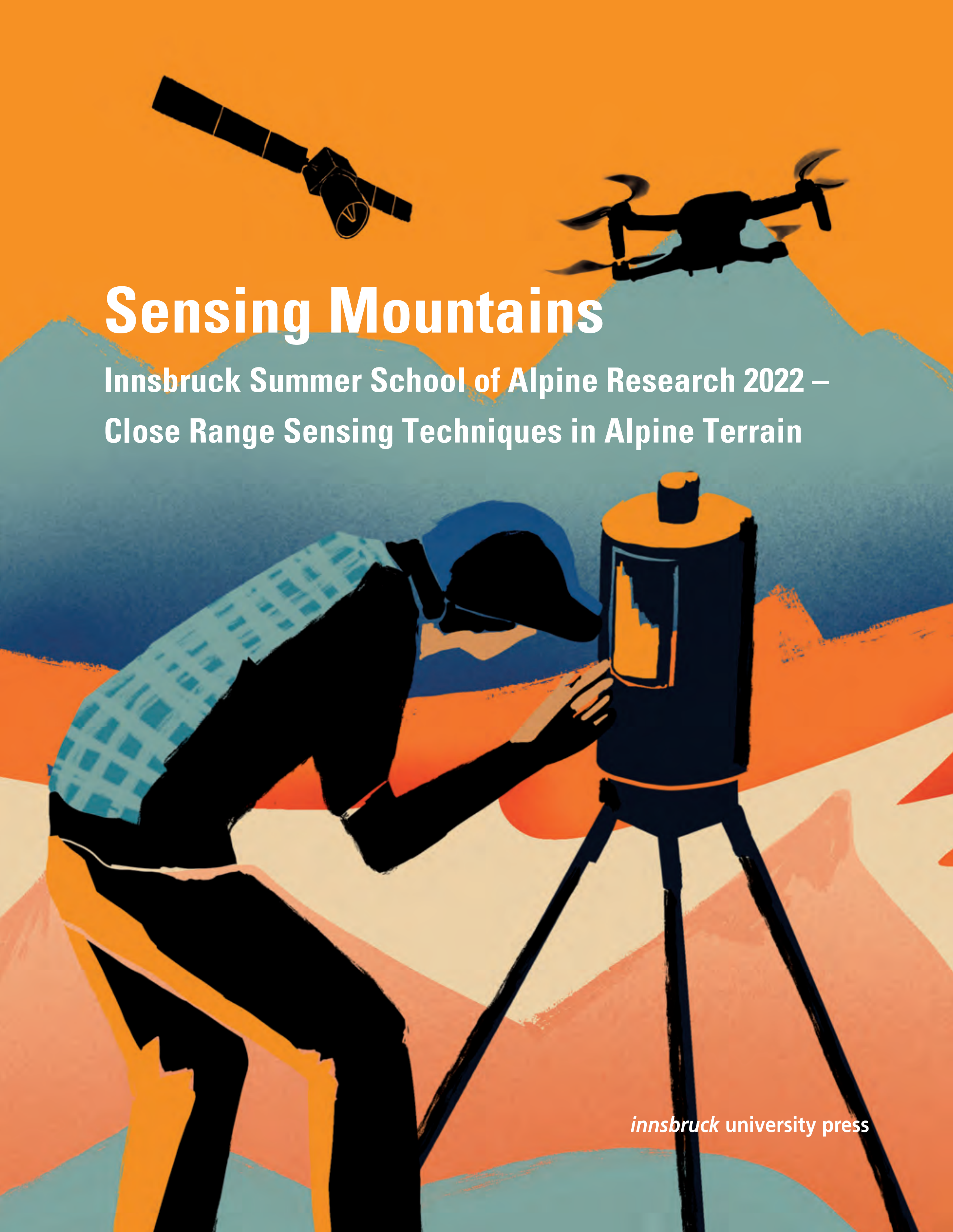

Sensing Mountains

Innsbruck Summer School of Alpine Research 2022 – Close Range Sensing Techniques in Alpine Terrain

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Martin Rutzinger, Katharina Anders, Magnus Bremer,
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Marco Scaioni, Hanna Tolksdorf, Thomas Zieher (Eds.)

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Content

Foreword

Sensing mountains by close-range and remote techniques is a challenging task. The 4th edition of the international Innsbruck Summer School of Alpine Research 2022 – Close-range Sensing Techniques in Alpine Terrain brings together early career and experienced scientists from technical-, geo- and environmental-related research fields. The interdisciplinary setting of the summer school creates a creative space for exchanging and learning new concepts and solutions for mapping, monitoring and quantifying mountain environments under ongoing conditions of change.

List of Organisation Committee and Lecturers

First name	Last name	Institution
Martin	Rutzinger	University of Innsbruck (Austria)
Katharina	Anders	Heidelberg University (Germany)
Magnus	Bremer	Austrian Academy of Sciences (Austria)
Anette	Eltner	Technische Universität Dresden (Germany)
Bernhard	Höfle	Heidelberg University (Germany)
Roderik	Lindenbergh	TU Delft (The Netherlands)
Andreas	Mayr	University of Innsbruck (Austria)
Sander	Oude Elberink	University of Twente - ITC (The Netherlands)
Francesco	Pirotti	CIRGEO - University of Padova (Italy)
Marco	Scaioni	Politecnico di Milano (Italy)
Thomas	Zieher	Austrian Academy of Sciences (Austria)

List of Keynote Speakers

First name	Last name	Institution
Stuart	Lane	Université de Lausanne (Switzerland)
Sandra	Lorenz	Helmholtz-Zentrum Dresden-Rossendorf (Germany)
Gottfried	Mandlburger	TU Wien (Austria)
Martin	Mokroš	3DForEcoTec COST Action partner (Czech Republic)
Andrew	Skidmore	University of Twente (The Netherlands)
Xiaoxiang	Zhu	TU Munich (Germany)

List of Participants

Firtst name	Last name	Institution
Nicholas James	Allen	Newcastle University (United Kingdom)
Moritz	Altmann	Catholic University Eichstätt-Ingolstadt (Germany)
Johannes	Branke	University of Innsbruck (Austria)
Francisco	Castro Venegas	University of Concepcion (Chile)
Bastien	Charonnat	École de technologie supérieure Montreal (Canada)
Felix	Dahle	TU Delft (The Netherlands)
Martin	Denter	University of Freiburg (Germany)
Paco	Frantzen	TU Delft (The Netherlands)
Elisabeth	Hafner	WSL Institute for Snow an Avalanche Research SLF (Switzerland)
Danielle	Hallé	University of Waterloo (Canada)
Doris	Hermle	TU Munich (Germany)
Clemens	Hiller	Austrian Academy of Sciences (Austria)
Theresa	Himmelsbach	University of Innsbruck (Austria)
Philipp-Roman	Hirt	Ludwig-Maximilians-Universität München (Germany)
Anna	Iglseder	TU Wien (Austria)
Francesco	Ioli	Politecnico di Milano (Italy)
Marián	Jančovič	Slovak Academy of Sciences, Bratislava (Slovakia)
Erika	Kozamernik	Slovenian Forestry Institute (Slovenia)
Margit	Kurka	University of Graz (Austria)
Erico Heinz	Kutchartt Ruedlinger	University of Padua (Italy)
Lukas	Lucks	TU Munich (Germany)
Josie	Lynch	University of Worcester (United Kingdom)
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Gaia	Roati	Università di Trento (Italy)
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Program

Time	**Sunday** 9/18/2022	**Monday** 9/19/2022
7:30-8:30		***Breakfast***
8:30-9:30		**Gottfried Mandlburger**: 3D point clouds from photogrammetry & laser scanning
9:30-10:30		**Xiaoxiang Zhu**: Artificial intelligence
10:30-11:00		***Coffee break***
11:00-12:00		Excursion
12:00-13:00		
13:00-14:00		
14:00-15:00		
15:00-17:30	Arrival of Participants	
17:30-18:00		1 min group wrap-up
18:00-19:30	***Dinner***	***Dinner***
19:30-20:00	**Martin Rutzinger**: Welcome	Poster session
20:00-20:30	Poster session	
20:30-21:00		
		Social event

Time	**Tuesday** 9/20/2022	**Wednesday** 9/21/2022
7:30-8:30	***Breakfast***	***Breakfast***
8:30-9:30	**Stuart Lane**: Earth surface dynamics in mountain areas	Group assignment
9:30-10:30	**Martin Mokroš**: Three-dimensional forest ecosystem monitoring and better understanding by terrestrial-based technologies (COST partner)	
10:30-11:00	***Coffee break***	
11:00-12:00	Demo: Riegl GmbH	
12:00-13:00	Demo: DMT GmbH	
13:00-14:00	Group assignment: Get in touch with sensors and methods	
14:00-15:00		
15:00-17:30		
17:30-18:00	1 min group wrap-up	1 min group wrap-up
18:00-19:30	***Dinner***	***Dinner***
19:30-20:00	**Anette Eltner**: Image velocimetry	**Andrew Skidmore**: Essential variables from remote sensing
20:00-20:30	**Marco Scaioni**: SfM photogrammetry	
20:30-21:00	Poster session	**Sandra Lorenz**: Multi- and hyperspectral sensing

Time	**Thursday** 9/22/2022	**Friday** 9/23/2022
7:30-8:30	***Breakfast***	***Breakfast***
8:30-9:30	**Bernhard Höfle**: Point cloud simulation **Roderik Lindenbergh**: Change detection	Group assignment
9:30-10:30	**Sander Oude Elberink**: Point cloud registration & segmentation **Francesco Pirotti**: Point cloud classification	
10:30-11:00	***Coffee break***	***Coffee break***
11:00-12:00	Group assignment	Group assignment
12:00-13:00		
13:00-14:00		
14:00-15:00		Final presentations
15:00-17:30		
17:30-18:00	1 min group wrap-up	
18:00-19:30	***Dinner***	***Dinner***
19:30-20:00	Photo contest award	
20:00-20:30	Group assignment	
20:30-21:00		

Time	**Saturday** 9/24/2022
7:30-8:30	***Breakfast***
8:30-9:30	
9:30-10:30	Departure of all

Abstracts - Keynote Speakers

Close range remote sensing for more sustainable Alpine hydropower management

Stuart N. Lane

Institute of Earth Surface Dynamics, Université de Lausanne, Switzerland

As Europe is currently facing its most severe energy crisis in more than a generation, we are reminded of the importance of non-fossil fuel energy sources. In order to keep global warming clearly below 2°C, global hydropower production has to increase by 25% to 2030 and 60% to 2050 (IRENA, 2020). At the same time, we have to accept that hydropower can have significant negative impacts on streams and rivers because of the ways in which it modifies the fluxes of water, sediment and organic matter. Nowhere is this trade-off better illustrated than in Switzerland where the Federal Energy Office is seeking an increase in hydropower production of 10% by 2035 whilst the Federal Office of the Environment is requiring all hydropower operators to complete implementation of the Swiss Water Law, and notably releases of water downstream from dams and flow abstract sites. In this paper I will show how close rate remote sensing is central to achieving more intelligent trade-offs between these two seemingly contradictory goals; but also highlight some of the wider contributions of close range remote sensing to sustainable Alpine environmental management. Alpine hydropower commonly involves either or both of (1) the storage of water behind dams and (2) the withdrawal of water from rivers and its transfer to storage dams. Research suggests that upwards of 80% of Alpine rivers are impacted by hydropower making it one of the most iconic environmental impacting activities in Alpine regions. Whether it is storage or withdrawal, the primary environmental impact is severe modification of river flow downstream from hydropower infrastructure. Sediment and organic matter flux may also be modified, either eliminated completely due to storage behind dams, or maintained, but modified in ways that have significant negative environmental impacts downstream such as when sediment is flushed. Central to maintaining and expanding hydropower in the face of its negative environmental impacts, then, is designing artificial water releases that can compensate these impacts. These are called environmental flows or "e-flows". These commonly involve a minimum guaranteed flow, as well as re-introduction of some flow variability, sufficient to introduce more natural river morphodynamics and ecosystems downstream of hydropower infrastructure. Close range remote sensing is revolutionising our ability both to propose e-flows that achieve an optimal environmental-economic trade off and to evaluate their effectiveness. In this talk I will illustrate this using the framework in Figure 1 (Lane et al., 2020). Using Uncrewed Airborne Vehicles (UAVs) with supporting survey where needed allows very high-resolution, spatially-continuous topographic and grain-size data to be obtained over potentially large areas. Provided basic challenges can be overcome (e.g. bathymetric correction of the effects of refraction at the air-water interface; spectral confusion due to the effects of micro-relief on shading), these data can be combined with hydrodynamic and habitat models to quantify the key environmental system services that are delivered by different river flows. With these, it is possible to propose optimal minimum e-flows that need to be secured year-round, the size and frequency of flood events needed to mimic some parts of natural flow variability, and the modification of flushing flows to minimise their environmental impact. Repeating such survey allows proposed the impact of e-flows to be evaluated. The result is e-flows that can be optimised for individual hydropower schemes so achieving the best trade-off between environmental improvement and electricity generation (e.g. Fig. 2). In the final part of the talk, I will reflect upon the challenges associated with implementing Figure 1 and show that crucial to the successful application of close range remote sensing in not only this, but other aspects of Alpine environmental management is a close collaboration with specialists in the underlying remote sensing technologies. The declining costs of UAVs plus the growth of "plug and play" software has opened up methods like SfM-MVS photogrammetry to non-experts; but it has also resulted in a series of disappointing outcomes for some. Close range remote sensing is becoming more and not less dependent upon the correct application of basic engineering surveying principles.

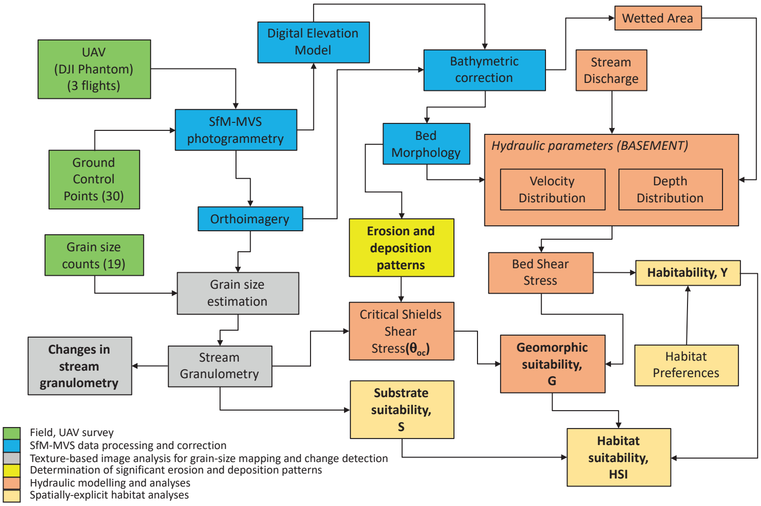

Figure 1: Integrating close range remote sensing into Alpine hydropower management to balance ecological needs against electricity production.

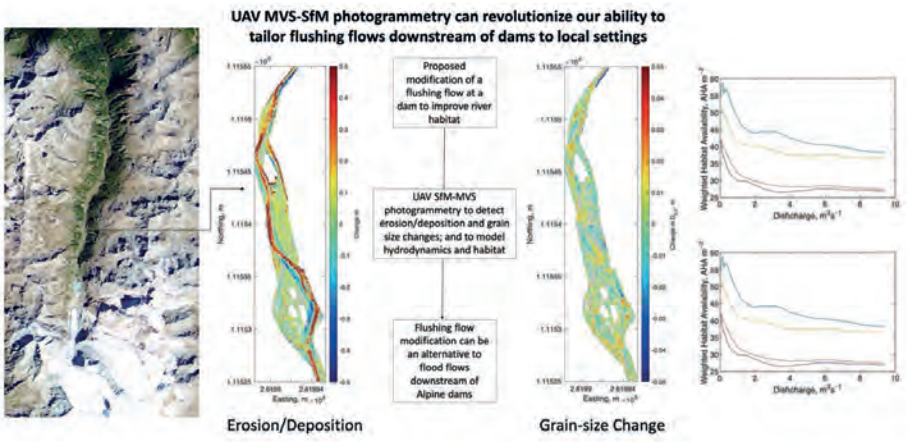

Figure 2: Erosion and deposition, grain-size changes, and habitat modelling quantified using the framework in Figure 1 (after Lane et al., 2020).

IRENA (2020), Global Renewables Outlook: Energy transformation 2050. International Renewable Energy Agency, Abu Dhabi.

Spectral Mountains – Enabling oblique hyperspectral mapping for steep targets

Sandra Lorenz, Sam Thiele, Moritz Kirsch, Richard Gloaguen

Helmholtz-Zentrum Dresden-Rossendorf, Helmholtz Institute Freiberg for Resource Technology, Division Exploration Technology; Germany

Light reflected or emitted from a natural surface contains material-characteristic, spectral signatures like fingerprints. Hyperspectral imaging sensors can capture this information in image rasters with hundreds of discrete spectral channels. The resulting spectral data cube can be analysed to create detailed maps of the surfaces' material composition. Hyperspectral imaging is experiencing rapid transformation, mostly due to the ongoing miniaturization of sensors, the boost in computer processing power and the need for fast and non-invasive characterization technologies. The technology is versatile in regards to application type and scale, and can be applied using passive illumination, e.g., sun- or skylight. Hyperspectral imaging already supports a variety of application fields in earth observation, such as agriculture, geoscience, urban planning and environmental monitoring, ranging from global (satellite-borne) down to sample scale (lab). Mountainous environments pose a specific challenge for hyperspectral imaging, as topographic complexity often requires oblique (non-nadir) acquisition, while illumination conditions strongly vary in time and space, and entrenched 2-D data analysis techniques (e.g. using 2-D gridded data such as DEMs and orthomosaics) are of limited applicability. It is important to move beyond the current usage of hyperspectral data as 2D rasters and go towards a more complex, but also more realistic 3D representation. This avoids occlusion and false-neighbourhood effects and allows us to accurately correct illumination effects induced by the geometry of the target with respect to the illumination source and the sensor positions. It enables the deployment of hyperspectral sensors from innovative, yet challenging platforms and non-nadir observation angles, occurring with tripod- and drone-based acquisitions (Fig. 1). The required transfer of hyperspectral data to a 3D “hypercloud”, i.e., a geometrically and spectrally accurate combination of a photogrammetric point cloud and the hyperspectral datacube (Fig. 2), ultimately allows the fusion of multi-scale and multi-platform scenes as well as the integration of sample data or subsurface information. With careful correction, the resulting dataset can provide tremendous value in mountain research, e.g., for the estimation of variation in mineralogical composition for better understanding of rock-forming processes, the detection of plant species and lichen coverage or monitoring of environmental changes. With this contribution, we give an overview of the challenges and opportunities of spectral imaging in the context of mountain research. We showcase best practices and trends in data acquisition, platforms and data correction workflows, and highlight the advantages of the hypercloud approach for the mapping of steep and complex targets. We give examples from geoscience and mineral exploration perspective, covering natural alpine outcrops and cliffs of different scale and geological setting, as well as artificial outcrops in mining and exploration context.

Figure 1: Oblique hyperspectral mapping, using a) a terrestrial tripod-based setup (open pit mine, Namibia), b) drone-borne data acquisition (mountain side, Dolomites, Italy).

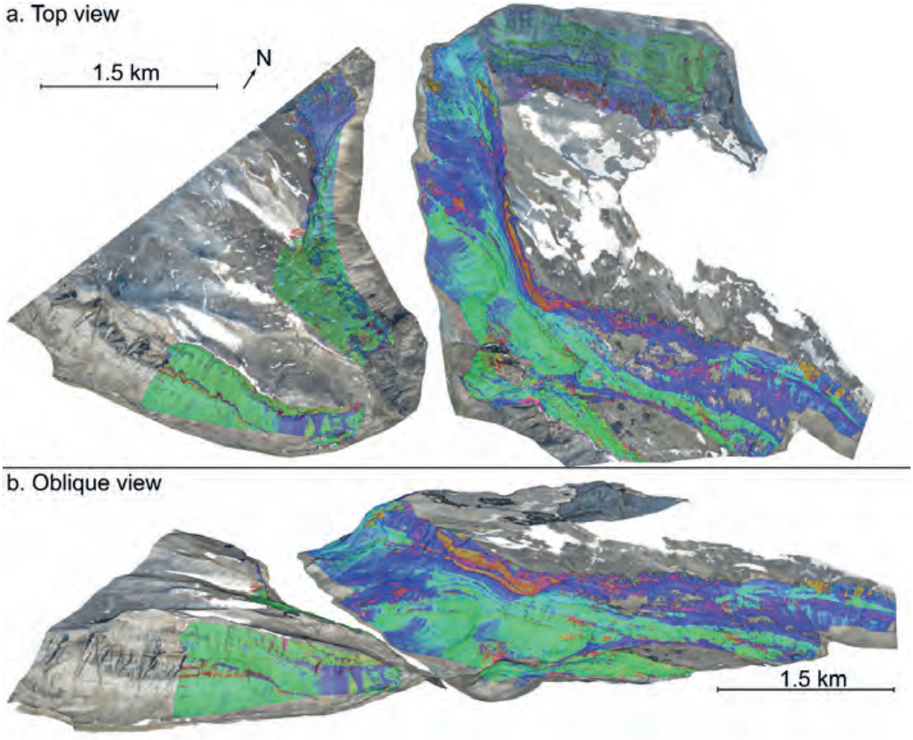

Figure 2: Top (a) and oblique (b) view of a hypercloud representing 3D surface material composition at a fjord cliff in West-Greenland. Colours are saturation enhanced hull-corrected absorbance at 2200, 2250 and 2350 nm, highlighting differences in mineral composition. Background RGB values are from a photogrammetric point cloud.

3D point clouds from photogrammetry and laser scanning

Gottfried Mandlburger

Department of Geodesy and Geoinformation, TU Wien, Austria

Accurate 3D geo-data are a prerequisite for all kinds of environmental sciences like geomorphology, natural hazard management, and climate research. In particular, high-quality 3D point clouds are of crucial importance for addressing current challenges in the alpine region and for supporting sustainable development of this sensitive area. Among the potential applications are monitoring of soil erosion and rock stability, quantification of glacier retreat, mapping of sediment transport rates in alpine river systems, and the like. This implies multi-temporal data acquisition with a high demand of geo-location accuracy in order to separate measurement errors from true topographic or bathymetric change (Zahs et al., 2019; Mayr et al., 2019; Paffenholz et al., 2019; Lane et al., 2020; Geissler et al.,2021, Winiwarter et al., 2021; Mandlburger et al., 2015).

In photogrammetry, one can generally distinguish between active and passive data acquisition techniques. In image-based stereo-photogrammetry, 3D points of the environment can be obtained from overlapping images, if both the interior and exterior orientation of the cameras are known. The interior orientation (focal length, principal point, lens distortion) describes the geometry of the camera system, while the exterior orientations provide the position and attitude of each individual exposure. 3D positions are calculated be identifying homologues points in two or more overlapping images and by spatial forward intersection of the respective image rays. Modern software allow for automatic orientation of entire image blocks based on Structure-from-Motion (SfM) even without or with only a few ground control points if the measurement platform is equipped with high-quality GNSS (Global Navigation Satellite System). While distinct tie point features are necessary for image orientation and calibration, Dense Image Matching (DIM) today allows height estimation for each single pixel. This means that Digital Elevation Models (DEM) can be derived with a spatial resolution corresponding to the Ground Sampling Distance (GSD) of the employed images, which is typically in the range of 2-20 cm depending on the flying altitude and the focal length.

In contrast to stereo-photogrammetry, laser scanning is an active technique where the roundtrip time of a short laser pulse, emitted from a terrestrial or airborne platform and reflected from the Earth’s surface, serves as the basis for deriving dense 3D point clouds. In the airborne case, this requires sophisticated sensors for measuring the position and attitude of the platform. Together with beam deflection via rotating, oscillating, or nutating mirrors, the terrain around or below the sensor is systematically scanned resulting in dense 3D point clouds with typical point densities of 20-500 points/m^2. A major advantage of LiDAR (Light Detection and Ranging) is the multi-target capability of the scanners operating with the Time-Of-Flight (ToF) principle. This means that more than one 3D point can be captured for a single laser pulse including vegetation penetration through small openings in the foliage. While infrared laser radiation is predominantly used for topographic applications, employing green lasers allows water penetration and, thus, measuring the ground of clear and shallow alpine rivers (Mandlburger et al., 2015).

The spatial resolution of a 3D point cloud derived by active or passive photogrammetry generally depends on the sensor-to-target distance. For airborne applications, flying altitude and flight velocity constitute the essential parameters. With the advent of powerful Unmanned Aerial Systems (UAS) as carrier platforms for both cameras and laser scanners, 3D point cloud acquisition has entered a new area, which can be termed "close range aerial photogrammetry". While, in the meantime, there is a relative long history for UAS-based image acquisition, the integration of powerful high-end laser scanners only became feasible in the recent years with advances in UAS-technology (Mandlburger 2022). Today, not only topographic but also topo-bathymetric laser scanners are mounted on UAS-platforms enabling very detailed description of alluvial topography above and below the water table including submerged ground, deadwood, and underwater vegetation like shown in the example of Figure 1 at the pre-alpine Pielach River.

Figure 1: Topo-bathymetric 3D LiDAR point cloud of Pielach River coloured with simultaneously acquired aerial RGB images acquired from an octocopter UAS platform

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Three-dimensional forest ecosystem monitoring and better understanding by terrestrial-based technologies (3DForEcoTech)

Martin Mokroš

Department of Excellent Research EVA 4.00, Czech University of Life Sciences Prague, Czechia

Forest ecosystems are under high pressure due to climate changes. We need to work on their transition to adapt to these challenges. It is crucial to make forest ecosystems resilient enough to be able to resist and face these challenges. The aim should be to strengthen them with close-to-nature forestry. Implementing such approaches and monitoring their progress requires accurate knowledge about forest ecosystems that rely on forest in situ data at high spatial and temporal resolution. In our research, we are focusing on novel close-range technologies that are playing an important role to face these challenges. In recent years we are witnessing a booming development of such technologies. From terrestrial laser scanning through mobile and handheld laser scanning to terrestrial photogrammetry. From the above perspective, a high number of different unmanned aerial vehicle types are equipped with active or passive sensors. Currently, other technologies are coming that can bring another perspective to data collection. One example is a LiDAR type of sensor equipped in smartphones. We can see already applications dedicated to forest inventory purposes (forest-scanner.com; iscanforest.fld.czu.cz). The numerous technologies providing high volumes of three-dimensional data, the challenge is to coordinate the steps of data collection, data processing and usage of such technologies and data for a variety of forest inventory and forest ecology purposes. Various research groups across the EU and beyond are testing such technologies or developing processing algorithms for precision forestry and forest ecology. But further cooperation is strongly required. That is the aim of the 3DForEcoTech project (3DForEcoTech.eu) where we are establishing a strong network of scientists and stakeholders (i.e. practitioners) and sensor manufacturers to synchronise the knowledge, develop general protocols and algorithms for forest ecosystem state survey and forest functioning, and make these novel technologies available to a broad audience. Currently, the network consists of approximately 220 scientists from 47 countries. The main goals of 3DForEcoTech are to develop protocols for data acquisition, processing, and fusion for forest inventory and ecological applications and will establish open-data and open-source algorithm databases.

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3DForEcoTech
Three-dimensional forest ecosystem monitoring & better understanding by terrestrial-based technologies

Essential variables from remote sensing: Can ECVs = EBVs = EVs?

Andrew Skidmore

Department of Natural Resources, Faculty of Earth Observation and Geo-Information Science (ITC), University of Twente, The Netherlands

To monitor the Earth, policy makers have suggested a set of Essential Variables (EVs). These EVs are fundamental variables that could be measured and used to monitor change. Here I examine two well developed concepts, namely Essential Climate Variables (ECVs) and Essential Biodiversity Variables (EBVs). Can a single set of common Essential Variables be derived to represent both climate and biodiversity? And what about other proposed "Essential Variables" such as Essential Ocean Variables (EOVs)?

Abstracts - Lecturers

Earth observation in mountain regions - from close-range to remote sensing

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

[1]Institute of Geography, University of Innsbruck, Innsbruck, Austria
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Earth observation provides basic data sets for the fundamental understanding of phenomena and processes in mountain areas. In the last decades close-range sensing technologies evolved as stand-alone methods for high-resolution data acquisition at micro, local and regional scales. Simultaneously, earth observation by airborne and satellite remote sensing is covering low-resolution global to high-resolution regional and local scales. Thus, close-range sensing instruments provide base-data as digital laboratories investigating process characteristics in highest level of detail and provide calibration and validation data for time series analysis and scenario simulations (Fig. 1). To date close-range sensing comprises mapping by fixed terrestrial, or moving and flying platforms of all kinds in combination with various sensor types (Fig. 2). It provides mono- and multi-temporal maps or (near) real-time data streams in addition and complementary to geosensor networks and can be assimilated into earth observation time series and process models. Recent research of our group uses such approaches amongst others for the monitoring and process investigation of for example shallow and deep-seated mass movements, snow cover, thermal micro-patterns, glaciers and rock glaciers and for ecological investigations of grassland and forest structure. Future sensing applications will integrate ubiquitous sensor strategies such as neo-geography concepts and sensing by mobile robotic platforms and autonomous unmanned aerial vehicles. Besides the large scientific potential offered by new sensors and sensing strategies, earth observation science needs to continue to be specific on limitations by accuracy and error budgets and to assess the efficiency of sensor usage in outdoor environments. Furthermore, ethical issues such as data ownership, privacy and geoethics need to be considered in order to ensure sustainable scientific development aiding society and scientific progress.

Figure 1: Long-term monitoring of shallow landslides by terrestrial laser scanning.

Figure 2: Multi-sensor unmanned aerial vehicle as agile surveying platform for mountain areas.

Bremer, M., Zieher, T., Pfeiffer, J., Petrini-Monteferri, F., & Wichmann, V. (2019). Monitoring der Großhangbewegung Reissenschuh (Schmirntal, Tirol) mit TLS und UAV-basiertem Laserscanning. 20. Internationale Geodätische Woche Obergurgl 2019, 321–330.

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Pfeiffer, J., Zieher, T., Bremer, M., Wichmann, V., & Rutzinger, M. (2018). Derivation of Three-Dimensional Displacement Vectors from Multi-Temporal Long-Range Terrestrial Laser Scanning at the Reissenschuh Landslide (Tyrol, Austria). Remote Sensing, 10(11), 1688.

Point-cloud classification: the context of spectral and geometric features

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Point clouds contain a lot of information in an unstructured lattice. They inherently contain geometric information, as they represent a discrete representation of shapes of the objects that are present in the scanned area. This geometric representation can be more or less detailed depending on the characteristics of the survey and of the area itself; obstructions regarding objects can lead to partial representations or very different point density from different perspectives. Laser backscatter intensity reaching back the sensor is another bit of information that can be used to discriminate objects, as some surfaces provide stronger backscatter. This is dependent on may factors, including incidence angle, surface roughness and color, as well as the "permeability" of the surface to the laser light in some surfaces. For examples leaves often provide partial reflectance and thus a lower backscatter value with respect to surfaces that completely intercept the laser beam. Often scans are coupled with spectral sensors that provide color information to the points. Photogrammetry also provides point clouds with color information, with more limitations regarding the obstruction due to the required match of concurrent features in two or more images – for this reason mixed surveys can be complementary (Mandelburger et al., 2017). Collecting color information and geometric information together can lead to a datarich environment that can be used in the context of machine learning algorithms for the training-validation-testing procedure with the aim of assigning points to specific user-defined labels. Geometric features can be assigned to each point by transforming the coordinates of a set of neighbours to eigen values to extract descriptors of shapes, e.g. planarity, sphericity, linearity (Hackel et al., 2016). The definition of neighbourhood requires specific attention (Weinmann et al., 2015) as it impacts performance and computation time. The final data to be classified can therefore have several features that can be used as descriptors in the machine learning process. The next step requires identification of subsets of points that represent the classes that the are required. These subsets are then used for training and final testing for accuracy metrics. In the context of a non-urban area in a mountain region, classes can include different types of soil, low and high vegetation, rocks and water bodies (Bernsteiner et al., 2020). Several open source tools can be used to carry out the processing steps. Cloud Compare can be used to extract geometric descriptors for each point and also extract subsets of point clouds for training and testing. Python or R can be used to train and classify the data using several available machine learning methods in these two programming environments. In the lecture a live demo will be shown over the R environment to follow a workflow from a point cloud to classified point cloud, with accuracy metrics to estimate the performance of the method.

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Virtual laser scanning – simulation of synthetic 3D/4D geographic point clouds

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Virtual Laser Scanning (VLS) is a method to perform 3D laser scanning in a computer simulation. Since such real laser scanning acquisition in the field is expensive and not always possible, laser scanning simulations can complement real data and support a multitude of applications in geosciences and environmental sciences (cf. Weiser et al. 2021). A main advantage is the augmentation of real datasets with an abundance of synthetic datasets that have known reference data and acquisition settings. As with real laser scanning, in VLS the point cloud is determined by the laser scanning system used (e.g. static vs. mobile), the system settings (e.g. pulse repetition frequency), and the acquisition strategy (e.g. scan 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, quasi-Monte Carlo ray tracing can be chosen (Gastellu-Etchegorry et al. 2016). A more straightforward single scattering method is implemented in the general-purpose VLS software HELIOS++ (HELIOS++ 2022, Winiwarter et al. 2022). All VLS approaches have in common (Fig. 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 4) the survey component, which defines how the campaign shall be performed. As a result, the user obtains full-waveform LiDAR data, full-waveforms and point clouds in standard data formats (ASCII, LAS or LAZ files), similar to the result of a real campaign. Those VLS point clouds can be input to your methods and processing workflows and can be studied in point cloud visualization software (e.g. CloudCompare). The modification of VLS campaigns and “playing around” with settings is very straightforward via the Python bindings *pyhelios* of HELIOS++ where changes can be applied in a scripting manner and brute force tests become possible. VLS is specifically well suited for the following scientific use cases (cf. Winiwarter et al. 2022):

1. **Algorithm and computational method evaluation:** Generation of a large variety of synthetic point clouds with "perfect" reference data and known settings. VLS data can be used to validate your algorithms and they can serve as training data for machine learning and in particular deep learning approaches.
2. **Data acquisition planning and study of scan setting effects:** Planning of research experiments and field surveys can be supported, such as to find the best scan positions; or to test acquisitions with different sensor models (even not yet existing hardware).
3. **Education**: Students can learn how laser scanning works by using a VLS software with a graphical user interface. No need to possess the hardware.
4. **Sensor development and evaluation**: Implement and test your own scanner design and newly available sensors before purchasing them.

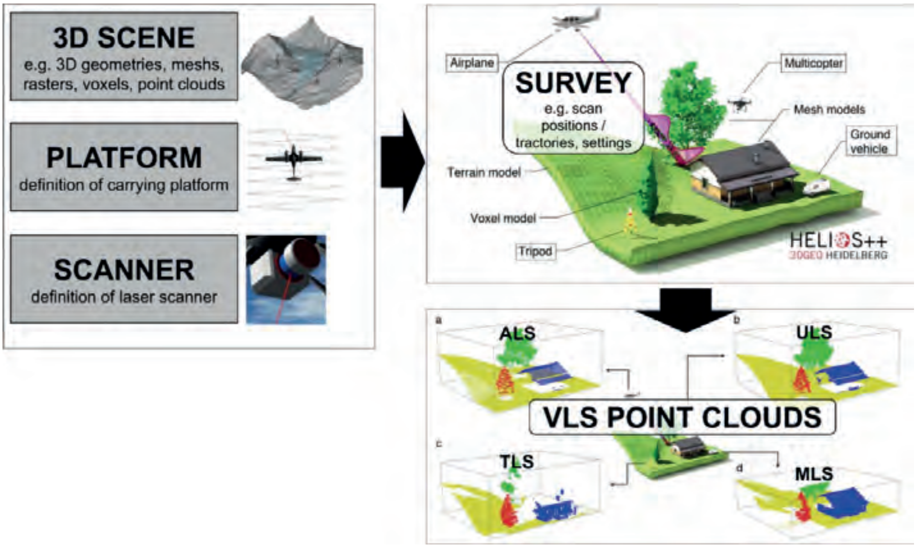

Figure 1: Components (3D scene, platform, scanner) and survey process of Virtual Laser Scanning (VLS) leading to a virtual point cloud (modified from Winiwarter et al. 2022; Bechtold & Höfle 2016).

This lecture will introduce the principle of VLS and it will demonstrate hands-on examples of VLS in the context of alpine and environmental research.

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Image velocimetry – using UAV data to measure river surface flow velocities

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Uncrewed Aerial Vehicles (UAV) are becoming a widely used measurement tool in hydro-morphology due to their cost, flexibility and ease of use. Entire river reaches can be assessed in regard of various aspects, such as bathymetry, grain size mapping, topographic survey, habitat mapping and restoration monitoring. Furthermore, UAV based hydrometric measurements are enabled due to the tracing capabilities of patterns at the river surface in spatio-temporal data with very high resolution. In this lecture hydrometric measurement methods at reach scale are introduced. Thereby, RGB as well as thermal imagery is considered in combination with particle tracking velocimetry (PTV) and particle image velocimetry (PIV), respectively, to retrieve river surface velocities. The principles of pre-processing steps such as image co-registration to stabilize the captured video and ortho-rectification to scale the velocity measurement are discussed. Different case studies are chosen to demonstrate the vast applicability of UAV remote sensing for hydrometric monitoring.

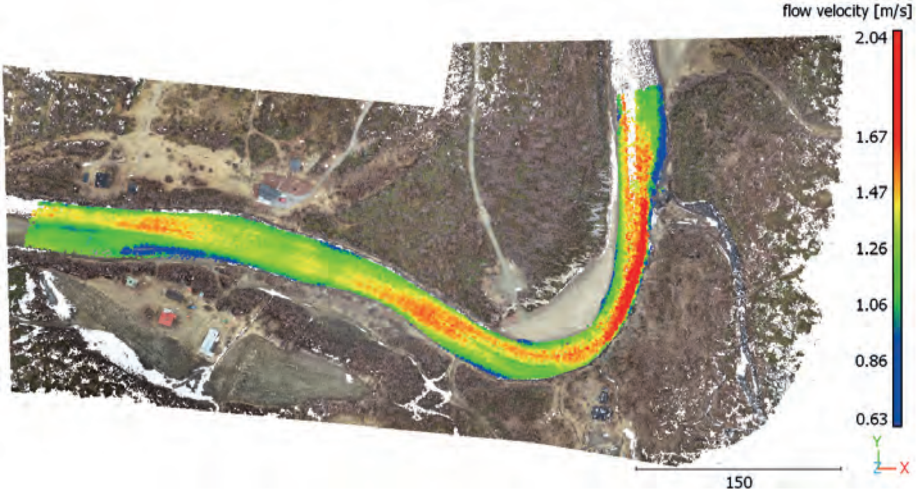

Figure 1: 3D point reconstructed from UAV imagery and flow velocity measured with UAV video.

Morphological change detection from point cloud data

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Morphological topographic changes tell about landscape development and, therefore, change assessment is in high-demand by managers and researchers of (semi-) natural areas. Laser scanning and also photogrammetry are efficient sensor techniques to repeatedly acquire topographic data in natural areas with their capability to acquire dense point clouds. Detecting and notably interpreting changes from repeated topographic data is less straightforward. Complications include the presence of irregular spatial patterns with variations in relief, vegetation and surface roughness, while individual point quality is strongly varying throughout a point cloud due to the combined effect of measurement geometry and surface and atmospheric properties. In addition, temporal changes vary between instantaneous, as in a rockfall event, and minimal but persistent through time, for example aeolian sand accumulation, compare Fig. X, red cluster. In the lecture a short overview will be given of methods to detect and understand changes in different scenarios. Methods exist, e.g. (Van Gosliga et al., 2006), and (Lague et al., 2013), that explicitly incorporate the level of significance to distinguish actual changes from changes between epochs caused by measurement errors. These methods are well suited in scenarios with two epochs/data acquisitions (a before/after scenario). When more epochs are available, also the number of possible change scenarios increases rapidly, and best methods to identify such changes are still under active development. One recent method detects so-called 4D objects-of change, (Anders et al., 2020), by performing a spatial spatio-temporal segmentation. Alternatively, similar time-series are clustered using an unsupervised classification method, compare Fig. X and (Kuschnerus et al., 2021). The further development of these methods is strongly driven by the recent availability of data sets consisting of many (e.g., 1000s) epochs of consecutive topographic point cloud data, (De Vos et al., 2022).

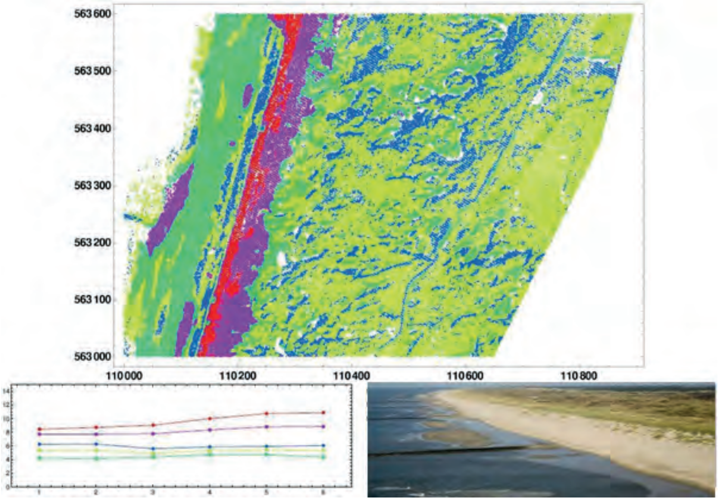

Figure 1: Clustering of time series of yearly airborne laser scanning data. K-means clustering (K=5) is applied to 6 epochs of airborne laser scan data of coastal dunes. Top: grid points coloured by cluster Id. Bottom left: average time series per cluster. Bottom right: photo of considered coastal dunes. (Modified from Lindenbergh et al., 2019).

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Point cloud registration and segmentation

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The principle of point cloud registration is to associate a point cloud to a common coordinate system. Still, the registration can have different meanings, depending on the context. Roughly, these can be divided into two flavours: relative and absolute registration. In a relative registration, two or more point clouds are translated to one common coordinate system, that is often into a coordinate system of one of the datasets. In an absolute registration process the point cloud is linked to an absolute (national or global) coordinate system, e.g. by using ground control points or a direct referencing method. Point cloud registration is useful for monitoring purposes, updating, data fusion with other georeferenced data.

Also, point cloud segmentation may have different meanings: the most common terms are planar segmentation, semantic segmentation, and instance segmentation. In this presentation, we focus on the general concept of grouping points that belong to a certain object or part of an object. The grouping itself depends on geometric relations between a point and its neighbours. The challenge with point clouds is to decide where is the edge of the object, and thus the boundary of a segment. After all, a point cloud is a collection of discrete points without a direct indication of object boundaries. Techniques and tools to group points on planar surfaces, or random surfaces are explained.

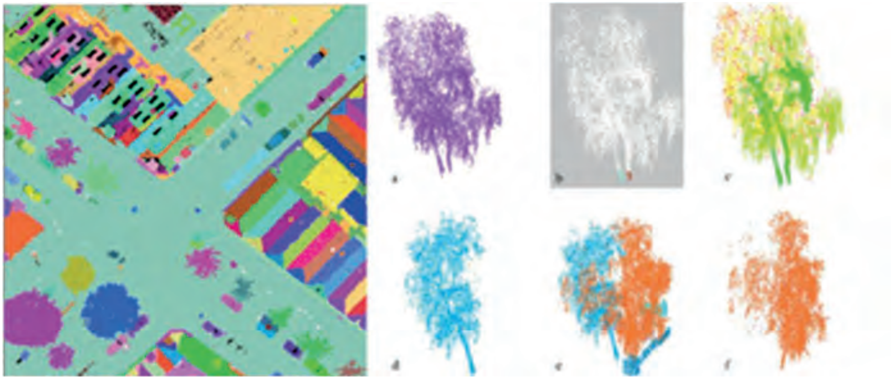

Figure 1: Not every object is planar (left), and how do you find two trees in a collection of points(right)?

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Structure-from-motion photogrammetry: A framework for image-based 3D reconstruction

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Structure-from-Motion Photogrammetry (SfM) is referred to as the main technique to derive 3D point clouds (and related by-products) from images. Its popularity has impressively grown in many scientific domains during last ten years, but a remarkable success has been recorded in the Geosciences. Several factors have contributed to this: (1) the chance of using low-cost cameras; (2) the almost fully automatic workflow, implemented in efficient open-source or low-cost software packages; (3) the simple access to the use of drones to extend the operational capability to large and involved areas. SfM has been also 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). This option allows to easily reprocess archival aerial photos to be used in retrospective studies.

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

Camera selection and calibration: Which type of camera could be used for SfM? Are panoramic and 360 cameras usable within SfM pipeline? Why, how and when camera calibration should it be done?

Image acquisition organization: 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 to training. Which are the basic rules for data acquisition? How can one get trained?

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

Ground control points (GCP): which are the purposes of GCPs? When should they be used and where should be positioned? Are there other solutions to setup the spatial datum?

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

Main by-products of SfM: whatever else can be derived after SfM? Are guidelines available to help a correct generation of orthoimages, raster digital elevation models, and realistic Virtual Reality Models.

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

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Abstracts - Participants

Mapping hedgerows

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Hedgerows are common historic features in agricultural lands in North Western Europe which are important for cultural, ecological and environmental reasons. Indeed, a mosaic of hedgerows, grassland and forests provide maximal benefits to local ecosystems at local and landscape scales in terms of biodiversity (Lecq, 2017; Staley et al., 2013), connectivity (Crowe et al., 2020; Lenoir et al., 2019) and ecosystem service delivery (Morandin and Kremen, 2013; Sutter et al., 2018; Bert et al., 2017). The extent of hedgerows in the UK has halved since the 1960s (Cornulier et al., 2011), and some farm bird species have declined by up to 95% (Daskalova et al., 2019). At a global scale, the UK is part of the Convention on Biological Diversity (CBD) which states member countries should not allow habitats and populations to decline further and instead take measures to re-invigorate them. At a European level, the Natura 2000 identified key habitats and species which are a priority for conservation, and pushed for planning to take them into account, as well as the interconnectivity of habitats at a landscape scale (Evans, 2012). Measuring habitat characteristics such as vegetation density, height and width, which relate to ecosystem services and habitat quality (Graham et al., 2018), combined with indicators of resource availability such as flowers and fruits with links to biodiversity (Vickery et al., 2009), through monitoring at small and landscape scales should be a priority to understand the drivers of biodiversity collapse (Stacey, 2018). Novel technologies, including hardware and software, have been maturing to a level where they may enable processes to be automated, leading to consistent, cheaper and more useful data for the provision of environmental and ecological services (Allan et al., 2018). Satellites, Unmanned Aerial Vehicles (UAVs) and ground-based platforms together with the range of sensors available today (RGB, topographic LiDAR, hyperspectral imagery, radar, etc.) can work at a range of scales, from landscapes to leaves. This PhD seeks to tie the recent advances in technology to the needs of policy and landowners, which requires new methods and algorithms targeting the right proxies. Furthermore, the implementation of solutions is also a key part of the project. I have already collected data through semi-structured interviews of key stakeholders, namely: ecologists, farmers, policy experts and government departments (Department for Environment, Food and Rual Affairs - DEFRA and Rural Payments Agency - RPA), relating to field parameters and implementation. Overall this multiscale and multifaceted project aims to develop key tools for a variety of stakeholders with the aim of improving habitats to maximise its biodiversity and carbon storage potential.

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Determination of glacier extents by monoplotting using historical terrestrial oblique images

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The melting of glaciers in recent decades is well documented in the Alps through comprehensive historical aerial images available since the 1940s. Less well documented are the glacier extents in the late 1800s and in the first half of the 20th century. In addition to historical maps, historical terrestrial oblique images play an important role for this period and can be georeferenced and analysed by digital monoplotting (Bozzini, 2012; Wiesmann 2012). These images are often the only useful source for reconstructing changes in these areas and thus offer an effective way of documenting landscape dynamics. Private and public archives (such as the archives of the DAV and ÖAV) have a large number of high-resolution historical oblique images. Using three historical photos, we show the changes in glacier extents from 1890 to about 1935 using the example of the Gepatschferner in the Kaunertal with the monoplotting tool Mono3D, which was developed at the Department of Geodesy and Geoinformation at the TU Wien (Flöry et al., 2020). Ground control points (more than

10 per image) were selected via a 3D viewer and both the interior and exterior orientation of the images estimated using OrientAL (Karel et al., 2013). With the estimated camera parameters and a reference DEM (2017, 1m resolution) the object coordinates of image pixels are calculated by monoplotting. In this way, the glacier extents were digitised and extracted as spatially referenced vector data (Fig. 1). Together with the glacier extents at the end of the Little Ice Age around 1850 (Groß and Patzelt, 2015) and the glacier extent mapped by an orthophoto from 1953 (aerial images were provided by the BEV (Austrian Federal Office of Surveying and Metrology, Vienna/Austria)), this period of around 100 years can be partially closed.

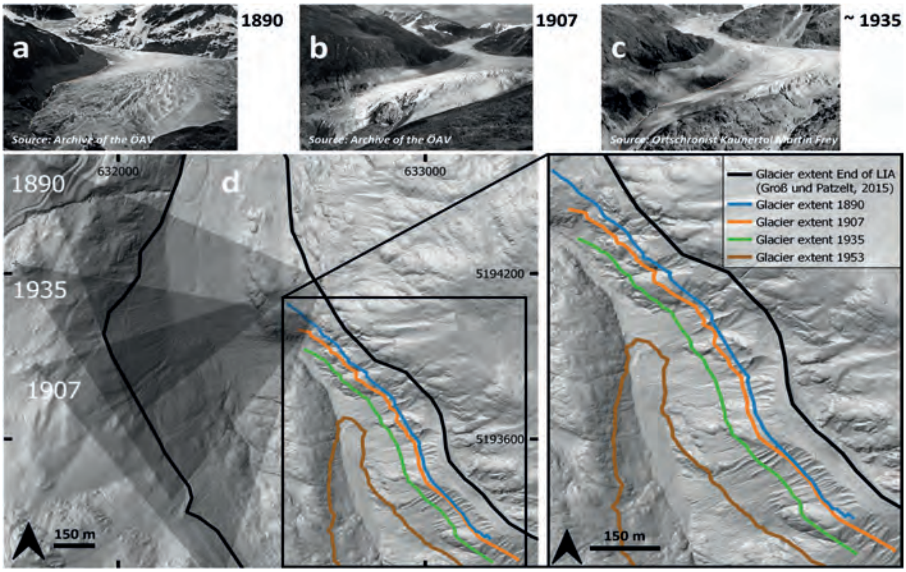

Figure 1: Glacier extents extracted by digital monoplotting: (a-c) Historical images and mapped lines, 1890, 1907 and ~1935 (estimated), (d) Point of taking the historical image and extracted glacier extents.

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Assessing the interlinked dynamics of cascade processes at a deep-seated gravitational slope deformation - from past movement activity towards modeling

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Deep-Seated Gravitational Slope Deformations (DSGSDs) pose serious threats to buildings and infrastructure in mountain regions. The understanding of past movement behavior is an essential requirement for enhancing process knowledge and potential mitigation measures. In this context historical aerial imagery provides a unique possibility to assess and reconstruct the deformation history of DSGSDs. We investigate the feasibility of 3D point clouds derived from historical aerial imagery using Free and Open-Source Software (FOSS) photogrammetric tools for analyzing the long-term behavior of the Reissenschuh DSGSD (cf. Branke et al., 2020; Bremer et al., 2019; Pfeiffer et al., 2019; Pfeiffer et al., 2018), in the Schmirn valley (Tyrol, Austria) (Fig. 1) and assessing related secondary processes as changes in creep velocity, rockfall or debris flows. For the photogrammetric analyses, scanned analogue and digital imagery of six acquisition flights, conducted in 1954, 1971/1973, 2007, 2010, and 2019, have been processed using the FOSS photogrammetric suite MicMac. Further point cloud processing was carried out in CloudCompare. An improved version of the IMage CORRelation approach (IMCORR) implemented in SAGA GIS was used for the area-wide assessment of slope deformation. For the georeferencing and scaling an Airborne Laser Scanning (ALS) point cloud of 2008 provided by the Federal State of Tyrol (Austria) was used. In total five photogrammetric 3D point clouds covering the period from 1954 to 2019 were derived and analyzed in terms of displacement, velocity and acceleration. The accuracy assessment with computed Multiscale Model to Model Cloud Comparison (M3C2) distances between photogrammetric 3D point clouds and reference ALS 3D point cloud, showed an overall uncertainty of about ±1.2 m (95% quantile) for all 3D point clouds produced with scanned analogue aerial images (1954, 1971/1973 and 2007), whereas 3D point clouds produced with digital aerial imagery (2010, 2019) showed a distinctly lower uncertainty of about ±0.3 m (95% quantile). Also, digital elevation models (DEM) of difference (DoD) for each epoch were calculated. IMCORR and DoD results indicate significant displacements up to 40 meters in 65 years for the central part of the landslide. The historical data sets further indicate a change of spatio-temporal patterns of movement rates (Fig. 2) and a minor but overall acceleration of the landslide. The main challenges were the (i) gaps in the 3D point clouds on areas of steep, shadowed slopes and high vegetation, (ii) ground filtering on the photogrammetric point clouds for accurate calculation of digital terrain models (DTMs) and (iii) the quality of the scanned aerial imagery showing scratches, cuts, color irritations and linear artefacts. The research enabled the characterization of the spatio-temporal movement patterns of the Reissenschuh DSGSD over more than six decades. Further research will incorporate the results as reference for modeling the discussed multi-hazard processes (cf. Kappes et al., 2012). For this specific approach field sampling of soil material was conducted and is currently being assessed in terms of friction angle and cohesion by triaxial shear tests within the geotechnical laboratory of the University of Innsbruck (cf. Schneider-Muntau et al., 2018).

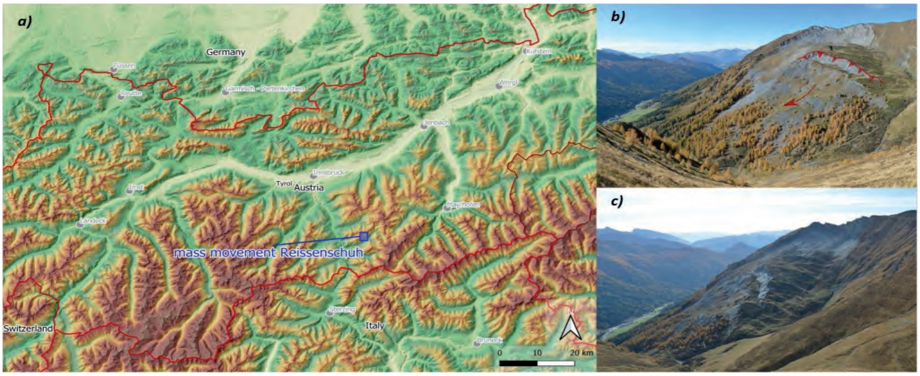
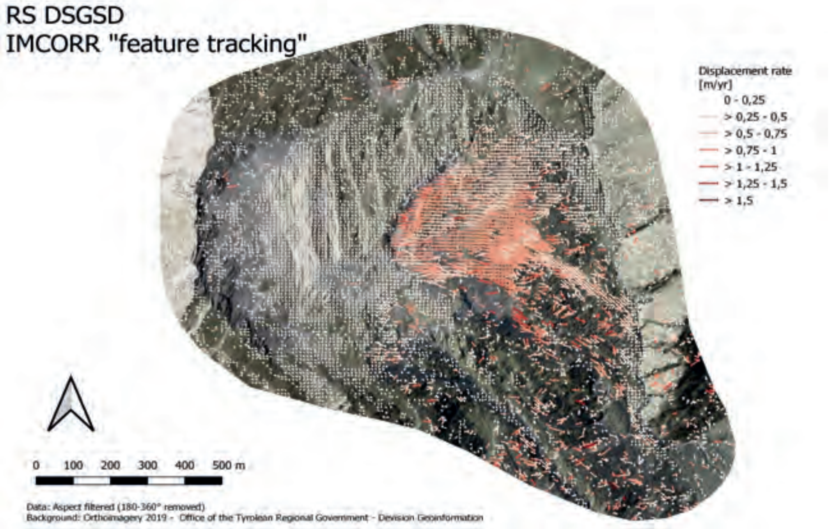


Figure 1: Overview of the study site location. a) Location of the mass movement Reissenschuh, b) photograph of Reissenschuh (J. Branke, 23.10.19) with sketched recent movement (black dotted) and active slab part (red) with movement direction (arrow); c) other perspective photograph (J. Branke, 23.10.19) with compression ripples.



Data: Aspect filtered (180-360° removed)
Background: Orthoimagery 2019 - Office of the Tyrolean Regional Government - Devision Geoinformation

Figure 2: Displacement rate in meters per year derived from IMCORR feature tracking approach resulting from surface data acquired by photogrammetry (1954, 1973, 2007, 2010 and 2019) and the airborne laser scanning mission 2008 by the Federal State of Tyrol, combining 65 years of displacement information.

Branke, J., Zieher, T., Pfeiffer, J., Bremer, M., & Rutzinger, M. (2020). Extending the integrated monitoring of deep-seated landslide activity into the past – preliminary results of the project EMOD-SLAP. Proceedings of the disaster research days 2020, 198-199.

Bremer, M., Zieher, T., Pfeiffer, J., Petrini-Monteferri, F., & Wichmann, V. (2019). Monitoring der Großhangbewegung Reissenschuh (Schmirntal, Tirol) mit TLS und UAV-basiertem Laserscanning. 20. Internationale Geodätische Woche Obergurgl 2019., 321-330.

Kappes, M. S., Keiler, M., von Elverfeldt, K., & Glade, T. (2012). Challenges of analyzing multi-hazard risk: a review. Natural hazards, 64(2), 1925-1958.

Pfeiffer, J., Zieher, T., Bremer, M., Wichmann, V., & Rutzinger, M. (2018). Derivation of Three-Dimensional Displacement Vectors from Multi-Temporal Long-Range Terrestrial Laser Scanning at the Reissenschuh Landslide (Tyrol, Austria). Remote Sensing, 10(11), 1688.

Pfeiffer, J., Zieher, T., Rutzinger, M., Bremer, M., & Wichmann, V. (2019). Comparision and time-series analysis of landslide displacement mapped by airborne, terrestrial and unmanned aerial vehicle-based platforms. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. IV-2/W5, 421-428.

Schneider-Muntau, B., Schranz, F., & Fellin, W. (2018). The possibility of a statistical determination of characteristic shear parameters from triaxial tests. Beton-und Stahlbetonbau, 113, 86-90.

Landslide assessment: Metropolitan area of Concepción, south-central Chile

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Landslides are gravitational processes of mobilization of rocks or soil at different speeds (Cruden & Varnes, 1996), being one of the hazards that cause more loss of lives. To mitigate the landslide damage, it is necessary to evaluate the factors that provoke them and identify the prone areas (Fell et al., 2008;). In Chile, 52 fatal landslides have been recorded during the period 1928-2017, causing the death of 882 people (SERNAGEOMIN, 2016). Although the zoning of these hazards should be integrated into a local scale in the Communal Regulatory Plans (PRC), these instruments do not include a clear methodology for landslide assessment, affecting the quality of landslide hazard maps. Current databases offer little detail about individual events, as generally they are only recorded as a list of coordinates. Type of process, volume transported, scarps and deposition zones are rarely registered. Therefore, one of the main tasks of this research is to develop a detailed inventory of landslides that will allow accurate hazard's mapping of the Concepción Metropolitan Area. We are compiling information from the local press and previous studies, combined with field and remote sensing data (Fig. 1). At a later stage, we will study the most evident relationships between factors and landslide occurrence using machine learning methods.

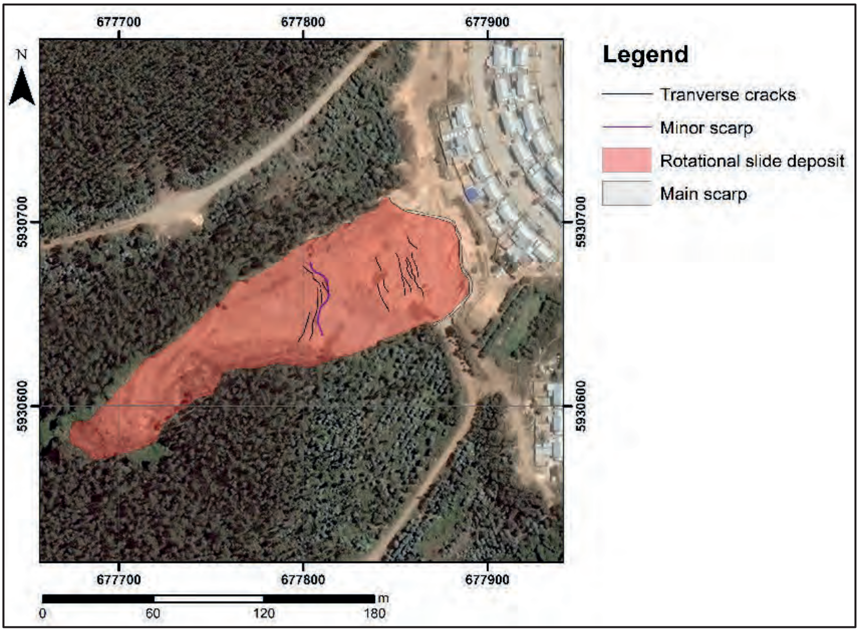

Figure 1. Example of Rotational slide, Penco, August 2016. Google Earth image.

Cruden, D. & Varnes, D. (1996). Landslide types and processes. A.K. In Turner K. and R. Schuster (Eds.). Landslides, investigation and mitigation, Special report 247, 36-75. Washington D.C.: Transportation Research Board, National Research Council.

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., & Savage, W. Z. (2008). Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning. Engineering geology, 102(3-4), 99-111. doi:10.1016/j.enggeo.2008.03.022

SERNAGEOMIN (2016). Registro de los principales desastres de origen geológico en Chile y efectos sobre la población y bienes públicos y privados desde 1980. Unidad de Peligros Geológicos y Ordenamiento Territorial. 32 p.

Multi-method characterization of the hydrological behaviour of a glacier-debris-covered glacier-rock glacier-complex in Grizzly Creek (Yukon, Canada)

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The increase in temperatures due to climate change highly impacts the mountain cryosphere, causing glacial retreat and permafrost thaw. Cryospheric complexes with diverse features (glaciers, debris-covered glaciers, rock glaciers, permafrost…) react to those changes. My research focuses on the hydrological behaviour of a cryospheric complex in Yukon (Canada) and its temporal evolution. It exhibits little visible discharge and no significant outlet, thus most of the water is supposed to flow underground. This watershed can therefore be representative of the important role of groundwater contribution in high mountain watersheds outflows (Baraër et al., 2015). By characterizing a complex as one hydrological system, the goal is to explain cryo-hydrological processes and interactions between cryosphere features at the scale of a watershed. A first step of the project is to monitor visible surface phenomena that can give us some knowledge about the hydrological behaviour of the system, such as icing formation (Chesnokova et al., 2020) and the life cycle of lakes forming on the rock glacier and the debris-covered glacier. Diverse methods are used for icing monitoring such as hydro-meteorological measurements, remote sensing and historical imagery analysis, time-lapse monitoring, ground-based Lidar measurement and photogrammetry. GPR surveys and photogrammetry are used to image the internal structure of the debris-covered glacier where a lake sometimes occurs during ablation season.

Baraër, M., McKenzie, J., Mark, B. G., Gordon, R., Bury, J., Condom, T., Gomez, J., Knox, S., & Fortner, S. K. (2015). Contribution of groundwater to the outflow from ungauged glacierized catchments: A multi-site study in the tropical Cordillera Blanca, Peru. Hydrological Processes, 29(11), 2561–2581. https://doi.org/10.1002/hyp.10386

Chesnokova, A., Baraër, M., & Bouchard, É. (2020). Proglacial icings as records of winter hydrological processes. The Cryosphere, 14(11), 4145–4164. https://doi.org/10.5194/tc-14-4145-2020

Antarctic time machine: Unveiling five decades of ice sheet changes

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The Antarctic Peninsula is one of the fastest changing regions on our planet and experienced a rapid warming in the late-20th century. A long-term perspective of the mass balance changes is still lacking. In my project, I will unlock the potential of a vast archive of aerial photographs, obtained by the U.S. Navy since the 1940s (see Fig. 1). These images were acquired using a set of cameras pointing vertical, left and right, spanning a large area of the Antarctic continent and were later digitally scanned. However, these images are not georeferenced and are difficult for work with (grey-scale, scanning errors, low contrast and very complex terrain). Using the overlap between consecutive acquisitions in a Structure from Motion photogrammetry approach, historical digital elevation models of the Antarctic Peninsula will be derived. These photos have been used earlier to derive elevations in the extent of glaciers and ice shelves (e. g. Kunz et al., 2012), but this project will be the first of its kind to derive elevations from this data set for the full Antarctic Peninsula. As the archive consists of around 330,000 images, a manual approach is not feasible and should work as autonomously as possible. These models will be compared to present-day elevation data to obtain a detailed picture of elevation and mass changes over the past 50 years, like done in smaller scale by Berthier et al. (2012). Furthermore, additional remote sensing data will be employed to put the observed changes in a broader climatological perspective. This project will provide a unique insight into the long-term impact of changing climate conditions on Antarctica's glaciers and their dynamical response to ice shelf weakening and disintegration. Furthermore, it provides essential validation data for ice modelling efforts and mass balance changes.

Figure 2: Example of images (left, vertical, right) from the archive

Berthier E., Scambos T. A., and Shuman C. A. (2012). Mass loss of Larsen B tributary glaciers (Antarctic Peninsula) unabated since 2002. Geophys. Res. Lett., 39(13). https://doi.org/10.1029/2012GL051755

Kunz, M. et al. (2012). Multi-decadal glacier surface lowering in the Antarctic Peninsula," Geophys. Res. Lett, 39(19). https://doi.org/10.1029/2012GL052823

Short focal length enhances SfM reconstruction of forest areas

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[3] Remote Sensing Centre for Earth System Research, Leipzig University, Germany
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[5] Department of Forestry and Wood Science, Stellenbosch University, South Africa

Uncrewed aerial vehicles (UAV) with RGB-cameras are affordable and versatile devices for a series of forest inventory tasks. The focal length, which determines the opening angle of the camera lens, is one important image acquisition parameter for reconstruction quality. Despite its importance, the effect of focal length on the quality of 3D reconstructions of forests has received little attention in the literature. Since small angular errors lead to large positional errors in narrow opening angles, shorter focal lengths result in more precise distance estimates in the nadir direction. In this study, 3D reconstructions of four UAV acquisitions with different focal lengths (21, 35, 50, and 85 mm) were compared to reference points clouds derived from terrestrial laser scanning (TLS) data. The agreement with TLS scans and thus reconstruction quality was highest at shorter focal lengths (21 and 35 mm), decreased at 50 mm and at 85 mm a considerable quality loss was observed. Based on our results we recommend a focal length no longer than 35 mm during UAV Structure from Motion data acquisition for forest management practices.

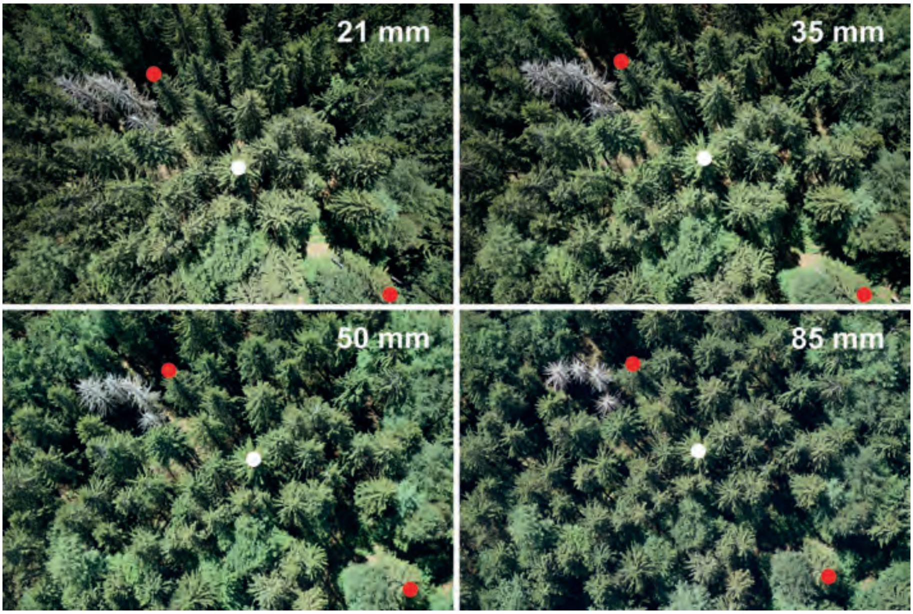

Figure 1. Images of each UAV acquisition with different focal lengths (21-85 mm) of the same forest patch. White and red circles are marking the same trees in each image. With decreasing focal length, the images show a strong perspective view from the side towards the edge of the images.

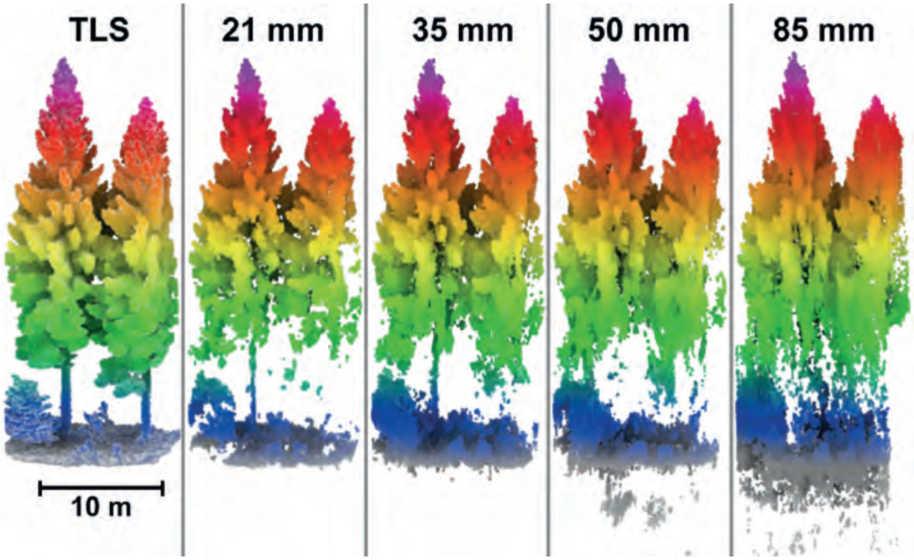

Figure 2. Visualization of the tree structure as represented in the TLS and UAV point clouds. With longer focal lengths the amount of falsely reconstructed points in the crown and particularly below and above the ground increases.

Frey, J., Kovach, K., Stemmler, S., & Koch, B. (2018). UAV Photogrammetry of Forests as a Vulnerable Process. A Sensitivity Analysis for a Structure from Motion RGB-Image Pipeline. *Remote Sensing*, *10*(6), 912. doi: 10.3390/rs10060912

Observing high alpine geomorphological processes using permanent laser scanning time series

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High spatial resolution analysis of high alpine surface elevation change has traditionally been performed using a small number of repeated observations, using techniques such as airborne laser scanning, terrestrial laser scanning or photogrammetry. Alternatively, high temporal resolution can be achieved using point observations at a sparse spatial coverage (Heckmann & Morche, 2019). With the installment of a permanent laser scanner on the Im Hinteren Eis mountain, surface elevation observations can be obtained on a close to daily resolution, at a sub meter spatial scale. This combination resolutions over longer periods of time could provide insights in topographic change on a seasonal scale, which cannot be obtained through a yearly repetition of observations. The aim of this research is to perform a time series analysis on the surface elevation change of a proglacial rock wall located above the Hintereisferner glacier. The time series analysis will be performed using observations from autumn 2016 to autumn 2021, with near-daily observations starting in spring 2019. Utilizing the fact that the permanent laser scans are consistently performed from roughly the same position and orientation, the laser scanning data will be processed in the form of range images. As the laser scanner cannot be assumed to have the exact same observation geometry for different scans, a registration of the different scans is performed through the use of key point matching based on these range images. Preliminary results show range image matching can be used for the registration of the different laser scan observations. Furthermore, different areas of surface elevation change have been identified at a four-year time scale. The next steps in this research will revolve around the improvement on the range image registration method, as well as a time series analysis, resulting in an estimation on surface elevation change at seasonal time scales.

Heckmann, T., & Morche, D. (2019). Geomorphology of proglacial systems. Landform and Sediment Dynamics in Recently Deglaciated Alpine Landscapes. Cham, Switzerland: Springer International Publishing.

Automatically identifying avalanches in optical remote sensing data

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[3]EcoVision Lab, Photogrammetry and Remote Sensing, ETH Zurich, Zurich, 8092, Switzerland
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Accurate and timely information on avalanche occurrence is key for avalanche warning, crisis management and avalanche documentation. Still, this information is incomplete today and only available for limited areas and time periods. In recent years, optical SPOT6/7 data was used to manually map two extreme avalanche periods with 24,737 avalanches (22,000 km^2; Bühler et al., 2019). Additionally, Hafner et al (2021) statistically confirmed the suitability of SPOT6/7 to reliably capture avalanches. To bypass the time-consuming manual mapping, we are using Artificial Intelligence to quickly identify avalanches. Relying on the manually mapped avalanches for training, validation and testing we use an a fully convolutional neural network (CNN) providing us with a per pixel scores for avalanche occurrence (Hafner et al., 2022). Our network is based on a DeeplabV3+ architecture adapted to specifically learn how avalanches look like by for example explicitly including height information from a digital terrain model (DTM). The network achieves an F1 score of 62.5% (threshold 0.5), which is as good as human expert agreement. For the future, we will be further exploring automatic avalanche area extraction from remote sensed imagery relying on machine learning. Additionally, we plan on automating the retrieval of other important avalanche attributes.

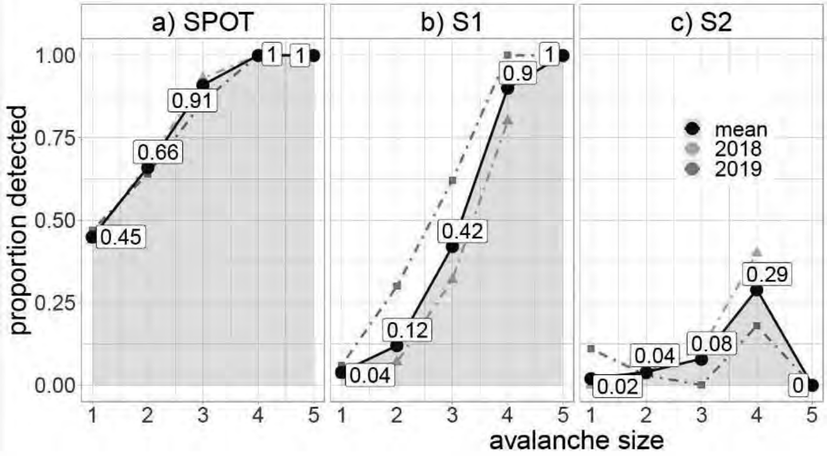

Figure 1: POD by size (black dots/line: average; yellow triangles: 2018; turquoise squares: 2019) for each of the avalanche mapping methods tested (SPOT = SPOT6/7, S1 = Sentinel-1, S2 = Sentinel-2). (Hafner et al. 2021)

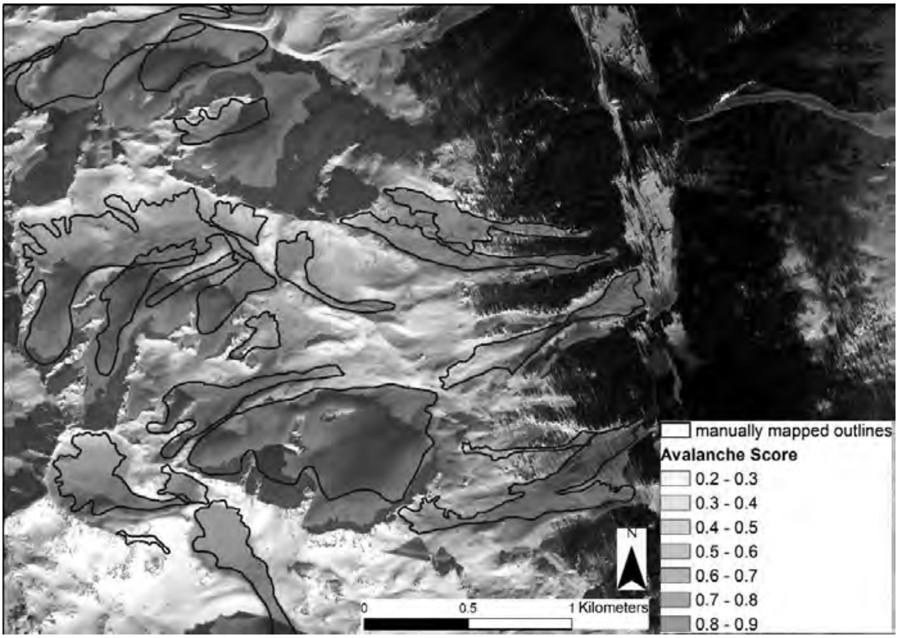

Figure 2: Results from our adapted DeepLabV3+ (SPOT 6 data © Airbus DS 2018; Hafner et al. 2022).

Bühler, Y.; Hafner, E.D.; Zweifel, B.; Zesiger, M.; Heisig, H., (2019). Where are the avalanches? Rapid SPOT6 satellite data acquisition to map an extreme avalanche period over the Swiss Alps. The Cryosphere, 13, 12, 3225- 3238. doi:10.5194/tc-13-3225-2019

Hafner, E.D.; Techel, F.; Leinss, S.; Bühler, Y., (2021). Mapping avalanches with satellites - evaluation of performance and completeness. The Cryosphere, 15, 2, 983-1004. doi:10.5194/tc-15-983-2021

Hafner, E.D., Barton, P., Daudt, R.C., Wegner, J.D., Schindler, K., and Bühler, Y. (2022). Automated avalanche mapping from SPOT 6/7 satellite imagery: results, evaluation, potential and limitations, The Cryosphere Discuss., doi:10.5194/tc-2022-80, in review.

Impacts of increased melt on glaciers and ice caps in the canadian high arctic

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The goal of this project is to use field-based methods and remote sensing techniques, specifically synthetic aperture RADAR (SAR) data, to map and analyze the recent changes in glacier and ice cap (GIC) surface conditions at the glacier basin scale and at the larger regional scale across the Canadian Arctic Archipelago (CAA) (Abdalati et al., 2004). The project will unfold in three main parts: **(a)** First at the glacier basin scale, by assessing the increase in melt on several small polar valley glaciers and in the Inuit community of Grise Fiord, Nunavut; **(b)** The second objective is at the regional CAA scale, that will develop a methodology that systematically creates sub-monthly maps of glacier surface melt/facies using SAR data, and; **(c)** The third objective remains at the regional scale, with the goal to extract regional rates of firn densification from the glacier melt maps to understand the impacts of warmer air temperatures on the firn layer. The first aspect of the project (a) is assessing melt at the basin scale using field methods, glacier surface energy balance modelling and remote sensing methods to quantify glacier changes throughout the last two decades and project changes to the end of this century. An Uncrewed Automatic Vehicles (UAV) will be used to survey the valley glaciers before and after the melt season to map the glaciers and quantify the snow water equivalent from the seasonal snowpack. The second and third part of the project **(b)** is an analysis at the CAA regional scale and will use SAR data, due to its high temporal and spatial resolutions. Following previous methods of analyzing the backscatter from SAR imagery, regional scale glacier melt, and facies products will be generated (*Fig.1*) (Barzycka et al., 2019). The resulting maps will be validated with *in situ* data, such as firn cores, from historical and future field work in the CAA in collaboration with the Geological Survey of Canada. The third part of the project **(c)** will detect firn densification changes from the years 2009 to 2023. Overall, the work will seek to understand impacts of a warming climate on glacier and ice caps in the high Arctic environment of Canada.

Abdalati, W., W. Krabill, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, J. Yungel,and R. Koerner (2004). Elevation changes of ice caps in the Canadian Arctic Archipelago, J. Geophys. Res., 109, F04007, doi:10.1029/2003JF000045.

Barzycka, B., Błaszczyk, M., Grabiec, M., & Jania, J. (2019). Glacier facies of Vestfonna (Svalbard) based on SAR images and GPR measurements. Remote Sensing of Environment, 221, 373-385.

Assessment of complex landslide behaviour by phase correlation and optical flow image registration algorithms

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[2]NHAZCA S.r.l., Rome, Italy
[3]GEORESEARCH Forschungsgesellschaft mbH, Puch bei Hallein, Austria

Future alpine safety depends on the knowledge of accurate remote sensing techniques to detect and assess high–alpine landslides behaviour (Dietrich und Krautblatter 2017). For monitoring and investigating acceleration phases, optical imagery of spatiotemporal high resolution satellite images (S-2, PlanetScope) and high resolution and accuracy UAS (unmanned aerial system) data can be employed to derive ground motion using image registration algorithms. These high frequency measurements offer the potential to investigate short–term changes, and if archive data exists, analyse long–term past as well as ongoing activities (Mazzanti et al. 2020). However, the limitations of this data, utilising algorithms such as phase correlation (PC) (Ayoub et al. 2009) and optical flow dense inverse search (DIS) (Kroeger et al. 2016) to estimate landslides and release reliable early warnings of gravitational mass movements, have not yet been analysed and extensively tested (Altena und Kääb 2017). In this study we applied image registration techniques using PlanetScope Ortho Tile satellite imagery (3.125 m, daily revisit rate, 2017-2021) and high accuracy UAS orthoimages (0.16 m, 7 acquisitions from 2018-2021). On the basis of these different datasets, the results of two algorithms were compared: PC, a robust area–based algorithm implemented in COSI-Corr, and an intensity–based DIS optical flow algorithm performed by IRIS (Kroeger et al. 2016). We tested these algorithms on a benchmark landslide of complex behaviour and fast ground motion, located in a steep, glacially–eroded, high–alpine cirque, the Sattelkar (2’130-2’730 m a.s.l.), Austria. Surrounded by a headwall of granitic gneiss, its cirque infill is characterised by massive volumes of glacial and periglacial debris, rockfall deposits, and remnants of a dissolving rock glacier (Anker et al. 2016; GeoResearch 2018, 2020). Process dynamics have been accelerating since 2003 with variable displacement rates, ranging from 1-14 m in only 42 days, and erosion rates from 80.000 m³ in 2018, increasing to 200.000 m³ in 2020 (Hermle et al. 2021). Derived displacements based on satellite images partially estimate false–positive ground motion for both algorithms PC and DIS, due to poor image quality and imprecise image– and band co–registration. On the other hand, results from PC on UAS data return reasonable displacements, but detection is limited up to 12 m because of decorrelation and ambiguous displacement vectors (Hermle et al. 2022). This can be attributed to excessive ground motion and surface changes

(Travelletti et al. 2013), whereas there is no upper limit for DIS returning unambiguous ground motion. In comparison, PlanetScope reveals spatially located similar areas of variable ground motion. Although there is no decorrelation, some image pairs have a poor signal–to–noise ratio, and the landslide body can only be demarcated and confirmed based on existing UAS results. This shows that profound knowledge of data potential and its applicability is necessary to detect gravitational mass movements reliably. Displacement results from PlanetScope cannot clearly delimit the real active landslide due to the lack of quality spatial resolution, precision, and accuracy and require additional comparison from other data, in this case derived ground motion from UAS (Fig. 1). It has the potential to provide trustworthy, relative ground motion rates for low to high velocities, thus enabling us to first draw conclusions regarding internal landslide processes and second, to use optical satellite data for validation purposes. Image registration on optical imagery enables landslide displacement investigations. Nevertheless, both algorithms profit from each other, as DIS is able to reflect a wide velocity range but seems to underestimate displacements revealed by PC (Fig. 2). This results in noise if displacements are too high.

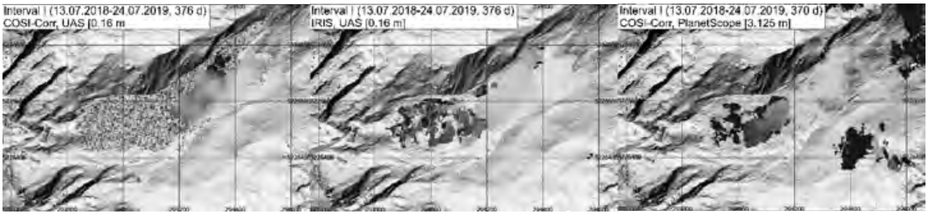

Figure 1: Total displacement results of phase correlation algorithm for UAS (0.16 m) and PlanetScope (3.125 m) for the same interval (13.07.2018-24.07.2019, 376 days). UAS results are calculated using COSI-Corr (left) and IRIS (middle).

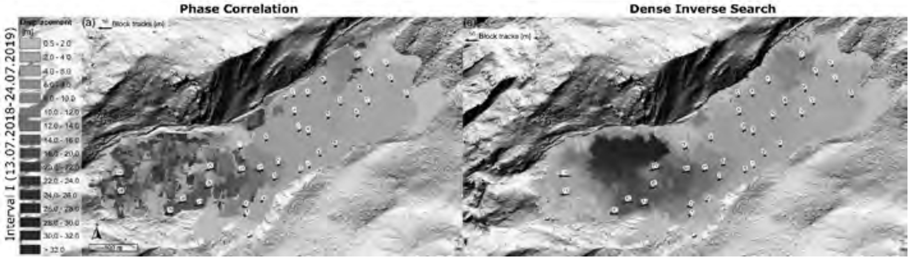

Figure 2: Total displacement results of phase correlation algorithm (IRIS) and optical flow dense inverse search (IRIS) for the first UAS time interval (13.07.2018-24.07.2019, 376 days). Arrows indicate manually measured boulder tracks for the corresponding interval based on UAS orthophotos.

Altena, B., Kääb, A. (2017). Weekly Glacier Flow Estimation from Dense Satellite Time Series Using Adapted Optical Flow Technology. Frontiers in Earth Sciences 5 (53), 1–53. DOI: 10.3389/feart.2017.00053.

Anker, F., Fegerl, L., Hübl, J., Kaitna, R., Neumayer, F., Keuschnig, M. (2016). Geschiebetransport in Gletscherbächen der Hohen Tauern: Beispiel Obersulzbach. Wildbach- und Lawinenverbauung 80, 86–96.

Ayoub, F., Leprince, S., Avouac, J-P. (2009). Co-registration and correlation of aerial photographs for ground deformation measurements. In: ISPRS Journal of Photogrammetry and Remote Sensing 64 (6), 551–560. DOI: 10.1016/j.isprsjprs.2009.03.005.

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Deriving key input data for hydraulic modelling of sediment transport in an Alpine proglacial outwash plain

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The evident mass loss of glaciers over the past decades is coupled with shifting runoff dynamics and highly intensified geomorphic processes particularly in headwater catchments on the verge of deglaciation (e.g. Fischer et al., 2021; Heckmann et al., 2016). The progressive down wasting of glaciers results in an increasing exposure of unconsolidated sediments impacting the catchment-scale sediment dynamics. The induced changes in sediment fluxes can have considerable implications for the operation and management of water resources, especially for hydro-electric power facilities in otherwise non-regulated glaciated catchments. Bedload-bearing outwash plains are a widespread feature in deglaciating catchments and often serve as an area of re-deposition under average runoff conditions (e.g. Porter et al., 2019). During high, respectively extreme runoff events, the proglacial areas connect with the downstream catchment, delivering subglacial sediments to lower stream sections (e.g. Comiti et al., 2019; Lane et al., 2017). As such, they represent key elements in high-alpine river systems and are an important component in determining the upstream boundary conditions of a catchment. Yet quantifying bedload transport in the paraglacial transition zone is a challenging task. The typically remote location of outwash plains in the proximity of retreating glaciers usually complicates direct measurements, especially since the area under investigation is prone to frequent geomorphic processes and changes. However, quantitative data on sediment yields from glaciated catchments is needed to contribute to the sustained effort of the research community to understand global to local and inter- and intra-catchment controls (Carrivick and Tweed, 2021) on sediment yields. In this work we present a feasible methodological approach to parameterize key characteristics of an Alpine proglacial outwash plain (Jamtal valley, Austria). Close range sensing techniques such as RGB imagery obtained from terrestrial and UAV-borne cameras are engaged in addition to conventional runoff measurements to overcome data scarcity in the paraglacial process domain, enabling modelling of sediment fluxes on sub-catchment scale. The key parameters considered in this study include (i) high spatial and temporal resolution models of the frequently changing topography as well as (ii) discharge and (iii) sediment properties in the investigated proglacial outwash plain (Fig. 1). Such data are crucial for model parameterization and calibration in the context of hydro-morphological modelling. In this work, we employed UAV-based surveys using RGB imagery to reliably capture (i) topographic information together with geometric surface roughness and (iii) grain size distribution in a combined approach. Discharge properties (ii) such as inundation areas and water level elevations are semi-automatically derived from stationary time-lapse images (Fig. 2), supported by maximum water level gauges located in the outwash plain. This multi-method approach provides key input and calibration data for applied hydraulic modelling. In summary, we present how the different data sets are derived and combined to finally obtain a best estimate of the parameterization of the hydraulic and morpho-dynamic model.

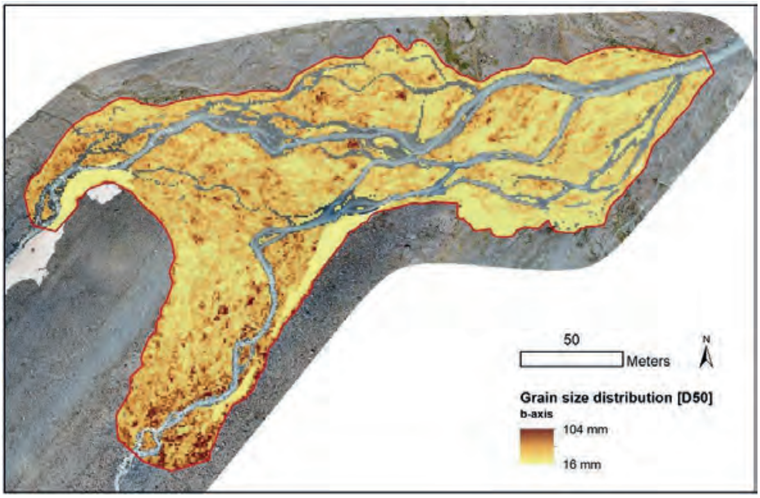

Figure 1: Grain size distribution (D50), derived from geometric surface roughness in the outwash plain of the Jamtalferner glacier. The underlying topographic model and orthophoto are based on SfM-MVS photogrammetry.

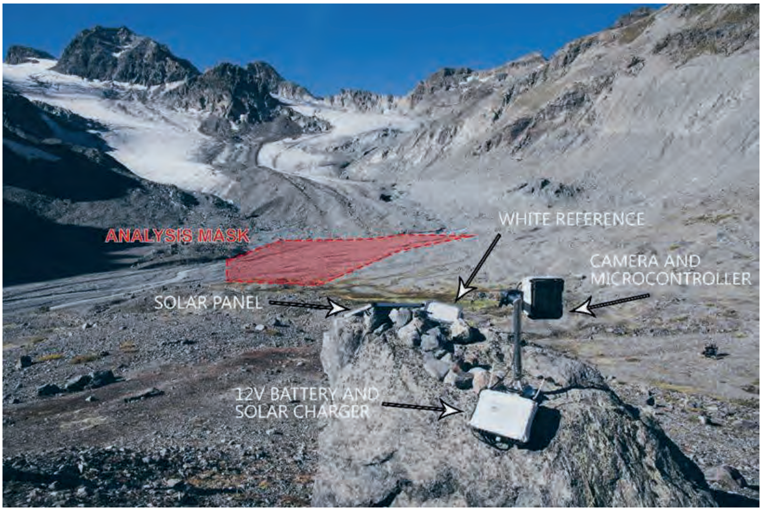

Figure 2: Setup of terrestrial time-lapse camera near Jamtalferner glacier (view to south-west), overlooking the proglacial outwash plain highlighted in red. Adapted graphic after Weisleitner, K. 2021.

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Application of high-resolution bathymetric laser scanner data on sediment transport models of alpine rivers considering micro- and macro-structures

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The application of hydrodynamic-numerical models and sediment transport models support the understanding of hydraulic and morphological processes in rivers. While sediment transport models deliver reliable results for gravel-bed rivers, their application comes with high uncertainties for steep, alpine rivers. Alpine rivers are characterized by complex micro and macro structures. Neglecting these structures lead to an overestimation of transport capacities and thus, uncertainties in the model results (Gems, 2011; Rickenmann, 2017). Applying sediment transport formulas and modelling morphological processes, first sedimentological parameters for boundary conditions need to be acquired (Klar, 2016; Tritthart, 2011). While traditional mechanical sieving and surface sampling are time consuming, cost and labor intensive (Fehr, 1987; Bunte and Abt, 2001), the estimation of grain size distribution out of ground-level images already accelerates the data acquisition (Adams, 1979; Ibbeken und Schleyer, 1986). Considering large-scale catchment areas, UAV-based photogrammetry offers the more efficient method (Lang et al., 2021; Buscombe, 2020). Despite a successful trained convolutional neural network to acquire grain size distribution the method shows lower performance by larger grain variability and larger, individual grains (Lang et al., 2021). Here, a topographic laser scanner using the infrared wavelength can capture high-resolution topographic data. For topo-bathymetry laser scanner data, the green wavelength range ($\lambda = 532$ nm) is applied (Mandlburger et al., 2011; Steinbacher et al., 2012). Airplane-based topographic and bathymetric laser scanner data have already been applied to a number of different hydrodynamic-numerical and sediment transport models (Sundt et al., 2021; Tonina et al., 2020). After airplane-based data acquisition, now UAV-borne topographic and bathymetric laser data offer a promising method for higher resolution and better data acquisition in difficult to access high-mountain areas. With the ongoing developments in airborne laser scanning and photogrammetric data acquisition, there is an efficient method to acquire relevant morphological features in more detail. Capturing micro and macro structures in high resolution data, sediment transport process in alpine rivers can be modelled more precisely. With my PhD-project, I want to show, that the application of high-resolution topographic and bathymetric data in sediment transport models can reduce these uncertainties by considering micro and macro structures in detail.

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Reconstruction and monitoring of urban trees from dense MLS point clouds

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Trees are an indispensable part of the environment in most regions of the world. In combination with densely urbanized areas, monitoring of trees, especially along road corridors, becomes more and more important. On the one hand, trees contribute to an improvement of their direct surrounding's micro-climate and quality of living. On the other hand, conflicts regarding spatial extent in densely populated areas or possible dangers by breaking tree parts must be dealt with. To meet these requirements, we propose tree monitoring by evaluation of 3D point cloud data. In urban areas, Mobile Laser Scanning (MLS) is a fitting choice for road corridors and traffic space. In more natural environments, precise and detailed measurements of a tree's structure can be obtained by Terrestrial Laser Scanning. This work focuses on the processing of dense point clouds, including the fine structure of branches. Our proposed workflow starts with the segmentation of individual trees [overview in Hirt et al., 2021a], so that a point cloud for each tree can be derived. The main step consists of modeling trees. Here the question of the type of modeling is of great importance. For simple tree inventories, parametric description of the trees in terms of height, diameter at breast height and crown extent might be sufficient. Figure 1 gives a visualization of simple tree models derived from DBH and height. This can be useful in the context of urban planning. For more detailed, structural monitoring, a model of the inner crown structure is needed, too. In that context, skeletonization and Quantitative Structure Models are investigated. On the basis of geometric measurements and model representation, the last step is the detection of changes between several epochs. As shown in a recent publication [Hirt et al., 2021b], detailed geometric change evaluation is possible on the basis of occupancy grids (Fig. 2). Moreover, the direct comparison of tree objects in terms of their parametric representation gives information on growth or changes in tree stock. In conclusion, the general direction of research aims at methods for processing dense point clouds of irregularly shaped objects. The main challenges are the properties of trees: no simple geometric primitives are available for straightforward modeling; the continuous change of an object by growth must be distinguished from changes caused by external factors; and the general appearance changes over the course of the year. Applications lie - defined by the topic - primarily in urban areas. However, this can be extended to all areas where in general monitoring is necessary, e.g. the surroundings of railway routes or exposed areas, where storms might cause damage.

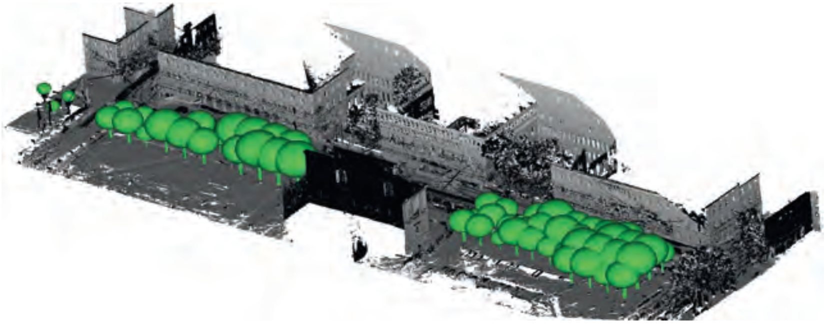

Figure 1: Simple parametric tree models in the context of an urban MLS point cloud.

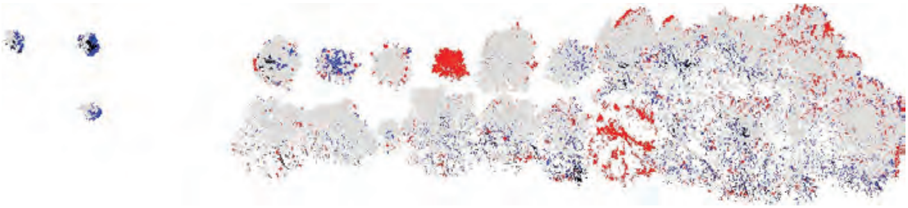

Figure 2: Changes in point clouds between 2016 and 2018 (seen from above). Blue color indicates voxels with new occupation, red color areas where points disappeared. At black voxels, a decision is not possible due to missing information in one of the epochs. Grey means no change.

Hirt, P.R., Hoegner, L., Stilla, U. (2021a). A concept for the segmentation of individual urban trees from dense MLS point clouds. The International Archives of the Photogrammetry, Re- mote Sensing and Spatial Information Sciences, XLIII-B2-2021, 171–178. doi:10.5194/isprs- archives-XLIII-B2-2021-171-2021.

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Combining high resolution point clouds and Sentinel data for habitat classification and monitoring

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Green spaces, from small urban structures like rooftop gardens and single street trees up to large grass and forest areas, serve as important resources for climate-relevant, ecological and social environment functions. The monitoring of these areas in order to protect and improve the current functional status is an important topic. Classification and monitoring of areas with biodiversity worth of protection (e.g. Natura 2000 areas, EU's Habitat's Directive, see European Commission 2006) as well as green infrastructure in settlement areas are legally required and obligatory within the scope of national and international reporting agreements. By date, the majority of these surveys is conducted (semi-) manually with expert-based field classification. Due to the resulting expenses of field work, the repetition rates of these surveys necessary for monitoring and change detection are limited. The motivation of my current research is to support this labor-intensive process with machine learning classification based on the combination of spatial high resolution airborne laser scanning (ALS) and image matching (IM) data with temporal high resolution data from ESA's Sentinel missions (Sentinel 1 & 2). Previous studies have shown the high potential of ALS and IM data for morphological plant characteristics (Hollaus, et al., 2009, Koenig and Höfle 2016, Puliti, et al., 2017) as well as the potential of Sentinel data for phenological characteristics (Dostálová, et al., 2018, Immitzer et al., 2019, Dostálová, et al., 2021), which both show great relevance for characterizing plant types, communities and their conditions. The aim of the approach is, besides initial classification, an (semi-) automated process for constant monitoring. First results on test areas (see Fig. 1 and Fig. 2) within the City of Vienna show that the combination of Sentinel data with ALS and IM based features have high potential for delineation of different habitat types following the EU's Habitat's Directive.

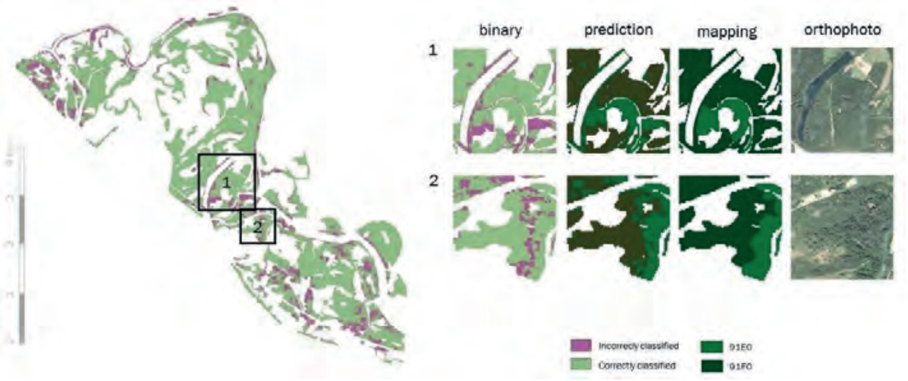

Figure 1: Forest habitat classification according to the EU's Habitats Directive Classification (European Commission 2006) using a 10-fold spatial cross validated random forest model at the test area Lobau, Vienna.

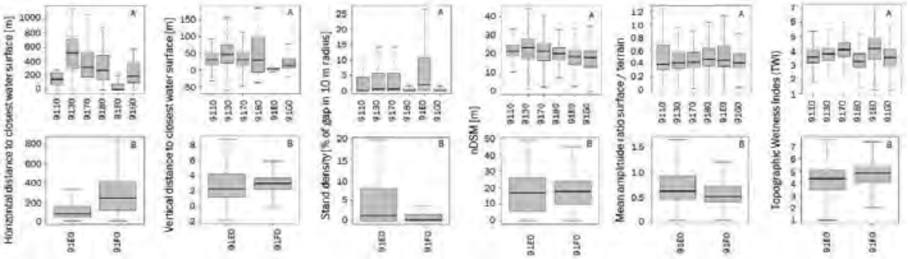

Figure 2: Explorative analysis of the distribution of chosen ALS-features grouped by different forest habitat types (European Commission 2006)

Dostálová, A., Lang, M., Ivanovs, J., Waser, L. T., Wagner, W. (2021). European Wide Forest Classification Based on Sentinel-1 Data. Remote Sensing, 13(3), 337. doi.org/10.3390/rs13030337.

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Low-cost stereo-cameras and photogrammetry for high-frequency 3D reconstruction of alpine glaciers morphology

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Photogrammetry and Structure-from-Motion are widely assessed tools for geomorphological 3D reconstruction and monitoring hardly accessible alpine environments. Time-lapse cameras are frequently used to retrieve information on glacial flows (Messerli et. al., 2015). However, only one camera is often employed, preventing photogrammetric reconstructions. This work presents a low-cost stereoscopic system composed of two time-lapse cameras for monitoring the north-west tongue of the Belvedere Glacier in the Italian Alps (Ioli et al., 2022). Each monitoring station includes a DSLR camera, an Arduino microcontroller for camera triggering, and a Raspberry Pi Zero with a SIM card for sending images to a remote server. The instrumentation is enclosed in waterproof cases. The system was built as part of the DREAM (DRone tEchnnology for wAter resources and hydrologic hazard Monitoring) project, involving teachers and students from Alta Scuola Politecnica of Politecnico di Milano and Politecnico di Torino. During summer 2021, the cameras were installed on each side of the glacier terminus, and they are currently taking daily images. Due to the wide baseline (i.e., ~260 m), Feature-Based Matching (FBM) techniques fail to find enough homologous points for estimating the orientation of the cameras. State of the art deep learning matching methods, such a SuperGlue (Sarlin et al., 2020), outperform traditional FBM. Learning-based densification algorithms are currently under study for obtaining dense point clouds of the glacier terminus, to be used for glacier motion estimation. Once properly tuned, this low-cost stereoscopic system will enable continuous photogrammetric monitoring of an alpine glacier, along with computation of short-term velocities and ice volume variations.

Figure 1. One of the two monitoring stations, with the camera enclosed in the waterproof case

Figure 2. Stereo-pair of images acquired from the two cameras on 11.08.2021.

Ioli, F., Bianchi, A., Cina, A., De Michele, C., Maschio, P., Passoni, D., & Pinto, L. (2022). Mid-term monitoring of glacier's variations with UAVs: the example of the Belvedere Glacier. Remote Sensing, 14(1), 28.

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Dynamics of the river landscape as a natural hazard to segregated Roma settlements

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One of the manifestations of climate change is the worldwide increase in the intensity and frequency of extreme hydrological events, such as floods or droughts. In Slovakia, a significant number of settlements lie close to rivers and are therefore potentially exposed to floods. Besides the river proximity, the flood risk is dependent on resilience and coping capacities of affected communities, too. Processes such as spatial segregation can then affect an excluded community twice. On the one hand, by pushing them into otherwise uninhabited floodplains, which are more susceptible to flooding and, on the other hand, by increasing their flood vulnerability. A prime example of spatial segregation in Slovakia are marginalised Roma communities (Rochovská & Rusnáková, 2018). While the aspect of their increased vulnerability has been addressed in several studies (Filčák, 2012), the natural hazards that their environment poses to them has not been addressed so far. Our research therefore focuses on the assessment of the flood hazard in those communities on the national level. Higher flood hazard among Roma communities in relation to the rest of the population could be the prove of environmental injustice towards them. But the flood hazard only describes the state at a given point in time and contains no information in regard of the dynamics of inundation processes. It cannot describe the spatio-temporal changes that are taking place in the human-river system. Therefore, we also focus on the selected communities individually and study their evolution as a coevolution of these systems, applying a socio-hydrological approach (Sivapalan et al., 2012).

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Capturing forest diversity: Mapping forest habitat types for nature conservation using remote sensing technics

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Priority habitat types (HT) within the Natura 2000 network are of the highest conservational importance in Europe. However, they often occur on smaller areas and their conservation status lacks trustworthy information. Among them is also the HT of Tilio-Acerion forests of slopes, screes and ravines. To improve the assessment of conservation status and management of this priority HT we performed a study in Natura 2000 site Boč-Haloze-Donačka gora in Slovenia. Our research was conducted in two phases: (1) field mapping of selected 9180* HT (in 2020) and (2) assessment of their characteristics using remote sensing data in relation to stand structure and topographic factors. We distinguished between four pre-defined habitat subtypes: a) *Acer pseudoplatanus-Ulmus glabra* stands growing mostly in concave terrain; b) *Fraxinus excelsior* stands growing on slopes; c) *Tilia sp.* stands with thermophilous broadleaves occurring on exposed ridges and slopes; d) *Acer pseudoplatanus* stands occurring on more acidic soils with frequent admixture of *Castanea sativa*. Our results show that subtypes of *Tilio-Acerion* HT differ significantly in terms of area they cover and can be distinguished based on the tree species composition, forest stand characteristics, relief features and various threats they experience. This study provides a baseline information for setting more realistic objectives for conservation management and increasing conservation efforts of priority forest HT.

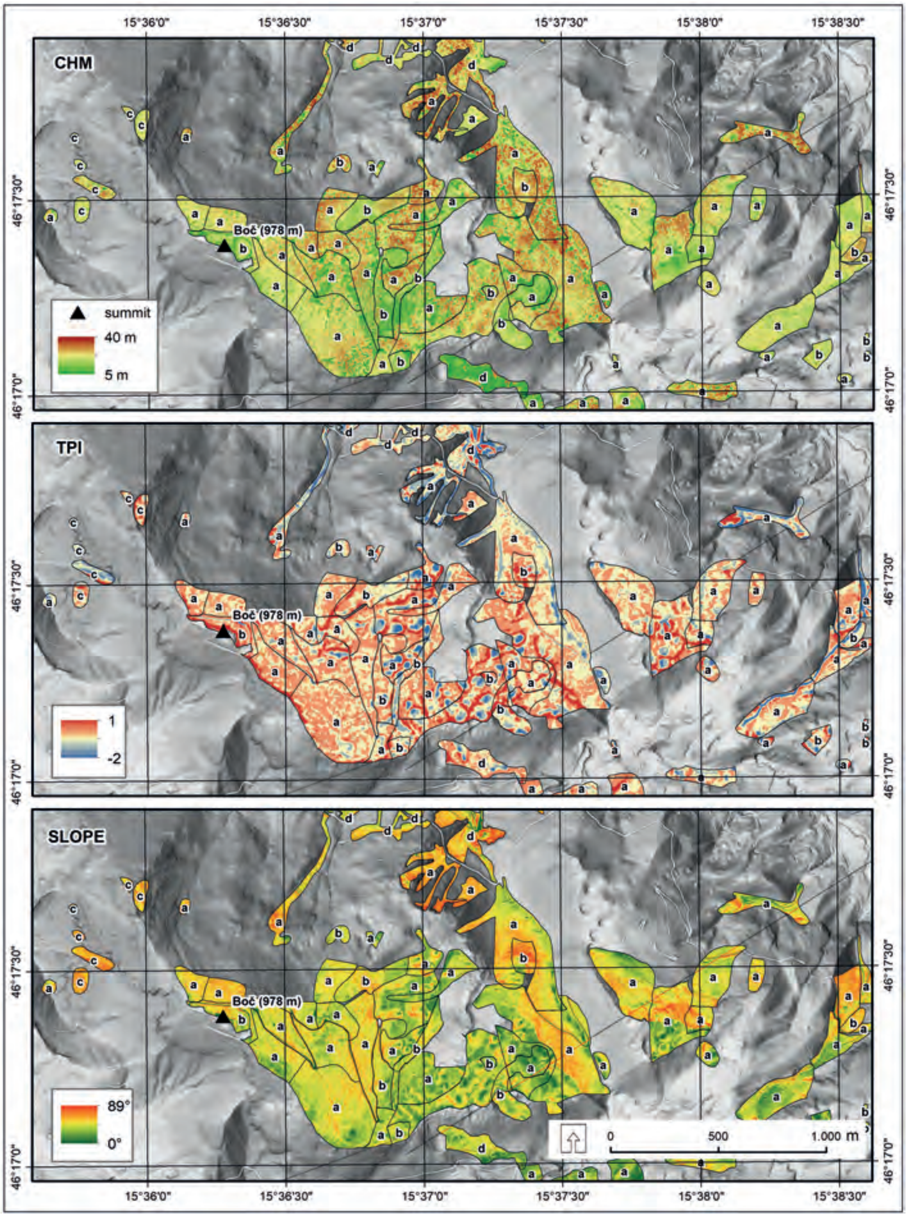
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Figure 1: Maps illustrating the Canopy Height Model (CHM), Topographic Position Index (TPI) and Slope. Higher TPI values denote convex topography (e.g., ridges) whereas lower TPI values are for concave terrain (e.g., dolines). The letters within the polygons represent the forest habitat subtypes which are the following: (a) – Acer pseudoplatanus-Ulmus glabra stands, (b) – Fraxinus excelsior stands, (c) – Tilia sp. stands and (d) – Acer pseudoplatanus stands on acidic soils with admixture of Castanea sativa.

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Optimizing estimation of regolith cover to improve landslide analysis

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Proposed research understands regolith as the entirety of the unconsolidated material above fresh bedrock. Knowledge regarding the regolith's spatial extent and its geophysical properties is crucial to evaluate landslide hazards. However, Reichenbach et al. (2018) illustrate the absence or limited input of regolith's spatial and geotechnical parameters in susceptibility studies, likely due to lack or heterogeneity of geological data in general, and regolith in particular. The objectives of the research are to optimize existing or develop new cost- and time-efficient methods to determine spatial extent and geophysical properties of regolith on a regional scale within an alpine environment. Two research areas were selected for this purpose: Walchental and Eselsbergbachtal in Styria, Austria. Besides conventional field methods, optimized estimation of regolith over large areas in mountainous terrain is believed to be possible with landscape evolution modeling (Richter et al., 2020) and remote sensing methods.

Besides evaluating existing terrain analysis and evolution computer models, the research will target remote sensing methods, such as hand-held LiDAR sensors and geophysical sensors (electromagnetic, magnetic, multispectral, radiometric) mounted on drones. It is anticipated that an optimized understanding of the regolith cover will be useful for improving landslide analysis, which subsequently will aid in communal and regional decision- making processes with regard to landslide prediction, monitoring and prevention. However, benefits of the results will extend to other application fields, such as forestry, hydrogeology and hydrology.

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Gap-fraction estimation in temperate rainforests from field and remote sensing UAV photogrammetry: challenges and opportunities

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[3] Interdepartmental Research Center of Geomatics (CIRGEO), University of Padova, Italy

This work compared methods for canopy gap-fraction estimation in temperate rainforests, southern Chile. The forest stands selected were classified by four different level of alterations, being altered mainly by anthropogenic factors, *e.g.*, forest fires, livestock, among others. Therefore, the main goal was to assess if alterations in *Araucaria-Nothofagus* forests can be detected to close range sensing techniques (*e.g.*, Dietmaier et al., 2017). Two field survey techniques to determine canopy cover, which are standardized methods within a conventional forest inventory (Hale & Brown, 2005) and four remote sensing (RS) methods that use unmanned aerial vehicle (UAV) imagery for extracting 3D point clouds were analysed to understand their ability to estimate gap-fraction and to detect alteration in temperate rainforests. The two field-based methods used were the canopy-scope instrument (CS) and the hemispherical photography (HP). The four RS methods spatially analyse the 3D points from the canopy to estimate gap-fraction values.

Main outcomes:

- the two-field survey methods gap-fraction results correlate with $R^2=0.58$
- two of the four RS methods have strong correlation with HP gap-fraction values ($R^2=0.68$); both weakly but significantly correlate with CS results with ($R^2= 0.34$ and 0.44, $p < 0.01$)
- no, low and medium categories can be distinguished significantly using either field methods or the two better performing RS methods, thus proving that RS is a viable alternative to field surveying
- discrimination between all categories, including medium and high can only be obtained by the best RS method tested and with high number of samples (Fig. 2)

The better remote sensing method has been developed ad-hoc for this work and is available as open source for further testing and applications (Pirotti, 2021).

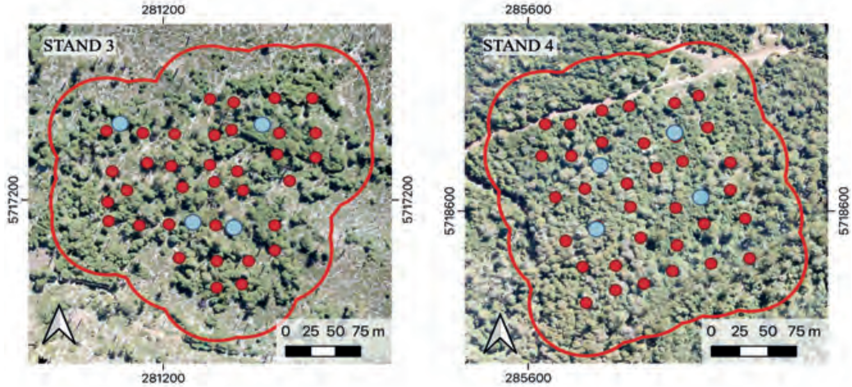

Figure 1: (left) Stand 3 and (right) Stand 4; systematic plots (red circles) and the four positions per stand (sky blue circles) where hemispherical photography and canopy-scope were used together. Coordinates are related to the coordinate reference system WGS 84 / UTM zone 19S.

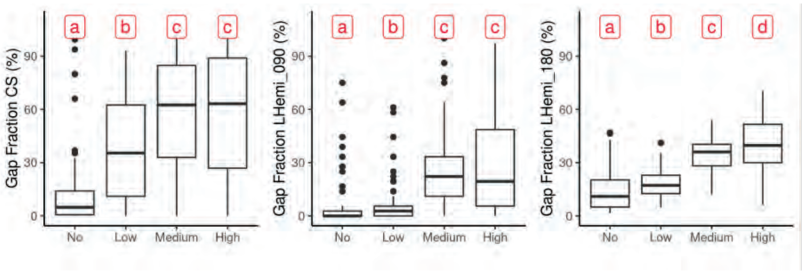

Figure 2: Canopy Scope (CS) (left), LAS Hemispheric photo simulation (LHemi) with 90° field of view (FOV) (center) and LHemi with 180° FOV (right) methods tested for group differences using Dunn test at 95% confidence over the 374 plots.

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Photogrammetric change analysis of rock structures in the alpine environment

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A major hazard potential in mountain regions are gravitational mass movements such as rock- and landslides. The increase in extreme weather events means an accumulation of such events. To better predict potential hazards, an effective monitoring is needed. For this purpose, we developed an acquisition strategy based on terrestrial images (Dinkel et al., 2020). To study the occurring motion, we follow two strategies. First, we are using point clouds from different epochs, which can be obtained by bundle adjustment and dense image matching. For comparison, the M3C2 distances (Lague et al., 2013) are calculated. The changes between two epochs are shown in Figure 1. The mean shows a value of 52 mm. The disadvantage of this strategy is, that the computed distances only detect the motions along the local surface normals. To solve this problem, we used the following strategy. By means of SIFT features (Lowe, 1999), corresponding key points in different epochs are found. From these results and the point coordinates, 3D motion vectors can be computed. The vectors are checked for significance based on their accuracy (Fig. 2). On average, a motion of 75 mm occurs. The vectors have a high spatial resolution compared to manually signed target points and are automatically detectable. A prominent example of such rock slope failure is the Hochvogel mountain in the Allgäu Alps. The Hochvogel consists of brittle carbonate rock and its flanks have an enormous steepness, which results in intense erosive activities. The summit is characterized by a huge crevice with a width from two to six meters and a depth up to 60 meters. The crevice divides the summit into a stable and unstable part. The expected rock slope failure has an estimated volume of potentially 260,000 m³ (Leinauer et al., 2020).

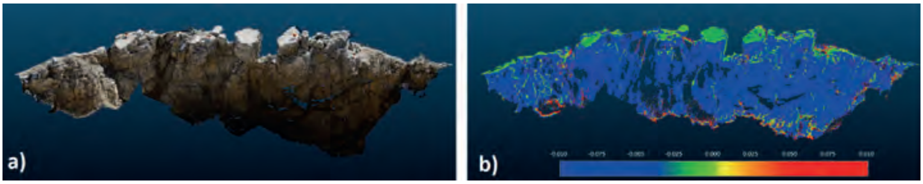

Figure 1: a) Point cloud of the sidewall of the crevice, b) M3C2 distances [m]. Changes corresponding to erosion have been removed.

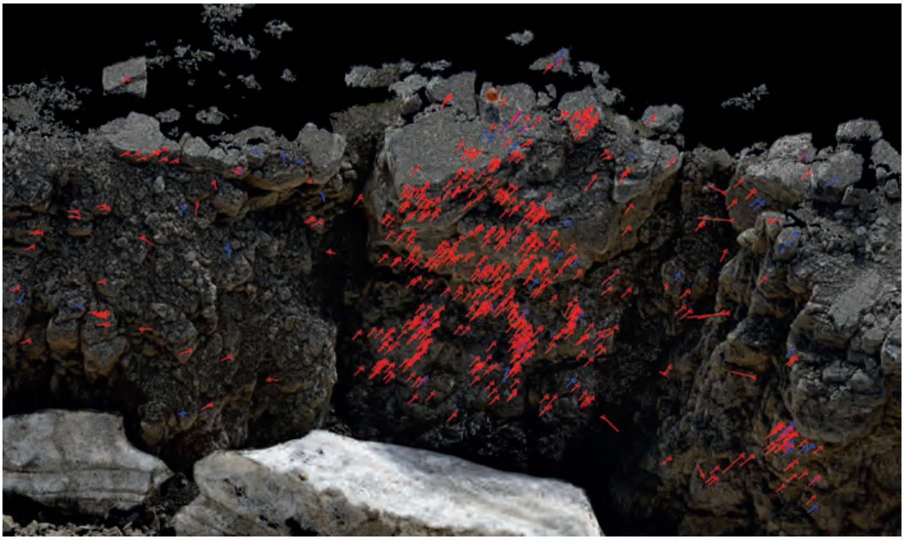

Figure 2: Motion vectors between the epochs. Red arrows belong to significant and blue ones to non-significant vectors.

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A methodological study testing the accuracy of uncrewed aerial systems (UAS) for monitoring the effects of conservation tillage on soil erosion

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Soil in good health is the cornerstone of agriculture. Holding global, national, and local importance fertile topsoil in England and Wales is being eroded ten times faster than it is created (WWF 2018). This can result in lowered crop yield, increased river pollution and heightened flood risk. Some farming practices, such as conventional ploughing, leave soils more vulnerable to erosion due to the heavy overturning of soil. Traditional methods of soil erosion monitoring can be labour intensive, time consuming and provide low resolution, sparse point data not representative of overall erosion rates. However, technological advances using Uncrewed Aerial Systems (UAS) can obtain bespoke, cost-effective, high-resolution data (typically 1-3 cm, dependent upon flight altitude) with relative ease, providing near-contactless data capture and complete coverage of the soil surface (Hugenholtz et al., 2015). Typically, analysing UAS-SfM derived Digital Terrain Models (DTMs) requires a survey prior to the erosion event with repeat monitoring for change over time to be quantified (Wheaton 2017). However, the ability of volume loss estimations without the pre-erosion data has emerged (Báčová et al., 2019). Therefore, this PhD research utilises UAS technology to; i) test the sensitivity of Rillstats software to calculate soil erosion volume by designing an optimum data collection workflow for, ii) determining whether conservation tillage reduces soil erosion compared to conventional ploughing.

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Digitalization and modeling of risk areas at the border territory: Understanding the past to save the future

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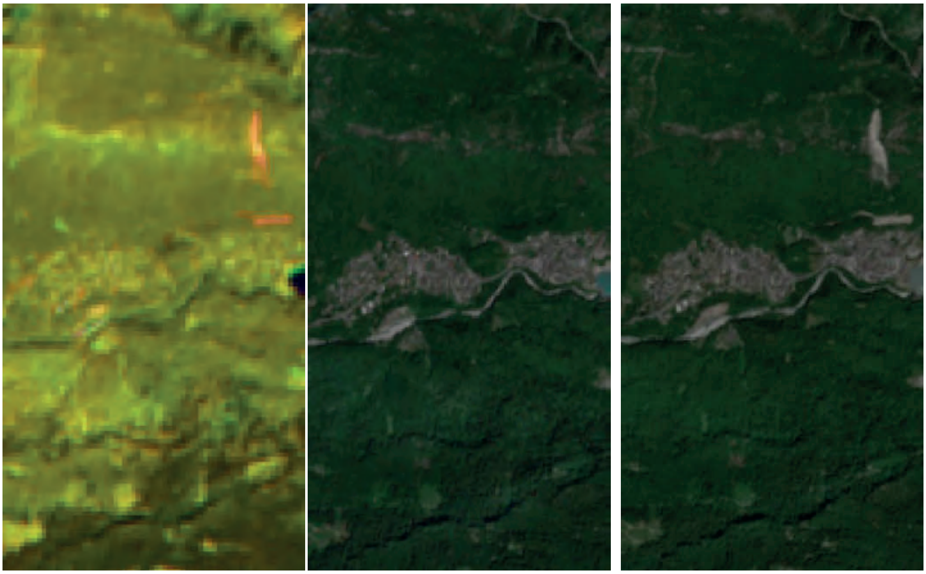
High resolution Digital Terrain Models (DTMs) are crucial to reconstruct the hydrogeological processes that shaped the Earth (Rocha et al, 2020). Where dense vegetation prevails, the production of high resolution DTM is not easy. The research is then centered on Mobile Mapping Systems (MMSs) based on SLAM algorithm: their use in environments that cannot be surveyed with other instrumentation makes them vital to produce high-resolution models (Marotta et al, 2021). The main weakness of this kind of devices lies in the achievable accuracy, since they do not rely on external georeferenced data; tests for improving the accuracy of such systems are carried out, taking advantage of sensors already integrated in the systems and complementary instrumentation (Marotta et al, 2022). The research project therefore focuses on the integration of point clouds acquired using several instruments to model changes occurred in the environmental heritage over time. This results in the integration of regional and large-scale local surveys. The case study identified in the IT-CH Interreg project A.M.AL.PI.18 is intended to be an example of integration of competences in the surveying of the territory. The last aspect of the research concerns the proposal of a rapid landslide inventory mapping by using satellite Sentinel-2 images; change detection analysis of couple of images is proposed. The automatic classification of these changes could be used to automatize the mapping process of updating in a rapid way the cadaster of natural disasters.

Figure 1: Ground point cloud of Piuro Valley, 4.5 km^2. IT-CH Interreg Project A.M.AL.PI.18 case study.



(a) (b) (c)

Figure 2: (a) Use of Sentinel-2 images to detect a landslide occurred in 2019. Images from (b) 2018 and (c) 2021.

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Assessing the vulnerability of alpine plants to extinction in a warming world

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Within mountain systems warming temperatures associated with climate change is altering plant species distributions. Many species upper elevational limits are moving upslope, as they attempt to track favourable climate (e.g. Jump et al., 2012). Species that exist close to mountain summits are expected to face population declines, however, as the land available for dispersal decreases towards the mountaintop. This 'elevator-to-extinction' will be exasperated by increasing competition with more generalist species and an advancing treeline. My project aims to assess the risk of alpine plant species to extinction in the Central Mountain Range (CMR) of Taiwan (Fig. 1.). To achieve this aim, I will map the current distribution of alpine plants and habitat in the CMR using remote sensing techniques. Extensive ground-truthing in the CMR will be conducted using Uncrewed Aerial Vehicle (UAV) devices with attached sensors, to ensure the accuracy of the vegetation mapping. I will then model the vulnerability of these distributions to future warming and changing tree species distributions using Species Distribution Models (SDMs). I will also quantify the relationship between mountain slope microclimate and vegetation composition using surface temperature measurements recorded with a thermal camera. The findings of my research will contribute to a greater understanding of the consequences of climate warming on tropical mountain biodiversity.

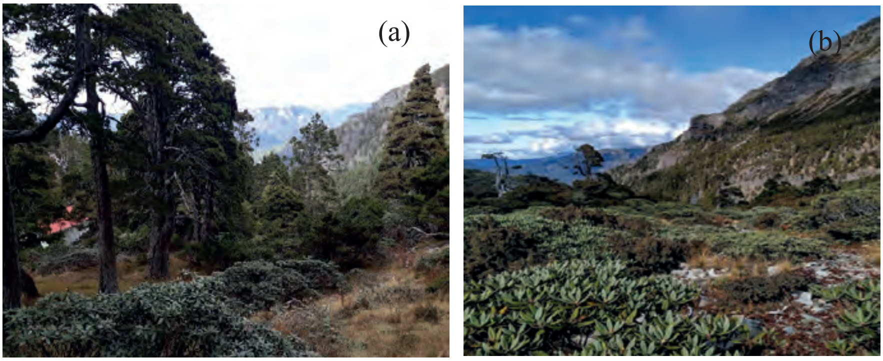

Figure 1: High-alpine habitat found within the Central Mountain Range of Taiwan. (A) shows habitat associated with the treeline ecotone and (B) shows an area dominated by Rhododendron shrubs above the treeline. Photographs: Stoll, E, 2019.

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Beach vulnerability assessment at the Island of Hvar

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Coastal areas are dynamic and complex geomorphological systems often today under strong socioeconomic pressure. One of the most endangered coastal geomorphological forms are beaches. Some recent work shows that 24% of beaches are subject to erosion and 28% of beaches are prograding, while 48% are relatively stable (Luiendijk et al., 2018). Climate change, sea level rise, and increasing anthropogenic pressures make beaches highly vulnerable today. One of the most appropriate methods to calculate and assess their vulnerability is the BVI - Beach Vulnerability Index. The BVI has evolved from the CVI - coastal vulnerability index (Gornitz, 1990) and was developed by Alexandrakis and Poulos (2014). In this work, the vulnerability of beaches on the island of Hvar is assessed by combining different parameters such as beach erosion, morphometric characteristics, land cover change, wave action and anthropogenic impacts at about 40 sites. Different methods are used to analyze each parameter, including method of repeat photography, analysis of archival maps, field work (Fig. 1ab) and remote sensing method using UAV (uncrewed aerial vehicle) and satellite imagery. Remote sensing methods revealed to be very satisfactory for beach geomorphological investigations (Mićunović et al., 2021), therefore the application of remote sensing is further developed in this work. Data collected from the UAV or satellite imagery has been processed in combination with GNSS control points in Drone2Map and Agisoft photogrammetric software (Fig. 1c), and data analyses has also been performed using ESRI ArcGIS Pro software. During my PhD research, data will be collected by UAV several times a year to monitor changes in beach morphology. These results and those calculated by BVI, should contribute to further sustainable coastal management.

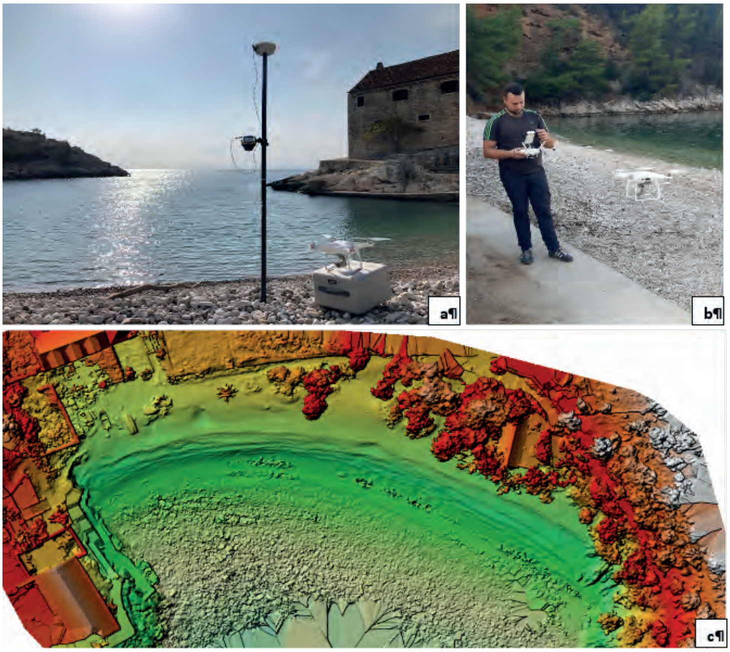

Figure 1: a & b – fieldwork and equipment; c –Dubovica beach DSM (0.02 m resolution)

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Cross-correlation of optical satellite data for the detection and monitoring of slow-moving landslides in northwestern Argentina

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The increase in freely available optical satellite data with 10-15 m spatial resolution provides new opportunities to detect and monitor slow-moving landslides through image cross-correlation in difficult-to-access regions world wide (e.g. Lacroix et al., 2018, 2019, Stumpf et al., 2018). Here, we explore this potential using Landsat-8 and Sentinel-2 optical satellite imagery to detect and quantify slope movements in the northwestern Argentine Andes over the past eight years. Our study takes advantage of the large spatial and temporal availability of optical satellite imagery, but also highlights the caveats associated with cross-correlation for slow-moving targets. The northwestern Argentine Andes, particularly the mountain ranges that border the Central Andean Plateau (Altiplano-Puna Plateau), are predisposed to slope movements because of their steep hillslopes, weakened lithologies, sparse vegetation cover, and frequent rainfall events (Bookhagen and Strecker, 2012). Previous studies based on radar interferometry have identified several landslides moving at ~1 m/yr throughout our study area (Aref et al., 2021). We use these areas of known offset together with synthetically generated displacement fields to identify optimal processing routines, evaluate their accuracy, and define the limitations of monitoring the movement of slow-moving landslides with optical imagery. To cope with the difficulties associated with offset tracking over slow-moving areas (limited resolution, decorrelation over longer time spans), we develop pre- and post-correlation filtering approaches to reduce noise and increase signal strength. Our results are further validated through correlating higher-resolution PlanetScope imagery (3 m), see Figure 1, which has been shown to measure offsets to the precision of 1/100 of a pixel = 0.03 m (Mazzanti et al., 2020). In this way, we aim to better constrain the distribution of slow-moving landslides throughout our study area and understand the driving factors of past and present slope movements at the regional scale.

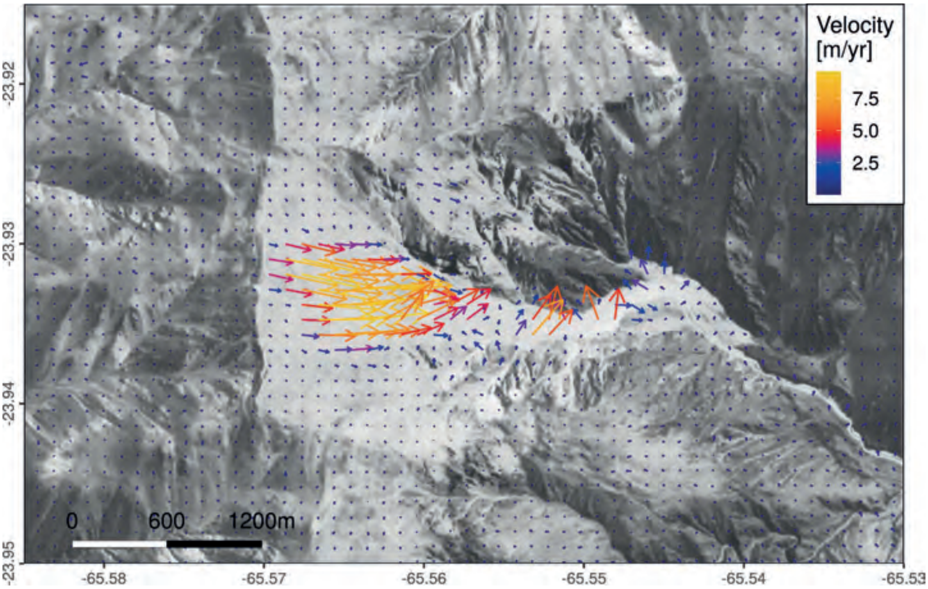

Figure 1: Estimated motion velocity of a slow-moving landslide close to Volcán, Jujuy, Argentina. The offset was derived using autoRIFT (Gardener et al., 2018) together with 3 m resolution PlanetScope imagery acquired in October 2017 and 2019.

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Quantification of soil erosion by water using high-resolution contactless measuring methods on arable land

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Soil erosion by water is a widespread problem in Europe and elsewhere (Panagos et al. 2016), which is particularly aggravated by the current increase of summer drought combined with extreme heavy rainfall events (European Union 2006). The complexity and discontinuity of erosion processes on cultivated farmland make it difficult to quantify the amount of soil material that is eroded and relocated. High-resolution measurement methods like UAV-photogrammetry or terrestrial laser scanning (TLS) have already been used in different studies to estimate soil erosion under controlled conditions (Eltner et al. 2013; Eltner et al. 2016; Meinen and Robinson 2020; Cândido et al. 2020). In my work I aim at the quantification of especially diffuse soil erosion (sheet and interrill erosion) on cultivated cropland. Within a multi-temporal approach, I use TLS as well as a Structure-from-Motion technique to capture the microtopography of the soil surface and monitor soil surface changes. The study area is located on farmland which is, for 20 years, part of a long-term soil erosion monitoring program in Northern Germany (Steinhoff-Knopp and Burkhard 2018). A first field campaign was carried out in late spring of 2021 (Fig. 1), in the course of which four plots were selected based on previously recorded erosion events considering different gradients in the microtopography within a thalweg. To reduce masking of soil surface changes due to erosion by other surface processes I used a higher observation frequency on weekly basis from spring to early summer and recorded further parameters like rainfall, bulk density and soil moisture. Capturing these influencing factors contributed significantly to the identification of the processes changing the soil surface. While the georeferencing of the received data in the field could be kept (relatively) stable, the high clay content of the soil in combination with changing soil moisture content is very likely to have caused changes in soil height due to swelling-and-shrinking processes. Furthermore, the growing vegetation coverage led to increasing registration uncertainties as well as expected enlarging shadows in the point clouds. The field campaign revealed that the used measuring system has the potential to detect soil erosion under field conditions but has to be improved as to increase the registration certainty, the vegetation detection and the frequency of parameter acquisition. An improved concept is in the planning to be tested this summer. Furthermore, the performance of different filter methods for cleansing the point cloud of vegetation is tested in the software CloudCompare to further enhance the results (Fig. 2).

Figure 1: Measurement set-up at one plot in Lamspringe (Lower Saxony, Germany). Photograph: Ott, S. 2021.

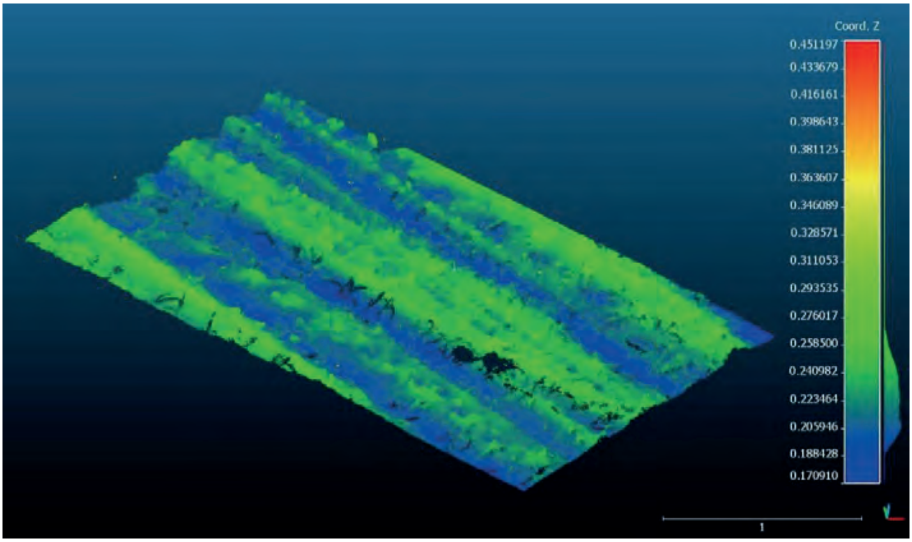

Figure 2: Point cloud representing the approximated soil surface after filtering with CANUPO and CSF algorithms to eliminate vegetation points. Design by Ott, S. 2022

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Methods of deformation analysis in 3D point clouds for geo-monitoring applications

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Geo-monitoring gains more and more on importance and has already become an indispensable part of risk prevention in the Alps. Nowadays, various instruments and methods for the detection of deformations in the context of geo-applications such as landslides, rockfalls, solifluctional processes or other mass movements are available, each providing different characteristics in temporal resolution, spatial resolution and measurement accuracy. Geodetic measurement instruments like GNSS receivers and tacheometers are capable to determine 3D deformation vectors including the displacement direction and magnitude. However, these point-wise measurement methods are limited to a number of preselected points. Only with the inclusion of areal measurement systems, the whole hazardous area can be covered in detail. Therefore, terrestrial laser scanning (TLS) and areal deformation analysis are already established in geo-monitoring. Point clouds provide a nearly continuous digitalization of the reality that allows for detecting geometric changes with high spatial resolution. However, using point clouds for geo-monitoring poses new challenges. Amongst others, a major challenge is the absence of identical points across the different measurement epochs. Dealing with this issue, several approaches have been developed to calculate deformations from two point clouds. Nevertheless, a statistical congruency test based on identical measurement points is still only possible in a few cases (e.g., Wunderlich et al. 2020). The implementation of such a rigorous strategy is still a matter of research. Within the project AlpSenseRely, my research pursues a novel monitoring approach for the integration of laser scan data into rigorous deformation analysis. This strategy includes (i) the extension of point- wise measurements by small-scale laser scans, (ii) the extraction of virtual target points from those point clouds based on ICP matching, and (iii) the integration of those points into network adjustment and subsequent deformation analysis. This allows to set up a combined monitoring network consisting of signalized and non-signalized points. The research project includes the monitoring of Mt. Hochvogel (Fig. 1) where the developed method is applied and verified. We already showed that with our combined approach we were able to improve the monitoring network and thus the resulting deformation vectors at Mt. Hochvogel (Raffl & Holst, 2022).

Figure 1: Mt. Hochvogel (2592 m a.s.l.) is one study site within the research project AlpSenseRely where new geo-monitoring strategies are developed and tested.

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The GEOframe system for the hydrological modelling and water budget quantification of the Po river basin - snow runoff production

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Snow is an essential component of the hydrological cycle in mountainous areas and in higher latitudes regions. Snow can accumulate and store important quantities of precipitation and modulate the water flow downstream at daily and monthly timescales. This influence is particularly important for the water supply during summers and dry periods, especially in a basin like the one of the Po River, characterized by the presence of the Alps along all of its route. Snow distribution in alpine regions can dominate local and regional hydrology, strongly influencing vegetation growth and the utilization of water resources (Wu et al., 2015). For this reason, a more accurate measurement or estimation of the snow precipitation and accumulation, both in time and in space, would be fundamental in water supply prediction and, thus, management. An improvement in this subject would also permit the study and development of an accurate tool calculating snowmelt, enabling a better modelling and forecast of the water availability in the Po River basin, also in a climate change scenario. Different methods and technologies to estimate snow precipitation and snow melt have been developed, especially for high elevation terrain areas, not easily reachable, in which the snow component measures and monitoring results are more difficult to achieve. Furthermore, in situ observations are of limited use for predicting snowmelt dynamics and are being outpaced by remotely sensed data and modelling approaches (Rice & Bales, 2010), which allow to monitor large regions also at longer timescales. However, snow cover data provide no or limited information on the actual amount of water stored in a snowpack, namely the snow water equivalent (SWE), which represents an essential hydrologic variable to evaluate the hydrological balance. The estimation of both the spatial and temporal distribution of the snow water equivalent and snow melt is important not only for flood or drought forecasting, but also for hydropower and irrigation in downstream areas. Even if the snow water equivalent can be reconstructed based on the integration of a simulated melt flux over the time period of remotely sensed observed snow cover, this method generates data only on the peak SWE value and introduces errors when snowfall occurs during the melt season (Durand et al., 2008; Molotch et al., 2009). The selection of a suitable snow model is essential to correctly represent snow cover and SWE. In this work, we are going to improve the snow component of the *GEOframe* modelling system (Abera et al., 2017; Bancheri et al., 2020), comprising the estimation of snow precipitation, accumulation, and snowmelt. The above-mentioned modelling system is a conceptual semi-distributed hydrological model, developed in the University of Trento, which is particularly suited for operational applications, thanks to its flexibility and modularity, and has been chosen by the Po River District Authority (AdbPo) to update the existing numerical modelling for water resource management in the whole the district. The implementation of the snowmelt component is expected to better estimate the main hydrological variables characterizing the territory of the Po River District, enhancing the capacity of water resources management impacts resulting from climate change or land use changes scenarios.

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Development of a drone-based ground-penetrating radar system to study internal glacier dynamics

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Ground-penetrating radar (GPR) has served as a key tool in the field of glaciology for more than 50 years thanks to the excellent propagation characteristics of radar waves in ice. Typically, alpine glacier GPR surveys are carried out directly on the surface of the ice (on foot, skis, or with snowmobiles), or via helicopter several tens of meters above the glacier. An advantage of helicopter-based acquisitions is that they allow the coverage of large areas; however, this comes at the expenses of reduced resolution of glacier internal structures, particularly in the context of 3D surveys (Grab et al. 2018). With ice-based acquisitions detailed 3D imaging is possible, but it is very time consuming to cover large areas (Egli et al. 2021). Surface features such as crevasses and moulins can make such surveys extremely dangerous and render many regions of the glacier inaccessible. Recent advances in the development of drones' technologies open new data acquisition possibilities for glacier GPR, which combine the advantages of both methods. We are in the process of developing a drone-based GPR system that allows for safe and efficient high-resolution 3D and 4D data acquisition on alpine glaciers. Our custom-built GPR instrument used real-time sampling to record traces of length 2800ns, which corresponds to a depth of over 200m in glacier ice. Traces are recorded at a rate of 14Hz, meaning that a drone speed of at least 4m/s can be considered while maintaining a sufficient high trace density for high-resolution studies. This is at least four times faster than a conventional survey on foot. We performed initial tests in the summer 2021 on two Swiss alpine glaciers (Fig. 1), and the recorded high-density 3D GPR data were successfully used to respectively investigate the ice-thickness distribution (Fig. 2) and the water-channels network of the glaciers. We are able, in a single day, to record more than 10km of high-resolution GPR data, with no physical effort and staying completely safe. Surveying the exact same area on a regular basis enables the investigation of temporal changes inside the ice (Church et al. 2020), and with our drone-based GPR system, we might be able to record high-density 4D GPR data and use them to track features inside the ice to quantify how much and in what direction the interior points of the glacier move, in 3D. The outcome of this work would be compared with the results of existing ice-flow models, to comfort or question their performances. To analyze these 4D GPR images, a statistical method, inspired from 4D seismic images analysis techniques, will be developed, starting with synthetic 2D and 3D data before moving toward real glacier 4D data. Finally, at the end of the project, the last objective would be to apply our new technology to some of glacier's most mysterious behaviors, as for instance glaciers surge mechanism or internal sediment's transport.

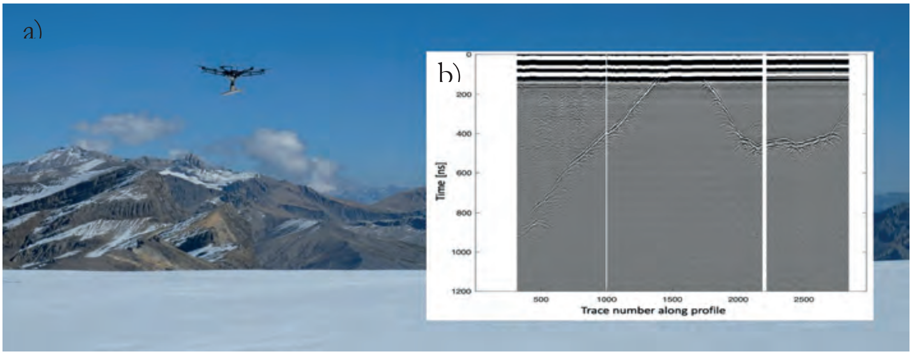

Figure 1. a) Drone-based GPR system operating over the Tsanfleuron glacier, b) Example of a GPR profile recorded with the system. The interface between rock and glacier is clearly visible.

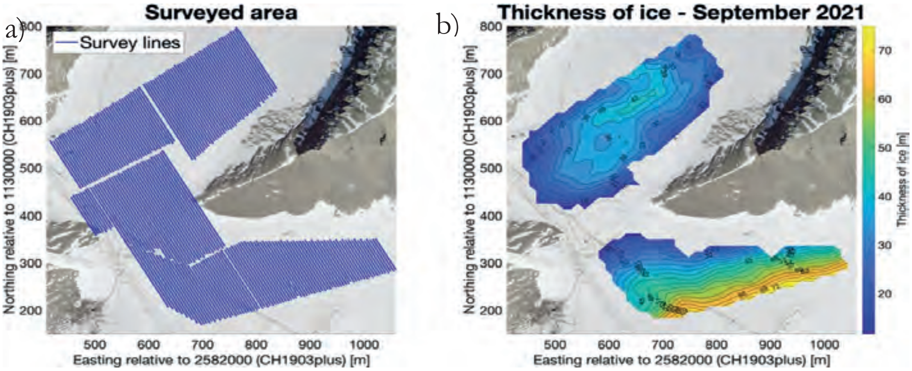

Figure 2. a) GPR survey lines flown on the Tsanfleuron glacier, b) Ice-thickness distribution below the surveyed area determined from the 3D GPR data (09/21).

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Efficient sensor pre-calibration for SfM photogrammetric surveys

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RPAS based SfM photogrammetry is widely applied in geomorphological research and there is a consensus that pre-calibration can improve the accuracy of the results in many scenarios by mitigating systematic errors from erroneous camera calibration. Using a separate calibration dataset avoids compromises in the acquisition of the survey dataset. This is especially useful when the application purpose restricts the optimization of flight plans towards convergent image networks. However, previous pre-calibration methods that follow the best practice established e.g., by Luhmann et al. (2016) were not designed for the application in fieldwork. Restricted fieldwork time schedules often conflict with calibration methods, especially, in repeat surveys and when multi-sensor RPAS are used. We have developed a targetless pre-calibration workflow (Fig. 1) that utilizes an on-site 3D structure, e.g. a building, as calibration object, by extracting coordinates of natural features from lidar scans, thermal and RGB sensor imagery (Senn et al., 2020). We have applied the approach to generate calibration parameters using different software solutions and scan setups and achieved calibration accuracies below one-third (optical) and one-quarter (thermal) of a pixel. Subsequently, we transferred the sensor parameters to pre-calibrate an SfM photogrammetric survey at a Scottish river and compare the results to a self-calibrated workflow (Senn et al., 2022). In a systematic experiment using the optical river survey dataset, we assessed the effectiveness of pre-calibration, oblique imagery, scale variation and masking to mitigate systematic DEM errors (Fig. 2). We achieved the overall lowest vertical offsets using pre-calibrated camera parameters generated by the specialized calibration software vision measurement system (VMS) and applied to a single-scale (30 m) nadir-only survey dataset. This finding could have implications for geomorphological surveys, in which single-scale datasets are widespread practice, despite literature's urge towards more complex imaging networks. In the self-calibrated scenarios, we found the best results by maximizing the variation of scale and view angles, whereas single-scale nadir-only resulted in the overall largest errors. Furthermore, we demonstrated the multi-sensor suitability of the approach by generating an orthophoto from a simultaneously acquired thermal dataset.

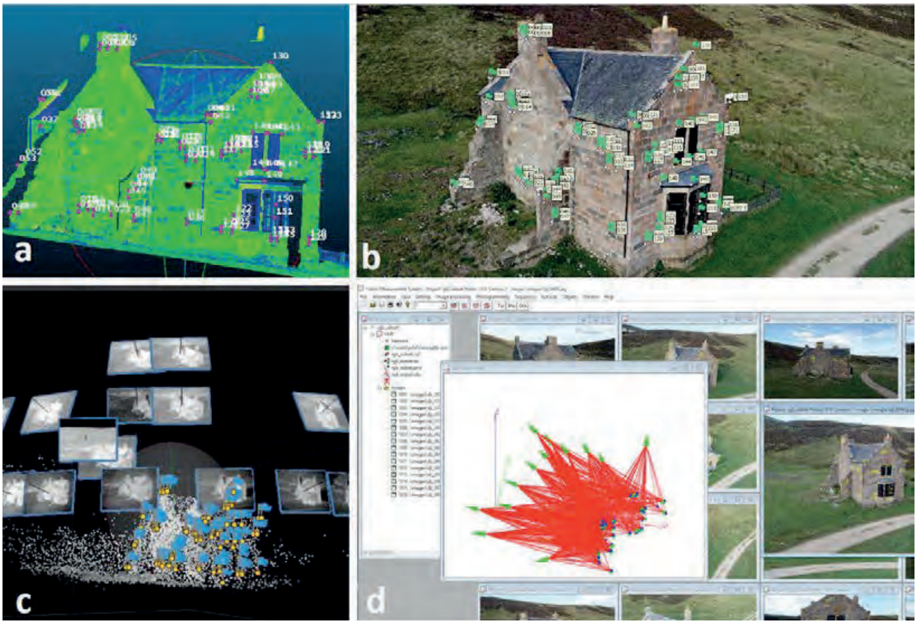

Figure 1: The sensor pre-calibration workflow illustrated by its application on a stone building at Corn- davon Lodge, River Gairn, Scotland (a) TLS point cloud, with reference points, (b) target observations on visible imagery in Agisoft Metashape (c) markers, aligned thermal imagery and sparse point cloud in Agisoft Metashape, (d) GUI with target observations in VMS.

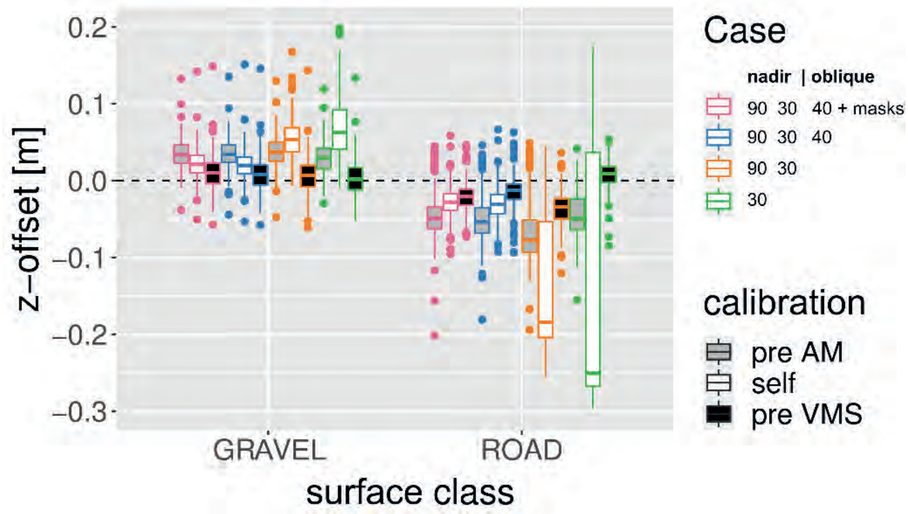

Figure 2: Vertical offsets between the GNSS reference points and the DEMs generated using different calibration methods and subsets of survey flights combining different flying heights and view angles.

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Mapping snow depth distribution and snow avalanches by unmanned aerial systems (UAS) in mountain ranges in Czechia

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Snow avalanche hazard in Czechia is mainly constrained to Krkonoše mountains. Although snow avalanches do not present a significant risk to the population in Czechia, the rising popularity of winter sports (off-piste skiing and ski touring) in recent years has led to an increase in social exposure to snow avalanches and thus a growing number of victims (Součková et al., 2022). Due to climate change, it is probable that more wet avalanches will occur, and the avalanche flow regime will change despite the current trend of declining snowpack and snow cover duration. There are approximately twenty snow avalanche releases every year which require the intervention of the mountain rescue team to help buried people. Although snow avalanches are a devastating natural disaster and cause economic damage and sometimes loss of life, not enough attention is paid to a spatial-temporal variability of snow depth of snow cover. High-resolution spatial-temporal snow depth information will contribute to detecting avalanche release zones to estimate and mitigate avalanche hazard. Moreover, ski resorts would also benefit from high-resolution snow depth maps to better redistribute snow on slopes throughout the season. A suitable tool for obtaining spatial information of snow depth might be UAS as they have the potential to enable timely, flexible, cost-effective, and primarily safer data acquisition in inaccessible, dangerous mountain terrain (Bühler et al., 2016). UAS can generate a digital surface model, terrain model, and orthophoto maps with high accuracy, of the order of cm to dm. Mapping snow depth of avalanche-prone zones and detection of the extent, and volume of an avalanche deposition will improve input data reliability to RAMMS model estimation and prediction of snow avalanche extent, in order to minimize the hazard.

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Interannual and seasonal surface change in a glacial-periglacial (de)coupled landscape and its implications on local hydrology in the semi-arid catchment of the Agua Negra river, Argentina

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High mountain regions are highly sensitive to changes in the global climate which is most clearly expressed in the near-global data sets on the retreat of mountain glaciers. While alpine ice glaciers are direct indicators of climate change, the effects of rising temperatures on the degradation of mountain permafrost are less obvious. Meltwater from glacial and periglacial features alike impacts the hydrological regimes as well as the sediment transport in the areas that the features are located in. In times of water scarcity and global warming special attention should be drawn to this effect. Glacial and periglacial features in the Agua Negra catchment (ca. 30°S and 69°W), located in the semi-arid Andes of Argentina, represent an essential water storage in the high-mountain environment. Due to sparse precipitation agricultural, industrial and domestic water use are dependent on meltwater from glaciers and snow as well as releases from the permafrost and its active layer (Falaschi et al., 2014; Lliboutry, 1998). The active layer within the discontinuous permafrost belt at 4000 m a.s.l. generally varies between 2-3 m and is reduced to a few centimeters above 5000 m, where continuous permafrost is present (Schrott, 1996 and 1998; Halla et al., 2021). Quantifying surface changes of the permafrost landforms (e.g. rock glaciers, block slopes) in the study area can substantially contribute to an understanding of subsurface ice, frost and permafrost variations. Furthermore, surface changes are indicators of gradual as well as catastrophic mass movements, thus, knowledge thereon being important for hazard analysis (e.g. Tanteri et al., 2017). Thawing and refreezing processes as well as permafrost degradation and debris movement can explain not only local patterns of surface changes but also meltwater contribution to runoff (e.g. Blöthe et al., 2021; Halla et al., 2021; Vivero and Lambiel, 2019). High-resolution investigations of surface processes are often drone-based using the techniques of structure from motion and feature tracking. Many of these studies spatially focus on one permafrost feature and are restricted in temporal resolution due to the need for field stays. Regional studies are commonly based on space-borne approaches, indicating regional trends but lacking error margins that allow for a spatially downscaled analysis. Most interestingly, neither the object-focused studies nor the regional studies are focusing on the catchment scale, despite the relevance for hydrological, often catchment-focused studies. This PhD work is focusing on deciphering the spatio-temporal variability of interannual and seasonal surface changes in the permafrost environment of the Agua Negra river catchment and its implications for the surrounding hydrology. It focuses on DEM and consequent DEM of difference (DoD) generation based on different remotely sensed products, supported and validated by fieldwork. Conceptionally, it builds on the idea of bridging scale and emphasises the need to study glacier-permafrost interactions to fully understand the hydrological significance of the landscape.

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Investigating past changes, present development and impacts of climate change on future conditions of subarctic land forms and processes

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Subarctic land forms and processes are highly connected to the cold climatic conditions of northern areas; therefore they are influenced by the expected worldwide changes of the climate, such as temperature or precipitation changes (IPCC 2018). Especially vulnerable landscape structure elements, such as (dis)continuous permafrost areas, glaciers or boreal forests, whose occurrence is connected to the very specific climate conditions in those areas, are in danger to change or be destroyed (IPCC, 2019; Meier, 2015; Seppälä, 1994). Discontinuous permafrost areas, which are including little mounds (so called Palsas) or larger hills (Pingos), are most vulnerable to climate changes. These mounds and hills, which are including permafrost ice cores, are located in the sufficiently wet transition zones between permafrost areas and boreal forests (Meier, 2015; Seppälä, 2011). Palsas and Pingos can be used as indicators for changes triggered by climate change. Hence, knowledge about these land forms must be sufficiently high. Long-term monitoring as well as studies about influences by seasonal weather conditions on these land forms can increase the knowledge about the impact of climate change on them. Innovative methods (machine learning modelling, GIS-based analyses of data) combined with state-of-the-art field measurement technology (Real Time Kinematic (RTK) GPS, Unmanned Aerial Vehicle (UAV) remote sensing, Terrestrial Laser Scanning (TLS), Ground Penetrating Radar (GPR), peat drilling, core sampling and radiocarbon dating) are necessary to monitor changes of these subarctic land forms and to collect data about actual and future dynamics. Since 2015, an international field course is annually taking place, embedded in a Study Project module at the Institute of Physical Geography and Landscape Ecology at Leibniz University Hannover. During this project, field data about subarctic elements are taken annually with the methods described above (Fig. 1). These data will be used and combined with additionally recorded data to monitor past changes and actual development of subarctic elements and mainly Palsas. One main focus will be to detect differences and similarities resulting of the data evaluation of these new methodological approaches in order to give advices for further usage of remote sensing and close range monitoring devices in small-scaled investigation areas.

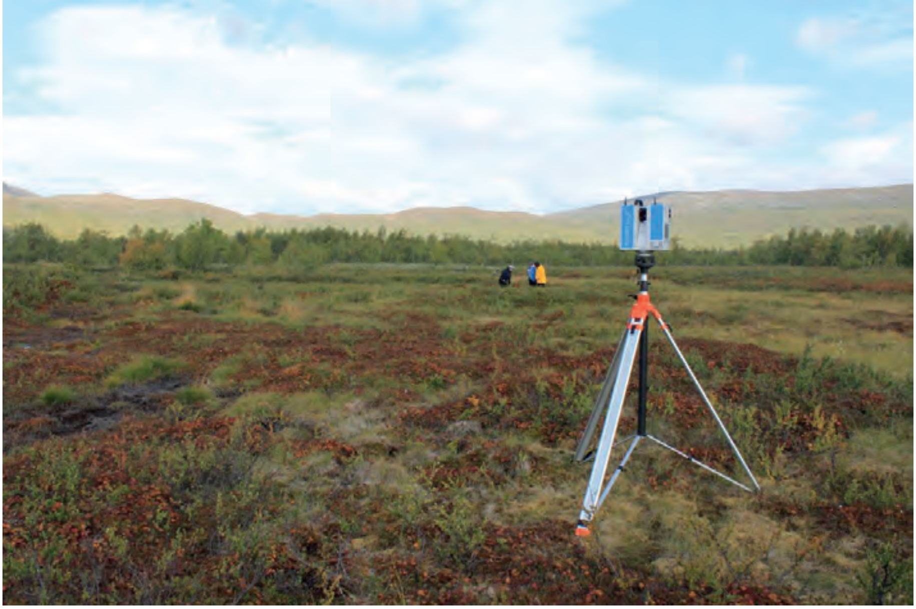

Figure 1: Usage of Z+F Imager 5010X during Field Course in a Palsa area in Northern Finnish Lapland (Picture taken by B. Burkhard).

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A multimethod approach to monitoring mountain seasonal snowpack and hydrological behaviour, (Grizzly Creek, Yukon, Canada)

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[2]Department of Earth and Planetary Science, McGill University, Montreal (Quebec), Canada

The alpine cryosphere is diminishing at a high rate due to ongoing climate changes, affecting the hydrology of downstream areas. Despite the urgent need for adaptation measures, there are still open questions regarding the processes that drive complex alpine watersheds hydrology. Our research focus on the hydrological behaviours of a subarctic catchment. The Grizzly Creek valley, located in southern Yukon, Canada, is composed on diverse cryospheric elements: bare glaciers, debris-covered glaciers, rock glaciers, permafrost, seasonal snow cover. Thus, this valley is highly sensitive to cryosphere change, already evidenced by high ablation rates of bare glaciers and debris-covered glaciers. However, the valley has no significant surface-water discharge nor an outlet, suggesting important underground flows. Thus, this system may be representative of how high mountainous watershed groundwater could contribution to downstream rivers in the future (Baraer et al., 2015). Identify and quantify the hydrological groundwater paths and fluxes in this type of watershed is crucial to understand climate changes impact mountain regions. Using several approaches our research aims to evaluate and quantify groundwater pathways and source water identification. Seasonal snow cover is one of the largest elements of mountain outflows, but its quantification is complex for remote studies (Deems et al., 2017). Therefore, snow cover is quantified with a multimethod approach. The use of ground-based lidar measurement, snow depth, SWE monitoring, UAV-based photogrammetry, time-lapse RGB, multispectral camera, and remote sensing lead to a quantification of snow water distribution in space and time. Our multimethod approach provides snow cover information across several scales measurement and allows us to examine methodological uncertainties. The results of the research provide an improved understanding of snow distribution in a northern mountain catchment, with implications for improving hydrologic models and forecasting.

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High resolution cryosphere elevation datasets derived from satellite stereo photogrammetry, UAV structure from motion, and/or lidar

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We have processed several years of UAV structure from motion datasets collected over the Easton Glacier on Mount Baker over 2014-2021 (see Fig. 1 for an example output). With co- registration over bare ground we can analyze large changes of the glacier extent and surface elevation over the years. We continue to investigate ways to produce better elevation datasets with UAVs. Besides SfM, we are on the way to testing the DJI Zenmuse L1 RGB + Lidar drone. We hope to generate more high-resolution validation data for future work, so acquiring lidar, optical, and other imagery simultaneously gives us new possibilities. Tools we use for processing include the pc_align tool from the Ames Stereo Pipeline open source toolkit (Shean et al., 2016; Beyer et al., 2018). This approach has worked well with satellite imagery co- registration of WorldView stereo DEMs with ICESat, airborne LiDAR and global reference DEMs (Shean et al., 2016, 2019, 2020) so should be applicable to close range datasets. We are also using machine learning to refine elevation models using high resolution optical (satellite) or lidar data. Deep learning has been widely used for information extraction from 2D remote sensing imagery, but computer vision researchers are also actively using deep learning for low-level lidar+stereo fusion and stereo depth estimation research, with most applications involving urban or indoor scenes for robotics, mobile devices, and self-driving vehicles (Cheng et al., 2019; Wang et al., 2019; Park et al., 2020; Choe et al., 2021; Poggi et al., 2021). Recent efforts are primarily focused on urban scenes to reconstruct buildings and other human infrastructure characterized by rectilinear shapes, planar surfaces, and repetitive textures (Stucker and Schindler, 2021; Wang et al., 2021). My primary research project at the moment is investigating these models applied to glaciated and vegetated terrain. Multispectral inputs and other sensing data can also be incorporated, the processing of which (I hope) is further advanced in the close range setting given the hardware available. Variable illumination, acquisition geometry, changes in appearance due to seasons or glacier flow are all recurring problems also common to close range datasets. Figure 2 shows a preliminary experiment adapting the ResDepth (Stucker and Schindler, 2021) convolutional neural network which, given a stereo orthoimage pair and the corresponding initial stereo DSM, suggests refinements that approximate the detailed terrain features captured by airborne DSMs/DTMs. In order to train the model well, we have to work carefully with the lidar processing to produce a good "ground truth" representation and produce pixel-aligned stack of raster data. I have found that the ground truth dataset used in these projects is quite important and requires thorough investigation of multiple processing steps (e.g. PDAL and ASP tools for co-registration, interpolation).

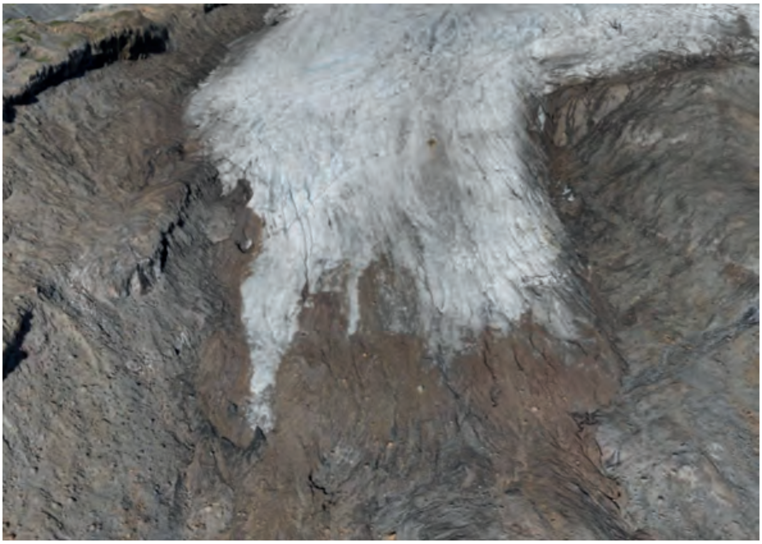

Figure 1 Overview of Easton Glacier 3D mesh from September 2021 UAV SfM survey.

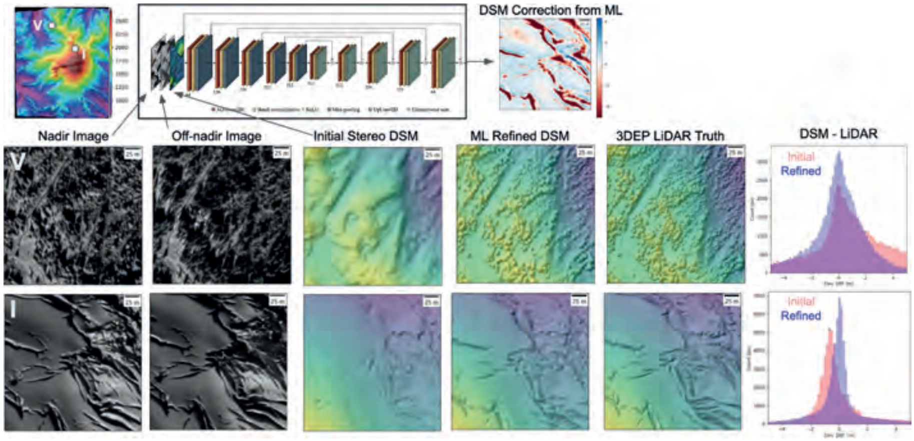

Figure 2: Top row) Satellite Stereo DSM for Mt. Baker, WA produced with ASP; CNN model architecture that accepts input orthoimages and initial stereo DSM to generate height correction grid. Middle row) Validation tile (unseen during training) over coniferous forest (V) shows how refined ML DSM corrects artifacts in initial DSM based on orthoimages, with ability to resolve individual trees. Bottom row) Validation tile over glacier (I) shows similar refinement for steep, narrow crevasses. Histograms highlight accuracy and precision improvement of refined DSM relative to ground truth lidar DSM.

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Glacier models constrained by remote sensing measurements of ice thickness to update Aosta valley regional glacier database: Development of a drone-borne ground penetrating radar system for glacier exploration.

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In glacier modeling, for estimating the glacier thickness, or forecasting the retreat of glaciers due to climate change, the geometry and the ice properties are commonly only estimated. The technical and logistical effort in measuring those data through geophysical surveys is high (see, for example, the ITMIX project by Farinotti, 2017), due to harsh environment that in some case could also pose the operator at risk. The goal of my research is to update the Aosta Valley regional glacier-thickness database (now reports thickness data at 2008). In this regard, I am currently working on the Glabtop model constrained by remote sensing measurements of ice thickness. However, remote sensing measurements of ice thickness cover just a small percentage of the glaciated area in our region. Therefore, I have been studying how to interconnect glacier modeling and geophysical surveys. I read about the different modeling techniques: Minimal Glacier model, linear models, Glabtop model, Open Global Glacier Model (Maussion et al, 2019), Shallow Ice Approximation, and Elmer/Ice models. Then, I began implementing the linear model to glaciers in Italy (e.g., Rutor and Indren). Meanwhile, I followed actively the development of a drone prototype big enough to carry geophysical radar antennae (Fig. 1 and 2). It is meant to extend the survey capabilities of traditional ground-coupled GPR surveys to areas which are remote or inaccessible (Jessen et al., 2020). Our research group planned to produce new GPR data of glacier thickness in some important areas, such as that of Rutor Glacier, also with the help of the drone. Finally, since the summer school is about remote sensing, I would like to explain better the remote-sensing part of my current work citing a brief abstract of the paper, under submission, about the drone prototype. Ground-penetrating radar (GPR) is one of the most commonly-used instruments to map the Snow Water Equivalent (SWE) in mountainous regions. However, some areas may be difficult or dangerous to access; besides, some surveys can be quite time-consuming. We test a new system to fulfill the need to speed up the acquisition process for the analysis of the SWE and to access remote or dangerous areas. A GPR antenna (900 MHz) is mounted on a drone prototype designed to carry heavy instruments, fly safely at high altitudes, and avoid interference of the GPR signal. A survey of two test sites of the Alpine region during winter 2021 is presented, to check the prototype performance for mapping the snow thickness at catchment scale. We process the data according to a standard flow-chart of radar processing and we pick both the travel times of the air-snow interface and the snow-ground interface to compute the travel time difference and to estimate the snow depth. The calibration of the radar-snow depth is performed by comparing the radar-travel times with snow depth measurements at preselected stations. The main results show fairly good reliability and performance in terms of data quality, accuracy, and spatial resolution in snow depth monitoring. We tested the device in condition of low snow-density values (< 200 kg/m^3) and this limits the detectability of the air-snow interface. This is mainly caused by low values of the electrical permittivity of the dry soft snow soft, providing a weak reflectivity of the snow surface. To overcome this critical aspect, we use the data of the rangefinder to properly detect the travel time of the snow-air interface. This sensor is already installed in our prototype and in most commercial drones for flight purposes. Based on our experience with the prototype, various improvement strategies and limitations of drone-borne GPR acquisition are discussed.

In conclusion, drone technology is found to be ready to support GPR-based snow depth mapping applications at high altitudes, provided that the operators acquire adequate knowledge of the devices, in order to effectively build, tune, use and maintain a reliable acquisition system.

Figure 1: Our drone at Gressoney test site (Valle d'Aosta, Italy)

Figure 2: Our drone at Cheneil test site (Valle d'Aosta, Italy)

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Detection of glacier surface changes with a long-range permanent TLS system at Hintereisferner (Austria)

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The mass balance information of glaciers can be substantially improved when analyzing the mass and energy fluxes that drive glacier changes using (spatially) distributed modeling at high temporal resolution. The largest unknown to be overcome is the development of the snow cover, and the physical processes governing its development: accumulation, densification, and its wind-induced redistribution. A method to gain knowledge about the spatial and temporal distribution of snow on the glacier is with a terrestrial laser scanner (TLS). A TLS has been permanently installed and automated (Voordendag et al., 2021) to study the Hintereisferner, a large valley glacier in the Ötztal Alps, Austria (Fig. 1). The potential of this long-range TLS system has been assessed to affirm the possibility to measure snow distribution over the glacier. Three main uncertainty sources are identified: the influence of the atmosphere, the scanning geometry, and the mechanical precision and stability of the TLS (Voordendag et al., 2022; Voordendag et al., in prep.). The mechanical precision of the inclination sensors causes the biggest uncertainty to the TLS data, followed by the scanning geometry and influence of the atmosphere on the laser beam respectively. With an overall accuracy between ±5 and 65 cm (Fig. 2), strongly depending on the distance from TLS to surface, the system enables to measure snow fall events and snow drift. Future studies aim to understand the processes involved in glacier-atmosphere interactions and to validate different high-resolution atmospheric models that explicitly compute snow redistribution by wind with the TLS data. The work presented is part of the SCHISM project: Snow-Cover dynamics and High resolution Modeling. It is a collaboration between the University of Innsbruck (PI: Georg Kaser, georg.kaser@uibk.ac.at) and the Friedrich-Alexander-Universität Erlangen-Nürnberg (PI: Tobias Sauter, tobias.sauter@fau.de) and is co-funded by the Austrian Science Fund (FWF) and the German Research Foundation (DFG).

Figure 1: Panorama overview of Hintereisferner. The TLS is located in the white container on the bottom of the image.

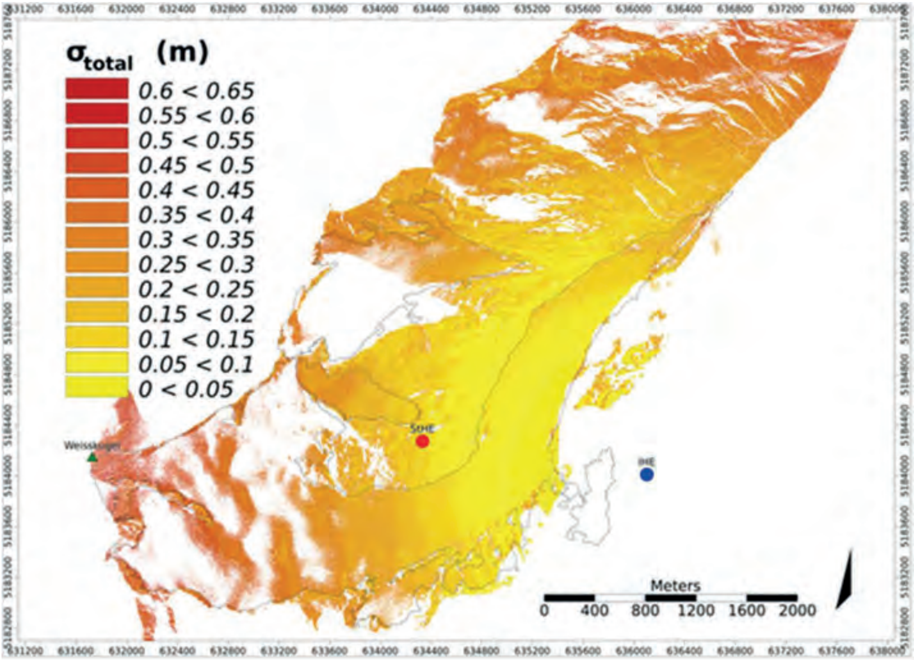

Figure 2: Uncertainty of TLS data at Hintereisferner for grids of 1 m. The TLS is located at the blue dot (IHE).

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Advancing forest inventories with close-range sensing techniques and laser scanning simulation

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Trees play a critical role for ecosystems and humans. Due to their ability to sequester carbon and to produce oxygen, sustainable management of forests is important in the context of global warming (Canadell et al., 2008). Forests fulfil different ecosystem services, such as climate regulation, formation and protection of soils via decomposition, and timber production, and provide habitat for many species (Simons et al., 2021). In cities, trees are important for air quality and heat management, e.g., by providing shade (Lin et al., 2010). Close-range sensing methods like laser scanning and photogrammetry allow capturing three-dimensional data of trees. Combined with remote sensing products, such as aerial and satellite imagery, this opens up the possibility of automating forest and tree inventories. Forest inventories provide the data needed to assess the state and dynamics of forests and thus form the basis for sustainable forest management. Further research is needed to fully understand how point cloud metrics relate to tree and forest characteristics and how changes in forest growth, forest structure and forest condition can be detected and quantified from 3D point clouds. For the investigation of such research questions, laser scanning data must be available, ideally from multiple platforms. This is where we contributed with our own dataset, which can be openly accessed on the PANGAEA data repository

(Weiser et al., 2021a, Fig 1). It encompasses overlapping point clouds of forest plots acquired by airborne (ALS), UAV-borne (ULS), and terrestrial (TLS) laser scanning, from which we extracted 4205 individual tree point clouds of 1491 trees. As we learned during the creation of our dataset, planning and conducting LiDAR surveys in the field and then georeferencing and aligning them is usually costly and time-consuming. Simulations of laser scanning may be used to plan and optimise data acquisition, e.g., in terms of the locations of scan positions (in the case of TLS) or flight strips (in the case of ALS/ULS) or the required resolution for a specific application. But simulated laser scanning data can also complement real data for addressing some of the research questions related to close-range or remote sensing-assisted forest inventories. Virtual laser scanning (VLS) can help to study the interactions between the laser beams and the vegetation and how these interactions are influenced by varying acquisition settings, including different sensors and platforms. Furthermore, laser scanning simulations can be used to create vast amounts of training data for machine learning with relatively little effort. This can help to solve important problems of close-range sensing-assisted forest inventories (Fassnacht et al., 2021), e.g., tree instance segmentation, leaf-wood classification, or tree species classification. One important premise for using VLS is an appropriate representation of the trees in the laser scanning simulations. Options include artificial 3D models, 3D meshes computed from real laser scanning data, or voxel-based approaches. There is typically a trade-off between level of detail of the tree models and computational burden of the simulation. We addressed this problem by developing a voxel-based tree modelling approach where opaque voxels are scaled according to the local plant area density estimated from terrestrial laser scanning point clouds (Weiser et al., 2021b,c, Fig 2). In contrast to the use of fixed-size voxels, the scaling approach allows for modelling trees with a comparably low number of voxels while maintaining high accuracy of point cloud-derived tree metrics.

a) ALS leaf-on a) ULS leaf-on a) ULS leaf-off a) TLS leaf-on

Figure 1: Point clouds of a European Beech (Fagus sylvatica) acquired from multiple platforms and under different canopy conditions (Weiser et al., 2021a). Point clouds are coloured by reflectance. ALS = Airborne Laser Scanning, ULS = UAV-borne Laser Scanning, TLS = Terrestrial Laser Scanning.

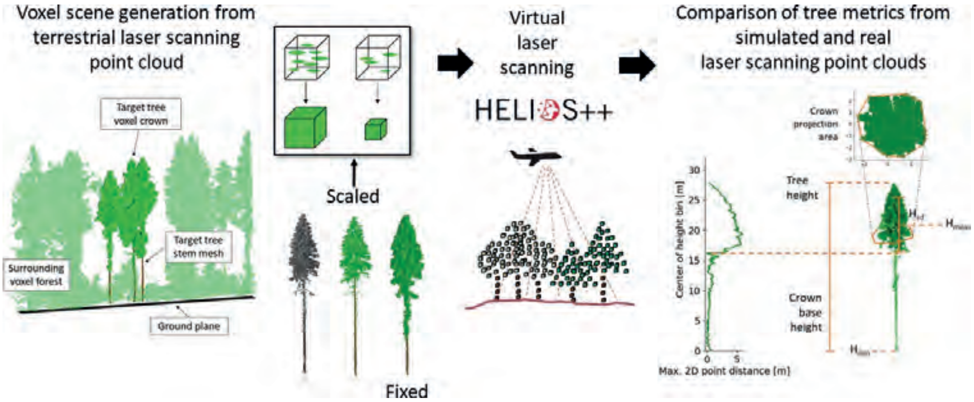

Figure 2: Summary of our research to investigate the influence of different voxel-based tree representations in laser scanning simulations with HELIOS++ by comparing tree metrics derived from simulated and real point clouds (Weiser et al., 2021b,c).

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Targetless registration and identification of stable areas for deformed TLS point clouds

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Accurate and robust 3D point clouds registration is the crucial part of the processing chain in terrestrial laser scanning (TLS)-based deformation monitoring that has been widely investigated in the last two decades. For the scenarios without signalized targets, however, automatic and robust point cloud registration becomes more challenging, especially when significant deformations and changes exist between the sequence of scans which may cause erroneous registrations. In this contribution, a fully automatic registration algorithm for point clouds with partially unstable areas is proposed, which does not require artificial targets or extracted feature points. In this method, coarsely registered point clouds are firstly over-segmented and represented by supervoxels based on the local consistency assumption of deformed objects. A confidence interval based on an approximate assumption of the stochastic model is considered to determine the local minimum detectable deformation for the identification of stable areas. The significantly deformed supervoxels between two scans can be detected progressively by an efficient iterative process, solely retaining the stable areas to be utilized for the fine registration. The proposed registration pipeline is demonstrated on two datasets (both with two-epoch scans): An indoor scene simulated with different kinds of changes, including rigid body movement and shape deformation, and the Nesslrinna landslide close to Obergurgl, Austria. The experimental results show that the proposed algorithm exhibits a higher registration accuracy and thus a better detection of deformations in TLS point clouds compared with the existing voxel-based method and the variants of the iterative closest point (ICP) algorithm. Further work will involve integrating a more realistic stochastic model of TLS point cloud and more accurate supervoxel-based segmentation techniques into the workflow.

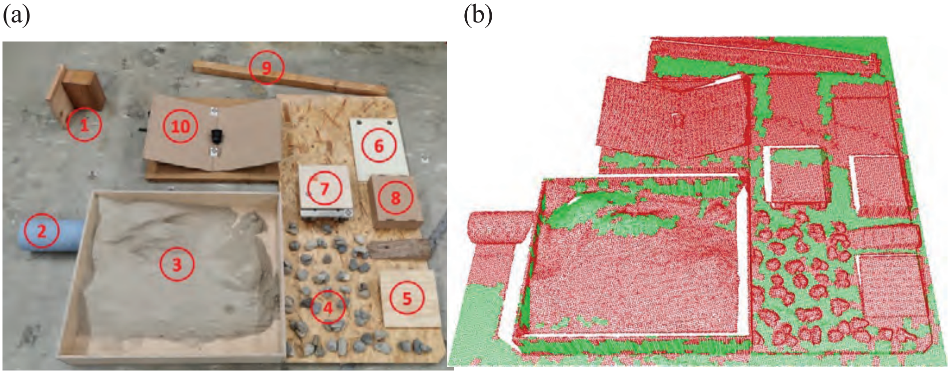

Figure1. (a) Experimental setup of the indoor simulated scene where objects with numbers are moved or changed; (b) Identification of stable (green) and unstable (red) areas of the point cloud in epoch-2.

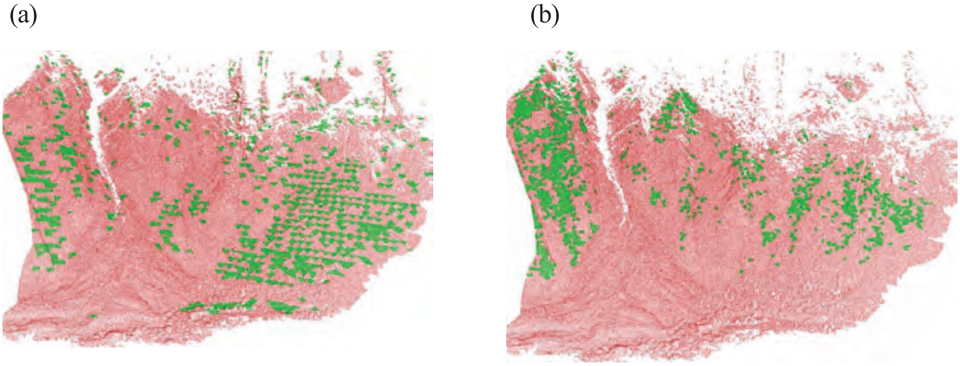

Figure 2. Identification of stable (green) and unstable (red) areas of the TLS point clouds of Nesslrinna landslide by the voxel-based method (a) and the proposed method (b).

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The use of low-cost stereo camera systems for tree stability and health monitoring

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Tree failure can incur high economic and societal costs, both in urban environments, as well as managed forests and rural areas. Uprooted trees and broken branches can cause significant damage to the infrastructure and lead to injury and even a loss of life. Due to the climate change, extreme weather events are becoming more frequent and so the frequency of tree failure is also increasing (van Haaften et al., 2021). Current methods of tree stability assessment such as Visual Tree Assessment (VTA) (Mattheck and Breloer, 1994) or Static Integrated Approach (SIA) (Sinn and Wessolly, 1989) rely on periodic field surveys and do not account for the local conditions and the extreme weather events. While it is still vital to consider the existing damage to the trees and their health while conducting the risk assessment, more data is required to fully understand the tree response to wind. Previous studies have collected data on tree tilt through on-tree accelerometers, inclinometers and strain gauges to investigate the tree's response to wind (Abbas et al., 2020; Jackson et al., 2020). A visual component, such as near-infrared stereo imagery, could enhance those measurements by not only tracking the movement of a tree in three dimensions, but also providing the spectral information, which may be used for monitoring the overall tree condition. The Raspberry Pi NoIR camera provides a low-cost off-the-shelf alternative to commercial camera systems, without significant compromise on the image quality (Wilkinson et al., 2021). Our project uses two Raspberry Pi cameras with a fixed baseline, synchronised through an external timer module to capture a simultaneous timelapse imagery (Fig. 1). Using the principles of stereo vision, the images are then converted into depth maps and point clouds to retrieve the tree structure in three dimensions. The timelapse allows for the monitoring of tree movement. The near-infrared component of the images can then be used for calculation of Normalised Difference Vegetation Index (NDVI).

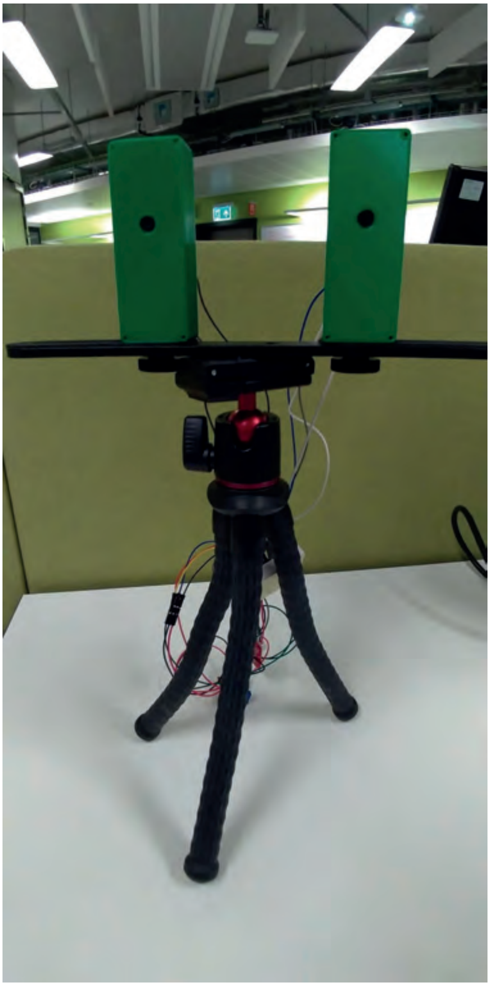

Figure 1. Stereo camera system built using two Raspberry Pi v2 NoIR cameras connected to Raspberry Pi Zero W computing boards. The boards are synchronised via an external timer signal.

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