# Integrated Monitoring of a Slowly Moving Landslide Based on Total Station Measurements, Multi-Temporal Terrestrial Laser Scanning and Space-Borne Interferometric Synthetic Aperture Radar

Zieher, Thomas; Pfeiffer, Jan ; van Natijne, Adriaan; Lindenbergh, Roderik

**DOI**
10.1109/IGARSS47720.2021.9553324

**Publication date**
2021

**Document Version**
Final published version

**Published in**
2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS

**Citation (APA)**
Zieher, T., Pfeiffer, J., van Natijne, A., & Lindenbergh, R. (2021). Integrated Monitoring of a Slowly Moving Landslide Based on Total Station Measurements, Multi-Temporal Terrestrial Laser Scanning and Space-Borne Interferometric Synthetic Aperture Radar. In *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS: Proceedings* (pp. 942-945). Article 9553324 (International Geoscience and Remote Sensing Symposium (IGARSS); Vol. 2021-July). IEEE. https://doi.org/10.1109/IGARSS47720.2021.9553324

IGARSS 2021 - 2021 IEEE International Geoscience and Remote Sensing Symposium | 978-1-6654-0369-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/IGARSS47720.2021.9553324

# INTEGRATED MONITORING OF A SLOWLY MOVING LANDSLIDE BASED ON TOTAL STATION MEASUREMENTS, MULTI-TEMPORAL TERRESTRIAL LASER SCANNING AND SPACE-BORNE INTERFEROMETRIC SYNTHETIC APERTURE RADAR

*Thomas Zieher, Jan Pfeiffer*

Institute for Interdisciplinary Mountain Research
Austrian Academy of Sciences
Technikerstr. 21a, 6020 Innsbruck, Austria

*Adriaan van Natijne, Roderik Lindenbergh*

Department of Geoscience and Remote Sensing
Delft University of Technology
P.O. Box 5048, 2600 GA Delft, The Netherlands

## ABSTRACT

Continuous landslide monitoring is a crucial task for the management of natural hazards for identifying suitable mitigation measures, including nature-based solutions. In the present study, three monitoring techniques including (i) an automated tracking total station (ATTS), (ii) multi-temporal terrestrial laser scanning (TLS) and (iii) space-borne interferometric synthetic aperture radar (InSAR) are applied to monitor the spatio-temporal displacement patterns of the Vögelsberg landslide (Tyrol, Austria) between 2016/05 and 2020/06. The landslide shows spatially and temporally varying displacement rates with up to 12 cm/a and a mean annual displacement of 4 cm/a. The results show that only the ATTS provides sufficient temporal resolution and spatial accuracy for assessing the temporal behaviour of the landslide's movement. However, ATTS measurements are only available at the installed 53 retro-reflecting prisms. Multi-temporal TLS can provide additional insight into the spatial displacement pattern at various man-made and natural objects such as walls, fences, poles and tree stems. But the respective accuracy and data acquisition intervals do not allow to draw conclusions about the temporal dynamics of the landslide's movement. Results of the InSAR technique based on Sentinel-1 imagery show good agreement with ATTS measurements, but cannot provide real-time information on the landslide's acceleration and deceleration phases. However, in combination, the measurement techniques provide vital information in both the spatial and temporal domain.

***Index Terms*—** Deep-seated landslide, remote sensing, displacement monitoring, spatio-temporal analyses, OPERANDUM

## 1. INTRODUCTION

Slowly moving deep-seated landslides pose an immenant threat to settlements and infrastucture in mountain regions. The continuous monitoring of active landslides is therefore a crucial task to better understand the main causes and drivers of their spatio-temporal activity and to prevent potential impacts. Various techniques can be employed to monitor a landslide's movement at specific points, along profile lines or area-wide. Measurement techniques applicable at specific points include repeated position estimates with a differential global navigation satellite system (DGNSS) and distance measurements between two points using wire extensometers, laser distance meters or a total station [1]. Displacement monitoring along profile lines are typically based on inclinometers or fibre optics [2]. Area-wide monitoring can be efficiently implemented based on remote sensing techniques including (i) laser scanning from terrestrial (TLS) and airborne platforms (ALS) [3, 4], (ii) ground-based and spaceborne interferometric synthetic aperture radar (InSAR) [5] and (iii) photogrammetric techniques based on terrestrial, airborne or spaceborne imagery [6]. However, each technique has its own advantages and limitations, particularly regarding the spatio-temporal resolution and coverage [7]. Measurement techniques applicable at specific points or along profile lines usually feature a high temporal resolution (i.e. hourly or daily), while the repetition rate of area-wide data acquisition campaigns using terrestrial or airborne platforms depends on the scope and budget of a study. Available SAR imagery from spaceborne platforms (e.g. from the Sentinel-1 mission) can be exploited for landslide monitoring. Revisiting intervals of a few days can provide a sufficient temporal resolution for assessing the dynamics of slowly moving landslides [8].

Monitoring setups typically include two or more measurement techniques aiming at exploiting synergy effects, to overcome their individual limitations and to derive comparable results for validation. In the present study the displacement of an active deep-seated landslide located in Vögelsberg (Tyrol, Austria) is monitored by different remote sensing techniques (Fig. 1). The slowly creeping landslide covering about 0.25 km$^2$ in the lower part of the north-east facing slope shows phases of acceleration and deceleration over the year, endangering several buildings, roads and other infrastructure. Drillings through the landslide body revealed the depth of the failure plane at about 48 m below the surface. Phases of enhanced activity can be tied to exceptionally wet periods during prolonged rainfalls and/or snow melt. In order to identify suitable mitigation measures, including nature-based solutions, the landslide's activity must be understood in detail in both space and time. To reach this goal, point-based (automated tracking total station; ATTS) and area-wide techniques (TLS, spaceborne InSAR) are combined and integrated at the object-level. The objectives of the study are to (i) evaluate on the potential of the considered techniques for monitoring the slowly moving landslide, (ii) compare the results of the techniques at the object-level and (iii), conclude on the synergy effects of the multi-technique monitoring setup.

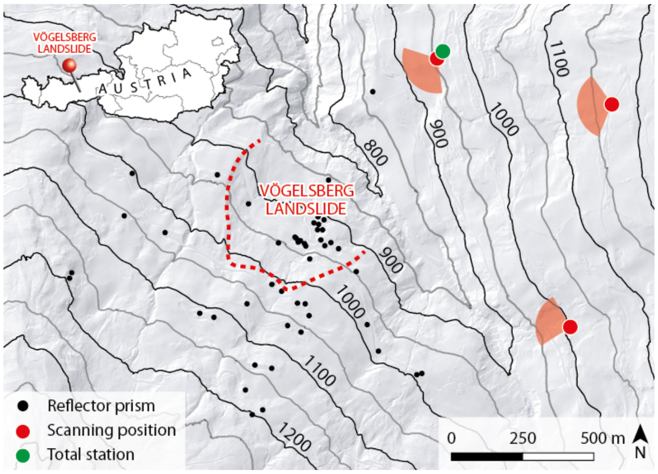

**Fig. 1**. Location of the Vögelsberg landslide and on-site monitoring setup.

## 2. MATERIALS AND METHODS

The on-site monitoring campaigns were started in mid-2016 with the implementation of the ATTS system including 53 retro-reflecting prisms within the active landslide area and its surroundings. The monitoring period considered in this study includes measurements from 2016/06 to 2020/06. The total station was installed on the opposite side of the valley and conducts measurements over distances between 600 and 1700 m. The resulting measurement accuracy was assessed based on the time series acquired at 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 a measurement uncertainty less than ±0.2 cm (two-fold standard deviation), also depending on the measurement range.

In July 2016, the first area-wide laser scanning campaign was conducted using a Riegl VZ-4000 long-range laser scanner. Within the monitoring period considered in this study, 5 area-wide TLS acquisition campaigns (one per year) were available. From 2018 onwards a Riegl VZ-6000 long-range laser scanner was used. During each TLS campaign 3D point clouds were acquired from three scanning positions on the opposite side of the valley, covering a range between 600 and 2500 m. The accuracy of the resulting TLS point clouds depends on various factors including the scanners's characteristics (e.g. beam divergence), incidence angle of the laser beam, measurement range, surface roughness and atmospheric conditions. Except for the latter which is still difficult to consider in long-range TLS studies, the respective effects have been considered in the processing workflow. The uncertainty for each measured point was estimated based on the reconstructed footprint size following [9], taking into account the beam divergence of the respective laser scanner device. The registration of the TLS point clouds was performed with extracted roofs and walls of buildings in the comparably stable sourrounding area, as identified in the ATTS time series. For the selection of suitable building facets, thresholds for the estimated uncertainty, the planarity and the deviation from locally fitted planes have been introduced. After fine registration based on the iterative closest point algorithm [10], point-to-plane distances to a selected reference TLS point cloud were computed, revealing a measurement uncertainty of ±2.0 cm (two-fold standard deviation) which is slightly below the estimated mean footprint size of 4.1 cm. This must be considered as detection limit when assessing landslide-induced displacements and deformation in two successive TLS acquisitions and is about ten times higher compared to the ATTS measurements. Based on extracted buildings within the area of interest an object-based change detection approach utilizing the 3D point cloud following [3] was applied to derive the displacement time series.

For the processing of the spaceborne radar imagery from the European Space Agency's Sentinel-1 mission two orbits were considered (117 - ascending and 168 - descending). A persistent scatterer method based on StaMPS [11] was employed for processing the time series between 2015 and mid-2020 using the data of both orbits. This technique detects phase changes in the reflected signal from strong natural and man-made scatterers. These phase changes can be translated into line-of-sight displacement of the respective object/scatterer. The implemented workflow was designed to be automated and portable, and requires limited operator intervention. This allows the system to operate autonomously as new data becomes available, at the cost of reduced data quality.

## 3. RESULTS AND DISCUSSION

The displacement time series of the ATTS indicate a total displacement of up to 20 cm within the considered monitoring period. Furthermore, distinct acceleration and deceleration phases can be identified in the velocity time series with displacement rates up to 12 cm/a. The displacement of buildings within the active area is clearly discernible from the measurements on the comparably stable surroundings. Comparing the derived displacement magnitude and direction, the results of the ATTS and TLS monitoring are generally in agreement. An example for the derived displacement time seriesbased on ATTS and TLS for a building travelling on top of the landslide is shown in Fig. 2. Considering the shaded measurement uncertainty, the cumulative displacement in each direction component derived from the multi-temporal TLS data is in agreement with the ATTS time series. However, it is clearly observable that variations in the landslide's movement rate cannot be derived from the TLS time series. Differences are mainly caused by the different assessment strategies of the point-based ATTS monitoring and the object-based analyses of the TLS data.

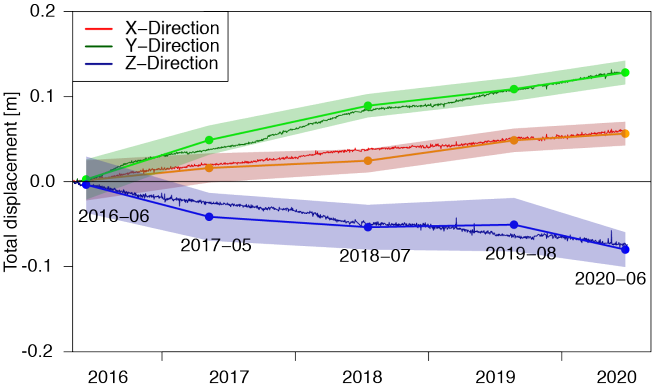

**Fig. 2**. Comparison of the displacement derived from ATTS (dense time series) and TLS, split into the direction components. The shading indicates the uncertainty of the TLS results.

The ATTS data are available for points where the retroreflecting prisms have been installed. Their number is limited to the presence of suitable objects to monitor and the desired temporal resolution of the monitoring (i.e. the time needed to perform the measurements). Particularly in the northern part of the landslide hardly any information about the landslide's activity was obtained due to a lack of retroreflecting prisms. There, the multi-temporal TLS point clouds allow to extend the displacement analysis to other objects like walls, poles or tree stems which are not covered by the ATTS. This provides additional insight into the spatial displacement pattern (Fig. 3) and provides evidence that the nothern part of the landslide moves considerably faster than the southern part. Also the upper limits of the actively moving part can be delineated more precisely with that additional information.

For comparing the ATTS time series with the time series derived from the processing of the SAR imagery, the latter have to be scaled from the satellite perspective to down-slope displacements first. The comparison of the respective down-slope displacement shows the same trend (Fig. 4). However, like the TLS time series, the acceleration and deceleration phases are not readily visible in the PS-InSAR time series. Furthermore, there are limited permanent scatterers within the landslide, grouped around the five clusters of houses. Additional processing may reduce the noise in the signal, at the cost of additional manual interventions in the automated processing.

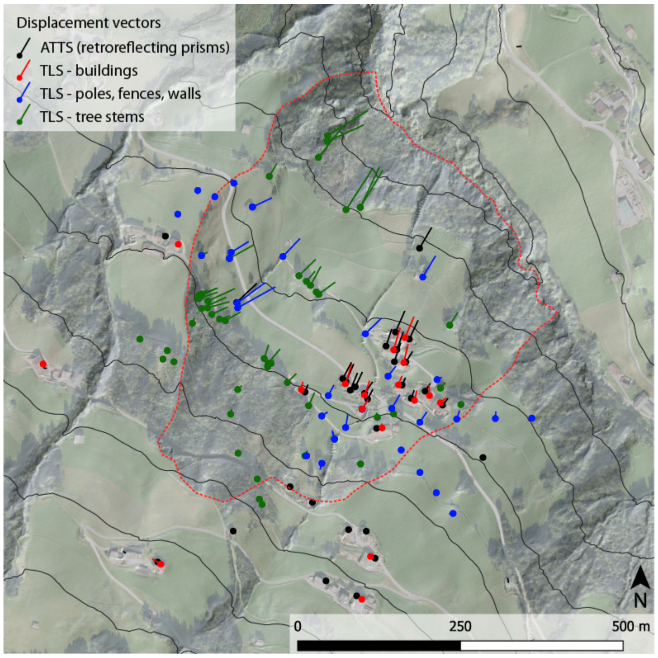

**Fig. 3**. Displacement vectors derived at the Vögelsberg landslide. The vectors are exaggerated by a factor of 1000 for visualization purposes.

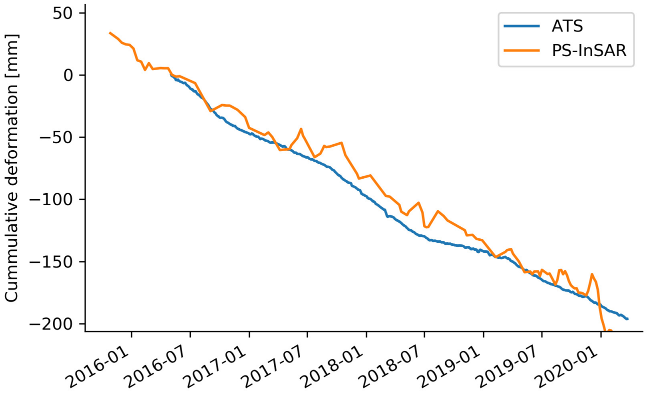

**Fig. 4**. Comparison of 3D displacements from the ATTS and the PS-InSAR analysis.

## 4. CONCLUSIONS

Three different monitoring techniques have been applied to assess the spatio-temporal displacement of a slowly moving deep-seated landslide in Vögelsberg (Tirol, Austria). The results have been evaluated and compared to conclude on their performance and to allow conclusions about their synergy effects.

The ATTS monitoring allows detailed insight into the temporal behaviour of the landslide. However, the spatial displacement pattern relies on the number and density of the installed retro-reflecting prisms which is generally limited by the time needed to perform the distance measurements. This limitation can be overcome by a supplementary TLS monitoring which can provide additional information on the spatial displacement pattern. However, the lower accuracy of the TLS point clouds may prevent a robust displacement analysis in a rather short monitoring period (e.g. less than one year in case of the Vögelsberg landslide) because the observed displacement would not overcome the detection limit. In case of the Vögelsberg landslide the InSAR monitoring was mainly limited by the absence of well-distributed persistent scatterers. Furthermore, the restriction to the line-of-sight component of the deisplacement may limit the interpretability of the results. However, the comparison of the results shows a promising performance of the technique which can be efficiently transferred to other landslide study areas.

## 5. ACKNOWLEDGEMENTS

We thank the Division of Geoinformation (Federal State of Tyrol) for providing the ATTS monitoring time series, the initial TLS datasets and their valuable insights into the monitoring setup. The present study was conducted within the OPERANDUM project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776848.

## 6. REFERENCES

[1] R Hofmann and JT Sausgruber, "Creep behaviour and remediation concept for a deep-seated landslide, Navistal, Tyrol, Austria," *Geomechanics and Tunnelling*, vol. 10, no. 1, pp. 59–73, 2017.

[2] L Simeoni and L Mongiovì, "Inclinometer Monitoring of the Castelrotto Landslide in Italy," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 133, no. 6, pp. 653–666, 2007.

[3] J Pfeiffer, T Zieher, M Bremer, V Wichmann, and M Rutzinger, "Derivation of Three-Dimensional Displacement Vectors from Multi-Temporal Long-Range Terrestrial Laser Scanning at the Reissenschuh Landslide (Tyrol, Austria)," *Remote Sensing*, vol. 10, no. 11, 2018.

[4] T Zieher, M Bremer, M Rutzinger, J Pfeiffer, P Fritzmann, and V Wichmann, "Assessment of landslide-induced displacement and deformation of above-ground objects using UAV-borne and airborne laser scanning data," *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. IV-2/W5, pp. 461–467, 2019.

[5] M Darvishi, R Schlögel, Ch Kofler, G Cuozzo, M Rutzinger, T Zieher, I Toschi, F Remondino, A Mejia-Aguilar, B Thiebes, and L Bruzzone, "Sentinel-1 and Ground-Based Sensors for Continuous Monitoring of the Corvara Landslide (South Tyrol, Italy)," *Remote Sensing*, vol. 10, no. 11, pp. 1781, 2018.

[6] J Balek and J Blahut, "A critical evaluation of the use of an inexpensive camera mounted on a recreational unmanned aerial vehicle as a tool for landslide research," *Landslides*, vol. 14, no. 3, pp. 1217–1224, 2017.

[7] T Zieher, I Toschi, F Remondino, M Rutzinger, Ch Kofler, A Mejia-Aguilar, and R Schlögel, "Sensor- and scene-guided integration of TLS and photogrammetric point clouds for landslide monitoring," *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLII-2, pp. 1243–1250, 2018.

[8] AL van Natijne, RC Lindenbergh, and TA Bogaard, "Machine Learning: New Potential for Local and Regional Deep-Seated Landslide Nowcasting," *Sensors*, vol. 20, no. 5, 2020.

[9] Philipp Schaer, Jan Skaloud, S Landtwing, and Klaus Legat, "Accuracy estimation for laser point cloud including scanning geometry," in *Mobile Mapping Symposium 2007, Padova*, 2007, number CONF.

[10] PJ Besl and ND McKay, "A method for registration of 3-D shapes," *IEEE Transactions on pattern analysis and machine intelligence*, vol. 14, no. 2, pp. 239–256, 1992.

[11] A Hooper, H Zebker, P Segall, and B Kampes, "A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers," *Geophysical research letters*, vol. 31, no. 23, 2004.