Observation and Modeling of CAscade Processes

at the Reissenschuh (Schmirn, Austria)

OMCAP

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1. Motivation

Landscape evolution underlies geological, geomorphological and hydrological processes organized in cascades and in a net of interlinked dynamics and sediment transport systems. In the case of deep-seated gravitational slope deformations (DSGSDs) the mass movement as primary process can trigger a couple of secondary processes such as rock falls at the head wall, shallow landslides and rock avalanches on top of the landslide body and debris flows at the landslide foot. Acceleration or re-activation of DSGSDs are typically triggered by groundwater, due to snow melt, rainfall and anthropogenic interventions modifying pore pressure. Seepage forces, acting as additional driving forces in the system, can further enhance the activity of the primary process and related secondary processes, potentially endangering human life, infrastructure and economic loss.

The DSGSD cascade system below the Reissenschuh summit in Schmirn located in Tyrol, Austria is observed by a combined area-wide remote sensing and point-based monitoring program (differential global navigation satellite system, DGNSS) since June 2016. It shows mean displacement rates of 0.8 m per year and is one of the most active DSGSD in the region (Prager et al. 2008). Within this PhD-project observation time series integrating earth and field observation will be applied to better understand, model and quantify spatio-temporal patterns and triggers of process cascades linked to DSGSDs in an alpine catchment.

2. Research Objectives

The main objective of this PhD-project is the development of an automated workflow for integrating time series of earth observation variables and field observations with geotechnical process models (like numerical modeling approaches) identifying triggers and investigating the interlinked process cascades. As primary investigation site, the Reissenschuh DSGSD (Schmirn, Austria) will be considered.

The research topis will deal with the derivability of boundary conditions for landslide modeling from remote sensing data and the modeling of landslide processes it-self and the related sub-processes as cascading events. The following research questions and sub-questions can be addressed:

- How can observed processes and related sub-processes of a cascade system be modeled for better understanding processes, triggering factors and consequences in terms of risk management and what data do we need?

  - Which individual approach is suited to model each process, which integrated approach is suited (e.g. finite element method, material point method, sediment connectivity) and how comparable are the results?
  - How can models help to better understand process dynamics and to identify triggering i.e. accelerating factors and potential tipping points?
  - Can models confirm the interlinking of cascade processes identified by remote sensing and field observations?
  - What are the likely scenarios for the process cascades of the DSGSDs at Reissenschuh and what are the consequences in terms of risk assessment?

- What are the essential variables from remote sensing in order to identify links between geomorphological, geological and geotechnical process dynamics and to quantify displacement rates and sediment transitions from one process to the other?
  - Which essential variables can be automatically derived from earth and field observation for validating geotechnical process modeling?
  - How to automatically integrate displacement rates derived from 3D laser scanning, orthophoto time series, satellite remote sensing and DGNSS measurements by spatio-temporal time series analysis and deep-learning?
  - Is it possible to extend the existing area-wide displacement monitoring time series by means of photogrammetric reconstruction based on UAV-borne imagery?
  - How to identify the correlation of magnitude of primary processes (DSGSD) with the frequency of secondary processes (e.g. rockfall, shallow landslides, debris flows, …) within the cascade system?

3. Related Work

Deep-seated landslides (often also referred to as deep-seated gravitational slope deformations, DSGSDs) are wide-spread phenomena in the province of Tyrol. In a comprehensive study, Prager et al. (2008) investigated the age and potential causes of landslides in Tyrol and surrounding areas. More than 480 landslides, triggered since the late-glacial until recent ages, were compiled in a database. The authors conclude that the propensity for deep-seated landslides is typically related to time-varying preparatory factors (e.g. deglaciation, seismic activity, pore pressure variations). In a regional study conducted by the Austrian Service for Torrent and Avalanche Control (WLV), the extent and activity of deep-seated landslides was mapped based on shaded reliefs computed from derivatives of airborne laser scanning (ALS) (Elsner et al. 2015). The study was carried out within a region including the main valleys south of Innsbruck. Landslide activity was assigned based on expert knowledge with five landslides classified as 'active'. Three of them are located in the Schmirn valley, one in the Navis valley and one in the Stubai valley. Also, the Reissenschuh landslide, which is investigated in detail in the proposed study, was rated active.

The landslide has been investigated in the previous research projects LEMONADE (LandslidE MOnitoriNg And Data intEgration) and EMOD-SLAP (Extending the integrated Monitoring Of Deep-Seated Landslide Activity into the Past), starting in 2016. In the LEMONADE project a monitoring framework was established including different sensors for quantifying the landslide's displacement, including terrestrial laser scanning (TLS) and measurements with a differential global navigation satellite system (DGNSS). Pfeiffer et al. (2018) derived area-wide 3D displacement vectors based on multi-temporal TLS. Based on their analyses, the magnitude and direction of movement could be assessed covering almost the whole active part of the landslide. The results were validated with DGNSS measurements at installed observation points throughout the landslide. The authors also analyzed the spatial displacement patterns and provided evidence that some parts of the landslide moved markedly faster than others. Bremer et al. (2019) surveyed the active part of the Reissenschuh using an unmanned aerial vehicle (UAV) as platform for laser scanning and analysed topographic changes compared to TLS data acquired a year before. The results revealed a detailed spatial displacement pattern of the landslide body and revealed signs of secondary processes like shallow landslides and rock avalanches. Branke et al. (2020) extended the area-wide monitoring time series into the past to 1954 with the help of photogrammetric techniques using historical aerial imagery. With the resulting 3D point clouds, the long-term topographic changes due to the DSGSD were analysed.

The results have been compiled and visualized in a web viewer, to provide them to the municipality and residents:

http://remote-sensing.mountainresearch.at/monitoring_reissenschuh

This data is available for this PhD-project and the monitoring campaigns will be continued within this project.

4. Test site

The active DSGSD Reissenschuh is located in a catchment south-east to the village Schmirn (Tyrol, Austria) situated in an elevation range from 1700 to 2200 m a.s.l. The processes in the catchment can be seen as a cascade system whereas the DSGSD is the primary driver embedded with various secondary processes such as rock falls from the primary head wall up to the Reissenschuh summit (2470 m a.s.l) and debris flows, shallow landslides and rock avalanches in the lower part (<1700 m a.s.l).

The geologic substratum consists of penninic Bündner schist. The calcareous rich schists are overlayed by calcareous-deficient schists and sequences of fine foliated black shists (Rockenschaub et al., 2003; Rockenschaub and Nowotny, 2009).

The main body of the active landslide is covered by vegetation i.e. sparse larch (*Larix decidua*) and spruce (*Picea abies*) <2000 m a.s.l., Alpine rose (Rhododendron hirsutum), mountain pine (*Pinus mugo*) and Alpine meadows used for sheep pasture >2000 m a.s.l. Vegetation free areas are bedrock outcrops and scarps, counter scarps, blocky screes and randomly distributed single boulders.

On the valley bottom close to the landslide a meteorological station of the ZAMG (station Toldern, 1461 m) records continuous meteorological time series including temperature, precipitation and snow height. The mean annual precipitation sum at Toldern station amounts to about 1000 mm, while seasonal sums show a clear maximum during the summer months. The mean annual air temperature is 5.0°C. The temperature drops distinctly below zero during the winter months, facilitating the accumulation of considerable amounts of snow. During snow melt in late spring the pore pressures at the sliding surface could increase distinctly which could lead to an acceleration of the landslide.

Starting in May 2016, the landslide has been monitored at installed observation points with the help of a DGNSS and area-wide by means of TLS on an annual basis (Fig. 2). In total, 30 observation points have been installed within the highly active area (n = 18) and its surrounding. To sufficiently cover the landslide by TLS surveys, two scanning positions from

the opposite ridge have been considered. Also, from the opposite side of the valley floor surveys have been conducted to cover the lower part of the landslide and the secondary landslide processes.

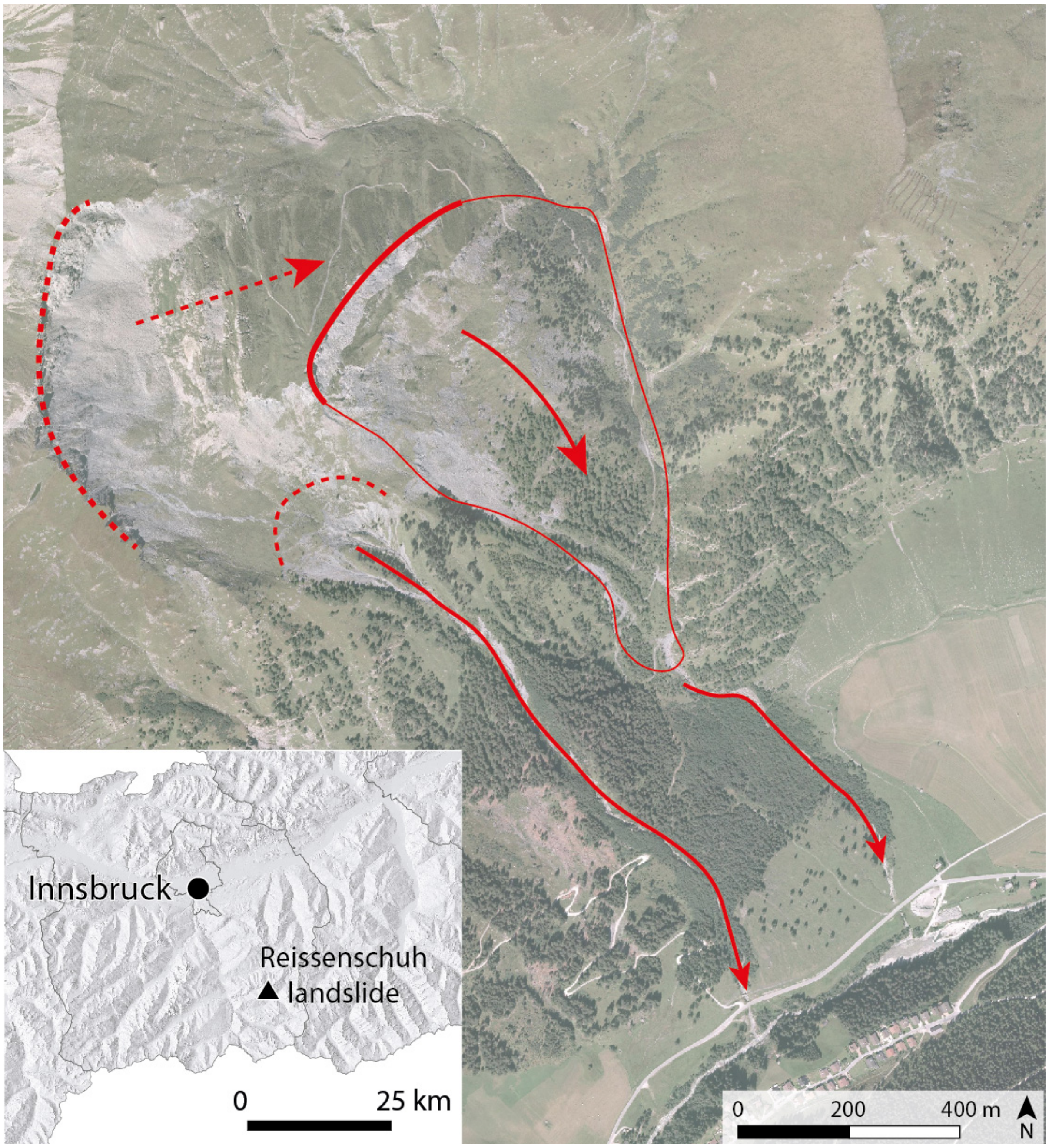

Figure 1: Map of the study area with processes.

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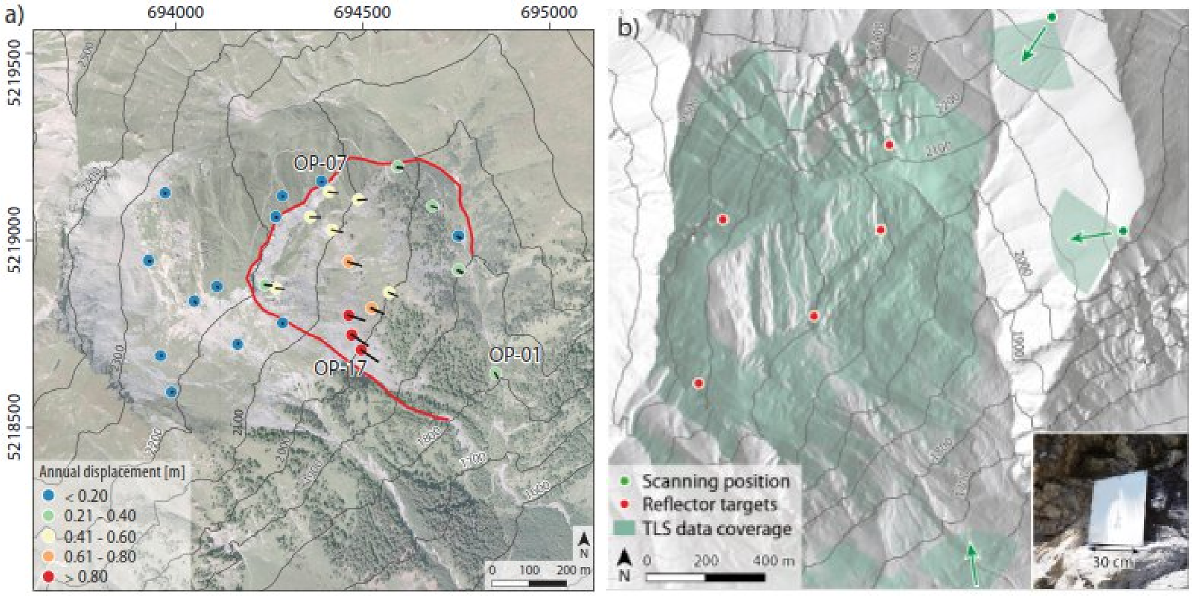

Figure 2: Locations of the installed DGNSS observation points (a) and setup of the periodical TLS monitoring (b). Source: Pfeiffer et al. 2018 (modified)

5. Materials and Methods

The PhD-project continues the DGNSS monitoring and bi-annual 3D mapping activities by laser scanning, which is required as base data for the modeling of the primary and secondary processes. Based on the available monitoring data sets essential variables will be defined and spatio-temporal time series will be interpolated and integrated implementing a deep-learning approach (Reichenstein et al. 2019). Finally, essential variables for geo-hydraulic modeling and model validation will be derived from the generated spatio-temporal time series.

As input for all modeling approaches a knowledge of the prevailing ground conditions is necessary. Especially in the case of cascading effects, the composition of the material may vary from location to location within the investigation area. Therefore samples will be taken at different places related to different processes within the DSGSD. This samples will be used to determine relevant geotechnical parameters, as grain size distributions, strength and permeability parameters (at different locations related to the process) in the geotechnical laboratory of the University of Innsbruck (Schneider-Muntau et al. (2018a)).

For the assessment of DSGSD, different numerical approaches are needed. The stability of the process can be estimated with strength reduction methods (either analytically (GGU/Slide) or with Finite Element approaches (Abaqus/Plaxis), see e.g. Schneider-Muntau et al. (2018b), Tschuchnigg et al. (2019), Zieher et al. (2017)). Time dependent deformation has to be calculated with hydro-mechanically coupled time dependent calculations on a Finite Element basis (Schneider-Muntau (2020)). Those will reveal creep velocity and internal deformations of the DSGSD. The results of not mesh based methods, as the material point method or discrete element methods can be use as a comparison to the Finite Element approaches.

The related sub-processes, e.g. rockfall, debris flows, shallow landslides will be modeled accordingly. Also for the sub-processes stability calculations will be performed (see above) and a focus will be laid on run-out simulation (RocFall, Rocky DEM, ...).

Holistic models, as e.g. particle flow code or material point method will be used to simulate the hole cascading process, including all sub-processes (creep deformation leading to disintegration leading to debris flows, ...) in one generalized model. This model will be based on a geotechnical background, especially regarding the material models. Those results will be compared to the results gained in the FE or DEM calculations. Advantages and shortcomings of the holistic model will be discussed.

6. Supervision

The PhD-student will be supervised by an interdisciplinary team of researchers at UIBK, who are each member of the doctoral program “Natural Hazards in Mountain Regions”. The PhD student will be associated to the Institute of Infrastucture, Unit of Geotechnical Engineering. Main supervisor is Barbara Schneider-Muntau, further co-supervisors are Bernhard Gems (Unit of Hydraulic Engineering), Margreth Keiler (Institute of Geography, Institute for Interdisciplinary Mountain Research), Martin Rutzinger (Institute of Geography), and Thomas Zieher (Institute of Geography, Institute for Interdisciplinary Mountain Research).

References

Branke, J.; Zieher, T.; Pfeiffer, J.; Bremer, M., Rutzinger, M. (2020). Extending the integrated monitoring of deep-seated landslide activity into the past - preliminary results of the project EMOD-SLAP, *in* Disaster Competence Center Austria (DCNA), ed., 'Proceedings of the Disaster Research Days 2020'.

Bremer, M.; Zieher, T.; Pfeiffer, J.; Petrini-Monteferri, F.; Wichmann, V. (2019). Monitoring der Großhangbewegung Reissenschuh (Schmirntal, Tirol) mit TLS und UAV-basiertem Laserscanning. In: Hanke, K.; Weinold, T.: 20. Internationale Geodätische Woche Obergurgl 2019: 321-33

Elsner, B., Mölk, M., Jenner, A., Küfmann, C., (2015). Erfassung und Bewertung großdimensionaler Massenbewegungen aus hochauflösenden digitalen Geländemodellen – Entwurf zur Integration in den Wildbach- und Lawinenkataster (WLK). Zeitschrift für Wildbach-, Lawinen-, Erosions- und Steinschlagschutz.

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

Prager, C., Zangerl, C., Patzelt, G., Brandner, R., (2008). Age distribution of fossil landslides in the tyrol (austria) and its surrounding areas. Natural Hazards and Earth System Sciences 8 (2), 377–407.

Reichstein, Markus, et al. "Deep learning and process understanding for data-driven Earth system science." Nature 566.7743 (2019): 195-204.

Rockenschaub, M., Nowotny, A., 2009. Geologische Karte der Republik Österreich 1:50.000, 148 Brenner. Verlag der Geologischen Bundesanstalt (GBA), Wien.

Rockenschaub, M., Kolenprat, B., A., N., 2003. Das westliche Tauernfenster. Geologische Bundesanstalt - Arbeitstagung 2003: Blatt 148 Brenner.

Schneider‐Muntau, B. (2020), Modelling of the interaction between structures and creeping slopes. Geomechanics and Tunnelling, 13: 612-619.

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

Schneider-Muntau, B.; Medicus, G.; Fellin, W. (2018b): Strength reduction method in Barodesy, Computers and Geotechnics, 95, 2018, 57-67, ISSN 0266-352X,

Tschuchnigg, F.; Medicus, G.; Schneider-Muntau, B. (2019): Slope stability analysis: Barodesy vs linear elastic – perfectly plastic models. E3S Web Conf. 92 16014.

Zieher, T., Schneider-Muntau, B. & Mergili, M. (2017): Are real-world shallow landslides reproducible by physically-based models? Four test cases in the Laternser valley, Vorarlberg (Austria). Landslides 14, 2009–2023.