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PREFACE

Dear participants and readers of this abstract book of the GELMON 2022 workshop,

We are happy to present you 25 abstracts from scientists around the world, which cover a wide range of topics in geoelectric monitoring. A focus is set on geoelectric monitoring of contaminated sites, followed by hydrology and embankment, permafrost, data quality and data processing as well as technological developments and many others.

It should be mentioned that this is the last GELMON workshop held by the Geological Survey of Austria. Due to the fusion of the Geological Survey of Austria with the Central Institute for Meteorology and Geodynamics (ZAMG) with 1st of January 2023, the next (7th) GELMON workshop will be held by the new institution – the Geosphere Austria. It is intended, that the next GELMON workshop (most probably 2024) will be organized as a hybrid event, to include again the very important, almost forgotten, social gathering aspect of a workshop/conference and to enable also colleagues who cannot/or don't want to travel to Vienna to be part of the scientific discussions.

Enjoy reading,

Birgit Jochum, David Ottowitz and Stefan Pfeiler

(GELMON organization team / Geological Survey of Austria)

TIME SCHEDULE

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FURTHER TOPICS

Geoelectrical and electromagnetic monitoring for saltwater penetration on the Po di Goro river (Italy)

Enzo Rizzo[1,2], Enrico Ferrari[1], Giacomo Fornasari[1], Paola Boldrin[1], Luigi Capozzoli[2], Gregory De Martino[2], Valeria Giampaolo[2], Francesco Droghetti[1], Thomas Veronesi[3], Federica Neri[4], Alessandro Bondesan[4]

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Keywords: climate change, ERT, EM, seawater penetration

The climate change is heavily affecting our earth and the coastal zone is strongly sensitive to this changing. The sea-level rise and the reduction of river discharge are driven by climate change and they are controlling factors on the saltwater penetration in the delta system. The delta systems are characterized by complex dynamic between freshwater coming from continent and saltwater. Consequently, the upstream extent of the mixing zone leads to an increase of the salt content in aquifers and surface waters. These conditions can hinder the water use for irrigation purpose leading to salinization of soils. This summer all the world's news reports showed the Po River saltwater intrusion crisis, the Italian's largest river delta system is affecting seawater penetration endangering the sustainability of the freshwater resources. The typical approach to detect chemical-physical parameters (i.e. electrical conductivity-EC) is the multiparameter probe for water quality, but with a punctual acquisition system it is not simple to monitor a very long river (> 50km). Therefore, the research group proposed a fast geophysical approach for the monitoring of the saltwater penetration affecting the Po di Goro river, that is one of the Po river branches. Two geophysical methods, ERT and EM profiling, were applied detecting the water salinity in the river and its dynamic iteration with the subsoil around the riverbanks. The field activities are planned in two different periods (July and October 2022). During the first period, three Electrical Resistivity sections, four EM map surveys and a long EM profile were carried out in different areas along the Po di Goro river (Figure). The ERT sections highlighted how the river water interacts with the surrounding subsoil, while the EM data sets define the dynamic system between the saltwater penetration and the freshwater in the river detecting the salty plume front. The first results highlight the great potential of the proposed geophysical approach to monitor the saline plume during crisis periods. In the second period, the same geophysical approach will be applied, in order to monitor the withdrawal of the saltwater penetration.

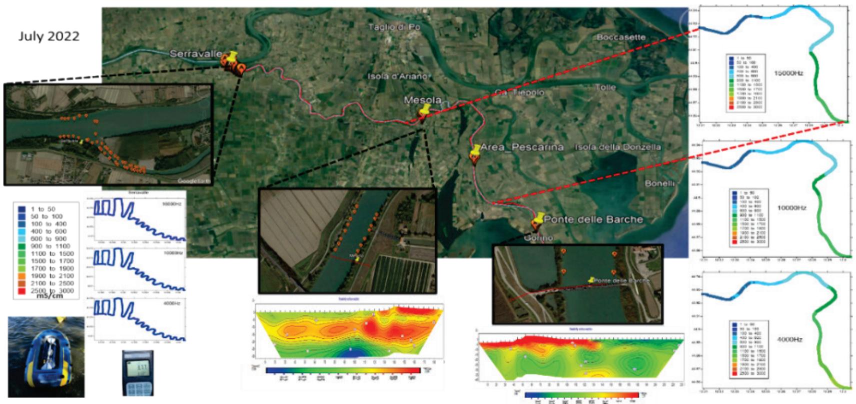

Figure: The map shows the four test sites. Several EM profiles were carried out across the river by AMP-300 instrument located on an inflatable boat pulled by a kayak. Three ERTs were acquired with electrodes floating on the water and some installed on the land across the riverbanks. A long continuous EM profile was carried out along part of Po di Goro river (15km) using three different frequency of AMP-300 instrument located on an inflatable boat pulled by a kayak. All the data were calibrated by an EC probe.

Assessing the performance of urban drainage systems for groundwater recharge

Sebastian Uhlemann[1], Craig Ulrich[1], Scott Struck[2], Abdul Haikal[3], Yao Kouwonou[3], Chad Vellinga[4], Brett Mooney[4], Giles Coon[3]

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Keywords: groundwater recharge, SUDS, urban hydrology

The prolonged drought in the Western States of USA has increased the use of groundwater for water supply and other uses. Consequently, aquifers are over-pumped and increasingly stressed and groundwater recharge program provides a potential solution to mitigate this stress and provide sustainable groundwater resources. Groundwater recharge program often leverages the Low impact developments (LIDs) or sustainable urban drainage systems (SUDS) built for urban stormwater management, to infiltrate the urban runoffs. To diversify the water supply portfolio, agencies are implementing groundwater recharge programs and there is a need to understand the surface water and groundwater interaction at these LIDs. This triggered recent research into their performance and effectiveness for groundwater recharge. Here, we investigate the performance of two SUDS types, a dry well and a bioswale. A representative site has been identified for each of those within Los Angeles County, California. At each site, boreholes were drilled and electrodes attached to the PVC casing for 2D and 3D electrical resistivity tomography (ERT) monitoring. At each site, a controlled infiltration experiment was conducted and monitored using ERT and soil moisture measurements along the boreholes. While the drywell showed rapid and deep infiltration below its two wells (pretreatment and main infiltration well), the bioswale showed changes in the upper 2-meter only. This highlights that drywells can provide considerably more recharge to the aquifer than bioswales. Monitoring of real storm events at the dry well site confirmed the infiltration pattern observed during the controlled experiment, but also highlighted more complexity as water from outside enters the imaging domain.

Groundwater recharge models are currently being developed that will be calibrated on the geophysical monitoring data and will provide more insight on the distribution of hydraulic conductivity, and will allow for a quantitative assessment of groundwater recharge. These developments contribute considerable insight into the functioning of SUDS for groundwater recharge, and will help urban planners to design appropriate SUDS not only for stormwater management but also groundwater recharge.

Geoelectrical Monitoring of freshwater/saltwater interactions at the high-energy beach of Spiekeroog (DynaDeep)

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Keywords: ground water, coastal processes

Subterranean estuaries are hidden connective zones between inland aquifers and the open sea where meteoric freshwater and circulating seawater mix and undergo major biogeochemical changes. Hence, they are considered powerful biogeochemical reactors affecting elemental net fluxes to the sea. In particular, at high-energy beaches undergoing significant changes even at short time scales, the effect of hydro- and morphodynamics on subsurface flow and transport is yet unclear and related consequences on biogeochemical reactions and microbial habitat characteristics have not been investigated. The recently started research unit DynaDeep studies the groundwater flow patterns as a function of hydro- and morphodynamics, together with investigating rates of biotic and abiotic transformation of organic matter and related redox processes. Furthermore, the project assess the transformation and fractionation of trace metals and metal isotopes as well as microbial interactions with organic matter. The DynaDeep project focused on the beach of the north-sea barrier island of Spiekeroog.

Investigating the dynamics of the saltwater/freshwater interface presents an ideal target for geoelectrical monitoring. We collect ERT data in the intertidal zone in a regular six-week interval and support them by direct-push measurements, pore water sampling and the installation of a vertical electrode chain SAMOS (Ronczka et al., 2018) starting summer 2022. ERT data set have been collected repeatedly since 12/2021 investigating the current state of the upper saline plume (UPS) and freshwater discharge tube (FDT), the two main features defining the fresh/saltwater interface.

We conduct all ERT measurements using the ABEM Terrameter LS2, 2.5 m electrode spacing and a gradient array. We use up to four chains of electrodes with 32 electrodes each. The main profile is oriented south north from the dunes to the North Sea, i.e. crossing the east-west oriented beach. The actual length of the profiles depend on the current beach and tidal conditions affecting the mean low-water line. We invert the ERT data using the pyGIMLi framework (Rücker et al., 2017) and using geostatistical regularization (Jordi et al., 2018). The geostatistical regularization parameter are mesh independent and more likely to remain stable, when the topography is changing with time.

In the following three years, the monitoring will help to get an understanding of how topography changes in this high-energy environment are affecting the USP and FDT as well as the origin and behavior of temporal freshwater discharge locations known as runnel. Once we monitored a full hydrogeological year, the focus can shift to distinguish effects of seasonal origin or caused by storm events in general.

Jordi, C., Doetsch, J., Günther, T., Schmelzbach, C., Robertsson, J. O. (2018): Geostatistical regularization operators for geophysical inverse problems on irregular meshes. *Geophysical Journal International*, *213*(2), 1374-1386.

Ronczka, M., Günther, T., Grinat, M., Wiederhold, H. (2020): Monitoring freshwater–saltwater interfaces with SAMOS–installation effects on data and inversion. *Near Surface Geophysics*, *18* (Geoelectrical Monitoring), 369-383.

Rücker, C., Günther, T., Wagner, F. M. (2017): pyGIMLi: An open-source library for modelling and inversion in geophysics. *Computers & Geosciences*, *109*, 106-123.

Geoelectrical long-term monitoring with the SAMOS system using vertical electrode sections

Michael Grinat[1], Mathias Ronczka[1], Thomas Günther[1], Nico Skibbe[1], Dieter Epping[1], Vitali Kipke[1], Mike Müller-Petke[1]

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Keywords: ground water, coastal processes, vertical electrode sections

The Leibniz Institute for Applied Geophysics (LIAG, www.leibniz-liag.de) is carrying out long-term geoelectric measurements with vertical electrode sections at currently five different sites at the North Sea coast of Lower Saxony (Germany): The measurements with the SAMOS system are carried out on the North Sea island of Borkum in the two water catchment areas Waterdelle and Ostland (installation within the framework of the EU project CLIWAT, www.cliwat.eu/), on the North Sea island of Spiekeroog in the dunes as well as directly on the beach (project go-CAM, https://bmbf-grow.de/de/go-cam and DFG project DynaDeep, https://uol.de/icbm/verbundprojekte/dynadeep), and on the mainland near Abickhafe (project go-CAM). The objective is always to record changes in the transition zone between fresh water and salt water.

The monitoring started on Borkum island in 2009 in cooperation with Stadtwerke Borkum (two systems). The third and the fourth system were installed near Abickhafe in 2018 and on Spiekeroog in 2020 together with the Oldenburg East Frisian Water Association (OOWV). The last SAMOS station was recently installed (2022) at the shore of Spiekeroog as part of a multi-sensor monitoring approach to investigate physical and biogeochemical processes at high-energy beaches. The vertical electrode sections, each with about 80 electrodes, cover the depth range 44-65 m below terrain on Borkum, 35-55 m below terrain in Abickhafe and 29-53 m below terrain in the dunes of Spiekeroog. The system at the beach of Spiekeroog covers the depth range between terrain and about 21 m depth. The spacings between adjacent electrodes are 0.25 m or 0.30 m respectively. A 4 point light 10W is used to carry out measurements with different arrays (Wenner-alpha, dipole-dipole, Wenner-beta). The data transfer, which previously took place automatically to a server in LIAG, has already been converted to a cloud solution at Abickhafe.

The measuring system allows the detection of resistivity changes of less than 1 Ωm. Up to now the temporal resistivity variations are generally small. Major seasonal changes in some depths at Borkum (Ostland) are attributed to changes in production rates in neighbouring wells as well as to changes in the groundwater recharge rate. In longer time-series (Borkum) resistivity decreases lasting for several years as well as resistivity increases (due to reduced water demand as a result of the pandemic?) can be observed. The small variations also make differences between different measuring equipment visible. Temperature effects are small at greater depths as expected and are only of greater importance for the measurements at the shore of Spiekeroog. The measurements directly after installation can be disturbed by the drilling process at small electrode distances and show a gradual re-alignment with the natural environmental conditions. Using an inversion algorithm that takes the correct geometry into account the near-borehole and undisturbed resistivity can be separated. By monitoring the transition zone between salt water and fresh water the SAMOS system serves the waterworks as an early warning system for possible salt water upconing in groundwater extraction areas.

3D time-lapse imagery of leachate and biogas behaviors in a landfill bioreactor by electrical resistivity monitoring

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Keywords: landfill, ERT monitoring, time-lapse

The continually growing volumes of household waste and their long degradation times under normal conditions put landfill owners in an environmental, financial and logistic dilemma. Over the past decades, the concept of bioreactors has been developed to accelerate waste biodegradation with the result of aftercare cost reduction, space gain for new deposits and energy generation through biogas production. Bioreactors consist of sealed cells where degradation mechanisms are enhanced through leachate infiltrations (waste wetting) pumped at the cells bottom. Special attention should be paid to the homogeneous wetting of waste material, while preferential flow paths of the injected leachate allowing to bypass large parts of targeted waste should be avoided.

This work studies the leachate circulation during injection into a landfill cell of the Bistade landfill (France). The main goal was to monitor the proper functioning of the bioreactor and to detect eventual preferential paths considering its multiple structural challenges, such as a biogas pumping well and an overlaying geomembrane. We conducted a 3D electrical resistivity survey consisting of 4 profiles around an injection drain and the biogas well; two consecutive 5-hour injections of leachate were carried out at 20 hours intervals. All along the experiment, electrical resistivity was measured every 30 min using the 3D ERT setup. The collected data were then analyzed and inverted using the pyGIMLi open-source code.

The analysis of the spatial and temporal variations of the electrical resistivity allowed the identification of several preferential leachate pathways as well as the accumulation of biogas in certain zones of the waste cell. The results of the study can be used by the site owner to optimize the leachate recirculation in existing waste cells and to improve the design of future cells.

3D borehole DC data processing and inversion for remediation monitoring

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Keywords: DC, contaminant remediation, instrumentation

Contaminant remediation campaigns often inject an electrically conductive agent that chemically transforms the underground pollutant into a less toxic substance. Given that the subsurface is generally unknown, the injected remediation agent can flow through unexpected, underground, three-dimensional paths. When this happens, the underground pollutant might be missed by the remediation agent. This in turn raises the cost of the remediation campaign by excessively injecting in order to cover the spatial gaps. We aim to address this issue by in-situ monitoring in feasible time the contaminated region using DCIP borehole data.

Here, we present a proof-of-concept remediation campaign by introducing three novel technologies: (1) a new DCIP instrument that is able to measure large amounts of data in relatively short periods of time (10 thousand quadrupoles in 20 minutes) and with a sample rate of 4kHz, (2) a robust and computationally light IP signal-processing routine that yields 90% of DC data under a 3% standard deviation, and (3) a 3D inversion algorithm that can handle large amounts of data (60 thousand data-points), and a very fine discretization of the domain (300 thousand model unknowns) without losing resolution between forward and inverse models.

We test our instrument, signal processing routine, and inversion algorithm in an uncontaminated site near Aarhus, DK. The site exhibits two distinct geological layers of clay (shallow 10 m) and sand (below 10 m). Our results show a distinct increase in conductivity where the remediation agent was injected.

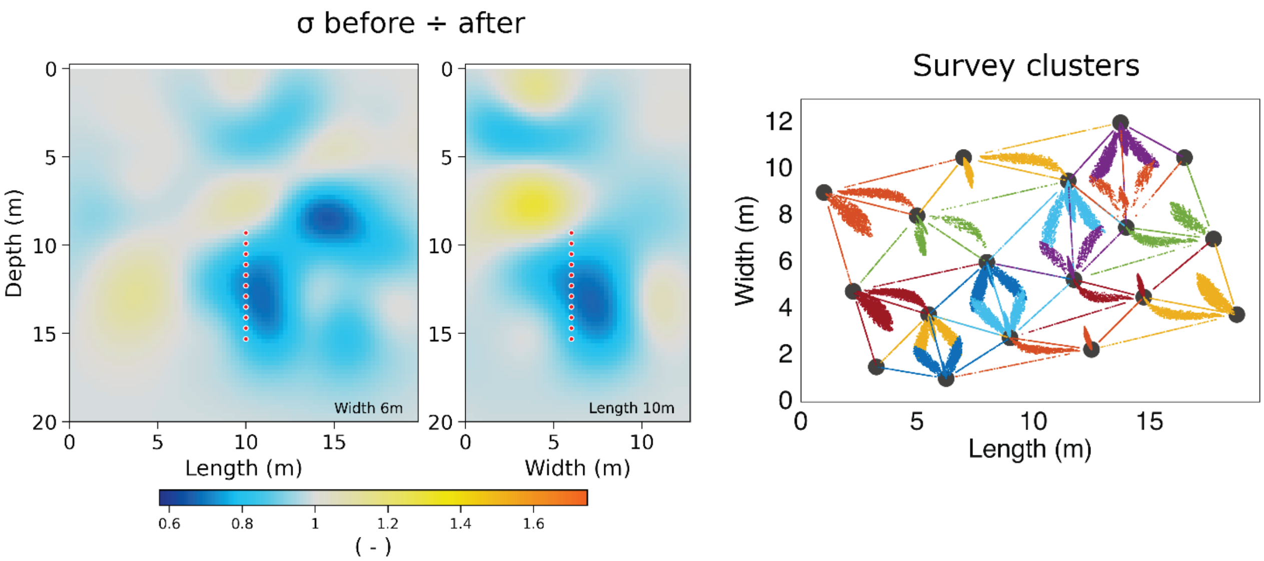

Figure: Left: slices in width and length of the 3D time-lapse quotient of recovered conductivities before and after injection of the remediation agent. Red dots denote the injection locations of the remediation agent. Each element in the domain is a cube with a side length of 0.25m. Right: top view of the pseudo-locations (colored points) of all measurements performed in our survey (60 thousand DC data-points). The gray dots denote electrode borehole locations. This survey took 7.5 hours of field acquisition.

A multiscale accuracy assessment of moisture content predictions using time-lapse electrical resistivity tomography in mine tailings

Adrien Dimech[1,3], Anne Isabelle[2,3], Karine Sylvain[2,3], Chong Liu[1], Lizhen Cheng[1,3], Bruno Bussière[1,3], Michel Chouteau[2,3], Gabriel Fabien-Ouellet[2], Charles Bérubé[2], Paul Wilkinson[4], Philip Meldrum[4], Jonathan Chambers[4]

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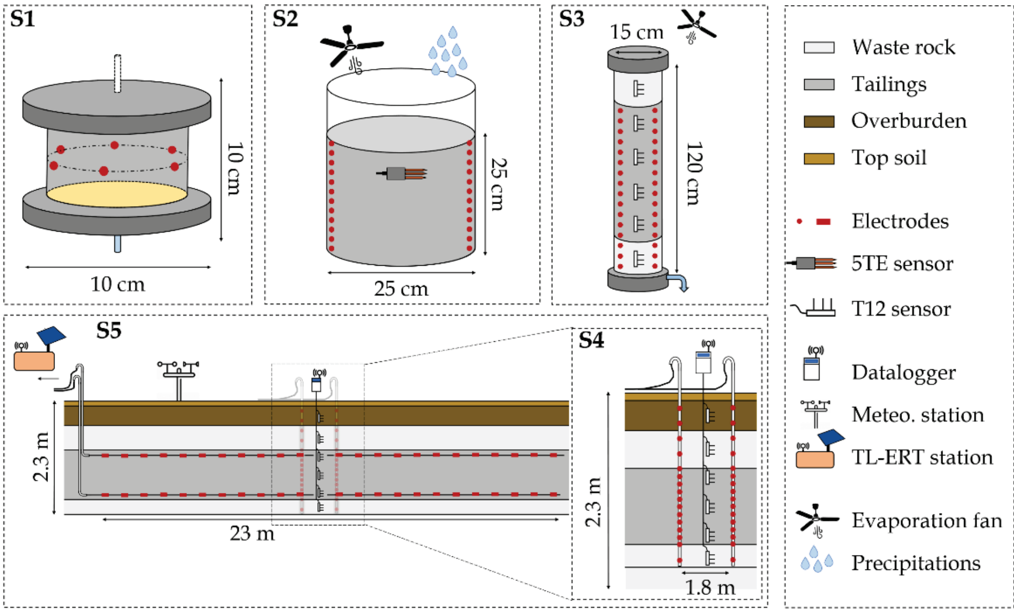
Keywords: mining wastes monitoring, moisture content accuracy, multiscale petrophysics

Accurate and large-scale assessment of volumetric water content (VWC) plays a critical role for mining waste monitoring to mitigate the geotechnical and environmental risks they can represent. In recent years, time-lapse electrical resistivity tomography (TL-ERT) has emerged as a promising monitoring approach that can be used in combination with traditional invasive and point-measurements techniques to predict VWC in mine tailings across larger scales. Generally, the bulk electrical conductivity (EC) imaged using TL-ERT is converted into VWC in the field using petrophysical relationships that have been calibrated in the laboratory at sample scales. This study is the first to assess the scale effect on the accuracy of ERT-predicted VWC in mine tailings.

A simultaneous and co-located monitoring of bulk EC and VWC is carried out in mine tailings at five different scales, ranging from a few centimeters sample-scale cells, to a 20 m-long experimental cover in the field. At each scale, the hydrogeophysical datasets are used to calibrate an Archie petrophysical model, which is used to predict VWC from TL-ERT data at the other scales. Overall, the accuracy of ERT-predicted VWC is ±0.03 m^3/m^3 at the scales studied, and the petrophysical models determined at sample-scale in the laboratory remain valid at larger scales. Notably, the impact of temperature and pore water EC evolution plays a major role for VWC predictions at the field scale (tenfold reduction of accuracy), and therefore, must be properly taken into account during the TL-ERT data processing using complementary hydrogeological sensors. Based on these results, we suggest that future studies using TL-ERT to predict VWC in mine tailings could use sample-scale laboratory apparatus (similar to the electrical resistivity Tempe cell presented here) to calibrate petrophysical models, and carefully upscale them to field monitoring applications.

Figure: Illustration of the five scales studied to assess the accuracy of predicted VWC in tailings. S1 to S3 refer to laboratory application (≈ cm). S4 and S5 refer to experimental field scale covers (≈ m) at Canadian Malar-tic gold mine in Québec, Canada.



A review on applications of time-lapse electrical resistivity tomography over the last 30 years: perspectives for mining waste monitoring

Adrien Dimech[1,3], Lizhen Cheng[1,3], Michel Chouteau[2,3], Jonathan Chambers[4], Sebastian Uhlemann[5], Paul Wilkinson[4], Philip Meldrum[4], Benjamin Mary[6], Gabriel Fabien-Ouellet[2], Anne Isabelle[2,3]

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Keywords: mining wastes monitoring, geotechnical and geochemical stability, literature review

Mining operations generate large amounts of waste, which are usually stored into largescale storage facilities which pose major environmental concerns. They must be properly monitored to manage the risk of catastrophic failures and to control the generation of contaminated drainage. In this context, non-invasive monitoring techniques such as time-lapse electrical resistivity tomography (TL-ERT) are promising since they provide large-scale subsurface information that complements surface observations and traditional monitoring tools, based on point measurements.

This study proposes an overview of TL-ERT applications and developments over the last 30 years, which helps to better understand the current state of research on TL-ERT for various applications. In particular, the review focuses on the applications of ERT for mining waste characterization and monitoring to identify promising applications for long-term autonomous geoelectrical monitoring of the geotechnical and geochemical stability of mining wastes. Reference libraries have been created and made available online to facilitate future research on mining wastes using TL-ERT.

The review considers recent advances in instrumentation, data acquisition, processing and interpretation for long-term monitoring. It also draws future research perspectives and promising avenues which could help to address some of the potential challenges that could emerge from a broader adoption of TL-ERT monitoring for mine waste rock piles (WRP) and tailings storage facility (TSF) monitoring.

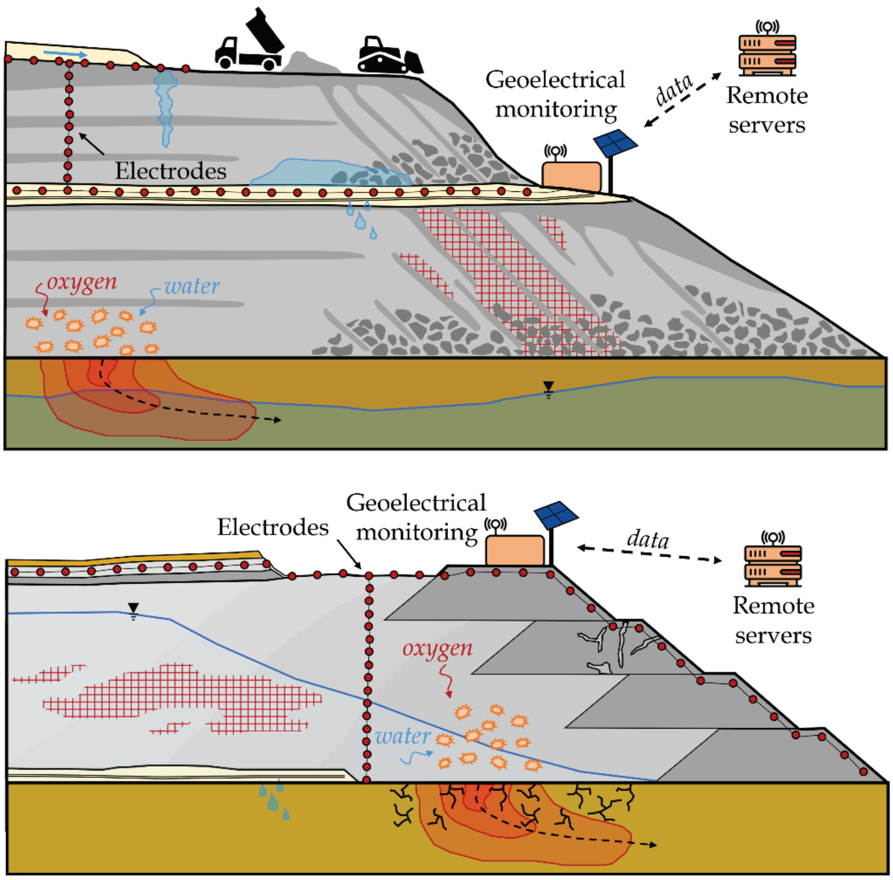

Figure: Graphical review of the main characteristics that could be monitored using TL-ERT for geotechnical and geochemical stability monitoring of WRP (top figure) and TSF (bottom figure).

A collection of Jupyter Notebooks for coupled hydrogeophysical inversion of geophysical monitoring data

Line Meldgaard Madsen[1,2], James Boyd[2,3], Paul McLachlan[1], Joshua Thompson[4], Andrew Binley[2]

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Keywords: hydrogeophysics, coupled inversion, geoelectric monitoring

Geophysical monitoring data are increasingly being used for calibration of hydrological models. In a coupled hydrogeophysical inversion approach, the geophysical data are not inverted in a traditional manner. Instead, the geophysical data and realizations of a hydrological model are combined in an optimization process for calibration of the hydrological model parameters. In a coupled approach, this process minimizes the misfit between the observed geophysical data and geophysical data computed from the hydrological realizations using petro-physical relations.

Here, we present a series of flexible Jupyter Notebooks that can be used for coupled hydrogeophysical inversion. A flexible optimization scheme allows the user to combine different geophysical modalities (electric resistivity, TEM, and FEM data) and hydrological modelling software (e.g. HYDRUS, SUTRA, and MODFLOW) in order to adapt the notebooks for calibration of a specific hydrogeophysical problem.

In two examples, we present the calibration of a 1D infiltration problem (see Figure) and a 3D tracer test, where 1D and 3D electric resistivity monitoring data, respectively, have been used to determine the hydraulic conductivity of the models. We use the Jupyter Notebooks to compare different survey setups and the use of other complementary geophysical methods to assess their sensitivity and value in coupled hydrogeophysical inversions.

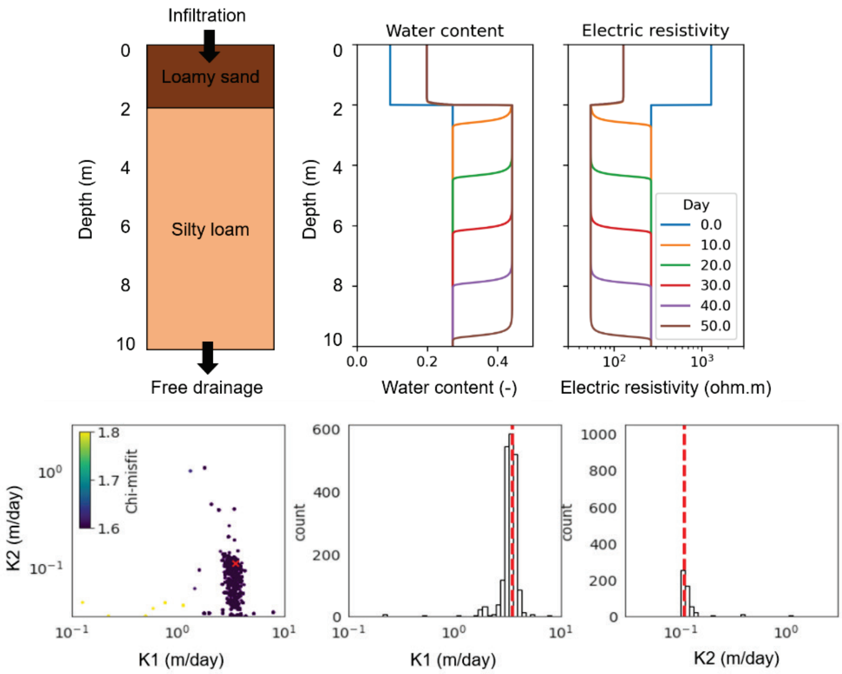

Figure:
Top panel: The two-layer hydrological model of an infiltration experiment, the resulting water content and the equivalent electric resistivity profile.
Bottom panel: calibration results of the hydraulic conductivity in the two layers (K1 and K2) using synthetic 1D resistivity monitoring data. The dashed red line is the true model.

Geostatistical regularization methods for synthetic ERT crosshole imagery

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Keywords: geostatistical regularization, crosshole imagery, smoothing constraints

Electrical resistivity tomography (ERT) is used for imaging and monitoring method with plenty of applications in geology, hydrogeology, environmental investigations hydrogeophysics, etc. A special implementation of ERT is crosshole ERT where electrodes are in boreholes. Although it requires greater effort, this setting allows for better resolution at depth and long-term monitoring even where surface electrodes cannot be left in place at the ground surface.

The most common imaging method in ERT is based on a formulation of the inverse problem as an optimization problem. Solving this ill-posed inverse problem depends on the minimization of a function (Φ) that is comprised by two terms. The first term corresponds to the misfit between the reconstructed model response and the observed data, while the second term, constrains for the uniqueness of the minimization problem.

With the classical regularization, the constraints in the second term are defined between a cell and adjacent cells. In contrast, the geostatistical operators consider expected correlations between reconstructed parameters in a wider neighbourhood around a particular cell. In slightly deformed stratified media, geostatistical regularization showed that it leads to geologically more realistic and accurate results than approaches based on classical smoothing constraints with anisotropy (Jordi et al., 2018). However, one of the main challenges is the determination of the correlation model to be used in the constraints. This correlation model could be derived from prior knowledge (e.g. local geological setting) or from observations and sampling conducted during the drilling of the boreholes.

To assess how the correlation model parameters could be derived from observations in the boreholes, we designed a set of synthetic cases. In these cases, the resistivity field is the realization of a geostatistical random function characterized by a known correlation function with geometric anisotropy. The random fields (synthetic reality) were then sampled along vertical lines representing boreholes. From the geostatistical analysis of these samples, a coarse model of the main directions and correlation lengths of the resistivities, represented by an ellipsoid, is derived. Using this information in the geostatistical constraints of the regularization term, we could obtain inverted sections that are closer to the synthetic reality than using classical smoothing constraints.

In a second step, alterations of the random field were made to simulate local changes in the resistivity field. These experiments reflect the dynamic nature of phenomena that could be monitored by crosshole long-term ERT monitoring systems.

Jordi, C., Doetsch, J., Günther, T., Schmelzbach, C., Robertsson, J. O. (2018): Geostatistical regularization operators for geophysical inverse problems on irregular meshes. *Geophysical Journal International*, *213*(2), 1374-1386, https://doi.org/10.1093/gji/ggy055.

A Study of TX/Electrode Noise on ERT Measurements

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Keywords: data processing, ERT, instrumentation

In electrical resistivity tomography (ERT) surveys, the same electrodes are often used as both transmitters and receivers. To study this error source, tests were carried for different metal electrodes. These tests included both "experienced" electrodes from previous field projects and electrodes that were sanded and cleaned with a descaling compound. The study used 100% duty cycle waveforms from 0.75 Hz to 7.5 Hz. The electrode responses are dominated by the final transmitter pulse so the A response is negative and the B positive. For each test, four electrodes were tested with each serving as both an A and B electrode.

The upper panel shows electrode voltage responses for cleaned stainless steel electrodes at source currents of 50 and 400 ma. These have been filtered to remove powerline harmonics. Both A and B responses are roughly of the form $(t) \cong a\,(t+b)^{-\frac{1}{2}} + \mathrm{c}$. Responses are largest at early times and at high currents but there are significant errors at long times and at low current flows. The responses are very nonlinear with respect to source current and even very small source current can produce electrode error voltages of hundreds of millivolts.

The lower panel of the figure shows the estimated errors in processed voltages for progressively higher order stacking approaches. Here, the order of the stack method, *n*, is highest order polynomial, t^n, which is removed by the stack method. For example, for *n*=0, the lowest order stack approach, the stacked voltage, $V_0(t)$, at time, *t*, is given by $V_0(t) = ½(\,v(t) - v(t+h))$, where *h* is ½ waveform length. This stack approach will remove a constant voltage offset but won't remove voltages that vary linearly with time. In this test, for *n*=0, the resulting error voltages are greater than 1 mV for time as late as 30 seconds. However, high order stack approaches drop the electrode response below the system/site noise floor in about 8 seconds.

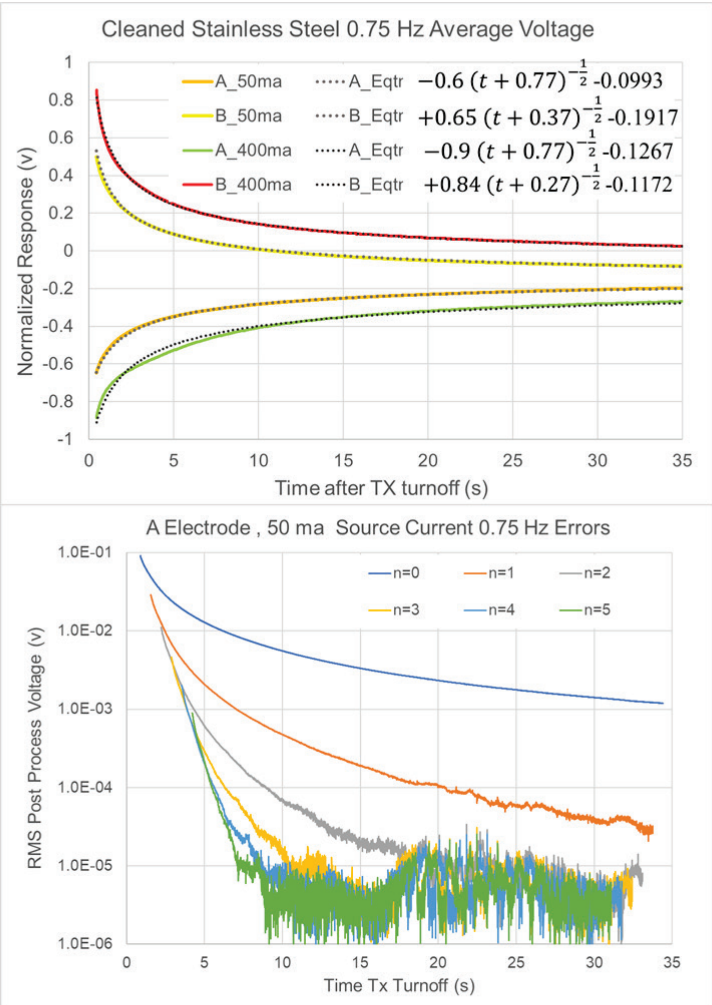

Figure: The upper graph shows the voltage decays due to transmitter charging cleaned, stainless-steel electrodes. The lower graph shows the root-mean-squared errors for single stacks with orders from 0 through 5. Each filter has n+1 points and the plot point is the center time of the stack sequence.

Quantification of connectivity in ERT images based on Euler-Poincaré-characteristic

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Keywords: ERT, connectivity, inversion

Flow processes in the heterogeneous subsurface are controlled by the spatial distribution of regions with contrasting hydraulic (water flow) or thermal properties (heat flow). The dynamics of water and heat flow are not only controlled by the amount of conductive regions but by their connectivity as well to ensure that the processes are not obstructed by regions with low conductivity. The quantification of structure connectivity and its preservation in the inversion of ERT images is therefore required for modelling flow and transport. In addition to the percolation threshold (defining the critical electrical conductivity value that must be exceeded to form continuous structures across the boundaries of the system), the Euler-Poincaré-characteristic (EPC) can be used to quantify the connectivity of the subsurface. The EPC is a topological measure defined by the numbers of vertices, edges, and faces (in 3D) of a geometric figure. In binary images, the EPC is the number of disconnected regions of interest minus the number of holes in these regions. The EPC is high for systems with many disconnected regions and becomes negative for a highly connected network (a single structure with many holes). In contrast to percolation thresholds that must be calculated by testing the occurrence of structures spanning the entire system (requiring a 'global' analysis of the system), the EPC can be calculated easily as sum of local attributes (number of edges and vertices). To apply EPC in ERT images, a resistivity threshold ω is applied to separate more conductive regions with lower resistivity values from less conductive regions. By changing the threshold systematically from small to large values, the EPC as function of resistivity value EPC(ω) is obtained. The objective of the presentation is to introduce the EPC with illustrative examples and to apply it for a series of measured and synthetic ERT images. We will discuss the added value of EPC(ω) as descriptor of conductivity patterns and show the sensitivity of the EPC as function of parameter values and electrode arrays in the inversion process.

An efficient and low-cost measurement system for IP monitoring of deep structures by long survey line

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Keywords: TDIP, mining, ethernet cable

The present study developed a low-cost and lightweight potential receiver system using ethernet cables and small switch boxes, to perform a time-domain IP measurement on a long survey line for the purpose of monitoring the IP property structure at depths. Various measurement systems have been developed to monitor resistivity structures in a shallow subsurface, in order to understand temporal changes in groundwater flow and passive remediation of contaminants. In particular, multi-core cables and scanners have made it possible to efficiently acquire data with a very large number of channels, and been used for ERT monitoring and other applications. However, in the case of IP measurement at deeper depths, using a single multi-core cable both for current injection and potential measurement may result in poor data quality due to EM coupling. In addition, multi-core cables tend to be thick and heavy, and the total weight of a long measurement line exceeding several hundred meters becomes very large and costly. Furthermore, wiring multi-core cables is a difficult task when measuring in mountainous areas where the terrain is rugged. In this study, the cable system for current injection and the system for potential measurement were separated, to avoid EM coupling by current injection. Therefore, the multi-channel measurement system using ethernet cables less susceptible to crosstalk was developed to improve data quality, increase work efficiency, and reduce costs.

In this system, equally spaced potential electrodes are connected to the switch boxes, and each switch box is connected by the ethernet cables. The ethernet cable, consisting of 8 cores, enables simultaneous acquisition of up to n=7 data with a single current injection using Dipole-dipole array. A time-domain IP measurement was tested at a mine in Japan using this system. The survey line has a length of 700 m with 50 m electrode spacing. It is known that this mine is a black ore-type deposit, containing sulphide veins and disseminated sulphides composed of pyrite, chalcopyrite, and sphalerite at depths below about 50 m below sea level. In this experiment, IP anomalies corresponding to these locations were successfully detected. In addition, the ethernet cable system is lightweight, weighing only about 2 kg even with a length of 50 m, so it was possible to significantly reduce the burden of wiring work in spite of the heavily rugged topography of the investigated area with an obliquity of about 30°. This system would be suitable for repeated time-domain IP measurements for deep structures.

New developments of OhmPi, an open-source and open Hardware resistivity-meter

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Keywords: low-cost, monitoring, resistivity, electronics

A major research effort in recent decades has led to the development of multi-electrodes, multi-channels, accurate, robust and versatile resistivity meters. This work has contributed to the emergence of the electrical resistivity tomography technique and has led to major advances in many fields such as geosciences or the environment or civil engineering. The main limitation of this equipment does not lie in its quality or robustness in the field. It concerns the cost of the equipment and its low adaptability for specific scientific problems.

For these reasons, the method is underused for humanitarian applications, in developing countries and for non-profit applications (archaeology, environment). In the field of environment, civil engineering or geosciences, geophysical monitoring has become a key to assess natural systems and phenomena. For these problems, the immobilisation of one or more resistivity meters is not always technically and financially possible. Finally, many applications today require the ability to control the measurement with external information and thus optimise the measurement in the context of a "big data". The OhmPi project aims at proposing an open source hardware and software resistivity meter to the community and the academic world. The objective of this work is to present OhmPi, an open source resistivity meter based on a Raspberry Pi board for dedicated applications. In a first step, we will briefly present the hardware required for multiplexed 4-points measurement. In a second step, we will present the results obtained during laboratory and field experiment. In the last step, we will introduce the latest developments, in particular the proposed communication protocol and the new graphical user interface.

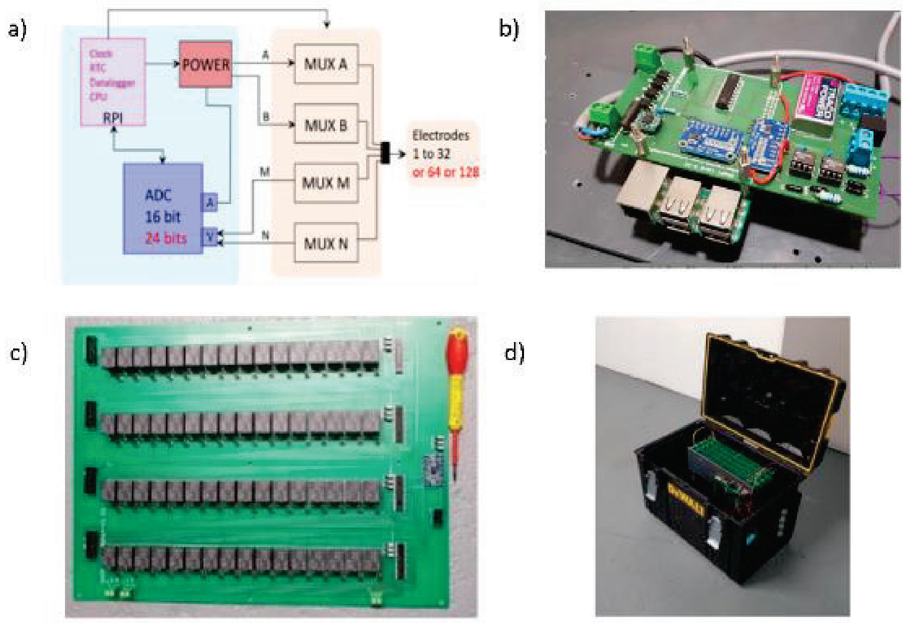

Figure: Ohmpi v2 description: a) schematic of Ohmpi, b) new plug and play acquisition board plugged on a raspberry Pi 3B, c) new I2C multiplexer board 64 electrodes, d) Ohmpi in the box.

The GEOMON4D-IP resistivity meter – comparison to the old GEOMON4D system and improvements for monitoring applications

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Keywords: resistivity meter, monitoring, IP

Although several commercial resistivity meters were put on the market (e.g. the IRIS Syscal, the AGI Super Sting R8, the ABEM Terrameter, etc.), a couple of research groups are developing their own resistivity meters. The motivation for those in-house developments is mainly the request to have a system at low hardware costs, which is highly adaptable to specific research questions. For monitoring applications, the full insight to system details as well as the possibility of quick repair of technical malfunctions (e.g. replacement of hardware components) play an important role.

The GEOMON4D system, developed by the Department of Geophysics at the Geological Survey of Austria (Supper et al., 2012), has been in operation in different monitoring applications and in standard field surveys for almost 2 decades. Within this period, just a few minor technical adaptions were made. Thus, the electro-technical components were not up to date anymore and a reliable supply of some specific spare parts became difficult. Subsequently, a larger redesign of the geoelectric system became necessary. In the course of this redesign, the GEOMON4D was extended to the possibility of time domain IP measurements. In a first step, the new GEOMON4D-IP resistivity meter was developed as a robust ERT/IP system for standard field surveys (in use since 2020). In a second step, all necessary tools for monitoring applications were implemented (remote access, definition of monitoring jobs, etc.) and final adaptions, based on the feedback from extensive field use, were made.

Compared to the old system, the new system received several improvements for monitoring applications. In addition to resistivity monitoring, now also time domain IP-effects can be monitored – this includes the possibility to define complete arbitrary measuring sequences (time of current injection, recording time (windows)) up to the option of a full waveform recording. Furthermore, current injection was changed from a constant voltage to a constant current source and the measured voltage range was expanded from 10 to 80 V. The sample frequency can be varied in defined steps from 2 to 15 kHz (resolution versus data amount). Similar to the former system, the full sample data can be read out from the GEOMON4D-IP and can be used for further processing steps (QC, filtering options, etc.). The reduced system/standby power consumption (20 W to 5 W now) saves energy and is a special improvement for remote monitoring locations without connection to the power grid. The update to the newest electro-technical components caused a higher measuring accuracy, which is particularly important for monitoring data. The final development step, which is planned for the next year, is the implementation of a climate box for corresponding temperature sensitive electronic parts, as well as the expansion to a two-channel system.

Supper, R., Römer, A., Kreuzer, G., Jochum, B., Ottowitz, D., Ita, A., & Kauer, S. (2012). The GEOMON 4D electrical monitoring system: current state and future developments. *Berichte der Geologischen Bundesanstalt*, **93**, 23–26.

Long-term Geoelectrical Monitoring of bedrock permafrost in the Kammstollen, Zugspitze (Germany/Austria)

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Keywords: permafrost, ERT, tunnel

In the last decades, electrical resistivity tomography (ERT) became the standard technique for permafrost monitoring. Changes in resistivity allow to quantify the response of permafrost to the recent climate change. In high alpine environment, especially in steep bedrock walls, consequences can be critical, putting infrastructures and people at high risk. Numerous locations are monitored along the Alps, mainly installed at the rock surface, and measured once a year. In a few cases, automatic systems have been installed to monitor changes all-year around, but this often implies bad coupling of electrodes, high costs and/or repeated failures.

In 2007, we instrumented a former touristic tunnel at about 2800 m asl on the Mount Zugspitze (D/A) in a unique setup for ERT and temperature measurements. (i) The location can be easily reached by cable car and is accessible all year around, independently from weather conditions. (ii) Measures are taken from the inside towards the rock surface. (iii) An ideal compromise between continuous automatic systems and single annual measurements is achieved with monthly repeated measurements: this allows detailed interpretation of bedrock permafrost reactions to seasonal variations as well as of long-term changes, without the burden of fix costs and the complications of automatic setups. (vi) Standard procedures and permanently installed electrodes allowed the collection of a unique dataset of consistent monthly measurements since 2014. (v) Resistivity-temperature calibration (see Krautblatter et al., 2010) enable an advanced quantitative interpretation of the results.

Results from 25 rock temperature loggers show an increase of rock temperatures in the last decade, with a gradient decreasing with depth - in good agreement with other locations in the Alps. Inversion results from the ERT fit well to this trend, especially in the summer months where a steady decrease of resistivities is measured. Winter months are strongly influenced by the duration and depth of snow cover, showing therefore more variations.

Krautblatter, M., Verleysdonk, S., Flores Orozco, A., Kemna, A. (2010): Temperature-calibrated imaging of seasonal changes in permafrost rock walls by quantitative electrical resistivity tomography (Zugspitze, German/Austrian Alps). Journal of Geophysical Research. 115. https://doi.org/10.1029/2008JF001209.

Figure: from up left, clockwise.
a) Measurements with ABEM Terrameter.
b) Frozen part of the side tunnel in March 2020. c) Outside view of the steep walls and the location of the tunnel in red. d) Main tunnel with pipelines for logistic and communication. Authors: Scandroglio, Leinauer

Quantification of liquid phase connectivity in permafrost soils

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Keywords: ERT, permafrost, connectivity

In recent years, ERT imaging is more frequently used in the context of monitoring of climate induced thawing of permafrost soils. However, to detect the unfrozen water in the active layer using geoelectric methods, resistivity values must be linked to the liquid water content in the subsurface. By comparing ERT and borehole data from the Swiss permafrost monitoring network (PERMOS) at the Schilthorn site (Switzerland), conditions with frozen and liquid water could be distinguished. To classify electrical conductivity values with respect to the presence of a continuous liquid phase, we calculated various connectivity measures like the Euler-Poincaré-characteristic and (local) percolation thresholds of resistivity patterns in frozen and unfrozen soils. By increasing systematically the electrical resistivity values separating an ERT image into regions of high and low conductivity, a resistivity threshold could be defined that must be exceeded to form a continuous pattern of the conductive regions. We show that this critical resistivity value is systematically lower for unfrozen soils, and we apply it to classify ERT-transects with respect to the existence of continuous liquid structures without complementary borehole measurements. The definition of such critical resistivity value separating between frozen and unfrozen regions depends on the relationship between temperature, volumetric water content, and electrical conductivity. This relationship is ambiguous and depends on the amount of liquid water at onset of freezing and the spatial arrangement of the four phases (grains, air, water, and ice). By comparing point measurements of water content and electrical conductivity in a soil profile with ERT transect data, the magnitude of the hysteretic relationship could be quantified to assess its effect on classifying ERT patterns with respect to liquid phase continuity.

Geophysical monitoring of hydrological dynamics across an Arctic watershed

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Keywords: permafrost, infiltration, climate change

Increasing temperatures are rapidly changing the Arctic ecosystem. Yet, we are missing a predictive understanding of the interactions within the bedrock to atmosphere column that are driving ecosystem evolution and carbon-climate feedback. A critical knowledge gap within these systems are the dynamics of surface water - groundwater interactions, and infiltration and groundwater flow processes, which drive permafrost thaw and biogeochemical processes. Geophysical techniques have been shown to be a valuable tool to assess the intermediate depths (1 - 10’s of m) that are particularly important to understanding the impact of climate change on permafrost thaw dynamics and related hydrological dynamics. In this study we compare the results of two geoelectrical monitoring transects that are installed in the lower and upper part of a watershed located in a discontinuous permafrost region, and that are exposed to different temperature and snow regimes.

Given the remote environment, we will first introduce the field setup that allowed us to acquire continuous data throughout the last 3 years. We present the variations in ground conditions and associated changes in data quality, which highlight the expected poor data during the winter season, once the ground is frozen. Comparing the results of the lower and upper monitoring line shows distinct infiltration patterns. The lower transect, which is characterized by warmer temperatures, shows snow infiltration weeks before the upper transect, and a response to rainfall events, which is driven by the distribution of shallow permafrost. The upper transect indicates that summer rainfall events drive distinct infiltration patterns at locations of a deep active layer, as well as variations in the groundwater table. These observations provide additional data that will help in better understanding the complex hydrological processes taking place in discontinuous permafrost environments.

Monitoring permafrost dynamics in Antarctica with automated electrical resistivity tomography: Advances in instrumentation and data processing

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(3) University of Fribourg, Switzerland

Keywords: permafrost monitoring, low-cost automated ERT setup, quasi-continuous ERT measurements, automated data processing

Studies of active layers and permafrost dynamics in Antarctica are typically conducted through boreholes, which are invasive, expensive, and rarely representative at the field level. Electrical Resistivity Tomography (ERT) has become one of the most widely used tools for permafrost research as it allows for non-invasive and cost-effective permafrost investigations in two or three dimensions due to the strong contrast in electrical resistivity between unfrozen and frozen materials. ERT surveys can also provide insights into the dynamics of permafrost and active layer distributions if repeated. However, few operational ERT monitoring sites exist in permafrost terrain due to the logistical requirements of repeating individual profiles annually. In contrast to manually repeated measurements, automated systems (A-ERT) enable continuous measurement of ERT, however such systems are scarce worldwide, and processing large datasets generated by A-ERT can be challenging.

We developed a low-cost and robust automated electrical resistivity tomography setup with a solar panel-driven battery and multi-electrode configuration for autonomous and non-invasive monitoring of active layer and permafrost dynamics. We implemented this system at several sites in the Western Antarctic Peninsula with existing GTN-P and CALM monitoring networks. ERT data were collected in 6-hour intervals, producing long-term quasi-continuous measurements. We also developed an automated data processing workflow to efficiently filter and invert the large obtained datasets, where the inversion process was carried out using the open-source pyGIMLi library. Extracting inverted resistivity values at a virtual borehole enabled assessment of changing site conditions over short and long-time scales and allowed for comparison to measured temperatures and frost probing. Maximum vertical resistivity gradients accurately indicated the depth of the thawed layer in the summer, showing that A-ERT can be used to autonomously monitor active layer depth.

Analyzing the obtained A-ERT datasets, we demonstrate that such low-cost A-ERT setups can operate in remote and extreme environments such as Antarctica and obtain high-resolution ERT data of high quality. Furthermore, we show how we are able to extract key information from a large amount of A-ERT data efficiently and quickly using this developed processing workflow.

Building a Canadian database of geoelectrical surveys of permafrost: Initial time-lapse results

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Keywords: electrical resistivity tomography, permafrost, monitoring

Electrical resistivity tomography (ERT) is increasingly being used by scientists and engineers in Canada to investigate permafrost distribution and characteristics, since frozen/ice-rich ground tends to be highly resistive. Although ERT surveys are now commonly performed, there has been no framework for data sharing, making it difficult or impossible to find and view existing datasets.

Our goal is to create a database of ERT surveys of permafrost so that the data are easily findable. We are also designing a web interface that can easily search for and plot the surveys. Making this data easily accessible will enable a deeper understanding of permafrost conditions in Canada. Additionally, we hope its existence will promote repetitions of historical surveys in order to better understand how permafrost conditions are changing over time in response to climate warming.

Here, we present the database-in-progress and explore examples of repeat ERT surveys. Some repeat surveys (like those in the figure below) show a reduction in permafrost resistivity and spatial extent, indicating warming and thawing of permafrost. Case studies like this illustrate how repeat measurements can be used to understand permafrost change and demonstrate the usefulness of a centralized database to store these surveys.

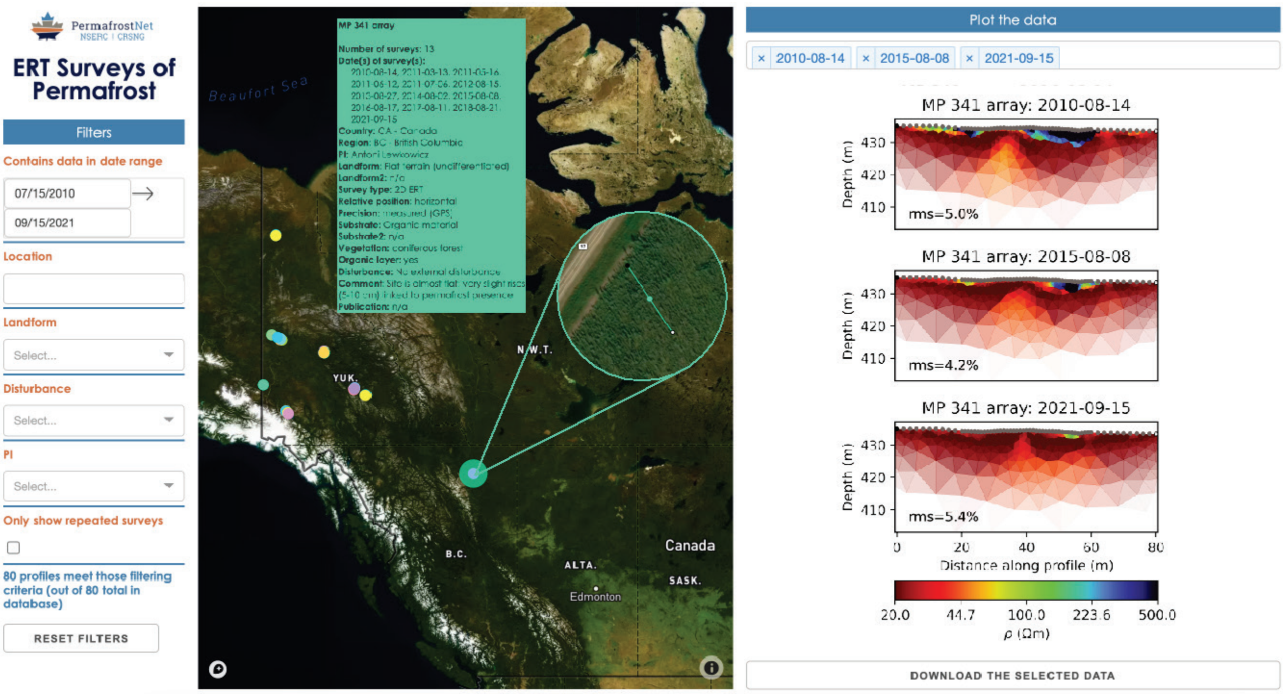

Figure: Screenshot of interactive database showing time-lapse ERT results from a monitoring site along the Alaska Highway.

An international database of geoelectrical surveys on permafrost to promote data sharing, survey repetition and standardized data reprocessing

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Keywords: permafrost, database

Geoelectrical methods are widely used for permafrost investigations by research groups, government agencies and industry. Electrical Resistivity Tomography (ERT) surveys are typically performed only once to detect the presence or absence of permafrost. Exchange of data and expertise among users is limited and usually occurs bilaterally. Neither complete information about the existence of geophysical surveys on permafrost nor the data itself is available on a global scale. Given the potential gain for identifying permafrost evidence and their spatio-temporal changes, there is a strong need for coordinated efforts regarding data, metadata, guidelines, and expertise exchange. Repetition of ERT surveys is rare, even though it could provide a quantitative or at least semi-quantitative spatio-temporal measure of permafrost evolution, helping to quantify the effects of climate change at local (where the ERT survey takes place) and global scales (due to the inventory).

Our International Permafrost Association (IPA) action group (2021–2023) has the main objective of bringing together the international community interested in geoelectrical measurements on permafrost and laying the foundations for an operational International Database of Geoelectrical Surveys on Permafrost (IDGSP). Our contribution presents a new international database of electrical resistivity datasets on permafrost. The core members of our action group represent more than 10 research groups, who have already contributed their own metadata (currently ~ 300 profiles, including ~400 surveys, covering 12 countries) and have started to answer to the recent call for resistivity data. These metadata will be fully publicly accessible in the near future whereas access to the resistivity data may be either public or restricted (according to the data policy of the database). Thanks to this open-access policy, we aim at increasing the level of transparency, encouraging further data providers and fostering survey repetitions by new users.

The database is set up on a virtual machine hosted by the University of Fribourg. The advanced open-source relational database system PostgreSQL is used to program the database. Homogenization and standardization of a large number of data and metadata are among the greatest challenges, yet are essential to a structured relational database. In this contribution, we present the structure of the database, statistics of the metadata uploaded, as well as some exemplary results of repetitions from legacy geoelectrical measurements on permafrost. Guidelines and strategies are developed to handle repetition challenges such as changing survey configuration, changing geometry or inaccurate/missing metadata. Strategy and first steps toward transparent and reproducible automated filtering and inversion of a great number of datasets will also be presented. By archiving geoelectrical data on permafrost, the ambition of this project is the reanalysis of the full database and its climatic interpretation.

Detection of smouldering by electrical resistivity tomography

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(5) National Centre of Excellence in Geology, University of Peshawar, Pakistan

Keywords: fire detection, resistivity tomography, waste fires, biofuel fires, smouldering fires

Spontaneous fires at waste and biofuel storage sites are a serious concern for waste management and biofuel companies and authorities. The toxic emissions from such fires pose a serious threat to the surrounding population and ecosystems. Smouldering fires are difficult to detect because hotspots are usually developed deep inside the stored material. Due oxygen deficient conditions, smouldering fires are non-flaming in nature and are often noticed some days or weeks after its initiation. The main goal of this study was to test electric resistivity tomography (ERT) as a technique to detect smouldering fires. A motivation to employ ERT for detecting the smouldering hotspot was its sensitivity to moisture content and density that varies at smouldering hotspots

A series of tests were performed in this study. To perform the experiments, a plastic bucket was used for holding the test material. The test bucket was equipped with 4 rings of electrodes (8 electrodes per ring). Electrodes were comprised of stainless steel screws that were inserted in the walls of the bucket to allow the flow of current through the test material. An externally controlled hot wire was placed within the test material to trigger smouldering fire within the test material. The full set of ERT measurements was repeated after every 20 min. The data was processed using the freeware pyGIMLi and 3D resistivity plots were created.

From the inversion results it was observed that the resistivity first decreased in the zone around the heat source (Figure B vs. Figure A), which probably can be related to the initial rise in temperature of the test material. At later time steps a zone of higher resistivity developed around the heat source (Figure C), potentially because of drying out of the material surrounding the hotspots. A physical examination of the test material after the trials reveals that the smouldering hotspot travelled in the upward direction. The results suggest that ERT has a potential for early detection of smouldering fires.

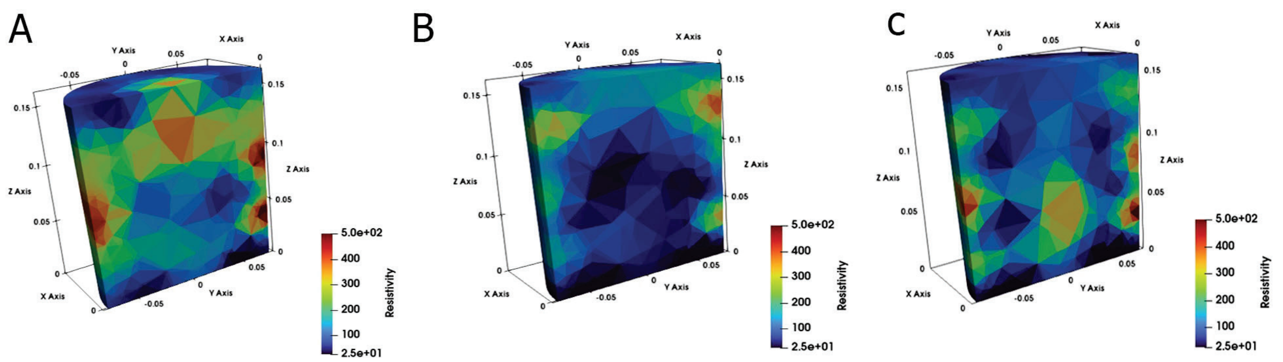

Figure: Vertical cut through view of the 3D resistivity model at three different timesteps; A) at time zero, B) after 100 minutes, C) after 380 minutes.

Acknowledgments: This work is sponsored by ÅForsk under grant number 21-106

Monitoring internal erosion in embankment dams using 3D Electrical Resistivity Tomography: Älvkarleby test embankment dam

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Keywords: electrical resistivity tomography, embankment dam, monitoring internal erosion

One major risk threatening embankment dam integrity is internal erosion of the core. Occurring internal erosion progresses inside the dam structure, but it is difficult to detect with conventional methods. Electrical Resistivity Tomography (ERT) is a potential-based method that can sense the interior of the dam. Leaking zones are typically reflected by larger variations in temperature and total dissolved solids (TDS). Such variations in the reservoir water create resistivity variations inside the dam as the water seeps through the dam body. This study aims to evaluate the capability of ERT as a complementary monitoring technique for discovering unwanted processes such as internal erosion. A test embankment dam with some simulated defects incorporated inside the core and fine filter in Älvkarleby, Sweden has been constructed with the purpose of assessing different monitoring systems including ERT. Buried electrodes and a measurement sequence of around 11’000 data points on a daily basis have been used since around two years ago. The collected data were inverted using a 3D time-lapse inversion model implemented in the pyGIMLI/pyBERT package. The inversion model was partly successful in finding the locations of 3 out of 6 defects. The defects made of crushed rock (Defect 2 & 3) and concrete (Defect 4) in the core were discovered except for the crushed rock zone at the abutment (Defect 5). The defect in the fine filter and a defect made of wood (Defect 1) in the core were not detected. Unintentional anomalous zones, that at least in one case can be associated with other sensor installations, were also detected.

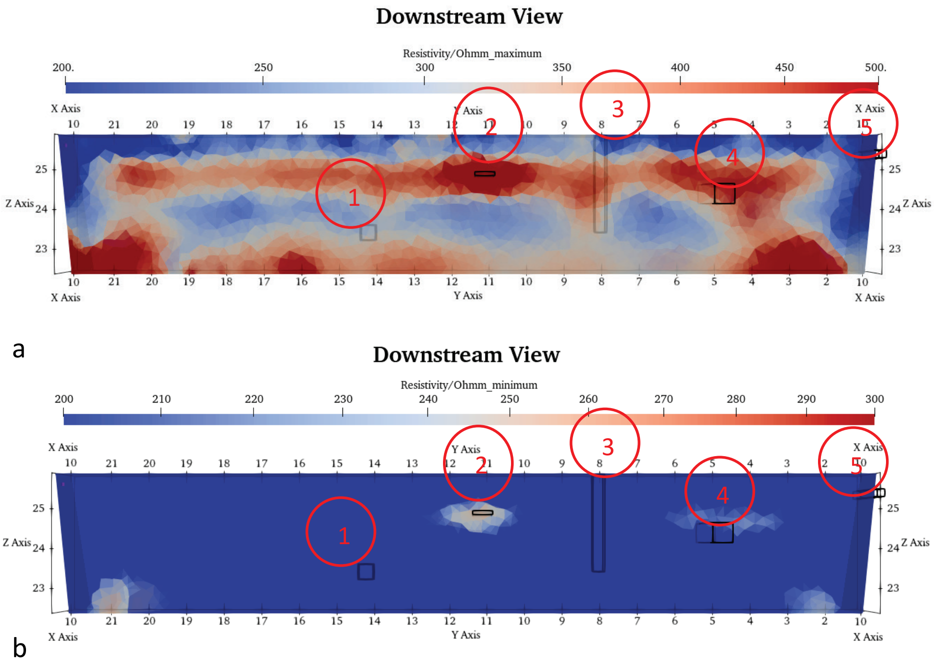

Figure: a) The maximum value of the inverted resistivity through the whole period (from 2019-12-12 to 2022-01-28) for weekly basis data sets; b) The minimum value of the inverted resistivity through the whole period (from 2019-12-12 to 2022-01-28) for weekly basis data sets.

Time-lapse electrical resistivity imaging (ERI) for embankment seepage monitoring

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Keywords: resistivity, embankments, seepage

In recent years measurement of resistivity variations over time i.e., time-lapse ERI, has been used to image subsurface processes, including the movement of water. The technique is of special interest for non-invasive investigation of seepage/leakage through embankment dams and levees where the resistivity of water seeping through these structures varies seasonally with both ion content and temperature. However, modelling and field trials are required to investigate the method's sensitivity and viability.

Since October 2019, a time-lapse ERI system has been operating at the Mactaquac Generating Station in New Brunswick, Canada, as part of a seepage monitoring research program sponsored by NB Power and NSERC. The system, employing 123 electrodes distributed over a 70 m x 25 m area adjacent to a concrete sluiceway structure, runs autonomously each night, yielding data that are typically averaged over one-week periods and subsequently inverted to yield weekly snapshots of the 3D resistivity distribution.

Over the past year, the system's sensitivity to variations in the dam's clay-till core has been substantially improved by incorporating electrodes buried under the road along the dam crest, robust data processing routines and improved topographic modelling. These changes have proven highly effective, as illustrated by data collected between September and December 2021, during which time the resistivity of water in the dam's reservoir more than doubled, allowing the water to be used as a resistive tracer that highlighted regions within the core that appeared to experience preferential flow. Recent data from April to August 2022 is yielding similar models albeit with a seasonal decrease in water resistivity instead. The most strongly anomalous region appears to be in the upper part of the core above ~8 m depth, in agreement with inferences from temperature monitoring in a borehole drilled into the concrete abutment immediately adjacent to the clay-till core. However, the resistivity change images have yet to be compensated for the fact that seasonal fluctuations in reservoir water temperature (and hence resistivity) also decline with depth.

With an adequately long monitoring time series, it may be possible to make order-of-magnitude estimates for seepage flux (and its spatial variation) by analysing the time lag between resistivity changes in the reservoir and in the dam core. While prior time-lapse ERI studies have been conducted using 2D imaging along a dam crest, the system at Mactaquac is novel for its 3D coverage and application to a dam abutment region.

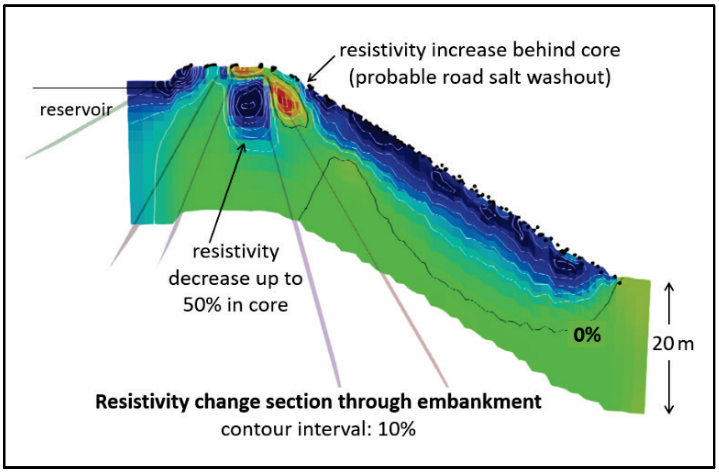

Figure: Cross-section through the embankment, adjacent to concrete structure, showing resistivity change between April 20 and August 19, 2022. A prominent resistivity decrease (dark blue) is evident in the upper core region below the crest.

On the applicability of spectral IP for the characterization of floodplain soils

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Keywords: spectral IP

Induced polarization (IP) can offer additional information on the textural and biogeochemical properties of sediments, for example, to derive robust petrophysical relationships for properties, or states, that commonly covary, e.g., texture and soil water content (SWC). Such relationships have been proposed to interpret geoelectrical monitored data. However, they have principally been explored in lab-based studies; application to field-based studies is comparatively limited.

In this work, single quadrupole measurements were made using an Ontash and Ermac PSIP device at two sites on a river floodplain. In situ measurements of volumetric water content and temperature were made to explore published petrophysical relationships, and samples were collected for gravimetric water content, texture, and cation exchange capacity measurements. The intrusive samples were collected to coincide with the depth of investigation of the spectral IP measurements.

The complete analysis included obtaining Cole-Cole parameters for each of the measured spectra. The Figure summarises some initial patterns in the data. Fig. a displays the expected increasing real electrical conductivity for increasing SWC. Fig. b shows the expected covariance of cation exchange capacity (CEC) and SWC. Fig. c and d show the relationship of imaginary conductivity, a common proxy for surface electrical conductivity, with CEC and sand content. While the measurements in the south field exhibit the expected trend, the relationship for the north field is weak. These results indicate that generalizable relationships may also require information about soil physicochemistry.

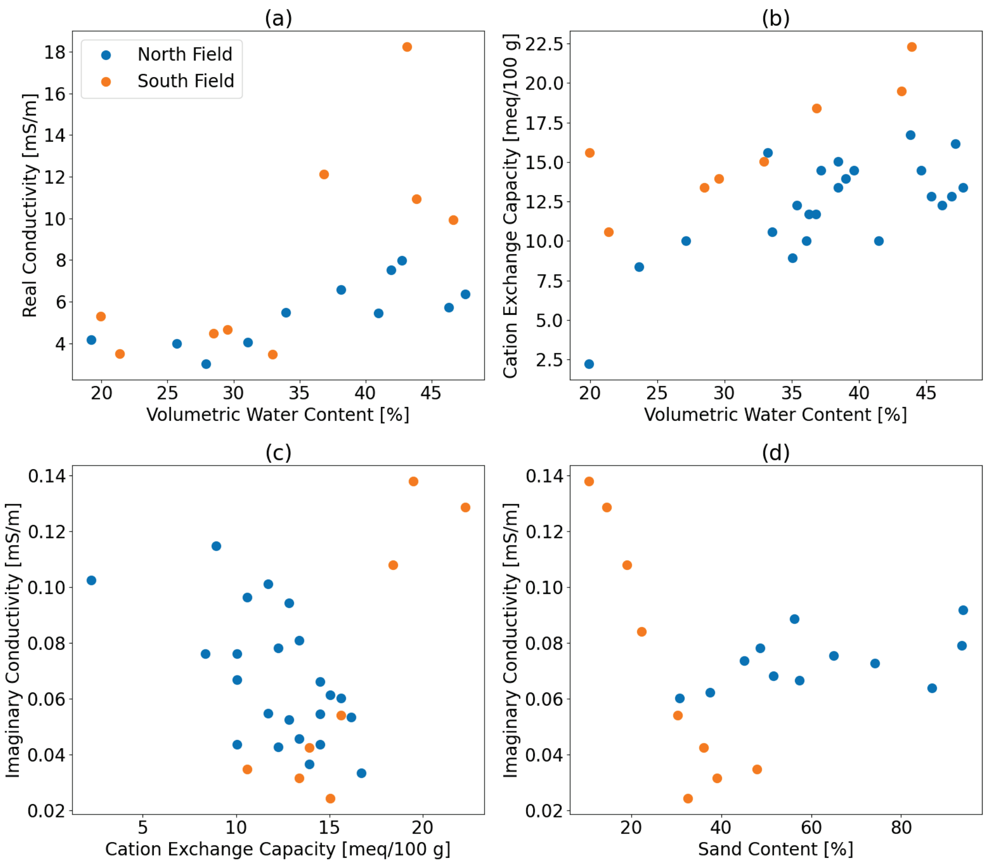
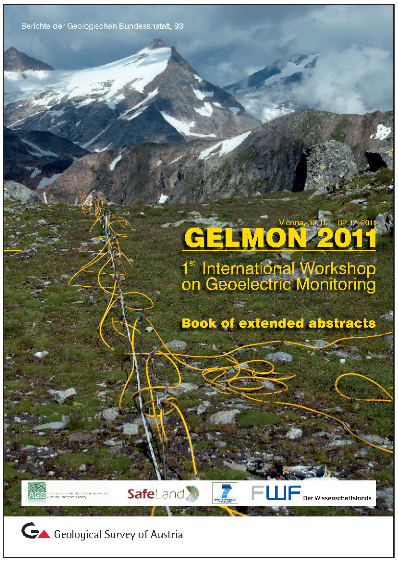


Figure: Summary plots showing covariance of IP and soil parameter



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