Doctoral Days 2025 –Weaving Networks, Growing Ideas

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Campus Telegrafenberg, Building H

Book of Abstracts

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Feasibility study on the repurposing of the doublet well at the Groß Schönebeck research platform

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Since 2000, the Groß Schönebeck site has served as a multidisciplinary research platform, investigating the extraction of geothermal energy via a ~4.4 km doublet well system. As part of the TRANSGEO project, a study was conducted to explore alternative geothermal development options at the site. The study considered the potential of utilising the existing infrastructure for electricity generation and heating purposes. Although the Rotliegend formation was identified as a potential geothermal reservoir with a temperature of ~150℃, it was found to be insufficiently permeable for commercial-level heat production. The study therefore implemented two new technological approaches: an open-system development scenario involving a fracture-dominated Enhanced Geothermal Systems (EGS) and a closed-system scenario involving a single-well coaxial Deep Borehole Heat Exchanger (DBHE) concepts. The fracture-dominated EGS concept is designed to extract heat from the Rotliegend Formation at a depth of 4.2 km, while the coaxial DBHE concept utilises the highly conductive salt layers of the Zechstein Formation at a depth of 3.8 km. A series of numerical simulations were conducted using the CMG STARS software to assess the optimal energy yield from each well. The study's results are complemented by a discussion of measures that could be implemented to increase the feasibility of the concept, as well as an economic assessment of the investment required for the hypothetical development scenarios versus the potential revenue. In accordance with the local regulatory framework, the study provides a comprehensive overview of the procedural steps of the field development phase, with a particular focus on the two scenarios.

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RMT Field Campaign at Laacher See (Eifel): Imaging of CO2-rich fluids rising near the surface

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Since the last eruption of the Laacher See volcano (LSV) in the East Eifel volcanic field (EEVF) around 12.9 kyr ago, the volcanic activity beneath the LSV can still be traced by several gas emissions in the lake and its surroundings. This continuous gas flux is related to CO2 originating from the magmatic system in the upper mantle to the shallow crust at about 10 - 30 km depth, from where CO2 ascends to the surface along preferential fault pathways and leaks out at dry and wet (mixed with iron-rich water) CO2 springs, known as mofettes.

Here, we focus on the CO2 degassing sites of the EEVF on the east shore of the LSV and near the small town of Wassenach north of the LSV with the aim of identifying the CO2-enriched fluid pathways in the first ten to one hundred meters of depth. For this purpose, we have carried out Radio-Magnetotelluric (RMT) measurements in a frequency range of 1 - 256 kHz along six profiles that follow and cross the visible mofettes on the surface, thus indicating the directions of the faults and

fluid pathways at depth. RMT is a powerful electromagnetic (EM) method to determine the near-surface electrical conductivity distribution, as this parameter is very sensitive to fluids and volatile compounds.

The associated electrical conductivity models resulting from a 2D inversion of the measured RMT data support the hypotheses of distinct vertical and horizontal CO2 migration pathways, which are represented as conductive reservoirs and channels in contrast to the more resistive carbonate rocks in the upper 30 m. These findings underscore that the RMT method is a useful tool to further constrain the complex fluid and CO2 pathways underneath mofettes in more detail.

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Probabilistic Solar Wind Speed Forecasting Using Deep Distributional Regression With Solar Images

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The solar wind, a stream of charged particles originating from the Sun, poses significant risks to technology and astronauts. It is driven by large structures on the solar surface like coronal holes and active regions, which can be identified in extreme ultra-violet (EUV) solar images several days before they become geoeffective. In this work, we propose to use a distributional regression algorithm to forecast the solar wind speed at the Lagrange 1 point from solar images. Instead of predicting a single value, this method models the entire conditional distribution as a function of input features. It allows computing the uncertainty of predictions and specifying the probability of the solar wind speed exceeding certain thresholds, which is especially useful for extreme event predictions like coronal mass ejections and high-speed solar wind streams (HSSs). In a deep learning approach, we couple a vision transformer with a probabilistic regression head, additionally using physical input parameters, such as past solar wind properties and solar cycle information. We predict the solar wind speed distributions with a one-hour cadence four days in advance. Our method is trained and evaluated using cross-validation on 15 years of data. We perform a large study comparing different combinations of SDO channels and show that a combination of three different wavelengths provides the most accurate predictions. Our model reaches an RMSE of 75 km/s and an HSS peak RMSE of 78 km/s for the means of the predicted distributions. Additionally, the model approximates the heavy-tailed solar wind speed distribution well and predicts accurate confidence intervals. We show that our model is on par with current state-of-the-art models regarding the general accuracy of predictions, but predicts extreme events significantly better and furthermore enables full uncertainty quantification. That demonstrates the advantages of probabilistic models over standard regression approaches and highlights the potential for operational space weather forecasts.

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Learning to Learn Ahead: Parameter Forecasting in Neural Networks for the Prediction of Remote Sensing Observations

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The growing volume and frequency of streaming remote sensing data present challenges for real-time modeling and forecasting. Traditional batch learning is unsuitable for such dynamic environments, while standard online learning frameworks, though more adaptive, face key limitations. These include one-step-ahead forecasting, prediction latency due to retraining dependencies, and vulnerability to huge shifts in data distribution over time. To address these issues, we propose a novel framework that models the evolution of neural network parameters in relation to specific predictor variables. Our method trains an initial CNN on historical data, captures successive model weight snapshots during online updates, and applies an ML algorithm (e.g., Polynomial Regression) to forecast future parameter states. A new model instantiated with these forecasted weights can predict future data without waiting for retraining. This approach enables multi-horizon prediction, eliminates retraining delays, and, most importantly, is more robust to shifts in distribution. Experiments were conducted on the AMOC (Atlantic Meridional Overturning Circulation) collapse dataset to validate the performance of our model and compare it with traditional batch learning techniques.

Show yourself! / 7

Identifying and Modeling Pathways between Flood and Health in Vietnam and Germany

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Previous hydrological research has focused on the physical basis of flood events. Thereby hydrodynamic models are established often ignoring societal and economic factors. This omission can lead to mischaracterization of flood events. Recently, the pathways between flooding and economic damage have therefore been integrated into the models. However, impacts on physical and mental health are underrepresented in ongoing studies. The aim of my project is to bridging this gap. I plan to map the linkages between physical characteristics of floods, regional socioeconomic factors, and physical and mental health outcomes.
In the first part of the PhD project, a longitudinal structured household survey of Ho Chi Minh City (HCMC), Vietnam, conducted in 2020 and in 2023, is analyzed. HCMC faces recurring seasonal flooding, especially between June and November. The survey allows for a comparison of flood characteristics, flood perception, and disaster preparedness. Three flood events were reported across in the two survey waves. In total, 559 participants answered the questionnaire in both 2020 and 2023, of whom 303 described a recent and a severe event. Of the 559 participants, over half experienced a flood between the survey waves. Participants described self-reported morbidity of various diseases for several household members following the respective floods. The aim of the descriptive study is to identify potential connections between this morbidity and flood characteristics and/or household characteristics. In the next step of the project, the results of the descriptive analysis can be used to develop models describing the pathways between floods and health in HCMC which can eventually be transferred to other regions of Vietnam.

Show yourself! / 8

Investigations and approaches for modeling GNSS clocks in a global network

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Global Navigation Satellite Systems (GNSS) are one of the most important techniques for positioning, navigation and the realization of the International Terrestrial Reference Frame (ITRF), which forms the basis for many coordinate-related applications in the geosciences. The basic principle of GNSS is

to measure the time difference between the transmission of a microwave signal at the satellite and its reception at the ground station. For this reason, clock information is required on both sides.

The quality of the clocks used varies strongly and ranges from highly stable atomic clocks on board of the satellites (e.g. hydrogen masers) to less stable quartz oscillators, which are built into most GNSS receivers. To compensate for the resulting synchronization errors, current GNSS analysis models generally introduce epoch-wise clock biases into the observation equations. The often-made assumption of a pure white noise behavior for the estimated clocks leads to negative effects in the results, especially to high correlations between the clocks and other geodetic parameters. Modeling the clock behavior to reduce the number of unknowns can be a solution to this problem, but requires a high degree of stability for the corresponding clocks.

We present our comprehensive investigations into the clock quality within the station network of the International GNSS Service (IGS). Those IGS ground stations, that are connected to an external H-maser clock, are considered in a global network analysis over a period of one year. The generated clock products are used to compare the frequency stabilities within the station network, as well as with the mean behavior of different satellite blocks. Additionally, the results of first modeling approaches are shown.

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The Role of Triaxial Strain in Deformation Compartmentalizations of the Tibetan Plateau: Insight from "Scaled"Numerical Models

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The collision between the Indian and Eurasian Plates induces simultaneous widespread crustal shortening and extension in the Tibetan Plateau. Collision-induced crustal deformation at regional, orogenic scale is compartmentalized into networks of active faults of locally diverse tectonic regimes. Yet, the correlation between triaxial strain and deformation patterns requires better quantification. We carried out 3D "scaled"numerical models simulating and extending laboratory analogue models of triaxial tectonics involving simultaneous horizontal shortening and orthogonal extension. Our results demonstrate two strain fields, i.e., constriction and flattening strain, which are accommodated by four types of fault networks, respectively: Constriction strain is accommodated by (i) dominant normal faults linking with strike-slip faults and/or (ii) predominant strike-slip faults linking with normal faults, while flattening strain displays (iii) a predominant strike-slip pattern and/or (iv) thrust-dominant regimes with strike-slip faulting. An important implication of our models is that the locally diverse deformation styles are consistent with the regional principal strain tensor in the Tibetan Plateau. Responding to the same overall geological settings, flattening strain is characterized by strike-slip faults in the Shan Plateau and by thrust faults kinematically linked to strike-slip faults in Northern Tibet. Simultaneously, strike-slip as well as extensional regimes accommodate constriction strain in Central-southern Tibet.

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Interferometric radar satellite and in-situ well time-series reveal groundwater extraction rate changes in urban and rural Afghanistan

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Population growth, climate change, and a lack of infrastructure have contributed to an increase in water demand and groundwater exploitation in urban and rural Afghanistan, resulting in significant ground subsidence. Based on a 7-year-long Sentinel-1 radar-interferometric time-series (2015–2022), we assess country-wide subsidence rates. Of particular focus are urban Kabul and the growing agricultural sector of rural Ghazni. In Kabul, we compare spatiotemporal subsidence patterns to water table heights and precipitation amounts. In Ghazni, we monitored the transition from ancient to modern irrigation techniques by mapping solar-panel arrays as a proxy for electrical water pumping and evaluating the vegetation index as a proxy for agricultural activity. Several cultural centers (Kabul, Ghazni, Helmand, Farah, Baghlan, and Kunduz) exhibit significant subsidence of more than ~5 cm/yr.

In Kabul, ground subsidence is largest near the city center with a 6-year total of 31.2 cm, but the peripheral wells of the Kabul basin exhibit the highest water-table drops. In Ghazni, with a 7-year total of 77.8 cm, subsidence rates are dramatically accelerating since 2018. The barren land was transformed into farmland and traditional irrigation was replaced by electrical water pumps to tap groundwater. As a result, m-wide and km-long desiccation cracks appeared in the area with the highest irrigation volume and subsidence.

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Effects of the hydrogeochemical variability of pore water in the Opalinus Clay and its surrounding aquifers on uranium migration

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Pore water and groundwater from the containment providing rock zone (CRZ) and surrounding aquifers provide the initial chemical conditions and boundaries for reactive transport simulations of radionuclide migration in the context of the disposal of highly radioactive waste. Hydrochemical differences between these units cause gradients in the pore water profile across the CRZ, which affect sorption, diffusion and thus migration of radionuclides, like uranium. However, pore water and groundwater compositions differ on the spatial and temporal scales relevant to safety assessments. To quantify the impact of this variability, we performed one-dimensional simulations of uranium migration through Opalinus Clay using the geochemical code PHREEQC, varying both initial and boundary conditions. Our results show that uranium migration distances differ by several decametres over one million years depending on the initial pore water composition in the CRZ. Variations in groundwater chemistry only affect natural uranium concentrations close to the contacts between CRZ and its bounding aquifers. Consequently, the pore water composition in the CRZ is more decisive for uranium migration than hydrochemical variations in embedding aquifers.

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Intersecting economic and disease burden of flooding in Can Tho, Vietnam

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Flood risks pose increasing threats to societal every-day life resulting in cascading impacts on the economy and burden on health and wellbeing of flood-affected populations. In growing urban areas, flooding contributes to increased disease burden through exposure to microbial pathogens. Risk assessments focusing exclusively on economic costs overlook these complex and interconnected impacts resulting in a biased picture of the risk. Our study aims to address this shortcoming by quantifying spatial and distributional disparities in flood risks with a focus on direct economic consequences and disease-burden in Can Tho City, a flood-prone urban area in Vietnam's Mekong Delta. In this respect, we aim to 1) Advance state-of-the-art economic loss models by introducing probabilistic modelling approaches enhancing prediction reliability and ability to capture the uncertainties inherent in flood risk assessment. 2) Develop probabilistic models to predict disease burden corresponding to exposure to E. coli and Rotavirus A. 3) Quantify economic risk metrics –Value at Risk (VaR) and Expected Annual Damage (EAD), and health burden metrics –Population Health at Risk (PHaR) and Expected Annual Cases (EAC), based on probabilistic fluvial-pluvial flood hazard simulations. Our economic loss models are calibrated and validated based on quantitative survey data obtained from residential-use (n = 480) in Can Tho city after the severe flooding in 2011. Additionally, we used pathogen concentrations (E. coli and Rotavirus A, measured in CFU/mL and gc/mL, respectively) obtained from floodwater samples (n = 30) collected after the 2016 flood to estimate the risk of illnesses through quantitative microbial risk assessment (QMRA). Results from the impact models along with the spatial distribution of the multisectoral risk will be presented along with critical insights for equitable adaptation and risk management practices.

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Exploring the impact of river engineering on carbon dynamics of fluvial landscapes

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River systems are a critical link between the short-term biological and long-term geological global carbon cycles. Fluvially transported organic matter and carbon sequestered by biomass can be stored and transformed in floodplain sediments before being transferred by rivers to long-term sinks in the deep ocean. Carbon fixed by plants from atmospheric CO2 can be stored as soil organic carbon (OC) in the floodplain. Conversely, oxidation of organic matter in these environments has been shown to represent a significant CO2 source. The reworking of particulate organic matter during river transport and its intermediate storage in floodplains can promote formation of organo-mineral complexes, facilitating the formation of stable soil OC that eventually feeds back into the geological carbon cycle. Over the past several thousand years, human activities in fluvial landscapes, including river engineering and land use changes, have profoundly altered these biogeochemical fluxes. River straightening and floodplain drainage have disrupted channel–floodplain connectivity, but the net effect on OC dynamics remains poorly constrained. This study traces OC fluxes in both (near-)natural and engineered river systems in Central Europe, focusing on the Odra (Oder) River catchment in Poland and northeastern Germany.

We investigate the record of OC dynamics within a meander loop of the Odra River that was active prior to river straightening in the late 18th century. By analyzing total organic carbon (TOC) content and bulk carbon isotopes (d13Cbulk), we quantify soil carbon stocks and identify carbon sources. Radiocarbon dating (14C), alongside independent sediment age constraints, will be used to estimate OC residence times. Integrating geochemical analyses with remote sensing data will allow

to reconstruct baseline, i.e. pre-engineering, river and carbon dynamics at the site. This will inform implications of meander cut-off on the export of aged soil OC downstream. Planned complementary measurements include assessments of CO2 outgassing from fluvial deposits in the river basin and OC fluxes in the modern, engineered river channel. Together, these efforts aim to advance understanding of the short- and long-term impacts of river management practices on fluvial landscape carbon budgets. This framework is critical for evaluating future landscape management strategies aligned with net-negative land use goals.

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Capturing Flood Vulnerability using SocioHydrological Flood Risk Models: A data-driven Framework

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From dryproofing buildings to installing barriers, private precautionary measures reduce flood losses. Yet their implementation greatly varies with past flood experiences and community risk awareness. Capturing the uptake differences is imperative to understand the evolution of flood adaptation in societies. In this respect, sociohydrological flood risk models (SH-FR) were developed. Based on system dynamics ordinary differential equations are used to link hydrological and societal forces. Owing to the variability in human-flood processes, the application of SH-FR models remains region-specific, limiting generalization and transferability. In my research, I seek to establish a reliable data-driven framework to capture flood-related societal shifts across Germany. I work on developing a deeper process understanding by studying 24 German case studies in order to capture long-term vulnerability trends across regions.
The SH-FR models will be calibrated at the NUTS3 level for the time period between 1950 and 2020 using data from the Global Runoff Data Centre, GFZ post event surveys, and historic data by the HANZE flood archive. Although, this combined data sets represents a valuable resource, it has many limitations, such as data incompleteness and sparseness. The SH FR models will be evaluated using a synthetic data set of 100 regions, that enables tests of performance, sensitivity, and reliability across varied levels of data availability. Insights from the synthetic experiments will inform the application of the SH FR framework to the 24 German case studies, allowing me to assess the approach in both data rich and data scarce contexts.
Through the study of human-flood systems and especially vulnerability dynamics, this work advances the integration of the social component of flood risk with hydrological systems.

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Can NSO compounds help to better understand the role of organic matter in ore-forming processes in the Kupferschiefer?

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The Late Permian Kupferschiefer Formation, a fine-grained, organic-rich marine sediment in north-central Europe, is one of the world's most significant sediment-hosted stratabound copper (SSC) deposits. Economically important accumulations of base metals (Cu, Zn, Pb), rare earth and other metals also occur in the underlying Lower Permian sandstones and in the overlying Ca1 carbonate, summarized as the so-called "Kupferschiefer system". Despite a long history of exploration and research, the mechanisms and precise timing of the formation as well as the source of mineralizing fluids remain debated. Growing evidence supports a multi-phase epigenetic mineralization model involving basinal brines and hydrothermal fluids. The precipitation of metal sulfides was likely driven by the interaction of sulfate-poor but chloride-rich and oxic aqueous fluids with an anoxic pore fluid in micro-environments in the shale (Mohammedyasin et al., 2025). These reactions are expected to have established redox gradients leading to zonation, with copper sulfides enriched near an oxidized zone characterized by hematite staining, the so-called "Rote Fäule", and subsequent zones dominated by lead and zinc sulfides precipitating under progressively more reducing conditions and distance to the Rote Fäule (Hitzman et al., 2010).

Organic matter (OM) is considered to have played a significant role in the Kupferschiefer metallogenesis. Previous studies have reported a strong alteration of OM in mineralized zones close to the Rote Fäule, as particularly indicated by bulk geochemical parameters and non-polar biomarkers (Bechtel and Gratzer, 2001; Püttmann et al., 1991). However, more subtle changes in OM alteration in terms of molecular composition might remain undetected. Recent work from Poetz et al. (2022) has introduced nitrogen-, sulfur-, and oxygen-bearing (NSO) organic compounds as potential sensitive tracers of OM alteration and fluid-rock interaction. However, a systematic investigation of their alteration in mineralized versus unmineralized zones of Kupferschiefer that allows to conclude on their role during mineralization (active player versus by-product) was not conducted yet.

This study aims to fill this gap by examining samples from five boreholes representing different zones of mineralization and redox conditions in the Kupferschiefer. The sample set consists exclusively of TOC-rich Kupferschiefer T1 and includes two boreholes from the Mansfeld district (Cu-rich zone near the Rote Fäule and Pb/Zn zone), and one borehole from a nearly barren Zn-bearing zone from the north of Saxony Anhalt, along with two additional samples from the oxidized Rote Fäule (southern Saxony Anhalt). To assess OM alteration and its role in fluid–rock interactions, conventional geochemical analyses (e.g., Rock-Eval pyrolysis, GC-MS) were combined with high-resolution molecular data obtained by Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS) and compared with previously published data from Poetz et al. (2020) about two Spremberg boreholes located in Cu-dominated and Pb/Zn-dominated mineral zones. While bulk geochemical parameters and biomarker data are available for the entire sample set, FT-ICR-MS data are currently limited to the boreholes from the Mansfeld district.

The main focus of the NSO compound analysis is to trace any secondary alteration of the OM caused by, e.g., contact with mineralizing fluids like oxidation, which has been proposed as a key driver in the Kupferschiefer alteration (Püttmann et al., 1989), and to examine sulfur species in order to assess whether organically bound sulfur may have contributed the formation of metal sulfides. Initial ESI-FT-MS data show depth-related changes in the NSO composition in the Kupferschiefer. Among the acidic NSO compounds, a slight increase in the O/C ratio of the bitumen fraction with depth is observed, while the bulk oxygen index (OI) of the kerogen decreases. This suggests a stronger oxidation of the bitumen in the deeper parts of the Kupferschiefer formations in these boreholes. Nevertheless, the lack of correlation between O/C data and both the mineral distribution in the Kupferschiefer and redox conditions (distance to the Rote Fäule) in the individual boreholes suggests that the depth-related oxygen variations are not directly linked to mineralization but rather reflect a by-product of fluid interactions.

In the Cu-rich zone of the Mansfeld borehole, located right above the Rote Fäule, acidic NSO compounds show a consistent trend with depth of decreasing carbon numbers, molecular weights and hydrogen index (HI) alongside increasing double bond equivalents (DBE), suggesting enhanced demethylation and aromatization of the OM. This transformation is supported by rising phenanthrene/methylphenanthrene (Phen/MePhen) ratios and elevated PAH concentrations with decreasing distance from the Rote Fäule. Similar trends can be observed between boreholes, which are affected to varying degrees by the Rote Fäule.

Acidic sulfur-bearing NSO compounds in mineralized samples from Mansfeld are broadly similar to those described by Poetz et al. (2020) in Spremberg. First results on the sulfur components in the Mansfeld district show minor increases in S/C ratios and sulfur-bearing species with depth are noted, which might also indicate redox processes at the Kupferschiefer base.

To better understand NSO compound alteration associated with mineralization in the Kupferschiefer, further comparisons with FT-ICR-MS data from the barren Zn zone and Rote Fäule samples are ongoing.

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Laboratory-scale investigation of fluid-induced fault slip: Effect of initial effective pressure and injection rate

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Injecting high-pressure fluid into deep reservoirs could promote natural fault reactivation and induce damaging earthquakes. Recent observations suggest that fluid injection rate and effective confining pressure (ECP) could affect the slip behavior; however, their coupling effect on slip patterns is still unclear. We report triaxial laboratory experiments aimed to investigate the combined effect of fluid injection rate and initial ECP on the characteristics of injection-induced fault slip behavior on cylindrical Bentheim sandstone samples containing precut faults, with varying values of fluid pressurization rate and initial confining pressures. Our results show that the fluid injection rate controls fault slip mode at low initial ECP, whereas at high initial ECP, high fluid pressure accelerates fault slip. The acoustic emissions source types, determined from the P-wave first-motion polarity, reveal that shear failure is dominant at low initial ECP, while at high initial ECP the source types are dominated by shear and compaction. A transition from slip strengthening to slip weakening was observed in samples with low initial ECP, while consistent slip strengthening was documented in samples with high initial ECP. At the same injection rate, high initial ECP impedes fast fault slip due to the stabilizing effect of a wider developed gouge layer. Under the same initial ECP, a faster fluid injection rate promotes a higher fault slip rate. We applied a one-dimensional numerical model to study the effect of initial ECP and injection rate on injection-induced slip behavior by considering the rate-strengthening effect. Our results show that the fault slip features are controlled by the coupling between fluid pressurization rate and initial ECP.

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Methanosphaerula subterranea EG compromises cell defense systems in exchange for stable energy metabolism pathways under high CO2 conditions

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Microbial adaptation to high CO2, especially through evolution at the genomic level, can provide insights into the metabolism and survival strategies that may have been employed by the primitive life forms on early, CO2-rich Earth. From the natural high CO2 subsurface environment in Hartousov, Eger rift area, Czech Republic, we isolated an active methanogen strain, Methanosphaerula subterranea EG. Both M. subterranea EG and its sister species, M. palustris E1-9c, share a similar lacustrine origin but have since adapted to contrasting environments (ambient vs. high-CO2) and therefore provide an ideal system for exploring genomic adaptation to high-CO2 conditions. Pan-genomics analysis of Methanosphaerula and their closest relative, the uncultivated genus UBA288, reveals a significant genome reduction on the cell defense systems against viruses. Specifically, strain EG contains only one set of type IV restriction-modification system that relies on a standalone m5C specific restriction enzyme, a single set of type I-E CRISPR system, and limited toxin-antitoxin system, even though virus communities are as influential in high CO2, as in low-CO2 environments. By comparison, most of the reference genome and metagenome-assembled genomes (MAGs) possess more than one set of related systems. In contrast, energy metabolism pathways are much more conserved, as the pathway completeness involving energy harvesting and carbon fixation across the analyzed genomes and MAGs show far fewer differences. The persistence of the high CO2-adapted strain EG in maintaining its methanogenesis and acetyl CoA pathway intact, while compromising its other functional systems, supports the hypothesis that these pathways represent the most ancient biological processes.

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Microbial-induced pedogenesis: Microaggregates as nucleus for initial soil formation

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Soil formation in Antarctica begins immediately after the retreat of ice and snow. Because the continent is almost completely devoid of higher plants and burrowing animals, these processes are shaped primarily by microorganisms. This unique setting provides an opportunity to study the direct role of microbial communities in the earliest stages of pedogenesis. Previous studies have shown that microorganisms respond rapidly to changing environmental conditions and that the formation of soil microaggregates is an initial step in soil development. These aggregates have distinct physical boundaries, suggesting that early soil formation is spatially heterogeneous, with different microhabitats forming inside and on their surfaces. The aim of this project is to investigate interactions between microorganisms, aggregate structure, and soil chemistry using approaches that overcome the limited spatial resolution of conventional bulk soil analyses. To achieve this, we will analyse different microaggregate size fractions and separately examine their interiors and exteriors. Microorganisms will be differentially fluorescently labelled, and flow cytometry will distinguish surface-associated from interior microbial communities. First experiments developing this labelling technique and establishing a protocol for aggregate fractionation are already ongoing. In addition, complementary methods such as micromorphology, fluorescence microscopy, µCT, SEM-EDX, and NanoSIMS will provide structural and chemical data across multiple spatial scales, which will be integrated into a spatially resolved picture of aggregate architecture and microbial distribution. These methods will then be applied to samples from climate-change simulation experiments, designed to mimic shifts in moisture availability, temperature regimes, and freeze–thaw dynamics, in order to assess their impact on early soil development and to clarify microbial interactions with organic matter, soil moisture, clay content, and microaggregation under changing climatic conditions. Finally, all datasets will be merged and analysed using machine learning to model, for the first time, the earliest stages of soil formation.

19

Density Dependency in VERB Simulation: A Case Study in Radi-

ation Belt Physics Using Statistical Sheeley Density and Variable Density from RBSP to Analyze Storm Events

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This study examines how plasma density affects ultra-relativistic electrons (UREs) during geomagnetic storms, using Van Allen Probes observations. We analyze density conditions with both an empirical model and direct spacecraft measurements, and use VERB simulations at very high energies in the URE range to test prediction accuracy. The results show that density variations strongly influence electron responses during storm-time processes.

20

The multiple sulfur isotope composition of diagenetic and hydrothermal sulfides from the Barney Creek Formation (McArthur Basin, Australia): implications for Zn metallogenesis

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The mid-Proterozoic stratigraphy of the McArthur Basin (Australia) contains some of the most well-preserved sedimentary rocks of Precambrian age, which also host giant, clastic dominant (CD-type) massive sulfide Zn deposits. Previous studies on CD-type deposits have investigated δ34S values in order to reconstruct sulfide precipitation pathways; however, δ34S values can be influenced by multiple environmental factors and it is often challenging to differentiate between organoclastic sulfate reduction (OSR), anaerobic oxidation of methane coupled with sulfate reduction (AOM-SR), and thermochemical sulfate reduction (TSR). In this study, we present multiple sulfur isotope data on mineralized and unmineralized samples from the Barney Creek Formation, which hosts the Teena Zn deposit, to try and resolve different pathways of diagenetic and hydrothermal sulfate reduction. The sulfide mineralogy and paragenesis is characterized by fine-grained early diagenetic pyrite, which is then overgrown and partly replaced by coarser grained pyrite and sphalerite. Bulk rock sulfur in powdered drill core samples was extracted from pyrite as chromous reducible sulfur (CRS; n=40) and from sphalerite and galena as acid volatile sulfur (AVS; n=13). The sulfur isotope composition of CRS and AVS broadly overlap, with a wide range of δ34S, Δ33S and Δ36S values, between -2.8 and 35.7 ‰, -0.08 and 0.05 ‰ and -0.40 and 0.67 ‰. A series of Rayleigh distillation trends have been modelled to evaluate possible mixing scenarios. The data plot as convex arrays in $\delta^{34}S$–$\Delta^{33}S$ space, consistent with OSR. There is no evidence of mixing between OSR and AOM-SR, which should result in a concave trajectory; nor is there evidence of TSR, which should produce lower Δ33S values compared to microbial processes. Importantly, the results suggest that hydrothermal sulfides most likely precipitated from sulfur that was derived from the replacement of pre-existing diagenetic pyrite.

21

Investigating Permeability Evolution in Shear, Tensile, and Saw-Cut Fractures under Injection-Induced Slip in Odenwald Granodiorite

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Enhanced Geothermal Systems (EGS) rely on engineered fracture networks to facilitate fluid circulation and heat exchange in low-permeability, high-temperature rock formations. Unlike the conventional gel-proppant hydraulic fracturing techniques used in hydrocarbon extraction, many EGS projects employ hydraulic shear stimulation to enhance permeability. This method leverages the self-propping effect, where rough fracture surfaces remain open due to injection-induced slip. However, the effectiveness and sustainability of self-propping remain unclear, particularly for different rock and fracture types under varying stress conditions. To address this, we conducted laboratory experiments on Odenwald Granodiorite samples to compare the permeability evolution of shear fractures with tensile and saw-cut fractures. Cylindrical specimens containing pre-existing fractures were subjected to critical stress states and increasing injection pressures, while their hydromechanical responses were monitored. Our findings indicate that shear fractures initially exhibit significantly higher permeability than tensile and saw-cut fractures, yet experience a notable permeability reduction due to shear-induced asperity degradation and clogging by fine particles. In contrast, tensile and saw-cut fractures display lower initial permeability but show a modest increase prior to slip, attributed to elastic opening. During injection-induced slip, both fracture types undergo a substantial permeability enhancement, suggesting self-propping effects. Post-slip permeability, however, declines with decreasing injection pressure, primarily due to elastic fracture closure. These results emphasize the key roles of fracture type, rock properties, in-situ stress conditions, and injection pressure in governing permeability evolution and self-propping behavior in EGS applications.

22

Upper-Band Chorus Wave Observations During the Closest Conjunction of NASA's Van Allen Probe B and JAXA's Arase Spacecraft

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The outer radiation belt of Earth is a highly dynamic and complex system. Chorus waves, naturally occurring plasma waves, are considered among the most important drivers of electron acceleration and precipitation in this region. They have in two distinct bands based on their frequency: Upper Band Chorus (UBC; 0.5 fce < f < fce) and Lower Band Chorus (LBC; 0.05 fce < f < 0.5 fce), where fce is the equatorial electron gyrofrequency. Due to their spatial and temporal variability, a single satellite mission cannot provide a comprehensive view, making it essential to combine data from multiple missions for effective understanding and modeling.

In this study, we analyze UBC measurements obtained during a conjunction of NASA's Van Allen Probe B (RBSP-B) and JAXA's Arase spacecraft on April 12, 2018, when the satellites approached within a minimum separation of approximately 865 km. The conjunction event was identified using window criteria of L-shell ±0.25, magnetic local time (MLT) ±0.25, and magnetic latitude ±2 degrees.

The correlation between extracted UBC wave amplitudes measured by the two satellites was small (~–0.2), reflecting the strong spatial–temporal variability of plasma waves. This result is consistent with

existing literature, as a separation of ~1000 km is insufficient to overcome local variability.However, the Probability Density Function (PDF) of chorus amplitudes from the two satellites shows comparable spread and well-aligned peaks, indicating good agreement between their observations. After flipping the RBSP dataset in time order, the Cumulative Distribution Function (CDF) of the maximum of ratios shows that 85% of the pointwise maximum ratios between the two datasets fall within a factor of 2, further supporting strong agreement.

These findings reinforce the feasibility of combining data from both satellite missions with minimal intercalibration effort.

23

Regional Impacts of the El Niño-Southern Oscillation on Hydrologically Excited Length-of-Day Variations: A Cross-Correlation Approach

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The El Niño–Southern Oscillation (ENSO) is a major driver of interannual climate variability, influencing terrestrial water storage (TWS) via global atmospheric teleconnections. ENSO-driven climate anomalies modify continental water mass distributions and subsequently alter Earth's angular momentum, thereby inducing measurable variations in the Length-of-Day (LoD) and polar motion.

In this study, we revisit the regional relationship between ENSO-induced TWS anomalies and the axial component of the hydrological angular momentum (HAM), which reflects variations in Earth's rotation and results in changes in the LoD. Therefore, we utilize four largely independent datasets, including TWS observations from the GRACE/-FO satellite missions; reconstructed TWS from GTWS MLrec that utilized machine-learning techniques; and numerically simulated TWS from two hydrological models (LISFLOOD XR0 and LSDM). Using a lagged cross-correlation method, we identify regions with significant and temporally coherent ENSO responses and quantify their contributions to variations in the LoD applying a basin-based empirical orthogonal function (EOF) decomposition.

Our results demonstrate a robust ENSO imprint on LoD across all datasets, with the Amazon basin emerging as the dominant contributor. LISFLOOD XR0 provides the most consistent representation, while LSDM exhibits artificial variability due to changes in atmospheric forcing, and GTWS MLrec shows damped variability inherent to its statistical reconstruction. GRACE/GRACE-FO confirms the large-scale ENSO signal but is limited by its relatively short data record.

24

Integration of GNSS-T VOD in Multi-scale Forest Structure Monitoring

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Vegetation Optical Depth (VOD), derived from passive microwave remote sensing, is increasingly recognized as a valuable proxy for vegetation water content (VWC) and above-ground biomass

(AGB). However, challenges remain in physically interpreting VOD signals due to the entangled influences of canopy structure and dynamic water content, especially across complex, heterogeneous forest landscapes. This project leverages a multi-scale approach integrating GNSS-Transmissometry (GNSS-T), airborne and ground-based LiDAR, DHP cameras, and in situ hydrological sensors to resolve the structural and hydrological components of VOD. Through analyzing field data across a network of established forest monitoring sites in Germany (VODnet) and and at a high-resolution experimental domain (~100 ha) across a variety of biomes, the study addresses three key objectives: (1) characterizing seasonal VOD variability due to canopy phenology and water loss, (2) mapping structural control over spatial VOD magnitude, and (3) developing a structure-aware surrogate VOD product using machine learning and remote sensing covariates. Additionally, derivation of a relative Live Fuel Moisture Content (LFMC) proxy by decoupling water-sensitive VOD residuals from a structure-based baseline, offers a scalable, non-destructive indicator for forest drought stress and fire risk. Together, these analyses advance the ecological relevance and spatial applicability of VOD for forest hydrology and disturbance monitoring.

25

2,500 years of Ethiopian Hydroclimate from Lake Babogaya

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Ethiopia and the Horn of Africa are densely populated regions that are particularly vulnerable to changing precipitation patterns. Current climate trends show that extreme rainfall events over the Ethiopian highlands cause severe floods in the downstream Nile Valley, such as the flooding of Khartoum in 1999 and 2020. Understanding past precipitation intensity recorded in lake systems under changing climate conditions is crucial for improved flood risk assessments. However, the instrumental record does not extend far enough back to reliably reconstruct longer decadal- and centennial hydroclimate changes and their drivers. Here we present a new hydroclimate reconstruction covering the past 2,500 years from Lake Babogaya (Central Ethiopia).

Lake Babogaya is situated close to the Blue Nile catchment, which is one of the main sources of the Nile River. We applied a multi-proxy approach combining micro-facies analyses, micro-X-Ray Fluorescence (XRF) mapping, and hydrogen (δ2H) and carbon (δ13C) isotope ratios of n-alkanes from plant waxes. The chronology is based on varve counting and radiocarbon analysis of charcoal deposits, which provide the ages for several tephra layers preserved in the core. The samples are dominated by short-chain n-alkanes (nC21 and nC23) likely derived from submerged aquatic plants, with long-chain n-alkanes (nC29, nC31 and nC33) from leaf waxes of higher terrestrial plants also present. Based on preliminary data, we observe pronounced variability in δ2H values over the past 2,500 years, with δ2H values of short-chain n-alkanes ranging from -40‰ to -140‰ and from -100‰ to -160‰ for long-chain n-alkanes. Rapid shifts between 2,000 and 1,200 yr BP might be related to changes in rainfall amounts, moisture sources or vegetation cover. More negative δ2H values around 2,100-1,900 yr BP and 1,300-1,100 yr BP contrast with less negative values around 1,800-1,500 yr BP and 700-600 yr BP, suggesting alternating hydroclimate conditions. In addition, varved sediment intervals predominantly occur during periods of more negative δ2H values, which is potentially related to reduced lake mixing and enhanced varve preservation. Both aquatic and terrestrial n-alkanes show coherent patterns, indicating regional-scale hydroclimate changes affecting both lake and catchment environments.

26

Tracing the influence of minor hydrocarbon seepage on sulfur cycling in marine subsurface sediments

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All hydrocarbon (HC) reservoirs tend to leak to some extent, releasing small quantities of HCs that migrate upwards into the overlying sediments, e.g. seeps. Through microbial activity, these HCs can be completely metabolized before reaching the seafloor, thus not creating any surface manifestations. Despite their inconspicuous nature, these HC fluxes can potentially influence the geochemistry of surrounding sediments and the composition and activity of microbial populations therein, as they add electron donors into the system.
We analyzed 50 gravity cores from the South Western Barents Sea. The sampling sites were located in three areas overlying known HC reservoirs (HC sites) and two reference areas (reference sites) of pristine seabed not affected by HC leakage. Despite the very similar nature of their sediment composition (clay-rich, organic-poor), the 50 gravity cores revealed considerable variability in pore water concentration gradients of various dissolved ions. Nearly linear profiles of pore water sulfate and alkalinity were observed, indicating that there is minimal to no net production or consumption of these ions within the sediment. Still, low rates of sulfate reduction (pmol × cm^3 × d^{-1}) were measured and modeled, primarily at HC sites. Transcriptomic analysis of functional marker genes provided further evidence of enhanced metabolic activity by sulfate-reducing bacteria and methanogenic/methanotrophic archaea at HC sites.
Our findings demonstrate that inconspicuous HC seepage plays a significant role in sedimentary biogeochemical cycles by shaping pore water concentration gradients, influencing sulfate reduction rates, and altering the microbial community composition and activity in marine subsurface sediments. Therefore, sediment geochemistry combined with omics potentially constitutes as a non-invasive tool for HC exploration.

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BIOMETARCHIVE –GEOMICROBIOLOGY OF THE 1 MA SEDIMENTARY ARCHIVE OF FERRUGINOUS LAKE TOWUTI, INDONESIA.

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Lake Towuti, Indonesia, is an oligomictic system that has undergone significant changes in trophic state and redox conditions since the Mid-Pleistocene. Tropical weathering of lateritic soils supplies the lake with high iron inflows but minimal sulfate, resulting in anoxic ferruginous conditions below 130 m water depth. These conditions make Lake Towuti a suitable analogue for Archean and Proterozoic oceans.
In 2015, the International Continental Scientific Drilling Program (ICDP) recovered a 113-m-long sediment core as part of the Towuti Drilling Project. This core, covering approximately 1 million years of depositional history, was dedicated to geomicrobiological investigations. A contamination tracer was added to the drilling fluid to identify uncontaminated core sections, ensuring the integrity of the samples. The project BioMetArchive aims to provide a complete characterization of the lacustrine subsurface biosphere through taxonomic and metagenomic analysis, complemented by environmental and geochemical datasets. This includes identifying the prime microorganisms involved in iron

mineralization and organic matter (OM) remineralization under ferruginous conditions to shed light on the biogeochemical processes that shape Lake Towuti's unique subsurface ecosystem, and transpose these findings to Earth's ancient oceans.
Geochemical analyses showed that water column stratification in Lake Towuti leads to a depletion in terminal electron acceptors (O2, Fe3+, SO42-), just below the sediment-water interface. This resulted in a significant decrease in cell counts (109 to 104 cells × cm-^{3}) and a shift in microbial community composition marked by a transition from sulfate-reducing bacteria (SRB) to fermentative archaea represented by uncultivated clades of Bathyarchaeia. Metabolic features attributed to this class include sulfur transformation and acetogenic fermentation. 16S rRNA gene profiling of microbial populations revealed a drastic decrease in taxonomic diversity inherent to substrate depletion during shallow burial, whereas increased compositional variability in SRB populations was observed in the vicinity of tephra layers and diatom oozes. Microbial alpha and beta diversity also varied with different lithologies across stratigraphic units. Unit 1a, making up the upper 20 m below lake floor (mblf), shelters an active and diverse microbial community, essentially composed of Bathyarchaeia, Hadarchaeota, Acidobacteriota, and Chloroflexota, involved in OM remineralization, as shown by the effective turnover of volatile fatty acids and other solutes in the pore water. Unit 1b, i.e. 20 to 70 mblf, harbours a deep biosphere community adapted to a nutrient-depleted environment, with the relative abundance of Bathyarchaeia exceeding 70%. The lowermost unit 1c, i.e. 70 to 100 mblf, is characterized by deltaic inflows and displays an increased microbial diversity, with Proteobacteria and Actinobacteria as terrestrial elements remobilized from the catchment, alongside dominant Bathyarchaeia.
Thus, variations in 16S rRNA gene assemblages reveal that microbial diversity and composition are closely related to the depositional history of Lake Towuti across the different stratigraphic layers. We conclude that dynamic shifts in Lake Towuti's depositional conditions are tractable in the taxonomic and functional diversity of the subsurface biosphere. During burial, sediment substrate depletion actively selects for acetogenic Bathyarchaeia, highlighting their adaptability and persistence as prime constituents of microbial life in deep sediments.

28

Climate, Tectonics, and Landslides in the Tien Shan: Shaping Alluvial Landscapes in Central Asia

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Fluvial terraces are key archives in understanding alluvial river long-profile evolution in response to drivers like climatic changes, tectonic activity, or geomorphic events of low frequency but high amplitude like landslides. The Tien Shan is an excellent location to study this due to tectonic uplift associated with the India-Eurasia collision and the numerous glaciers reacting broadly to global climate. In detail, the Naryn river and its tributaries host several and widespread terrace generations as well as the largest known landslide in Central Asia.

This study investigates the relative contributions of climate, tectonics and a landslide to terrace formation and long-profile evolution. We combine a set of 38 cosmogenic nuclide exposure samples with 10 optically stimulated luminescence samples to constrain aggradation and incision phases of the rivers that are compared to paleoclimate proxies and other alluvial archives. Additionally, we run a numerical model of long-profile river evolution to understand better the lag time and terrace extent to certain forcings.

Our results suggest that, even when considering the impact of a significant landslide-dammed lake, climate is the key driver of terrace formation. This study demonstrates how a multi-method approach, incorporating recent modeling advances, can enhance the interpretation of alluvial river archives even in complex natural settings and understand the key drivers in landscape change.

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Detecting Climate Transitions with Recurrence Plots: A Case Study of the Younger Dryas

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Biomarker records from lake sediments provide valuable insights into paleoclimate and its transition. This study focuses on n-alkanes (C27, C29, C31), biomarkers derived from plant waxes, and preserved in lake sediment cores. These compounds serve as proxies to reveal paleoclimate conditions.

Biomarker time series from two nearby sediment records, are compared to reconstruct the climate transitions during the Younger Dryas event. In this research, we use lake sediments proxy records from a modern lake and a paleolake in Poland, which were connected with each other. To better capture the phase transition in proxy data, the three compounds (C27, C29, and C31) are combined as components of a reconstructed phase space representing the dynamics of the proxy system. A key challenge is defining and quantifying shared paleoclimate transitions across these records.

To address this, recurrence-based techniques, specifically recurrence plots (RP) and joint recurrence plots (JRP), are applied to analyze and compare the dynamics of the two systems. These methods reveal similarities and differences in the temporal evolution of the paleoclimate. In particular, the joint recurrence plot presents intervals of shared dynamical behavior between two records, allowing to quantify the timing and duration of the Younger Dryas transition.

This study demonstrates how recurrence methods can be applied to paleoclimate proxy data to better characterize regional patterns of abrupt climate events such as the Younger Dryas.

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In-situ Snow depth measurements (1963-2023) in the Chirchik Basin in the western Tien Shan.

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Winter snow accumulation is important for water supply during the summer in Central Asia. Based on daily snow depth measurements, this research quantifies historical changes in snow depth in the Chirchik catchment (Tien Shan region, Uzbekistan) from 1963 to 2023. All snow parameters exhibit a trend towards shorter snow cover and less snow. A more pronounced reduction in the seasonal snow depth was noted during the last 20 years (2003-2023) compared to the long-term periods (60 and 40 years), with a significant reduction of 44.2 cm in the mean seasonal snow depth due to shifts in climatic parameters. Consequently, the discharge volume increased by 11.6% from April to May and reduced by 9.5% from June to September in the Chirchik catchment over the last decades. The changes in the downstream discharge regime are a consequence of the cryospheric changes in the alpine regions with far-reaching impacts.

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The Effect of β-Glycerophosphate on the Crystallization of Amorphous Calcium Carbonate (ACC)

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Calcium carbonate ($CaCO_3$) minerals are widely distributed in organisms as skeletons and hard tissues. This biomineralization process, which controls the formation of $CaCO_3$ in nature, often proceeds via amorphous calcium carbonate (ACC), a metastable precursor phase. However, the mechanisms of ACC stability and transformation remain unclear, particularly the impact of organic phosphates, which play a crucial role in microbial metabolic processes. Here, we investigated β-glycerophosphate (β-GP), a model organic phosphate ligand containing phosphate and glycerol groups, to evaluate its influence on the nucleation and growth dynamics of ACC and on its crystallization to stable $CaCO_3$ polymorphs. Using in-situ UV-Vis spectroscopy, in-situ dynamic light scattering (DLS), scanning electron microscopy (SEM), and X-ray diffraction, we show that β-GP affects the lifetime of ACC, stabilizes vaterite, and influences the sizes of initially formed ACC. These findings suggest that β-GP plays a key role in ACC stability and size, highlighting the relevance of organic compounds in biogenic $CaCO_3$ formation.

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Reactive transport modelling of ore formation in sedimentary basins: non-isothermal compressible fluid flow

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Sediment-hosted ore deposits are major resources for base metals like Zn, Pb and Cu. These deposits form by basin-scale flow of hydrothermal fluids through permeable aquifers and fault structures, incorporating metals from source rocks and transporting them to a deposition site where metals precipitate as sulfide minerals due to fluid reduction and/or fluid mixing. Metal enrichment in hydrothermal systems requires favorable combinations of chemical and physical processes on different temporal and spatial scales. Numerical models can help to identify first-order controls on ore formation and quantify the potential to generate world-class deposits. The aim of this project is to further develop and apply a reactive transport model for the formation of Zn-Pb deposits in sedimentary basins, using fluid flow modelling (CSMP++) coupled with geochemical modelling (GEMS3). The fully coupled numerical model will be able to 1) capture the interplay between the chemical and physical processes relevant for metal mobilization, transport and precipitation, and 2) constrain the temporal and spatial scales required for metal enrichment to economic grades. Geodynamic modeling results of continental rifting and basin formation (Glerum et al., 2024) will eventually inform the model setup to incorporate larger-scale geodynamic controls as well.
The subproject presented here focusses on the numerical representation of non-isothermal compressible fluid flow with CSMP++ within the coupled reactive transport model. In a first step, we developed simplified hydrothermal systems as 1D- and 2D-simulations with basin-scale heat flux and fluid flow based on idealized benchmark simulations (Weis et al., 2014). First tests used existing proxies for the temperature- and salinity-dependent solubility of Cu, Pb and Zn in the ore fluid from Stoltnow et al. (2023). In a second step, we added the full chemistry calculations by coupling with

GEMS3 (Yapparova et al., 2017). We will present preliminary simulations capturing non-isothermal compressible fluid flow and fluid-rock interactions.

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Unraveling the spatiotemporal fault activation in a complex fault system: the run-up to the 2023 MW 7.8 Kahramanmaraş earthquake, Türkiye

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Earthquakes are assumed to be unpredictable, but their forecasting may improve if signatures of preparatory processes can be reliably identified through continuous monitoring. Recent results suggest that years to months before large earthquakes, progressive rock weakening can lead to seismicity localization and coalescence, facilitating fault rupture. If this holds generally, comprehensive, years-long analyses of seismicity may help detect transients signaling proximity to large failure. We test this hypothesis by considering the 2023, Mw 7.8 Kahramanmaraş, Türkiye, earthquake as a case study. A previous study identified an 8-month long activation of seismicity clusters in a complex fault network within 50 km of the future epicenter. To track earthquake evolution at higher resolution, we developed an enhanced seismic catalog combining deep-learning and classic techniques for the six years preceding the mainshock. Recurrent seismicity on the Narlı Fault, a secondary fault where the mainshock nucleated before propagating onto the major East Anatolian Fault Zone intensified months before the event, exhibiting increased localization and interaction. Moreover, in the weeks preceding the mainshock, seismicity surged on a previously quiescent branch aligning with the future rupture plane, yet no immediate foreshocks were observed in the final hours. We propose that persistent damage-induced weakening near the nucleation region primed the system for failure, ultimately enabling rupture propagation toward the main fault. Our findings underscore the importance of long-term, and consistent high-resolution seismic monitoring and analysis for tracking spatiotemporal seismicity transients that may serve as indicators of proximity to rupture.

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3D Lithospheric-Scale Structural, Thermal, and Rheological Modeling of the Southern Central Andes

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Understanding the coupled multi-scale geodynamic processes related to the subduction of the oceanic Nazca Plate beneath the South American Plate is one pre-requisite to better assess seismic hazards in the region. It is essential to identify all relevant forces within the system, such as negative buoyancy of the subducting slab or mechanical coupling between the Andean domain and the Pampean foreland, to analyze tectonic processes like subduction or strain transfer and localization. We approach this by initially investigating the present-day physical state of the subsurface, including first-order variations in pressure caused by mean lithostatic stress, temperature, and rock composition as constrained by multi-disciplinary observations.

For this we build data-based 3D lithospheric models to characterize the system's response to these forces, with particular attention to the rheological behaviour dictated by rock composition, temperature, and pressure. By employing an integrated methodology combining seismic velocity conversions with gravity modelling (IGMAS+), we create refined 3D models of the crust and lithosphere that capture structural, thermal, and rheological properties of the subsurface, as these exert significant control on spatial variations in lithospheric strength and deformation behaviour.

Datasets such as surface heat flow, earthquake catalogues, as well as geodetic observations can then be used to validate the models and shed light onto the underlying geophysical processes active in the region.

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Investigating Ionospheric F-Layer Irregularities through Multi-Source data

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The rapid growth of space-based applications and the space industry requires closer examination of ionospheric irregularities that affect radio signal propagation used for satellite telecommunications and navigation. This research will focus on large-to-small scale plasma irregularities occurring in the ionospheric F-layer. This PhD research aims to study the occurrence climatology, physical origins, and variability of these irregularities by integrating multiple observational techniques, including ground-based GNSS stations, GNSS radio occultation, ionosonde measurements, and geomagnetic data from space missions such as Swarm.

A central objective is to characterize their driving mechanisms, both internal (e.g., atmospheric dynamics) and external by solar activity. The research will also examine coupling processes between different atmospheric layers in order to characterize how the different drivers lead to variations in the electron density. The potential of Artificial Intelligence techniques for automated detection and classification of different irregularity types will also be explored.

By combining and comparing diverse datasets and methodologies, this work seeks to advance the understanding of ionospheric irregularities, their drivers, and their implications for the performance and reliability of satellite-based communication systems.

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Geodynamic controls on the geothermal potential in the Upper Rhine Graben, France-Germany: a multi-scale numerical modelling approach

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The Upper Rhine Graben (URG), situated along the border of France and Germany, is part of the intraplate European Cenozoic Rift System. The graben is widely recognized for its abundant geothermal resources, making it a key region for energy transition initiatives. However, the characterization of the URG's geothermal potential remains poorly constrained due to its highly variable hydrothermal conditions and large observational gaps. Previous studies on fault criticality have often overlooked the role of historical plate movements, oversimplifying the intricate interactions that govern the thermal and structural evolution of the URG over the past ~40 million years.

Using the numerical geodynamic code ASPECT coupled with the landscape evolution code FastScape, we simulate the lithospheric-scale development of fault networks within the URG under geodynamically realistic stress and strain conditions. Our models incorporate various forms of structural and rheological heterogeneities inherited from the earlier Variscan Orogeny, along with a two-stage Cenozoic kinematic history involving rift-orthogonal extension followed by sinistral strike-slip. Preliminary results show the first-order impact of structural inheritance and divergence obliquity on strain localization, which shape the orientation, spacing, and strain rate of the resulting fault network. These results will lay the groundwork for subsequent basin-wide modelling with the thermo-hydro-mechanical code GOLEM, coupling geodynamically controlled basin development with heat and fluid flow simulations that involve shorter-term rock and fracture mechanics. Throughout all modelling stages, we compare our models with available geological and geophysical observations.

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3D data-derived structural, thermal and rheological configuration of Corinth Rift system

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The main objective of the project is to develop an integrated digital twin of the Corinth Rift to test several hypotheses on localization of deformation in the present-day area. The distribution of sub-surface data available in the Corinth Rift and 3D potential field modelling using satellite gravity data will be used to build a 3D model of the subsurface. Tomography models of the upper mantle shear wave velocity field will be converted to temperature and density distributions to test different compositions of this part of the model. This integration of observations with physics-driven simulations will allow a 3D representation of the thermomechanical and isostatic state of the Corinth Rift. The 3D configuration resolving the first-order heterogeneity in physical properties will be compared to observed seismicity distribution. The obtained results will be used to design forward numerical experiments, in collaboration with partners from the University of Bergen.

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Pore Pressure Cycling and Permeability Evolution of Bentheimer Sandstone: Implications for Underground Hydrogen Storage Operations.

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Underground hydrogen storage (UHS) in deep saline aquifers provides a viable approach for large-scale energy storage and mitigates the intermittency of renewable energy sources. The effectiveness of UHS depends on the complex interactions among geomechanical, multiphase fluid flow, and geochemical processes. Cyclic injection and withdrawal operations cause periodic changes in pore pressure, resulting in substantial modifications to reservoir petrophysical properties, including permeability and porosity. To simulate cyclic operation in UHS, a pore-pressure cycling experiment was conducted on a Bentheimer sandstone core under Ketzin reservoir conditions, with a confining pressure of 150 bar, pore pressure between 10 and 120 bar, and a temperature of 37 ℃. Flow behavior and electrical properties as functions of effective stress were evaluated as part of the GeoZeit project. Results demonstrate that porosity decreases as confining stress increases from 0 to 150 bar, and permeability declines with increasing effective stress from 30 to 140 bar. The bulk electrical resistivity of the sample rises with higher effective stress. The permeability-compressibility coefficient *ß* for this pressure range is 8.65 GPa-1 (~0.008 MPa-1), indicating a 0.865% reduction in permeability per additional MPa of effective stress. Compaction-dominated deformation, including grain rearrangement and compression of pore throats, primarily drives the observed reductions in porosity and permeability by decreasing pore volume and connectivity. This effect is most significant during the initial cycles, after which the rock approaches mechanical stability. A comprehensive understanding of these coupled hydro-electrical-mechanical processes is essential for evaluating the integrity and performance of seasonal UHS in saline aquifers

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Geomagnetic field changes during excursions and reversals

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The Earth's magnetic field is characterized by regular and complex changes, reflecting various geodynamo processes. Numerous paleomagnetic studies have provided evidence of multiple geomagnetic polarity reversals and excursions throughout Earth's history. We use data-based paleomagnetic field models such as LSMOD.2, GGFSS70, GGFMB and PADM2M, encompassing different time periods, to analyse the field characteristics during these extreme variations. In particular we study the asymmetry in growth and decay of dipole moment and paleo secular variation (PSV) index during different events. A sawtooth pattern of gradual dipole decay followed by rapid recovery during reversals, as proposed by past studies, has been observed in our study on the Matuyama Brunhes reversal. But, in contrast, we observed an opposite behavior of fast decay and slow recovery during most of the studied excursions, suggesting the possibility that excursions may be governed by a mechanism distinct from that of reversals. Although less pronounced than in the dipole moment, the PSV index also exhibits an opposite asymmetric pattern during excursions and reversals.

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Leveraging Large Language Models for Content Modeling and Assessment of National Flood Adaptation Plans

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With millions of people exposed, global riverine flood risk is one of the major natural hazards worldwide, having caused an estimated direct average annual loss of US$ 104 billion (2015 values) and 7 million fatalities in the twentieth century. Amidst increasing calls for accelerated climate adaptation, including the recent UNEP report, a pivotal question remains: what are the status, effectiveness, and potential of adaptation efforts to reduce future flood risks? National adaptation plans are key instruments in climate risk governance driving adaptation, yet their length and heterogeneity poses challenges to a systematic and automated comparison. Extracting structured insights from these plans requires advanced methods from natural language processing (NLP) and machine learning.

This project develops large language model (LLM)-based methods for topic modelling and content analysis of national flood plans. Our workflow combines text preprocessing, embedding, and guided topic modelling that incorporates 18 predefined flood adaptation measure categories from the EU Floods Directive. This enables structured analysis of adaptation measures, assessment of their diversity and prevalence across countries and regions, and exploration of correlations with hazard characteristics, damages, and economic indicators. In addition, the workflow supports the detection of emerging or overlooked adaptation strategies.
(Project ongoing)

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Model calibration without calibration data

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Geomechanical–numerical modeling aims to predict the 3-D in situ stress field for example to assess the distance to failure of larger rock volumes. However, model calibration typically relies only on few stress magnitude measurements that are expensive to acquire. In addition, these in-situ measurements represent meter-scale conditions and may not capture the stress state over larger rock volumes. Here I propose to overcome these limitations by using alternative data from borehole images that are routinely collected during site exploration as well as formation integrity tests (FITs). Even though image data provide only upper and lower limits of the stress state, their advantage is that they scan the rock volume along the entire borehole with high resolution.
In the Zürich Nord-Ost siting region for deep geological repository for radioactive waste in northern Switzerland, we have access to an exceptional calibration dataset of stress magnitude data. This dataset combines extensive laboratory measurements of Young's modulus and rock strength with borehole imaging and FITs. Using the stress magnitude data alone yields accurate stress predictions and therefore serves as a benchmark to evaluate models calibrated solely with indirect indicators of stress.
Our approach integrates from the borehole images the interpreted borehole breakouts (BOs), drilling-induced tensile fractures (DITFs), FITs, and the documented absence of BOs and DITFs at locations where stress magnitudes were measured. We developed a numerical framework that explores ~63,000 combinations of boundary conditions, estimates the local stress state at each observation point, and quantifies the agreement between predicted and observed stress indicators to identify the best-fitting boundary conditions.

Results show that stress predictions based only on indirect observations are as precise as those calibrated with direct stress magnitude measurements. This demonstrates that indirect datasets, readily available during routine site exploration, can provide reliable, uncertainty-quantified stress predictions for subsurface projects such as energy storage, CO_2 sequestration, and tunneling.

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Influence of iron on glacier ice algae growth, color and photophysiology

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Glacier ice algae of the genus *Ancylonema* are the main primary producers on glacier ice surfaces, where they thrive under harsh conditions, including high irradiation and low nutrient availability. They produce the dark pigment purpurogallin to protect themselves from high irradiation, thereby darkening large areas of the ice surface. This leads to a reduction in ice surface albedo and an associated enhanced surface melting. The increase in surface meltwater, in turn, promotes algal growth, resulting in a positive feedback loop accelerating the melting of glaciers and ice sheets. One essential, and possibly limiting, trace metal for microalgae on the Greenland ice sheet is iron, which plays a vital role in several cellular processes including photosynthesis. In this study, we used laboratory *Ancylonema* cultures to investigate the influence of iron on glacier ice algae growth, color and photophysiology. Media supplementation with iron did not significantly influence growth rates or photophysiology of the cells but contributed to the transition of cell color from green to brown. Preliminary analyses of extracted hydrophilic pigments indicated that the glacier ice algae formed purpurogallin in culture, which will be further confirmed using mass spectrometry. Analysis is underway to evaluate if intracellular iron precipitates could also be a cause for the change in color. Furthermore, scanning electron microscopy will be used to evaluate changes in cell morphology and ultrastructure linked to variations in iron availability. The results from the laboratory study will also be compared to an iron addition experiment performed on the Greenland ice sheet with environmental samples of glacier ice algae.

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Towards More Reliable Debris Flow Rainfall ID Thresholds under Changing Climate Scenarios

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Early warning systems (EWSs) are recognized globally as the most efficient and cost-effective strategy for mitigating debris flow risk. Most contemporary EWS rely on Rainfall Intensity-Duration (ID) thresholds due to their extended lead time. However, two critical limitations challenge the efficacy of conventional methods: data scarcity in remote or hazardous areas often precludes the derivation of robust thresholds, and the increasing complexity of unpredictable climate change compromises thresholds built solely on historical records.
Here, we propose a novel physics-informed framework to generate and validate ID thresholds applicable under various climatic conditions. Our approach begins by developing a calibrated physical model of a small catchment. We then bypass the historical data dependency by utilizing stochastic generation to produce thousands of idealized rainfall scenarios. The model enables more accurate rainfall ID thresholds to be determined and allows us to successfully identify debris flow

event. Furthermore, this study offers effective, transferable support for establishing highly reliable rainfall EWSs, particularly in ungauged and data-scarce catchments highly vulnerable to climate shifts.

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Understanding the multi-level and multi-sectoral interventions for strengthening mental health of flood-affected population: Insights from a longitudinal household survey in the North of Vietnam

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Background: Floods are the most frequent natural hazard in Vietnam, exacerbating mental health challenges such as depression, anxiety, and post-traumatic stress disorder (PTSD) among affected communities. Despite growing evidence of psychosocial impacts, longitudinal data on recovery trajectories and the effectiveness of multi-level mental health and psychosocial support (MHPSS) interventions and Disaster Risk Reduction measures (DRR) remain limited in low- and middle-income countries (LMICs).

Objectives: This longitudinal survey aims to examine the temporal dynamics of mental health outcomes in flood-exposed populations, identify risk and protective factors, and evaluate the role of MHPSS interventions and different DRR measures in promoting resilience. It integrates disaster risk management with public health to inform sustainable adaptation strategies.

Methods: The study will recruit 1,250 participants from two provinces (Lao Cai, Yen Bai) stratified into 3 groups by their hazard experiences (floods, landslides and both). Data will be collected at baseline, 6 months using validated scales for evaluating mental health problems including PHQ-9 (depression), GAD-7 (anxiety), PCL-5 (PTSD), and alcohol and substance consumptions. Linear mixed-effects models will analyze trajectories, accounting for individual variability and attrition (estimated 20%). Feasibility is ensured through local partnerships, with ethical approvals from Charité University and Hanoi Medical University.

Conclusion: This survey provides critical longitudinal insights into flood-related mental health in Vietnam, bridging gaps in evidence for targeted interventions amid climate change.

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Analytical Hiss Wave Model Derived from NASA's Van Allen Probes and JAXA's Arase Spacecraft Observations

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Hiss waves are whistler-mode emissions in the Earth's plasmasphere, characterized by broad frequency spectra and irregular structures, and they play a key role in the loss of radiation belt electrons. While numerous studies have investigated hiss wave distributions using satellite observations, no model currently combines their distributions across both low and high latitudes. To address this gap, hiss wave characterization needs to be extended to high latitudes using observations from NASA' s Van Allen Probes and JAXA's Arase spacecraft, enabling a more comprehensive understanding of their spatial variability.
As hiss waves are mainly located inside the plasmasphere, the first step of developing hiss wave model is to identify the plasmapause position. We successfully applied the hyperbolic tangent fitting method of Kim et al. (2019) to determine the plasmapause location. As a next step, we extract

hiss wave events from satellite observations. This provides the foundation for analyzing the spatial distribution of hiss waves. Additionally, surface wave structures on the plasmapause are identified, offering further insights into magnetospheric dynamics. The next stage of this study will involve developing empirical models of plasmaspheric hiss by first quantifying their occurrence rate, then characterizing the observed amplitude distribution, and finally integrating these results to construct a predictive model of wave intensity across the inner plasmasphere.

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Use of Physics-Based Machine Learning Surrogate Models for Optimal Sensor Placement

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The forcing exerted over subsurface reservoir during operations to extract geothermal heat causes changes in, for instance, the subsurface pressure and temperature state, which can lead to induced seismicity. Therefore, an appropriate consideration of the expected measurable response of the reservoir is needed to design reliable monitoring systems. Computer assisted simulations of thermo-hydraulic-mechanical (THM) processes in fractured reservoirs allow to get a prognosis of the reservoir state and its evolution during operations and to consequently get the expected seismic event number and ground motion amplitudes as design monitoring criteria. The caveat is that an optimal strategy requires a large number of simulations to testing possible monitoring configurations, which makes the usage of full order models unfeasible because of the high associated computational cost. To bypass this barrier, we explore the use of physics-based machine learning surrogate models using the non-intrusive reduced basis method, to obtain fast and accurate solutions. We showcase this methodology for the construction of reliable surrogate models for a reservoir in the transition between convection and conduction dominated heat transfer, which is representative for a wide range of common conditions encountered in geological reservoirs. We especially highlight the differences, to entirely data-driven approaches. We finally illustrate the integration process into algorithms for optimal sensor placements, and how application specific-constraints can be considered.

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Physiological Comparison of Four Cryogenic Arctic Snow Algae Strains

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Snow algae belong to the photoautotroph freshwater microorganisms successfully thriving on semi-permanent to permanent snow and ice fields around the world. They are well known for their large, colorful blooms in cryospheric environments exposed to extreme conditions such as low temperatures and high irradiance in the summer month. Apart from green chlorophyll, other pigments such

as xanthophyll or secondary carotenoids are known to be produced under high-light stress which turn the snow red or yellow. Their pigments darken snowfields worldwide, reducing albedo and thereby accelerating melt of snowpacks. Although knowledge of distinct phylogeny within snow algae is increasing, we do not know how these species respond to varying levels of light intensities. We investigated four snow algae strains - *Microglena sp., Chloromonas remiasii, Sphaerocystis sp., and Raphidonema sempervirens* - focusing on their physiology under high light conditions (500–700 µmol m^{-2} s^{-1}). We employed pulse amplitude modulated (PAM) fluorometry combined with algal growth rate measurements, and quantified intracellular reactive oxygen species (ROS) in cultures exposed to high light conditions and controls. Our results show that among all four species, *Microglena sp.* was the only strain to efficiently grow under these conditions. Its response to high light included a progressive reduction in electron transport rate, indicating decreased photosystem efficiency under prolonged exposure, while ROS production remained stable, which further suggests increased resilience to light stress. This work increases our understanding of physiological responses of snow algae to environmental stressors relevant in future scenarios where melt seasons will extent and shifts in their habitats will occur faster.

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Nutrient fluxes from a subarctic glacial river to the ocean

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Glacial rivers play an important role in the biogeochemical cycles of macro- and micronutrients. Abiotic and biotic processes in supra-, sub- and proglacial environments enrich meltwaters with dissolved and particulate nutrient species that may undergo substantial changes in concentration and speciation along glacial rivers due to lateral inputs and in-channel processes. Once delivered to coastal waters, these nutrient fluxes can influence oceanic primary productivity, especially in the nutrient-limited subarctic waters.
The magnitude and timing of these exports remain poorly constrained for many glacial rivers globally. With the development of new in situ chemical sensors, it is now possible to monitor diurnal and seasonal changes in nutrient concentrations in these challenging environments.
This work presents results from multiple deployments of in situ microfluidic sensors for nitrate, phosphate and dissolved silica, and a water autosampler, combined with transects along an undammed Icelandic glacial river across seasons.
Diurnal fluctuations were observed in dissolved nitrate concentrations, with an increase during the day and a decrease at night. In contrast, dissolved phosphate only exhibited seasonal variability while dissolved silica remained relatively stable. Glacier-to-ocean transects also showed an enrichment in dissolved organic carbon (DOC) and iron (Fe) with distance from the glacier, likely reflecting soil-derived lateral inputs.
These findings highlight the spatial and temporal variability of nutrient export from glacial rivers to the ocean, showing the relative contribution of different nutrient sources depending on the season and distance from the glacier

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Understanding the Radiation Belt Dropouts During May 2017 storm by VERB simulations

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The Earth's outer radiation belt is a highly dynamic region populated by energetic electrons that can pose potential threats to the satellites running in outer space. Among the most dramatic variations is the radiation belt dropout, defined as MeV electron fluxes drop by orders of magnitude within a short timescales. Two main mechanisms have been proved to explain these losses: electromagnetic ion cyclotron (EMIC) waves scattering and outward transport across the magnetopause (MP), also known as MP shadowing. However, the relative contribution of these processes during storm-time conditions is still unknown. In this study, we investigate a dropout event observed by the Van Allen Probes during the intense geomagnetic storm of May 2017. The electron flux shows significant losses during the storm main phase, with a pronounced butterfly pitch angle distribution structure, indicating a strong influence of MP shadowing. Phase space density profiles are further analyzed to reveal the real loss mechanisms. Then, simulations are performed with the Versatile Electron Radiation Belt (VERB) code to quantitatively assess the role of each mechanism. Specifically, different MP models are implemented and used to reproduce the observed electron losses. In parallel, the contribution of EMIC waves is quantified by enabling or disabling EMIC-driven pitch-angle diffusion (with other drivers held fixed) and comparing the resulting loss signatures.

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Microbially Mediated Weathering Pathways along the Chilean Climate Gradient

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Traditionally, mineral weathering has been considered to be driven mainly by abiotic factors. However, recent studies have revealed that microorganisms can survive, sustain metabolic activity, and even actively contribute to mineral weathering. Even under extremely dry and oligotrophic conditions, microorganisms play a significant role in the formation and development of Earth's soil through their metabolic activity on the surface of mineral rocks. In the context of today's global climate change, understanding microbially mediated weathering has become increasingly important. Climate is one of the major drivers shaping the composition and functional potential of microbial communities, which in turn influences how microorganisms contribute to weathering and pedogenesis. In this study, we aim to investigate how microorganisms and climate interact to drive granite weathering, focusing on sites sharing the same granite bedrock but characterized by different climates (arid, semi-arid, Mediterranean, and humid) along the Chilean Coastal Cordillera. Intracellular (iDNA) and extracellular DNA (eDNA) extraction techniques will be employed to identify microbial communities that are alive and actively participate in the weathering process. Subsequently, metagenomic and metatranscriptomic analyses will be conducted to understand the metabolic pathways involved in microbially mediated weathering across the gradient. This work is expected to provide a comprehensive understanding of climate-driven shifts in microbial functional potential and to improve predictions of the future microbially mediated weathering processes under changing climates.

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The digital Progress of a Geothermal Underground Research Lab in the Odenwald Germany: GeoDT contribution

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Due to the currently increasing demand of renewable energy, the exploration of the crystalline basement for geothermal purposes plays in the future an important role. The use of fractured and permeable crystalline rocks for geothermal purposes will be possible once the GeoLaB (Underground Research Lab for geothermal energy) will be built.

Since January 2025 the first research project GeoDT (Digital Twin for GeoLab) has started. The exploration efforts were conducted and implemented so far in the Tromm area Odenwald, as one of the possible sites where GeoLaB could be built.

GeoDT aims to create comprehensive base models with all parameters included, integrate them into a single Digital Twin, and collect, process, analyze and implement the necessary data and results to support the selection of a future GeoLaB location. Datasets used for model construction will include borehole logging, well tests, a broad investigation plan on the drill cores including mineralogical, petrological and geomechanical investigations, GIS, hydrogeological data and geophysical surveys delivering reflection seismic data.

Goals of GeoLaB are to develop more efficient construction strategies and sustainable utilization methods for geothermal powerplants, achievable through CHFE (Controlled High Flow Experiments). It also aims to foster more transparent collaboration between scientists and connect their thermal-hydraulic-mechanical-(bio)chemical (THMC) research findings with a up to date Digital Twin for modern visualization of the area.

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noise characterization in sub-daily GNSS solutions and amplitude detection thresholds.

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Sub-daily GNSS positioning provides a unique opportunity to monitor crustal deformation at timescales relevant to transient geophysical processes. However, the reliability of such observations is limited by the presence of correlated noise and modeling deficiencies, which complicate the detection of small deformation signals. In this study, we assess the noise characteristics of kinematic GNSS time series under varying instrumental and tectonic conditions. We estimate noise floors across multiple stations and evaluate how they constrain the minimum detectable signal amplitude. By modeling the noise spectrum and deriving variance–covariance matrices, we propose a framework to statistically define amplitude thresholds for robust signal detection. Our results highlight differences in site-specific noise behavior and demonstrate how noise-informed detection criteria improve the interpretation of transient deformation in sub-daily GNSS solutions.

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Fluxes across scales in Alpine Landscape: From Towers to Pixels

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Recent advances in ecosystem monitoring increasingly emphasize flux measurements at larger spatial scales, enabling better integration with satellite remote sensing products and Earth system models. However, alpine ecosystems remained undersampled globally, limiting the ground validation of these model results and satellite-derived carbon estimates. Despite being in one of the most extreme environmental conditions on Earth, these ecosystems play a vital role in the exchange of water, energy, and carbon. Here, we present continuous carbon and energy flux estimates measured at 19 m in an alpine steppe ecosystem on the Tibetan Plateau (TP) from July 2018 to June 2019. The measured fluxes were compared with the fluxes obtained at 3 m over the same ecosystem, and the measured gross primary productivity (GPP) was additionally compared with the MODIS global GPP product. While the 3 m flux footprint represents a relatively homogeneous patch, the 19 m integrates fluxes across a broader, more heterogeneous area, better matching the spatial resolution of MODIS, enabling landscape-scale comparisons. By capturing variability across microtopographic and ecological gradients, these observations provide new opportunities to assess flux variability at spatial scales directly relevant to satellite remote sensing and ecosystem modelling.

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Surface deformation of the Eastern Central Andes, observed by wide-swath radar interferometric time-series

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The convergent plate boundary along the Chilean Andes forms a natural laboratory for studying the role of the seismic cycle in the formation of orogens. Geological records and modern geodetic data provide evidence that crustal deformation occurs both in the forearc (at the Nazca–South American plate interface) and in the backarc (east of the Andes) where crustal strain with the potential to trigger a Mw 7.8 earthquake is accumulating. We focus on the sparsely instrumented backarc region of northwestern Argentina/southwestern Bolivia to measure the ongoing E-W shortening of the Eastern Andes.

We analyzed Interferometric Synthetic Aperture Radar (InSAR) imagery from the Eastern Andes to generate high-resolution surface deformation maps and time series. We processed ten years of ALOS-2 radar imagery acquired in L-band and wide-swath (~350 km) ScanSAR mode, considering only dry-season acquisitions to reduce atmospheric signal delay. We used the alos2stack workflow in the ISCE-2 software, and substantially downsampled the images to suppress noise. We then generated deformation time-series with the MintPy software and applied corrections for topography, solid Earth tides, and stratified tropospheric signal delay using ERA5 weather models. A key limitation of L-band is its sensitivity to ionospheric turbulence, which produces a dispersive phase shift. Consequently, we paid particular attention to carefully suppress the ionospheric phase contribution by applying the range split-spectrum method. The resulting surface deformation rate maps are complemented with pointwise displacement rates from accurate positioning (GNSS), which were projected into the satellite's line-of-sight (LOS) for direct comparison.

The resulting LOS surface deformation rate maps provide, for the first time, detailed insights into the kinematics from the Eastern Cordillera/Puna Plateau down to the highly vegetated Subandes, including the frontal Mandeyapecua thrust. They reveal a variety of active processes in the Central Andean backarc: The dominating, long-wavelength crustal shortening signal is overlaid by local processes like inflation at Cerro Overo volcano (~1.5 cm/yr LOS), the dynamics of salars such as the Salar de Arizaro (~0.5 cm/yr LOS), coseismic displacement of ~8 cm associated with the 2020 Mw 5.8 Humahuaca earthquake, and landslides. Our preliminary results suggest that the Mandeyapecua fault is currently inactive.

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Impact of Glacial–Interglacial Cycles on Transient 3D Thermophysical Models of Salt-Dominated Areas within the North German Basin.

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Understanding the underground temperature distribution is required to determine geothermal energy potential, heat flow, mechanical behaviour of lithological units, and also the long-term safety of heat-producing waste in repositories. As temperature observations in the subsurface are sparse, numerical modelling is utilized to make predictions and risk-assessments. In contrast to statistical models, numerical physical approaches can account for contrasts in thermal properties, given well informed structural and parametrical models of the subsurface.
Recent studies suggest that the Last Glacial Period and the Holocene Climate Optimum present the largest contribution to the climate impact on the modern subsurface temperature distribution in Germany. Previous studies, mainly in Northern Europe, have shown, that an additive effect of the Pleistocene Glaciations can be observed, with a total cooling of several Kelvin in up to two kilometer depth.

In the NGB, complex salt dynamics shape the structure of overlying sediment layers. Given the spatial orientation and contrast in thermal parameters, heat refraction may play a significant role on how the paleoclimatic imprint is distributed in the subsurface thermal field. To understand the influence of transient processes we discretized the stratigraphic succsession in the NGB to thermally relevant units. We create 3D structural models of regions with salt-dominated areas. The structural models are discretized into unstructured 3D finite element meshes and the model units are parametrized considering regional constraints. We apply a heatflow dervied from boreholes in the model regions as lower thermal boundary condition. The upper boundary condition is derived from soil temperatures in transient global circulation models starting at the last glacial maximum and scaled $\delta^{18}O$ as a proxy for the time prior.

The results indicate a clear correlation between the complex structural configuration of the model and the transient effects of the applied boundary conditions. The predicted subsurface thermal field is discussed and compared to temperature observations and statistical models of the temperature field in the model region.

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Development and resilience of microbial CH4 oxidizers in rewetted fens

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Peatlands cover only ~3% of Earth's land area yet store nearly a third of global soil carbon. When drained, they release vast amounts of CO_2, but rewetting—an increasingly used restoration strategy—often increases CH_4 emissions. Methane-oxidizing microorganisms (methanotrophs) can mitigate these emissions by acting as a biological CH_4 filter, yet their post-rewetting development, resilience to disturbance, and functional role in regulating CH_4 fluxes remain poorly understood. This PhD project (Project A5 in WETSCAPES 2.0—a DFG TRANSREGIO collaborative research center on peatland rewetting and its ecological, hydrological, and biogeochemical consequences) takes a holistic approach to soil methanotrophy, linking spatiotemporal microbial dynamics with biogeochemistry and ecosystem CH_4 fluxes. Three complementary approaches are combined: a spatial screening across ~100 rewetted sites to test how hydrology, vegetation, and peat type shape methanotroph diversity and resilience; high-resolution temporal monitoring at the Zarnekow fen, a core site of the TERENO observatory Northeast coupling DNA/RNA-based community analyses with CH_4 flux and porewater data; and mesocosm experiments to probe community vulnerability and recovery after controlled stress events. Special focus is placed on the role of anaerobic methane oxidation (AOM), mediated by poorly constrained taxa such as *Candidatus* Methanoperedens, which may use alternative electron acceptors and significantly alter CH_4 balances under anoxic conditions. Together, these studies aim to disentangle the drivers of methanotrophic community assembly, clarify the contributions of both aerobic and anaerobic methane oxidizers, and achieve a predictive understanding of methanotroph dynamics in the heterogeneous landscapes of rewetted fens.

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Evaluating the state of flood adaptation in Europe

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The adverse impacts of floods are on the rise. Hence, effective adaptation to flood risk is urgently needed. However, defining and quantifying adaptation progress remains challenging. Flood Risk Management Plans (FRMPs), required by the EU Floods Directive (2007/60/EC), are intended to improve and document adaptation progress in Europe. Member States are required to prepare and update these plans every six years in accordance with a common framework for the entire Union. However, a systematic assessment of FRMP quality remains limited, and if there is a correlation between the quality of management plans and flood risk remains unanswered.
This study develops a comparative index of FRMP quality, as a means to evaluate adaptation planning and implementation within the broader effort to quantify adaptation measures effects over space and time. Using directed qualitative content analysis, the FRMPs for the first (2010–2015) and second (2016–2021) reporting cycles are coded, based on six well-established quality principles from literature: fact base, objectives, measures, implementation and governance, monitoring and evaluation, and participation, across three dimensions, including breadth, depth, and expert-judgment. A composite quality index is created for each Member State, and for each of the two reporting cycles. In the next stage we explore links between management plan quality and flood indicators, such as reported flood losses, exposure, and protection standards, to assess whether improvements in planning are associated with reductions in risk.

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Insights into structure of Carbonate Glass under High Pressure from Time-resolved Fluorescence Spectroscopy

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The presence of carbonates in the mantle is supported by various evidence from seismology, experiments, inclusions in diamonds , and calculations [1]. While the pressure-induced structural changes in crystalline carbonates are relatively well understood, little is known about the P-induced structural changes in carbonate melts due to technical challenges in direct measurements of melt properties. To a certain extent, glasses can serve as a proxy for melts under high P [2], and experimental studies on carbonate glasses may provide valuable insight into the structure and properties of deep carbonate melts.

Here we report on the structural characteristic of Mn^{2+}-doped carbonate glass probed by time-resolved laser fluorescence in a diamond anvil cell. The wavelength, intensity, and lifetime of Mn^{2+} is sensitive to coordination number (CN) by oxygen and symmetry of the Mn^{2+} site, and shows a strong pressure dependence. To interpret the pressure-induced changes in Mn^{2+} fluorescence we performed references experiments on calcite and magnesite' (also doped with Mn^{2+}), whose high-pressure behavior is well-documented.

Our results show that upon compression the median CN of Mn^{2+} increases from ~6 (at 1 atm) by ~30% (at 13-14 GPa). More broadly, time-resolved laser fluorescence experiments offer a novel spectroscopic probe into the local structure of geologically-relevant glasses at mantle pressure conditions.

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[2] Seifert et al. (1981), Geochim. Cosmochim. Acta. 45, 1879–1884

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Mechanical, hydrogeological and thermal response of the subsurface to climate change in North Central Europe

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The subsurface of North-Central Europe has been shaped by repeated glaciations, which have changed underground pressure, temperature, and water flow over thousands of years. Understanding these changes is important for managing groundwater, using geothermal energy, and safely storing materials like CO_2.
In this project, we are building a digital twin of the region's subsurface to study how it reacts to climate changes. This digital twin will combine geological data, climate information, and advanced models to simulate heat, water, and mechanical stresses underground. We will also study key processes, such as how salty and fresh water mix, and explore how these processes are affected by changes in climate. To make the simulations faster and more efficient, we will use special surrogate models that keep the physics realistic while reducing computing time.
The results will help us better understand how past glaciations shaped the subsurface and how future climate changes might affect it. This knowledge will support decisions about water resources, geothermal energy, and safe underground storage, helping to plan for a changing climate.

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Highlights of the evolution of various rift configurations and the influence of strain healing

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Rift systems play a crucial role in the Wilson cycle, where the extension and breakup of continental plates can lead to the formation of new oceans. Earth's rift systems exhibit various stages, from initiation to breakup, with the latter representing 'successful' rifting, as observed along the Atlantic margins. Whereas rifted margins can record successful extensional plate dynamics, deformation can also stop at earlier stages or shift to more favourable locations, resulting in 'failed' rifts, such as the North Sea or the Atlas rift. However, the mechanisms that control whether a rift fails or is successful are not very well known.

Understanding the dynamics of continental extension and tectonic processes in rift systems requires examining their initial conditions and subsequent evolution, with the latter influenced by both strengthening and weakening processes of the lithosphere. Here we numerically simulate rift evolution using geodynamic finite-element 2D ASPECT models incorporating shear zone ("fault") dynamics and strain softening within a visco-plastic rheological framework. We use the landscape evolution model FastScape to simulate surface processes.

To understand which processes lead to the success or failure of a rift, we explore the role of strengthening and weakening processes. Our modelled strengthening processes comprise (1) lithospheric cooling, which enhances the strength of ductile domains via temperature-dependent viscosity, (2) gravitational potential energy gradients that impose a degree of compression outboard of high-elevation domains; and (3) fault healing, which strengthens frictionally weakened regions over time as a function of temperature. We also account for the following weakening processes: (1) frictional softening, which causes an increase in fault activity; (2) lithospheric necking, which thins and thereby heats the lithosphere beneath the rift centre; (3) erosion and sedimentation, as simulated by FastScape, which alters the distributions of surface loads in a way that increases fault longevity. Within the framework of these processes, we examine the effects of crustal thickness, extension rate, rheology, and friction angle, on the spatial and temporal occurrence of rift success and failure. To quantify the results, we analyse fault geometry and dynamics, as well as the forces required for continued extensional plate motion.

Preliminary results indicate the existence of a lower limit for the full extension velocity to achieve breakup. For models with typical continental lithosphere this limit is ~2 mm/yr. Lithosphere that is extending at a smaller velocity thins temporarily, but strengthening mechanisms ultimately outweigh weakening processes, resulting in relocalisation of deformation. Our analysis highlights the internal and external processes that influence rift systems at different evolutionary stages and provides criteria for understanding and predicting rift evolution.

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Refractive Index Measurements on Hydrous Silicate Gel Under High Pressures

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The chemical evolution of the primordial Earth during the transition from a molten to a solid state is largely controlled by density. The density contrast between the solid and liquid phases determines whether the crystallized particles sink or float. Geophysical observations of low-velocity zones, infer

the existence of hydrous melt at the upper mantle transition, but experimental density measurements of hydrous silicate melt are limited to < 30 GPa [1]. In-situ density measurements of hydrous silicate melts under Earth's mantle conditions are extremely difficult to conduct because of the tiny sample size, melt chemical reactivity and lack of crystalline structure [2].
This study is part of the project Glass2Melt, which aims to develop a universal density model for silicate melts in the pressure range up to 135 GPa (i.e., across the pressure range of the entire mantle). To mitigate some of these challenges highlighted above, silicate melts rapid-quenched to glasses are used as proxy material to investigate the structural behavior and density at high pressure and room temperature conditions using a diamond anvil cell [3].
This study investigates the structural effect of volatiles (H2O and CO2) on silicate glasses. The all-optical determination of the refractive index and density of silicate glasses is carried out with a supercontinuum laser. Here I report on the evolution of the refractive index of hydrous silica gel (SiO2) up to ~ 65 GPa. Silica gel is an amorphous porous form of SiO2, which is structurally similar to silica glass [4], but can easily incorporate over 30 wt.% of H2O in its silicate structure [5]. Preliminary results show a reduction of the refractive index with water content at pressures > 30 GPa. Further investigations of glasses with a wide range of chemical compositions in the H2O –CO2 –Al2O3 –SiO2 –MgO –Na2O –CaO system are planned.

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Global Rift Analysis for Long-Term Carbon Cycle Modeling

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Over geological timescales, the release of carbon at tectonic settings has strongly influenced Earth's long-term climate. Continental rifts, in particular, are thought to play a major role in CO_2 degassing by activating deep carbon reservoirs (Foley and Fischer, 2017). Previous studies even suggest a possible link between rifting and the rise of atmospheric CO_2 during the Cenozoic (Brune et al., 2017). However, substantial uncertainties remain, as the incomplete geological record makes it difficult to constrain the timing and magnitude of rift-related CO_2 release.

To quantify CO_2 degassing from rift systems over time and reduce the associated uncertainties, we combine plate tectonic reconstructions with automated geoinformation workflows, building on a global database of Phanerozoic rifting events. In addition, new measurements of rift-related CO_2 fluxes and contributions from numerical modeling will be integrated, enabling the generation of a comprehensive degassing time series. The resulting time series is evaluated against paleoclimate proxy data by incorporating it into biogeochemical carbon cycle models (Mills et al., 2021).

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Compressibility of Fe-rich Pyroxene Glasses at High Pressure Derived from All-Optical Measurements of Refractive index and Absorption Coefficient

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The density of silicate melts is essential for comprehensive modeling of the early Earth's evolution, when the Earth was largely composed of molten silicates encased in a magma ocean. However, fundamental insights into evolution of the density of melts with pressure are often experimentally inaccessible. Nevertheless, some experimental challenges might be overcome by using quenched glasses as structural proxies of their melts. Here we report on the compressibility of Fe-rich pyroxene glasses along the enstatite–ferrosilite compositional binary in the pressure range from 20 to 60 GPa. The compressibility was measured by a recently developed all-optical method in a diamond anvil cell and was inferred from the refractive indices and the absorption coefficients of the glasses under study. Further experiments at pressures of 0-20 GPa and 60-150 GPa will allow us to obtain an experimental model of the density of MgO-FeO-Fe₂O₃-SiO₂ glasses at the pressure conditions of the Earth's mantle.

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Satellite-Based Monitoring of Global Ocean Circulation: Assimilating Electromagnetic Signals

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Ocean circulation plays a crucial role in redistributing heat and carbon globally, influencing climate dynamics. While satellite altimetry and in-situ observations provide valuable data, a comprehensive understanding of three-dimensional ocean circulation, particularly at deeper levels, remains a significant challenge.

Ocean-induced magnetic fields (OIMF) are generated by the motion of conductive seawater through Earth's geomagnetic field. These electromagnetic signals, potentially observable by future satellite missions, contain valuable information about depth-integrated ocean flows, including deep ocean currents that are difficult to monitor with traditional methods. While current satellites like Swarm can detect OIMF from tides, circulation-induced signals remain challenging to observe. The assimilation of these signals into ocean circulation models remains largely unexplored.

This work focuses on developing an assimilation framework to integrate OIMF observations into high-resolution ocean models. An electromagnetic forward modeling approach has already been established, and work is underway to couple the Max Planck Institute Ocean Model (MPIOM) with the Parallel Data Assimilation Framework (PDAF) using Kalman filter-based methods to conduct Observing System Simulation Experiments (OSSEs) with synthetic OIMF data. The goal is to assess whether OIMF assimilation can improve estimates of depth-integrated oceanic variables such as transport, temperature, salinity, and bottom pressure, with a particular emphasis on enhancing the representation of deep currents in observation-limited regions.

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Stress testing approaches for High-Impact-Low-Probability floods: A review

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Highlighted by the July 2021 floods in central Europe, climate change contributes to an increase in the occurrence of devastating and unprecedented flood events. The floods exhibited magnitudes far exceeding the commonly used worst-case scenario of the 1-in-100-year flood, illustrating that this standard may no longer be adequate. However, the lack of data on the physical mechanisms and anthropogenic responses limits the ability to anticipate and prepare for unprecedented floods. This review will show the multitude of different approaches used in the state-of-art literature to analyze hypothetical High-Impact-Low-Probability floods. The review is limited to studies considering very extreme pluvial and riverine floods including their human-centric impacts. A systematic SCOPUS keyword search coupled with a large language model filtering out irrelevant studies left 96 papers which are considered relevant. The scientific works are delineated by how physical boundary conditions are derived, floods are modeled, impacts are quantified and based on their overarching framing. Predominantly, studies use univariate statistics to create the physical boundary conditions. However, a variety of approaches are used, including counterfactuals, weather generators, and reforecasts. Approximately 60% of studies are limited to exposure assessment. Where, impacts are estimated studies are framed as cost-effectiveness analyses, cascading impact assessments, and some even consider post disaster recovery. Additionally, we identify stress-test approaches for High-Impact-Low-Probability floods which are still lacking, but could provide valuable scientific insight.

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Flood monitoring and early-warning with satellite gravimetry

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The wetness conditions of a river basin, besides rainfall characteristics, are important factors for the amount of runoff that is generated, eventually leading to a flood event. Satellite gravimetry with GRACE and its successor mission GRACE Follow-On (GRACE-FO) allows for retrieving terrestrial water storage (TWS) anomalies by measuring temporal variations of the Earth's gravity field. This opens the possibility of estimating the wetness conditions before and during flood events. However, its use in flood monitoring and flood warning applications so far has largely been limited by the insufficient temporal and spatial resolution. The goal of this project in collaboration with ETH Zürich and the University of Bern and Braunschweig is to improve the monitoring and forecasting of flood events by using TWS anomalies derived from GRACE/GRACE-FO with daily resolution and spatially downscaled to a resolution of 50 km globally.

This study will explore if and up to which regional scales (< 100,000 km²) the high-resolution GRACE-based TWS anomalies can provide useful information for flood monitoring and flood forecasting. To this end, information on flood events on a global scale since 2002 gathered in the Dartmouth Flood Observatory (DFO) and from other sources, and hydro-meteorological data that may be explanatory factors for the generation of flood events besides TWS will be collected, such as river discharge, precipitation, snow or soil moisture. It will be assessed on the global scale whether during the flood events exceptionally high TWS can be observed, and which types of floods and for which hydro-climatological regions the GRACE/-FO-based data are particularly useful. For early-warning purposes, a gravity-based wetness index as an indicator of flood potential will be developed and evaluated at the global scale. In collaboration with the project partners, the index will also be incorporated and assessed in a machine-learning-based flood forecasting approach and in an operational flood modelling system for small river basins in Lower Saxony, Germany.

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Insights on Denudation Controls of Volcanic Tropical Islands from Meteoric 10Be/9Be Ratios

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Weathering of volcanic rocks accounts for approximately one third of global CO_2 consumption in the silicate weathering cycle. Tropical volcanic islands contribute to this process due to their extreme denudation rates, thought to be mainly driven by high and episodic precipitation, which may sustain high weathering fluxes. However, how total denudation (D) divides into erosion (E) and weathering (W) fluxes, and what controls their long-term rates on tropical islands remains unclear. This uncertainty arises from the lack of methods to quantify these rates over centennial to millennial timescales. Common approaches face challenges like absence of quartz for in situ-10Be or unevenly-distributed olivine for in situ-3He analysis, limited long-term observational data for gauging, and the impacts of caldera collapse and infilling of river valleys from eruptions that complicate erosion rate estimates from topographic reconstructions. The recently developed meteoric 10Be/9Be ratio that uses meteoric 10Be as an atmospheric flux tracer together with stable 9Be released during rock weathering provides an alternative to estimate D and weathering intensity from soils to entire watersheds independent of specific minerals.
We applied this method to Réunion and Guadeloupe, two islands with extreme precipitation regimes (up to 11,000 mm/yr), steep slopes, high elevations, and warm mean annual temperatures. Both islands have catchments on lavas of similar emplacement ages (5 Kyr to 1.8 Myr), but differ mainly in lithology: Réunion's hotspot volcanism produces basalts, whereas Guadeloupe's arc volcanism generates andesites. To isolate key controlling parameters, we sampled catchments with uniform lava deposition ages across varying precipitation regimes.
Preliminary results reveal a stark contrast in denudation (D). On Réunion, catchment-averaged D´s are 4,000 t/km²/yr (n=11, ranging from 11 t/km²/yr in very small catchments to 15000 t/km²/yr), while Guadeloupe´s average D is 300 t/km²/yr (n=13, ranging from 100 to 1000 t/km²/yr). Weathering intensity measured on sediment from Guadeloupe are, on average, significantly higher than for Reunion. This result aligns with the observation that lower erosion rates promote more intensive soil leaching. Our denudation rates compare well to published gauging-based rates of 1200 to 9,000 t/km²/yr for Réunion1 and 800 to 4,000 t/km²/yr for Guadeloupe2. Large-scale topographic reconstructions range from 9,000 to 28,000 t/km²/yr for Réunion3,4 and 1,250 to 5,250 t/km²/yr for Guadeloupe´s youngest volcanic complex5.
Our preliminary findings suggest that volcanic emplacement age does not control D, while the role of lithology requires further investigation. Future work will involve determining local depositional fluxes of meteoric 10Be, and analyzing additional data from weathering profiles and river sediments.

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Increasing Safety and Efficiency of Deep Geothermal Wells with Fiber Optics

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Deep geothermal boreholes require robust monitoring of extreme downhole conditions to ensure safe and efficient production. Conventional tools provide only snapshots in time and space, creating an information gap, while fiber optic sensing offers continuous data collection without well intervention. At the Geothermal Site Schäftlarnstraße in Munich, Germany, the fiber optic infrastructure enabled monitoring of primary cementing by tracking different fluid interfaces, allowing for the assessment of displacement efficiency. Furthermore, it can facilitate the profiling of the fluid intake contributions from the deep geothermal injector, down to very low velocities. This work demonstrates how fiber optic sensing can support achieving well integrity and sustainable geothermal reservoir management.

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Effects of Permeability and Pyrite Distribution Heterogeneity on Pyrite Oxidation in Flooded Lignite Mine Dumps

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The role of sedimentary heterogeneity on reactive transport processes is becoming increasingly important as closed open-pit lignite mines are converted into post-mining lakes or pumped hydropower storage reservoirs. Flooding of the open pits introduces constant oxygen-rich inflows that reactivate pyrite oxidation within internal mine dumps. A reactive transport model coupling groundwater flow, advection-diffusion-dispersion, and geochemical reactions was applied to a 2D cross-section of a water saturated mine dump to determine the processes governing pyrite oxidation. Spatially correlated fields representing permeability and pyrite distributions were generated via exponential covariance models reflecting the end-dumping depositional architecture, supported by a suite of scenarios with systematically varied correlation lengths and variances. Simulation results covering a time span of 100 years quantify the impact of heterogeneous permeability fields result in preferential flow paths, which advance tracer breakthrough by ~15 % and increase the cumulative solute outflux by up to 39 % relative to the homogeneous baseline. Low initial pyrite concentrations (0.05 wt %) allow for deeper oxygen penetration, extending oxidation fronts over the complete length of the modeling domain. Hereby, high initial pyrite concentrations (0.5 wt %) confine reactions close to the inlet. Kinetic oxidation allows for more precise simulation of redox dynamics, while equilibrium assumptions substantially reduce the computational time (>10 ×), but may oversimplify the redox system. We conclude that reliable risk assessments for post-mining redevelopment should not simplify numerical models by assuming average homogeneous porosity and mineral distributions, but have to incorporate site-specific spatial heterogeneity, as it critically controls acid generation, sulfate mobilization, and the timing of contaminant release.

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SLIDER - SLope Instability, DEformation and the Role of fluid's at Mt. Etna

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The eastern flank of Mt. Etna volcano poses a significant threat of a tsunamigenic landslide to the local population: at centimeter/year rates it is creeping and collapsing eastward into the Strait of Messina. But the geometry and depth of the sliding surface are yet poorly understood, with multiple conflicting models proposed over the years.
We analyze satellite-geodetic time-series from radar interferometry (InSAR) and accurate positioning systems (GNSS) of the past five years to create a 3D surface deformation field of the volcano. Our approach aims to isolate the pure instability signal by removing magmatic inflation/deflation, topographic and atmospheric noise, allowing us to trace the actual shape of the sliding mass using resultant displacement vectors. Using structural geology and kinematic modeling of the main fault systems, along with seismicity constraints, we work to define the 3D-geometry of the moving blocks and the depth of the detachment surface. This effort is coupled with understanding how fluids (water, magma) and slow slip events correlate with deformation transients and drive the propagation of instability. This geodetic-based methodology will provide important information to constrain the sliding surface geometry, with direct implications for hazard assessment and ongoing drilling projects aiming to reach the base of the instability.

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Numerical Modeling of Lithium Adsorption Experiments using Manganese-Chitosan Ion Sieves: Evaluation for Industrial Scalability

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In recent years, lithium (Li), which is mostly used for battery components, has emerged as one of the most promising elements for exploration and extraction from underground reserves and used for further industrial applications. In particular, the co-production of Li and heat from geothermal brines offers the advantage of minimal additional environmental impact of Li mining and increasing returns on investment for geothermal operators.
As part of the final objective to develop a process to efficiently and cost-effectively recover Li-ions from geothermal brine, we present a numerical model and sensitivity analysis of critical raw materials (CRM) extraction by implementing an adsorption method in a fixed-bed column model. Batch experiments using synthetic brine under normal and high-temperature conditions were performed to analyze the adsorption equilibrium, kinetics, and breakthrough curves of the system. Sensitivity studies were conducted to identify the influencing parameters and optimize the operating conditions for future upscaling of the process.

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Vantastic Varves: Decoding Annual Signals in Lake Van

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Lake Van, the world's largest soda lake, is highly sensitive to hydrological balance, and past lake-level changes directly reflect variations in the precipitation-to-evaporation ratio. During the transition from MIS 6 to MIS 5e (the Last Interglacial), sediment proxies record rising lake levels and environmental shifts are preserved in varved deposits. These annually deposited sediments allow high-resolution reconstructions of climatic variability on seasonal time-scales. Such studies are essential, as MIS 5e is widely regarded as an analogue for ongoing global warming. However, despite their importance, detailed sedimentological analyses of these laminations are still lacking.
Here we present the first microscopic description of Lake Van sediments from Termination II. Initial microfacies and XRF analyses reveal that laminations are more complex than previously assumed, consisting of alternating detrital calcite, authigenic aragonite, and diatoms, with shifts reflecting both external climate forcing and internal lake dynamics.
These results demonstrate the potential of combining sedimentology and geochemistry to refine high-resolution climate reconstructions, providing new insights into environmental variability during the onset of the last Interglacial.

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Image-Based Vegetation Classification of Rewetted Peatlands; an Example on the FluxNet-Site Zarnekow

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Drained peatlands have a high potential in mitigating anthropogenic climate change through the process rewetting. The Intergovernmental Panel on Climate Change (IPCC) provides a binary distinction of these biotopes: Peatlands remaining Peatlands and Land converted to Peatlands, and associates GHG emission factors to these classes. However, this distinction is not able to grasp the transition of these states, which is also characterized by highly dynamic GHG fluxes. Tracking the progress and impact of rewetting peatlands is needed to monitor the goal of policymaker decisions and further understand the peatland characteristics. Conventional methods such as chamber or eddy-covariance measurements are highly local and thus not suitable for upscaling. A key to that lies in the Greenhouse Gas Emission Site Type (GEST). This approach allows emission estimation based on dominant vegetation species and water table depth. The first part of this approach is the focus of this study: vegetation mapping. The combination of high resolution Uncrewed Aerial Vehicle (UAV) imagery and dominant vegetation species survey data, Machine Learning (ML) models are used to tackle the task. This case study uses data collected in the rewetted peatland of Zarnekow in Mecklenburg-Western Pomerania. The sites rewetting started in late 2004 and its developement is tracked by Eddy-Covariance measurements from 2007 to 2009 and from 2013 ongoing. The datasets consist of a RGB-orthomosaic which was used to plan and do a vegetation survey aiming at spatially dominant species, which can visually be delineated. The collected ground truth dataset was then expanded by visual interpretation of the orthomosaic. The two datasets (ground-truth and expanded) span 5.7ha and 0.75ha hectares and are used to train four different ML methods. Random Forests (RF) are explainable and frequently employed. Being dependent on precalculated features, this technique suffers from heterogeneous datasets, such as the one collected in the field. To boost model robustness, handcrafted features (Haralick-Features in different scales) are used to expand the datasets feature space. Neural Networks (NN) are able to calculate and find features automatically. While this decreases the models explainability, a high degree of specialization can be achieved leading to increased prediction accuracy. In this highly dynamic field of research new concepts are frequently proposed. In the computer vision domain, however two approaches gained popularity

for their classification capabilities: Convolutional Neural Networks (CNN) and Vision Transformers (ViT). A model-architecture of each of these category as well as a vanilla RF and a RF with additional handcrafted features are trained with the dataset. While being quantitatively superior, the NN, when judged qualitatively, falls short of the traditional RF approaches performance.

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Estimating land cover change area using high spatiotemporal resolution land cover products: case study of Uganda.

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Anthropogenic activities within the Agriculture, Forestry and Other Land Use (AFOLU) sector represent a major driver of greenhouse gas (GHG) emissions and a critical factor in global climate change. Accurate, transparent, and consistent monitoring of land use and land cover (LULC) dynamics is therefore essential to support climate mitigation frameworks such as the Paris Agreement (PA), the United Nations Framework Convention on Climate Change (UNFCCC), and Land Degradation Neutrality (LDN) targets under Sustainable Development Goal (SDG) 15.3. Despite global efforts to harmonize National Greenhouse Gas Inventories (NGHGIs), significant discrepancies persist across countries, primarily due to inconsistent methodologies and limited access to reliable land cover data. Recent advancements in cloud computing and remote sensing, particularly the emergence of high-resolution Global Land Cover
(GLC) products, present a promising opportunity to enhance AFOLU-related monitoring and reporting. However, these datasets—derived from distinct classification algorithms—require systematic evaluation to determine their suitability for national-scale applications and uncertainty quantification.
This study presents a methodological framework for evaluating two open-access 10 m-resolution GLC products, Dynamic World (DW) and Esri LULC, for national-scale LULC change detection in Uganda from 2019 to 2023. Uganda serves as a representative case study among African nations, where the AFOLU sector contributes substantially (76% in 2019) to total GHG emissions. The research develops a statistically robust reference dataset and applies IPCC-compliant sampling and estimation methods to assess the accuracy, consistency, and usability of the two products for AFOLU and LDN reporting. Comparative analysis highlights key LULC transitions relevant to emission accounting, including forest loss, cropland expansion, and settlement growth.
The findings demonstrate the potential of high spatiotemporal GLC products to strengthen AFOLU emission reporting, enhance transparency under the UNFCCC, and support sustainable land management in data-scarce developing countries.