Martin Rutzinger & Kati Heinrich (eds.)

Close Range Sensing Techniques in Alpine Terrain

Andrea Fischer & Harald Pauli (eds.)

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Close Range Sensing Techniques in Alpine Terrain

Proceedings of the Innsbruck Summer School of Alpine Research 2019,
16.–22.06.2019 in Obergurgl, Austria

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Content

Foreword

Mountain research requires increased accuracy of measurement and spatial and temporal resolution data. A detailed understanding of measurement principles and analysis methods helps to answer complex human-environment research questions in mountain areas. This proceedings book is being published to complement the 3rd Innsbruck Summer School of Alpine Research – Close Range Sensing Techniques in Alpine Terrain. The summer school is jointly organised by the University of Innsbruck, the Austrian Academy of Sciences, and the International Society for Photogrammetry and Remote Sensing. The aim of the summer school is to provide an innovative theoretical and practical access to state-of-the art close-range sensing techniques in a mountain research context. Participants are testing sensors and techniques for analysing mountain processes, characterising complex surfaces, detecting objects and quantifying changes. International experts provide the theoretical background in their keynotes and lectures. During the week participants work on a group project that combines project planning, measurements in the field, data analysis, interpretation and presentation of results. The unique location of Obergurgl is the perfect setting to research and teach the mapping and analysis of environmental processes with innovate sensing techniques.

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Francescoo Pilla
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Department of Geodesy and Geoinformation, TU Vienna, Austria

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Programme – Overview

	Sunday 6/16/2019	Monday 6/17/2019
7:30		Breakfast
8:30		Fabio Remondino: Past, Current and Future Developments in Photogrammetry
9:30		Norbert Pfeifer: Laser Scanning Fundamentals and Challenges for Mountain Research – From Active Sensors to Point Clouds
10:30		Coffee Break
11:00		Excursion
15:00	Arrival of Participants	
17:30		1 min group wrap-up
18:00	Dinner	Dinner
19:30	Martin Rutzinger: Welcome	Poster Session
20:00	Rudolf Sailer & Johann Stötter: Permanent Laser Scanning Station Hintereisferner	
21:00		Social Event

Keynote
Lecture
Demo, Poster, Presentations
Social Events
Excursion
Group Assignment

	Tuesday 6/18/2019	Wednesday 6/19/2019
7:30	Breakfast	Breakfast
8:30	Heather Viles: Biogeomorphology in the Anthropocene	Group Assignment
9:30	Georg Wohlfahrt: Addressing bio-physical feedbacks to climate at small spatial scales – the EcoBot concept	
10:30	Coffee Break	
11:00	Demo: EcoBot	
13:00	Group Assignment get in touch with sensors and methods	
15:00		
17:30	1 min group wrap-up	1 min group wrap-up
18:00	Dinner	Dinner
19:30	Marco Scaioni: Hands-on Photogrammetry	Sander O. Elberink: Hands-on Segmentation & Francesco Pirotti: Hands-on Clas-sification
20:00–21:00	Simon Buckley: Combining remo-te sensing and geoscience data as the framework for virtual field trips	Bas Altena: ICECUBES – observing the ice of our planet with daily cubesat imagery

Keynote
Lecture
Demo, Poster, Presentations
Social Events
Excursion
Group Assignment

	Thursday 6/20/2019	Friday 6/21/2019
7:30	Breakfast	Breakfast
8:30	Bernhard Höfle: Hands-on Point Cloud Simulation & Roderik Lindenbergh: Hands-on Change detection	Group Assignment
9:30	Francesco Pillar: Bottom up approaches to co-design nature based solutions	
10:30	Coffee Break	Coffee Break
11:00	Group Assignment	Group Assignment
14:00		Final Presentations
15:00		
17:30	1 min group wrap-up	
18:00	Dinner	Dinner
19:30	Photo Contest Award	
20:00–21:00	Group Assignment	

	Saturday 6/22/2019
7:30	Breakfast
8:30–10:30	Departure

Abstracts of the keynote speakers and lecturers

Observing the ice of our planet with daily cubesat imagery

Bas Altena

Department of Geosciences, University of Oslo, Norway

Keywords: Cryosphere, glaciers, optical remote sensing, kinematics, cubesats

Processes in, at or under a glacier occur at different timescales. For example, gravitational pull makes the ice in the glacier deform and flow like a viscous fluid. The magnitude of this internal deformation is mostly dependent on the ice thickness and its temperature (Glen 1954). In a warmer climate, over the course of decades, the thickness might decrease (resulting in slower flow), and the ice might warm up (resulting in easier deformation). At an annual timespan it is mostly summer melting that results in an excess of meltwater, draining through surface crevasses to the glacier base. Here it is able to lubricate the ice-rock interface, reducing the friction and so letting the ice slip more easily.

Many processes that result in kinematics of glacial ice are shown in Figure 1. The size of the blobs corresponds to the score for the Deborah-number; that is the amount of relaxation over the observational timespan (Reiner 1964). This number assumes linear behaviour, which holds when continuous forces or slowly oscillating systems influence the movement. For example, the driving stress of a glacier is primarily dependent on the ice thickness, thus its creep flow can be considered continuous. A clear example of an oscillating system is the tidal forcing on ice shelves. For most of these processes the forcing is isolated. When complexity increases, displacements occur because of the interplay between different forces. Consequently, the nature of the signal can be perceived as sporadic.

Earth observation used to be observed at an annual or monthly cadence. Consequently, over long timespans processes of slip and viscosity might be separated. But the temporal and spatial resolution of observations has increased in recent years. Hence it is now possible to look at processes on shorter timescales. More complex processes can be measured and quantified. This opens-up a wealth of new insights, where new information can be extracted from established techniques. One can think of the monitoring of ice cauldrons, or time-dependent supra-glacial melt pond connectivity, precursor motion of calving icebergs, or full fjord circulation, just to name a few.

Glen, J. 1954. Experiments on the deformation of ice. *Journal of Glaciology* 12(2): 111–114.

Reiner, M. 1964. The Deborah number. *Physics today* 17(1): 62.

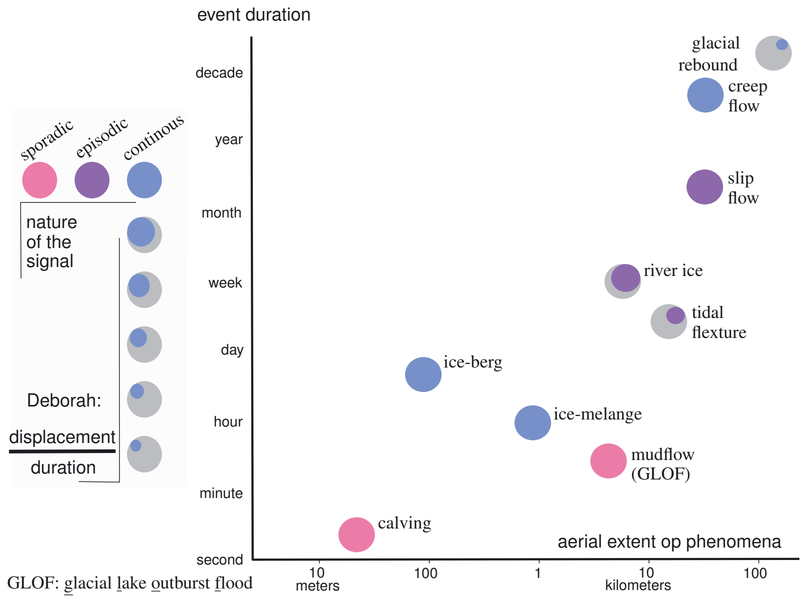

Figure 1: Stoffel diagram of the occurrence, duration and extent of different glacial events or glacier-related processes. Blob sizes correspond to the score for the Deborah-number.

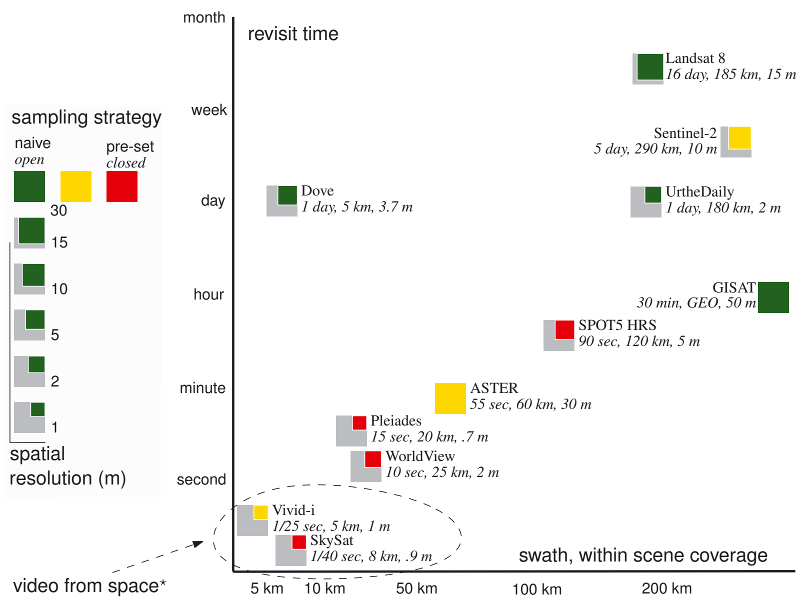

Figure 2: Geometric and temporal characteristics of a selection of present day optical remote-sensing constellations. The Vivid-i and SkySat satellites are video from space, thus for these systems the revisit rate corresponds to the frame rate of the video.*

Combining remote sensing and geoscience data as the framework for virtual field trips

Simon J. Buckley[1], N. Naumann[1], K. Ringdal[1], J. Vanbiervliet[1], B. Tong[1], B. Dolva[1], J.A. Howell[2]

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[2] *Geology & Petroleum Geology, University of Aberdeen, UK*

Keywords: Data fusion, visualization, registration, education, photogrammetry

Over the last 15 years, the employment of close-range remote-sensing methods in geoscience applications has intensified. Increased access to field acquisition hardware, a widening choice of sensors, and availability of public data sources have all contributed to lowered thresholds for adoption. The result is the empowerment of geoscientists to gather and analyse spatial data, resulting in new applications and opportunities. With these come challenges that must be addressed, increasingly in a multidisciplinary manner, as the boundaries blur between traditional geomatics, computer science and geoscience. Multi-scale, multi-sensor and multi-temporal solutions require advanced methods, workflows and software for ensuring co-registration, co-visualization, interpretation and analysis appropriate to a specific application.

Geology is one discipline that has benefited from high interest in close-range remote-sensing methods. Digitisation of exposed outcrops using terrestrial laser scanning and photogrammetry allows geologists to interpret, map and quantitatively analyse the occurrence and distribution of geometric features. Complementary work on hyperspectral imaging shows the potential for automating the identification and mapping of minerals and rocks in outcrops. Combining these 3D and metric image datasets with conventional geoscience data (which may or may not be precisely georeferenced) has increasing value to support integrated interpretation. The possibilities associated with a wide range of data sources, access to multiple 3D datasets, and modern visualization environments have rejuvenated interest in digital field trips to support field geoscience. The 3D framework allows for communication of geoscience content, e. g. to university classes, at different stages of the learning process. Examples are introduction and familiarization with a field area prior to travel, as well as revisiting the field site and concepts to reinforce learning.

In this presentation, we examine topics related to the visual integration of multiple datasets in geology and digital geoscience, leading to the development of virtual field trips. The material is illustrated using case studies presented within in-house LIME software (Buckley et al. 2019).

Buckley, S.J., Ringdal, K., Naumann, N., Dolva, B., Kurz, T.H., Howell, J.A., Dewez, T.J.B. 2019. LIME: Software for 3-D visualization, interpretation, and communication of virtual geoscience models. *Geosphere* 15(1): 222–235. doi: 10.1130/GES02002.1.

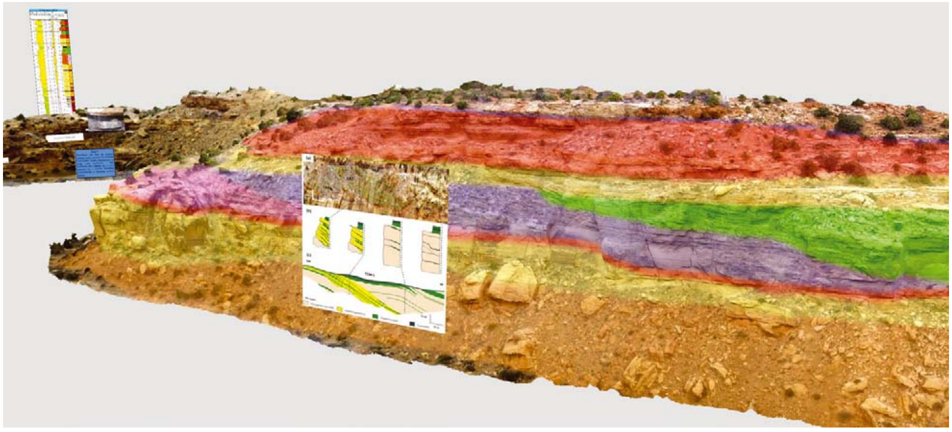

Figure 1: Digital outcrop environment showing integrated geological interpretation and supplementary information. Location is Thompson Canyon, Utah, USA. Size of outcrop c. 60 m. Data from the SAFARI project (https://safaridb.com).

Virtual Laser Scanning – Simulation of Synthetic 3D Point Clouds

Bernhard Höfle

3DGeo Group, Institute of Geography, Heidelberg University, Germany

Keywords: LiDAR, Point Cloud, Simulation, Virtual Laser Scanning (VLS), HELIOS

Virtual Laser Scanning (VLS) is a method to perform 3D data acquisition in a computer simulation which runs 3D laser scanning in a virtual environment. The laser scanning point cloud is determined by the laser scanning system used (e.g. static vs. mobile), the system settings (e.g. point spacing) and also the acquisition strategy (e.g. positions, trajectory). Each 3D measurement is a result of laser beam interaction with the scanned surface(s), measurement errors, atmospheric effects, signal processing, etc. The laser-object interaction can be simulated with different approaches and levels of complexity. To simulate very realistic waveform returns and account for multiple scattering etc., quasi-Monte Carlo ray tracing can be chosen (Gastellu-Etchegorry et al. 2016). A more straightforward single scattering method is implemented in the VLS software HELIOS (HELIOS 2019). All VLS approaches have in common (Figure 1) that they need 1) a 3D input scene, 2) the definition of a carrying platform (e.g. TLS, ALS) and 3) the definition of the scanner system (e.g. deflection mechanism). These VLS components are then connected in the 4) survey component, which defines how the campaign shall be performed.
VLS is particularly well suited for the following scientific uses:

- **Generate synthetic point clouds** with "perfect" ground truth (e.g. Hämmerle et al. 2017): Those can be used to validate your algorithms and they can serve as training data for machine learning.
- **Planning** of research experiments and field surveys: e.g. find best scan positions; test with different sensor models (even not yet existing hardware).
- **Education**: Students can learn how laser scanning works by using a VLS software with a graphical user interface. No need to possess the hardware.
- **Sensor development**: Implement and test your own scanner design.

Bechtold, S. & Höfle, B. 2016. HELIOS: A Multi-Purpose LiDAR Simulation Framework for Research, Planning and Training of Laser Scanning Operations with Airborne, Ground-Based Mobile and Stationary Platforms. *ISPRS Annals* III-3: 161–168.

Gastellu-Etchegorry, J.-P., Yin, T., Lauret, N., Grau, E., Rubio, J., Cook, B.D., Morton, D.C. & Sun, G. 2016. Simulation of satellite, airborne and terrestrial LiDAR with DART (I): Waveform simulation with quasi-Monte Carlo ray tracing. *Remote Sensing of Environment* 184: 418–435.

Hämmerle, M., Lukač, N., Chen, K.-C., Koma, Z., Wang, C.-K., Anders, K. & Höfle, B. 2017. Simulating Various Terrestrial and UAV LiDAR Scanning Configurations for Understory Forest Structure Modelling. *ISPRS Annals* IV-2/W4: 59–65.

HELIOS 2019: HELIOS – Heidelberg LiDAR Operations Simulator. Available at: http://uni-heidelberg.de/helios (accessed: 15.05.2019).

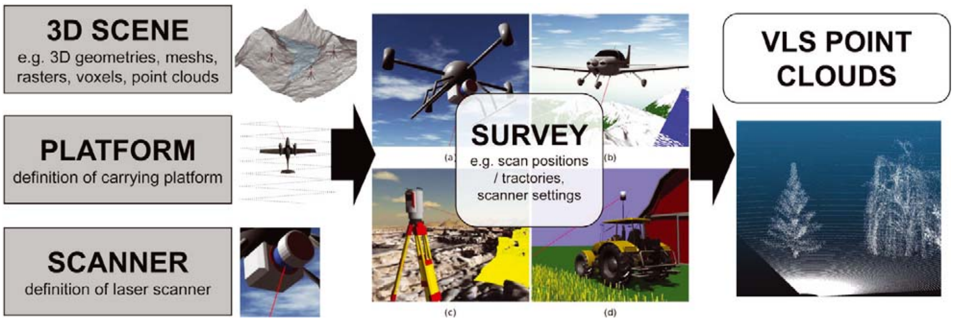

Figure 1: Components and process of Virtual Laser Scanning (VLS) (cf. Bechtold & Höfle 2016)

Segmentation of point clouds for classification and change detection

Sander Oude Elberink

University of Twente, the Netherlands

Keywords: Segmentation, point cloud, neighbourhood, laser scanning, stereo imagery

A point is just a point. The meaning of a point is defined by its context. Segmentation is a general step to group points that belong to a certain (part of an) object. But what is the best segmentation strategy if you do not know what kind of objects to expect, and can we use additional data like topographic maps to guide the segmentation (Wang & Oude Elberink 2016)? This short presentation will focus on object-based segmentation for classification and change detection. It is shown that segment properties can be of use to aid the classification (Vosselman 2013). Examples are shown for point clouds generated from stereo image matching or from laser scanners.

Vosselman, G. 2013. Point cloud segmentation for urban scene classification. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-7/W2: 257–262.

Wang, Y. & Oude Elberink, S.J. 2016. Map based segmentation of airborne laser scanner data. In: *Proceedings of GEOBIA 2016: Solutions and synergies*. 14–16 September 2016, Enschede, Netherlands. University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC). doi: 10.3990/2.424.

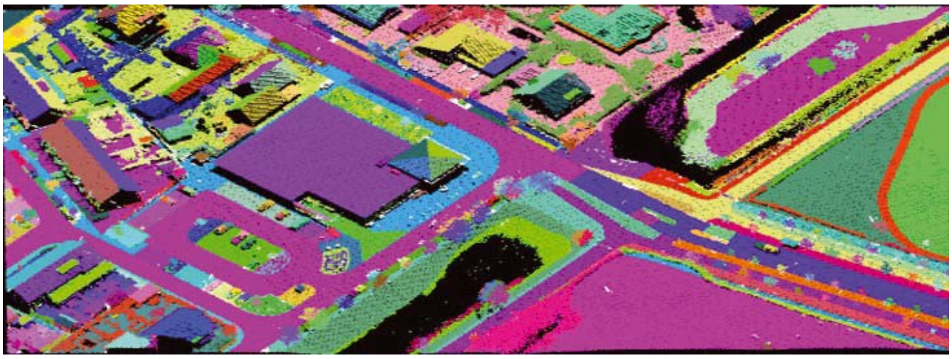

Figure 1: Map-based segmentation result from Wang and Oude Elberink 2016.

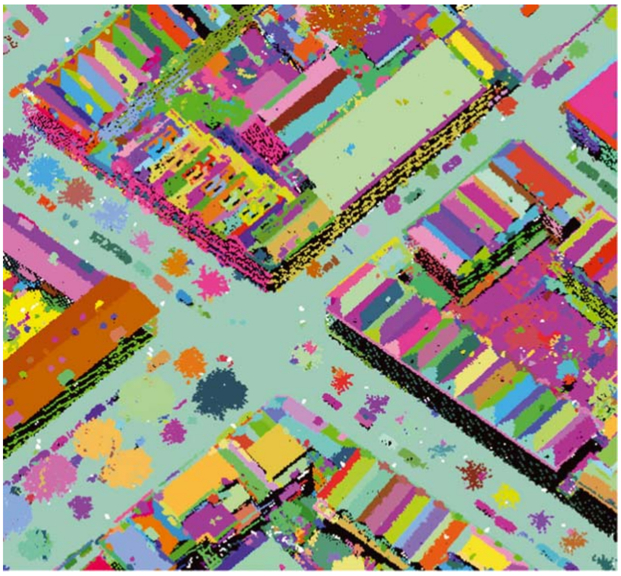

Figure 2: Constrained connected component segmentation after a planar segmentation step (Vosselman 2013).

Classification of point clouds using point and segment features: applying decision trees and convolutional neural networks

Francesco Pirotti

University of Padova, Italy

Keywords: Classification, point cloud, neighbourhood, laser scanning

"Un-mixing mixtures" is a key process in the analysis of remote sensing data. Commonly used over imagery that provides reflectance values over regular grid lattices, this task is now also applied to point clouds to provide class labels to each point. Correct assignment of class-to-point requires that each point contains a number of features that allow to assign it to a specific class with a certain reliability / accuracy. Ideally, the features have an intra-class variability lower than their inter-class variability and are not linearly correlated (multi-collinearity). Features can be already present as point characteristics (e. g. intensity of reflected pulse, return number ratio), extracted from a 3D context (e. g. index of linearity, planarity, scattering) and also be assigned from segment-based characteristics (Vosselman 2013). To model the most accurate way to use these feature vectors for classification, several learning approaches are being investigated lately. Terms like machine learning, data mining, deep learning and the like describe shades of similar methods that iteratively find best combinations of features to classify each point. Decision trees (e. g. random forest™) and convolutional neural networks (e. g. TensorFlow framework) are highly investigated and also provide a significant degree of accuracy when applied to the problem of classifying point clouds .

Pirotti, F., Zanchetta, C., Previtali, M. & Della Torre, S. 2019. Detection of building roofs and facades from aerial laser scanning data using deep learning. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, in print.

Vosselman, G. 2013. Point cloud segmentation for urban scene classification. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-7/W2: 257–262. doi: 10.5194/isprsarchives-XL-7-W2-257-2013.

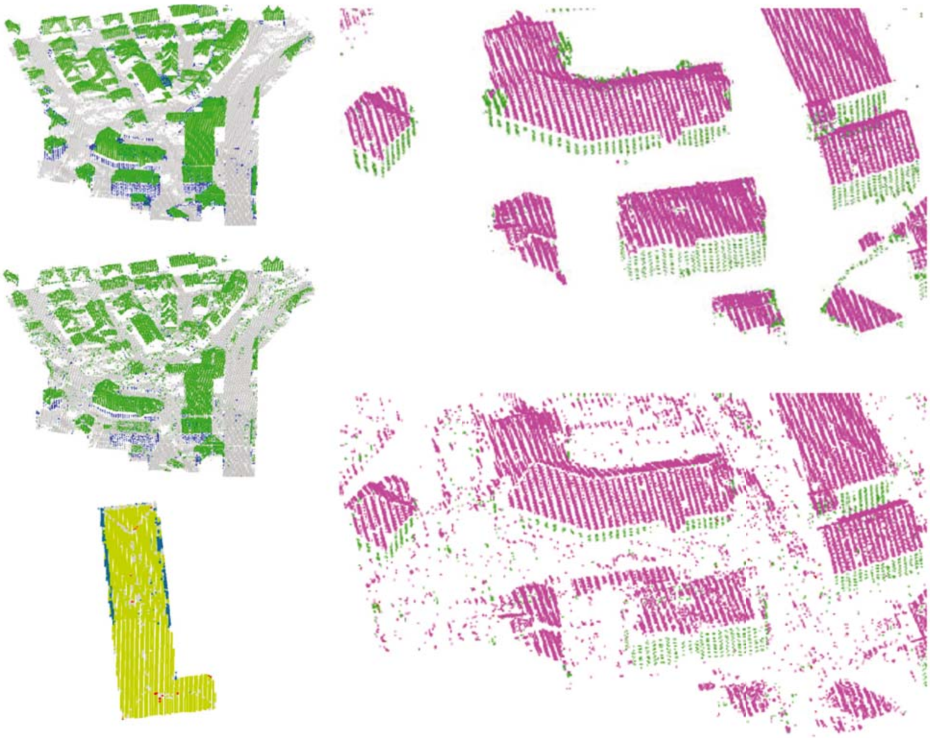

Figure 1: Classification of roof and façade using TensorFlow: from (Pirotti et al. 2019).

Sensing mountains – digitizing landscapes for environmental monitoring

Martin Rutzinger[1], Magnus Bremer[1,2], Andreas Mayr[2], Thomas Zieher[1]

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Keywords: Mountain research, geomorphology, vegetation mapping, natural hazard research, earth observation

Mountain research is an interdisciplinary scientific field that integrates research on the physical environment and human interaction in mountain areas with the aim of supporting sustainable development under current global change conditions. Relevant scientific disciplines connecting via mountain research are geography, geoscience, geomorphology (e.g. Mayr et al. 2018), environmental sciences, bioscience (e.g. Niederheiser et al. 2018), forestry (e.g. Bremer et al. 2017), agricultural sciences, tourism, natural hazard research, infrastructure, construction and planning, and conservation. Sensing mountains means the quantitative and contactless measurement of physical properties by observing mountain phenomena, i.e. processes on a defined spatial extent, resolution and frequency of measurement repetition. This includes both remote sensing and close-range sensing techniques comprising satellite, airborne and terrestrial sensing platforms (Figure 1). Sensing an object and phenomena of interest includes the enhancement or continuation of existing traditional field observations and reference data, which often exist only in a nested selective manner. Close-range sensing might thus bridge the gap between field measurements and satellite remote sensing, whereas scaling and integration of measurements from different systems is still a matter of research (Zieher et al. 2018). Within this summer school, we provide inspiration for tackling new research questions in mountain research by making use of sensing techniques. It is a contribution to the digitization of mountain landscapes (Figure 2). This covers understanding the phenomena of interest, tailored planning of a sensing monitoring campaign, handling of the measurement device, knowledge of the data processing methods and information extraction tools, interpretation of the accuracy of the data and results (Rutzinger et al. 2018). Additionally, sensing mountains aims at a high degree of automation of analysis, which requires programming skills. This allows area-wide processing and analysis of time series and ensures the repeatability and transferability of methods, which is today also required for open science .

Bremer, M., Wichmann, V. & Rutzinger, M. 2017. Calibration and Validation of a Detailed Architectural Canopy Model Reconstruction for the Simulation of Synthetic Hemispherical Images and Airborne LiDAR Data. *Remote Sensing* 9(3): 1–22.

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.

Niederheiser, R., Rutzinger, M., Bremer, M. & Wichmann, V. 2018. Dense image matching of terrestrial imagery for deriving high-resolution topographic properties of vegetation locations in alpine terrain. *International Journal of Applied Earth Observation and Geoinformation* 66: 146–158.

Rutzinger, M., Bremer, M., Höfle, B., Hämmerle, M., Lindenberger, J., Oude Elberink, S., Pirotti, F., Scaioni, M., Wujanz, D. & Zieher, T. 2018. Training in innovative technolgies for close-range sensing in alpine terrain. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* IV-2: 239–246. doi: 10.5194/isprs-annals-IV-2-239-2018.

Zieher, T., Toschi, I., Remondino, F., Rutzinger, M., Kofler, C., Meija-Aguilar, A. & Schlögel, R. 2018. Sensor- and scene-guided integration of TLS and photogrammetric point clouds for landslide monitoring. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-2: 1243–1250. doi: 10.5194/isprs-archives-XLII-2-1243-2018.

Figure 1: Unmanned Aerial Vehicle laser scanning in Rotmoos Valley (Ötztal, Austria). Photograph: Rutzinger, M. 2018.

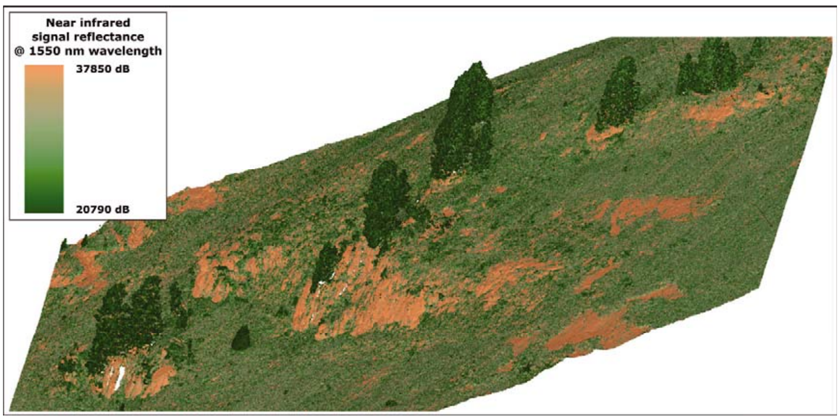

Figure 2: Near infrared coloured point cloud from Unmanned Aerial Vehicle laser scanning. Design by Mayr, A. 2019.

Structure-from-Motion photogrammetry: a framework for image-based 3D reconstruction

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Keywords: Calibration, orientatiion, orthoimages, photogrammetry, Structure-from-Motion

Structure-from-Motion photogrammetry (SfM) means the entire pipeline to produce 3D models (and related by-products) from images. Its popularity has grown impressively in many scientific domains during the last ten years, but a remarkable success can be recorded in the geosciences. Several factors have contributed to this: (1) the chance of using low-cost imaging sensors; (2) the almost fully automatic workflow, implemented in low-cost and open-source software packages; (3) the easy access to the use of drones to extend operational capability. Today, SfM has also been demonstrated to be competitive in processing large-format aerial photos such as the ones captured during missions for topographic mapping or analogue aerial photos (after scanning).

Yet a mature use of SfM requires a basic knowledge of the theoretical background that supports its usage. Briefly, the scheduled lecture will try to answer the following questions.

Camera calibration: Why, how and when should it be done?

Image acquisition: This task is the only one in the SfM pipeline that is totally under the user's control. A correct image acquisition may come from the application of some rules combined with training. Which are the basic rules for data acquisition? How can one get trained?

Image orientation / alignment: What is the purpose of this step? What is the relationship with the so-called sparse point cloud made up of tie points? What are key-points?

Ground control points (GCP): What is the purpose of GCPs? When should they be used and where should they be positioned? Are there other solutions to set up the spatial datum?

Dense surface matching: What are the basic principles and obtainable performances? What are control parameters and how do they work?

Main by-products of SfM: What else can be derived after SfM? What are the guidelines to drive a correct orthoimage, raster digital elevation model, and realistic Virtual Reality Models?

Quality assessment: How can the quality of different steps of SfM and final products be assessed?

Eltner, A., Kaiser, A., Castillo, C., Rock, G., Neugirg, F. & Abellán, A. 2015. Image-based surface reconstruction in geomorphometry – merits, limits and developments. *Earth Surf. Dyn*. 4: 359–389.

Giordan, D., Hayakawa, Y., Nex, F., Remondino, F. & Tarolli, P. 2018. Review article: the use of remotely piloted aicrafts systems (RPASs) for natural hazards monitoring and assessment. *Nat. Hazards Earth Syst. Sci.* 18: 1079–1096.

Granshaw, S.I. 2018. Structure from Motion: Origins and Originality. *Photogramm. Rec.* 33: 6–10.

James, M.R., Robson, S., Smith & M.W. 2017. 3-D uncertainty-based topographic change detection with structure-from-motion photogrammetry: precision maps for ground control and directly georeferenced surveys. *Earth Surf. Proc. Land.* 42: 1769–1788.

Addressing biophysical feedbacks to climate on small spatial scales – the EcoBot concept

Georg Wohlfahrt

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Keywords: Albedo, surface temperature, plant canopy, land use, energy balance

Changes in land surface properties, e. g. due to changes in land-use, affect the radiative and energy balance of the surface and these changes in turn have the potential to affect climate within the frame of so-called biophysical feedbacks (e. g. Alkama & Cescatti 2016; Lee et al. 2011). Research into these biophysical feedbacks typically either relies on data on a local scale, e. g. weather station or eddy covariance flux tower data, or on large spatial scales, e. g. remote-sensing data, while intermediate scales, in particular within-pixel heterogeneity, remain largely unresolved. To overcome this limitation, Wohlfahrt and Tasser (2015) have proposed the EcoBot concept, which we will present and whose strengths and weaknesses, both for research and education, we will discuss on the basis of our previous work within research projects, but also practical class work.

The EcoBot version 2.0 (Figure 1) consists of a backpack with a battery-powered data logger, a GPS and a range of environmental / meteorological sensors. The EcoBot is carried around by the operator and allows making georeferenced spatially distributed measurements of wind speed (and, with less precision, of wind direction), air temperature and humidity, the four components of net radiation, the normalized difference vegetation index (NDVI), the phytochemical reflectance index (PRI) and soil temperature and volumetric soil moisture.

Based on these primary data, a number of additional land surface state variables can be inferred: The land surface temperature can be inferred from the up-welling longwave radiation, the up- and down-welling solar radiation measurements allow calculating the surface albedo. In addition, based on the net radiation, an estimate of the soil heat flux (e. g. based on the air to soil temperature difference), an estimate of the sensible heat flux (from the air to surface temperature difference and an estimate of the aerodynamic resistance), and the latent heat flux can be derived as the residual of the energy balance (Wohlfahrt & Tasser 2015). Common remote-sensing indices, such as NDVI and PRI, measured with the EcoBot can be used as ground truth for remote-sensing products and be used for scaling EcoBot-based biophysical properties.

Alkama, R. & Cescatti, A. 2016. Biophysical climate impacts of recent changes in global forest cover. *Science* 351: 600–604. doi: 10.1126/science.aac8083.

Lee X., Goulden M.L., Hollinger D.Y., Barr A., Black T.A., Bohrer G., Bracho R., Drake B., Goldstein A., Gu L., Katul G., Kolb T., Law B.E., Margolis H., Meyers T., Monson R., Munger W., Oren R., Paw U K.T., Richardson A.D., Schmid H.P., Staebler R., Wofsy S. & Zhao L. 2011. Observed increase in local cooling effect of deforestation at higher latitudes. *Nature* 479: 384–387. doi: 10.1038/nature10588.

Wohlfahrt G. & Tasser E. 2015. A mobile system for quantifying the spatial variability of the surface energy balance: design and application. *International Journal of Biometeorology* 59(5): 617–627. doi: 10.1007/s00484-014-0875-8.

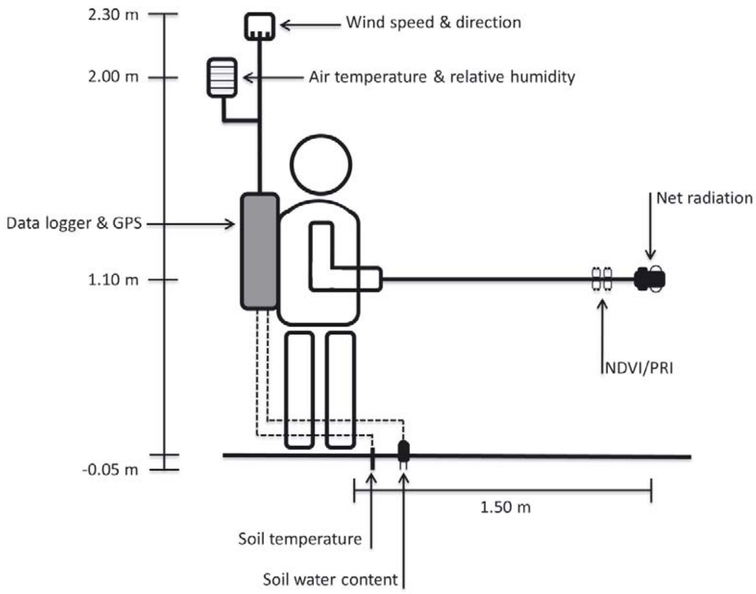

Figure 1: Schematic of the EcoBot version 2.0 design (adapted from Wohlfahrt & Tasser 2015).

Biogeomorphology in the Anthropocene

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University of Oxford

Keywords: Resilience, rock breakdown, human-environment interactions

The complex web of interrelationships which link life and landscape constitute a very important element of the Earth system and can be understood using the framework of biogeomorphology. This framework acknowledges that organisms play a key role in most earth surface processes, while in turn geomorphology sets the stage for ecological processes. Much recent progress has been made in understanding biogeomorphological interactions and quantifying their importance. In the Anthropocene, human activities are increasingly influencing biogeomorphological interactions, often producing complex, non-linear responses. Improved management and stewardship of the Earth at all scales requires better understanding of, and cooperation with, biogeomorphological interactions.

Abstracts of the participants

Integrating machine learning and brightness temperature assimilation to improve snow estimates over High Mountain Asia

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Snow influences the water supply of over 1 billion people in high mountain Asia (HMA). In HMA, the impact of snowfall patterns is not only limited to the water supply system but also affects the local economy. This study aims to improve the spatio-temporal variability of snow water equivalent (SWE) estimates across HMA using a framework that integrates machine learning with passive microwave brightness temperature assimilation. The NASA Land Information System (LIS) is the software framework used here to simulate the hydrologic cycle and to assimilate brightness temperature spectral difference observations using an ensemble Kalman filter. Trained support vector machines act as the observation operator within the assimilation framework and map the LIS-simulated geophysical states into brightness temperature spectral difference space. Snow estimates (with and without assimilation) are compared to ground-based observations for performance evaluation. Recently acquired in-situ snow depth measurements are being leveraged for validation of the designed data assimilation framework. The assimilation framework exhibits potential in improving the land surface model-based snow estimates. However, machine learning pitfalls, such as controllability and under-determined systems, do exist at certain locations in time and highlight some of the challenges of utilizing machine-learning algorithms within data assimilation frameworks.

Topographic LiDAR as a tool for timber assortment assessment and characterization in mountain forests

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Topographic LiDAR (Light Detection and Ranging), an active remote-sensing technique by measuring the reflected pulse, is capable to elaborate directly and indirectly spatial and three-dimensional measurements of tree structure. Forest characteristics may be recorded from several measurements (i. e. small-footprint and full-footprint airborne topographic LiDAR, etc.) and can be acquired from a single device or from a combination of several devices. Airborne topographic LiDAR is optimal for large areas (i. e. Airborne Laser Scanning, ALS), whereas terrestrial topographic LiDAR is optimal for small areas (i. e. Terrestrial Laser Scanning, TLS).The vegetational parameters directly recorded as point clouds are processed using a software suite (i. e. LAStools) and are described as topographic LiDAR metrics, which depict the segments of trees and morphological analysis using algorithms, modelling and measurements statistics. My work deals with a comparison of parametric and non-parametric forest models estimated at single tree level using terrestrial and aerial topographic LiDAR devices in Italian mountains. This article focuses on assessing the accuracy of prediction of two topographic LiDAR devices (ALS and TLS) at tree-level scale. Specific objectives were: on ALS data, (1) individual tree segmentation using eCognition image analysis (Figure 1), (2) estimating tree height, diameter breast height (DBH) and stem volume to single trees detected using parametric and non-parametric statistics processes. In contrast, for TLS data: (3) identification of trees within the study area using topographic LiDAR software (4) assessment of tree height, DBH and stem volume using parametric and non-parametric statistic processes, and considering those 18 models produced, (5) comparing parametric and non-parametric forest models created. Considering the two highest layers of ALS, we observed a high tree detection from 87.5 to 100% in all study areas (Figure 1). Goodness values of correlation were found both for parametric and non-parametric models (Figure 2). TLS results showed a more accurate prediction considering the overfitting and underfitting models prediction. LiDAR is an optimum data to determine stem volume at tree level in broadleaf natural forests.

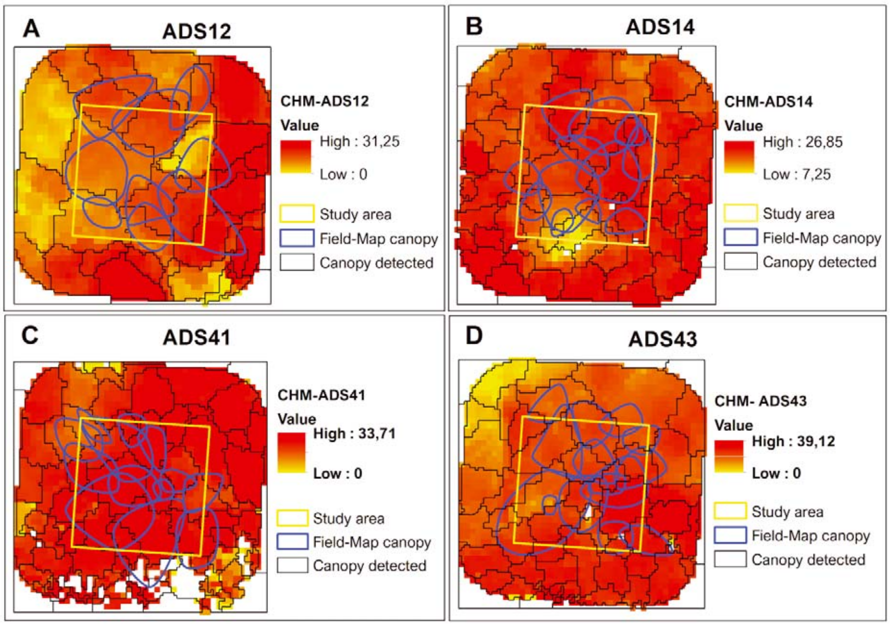

Figure 1: Individual tree detection using eCognition software on 4 study areas (A–D).

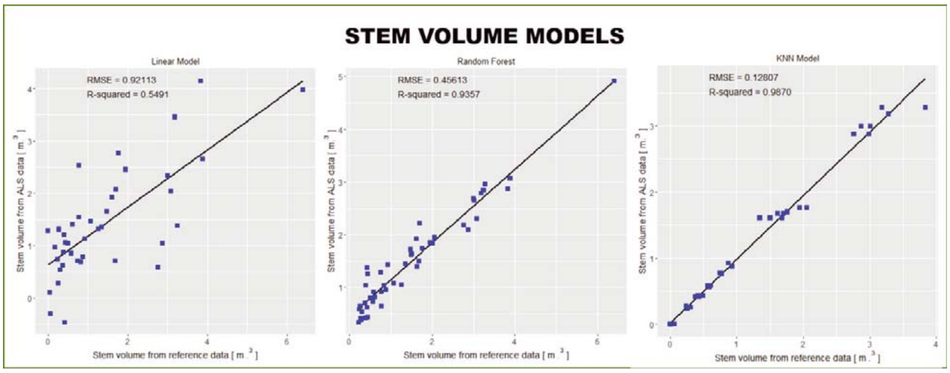

Figure 2: Regression models based on relationships between stem volume from reference data and system volume from ALS data using three statistics models.

Deciphering the evolution of the *Bleis Marscha* rock glacier (Val d'Err, Eastern Switzerland) with image correlation, exposure dating, and finite-element modelling

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Keywords: Rock glacier, image correlation, orientation image, exposure dating, inverse problem

We reconstruct the formation of the Bleis Marscha rock glacier in the Val d'Err (Grisons, Eastern Switzerland), a talus rock glacier with an active upper part that overrides a lower part. Internal front scarps separate the rock glacier into different units, each with its own activity phase.

The internal structure of the rock glacier is studied with numerical finite-element modelling (inverse problem). Surface exposure dating with cosmogenic ^{10}Be and ^{36}Cl allows us to place a long-term temporal framework on rock glacier movement periods. We constrain the short-term, present a horizontal surface velocity field with the correlation of orientation images derived from bi-temporal orthoimages (Fitch 2002; Matlab tool ImGRAFT, Messerli & Grinsted 2015).

The image correlation results (Figure 1) support the morphologically-motivated subdivision of the Bleis Marscha rock glacier in an active upper part and a relict, collapsing lower part. The latter shows clear morphological signs of inactivity, yet it is moving at speeds of up to 30 cm/a. Although the deformation mechanism is not known, this possibly hints at the presence of subsurface ice.

Fitch, A.J., Kadyrov, A., Christmas, W.J. & Kittler, J. 2002. Orientation correlation. In: Marshall, D. & Rosin, P.L. (eds.), *Proceedings of the 13th British Machine Vision Conference, University of Cardiff, England, 2–5 September 2002*: 133–142.

Messerli, A. & Grinsted, A. 2015. Image georectification and feature tracking toolbox: ImGRAFT. *Geoscientific Instrumentation, Methods and Data Systems* 4: 23–34.

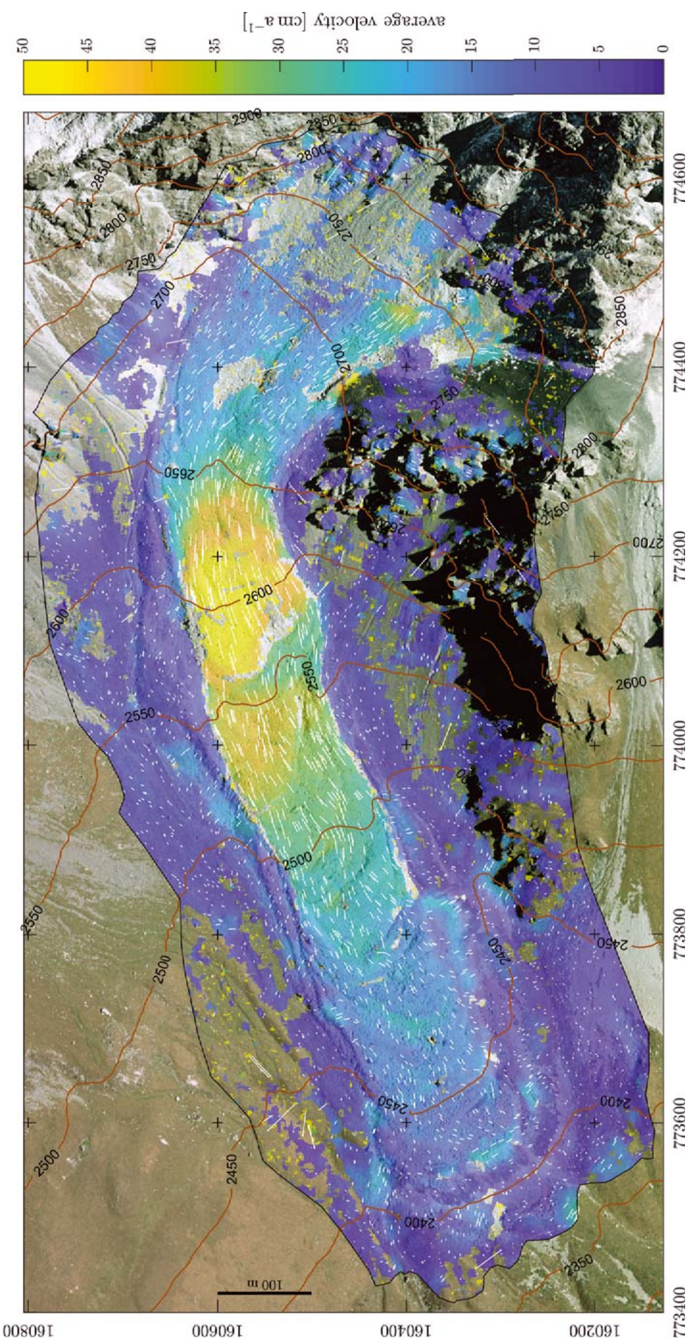

Figure 1: Noise-filtered horizontal surface velocity field 2003–2012, draped over the 2003 aerial image. Magnitude shown by colours, direction by white arrows. Significance level is 5 cm/a. The transition from relict to intact as suggested by the velocity field (threshold velocity of 35 cm/a) lies between 2550 and 2600 m a.s.l. Orthophotos provided by swisstopo, © 2018 swisstopo (JD100042)

Identification of distinct features within terrestrial laser scans of natural environments

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Keywords: Saliency, distinctness, terrestrial laser scans, feature extraction, natural environment

The expanding use of laser scans for mapping requires efficient means to handle, analyse and interpret the obtained data. Much research has been invested in information extraction from the acquired point cloud, focusing mainly on man-made entities in urban environments. Nonetheless, natural scenes offer a more complex environment where entities of interest may be embedded within the topography, making the application of standard processing procedures inapplicable. In this regard, saliency maps are frequently used in image processing applications as preliminary cues for object recognition. Though their advantage is largely acknowledged (e. g., Cheng et al. 2014; Chernov et al. 2019; Ren et al. 2014; Yu et al. 2019), little research has been carried out concerning 3D data, and even less in relation to terrestrial laser scans. Those who have considered this measure focused mainly on urban scenes and on distinct landmarks therein. In this presentation, we propose a new saliency measure for point clouds, governed by surface curvature, direction and point neighbourhood size. The proposed model requires no pre-processing and is based solely on the points' geometric attributes. It opens the opportunity for a myriad of applications, such as feature and pattern extraction, registration, viewpoint selection, point-cloud simplification, etc. We apply it to terrestrial laser scans of open, natural scenes, featuring various types of entities, either natural or artificial, which are embedded within the topography (e. g., Figure 1).

Cheng, M.-M., Mitra, N.J., Huang, X. & Hu, S.-M. 2014. SalientShape: group saliency in image collections. *Vis. Comput.* 30: 443–453. doi: 10.1007/s00371-013-0867-4.

Chernov, T., Ilyuhin, S. & Arlazarov, V.V. 2019. Application of dynamic saliency maps to the video stream recognition systems with image quality assessment. In: Nikolaev, D.P., Radeva, P., Verikas, A. & Zhou, J. (eds.), *Proc. SPIE 11041, Eleventh International Conference on Machine Vision (ICMV 2018), 110410T (15 March 2019)*. doi: 10.1117/12.2522768.

Ren, Z., Gao, S., Chia, L.-T.& Tsang, I.W.-H. 2014. Region-Based Saliency Detection and Its Application in Object Recognition. *IEEE Trans. Circuits Syst. Video Technol.* 24: 769–779. doi: 10.1109/TCSVT.2013.2280096.

Yu, L., Xia, X. & Zhou, K. 2019. Traffic sign detection based on visual co-saliency in complex scenes. *Appl. Intell.* 49: 764–790. doi: 10.1007/s10489-018-1298-8.

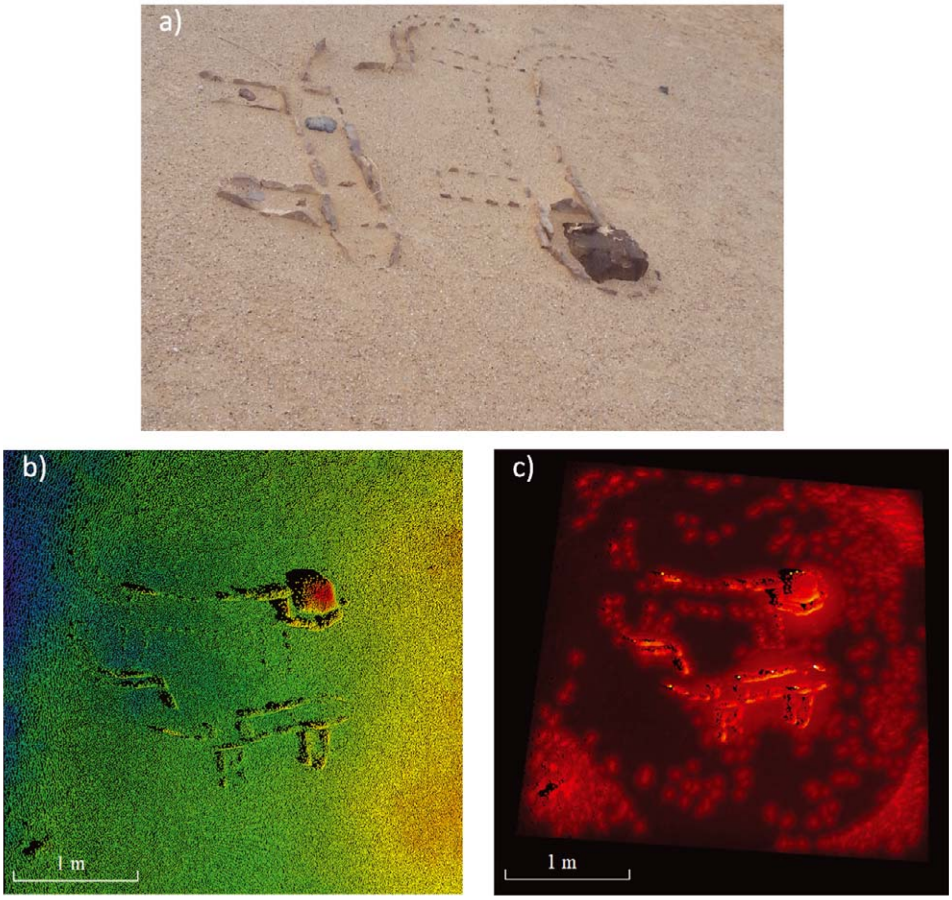

Figure 1: A detail from Tigers Temple in the Ovda Valley, Southern Israel, an archaeological site which features artificial entities embedded within the topography; a) as depicted in an image (Photograph: © Sagi Filin, 2014); b) as captured by terrestrial laser scan (colors represent elevations); c) a saliency map highlighting the 'tigers'.

Intensified landslide dynamics in the arid Nepalese Himalaya – The earthflow at Khingar / Jharkot revisited

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Keywords: Himalaya, natural hazards, landslide, monitoring, SfM

The Nepalese Himalaya is dissected by a major rift valley, the Thakkhola half graben (THG). Along this fault-bounded valley, the Kali Gandaki flows from the Tibetan plateau in the north towards the Dhaulagiri and Annapurna massifs in the south, where it forms the deepest gorge on earth. The THG has been filled with up to 3 km thick Plio- and Pleistocene sediments, underlain by clay shales of the Jurassic Spiti Formation, which are strongly water swellable and prone to landslides. These preconditions led to a complex and recently highly active landslide system in the Muktinath Valley (92.5 km^2), a tributary of the Kali Gandaki, with strong effects on infrastructure and local population. In this semi-arid mountain environment, water as most important driver of the system is provided by infrequent precipitation events, mainly during the summer monsoon (annual rainfall: ~ 350 mm) and artificial irrigation.

This study aims i) to better understand drivers and controls of the landslide system, ii) to identify hotspots and quantify rates of recent movement, and iii) to provide strategies for mitigation.

Based on previous work of Fort (1985), Baade et al. (1998), Miehe & Weidinger (2015) and our own field campaigns in 2018 and 2019, we present first results on the dynamics of the currently most active part of the landslide. Recent dynamics are reconstructed using multi-temporal (ortho-)photo interpretation, UAV/SfM-based high-resolution DSM and point cloud comparisons, as well as different approaches of geomorphic change detection. Our first results reveal high rates of recent movement, a strongly enlarged area of active landsliding due to the heavy monsoon of 2018, with several indications for a strong acceleration in the near future.

Baade, J., Mäusbacher, R., Wagner, G.A., Heine, E. & Kostka, R. 1998. Landslides and deserted places in the semi-arid environment of the inner Himalaya. In: Kalvoda, J. & Rosenfeld, C.L. (Hrsg.), *Geomorphological hazards in the high mountain areas*: 49–61. Kluwer Academic Publishers, Dordrecht.

Fort, M. 1985. Contribution of Sedimentary and Geomorphic Data to the Knowledge of Palaeoclimates in Nepal Himalayas. *Current Trends in Geology* VI: 159–189.

Miehe, G. & Weidinger, J.T. 2015. Himalayan landforms and processes. In: Miehe, G., Pendry, C. & Chaudhary, R. (eds.), *Nepal. An introduction to the natural history, ecology and human environment of the Himalayas. A companion to the Flora of Nepal*: 103–124. Royal Botanic Garden Edinburgh.

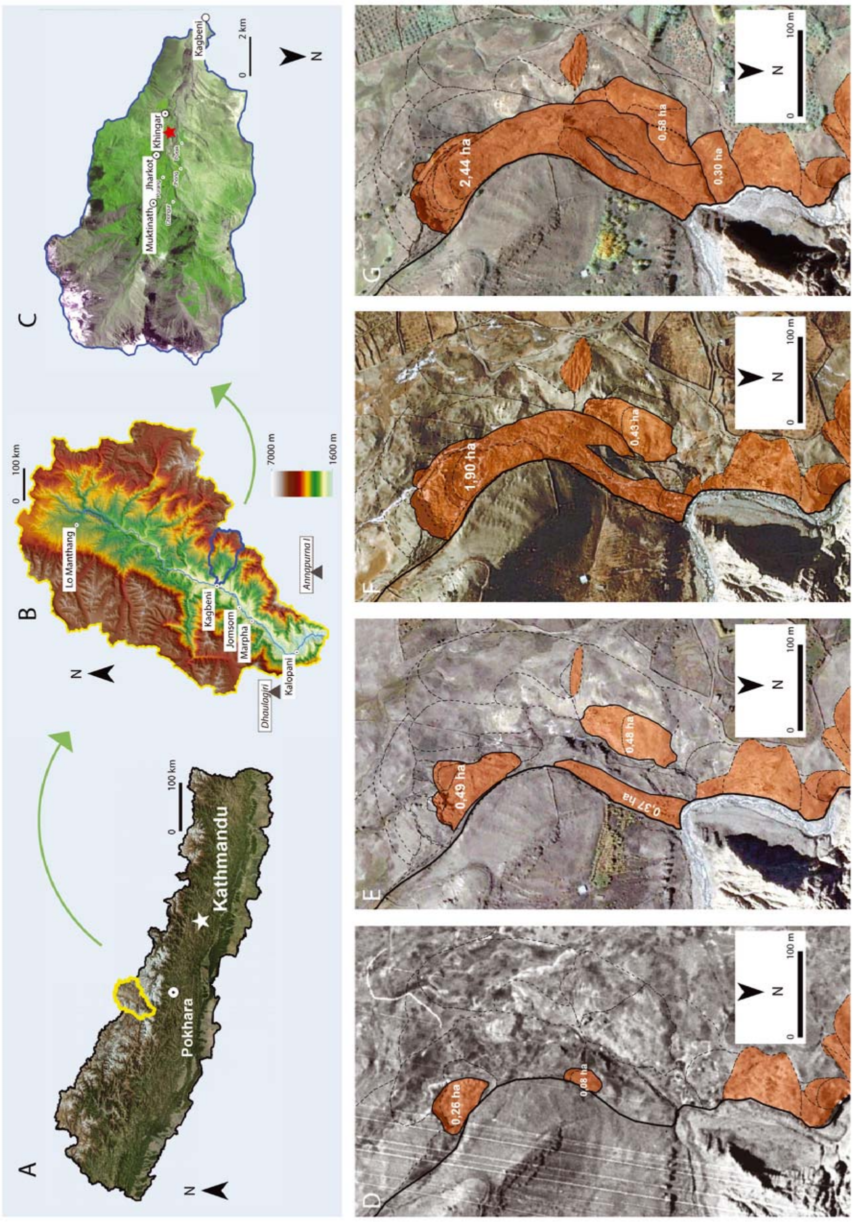

Figure 1: (A) Location of the study area in Nepal. (B) Hillshaded SRTM data of the Upper Kali Gandaki Catchment within the Mustang District, showing the main settlements and the catchment of the Jhong Chu ("Muktinath Valley"). (C) Pleiades 1B Orthophoto of the Muktinath Valley with main settlements and the location of the most active landslide area (red). (D) to (G) Evolution of the most active part of the landslide complex showing a dramatic expansion based on Corona 1964 (D), Quickbird 05.10.2002 (E) World-View-2 28.12.2011 (F), and Pleiades 1B 02.10.2018 (G) data.

The effect of windthrow on forest protection capacity

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Keywords: Windthrow, protection gap, avalanche starting zones, natural regeneration, woody debris

Windthrow creates large amounts of surface roughness, such as fallen stems, root plates and stumps. During the first years after a disturbance, these roughness elements have a considerable protective function against avalanches in windthrow areas (Wolgemuth et al. 2017). The surface roughness not only affects the potential avalanche release (Schweizer et al. 2003; McClung & Schaerer 2006), but it may also contribute to small- to medium-sized avalanches decelerating through snow detrainment (Feistl et al. 2014; Teich et al. 2014). However, if an extreme amount of snow covers the surface roughness elements, a windthrow area may become prone to avalanche release. Snow accumulation may produce terrain smoothing, which is an important factor in avalanche formation (Veitinger et al. 2014).

The effective heights of roughness elements in windthrow areas decrease with time, as the fallen trees decompose. However, windthrow also creates favourable conditions for tree regeneration. Information on wood decay in combination with tree regeneration was evaluated using data from long-term post-disturbance observation in the study area of Disentis (Switzerland, windthrow Vivian 1990) in order to model effective protection capacity against natural hazards.

To assess the effect of snow on surface roughness in windthrow areas, we quantified terrain smoothing using the vector ruggedness measure (Sappington et al. 2007) and the snow heights. Elevation models from summer and winter terrain in the windthrow area close to Bergün (Switzerland, windthrow Vaia 2018, Figure 1) were produced from repetitive drone flights.

Based on these data series, we can quantify how surface roughness is smoothed depending on the snow height. Increasing snow height leads to decreasing surface roughness, which can produce local release areas. We expect that, with continuous increase of snow height, these release areas expand in size. Good information on the effective heights of roughness elements and maximum snow heights is essential in evaluating the avalanche risk in windthrow areas.

Feistl, T., Bebi, P., Teich, M., Bühler, Y., Christen, M., Thuro, K. & Bartelt, P. 2014. Observations and modeling of the braking effect of forests on small and medium avalanches. *Journal of Glaciology* 60 (219): 124–138.

McClung, D. & Schaerer, P. 2006. *The avalanche handbook*. 3rd ed. Mountaineers Books, 342 p.

Sappington, J., Longshore, K. & Thomson, D. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using Bighorn Sheep in the Mojave Desert, J. *Wildlife Manage* 71: 1419–1426.

Schweizer, J., Jamieson, J.B. & Schneebeli, M. 2003. Snow avalanche formation. *Reviews of Geophysics* 41(4): 1016.

Teich, M., Fischer, J.-T., Feistl, T., Bebi, P., Christen, M. & Grêt-Regamey, A. 2014. Computational snow avalanche simulation in forested terrain. *Natural Hazards and Earth System Science* 14(8): 2233–2248.

Veitinger, J., Sovilla, B. & Purves, R.S. 2014. Influence of snow depth distribution on surface roughness in alpine terrain: a multi-scale approach. *The Cryosphere* 8: 547–569.

Wolgemuth, T., Schwitter, R., Bebi, P., Sutter, F. & Brang, P. 2017. Post-windthrow management in protection forests of the Swiss Alps. *European Journal of Forest Research* 136(5-6): 1029–1040.

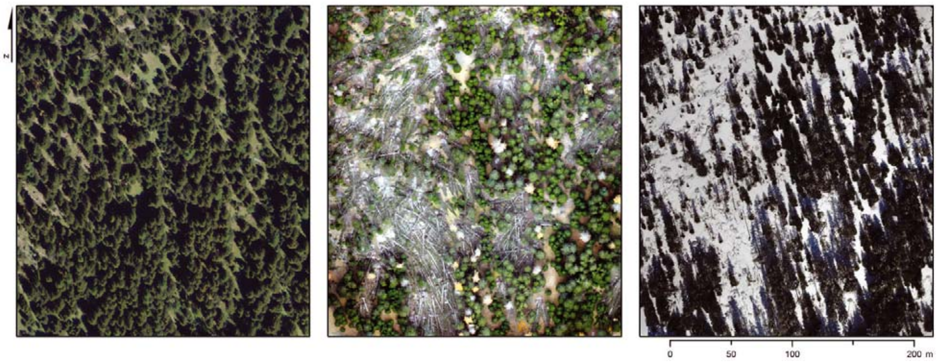

Figure 1: Windthrow area close to Bergün, locality of Val Mela. Healthy forest stand on the left (Swissimage © 2017 swisstopo (5704 000 000)), windthrown forest after the storm Vaia (October 2018) in the middle (drone flight from 13.11.2018, Yves Bühler and Andreas Stoffel), and the same area under the snow cover (drone flight from 6.2. 2019, Yves Bühler and Andreas Stoffel).

Patagonian Ice Sheet deglaciation and paleo-lake evolution in the Río Cisnes-Ñirehuao-Toqui basins, Chile (44–45° S)

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Keywords: Sub-centennial, millennial, varves, climate, ice sheet reconstruction

In order to understand the mechanisms behind Southern Hemisphere (SH) paleo-ice sheet response to the Last Glacial-Interglacial Transition (LGIT), the development of high-resolution sub-centennial chronologies is essential (Bendle et al. 2019). Millennial-scale Patagonian Ice Sheet reconstructions using radiometric dating techniques have improved our understanding of SH glacial-interglacial climate, glacier dynamics and the response of early humans to periods of environmental change. However, these techniques cannot distinguish local from regional controls on glacier retreat, nor do they capture modes of interannual climate variability, such as the Southern Hemisphere Westerlies (SWWs). Today the SWWs drive regional climate through forcing of SH ocean circulation, with effects on an interhemispheric scale. Nevertheless, a lack of high-resolution LGIT archives limits the modelling capacity of numerical reconstructions. In particular, glaciolacustrine varves offer the potential to initiate a step-change in our understanding of ice sheet response to rapid SH climate transitions through the generation of chronologies at centennial and decadal resolutions.

This project aims to reconstruct Patagonian Ice Sheet (PIS) deglaciation and proglacial lake formation, duration and drainage at millennial, centennial and decadal resolutions across the LGIT in the Cisnes-Ñirehuao-Toqui basins (44–45° S), Chile. Data sources (ASTER, LandSAT and Sentinel) will be processed using ArcGIS to produce glacial geomorphological maps of the catchment, and remote sensing will be undertaken using UAVs to generate high-resolution DEMs of glacial landforms. Beryllium-10 dating of moraine crest boulders, glaciolacustrine varve chronologies and Bayesian Age Modelling will be used to better reconstruct the response of PIS glacier dynamics to rapid SH palaeoclimate transitions.

Bendle, J., Palmer, A., Thorndycraft, V. & Matthews, I. 2019. Phased Patagonian Ice Sheet response to Southern Hemisphere atmospheric and oceanic warming between 18–17 ka. *Scientific Reports* 9(4133): 1–9.

Dynamics of slow-moving deep-seated landslides in the tropics: insights from combined analyses of long InSAR time series and ground-based measurements

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Keywords: Landslide mechanisms, causes and triggers of landsliding, UAV-SfM, InSAR, Tropical Africa

Landslides represent one of the main hazards in dissected landscape, especially in tropical areas where a combination of active tectonics, steep topography, intense rainfall and high population density is found (Maes et al. 2017; Stanley and Kirschbaum 2017). Many regions of the Global South are facing such a situation, with landslides resulting every year in fatalities, structural and functional damage to infrastructures and serious disruptions of the organization of societies. The rapidly expanding city of Bukavu (DR Congo), located in the Kivu Rift, is experiencing such a challenging situation (Nobile et al. 2018).

In this research, we combine remote sensing and ground-based approaches to gain insights into the mechanisms that control ground displacements linked to landslides in the tropics. Satellite interferometry (InSAR), archive aerial photographs ('50s and '70s), differential GNSS and multi-temporal topographic reconstructions obtained from UAV-SfM photogrammetry are used to unravel both the long-term and seasonal behaviours of two key landslides in the city and its surroundings. This combination allows for exhaustive validation of remote-sensing products, but also provides complementary information in zones of rapid deformation where InSAR measurements are restricted by coherence loss.

We detailed the mechanisms of the landslides, highlighting the presence of different kinematic units of contrasting movement style and mean velocities (Figure 1). By confronting the deformation time series to on-site rainfall and seismic records, we show that the seasonality of the precipitation pattern influences slides behaviours. The long-term analysis of the hillslopes stabilities allows further exploration of the interplay between natural and human controls over several decades. It also strengthens the importance of considering underlying landslide causes, such as weathered-related weakening of the slope strength, to unravel controls of slope instability in such a tropical mountain context. The outputs of the research should help improve the evaluation of landslide hazard and mitigation in the area, but also across other regions where similar environmental conditions exist. This research is carried out within the framework of the RESIST and MODUS projects, funded by the Belgian Science Policy Office (BELSPO).

Maes, J. et al. 2017. Landslide risk reduction measures: A review of practices and challenges for the tropics, *Progress in Physical Geography* 41(2): 191–221. doi: 10.1177/0309133316689344.

Nobile, A. et al. 2018. Multi-temporal DInSAR to characterise landslide ground deformations in a tropical urban environment: focus on Bukavu (DR Congo). *Remote Sensing* 10(626). doi: 10.3390/rs10040626.

Stanley, T. & Kirschbaum, D.B. 2017. A heuristic approach to global landslide susceptibility mapping. *Natural Hazards* 87(1): 145–164. doi: 10.1007/s11069-017-2757-y.

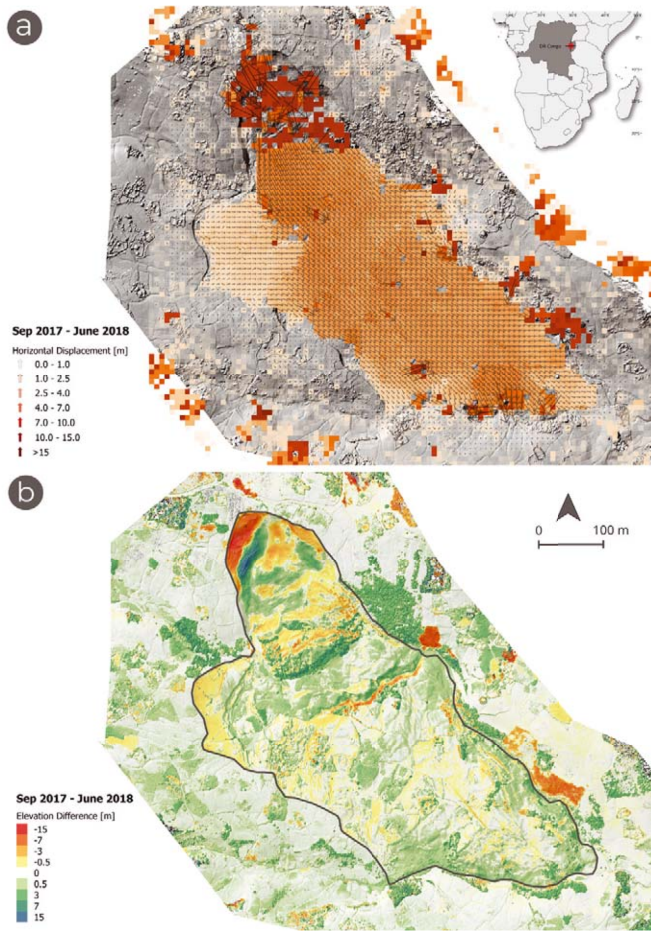

Figure 1: a) Horizontal displacements measured at Ikoma landslide (2.54° S, 28.73° E) between two UAS acquisition campaigns (Oct. 2017–June 2018). Arrows displays the direction of the displacements. b) Vertical displacement over the same period obtained through a differencing of the respective DSMs. The location of three zones (kinematic units) of different movement styles is highlighted.

Using drone-based imagery systems to study climate, herbivore and vegetation interactions in the arctic tundra

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UiT The Arctic University of Norway, Aarhus University, Norwegian Polar Institute

Keywords: Arctic tundra, herbivore, remote sensing, snowmelt, UAV

Climate change has profound effects on the arctic tundra and its herbivores. In Svalbard, drivers of change include higher ambient temperatures, changes in snow properties, icing events, snowmelt patterns and the onset of greening (Hansen & Aanes 2012). Multiple drivers, such as slow-changing trends or major disturbance events, can change the state of the arctic tundra ecosystem. Most of these landscape-changing processes occur at low spatial and temporal frequencies that would not be captured by traditional field-based monitoring. The rise of satellite and unmanned aerial vehicle (UAV) technologies has opened up new options for monitoring landscapes in remote locations like Svalbard. The advantage of UAVs is that they can cover relatively large areas of several hectares at sub-centimetre resolution and can be a useful link between field-based data and satellite images (Riihimäki et al. 2019). The overall aim of my research project is to develop photogrammetry-based methods to advance our capability of monitoring state changes in arctic tundra ecosystems. This will be achieved by combining drone imagery, field measurements and satellite images to better understand how multiple disturbances (e. g. herbivores and permafrost thaw) together shape heterogeneous landscapes. I am in the process of developing a vegetation map of Svalbard's moss tundra that includes disturbances like goose grubbing and icing. Further, I will closely monitor snowmelt with the help of various remote-sensing platforms to optimize a snowmelt model of the region (Liston & Elder 2006), capture pink-footed goose grubbing behaviour and quantify vegetation disturbance in relation to the retreating snow line. With advancements in vegetation and snow classification, as well as animal detection from UAV images, I hope to develop tools to better quantify herbivore abundances and disturbances across Svalbard's tundra through different seasons.

Hansen, B.B. & Aanes, R. 2012. Kelp and seaweed feeding by High-Arctic wild reindeer under extreme winter conditions. *Polar Research* 31:1–6.

Liston, G.E. & Elder, K. 2006. A distributed snow-evolution modeling system (SnowModel). *Journal of Hydrometeorology* 7(6): 1259–1276.

Riihimäki, H., Luoto, M. & Heiskanen, J. 2019. Estimating fractional cover of tundra vegetation at multiple scales using unmanned aerial systems and optical satellite data. *Remote Sensing of Environment* 224: 119–132.

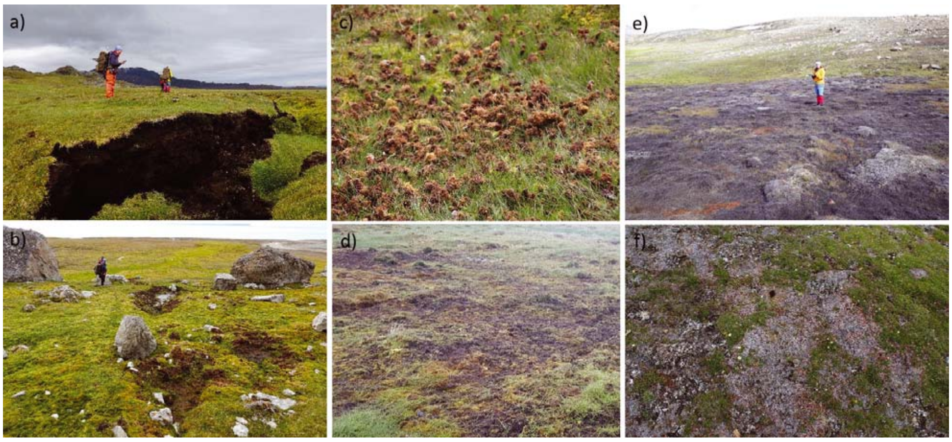

Figure 1: Structural disturbances in arctic moss tundra on Svalbard. a), b) permafrost thaw, b), c) goose grubbing, and e), f) ice damage on vegetation. Photograph credits are: a), b) Jakob Assman/NP, c), d), f) Cornelia Jaspers and Virve Ravolainen/NP

Modeling dry mass flow with MWDiEM

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Keywords: Granular flow, mass wasting, mass transport, modelling

MWDiEM is a new open-source, discrete element model-based numerical tool that is able to effectively model the dynamics of cohesionless polyhedral and spherical granular particles. The tool is especially aimed at geological mass-waste applications where the fluid content of the flow is none or negligible, e. g. dry rock avalanches, boulder falls, dry sand, gravel and debris slides, dry debris flows and snow avalanches, that can be approximated as dry and cohesionless. The model is prepared for GIS implementation; includes possible entrainment and erosion of the particles; the use of different basal topographies and obstacles in the path of the movement is implemented and different slide initiation / slope failure methods are realized, like vibrations or forced breakup of a block of mass.

The most critical part of any DiEM code is the calculation of the overlap between the particles within the soft particle approach. This is well established for spheres, but is not easily applicable to non-spherical shapes, especially because of the computational limitations. Therefore one focal point of the code development was finding the best suitable algorithms for this task. After carefully testing a large number of algorithms, including different versions of the separating axis methods (Boyd & Vandenberghe 2004), geometrical approaches and Gilbert-Johnson-Keerthi (GJK; Gilbert et al. 1988) alternatives, we concluded that for our purposes a special self-developed version of the GJK algorithm (Muratori 2016; Linahan 2015), followed by an expanding polytope algorithm (EPA), is best suited (see Figure 1). The time integration of the Newton equations is achieved by a quaternion-based Verlet algorithm.

Currently some subsequent minor points within the code development are being addressed and the selection of the model validation cases has been started. Once the code is ready for application, the simulations will give us an opportunity to look inside the dynamics of mass flow events, including flow velocities, shear rates, segregation patterns, and to explain any unexpected run-out zone geometries, providing a useful tool in the future for both scientists and natural hazard professionals. As a first use case, the effect of shape and/or size segregation in dry mass-flow events on the flow dynamics and runout zone geometry will be addressed, including answering some of the questions: (a) What kind of particle shape and/or size distribution causes the largest change in the runout zone geometry? (b) Is there any distinct point during the flow when segregation is not important any more? (c) How does the length and shape of the flow path influence the runout geometry? (d) Can we see any fingering or self-channeling of the flow due to shape segregation? (e) What is the mechanism behind any observed segregation? Is it similar to kinetic sieving or something very different? (f) Is there any crystallization associated with the polyhedral shape of the particles? (g) Is there any kind of "lubrication" effect associated with the shape segregation, so is there less force needed to shear the material once the segregation has started?

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Boyd, S. & Vandenberghe, L. 2004. *Convex Optimization*. Cambridge University Press.

Gilbert, E.G., Johnson, D.W. & Keerthi, S.S. 1988. A fast procedure for computing the distance between complex objects in three-dimensional space. *IEEE Journ. of Robotics and Automation* 4(2): 193–203. doi: 10.1109/56.2083.

Muratori, C. 2016. *Implementing GJK (2006)*. Available at: https://mollyrocket.com/849 (accessed on: 15.05.2019).

Linahan, J. 2015. A Geometric Interpretation of the Boolean Gilbert-Johnson-Keerthi Algorithm. CoRR, abs/1505.07873.

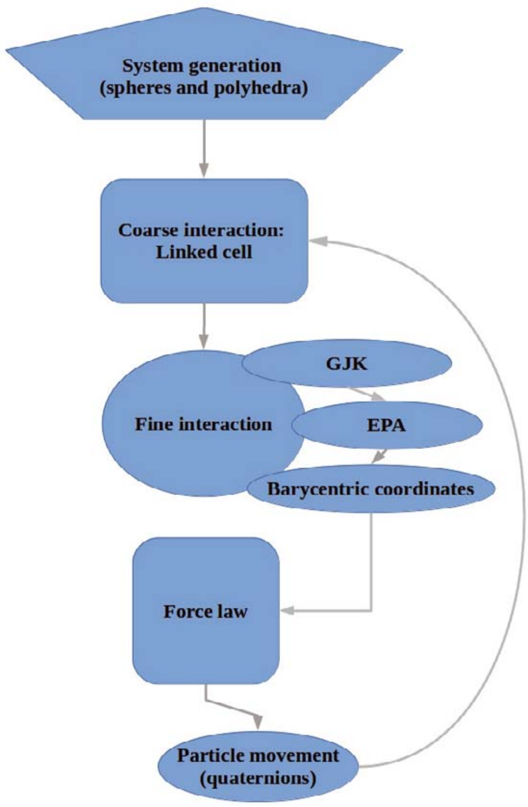

Figure 1: The main workflow behind MWDiEM.

Dynamics of small steep mountain glaciers in Svalbard

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Keywords: Structure-from-Motion, small Unmanned Aircraft Systems, mountain glaciers, steep alpine environment, High Arctic

Geoscientists are increasingly utilizing very high resolution 3D models produced from small unmanned aircraft systems (sUAS)-acquired image data, processed with Structure-from-Motion (SfM) photogrammetry (e.g. Westoby et al. 2012; Tonkin et al. 2014).

This study aims to investigate the annual surface flow changes and dynamic behaviour of a selection of small and steep mountain glaciers in Svalbard by repeated very high-resolution 3D models from sUAS. The selected glacier sections on Spitsbergen and Prins Karls Forland were chosen to derive high-resolution 3D models with a ground pixel size of a few cm. Due to the crevassed surface of these particular glaciers, creating a high-contrast surface, data can be recorded both summer and winter, making seasonal comparison possible (see Figure 1). Whereas traditional field mapping methods in the ablation season would demand a helicopter as the only possible logistic platform, we can perform our studies with comparatively low-cost access through snow-scooters in winter and by boat in summer. The project team used SfM photogrammetry on Svalbard during spring and summer 2018 (see Figure 2) in order to test how accurately heavily crevassed glaciers can be mapped and how well their change over time can be detected using sUAS. Some of these sites will be revisited in late spring 2019.

Westoby, M.J., Brasingtion, J., Glasser, N.F., Hambrey, M.J. & Reynolds, J.M. 2012. 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology* 179: 300–314.

Tonkin, T.N., Midgley, N.G., Graham, D.J. & Labadz, J.C. 2014. The potential of small unmanned aircraft systems and structure-from-motion for topographic surveys: A test of emerging integrated approaches at Cwm Idwal, North Wales. *Geomorphology* 226: 35–43.

Figure 1: Example of a suitable target glacier ice fall from Oscar 2 Land, Svalbard. Photo © Endre Før Gjermundsen, 2013.

Figure 2: Example of SfM 3D model of a section of Wahlenbergbreen, Svalbard, made from sUAS-data from field work during summer 2018, processed with AgiSoft Photoscan software. Images for the model recorded with DJI Mavic Air. © Endre Før Gjermundsen

Estimating crown diameter and tree height from fixed-wing UAV imagery

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Keywords: Unmanned aerial vehicle (UAV), fixed-wing type, forestry, crown diameter, tree height

My current research focuses on forest ecosystems, with an emphasis on the use of photogrammetry and unmanned aerial vehicles (UAV) in forest management. The forest inventory is an important instrument for sustainable forest management. Data acquisition during forest inventorying is demanding in time and cost. UAV photogrammetry offers possibilities for effective data acquisition. Crown diameter and tree height are important tree parameters that are collected during a forest inventory. Crown diameters and tree heights of individual trees in stand are measured separately by standard terrestrial methods. Canopy Height Models (CHM) and Digital Surface Models (DSM) created from high-resolution UAV imagery provide a fast way of determining tree crown diameters and tree heights for the whole stand.

The main goal of my research is to identify, from high-resolution UAV imagery, the influence of multiple factors on crown diameter and tree height estimate accuracy. Especially the influence of the vegetation season, flight patterns, tree species. The imagery of approximately 250 ha of forest land was done using eBee Plus RTK/PPK with two perpendicular flights. I established eight research plots with four different trees species in the imaging area. I chose two deciduous and two coniferous tree species: European beech (*Fagus sylvatica L.*), sessile oak (*Quercus petraea (Matt.) Liebl.*), Norway spruce (*Picea abies (L.) H. Karst.*), and European silver fir (*Abies alba Mill.*). The field measurements for all plots were collected in the same month as the aerial images acquisition was performed. The positions, tree heights and crown projections of all trees on all plots were measured by FieldMap technology.

The preliminary results did not show a significant influence of tree species on the accuracy of estimating crown diameter from high-resolution UAV imagery. However, the results revealed the significant influence of tree species on the detection of the number of trees on the plot. The detection of tree numbers is higher for coniferous tree species. This is mainly due to the overlapping crowns. Currently, only two plots have been processed. In further research I will validate our results on the other plots with various tree species. Further, I will focus on identifying the influence of the vegetation season and impact of flight altitude on the estimate accuracy of crown diameter and tree height from high-resolution UAV imagery. In a complex way, I am focusing on the use of fixed-wing UAV to address spatial and temporal heterogeneity of forest ecosystems.

Geosciences for the exploration and heritage protection of a Mycenaean cemetery in Aidonia, Greece

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Keywords: Terrestrial Lidar, Ground Penetrated Radar, Geological Field Mapping, Aidonia Cemetery, Mycenaean

Ten kilometers northwest of New Nemea, Greece, a Mycenaean cemetery was discovered in the Aidonia village in the mid-1970s (Figure 1). The cemetery from ca. 1200 BCE consists of several chamber tombs containing Mycenaean burials. Burials are mainly composed of human and horse bone remains, gold and jewelry. The Aidonia tombs were dug into a hillside in the natural rock formation composed of Cenozoic layers of calcareous white marlstones.

Previous fieldwork in Aidonia revealed the collapse of tomb roofs. The observations suggest that tombs may have collapsed following a pattern. A transition zone between well-preserved tombs and collapsed tombs was observed on the site (Figure 1). The cause of the collapse pattern is unknown and is a main motivation for this study.

The aim of this research is to contribute to heritage protection and exploration of the Late Bronze Age Mycenaean Cemetery. The main objective is to apply methods traditionally used in geoscience to determine relevant geological processes (structural, sedimentological and stratigraphic) and anthropogenic activities (e. g. farming and agriculture) responsible for the collapse pattern of the Mycenaean chamber tombs.

The main tasks that will support the objective are: (1) create a digital surface model (DSM) from terrestrial Lidar point clouds; (2) generate a geologic field map of the study area; (3) create sub-surface geophysical profiles using ground-penetrating radar (GPR); and (4) integrate the DSM, geologic field map, and geophysical profiles to generate a holistic 3D model of the Mycenaean Cemetery.

Up to date, the project progress focuses on processing Lidar point clouds collected in the 2017 fieldwork (Figure 2). Further activities will involve the generation of the first DSM and the acquisition of preliminary digital measurements on the model. In addition, a second visit to the archeological site is planned for summer 2019. The visit will include a second Lidar data collection, geological field mapping, and GPR surveying.

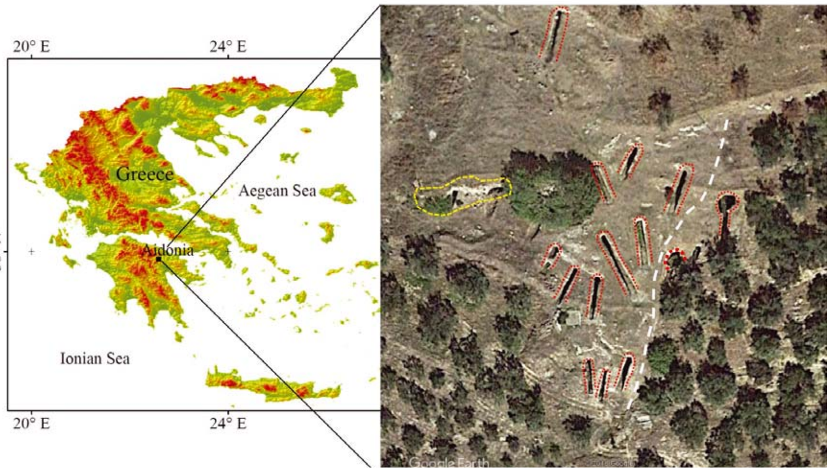

Figure 1: Map of Greece showing the location of Aidonia village (left). Google Earth imagery showing the Aidonia Cemetery (right) and tombs layout (Map data from Google Earth © 2018 Google). Red dashed lines highlight the tomb entrance corridor; white dashed line indicates a transition zone between well-preserved tombs and collapsed tombs. Since capturing of the satellite imagery, three more collapsed tombs have been identified in the field. They are situated to the right of the white dashed line. The yellow dashed line highlights attempted looting.

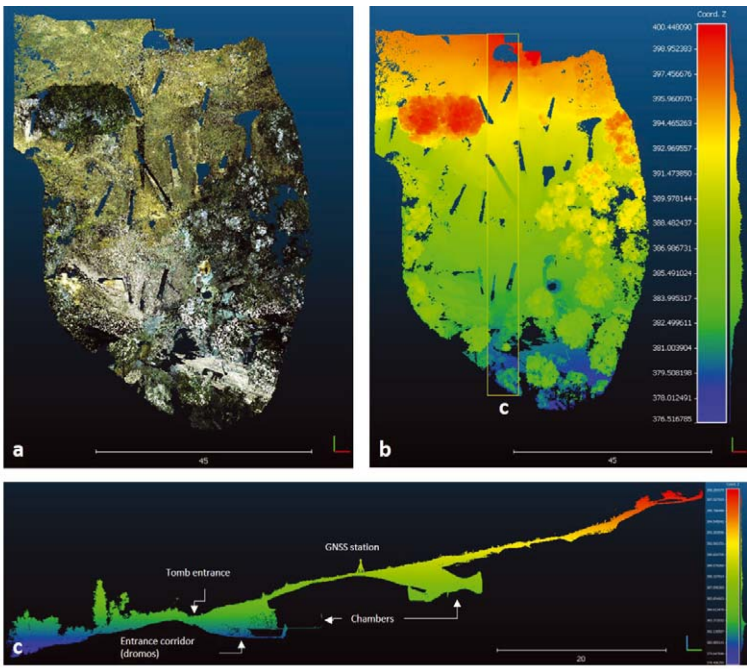

Figure 2: a) Top view of sub-sampled point cloud collected in 2017. Points are coloured by RGB. b) Top view of sub-sampled point cloud coloured by height values. The outlined yellow rectangle indicates the position and orientation of segmented area shown in c. c) Lateral view of point cloud segmentation coloured by height.

Remote sensing of belowground processes in grassland ecosystems

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Keywords: Spectroscopy, plant traits, aboveground / belowground linkages, soil microbial communities, ecosystem processes

Soil microbes represent one of the largest reservoirs of biological diversity on earth, and play a fundamental role in the functioning of all terrestrial ecosystems (Bardgett & van der Putten 2014). Links between soil communities and plant functional traits are emerging as a research focus in ecology, and provide a means by which belowground communities and processes can be predicted from above ground. Remote sensing, particularly spectroscopy, is emerging as a valuable tool in ecology and can be used to provide rapid, spatially explicit estimates of plant structural and chemical properties across a range of spatial scales (Pettorelli et al. 2014). Spectral data has also been found to correlate directly with belowground processes in aspen forest stands (Madritch et al. 2014). This project investigates the links between soil communities, plant traits, spectral data and ecosystem functioning in a long-term grassland restoration experiment located in the Yorkshire Dales, UK (Smith et al. 2000). Initial fieldwork, scheduled for summer 2019, will collect spectroscopy data at the canopy and leaf level, plant trait data, including chlorophyll, leaf nitrogen and leaf area metrics, and soil microbial data, including the ratio of fungi to bacteria. These will be used to identify the fundamental drivers of spectral variation in grassland foliage and determine whether variation in grassland belowground processes can be detected through optical sensing of aboveground foliage.

Bardgett, R.D. & Van Der Putten, W.H. 2014. Belowground biodiversity and ecosystem functioning. *Nature* 515(7528): 505–511. doi: 10.1038/nature13855.

Madritch, M.D., Kingdon, C.C., Singh, A., Mock, K.E., Lindroth, R.L. & Townsend, P.A. 2014. Imaging spectroscopy links aspen genotype with below-ground processes at landscape scales. *Philosophical Transactions of the Royal Society B* 369(1643): 20130194. doi: 10.1098/rstb.2013.0194.

Pettorelli, N., Safi, K. & Turner, W. 2014. Satellite remote sensing, biodiversity research and conservation of the future. *Philosophical Transactions of the Royal Society B* 369: 20130190. doi: 10.1098/rstb.2013.0190.

Smith, R., Shiel, R., Millward, D. & Corkhill, P. 2000. The interactive effects of management on the productivity and plant community structure of an upland meadow: an 8-year field trial. *Journal of Applied Ecology* 37: 1029–1043. doi: 10.1046/j.1365-2664.2000.00566.x.

The application of millimetre wave radar to the study of volcano-glacier interactions and ice-ocean interactions in conditions of reduced visibility

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Keywords: Radar, signal processing, millimetre waves, glacier, volcano

Satellite sensors are inhibited by low spatial and temporal resolution, thus ground-based remote-sensing methods have been developed to compensate for these weaknesses. My PhD project will develop the utility of millimetre wave radar for 3D glacier mapping in order to improve our understanding of glacier processes. I will use the field-portable All-weather Volcano Topography Imaging Sensor (AVTIS) operating at 94 GHz for this purpose, which was originally designed to image volcanic lava domes (Macfarlane et al. 2013). AVTIS measures the range to a target across multiple azimuth and elevation angles, from which a 3D point cloud is generated and a Digital Elevation Model (DEM) produced. Millimetre waves can image though obscurants (e. g. fog, cloud) and at high spatial resolution, offering a distinct advantage over optical instruments and lower frequency radars. Millimetre wave radars can image in most weather conditions, are portable and acquire detailed images of surface elevation and surface reflectivity, but have never been tested on glaciers.

The project will look to answer the following research questions:

1) What are the properties of backscatter from glacial ice at millimetre wavelengths?
2) What are the implications of the beam footprint size on surface elevation extraction algorithms?
3) What information can be gained from using a portable millimetre wave radar to investigate glacier-volcano and ice-ocean interactions.

The scattering properties of ice at millimetre wavelengths are not known (Warren & Brandt 2008), thus I will initially characterize the Normalised Radar Cross Section (NRCS) of glacial ice from field measurements at Rhône Glacier in the Swiss Alps. This will aid the development of terrain classification algorithms. I will then look to quantify the effect of the beam footprint on the surface elevation extraction algorithm, apply correction methods and improve the generation of DEMs from AVTIS data. AVTIS will ultimately be deployed at a marine- or lake-terminating glacier to examine frontal ablation processes (e. g. calving), as well as at an ice-capped volcano to assess glacio-volcanism, so that I can analyse the best possible deployment of the AVTIS millimetre wave radar for future studies.

Macfarlane, D.G., Odbert, H.M., Robertson, D.A., James, M.R., Pinkerton, H. & Wadge, G. 2013. Topographic and Thermal Mapping of Volcanic Terrain Using the AVTIS Ground-Based 94-GHz Dual-Mode Radar/Radiometric Imager *IEEE Trans. Geosci. Remote Sens.* 51(1): 455–472. doi: 10.1109/TGRS.2012.2202667.

Warren, S.G. & Brandt, R.E. 2008. Optical constants of ice from the ultraviolet to the microwave: A revised compilation. *Journal of Geophysical Research* 113: D14220. doi: 10.1029/2007JD009744.

Figure 1: The AVTIS millimetre wave radar. Photograph: William D. Harcourt, 2019.

Quantification of feedbacks between small-scale erosion and ecological succession on slopes in a high-mountain environment

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Keywords: Biogeomorphology, biogeomorphic feedbacks, ecological succession, sediment transport, structural equation modelling

Earth surface processes and vegetation succession form a dynamic relationship that is affected by the functional composition and diversity of plant traits. High-mountain environments provide a textbook surrounding for biogeomorphic research approaches, as high geomorphic activity and initial conditions for primary succession provide an expedient area for investigation. Up to now, biogeomorphic studies have mainly focused on the qualitative description of relationships and feedbacks between biotic and abiotic processes. However, in order to further investigate multidirectional relationships, it is necessary to jointly quantify (i) geomorphic process rates as a function of vegetation and (ii) successional development as a function of geomorphic conditions.

The proglacial area of the Gepatschferner (Kaunertal) in the crystalline Central Eastern Alps presents a showcase environment to investigate these interactions as the retreating glacier and highly active slope processes provide the ground for different stages of ecological succession and promote high rates of sediment reworking within the proglacial deposits.

In this particular study, we investigate small-scale biogeomorphic interactions at 57 test sites of 2 m x 3 m size. Experimental plots are established on slopes along an ecological succession gradient that reflect different stages of erosion-vegetation interaction. Morphometric characteristics and edaphic variables were determined to cover the abiotic condition for the plot sites. In order to quantify abiotic process rates, we combine mechanical measurements (i. e. erosion plots) with digital surface-change detection techniques (i. e. structure from motion analyses). Relative dating, historical image analysis and knowledge of glacial retreat helped to estimate time since last perturbation. A detailed vegetation survey was carried out to capture biotic conditions at the sites. Species distribution at each site, as well as individual plant traits (i. e. root volume, root length and leaf size), provide information on successional stage and functional diversity.

To address reciprocal causality between abiotic and biotic variables, we conduct structural equation modelling typically used in ecological studies. It allows evaluation of complex, multivariate relationships with more than one causal pathway.

Hence, combination of geomorphic and vegetation characteristics with erosion rates at various stages of ecological succession is possible and biogeomorphic feedback effects can be highlighted.

Figure 1: Mechanical erosion plot in the Kaunertal with plant cover 25–30% (Photo: Stefan Haselberger 2018).

Quantifying the Alpine sediment cascade using multi-temporal high-resolution topographical surveys: case studies from the Valais, Swiss Alps

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Keywords: Point clouds, UAV, TLS, Alpine environment, permafrost

Climate change-induced permafrost degradation can affect the frequency and magnitude of mass wasting processes in high Alpine environments, potentially altering sediment redistributions, as stated by several authors (cf. Beniston et al. 2018). Talus slopes are one of the most common landforms in these environments, collecting debris through rock fall from adjacent rock walls. They form the first step in the Alpine sediment cascade and are a potential source for other geomorphic processes leading to sediment transfers (Figure 1A). It is therefore important to study both permafrost distribution and geomorphic change in talus slopes and their headwalls to increase our understanding of the driving environmental factors.

The main objective of this research is to contribute to the understanding of the overall sediment cascade in an Alpine environment with specific focus on talus slope and rock glaciers as sediment conveyors (Figure 1B). Since monitoring of topographic changes is fundamental to studying sediment dynamics (Cucchiaro et al. 2018), multi-temporal high-resolution data (5 ± 2 cm) from Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicles (UAV) photogrammetry are gathered (Figure 2), together with data of ground temperature, geophysical data, meteorological data and time-lapse terrestrial photography.

Geomorphic processes, such as rock fall, channel fill, rock tumbling and rock tilting, can be detected and quantified in a timeframe of one year using UAV- and TLS-based point cloud acquisition (Figure 2). The integration of multi-year datasets will enable us to understand the geomorphologic dynamics of the area and the driving environmental factors behind these sediment redistributions.

Beniston, M. et al. 2018. The European mountain cryosphere: A review of its current state, trends, and future challenges. *Cryosphere* 12: 759–794. doi: 10.5194/tc-12-759-2018.

Cucchiaro, S. et al. 2018. Monitoring topographic changes through 4D-structure-from-motion photogrammetry: application to a debris-flow channel. *Environmental Earth Sciences* 77(18): 632. doi: 10.1007/s12665-018-7817-4.

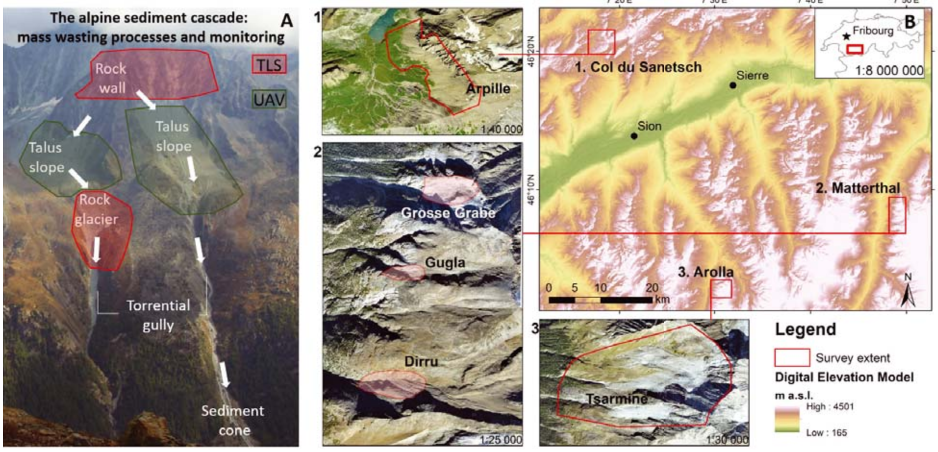

Figure 1: (A) Conceptual model of the Alpine sediment cascade and the case studies investigated in this PhD research, (B) using Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicles (UAV) surveys at the three study sites. Photographs: Alexander Nestler, 2018; Graphics by Hanne Hendrickx.

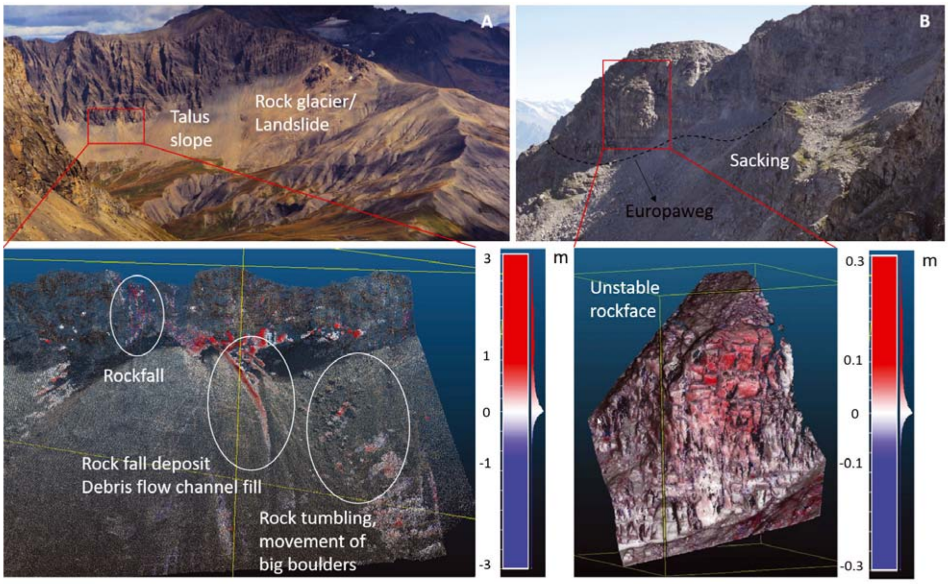

Figure 2: Preliminary results and point clouds of (A) UAV photogrammetry data from Arpille (study area 1, Figure 1B) and (B) TLS data from Grosse Grabe (study area 2), showing geomorphic processes that can be detected within one year (2017–2018). Photographs: Alexander Nestler, 2018; Graphics by Hanne Hendrickx.

Boulders for paleohydrology – using allochthonous boulders in fluvial channels for peak discharge and maximum flood height estimates

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Keywords: Paleohydrology, boulder, flood discharge, sediment transport, flow velocity

Large allochthonous clast-sizes are commonly found along mountainous streams. The Matlab® code package presented here allows fast and simple application and comparison of three different approaches for paleo-hydrological peak discharge and maximum flood height estimates from fluvially transported boulder clasts in delimited channel reaches.

All approaches drawn from existing literature follow the incipient motion principle (Costa 1983; Clarke 1996): They compute flow velocities for turbulent Newtonian fluid flow, when a boulder of given diameter (D) initiates motion on the channel's bed. Threshold conditions required for movement of large grain sizes only occur during high-magnitude flood events and maximum transported grain sizes can represent maximum flow conditions in a fluvial channel. The Gauckler-Manning formula was used to convert cross-sectional average flow velocities to peak discharge estimates and maximum flood heights in a fluvial channel (e. g. Manning 1891).

All the paleo-hydrological calculations performed in this code package are based on the assumption of turbulent Newtonian fluid flow without shear strength. The most recently published study by Alexander and Cooker (2016) produces the lowest values by including the more advanced impulsive force consideration into their formulation. Therefore their values could potentially be more representative than values from the other two approaches.

The Matlab® code package is accessible via following URL:
https://gitlab.com/mlh300/bouldersforpaleohydrology

Alexander, J. & Cooker, M.J. 2016. Moving boulders in flash floods and estimating flow conditions using boulders in ancient deposits. *Sedimentology* 63(6): 1582–1595.

Clarke, A.O. 1996. Estimating probable maximum floods in the Upper Santa Ana Basin, Southern California, from stream boulder size. *Environmental & Engineering Geoscience* 2(2): 165–182.

Costa, J.E. 1983. Paleohydraulic reconstruction of flash-flood peaks from boulder deposits in the Colorado Front Range. *Geological Society of America Bulletin* 94(8): 986–1004.

Manning, R. 1891. On the flow of water in open channels and pipes. *Transactions of the Institution of Civil Engineers of Ireland* XX: 161–207.

Figure 1: Fluvial channel with boulders, Balephi Khola, Sunkoshi Valley, Nepal (2016). Photograph: Marius Huber.

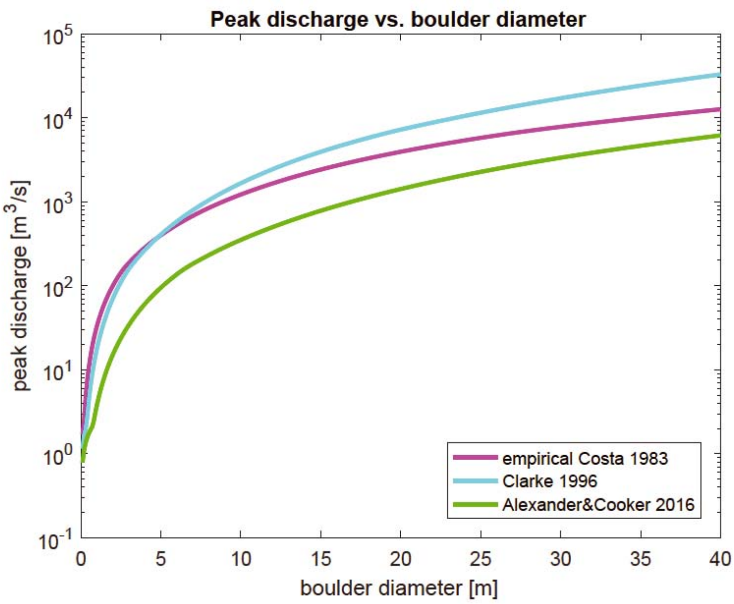

Figure 2: Calculation output: peak discharge vs. boulder diameter.

Remote Sensing for Understanding Landslide and Rock fall Behaviour via Object-based Image Analysis techniques

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Keywords: Landslide, rock fall, Object-Based Image Analysis (OBIA), semantics, detection, characterization

Landslides and rockfalls are usually disastrous geohazards that pose continuous risk to the living environment in mountainous areas around the world. In recent decades, a variety of remote-sensing tools, ranging from passive sensors to active ones, have been extensively used for accurate detection and detailed mapping. However, in recent years, Unmanned Aerial Vehicles (UAVs) are being extensively applied in landslide applications like identification and monitoring, and for hazard analysis purposes. However, most landslide studies lack valuable semantic information about landslide connecting elements and how they react with the natural and man-made environment. The current paper presents preliminary results of landslide and rockfall mapping from ultra high-resolution UAV imagery using an object-based approach to identify and understand the mechanism of geohazards. Aerial imagery was collected with UAVs from different landslide and rock fall sites and analysed using Structure-from-Motion (SfM) procedures. The latter enabled accurate and detailed reconstruction and mapping of landslide and rockfall phenomena in a cost-effective manner compared with traditional methods. The pros are the spatially holistic distributed data collection from slopes. In addition, ultra high-resolution datasets, in combination with the low cost and real time applicability, constitute UAVs as indispensable tools for landslide management. Last but not least, the advantage of collecting data from hazardous rockfall and landslide sites while eliminating user's risk is a great asset.

Object-Based Image Analysis (OBIA) is an image analysis technique, remarkably developed during the last decade, resulting from recent advances in computer vision and machine learning. Its main task is to automatically replicate human interpretation to identify objects in remote-sensing images. OBIA methods have proved to substantially outperform the pixel ones, for instance in the elimination of false positives missed by pixel-based approaches. It allows greater interaction and flexibility in the input parameterization compared with conventional pixel-based methods. The final result of classification is heavily dependent on proper segmentation. Therefore attention had to be paid to over-segmentation and under-segmentation issues of the case site (Figure 1). In detail, a sequence of image-based processes was applied, including multi-scale object segmentation, spectral, morphometric and contextual information extraction for landslide detection. The following phase was set up for object classification in meaningful and homogeneous landslide classes (e. g. scarp, depletion zone, accumulation zone) which are spatially connected by introducing contextual information in the ruleset. The last step was the validation of the results, based on accuracy assessment against a digitized landslide map and field investigations. The outcome of the current research aims to highlight the usefulness of photogrammetry and UAV platforms to assess and mitigate the potentially negative consequences of landslide hazard via object-based approach.

a)

b)

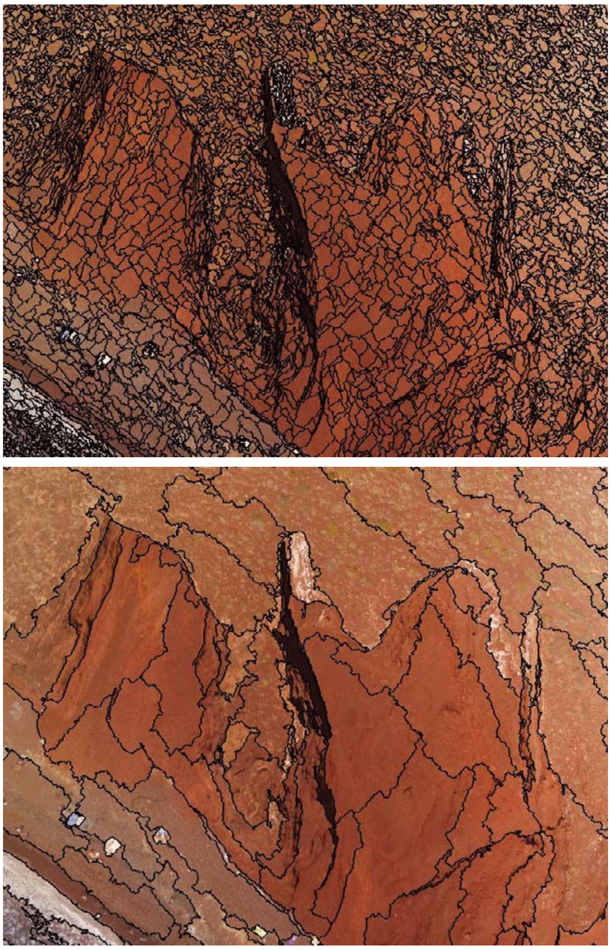

Figure 1: Examples of oversegmentation (a) and undersegmentation (b).

Extraction of phenological metrics from Sentinel-2 time series: Performance of Smoothing Algorithms

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Keywords: Phenology, Sentinel-2, time series, smoothing algorithms, Tyrol

Phenology is the science of life-cycle events in flora and fauna, e. g. leafing or senescence. As such, it is closely related to climate. Furthermore, mass and energy exchange between terrestrial ecosystems and the atmosphere are influenced by these events. Optical satellite imagery has long been used to monitor land surface phenology (LSP) from regional to global scales. High-resolution satellite imagery, such as time series acquired by Sentinel-2 (S2), now allow for an unprecedented area-wide monitoring of many different phenomena, including LSP (Helman 2018).

Start and end-of-season (SOS/EOS) for the year 2018 were extracted for two tiles of S2 imagery covering a vast part of the state of Tyrol, Austria. Cloud- and snow-contaminated pixels are masked out during preprocessing, based on a classification provided by the Sen2Cor software. Remaining noise is dealt with by different smoothing algorithms (Savitzky-Golay filter, Whittaker smoother, curve fitting). First tests indicate that the number of observations influences the timing of SOS and EOS. Two distinct patterns can be spotted in the upper left corner of Figure 1, which correspond to the different number of available observations on the left and right side of the red line. This raises the question how the number of valid observations affects derived phenological metrics. Therefore an empirical investigation is conducted by iteratively eliminating a number of observations in time series of both synthetic and real data and re-estimating SOS and EOS, similar to White et al. (2014), but considering S2 characteristics.

It is challenging to assess the performance of smoothing algorithms when no ground-truth data is available. Atzberger and Eilers (2011) propose several measures to address this. One of these criteria, the separability of land-cover types after filter application, will be used to investigate a set of parameters and algorithms.

Atzberger, C. & Eilers, P.H.C. 2011. Evaluating the effectiveness of smoothing algorithms in the absence of ground reference measurements. *Int. Journal of Remote Sensing* 32(13): 3689–3709.

Helman, P. 2018. Land surface phenology: What do we really ‚see‘ from space? *Science of The Total Environment* 618: 665–673.

White, K., Pontius, J. & Schaberg, P. 2014. Remote Sensing of spring phenology in northeastern forests: A comparison of methods, field metrics and sources of uncertainty. *Remote Sensing of Environment* 148: 97–107.

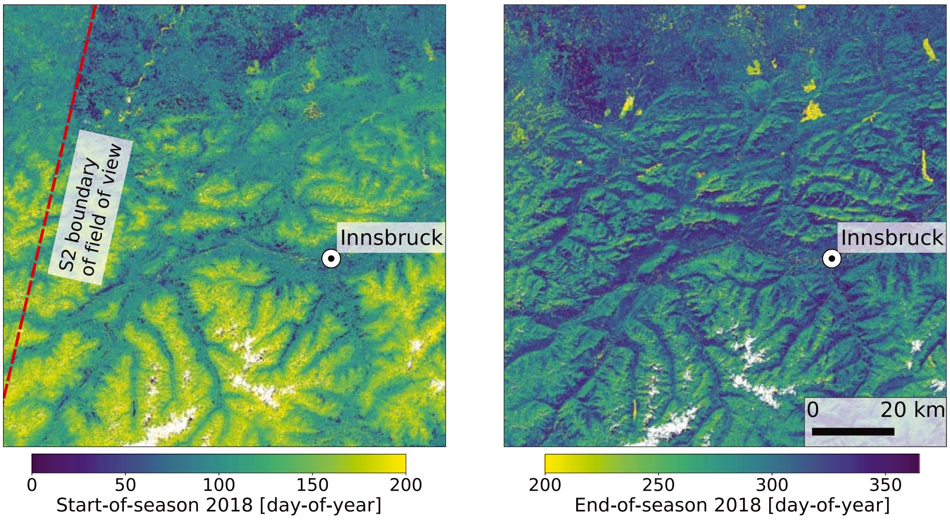

Figure 1: Phenological metrics derived from Sentinel-2 time series (tile T32TPT). Graphics: Kollert, 2019.

CoastScan – Clustering 4D Permanent Laser Scanner Data

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Keywords: Permanent laser scanner, LiDAR, point clouds, time series analysis, clustering algorithms

Coastal zones are highly dynamic areas subject to continuous changes. The intensification and higher frequency of extreme weather events due to climate change make it essential that coastal deformations can be modelled and predicted accurately.

The continuous collection of topographic LiDAR point clouds with a terrestrial laser scanner (TLS), so-called permanent laser scanning (PLS), allows stable monitoring of coastal areas over extended periods of time (several months up to years). Point cloud representations of the observed areas can be collected at spatial and temporal resolutions (e.g. at cm level and hourly intervals) that are higher than, for example, for satellite observations (Vos et al. 2017). This allows the detection and observation of small-scale change patterns that would not be visible with conventional techniques.

The present data set contains four months of hourly scans of a part of the coast at Kijkduin, the Netherlands, including dry parts of the sandy beach and dunes. The data is generated with a Riegl VZ-2000 laser scanner mounted on top of a hotel next to the dunes. In order to understand the benefits as well as the challenges of PLS for coastal areas, we investigate the use of different clustering and classification algorithms. We analyse the possibilities of unsupervised learning algorithms to cluster the temporal evolution of point cloud representations of the observed area. In this way, small-scale deformation processes and patterns can be detected and grouped. The goal is to find suitable methods to use TLS data for improving the understanding of dynamic processes of coastal zones and to facilitate the preparation of data for developing and improving coastal modelling.

Vos, S., Lindenbergh, R. & de Vries, S. 2017. CoastScan: Continuous Monitoring of Coastal Change using Terrestrial Laser Scanning. In: Aagaard, T., Deigaard, R. & Fuhrman, D. (eds.), *Proceedings of Coastal Dynamics* 2017: 1518–1528.

Figure 1: Point cloud of the beach at Kijkduin on 01.01.2017 with surface classification for a selected area. Yellow points represent dry sand, green points represent the dune area, pavement is coloured in grey and people and buildings are shown in red and blue respectively.

Figure 2: The Riegl VZ-2000 laser scanner on top of a building in Oostende, Belgium. Photograph: Roderik Lindenbergh.

Delineation of Debris-Covered Glaciers With Interferometric SAR (InSAR) Coherence

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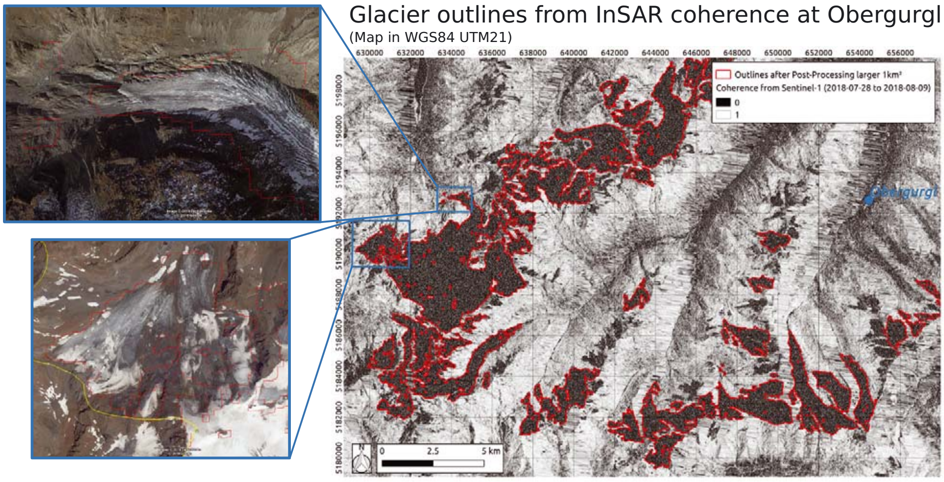
Keywords: debris-covered glaciers, glacier monitoring, remote sensing, SAR, Sentinel-1

Mapping debris-covered parts of the glacier is still limited because of its spectral resemblance with surrounding areas in case of optical technique and the insulating effect of thick debris cover in case of thermal technique. This causes an immense work load of manually editing the glacier outlines, which hampers regular updates of global glacier inventories. Interferometrically derived SAR (InSAR) coherence can be used as an alternative to overcome these limitations. It is a quantitative measure of cross-correlation of the observed surface. The coherence value of 1 signifies stability, while 0 shows complete temporal decorrelation of the surface.

In Lippl et al. (2018), an automatic processing chain to delineate glacier outlines using InSAR coherence as a primary estimator, and slope as well as morphological operations as secondary filters, was evaluated in terms of processing parameters and compared for different sensors in the Karakoram. The intermediate radar frequency C-band data from Sentinel-1 outlined the glacier boundary with the least misclassifications and a type II error of 0.47% compared with Global Land Ice Measurements from Space (GLIMS) data. Therefore, Sentinel-1's short repeat intervals, together with the automatic processing chain, can provide a step further for real-time monitoring of glacier changes on a large scale.

The processing chain was applied for a Sentinel-1 scene from summer 2018 at Obergurgl to produce an inventory for all glaciers larger than 1 km². The overlay of the outlines with aerial images reveals that debris-covered parts are included. However, data are showing small inconsistencies, probably due to sensor resolution or instable ground, which underlines the necessity of in-situ measurements like in the Innsbruck Summer School of Alpine Research.

Lippl, S., Vijay, S. & Braun, M. 2018. Automatic delineation of debris-covered glaciers using InSAR coherence derived from X-, C- and L-band radar data: a case study of Yazgyl Glacier. *Journal of Glaciology* 64(247): 811–821. doi: 10.1017/jog.2018.70.



Glacier outlines from InSAR coherence at Obergurgl. Map data (left): © 2018 Google, DigitalGlobe. Background coherence (right) from Sentinel-1 (2018-07-28 and 2018-08-09).

Monitoring mountain cryosphere dynamics by time-lapse stereo photogrammetry

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Keywords: Photogrammetry, cryosphere monitoring, time-series analysis, stereo time lapse, image registration

Classical methods to monitor the mountain cryosphere dynamics, such as those of glaciers and rock glaciers, rely on repeated in-situ fieldwork to acquire data. One way to collect displacement vector fields at high spatial resolution is to use expensive laser scanning (topographic LiDAR) or unmanned aerial vehicles (UAV) to construct 3D models by stereo photogrammetry, but these methods lack temporal repeatability (Bodin et al. 2018). However, to achieve high temporal resolution, one can use permanent GPS on the study site to capture seasonal changes, but GPS measurements can only be collected at selected spatial positions (Lambiel & Delaloye 2004). To combine both high spatial and temporal resolution, we propose a time-lapse stereo photogrammetry device, made up of two high-resolution single lens reflex (36Mpx) cameras at two different locations capturing several images per day. To be able to capture the surface dynamics of the cryosphere (Figure 1) and to highlight seasonal changes (Figure 2) from images taken by the device, we need to address challenges in the domain of computer vision and time-series analysis. Regarding computer vision, we need to address the problem of image registration across time, 3D reconstruction from pairs of images and optical flow computation between images taken at different times. The challenge for time-series analysis is to find methods to take advantage of temporal redundancy of displacement fields to construct displacements time-series robust to noise and outliers. This device has been installed on two study sites : the Argentière glacier (Mont Blanc massif, France) and the Laurichard rock glacier (Ecrins massif, France). The two sites present very different types of dynamics: during summer the velocity of the Argentière glacier is around 10–20 cm / day at the study area (Vincent & Moreau 2016), whereas the annual velocity of the Laurichard rock glacier is around 1–1.5 m / year [1].

Bodin, X., Thibert, E., Sanchez, O., Rabatel, A. & Jaillet, S. 2018. Multi-annual kinematics of an active rock glacier quantied from very high-resolution dems: An application-case in the French alps. *Remote Sensing* 10: 547.

Lambiel, C. & Delaloye, R. 2004. Contribution of real time kinematic gps in the study of creeping mountain permafrost: Examples from the western swiss alps. *Permafrost and Periglacial Processes* 15: 229–241.

Vincent, C. & Moreau, L. 2016: Sliding velocity _uctuations and subglacial hydrology over the last two decades on argentière glacier, mont blanc area. *Journal of Glaciology* 62(235): 805–815.

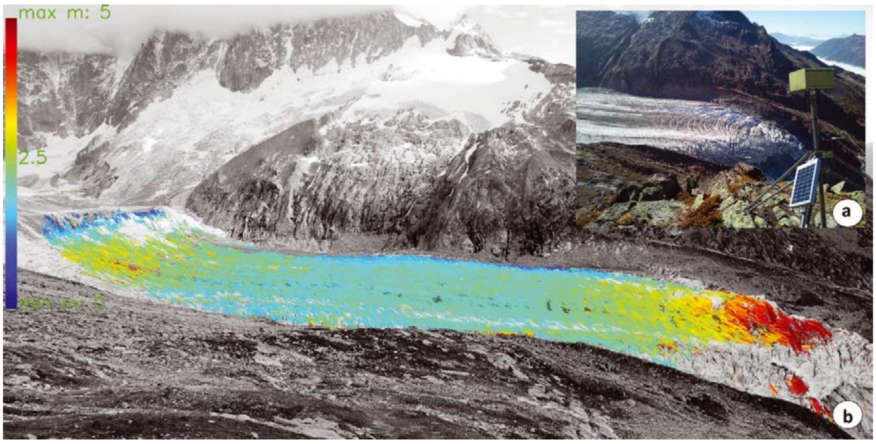

Figure 1: One of the two cameras looking at the Argentière glacier. The camera is mounted on a tripod fixed to the ground. b) Displacements in metres between images taken on 07 July 2017 and on 20 July 2017.

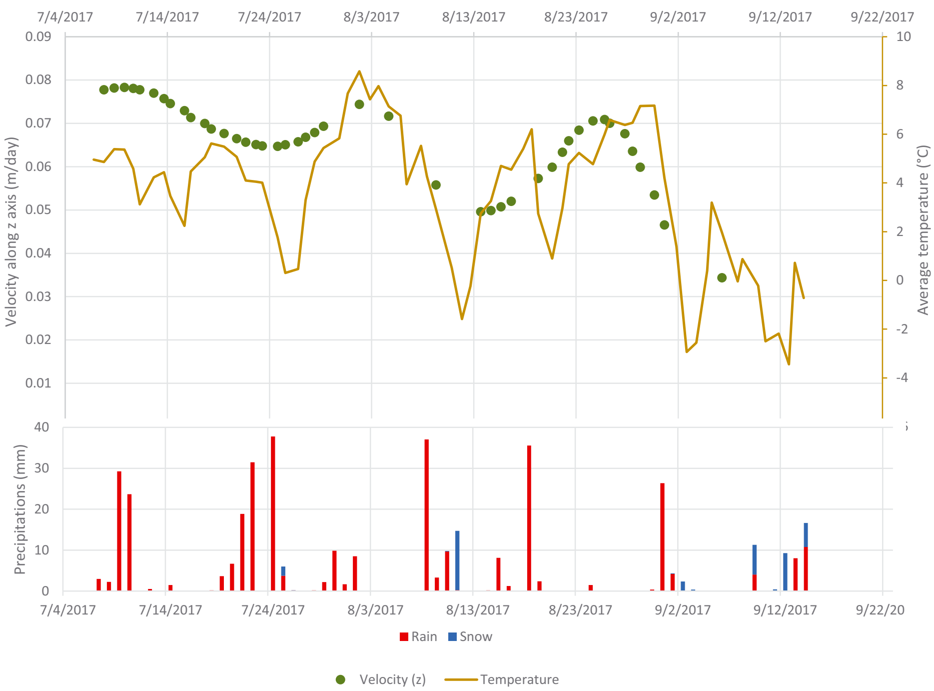

Figure 2: Mean vertical component of the glacier velocity calculated by our device during summer 2017. The weather data is issued by the Arome weather forecast model. We can see that vertical velocity follows a temperature trend, especially around 11 August 2017, when a snowfall occured, velocity decreased to a local minimum.

Tug o' war between glacial and periglacial controls: Glacial lake dynamics and the de-icing of a marginal moraine, NE Snøhetta, Dovrefjell, Norway

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Keywords: Glacier-permafrost interactions, ice-cored moraines, proglacial hydrology, thermokarst, moraine-dammed glacial lakes

Even though permafrost and glaciers often occur in parallel in cold regions, permafrost and glacier studies are commonly not conducted hand-in-hand (Harris & Murton 2005). Many proglacial zones, however, constitute an interface of glacier-permafrost interaction, most prominently ice-cored moraines. This glacial landform is subject to periglacial reworking and thermal erosion by glacial meltwater.

By explicitly studying the role of surface and near-surface hydrology, glacier-permafrost linkages were explored along the altitudinal gradient of the north-eastern flank of the Snøhetta massif, Dovrefjell, South Norway, encompassing a polythermal glacier, a glacial lake and an ice-cored moraine complex. Combining stable oxygen isotope analysis along meltwater pathways with remote sensing observations of glacier lake dynamics, air and ground temperatures, this study presents results from a first field visit and a landscape inventory.

First results suggest a two-fold threshold for the periodical drainage of the glacial lake, namely glacial ablation rate and active layer depth within the ice-cored moraine. Drainage appears to follow preferential subsurface pathways, hereby thermally eroding the ice-core and producing thermokarst structures within the moraine.

Based on this pilot study, further research could substantially benefit from close-range sensing techniques. Multi-temporal, high-resolution terrain models extracted from UAV or Terrestrial Photogrammetry, as well as Terrestrial Laser Scanning could allow a precise quantification of thermokarst-related processes leading to sinkhole structures in the moraine. Thermal surveys may further reveal instances of ground ice. Further investigation could substantially contribute to bridging the gap between glacier and permafrost research and to understanding transient landform patterns in a changing climate.

Harris, C. & Murton, J. (eds.) 2005. Cryospheric systems: Glaciers and permafrost. *Geological Society, London, Special Publications* 242. Available at: http://sp.lyellcollection.org/content/242/1 (accessed on 15.05.2019).

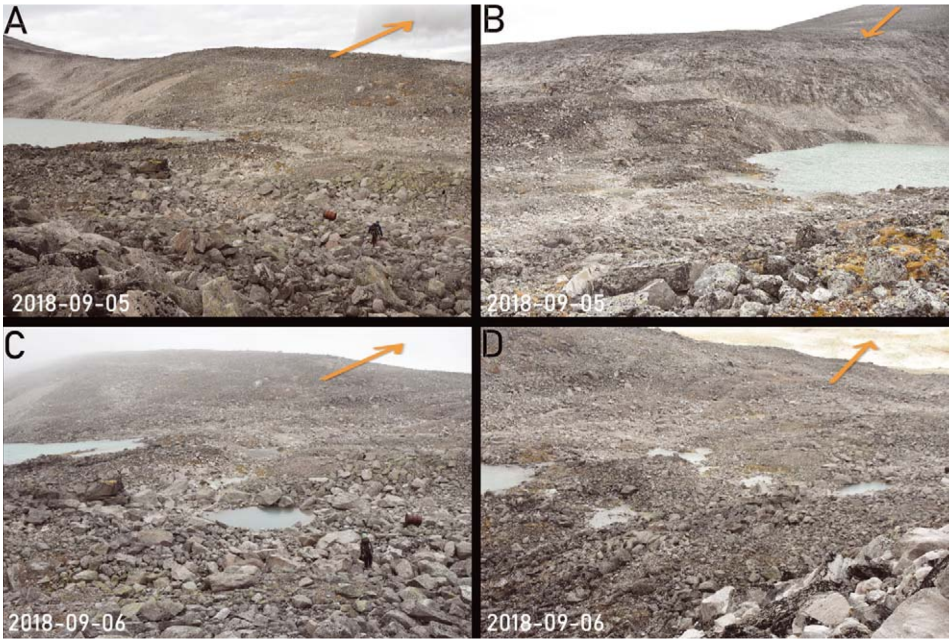

Figure 1: Drainage of moraine dammed glacier lake. (A) and (B) situation on 05.09.2018. Note most thermokarst / depression features are empty. (C) and (D) situation on 06.09.2018. Note most sinkholes are water-filled. Note rustic barrel in (A) and (C) for orientation. North as indicated by orange arrow. Photographs by Floreana Miesen, 2018.

Accuracy of optimization of UAV photogrammetric techniques for environmental monitoring

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Keywords: UAV, GCPs, geometric accuracy, coastal monitoring, cultural heritage

A wide research project that embraces several application was outlined, focusing the studies on the methodological innovations and product improvements achievable using Unmanned Aerial Vehicle (UAV) systems in environmental monitoring. Several tests were performed on the Structure-from-Motion algorithms and on the strategies of UAV surveys planning aimed at optimizing geometric accuracy in photogrammetric 3D reconstructions. First results have been published in two papers.

In brief, in two dense point clouds from the same UAV dataset were compared to evaluate the discrepancies resulting from two relative exterior orientations, using GNSS position recorded by on-board receiver or GCPs measured with high accuracy (Saponaro et al. 2018a). After that, three absolute exterior orientations were assigned based on GCPs detected from three open geo-data sources (Google Maps, Bing Maps, SIT Puglia). Georeferencing accuracies of the same orthomosaic were then verified (Figure 1).

In a comparative analysis of seven 3D models derived from the corresponding UAV image datasets was performed (Saponaro et al. 2018b). Different flight strategies and pre-arranged processing parameterizations were analysed to understand their impact on the final product accuracy.

Currently several UAV applications are tested in order to recognize the impact of a reasonable number and spatial distribution of GCPs on the final accuracy, converging on the Direct Georeferencing case. At the same time, my research also focuses on the acquisition techniques and pre-treatment of multi-source geospatial data oriented to producing thematic maps for territorial analysis and risk prevention. A multi-temporal and multi-scale image analysis project of coastal areas subject to hydrogeological instability has thus been undertaken (Figure 2) in order to obtain useful change detection data by optimizing the study techniques in terms of time and costs.

Saponaro, M., Tarantino, E. & Fratino, U. 2018a. Geometric Accuracy Evaluation of Geospatial Data Using Low-Cost Sensors on Small UAVs. Presented at the Computational Science and Its Applications – ICCSA 2018, Cham, 04/07/2018.

Saponaro, M., Tarantino, E. & Fratino, U. 2018b. Generation of 3D Surface Models from UAV Imagery Varying Flight Patterns and Processing Parameters. In: *International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2018)*, Rhodes, Greece (in press).

Figure 1: Example of orthomosaic georeferenced using GCPs from the Google Maps source (Image © 2018 DigitalGlobe, European Space Imaging).

Figure 2: An orthomosaic of a coastline stretch achieved from UAV imagery.

SYSSIFOSS – Synthetic structural remote sensing data for improved forest inventory models

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Keywords: Forest inventory, synthetic data, LiDAR, 3D, HELIOS

Owing to technical and methodological improvements, remote sensing methods now play a vital role for forest inventory data acquisition. In particular, applications that operate with the principles of LiDAR and laser scanning are increasingly investigated and implemented. Næsset (2014) emphasized the advantages of so-called 'area-based approaches', which combine remote sensing data with field reference plots. The challenge here is to acquire the full variability of all environmental and technical parameters that are required. In order to do so, the Institute of Geography and Geoecology at Karlsruhe Institute of Technology (KIT) and the 3DGeo Research Group at Heidelberg University are developing a new approach, Generating Synthetic Forest Remote Sensing Data (GeForse), to investigate the combination of synthetic forest inventory data and simulated LiDAR data. KIT will use the forest growth simulator SILVA (Pretzsch et al. 2002) to derive a detailed forest inventory dataset. We will create a database to store 160 point clouds of model trees (derived from terrestrial laser scanning (TLS) and airborne laser scanning (ALS)) alongside additional tree parameters (e.g. crown diameter, height, diameter at breast height, global coordinates). The connection of SILVA with our database will enable the creation of a synthetic 3D forest (Figure 1). This forest will be drawn upon within the Heidelberg LiDAR Operations Simulator (HELIOS), which we use to simulate LiDAR acquisitions with different sensors and parameters, including spatial resolution or laser pulse repetition rate (Bechtold & Höfle 2016). Based on these simulations, sensitivity analyses will be conducted to identify optimization potentials and limiting factors for the creation of simulated forest inventories as well as for the real data acquisition with TLS and ALS.

Bechtold, S. & Höfle, B. 2016. HELIOS: A multi-purpose LiDAR simulation framework for research, planning and training of laser scanning operations with airborne, ground-based mobile and stationary platforms. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.* III-3: 161–168, doi: 10.5194/isprs-annals-III-3-161-2016.

Fassnacht, F.E., Latifi, H. & Hartig, F. (submitted). Analyses based on synthetic remote sensing data question earlier reported benefits of large field plot sizes for remote sensing based forest biomass estimation. *Remote Sensing of Environment*.

Næsset, E. 2014. Area-based inventory in Norway – from innovation to an operational reality. In: Maltamo, M., Næsset, E. & Vauhkonen, J. (eds.): *Forestry Applications of Airborne Laser Scanning, Concepts and Case Studies*. Springer: 215–240.

Pretzsch, H., Biber, P. & Durský, J. 2002. The single tree-based stand simulator SILVA: construction, application and evaluation. *Forest Ecology and Management* 162: 3–21.

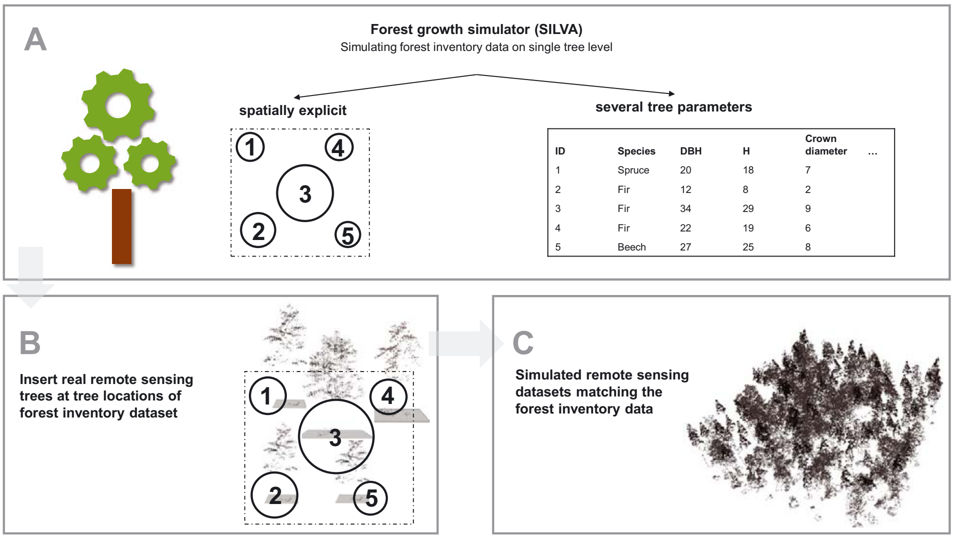

Figure 1: Principle of the GeForse approach to (A) simulate spatially explicit forest inventory data at the individual tree level, (B) insert 3D model trees from a database and (C) to generate a complete synthetic 3D forest inventory for LiDAR acquisition simulations (adapted from Fassnacht et al., submitted).

Development of an automated monitoring system for deformation analysis based on terrestrial laser scanning

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Keywords: Multi-temporal 3D point cloud analysis, online monitoring, terrestrial laser scanning, slope monitoring, mining

Previous work

The aim of a project in 2015 at the University of Applied Sciences in Mainz was to evaluate a terrestrial laser scanner with regard to the use in area monitoring of a dam and to quantify influencing factors.

A measurement concept was developed that matches the corresponding technical regulations. Furthermore, the measured data can be evaluated within a classical deformation analysis. To assess the measurement concept, a series of observations were conducted in multiple epochs in the laboratory for 3D metrology in Mainz and at the Ennepetalsperre reservoir dam.

The laser scanner itself records an object using a grid of points without any discrete points. This fact must be taken into account in georeferencing as well as in any further processing. The derivation of discrete measuring points for the evaluation within a deformation analyses was carried out on the basis of a number of voxels. For such a system to be used reliably, however, questions on georeferencing and stochastic modelling must be further investigated.

Current work

Since 2016 I have been with DMT GmbH & Co. KG as a project engineer in various monitoring projects. In the course of the RFCS-funded project i^2MON I continue my work and I also study for a doctorate at TU Darmstadt under the supervision of Prof. Dr. Eichhorn. For the research and development in the project, a VZ-2000i laser scanner from RIEGL is available. My research work focuses on questions of georeferencing and on multi-temporal comparison of point clouds, especially within open pit mines. In addition to this, the hardware will be used to develop an automated monitoring system that will allow continuous measurement of an object to be monitored.

The project has been running for eight months and current development topics are:

- Cloud connectivity within a sensor network.
- The scanner within a multi-sensor system (e. g. combination with GNSS, climate sensors, inclination sensors).
- Different methods of georeferencing (e. g. point-based vs. geometry-based).
- Evaluation of the stochastic model of a scan (e. g. meteorological influences or reflection characteristics at different objects).
- Methods for multi-temporal analysis (e. g. point-based, point cloud-based, surface-based, geometry-based, parameter-based).

Müller, M., Schmenger, F., Schröder, D. & Zschiesche, K. 2016. Evaluierung eines modernen Messverfahrens zur Deformationsanalyse flächenhafter Ingenieurbauwerke am Beispiel der Ennepetalsperre. In: Hochschule Mittweida, University of Applied Science (Hrsg.), *Scientific Reports der Hochschule Mittweida*. ISSN 1437-7624.

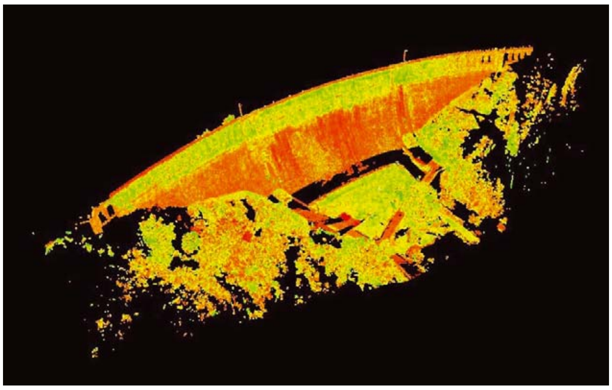

Figure 1: 3D laser scanning of the Ennepetalsperre reservoir dam, including the embankment areas, coloured by intensity values (Müller et al. 2016)

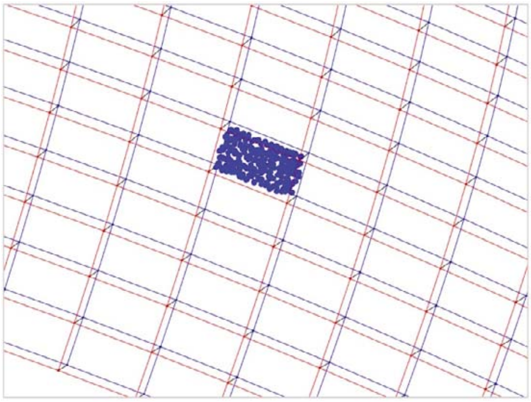

Figure 2: Representation of a voxel with data of the dam (Müller et al. 2016)

Assessment of hedgerow condition with UAV-borne remote sensing

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Keywords: hedgerow, flowering, canopy structure, UAV, multispectral

Agricultural expansion and intensification of agricultural practices is having a negative impact on biodiversity levels in rural areas due to habitat fragmentation, with remnant patches of natural and semi-natural land cover being the only safe havens for wildlife. Among these are forest fragments, wetlands, abandoned fields as well as field margins where hedgerows are common. Hedgerows are lines of shrubs interspersed by trees along the edge of a road or field; they play a vital role in the British agricultural landscape and are currently protected under British law for their environmental importance. Hedgerows support flora and provide critical habitat to a wide variety of bird, mammal and invertebrate species, which depend on them for food and shelter. Any changes in timing and incidence of flowering and fruiting, e. g. due to poor management, could therefore lead to major implications on the wildlife that depends on this habitat.

Despite the prevalence of hedgerows in rural areas, information about their composition, structure and condition is very limited. This is due to field surveys being labour-intensive and requiring an appropriate level of knowledge, which makes them a feasible option only for a limited number of sites. This project investigates the potential of using UAV-borne remote sensing for performing hedgerow condition surveys. For this purpose, UAV-borne LiDAR data, multispectral and RGB imagery will be acquired for two types of hedgerow in Stocksfield, UK. The work will involve extraction of hedgerow dimensions, distribution and connectivity using both LiDAR data and SfM photogrammetry, as well as detection and assessment of flower abundance using multispectral imagery. Better understanding of hedgerow structural parameters and flower abundance on a local scale, which UAV-borne surveys can potentially provide, would enable better informed decisions on hedgerow habitat management and conservation.

Spatial and temporal variability of snow cover at Signy Island, South Orkney Islands, Maritime Antarctica

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Keywords: Snow cover, Antarctica, spatial variability, topography, climate

Snow cover plays an important role in Antarctic ice-free areas. It has a significant influence on the ground thermal regime, influencing permafrost evolution and active layer thickness (Zhang 2005). Snow cover also has important effects on ecosystems, affecting vegetation (Callaghan et al. 2011) and soil invertebrates distribution (Gooseff et al. 2003). The relevant role of snow cover and its heterogeneity requires observations on its spatial and temporal variability.

The aims of this work are: 1) to analyse the spatial and temporal variability of snow cover at small scale on Signy Island in the 2009–2018 period; 2) to understand the role of topographic, climatic and vegetational factors influencing this variability.

The study site is located on Signy Island (60°43' S, 45°38' W), located in the maritime Antarctic in the South Orkney Islands.

An automatic digital snow camera recorded two images per day of a matrix of 19 banded snow stakes (Figure 1) that form an irregular grid of 15 x 20 m. The stakes are marked with 10 narrow (2 cm wide) alternate white and red bands over the lower 20 cm and 5 cm wide bands above these to a height of 85 cm (Guglielmin et al. 2012).

It was possible to obtain snow depth data for each stake for the period from February 2009 to January 2018.

The first results of snow depth data show large spatial variability, with mean snow depth values for the entire study period between 3.9 and 25.3 cm (Figure 2) for the different stakes.

We will investigate what is the temporal variability of snow depth in the study period. We will then try to identify what is the relationship between snow depth and topographic, climatic and vegetational factors.

Callaghan, T.V., Johansson, M., Brown, R.D., Groisman, P.Y., Labba, N., Radionov, V. et al. 2011. Multiple effects of changes in Arctic snow cover. *Ambio* 40(1): 32–45.

Gooseff, M.N., Barrett, J.E., Doran, P.T., Fountain, A.G., Lyons, W.B., Parsons, A.N. et al. 2003. Snow-patch influence on soil biogeochemical processes and invertebrate distribution in the McMurdo Dry Valleys, Antarctica. *Arctic, Antarctic, and Alpine Research* 35(1): 91–99.

Guglielmin, M., Worland, M.R., & Cannone, N. 2012. Spatial and temporal variability of ground surface temperature and active layer thickness at the margin of maritime Antarctica, Signy Island. *Geomorphology* 155: 20–33.

Zhang, T. 2005. Influence of the seasonal snow cover on the ground thermal regime: An overview. *Reviews of Geophysics* 43(4): 1–23.

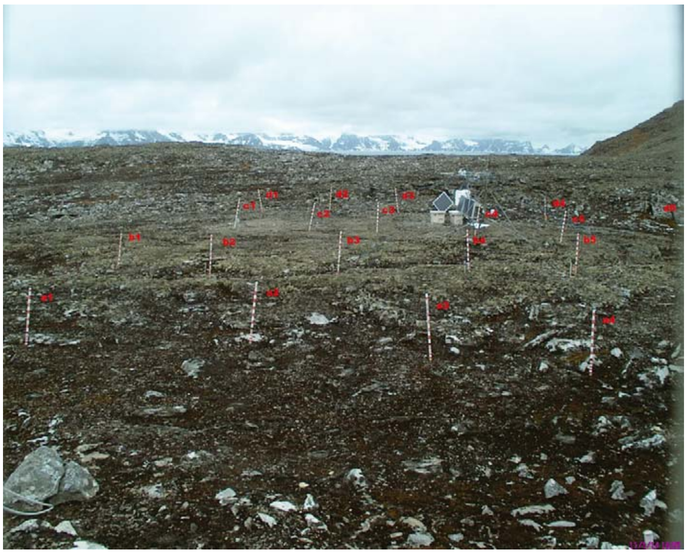

Figure 1: View of the snow grid. Photograph: PNRA (Programma Nazionale di Ricerche in Antartide), BAS (British Antarctic Survey).

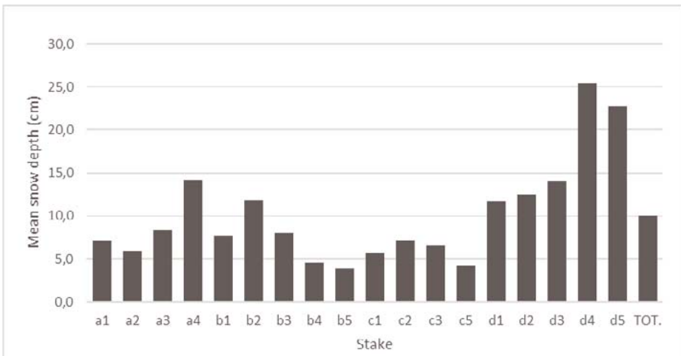

Figure 2: Mean snow depth (cm) at each stake for the entire study period.

A machine learning approach for shallow water Satellite-Derived Bathymetry

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Keyword: Satellite-derived bathymetry, coastal erosion, machine learning, random forest, 3D model

The study of bathymetry is particularly important for understanding erosion phenomena of the coasts. The dynamics of water currents are linked to the morphology of the sea floor. Traditionally, water depth data are collected with different sonar types installed on a boat; this kind of collection techniques provides point data. Recently Satellite-Derived Bathymetry (SDB) techniques became an option for the study of sea-floor erosion in shallow water. Correlation between reflectance (penetration) with depth allows to reconstruct a three-dimensional model of the sea floor. Knowledge about the accuracy of these methods is important to understand their applicability.

In this work, the relationship between Planet Scope image (Planet Team 2017) bands reflectance and water depth is investigated. In particular, Planet Scope data are collected at four different bands (three optical visible and one NIR) with a spatial resolution of 3 m x 3 m. Around 15000 points with depth values have been collected in the Cesenatico area (Forlì-Cesena, Italy).

These data were analysed using a machine-learning approach with Random Forest (RF) algorithm. Regression was applied with RF training 10% of the points and using the rest for validation with a K-fold approach with K = 10. Twenty runs were applied to assess the variance of accuracy metrics. The model was finally tested to analyse its prediction capability. The validation phase show that the model has good prediction capability; in fact, the correlation between observed and predicted water depth results in a mean and standard deviation (in parenthesis) of R^2 = 0.899 (0.0021) and RMSE = 0.34 m (0.004 m). The image (cf. Figure 1) shows that depths between zero and 2 m are more accurately represented than higher values of depth. It is logical to say that waters deeper than 2 m show higher residuals. Basing on this analysis, a 3D model of the coast was reconstructed.

In future it will be important to test the potential of SDB with high-resolution satellite images and of closer-range sensors with different conditions (for example, different areas with different water turbidity) to evaluate the best use-cases.

Planet Team (2017). Planet Application Program Interface: In Space for Life on Earth. San Francisco, CA. https://api.planet.com

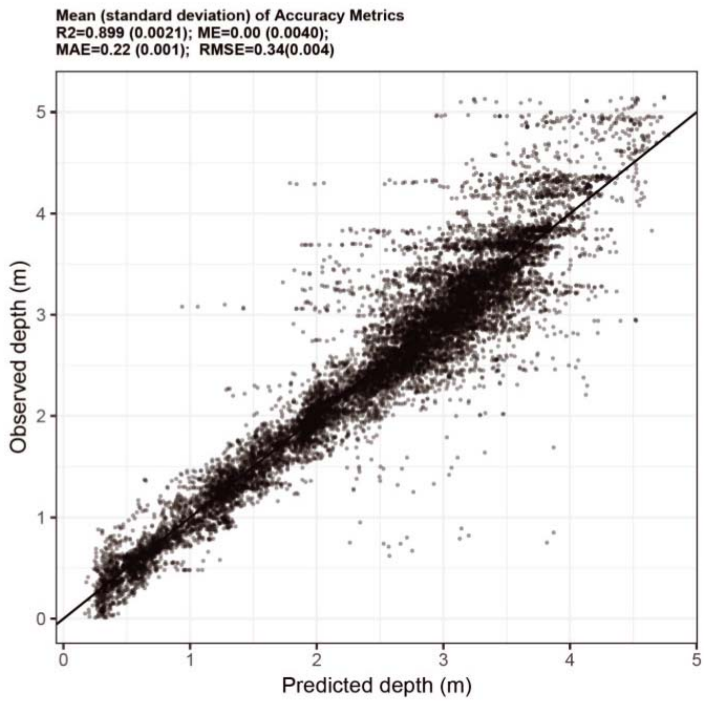

Figure 1: Correlation between observed and predicted depth.

V-SLAM algorithms: main approaches and methodologies

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Keywords: Visual SLAM, 3D reconstruction, mapping, robotics, photogrammetry

The problem of estimating, in real-time, the structure of the environment using only images is called Visual SLAM (V-SLAM). This technology enabled modern applications like autonomous navigation system, Augmented Reality (AR) and robotics (Davison et al. 2007; Engel et al. 2014; Mur-Artal et al. 2015). Using passive sensors like cameras and IMU, as an alternative to active laser-based sensors, permitted lowering the mobile mapping systems costs in terms of power efficiency, weight and money. This boosted a strong research interest in Visual SLAM (V-SLAM) in recent years.

V-SLAM algorithms can be divided into three main categories: each category employs different methodologies to process and match the content of the images. Feature-based methods (Klein et al. 2009; Mur-Artal et al. 2015) extract salient characteristics of the images, called features, which are highly representative of the images themselves. Common choices for features are image corners, edges and blobs. Direct methods (Engel et al. 2014) do not compute feature representations of the images as the image matching phase is based directly on pixel intensities. Finally, hybrid methods (Forster et al. 2014) combine elements of both feature-based and direct methods, trying to inherit the strengths of both approaches. SLAM is still considered an open problem and the main problems of the current solutions are the accumulation of errors in long trajectories and being difficult to work in dynamic environments in which multiple objects move around. Ways of reducing the accumulated error, like the detection of already visited places, and ways to cope with moving objects, like applying quality controls on the estimated structure of the environment, do not always provide satisfactory solutions to these problems.

My research topic is focused on the analysis of the main algorithms and the main methodologies employed in indoor and outdoor 3D reconstructions. I am interested mainly in systems that work in real-time, using cameras and Inertial Measurements Units (IMU) as sensors. For my PhD applications in the field of environmental mapping, indoor modeling, heritage documentation and AR/VR will be exploited to test and validate the developed solutions.

Engel, J., Schöps, T. & Cremers, D. 2014. LSD-SLAM: Large-scale direct monocular SLAM. In: Fleet, D., Pajdla, T., Schiele, B. & Tuytelaars, T. (eds.), *Computer vision – ECCV 2014. ECCV 2014. Lecture Notes in Computer Science*: 834–849. Springer, Cham.

Forster, C., Pizzoli, M. & Scaramuzza, D. 2014. SVO: Fast semi-direct monocular visual odometry. *2014 IEEE International Conference on Robotics and Automation* (ICRA): 15–22. doi: 10.1109/ICRA.2014.6906584.

Klein, G. & Murray, D. 2009. October. Parallel tracking and mapping on a camera phone. *2009 8th IEEE International Symposium on Mixed and Augmented Reality*: 83–86). doi: 10.1109/ISMAR.2009.5336495.

Mur-Artal, R., Montiel, J. & Tardos, J. 2015. ORB-SLAM: A Versatile and Accurate Monocular SLAM System. *IEEE Transactions on Robotics* 31(5): 1147–1163. doi: 10.1109/TRO.2015.2463671.

Tateno, K., Tombari, F., Laina, I. & Navab, N. 2017. Cnn-slam: Real-time dense monocular slam with learned depth prediction. *2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*: 6243–6252. doi: 10.1109/CVPR.2017.695.

a)

b)

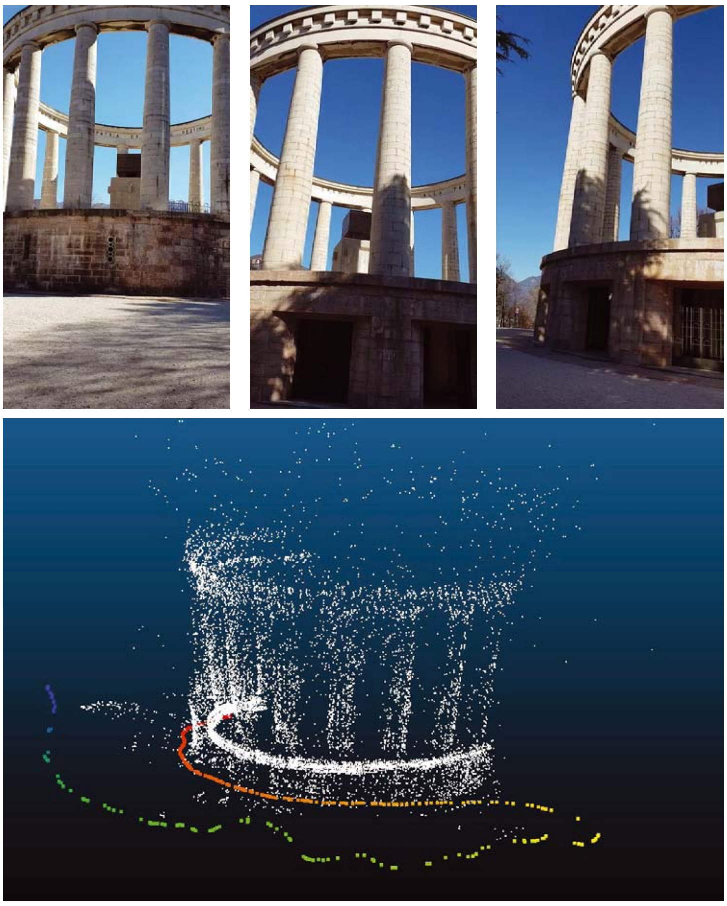

Figure 1: a) Some input images and b) the real-time reconstruction of the monument of Cesare Battisti in Trento using ORB-SLAM. The position of the cameras is colour-coded by image timestamp, from blue (first images) to red (last images). Photographs: Alessandro Torresani.

Debris-flow channel evolution at the triggering and transport zone: learning from a very active case study in the Dolomites

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Keywords: Morphology, remote sensing, sediment evolution, erosion, connectivity

Understanding morphology changes and sediment spreading along a debris-flow channel is a key step in hazard mitigation planning.

This research analyses a 10-year evolution of erosion / deposition patterns in an active debris-flow upper channel located in the Dolomites (rio Soial, Val di Fassa, Trento, Italy). The morphologic evolution of the channel has been analysed by performing a Difference of DEM (DoD) (Cavalli et al. 2015; Wheaton et al. 2010). DEM differencing enables quantitative and spatially-distributed representation of erosion and deposition within the analyzed time window, at both the channel reach and the catchment scale. In this study, the analysis was performed using two high-resolution Digital Terrain Models (DTMs). The 2008 LiDAR-derived DTM of the Autonomous Province of Trento with a DTM created from a UAV-based point cloud from July 2018 were compared. This data set was also used to determine the changes in the sediment Connectivity Index (CI), which explains the existing degree of linkage between sediment sources and the channel network (Cavalli et al. 2013). During the period 2008–2018, five debris flow events occurred. Each associated rainstorm was analysed in order to assess the evolution of the triggering threshold rain intensities in relation to the evolution of the channel-valley morphology.

The results on the CI analysis show a general decrease in CI values, meaning an increased disconnection between the head basin areas and the outlet at the end of the transport reach. Also, the rain thresholds show a slight increase after the lasts event, indicating a gradual stabilization of the basin and a possible reduction of the expected frequency of debris flow events.

Cavalli, M., Goldin, B., Comiti, F., Brardinoni, F. & Marchi, L. 2017. Assessment of erosion and deposition in steep mountain basins by differencing sequential digital terrain models. *Geomorphology* 291: 4–16. doi: 10.1016/j.geomorph.2016.04.009.

Cavalli, M., Trevisani, S., Comiti, F. & Marchi, L. 2013. Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments. *Geomorphology* 188: 31–41. doi: 10.1016/j.geomorph.2012.05.007.

Wheaton, J.M., Brasington, J., Darby, S.E. & Sear, D.A. 2010. Accounting for uncertainty in DEMs from repeat topographic surveys: Improved sediment budgets. Earth Surface Processes and Landforms 35: 136–156. doi: 10.1002/esp.1886.

'Live' landslide deformation from hydro-meteorological conditions

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Keywords: landslides, remote sensing, hydrology, deformation, machine learning

Landslides are major hazards to human life and business. In Europe alone, landslides cost 1370 lives in the period 1995–2004 and caused an average economic loss of 4.7 billion Euros per year (Haque et al. 2016). Therefore an extensive understanding of these phenomena is required.

Changes in hydrology may change the deformation rate of a landslide (Bogaard & Greco 2016), resulting in acceleration or stabilization. My project considers slow-moving, deep-seated, landslides on natural slopes for which deformation is controlled by hydro-meteorological conditions. The aim is to develop machine-learning methods capable of finding the relations between hydro-meteorological conditions and deformation. For these slow-moving landslides, deformation, hydro-meteorological factors and other parameters (e. g. vegetation) have been and will be monitored and modelled over at least multiple years. Monitoring during this slow deformation phase has the advantage over collapse monitoring that it enables continuous learning of the relations between hydro-meteorological conditions and deformation during years of average conditions rather than during short periods of collapse-inducing extremes.

To achieve this, all available local and remote sensing data has to be brought together and aligned, as shown in Figure 1. The data, with different temporal and spatial resolutions, has to be resampled to a unified reference frame in space and time, suitable for the training of machine-learning techniques. Data unification includes collection, preparing and pre-processing data from different sensors and sources. The relations found will be used to create a regional system capable of estimating the current deformation conditions of Alpine landslides, a first step towards Early Warning Systems.

Bogaard, T.A. & Greco, R. 2016. Landslide hydrology: from hydrology to pore pressure. *WIREs Water* 3(3): 439–459. doi: 10.1002/wat2.1126.

Haque, U., Blum, P., Da Silva, P. F., Andersen, P., Pilz, J., Chalov, S. R., Malet, J.-P., Auflič, M. J., Andres, N., Poyiadji, E. et al. 2016. Fatal landslides in Europe. *Landslides* 13(6): 1545–1554. doi: 10.1007/s10346-016-0689-3.

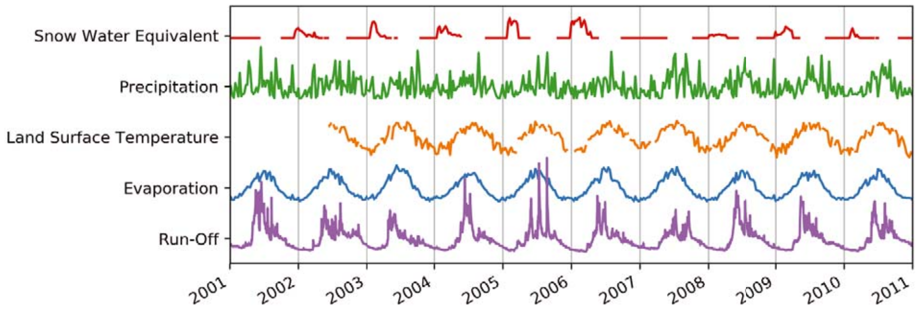

Figure 1: Example of a hydro-meteorological time series on a landslide. Precipitation, evaporation and runoff are indicative of the hydrologic processes and can be linked to the deformation time series. (Data: Earth System Data Lab and eHyd Austria)

Studying ice dynamics of the Morteratsch glacier complex (Switzerland) with UAV-acquired photography and Structure from Motion (SfM) algorithms

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Keywords: Morteratsch glacier, UAV, structure from motion, elevation differences, ice velocity

Glacier variations are key indicators of climate change. Monitoring of glacier activity is mostly based on ground-based measurements and on satellite observations. However, these measurements lack the spatial and/or temporal resolution that is required for accurate interpretations. Therefore Unmanned Aerial Vehicles (UAVs) are increasingly used to study glacier dynamics, bridging the gap between direct field observations and satellite images.

In this research, the usability of UAVs and SfM algorithms to study glacier dynamics was assessed and applied to reconstruct high-resolution digital surface models (DSMs) of the ablation area of the Morteratsch-Pers glacier complex in Switzerland. We performed annual field campaigns between 2014 and 2018 to assess the accuracy of UAV images and to calculate high resolution elevation differences.

The accuracy of UAV measurements was assessed in detail as a function of ground control point (GCP) density, GCP distribution, flight direction, visual content, and RTK positioning. We also compared the different reconstructed DSMs with each other and with DEMs created by SwissTopo in 2015 and 1991. Based on these comparisons, we found that the Pers glacier is thinning more rapidly than the Morteratsch glacier at the same elevation. In addition, the highest elevation differences were found for the front of the Morteratsch glacier, with a decrease of almost 150 metres since 1991. For the almost stagnant front of the Morteratsch glacier, the elevation decrease goes up to –10 m / y which corresponds to the local surface mass balance as measured directly from a stake network. Different glacier features like ogives, surface melt channels and crevasses were detected and used for feature recognition. This allowed calculating surface velocities that appeared to be very heterogeneous for the glacier complex. We conclude that SfM algorithms applied on UAV images have great potential for studying glacier dynamics accurately at high resolution.

Multi-temporal 3D Point Cloud-Based Quantification and Analysis of Geomorphological Activity at an Alpine Rock Glacier Using Airborne and Terrestrial LiDAR

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Keywords: 3D, Geomorphological Activity Quantification, lidar, point cloud, rock glacier

Active rock glaciers are recognized as creep phenomena of mountain permafrost, with potentially unstable slopes and solid water reservoirs (Monnier et al. 2013). Therefore the quantitative analysis of the geomorphological activity at rock glaciers is important because it can reveal the adaptation of surface and subsurface processes to changing environmental conditions on different timescales. Given the varying surface orientation and roughness of rock glaciers, a full three-dimensional (3D) change analysis is required. In a recent study (Zahs et al. 2019), we therefore propose a novel approach for accurate 3D point cloud-based quantification and analysis of geomorphological activity on rock glaciers. In this study, we use multi-temporal and multi-source topographic LiDAR data to quantify local surface changes at the rock glacier Äußeres Hochebenkar (Ötztal Alps, Austria) based on different timescales within the period 2006–2018. The quantified changes are analysed with respect to their spatial and temporal characteristics and are complemented with subsurface findings obtained from electrical resistivity tomography (ERT). The analysis reveals variable spatial and temporal geomorphological activity in the investigated area. Levels of surface change detection directly from multi-source LiDAR point clouds range between 0.09 m and 0.65 m at 95% confidence. We consider the proposed approach, which accounts for the complexity of rock glacier surfaces, a valuable addition to established methods for the quantification and analysis of geomorphological activity on rock glaciers and features with similar properties, such as landslides or glaciers.

Our future research on the dynamically changing surface morphology of rock glaciers and similar objects will focus on higher-frequency (e. g. weekly or daily) and longer-term (e. g. an entire summer period) 3D point cloud-based change analysis using different LiDAR platforms (terrestrial, unmanned aerial vehicle) and multi-temporal ERT data. This is expected to estimate more precisely the magnitude and frequency of surface change processes and to reduce the effect of mutual neutralization of complex interacting processes (Williams et al. 2018). Moreover, we aim to enhance the full-3D methods (e. g. automated boulder segmentation and tracking), which are required to quantify individual surface change processes.

Monnier, S., Camerlynck, C., Rejiba, F., Kinnard, C. & Galibert, P.Y. 2013. Evidencing a large body of ice in a rock glacier, Vanoise Massif, Northern French Alps. *Geografiska. Annaler: Series A, Physical Geography* 95(2): 109–123. doi: 10.1111/geoa.12004.

Zahs, V., Hämmerle, M., Anders, K., Hecht, S., Sailer, R., Rutzinger, M., Williams, J.G. & Höfle, B. 2019. Multi-temporal 3D Point Cloud-Based Geomorphological Activity Quantification and Analysis at an Alpine Rock Glacier Using Airborne and Terrestrial LiDAR. *Permafrost and Periglacial Processes.* (accepted).

Williams, J.G., Rosser, N.J., Hardy, R.J., Brain, M.J. & Afana, A.A. 2018. Optimising 4-D surface change detection: an approach for capturing rockfall magnitude-frequency. *Earth surface dynamics* 6(1): 101–119. doi: 10.5194/esurf-6-101-2018.

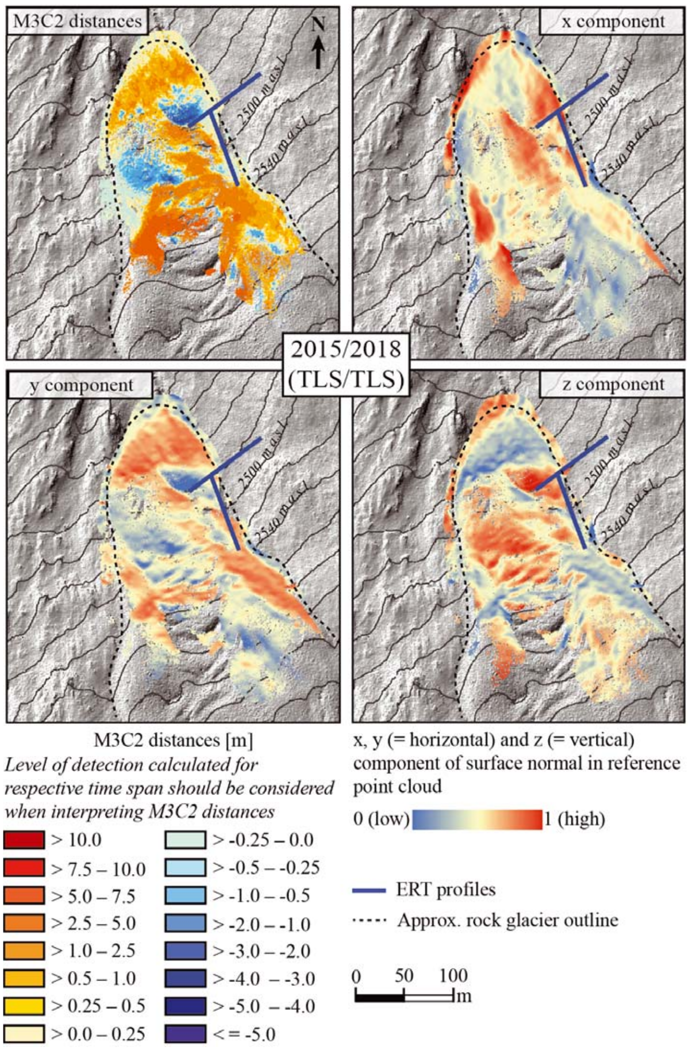

Figure 1: Surface changes quantified in the lower tongue area of Äußeres Hochebenkar rock glacier with the M3C2 distance calculation algorithm and orientation of surface normal vectors in the reference (earlier acquired) point cloud for the time span 2015/2018 based on two terrestrial laser scanning (TLS) datasets. The 3D direction of surface changes can be interpreted considering surface normal orientations. Underlying hill-shaded digital elevation models are based on airborne laser scanning (ALS) data funded and provided by the Tyrolean Government, the Austrian Climate and Energy Funds (C4AUSTRIA project, ACRP-A963633), and alpS – Centre of climate change adaption strategies (MUSICALS project) for the analysis presented in Zahs et al. 2019.

Spatio-temporal Analysis of Soil Degradation in Swiss Alpine Grasslands Using Object-based Image Analysis and Deep Learning

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Keywords: Soil erosion mapping, shallow landslides, OBIA, CNN, aerial images

Grassland areas in the Alps can be strongly affected by soil degradation due to various processes of soil erosion, intensified by the prevailing extreme topographic and climatic conditions. Furthermore, climate change is predicted to have a pronounced impact on the Alpine regions, causing not only higher temperatures but also a change in the frequency and intensity of precipitation events as well as strongly altered snow dynamics. In combination with changing land-use practices, an increase in soil degradation is expected. As such, monitoring tools to map soil erosion features with spatial and temporal resolution are urgently needed.

We present a holistic approach to identifying the main erosion processes that cause soil degradation on Alpine grasslands (sheet erosion (e. g. rill and inter-rill erosion), livestock trails, land sliding, management effects). The study is conducted on a catchment scale in the Urseren Valley (Canton of Uri, Central Swiss Alps) and allows for spatial and temporal analysis due to the use of multiple RGB orthophotos taken between 2000 and 2016. To map the degraded soil areas, we apply Object-based Image Analysis (OBIA) to the orthophotos (SwissImage). In addition to mapping the erosion features, the sites are classified according to their prevailing erosion process (shallow landslides, sheet erosion) or their triggering factor (livestock trails, management effects) (Figure 1). Simultaneously, we are developing a Deep Learning approach to increase mapping speeds, automate workflows and increase objectivity (Figure 2). In this way we are preparing for large-scale assessments of soil degradation (e. g. analysis throughout the Alps).

An overall increase in degraded sites can be observed for all erosion classes in the observed period. Spatial analysis highlights areas especially prone to newly emerging erosion. Lower areas are increasingly affected due to intense land-use, shown by the growing number of livestock trails and sheet erosion through trampling and grazing and management effects. Degradation at higher elevations (shallow landslides and sheet erosion) may be linked to changing climate conditions. The results provide an extensive understanding of the ongoing degradation processes and the techniques can serve as a tool to improve our comprehension of the status and trends of Alpine grassland soil degradation.

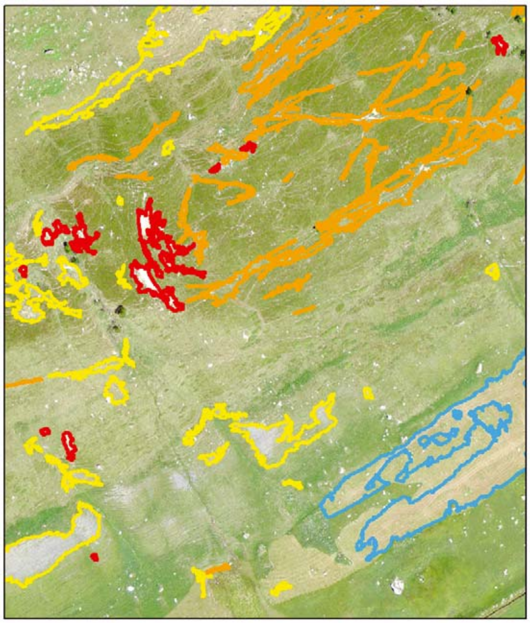

Figure 1: Results of Object-based image analysis applied to the orthophoto taken in 2016. Mapped erosion sites are assigned to classes: shallow landslides (red), sheet erosion (yellow), livestock trails (orange), management effects (blue). Geodata © Swisstopo

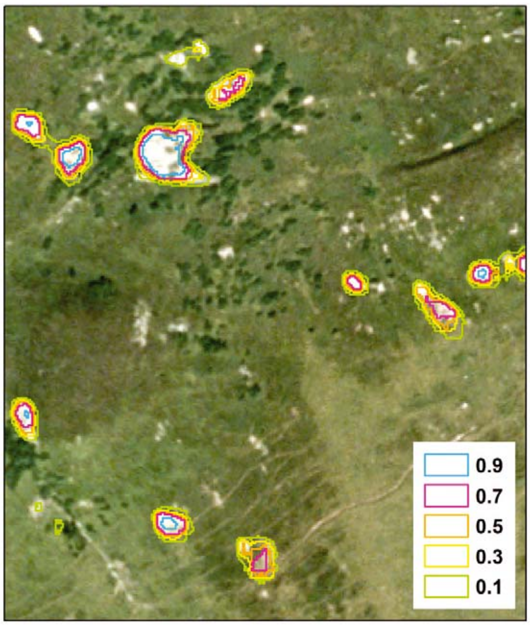

Figure 2: The deep learning approach yields results with probabilities for shallow landslides (orthophoto taken in 2004). Thresholds can be chosen according to application purpose (i. e. higher thresholds for conservative assessments). Geodata © Swisstopo

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