The TEMPEL geoelectrical monitoring network for landslides: highlights of recent monitoring result

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Introduction

In the frame of the FP7 project SafeLand, which was funded by the European Commission, the Geological Survey of Austria (in cooperation with several different European partners) started to set up a European landslide monitoring test site network (SUPPER et al., 2012a, b, c). This network setup was supported and further continued within the TEMPEL project, which was funded by the Austrian Science Fund (TRP 175-N21). Currently, the active network, which is attended by the Geological Survey of Austria, consists of five landslide monitoring sites in Austria (Gschliefgraben, Laakirchen), France (Super-Sauze) and Italy (Bagnaschino, Ancona) and one permafrost monitoring site in Austria (Magnetköpfl). Three further monitoring sites in Austria have already been abandoned (Sibratsgfäll, Mölltaler Glacier, Ampflwang-Hausruck) and one monitoring system will be installed in summer 2012 in Italy (Rosano). In the following, the results of two test sites of the Austrian network are described in detail.

Case Study Gschliefgraben

The Gschliefgraben site is one of the most prominent and extensively studied slope failures in Central Europe. The area of Gschliefgraben (Fig. 1) is a 2.85 km long and 0.85 km wide valley along the foot of the Northern Calcareous Alps and comprises a large complex of geologically controlled slides, earth flows, topples, rockfalls and deep-seated gravitational deformations.

In late November 2007, an earth flow of about 3.8 million m^3 of colluvial mass was reactivated in the central and western parts of the valley. The displacement velocity was up to 4.7 m/day at the beginning. Consequently, in the frame of the first emergency measures, 55 buildings had to be evacuated. Recently, the Gschliefgraben landslide has been a test site of the European FP7 project SafeLand where new techniques have been tested for rapid mapping monitoring and effective early warning, consisting of, e.g., airborne and ground-based geophysical surveys and the GEOMON4D (continuous geoelectrics) and D.M.S. (automatic inclinometer) monitoring systems.

After a first phase of mitigation in 2008, where major measures were focused on property and infrastructure protection and slow-down of the moving mass (drainage of the sliding mass, removal of sliding material), multi-disciplinary investigations including drilling, borehole logging and complex geophysical measurements (e.g. geoelectric, seismic and GPR surveys), were performed to investigate the structure of the landslide area in order to evaluate maximum hazard scenarios as a basis for planning further measures. Based on these results, a complex monitoring system was installed, where geoelectric monitoring was coupled with high resolution DMS. Two perpendicular geoelectric profiles of 120 m length (electrode separation 3 m, 41 electrodes) and 192 m length (electrode separation 4 m, 49 electrodes) were installed. The DMS was installed at their intersection point.

The monitoring started in September 2009 and the system has been operating since that time with only one short interrupt due to a torrential rain event, which flooded the retention channels and damaged the geoelectrical cables.

Fig. 1: General setting of the Gschliefgraben site: (A) Position within Austria, B) Airborne photo of the Gschliefgraben valley and Mt. Traunstein from the west (Photo by: R. Supper, 2009).

Figure 2 clearly highlights the correlation of the geoelectric pattern with areas of different displacement characteristics. The low resistivity structure at the top correlates with the most active top layer, whereas the region with higher resistivity below exhibits only a slowly creeping behaviour. The sliding plains detected by the DMS inclinometer are clearly marked by high gradients of resistivity.

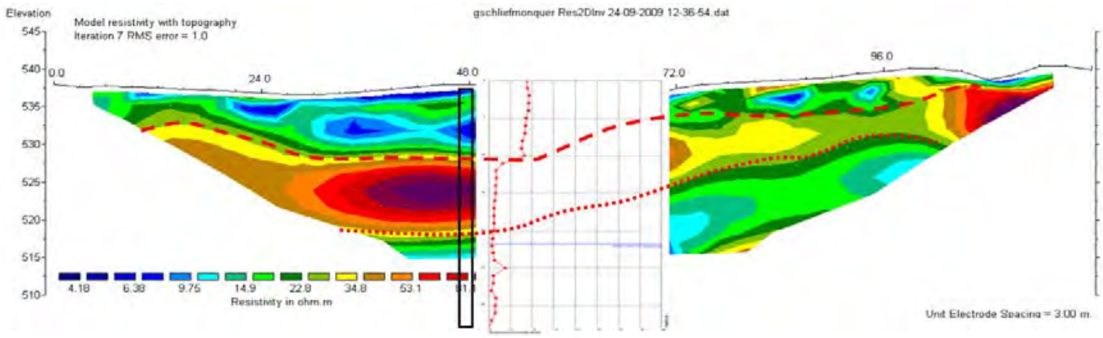

Fig. 2: Correlation of resistivity layers with sliding surfaces determined by a permanent inclinometer (red curve) in the area of Gschliefgraben.

During the whole survey only one small triggering event (1st of May 2010; acceleration from approx. 2 mm/12 days to 6 mm/12 days) with longer lasting aftermaths could be detected.

Consequently a correlation of resistivity anomalies with landslide acceleration is not possible and we can only focus on a correlation with very small changes in displacement velocity, which in fact are not relevant for early warning purposes, but might help to understand the dynamics of the landslide under "normal" conditions and to derive information on the background variations of subsurface resistivity.

Fig. 3 shows the variation of some selected values of apparent resistivity over the whole survey period. It can be recognised that the major variations of resistivity, which are very small (+/- 3 Ohmm), are due to seasonal temperature variations. In some cases, sudden resistivity changes correlated with major rainfalls (resistivity increase or decrease), depending on the sensitivity of the respective array and on the absolute apparent resistivity value. Fig. 4 zooms in on the 1st of May event. In the presented cases the rainfall event and the connected acceleration of the landslide was correlated with a (very small, but detectable) decrease in apparent resistivity (below 2 Ohmm!). The response times are difficult to calculate, since the starting time of acceleration cannot exactly be determined. However the results suggest a delay between 6-24 hours between the onset of the resistivity decrease and the initiation of the acceleration.

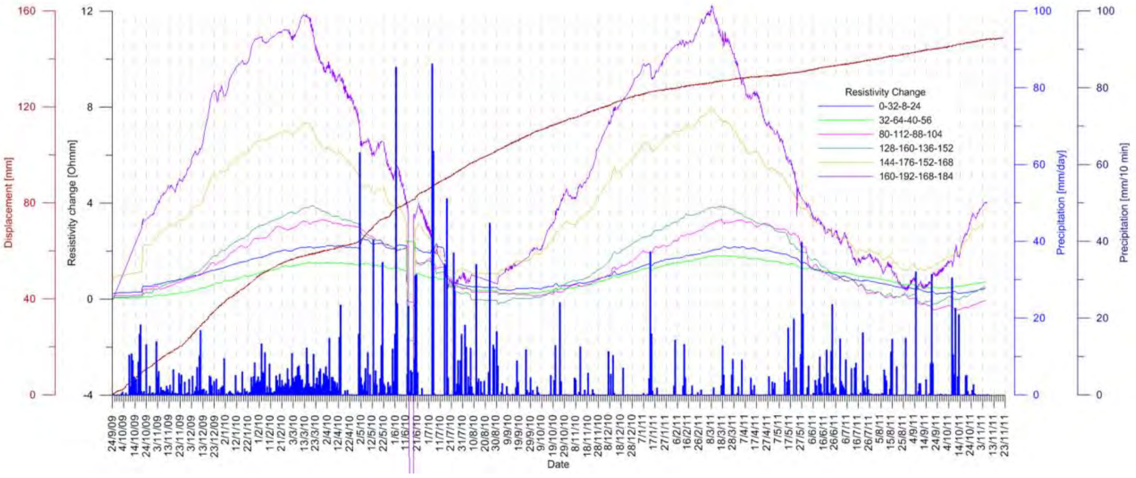

Fig. 3: Correlation of selected apparent resistivity data with displacement and precipitation for the entire survey period.

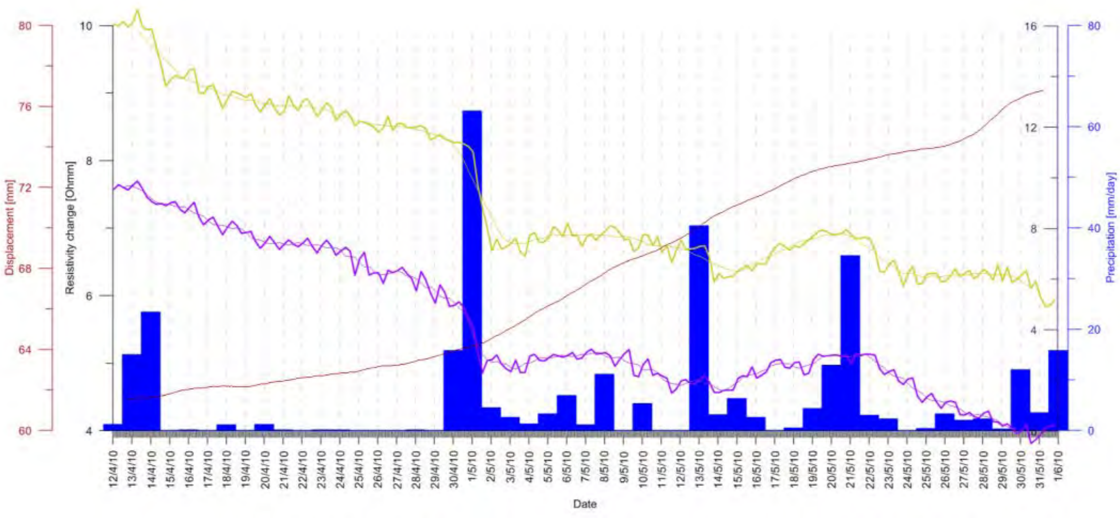

Fig. 4: Correlation of selected apparent resistivity data (yellow, purple) with displacement and precipitation for the event on March 1^{st}, 2010.

We can conclude that resistivity monitoring helped to understand the process that led to a minor acceleration of the landslide in May 2010. However, apart from that, no significant changes of subsurface resistivity took place over the whole survey period. Most variations can be associated with seasonal temperature changes or short time precipitation events. Since no major triggering event happen during the entire survey period, no detailed correlation between resistivity and displacement could be investigated. Longer survey periods have to be envisaged.

Case Study Ampflwang/Hausruck

The Ampflwang monitoring site (Fig. 5) is situated in the Hausruck Hills in NW Austria, where a recent landslide was activated in March 2010 within the area of an old deep-seated landslide, following snow melting and heavy rainfalls. The old dormant landslide is about 650 m long, 900 m wide and has an estimated depth of failure of about 20-30 m b.g.l. The reactivated part, as recognized by topographic changes and inclinometric data, is about 40 m long, 40 m wide and about 4 m thick. It is a shallow rotational-translational landslide of an elliptic shape and quite smooth topography. It is rather in initial evolution stage. However, a newly constructed family house was partly damaged by the crown of the landslide in 2010.

Therefore, a geoelectric and DMS monitoring system was implemented in cooperation with the geotechnical bureau of Moser/Jaritz, C.S.G. and the Geological Survey of Austria in order to investigate the behaviour of the landslide and its triggering in more detail and to develop an optimized strategy for site specific remediation measures.

Two D.M.S. columns were installed, which consisted of tilt/displacement, temperature and piezometric sensor modules and they hourly registered displacement data down to the depth of 5 and 7 m b.g.l., respectively. The transversal geoelectric GEOMON4D profile comprised 60 electrodes at a spacing of 1 meter. Precipitation data was taken from the weather station of Wolfsegg, courtesy of the Central Institute for Meteorology and Geodynamics (ZAMG) in frame of the cooperation contract between GSA and ZAMG. The monitoring data were sent via GPRS to the GSA and C.S.G. office in order to be analysed and interpreted.

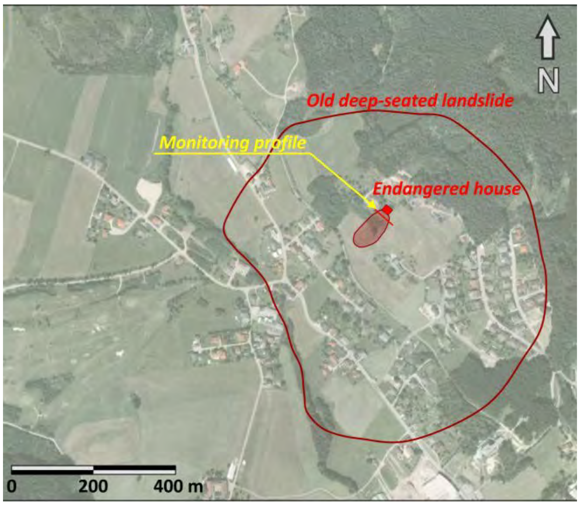

Fig. 5: Orthophoto with the marked landslides and geoelectric monitoring profile. Source of map: GoogleEarth.

Resistivity measurements were performed along one profile close to the DMS column 2. One set of data comprising around 4000 gradient-type measurements was taken every 4 hours. For power supply a connection to the local power grid was installed. The data was sent every day to the GSA office, where the results were checked for quality and time sequences of apparent resistivity and inversions were automatically generated each day. Fig. 6 shows the time series of selected apparent resistivity values in correlation with precipitation and displacement, whereas Fig. 7 gives a closer up look at the winter and spring period, during which all major displacement events took place. From these figures it is obvious that most major rain events were accompanied by a resistivity decrease.

Fig. 8 shows details of the period of the major displacement event which took place on the 13th of January 2011. Resistivity values already start to decrease around the 8th of January most probably due to additional inflow of water from snow melting. In the period after this trend continues until a first short rainfall on January 12th after which the decrease accelerated. After the start of an intense rainfall after midnight of January 12th, apparent resistivity decreased further until around 4 o´clock, when the landslide successively started to move with increased speed. Around 16 o´clock, after the main acceleration phase, resistivity started to increase rapidly although precipitation continued with less intensity for almost one day.

Data from the events 2 and 3 in February (cp. Fig. 7) show a quite similar behaviour. Resistivity started to decrease in the afternoon of February 4th and 5th, thus starting to speed up the landslide on the 5th, without any influence of rainfall. Again the reason could be melting of snow. The resistivity decrease took place before and during the acceleration phase. During the period of constant (but increased) speed, also resistivity remained approximately constant until the first rainfalls had taken place in the morning of February 11th. Interestingly, during the first hours of rainfall on the 12th, the landslide slowed down, indicated also by a short increase of resistivity. After that, resistivity started to decrease significantly until 14 o´clock, when the landslide started to speed up again. During the acceleration phase resistivity values became almost constant and started to increase again after the major acceleration phase on February 13th.

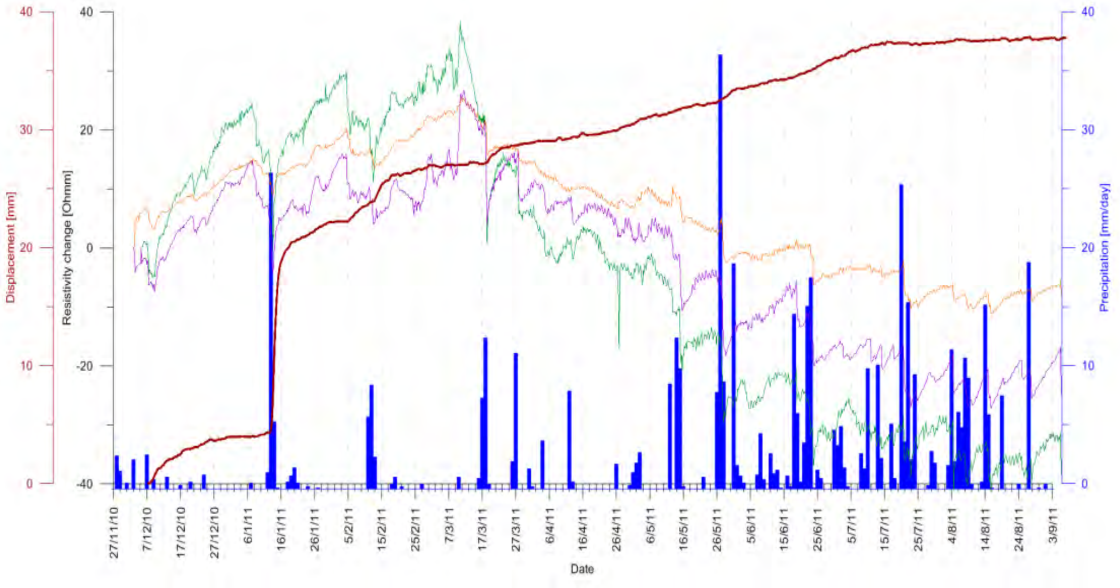

Fig. 6: Display of displacement (red), precipitation (blue; courtesy of the Central Institute for Meteorology and Geodynamics (ZAMG)) and apparent resistivity at different relative apparent depths (green: 1 m; purple: 2 m; orange: 4 m) for the whole survey period.

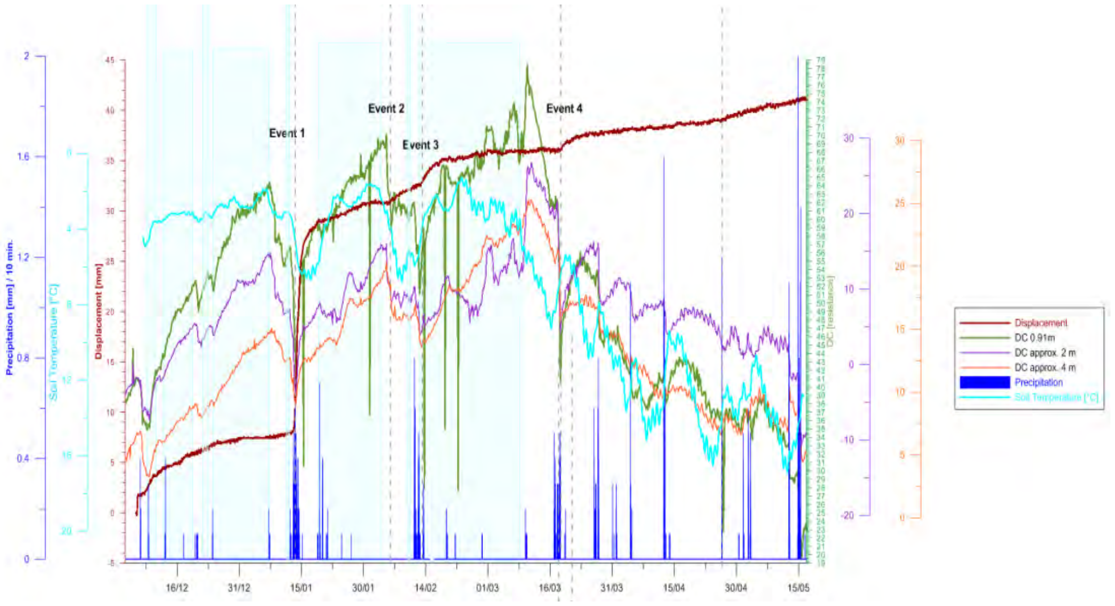

Fig. 7: Display of displacement (red), precipitation (blue; courtesy of the Central Institute for Meteorology and Geodynamics (ZAMG)) and apparent resistivity at different relative apparent depths (green: 1 m; purple: 2 m; orange: 4 m) in the winter/spring period.

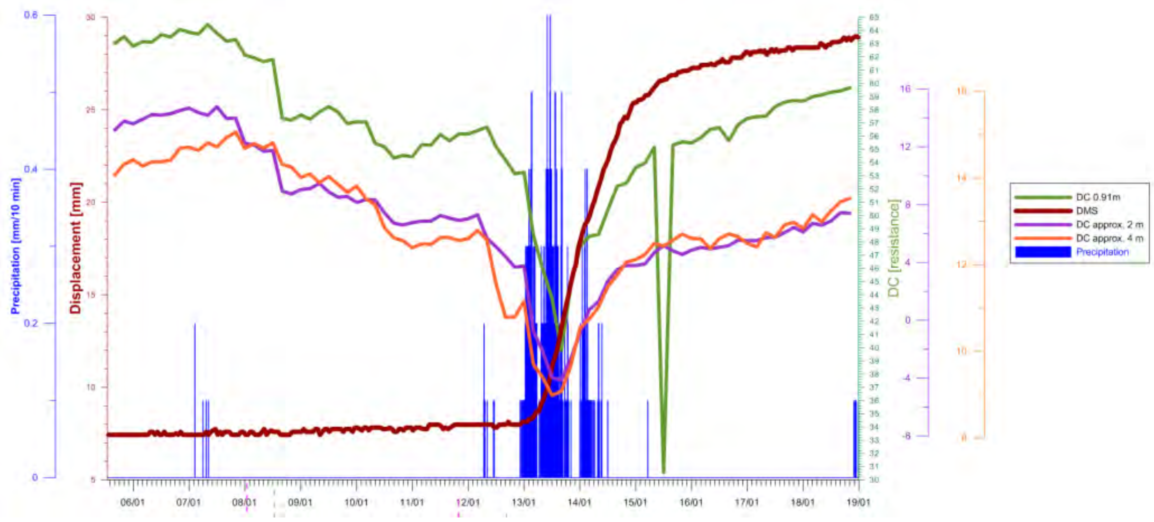

Fig. 8: Display of displacement (red), precipitation (blue; from the station Wolfsegg, courtesy of the Central Institute for Meteorology and Geodynamics (ZAMG)) and apparent resistivity at different relative apparent depths (green: 1 m; purple: 2 m; orange: 4 m) for the time around the major displacement event ("event1") in January 2011.

Based on the results described above we can conclude that decreasing values in the time series of apparent resistivity definitely correlate with the penetration of wetting fronts into the subsurface due to rainfall or snow melt events. However no information could be derived under which circumstances a movement of the landslide is triggered in case of rainfalls, since no acceleration event could be monitored in late spring and summer time, when even more intense rainfalls took place. However the reason for that could be that the landslide generally stabilised during that period. Further facts to understand this behaviour could only be derived if the monitoring would be continued for another year, which, in this case is not possible.

Conclusion

Results from the landslide monitoring studies, which were carried out in the frame of the SafeLand and TEMPEL projects, provide a solid basis for further research of landslide triggering events and early warning parameters. As mass movement events happen rarely, longer observation periods will be necessary. Real progress will only be possible, if many triggering events in different geological settings are analysed.

Even though, some conclusions concerning landslide monitoring and early warning can already be drawn:

- Almost all of the observed events were triggered by rainfall or melting water.
- Important parameters of landslide monitoring are displacement, velocity and acceleration, groundwater level fluctuations, pore-water pressure and micro seismicity, electrical resistivity, induced polarization and self-potential.
- For detailed interpretation of the results and to establish correlations, a high data sample interval of at least one hour or even less is necessary, depending on the velocity of the mass movement.

Acknowledgements

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