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## From UAV-photogrammetry to displacement rates – monitoring slope deformations in Alpine terrain

**Christian Demmler**<sup>1</sup>, Marc Adams<sup>2</sup>, and Anne Hormes<sup>1,2</sup>

<sup>1</sup>sky4geo e.U., Planötzenhofstrasse 29b, 6020 Innsbruck, Austria

<sup>2</sup>Austrian Research Centre for Forests (BFW), Rennweg 1, 6020 Innsbruck, Austria

Mountainous areas bring unique challenges for surveying and natural hazard monitoring – inaccessibility, dangerous terrain, snow coverage and line-of-sight problems often make it next to impossible to perform ground-based monitoring or even to provide a good vantage point for close-range sensing (e.g. terrestrial laser scanning (TLS) or terrestrial photogrammetry). Airborne or satellite-based methods are often the only way to gain information about geodynamically active sites. Here, structure-from-motion (SfM) photogrammetry from unmanned aerial vehicle (UAV) imagery in particular can provide an inexpensive and easily implemented monitoring option. The Vigilans research project attempts to evaluate the feasibility of UAV-photogrammetry against more established surveying methods (e.g. in situ data from extensometers or total stations).

Our study site Marzellkamm is located in the Central Ötztal Alps of Western Austria. The active rock slope deformation we are monitoring in Vigilans lies at 2450-2850 m asl. on a SE-facing slope. Annual displacement rates of up to 1.5 m/year in the early 2010's triggered monitoring and research interest. Due to the remote location, mitigation methods were not implemented, but a hiking trails was relocated. Orthoimage photogrammetry and ground-based monitoring instrumentation (extensometers, terrestrial laser scanning, total station measurements combined with GNSS and geodetic surveys) collected data 1971-2019.

In the last years, movement along the slope has slowed down considerably. The rather slow current movements provide a valuable challenge for detection, with rates of <0.05 m/year occurring in the more stable upper sections, while the NW section in particular still shows pronounced movement of up to 0.3 m/year. For this reason, Marzellkamm provides excellent evaluation for new methods such as UAV-SfM.

In three separate missions between summer 2018 to fall of 2019, UAV-SfM 3D-models of the site were created for displacement rate evaluations; it is planned to continue this monitoring for a total of three years as part of the Vigilans project. Photogrammetric missions were performed in conjunction with total station measurements of more than 30 ground control points.

The required level of precision is becoming achievable and affordable with new RTK/PPK-equipped (Real-Time-Kinematics/Post-Processed Kinematics) UAVs. However, evaluating the resulting 3D-model in terms of movement rates remains non-trivial. The most common algorithm for change

detection in point clouds, M3C2, is not well-suited to detect a laterally moving surface as a whole, as it detects changes along the normal orientation of a surface (such as subsidence). Therefore, the point cloud needs to be very selectively reduced, requiring complex filtering operations and expert input as well as expensive software packages.

This contribution will present a workflow to simplify such evaluation, based on 2.5D (DEM-based) algorithms such as IMCORR and DoD (Difference-of-DEMs), in comparison with the more complex 3D-pointcloud based processing. The presented workflow is based on Agisoft Metashape and Open-Source software tools QGIS and Saga GIS. It aims to streamline UAV-based surveying work, 3D-model generation and simplified change detection into a repeatable and easily automatable framework. Special emphasis will be put on estimating the quality of the recorded data.