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Editorial: Advances in the application of multi-dimensional geophysical surveys in Earth and environmental sciences

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Editorial on the Research Topic
Advances in the application of multi-dimensional geophysical surveys in Earth and environmental sciences

Geophysical methods provide information on the physical properties of the subsurface, the spatial distribution of these properties, and by inference, the structure of the subsurface. For this reason, in recent years the application of multi-dimensional geophysical techniques has become increasingly important for various geomorphologic and hydrological problems. This is especially because landforms and soil systems are inherently 3D structures, often exhibiting small-scale spatial heterogeneity of subsurface conditions. Flow and transport processes in these systems tend to be complex both in space and in time. Modern geophysical methods have the potential to provide spatial or even volumetric information on the subsurface internal structure and property variations of landforms, soils, and ecosystems. This is in contrast to mapping methods, such as remote sensing or aerial photography that are limited to providing surface information, and to intrusive methods (e.g., boreholes) that provide subsurface data only at point locations.

In this Research Topic, we have collated a set of papers that document a wide range of different applications to share some of the latest findings and highlight current and future potential of multidimensional geophysical imaging, both for survey and monitoring approaches.

Watts et al. explore the application of three geophysical methods to a proglacial environment, namely ground penetrating radar, seismic refraction, and multi-channel analysis of surface waves. Three glacial landforms with contrasting morphologies and sedimentary characteristics were investigated. Their findings highlight that a combined geophysical approach can provide valuable information on subsurface material properties and architecture if appropriate survey practices are applied. Since the success of the individual methods applied here varied depending on subsurface composition and structural complexity, the combined analysis helped to overcome the inherent non-uniqueness in the results and allowed sedimentological interpretations to be drawn. Strengths and limitations of the applied geophysical techniques are evaluated and a number of recommendations for studies in these geologically complex environments are defined.

Johnson et al. demonstrate a novel application of time-lapse 3D electrical resistivity tomography and temperature monitoring where an array of thermistors installed beneath a riverbed double as resistivity electrodes. Although ERT imaging was not considered when designing thermistor spacings, and the array was not optimized for imaging at this scale at the presented study site, their approach demonstrates that temperature time-series at each thermistor location and time-lapse 3D images of changes in bulk electrical conductivity together provide a detailed description of fluid exchange dynamics over the investigated section of the riverbed. The combined results reveal highly variable flux behaviour throughout the monitoring domain including both horizontal and vertical exchange flows.

Gallistl et al. present an approach that predicts hydraulic conductivity from multi-methodical geophysical data collected on a hillslope affected by landslides. The objective of this study was the spatial characterization of the investigated slope to derive hydrogeological structures and preferential flow paths. The geophysical data sets used consisted of conductivity imaging profiles, transient electromagnetic soundings and refraction tomography profiles. Using additional lithological data from boreholes and soil-textural data, the derived hydrogeophysical 3D models delineated the geometry of an acquiclude and the analysis of preferential flow paths.

Combining electromagnetic and electrical measurements with constant head infiltration tests, Uhlemann et al. present an approach to map the 3D distribution of hydraulic conductivity derived from calibrated 3D models of electrical resistivity of the subsurface. Linking these data with hydrological models, infiltration rates were estimated. They apply this technique to map the infiltration and eventually recharge potential of a various ponds of a groundwater recharge facility and show that through this information management activities can be informed that could raise the recharge potential of such ponds by more than 250%.

Commer et al. present an enhanced multi-dimensional inversion through target-specific inversion parameter bounds. The purpose of enlarged parameter bounds that correlate spatially with predefined targets is to let the inversion explore a larger solution space, thus increasing the potential to resolve otherwise hidden anomalies. Parameter constraints in form of spatially variable lower and upper bounds provide a straightforward way of incorporating spatial prior model information pointing to focus zones in an inversion workflow. Contrary to the common way of scaling the width of model parameter bounds with the uncertainty of prior information, Commer et al. enlarge bounds in zones that host anticipated anomalies. While they cannot improve the lack of data sensitivity, widened bound intervals are a means of selectively increasing model fidelity in target zones.

Recent advances in geoelectrical monitoring instrumentation are leading to ever larger time-lapse data sets, and the need for practical and efficient near real-time data assessment techniques. Wilkinson et al. compare existing time-lapse inversion approaches, and present a methodology to enable near real-time data inversion, while still applying time constraints by using a windowed-inversion approach. They show that the windowed approach using 3 and 5 consecutive time-steps provide similar results to a full 4D inversion of various data sets, and that this approach yields superior results compared to, e.g., difference inversion.

Doro et al. used ERT as a non-invasive geophysical technique for locating clandestine graves and monitoring human decay within the subsurface. Their approach included time-lapse 2D and quasi-3D electrical resistivity imaging over an experimental mass grave and individual graves containing human cadavers to assess resistivity anomalies resulting from graves and the presence of decaying human remains in them. The value of different electrode arrays and electrode spacing in identifying the contrast between the graves was assessed using forward modelling of resistivity data before data collection in the field. Their study validates the potential of 2D and 3D ERT as a forensic search tool for locating clandestine mass and individual graves and as a non-invasive imaging and monitoring technique to support human decomposition research.

Outside of the articles compiled here, there are new examples of applications in neighbouring scientific disciplines. While 2D geophysical surveys can be considered state-of-the-art for imaging and monitoring (i.e. 2D + time) subsurface properties, 3D applications including monitoring (i.e. 3D + time *or* 4D)–depending on the scientific discipline–are still an emerging approach with ongoing and rapid new developments. Throughout the whole range of different methods applied in near-surface geophysics, multi-dimensional approaches enable detailed imaging of complex subsurface structures and dynamics. Geophysical tools have great potential to better characterize processes and interactions governing the soil-plant-atmosphere continuum in agricultural ecosystems, which is why there are numerous applications in the comparatively new field of agrogeophysics (Garré et al., 2021).

Especially in the last 2 decades, electrical resistivity imaging (ERI) monitoring approaches have increasingly gained prominence for the detection and monitoring of temporal changes in the near-surface subsurface, which are usually of a hydrological, chemical or thermal origin. While general studies of soil moisture using ERI including time-lapse approaches are widespread, its application to forest sites has been very rare so far (e.g. Dick et al., 2018; Carrière et al., 2020). This is possibly because forest stands usually do not have homogeneous field conditions, as the subsoil is comparatively heterogeneous due to the root system of the trees and the soil hydrology is very complex influenced by interactions with vegetation coverage. Roots as well as associated mycorrhizal fungi have an impact on the apparent resistivity. Trees secrete root exudates for nutrient mobilization, which increase the electrolyte content of the soil solution and consequently decrease apparent resistivity, making ERI time-lapse data more difficult to interpret for monitoring soil moisture variability. Nonetheless, ERI monitoring approaches offer great potential for small-scale monitoring of soil moisture changes even in forest stands with heterogeneous subsurface conditions (*cf.* Fäth et al., 2022). ERI as a non-invasive method, in combination with additional data, e.g., on the vitality status of individual trees, could help to better understand root water uptake and water supply to trees, especially during periods of drought (Rieder and Kneisel, accepted). This also highlights the application of near-surface geophysical techniques in the critical zone, where hydro-biogeochemical processes are often complex, both in space and in time. Characterizing this zone in detail is hence particularly important and near-surface geophysics integrated with borehole and remote sensing data has been applied successfully for assessing water holding capacity (Flinchum et al., 2018) and fracture density (Uhlemann et al., 2022) across hillslopes and entire watersheds. Similar trends are also taking place in Arctic and Antarctic environments, where near-surface geophysical techniques have been recognized for providing valuable information on the subsurface structures and processes controlling thermo-hydrological dynamics. Although the environments are harsh, in particular time-lapse studies are starting to provide valuable information on the subsurface dynamics that control permafrost evolution (Minsley et al., 2022).

Author contributions

The idea of and concept of this Research Topic came out from the discussion among the guest editors. All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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References

Carrière, S. D., Ruffault, J., Pimont, F., Doussan, C., Simioni, G., Chalikakis, K., et al. (2020). Impact of local soil and subsoil conditions on inter-individual variations in tree responses to drought: Insights from electrical resistivity tomography. *Sci. Total Environ.* 698, 134247. doi:10.1016/j.scitotenv.2019.134247

Dick, J., Tetzlaff, D., Bradford, J., and Soulsby, C. (2018). Using repeat electrical resistivity surveys to assess heterogeneity in soil moisture dynamics under contrasting vegetation types. *J. Hydrology* 559, 684–697. doi:10.1016/j.jhydrol.2018.02.062

Fäth, J., Kunz, J., and Kneisel, C. (2022). Monitoring spatiotemporal soil moisture changes in the subsurface of forest sites using Electrical Resistivity Tomography (ERT). *J. For. Res.* 33, 1649–1662. doi:10.1007/s11676-022-01498-x

Flinchum, B. A., Holbrook, W. S., Grana, D., Parsekian, A. D., Carr, B. J., Hayes, J. L., et al. (2018). Estimating the water holding capacity of the critical zone using near-surface geophysics. *Hydrol. Process.* 32, 3308–3326. doi:10.1002/hyp.13260

Garré, S., Hyndman, D., Mary, B., and Werban, U. (2021). Geophysics conquering new territories: The rise of "agrogeophysics". *Vadose Zone J.* 20, e20115. doi:10.1002/vzj2.20115

Minsley, B. J., Pastick, N. J., James, S. R., Brown, D. R. N., Wylie, B. K., Kass, M. A., et al. (2022). Rapid and gradual permafrost thaw: A tale of two sites. *Geophys. Res. Lett.* 49, e2022GL100285. doi:10.1029/2022GL100285

Rieder, J. S., and Kneisel, C. (accepted). Monitoring spatiotemporal soil moisture variability in the unsaturated zone of a mixed forest using electrical resistivity tomography. *Vadose Zone J.*

Uhlemann, S., Dafflon, B., Wainwright, H. M., Williams, K. H., Minsley, B., Zamudio, K., et al. (2022). Surface parameters and bedrock properties covary across a mountainous watershed: Insights from machine learning and geophysics. *Sci. Adv.* 8, eabj2479. doi:10.1126/sciadv.abj2479