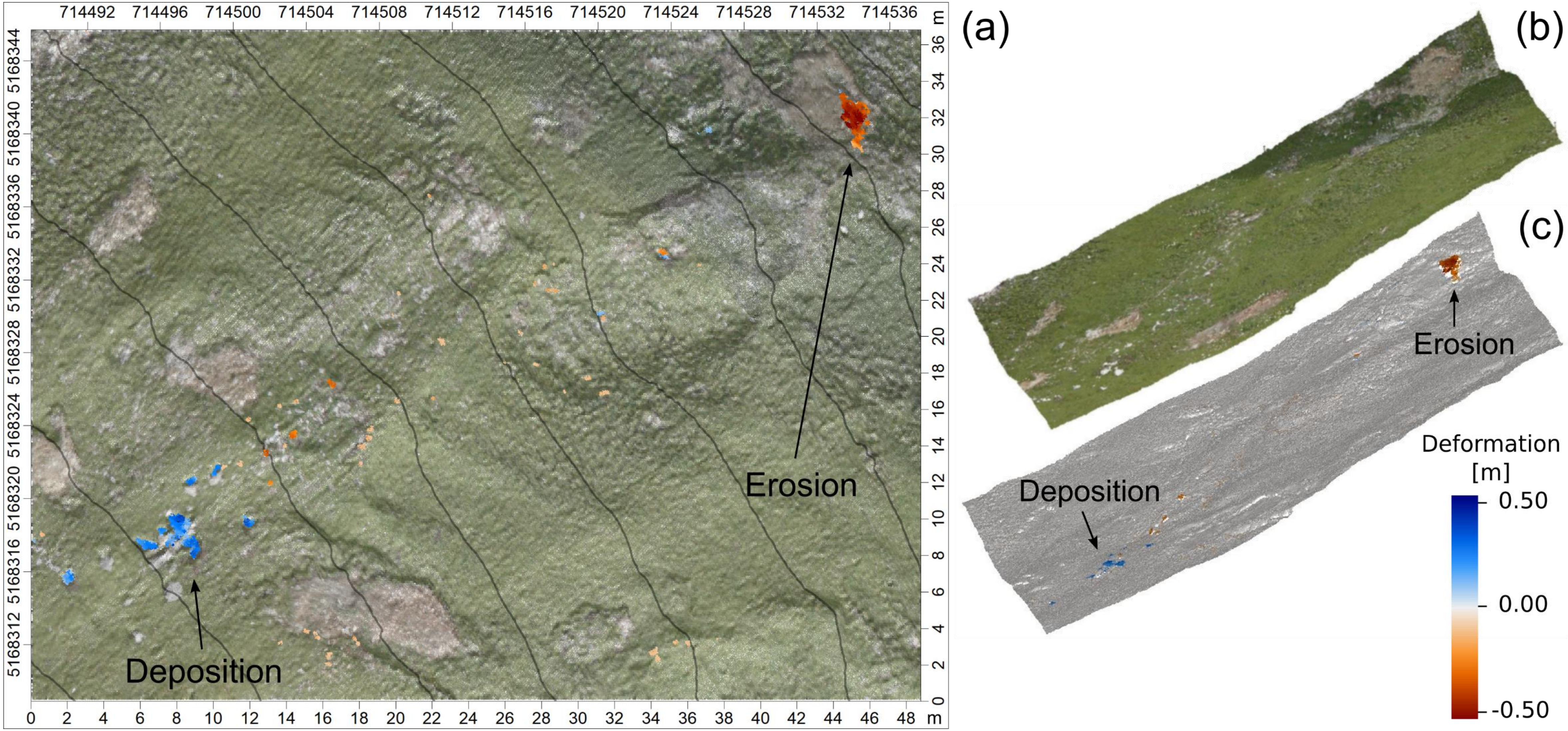
	t_{pe} [m]	
	0.20	0.04
LOD_{95} minimum [m]	0.045	0.045
LOD_{95} maximum [m]	0.359	0.139
LOD_{95} mean [m]	0.090	0.073
LOD_{95} standard deviation [m]	0.020	0.010
Number of points	40.4 Mio	34.7 Mio
Number of points with a valid distance and LOD_{95}	32.9 Mio	28.2 Mio

LOD for different point error thresholds

ULS for erosion monitoring

Example: Secondary erosion and deposition

Mayr et al. 2020. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, forthcoming.



Summary and conclusions

Close-range sensing and object-based analysis of shallow landslides and erosion

- suited for **reference data acquisition** to validate an erosion mapping with aerial orthophotos
- close-range sensing enables a **systematic monitoring** of shallow erosion with **LODs at (sub-)decimetre-level** (depending on the specific survey configuration (ground control, range etc.))
- monitoring of geomorphic processes:
  - **estimate the volume of material** that is redistributed during the development of **new eroded areas** (ULS case study)
  - **secondary development**:
    - retrogressive erosion of **landslide scarps**
    - **reactivation** of the main body of a landslide
- **object-based approaches** helped to detect and quantify erosion processes in close-range sensing data and, thus, are found to improve the **data interpretability**
- **geomorphic objects** (at different spatial levels) are characterized by both **morphometric and spectral signatures;** a **combination of morphometric and spectral features** may be ideal (data quality!?)
- **fuzziness and variability of natural objects** are problematic

References

Edelsbrunner, H., Kirkpatrick, D. G., Seidel, R. (1983). On the shape of a set of points in the plane, *IEEE Transactions on Information Theory, 29* (4), 551–559. https://doi.org/10.1109/TIT.1983.1056714

Fey, C., Wichmann, V. (2017). Long-range terrestrial laser scanning for geomorphological change detection in alpine terrain–handling uncertainties. *Earth Surface Processes and Landforms*, *42*(5), 789-802. https://doi.org/10.1002/esp.4022

Lague, D., Brodu, N., Leroux, J. (2013). Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (NZ). *ISPRS Journal of Photogrammetry and Remote Sensing*, *82*, 10-26. https://doi.org/10.1016/j.isprsjprs.2013.04.009

Mayr, A., Bremer, M., Rutzinger, M., Geitner, C. (2019). Unmanned aerial vehicle laser scanning for erosion monitoring in Alpine grassland. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, IV-2/W5*, 405-412. https://doi.org/10.5194/isprs-annals-IV-2-W5-405-2019

Mayr, A., Rutzinger, M., Bremer, M., Geitner, C. (2016). Mapping eroded areas on mountain grassland with terrestrial photogrammetry and object-based image analysis. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, III-5*, 137 – 144. https://doi.org/10.5194/isprs-annals-IV-2-W5-405-2019

Mayr, A., Rutzinger, M., Bremer, M., Oude Elberink, S., Stumpf, F., Geitner, C. (2017). Object-based classification of terrestrial laser scanning point clouds for landslide monitoring. *The Photogrammetric Record, 32* (160), 377 – 397. https://doi.org/10.1111/phor.12215

Mayr, A., Rutzinger, M., Geitner, C. (2018). Multitemporal analysis of objects in 3D point clouds for landslide monitoring. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, *XLII* (2), 691-697. https://doi.org/10.5194/isprs-archives-XLII-2-691-2018

Schär P., Skaloud J., Landtwig S., Legat K. (2007). Accuracy estimation for laser point cloud including scanning geometry. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., 37*, 851-856.

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ERODYN project, http://erodyn.mountainresearch.at/

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