Integration of remote and terrestrial monitoring data for analysing alpine geomorphic processes – examples from Switzerland and Italy

Volkmar Mair, Ph.D.[1]; David Mosna, MSc[1]; Robert Kenner, Ph.D[2]; Giulia Chinellato, MSc[3]; Marcia Phillips, Ph.D[2];
Claudia Strada, Ph.D[1]; Benni Thiebes, Ph.D.[3]

ABSTRACT

Radar satellite systems represent a viable solution for monitoring geomorphic processes and slope instabilities in alpine environments as they cover large areas and have a sufficient spatial and temporal resolution. In this paper, we present some results of the Interreg project SloMove that focused on monitoring slow mass movements in high alpine areas using terrestrial and remote sensing techniques. We found that DInSAR is well suited for monitoring of geomorphic processes if the test sites are carefully selected, matching the geographical situation of the slope with the geometric conditions of the satellites. Movement trends and areas of increased activity can then be identified with high reliability. However, satellite remote sensing needs to be supported by terrestrial measurements, particularly in the case where the results aim for supporting civil protection purposes. The validation with ground-based methods, in our case DGNSS and TLS, showed that the magnitude of displacement cannot be assessed with the same accuracy and that punctual data represent good reference points for comparisons of the different measurement techniques.

KEYWORDS

InSAR; GNSS; TLS; rock glaciers; monitoring

INTRODUCTION

Over the last ten years, space-borne methods have become more frequently applied for the monitoring of landslides, rockslides and active rock glaciers. Differential interferometric synthetic aperture radar (DInSAR) has particularly gained in popularity due to its ability to detect and monitor ground displacements along the line of sight with very high accuracy (in the range of cm to mm). The main benefit of DInSAR is its possibility to investigate large areas at relatively low costs by analysing the phase differences from sets of SAR images. Several examples of SAR applications to geomorphic processes have been presented recently, e.g. for landslides and rock glaciers (Calò et al., 2014; Liu et al., 2012; Mair et al., 2008; Papke et al., 2012; Schlögel et al., 2015).

1 Office for Geological Surveys and building material test, Autonomous Province of Bozen/Bolzano, Italy, david.mosna@provinz.bz.it
2 WSL Institute for Snow and Avalanche Research SLF, Switzerland
3 Institute for Applied Remote Sensing, European Academy of Bozen/Bolzano (EURAC), Italy

Nevertheless, DInSAR has some limitations, in particular if the method is applied to alpine environments. These are related to the recording conditions of the acquiring satellite such as ascending and descending tracks, look direction, shadowing or the conditions at the study sites. In addition, temporal changes of surface reflectivity, e.g. related to vegetation or snow, can make it difficult to correctly correlate the images. However, the use of natural persistent scatterers may help to enhance the correlation and therefore allows analysing a greater set of images and larger time spans. Areas far from settlements and without infrastructure often only have few fix points that can be identified or presumed to be persistent or permanent scatterers (PS). The installation of artificial corner reflectors can provide ideal PS, as it allows to detect a known point and should thereby help to minimise de-correlation (see Mair et al. Interpraevent 2016). To have an independent control for the slope movements, we analysed two DInSAR test sites with terrestrial laser scanning (TLS) which required the installation of reference targets. Moreover, differential GPS (DGPS) measurements were carried out utilising the corner reflectors which were specifically designed to be used in combination with GNSS systems. Reference measurements were not only taken within the actively moving areas but also included measurements in the areas known to be not affected by displacements

TEST SITES

Test sites have to be selected very carefully due to the limitations given by the slopes and the restrictions implicated by the satellite system. For slopes factors such as orientation, geometry, the assumed movement rates and the vegetation and snow cover have to be considered very carefully, and in particular the presence and the distribution of natural persistent scatterers. For the satellite system the orbital period, the direction of the tracks, the line of sight and the look direction (geometrical distortion, shadowing) have to be determined, amongst other factors. In addition especially for the TLS-monitoring and the maintenance of the corner reflectors and the GPS, the logistics must be considered, including accessibility and, last but not least, the expenditure of time for every single measuring campaign. Careful planning is necessary for a long-term monitoring system that takes into account the potential of these methods.

Within the SloMove project presented here, two test sites were identified, located between 2500 and 3000 m asl, in South Tyrol, Italy, and Grisons Canton, Switzerland. The Italian site is located in the NE of Schnalstal (Val Senales), in the Kurzras (Maso Corto) ski resort, Schnals Municipality, Autonomous Province of Bolzano. The eastern flank of the Steinschlag-spitze (Punta delle Frane) is affected by a rockslide that evolves into different rock glacier lobes, while the northern part features a large active rock glacier. The Swiss test site Foura da l’amd Ursina is located on the Schafberg above Pontresina, Upper Engadine, Canton Grisons, and includes three active rock glaciers named Ursina I-III.

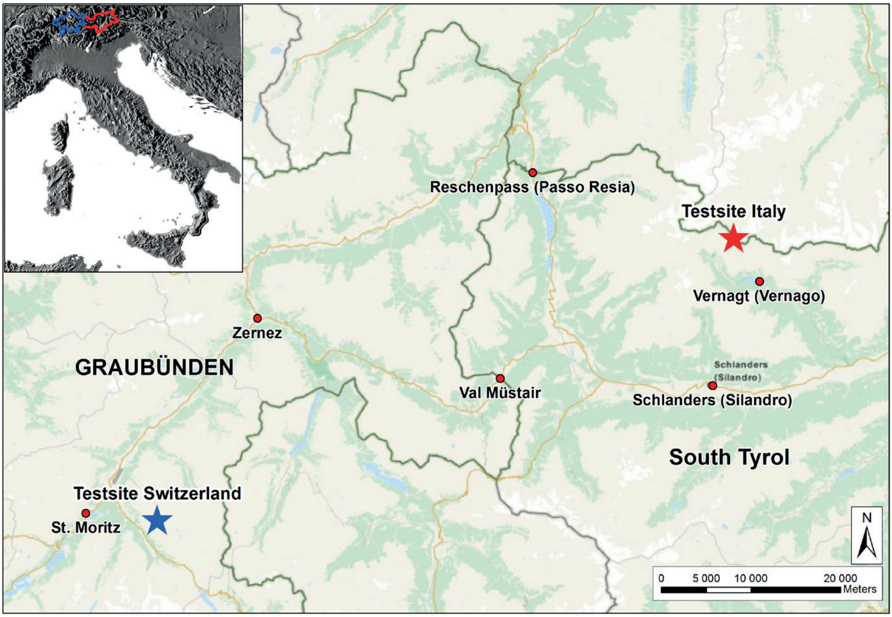

Figure 1: Sketch map of the two test sites in Graubünden and South Tyrol

METHODS

Monitoring of the test sites was carried out in 2012, 2013 and 2014 using the following methods: (i) DInSAR, (ii) TLS, and (iii) DGPS.

DInSAR processing relied on SAR images acquired by COSMO SkyMed CSK® and used the Small BAseline Subset (SBAS) algorithm (Berardino et al., 2002). The SBAS approach uses a stack of SAR acquisitions and implements an easy combination of a properly chosen set of multi-look DInSAR interferograms computed from these data. It allows the generation of mean deformation velocity maps and displacement time series. As each interferogram is calibrated with respect to a single pixel located in an area that can be assumed stable or at least, with known deformation behaviour, this point is referred to as reference SAR pixel (Casu et al., 2006). This requires well known natural reflectors or, in addition, the use of artificial corner reflectors provide the possibility to detect a known point and thereby minimise de-correlation. We designed and installed new specific artificial reflectors with an additional arm attached to accommodate a GPS antenna for periodic surveys. To facilitate the data cross validation and, in the perspective of an operational use, to be able to consistently switch from one system to the other, we also installed reference targets for TLS measurements. In this way, the artificial corner reflectors can be used as reference stations for all three monitoring technologies.

Due to seasonal limitations (snow cover in winter causes de-correlation) and internal management decisions of the SAR image provider (i.e. the Italian Space Agency), only 12 images were available for the Italian test site, and 22 for the Swiss study area in an acquisition period of 3 years (2011-2013). According to Colesanti et al. (2003), accurate processing with the SBAS algorithm requires at least 20 consecutive images. Consequently, no advanced interpretations can be provided for the Italian test site.

TLS campaigns were carried out annually using Riegl long range scanners (LPM321 and VZ-6000) and artificial reflectors for improved merging of point clouds acquired from different scan positions. The scans were performed with a resolution of < 10cm. The acquired point clouds were filtered in order to homogenize the spatial resolution and to remove outliers. Following Chen and Medioni (1991) the iterative closest point (ICP) algorithm was applied to match unchanged terrain parts in the scan and to achieve an optimal relative referencing of the multi-temporal scans. The set of relative registered point clouds was then transformed into global coordinates. Finally, the point clouds were transformed into grid based digital elevation models (DEM) with 20cm resolution. Based on similar surface patterns, individual patches of multi-temporal DEMs were correlated to obtain horizontal displacement information.

Seven differential GNSS campaigns with double frequency sensors (Leica Viva GS10 and Leica GS530) were carried out in the summer months of 2012 - 2014. In total, 18 and 14 fixed points were measured with rapid static surveys for at least 30 minutes and a sampling rate of 5 seconds in the Italian and Swiss study areas, respectively. Every measurement campaign utilised a mobile rover and two GPS base stations. The post-processing of the collected GNSS data was performed using the Leica Geo Office software by Leica Geosystems. In order to refer the local net to the global reference system the base stations were connected to permanent reference stations belonging to the geodetic network of Switzerland (SWIPOS) and South Tyrol (STPOS). The results between two measurement campaigns were referred against each other by correcting the point coordinates using the local reference stations. The accuracy was defined by evaluating the deviation of the corrected reference station coordinates between two measurement campaigns.

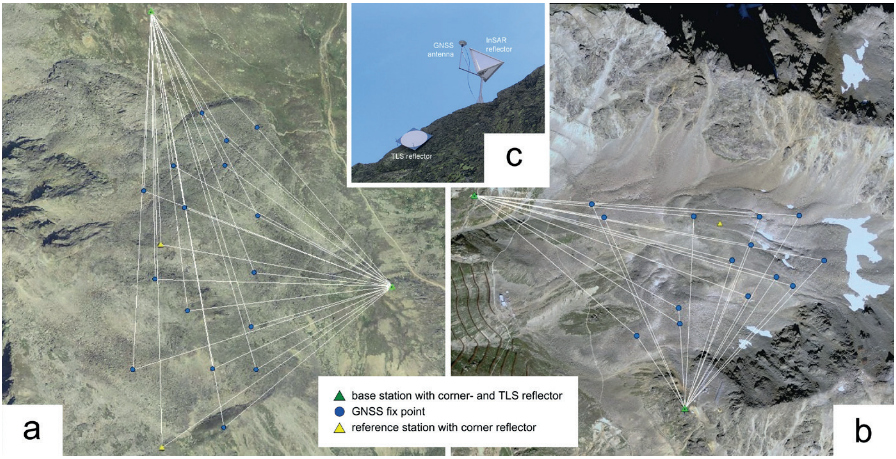

Figure 2: Test sites monitoring line-up; a) test site "Steinschlagspitze Schnals Valley, South Tyrol; b) test site "Schafberg" Pontresina, Switzerland; c) new type of artificial corner reflector with GPS-antenna and TLS reflector at the base.

DISCUSSION

Data acquisition by different monitoring techniques of the same process within the same area in general leads to dissimilar information. The evaluation of the data obtained by these independent basic principles, techniques and calculation procedures, e.g. remote data acquisition compared to punctual on site data measurements, does not allow a direct comparison of the single results. The concept of real data integration to obtain a unique and coherent final product not only requires a straightforward comparison between single data sets or a mutual validation of them, but also the assimilation of the various input information.

In all cases, it is necessary to have carefully georeferenced data sets that are attributable to the same spatial and temporal dimension. This requires extensive calculations and projections of the different vectors on a Cartesian coordinate system where in some cases the results are not distinct, e.g. when the movements are perpendicular to the line of sight of the satellite. This problem may be solved by analysing longer time-periods and by utilising larger data sets.

With the described set-up, detailed information on the movement of the geomorphic features was acquired for both test sites. In general, the methods provide similar results and assess comparable movement trends. However, at some points the magnitude of displacements differs remarkably, or even shows a reverse trend. This is related to the fact that GPS and DInSAR analysis of the artificial corner reflectors do only measure single points and not changes of larger areas like TLS or DInSAR based on extensive natural scatterers.

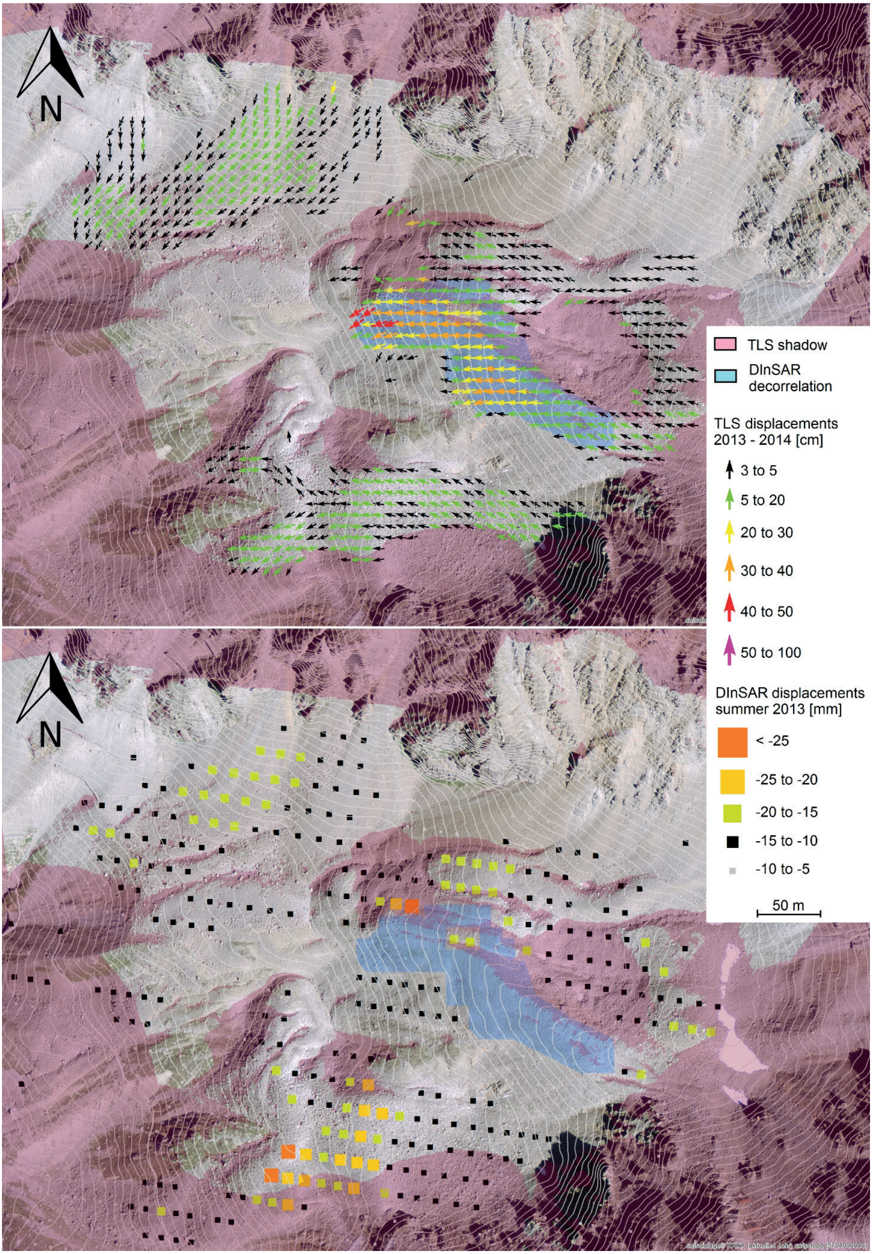

Figure 3: Comparison of horizontal TLS creep rates and DInSAR displacements. Different sources for data gaps are evident: red areas – shadow effects of TLS; blue areas – de-correlation of SAR images due to fast creep processes.

CONCLUSIONS

The integration of the data collected with the three applied monitoring techniques allows to draw the following conclusions:

- Punctual information obtained from accurate selective data such as recorded with DGPS measurements or PS interferometry, represents a good reference point for comparison between different measurement techniques and principles.
- Spatial information, collected by TLS- and SAR-images, is less accurate with respect to single points, but better represents the overall trends of the investigated mass movement.
- Even with a limited number of SAR images, it was possible to obtain comparable information to the other planar monitoring techniques using the SBAS-algorithm.

The suitability of the various methods for applications in the field of hazard management can be determined on the basis of our experiences with the different technologies:

- DGPS only provides sparse information but accurate punctual results on the deformation of a large sliding mass. Very fast motions or non-uniform acceleration can be monitored efficiently. This technique requires a greater effort on site because of the installation of measuring devices and due to the longer data acquisition times. It is economically applicable only in specific cases for local civil protection matters. DGPS is thereby well suited for automatic alerting systems, however, the equipment remains expensive.
- The TLS-technique allows the monitoring of larger areas in short periods of time.
  The use depends on two major factors:
  (i) Finding a suitable position for the measuring instrument and the reflectors (view angle and distance), from which it is possible to record the entire study area.
  (ii) The accessibility of the monitoring site and the weather conditions, because it works only with good visibility.
  This technology may be strengthened using new sensors and the improvement of the automatic data processing. An application for automatic alerting systems would be possible and some research activities in that direction have already been reported (Canli et al., 2015).
- DInSAR allows for the monitoring of larger areas that must be well pre-selected matching the geographical situation of the slope with the geometric conditions of the satellites. However, SAR image acquisition is only being carried out at relatively long time intervals and assessing surface deformation is a lengthy process.
- The shortened intervals between two data acquisitions by satellites of the last generation like Cosmo Sky Med® and Terra SAR X® are already not suitable for monitoring of processes that require rapid data acquisition and evaluation and also for automatic alerting systems.

At present, this technology is only suitable for science and land-use planning, as there is no guarantee for the delivery of SAR-images and coherent data sets. To use the technology for continuous monitoring and for civil defence affairs, it is necessary that this technology moves from a purely strategic and military application to a civil use. It should be ensured that data acquisitions are carried out following a user-defined program and that data processing and interpretation can be done continuously and – ideally - by technicians with local experience. In order to exploit the full potential of this technology, the following should be enhanced:

- Establishment of research and evaluation institutions near the monitoring areas;
- Reduction of revisiting times and costs for the data analysis
- Development of new algorithms that allow good data processing and interpretation of a small number of SAR images.

ACKNOWLEDGEMENTS

The described research was co-funded by the Interreg IV Italia-Svizzera Program, European Regional Development Fund.A9 and by the IFFI-programme of the Autonomous Province of Bozen, Italy.

REFERENCES

- Berardino P., Fornaro G., Lanari R., Sansosti E. (2002): A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms, in: IEEE Transactions on Geoscience and Remote Sensing, v. 40, no. 11, p. 2375–2383
- Bollmann E., Rieg L., Spross M., Sailer R., Bucher K., Maukisch M., Monreal M., Zischg A., Mair V., Lang K., Stötter J. (2012): Blockgletscherkataster Südtirol: Erstellung und Analyse, in: Innsbrucker Geographische Studien Bd. 39: Permafrost in Südtirol, p. 147-171
- Calò F., Ardizzone F., Castaldo R., Lollino P., Tizzani P., Guzzetti F., Lanari R., Angeli M.-G., Pontoni F., and Manunta M. (2014): Enhanced landslide investigations through advanced DInSAR techniques: The Ivancich case study, Assisi, Italy: Remote Sensing of Environment, v. 142, p. 69–82
- Canli E., Thiebes B., Höfle B., Glade T. (2015b): Permanent 3D laser scanning system for alpine hillslope instabilities, in: 6th International Conference on Debris-Flow Hazards Mitigation. Presented at the 6th International Conference on Debris-Flow Hazards Mitigation, Tokyo, Japan
- Casu F., Manzo M., Lanari R. (2006): A quantitative assessment of the SBAS algorithm performance for surface deformation retrival from DInSAR data, in: Remot Sensing of Environment 102, p.195-210
- Colesanti C., Ferretti A., Prati C., Rocca F. (2003): Multi-Image Satellite SAR Interferometry: State of the Art and Future Trends, in: Proc Radar Conference, Adelaide. 2003. p. 239-244
- Liu L., Millar C.I., Westfall R.D., Zebker H.A., and others (2012): Surface motion of active rock glaciers in the Sierra Nevada, California, USA: inventory and a case study using InSAR: The Cryosphere Discuss, v. 7, p. 343–371
- Mair V., Zischg A., Krainer K., Stötter J., Zilger J., Belitz K., Schenk A., Damm B., Kleindienst H., Bucher K., Lang K., Tagnin S., Munari M. (2008): PROALP – Rilevamento e monitoraggio dei fenomeni permafrost. Esperienze della Provincia di Bolzano, in: AINEVA, 64, p. 50-59

- Papke J., Strozzi T., Wiesmann A., Wegmueller U., Tate N.J. (2012): Rock glacier monitoring with spaceborne SAR in Graechen, Valais, Switzerland, in: Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International, IEEE, p. 3911–3914.
- Schlögel R., Doubre C., Malet J.-P., Masson F. (2015): Landslide deformation monitoring with ALOS/PALSAR imagery: A D-InSAR geomorphological interpretation method, in: Geomorphology, v. 231, p. 314–330.