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Foreword

Geoelectrical monitoring has significantly developed over the recent years and is now a strongly emerging branch in applied geophysics. As the big success of the "Workshops on Geoelectrical Monitoring – GELMON" held in 2011 and 2013 in Vienna, proved, geoelectrical monitoring is now one of the most innovative areas of applied geophysics. Today it is being applied to solve problems in key areas of public and political interest, including natural hazard mitigation, agriculture optimization, CO_2 storage, and groundwater remediation and exploration.
This emerging potential is due to the fact that many environmentally relevant processes are in some way related to moisture content, water quality and subsurface temperature variations. Resistivity, the determining parameter in geoelectric surveying, mainly depends on parameters that are intimately linked to such processes, i.e., porosity, saturation, pore fluid conductivity, clay content, temperature, and tortuosity of current paths. For example landslides can be triggered by infiltration of precipitation (change of saturation); hydrological processes involve changes in saturation and fluid conductivity (e.g., saline intrusions, groundwater pollution); for permafrost observations, changes in porosity and temperature can be expected; in geothermal applications and CO_2 monitoring, changes in temperature and porosity are of importance.

Geoelectrics is one of the oldest methods applied in geophysical prospection, which goes back to the early works of Conrad Schlumberger in 1912. However significant improvements in the validity of the results were only achieved with advances in computer science, electronics and software development during the nineties, when the first commercial multi-electrode systems and 2D resistivity inversion codes became available. Such developments made it possible for the first time to collect and process large measurement sets – both necessities if reliable spatial subsurface information is to be derived. However, available instrumentation at that time was designed for manual survey activities, and was not adapted for automated and seamless remote field operation, telemetric data transfer, automated processing and data delivery. Therefore around the year 2000 (with the beginning of the new millennium) several groups independently started to develop new equipment specifically designed for monitoring applications, e.g. the ALERT system (Ogilvy *et al*. 2009), the GEOMON system (Supper *et al*. 2002) and the LEERT system (Daily *et al*. 2004). Automated remote field scale monitoring activities (lasting for several months with at least daily measurements) quickly followed, and included landslide monitoring, hydrological and pollution monitoring. The practical implementation of monitoring installations in remote areas has been significantly supported by recent developments in alternative energy supply technology, such as fuel cell and wind turbine technologies – complementing solar power, which is often limited during winter months. The availability of a large amount of time series monitoring data has also necessitated the development of time-lapse (e.g., Loke 1999) and 4D inversion (Kim *et al*. 2009, Karaoulis *et al*. 2011, Karaoulis *et al*. 2013) codes. Improvement to these codes is still an active research topic today (Kim *et al*. 2013).

This special issue of *Near Surface Geophysics* provides an overview on the current state-of-the-art in geoelectrical monitoring. It summarizes the results of the most recent developments in data acquisition, modelling and inversion, and illustrates the broad variety of applications through a range of case studies. The collection of papers is based on papers given at the '1st International Workshop on Geoelectrical Monitoring', organized by the Geological Survey of Austria in December 2011, which was attended by scientists from 18 different countries. A selection of 12 papers has been accepted for final publication in this special issue.

The first two papers deal with innovations in ***time-lapse and 4D inversion***.

Loke *et al*. ("Smoothness-constrained time-lapse inversion of data from 3-D resistivity surveys") present an approach involving the simultaneous inversion of 3D data sets incorporating roughness filters in the space and time domains. They demonstrate, using both synthetic and field examples, the improved performance of this approach compared to independent inversions.

Karaoulis *et al*. ("4D time-lapse ERT inversion: introducing combined time and space constraints") propose a new inversion approach for 4D time-lapse ERT data by transforming the space and time constraints to be active. Using this strategy, prior information can be naturally incorporated into the time-lapse inversion scheme which is now able to favour areas where the expected changes are likely to occur while filtering out areas where no changes should occur.

The largest topic covered in this special issue is the application of geoelectrics to ***hydrological monitoring***.

Dahlin *et al*. ("Soil resistivity monitoring of an irrigation experiment") presents the results of geoelectric monitoring to trace water transport during a three-year irrigation study on cultivars of willow coppice. The results proved the potential of this method to monitor changes in soil water and ion content as well as for imaging plant root development.

Martorana *et al*. ("Integrated geophysical survey for 3D modelling of a coastal aquifer polluted by seawater") describe a geophysical survey and monitoring programme, comprising geoelectrical (ERT & TDEM) and seismic methods (MASW), to investigate a coastal aquifer in southern Italy, which is under threat due to overexploitation. The combined geophysical techniques were used to construct a 3D model of the aquifer and define the extent of saline intrusion. Focussed time-lapse ERT monitoring identified seasonal changes in the aquifer at the saline-freshwater interface – which were linked to both natural and anthropogenic processes.

Chambers *et al*. ("4D electrical resistivity tomography monitoring of soil moisture dynamics in an operational railway embankment") develops geoelectric monitoring as a non-invasive tool for characterizing and observing earth embankments. The given example illustrates the possibility of monitoring seasonal changes in moisture content. The results were calibrated with temperature and soil moisture monitoring as well as with geotechnical testing and core samples.

Cho *et al*. ("Effects on 2D resistivity monitoring in earth-fill dams") studied the 3D effects created by specific dam geometry and fluctuation in reservoir water levels when 2D resistivity data were monitored along the dam crest. Time-lapse inversion experiments show that the 3D effects are significant and, in particular, the water level changes result in a spurious near-surface layer in difference images. To alleviate this problem, they introduce a combined reference model in the time-lapse inversion algorithm, which is applicable when the change in water level is small.

Kang *et al*. ("SP monitoring at a Sea Dyke") present the results of a time-lapse SP survey to detect seepage zones on a sea dyke. Given the difficulty of correlating measured SP voltages with the streaming potentials associated with ground water they propose an interpretation method for SP monitoring data which reduces spurious SP anomalies and helps to highlight actual temporal changes in seepage flow.

Within recent years geoelectrical monitoring has emerged as a standard monitoring method for ***permafrost*** observation. Two papers emphasize the importance of this field of application.

Supper *et al*. ("Geoelectrical monitoring of frozen ground and permafrost in Alpine areas: field studies and considerations towards an improved measuring technology") first give a résumé on the general background for the application of geoelectrics for permafrost monitoring and then present the results of monitoring at two test sites, each for a monitoring period of almost a full seasonal cycle with a sample interval of one data set per day.

The article by Kneisel *et al.* ("Frozen ground dynamics resolved by multi-year and year-around electrical resistivity monitoring at three alpine sites in the Swiss Alps") summarizes the results of several years of monitoring at three different permafrost test site and compares these results, which in all three cases allowed the interface between frozen and unfrozen ground to be detected.

The last three papers highlight the applicability of geoelectrical monitoring to ***natural or anthropogenic hazard mitigation***.

Supper *et al*. ("Geoelectrical monitoring: an innovative method to supplement landslide surveillance and early warning") present two case histories for which the GEOMON resistivity monitor system is used to investigate the subsurface changes associated with landslides in mountainous regions of Austria and Italy respectively. They describe the linkages between precipitation and changes in subsurface geophysical properties before, during and after slope failure events.

Rucker *et al*. ("Real-time electrical monitoring of reagent delivery during a subsurface amendment experiment") conducted resistivity monitoring on a mine heap to track reagent movement during high pressure injections. For real-time tracking of conductive fluid movement in the subsurface, they proposed to monitor the raw output current and transfer resistance, and they were able to track the reagent movement in real-time. The effectiveness of the method was verified with a post-injection time-lapse 3D inversion.

Sauer *et al*. ("Joint interpretation of geoelectrical and soil-gas measurements for monitoring CO_2 releases at a natural analogue") used a joint interpretation of geoelectrical and soil gas measurements for the detection of CO_2 spread in the subsurface. The authors conclude that the proposed monitoring concept could provide a comprehensive insight into the investigated subsurface processes.

The case studies included in this special issue clearly demonstrate that geoelectric monitoring can help to improve our knowledge about a wide range of environmental processes with strong social and economic relevance – and in doing so helps to assure the security of modern society. However the content of the issue also helps us to consider possible future developments. A number of special areas of application, e.g. for permafrost monitoring, require more flexible inversion routines adapted to the special settings of the problem. Also, to provide more detailed subsurface information, IP and SIP monitoring could be further explored, as well as further development of geoelectrical monitoring for applications such as volcano and hydrocarbon reservoir monitoring.

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Guest Editors

REFERENCES

Daily W., Ramirez A., Newmark R. and Masica K. 2004. Low-cost reservoir tomographs of electrical resistivity. *The Leading Edge* **23**, 472–480.

Kim J.-H., Supper R., Tsourlos P. and Yi M.J. 2013. Four-dimensional inversion of resistivity monitoring data through Lp norm minimizations. *Geophysical Journal International* **195**(3), 1640–1656.

Kim J.-H., Yi M.J., Park S.G. and Kim J.G. 2009. 4-D inversion of DC resistivity monitoring data acquired over a dynamically changing earth model. *Journal of Applied Geophysics* **68**(4), 522–532.

Karaoulis M.C., Kim J-H and Tsourlos P.I. 2011. 4D active time constrained resistivity inversion. *Journal of Applied Geophysics* **73**(1), 25–34.

Karaoulis M., Revil A., Tsourlos P., Werkema D.D. and Minsley B.J. 2013. IP4DI: A software for time-lapse 2D/3D DC-resistivity and induced polarization tomography. *Computers & Geosciences* **54**, 164–170.

Loke M.H. 1999. Time lapse resistivity imaging inversion. *Proceedings of the 5th Meeting of the Environmental and Engineering European Society*, Em1.

Ogilvy R.D., Kuras O., Meldrum P.I., Wilkinson P.B., Gisbert J., Jorreto S., Frances I. and Pulido Bosch A. 2009. Automated time-Lapse Electrical Resistivity Tomography (ALERT) for monitoring Coastal Aquifers. *Near Surface Geophysics* **7**, 367–375.

Slater L.D., Binley A. and Brown D. 1997. Electrical imaging of fractures using ground-water salinity change. *Groundwater* **35**, 436–442.

Slater L. and Sandberg S. 2000. Resistivity and induced polarization monitoring of salttransport under natural hydraulic gradients. *Geophysics* **65**, 408–420.

Supper R., Römer A. and Hübl G. 2002. Development of a new fast remote controlled3D geoelectrical monitoring system for subsurface surveillance. *Proceedings of the Environmental and Engineering Geophysical Society, 8th Meeting Aveiro*, Portugal.