**23rd of May, 2019 - University of Lausanne**

| Time | Speaker | Title |
|---|---|---|
| 09:30 | *Welcome words* | |
| **Morning: talks** | | |
| 09:40 | Przemyslaw Juda | Cross-validation technique for geostatistical model selection |
| 10:00 | Jeremy Zimmermann | Compound-Specific Isotope Analysis is a Powerful Tool in Contaminant Hydrogeology |
| 10:20 | Dorothee Kurz | A microfluidic study on biofilm and preferential path formation in porous media |
| 10:40 | Batoul Gisler | Numerical simulation of the effects of silica dissolution/precipitation on the evolution of the porosity of rocks |
| 11:00 | *Coffee break* | |
| 11:30 | Harsh Beria | Is unweighted mixing a reliable tool for hydrological source apportionment? |
| 11:50 | Robin Weatherl | Identifying sources and processes impacting groundwater recharge in the human environment |
| 12:10 | Moctar Dembele | Improving spatial patterns of hydrological processes for water accounting in the Volta River basin using earth observation |
| 12:30 | Álvaro Pardo Álvarez and Morgan Peel | Hydrodynamic and geochemical response of a pre-alpine alluvial aquifer to controlled hydraulic forcing |
| 13:00 | *Lunch break* | |
| **Afternoon: talks** | | |
| 14:00 | Marco Dal Molin | Comparing different approaches for predictions in ungauged catchments |
| 14:20 | Nicolas Oestreicher | Patterns of reversible ground surface deformations in crystalline rock slopes |
| 14:40 | Pascal Egli | Using GPR to investigate the sub-glacial hydrology of an alpine glacier |
| 15:00 | *Coffee break* | |
| 15:15 | Andrea Popp | A new on-site method for tracing denitrification in riparian groundwater |
| 15:35 | Maria Kakurina | How does the 3D displacement data from a Fault reactivation experiment can improve the estimation of the in-situ stress? |
| 15:55 | Nathan Dutler | Hydromechanical behavior of fractures during the in-situ hydraulic fracturing experiment |
| **Afternoon: posters** | | |
| 16:15 | Poster session | |
| 17:45 | *End of the conference* | |

**Posters**

| Speaker | Title |
|---|---|
| Alejandro Romero Ruiz | Field based geophysical characterization of soil structure |
| Benard Brixel | Insights on 3-D heat transport in low-permeability hard rocks |
| Nicole Burri | Spatial and temporal water budget calibration at the regional-catchment scale using remotely sensed data: Thur Catchment, Switzerland |
| Lucile Chauveau | The Phenix project: development of tools to build efficiently reliable hydro-geological models for the Quaternary in Switzerland |
| Simone Hintze | Towards a better understanding of the long-term fate of pesticide metabolites in groundwater |
| Dan-Thuy Lam | Conditioning of groundwater flow parameters by iterative ensemble smoothing: Application to a synthetic model inspired by the artificially induced flow at the Andra's Meuse/Haute-Marne site |
| Ishaan Markale | Reactive transport in 3D porous media: A Magnetic Resonance Imaging approach |
| Tom Müller | Understanding groundwater connectivity and storage in alpine glaciated catchments – the case of the Otemma glacier |
| Léa Perrochet | Determine fault criticality using seismic monitoring and fluid pressure analysis |
| Maximilian Ramgraber | Nested particle filters for data assimilation and sequential parameter optimization |
| Andres Felipe Velasquez Parra | Water saturation impact on solute mixing in 3D porous media |
| Hanna Wey | Nitrate leaching from arable fields above a groundwater aquifer |

**Students who could not come**

| | |
|---|---|
| James M. Thornton | From the snowpack to deep groundwater: integrated hydrological modelling of a steep, geologically complex Alpine catchment |
| Kalliopi Koutantou | UAV-based remote sensing for water groundwater interactions |
| Valentin Dall'Alba | 3D Multiple-point Statistics Simulations of the Roussillon Continental Pliocene Aquifer using DeeSse |

# Cross-validation technique for geostatistical model selection

**Przemyslaw JUDA, Philippe RENARD, Julien STRAUBHAAR[1]**

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In groundwater flow models, the choice of spatial interpolation methods for subsurface properties is crucial when dealing with heterogeneous media. Multiple-point statistics (MPS) algorithms allow to simulate complex heterogeneous fields but they are controlled by many parameters whose choice is often tedious. Moreover, there are many different geostatistical algorithms available. Therefore, an effective strategy for selecting the best model for a given set of observations (conditioning data) is desired. While such simple strategies exist for continuous variables and classical geostatistical algorithms, there is a need for model selection methods for categorical variables generated by MPS algorithms.

In this work, we present an application of K-fold cross-validation for selection of the spatial interpolation model. Our technique allows to easily rank models based on their predictive accuracy and is completely generic: it can handle categorical and continuous variables, as well as compare MPS algorithms to variogram-based algorithms. It can be used for the selection of all types of parameters, including the choice of the best training image (a conceptual geological model for multiple point simulation) for the given observation set.

Keywords: geostatistics, K-fold cross-validation, multiple point statistics, model selection

# Compound-Specific Isotope Analysis is a Powerful Tool in Contaminant Hydrogeology

**Jeremy Zimmermann[1], Daniel Hunkeler[1]**

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Compound-specific isotope analysis (CSIA) is an analytical method for measuring the ratios of certain stable isotopes in environmental samples. In organic contaminants, these ratios can change through reactive processes, such as biotic or abiotic degradation, leading to an isotopic fractionation. The underlying principle is the preferential cleavage of bonds involving light isotopes, which results in an enrichment of the heavy isotope in the remaining fraction and of the light isotope in the degradation products. Physical, non-reactive processes such as dilution and diffusion on the other hand have a much smaller influence on isotopic composition.

As modern mass spectrometers have made it possible to measure isotope ratios very precisely, CSIA can be used to trace the sources and origins of contaminants. In the context of monitored natural attenuation, CSIA not only makes it possible to distinguish degradation pathways in cases where different initial contaminants might degrade to identical degradation products, but can even be used to gain knowledge of underlying reaction mechanisms. Using this information, degradation rates can be determined independently of concentration measurements or the observation of degradation products.

Results that are even more significant can be obtained by measuring the isotope ratios of multiple elements in a compound, but there are still unresolved analytical challenges to overcome in non-traditional isotope measurements at trace level concentrations and in standardized reporting of the results.

Keywords: remediation, biodegradation, contaminant hydrogeology, environmental chemistry

# A microfluidic study on biofilm and preferential path formation in porous media

**Dorothee Luise Kurz[1,2], Eleonora Secchi[1], Vicente Fernandez[1], Roman Stocker[1] and Joaquin Jimenez-Martinez[1,2]**

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In environmental (bioremediation and ecology) and industrial (chemical engineering) applications, it is of growing importance to understand the interplay between biogeochemical processes and hydrodynamics. The mosaic of regions of high and low flow velocity in porous media permits soil microorganism a free swimming lifestyle and to form surface-attached communities known as biofilms. The growth of biofilms influences pore geometries by clogging them, redirecting the flow and thereby affecting biofilm development. Besides clogging of pore spaces, preferential flow paths can be formed which show a dynamic behavior. We study these phenomena with a soil-born microorganism, *Bacillus subtilis,* in porous media analogs created in microfluidic devices to obtain a mechanistic understanding of the interplay of the hydrodynamics and biofilm development at the microscale.

Experiments were performed in carefully designed porous geometries while biofilm growth was continuously imaged using phase-contrast microscopy during 48 hours. Both hydraulic and geometric parameters of the porous medium influence the biofilm growth rate. For the same porous geometry, the initiation of biofilm formation and the definition of preferential flow paths occurs earlier in time with increasing flow rate. Above a critical flow rate, this trend is inverted. The preferential paths for fluid flow through the biofilm show an intermittent opening and closing behavior, intermittent bioclogging. Besides the impact of flow rate and geometry of the porous medium, this intermittent behavior is also controlled by the biofilms' rheological properties. The results shed light on the mechanisms involved in biofilm formation, clogging and its impact on the hydraulic properties of porous media.

Keywords: Biofilm, Porous media, Bioclogging, Microfluidics

# Numerical simulation of the effects of silica dissolution/precipitation on the evolution of the porosity of rocks

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**Abstract:**

Reactive transport in porous media is an important factor in subsurface processes at a range of length and timescales. In geothermal projects like heat deep mining, or enhanced geothermal systems, dissolution and precipitation might impact the overall behavior and viability of the system. Reactive transport causes scaling, which diminishes the permeability, consequently affecting the machinery, and hindering the productivity of the geothermal energy project. Furthermore, permeability decrease due to deposition has been proposed as an important factor in fluid triggered aftershock sequences. Specifically silica dissolution/precipitation, as it might be the driving chemical reaction in these processes. In this work, we numerically investigate the influence of silica dissolution/precipitation on porosity evolution processes. Previous models of the coupled thermal-hydro-chemical (THC) system exist in literature, but only focused on the effects of silica precipitation in the porosity reduction and pore pressure development. The effects of silica dissolution/precipitation in fracture aperture have been investigated previously as well. In this work, we present a closed system of equations for coupled THC systems including silica dissolution and precipitation effects on porosity. We use the equivalent continuum approach to derive the equations for field scale domains. In particular, we focus in deriving a reaction rate equation for silica dissolution/precipitation within the porous bulk. Preliminary results of this coupled rock-water interaction model and heat transport model are presented.

**Keywords:** reactive transport, porous media, quartz dissolution/precipitation, geothermal reservoirs, porosity reduction, heat diffusion, numerical simulation

# Is unweighted mixing a reliable tool for hydrological source apportionment?

**Harsh Beria[1], Josh Larsen[2], Bettina Schaefli[1]**

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Tracers have been used for over half a century in hydrology to quantify the different hydrological fluxes that make up flow in a stream or in groundwater. Bayesian mixing models have been proposed in the last decade to solve linear mixing as they also quantify uncertainty in the mixing ratio. In classical Bayesian inference, a large number of samples for each source is required, which is seldom the case in hydrology. Recently, we proposed a new Bayesian inference framework called HydroMix which relaxes the need for a large sample size. In this approach, every combination of the source concentrations are mixed with every target concentration, thus requiring fewer samples to describe the system.

Another important bias in Bayesian mixing models arise when there is a large divergence between the number of collected source samples and their flux magnitudes. We account for this bias by using composite likelihood functions that effectively weight relative magnitude of different source fluxes. Using a hydrological model, we show that the error in the mixing ratio estimates can improve by up to 50% if weights of different sources are accounted for. Using composite likelihoods to weight source samples has not been addressed in the literature and represent a significant improvement in tracer hydrology.

Keywords: stable water isotopes; Bayesian; hydrograph separation; tracer;

# IDENTIFYING SOURCES AND PROCESSES IMPACTING GROUNDWATER RECHARGE IN THE HUMAN ENVIRONMENT

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Understanding groundwater dynamics around areas of human influence is of critical importance for ensuring sustainable water management. Anthropogenic exploitation of the land can have significant impacts on a local water cycle, by changing the magnitude of existing parameters, changing the nature of surface water-groundwater interactions, changing infiltration pathways, or creating new, artificial sources and sinks of groundwater. All of these changes are consequential for the resulting quantity and quality of a groundwater body.
We present the results of an ongoing site investigation in a small catchment aquifer located in Canton Zürich. Several methods have been applied in an attempt to characterize the impact of land use on groundwater dynamics. A first approach involves the estimation of groundwater recharge via water balance, accounting for changes in runoff and evapotranspiration terms due to changes in land cover as well as the impact of potential artificial source and sink terms. We then made use of synthetic organic compounds as chemical indicators of specific recharge sources and potential pathways from the surface into the water. Micropollutants are fully anthropogenic in origin and so can be used to identify input from treated or untreated wastewater, irrigation, and surface waters. Micropollutant datasets have proven to be highly censored, requiring appropriate statistical methods for proper interpretation that avoids bias. Finally, stable water isotopes and inorganic chemistry are used as independent validation (or dissention) of the conclusions drawn from micropollutant data. From these analyses, a conceptual model of the modified water cycle in this catchment is offered.

Keywords: Groundwater recharge, micropollutants, land use change, censored data statistics

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# Improving spatial patterns of hydrological processes for water accounting in the Volta River basin using earth observation

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Competition for scarce water resources in the transboundary Volta river basin (VRB) of West Africa will increase in the near future due to the combined effects of urbanization, economic development, rapid population growth, and climate change. Information on current and future water resources and their uses is thus fundamental for water actors.

This research aims to provide quantified information on the current and projected state of the VRB water resources, incorporating available remote sensing products through a relatively new water accounting tool, namely the Water Accounting Plus (WA+) framework. The WA+ framework provides estimates of manageable and unmanageable water flows, stocks, consumption among users, and interactions with land use. So far, no studies have incorporated climate change scenarios in the WA+ framework to assess future water resources, which would be desirable for developing mitigation and adaptation policies. Moreover, WA+ has been implemented using remote sensing data while hydrological modeling can be associated for projections on the future water accounts.

However, it is important that the hydrological simulations used to inform the WA+ framework provide a realistic representation of the spatial and temporal variability of hydrological fluxes and states. This can be achieved by calibrating distributed hydrological models based on the spatial patterns of satellite remote sensing data.

Preliminary results show an improvement of the spatiotemporal representation of different components of the hydrological system. Such improvement is an asset for WA+ and spatial hydrology in general.

Keywords: water accounting; distributed hydrological modeling; satellite remote sensing; climate change; Volta River basin

# Hydrodynamic and geochemical response of a pre-alpine alluvial aquifer to controlled hydraulic forcing

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Texte

The interactions between surface water (SW) and groundwater (GW) in alluvial river-aquifer systems can be extremely dynamic and complex. Environmental tracers have been widely applied in the last decades for the characterization of such dynamic systems, proving to be highly suited to inform complex SW-GW interactions. In this way, multitracer studies, where tracers with different chemical composition and measurement time scales are combined, provide the perfect framework for a sound estimate of the sources, pathways and residence times of GW in alluvial valleys. On the other hand, new developments in UAV and sensor technology have enhanced the acquisition and frequency of remote sensing data targeted for SW-GW exchange processes characterization. This improvement is critical for extremely dynamic systems, where the hydraulic conditions of the site undergo continuous and rapid changes.

Following the aforementioned, a multitracer experiment was conducted during a unique 6-week transient pumping test implemented by the water authorities of Bern (WRVB) to an important alluvial drinking water aquifer in Switzerland (Emme site). Throughout this period, the abstraction rate was progressively increased up to 35000 l/min at the end of experiment, providing the optimal conditions for analysing how the tracer measurements reflect system transience. The increasing pumping rates were expected to lead to (1) altered SW-GW interactions and (2) a change in the pumped water sources. To investigate the system response, discrete GW and SW samples as well as continuous GW samples were collected immediately before, during and after the pumping experiment for analysis of environment tracers and chemical parameters. In parallel, hydraulic heads were continuously monitored at 22 piezometers and river discharge and temperature measurements were performed on ground and complemented with UAV-thermal imaging data. This combination of tracer-based, hydraulic and UAV-based data provide an adequate basis for a reliable characterization of SW-GW alluvial systems.

Keywords: surface water-groundwater interactions, environmental tracers, UAV-thermal imaging, pumping test

# Comparing different approaches for predictions in ungauged catchments

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In this work, two different approaches for predictions in ungauged basins are tested: streamflow signatures regionalization and model parameters regionalization. The first consists in calibrating the parameters of a lumped hydrological model using estimated streamflow signatures instead of the complete time series; the second involves transferring the parameters of a calibrated semi-distributed hydrological model to the ungauged site. The case study consists of some subcatchments of the Thur catchment (Switzerland) characterized by different meteorological and physical properties. For the first approach, the streamflow signatures are derived from the seasonal flow duration curves estimated using an analytical mechanistic model; in the second approach a semi-distributed hydrological model was built on the entire Thur catchment and calibrated using some gauged sites. In both cases a Bayesian approach was used to account for the various sources of uncertainty. Overall both approaches provide reliable estimates of streamflow prediction uncertainty and show, therefore, their usefulness for prediction in ungauged catchments.

Keywords: ungauged catchments, hydrological signatures, semi-distributed modeling, Bayesian analysis

# Patterns of reversible ground surface deformations in crystalline rock slopes

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**Abstract**

Fractured rock-masses deform in response to changes in pore pressure. In alpine catchments, groundwater flow dynamics is generally dominated by strong recharge signal from snowmelt infiltration in spring / early summer and in early winter, and punctuated by large rainstorms in snow-free periods. In crystalline rock slopes, infiltration occurs along discontinuities, such as faults and joints. Under constant normal stress joint apertures increase non-linearly during pore pressure increase, increasing the volume of saturated rock masses and leading to surface deformation. The latter can be measured with high-resolution geodetic monitoring systems and remote sensing methods such as DInSAR.

In this work, we discuss temporal and spatial variations of reversible ground surface deformation measured in the Aletsch region, Switzerland. The study area is situated in the vicinity of the tongue of the Great Aletsch Glacier, central Swiss Alps, in the gneissic and granitic bedrock of the Aar massif. The valley (1550 to 2300 m.a.s.l.), is roughly oriented parallel to the main Alpine foliation (NE-SW) and to major fault zones. Total annual precipitation is less than 1 m/y, but snow depth frequently reaches 2 m during winter, with strong spatial variability. We use a network of 4 continuous Global Positioning System (cGPS) stations and 90 reflectors linked to 2 total stations (TPS), operating since 2014, to track deformation at millimetric to centimetric scale. We use weather and hydrological data from surrounding stations to estimate the timing of infiltration.

At some locations in our study area we observe peak-to-peak magnitude of seasonal deformation over 2 cm, whereas other areas show no significant seasonal deformation. Measured displacement vectors are generally oriented towards the valley center in spring, when deformation rates are the highest (>0.5 mm/d). The start of the high-rate of deformation period also varies spatially, e.g. the South-facing slope starts deforming earlier than the North-facing slope. The vertical component of motion is generally smaller than the horizontal one, and often below the noise level. Finally, we discuss possible factors (e.g. topography and slope orientation, discontinuities' orientation and density, lithology, groundwater recharge magnitudes and durations) that might influence the spatial and temporal variations of reversible deformation on the slopes adjacent to the tongue of the Great Aletsch Glacier.

# Using GPR to investigate the sub-glacial hydrology of an alpine glacier

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Whereas glacial erosion rates are becoming better understood, how eroded sediment is transported out of a glacier remains poorly quantified. Field data show that coarse sediment export from temperate glaciers is an “on-off” phenomenon suggesting that it is hydraulically-controlled through the effects of changing subglacial discharge upon the excess of bed shear stress over critical shear stress. If sediment export is “on-off” then it is likely that there are diurnal cycles of erosion and deposition in subglacial conduits. Borehole imagery and speleological investigations have confirmed that some conduits have soft, unfrozen sediment beds. As such, they might be better viewed as both rivers under ice and channels eroded into the ice, which is supported by the presence of eskers post-glacier-recession. We still have little information about the geometry of such conduits, which is required to understand their sediment transport behaviour.

Here, we present the results of high resolution, three-dimensional ground-penetrating radar (GPR) surveying of a large temperate Alpine valley glacier, the Glacier d’Otemma in the south-western Swiss Alps. By looking at spatially dense grids of GPR measurements, we are able to identify the locations and geometry of sub-glacial conduits below the glacier tongue, for ice thicknesses between 30 m and 80 m. Validation is made by comparison with measurements made after glacier recession and snout collapse. The GPR data allow us to produce high resolution glacier bed-topography maps of the glacier snout margin, showing that in this case the glacier bed comprises mixed soft sediments and bedrock outcrops.

Keywords: GPR, sub-glacial hydrology, sediment transport, erosion, alpine

# A new *on-site* method for tracing denitrification in riparian groundwater

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Nitrate is among the most prevalent groundwater pollutants globally. Despite centuries of research on denitrification—the main process converting nitrate to nitrogen gas (N2)—we still lack a comprehensive understanding of its spatio-temporal dynamics. The high atmospheric background concentration of N2 has been recognized as a major impediment for advancement in this field. Previous research has shown that noble gases can be used to account for atmospheric N2 dissolved in groundwater. Thus, by a combined analysis of dissolved noble gases and N2, the amount of N2 stemming from denitrification can be quantified. Conventional dissolved gas analysis, however, is both expensive and labor intensive. We used a portable Gas Equilibrium Membrane Inlet Mass Spectrometer (GE-MIMS) system, which allows for a fast and efficient *on-site* analysis of dissolved gases (N2, O2, CO2, He, Ar, Kr) in groundwater. We employed the GE-MIMS system at three piezometers located in the riparian zone over a six months period. We thereby obtained spatio-temporal time series of N2 production due to denitrification. Moreover, we observed processes associated with nitrate respiration such as CO2 production and O2 depletion in the riparian zone. We can link spatial differences in denitrification dynamics to differences in streambank hydraulic conductivity and microbial activity. Our results demonstrate that the GE-MIMS system can accelerate a better understanding of denitrification in dynamic systems as it allows for high resolution sampling of groundwater.

Keywords: denitrification, riparian zones, *on-site* noble gas spectrometry

# How does the 3D displacement data from a Fault reactivation experiment can improve the estimation of the in-situ stress?

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Developing a methodology for measuring the in-situ stress in deep boreholes is one of the goals of the Fault Slip (FS) experiment, conducted in shale rocks at the Mont Terri Underground Research Laboratory (URL), Switzerland. The experiment consisted in fluid injections into the main tectonic fault zone to reactivate the fault planes and trigger the slip that is to be used for solving the stress inverse problem. The experiment was executed using the Step-Rate Injection method for Fracture in-Situ properties (SIMFIP) to quantify discontinuities, hydraulic and mechanical properties in situ using coupled pressure/deformation measurements in boreholes. In comparison to standard packer probes, the SIMFIP probe allows measuring the 3D displacement in the injection chamber together with the fluid pressure, flowrate and microseismicity. This study shows the preliminary results from the FS data analysis using the detailed structural model of the fault zone. It is demonstrated that the experimental 3D displacement orientations are controlled by the reactivation of the fault planes, new fractures have not been created. The 3D displacements below the Fault Opening Pressure are pressure dependent and mostly related to borehole expansion. Their orientation aligns with the minimum principal stress, which was independently determined by slip-tendency approach. The 3D displacements above the FOP align with the intermediate principal stress. The rock mass response to hydraulic injection during the FS experiment was also numerically simulated using the 3D distinct element code. The model identifies limitation of stress inversion methodologies based on slip orientation and slip sense caused by non-uniform stress field related to a fluid pressure source and complex fault geometry. A sensitivity study has been performed in order to quantify the impact of these limitations for stress-inversion methodology.

# Hydromechanical behavior of fractures during the in-situ hydraulic fracturing experiment

**Nathan Dutler[1]** Mohammadreza Jalali[2], Valentin Gischig[3], Hannes Krietsch[4], Bernard Brixel[4], Clément Roques[4], Benoît Valley[1] and Florian Amann[2]

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A total of six hydraulic fracturing (HF) experiments were conducted at the Grimsel Test Site (GTS), Switzerland, with the aim to improve our understanding of processes associated with high-pressure fluid injection in a moderately fractured crystalline rock mass.
The pressure decay curves after pump shut-in are analyzed using pressure derivative as diagnostic tools to estimate fracture closure pressure, which is related to the minor principal stress component. The Fracture-Compliance method after McClure (SPE Journal, 2016) was used for the complex G-function (Nolte, 1979). McClure assumes variable fracture compliance, where fracture retains a finite aperture after coming into contact (mechanical closure). Hence, fracture stiffness increases with fracture closure. When the fracture closes, fluid storage decreases. Fracture closure pressure is picked after the first point of deviation from linearity in a G x dP/dG vs. G-time plot. The fracture closure will be compared with the jacking pressure from the pressure-controlled step test. Special attention is given to the observed normal fracture stiffness increase during fracture closure using time series of pressure and strain observation points, which are located at one specific fracture. The pressure signal in the injection interval is dominated by the early fracture closure around the borehole which is largely influenced by the normal fracture stiffness increase.

Keywords: hydromechanics, ISC project, hydraulic fracturing, GTS

# Nitrate leaching from arable fields above a groundwater aquifer

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The loss of nitrogen (N) is one of the biggest unsolved environmental problems of our time. On one hand, nitrogen is a critical yield-limiting factor. On the other hand, part of the fertilizer is lost to other environmental compartments, which leads to the contamination of groundwater, among other issues. Consequently, nitrate limits for drinking water are now exceeded in many regions, including the Gäu region in the Swiss Plateau.

This study focuses on nitrate leaching on the field scale, more precisely on the hydrological transport processes in the unsaturated zone and the resulting concentration in the aquifer. Leaching monitoring systems have been installed in 11 fields in the Gäu region of Switzerland, where elevated nitrate concentrations in groundwater prevail. Farmers manage the fields according to their usual practices and disclose the fertilizer type and amount applied. Crop rotations include grass-clover leys, corn, canola and cereal. The instruments used are suction cups, a vadose zone monitoring system (VMS), nitrate passive samplers (SIA), and autumn and spring soil coring for mineral nitrogen (Nmin) analysis. The nitrogen content of the crops is assessed via unmanned aerial vehicle (UAV) surveys and, at harvest, via plant samples. Taking into account all this data, the nitrogen budget on a field scale is calculated.

In addition to this monitoring of the status quo, strip experiments are implemented in six fields in order to compare improved fertilisation practices to the baseline scenario. Results for the first year of the monitoring will be available by June 2019. We hypothesise that nitrate leaching happens mainly in autumn triggered by rainfall or in spring triggered by early fertilizer application.

Keywords: nitrate, leaching, monitoring, drinking water, fertilisation

# Water saturation impact on solute mixing in 3D porous media

**Andrés Velásquez-Parra[1,2], Michele Griffa[3], Rolf Kaufmann[3], Federica Marone[4] Joaquin Jimenez-Martinez[1,2]**

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The unsaturated zone, including soil and vadose zone, controls the exchange of water, heat and chemical substances between the soil surface and aquifers. It also hosts several processes involved in the transfer of nutrients, playing a key role in the availability of life-sustaining resources. Understanding how both water flow and transport of chemicals occur in this region is of major importance for the protection of groundwater sources, the remediation of polluted sites and the optimization of some industrial applications, such as radioactive material and urban waste disposal. A full 3D spatio-temporal visualization of these processes has proven to be very difficult due to the short temporal scale at which they occur and to the presence and interaction of several phases (i.e., air, liquid and solid). We analyse flow and transport processes in unsaturated media at pore scale using high spatio-temporal resolution X-ray computed tomography (synchrotron). 3D transport experiments through a synthetic porous medium using a contrast solution were performed at different saturation degrees. The experimentally inferred concentration fields combined with 3D numerical simulations of the fluid flow velocities allow us to assess the dependency of mixing on phase saturation. We discuss the impact of the third dimension on both solute transport and mixing in comparison with the existing 2D experimental approaches.

Keywords: unsaturated zone, saturation, pore scale, concentration field, mixing.

# Field based geophysical characterization of soil structure

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Soil structure exerts a significant influence on key soil hydrological, agricultural and ecological functions. Moreover, soil structure varies temporally and spatially in response to biological, anthropogenic and climatic perturbations. Soil structure variability often occurs at the pore scale, but may induce large changes in soil functioning at much larger scales. Advancing our understanding on the feedback between soil structure and its drivers and, thus, enabling sustainable strategies for soil management in agricultural and ecological contexts, partly relies on the systematic quantification of soil structure and its variations across temporal and spatial scales. Geophysical methods may contribute with observation capabilities at these larger scales. One promising approach puts emphasis on transport processes that are governed by soil structure and targets the indirect inference of soil structural elements throughout a framework in which in-situ time-lapse measurements are used to infer system properties. Minimally invasive geophysical methods are capable of monitoring the processes of interest, yet the development of strategies for data integration and modeling remains challenging. In this work, we present the signatures observed from different soil structures on time-lapse DC-resistivity data from a controlled field experiment in the vicinity of Zurich, Switzerland and discuss potential ways to integrate these observations within a coupled hydrogeophysical modeling framework designed for soil structure inference. The time-lapse DC-resistivity data, collected over a four-month period starting in the Spring of 2018, identifies clear signatures of soil structure (e.g., rates of drainage) for soils with different treatments and covers.

Keywords: geophysics, soil structure, soil functions

# The Phenix project: development of tools to build efficiently reliable hydro-geological models for the Quaternary in Switzerland.

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The aim and the methods of the Phenix project will be present on the poster. The Phenix project has to aim to build efficiently geological models for the specific environment of quaternary in Switzerland. We want to create a whole workflow from the data to the inversion with the step of modeling the geology, the properties and then simulate geophysics answer or hydrological variables. For the whole workflow we want to develop easy and fast tools without marring the quality of the models. Different type of data will be used as prior knowledge as outcrop, log and statistics to build different models using different type of geostatical tools (MPS, simulation). One of the first objective is to have a hierarchical workflow which allows to model the heterogeneity at a small scale. The second is to develop a joint inversion with geophysics and hydrogeological data. The machine learning is one of the idea to improve the speed of the inversion. This workflow will be a loop to be sure that the simulated model and its geophysical properties match the hard data. The whole workflow will be applied in the Aare Valley between Berne and Thoune.

Keywords: Quaternary, Modeling, geostatistics, heterogeneity

# Reactive transport in 3D porous media: A Magnetic Resonance Imaging approach

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The physical heterogeneity of subsurface environments results in complex water flow dynamics, characterized by preferential high-velocity paths interspersed amidst low-velocity zones. In the unsaturated zone, the presence of air adds more heterogeneity. This is expected to control the residence time and mixing of water transported chemicals, thus strongly affecting chemical reactions, which drive fundamental processes such as the fate of contaminants, soil respiration and geochemical cycles. We use Magnetic Resonance Imaging (MRI), a powerful technique to visualize chemical reactions in three dimensions, to characterize the transport of reactive fronts in optically opaque porous media. A packed bed of glass beads and a redox reaction are used for this purpose. Spatio-temporal resolved reaction rates are obtained, that along with velocity field computed numerically, allow us to characterize the impact of the heterogeneity, including the presence of an immiscible phase, and flow dynamics on the global reactivity of the system.

Keywords: reactive transport, porous media, MRI

# Conditioning of groundwater flow parameters by iterative ensemble smoothing: Application to a synthetic model inspired by the artificially induced flow at the Andra's Meuse/Haute-Marne site

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The calibration of groundwater flow models in transient state can be motivated by the expected improved characterization of the aquifer hydraulic properties, especially when supported by informative time series data. Within the framework of the Andra's (French National Agency for Radioactive Waste Management) project for a deep geological repository in a low permeable formation in northeastern France, a three-dimensional high-resolution numerical model of variably-saturated flow has been developed in order to understand the local flow behavior and improve the characterization of lithologic structures and heterogeneities of the Oxfordian aquifer system at the Meuse/Haute-Marne site. It is intended to make the best use of the 12-year hydraulic head and flowrate time series recorded since the excavation of the access shafts and the operation of the Underground Research Laboratory [1] in order to infer both the hydraulic conductivity and specific storage fields. Considering the high-dimensional nonlinear problem, we are currently leaning towards iterative forms of the ensemble smoother method [2, 3] which large-scale applicability has been showcased more especially in the fields of atmospheric sciences and petroleum engineering. By assimilating the calibration data in one single step, the algorithms update iteratively an initial ensemble of stochastic realizations of parameters generated on the basis of some prior geological information. This correction computed from the approximation of covariance matrices is particularly effective when the ensemble fields to update are multi-Gaussian. When applied to more complex non-Gaussian distributions however, these methods have proven to be not so efficient as they fail to preserve the non-Gaussian distribution and pre-existing geological structures [4]. Given the discrete nature of structures described in the Andra's geological model, a major goal is to investigate how to still best leverage the performance of the iterative ensemble smoother while keeping a final ensemble of updated realizations as conceptually acceptable as possible. The performance of selected algorithms combined with additional steps to help mitigate the effects of non-Gaussian patterns, such as Gaussian anamorphosis on the parameter and/or simulated data, and facies resampling based on updated conditioning in the case of categorical multipoint realizations, are assessed in terms of the model plausibility, quality of history match and uncertainty quantification achieved.

**References**

[1] H. Benabderrahmane, J. Kerrou, L. Tacher, G. Deman, P. Perrochet. Modelling of predictive hydraulic impacts of a potential radioactive waste geological repository on the Meuse/Haute-Marne multilayered aquifer system (France). *Journal of Applied Mathematics and Physics*, 2, 1085-1090, 2014
[2] Y. Chen and D. S. Oliver. Levenberg-Marquardt forms of the iterative ensemble smoother for efficient history matching and uncertainty quantification, *Computational Geosciences*, 17 (4), 689-703, 2013.
[3] A. A. Emerick. Analysis of the Performance of Ensemble-based Assimilation of Production and Seismic Data, *Journal of Petroleum Science and Engineering*, 136, 219-239, 2016.

# Understanding groundwater connectivity and storage in alpine glaciated catchments – the case of the Otemma glacier

## Poster presentation

**Tom Müller[1]**

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Rapid glacier recession related to recent climate change in alpine region exposes increasing areas of previously ice-buried till and bedrock. These newly created proglacial areas are composed of poorly sorted sediments and debris coming from a mix of subglacial (till), englacial and supraglacial origin, and are subject to rapid geomorphological and ecological modifications. They also constitute potential new groundwater reservoirs for rain, snowmelt and ice melt. The hydrology of such glaciated catchments is therefore evolving, but the connectivity between glacier meltwater and other paraglacial structures such as talus slopes or small lakes to these areas remains unclear. We propose here a conceptual model based on the Otemma glacier, which summarizes the key geomorphological structures and their temporal evolution and propose a general conceptual model of water connectivity and storage inside this glaciated catchment. We conclude with an analysis of potential hydrograph modifications linked to such new reservoirs and how it may evolve with increasing glacier retreat.

Keywords:

- Glacier recession
- Proglacial hydrology
- Proglacial geomorphology
- Otemma glacier
- Conceptual model

# Determine fault criticality using seismic monitoring and fluid pressure analysis

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Rupture mechanisms of critically stressed faults are of primary interest for underground projects. Since a critically stressed fault is close to failure, stress perturbations in the surroundings of the fault can lead to rupture and seismic energy radiation. Processes such as underground extraction or injection of fluids, loading or unloading at the earth surface will undoubtedly change the local stress state. If such processes occur near critically stressed fault, these stress changes can affect fault stability.

The fault's behavior depends on the surrounding stresses but also on its intrinsic properties such as asperities and the presence of fluids. An increase in groundwater pressure - due to seasonal snowmelt or important rainfall periods for example - reduces the effective normal stress to the fault, thus favoring failure.

The project JuraHydroTectonics aims to investigate the fault criticality of several strike-slip faults in the Jura Mountains - most likely critically stressed according to their orientation in the global stress-regime - by combining monitoring of hydrogeological conditions and microseismicity. If a fault system is on the verge of failure, relatively small fluid pressure changes might induce microseismicity. Correlation of low magnitude earthquakes with increasing springs discharge rates will help to develop a quantitative knowledge on what pressure change is affecting the seismicity and eventually use this knowledge to develop a straightforward methodology to assess fault criticality. In addition, the study of possible time lag between aquifer response and fault activation can provide valuable information on the deep-seated fluid circulation in the Jura Mountains.

Keywords: fault criticality, microseismicity, fluid pressure

# Spatial and temporal water budget calibration at the regional-catchment scale using remotely sensed data: Thur Catchment, Switzerland

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Although many regions rely on groundwater as a primary source of drinking water, both in lieu of its availability and its filtered quality, groundwater occurrence is generally unevenly distributed. Accurate water budget analysis is therefore an important tool for water managers. In additions, changing climate and global land use patterns; both significant fresh-water quantity determinants, are shifting rapidly and substantially, both spatially and temporally. As such, estimating a regions spatiotemporal water balance reliably, using current data, is fraught with complications. When estimating freshwater availability, the renewability of groundwater is an important factor to consider: adequate recharge, whether natural or artificial, can ensure an aquifer's productivity. In order to ameliorate regional scale (1700km$^2$) water budget estimates, we investigate the capability of a data-assimilation approach for the years 2001 - 2016, with a specific focus on groundwater. Historic and current precipitation data (using the RSOI method), along with current evapotranspiration (ETa) values from MODIS, were used in conjunction with long-term hydrological runoff data, groundwater levels and abstraction rates from the Thur catchment (Switzerland). Without any major natural or artificial barriers along its course (~130km), its naturally variable discharge rates (3 m$^3$/s - 900 m$^3$/s), and its 9 operational gauging stations, the Thur River is well suited to this study. Based on the resulting estimates, we aim to determine the spatiotemporal groundwater storage and water budget, and confirm the useful relationship between remotely sensed ETa, interpolated precipitation and monitored surface run-off data as a water management tool at the regional scale.

Keywords: Groundwater, water budget, data-assimilation, spatiotemporal, storage.

Nested particle filters for data assimilation and sequential parameter optimization

Authors: Maximilian Ramgraber[1,2], Matteo Camporese, Philippe Renard, Mario Schirmer[1,2]

**Abstract**:

The increasing availability of wireless sensor networks encourages the development of self-optimizing groundwater models. Based on a sequential Bayesian framework, such approaches may not only assimilate data to correct their own predictive shortcomings, but also optimize model parameters.

In hydrogeology, this optimization is particularly challenging: Numerical models generally involve vast numbers of unknown variables, while seeking compliance with a prescribed geological patterns limits the realm of viable solutions. As a consequence, the resulting probability distribution is both high-dimensional and complex, precluding an analytic solution. Instead, it is common practice to employ ensemble-based approaches. The Ensemble Kalman Filter (EnKF) has proven relatively robust in high-dimensional problems, but its simplifying assumptions are ill-suited for the pursuit of realistic geology. Particle filters could support the necessary complexity, but are generally disregarded in high-dimensional systems due to their intrinsic 'curse of dimensionality'.

However, a self-imposed restriction to a subset of parameter space – for example the subset corresponding to all parameter fields featuring the desired geology – can reduce the effective dimensionality substantially. Such an approach may render a particle filter implementation viable, but requires a way to draw random samples from (and efficiently navigate within) the chosen subset. This may be achieved through multiple-point statistics (MPS), a versatile tool capable of generating random realizations of parameter fields based on a training image.

Here, we present an implementation of a nested particle filter for sequential data assimilation and parameter optimization, using MPS to ensure conformance with a prescribed geology during optimization. We demonstrate the algorithm at a case study near Settolo, Italy.

# Towards a better understanding of the long-term fate of pesticide metabolites in groundwater

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Persistent substances are undesirable in groundwater. Among these substances, pesticides and their metabolites are particularly common, because of their large-scale application in agriculture and their persistence in the environment. Metabolites tend to occur more frequently and at higher concentrations than pesticides due to their higher mobility.

Measures like restrictions in application or the ban of certain pesticides have been introduced to reduce the impacts on groundwater quality. However, pesticide metabolites often show a high persistence with no concentration decline in groundwater for extended time periods. With nitrate for instance, the effects of management practices on the long-term dynamic of nitrate concentrations in groundwater have been studied in detail. However, there is less knowledge on the long-term fate of pesticides and especially pesticide metabolites in groundwater.

Therefore, the main aim of this study is to investigate how geological and hydrogeological factors influence the long-term persistence of pesticides and their metabolites in landscapes characterized by glacial and fluvial deposits. The study is carried out in two small catchments (~ 20 – 30 km2) on the Swiss plateau characterized by glacial and fluvial deposits. It focuses on the metabolites of the herbicide chloridazon, namely desphenyl-chloridazon and methyl-desphenyl-chloridazon, which are widely present in European groundwater. We investigated the catchment response to the termination of chloridazon application through field investigations and numerical modelling.

The field studies allowed identifying different mechanisms that control the long-term dynamics of the two chloridazon metabolites. First, the metabolite concentration in groundwater can be strongly influenced by the unsaturated zone acting as a reservoir for pesticides and metabolites. This leads to a retardation in leaching to the groundwater and to stable metabolite concentrations in groundwater even several years after stopping pesticide application. Secondly, the metabolites can be dislocated between different groundwater bodies via exfiltration to streams and re-infiltration into groundwater, hereby strongly increasing the catchment residence time. Furthermore, residence times might be underestimated within a groundwater body. Therefore, in order to reduce the impact of pesticide metabolites on groundwater quality, groundwater-surface water interactions that transfer the compounds between different groundwater bodies have to be considered.

Keywords: pesticide metabolites, long-term dynamics, groundwater, application stop

# Insights on 3-D heat transport in low-permeability hard rocks

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Here, we present field results from two cross-hole thermal tracer tests, performed in a crystalline rock at the Grimsel Test Site (GTS), Switzerland. Distributed temperature sensing (DTS) was achieved by deploying optical-fiber through two fully-open boreholes and three grouted boreholes (1st test) or using three packed-off and three fully-grouted boreholes (2nd test). Active heat injection was carried out by warming the injected water through an electrical flow heater at surface up to 50°C, over a duration of 10 days (1st tests) and 40 days (2nd test). Fluid injection took place across a discrete, 2-m long interval. Temperature in the injection interval was monitored using a downhole temperature probe. Multiple breakthroughs were observed, ranging from fast (< 10 hours) to late (>20 days) arrivals, with thermal anomalies up to 10°C monitored at 4-5 meters from the injection point. The deployment of optical-fiber loops allowed the detection of 3-D thermal fronts. Two responses are identified: (i) a fast, advection-dominated response which developed across a network of well-connected fractures and (ii) a slower, diffusion-dominated response that propagated through low-permeability rock mass primarily by heat conduction. The 3-D thermal response presented herein will be interpreted in the future using a discrete fracture network model.

Keywords: heat transport, geothermics, thermal tracer tests, FO-DTS

# From the snowpack to deep groundwater: integrated hydrological modelling of a steep, geologically complex Alpine catchment

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Climate change is threatening the established function of the European Alps as "water towers". The complex bedrock arrangements that are characteristic of such regions can strongly influence the broader hydrological cycle. Despite this, most predictions of climate change impacts continue to rely on conceptual hydrological models that employ highly simplified representations of groundwater flow (and indeed other processes). More physically-based, fully-distributed, integrated surface-subsurface models hold considerable potential in mountainous settings. For instance, they can directly incorporate 3D geological data where it exists, and are arguably unique in their ability to reproduce the dynamic, even ephemeral nature of headwater streams solely as a function of the meteorological forcing and domain properties. However, their application in steep, snow dominated, and geologically complex areas is impeded by a severe lack of the necessary 3D geological data, and by the fairly rudimentary approaches that are often taken with respect to modelling snow processes. Here, we present an energy balance simulation of snowpack dynamics that is subsequently combined with an integrated surface-subsurface flow model for a 37 $km^2$ catchment in the Swiss Alps. Wind and gravitational redistribution of snow are expected to be hydrologically significant, and are thus accounted for explicitly. Hourly, 25 m-resolution grids of i) snowmelt plus liquid precipitation, and ii) potential evapotranspiration form the input to the surface-subsurface simulator, whose structure is defined largely on the basis of a new bedrock 3D geological model and recent geophysical surveys. Uncertain subsurface hydraulic parameters are calibrated with regard to streamflow and groundwater level observations. The resultant model enables the spatio-temporal quantification of the water balance. Going forward, it will be applied firstly as a benchmark to assess the impact of various simplifying assumptions that are routinely made in integrated modelling, and secondly to predict the combined effects of anticipated changes in climate, vegetation, and permafrost on several hydrological variables.

# UAV-based remote sensing for surface water groundwater interactions

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My doctoral dissertation studies the hydro-geological processes taking place near the surface of the soil. The temporal and spatial dynamics of ground-vegetation-atmosphere interactions or groundwater and surface water interactions provide important information on hydrogeological processes. However, mapping these dynamics into a high spatial and temporal analysis brings together many challenges. My research is based on a state-of-the-art drone technology that can mount three different sensors, able to conduct different kind of research analysis: a Lidar scanner, a hyperspectral and a thermal camera. The aforementioned sensors allow the mapping of the surface structure, the thermal dynamics and spectral properties into unprecedented details. Thus we are aiming to produce new datasets for the scientific community and the areas of interest are Alpine forests, rivers, crops around Switzerland with high hydrogeological interest.

**Key-words:** hydrogeology, groundwater, surface water, remote sensing, Lidar, hyperspectral, thermal camera

# 3D Multiple-point Statistics Simulations of the Roussillon Continental Pliocene Aquifer using DeeSse.

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This study presents a novel workflow that was developed to model the internal heterogeneity of a complex 3D aquifer using the Multiple-point Statistics (MPS) algorithm DeeSse. The modeled aquifer is the Continental Pliocene layer (PC) that is part of the Roussillon Aquifer in the Perpignan's region in Southern France. The PC layer is a complex heterogeneous system formed by alluvial sediments.

We used in this study the direct sampling algorithm DeeSse and demonstrate its applicability for the first time on a large study site. MPS algorithms enable to create stochastic models that are based on geological information. The conceptual knowledge of the variable of interest is integrated into the simulation with the use of a training image (TI).

For representing the complex sedimentation history of the PC, a non-stationary training image was used. In order to control where each type of geological environment may occur in the plain, novel procedures were proposed to generate auxiliary variables maps by solving numerically a flow problem enabling to obtain plausible trends between the sources of the sediments and the outlet of the sedimentary system. Rotations maps were also generated to orient the patterns of the TI during the simulation, these rotations aimed to produce more realistic patterns. Both trend and rotation maps were based on geological insights gathered from outcrops and from a general knowledge of the processes occurring in these types of sedimentary environments. Finally, 52 well-logs were incorporated in the simulation as conditioning data.

At last, several sets of 100 simulations were produced and analyzed statistically. As compared to previous studies using MPS, this is the first time that such a multivariate approach is employed at a regional scale.

Keywords: Geostatistic, MPS, DeeSse, Geological Simulation.