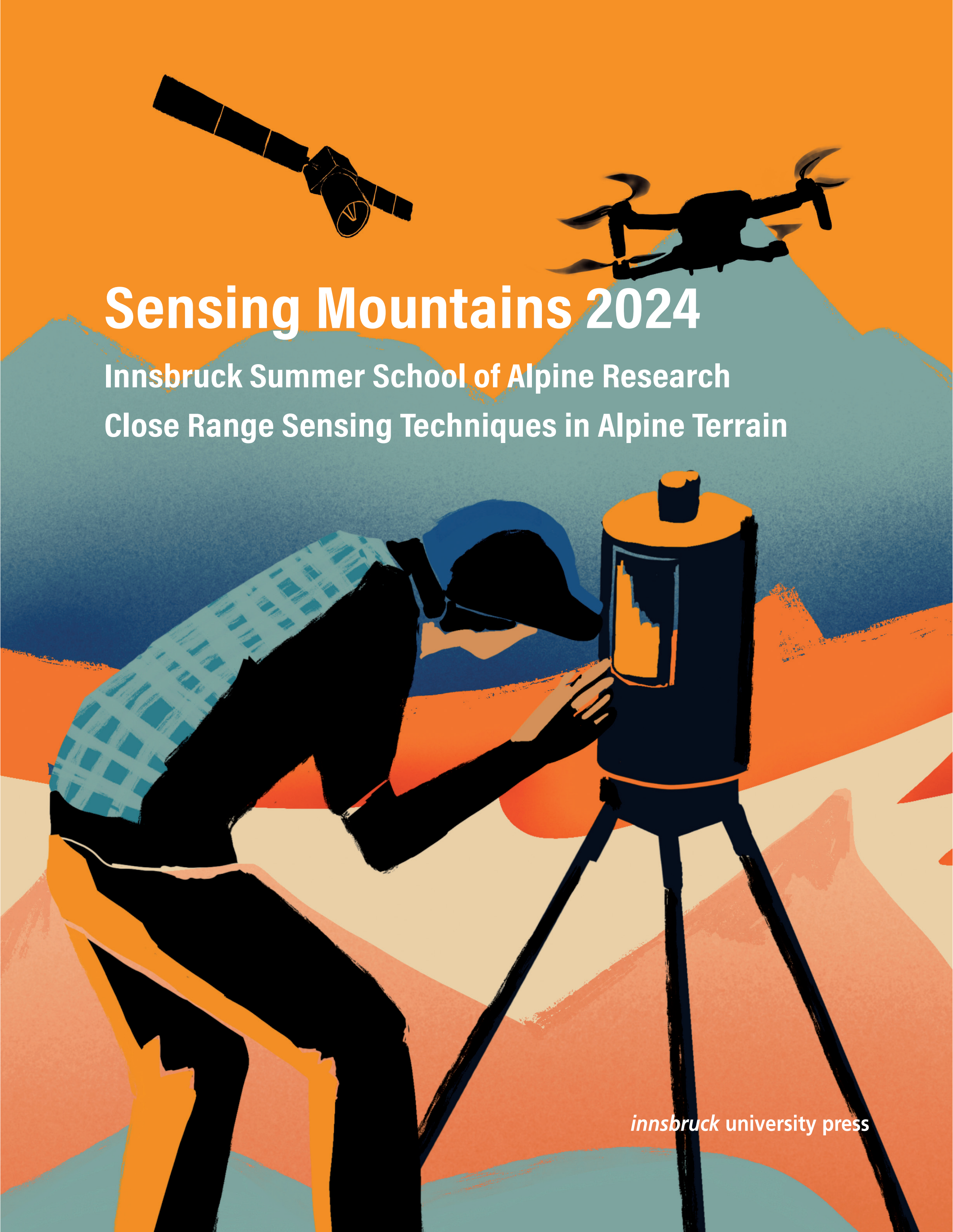

Sensing Mountains 2024

Innsbruck Summer School of Alpine Research

Close Range Sensing Techniques in Alpine Terrain

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Martin Rutzinger, Katharina Anders, Anette Eltner, Caroline Gevaert,
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Lea-Sophie Nopens, Sander Oude Elberink, Francesco Pirotti (Eds.)

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Martin Rutzinger – Department of Geography, Universität Innsbruck
Katharina Anders – Department of Aerospace and Geodesy, Technical University of Munich
Anette Eltner – Institute of Photogrammetry and Remote Sensing, TU Dresden
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Content

Foreword

Mountain areas are affected by current changes due to climate warming, drought, heavy precipitation and land use intensity. Research into changes on a local scale is possible thanks to the development of automated near and remote sensing techniques. However, data acquisition, validation and analysis are a challenging task, especially in mountainous areas. The 5th edition of the international summer school Sensing Mountains 2024 is an event, which brings together international early career scientists and experienced experts from technical, geo- and environment-related research areas. The interdisciplinary framework of the summer school creates a creative space for exchange and learning new concepts for researching recent natural process dynamics in mountain areas.

Disclaimer

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List of Keynote Speakers

Daniel	Czerwonka-Schröder	Bochum University of Applied Sciences (Germany)	Permanent terrestrial lidar monitoring - state of the art and perspectives
Jana	Eichel	Utrecht University (The Netherlands)	Go or grow? Moving mountain slopes meet shifting mountain plants
Hans-Gerd	Maas	TU Dresden (Germany)	Terrestrial photogrammetric techniques for glacier monitoring at very high spatial and temporal resolution
Josefine	Umlauft	University Leipzig (Germany)	Unraveling cryoseismological records with machine learning
Carlos	Cabo	University of Oviedo (Spain)	3DFin: 3D Forest inventor
Norbert	Pfeifer	TU Wien (Austria)	3D Point clouds from laser scanning for environmental mapping and monitoring
Lukas	Winiwarter	University of Innsbruck (Austria)	AI in 3D - Deep learning on topographic point cloud data: methods, applications, and trends

List of Participants

William	Albert	Heidelberg University (Germany)
Mattia	Balestra	Polytechnic University of Marche (Italy)
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Program

Sunday, 22.09.2024

15:00-17:30:	Arrival of Participants
18:00-19:30:	Dinner
19:30-20:00:	Martin Rutzinger: *Welcome*
20:00-21:00:	Poster Session

Monday, 23.09.2024

7:30-8:30:	Breakfast
8:30-9:30:	Jana Eichel: *Go or grow? Moving mountain slopes meet shifting mountain plants*
9:30-10:30:	Norbert Pfeifer: *3D Point clouds from laser scanning for environmental mapping and monitoring*
10:30-11:00:	Coffee Break
11:00-17:30:	Excursion
17:30-18:00:	1 min group wrap-up
18:00-19:30:	Dinner
19:30-21:00:	Poster Session
21:00-21:30:	Social Event

Tuesday, 24.09.2024

7:30-8:30: Breakfast
8:30-9:30: Hans-Gerd Maas:
Terrestrial photogrammetric techniques for glacier monitoring at very high spatial and temporal resolution
9:30-10:30: Josefine Umlauft:
Unraveling cryoseismological records with machine learning
10:30-11:00: Coffee Break
11:00-12:00: Karsten Zimmermann: *DMT SAFEGUARD:*
Monitoring Everything
Demo Laserdata GmbH
12:00-13:00: Daniel Czerwonka-Schröder:
Permanent terrestrial lidar monitoring - state of the art and perspectives
13:00-17:30: Group Assignment**:**
get in touch with sensors and methods
17:30-18:00: 1 min group wrap-up
18:00-19:30: Dinner
19:30-20:00: Carlos Cabo:
3DFin: 3D Forest inventor
20:00-20:30: Lukas Winiwarter:
AI in 3D - Deep learning on topographic point cloud data: methods, applications, and trends
20:30-21:00: Poster Session

Wednesday, 25.09.2024

7:30-8:30: Breakfast
8:30-17:30: Group Assignment
17:30-18:00: 1 min group wrap-up
18:00-19:30: Dinner

19:30-20:00: Roderik Lindenbergh, Bernhard Höfle und Katharina Anders:
Open scientific software for 3D/4D point cloud analysis & change detection
20:30-21:00: Group Assignment

Thursday, 26.09.2024

7:30-8:30: Breakfast
8:30-9:30: Anette Elter:
Introduction into thermal sensing
Francesco Pirotti*:*
Hands-on Machine Learning
9:30-10:30: Sander Oude Elberink:
Cesium in unity: how 3D geospatial data is integrated in a gaming environment
Caroline Gevaert:
Hands-on AI & Ethics
10:30-11:00: Coffee Break
11:00-17:30: Group Assignment
17:30-18:00: 1 min group wrap-up
18:00-19:30: Dinner
19:30-20:00: Photo Contest Award
20:30-21:00: Group Assignment

Friday, 27.09.2024

7:30-8:30:	Breakfast
8:30-10:30:	Group Assignment
10:30-11:00:	Coffee Break
11:00-14:00:	Group Assignment
14:00-18:00:	Final Presentation
18:00-19:30:	Dinner

Saturday, 28.09.2024

7:30-8:30:	Breakfast
8:30-9:30:	Departure of all

Abstracts of Participants

Considering wind effects in LiDAR simulation-based machine learning for point cloud classification in forests

William Albert[1]

[1]3D Geospatial Data Processing (3DGeo) Research Group, Heidelberg University, Germany

In recent years, the generation of synthetic point cloud training data from the combination of 3D artificial tree models and LiDAR simulation has played an important role in enabling more accurate biodiversity assessments, ecosystem monitoring, and precision forestry management strategies. As a matter of fact, virtual laser scanning (VLS) - i.e. simulating LiDAR acquisitions in a virtual computer environment - has proven useful for separation of leaves and wood and, as a result, facilitated leaf area quantification, biomass calculation, and analysis of branch structure via quantitative structure models (QSM) (Tao et al., 2015; Krishna Moorthy et al., 2020; Li et al., 2024; Esmorís et al., 2024). VLS allows to simulate multiple acquisition scenarios in terms of scene composition and survey settings, hence allowing diverse and large numbers of computer-generated datasets. As the output point cloud can include reference classification values transferred from the input mesh, the simulated point clouds can serve as training data for classification tasks.

In order to perform automatic semantic segmentation for leaf-wood separation in a tree point cloud, machine learning (ML) and deep learning (DL) models require a large amount of training data. As the input data can consist of a massive point cloud with over a billion points, acquiring and manually labelling each point would be too time consuming, if not impossible. Thus, replacing real training data with synthetic training data generated by VLS reduces the costs and, in case of limited real training data, can improve model performance (White et al., 2016; Wang, 2020). A central challenge here is achieving high realism and informativeness of simulated point clouds and closing the reality gap to real datasets.

Because trees cannot be in completely still condition when captured by LiDAR in the field, the movement of the branches and leaves during acquisition affects the quality of the output point cloud. In this work, we want to explore if and how such wind effects in the point cloud affect the performance of leaf-wood classification models.

We will classify leaves and wood by solely training on simulated data in two different controlled environments. The first environment consists of static trees (without wind), while the second has swaying trees (strong winds). We will then train two models separately on each simulated dataset and compare them by evaluating their performance on both static and swaying trees plots.

Five models of quaking aspen are created using the Blender software (Community, B.O., 2018) with the Sapling Tree Gen add-on (Weber & Penn, 1995). Each model is exported as both static and swaying, for a total of ten trees. Each tree (Fig. 1) is randomly duplicated and placed in each 20 by 20 m plot (Fig. 2). Upon placement, the 3D tree mesh model is then randomly rotated around the Z-axis and scaled in a range of ±30% of its original size. These steps were performed for both static and swaying trees, with two different tree densities for each. This results in a total of four datasets, each containing 100 plots. To simulate the terrestrial laser scanning (TLS) of the 400 forest plots, the HELIOS++ software (Winiwarter et al., 2022) and the multi_epoch_b2h blender plugin (Weiser, 2023) are used.

We hypothesize that training and target datasets are of similar quality, and hence that leaf-wood classification can be improved by replicating the effects observed in real datasets (e.g., wind effects) in our synthetic datasets. We expect that the model trained on swaying trees will perform better on the validation dataset of swaying trees than the model trained on static trees. Preliminary results with the random forest algorithm trained and tested on the static trees plots yielded a Kappa coefficient of 88% and a mean Intersection over Union (mIoU) of 77% for leaf-wood classification.

In summary, our study presents an approach to leaf and wood classification using simulated data from two controlled environments: static trees and swaying trees under strong winds. The results of this work have the potential to assist in creating more realistic synthetic training data for improved leaf-wood semantic segmentation on real datasets.

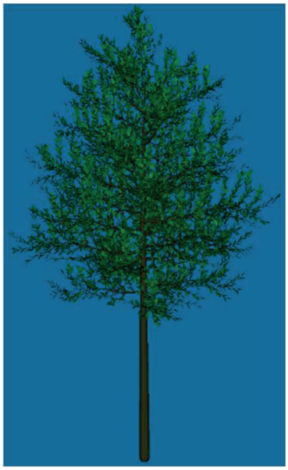

Figure 1: Example of a quaking aspen tree used for the simulation

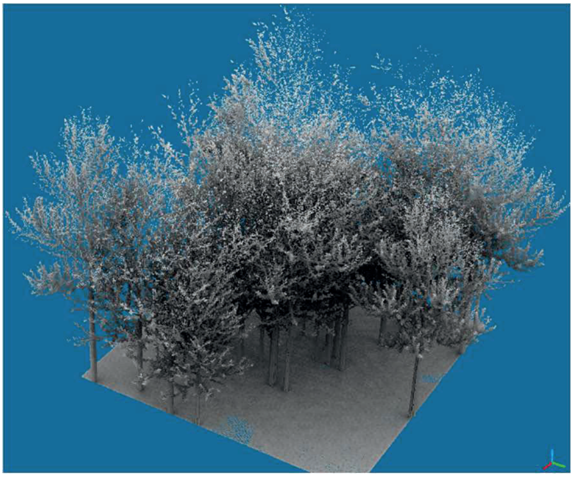

Figure 2: Example of a plot containing different trees which have been scaled ±30% of their original size and rotated on the Z-axis

Community, B. O. (2018). Blender - a 3D modelling and rendering package. Stichting Blender Foundation, Amsterdam. Retrieved from http://www.blender.org

Esmorís Pena, A., Weiser, H., Winiwarter, L., Cabaleiro Domínguez, J., & Höfle, B. (2024). Deep learning with simulated laser scanning data for 3D point cloud classification. https://doi.org/10.31223/X53Q3Q

Krishna Moorthy, S. M., Calders, K., Vicari, M. B., & Verbeeck, H. (2020). Improved Supervised Learning-Based Approach for Leaf and Wood Classification From LiDAR Point Clouds of Forests. IEEE Transactions on Geoscience and Remote Sensing, 58(5), 3057–3070. https://doi.org/10.1109/TGRS.2019.2947198

Li, W., Hu, X., Su, Y., Tao, S., Ma, Q., & Guo, Q. (2024). A new method for voxel-based modelling of three-dimensional forest scenes with integration of terrestrial and airborne LiDAR data. Methods in Ecology and Evolution, 15(3), 569–582. https://doi.org/10.1111/2041-210X.14290

Tao, S., Guo, Q., Xu, S., Su, Y., Li, Y., & Wu, F. (2015). A Geometric Method for Wood-Leaf Separation Using Terrestrial and Simulated Lidar Data. Photogrammetric Engineering & Remote Sensing, 81(10), 767–776. https://doi.org/10.14358/PERS.81.10.767

Wang, D. (2020). Unsupervised semantic and instance segmentation of forest point clouds. ISPRS Journal of Photogrammetry and Remote Sensing, 165, 86–97. https://doi.org/10.1016/j.isprsjprs.2020.04.020

Weber, J., & Penn, J. (1995). Creation and rendering of realistic trees. Proceedings of the 22nd Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH ’95, 119–128. https://doi.org/10.1145/218380.218427

Weiser, H. (2023). Blender Add-on for exporting dynamic/animated scenes from Blender to HELIOS++”. GitHub repository. github.com/3dgeo-heidelberg/dyn_b2h/

White, J. C., Coops, N. C., Wulder, M. A., Vastaranta, M., Hilker, T., & Tompalski, P. (2016). Remote Sensing Technologies for Enhancing Forest Inventories: A

Review. Canadian Journal of Remote Sensing, 42(5), 619–641. https://doi.org/10.1080/07038992.2016.1207484

Winiwarter, L., Esmorís Pena, A. M., Weiser, H., Anders, K., Martínez Sánchez, J., Searle, M., & Höfle, B. (2022). Virtual laser scanning with HELIOS++: A novel take on ray tracing-based simulation of topographic full-waveform 3D laser scanning. Remote Sensing of Environment, 269, 112772. https://doi.org/10.1016/j.rse.2021.112772

Digital marteloscope – virtual forestry training ground

Mattia Balestra[1], Roberto Pierdicca[2], Alessandro Vitali[1], Carlo Urbinati[1]

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[2]*Department of Construction, Civil Engineering and Architecture, Università Politecnica delle Marche, Italy*

Our latest research aims to implement a precision forestry approach to digitally reproduce a marteloscope in the Central Apennines (Italy). We used a handheld mobile laser scanner (MLS), the GeoSLAM Zeb Horizon, to survey one-hectare of beech forest where each tree was manually measured in the field, obtaining the Diameter at Breast Height (DBH) and the total tree height with traditional caliper and hypsometer. Both surveys were conducted in May 2023, and we processed the MLS point cloud data to obtain dendrometric parameters and to allow the comparison of those obtained in the field and the virtual dataset (Fig. 1). The MLS output has been processed using the plugin 3DFin into CloudCompare software (Cabo et al., 2018) (Fig. 2). Each tree point cloud was segmented and assigned the corresponding field ID. The segmentation resulted in 1092 trees, with DBH measurements showing a RMSE of 3.07 cm (5.5%) and tree height measurements displayed an RMSE of 2.41 m (20.5%). A virtual marteloscope has the advantage of being permanent (Döllner et al., 2023), unlike its physical counterpart, which will inevitably undergo harvesting or natural disturbances at some point. This virtual marteloscope could allow students or forestry technicians to visually observe field choices and conduct virtual thinning simulations and its continuous use over time, even years later (Murtiyoso et al., 2023). Thanks to it, we can visualize the plot before and after thinning, observing the gaps that will emerge post-intervention. We simulated a thinning intervention, removing 40% of the wood volume in the analyzed area, using a portion of the entire marteloscope. The trees selected in the field were subsequently removed in the 3D virtual representation, providing a visual representation of the outcome (Fig. 3). The results of this research revealed the efficacy of MLS to survey and modeling a marteloscope, obtaining its digital version and demonstrating its potential for ongoing education, virtual simulations, and informed decision-making in forest management practices.

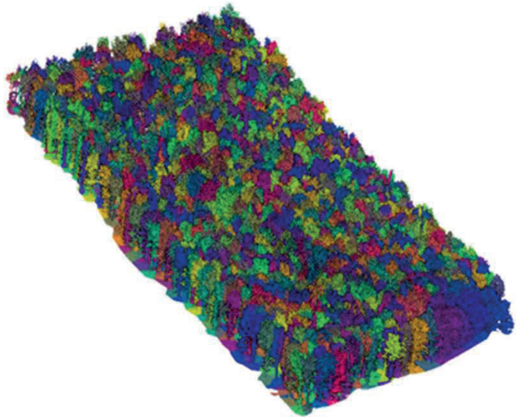

Figure 1*: Virtual marteloscope: each tree from the original MLS point cloud has been segmented and assigned a random color in the scalar field for enhanced visualization.*

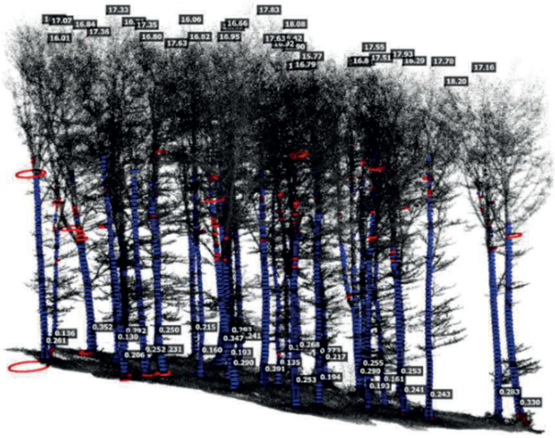

Figure 2*: 3DFin outputs displayed in a section of the marteloscope, with the visualizations of DBH and tree heights.*

***Figure 3**: 3D virtual marteloscope representation, providing a visual insight resulting from the removal of selected trees in the field.*

Cabo, C., Ordóñez, C., López-Sánchez, C. A., & Armesto, J. (2018). Automatic dendrometry: Tree detection, tree height and diameter estimation using terrestrial laser scanning. International Journal of Applied Earth Observation and Geoinformation, 69, 164–174. https://doi.org/10.1016/j.jag.2018.01.011

Döllner, J., De Amicis, R., Burmeister, J.-M., & Richter, R. (2023). Forests in the Digital Age: Concepts and Technologies for Designing and Deploying Forest Digital Twins. The 28th International ACM Conference on 3D Web Technology, 1–12. https://doi.org/10.1145/3611314.3616067

Murtiyoso, A., Holm, S., Riihimäki, H., Krucher, A., Griess, H., Griess, V. C., & Schweier, J. (2024). Virtual forests: A review on emerging questions in the use and application of 3D data in forestry. International Journal of Forest Engineering, 35(1), 29–42. https://doi.org/10.1080/14942119.2023.2217065

Exploring spectral and thermal response of forest habitats through satellite imagery

Chiara Bottaro[1,3], Giovanna Sona[1,3], Maria Laura Carranza[2,3], Michele Finizio[2,3], Michele Innangi[2]

[1]Department of Civil and Environmental Engineering (DICA), Politecnico di Milano, Italy
[2]Envix-Lab, Department of Biosciences and Territory (DiBT), Molise University, Italy
[3]NBFC, National Biodiversity Future Center, Palermo, Italy

Satellite image repositories represent a treasure trove of archived data documenting Earth ‘s systems. Through image analysis over time, we can gain awareness of dynamic processes characterizing our planet. Understanding how natural ecosystems respond to anthropic pressure is key to addressing conservation and management questions.

The study excerpt provided here, aims to explore the spectral and thermal response in time of various forest habitats in the Molise Region, Italy. The main objective is to assess whether the spectral and thermal information retrieved from satellite images varies across the different habitats and, if so, whether these variations reflect ecological characteristics. The information about forest habitats was obtained from the ‘Carta della Natura‘ a comprehensive cartographic product detailing regional ecosystems and habitats (Ceralli & Laureti, 2021). This chart facilitated the filtering and retrieval of the most extensive forest habitat types in the study region.

Satellite images for the analysis were accessed, collected and pre-processed through Google Earth Engine, a cloud-computing platform utilizing the JavaScript programming language (Gorelick et al., 2017). This platform offers efficient image management capabilities and provides access to an extensive catalog of geospatial data, freely available for educational and research purposes. Satellite imagery presents invaluable opportunities for research, albeit with inherent constraints on spatial and temporal resolution. For our study ‘s objectives, we opted to utilize Landsat 8 and 9 imagery, notable for its provision of Thermal InfraRed (TIR) band, enabling the derivation of Land Surface Temperature (LST). All Landsat bands have a spatial resolution of 30m and a revisit time of 16 days. In comparison, ESA ‘s Sentinel-2 multispectral imagery offers a higher spatial resolution of 10m and a shorter revisit time of 5 days but lacks scanning in the TIR band.

In addition to deriving LST data, we computed two key vegetation indices, the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Moisture Index (NDMI), to synthesize Landsat spectral information. Our methodology involved collecting all Landsat images for the year 2022 and extracting corresponding raster values for LST, NDVI, and NDMI at 10 randomly selected sampling points within each forest habitat (Fig. 1). Analysis of these data will then include exploratory statistics and tests to assess whether variances in observations differed significantly across forest habitats. To go further, ongoing efforts are directed towards two sides. Firstly, we aim to extend the time series analysis to encompass multiple years, enabling an examination of temporal trends of the variables of interest. Secondly, we seek to investigate if increasing image spatial resolution significantly changes the spectral and thermal response of the forest habitats analysed. This expansion attempt to yield a deeper understanding of multiscale assessment of forest habitats.

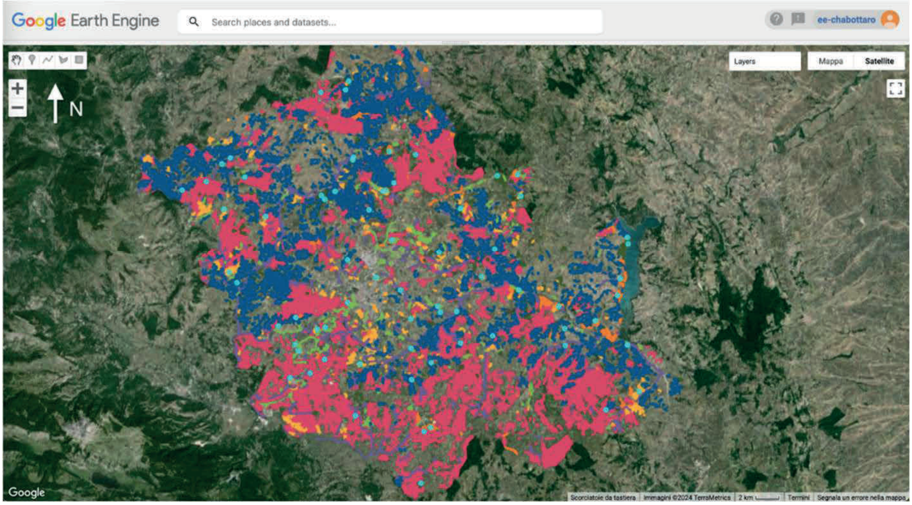

Figure 1: *Google Earth Engine Display representing in different colours the different forest types analysed and in cyan the random sampling points in the study area.*

Ceralli, D., & Laureti, L. (2021). *Carta della Natura della regione Molise: Cartografia e valutazione degli habitat alla scala 1:25.000* (p. 127). Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA).

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Combined application of multi-temporal monitoring and landslide investigations to assess the evolution of a complex, slow-moving landslide

Edoardo Carraro[1], Benedikt Müller[1], Philipp Marr[1], Thomas Glade[1]

[1]*ENGAGE – Geomorphological Systems and Risk Research, Department of Geography and Regional Research, University of Vienna, Austria*

Among the many different landslide types and processes, slow-moving landslides are often underestimated, even though their activity can impact land use planning and infrastructure for years and decades (Lacroix et al., 2020; Handwerger, 2019). Despite this, slow movements show complex kinematics that differ on spatial and temporal scales and exhibit a non-linear relationship with triggering mechanisms (Van Asch et al., 2007). Moreover, the episodic acceleration stages of the most unstable sectors can evolve rapidly, leading to substantial damage. Therefore, it is of great interest to identify and properly interpret displacement patterns in order to assess landslide dynamics.

This research aims to assess the spatial and temporal evolution of the Brandstatt landslide (Scheibbs municipality, Lower Austria), a complex earth slide system (Cruden & Varnes, 1996) active in the low mountain range between 405 and 540 m a.s.l. This landslide is located in the complex geological transition zone between the Flysch and Klippen Units and the Northern Calcareous Alps, which represents the main predisposing factor for slope instabilities in the region (Marr et al., 2023). Although landslide distribution and activity are widely known in the region, these slow processes still represent an underestimated risk and permanently affect private infrastructure and agricultural practices.

To achieve this goal, a combination of multi-temporal monitoring and landslide investigations has been applied. This approach takes advantage of the ongoing investigations and monitoring sensors installed on the unstable slope as part of the establishment of a landslide observatory embedded in the NoeSLIDE project (ENGAGE Research Group, University of Vienna; project information and real-time monitoring are available at www.noeslide.at). The fieldwork activities include the combination of surface and subsurface methods (i.e., DPH campaigns and inclinometric measures) to characterize the spatial extent of landslide geometry and deformation rates. In particular, these also consist of the use of multi-temporal close-range sensing techniques, such as TLS- and UAV-based surveys, to detect surface changes (Fig. 1). These technologies have allowed the collection of high-resolution data over broad areas, providing a more comprehensive understanding of landslide dynamics. The findings of this research will contribute to identifying subsystems characterized by different deformation patterns with the purpose of continuous monitoring over time to provide essential data for local authorities to implement effective mitigation measures.

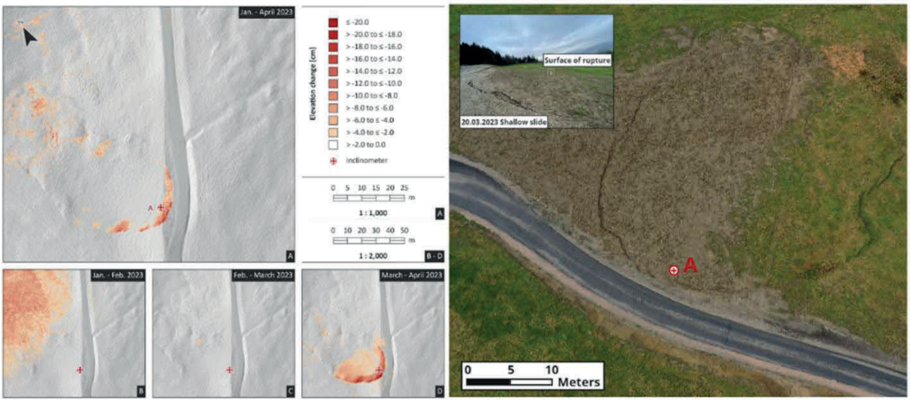

***Figure 1**: Multi-temporal UAV-based survey in the western sector of the Brandstatt landslide. (Left) Surface deformations mapped between January and April 2023; (Right) UAV image of the most unstable area in this sector, acquired in February 2024 (Photograph: E. Carraro).*

Cruden D.M. and Varnes D.J. (1996). Landslide types and processes. In: Turner AK, Schuster RL (eds) Landslides: Investigation and Mitigation. Transportation research board, US National Research Council. Special Report 247, Washington, DC, Chapter 3: 36–75

Lacroix P., Handwerger A.L., Bièvre G. (2020). Life and death of slow-moving landslides. Nature Reviews Earth & Environment, 1(8): 404-419.

Handwerger A.L., Fielding E.J., Huang M.H., Bennett G.L., Liang C., Schulz W.H. (2019). Widespread initiation, reactivation, and acceleration of landslides in the northern California Coast Ranges due to extreme rainfall. Journal of Geophysical Research: Earth Surface, 124(7): 1782-1797.

Marr P., Jiménez Donato Y. A., Carraro E., Kanta R., Glade T. (2023). The Role of Historical Data to Investigate Slow-Moving Landslides by Long-Term Monitoring Systems in Lower Austria. Land, 12(3): 659.

Van Asch T.W., Van Beek L.P.H., Bogaard, T.A. (2007). Problems in predicting the mobility of slow-moving landslides. Engineering geology, 91(1): 46-55.

Improving the large landslide investigation and zonation using multi-temporal orthoimage and point cloud datasets

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[2]Department of Civil Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan

After a landslide occurs, the primary task for authorities is to clarify the failure mechanism and impact area for disaster relief. For a large landslide, different failure mechanisms may coexist within the slope. Therefore, slope zonation is essential to design effective remediation strategies. However, in practice, most zonations only consider topography and landscape features and rely on data from one period. With the development of unmanned aerial vehicles (UAVs), slope observation has significantly improved in time and space resolutions. Chang et al. (2023a) compared the performance of different approaches to estimating landslide volume using UAV-based point clouds, including the DEM of difference (DOD) and M3C2 algorithm (Fig.1). With the aid of multi-temporal UAV images, Chang et al. (2023b) applied digital image correlation (DIC) analysis for interpreting the time-series slope kinematics in a progressive landslide. These preliminary studies show that high-resolution multi-temporal image datasets provide a chance for slope characterizing and monitoring purposes based on change detection techniques.

In this study, the potential and feasibility of the change detection techniques on large landslide monitoring are further discussed. The case study is an active large landslide located in central Taiwan. The landslide has attracted attention since 2018 due to significant deformation displacement (over 1m per day for approximately a year until 2021). We collected 52 orthoimages and 14 point clouds generated through UAV observations during the active period. The current work first utilized the DIC technique to obtain the two-dimensional (2D) full-field displacements based on UAV orthoimages. Although 2D displacements assist in understanding the time-series movement of a deformed slope (Fig. 2), DIC results are insufficient to interpret the failure mechanisms because of the limitation of the analysis dimension. We then applied the UAV-based point cloud data to analyze the landslide's three-dimensional (3D) deformation kinematics to this study using the M3C2 algorithm. Based on the DIC and M3C2 results, the deformation mechanism of the active landslide is expected to be well addressed. Moreover, the large landslide can be subdivided into representative sub-units, additionally considering landslide movement. Based on the case study, this research will propose an analytical suggestion for utilizing point cloud data and feasible analysis procedures of M3C2 and DIC techniques in practical engineering applications.

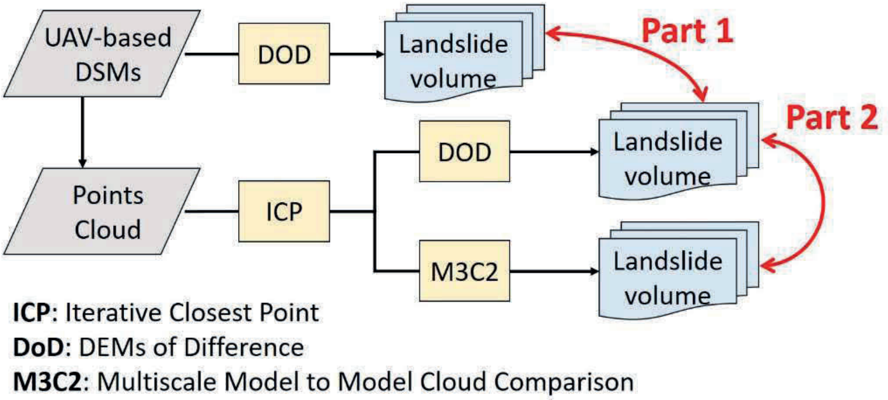

Figure 1*: The flow chart of the landslide volume estimation using different approaches (Chang et al., 2023a)*

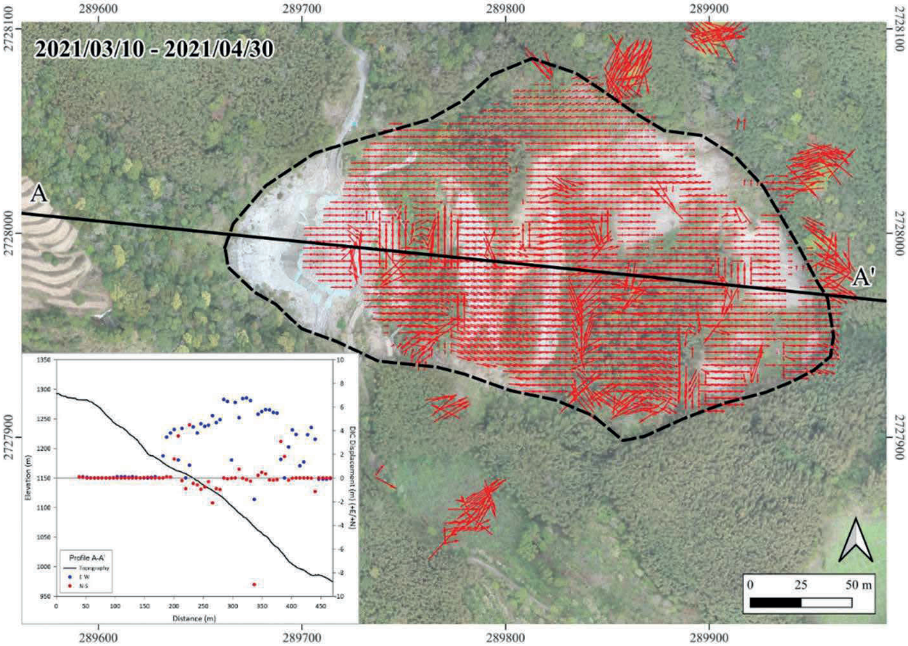

***Figure 2**: DIC analysis of the case study using UAV-based orthoimages*.

Chang, K.-Y., Huang, W.-K., Lin, C.-H. & Lin, M.-L. (2023a). A comparative study of UAV-based 3D point cloud analyses on landslide volume estimation for progressive rockslide. EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-3102.

Chang, K.-Y., Lin, C.-H., and Lin, M.-L. (2023b). Preliminary study on kinematic behavior of an active large landslide using multi-temporal UAV investigation and digital image correlation analysis., the 34th KKHTCNN, Pattaya, Thailand, 23-25 Nov 2023.

Simulation based analysis of high precision UAV tracking with robotic total stations

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Measurements from kinematic platforms such as UAVs are an integral part of modern surveying. Such multi-sensor systems require trajectory information to successfully geo-reference the data acquired by the imaging sensor, e.g. an airborne laser scanner (ALS) or cameras. Therefore, the need for reliable and accurate trajectory data of multi-sensor systems is present in a wide range of applications, ranging from infrastructure monitoring via robotics to photogrammetry. Improving the accuracy of the estimated trajectory accuracy is the primary objective of the TrackDrone research project, which uses a decentralized multi-sensor approach, where the involved sensors are spatially separated in a ground segment and a kinematic segment. This enables new possibilities for determining the position and orientation of the measurement platform by combining Robotic Total Stations (RTS), Image Assisted Total Stations (IATS), inertial measurement units (IMU), and imaging sensors like cameras or laser scanners.

RTS are often selected to measure trajectories of kinematic platforms, either to assess the accuracy of a GNSS/IMU-based navigation solution or as a measuring instrument for determining the trajectories themselves (Blaha et al., 2012; Paraforos et al., 2017; Roberts & Boorer, 2016). However, there is a lack of comprehensive research on the capabilities of RTS in scenarios, when high speeds and distances of these platforms relative to the RTS are taken into account, as most research is limited to slower near-range use cases (Kälin et al., 2023; Tombrink et al., 2023).

The main motivation is to improve the accuracy and reliability of existing methods, such as GNSS/IMU-based trajectory determination. The proposed method is independent of GNSS availability, and achieves higher accuracy. To achieve this, all sensors mounted on the kinematic segment are used and combined with the RTS data from the ground segment, finally resulting in an integrated trajectory estimate.

The involved systems and the overall concept of the described approach are schematically depicted in Fig. 1, where the GNSS/IMU-based trajectory of a UAV is improved by the polar observations of two IATS, the photogrammetric measurements based on the integrated telescope camera and the imaging sensor mounted on the UAV, to derive a 6-DOF trajectory.

At the current stage of development, the system is limited to the ground segment, i.e. an accurately time referenced 3D trajectory of the UAV is measured by multiple IATS, and the orientation of the platform can be extracted from the recorded videos of the coaxial cameras of the used IATS, comparable to the investigations of Niemeyer et al. (2012).

The integration of the onboard-sensors of the UAV will be the main task in the following project phase.

Being in its first year, the project focuses on the position component of the 6-DOF trajectory of the UAV. The integration of the orientation of the UAV will be emphasized in the next phase of the project.

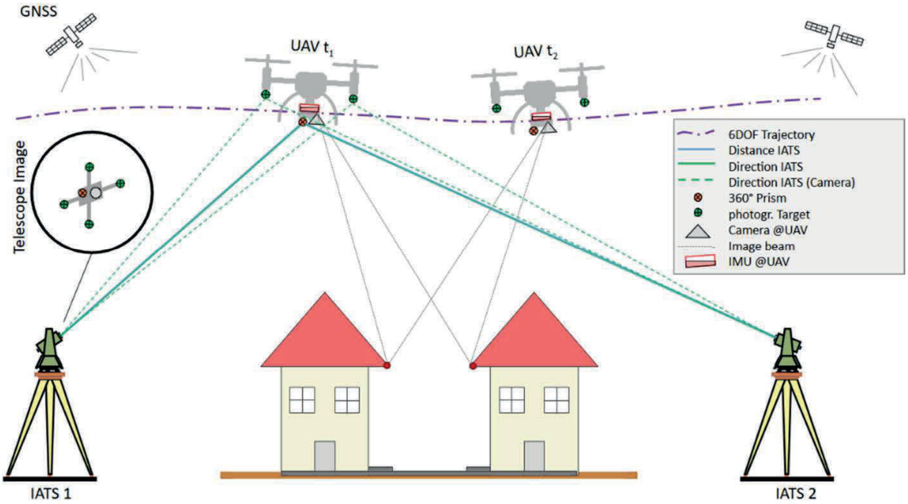

***Figure 1**: Concept for the integrated trajectory estimation in the scope of TrackDrone*

Blaha, M. & Eisenbeiss, H., Grimm, D. & Limpach, P. (2012). Direct Georeferencing of UAVs. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 38, 131-136.

Niemeyer, F., Bill, R. & Grenzdörffer, G. (2012). Konzeption und Genauigkeitsabschätzung für eine Bestimmung der äußeren Orientierung eines Unmanned Aerial Vehicles (UAV). Photogrammetrie-Fernerkundung-Geoinformation, 2012, 141-157.

Kälin, U., Hürzeler, M. & Grimm, D. (2023). Calibration of kinematic measuring systems.Ingenieurvermessung 23. Beiträge zum 20. Internationalen Ingenieurvermessungskurs Zürich, 2023, 195-207.

Paraforos, D., Reutemann, M., Sharipov, G., Werner, R. & Griepentrog, H. (2023). Total station data assessment using an industrial robotic arm for dynamic 3D in-field positioning with sub-centimetre accuracy. Computers and Electronics in Agriculture, 136, 166-175.

Robert, C. & Boorer, P. (2016). Kinematic positioning using a robotic total station as applied to small-scale UAVs. Journal of Spatial Science, 61(1), 29-45.

Tombrink, G. & Dreier, A., Klingbeil, L. & Kuhlmann, H. (2023). Trajectory evaluation using repeated rail-bound measurements. Journal of Applied Geodesy, 17(3), 205-216, https://doi.org/10.1515/jag-2022-0027.

Mapping shallow landslide under forest canopies using bi-temporal digital terrain models derived from topographic LiDAR datasets

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Shallow landslides (with a depth <2 m) occur worldwide and pose a large threat to the population and infrastructure in mountainous regions (Petley, 2012). To assess the risk that these shallow landslides pose to such communities, it is important to first understand where these landslides have occurred in the past. High quality risk assessments thus require that the inventories of past landslides are also of high quality (Guzzetti et al., 2012). However, many existing landslide inventories lack in their quality and completeness. Especially the completeness in forested areas is often lacking, due to the limitations of the methods that are commonly used to construct these datasets (Görüm, 2019; Steger et al., 2021). Examples are the use of aerial imagery, which cannot penetrate dense vegetation, and the use of field visits, where shallow landslides in forests often remain underreported due to the limited caused damage. It is therefore important that more research is performed on constructing landslide inventories in forested areas. Several studies exist that investigate the use of topographic Light Detection and Ranging (LiDAR) datasets for this, since this technique is capable of penetrating the forest canopy (Bernard et al., 2021). Many studies have also investigated how terrain models derived from topographic LiDAR datasets can be used to automatically map landslides (Jaboyedoff et al., 2018). However, limited research has focused on the use of the difference between two elevation models from multiple topographic LiDAR acquisition, or the difference of Digital elevation model (DoD), for landslide mapping.

In this study we investigate how the features derived from the difference between bi-temporal elevation models from aerial topographic LiDAR data, can be used in a semi-automatic workflow for mapping shallow landslides in forested areas. The study investigates an extreme precipitation event that occurred in the Sellrain valley (Tyrol, Austria) in 2015, triggering more than a hundred shallow landslides (Hübl, et al., 2016). The study makes use of several topographic features derived from two digital terrain models acquired around the event (dating from 2013 and 2017), such as the slope map and roughness index. These topographic features are then analyzed in a feature importance analysis to determine which features best describe the topography of a shallow landslide. With this we also focus on the differences between forested and non-forested areas. After the most important features have been identified, these features are then used in a logistic regression model to automatically map the shallow landslides that occurred between 2013 and 2017. The last step consists of filtering the model output from false positives, since the model outputs a large amount of noise due to the large timeframe that is analyzed and the degree of human activity in the study area. First results (see also Fig. 1 and 2) show a distinct difference in the feature importance of topographic features for mapping shallow landslides when forested and non-forested areas are compared. In addition, the performance of the model also greatly benefits from a separate training in forested and non-forested areas, with an increase in the Area Under the Curve (AUC) value from 0.84 to 0.89 with, respectively, unseparated and separated training. Further research will analyze the potential of additional supervised learning models for landslide detection and the benefits of semantic segmentation of the model input.

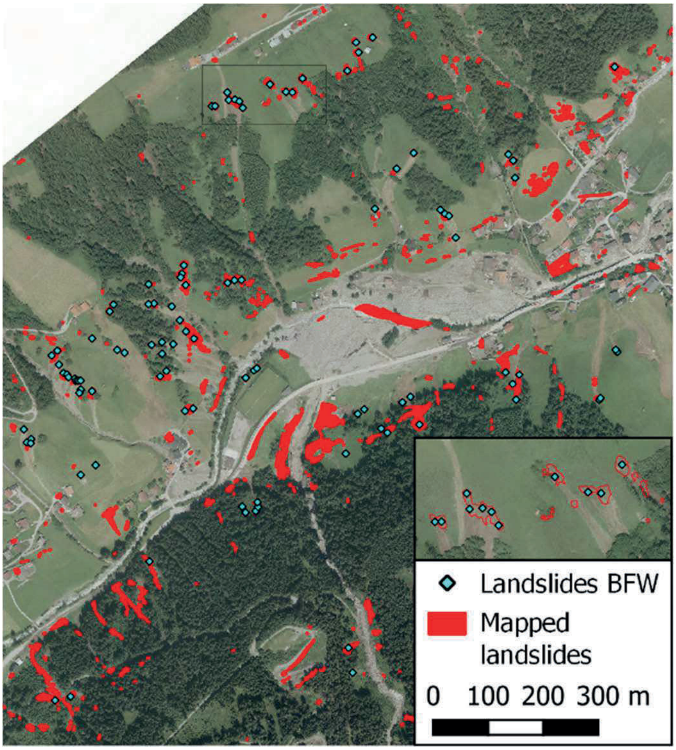

***Figure 1**: Map of detected landslides from the first results with the logistic regression model*

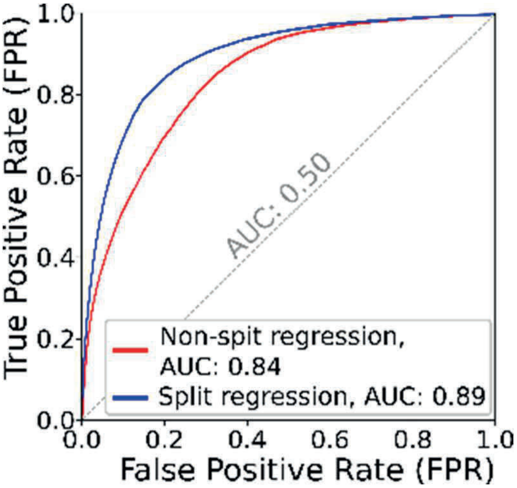

***Figure 2**: Performance of the trained logistic regression models*

Bernard, T. G., Lague, D., & Steer, P. (2021). Beyond 2D landslide inventories and their rollover: Synoptic 3D inventories and volume from repeat lidar data. Earth Surface Dynamics, 9(4), 1013–1044. https://doi.org/10.5194/esurf-9-1013-2021

Görüm, T. (2019). Landslide recognition and mapping in a mixed forest environment from airborne LiDAR data. Engineering Geology, 258, 105155. https://doi.org/10.1016/j.enggeo.2019.105155

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K.-T. (2012). Landslide inventory maps: New tools for an old problem. Earth-Science Reviews, 112(1), 42–66. https://doi.org/10.1016/j.earscirev.2012.02.001

Hübl, J., Beck, M., Zöchling, M., Moser, M., Kienberger, C., Jenner, A., & Forstlechner, D. (2016). Ereignisdokumentation 2015 (IAN Report 175) [Band 1]. Institut für Alpine Naturgefahren, Universität für Bodenkultur – Wien.

Jaboyedoff, M., Abellán, A., Carrea, D., Derron, M.-H., Matasci, B., & Michoud, C. (2018). Mapping and Monitoring of Landslides Using LIDAR. In R. P. Singh & D. Bartlett (Eds.), Natural Hazards (1st ed., pp. 397–420). CRC Press. https://doi.org/10.1201/9781315166841-17

Petley, D. (2012). Global patterns of loss of life from landslides. Geology, 40(10), 927–930. https://doi.org/10.1130/G33217.1

Steger, S., Mair, V., Kofler, C., Pittore, M., Zebisch, M., & Schneiderbauer, S. (2021). Correlation does not imply geomorphic causation in data-driven landslide susceptibility modelling – Benefits of exploring landslide data collection effects. Science of The Total Environment, 776, 145935. https://doi.org/10.1016/j.scitotenv.2021.145935

Generative approach to AI-based drone analytics

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The past decades have seen a proliferation of drone (UAV) technologies across various applications. In these applications, niche methodologies have been developed to make drone acquired imagery fit for that use-case (Kislik et al., 2018; Dainelli et al., 2021). Because these methodologies are developed only with the use-case in mind, making it hard to translate the findings to other areas. Therefore, when developing the use-case, it requires additional work to apply existing models, approaches and datasets. This increases the barrier to entry of UAV usage and the insights they provide, limiting adoption to those who require the benefits most (Diez et al., 2021). Lowering the barrier to entry for UAV image analysis requires these analytical models to be made more generalizable.

The first activity performed in the PhD project was to identify available UAV technologies, such as platforms, payloads and software across domains. This cross-domain understanding underlines the similarities and differences between adoption of the technology as well as the limitations to the technology as well as the quality of performed research. In this first work, a broad overview of applied UAV technology was given, by analyzing 73 systematic literature reviews spread across 10 domains including over 10 000 primary studies. The findings summarize the limitations of UAVs in regulatory, societal, technical and academic dimensions, as well as introducing pathways to improve research going forward. Luckily, the field seems to be highly adaptive and creative in developing UAV applications, and this ongoing innovation will see many of the barriers to entry lifted down the line (Doornbos et al., 2024).

The next phase of the project is focused on analysis-methodologies. First and foremost is developing evaluation approaches that accurately describe real-world applications. The time, location, sensor use, flight settings and model hyperparameters have a large influence on the result (Diez et al., 2021; Tuia et al., 2022). For UAV research to have real-world implementations, studies require an evaluation approach that also describe a generalization beyond the training dataset, especially in studies using Deep Learning, where models have more parameters than input values (Safanova et al., 2023). Dataset augmentation through generative models seems an especially potent step for increasing dataset variation in time, space and subject matter (Joshi et al., 2022).

This problem translates to my current work of analyzing the generalization of the Pix2Pix generative network in creating useful NDVI imagery from RGB data in the vineyard, similar to Farooque et al. (2023) and Davidson et al. (2022), measured across various dimensions of generalization. These dimensions are spatial, temporal and sensors. By evaluating the output of the model on a different vineyard, the same vineyard in a different date and using different RGB sensors than the Pix2Pix training dataset. Furthermore, the output maps are evaluated in real-world applications in the vineyard: through botrytis bunch rot prediction, as well as vineyard vigor mapping, going beyond the standard generative evaluation metrics of structural similarity, Fréchet inception distance or mean-squared error. This study shows that while GANs enable RGB sensors to create useful NDVI maps, it is questioned whether they outperform existing approaches. Furthermore, the proposed evaluation method, testing both out-of-training generalization as well as the practical applications, is seen as a key enabling step for future research to build upon (status: finishing up article).

Beyond these first studies, a further pathway for generalization in the PhD project will be explored through orthomosaic-chipping. Deep Learning models are often not specifically developed with UAV imagery in mind, with the model input resolution often being an order of magnitude lower than the UAV provides. Existing studies solve this problem by either slicing the input image to smaller ‘chips’ that can be used in the Deep Learning model, or down sample the complete image altogether, missing many of the high-resolution benefits UAV imagery offers. This planned work explores the chipping step as an opportunity for attaining higher model accuracy and improve out-of-sample generalization by providing four distinct, but compatible chipping techniques for training-set augmentation.

Dainelli, R., Toscano, P., di Gennaro, S. F., & Matese, A. (2021). Recent advances in unmanned aerial vehicles forest remote sensing—a systematic review. Part ii: Research applications. Forests, 12(4). https://doi.org/10.3390/f12040397

Davidson, C., Jaganathan, V., Sivakumar, A. N., Czarnecki, J. M. P., & Chowdhary, G. (2022). NDVI/NDRE prediction from standard RGB aerial imagery using deep learning. Computers and Electronics in Agriculture, 203, 107396. https://doi.org/10.1016/J.COMPAG.2022.107396

Diez, Y., Kentsch, S., Fukuda, M., Caceres, M. L. L., Moritake, K., & Cabezas, M. (2021). Deep learning in forestry using uav-acquired rgb data: A practical review. Remote Sensing, 13(14). https://doi.org/10.3390/rs13142837

Doornbos J., Bennin, K.E., Babur, Ö, Valente, J. (2024). Drone Technologies: a Tertiary Literature Review on a Decade of Improvements. IEEE Access, 1-19. https://doi.org/10.1109/ACCESS.2024.3364676

Farooque, A. A., Afzaal, H., Benlamri, R., Al-Naemi, S., MacDonald, E., Abbas, F., MacLeod, K., & Ali, H. (2023). Red-green-blue to normalized difference vegetation index translation: a robust and inexpensive approach for vegetation monitoring using machine vision and generative adversarial networks. Precision Agriculture, 24(3), 1097–1115. https://doi.org/10.1007/S11119-023-10001-3/METRICS

Joshi, A., Guevara, D., & Earles, M. (2022). Standardizing and Centralizing Datasets to Enable Efficient Training of Agricultural Deep Learning Models. http://arxiv.org/abs/2208.02707

Kislik, C., Dronova, I., & Kelly, M. (2018). UAVs in support of algal bloom research: A review of current applications and future opportunities. Drones, 2(4), 1–14. https://doi.org/10.3390/drones2040035

Safonova, A., Ghazaryan, G., Stiller, S., Main-Knorn, M., Nendel, C., & Ryo, M. (2023). Ten deep learning techniques to address small data problems with remote sensing. International Journal of Applied Earth Observation and Geoinformation, 125, 103569. https://doi.org/10.1016/J.JAG.2023.103569

Tuia, D., Kellenberger, B., Beery, S., Costelloe, B. R., Zuffi, S., Risse, B., Mathis, A., Mathis, M. W., van Langevelde, F., Burghardt, T., Kays, R., Klinck, H., Wikelski, M., Couzin, I. D., van Horn, G., Crofoot, M. C., Stewart, C. v., & Berger-Wolf, T. (2022). Perspectives in machine learning for wildlife conservation. Nature Communications 2022 13:1, 13(1), 1–15. https://doi.org/10.1038/s41467-022-27980-y

InSAR-based multi-scale integrated monitoring systems for cultural heritage and historic sites

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Cultural heritage (CH), and historic and archaeological sites are precious assets of each society with a high level of socio-economic significance and considerable physical and systemic vulnerability. They are permanently subjected to several types of natural and anthropogenic hazards and pressures: Geohazards such as landslides and ground settlements (Lombardo et al. 2020); Environmental conditions such as temperature variations (Masciotta et al., 2017), etc. Imposing extreme levels of tangible and intangible damage to these valuable assets, "Monitoring" these diverse types of hazards becomes an important operation in the context of risk management and mitigation. As an active microwave remote sensing technique, Satellite Synthetic Aperture Radar Interferometry (InSAR) is a promising tool for measuring ground deformation for several applications (Crosetto et al., 2016) with high accuracy and reliability. Despite the known unique capabilities and advantages, such as high spatial and temporal resolution and being a relatively low-cost technology (Scaioni et al., 2018), the technology is characterised by different levels of limitations, such as low coherence in sensor-unfriendly scenes (e.g., vegetated areas) and insensitivity to North-South direction of land surface displacements. Besides, integrating satellite InSAR-derived information with other techniques allows for a more robust and reliable monitoring scheme (Themistocleous & Danezis, 2020; Eskandari and Scaioni, 2023). Furthermore, the identification of multiple hazards and addressing the possible corresponding causes demand a comprehensive perspective of assessment through a multi-scale manner. This research focuses on the development of a framework for designing InSAR-based Multi-Scale Integrated Monitoring Systems (MSIMS) to identify and monitor different types of hazards threatening the historic site and corresponding infrastructure. The data from different techniques, such as environmental monitoring and close-range sensing, applied to several case studies will be used to validate and boost InSAR-based findings and calibrate different parameters in the framework to become able to design case-specific and robust monitoring systems.

Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., & Crippa, B. (2016). Persistent Scatterer Interferometry: A review. ISPRS Journal of

Photogrammetry and Remote Sensing, 115, 78–89. https://doi.org/10.1016/j.isprsjprs.2015.10.011

Eskandari R and Scaioni M (2023) Retrospective Study Of Vertical Ground Deformation In Como, Northern Italy: Integration Of Levelling And Psi Measurements. Int Arch Photogramm Remote Sens Spatial Inf Sci XLVIII-4/W2-2022: 31-38. doi: https://doi.org/10.5194/isprs -archives-XLVIII-4-W2-2022-31-2023

Lombardo, L., Tanyas, H., & Nicu, I. C. (2020). Spatial modeling of multi-hazard threat to cultural heritage sites. Engineering Geology, 277, 105776. https://doi.org/10.1016/j.enggeo.2020.105776

Masciotta, M.-G., Ramos, L. F., & Lourenço, P. B. (2017). The importance of structural monitoring as a diagnosis and control tool in the restoration process of heritage structures: A case study in Portugal. Journal of Cultural Heritage, 27, 36–47. https://doi.org/10.1016/j.culher.2017.04.003

Scaioni, M., Marsella, M., Crosetto, M., Tornatore, V., & Wang, J. (2018). Geodetic and Remote-Sensing Sensors for Dam Deformation Monitoring. Sensors, 18(11), 3682. https://doi.org/10.3390/s18113682

Themistocleous, K., & Danezis, C. (2020). Monitoring Cultural Heritage Sites Affected by Geo-Hazards Using In Situ and SAR Data: The Choirokoitia Case Study. In D. G. Hadjimitsis, K. Themistocleous, B. Cuca, A. Agapiou, V. Lysandrou, R. Lasaponara, N. Masini, & G. Schreier (Hrsg.), Remote Sensing for Archaeology and Cultural Landscapes (S. 285–308). Springer International Publishing. https://doi.org/10.1007/978-3-030-10979-0_16

Mapping of geological fractures: A CNN approach

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Geological features such as natural fractures and faults control the migration pathways of fluids – including groundwater, geothermal, or ore-bearing fluids – and can contribute to hazards such as rockfalls and landslides. Nowadays, detailed mapping of fractures is facilitated by high-resolution imagery obtained from drone-based sensors and satellites. However, quickly extracting meaningful information about geological fractures across multiple from these high-resolution scales from these high-resolution images still poses a real challenge. While considered to be effective, semi-automated processes are still time-consuming, as they require heavy input from experienced users, and are subject to interpreter bias. In our project, we explore deep learning-based methods to enable a fully automated workflow for mapping geological fractures. Initially, we trained a Convolutional Neural Network (CNN) using a publicly available dataset consisting of orthophotos and detailed fracture maps (Mattéo et al., 2021). The U-Net CNN (Fig. 1; Ronneberger et al., 2015) was then fine-tuned by exploring different parameters such as: optimizers, loss functions, activation functions, normalization, dropout, and class weighting. The resulting models (Fig. 2–4) will be evaluated as we seek to understand the efficacy, strengths, and limitations of this approach. This research could be expanded to explore the potential of deep neural networks for accurate and rapid mapping of other features in rocks such as mineral alteration due to fluid-rock interaction and weathering.

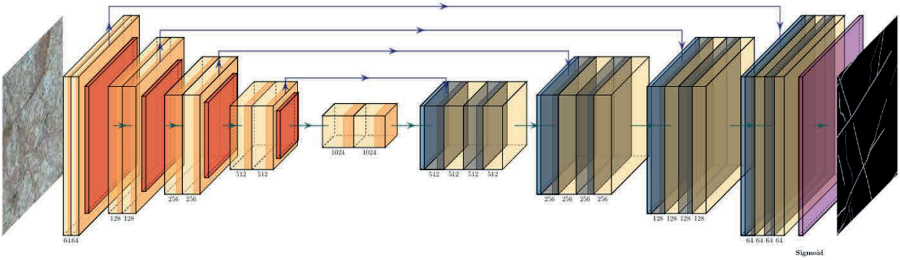

***Figure 1**: Architecture of the adopted U-Net*

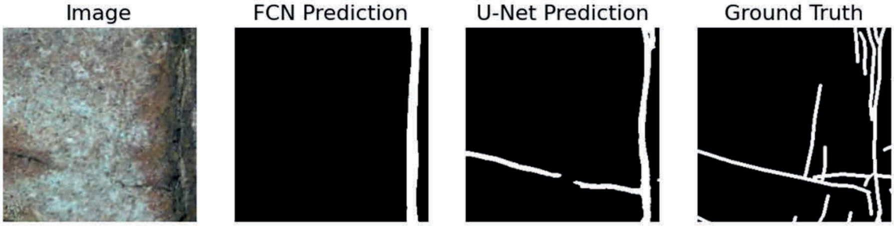

Figure 2: *First results of baseline FCN (Fully Convolutional Network) and U-Net (U shaped convolutional neural network) models*

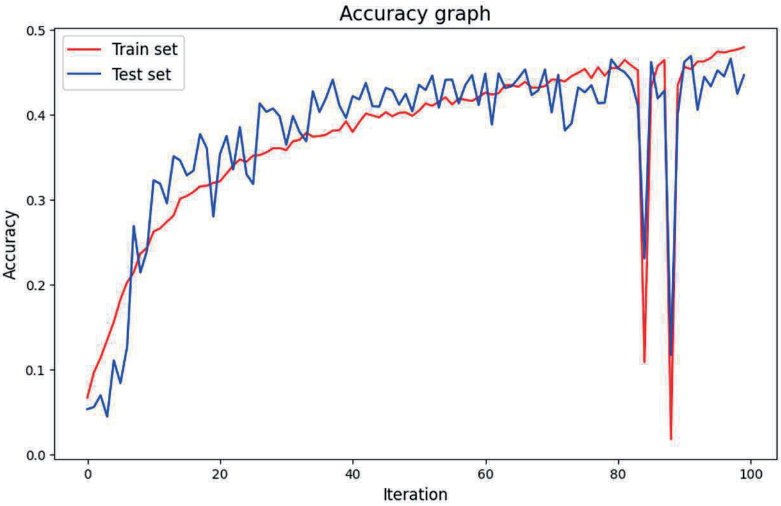

Figure 3*: Accuracy graph of the U-Net (the percentage of correct predictions throughout training)*

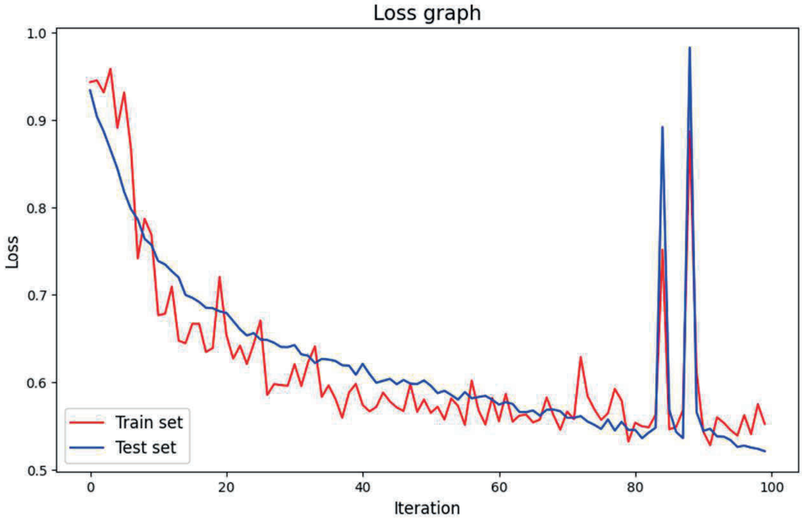

***Figure 4**: Loss graph of the U-Net (the average error according to the loss function between the model& apos;s predictions and the true values throughout training)*

Mattéo, L., Manighetti, I., Tarabalka, Y., Gaucel, J., Van Den Ende, M., Mercier, A., Tasar, O., Girard, N., Leclerc, F., Giampetro, T., Dominguez, S., & Malavieille, J. (2021). Automatic Fault Mapping in Remote Optical Images and Topographic Data With Deep Learning. Journal of Geophysical Research: Solid Earth, 126(4), e2020JB021269. https://doi.org/10.1029/2020JB021269

Ronneberger, O., Fischer, P., & Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation. In N. Navab, J. Hornegger, W. M. Wells, & A. F. Frangi (Hrsg.), Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015 (Bd. 9351, S. 234–241). Springer International Publishing. https://doi.org/10.1007/978-3-319-24574-4_28

Lab experiment for simultaneous reconstruction of water surface and bottom with a synchronized camera rig

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Introduction: In photo bathymetry, the bottom of a water body is observed with cameras in the air through the open and dynamic water surface. When entering water, the image rays are bended at the media boundary according to Snell’s law of refraction and blurring occurs due to scattering in the water column. In particular, e.g. Okamoto (1982) has shown that the presence of waves at the water surface causes significant errors. The main limiting factor for obtaining higher accuracy in photo bathymetry is therefore the ability to reconstruct or model the dynamic, wave-induced water surface. Existing work regarding the reconstruction of waves includes techniques based on very diverse approaches. Among them, there is the use of surface markers being deployed on an area of interest and their subsequent tracking (e.g. Chandler et al., 2008), which is not easily implementable in large-scale applications. Other examples use optical properties of the water surface, namely the specular reflection (e.g. Rupnik et al., 2015) or the refraction of the optical rays (e.g. Murase, 1992; Morris & Kutulakos, 2011). However, these contributions rely on assumptions such as knowledge of the mean water height or the topography, which is not applicable to our case of study since we aim to reconstruct both the topography and the water surface of an unknown water body. One option to approach the problem is using a camera rig for capturing both the water surface and bottom strictly at the same time with synchronized oblique and nadir images. In this contribution, we present the setup and first results of a feasibility study carried out in the measurement lab of TU Wien.

Camera rig: We have borrowed a complete camera rig from IPF Stuttgart. This setup is composed of four cameras and lenses, an Arduino Leonardo and the associated cabling. The Arduino serves as controller and synchronizes the cameras by sending a trigger signal in user-definable intervals via a cabled USB connection. Two cameras are used to capture the water surface, looking obliquely from the side, and the other two to capture the water bottom, looking nadir from above.

Lab experiment: For testing the idea of simultaneous image acquisition, we designed and conducted an experiment at the 4D measurement lab of TU Wien. As a prerequisite, we first installed an array of coded photogrammetric targets on the floor, walls, and measurement pillars in the corner of the lab and measured the 3D coordinates with sub-mm precision with a total station. These targets served as control and check points in the bundle block adjustment. In a second step, we installed a 200L mortar bucket and covered the bottom with gravel stones. Then we measured the topography of the stones with a conventional image block using a Structure-from-Motion and Dense Image Matching approach. After that, we filled the bucket with clear water, and installed and measured additional coded targets on the top and side of the bucket. Finally, we arranged the four cameras as explained above around the bucket. After these preparation steps, we took a series of synchronized images while creating moderate waves. The entire setup is shown in (Fig. 1).

First results: The entire image block can be oriented and georeferenced in high accuracy via the photogrammetric targets. Only the bottom is visible in the nadir images but not the water surface. From the nadir image pairs we repeatedly derived the bottom topography both for still or wave-induced water surfaces. For the undulated water surfaces, this resulted in the expected drop of accuracy. At the time of writing this abstract, data processing to reconstruct the water surface in 3D from the oblique images is in progress and additional leads are tested, like adding dust in the water to create turbidity. Depending on the final success of the lab experiment, we further plan to use a drone squadron for capturing real world scenes with the same concept.

***Figure 1**: Setup of the lab experiment. Water and stone filled 200L bucket, coded targets serving as control and check points, synchronized camera rig consisting of 2 oblique cameras (left) and 2 nadir looking cameras (top)*

Okamoto, A. (1982). Wave Influences in Two-Media Photogrammetry. Photogramm. Eng. Remote Sens., 48, 1487-1499.

Chandler, J., Wackrow, R., Sun, X., Shiono, K. & Rameshwaran, P. (2008). Measuring a Dynamic and Flooding River Surface by Close Range Digital Photogrammetry. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37.

Rupnik, E., Jansa, J. & Pfeiffer, N. (2015). Sinusoidal Wave Estimation Using Photogrammetry and Short Video Sequences. Sensors, 15(12), 30784-30809.

Murase, H. (1992). Surface Shape Reconstruction of a Nonrigid Transport Object Using Refraction and Motion. IEEE Trans. Pattern Anal. Machine Intell., 14(10), 1045-1052.

Morris, N. J. W. & Kutulakos, K. N. (2011). Dynamic Refraction Stereo. IEEE Trans. Pattern Anal. Mach. Intell., 33(8), 1518-1531.

Remote sensing methods for forest understory mapping

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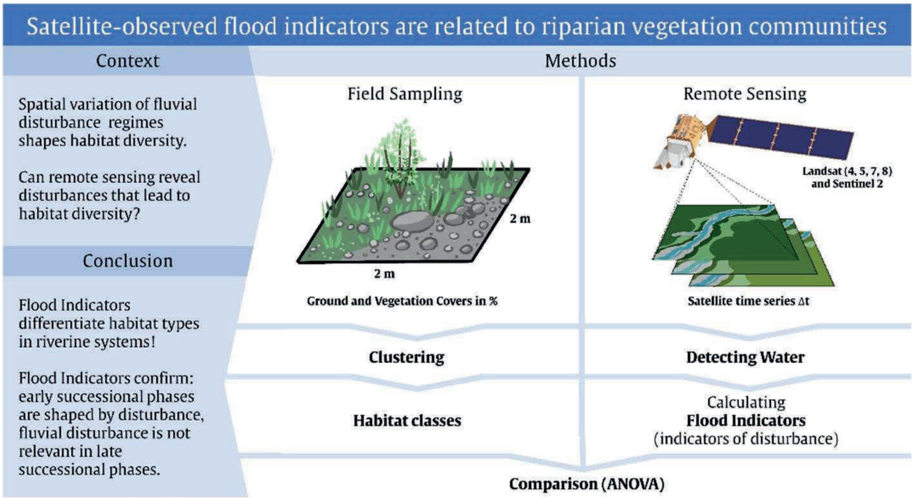
From an alpine mountain river observed through Landsat and Sentinel-2…

I just handed in a paper titled “Satellite-observed flood indicators are related to riparian vegetation communities“. In this work we detected flood patterns of the Lech River (Austria) from satellite data and compared local flood histories to vegetation communities we observed on site. The paper is based on my master thesis. For a quick overview have a look at the graphical abstract (Fig. 1).



Satellite-observed flood indicators are related to riparian vegetation communities

Context

Spatial variation of fluvial disturbance regimes shapes habitat diversity.

Can remote sensing reveal disturbances that lead to habitat diversity?

Conclusion

Flood Indicators differentiate habitat types in riverine systems!

Flood Indicators confirm: early successional phases are shaped by disturbance, fluvial disturbance is not relevant in late successional phases.

***Figure 1**: Graphical abstract showing the concept of a just finished paper on the relation between the flood history and local vegetation communities in an alpine river environment. By Hermann et al. (2024)*

… to forests in Bandenburg observed through TLS Scanning and RGB image mosaics

The main focus of my PhD project is the structure of forests in 3D space, especially understory vegetation and litter on the forest ground in relation to the structure of the overstory. Much research using remote sensing technology has focused on forest canopies. In contrast, remote sensing research on understory structure has been scarce as established optical remote sensing approaches from satellite or UAV platforms are hardly able to collect information from below the canopy.

In the summer of 2023, we collected data in 32 30x30 m plots in Brandenburg (Germany). For each plot we collected TLS scans, RGB drone images and RGB images of the forest floor using a GoPro camera on a pole to create continuous mosaics of the forest floor (Fig.2).

After the first field campaign and the first data processing phase we are now starting out into the first analysis steps using e.g. CloudCompare and the lidR package in R.

Ideas for upcoming data analysis include a) creating detailed continuous maps of different understory forest elements the RGB image mosaics, b) exploring the capacities of remote sensing methods compared to traditional, time-consuming, and potentially subjective field sampling, c) modeling forest understory elements as seen in RGB images and field samples from TLS data or satellite images and d) relating patterns detected by remote sensing to ecological processes.

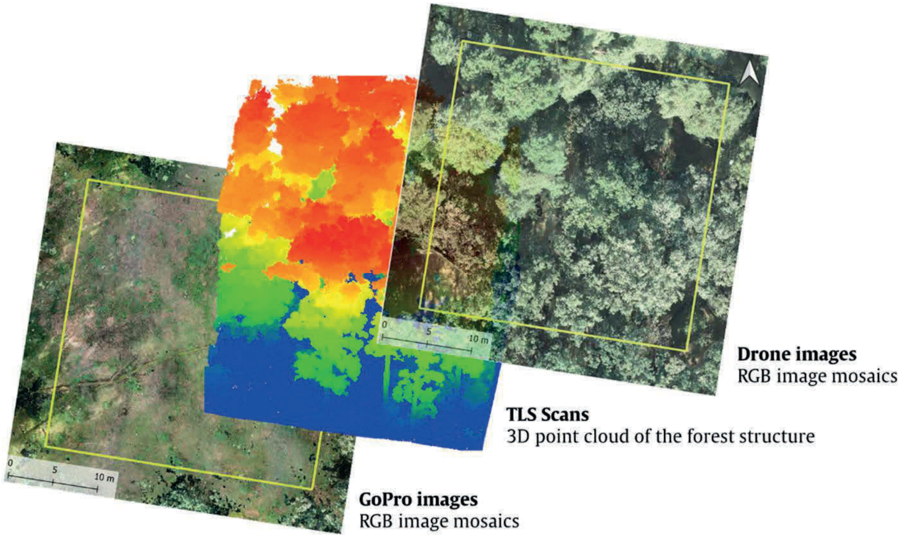


***Figure 2**: A look at our data set including different image mosaics, TLS scans and litter samples*

We are still expanding our data set! Possibly to the alpine region?

For the above described research, we are planning to expand our data set to further sites and regions. We are especially interested in other pine forest stands and plan e.g. to do sampling in Galicia (Spain) this summer. Another idea would be to expand the dataset to include mountainous forest stands by taking TLS scans after the summer school in Austria!

Herrmann, M., Schmidt-Riese, E., Bäte, D. A., Kempfer, F., Fassnacht, F. E., & Egger, G. (2024). Satellite-observed flood indicators are related to riparian vegetation communities. Ecological Indicators, 166, 112313.

Degradation and Fragmentation Effects on Structural Complexity in West-African Forest Patches

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Tropical forests worldwide face alarming rates of deforestation and degradation, driven mainly by agricultural land expansion (Fig. 1, Amani et al., 2021; Hansen et al., 2013; Poorter et al., 2021). West Africa is particularly affected by widespread forest fragmentation, leaving behind isolated forest patches in an agriculture-dominated landscape (Taubert et al., 2018; Wingate et al., 2022). Forest fragmentation and isolation can impact ecological characteristics, such as forest structural complexity, biomass, and species richness through various edge effects (Harper et al., 2005; Laurance & Peres, 2006). Consequent loss of biodiversity and ecosystem services is therefore expected to be more prominent in small and fragmented forests, and close to the edge (Olupot & Chapman, 2006; Peres & Palacios, 2007). We used terrestrial laser scanning to investigate patterns of forest structural complexity in 84 plots across seven forest patches in Togo, Benin, Nigeria, and Cameroon (Fig. 2). Forest structure, as quantified by the stand structural complexity index (SSCI, Ehbrecht et al., 2017), was analyzed with tree species composition, distance to edge, and the modelled potential SSCI of primary forests as ecological reference value to identify forest degradation. Spatial variability of SSCI within forest patches indicates various disturbances in different locations, ultimately accumulating to forest degradation. The overall trend suggests an increase in structural complexity, tree height, basal area, and tree species richness with increasing distance to the edge. However, these correlations are only significant for some of the forest patches analyzed. Comparison with the ecological reference value shows significant deviations for two forests, indicating degradation of forest structural integrity. Insights confirm and challenge theories of ecological dynamics in tropical forest patches in West Africa. Quantifying structural integrity helps to locate degradation and to preserve the last remaining forest patches crucial for biodiversity, climate regulation, and forest products.

Figure 1*: Agricultural fields encroach increasingly on the forest on the mount Agou, Togo.*

Figure 2*: Point cloud of a 25 x 25 m2 forest parcel on the hillside of mount Agou, Togo, colored according to x, y, and z-axis. The small boxes on the left side show scan positions of a FARO M70 terrestrial laser scanner. The same forest was also sensed with a LiDAR and multispectral UAV to allow future data fusion.*

Amani, B. H. K., N'Guessan, A. E., Derroire, G., N'dja, J. K., Elogne, A. G. M., Traoré, K., Zo-Bi, I. C., & Hérault, B. (2021). The potential of secondary forests to restore biodiversity of the lost forests in semi-deciduous West Africa. Biological Conservation, 259(109154), 1–10. https://doi.org/10.1016/j.biocon.2021.109154

Ehbrecht, M., Schall, P., Ammer, C., & Seidel, D. (2017). Quantifying stand structural complexity and its relationship with forest management, tree species diversity and microclimate. Agricultural and Forest Meteorology, 242, 1–9. https://doi.org/10.1016/j.agrformet.2017.04.012

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., & Townshend, J. R. G. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. Science, 342(6160), 850–853. https://doi.org/10.1126/science.1244693

Harper, K. A., Macdonald, S. E., Burton, P. J., Chen, J., Brosofske, K. D., Saunders, S. C., Euskirchen, E. S., Roberts, D., Jaiteh, M. S., & Esseen, P.-A. (2005). Edge Influence on Forest Structure and Composition in Fragmented Landscapes. Conservation Biology, 19(3), 768–782. https://doi.org/10.1111/j.1523-1739.2005.00045.x

Laurance, W. F., & Peres, C. A. (Eds.). (2006). Emerging threats to tropical forests. University of Chicago Press.

Olupot, W., & Chapman, C. A. (2006). Human Encroachment and Vegetation Change in Isolated Forest Reserves: The Case of Bwindi Impenetrable National Park, Uganda. In Emerging Threats to Tropical Forests. University of Chicago Press.

Peres, C. A., & Palacios, E. (2007). Basin-Wide Effects of Game Harvest on Vertebrate Population Densities in Amazonian Forests: Implications for Animal-Mediated Seed Dispersal. Biotropica, 39(3), 304–315. https://doi.org/10.1111/j.1744-7429.2007.00272.x

Poorter, L., Craven, D., Jakovac, C. C., Sande, M. T. V. D., Amissah, L., Bongers, F., Chazdon, R. L., Farrior, C. E., Kambach, S., & Meave, J. A. (2021). Multidimensional tropical forest recovery. Science, 374(December), 1370–1376.

Taubert, F., Fischer, R., Groeneveld, J., Lehmann, S., Müller, M. S., Rödig, E., Wiegand, T., & Huth, A. (2018). Global patterns of tropical forest fragmentation. Nature, 554(7693), 519–522. https://doi.org/10.1038/nature25508

Wingate, V. R., Akinyemi, F. O., Iheaturu, C. J., & Ifejika Speranza, C. (2022). A Remote Sensing-Based Inventory of West Africa Tropical Forest Patches: A Basis for Enhancing Their Conservation and Sustainable Use. Remote Sensing, 14(24), 6251. https://doi.org/10.3390/rs14246251

Exploring pretraining strategies for fractional cover mapping of evergreen broad-leaved species in Italian forests using Sentinel-2 time series

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The availability and amount of accurate training data in remote sensing and deep learning based mapping of environmental variables is a significant factor in performance across several studies and model architectures. Therefor many studies in forest satellite remote sensing are focusing on target variables that can easily be assessed by remote sensing techniques, manual labeling or are contained in large forest inventories. For more specific tasks plot observations have to be conducted in the field, which often leads to highly reduced sets of training data (Kattenborn et al., 2021; Hamedianfar et al., 2022). In the TRACEVE project (Tracing the evergreen broad-leaved species and their spread) we aim to map the past and future spread of evergreen broad-leaved species in Italian forests by combining Sentinel-2 annual time series with plot observations of fractional cover in protected forest areas. The modelling approach is based on deep learning techniques for time series extrinsic regression (Fawaz et al., 2020). In this context transfer learning can be used to partly overcome generalisability issues concerning the sparsely available training data from plot observations (Safonova et al., 2023; Ma et al., 2024). The focus of this study lies in investigating strategies for a time series based deep learning model for large scale mapping of forest fractional cover against the background of limited training data availability. Therefor the main objective of this study is to investigate three different (pre-)training approaches against robustness and prediction uncertainty when confronted with new, spatially explicit data. To accurately predict evergreen-broad-leaved cover an annual aggregate of two years of Sentinel-2 L2A time series including bands and derived indices is used. Outliers have been removed and the time series are processed using Whittaker smoothing to resemble the annual phenological cycle. The three tested training strategies are (i) using plot observations only, (ii) pretraining a forest type classifier on a large forest vegetation database (~17000 plots), and (iii) pretraining using a self-supervised approach based on the annual

Sentinel-2 time series (Fig. 1). To test the strategies against spatially independent reference data five areas in Italy (Sibillini, Gennargentu, Gran Sasso, Nebrodi and Cilento) were chosen for conducting plot observations. First results show RMSE values with a range from 0.14 to 0.17 during cross-validation, which is in line with other similar studies. Preliminary model results and mapping revealed that the lack of valid satellite observations during winter and leaf-off season in higher altitudes due to snow and extensive cloud cover is the largest error source in broad-leaved forest areas. Another problem poses needle-leaved forests that have a similar spectral signal and phenology as evergreen broad-leaved species (Fig. 2).

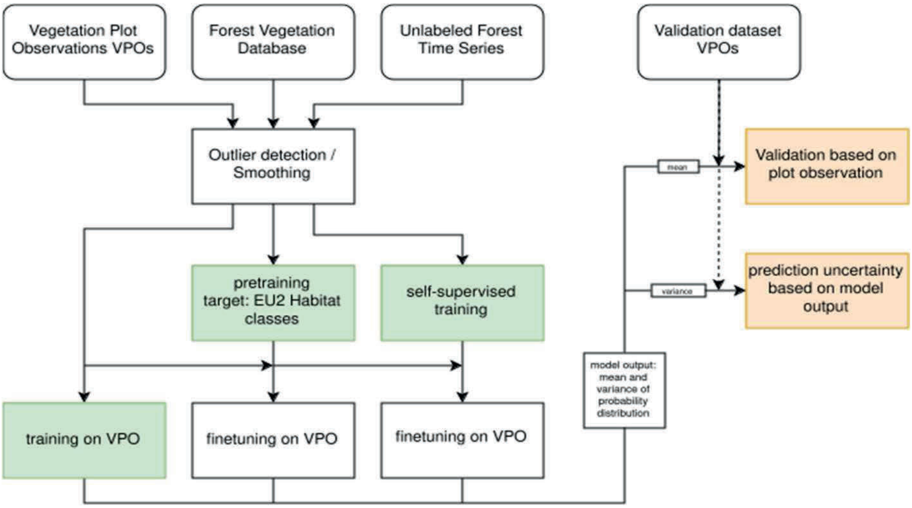

Figure 1*: Workflow and included data for (pre-)training and validation process. Figure by Hiebl, B. 2024.*

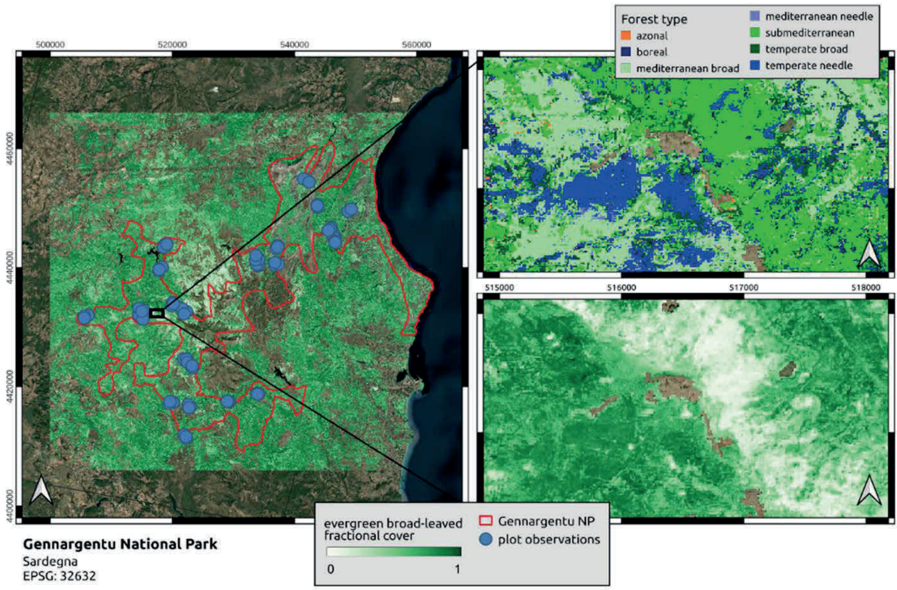

***Figure 2**: Evergreen broad-leaved species cover in forested areas around Gennargentu Nationalpark. In detail an area that shows the incorrect broad-leaved cover predictions in areas with high needle-leaved proportions. Figure by Hiebl, B. 2024.*

Ismail Fawaz, H., Lucas, B., Forestier, G., Pelletier, C., Schmidt, D. F., Weber, J., ... & Petitjean, F. (2020). Inceptiontime: Finding alexnet for time series classification. Data Mining and Knowledge Discovery, 34(6), 1936-1962.

Hamedianfar, A., Mohamedou, C., Kangas, A., & Vauhkonen, J. (2022). Deep learning for forest inventory and planning: a critical review on the remote sensing approaches so far and prospects for further applications. Forestry, 95(4), 451-465.

Kattenborn, T., Leitloff, J., Schiefer, F., & Hinz, S. (2021). Review on Convolutional Neural Networks (CNN) in vegetation remote sensing. ISPRS journal of photogrammetry and remote sensing, 173, 24-49.

Ma, Y., Chen, S., Ermon, S., & Lobell, D. B. (2024). Transfer learning in environmental remote sensing. Remote Sensing of Environment, 301, 113924.

Safonova, A., Ghazaryan, G., Stiller, S., Main-Knorn, M., Nendel, C., & Ryo, M. (2023). Ten deep learning techniques to address small data problems with remote sensing. International Journal of Applied Earth Observation and Geoinformation, 125, 103569.

The Influence of the Midlatitude Westerly Circulation and the Indian Summer Monsoon on Bhutan's Glaciers

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The global recession of the cryosphere raises significant concerns for the sustainability of water resources in high mountain regions, which are inhabited by nearly one-third of the world's population (Caretta et al., 2022; Castellazzi et al., 2019; Gärtner-Roer et al., 2019; Huss & Hock, 2018). Especially the catchments of the Himalaya depend on predictable summer contributions from snow melt and glacier runoff for agriculture, irrigation, hydropower, and potable water (Carey et al., 2017). However, the main climatic drivers of the environmental changes in the recent decades are barely identified as a combined contribution of westerlies and Indian summer monsoon (Joswiak et al., 2013; Mölg et al., 2014; Mölg et al., 2017). As an exemplary climatic proxy, the glacier mass balances in Bhutan will be analysed regarding the climatic factors. The data will be derived from the Bavarian Academy of Sciences (BAdW) and supported by open-source reanalysis data, as well as optical and radar satellite imagery (to be determined). Therefore, this study aims to quantify the influence of the westerlies and the Indian summer monsoon on the glacier dynamics in Bhutan. The results are targeted to give insights into the linkage of climatological large-scale dynamics and their manifestation on local to regional scales.

Caretta, M.A., Mukherji, A., Arfanuzzaman, M., Betts, R. A., Gelfan, A. Hirabayashi, Y., Lissner, T. K., Liu, J., Lopez Gunn, E., Morgan, R., Mwanga, S. & Supratid, S. (2022). Water, In: Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B. (eds.)], Cambridge University Press, 551-712.

Carey, M., Molden, O. C., Rasmussen, M. O., Jackson, M., Nolin, A. W. & Mark, B. G. (2017). Impacts of Glacier Recession and Declining Meltwater on Mountain Societies. Ann Am Assoc Geogr, 107 (2), 350-359.

Castellazzi, P., Burgess, D., Rivera, A., Huang, J., Longuevergne, L. & Demuth, M. N. (2019). Glacial Melt and Potential Impacts on Water Resources in the Canadian Rocky Mountains, Water Resour Res, 55, 10,191-10,217.

Gärtner-Roer, I., Nussbaumer, S. U., Hülser, F. & Zemp, M. (2019). Worldwide Assessment of National Glacier Monitoring and Future Perspectives, Mt Res Dev, 39 (2), A1-A11.

Huss, M. & Hock, R. (2018). Global-scale hydrological response to future glacier mass loss, Nature Climate Change, 8, 135-140.

Joswiak, D. R., Yao, T., Wu, G., Tian, L., & Xu, B. (2013). Ice-core evidence of westerly and monsoon moisture contributions in the central Tibetan Plateau. Journal of Glaciology, 59(213), 56–66.

Mölg, T., Maussion, F., & Scherer, D. (2014). Mid-latitude westerlies as a driver of glacier variability in monsoonal High Asia. Nature Climate Change, 4(1), 68–73.

Mölg, T., Maussion, F., Collier, E., Chiang, J. C. H., & Scherer, D. (2017). Prominent midlatitude circulation signature in High Asia's surface climate during monsoon. Journal of Geophysical Research: Atmospheres, 122, 12,702–12,712.

Self-organizing maps and permanent laser scanning for the analysis of surface dynamics

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[2]*Technical University of München, Germany*

Given projected climate change and its related pressure on complex dynamic environments, like sandy beaches and mountainous areas (Crozier et al., 2010; Vousdouskas et al., 2020), the understanding of geomorphological surface dynamics is necessary to ensure effective management strategies. However, understanding the drivers and characteristics of surface dynamics is challenging, as many natural and human forcings interplay, creating spatiotemporally stacked and diffuse types of surface dynamics. Permanent Laser Scanners (PLS), acquiring point clouds at (sub)hourly intervals for months to years provide the specifications necessary to overcome these challenges. The challenge that remains is extracting useful information of surface dynamics from the resulting point cloud time series in an automated and unsupervised way, which can be used to analyze relations between dynamics and driving environmental and human conditions.

In this research we propose the use of Self-organizing Maps (SOMs) to organize large point cloud time series and extract characteristic surface dynamics of the location of interest. The SOM enables the grouping and characterization of data for which boundaries between data clusters are not clear and subtle differences between characteristic patterns are expected. A SOM analysis may be achieved in two different ways. First, it can be done by creating daily grids of elevation change and organizing these in a SOM. Second, it can be used by first extracting spatiotemporal segments of surface activity as 4D objects-by-change (4D-OBCs, Anders et al., 2021) which are then organized and characterized using the SOM.

The first method has been tested on a three year long hourly point cloud dataset of a sandy beach in Noordwijk, The Netherlands. In a SOM the daily grids are sorted, and characteristic daily change states of a sandy beach are found (Fig. 1). Although most states show few changes, e.g., node E5), several states of higher degree of change are distinguished, e.g., node A1. The characteristic states can help in analyzing under which circumstances and in which sequence certain changes occur. For example, it can be found that state A7 occurs mostly after state H8 under circumstances of intermittent high wave height.

The second method has been tested on a 6-month sandy beach PLS dataset (Kijkduin, The Netherlands) and a dataset of snow cover changes on a glacier (Schneeferner, Germany). With a SOM, spatiotemporal segments are organized, and characteristic types of surface activity are identified (Fig. 2). For the sandy beach dataset, the SOM enables the identification of 4D-OBCs displaying a particular type of surface activity, and subtle differences between events of one surface activity. The snow cover dataset does not yet result in equal performance. Several groups of surface activity in the SOM contain a combination of 4D-OBCs representing different surface activity types.

The results already show that the methods enable long-term automated monitoring and understanding of surface dynamics in complex environments. Both methods allow for the identification of driving conditions of certain surface dynamics. Further analysis will be done on optimization, transferability, and understanding causal relations between drivers and surface dynamics through e.g., autoregressive logistic models, trained on the probabilistic sequences of elevation, surface activity type, and external drivers.

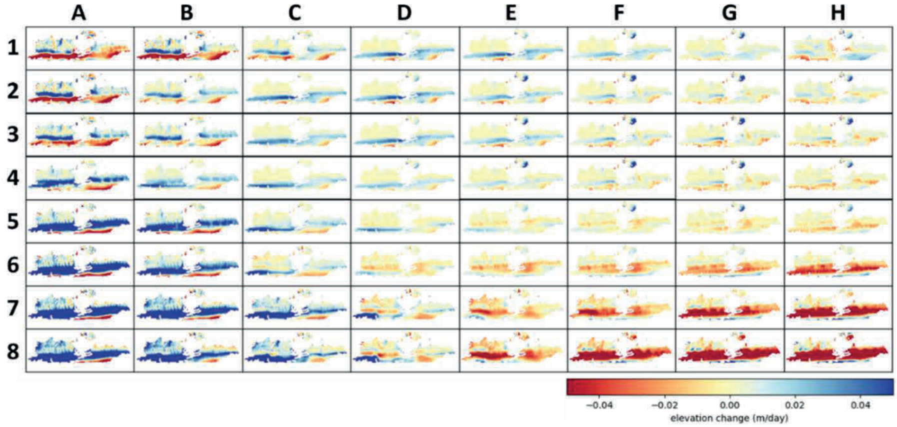

***Figure 1**: Self-organizing Map of the beach states. Each plot represents a distinctive pattern of elevation change over one day, i.e., SOM node. Y-axis is the cross-shore direction with the sea at the bottom, the X-axis is the along shore direction.*

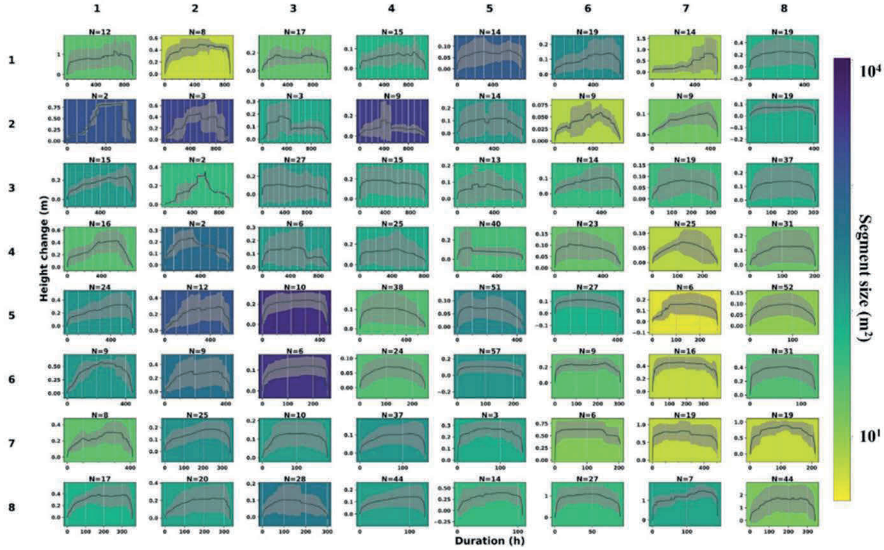

***Figure 2**: Self-organizing Map (SOM) of 4D objects-by-change (4D-OBCs). Each plot represents a distinct surface activity, i.e., SOM node. N equals the number of grouped 4D-OBCs in each SOM node. The black curves represent the mean time series of elevation change of the 4D-OBCs in the nodes, the colour represents the mean size of the 4D-OBCs*

Anders, K., Winiwarter, L., Mara, H., Lindenbergh, R., Vos, S. E., & Höfle, B. (2021). Fully automatic spatiotemporal segmentation of 3D LiDAR time series for the extraction of natural surface changes. ISPRS Journal of Photogrammetry and Remote Sensing, 173, pp. 297–308. doi: 10.1016/J.ISPRSJPRS.2021.01.015

Crozier, M. J. (2010). Deciphering the effect of climate change on landslide activity: A review. In Geomorphology, 124(3–4), pp. 260–267). doi: 10.1016/j.geomorph.2010.04.009

Vousdoukas, M. I., Ranasinghe, R., Mentaschi, L., Plomaritis, T. A., Athanasiou, P., Luijendijk, A., & Feyen, L. (2020). Sandy coastlines under threat of erosion. In Nature Climate Change, 10 (3). doi: 10.1038/s41558-020-0697-0

Monitoring multi-temporal snow depth distribution and regime over the Galeșu rock glacier, Retezat Mountains, using UAVs and SfM Photogrammetry

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Seasonal snow cover is a key factor in influencing the thermal regime of the ground (Zhang & Armstrong, 2001), directly affecting the spatial distribution of permafrost through its thermal insulation properties (Luetschg & Haeberli, 2005). Physical elements in the landscape, such as precipitation, air temperature, micro-topography, wind, or solar radiation (Wirz et al., 2011), interact in such a way that local snow variability becomes highly non-heterogeneous over small areas, ranging from a few centimetres to several meters, making precise quantification of depth challenging in mountainous regions (Miller et al., 2022). However, new field data acquisition techniques and devices, such as Unmanned Aerial Vehicles (UAVs), offer new perspectives on analyzing snow depth variations (Redpath et al., 2018) at resolutions that allow for centimetre-level accuracy (Harder et al., 2016). Additionally, advancements in computational power and software for photogrammetric image processing using modern algorithms, such as Structure-from-Motion (SfM), have led to increased efficiency in utilizing these systems (Sanz-Ablanedo et al., 2018).

The main objective of this work is to assess the evolution of snow depth distribution from winter to spring over the course of several years through the differencing of drone-based DSMs (Fig. 1), as well as to map the snow-free and snow-covered areas through supervised classification of the orthomosaics generated from the aerial images. Initial findings from the 2023 field campaigns reveal a pronounced local variability in snow distribution across the micro-topography of the Galeșu rock glacier, encompassing snow-free patches, depressions, and furrows with accumulations exceeding 3 meters (Fig. 2). The temporal evolution highlights a notable increase in snow depth from winter to spring across much of the study area, with significant augmentations predominantly observed in the upper reaches where active rock glacier dynamics are prevalent. Evaluation of data accuracy through field snow probes and an RTK GPS system yielded mean errors of -0.24 meters in winter and -0.14 meters in spring, demonstrating a close correspondence between observed values and modeled outputs.

These datasets will be correlated with climatic, geophysical and ground temperature data, as they represent a valuable resource for future permafrost distribution research as well as a relevant approach for hydrological models and water resource management.

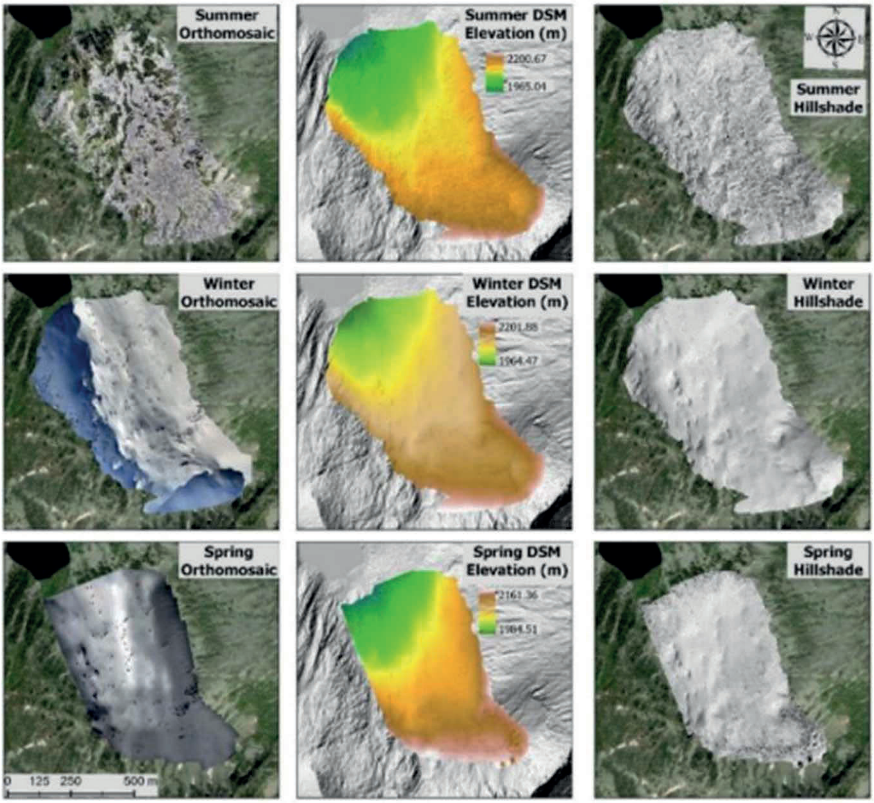

***Figure 1**: UAV Data acquired in the 2023 field campaigns*

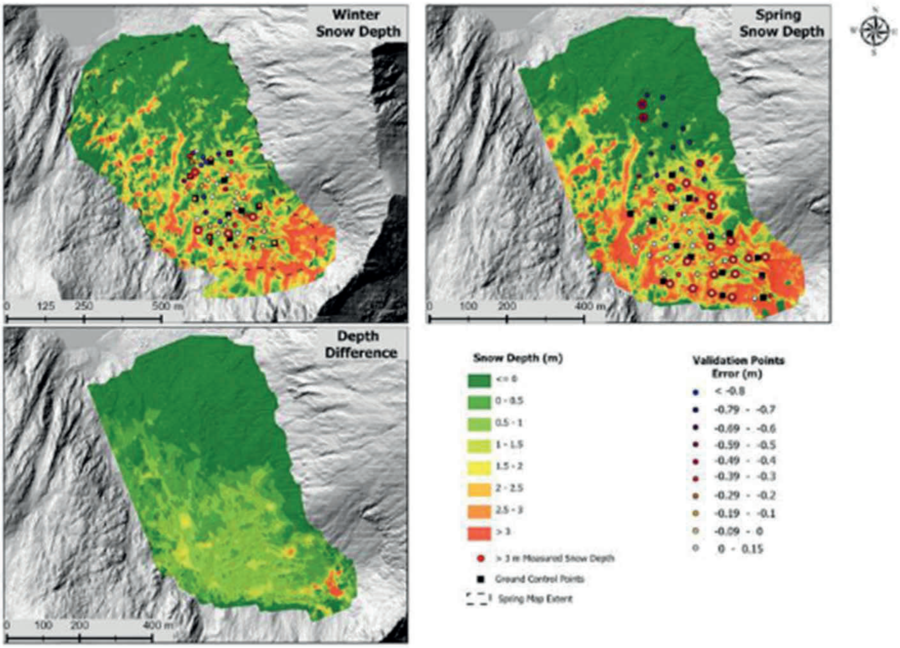

Figure 2*: Snow depth maps generated using DoD technique and the snow evolution map between seasons*

Harder, P., Schirmer, M., Pomeroy, J., & Helgason, W. (2016). Accuracy of snow depth estimation in mountain and prairie environments by an unmanned aerial vehicle. The Cryosphere, 10(6), 2559–2571.

Luetschg, M., & Haeberli, W. (2005). Permafrost evolution in the Swiss Alps in a changing climate and the role of the snow cover. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography, 59(2), 78–83.

Miller, Z. S., Peitzsch, E. H., Sproles, E. A., Birkeland, K. W., & Palomaki, R. T. (2022). Assessing the seasonal evolution of snow depth spatial variability and scaling in complex mountain terrain. The Cryosphere, 16(12), 4907-4930.

Redpath, T. A. N., Sirguey, P., & Cullen, N. J. (2018). Repeat mapping of snow depth across an alpine catchment with RPAS photogrammetry. The Cryosphere, 12(11), 3477–3497.

Detecting shallow landslides from point clouds in mountainous areas

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[3]*Austrian Research Centre for Forests, Innsbruck, Austria*

Shallow landslides occur frequently in mountains due to heavy rainfalls and in combination with snowmelt in spring, which pose a great threat to local communities and the environment. Mapping landslide inventories by estimating topographic changes is in high demand for analysing landslide susceptibility models (Bernard et al., 2021; Zieher et al., 2016). To observe topographic changes, 3D point clouds have obvious advantages compared against 2D imagery and GPS (Global Positioning System), due to high observation accuracy and spatial resolution under forest covers (Mohan et al., 2020). However, the topographic complexities in mountain areas pose challenges to change detection and assessment using point clouds.

In our study, we estimate topographic changes based on both location distance and orientation rotation from terrain point clouds. In this way, we avoid vegetation changes (shrubs and trees) in the point cloud comparison and can detect more significant changes, resulting in accurate and robust change estimation. More specifically, we first design 3D shape features for both location and orientation description. These features are then embedded into an encoder-decoder deep learning framework (Liu et al., 2022) for semantic segmentation to classify terrain point clouds. As for terrain point cloud comparison, we not only estimate significant changes from location differences, but also design the orientation uncertainty using the curvature to find the additional significant changes from orientation differences.

The developed method was applied in the Sellrain valley (Tyrol, Austria) to detect shallow landslides that occurred during an extreme rainfall event in 2015 (see Hübl et al., 2016). The detection was performed on pre-event (2013) and post-event 3D point clouds (2017) acquired by airborne laser scanning. We used the point cloud from 2013 (24 million points) as training and validation data for the semantic segmentation (following a ratio of 3:1), and predicted the point cloud from 2017 (41 million points). We then compared terrain point cloud between 2013 and 2017 for change estimation. The results (see Fig. 1) show that our semantic segmentation method achieved an overall semantic segmentation accuracy (OA) of more than 96%. The result in Figure 2 shows that our point cloud change estimation method captured 73.65% significant changes to locate 84 out of 88 shallow landslides, and estimated the changes in both location and orientation around them to analyse of the depositional area. Thus, this work explored the potential of point clouds for accurate and robust detection of shallow landslides in alpine areas.

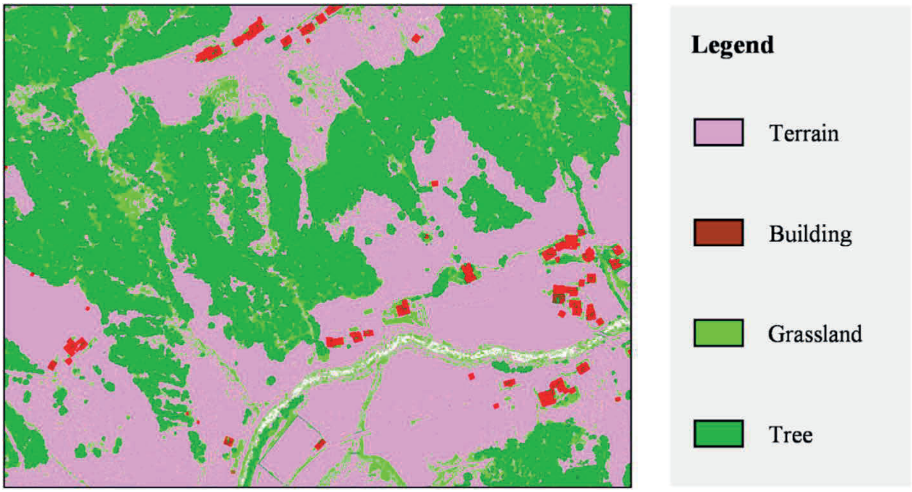

***Figure 1**: The result of point cloud semantic segmentation in Sellrain (Tyrol, Austria).*

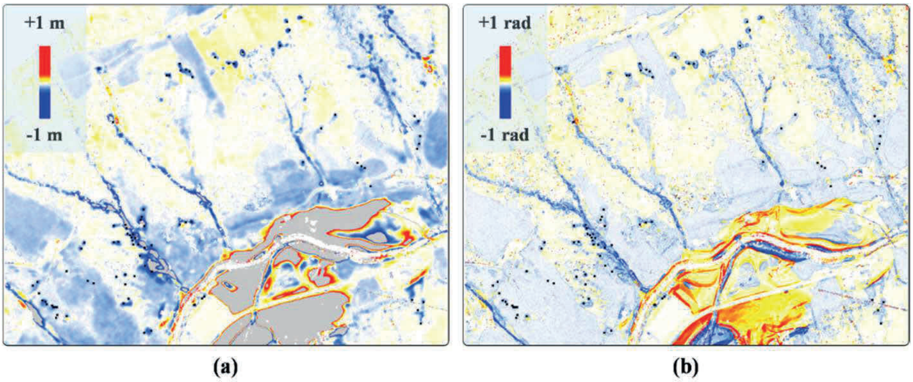

Figure 2*: Point cloud change estimation for shallow landslide detection in Sellrain (Tyrol, Austria), (a) the location differences of the points with significant changes, (b) the orientation differences of the points with significant changes.*

Bernard T.G., Lague D. & Steer P. (2021). Beyond 2D landslide inventories and their rollover: synoptic 3D inventories and volume from repeat lidar data, *Earth Surface Dynamics*, 9, 1013–1044.

Hübl J., Beck M., Zöchling, M., Moser M., Kienberger, C., Jenner, A. & Forstlechner, D. (2016). Ereignisdokumentation 2015. IAN Report 175, Vol. 1; Institut für Alpine Naturgefahren, Universität für Bodenkultur – Wien.

Liu C., Zeng D., Akbar A., Wu H., Jia S., Xu Z. & Yue H. (2022). Context-aware network for semantic segmentation toward large-scale point clouds in urban environments, *IEEE Transactions on Geoscience and Remote Sensing*, 60, 1-15.

Mohan, A., Singh, A. K., Kumar, B. & Dwivedi, R. (2020). Review on remote sensing methods for landslide detection using machine and deep learning. *Transactions on Emerging Telecommunications Technologies*, *32*(7), e3998.

Zieher, T., Perzl, F., Rössel, M., Rutzinger, M., Meißl, G., Markart, G. & Geitner, C. (2016). A multi-annual landslide inventory for the assessment of shallow landslide susceptibility–Two test cases in Vorarlberg, Austria. *Geomorphology*, *259*, 40-54.

Long-term suspended sediment monitoring in upper Kaunertal, Austria: Examining trigger mechanisms of high transport events

Diana-Eileen Kara[1], Toni Himmelstoss[1], Sarah Betz-Nutz[1], Moritz Altmann[1], Jakob Rom[1], Florian Haas[1], Tobias Heckmann[1], Michael Becht[1]

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Understanding suspended sediment transport in high Alpine catchments is essential due to its significant implications, including reservoir sedimentation. Heavy precipitation events, snow melt, and glacier melt can lead to high annual sediment yields, even though the peak of sediment transport may have already been passed in some alpine catchments (Schmidt et al. 2023).

This work includes the differentiation of events with high suspended sediment load based on their specific triggering mechanism and the quantification of the amount of suspended sediment supplied by the sub-catchments. Suspended sediment concentration data with a high temporal resolution of 15 minutes, were analysed at the Gepatschalm gauge station for the years 2012-2022 on the river Fagge at the Upper Kaunertal catchment in Tyrol, Austria. This time series was analysed alongside discharge and meteorological data, to assess the processes leading to high suspended sediment load. Additionally, in-situ measurements (Fig. 1) were carried out under various hydrometeorological conditions at multiple strategic stations. These measurements concentrate on snowmelt, glacier melt, and precipitation events. To categorise the high-transport events, we follow the approach described by Skålevåg et al. (2024). Furthermore, multi-temporal Digital Elevation Models (Fig. 2), based on UAV and airborne laser scanning, were used to correlate suspended sediment load with the observed changes in sediment storages.

These insights provide a comprehensive understanding of the mechanisms driving suspended sediment transport in the high Alpine regions. The findings underscore the importance of continuous, spatially distributed monitoring, which also facilitates the development of predictive models.

***Figure 1**: Water sampling for suspended sediment concentration measurement at Kauner Valley (Tyrol, Austria). Foto by: Kara, D.-E. 2023*

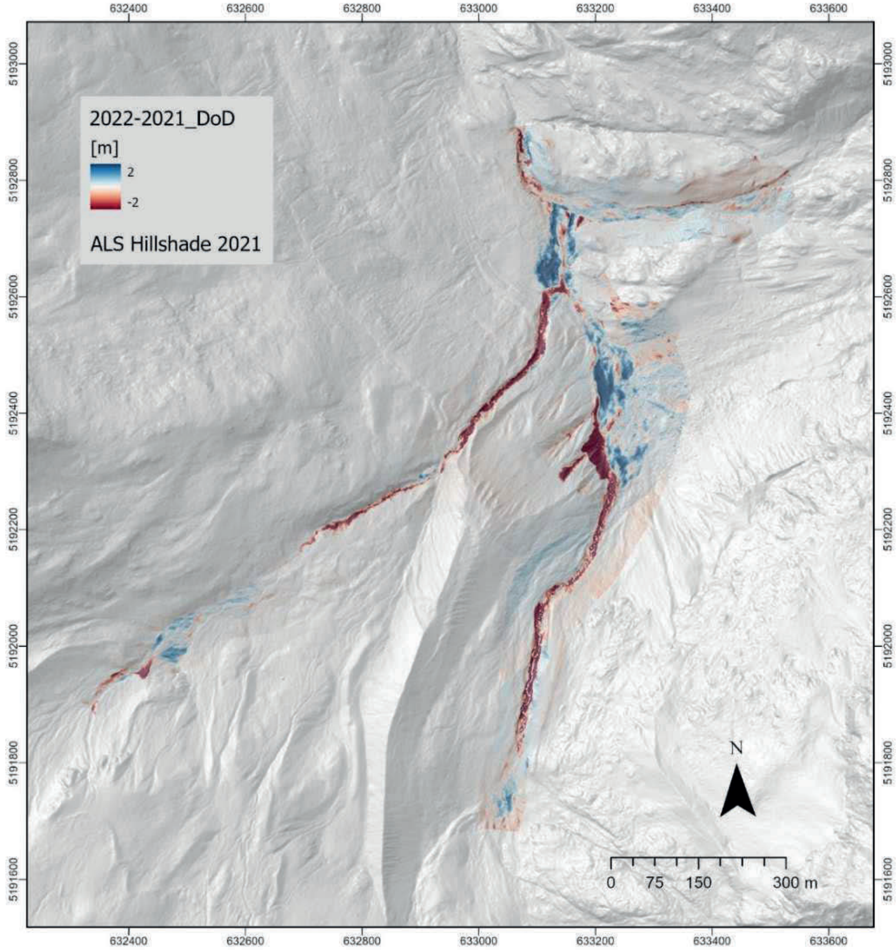

***Figure 2**: DoD 2022-2021 showing changes at Münchener Abfahrt on top of Hillshade (ALS-DHM 2021).*

Schmidt, L. K.; Francke, T.; Grosse, P. M. & Bronstert, A. (2023). Projecting sediment export from two highly glacierized alpine catchments under climate change: Exploring non-parametric regression as an analysis tool. In: Hydrology and Earth System Sciences. 28, 139-161.

Skålevåg, A.; Korup, O.& Bronstert, A. (2024). Inferring sediment-discharge event types in an alpine catchment from sub-daily time series. In: Hydrology and Earth System Sciences Discussions, in review.

Towards the automatic identification of agricultural terraces in the Eastern Mediterranean using open access Earth observation data

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[2]*Archaeology, Environmental Changes & Geo-Chemistry research group (AMGC), Vrije Universiteit Brussel, Belgium*

Agricultural terraces are one of the most significant anthropogenic land modifications in the mountains of the Mediterranean (Tarolli et al., 2019). They are constructed to decrease local slope gradients and promote cultivation in lands that are otherwise unfavorable for farming (Moreno-de-las-Heras et al., 2019). When terraces are built, they can reduce soil erosion, locally increase soil thickness, and enhance water infiltration. However, if not maintained or abandoned, there is an increased risk of erosion and/or slope failures (Koulouri & Giourga, 2007). Additionally, the increase in erosion can be associated with the lowering or even full removal of natural soil stoniness, which is necessary for constructing the stone walls and facilitating cultivation. This can further increase the soil susceptibility to erosion. Incorporating these complex effects of terraces in hydrological, geomorphic, and agronomic models often remains challenging, especially because accurate information on their locations and characteristics is lacking (Panagos et al., 2015).

The goal of this study is therefore to develop techniques that allow for the (semi-)automatic detection of terraces, based on freely available data products. We aim to create a scalable tool for terrace detection in large regions (> 1000 km²). For this, we first selected a test site: the Sagalassos territory in Turkey (~1200 km²). This area is located around the ancient city of Sagalassos and has significant archaeological importance, with human activity peaks during the Hellenistic and Roman times. The territory is characterized by smaller settlements, roads, and various agricultural parcels. This area has a history of human settlements and agricultural activity dating back to 8000 years BP and has a wide variety of terraced areas. These terraces vary from old abandoned ones with partially collapsed stone walls to newly constructed ones. The majority of the study area is located within the Taurus Mountain range at an elevation >1400 m.

To identify terrace locations within the study territory, we utilize current-day high-resolution optical imagery from Google Earth and medium-resolution ASTER DEM, which are openly available. Furthermore, for validation, we perform a UAV survey to construct a high-resolution DEM and orthoimage of selected test sites. We employ object-based image analysis (OBIA) on the segmented image (see Fig.1) to perform a simple binary classification between terraced and non-terraced areas. We test and compare various metrics such as texture measures and some custom approaches that can be used to differentiate terraced from non-terraced areas. These metrics are further incorporated into different machine learning classification approaches such as Random Forest and Support Vector Machine (SVM). Additionally, we plan to evaluate the performance of deep learning techniques, specifically using the U-Net and DeepLabV3+ architectures, which require more computational power, but are known to be the most accurate. Overall, our research aims are to find an optimal balance between classification accuracy and computational capabilities, enabling the applicability of the approach to other areas and ensuring scalability.

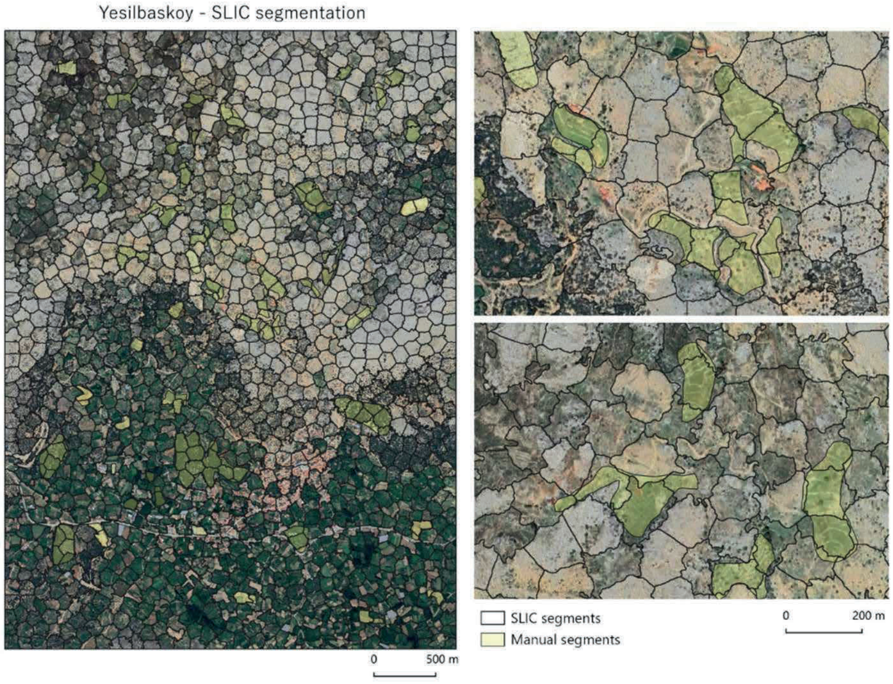

***Figure 1**: Results of the SLIC segmentation on the Yesilbaskoy test site. A preliminary step before the OBIA.*

Koulouri, M., & Giourga, Chr. (2007). Land abandonment and slope gradient as key factors of soil erosion in Mediterranean terraced lands. CATENA, 69(3), 274–281. https://doi.org/10.1016/j.catena.2006.07.001

Moreno-de-las-Heras, M., Lindenberger, F., Latron, J., Lana-Renault, N., Llorens, P., Arnáez, J., Romero-Díaz, A., & Gallart, F. (2019). Hydro-geomorphological consequences of the abandonment of agricultural terraces in the Mediterranean region: Key controlling factors and landscape stability patterns. Geomorphology, 333, 73–91. https://doi.org/10.1016/j.geomorph.2019.02.014

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E. H., Poesen, J., & Alewell, C. (2015). Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environmental Science & Policy, 51, 23–34. https://doi.org/10.1016/j.envsci.2015.03.012

Tarolli, P., Rizzo, D., & Brancucci, G. (2019). Terraced Landscapes: Land Abandonment, Soil Degradation, and Suitable Management. In M. Varotto, L. Bonardi, & P. Tarolli (Eds.), World Terraced Landscapes: History, Environment, Quality of Life (pp. 195–210). Springer International Publishing. https://doi.org/10.1007/978-3-319-96815-5_12

The relationship between biodiversity and forest structure in naturally regenerating woodlands in the Scottish Highlands

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The Centre for Landscape Regeneration (CLR) at the University of Cambridge is applying a whole systems approach to deliver the knowledge and tools necessary to regenerate UK landscapes using 'Nature-based solutions', which can contribute significantly both to preserving biodiversity and to achieving net zero emissions. The project brings together biodiversity and ecosystem science with engineering, computer science, chemistry, political science and economics, each of which has equal relevance in understanding how to deliver climate mitigation and landscape regeneration.

The PhD research will focus on a chronosequence of sites representing forest recovering in the Scottish Highlands, starting with open heathland, through the early stages of natural woodland expansion, through dense woodland stages to structurally diverse ancient woodland sites. The research will discover new links between carbon, habitat structure and biodiversity, and so enhance ongoing biodiversity and ecosystem service mapping work within the CLR. High resolution remote sensing (e.g. terrestrial laser scanning, drone LiDAR and structure from motion) to survey vegetation along the chronosequence will be used and consequently characterise how carbon and 3D habitat structure change across the range of regeneration. Biodiversity monitoring surveys will also take place in these sites (e.g. using acoustic sensors, eDNA, camera traps or traditional surveying approaches), and this information will also be linked to 3D habitat structure. These data will be used develop new understanding of the links between forest structure, abiotic conditions and biodiversity. Scaling these relationships with a recent aerial LiDAR survey of the area, and additional drone and/or satellite information, will create new structural proxies for habitat quality at landscape scales that may inform assessment of regeneration and restoration potential.

Testing the accuracy of terrestrial laser scanning technology for individual tree DBH estimation in urban pine stand

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[2]*Department of Geography, University of Zadar, Zadar, Croatia*
[3]*Geo Unit d.o.o., Zadar, Croatia*

Terrestrial laser scanning technology has been of interest in research about the possibilities of its practical application in forest surveys. A number of studies have already been conducted in the last decade for the static terrestrial laser scanning (TLS) while in the recent years hand-held personal laser scanning (PLS_{HH}) has increased the interest of laser scanning making its way into forest practices. The main goal of this research is to test the accuracy that terrestrial laser scanners have for diameter at breast height (DBH) estimation of individual trees. The research was conducted in one circular sample plot with radius of 15 m located in an urban black pine (*Pinus nigra L.*) forest stand in Zadar (Fig. 1). For this purpose, a detailed comparison of the estimation accuracy of the DBH of individual trees, between the data obtained on the basis of classic field measurements (calliper, diameter tapes), TLS and PLS, was carried out on 37 pine trees. TLS was carried out using multi-scan approach while PLS_{HH} was carried in four different scanning schemes of different complexity (from least to most complex) (Fig. 2). DBH measured with diameter tapes was used as a reference data (ground-truth data) and the following results are presented by mean absolute error (MAE). DBH measured by calliper produced MAE of 0.51 cm. The dataset obtained by TLS was modelled i.e. fitted by circle, column and ellipse for the DBH estimation in the LiDAR360 software (Fig. 2). Fit by circle DBH estimation gave the best result among the three fitting methods (0.89 cm). With that knowledge, PLS_{HH} datasets DBH estimation were carried out with fit by circle method. The most complex scanning scheme gave the best results (1.91 cm) while the least complex scanning scheme gave the worst results (2.79 cm). The obtained results confirmed the great potential of terrestrial laser scanning technology in the operational forest surveys, and further research should include forest stands of different management and age classes.

***Figure 1**: Urban black pine forest stand in Zadar, Croatia. Figure by Kokeza, A. 2023.*

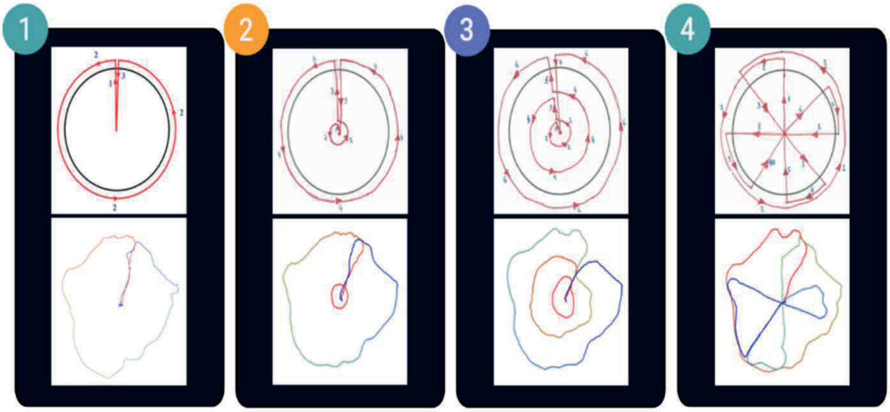


***Figure 2**: PLS_{HH} laser scanning schemes where the top row are planned schemes and the bottom row are carried out schemes. Figure by Kokeza, A. 2023.*

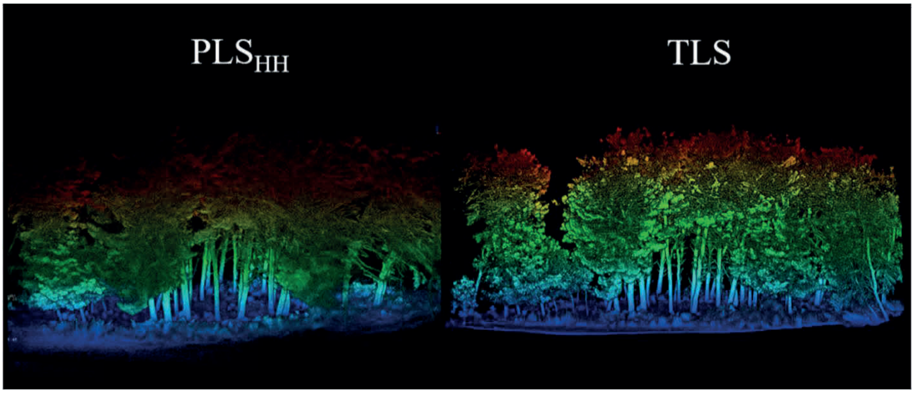


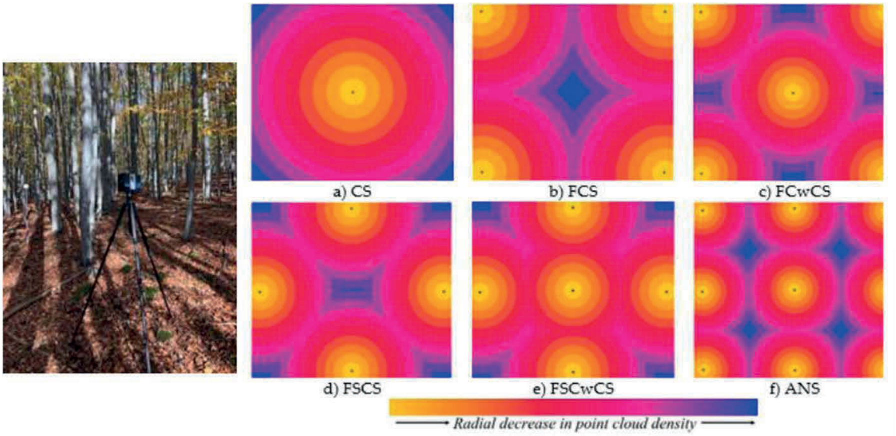
***Figure 3**: Visualization of PLS$_{HH}$ and TLS point clouds in LiDAR360 software. Figure by Kokeza, A. 2023.*

Effectiveness of multiplatform LiDAR and Photogrammetry in complete 3D modelling in Hilly terrains

S.K.P. Kushwaha[1], Kamal Jain[1]

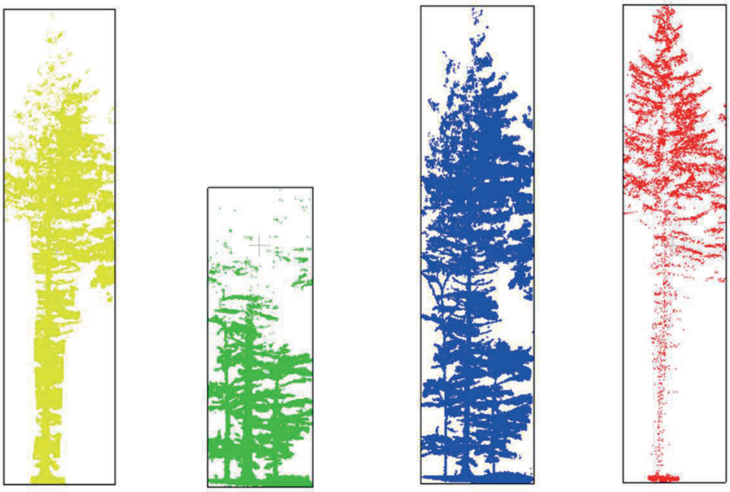
[1]*Geomatics group, Institute of Technology Roorkee, India*

Conducting close-range data acquisition and processing in hilly terrains poses significant challenges, primarily attributed to the intricate topography characterized by high undulations, unpredictable variations in tree heights, and slope instability. In the context of my research, which focuses on establishing multiple forest plots within the Himalayan alpine range, it becomes evident that traditional methods such as aerial close-range data acquisition face inefficiencies when dealing with under-canopy or ground-level information. Similarly, terrestrial close-range data acquisition proves less effective when capturing above-canopy or top-of-the-forest canopy details. To overcome these challenges, I have turned to the Terrestrial Laser Scanning (TLS) technique, a cutting-edge technology capable of generating exceptionally dense point clouds. However, the complexity of hilly terrains demands the exploration of various TLS scanning combinations to assess the impact of occlusions and data completeness (Kushwaha et al., 2023; Kushwaha et al., 2022). In the 3D data acquisition process from terrestrial platforms, the high slope variations inherent in hilly terrains contribute to occlusions and data incompleteness, presenting a formidable obstacle that my research aims to address. Moreover, altitude variations in the Himalayan region pose a unique challenge for Unmanned Aerial Vehicle (UAV) flight planning. The planning process heavily relies on ground distance, directly influencing the quality of the acquired data. The unpredictable nature of highly undulated landscapes adds another layer of complexity. For instance, in one of my study areas, heavy rains triggered drastic ground surface shifts, leading to landslides that, in turn, caused the loss of standing trees. This underscores the need to adapt UAV flight planning strategies to the dynamic conditions of hilly terrains. A crucial aspect of my research is dedicated to the second objective, which involves detecting changes in multi-temporal point cloud datasets. Given the dynamic nature of hilly terrains, understanding and quantifying alterations in the landscape over time are vital for comprehensive data analysis and effective environmental monitoring. In essence, my research seeks to overcome the challenges associated with close-range data acquisition and processing in hilly terrains, offering innovative solutions to advance our understanding of these complex ecosystems.



a) b)

***Figure 1**: a) TLS scanning in a high-altitude mountainous forest plot. b) different pattern of TLS scanning with the coverage and radial decrease in point cloud densities.*



a) b) c) d)

Figure 2: Tree point cloud acquired from multi-platform LiDAR a) Hand held, b) Backpack, c) TLS and d) ALS

Kushwaha, S. K. P., Singh, A., Jain, K., Cabo, C., & Mokros, M. (2023a). Accuracy Assessment of Stem Classification Obtained from Forest Point Cloud Using FSCT Algorithm. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, 4447–4450. https://doi.org/10.1109/IGARSS52108.2023.10283148

Kushwaha, S. K. P., Singh, A., Jain, K., Cabo, C., & Mokros, M. (2023b). Integrating Airborne and Terrestrial Laser Scanning for Complete 3D Model Generation in Dense Forest. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, 3137–3140. https://doi.org/10.1109/IGARSS52108.2023.10283032

Kushwaha, S. K. P., Singh, A., Jain, K., & Mokros, M. (2022). Optimum Number And Positions Of Terrestrial Laser Scanner To Derive Dtm At Forest Plot Level. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B3-2022, 457–462. https://doi.org/10.5194/isprs-archives-XLIII-B3-2022-457-2022

Kushwaha, S. K. P., Singh, A., Jain, K., Vybostok, J., & Mokros, M. (2023c). Qualitative Analysis of Tree Canopy Top Points Extraction from Different Terrestrial Laser Scanner Combinations in Forest Plots. ISPRS International Journal of Geo-Information, 12(6), 250. https://doi.org/10.3390/ijgi12060250

Singh, A., Kushwaha, S. K. P., Nandy, S., & Padalia, H. (2022a). An approach for tree volume estimation using RANSAC and RHT algorithms from TLS dataset. Applied Geomatics, 14(4), 785–794. https://doi.org/10.1007/s12518-022-00471-x

Singh, A., Kushwaha, S. K. P., Nandy, S., & Padalia, H. (2022b). Novel Approach For Forest Allometric Equation Modelling With Ransac Shape Detection Using Terrestrial Laser Scanner. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-4/W4-2022, 133–138. https://doi.org/10.5194/isprs-archives-XLVIII-4-W4-2022-133-2022

Use of point cloud dataset for assessing rock slope hazards near transportation system: Progress in Taiwan

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[2]*Institute of Mineral Resources Engineering, National Taipei University of Technology, Taiwan*

[3]*Department of Civil Engineering, National Taiwan University, Taiwan*

In mountainous areas, rock slope instabilities such as rockfalls and rock avalanches often pose a significant threat to the safety and maintenance of transportation. For developing countries such as Taiwan, the population migrating to nearby hills and suburbs also exposes the infrastructures to rock slope hazards. To provide information on landslide occurrence, failure mechanisms, and potential landslide-affected areas to transportation authorities soon after the rock slope hazard, an integrated research team, GeoPORT Working Group, was established in Taiwan in 2020. The Group proposed a system for rapid slope disaster information integration and assessment, which is composed of three units (Weng et al., 2022; Shiu et al., 2023; Yuen et al., 2023): 1) Geohazard rapid report based on a seismology-based monitoring network, 2) multidisciplinary geological survey report for identifying slope failure mechanisms, and 3) site-specific landslide simulation report through three-dimensional (3D) numerical modeling. Regarding the multidisciplinary geological survey, the recent advancement and proliferation of unmanned aircraft vehicles (UAVs) have made it possible to detect landscape changes and processes occurring at spatial and temporal scales that would be difficult to investigate using conventional field observations. Moreover, UAV-based point cloud data, which provides “true” three-dimensional information related to surface geomorphology and terrain, has been used for understanding the geological discontinuity characterization and volume estimation (Yang et al., 2022a, 2022b). In the current study, we focus on a railway where the rail line was built near high and steep rock slopes and exposed to high rockfall risk (Fig. 1). To enhance the safety margins of rockfall-hazard-related assessments, multi-temporal point cloud data will be used to facilitate the site-scale numerical simulation (Fig. 2). Challenges will involve the registration of multi-temporal and multi-scale datasets, interpretation of data and result accuracy, and the development of automated methodologies for processing and analysis.

***Figure 1**: Study area (Shimizu Tunnel of the North-link railway line) for the current research.*

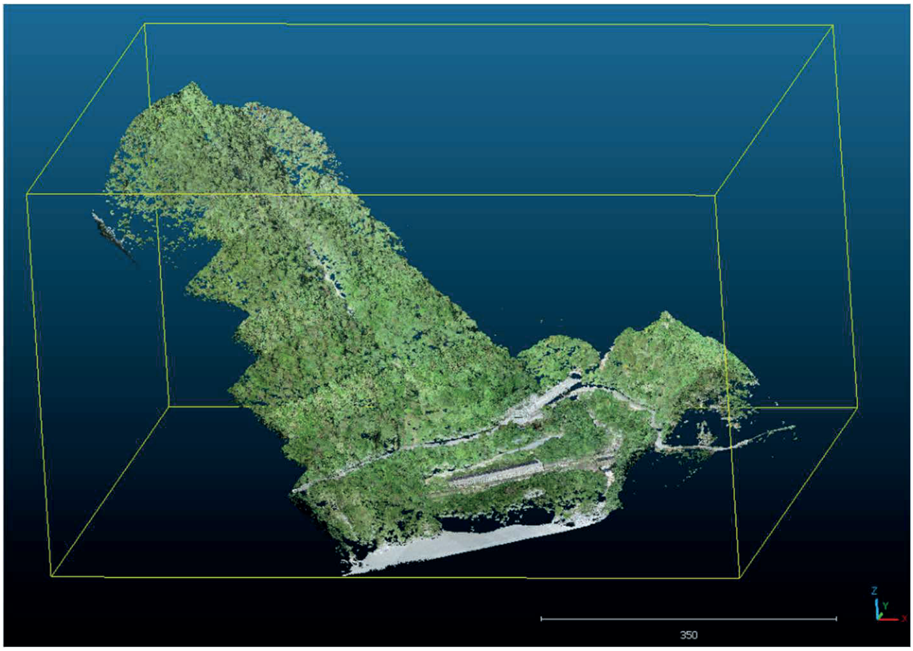

***Figure 2**: UAV-based point cloud for the study area investigated in January 2024.*

Weng, M. C., Lin, C. H., Shiu, W. J., Chao, W. A., Chiu, C. C., Lee, C. F., Huang, W.K. & Yang, C.M. (2022). Towards a rapid assessment of highway slope disasters by using multidisciplinary techniques. Landslides, 19(3), 687-701.

Yuen, T. Y., Weng, M. C., Fu, Y. Y., Lu, G. T., Shiu, W. J., Lu, C. A., Liu, C.Y., Chiu, C.C., Wen, T.H. & GeoPORT Working Group. (2023). Assessing the impact of rockfall on a bridge by using hybrid DEM/FEM analysis: A case study in Central Taiwan. Engineering Geology, 314, 107000.

Shiu, W. J., Lee, C. F., Chiu, C. C., Weng, M. C., Yang, C. M., Chao, W. A., W.A., Liu, C.Y., Lin, C.H., Huang, W.K. & GeoPORT Working Group. (2023). Analyzing landslide-induced debris flow and flow-bridge interaction by using a hybrid model of depth-averaged model and discrete element method. Landslides, 20(2), 331-349.

Yang, C. M., Chao, W. A., Weng, M. C., Fu, Y. Y., Chang, J. M., Huang, W. K., & GeoPORT Working Group. (2022a). Outburst debris flow of Yusui Stream caused by a large-scale Silabaku landslide, Southern Taiwan.

Yang, C. M., Lee, C. H., Liu, C. Y., Huang, W. K., Weng, M. C., & Fu, Y. Y. (2022b). Assessing the impact of rockfall on the retaining structures of a mountain road: a case study in Taiwan. Landslides, 19(11), 2737-2746.

Multitemporal characterisation of a proglacial system: A multidisciplinary approach.

Elisabetta Corte[1], Andrea Ajmar[2], Carlo Camporeale[1], Alberto Cina[1,] Velio Coviello[3,5,] Fabio Giulio Tonolo[4], Alberto Godio[1], **Myrta Maria Macelloni**[1], Stefania Tamea[1], and Andrea Vergnano[1]

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Under climate change the cryosphere, and in particular the Alpine mountainous areas, are subjected to strong changes and frequent natural hazards. Monitoring this changing and complex environment will be essential and challenging in the next years. Since 2020 thanks to the Glacier Lab of Politecnico di Torino the research has focused on an integrated approach of monitoring through different fields interconnected to build a complete multitemporal and multidisciplinary model of a glacier. The groups of researcher activities during the summer campaigns (Fig. 1) are usually coordinated to have coherent datasets in the different areas (e.g. hydraulics outflow measurements and sediment transport during the drone flights). All the different parts of the works are combined into a proper product where they can be accessed and shared with other users (for example https://arcg.is/Tyeju0).

Furthermore, the activities are used to orientate an aerial flight (repeated annually since the year 2020) that allows us, in collaboration with the Environmental Protection Agency of Aosta Valley, to monitor the annual mass melted in different glacier areas and use the Difference of DSMs to the annual mass balance computation at the end of each hydraulic year (Fig. 2).

Moreover, geomatic techniques, such as drones (Fig. 3) and LIDAR surveys help us to monitor carefully small parts of the glacier areas but the logistics and accessibility of these places with the instruments are often not simple and safe. Hence, we are focusing on how to better use the stereoscopic couples for extraction of photogrammetric products such as DSMs and orthophotos with different software and high-resolution products (for example with Pleiadès products 0.50 m of GSD) and on different glaciers evaluating the precision and the open issues.

***Figure 1**: Summer campaign activity, GNSS measurement, 2023*

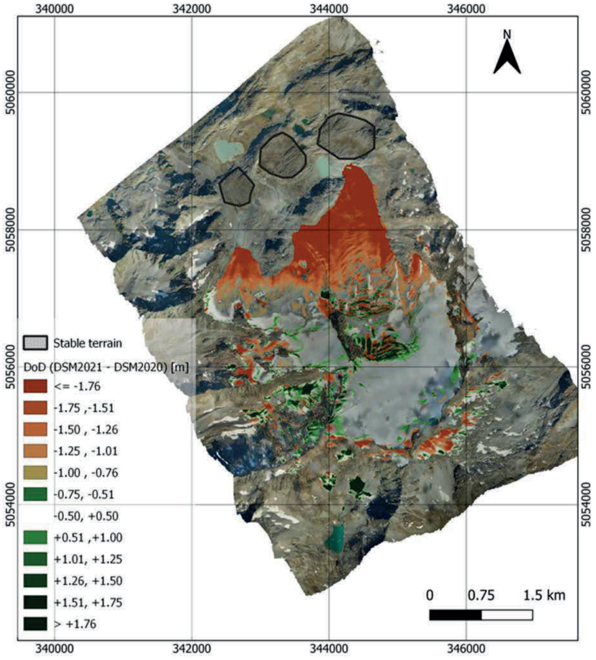

Figure 2: *Difference of DSMs to evaluate the glacier melting, Corte et al. 2023*

***Figure 3**: Drone flight over the glacier front, 2021*

Macelloni, M. M., Corte, E., Ajmar, A., Cina, A., Giulio Tonolo, F., Maschio, P. F., & Pisoni, I. N. (2022). Multi-platform, Multi-scale and Multi-temporal 4D Glacier Monitoring. The Rutor Glacier Case Study. In E. Borgogno-Mondino & P. Zamperlin (Hrsg.), Geomatics for Green and Digital Transition (Bd. 1651, S. 392–404). Springer International Publishing. https://doi.org/10.1007/978-3-031-17439-1_29

Macelloni, M. M., Cina, A., Grasso, N., & Morra Di Cella, U. (2023). Multi-Temporal And Multi-Sensor Glacier Monitoring. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-2/W3-2023, 165–171. https://doi.org/10.5194/isprs-archives-XLVIII-2-W3-2023-165-2023

Contribution pages 45-46 in Baroni C., Bondesan A., Carturan L., Chiarle M., Scotti R. (2023) – Campagna glaciologica annuale dei ghiacciai italiani (2022). Geografia Fisica e Dinamica Quaternaria, 46(1). https://doi.org/10.4454/gfdq.v46.883

Corte, E., Ajmar, A., Camporeale, C., Cina, A., Coviello, V., Giulio Tonolo, F., Godio, A., Macelloni, M. M., Tamea, S., & Vergnano, A. (2023). Multitemporal characterisation of a proglacial system: A multidisciplinary approach. https://doi.org/10.5194/essd-2023-94

Under publication, Myrta Maria Macelloni, Alberto Cina, Fabio Giulio Tonolo, and Umberto Morra di Cella Advantages and limitations of satellite-based glacier monitoring. The Rutor Glacier in Italy

Dynamics and mass exchange processes of mountain glaciers in the Pamirs

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Glaciers are essential components of the hydrological cycle in Central Asia, providing a large fraction of runoff in the dry summer months (Hoelzle *et al*., 2019). The vast glacierization of Tien Shan and Pamir also presents several glacier-related hazards such as surges, collapses and glacial lake outburst floods (GLOFs), which can be very damaging to settlements and livelihoods (Muccione & Fiddes, 2019). Accelerated climate change is impacting Central Asian glaciers, leading to significant changes in runoff patterns and hazard potential with still largely uncertain consequences. As such, both long-term monitoring and improved process understanding are crucial to reduce the current uncertainties; this goal requires a network of reference sites with detailed *in situ* observations, as well as contributions from numerical modeling and remote sensing (Barandun *et al*., 2020).

The present project aims to improve understanding of the dynamics and energy/mass balance of Central Asian glaciers, by combining detailed observations made in Soviet times with modern datasets and methods; including satellite- and drone-based remote sensing, autonomous on-glacier monitoring devices, and physical modeling at high spatial and temporal resolution. The investigated glacier sites include Abramov in Kyrgyzstan and Zulmart in Tajikistan.

Abramov is a valley glacier with almost 50 years of *in situ* measurements. It is suspected to be an unstable, pulsating glacier, periodically switching between episodes of fast flow and quiescent recovery; one first such episode was observed in 1972. In our work, we use satellite-based optical remote sensing to measure a second pulsation which took place in the early 2000s (while the glacier was not being actively monitored), as well as the present-day build-up to a third event (Mattea *et al*., 2023a). We quantify changes of terminus morphology, flow velocity and ice volume with multiple sensors, including SPOT, RapidEye, Sentinel-2 and Pléiades (Fig. 1). Using autonomous GNSS loggers we also measure the daily ice flow velocities and their annual cycle (Mattea *et al*., 2023b).

Zulmart is a cold glacier extending between 4700 and 5500 m asl in the dry Eastern Pamir. Knowledge of the trends and driving factors of glacier change in the region is virtually non-existent. Over the past few years, the site was equipped with two automatic weather stations and several timelapse camera setups (Fig. 2), and the glacier mass budget was measured both *in situ* and with consumer-grade drone surveys. Preliminary results suggest that ice sublimation and refreezing of meltwater play important roles in the mass exchange of this glacier. Our findings contribute to the overall understanding of current and future evolution of mountain glaciers across Central Asia.

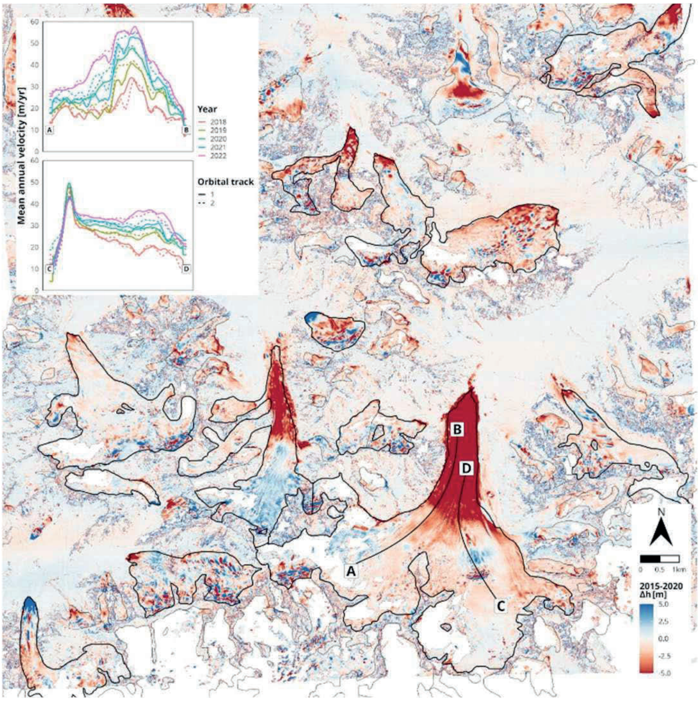

***Figure 1**: Changes in ice thickness and surface velocities at Abramov glacier from optical remote sensing. Data from Mattea et al. (2023a).*

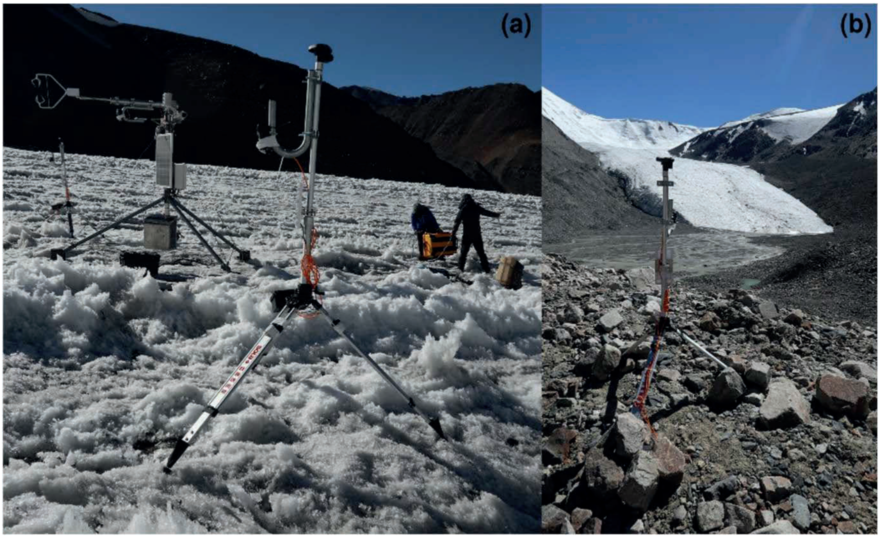

Figure 2*: (a) On-glacier automatic weather station and trail camera at Zulmart. (b) Timelapse monitoring camera overlooking the glacier tongue. Photos by E. Mattea, 2023.*

Barandun, M., Fiddes, J., Scherler, M., Mathys, T., Saks, T., Petrakov, D. & Hoelzle, M. (2020). The state and future of the cryosphere in Central Asia, Water Security, 11, 100 072, https://doi.org/10.1016/j.wasec.2020.100072

Hoelzle, M., Barandun, M., Bolch, T., Fiddes, J., Gafurov, A., Muccione, V., Saks, T. & Shahgedanova, M. (2019). The status and role of the alpine cryosphere in Central Asia, in: The Aral Sea Basin. Water for Sustainable Development in Central Asia, pp. 100–121, Routledge, London.

Mattea, E., Machguth, H., Berthier, E. & Hoelzle, M. (2023a). Minor pulsations of Abramov glacier (Kyrgyzstan) observed with multi-sensor optical remote sensing, in: EGU General Assembly 2023, Vienna, Austria, https://doi.org/10.5194/egusphere-egu23-6296

Mattea, E., Barandun, M., Saks, T., Garbo, A. & Hoelzle, M. (2023b). Monitoring daily flow velocities at Abramov glacier with low-cost, open-source GNSS loggers, in: Swiss Geoscience Meeting 2023, Mendrisio, Switzerland.

Muccione, V. & Fiddes, J (2019).: State of the knowledge on water resources and natural hazards under climate change in Central Asia and South Caucasus, Tech. rep., Swiss Agency for Development and Cooperation, Bern. https://www.zora.uzh.ch/id/eprint/181441, publisher: Swiss Agency for Development and Cooperation.

UAV surveys in high mountainous permafrost environment in Chilean Andes

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[2]*Pontifical Catholic University of Chile, Faculty of History, Geography & Political Science, Institute of Geography, Chile*

[3]*Eötvös Loránd University, Faculty of Sciences, Department of Physical Geography, Hungary*

[4]*PermaChile Research Network*

The Hungarian climate and environmental change analysis programme, which is based on the inactive 6893 m high Ojos del Salado volcano, the highest volcano on Earth, and its wider surroundings on the arid Puna de Atacama Plateau, has been operating at the highest environmental monitoring site on Earth since 2012. The research focuses on the processes of present climate change, with a particular focus on changes in ice cover. It explores present-day permafrost dispersion, permafrost degradation, and analyses and models the behaviour of the active layer.

The programme also investigates some of the processes of environmental change through high-resolution field mapping. The aerial mapping with UAVs, the production of orthophoto mosaics and relief models with appropriate resolution, is essential for sampling moraine ageing and for the determination of the extent of glaciation, but also provides excellent baseline data for the investigation of polygon networks and surface water presence, as well as for the evaluation of data from the continuously operating network of installed temperature sensors (Nagy et al., 2020).

Therefore, a custom-built Ardupilot-based quadcopter optimized for the high altitude, high wind and easy transportability was used to survey sample areas (Mészáros et al., 2019). Two Emlid Reach GPS units were used, one as base station built up on a lightweight tripod, and a second unit integrated onto the quadcopter and together with a Ricoh GR II digital frame camera made possible the recording of image positions during survey flights (Fig. 1.). Later, Emlid Studio software was used to post-process recorded GPS data to calculate precise image coordinates for later photogrammetric processing of aerial images. Using this method, we could eliminate the use of ground control points on the extreme terrain, orthorectifying image blocks with 5-6 cm average internal error.

The lowest point of the aerial survey is at 4200 m, where the polygonal system of the Puna de Atacama Plateau, which also serves as the survey site, was investigated. In a second location at 5200-5300 m, the moraine ridges of the former glaciers, the formations associated with the present-day melting of snow and firn, and the fluvial erosion and accumulation present in the rugged permafrost area were also mapped (Fig. 2.).

The results show that in a mountainous site, which is difficult to navigate and difficult to see, and where human activity is also severely limited, their use can be highly successful and indispensable for terrain interpretation and change analysis.

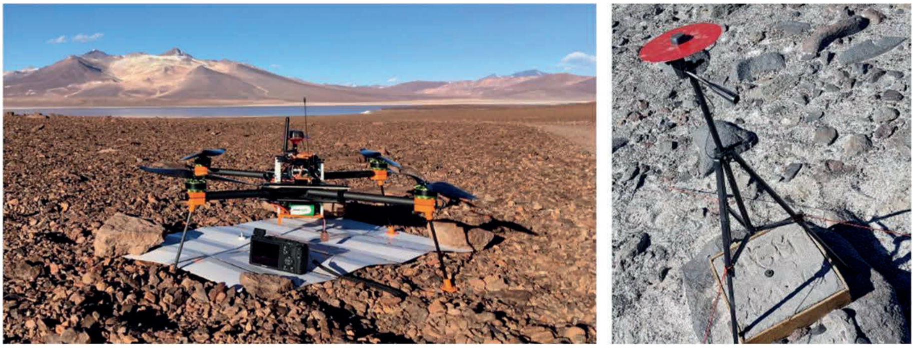

Figure 1*: UAV and GNSS base station used for surveys. Photos by Nagy, B. and Mészáros, J. 2019.*

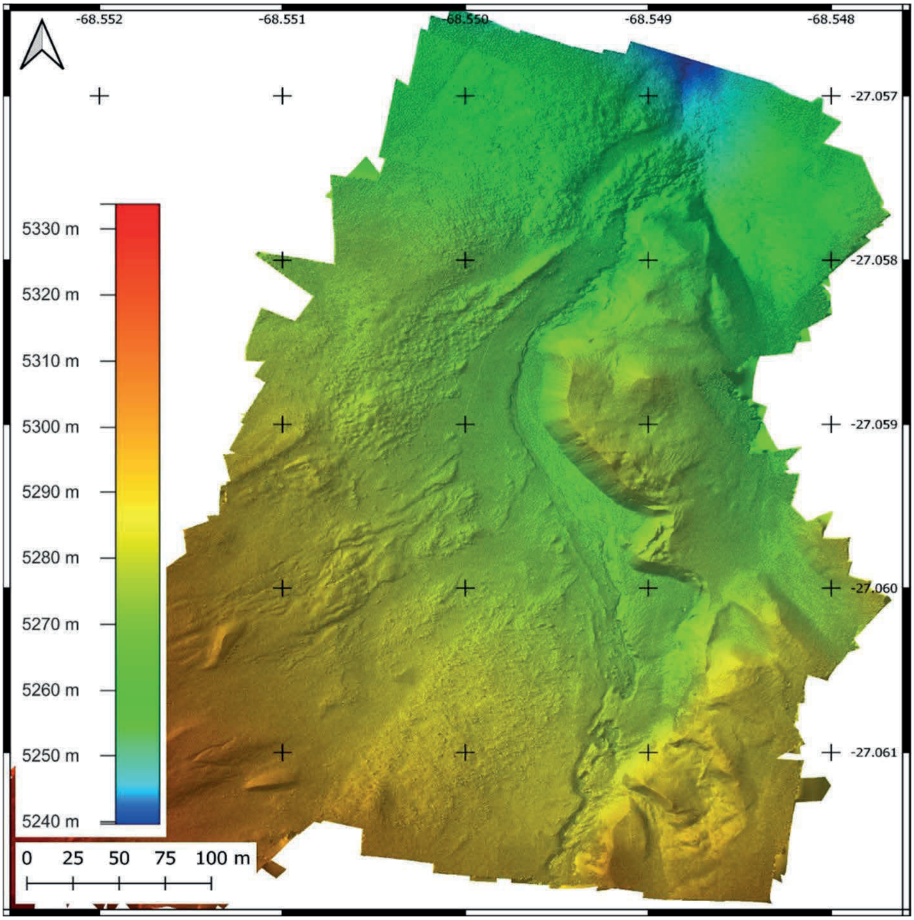

***Figure 2**: Digital Elevation Model about the lower end of a relict glacier valley on the Northern slope of Mt. Ojos del Salado, Chile. Figure by Meszaros, J. 2019.*

Nagy, B., Kovács, J., Ignéczi, Á., Beleznai, Sz., Mari, L., Kereszturi, Á. & Szalai, Z. (2020). The Thermal Behavior of Ice-Bearing Ground: The Highest Cold, Dry Desert on Earth as an Analog for Conditions on Mars, at Ojos del Salado, Puna de Atacama-Altiplano Region. Astrobiology 20 (6), 701–722.

Mészáros, J., Nemerkényi, Zs. & Nagy, B. (2019). UAV surveys in high mountain environment, Ojos del Salado, Chile. Workshop Harmonious, Coimbra, 2019

A novel, low-cost rockfall monitoring method.

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Rockfalls pose considerable social and economic risk to those who live in mountainous regions which has been compounded due to climatic changes (Wyss et al., 2022) and the expansion of tourism in these regions (Coe, 2020). There is significant evidence which indicates that there is a dynamic link between global warming and the instability of mountain slopes (Savi et al., 2021) and the frequency of rockfall events has also increased (Ballantyne, 2018; Krautblatter and Moser, 2009). Continuous, systematic, long-term monitoring systems can help improve understanding of rockfall mechanisms and thus improve models for rockfall prediction and hazard risk assessment (Coe, 2020). Additionally, by monitoring rock slopes continuously, it is hoped that rockfall rates and patterns on a short-term (daily temperature fluctuations to seasonal changes) and long-term scale (paraglacial periods) can be constrained and help build enhanced models. At present, a lack of affordable, wide area, continuous monitoring of rock slopes prone to failure exacerbates the risk. Current monitoring methods are incredibly accurate but are costly and require applied processing techniques which limits their widespread use to only the most high risk sites (Jaboyedoff et al., 2012; Westoby et al., 2012). Most rockfall monitoring methods don’t in-fact detect rockfalls but the evidence that they have occurred using rockfall scars and rock-bridges. In certain lithologies, rockfall scars appear visibly different to the surrounding weathered rock face (Fig 1.) and it is possible to map rockfall scar surfaces by exploiting the colour difference in RGB imagery between the scars and the rock face (De Vilder et al., 2017). This research plans to exploit the differences in colour between weathered rock and un-weathered rock to develop a low-cost rockfall monitoring system using Raspberry Pi cameras. By using multi-spectral imagery taken using these cameras, this method has the possibility of rivalling existing methods but being a fraction of the cost. This would improve the accessibility of monitoring rockfalls and, as a result, encourage more widespread, continuous monitoring campaigns. This method will also need to evaluate the large data volumes and processing complexity to maintain its accessibility.

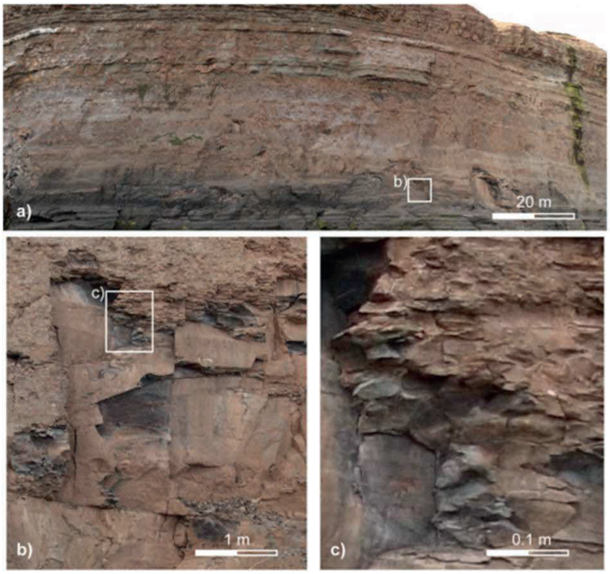

Figure 1*: a) Panoramic gigapixel image of the monitored cliff section. b) Close-up of a rockfall scar. c) Close-up of a freshly broken rock bridge. Figure by de Vilder et al., (2017)*

Ballantyne, C.K., (2018). Periglacial geomorphology. Wiley Blackwell, Hoboken, NJ Chichester.

Coe, J. A. (2020). Bellwether sites for evaluating changes in landslide frequency and magnitude in cryospheric mountainous terrain: A call for systematic, long-term observations to decipher the impact of climate change. Landslides, 17(11), 2483–2501. https://doi.org/10.1007/s10346-020-01462-y

De Vilder, S. J., Rosser, N. J., & Brain, M. J. (2017). Forensic analysis of rockfall scars. Geomorphology, 295, 202–214. https://doi.org/10.1016/j.geomorph.2017.07.005

Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M.-H., Loye, A., Metzger, R., & Pedrazzini, A. (2012). Use of LIDAR in landslide investigations: A review. Natural Hazards, 61(1), 5–28. https://doi.org/10.1007/s11069-010-9634-2

Krautblatter, M., & Moser, M. (2009). A nonlinear model coupling rockfall and rainfall intensity based \\newline on a four year measurement in a high Alpine rock wall (Reintal, German Alps). Natural Hazards and Earth System Sciences, 9(4), 1425–1432. https://doi.org/10.5194/nhess-9-1425-2009

Savi, S., Comiti, F., & Strecker, M. R. (2021). Pronounced increase in slope instability linked to global warming: A case study from the eastern European Alps. Earth Surface Processes and Landforms, 46(7), 1328–1347. https://doi.org/10.1002/esp.5100

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology, 179, 300–314. https://doi.org/10.1016/j.geomorph.2012.08.021

Wyss, R., Luthe, T., Pedoth, L., Schneiderbauer, S., Adler, C., Apple, M., Acosta, E. E., Fitzpatrick, H., Haider, J., Ikizer, G., Imperiale, A. J., Karanci, N., Posch, E., Saidmamatov, O., & Thaler, T. (2022). Mountain Resilience: A Systematic Literature Review and Paths to the Future. Mountain Research and Development, 42(2). https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1

Analysing 38 years of satellite-derived snow line elevation dynamics in the Central Andes

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[2]*German Remote Sensing Data Center (DFD), German Aerospace Center (DLR), Germany*

Santiago de Chile has experienced an exponential growth in population and economy during the last years. 6.5 million of Chile’s 17.9 million inhabitants live in Santiago. Water from snow- and ice melt in the Andes is a major contributor to the region’s water supply for irrigation, industry and hydroelectric power generation. The Andes are often referred to as a “water tower”, providing the main source of fresh water for Chile. Recent studies of retreating glaciers and snow cover are alarming as these developments threaten the future freshwater supply for the population of Central Chile (33°-37°S). Mid-tropospheric warming in the central Andes increases the proportion of precipitation that falls as rain rather than snow, leading to earlier melting and peaks in river runoff (Boisier et al., 2016). This can lead to flooding in winter and spring, followed by water shortages in late spring and summer (Barnett et al., 2005). Reliable estimates of future snow cover and SLE dynamics are, therefore, of paramount importance for policy and decision makers, planners and other stakeholders in Chile. In the inaccessible high mountain areas, spaceborne Earth Observation (EO) plays a key role in the acquisition of spatially and temporally continuous snow cover data.

The two studied catchments are located in the western Main Cordillera east of Santiago in Mediterranean Central Chile. Both catchments are W-E oriented and reach elevations up to 6954 m asl (Cerro Aconcagua). Snow line elevations (SLE) are known to increase strongly with latitude in the Andes Mountains (Saavedra et al., 2017).

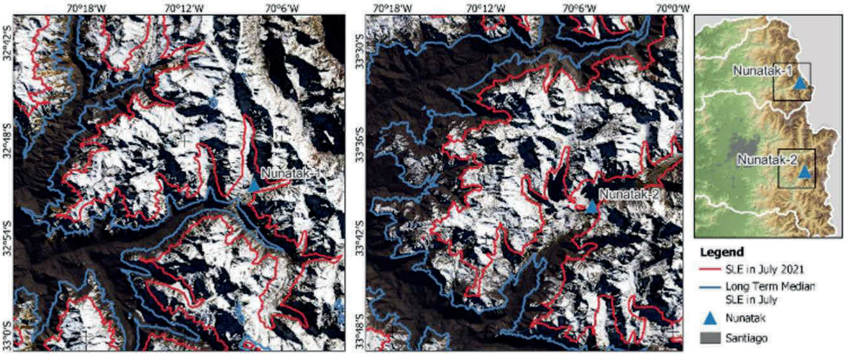

Figure 1*: Comparison of long-term median SLE in July to the SLE in July 2021 for the Aconcagua (left) and Maipo catchment (center). Background: Landsat 8 RGB from July 2021.*

We used the Copernicus Global Digital Elevation Model (GLO-30) for the retrieval of the snow line from Landsat-based snow classification images. As snow is an important hydrological parameter, we chose river catchments as the spatial unit of analysis for which the SLE is calculated. We used the HydroBASINS dataset from the HydroSHEDS project. As proposed by Hu et al. (2019) and tested for the entire Alps by Koehler et al. (2022), we employed a threshold-based snow classification scheme. In this approach, potential snow pixels are identified in a decision tree that checks for thresholds in the green and near-infrared spectral bands, in the temperature band, as well as the spectral indices, normalized difference snow index (NDSI), and the normalized difference vegetation index (NDVI).

Using the snow classification and the Copernicus DEM, the SLE was calculated for each Landsat observation from 1985 until 2023 on a catchment basis. We applied an approach originally developed by Krajčí et al. (2014) for MODIS imagery, and which was adapted to Landsat data by Hu et al. (2019). Here the SLE is described as a statistical measure that can be calculated as the minimum of the sum of the two cumulative histograms of “snow” and “clear land” pixels over the elevation. As a result, it is possible to estimate the SLE to some extent even under cloudy conditions, if enough cloud-free sample pixels are available.

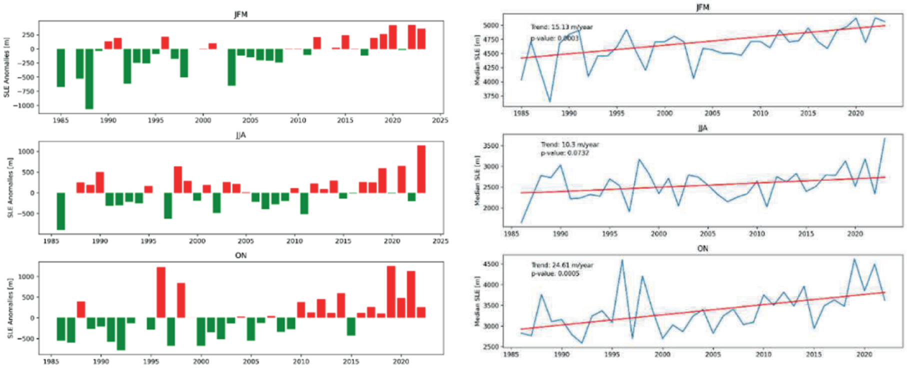

***Figure 2**: SLE anomalies (left) and median SLE time series (right) per season (JFM = January, February, March; JJA = June, July, August; ON = October, November) for the Aconcagua catchment. Red bars indicate SLE being above the long-term median (ref. period: 1990-2020) during the respective months and year.*

Our analysis showed that both catchments experienced a significant positive SLE change of more than 13 m/year for the period from 1985 to 2023. Figure 1 visualizes the SLE difference in July 2023 from the long-term median. The long-term median SLE is at 2410 m for the Aconcagua catchment and at 2020 m for the Maipo catchment. In July 2021 the SLE increased to 3083 m and 2825 m for the Aconcagua and Maipo catchment, respectively. We found unusually high anomalies of up to 1000 m SLE difference from the long-term median in October and November. These are also the months with the highest SLE increase of almost 25 m/year during the observation period. June, July and August (JJA) are usually the months with the highest snow cover extent and lowest SLE.

Further work will include analysis of the hydrological effects of increasing SLE on the catchment ecosystems, and incorporation of existing field data from Nunatak-1 and 2 ground stations, where snow properties are measured.

Boisier, J. P., Rondanelli, R., Garreaud, R. D. & Muñoz, F. (2016). Anthropogenic and natural contributions to the Southeast Pacific precipitation decline and recent megadrought in central Chile. *Geophysical Research Letters*, *43*(1), 413-421.

Barnett, T. P., Adam, J. C. & Lettenmaier, D. P. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, *438*(7066), 303-309.

Saavedra, F. A., Kampf, S. K., Fassnacht, S. R., & Sibold, J. S. (2017). A snow climatology of the Andes Mountains from MODIS snow cover data. *International Journal of Climatology*, *37*(3), 1526-1539.

Hu, Z., Dietz, A. J., & Kuenzer, C. (2019). Deriving regional snow line dynamics during the ablation seasons 1984–2018 in European Mountains. *Remote Sensing*, *11*(8), 933.

Koehler, J., Bauer, A., Dietz, A. J., & Kuenzer, C. (2022). Towards forecasting future snow cover dynamics in the European Alps—The potential of long optical remote-sensing time series. *Remote Sensing*, *14*(18), 4461.

Krajčí, P., Holko, L., Perdigão, R. A., & Parajka, J. (2014). Estimation of regional snowline elevation (RSLE) from MODIS images for seasonally snow covered mountain basins. *Journal of hydrology*, *519*, 1769-1778.

Space continuous deformation analysis of masonry structures based on TLS point clouds emphasizing the influence of the surfaces‘ geometric structure

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When we capture point clouds of an object of interest, we obtain a quasi-continuous representation of its surface. If we do so multiple times, we have multiple quasi-continuous representations of this object, whose relation can contain information about the stability in between the measured epochs. By definition, however, the absolute point position of a single point within a point cloud is not repeatable. Therefore the need for proper point cloud processing becomes evident. One approach to address this need involves using mathematical models to geometrically represent the acquired point clouds. Based on these models, we can derive a deformation analysis that is space-continuous, allowing us to determine the deformation at each point of the chosen mathematical model. When it comes to mathematically representing point clouds, B-spline curves, and surfaces often serve as suitable models for various scenarios. Promising efforts have already been undertaken in the development of deformation analysis methods built upon these mathematical models (e.g. Aichinger & Schwieger, 2022; Harmening, 2020; Kermarrec et al., 2020; Kerekes et al., 2022). In the context of those present approaches, room for development is left open, as until now, some are solely applied to simulated data, whereas others have been primarily applied to relatively small object sections, with the extension to large-scale test specimens remaining unexplored. When we look at artificial objects, that commonly need to be monitored on deformation, being dams, bridges, towers, retaining structures or cultural monuments, we see a common link between them. First, their spatial dimensions can extend over several tens of meters. Second, they often tend to have some sort of surface structure.

Having these two aspects in mind, the aim of my PhD research can be stated as an *application-driven development and investigation of a statistically sound space-continuous deformation analysis method based on B-spline surfaces of point clouds with large spatial extent.* And the superimposed research question on the infuence of recurring object-surface structure on the modelling of the point clouds and subsequently the derived deformation determination. Until now, here a restriction to masonried surfaces is made.

The mathematical model of a B-spline surface and its suitability in the course of a space-continuous deformation analysis approach shall be stated as follows: A B-spline surface can be represented as a combination of infinite B-Spline curves running in two different parameter directions u and v. One surface point is computed as the weighted sum of the control points, building the scaffold of the surface. Due to its locality characteristics, a local change in the surface results in a change in the position of corresponding control points (Harmening, 2020). When the parametrization, as being the knot vector, the degree and the order of the surface are set initially the control points can be estimated in the Gauss-Markov-Modell, where the observations are introduced as the point cloud of one measurement epoch. This further enables the introduction of a stochastic model of the point cloud. Subsequently, a deformation statement can be made by introducing the estimated control points of two measurement epochs in the well-established congruency model.

Until now, this procedure has been applied to two masonried objects, being on the one hand an aqueduct arc (Case study 1) and on the other hand an industrial chimney (Case study 2). In both case studies an own developed segmentation procedure is applied in a preprocessing step to eliminate the measured points within the joints. Further segmented and unsegmented point clouds are introduced in the deformation analysis process for the investigation of the surface structure *influences* on the surface modelling and the outcome of the deformation analysis. In the Figures 1 and 2 both case studies and one representative outcome of the processing chain is shown.

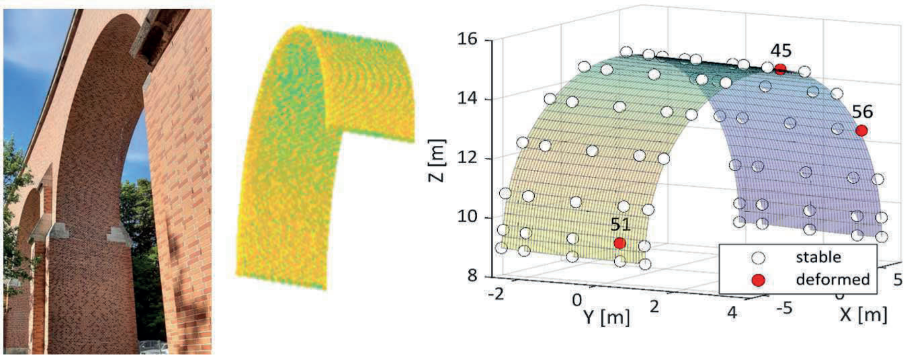

__Figure 1__: Case Study 1: left: picture of aqueduct arc; middle: point cloud of the object; right: the result of deformation analysis approach: significantly deformed control points of approximated b-spline surface (Ötsch E. et al. 2023)

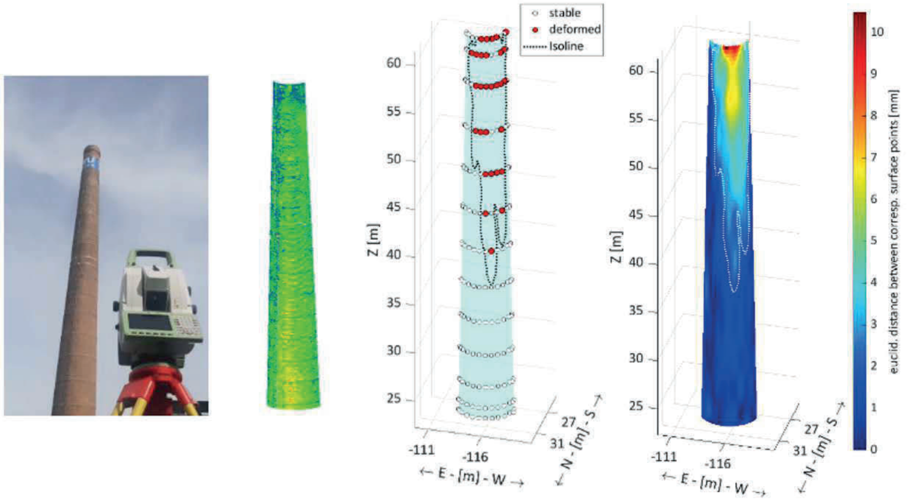

__Figure 2__: Case study 2: left picture and scan of the acquired data; right: an exemplary result of the deformation analysis approach: significanly deformed control points and their area of considerable influence on the constructed local area of the B-spline surface; deformation based on the surface point's differences (to be published soon)

Aichinger, J., & Schwieger, V. (2022). Studies on deformation analysis of TLS point clouds using B-splines – A control point based approach (Part I). Journal of Applied Geodesy, 16(3), 279–298. https://doi.org/10.1515/jag-2021-0065

Harmening, C. (2020). Spatio-temporal deformation analysis using enhanced B-spline models of laser scanning point clouds (S. 160 pages) [TU Wien; Application/pdf]. https://doi.org/10.34726/HSS.2020.57320

Kerekes, G., Raschhofer, J., Harmening, C., Neuner, H., & Schwieger, V. (2022). Two-epoch TLS deformation analysis of a double curved wooden structure using approximating B-spline surfaces and fully-populated synthetic covariance matrices. Proceedings of the 5th Joint International Symposium on Deformation Monitoring - JISDM 2022. 5th Joint International Symposium on Deformation Monitoring. https://doi.org/10.4995/JISDM2022.2022.13816

Kermarrec, G., Kargoll, B., & Alkhatib, H. (2020). Deformation Analysis Using B-Spline Surface with Correlated Terrestrial Laser Scanner Observations—A Bridge Under Load. Remote Sensing, 12(5), 829. https://doi.org/10.3390/rs12050829

Ötsch, E., Harmening, C., & Neuner, H. (2023). Investigation of space-continuous deformation from point clouds of structured surfaces. Journal of Applied Geodesy, 0(0). https://doi.org/10.1515/jag-2022-0038

Airborne multi-sensor geospatial 3D data fusion for more complete and precise digital representation

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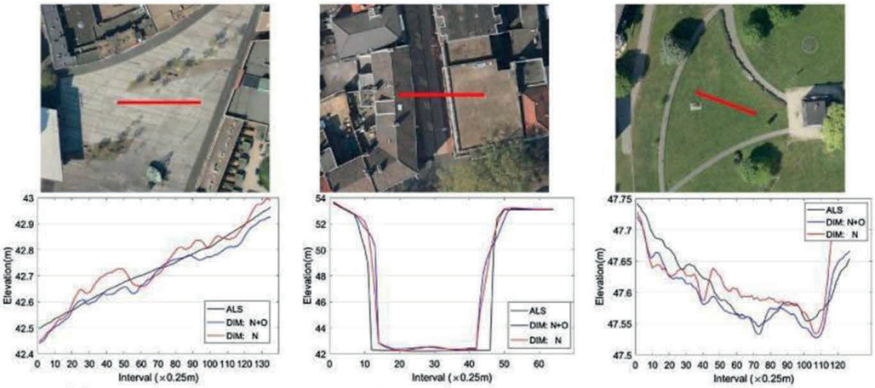
[1]*University of Luxembourg, Luxembourg*

Airborne Light Detection And Ranging (LiDAR) and aerial photogrammetry are two distinct methods of collecting spatial data, which are often combined due to their complementary strengths (Mandlburger et al., 2017, Zhang et al., 2019). New hybrid sensors that combine active LiDAR and passive photogrammetry sensors on the same platform are now being used in the airborne topographic and urban mapping industry, enabling the simultaneous capture of geospatial big data (Toschi et al., 2018). However, integrating point clouds from LiDAR with those from photogrammetric Dense Image Matching (DIM) remains a significant challenge in geospatial data processing. This is because the point clouds from airborne LiDAR and photogrammetry differ significantly in geometric accuracy (Fig. 1), precision, density, amount and size of data gaps, and available attributes (Huang et al., 2023; Zhang et al., 2018). In order to fuse the point clouds, they need to be registered precisely to eliminate geometric inconsistencies. We are developing a fusion approach for cross-source point clouds, which involves generating cross-sectional slices from both sets of data and fusing them locally using an algorithm. This approach addresses the challenges of integrating data from different sources and sensors. The fused data can then be used to perform machine learning algorithms for automatic point cloud classification, which can improve the automatic generation of detail geometry for 3D city models and related applications.



(a) Smooth square (b) Narrow alley (c) Grassland

Figure 1: 3D data profiles for three areas, The top row shows the orthoimages with profiles marked in red. The bottom row depicts the relevant profiles for ALS point cloud (black), DIM_Nadir+Oblique (blue), and DIM_Nadir (red). Figure by Zhang, Z. 2018.

Huang, X., Mei, G. & Zhang, J. (2023). Cross-source point cloud registration: Challenges, progress and prospects. Neurocomputing, 548, 126383.

Mandlburger, G., Wenzel, K., Spitzer, A., Haala, N., Glira, P. & Pfeifer, N. (2017). Improved topographic models via concurrent airborne LiDAR and dense image matching. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, IV-2/W4, 259–266.

Toschi, I., Remondino, F., Rothe, R. & Klimek, K. (2018). Combining airborne oblique camera and LiDAR sensors: investigation and new perspectives. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-1, 437–444.

Zhang, Z., Gerke, M., Vosselman, G. & Yang, M. Y. (2018). A patch-based method for the evaluation of dense image matching quality. International Journal of Applied Earth Observation and Geoinformation, 70, 25-34.

Zhang, Z., Vosselman, G., Gerke, M., Persello, C., Tuia, D. & Yang, M. Y. (2019). Detecting building changes between airborne laser scanning and photogrammetric data. Remote Sensing, 11(20), 2417.

Detecting and quantifying deforestation of old-growth forests in the Romanian Carpathian Mountains

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Background

The Romanian Carpathian Mountains contain some of Europe's last remaining old-growth forests, providing a home for Europe's largest populations of brown bears, wolves, and lynxes (Fundația Conservation Carpathia, n.d.; Endangered Landscapes & Seascapes Programme, n.d.). Old-growth forests are vital for biodiversity conservation and play a major role in carbon sequestration, thus mitigating climate change (Luyssaert et al., 2008). Over the past two decades, however, Romania's forests have been threatened by deforestation driven by logging (legal and illegal), livestock grazing, and development. Fundația Conservation Carpathia (FCC) was established in 2009 to protect these forests by creating Europe's largest forest wilderness National Park (Fundația Conservation Carpathia, n.d.). FCC's work focuses on the Făgăraș Mountains, the highest of the Southern Carpathians (Britannica, The Editors of Encyclopaedia, n.d.).

In partnership with FCC, this PhD research project will leverage remote sensing data and state-of-the-art processing pipelines to support the identification and conservation of old-growth forests in the Făgăraș region. Recent advances in remote sensing technologies, including Terrestrial Laser Scanning (TLS), mobile LiDAR scanning, and high-resolution satellite imagery, have revolutionised our understanding of forest ecosystems (Lines et al., 2022; Niță, 2021). Furthermore, advances in the tools and methods to process these new large datasets, including AI-powered tree segmentation (Puliti et al., 2023) and biomass calculations (Calders et al., 2022), can provide more accurate and timely information for conservationists.

Objectives

This research has three primary objectives:

1. **Identification of Old-Growth Trees from fused remote sensing datasets.** Combine FCC's existing dataset of 300 mobile LiDAR plot scans with tree canopy dimensions derived from high-resolution UAV and satellite imagery to identify old and ecologically significant trees. Fine-tune existing AI-based tree segmentation pipelines to identify and quantify old-growth trees based on their unique characteristics.
2. **Over-Logging Detection.** Validate the deforestation alarm system in the Carpathia Alert Portal (CarpathiaPortal, n.d.) with mobile LiDAR and TLS. Refine algorithms to detect, quantify and discriminate legal and illegal deforestation, including integration of Planet data. Develop a workflow to identify over-logging based on a comparison of remote sensing data analysis and publicly available legal logging licence records
3. **Biomass Extrapolation using TLS and Mobile LiDAR Data.** Augment FCC's existing dataset of 300 mobile LiDAR plot scans with fixed TLS scans to accurately quantify old-growth forests' value in terms of biomass. This will involve developing a suitable scanning strategy that mitigates risks, including high winds and steep, remote terrains.

Britannica, The Editors of Encyclopaedia. (n.d.). Făgăraş Mountains. Retrieved: February 20, 2024. [Online]. Available: https://www.britannica.com/place/Fagaras-Mountains

Calders, K., Verbeeck, H., Burt, A., Origo, N., Nightingale, J., Malhi, Y., Wilkes, P., Raumonen, P., Bunce, R. G. H., & Disney, M. (2022). Laser scanning reveals potential underestimation of biomass carbon in temperate forest. Ecological Solutions and Evidence, 3(4), e12197. https://doi.org/10.1002/2688-8319.12197

CarpathiaPortal. (n.d.). CarpathiaPortal—Lizmap. Retrieved February 20, 2024, Available: http://forestdesign.eu:8090/index.php/view/map/?repository=carpathia&project=CarpathiaPortal

Endangered Landscapes & Seascapes Programme. (n.d.). Carpathian Mountains. Retrieved February 20, 2024, Available: https://www.endangeredlandscapes.org/project/carpathian-mountains/

Fundația Conservation Carpathia. (n.d.). About Us. Retrieved February 20, 2024, Available: https://www.carpathia.org/about/

Lines, E. R., Fischer, F. J., Owen, H. J. F., & Jucker, T. (2022). The shape of trees: Reimagining forest ecology in three dimensions with remote sensing. Journal of Ecology, 110(8), 1730–1745. https://doi.org/10.1111/1365-2745.13944

Luyssaert, S., Schulze, E.-D., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., Ciais, P., & Grace, J. (2008). Old-growth forests as global carbon sinks. Nature, 455(7210), 213–215. https://doi.org/10.1038/nature07276

Niță, M. D. (2021). Testing Forestry Digital Twinning Workflow Based on Mobile LiDAR Scanner and AI Platform. Forests, 12(11), 1576. https://doi.org/10.3390/f12111576

Puliti, S., Pearse, G., Surový, P., Wallace, L., Hollaus, M., Wielgosz, M., & Astrup, R. (2023). FOR-instance: A UAV laser scanning benchmark dataset for semantic and instance segmentation of individual trees (Version 1). arXiv. https://doi.org/10.48550/ARXIV.2309.01279

Global spatiotemporal reconstructions and connectivity modelling of alpine biomes

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I am a second-year PhD researcher at the University of Bergen, Norway, and part of the PPF-Alpine (Past, Present, and Future of Alpine systems worldwide) research group.

I research how Quaternary climate change influenced the spatial distribution and connectivity of alpine biomes in mountains worldwide, and its legacy effect on present-day biodiversity. My findings contribute to understanding present-day biodiversity patterns in alpine biomes and prospecting the fate of alpine biomes under global climate change.

The alpine biome can be defined as the vegetation belt above the climatic treeline and below the limit of permanent snow. For my research, I use reconstructed past glacier dynamics as the upper delimitation for the area and an alpine biome extent together with paleoclimatic data, lapse, rates and temperature curves to reconstruct the lower limit, or treeline. I create a fully automated workflow that can model alpine biomes on a global scale over the last 120.000 years. Currently, a global reconstruction only exists at the LGM and for some smaller regions during the Holocene. This study would be the first to reconstruct alpine biomes on a global scale and over a continuous time period for the last 120.000 years.

The reconstructed alpine biome extent will be used to develop a mountain connectivity model that can be used to quantify alpine biome connectivity through time. I hypothesize that the glacial-interglacial cycles during the Quaternary result in repeated connection and isolation of alpine habitats. This, in turn, is thought to be key in explaining the present-day biodiversity patterns.

After looking into the past, I will turn my focus to the present and the future. The fully automated workflow will allow me to run the model at different spatial and temporal scales and future IPCC scenarios. I will assess the fate of alpine systems under changing climatic conditions. Which areas decrease first, and how fast? And which biomes will be the last to remain on earth? This part strongly links to nature protection and the development of monitoring frameworks. In 2025, I will travel to the Andes for fieldwork and I would like to have the practical skills to set up a close-ranging remote sensing campaign to complement my current research and plant the seeds for upcoming work.

I do not have any results to show yet from my PhD research and I figured that an action-shot of me programming is not very exciting. I therefore opted for a photo taken during my latest fieldwork in the alpine grasslands of Drakensberg, South Africa (Fig. 1) and a figure from my MSc research (Fig 2).

Figure 1*: The "Amphitheater" at 2800m elevation in Northern Drakensberg, South Africa.*

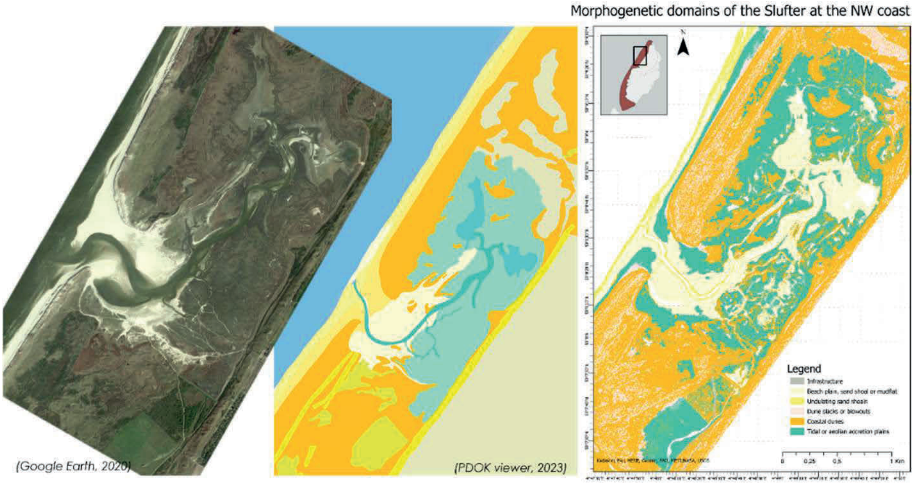

***Figure 2**: A Google Earth image of the Slufter natural area on Texel Island, The Netherlands (left). The same area according to the current geomorphological map of the Netherlands (middle) and the updated geomorphological map I created using laser altimetry data and an automated workflow in Google Earth Engine (right).*

Using archived aerial photography to measure long-term change in the surface elevation of Larsen a tributary glaciers from 1957 to 2018

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Total mass loss from eastern Antarctic Peninsula (AP) glaciers accounts for 72% of the total mass loss from the Northern Antarctic Peninsula (nAP) between 2003-2008 (Scambos et al., 2014). Of this, 18% was lost from glaciers, previously feeding the Larsen A ice shelf (Scambos et al., 2014), which collapsed dramatically in 1995. Ice shelf collapse is the primary process by which mass is lost on the AP (Royston & Gudmundsson, 2016), driven by rapid warming, resulting in the acceleration, and thinning of their tributary glaciers (Glasser et al., 2011). Significant changes in the surface elevation of glaciers have been observed but not accurately measured due to a lack of pre-satellite altimetry data and Ground Control Points (GCPs). Therefore, long-term change in the mass balance of tributary glaciers, both prior to and following ice shelf collapse, has yet to be measured. This research presents an updated method for building geographically accurate DEMs from archived aerial photographs, where in situ GCPs are limited and or nonexistent. DEMs of the Larsen A tributaries will be built using classic photogrammetric techniques, in modern photogrammetry software. Datasets include 1956/57 FIDASE (Fig. 1), 1968 USA TMA, and 2018 IceBridge vertical aerial photography. GCPs will be extracted from ICESat-2 and REMA DEM products, using existing techniques to ensure improved horizontal and vertical accuracy. The subsequent DEMs are used to produce difference DEMs (dDEM), to calculate the change in surface elevation and slope profile of Larsen A tributaries (Fig. 2) from 1957 to 2018, and therefore, the long-term impacts of ice shelf collapse on glacial mass balance.

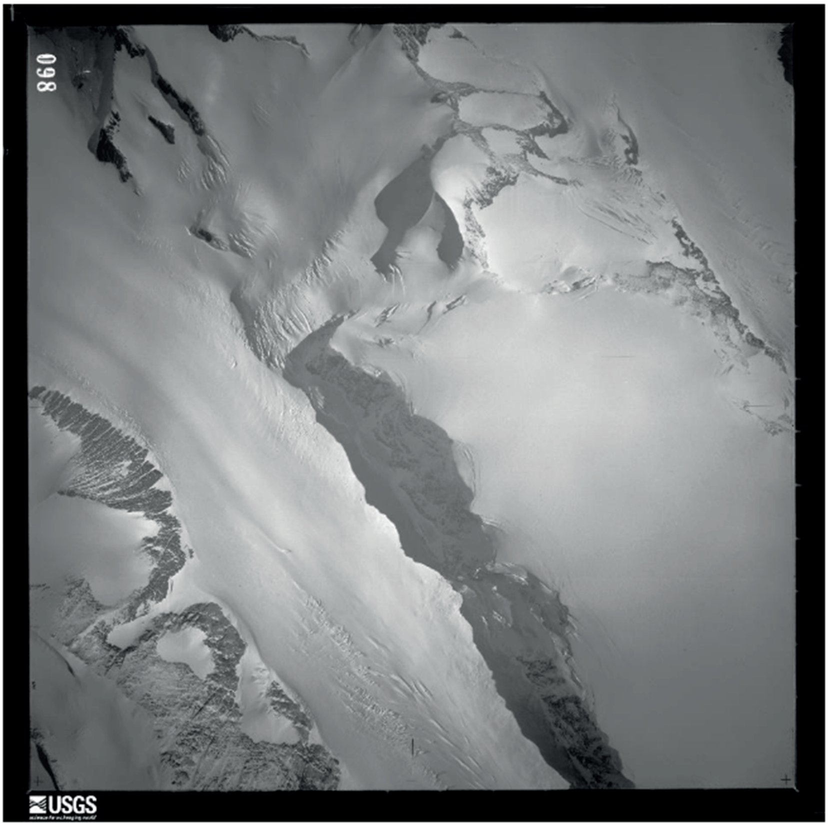

Figure 1*: An example of the 1956/57 FIDASE aerial photographs used in this study.*

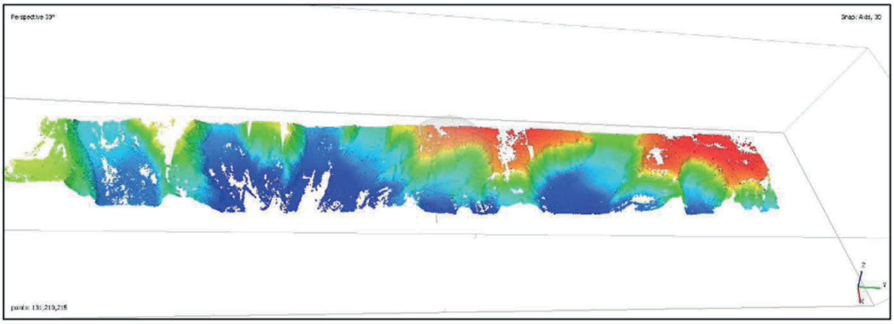

Figure 2*: A dense point cloud of smaller Larsen A tributaries (G1-G6), showing point elevation, built from 25 FIDASE aerial photographs*

Glasser, N. F., Scambos, T. A., Bohlander, J., Truffer, M., Pettit, E., & Davies, B. J. (2011). From ice-shelf tributary to tidewater glacier: continued rapid recession, acceleration and thinning of Röhss Glacier following the 1995 collapse of the Prince Gustav Ice Shelf, Antarctic Peninsula. Journal of Glaciology, 57(203), 397-406.

Royston, S., & Gudmundsson, G. H. (2016). Changes in ice-shelf buttressing following the collapse of Larsen A Ice Shelf, Antarctica, and the resulting impact on tributaries. Journal of Glaciology, 62(235), 905-911.

Scambos, T. A., Berthier, E., Haran, T., Shuman, C. A., Cook, A. J., Ligtenberg, S. R. M., & Bohlander, J. (2014). Detailed ice loss pattern in the northern Antarctic Peninsula: widespread decline driven by ice front retreats. The Cyrosphere, 8(6), 2135-2145

Towards automating forest stratum classification with a generative pipeline: Blending real and synthetic data for point cloud segmentation

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Forest stratification is a powerful tool to determine the vitality of forest stands with implicit forecasting support. It enables the extraction of vital information such as biomass, forest physiology, and rejuvenation capacity (Gilliam, 2007; Shankar, 2019; Hernandez-Santin et al., 2019; Camarretta et al., 2020). Given their importance, in situ stratification studies are performed despite their complex nature and high intrinsic costs (time, people, and equipment). These studies entail per-tree manual parameter acquisition, such as crown height and width, tree height, and trunk radius (Yun et al., 2022); and statistical models (Campbell et al., 2018). In contrast, airborne laser scans (ALS) and unmanned aerial vehicle laser scans (ULS) can generate high-density wide-area scans but lack annotations crucial to deriving information and training neural networks. To contribute towards automating the classification of stratification, we:

- propose a generative forestry scene pipeline that merges real and synthetic tree objects into ALS/ULS-like point clouds and provides their per-point annotation;
- study this data usage for training a point cloud segmentation neural network for stratification (Qi et al., 2017; Kalinicheva et al., 2022);
- measure the model performance on real data to assess its viability as a stratification tool.

The pipeline exploits synthetic trees and vegetation descriptor values like height and radius by randomly permuting them within defined limits, subsequently generating an arbitrary number of parametrised mesh objects. Besides, hand-annotated real ULS and terrestrial laser scans are captured for training and validation. Synthetic and real objects are then randomly placed in a scene to simulate ULS data acquisition (Winiwarter et al., 2021). The resulting point cloud is annotated using the known relation between the object parameters and its point cloud representation.

Although the pipeline can create arbitrary trees, this contribution focuses on alpine forest stands with various species, such as larch, spruce, and beech. Results verification is conducted using real ULS and terrestrial laser scans collected in Ebensee, Upper Austria. Moreover, we explore the potential benefits of mixing real with synthetic annotations for training.

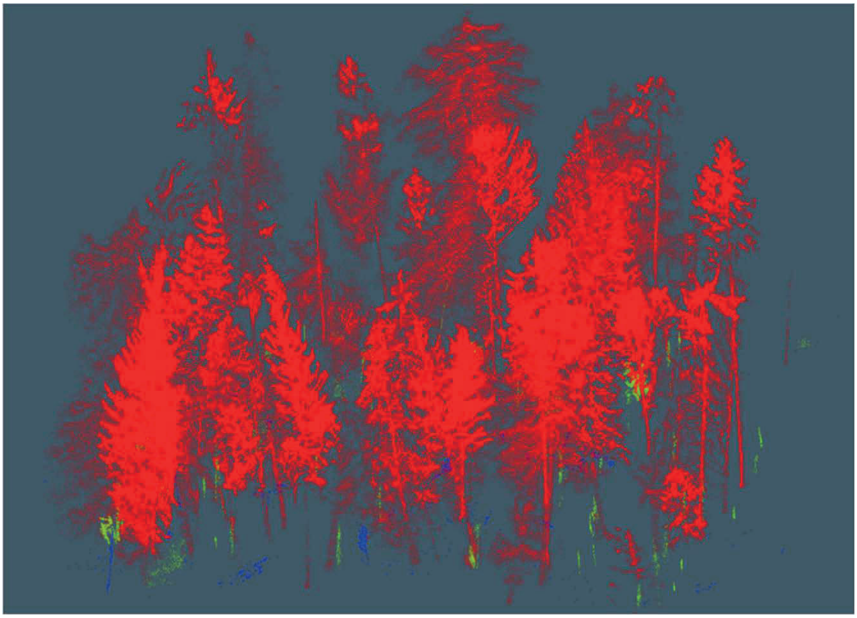

Figure 1: *A real/synthetic hybrid point cloud produced by our pipeline and used to train overstory/understory/ground vegetation semantic segmentation models.*

Camarretta, N., Harrison, P. A., Bailey, T., Potts, B., Lucieer, A., Davidson, N., & Hunt, M. (2020). Monitoring forest structure to guide adaptive management of forest restoration: A review of remote sensing approaches. New Forests, 51(4), 573–596. https://doi.org/10.1007/s11056-019-09754-5

Campbell, M. J., Dennison, P. E., Hudak, A. T., Parham, L. M., & Butler, B. W. (2018). Quantifying understory vegetation density using small-footprint airborne lidar. Remote Sensing of Environment, 215, 330–342. https://doi.org/10.1016/j.rse.2018.06.023

Gilliam, F. S. (2007). The Ecological Significance of the Herbaceous Layer in Temperate Forest Ecosystems. BioScience, 57(10), 845–858. https://doi.org/10.1641/B571007

Hernandez-Santin, L., Rudge, M. L., Bartolo, R. E., & Erskine, P. D. (2019). Identifying Species and Monitoring Understorey from UAS-Derived Data: A Literature Review and Future Directions. Drones, 3(1), 9. https://doi.org/10.3390/drones3010009

Kalinicheva, E., Landrieu, L., Mallet, C., & Chehata, N. (2022). Multi-Layer Modeling of Dense Vegetation from Aerial LiDAR Scans (Version 1). arXiv. https://doi.org/10.48550/ARXIV.2204.11620

Qi, C. R., Yi, L., Su, H., & Guibas, L. J. (2017). PointNet++: Deep Hierarchical Feature Learning on Point Sets in a Metric Space (Version 1). arXiv. https://doi.org/10.48550/ARXIV.1706.02413

Shankar, U. (2019). Phytosociology of stratification in a lowland tropical rainforest occurring north of the Tropic of Cancer in Meghalaya, India. Plant Diversity, 41(5), 285–299. https://doi.org/10.1016/j.pld.2019.08.001

Winiwarter, L., Pena, A. M. E., Weiser, H., Anders, K., Sanchez, J. M., Searle, M., & Höfle, B. (2021). Virtual laser scanning with HELIOS++: A novel take on ray tracing-based simulation of topographic 3D laser scanning (Version 1). arXiv. https://doi.org/10.48550/ARXIV.2101.09154

Yun, Z., Zheng, G., Geng, Q., Monika Moskal, L., Wu, B., & Gong, P. (2022). Dynamic stratification for vertical forest structure using aerial laser scanning over multiple spatial scales. International Journal of Applied Earth Observation and Geoinformation, 114, 103040. https://doi.org/10.1016/j.jag.2022.103040

Quantifying the controls on and glaciological impacts of glacier disconnections on ice masses in the Himalaya

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Glaciers in the Himalayas are important indicators of regional climate change (Stumm et al., 2021; Bolch et al., 2019) and serve as a vital freshwater resource for over 240 million people living in the region and 1.65 billion downstream, particularly during the dry season (Wester et al., 2019). However, they are currently undergoing rapid mass loss and retreat due to ongoing climate change (Bolch et al., 2019). Consequently, many glaciers in the region are experiencing fragmentation (Bajracharya et al., 2015; Khadka et al., 2020) and have the potential to disconnect along- flowline at steep ice cliffs and thinned, bare ice areas, isolating the ablation zone from ice supplies from the accumulation zone. Additionally, studies have highlighted the growth and expansion of debris cover extent on Himalayan glaciers (Shea et al., 2021; Thakuri et al., 2014) and in a few cases, the transition from clean ice to debris-covered (Ali et al., 2017). This trend is expected to continue with the current rate of warming that leads to increased permafrost thaw, subsequently leading to more exposed areas and mass movement. Understanding the past behaviour and current dynamics of these glaciers, particularly the transition from clean ice to debris-covered is essential for assessing their future evolution, predicting future water availability and potential hazards associated with debris-covered glaciers, including glacier lake outburst floods (GLOFs) (ICIMOD, 2023). Therefore, this research aims to investigate the glacier dynamics and the transition from clean ice to debris-covered glaciers in the Langtang Catchment, located in the Central Nepalese Himalaya (Fig. 1) using remote sensing, numerical modelling, and field surveys. To achieve this, we will **i**. assess the changes in glaciers' length, area, and volume **ii**. map and quantify glacier fragmentation, disconnection, and debris cover extent **iii**. analyse the relationship spatially and temporally between glacier dynamics, glacier fragmentation and disconnection, and the emergence of debris cover extent, and **iv**. conduct detailed field surveys for ground truthing and in-situ data collection to validate and complement the numerical modelling and remote sensing work. Before fieldwork, we will complete **i, ii**, and **iii** using numerical glacier model and remote sensing, **iv** focuses on field survey which will comprise of detailed topographic survey of glacier structures like crevasses, ice cliffs, exposed bare areas etc, geomorphologic survey of moraines, debris extent etc, glaciologic survey of glacier terminus of the debris-covered glaciers and glaciers at the risk of disconnections using drone, time-lapse cameras, dGPS etc. We also plan to install some low-cost sensors (ground temperature loggers, water level sensors at the outlet of proglacial lakes, etc.) to record important data for seasonal to long-term changes occurring on the glaciers. The datasets from these surveys will be used for generating high-resolution DEM and detailed maps of glacier disconnections and debris cover extent with prominent glacier features like ice cliffs, crevasses, exposed bedrocks, moraines, and supraglacial ponds which potentially govern the dynamics of glaciers and explains the present status of the glaciers in the catchment.

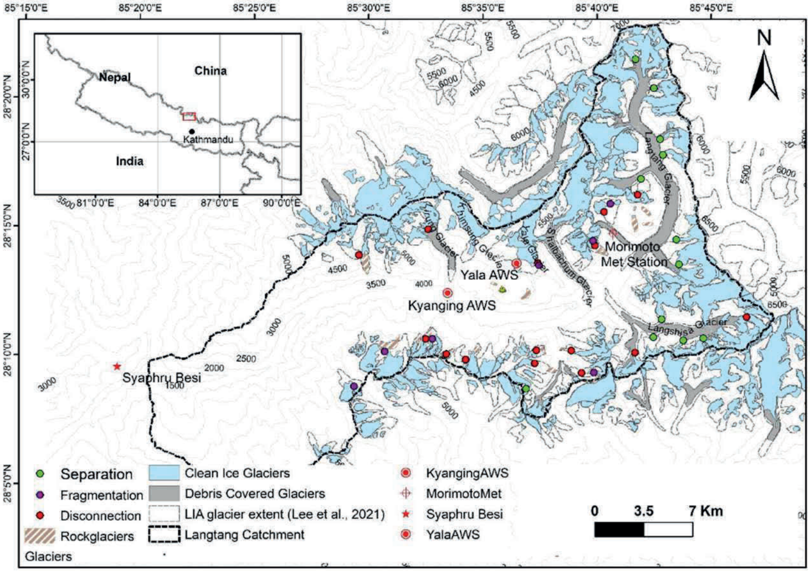

Figure 1*: Langtang catchment with placemarks for weather stations, major towns, and glacier fragmentation, disconnection, and separation.*

Ali, I., Shukla, A., & Romshoo, S. A. (2017). Assessing linkages between spatial facies changes and dimensional variations of glaciers in the upper Indus Basin, western Himalaya. Geomorphology, 284, 115–129. https://doi.org/10.1016/j.geomorph.2017.01.005

Bajracharya, S. R., Maharjan, S. B., Shrestha, F., Guo, W., Liu, S., Immerzeel, W., & Shrestha, B. (2015). The glaciers of the Hindu Kush Himalayas: Current status and observed changes from the 1980s to 2010. International Journal of Water Resources Development, 31(2), 161–173. https://doi.org/10.1080/07900627.2015.1005731

Bolch, T., Shea, J. M., Liu, S., Azam, F. M., Gao, Y., Gruber, S., Immerzeel, W. W., Kulkarni, A., Li, H., Tahir, A. A., Zhang, G., & Zhang, Y. (2019). Status and Change of the Cryosphere in the Extended Hindu Kush Himalaya Region. In P. Wester, A. Mishra, A. Mukherji, & A. B. Shrestha (Eds.), The Hindu Kush Himalaya Assessment (pp. 209–255). Springer International Publishing. https://doi.org/10.1007/978-3-319-92288-1_7

Khadka, N., Khadka, N., Ghimire, S. K., Chen, X., Thakuri, S., Hamal, K., Shrestha, D., & Sharma, S. (2020). Dynamics of Maximum Snow Cover Area and Snow Line Altitude Across Nepal (2003-2018) Using Improved MODIS Data. Journal of Institute of Science and Technology, 25(2), 17–24. https://doi.org/10.3126/jist.v25i2.33729

Shea, J. M., Kraaijenbrink, P. D. A., Immerzeel, W. W., & Brun, F. (2021). Debris Emergence Elevations and Glacier Change. Frontiers in Earth Science, 9, 709957. https://doi.org/10.3389/feart.2021.709957

Stumm, D., Joshi, S. P., Gurung, T. R., & Silwal, G. (2021). Mass balances of Yala and Rikha Samba glaciers, Nepal, from 2000 to 2017. Earth System Science Data, 13(8), 3791–3818. https://doi.org/10.5194/essd-13-3791-2021

Thakuri, S., Salerno, F., Smiraglia, C., Bolch, T., D'Agata, C., Viviano, G., & Tartari, G. (2014). Tracing glacier changes since the 1960s on the south slope of Mt. Everest (central Southern Himalaya) using optical satellite imagery. The Cryosphere, 8(4), 1297–1315. https://doi.org/10.5194/tc-8-1297-2014

ICIMOD (2023). Water, ice, society, and ecosystems in the Hindu Kush Himalaya: An outlook. International Centre for Integrated Mountain Development (ICIMOD). https://doi.org/10.53055/ICIMOD.1028

Wester, P., Mishra, A., Mukherji, A., & Shrestha, A. B. (Eds.). (2019). The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. Springer International Publishing. https://doi.org/10.1007/978-3-319-92288-1

Simulating laser scanning of dynamic virtual 3D scenes for improved 4D point cloud based topographic change analysis

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Mass movements, which occur with frequencies ranging from days to years, pose a risk to human life and critical infrastructure when their paths intersect. Monitoring of such processes is a complex task that is addressed by a variety of methods (Angeli et al., 2000). Terrestrial Laser Scanning (TLS) is a ground-based method that is capable of gathering high spatial resolution (sub-centimetre) 3D geodata (Eitel et al., 2016). Recent developments have enabled the permanent installation of TLS systems, specifically Permanent Laser Scanning (PLS) systems. These systems can effectively monitor an area of interest with high temporal (sub-hourly) and spatial resolution (Kromer et al., 2017). This revolutionises the monitoring of mass movements and the set of well-established methods for bi-temporal comparison of 3D data (Lague et al., 2013; Winiwarter et al., 2021; Zahs et al., 2022) needs to be reconsidered. With PLS systems the focus has shifted towards developing methods that take advantage of the newly available temporal resolution. Recent studies (Anders et al., 2020; Hulskemper et al., 2022) show the potential of such approaches for research and application.

The project aims to make full use of the temporal domain. Methods such as temporal aggregation, considering change over time, and others are investigated. Regardless of the method used, a point cloud time-series is a large dataset that requires approaches, specifically designed to handle large data volumes (e.g., thousands of point clouds) in PLS settings. To tackle this, hierarchical methods are developed with the goal of achieving near real-time performance. At each stage of the analysis the application of Machine Learning and Deep Learning (ML/DL) approaches, to detect and classify change events, is investigated. These steps require a large amount of both training and validation data of such change events, which is not readily available in real-world scenarios. To overcome this limitation, 4D scenes are simulated using a novel methodology. It can generate numerous physics-informed dynamic 3D scenes, such as ongoing rockfall events, for laser scanning simulation. Specifically, an adaptation of the Gravitational Process Path Model (Wichmann, 2017) generates gravitationally influenced process paths that serve as input for Virtual Laser Scanning, by using the open-source simulator HELIOS++ (Winiwarter et al., 2022). The performance and accuracy will be investigated with real PLS data collected during the AImon5.0 project funded by the BMBF. The results will be made open source and integrated into scientific software projects HELIOS++ and py4dgeo (py4dgeo Development Core Team, 2022).

In summary, this project aims to develop new methods for 4D change analysis, thereby advancing risk mitigation by taking a step towards near real-time monitoring.

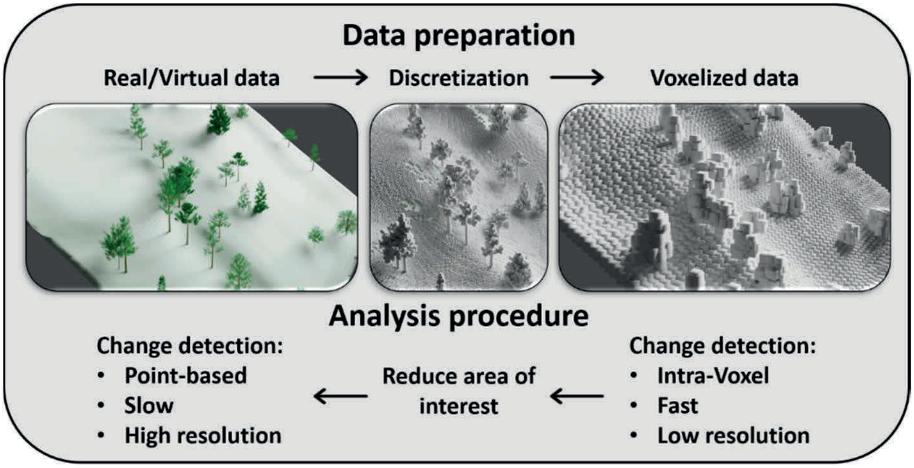

***Figure 1**: Schematic workflow for the hierarchical data analysis approach.*

Anders, K., Winiwarter, L., Lindenbergh, R., Williams, J. G., Vos, S. E., & Höfle, B. (2020). 4D objects-by-change: Spatiotemporal segmentation of geomorphic surface change from LiDAR time series. ISPRS Journal of Photogrammetry and Remote Sensing, 159, 352–363. https://doi.org/10.1016/j.isprsjprs.2019.11.025

Angeli, M.-G., Pasuto, A., & Silvano, S. (2000). A critical review of landslide monitoring experiences. Engineering Geology, 55(3), 133–147. https://doi.org/10.1016/S0013-7952(99)00122-2

Eitel, J. U. H., Höfle, B., Vierling, L. A., Abellán, A., Asner, G. P., Deems, J. S., Glennie, C. L., Joerg, P. C., LeWinter, A. L., Magney, T. S., Mandlburger, G., Morton, D. C., Müller, J., & Vierling, K. T. (2016). Beyond 3-D: The new spectrum of lidar applications for earth and ecological sciences. Remote Sensing of Environment, 186, 372–392. https://doi.org/10.1016/j.rse.2016.08.018

Hulskemper, D., Anders, K., Antolínez, J. A. Á., Kuschnerus, M., Höfle, B., & Lindenbergh, R. (2022). CHARACTERIZATION OF MORPHOLOGICAL SURFACE ACTIVITIES DERIVED FROM NEAR-CONTINUOUS TERRESTRIAL LIDAR TIME SERIES. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-2/W2-2022, 53–60. https://doi.org/10.5194/isprs-archives-XLVIII-2-W2-2022-53-2022

Kromer, R. A., Abellán, A., Hutchinson, D. J., Lato, M., Chanut, M.-A., Dubois, L., & Jaboyedoff, M. (2017). Automated terrestrial laser scanning with near-real-time change detection – monitoring of the Séchilienne landslide. Earth Surface Dynamics, 5(2), 293–310. https://doi.org/10.5194/esurf-5-293-2017

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

py4dgeo Development Core Team (2022): py4dgeo: library for change analysis in 4D point clouds. https://github.com/3dgeo-heidelberg/py4dgeo

Wichmann, V. (2017). The Gravitational Process Path (GPP) model (v1.0) – a GIS-based simulation framework for gravitational processes. Geoscientific Model Development, 10(9), 3309–3327. https://doi.org/10.5194/gmd-10-3309-2017

Winiwarter, L., Anders, K., & Höfle, B. (2021). M3C2-EP: Pushing the limits of 3D topographic point cloud change detection by error propagation. ISPRS Journal of Photogrammetry and Remote Sensing, 178, 240–258. https://doi.org/10.1016/j.isprsjprs.2021.06.011

Winiwarter, L., Esmorís Pena, A. M., Weiser, H., Anders, K., Martínez Sánchez, J., Searle, M., & Höfle, B. (2022). Virtual laser scanning with HELIOS++: A novel take on ray tracing-based simulation of topographic full-waveform 3D laser scanning. Remote Sensing of Environment, 269, 112772. https://doi.org/10.1016/j.rse.2021.112772

Zahs, V., Winiwarter, L., Anders, K., Williams, J. G., Rutzinger, M., & Höfle, B. (2022). Correspondence-driven plane-based M3C2 for lower uncertainty in 3D topographic change quantification. ISPRS Journal of Photogrammetry and Remote Sensing, 183, 541–559. https://doi.org/10.1016/j.isprsjprs.2021.11.018

Mountain glacier-rock glacier interactions: Exploring glacier-rock glacier transition on large spatial and temporal scales

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High mountain glaciers are vital for water supply in semi-arid regions. However, the drought-resistant, seasonally delayed source of freshwater they provide to the water-intensive economies and populations downstream is at risk of disappearing before the end of the century due to increasing air surface temperatures (Pritchard, 2019). Debris cover on glaciers can slow glacial melt rates and, under certain conditions, cause behavioural and dynamic changes that allow glaciers to transform into rock glaciers (Monnier & Kinnard, 2017). Rock glaciers are more resistant to climate change than glaciers as their thick debris layer thermally decouples them from the rising surface air temperatures above, allowing their freshwater stores to persist long after glaciers recede (Harrison et al., 2021). Our current understanding of glacier-rock glacier transition is very limited (Monnier & Kinnard, 2017), but it's potential as a widespread phenomenon could indicate that high mountain glacier water stores might be more resilient to climate change than previously thought (Shannon et al., 2019). Therefore, the overarching aim of my project is to provide insight into and continue developing hypotheses regarding the spatial and temporal evolution of glacier-rock glacier complexes (Fig. 1) using remote sensing datasets and field observation datasets. My project focuses on the glacier-rock glacier complexes of the semi-arid Andes (27°-35°S), which are some of the most advanced stage complexes in the world. A key component of the project involves conducting a comprehensive, high-resolution morphological and kinematic change assessment to identify the potential indicators and governing processes of transition on the Tapado glacier complex. This will be achieved through a combination of unmanned aerial vehicles, drone-mounted ground penetrating radar (Fig. 2), debris clast, and Differential GNSS surveys. The findings from these surveys will be combined and interpreted to evaluate whether transitional indicators can be reliably recognised using remote sensing datasets alone. Such a capability would facilitate the large-scale identification of glacier-rock glacier complexes undergoing transition. My project also investigates the morphological, velocity, and topographic changes of a selection of complexes in the region from the 1950s to the present. This aspect of the project uses contemporary high-resolution satellite and historical aerial imagery to begin addressing our lack of long-term measurements and observations regarding the spatio-temporal evolution of these complexes, which currently hinders our understanding of how they respond to changing climatic conditions. In addition to this work, I have been compiling a glacier-rock glacier inventory for the semi-arid Andes using remote sensing datasets, following the International Permafrost Association's guidelines. This process incorporates deep learning and object-based image analysis to minimize uncertainty derived from analyst subjectivity. This inventory not only facilitates the identification of complexes and areas of interest within the region but, upon publication, will also support the estimation of high mountain water store longevity. Through these diverse yet interconnected components, I aim to contribute to our knowledge of glacier-rock glacier complex evolution, the transitional process and its implication for freshwater supply in semi-arid regions.

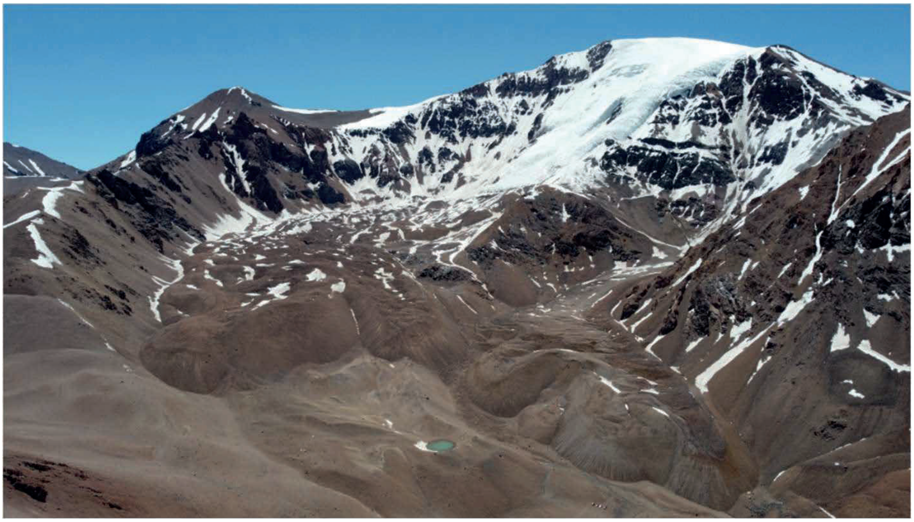

***Figure 1**: The Tapado glacier-rock glacier complex, La Laguna, Chile (30º08'55.66" S, 69º55'20.98" W). Two rock glacier lobes sit downslope of a debris-covered glacier while the steep (>30º) clean ice section towers above. Photo: Daniel Thomas*

***Figure 2**: A drone-mounted Malå ground penetrating radar system and DJI Phantom 4 at Galena Creek rock glacier, Shoshone National Forest, Wyoming. The Malå drone flies at a constant elevation (1 m) above the rock glacier surface to collect information about the debris-ice interface depth. Photo: Daniel Thomas*

Harrison, S., Jones, D., Anderson, K., Shannon, S., & Betts, R. A. (2021). Is ice in the Himalayas more resilient to climate change than we thought? Geografiska Annaler: Series A, Physical Geography, 103(1), 1–7. https://doi.org/10.1080/04353676.2021.1888202

Monnier, S., & Kinnard, C. (2017). Pluri-decadal (1955–2014) evolution of glacier–rock glacier transitional landforms in the central Andes of Chile (30–33° S). Earth Surface Dynamics, 5(3), 493–509. https://doi.org/10.5194/esurf-5-493-2017

Pritchard, H. D. (2019). Asia's shrinking glaciers protect large populations from drought stress. Nature, 569(7758), 649–654. https://doi.org/10.1038/s41586-019-1240-1

Shannon, S., Smith, R., Wiltshire, A., Payne, T., Huss, M., Betts, R., Caesar, J., Koutroulis, A., Jones, D., & Harrison, S. (2019). Global glacier volume projections under high-end climate change scenarios. The Cryosphere, 13(1), 325–350. https://doi.org/10.5194/tc-13-325-2019

Integrating advanced remote sensing and machine learning for glacier identification and monitoring in high mountain environments: A comparative analysis with historical traces

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[1]*Institute of Geodesy, Graz University of Technology (TU Graz), Graz, Austria.*

Glacier identification and monitoring in high mountain regions are crucial for understanding the impacts of climate change and informing environmental management strategies. This research aims to enhance current methodologies by integrating advanced remote sensing techniques, such as drone and sensor-based data collection, with historical traces, while also developing an automated machine learning approach for processing captured remote sensing datasets. The study utilises state-of-the-art remote sensing technologies to collect high-resolution imagery and point cloud data of glaciers in high mountain environments. This includes the deployment of drones equipped with multispectral cameras and LiDAR sensors, as well as ground-based sensors, to obtain comprehensive datasets. The collected data undergo rigorous processing using advanced feature extraction, classification, and change detection algorithms. To validate the accuracy and reliability of the results obtained from remote sensing techniques, a comparative analysis is conducted with historical traces, including ground-based observations and historical stereo images like Declassified Corona KH-4 (1962–1972) Stereo Imageries. This comparison enables the assessment of long-term glacier dynamics and provides insights into the extent of changes over time. Furthermore, this research proposes the development of an automated machine learning technique tailored for processing captured remote sensing datasets. The machine learning approach encompasses training algorithms to recognize glacier features, classify glacier boundaries, and detect temporal changes in glacier morphology. By automating these processes, the efficiency and accuracy of glacier identification and modelling can be significantly improved.

Barella, R., Callegari, M., Marin, C., Klug, C., Sailer, R., Galos, S. P., Dinale, R., Gianinetto, M., & Notarnicola, C. (2022). Combined Use of Sentinel-1 and Sentinel-2 for Glacier Mapping: An Application Over Central East Alps. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 15, 4824–4834. https://doi.org/10.1109/JSTARS.2022.3179050

Gaffey, C., & Bhardwaj, A. (2020). Applications of Unmanned Aerial Vehicles in Cryosphere: Latest Advances and Prospects. Remote Sensing, 12(6), 948. https://doi.org/10.3390/rs12060948

Ghuffar, S., Bolch, T., Rupnik, E., & Bhattacharya, A. (2022). A Pipeline for Automated Processing of Declassified Corona KH-4 (1962–1972) Stereo Imagery. IEEE Transactions on Geoscience and Remote Sensing, 60, 1–14. https://doi.org/10.1109/TGRS.2022.3200151

Giulio Tonolo, F., Cina, A., Manzino, A., & Fronteddu, M. (2020). 3d Glacier Mapping By Means Of Satellite Stereo Images: The Belvedere Glacier Case Study In The Italian Alps. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B2-2020, 1073–1079. https://doi.org/10.5194/isprs-archives-XLIII-B2-2020-1073-2020

Paul, F., & Kääb, A. (2005). Perspectives on the production of a glacier inventory from multispectral satellite data in Arctic Canada: Cumberland Peninsula, Baffin Island. Annals of Glaciology, 42, 59–66. https://doi.org/10.3189/172756405781813087

Peng, Y., He, J., Yuan, Q., Wang, S., Chu, X., & Zhang, L. (2023). Automated glacier extraction using a Transformer based deep learning approach from multi-sensor remote sensing imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 202, 303–313. https://doi.org/10.1016/j.isprsjprs.2023.06.015

Zhang, L., Zhang, L., & Du, B. (2016). Deep Learning for Remote Sensing Data: A Technical Tutorial on the State of the Art. IEEE Geoscience and Remote Sensing Magazine, 4(2), 22–40. https://doi.org/10.1109/MGRS.2016.2540798

AI empowered spatiotemporal feature extraction and characterization of 4D surface change objects

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[1]Professorship for Remote Sensing Applications, Technical University of Munich, Germany

The three dimensions of geospatial data acquired from laser scanning and photogrammetry are becoming popular datasets used in a wide variety of research and applications. Additionally, the temporal dimension is obtained through repeat acquisition of 3D point clouds, which enables the analysis and characterization of the surface changes. Especially the growing availability of near continuous point clouds acquired hourly provides valuable time series information to monitor high frequency changes in different geographic settings, such as landslides (Stumvoll et al., 2020), rockfalls (Williams et al., 2018), sandy beaches (Vos et al., 2022), soil erosion (Eltner et al., 2017), forest structure (Campos et al., 2020) and urban scenes (Stilla & Xu, 2023). Capturing and describing change events occurred within a landscape, whether driven by nature or human activities, are essential for advancing our understanding of underlying environmental processes and their intricate interactions with human activities. An inherent challenge remains in the comprehensive extraction and description of the significant change information from these vast datasets with billions of point clouds. While time series analysis of 4D point clouds has proved to be valid methods for automatic change detection (Anders et al., 2020, 2021; Winiwarter et al., 2023), there remains a gap in generally mining and characterizing the observed scene activities.

Over past years, modern neural networks (NN) and novel deep learning (DL) strategies have outperformed many traditional methods in the fields of spatiotemporal understanding of point clouds (Guo et al., 2020). However, it's nontrivial to migrate DL methodologies into geographic applications due to challenges like large-scale observations, missing semantic labels, and geospatial domain knowledge. Thus, the aim of this work is to investigate and discuss the use of deep learning methodologies in the processing and analysis of high-dimensional Earth observation data (e.g., 4D topographic point clouds), for enhancing AI-assisted geospatial data science in tasks like classification, segmentation, and modeling of surface dynamics, climate change impacts, and human-related geographic applications. The first contribution will lie on understanding and extracting spatiotemporal features from 4D surface change objects in an unsupervised manner (Fig. 1). This includes 1) exploiting suitable data model for representing 4D point cloud geodata and building readily trainable datasets for neural networks, 2) investigating models for capturing spatiotemporal features to reduce high-dimensional data into latent representation in an unsupervised manner, 3) Clustering and description of extracted features to identify key spatiotemporal descriptors, 4) Evaluating the scalability and transferability of the proposed workflow across diverse geographic settings. To this end, the proposed feature extraction will share the insights that deep features of 4D geodata can be used for more downstream geographic applications.

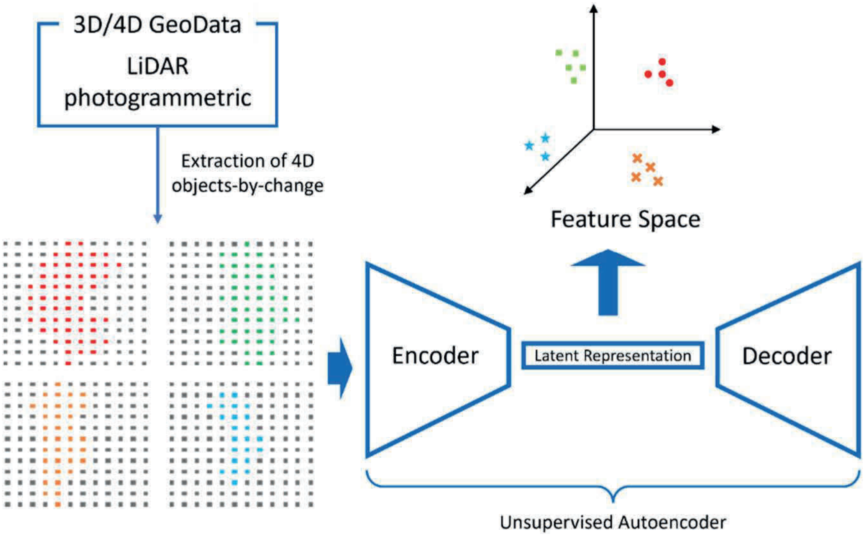

***Figure 1**: An unsupervised autoencoder-based deep feature extraction method for 4D change objects*

Anders, K., Winiwarter, L., Lindenbergh, R., Williams, J. G., Vos, S. E., & Höfle, B. (2020). 4D objects-by-change: Spatiotemporal segmentation of geomorphic surface change from LiDAR time series. ISPRS Journal of Photogrammetry and Remote Sensing, 159, 352–363. https://doi.org/10.1016/j.isprsjprs.2019.11.025

Anders, K., Winiwarter, L., Mara, H., Lindenbergh, R., Vos, S. E., & Höfle, B. (2021). Fully automatic spatiotemporal segmentation of 3D LiDAR time series for the extraction of natural surface changes. ISPRS Journal of Photogrammetry and Remote Sensing, 173, 297–308. https://doi.org/10.1016/j.isprsjprs.2021.01.015

Campos, M. B., Litkey, P., Wang, Y., Chen, Y., Hyyti, H., Hyyppä, J., & Puttonen, E. (2020). A Long-Term Terrestrial Laser Scanning Measurement Station to Continuously Monitor Structural and Phenological Dynamics of Boreal Forest Canopy. Frontiers in Plant Science, 11, 606752. https://doi.org/10.3389/fpls.2020.606752

Eltner, A., Kaiser, A., Abellan, A., & Schindewolf, M. (2017). Time lapse structure-from-motion photogrammetry for continuous geomorphic monitoring. Earth Surface Processes and Landforms, 42(14), 2240–2253. https://doi.org/10.1002/esp.4178

Guo, Y., Wang, H., Hu, Q., Liu, H., Liu, L., & Bennamoun, M. (2020). Deep learning for 3d point clouds: A survey. IEEE Transactions on Pattern Analysis and Machine Intelligence, 43(12), 4338–4364.

Stilla, U., & Xu, Y. (2023). Change detection of urban objects using 3D point clouds: A review. ISPRS Journal of Photogrammetry and Remote Sensing, 197, 228–255. https://doi.org/10.1016/j.isprsjprs.2023.01.010

Stumvoll, M. J., Canli, E., Engels, A., Thiebes, B., Groiss, B., Glade, T., Schweigl, J., & Bertagnoli, M. (2020). The “Salcher” landslide observatory—Experimental long-term monitoring in the Flysch Zone of Lower Austria. Bulletin of Engineering Geology and the Environment, 79(4), 1831–1848. https://doi.org/10.1007/s10064 -019-01632-w

Vos, S., Anders, K., Kuschnerus, M., Lindenbergh, R., Höfle, B., Aarninkhof, S., & de Vries, S. (2022). A high-resolution 4D terrestrial laser scan dataset of the Kijkduin beach-dune system, The Netherlands. Scientific Data, 9(1), Article 1. https://doi.org/10.1038/s41597 -022-01291-9

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

Winiwarter, L., Anders, K., Czerwonka-Schröder, D., & Höfle, B. (2023). Full four-dimensional change analysis of topographic point cloud time series using Kalman filtering. Earth Surface Dynamics, 11(4), 593–613. https://doi.org/10.5194/esurf-11-593-2023

Monitoring snow cover dynamics in the rhoen mountains using close-range sensing techniques

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The accumulation and depletion of the snow cover are among the most dynamic seasonal land surface changes in terrestrial environments. Therefore, knowledge about snow depths and melt-out days are of great importance for geomorphological, hydrological, microclimatological and ecological issues.

We use close-range sensing techniques to monitor the snow cover at a block accumulation in the Rhoen Mountains, Central German Uplands. For this purpose, we installed a low-cost trail camera with mobile radio transmission to observe the growth of a snowbank and its melting behaviour in real time (Fig. 1 b, c). The system has been operating for several years now. Automated calculation of snow-covered areas from common photos is possible by pixel thresholding (e.g., Kępski et al., 2017). Additionally, we performed terrestrial laser scans in three winters using a Leica MS 60 Multistation around the time of maximum snow depth (Fig. 1 a, d).

Applicability of these close-range sensing methods has already been tested in Arctic regions to assess risks posed from snow-cornice break-up avalanches (see e.g. Hancock et al., 2020; Veilleux et al., 2021). Optical data was compared with ground surface temperature time series that were registered by data loggers to evaluate the influence of the snow cover on the ground thermal characteristics (see e.g. Rödder & Kneisel, 2012).

Snow depths derived from laser scans were up to 3.6 m (winter 2021/22; Fig. 1 d) which was more than eight times of the snow height measured at the nearby WMO weather station. This is possible due to drifting and blowing snow forming a persistent snowbank during winter. In 2022, the remaining snow patch lasted until 03 May. However, snow depths and the duration of snow cover are interannually highly variable. Depending on accumulation in winter and the rate of melting in spring in different years the snow patch lasted between two and ten weeks longer than in the surrounding area (see number of snow days in Fig. 1 c). Therefore, snow affects the thermal regime of the block accumulation in winter and spring and provides melt water which might have had or still has a local geomorphological and hydrological impact.

Low-cost close-range sensing systems such as the mobile time-lapse camera set-up turned out to have a great potential for snow cover monitoring in mountainous areas as well. We have already successfully tested it at a perennial snowfield in the Allgäu Alps.

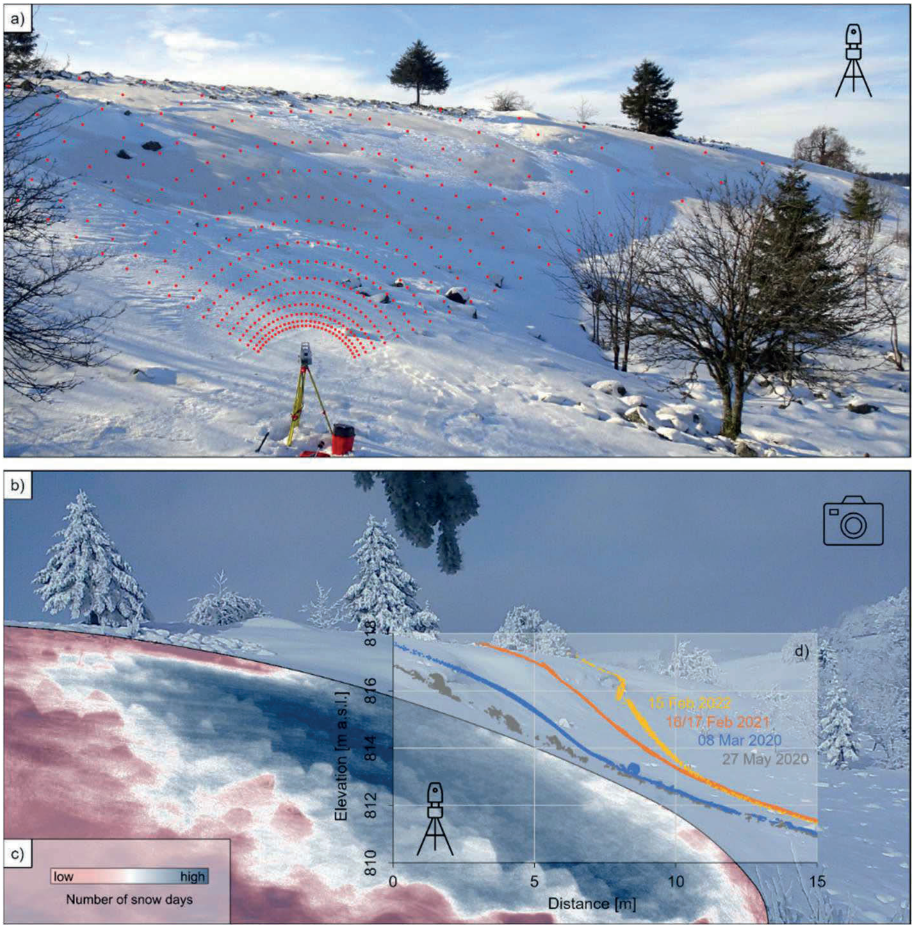

Figure 1*: a) Terrestrial laser scanning of the snowbank on 16 Jan 2021; Beige areas belong to an icy layer with Saharan dust deposits partly exposed by snow drift. b) A time-lapse photo taken on 09 Jan 2022. c) Number of snow days derived from time-lapse camera monitoring exemplified for the winter 2021/22. d) Snow surface and*

depths derived from terrestrial laser scans for different winters; Grey points represent the ground surface in summer. Figure by Wiegand, T. 2024.

Hancock, H., Eckerstorfer, M., Prokop, A. & Hendrikx, J. (2020). Quantifying seasonal cornice dynamics using a terrestrial laser scanner in Svalbard, Norway. Natural Hazards and Earth System Sciences 20(2), 603-623.

Kępski, D., Luks, B., Migała, K., Wawrzyniak, T., Westermann, S. & Wojtuń, B. (2017). Terrestrial Remote Sensing of Snowmelt in a Diverse High-Arctic Tundra Environment Using Time-Lapse Imagery. Remote Sensing 9(7): 733.

Rödder, T., Kneisel, C., 2012. Influence of snow cover and grain size on the ground thermal regime in the discontinuous permafrost zone, Swiss Alps. Geomorphology 175-176, 176-189.

Veilleux, S., Decaulne, A. & Bhiry, N. (2021). Snow cornice and snow avalanche monitoring using automatic time lapse cameras in Tasiapik Valley, Nunavik (Québec) during the winter of 2017–2018. Arctic Science 7(4), 798-812.

Advances in forest structure and genetics analysis: integrating lidar with genetic assessments in southern pine trees

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Southern forest is one of the most important sources in the U.S. timber market. About 45% of the region's total forested land is made up of loblolly (Pinus taeda L.), slash (Pinus elliottii Engelm.), and longleaf (Pinus palustris Mill.) pines. Genetic improvement of southern pine trees has significantly contributed to large increases in plantation productivity, producing a wide variety of highly productive open-pollinated (half-sib) and full-sib families and, more recently, clones. However, managing these forests sustainably requires a nuanced understanding of tree physiology, forest structure, and the response of these ecosystems to environmental stresses and management practices. Traditional methods of forest assessment, while valuable, often fall short in capturing the detailed spatial and structural complexity of forest landscapes. The introduction of laser scanning technologies has opened new avenues for forest research, offering unprecedented resolution and accuracy in the measurement of forest attributes. Terrestrial and airborne platforms provide complementary perspectives, with TLS capturing detailed structural information at the ground level and ALS offering broader overviews of forest canopies. My PhD thesis seeks to explore and expand the application of multi-source LiDAR data in the context of Southern Pine Forests. By developing and implementing deep learning algorithms for data analysis, the research aims to refine methods for leaf and wood separation, estimate phenotype attributes with greater precision from Quantitative Structure Model (QSM), and assess the impact of environmental interventions on tree growth and forest health, such as competition, thinning, and progeny testing. The research endeavors to provide actionable insights into forest management and genetic selection, contributing to the conservation and enhancement of southern pine ecosystems.

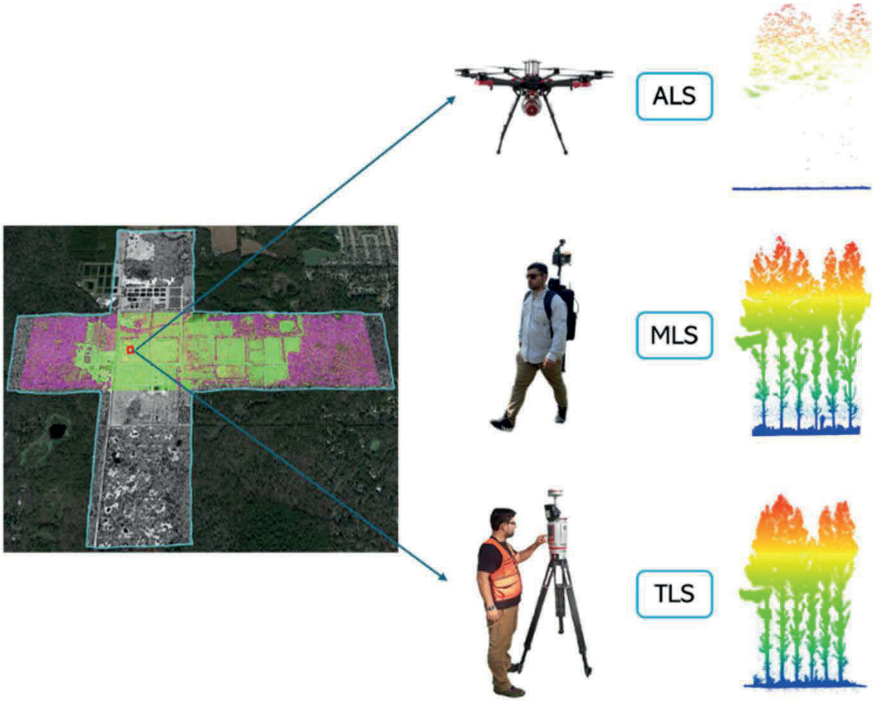

***Figure 1**: VARIETIES II trial in Florida with multi-sources of LiDAR data.*

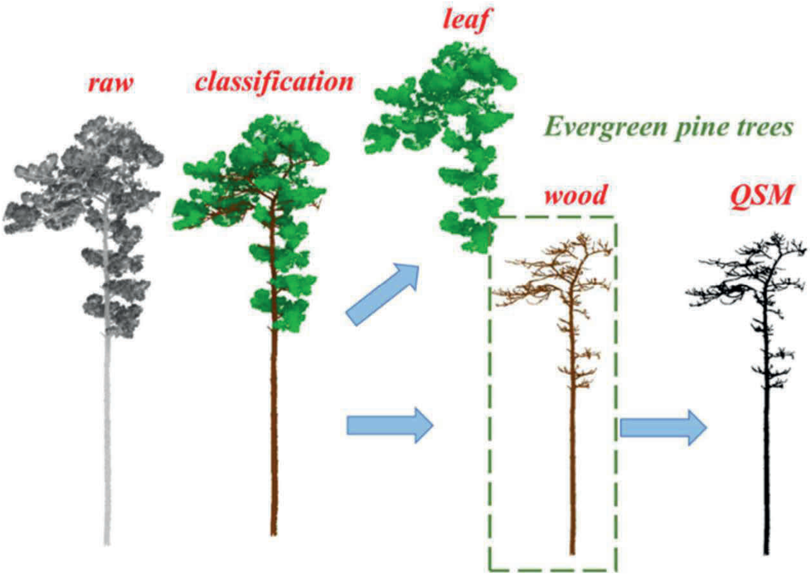

***Figure 2**: Leaf and wood classification to reconstruct Quantitative Structure Model (QSM) and estimate phenotype metrics.*

Jokela E J, Martin T A, Vogel J G. Twenty-five years of intensive forest management with southern pines: Important lessons learned[J]. Journal of Forestry, 2010, 108(7): 338-347.

Raumonen P, Kaasalainen M, Åkerblom M, et al. Fast automatic precision tree models from terrestrial laser scanner data[J]. Remote Sensing, 2013, 5(2): 491-520.

Villacorta A M G, Martin T A, Jokela E J, et al. Variation in biomass distribution and nutrient content in loblolly pine (Pinus taeda L.) clones having contrasting crown architecture and growth efficiency[J]. Forest Ecology and Management, 2015, 342: 84-92.

Bienert A, Georgi L, Kunz M, et al. Comparison and combination of mobile and terrestrial laser scanning for natural forest inventories[J]. Forests, 2018, 9(7): 395.

Wang D, Momo Takoudjou S, Casella E. LeWoS: A universal leaf-wood classification method to facilitate the 3D modelling of large tropical trees using terrestrial LiDAR[J]. Methods in Ecology and Evolution, 2020, 11(3): 376-389.

A methodology for snow cover estimation in alpine regions via climate data and satellite imagery synthesize

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Accurate snow cover estimation in mountainous regions presents significant challenges due to complex terrain, variable climatic conditions, and limited satellite data availability. Our study (Zakeri & Mariethoz, 2024) addresses these challenges by introducing a comprehensive approach that combines high-resolution satellite imagery with detailed climate data, aimed at enhancing snow cover estimation in the Swiss Alps. Utilizing Landsat and Sentinel-2 datasets, alongside meteorological data, we employ a novel synthesis methodology to generate daily snow cover maps at a 30m spatial resolution.

Our approach innovatively compensates for the temporal data gaps often encountered in the remote sensing of mountainous areas, providing continuous, accurate snow cover monitoring. The methodology is underpinned by an extensive validation process using a leave-one-out analysis, comparisons with PlanetScope, MODIS, and Copernicus High Resolution Snow & Ice Fractional Snow Cover On Ground (HRSI-FSCOG) images, and comparisons with data collected at ground stations, and a comparison with a simple snow accumulation and melt model. Figure 1 shows the results for synthesized short time intervals (i.e., a month) over much longer periods (20 years) for the Western Swiss Alps.

Furthermore, this research contributes to the development of more resilient and adaptable remote sensing applications, capable of providing reliable environmental monitoring under the constraints of challenging mountainous conditions. The implications of our findings extend beyond academic research, offering practical solutions for policymakers and stakeholders involved in environmental conservation, hydrological modeling, and climate change mitigation efforts in mountainous regions.

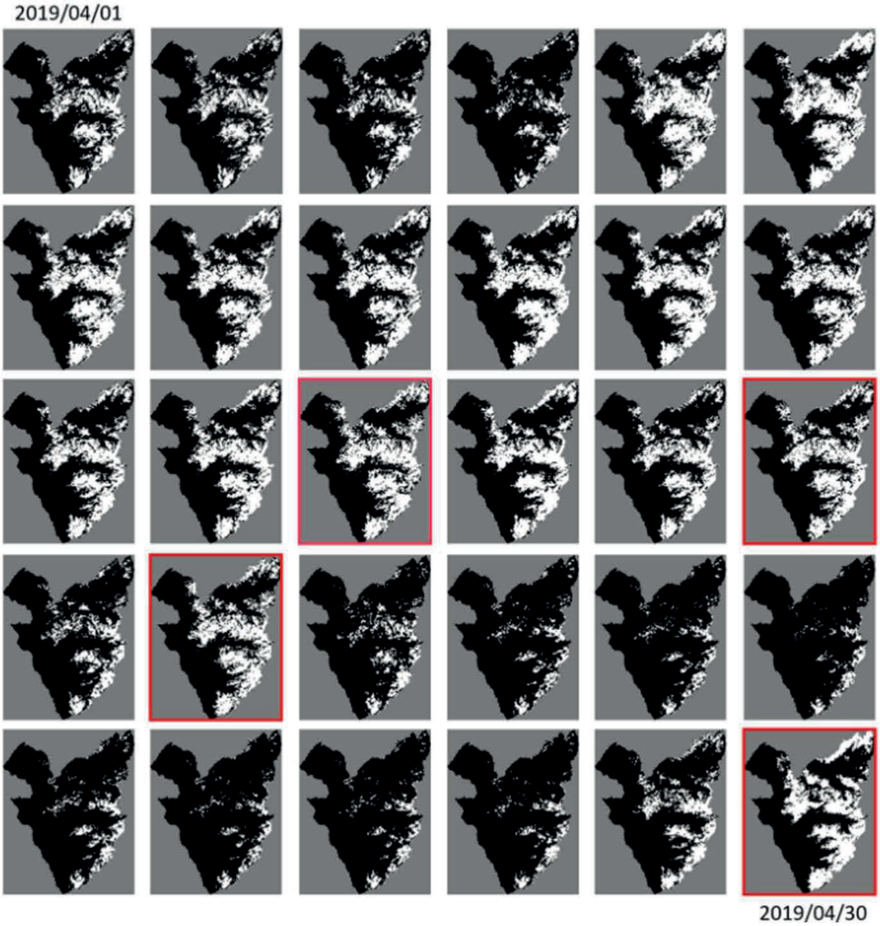

***Figure 1**: Western Swiss Alps daily simulated snow cover for April 2019. Images without red borders are synthetic, and those with red borders are actual acquisitions. Snow is represented in white, and no snow is illustrated in black (Zakeri and Mariethoz 2024).*

Zakeri, F., & Mariethoz, G. (2024). Synthesizing long-term satellite imagery consistent with climate data: Application to daily snow cover. Remote Sensing of Environment, 300, 113877

Changes are taking place in mountain regions due to global warming, drought, heavy precipitation and intensive land use. Research into changes on a detailed scale is possible thanks to the development of automated near and remote sensing techniques. However, data acquisition, validation and analysis are a major challenge in these areas. The 5th edition of the international Sensing Mountains 2024 Summer School brings together international early career scientists and experienced experts from engineering, geosciences and environmental sciences. The interdisciplinary framework of the summer school creates a creative space for exchange and learning new concepts to explore the current dynamics of environmental processes in mountains.

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