Integrated monitoring of a slowly moving deep-seated gravitational slope deformation based on multi-temporal terrestrial laser scanning and total station measurements – preliminary results of the OPERANDUM project

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Abstract

Deep-seated gravitational slope deformations (DSGSDs) are slowly moving mass-movement phenomena on mountain slopes continuously reshaping surface topography. Their permanent monitoring is an important task to understand their spatio-temporal activity, main causes and drivers and to prevent potential impacts. Currently, various monitoring techniques are employed to assess the movement of DSGSDs at points, along profile lines or area-wide. Each technique comes along with advantages and limitations, mainly regarding the spatio-temporal resolution and coverage. While measurements at points or along lines typically feature a high temporal resolution (i.e. continuous measurements), area-wide data acquisition techniques depend on the scope and budget of a study (e.g. frequency of laser scanning campaigns). Therefore, many monitoring projects rely on two or more data acquisition techniques for exploiting their synergies, to overcome their limitations and to provide independent results for validation purposes.

In the present study the displacement of an active sub-system of a DSGSD located in Vögelsberg (Tyrol, Austria) is monitored by means of multi-temporal terrestrial laser scanning (TLS) and an automated tracking total station (ATTS). The currently active part of the DSGSD covering about 0.25 km^2 in the lower part of the hillslope shows generally enhanced movements. Phases of acceleration and deceleration are clearly noticeable on parts of the slope and can be related with pore pressures measured in two groundwater wells. However, the precise continuous monitoring using the ATTS provides data for selected points (retroreflecting prisms) and does not readily allow an area-wide interpretation of the deformation pattern. Therefore, the analyses based on the temporally sparse but spatially distributed TLS time series can be used to overcome this limitation. In this regard, the advantages of both, the ATTS and the TLS monitoring can be exploited to deepen the understanding of the DSGSD.

Both monitoring campaigns started in mid-2016 and are still ongoing. The time period considered in the present study ranges from 2016/06 to 2019/11, including 13 TLS acquisition campaigns. Two long-range terrestrial laser scanners (Riegl VZ-4000 and Riegl VZ-6000) have been used to acquire 3D point clouds from at least three scanning positions located on the opposite side of the valley, covering a range between 600 and 2500 m. From an additional scanning position above the northern scarp of the active area scanning was only possible using the Riegl VZ-4000 due to eye safety restrictions of the Riegl VZ-6000. The accuracy of the used laser scanners depends on several parameters including sensor characteristics (e.g. the beam divergence), measurement range, incidence angle, surface roughness and atmospheric conditions. Except for the latter which is still difficult to consider in long-range TLS studies, these effects have been included during the processing of the point clouds, quantifying the resulting uncertainty for each point. The registration of the point clouds was done based on extracted roofs and walls of stable buildings identified in the ATTS time series. For the sampling of suitable building facets thresholds for the computed uncertainty, the planarity and the deviation of locally fitted planes have been introduced. After the fine registration based on the iterative closest point algorithm, point-to-plane distances to a selected reference TLS point cloud were computed, revealing an uncertainty of 6.5 cm (95% quantile) considered as detection limit for landslide-induced displacements and deformation. The ATTS conducts hourly measurements of the position of 53 retroreflecting prisms installed on buildings (n=46) and poles (n=6) within the active area and surrounding it. The ATTS has been installed on the opposite side of the valley with measurement distances between 600 and 1700 m. The total station's measurement accuracy has been assessed based on the measurement time series of 17 retroreflecting prisms on stable grounds with a total displacement less than 1 cm (on average less than 0.3 cm/year). The analysis revealed an uncertainty less than 0.4 cm (95% quantile), also depending on the measurement range.

Comparing the preliminary results of both monitoring techniques considering the buildings in the active and surrounding area, the magnitudes of the derived 3D displacement vectors for the period 2016/06 to 2019/11 are in general agreement (see boxplots in Figure 3). Particularly in case of the ATTS results the displacements of buildings within the active area are clearly discernible from the area around it. The laser scanning results for the same buildings show a distribution comparable to the ATTS results, but cannot be as clearly discerned from the surrounding area. This is certainly related to the higher positional uncertainty of the TLS point clouds. However, displacements of more than 5 cm can be detected. In case of slowly moving DSGSDs this means that a sufficient time span is necessary until this detection limit is surpassed. Further work will focus on the exploitation of all acquired TLS point clouds for reconstructing area-wide displacement time series. Furthermore, the displacement of other above-ground objects such as trees or poles will be evaluated to explore the spatial displacement pattern in more detail.

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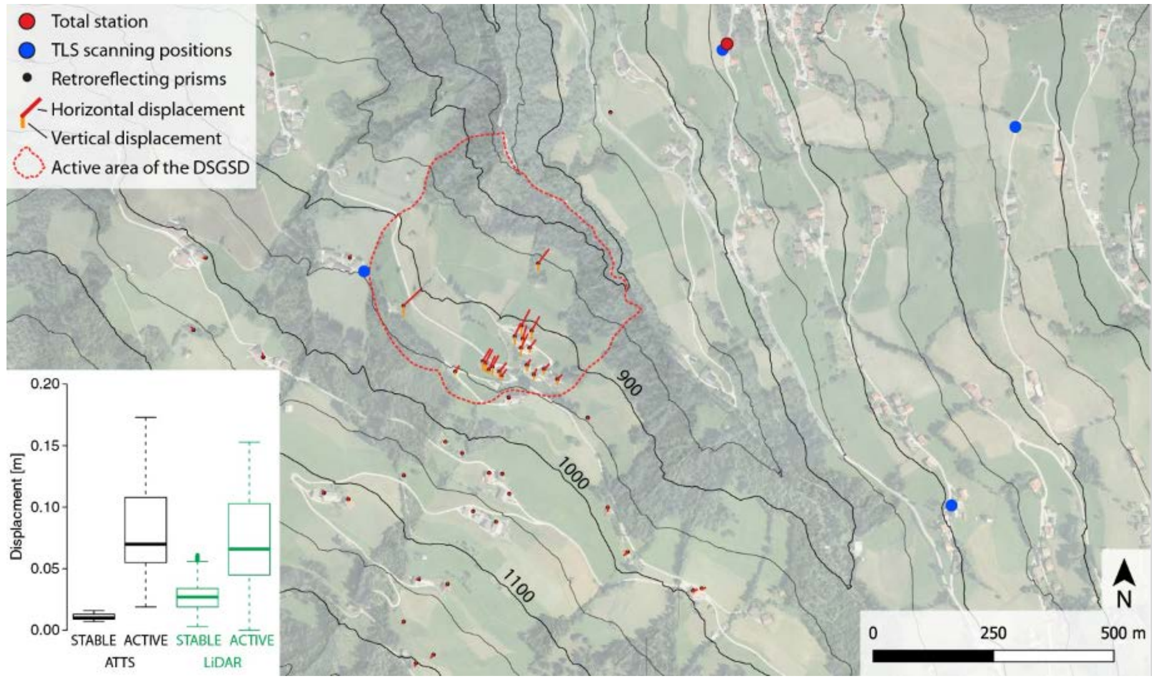

Figure 3: Monitoring setup and preliminary results of the displacement monitoring considering the period between 2016/06 and 2019/11.