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Shaping Earth:
From Planet Accretion To Microbes

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Sandra Borderie, Neil Mancktelow, Paul Tackley, Jonas Ruh

Swiss Tectonics Studies Group of the Swiss Geological Society

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1.1
Numerical modeling of poro-elasto-plastic behavior using graphical processing units (GPUs)

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Biot's theory (1962) describes the hydro-mechanically coupled physics of fluid-saturated porous rocks. This theory finds many applications in Earth Sciences. A dynamic response of such a system results in the two longitudinal waves and one shear wave. A quasi-static response results in fluid pressure diffusion. Adding plasticity to such a system enables us to model poro-elasto-plastic behavior, for example, associated with fracturing due to fluid injection.

We present a three-dimensional numerical implementation of poro-elastic physics using graphical processing units (Alkhimenkov et al., submitted). Only 95 seconds are needed to run 1000 time steps of a model having 1150^3 (1.5 billion) grid cells (Figure 1). This implementation can be used to obtain dynamic (wave propagation) and quasi-static (no inertia) results using the same code. Additionaly, we present a simulation considering an elasto-plastic medium in two dimensions (Figure 2). Currently, we are adding more physics to the present 3-D code to model poro-elasto-plastic responses due to fluid injection in a porous medium.

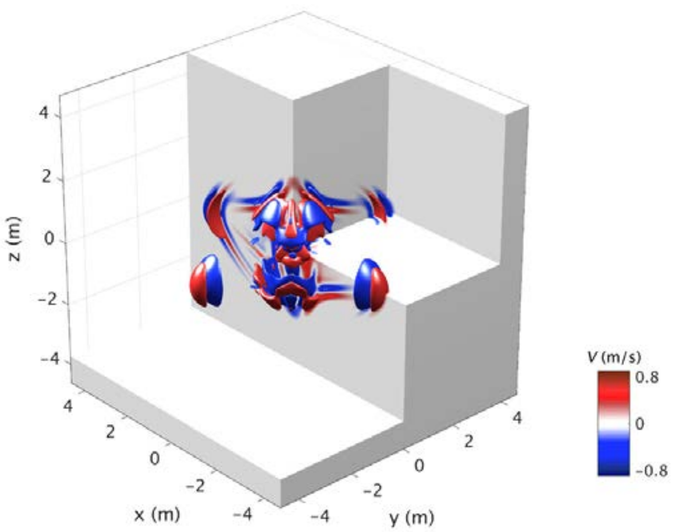

Figure 1. A snapshot showing the total solid particle velocity field in a poro-elastic medium (Alkhimenkov et al., submitted). This is a dynamic simulation (wave propagation).

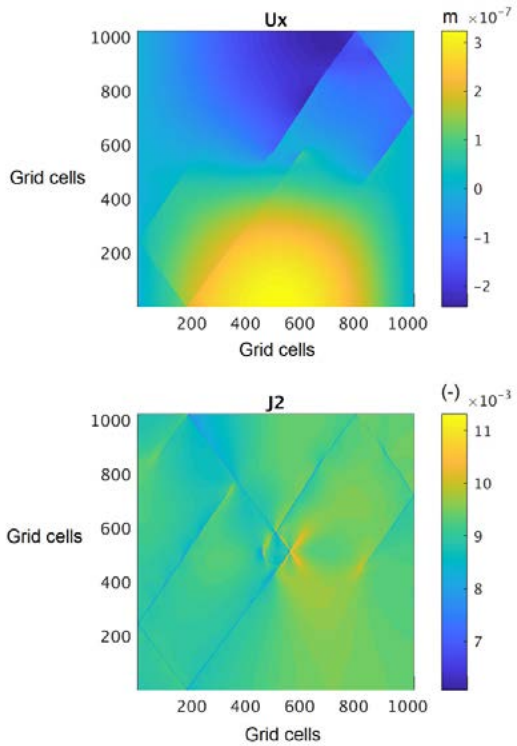

Figure 1. A snapshot showing the solid displacement and the second invariant of the stress tensor. The heterogeneous medium contains shear bands and is elasto-plastic. This is a quasi-static simulation (no inertia).

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1.2
Deformation processes and weakening mechanisms along a sediment-starved subduction megathrust

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The shallow plate interface in subduction zones accommodates both slow slip events and megathrust earthquakes as a function of pressure-temperature conditions, compositional and fluid-pressure heterogeneities, and deformation mechanisms. These heterogeneities control where, and how, strain localises as rocks are entrained and deformed on the plate interface. It is not well understood how mafic volcanic rocks and oceanic sedimentary rocks, which variably occupy the plate interface during subduction, weaken or deform with respect to one another. Due to the contrasting composition and rheology of these rocks, they are likely responsible for a variety of seismic behaviour.

We present results from field, microstructural, and experimental studies of volcanic and mixed volcanic-sedimentary tectonic mélange from the Chugach Complex of southern Alaska. In the Chugach, underplated slices of volcanic and sedimentary rocks were subducted to depths of 10 to 14 km and reached peak metamorphic conditions of 250-300°C during the Jurassic to Early Cretaceous. These slices of the shallow subduction interface shear zone are composed of either purely seafloor volcanic rocks or a tectonic melange of mixed sedimentary and volcanic rocks and are defined by sharp strain gradients in the field.

We document multiple structures in the Chugach that capture the progressive deformation of seafloor basalts with increasing strain. Several generations of fluid injection drive micro-brecciation of pillow basalt, followed by the development of a spaced tectonic foliation (S planes). Ongoing deformation leads to the formation of shear bands (C and C' planes) that isolate and wrap lenses of relict brecciated basalt and eventually localize into narrow zones of ultracataclasite. Where sediments (chert, mudstone, rare blocks of greywacke) directly overlie pillow basalt, deformation is more distributed and forms a mixed basalt-sediment clast-in-matrix mélange. Stronger, resistant fragments of chert and greywacke form angular, fractured clasts and altered basalt forms elongated, folded clasts; the clasts are wrapped by a sheared, cataclastic matrix that is derived from altered basalt and mudstone. We interpret these results in terms of the relative and absolute strength of the basalt and basalt-derived mélange and possible styles of seismicity.

1.3
Variscan Schlingen folding in the Central Alps

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Many polymetamorphic pre-Mesozoic basement units of the Alpine belt contain kilometre-scaled folds with steeply inclined axial planes and subvertical fold axes. Those amphibiolite facies structures are referred to as Schlingen folds and are described for the External Crystalline Massifs, the Austroalpine and Southalpine basements (Fig. 1). They deform the associated late-Ordovician metagranitoids and are cross-cut by late-Carboniferous intrusions. In the center of the Gotthard nappe (Central Swiss Alps) a well-preserved map-scale Schlingen fold (here called Tros-Schlinge) is the result of a combination of shearing and folding under amphibolite facies conditions. Detailed digital field mapping coupled with petrological and structural investigations reveal synkinematic migmatization in the fold hinge. Reconstructed axial trace of the Tros-Schlinge shows minor fold interference with a younger hitherto not reported prealpine deformation event (Vermigel phase). The superimposed Vermigel phase is locally embodied by a low grade foliation and a minor undulation of Schlingen structures. U-Pb dating of zircons separated from Schlingen axial plane parallel leucosomes yield cores that record a protolith age of 450 ± 3 Ma, and rims with a range of dates from 270 to 330 Ma. The main cluster defines an age of 316 ± 4 Ma. We ascribe this late-Carboniferous age to peak metamorphic conditions of the late Variscan Schlingen phase (water fluxed partial melting 650° – 700° C). The widespread Schlingen folding in pre-Mesozoic basement units of the Alps seems to correlate in time and tectonic style with the late-Variscan Iberian oroclines. Together, they may relate to crustal-scaled transpressive mega-shear zones, that particularly affected units south of the Moldanubian zone with pre-existing subvertical anisotropies (e.g. foliations, bandings) within peri-Gondwana terranes.

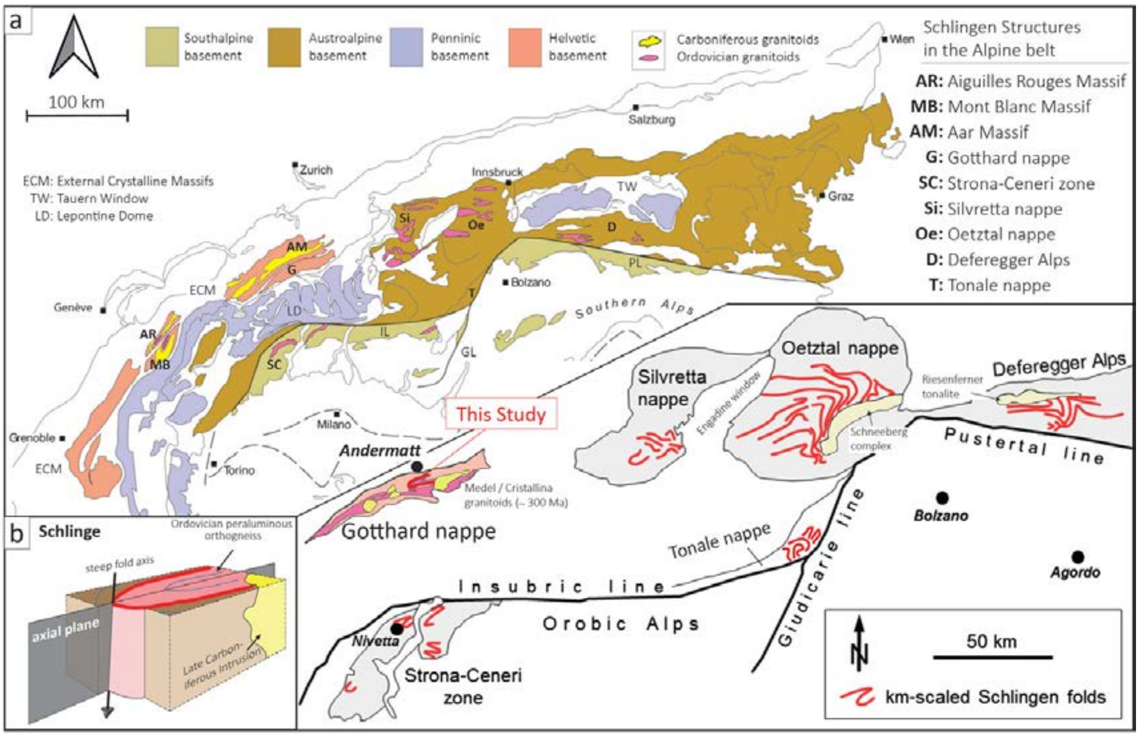

Figure 1. Schlingen structures in the Alps. (a) Compilation map of pre-Permian Schlingen structures described in polycyclic metamorphic basement units of the Alpine belt. (b) Simplified block model of a Schlinge showing a vertical fold with a steep fold axis and steep axial plane. Fig. 1a Modified after von Raumer et al. (2013) and Zurbriggen (2015).

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1.4
New Tomographic Models for High-Resolution Seismotectonic Interpretations in the Central Alps

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In this study, we present a new 3-D P and S wave velocity model of the upper crust of the Central Alps and their northern foreland. The tomographic model is derived from a high-quality data set of about 60’000 Pg and 30’000 Sg arrival times of local earthquakes, recorded by the exceptionally dense network of seismic stations in this region. The new tomographic models image the Vp and Vs velocity structure of the Central Alps’ upper crust at unprecedented resolution, including small-scale anomalies such as a (i) Permo-Carboniferous trough in the northern foreland, (ii) Subalpine Molasse units below the Alpine front or (iii) crystalline basement units within the Penninic nappes. The external Aar Massif is characterized by low Vp/Vs ratios of about 1.625-1.675 in the depth range of 2-6.5 km, which suggests differences in Vs resulting from metamorphism of the uplifted crustal block or layered anisotropy.

In addition, the new velocity model is used to improve the absolute location accuracy of hypocentres in the Central-Alpine region. In combination with a probabilistic hypocentre inversion procedure, the earthquake bulletin of the Swiss Seismological Service for the period 1984-2020 was consistently relocated in the new velocity model. The joint interpretation of the 3-D velocity structure and relocated seismicity, combined with information from focal mechanisms and geological and geodetic data, allows high-resolution studies of present-day seismotectonic processes within the upper crust of the Central Alps.

We focus our interpretation on the eastern Aar Massif as well as on the Rawil depression, located in-between the outcropping Aar and Aiguilles-Rouges Massifs. Both regions were recently affected by remarkable seismic events. The ML4.6 Urnerboden earthquake of 2017 occurred near the eastern termination of the Aar Massif, while a sequence of about 350 events occurred in the Rawil earthquake lineament north of the Rhone valley between the Sanetschpass and the village of Anzère in November 2019. Both sequences provide unique insights into active faults in the Central Alps and we image systems of sub-vertically oriented strike-slip faults of variable strike, which root in the crystalline basement in both regions. In the case of the Anzère sequence, high-precision earthquake locations and focal mechanisms image a complex faults system, including a constraining bend along an east-west striking strike-slip fault. In summary, our results document the existence of active strike-slip fault systems in the External Crystalline Massifs of the Central Alps in regions of maximum change in uplift rates.

1.5
Transition from a radial to a 3D buoyancy-driven hydraulic fracture

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Magmatic dikes are a naturally occurring type of fluid-driven fractures (Rivalta et al. 2015) propagating in the lithosphere due to buoyant forces emerging from the density difference between the host material and the injected fluid (more precisely the difference between the gradients of the in-situ minimum stress and the hydrostatic pore-fluid pressure).
The form of such buoyant fractures has been extensively studied in the context of magmatic dikes and shows the appearance of a head-tail structure (Rivalta et al. 2015). 2D plane-strain evaluations highlighted the fact that lubrication flow in the tail is driving the growth of the hydrostatic head (Lister & Kerr 1991; Roper & Lister 2005), which has been confirmed by Germanovich et al. (2014) for the 3D finger-like geometry.

We investigate the 3D transition of a radial hydraulic fracture emerging from a point source towards a buoyancy-driven fracture, focussing on the case of a constant injection rate in homogeneous conditions (homogeneous material properties and buoyancy contrast). We use scaling arguments to characterize the transition and the late time buoyant behavior of the fracture and validate the findings with the fully coupled planar 3D hydraulic fracture growth solver PyFrac (Zia & Lecampion 2020).

Our results confirm a characteristic transition time / length scale from a radial to a buoyant fracture depending on a single dimensionless parameter. The same parameter can be used to predict the fractures overrun (maximum breadth / stabilized breadth). A second, very slow transition takes place between the elongated fracture and the late time fully-developed 3D head-tail structure (similar to the solution of Germanovich et al. (2014)). Our simulations support the appearance of a 3D toughness dominated head structure. They also confirm the importance of the viscous tail as the driving mechanism for the dynamics of such a 3D Weertman's pulse (form of the head). We quantify how and when the transition from a radial to a buoyant fracture takes place, and it's implications on the late time behavior.

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1.6
3D geological modelling of the Doldenhorn nappe (external Central Alps, Switzerland): a glance beyond maps and cross sections

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The Aar Massif (external Central Alps, Switzerland) is the largest of the External Crystalline Massifs, which represent the crystalline basement of the former European passive continental margin that was exhumed during the Alpine cycle (Herwegh et al. 2020). The northwestern (NWRN) rim of the massif is overlain by a series of nappes (Wildhorn, Gellihorn, and Doldenhorn nappe; Burkhard 1988; Herwegh and Pfiffner 2005) that comprise the Mesozoic-Cenozoic parautochthonous sedimentary cover, tectonically detached from its substrate. The lowermost of these tectonic units is the Doldenhorn Nappe (DN). It consists of a large-scale recumbent fold with a thin inverted limb of intensively deformed sediments. The sedimentary rocks of the DN were deposited in a small-sized basin, which has been inverted during the compression of the Alpine orogeny (Burkhard 1988). This study presents a large-scale map and 3D geological model of the DN and the underlying western Aar massif based on two-dimensional cartographic and structural data managed with GIS and 3D modelling technology. The model visualizes the current structural position of the DN and the massif as well as the geometric and overprinting relationships of the articulated deformation sequence that shaped the investigated area throughout the Alpine evolution. Here we document that: (i) the DN is a strongly non-cylindrical recumbent fold that progressively pinches out toward the NE; (ii) the axial surface of the DN is moderately to steeply inclined (60-30°) toward the SW; and (iii) the progressive exhumation of the basement units towards the E and thrusting towards the N. Moreover, along NNW-SSE striking geological cross sections, restoration techniques reveal how the DN basin has been exhumed from ~ 12 km (Berger et al. 2020) to its present position at 4km elevation above sea level throughout several Alpine deformation stages. In this context, special emphasis is given to explore the role of inherited structures (e.g., Variscan-Permian and rifting related basement cover structures) on the Alpine deformation and related exhumation processes in 3D. In summary, today's structural position of the DN is the result of the inversion of a small basin in an early stage of thrusting, which was followed by sub-vertical buoyancy driven exhumation of the Aar massif and subsequent thrust related shortening. All three stages are deeply coupled with an original non-cylindrical shape of the former European passive continental margin.

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1.7
Subsidence or uplift stage? Surface denudation variations of the Otago upland (New Zealand).

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Landscapes are subjected to surface denudation during their complex and non-linear evolution. Yet, tectonic uplift and surface denudation rates are mostly averaged over multi-millennia. In result, temporal fluctuations are often unknown or even neglected. The recent development of the tor exhumation approach (TEA) focuses on the quantification of the later. It allows the determination of surface lowering rate variations over continuous time frames within the denudational zone. Here we present the exhumation patterns of eight tors (large residual rocks) in three different landscape locations (valley, ridge, off-site) at Otago, New Zealand. The in situ ^{10}Be ages average around 122 ± 12 ka and range from 836 ± 89 ka to 19 ± 2 ka. The exhumation and surface denudation patterns differ among the three locations. The valley commenced denudation around 200 ka with rates of ~0.22 [m ka-1] to ~0.02 [m ka-1]. In contrast, the ridge commenced on average about 0.03 [m ka-1]. The off-site location denuded continuously for ~120 ka at ~0.20 to ~0.05 [m ka-1]. Based on published tectonic uplift rates for the area, our modelled surface denudation rates would suggest that the off-site and valley locations are in a lowering state (with tendencies to steady-state), while the ridge location is still rising relative to sea level. Yet, are such different tectonic situations reasonable within 20 km^2?

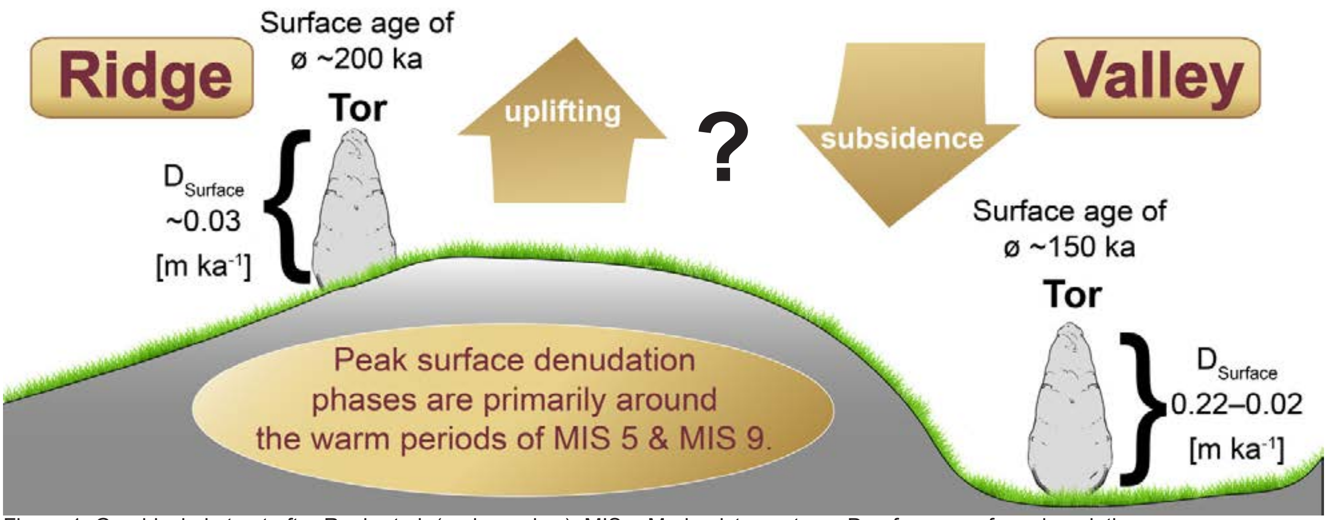

Figure 1: Graphical abstract after Raab et al. (under review). MIS = Marine istope stage, Dsurface = surface denudation.

REFERENCE

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1.8
Earthquake swarms activity in the Southern Red Sea, Afar and Gulf of Aden region from 1960 to 2016

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Rifting events periodically occur at divergent plate boundaries, consisting of magmatic intrusions, earthquake swarms, surface faulting and in some cases volcanic eruptions. While earthquake swarms also occur at other types of plate boundaries, those that have been observed in inland rift zones (e.g., in Afar and Iceland) and in a few offshore cases show in most cases an unambiguous relation with magmatic intrusions. These swarms typically last for a few days to a few weeks, and lack a clear mainshock-aftershock decay pattern pointing at an aseismic transient as a driver of the earthquake occurrences.

Here we present a study on earthquake swarms in the southern Red Sea, Afar and Gulf of Aden. We provide the first earthquake swarm catalogue for the region, which we compiled by integrating reexamined global and local earthquake catalogues with historical observations from 1960 to 2016. We find that in several cases in all the three areas, swarms have been re-occupying the same locations every few decades (e.g., in the Bada area in Eritrea and Port Sudan region in the southern Red Sea in 1967 and 1993, and in the western Gulf of Aden in 1979, 1997 and 2010-2012). When possible, we use focal mechanisms from the GCMT catalog to investigate the source parameters of the largest earthquakes to constrain their occurrence seismo-tectonically. The swarms show different degrees of seismic energy, many of them dominated by multiple earthquakes of Mw4 and Mw5, while occasional larger swarms have earthquake reaching Mw6, such as in the southern Afar region (the Serdo and Dobi areas). Of the three areas, Gulf of Aden shows the highest swarm activity and highest seismic energy release, followed by the Afar area and the southern Red Sea. Despite seeing the least amount of activity and lower magnitudes, the southern Red Sea has experienced multiple earthquake swarms and three volcanic eruptions (two of which resulted in new volcanic islands) from 2007 to 2013. The main characteristic of these earthquake swarms indicates they are driven by magmatic activity and suggests the existence of active spreading centers that are more active than previously thought. We show that the three areas have been subject to an almost simultaneous increase of earthquake swarm activity from 2005 to 2014, also evidenced by three rifting episodes. This period was much more active compared to the preceding decades (1960-2005) and might indicate an increase of magma supply in the region.

1.9
A thermo-kinematic model to investigate heat transfer through the nappes of the Lepontine Dome

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Heat transfer during the emplacement of nappes in an orogenic belt is controlled by three processes: advection, diffusion and production of heat. Production is mainly caused by radioactive decay and shear heating. The relative importance of these processes is contentious. Viscosity, velocity and strain rate affect primarily the contribution of advection and shear heating, which can generate a local temperature increase along the thrust surface. In order to evaluate the relative influence of production, diffusion and advection, we performed 2D thermo-kinematic simulations using the finite difference method. The 2D velocity field is prescribed by a kinematic trishear fault model. We investigate the relationship between nappes' and isogrades' geometries resulting from simulations characterized by different configurations of the velocity field. We calculate the thermal evolution and peak temperatures in order to compare the numerical results with field and petrological data. We use data from nappes of the Lepontine Dome (Central Alps, Ticino, Switzerland). These nappes show an extremely pervasive mineral and stretching lineation (NW-SE directed) indicating non-coaxial deformation during shearing at similar metamorphic conditions, and metamorphic amphibolite-facies isogrades locally dissecting the tectonic contacts. We compare the numerical results with field and petrological data collected along the Simano and Cima Lunga nappes.

In the field, the alternation of lithotypes is parallel to the nappe boundaries and constant over their whole, kilometer-scale length. The transition from the Simano to the Cima-Lunga nappe is marked by a progressive change in the texture of gneisses, in which the porphyroblasts become more stretched from the bottom to the top, and by the change in the constituent lithotypes. In the studied area, the Simano nappe is formed mainly by metagranitoids and by minor paragneisses. The Cima Lunga nappe is made of metasediments, mainly quartz-rich gneisses intercalated with amphibolite-gneisses, peridotitic lenses and local calcschists and/or marbles. Finally, the widespread paragneisses frequently contain garnets of different sizes and internal microstructure. Published and own petrological data of these garnet-bearing rocks are used to constrain the numerical simulations. We test multiple tectonic scenarios related to heat transfer during nappe formation, such as: radiogenic heating; additional heat flux at the bottom of the nappes, due to e.g. magmatic underplating or delamination; or shear heating along nappe boundaries. The results show that transport of heat through advection can't reproduce an inverted metamorphism below the thrust sheet.

1.10
Deep underplating in an erosive subduction margin: implications for interface rheology and continental recycling

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The viscous subduction interface shear zone downdip of the megathrust impacts large-scale subduction processes, including interplate coupling, mass and volatile recycling, and seismic behavior. Deep underplating, evidenced in the geophysical, geodetic, and rock records, preserves information on these processes, with specific implications for subduction interface rheology and continental mass recycling. We characterized deep underplating processes in the Condrey Mountain Schist (CMS, Fig. 1a), a Late Jurassic to Early Cretaceous subduction complex in northern California. The CMS contains voluminous hemipelagic metasediment with m- to km-scale metamafic and metaserpentinitic ultramafic lenses, all at epidote blueschist facies (0.8-1.0 GPa, 450°C). Limited retrogression and 10+ km of exposed structural thickness make the CMS an ideal location for investigating underplating processes.

We combined geochemical and structural data to identify structures responsible for underplating and to fingerprint protolith sources. We identified two major ductile thrust zones which define map-scale drag folds cored by km-scale ultramafic lenses (Fig. 1b). Above, below, and between these thrust zones, 3+ km thrust sheets record distributed deformation in predominantly sedimentary protoliths. Although kinematics within each ductile thrust zone are consistent across heterogeneous lithologies, stretching directions within the two zones are nearly orthogonal to each other. Consistency of structures in each ductile thrust zone suggests assembly of lithologies prior to underplating. Major and trace element geochemistry, however, indicate a suprasubduction zone source for all ultramafic and some mafic lenses (Fig. 1b). We interpret this combination of structure and geochemical data as indicating a) shallow subduction erosion that sourced the suprasubduction zone-affinity lenses, b) assembly and coherent deformation of heterogeneous lithologies during subduction, and c) protracted underplating at depth.

Underplating processes in the CMS have implications for both 1) interface rheology and 2) continental mass recycling. 1) The CMS records distributed deformation across a sediment-dominated, 3+ km thick shear zone despite subducting along a sediment poor, tectonically erosive margin. Periodic strain localization occurred when rheological heterogeneities (i.e., km-scale mafic and ultramafic lenses) were introduced to the interface. This characterization of interface rheology provides insights into the roles of sediment in interplate coupling/decoupling, as well as transient slip and associated seismic behavior. 2) Modern erosive margins with no assumed underplating serve as the primary recycling path for continental material to the deep interior. Estimated losses to Earth's interior outstrip continental growth rates, inconsistent with craton stability. Using modern sediment supply rates at erosive margins, CMS underplating rates were 7-22 km^3/m.y./km, representing significant sediment storage. Global application of similar techniques to determine a characteristic underplating rate at erosive margins may help balance continental material budgets.

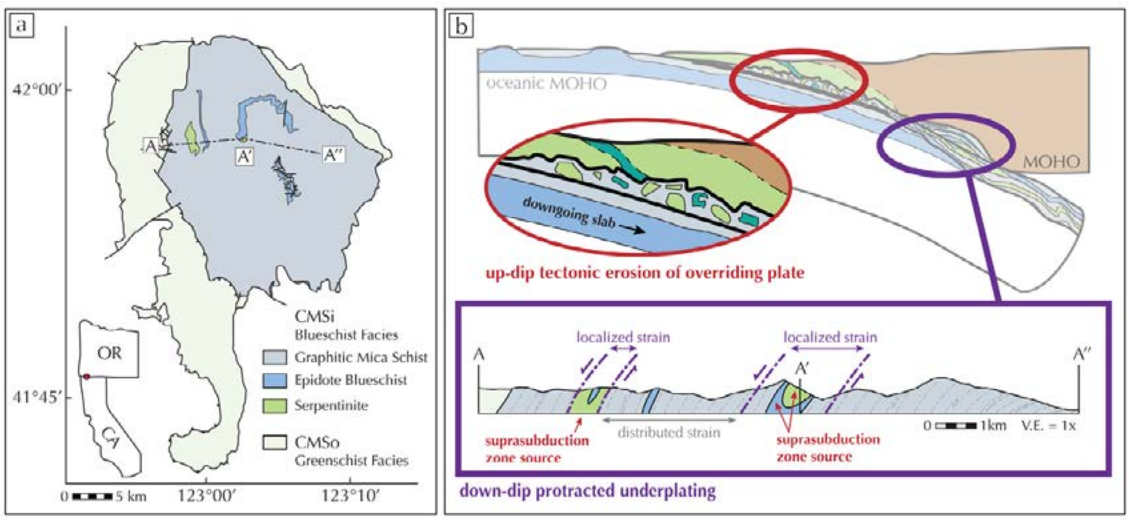

Figure 1. a) Simplified geologic map of the Condrey Mountain Schist (CMS, red dot on inset). b) Schematic of up-dip tectonic erosion and down-dip underplating to form the CMS. Cross-section shows extant orientations of lithologies, protolith sources, and structures responsible for schist assembly. Structures were overturned during Neogene doming from primary east-dipping orientation.

1.11
Successive Au mineralizing events in Archean vein networks during prograde amphibolite facies metamorphism revealed by topological investigations coupled to Au-grade distribution

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Stockwork-hosted Precambrian ore deposits are targets for base and precious metals, such as volcanogenic massive sulfides (VMS) or orogenic Au deposits. Precambrian vein-hosted Au deposits are commonly emplaced under greenschist facies conditions, and in some cases superimposed by amphibolite facies metamorphism and deformation that may lead to Au redistribution. The structural characterization of vein networks and the prediction of the metal grade distribution in such contexts are key challenges for mineral exploration and production.

The Cheechoo gold deposit is hosted by an Archean deformed granodioritic to tonalitic intrusion emplaced into wacke in the Eeyou Istchee James Bay (Quebec, Canada) area in the Superior Province (Fontaine et al. 2018), and that underwent several stages of deformation, hydrothermal alteration and formation of Au-bearing veins recrystallized and metamorphosed during prograde amphibolite facies metamorphism. The first veins are quartz-feldspar-diopside (Qtz-Fsp-Di) veins with albite halos, followed by Qtz veins and pegmatites. Chlorite (Chl) veins that correspond to retrogressive chlorite-coated fractures crosscut all previous veins and structures (Fontaine et al. 2018; Turlin et al. 2019).

In a previous study, we argue that high-grade metamorphism and related deformation of the Au-bearing veins do not allow the use of classical geometric approaches to characterize the stockworks (Turlin et al. 2019). Indeed, these approaches are based on the orientation, relative position and shapes of the veins that have been modified by deformation. Accordingly, we demonstrated that in such cases, the topological approach defined by Sanderson and Nixon (2015) based on the connexions between veins that are not modified during metamorphism, is best suited to decipher the stockwork evolution (Turlin et al. 2019). In addition, it allows an estimation of the networks' connectivity.

In this study, we couple the topological approach described above with a detailed structural analysis and Au grade and veins distributions. Altogether, the results demonstrate a polyphased Au mineralization. The first phase of veining is represented by Qtz-Fsp-Di and Qtz veins that exert a strong control on the mineralization, as shown by the close relationship between the lognormal distribution of Au grade and the density and connectivity of the vein networks. Zones of strong albitic alteration that are associated with these veins are characterized by a similar density and topological vein distribution, but the multimodal Au grade distribution is typical of nugget effects. The injection of syn-kinematic Au-bearing pegmatites is initiated after peak metamorphism and they crosscut the previous vein networks and alteration zones. In these pegmatites, the Au grade distribution is also multimodal as shown by local high-grade values that reach up to several g/t, and that we interpret as a result of Au remobilization during pegmatite emplacement.

Accordingly, in this contribution we demonstrate that (i) the network topology is a strong tool that can be used to characterize deformed and metamorphosed vein networks. Moreover, the combination of (ii) Au grade distribution, (iii) topological characterization of successive vein networks and (iv) a structural analysis allows to decipher mineralizing events (metal input and/or remobilization) and predict metal grade distribution in such metamorphosed and polyphased vein-hosted deposits.

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1.12
Correlation between Fracture Network Properties and Stress Variations near Shear Zones

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Spatial stress variations have been observed widely within fault damage zones (Faulkner et al. 2006), which can have a significant influence on scientific and industrial endeavors, such as fault strength, reservoir stimulation, geologic CO_2 sequestration and associated induced seismicity. Based on elastic crack theory (Pollard and Segall 1987), we first derive a complete set of analytical solutions for fractures with elastic resistance and frictional properties under both loading and unloading conditions, which is then applied to a 2D multi-layer model with different fracture density. In this model, we quantitatively relate the global stress response to local fracture deformation with emphasis on specific boundary conditions, i.e., constant strain parallel to the fault strike and constant stress in the off-fault direction.

Simulations are performed to investigate the influences of fracture density, fracture stiffness, fracture frictional coefficient, and pore pressure on the stress variations in four scenarios in which the far-field maximum principal stress is applied at an angle (θ) of 10°, 30°, 60° and 80°, respectively, to the fault strike direction. Results show that both the mean stress and differential stress decrease when the far-field θ is less than 45° and that, when the far-field θ is larger than 45°, the mean stress increases and differential stress decreases with fracture density, as shown in Figure 1. For all cases, the angle θ generally approaches to 45° with the increase of fracture density. The decrease in fracture shear stiffness and frictional coeffcient and elevated pore pressure can generate larger stress rotations.

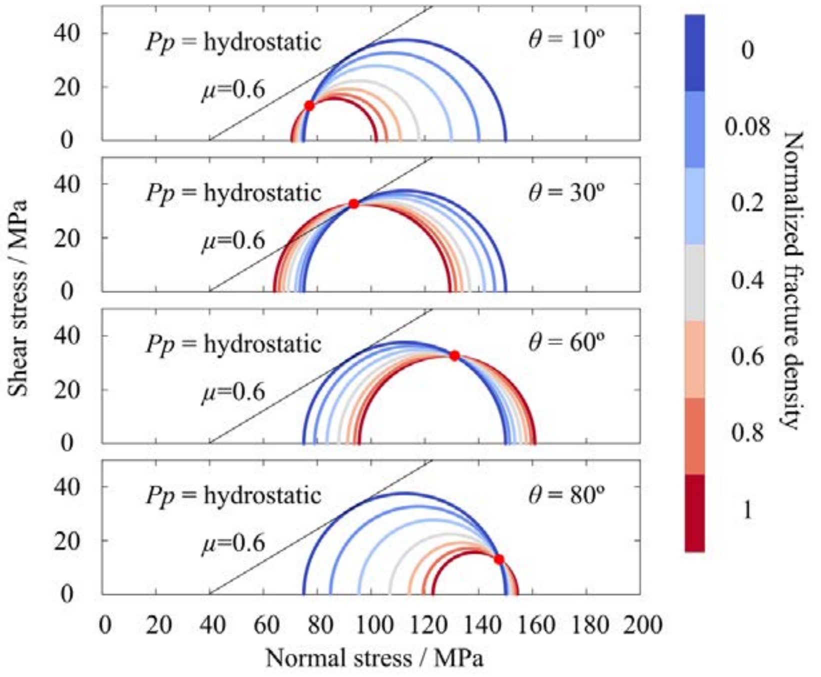

Figure 1. Mohr diagrams illustrating the stress rotations with the increase of fracture density in four cases with an angle (θ) of 10°, 30°, 60° and 80°, respectively, that the far-field maximum principal stress make with the fault strike. For all cases, hydrostatic pore pressure is assumed and the far-field stress is set to be limited by the frictional equilibrium (μ = 0.6).

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1.13
Ductile, brittle and hydrothermal overprint of the Aar Massif`s southern rim (Chli Furkahorn, Switzerland)

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In the course of the exit from nuclear and fossil-fuel energy the research of renewable energies, as the deep-seated geothermal energy, gets an increasing important significance. The present Master`s thesis is contextualized within the scope of orogenic geothermal systems, Alpine hydrothermal systems and deep-seated geothermal energy using the example of the Alps. The up to now rarely investigated research area of Chli Furkahorn in the Aar Massif`s southern rim allows to hypothesize hydrothermal activity as it is manifested in the nearby Grimsel area. The present Master`s thesis concerns firstly with the geological history in general and secondly with the brittle deformation of the present rocks in particular. In addition to that, characteristics for paleohydrothermal zones are investigated and the very are integrated in the context of the Grimsel`s paleohydrothermal system. To make statements referring to this multi-scale approach from the kilometer`s range to the micrometer`s range was applied. It was produced both geological-structural maps with lineaments and detailed maps of the paleohydrothermal zones. For the purpose of the identification of pore space cements and microstructures thin sections, REM scans and CL scans were consulted. Furthermore, microthermometry and Raman spectroscopy were chosen in order to determine chemical properties and physical conditions of paleofluids. The hydrothermal system Chli Furkahorn is divided into three hydrothermal stockworks: (1) “deep” hydrothermal stockwork A within the ductile regime, (2) a middle hydrothermal stockwork B at the brittle-ductile transition zone, (3) a shallow hydrothermal stockwork C in the brittle field. The “deep” hydrothermal stockwork A implies at least two generations of ductile deformed quartz veins cross-cutting mainly the mylonites of the compressive Handegg phase and moreover mylonites of dextral, transpressive Oberaar phase. Throughout the Handegg phase shear zone bridges or linkage zones are being formed, later on these bridges were reactivated by the Oberaar phase as oblique strike-slip faults. This ductile initiation of the large-scale shear zone pattern does manifest in form of a wedge geometry within the paleohydrothermal zones. These shear zone bridges represent the tectonic pre-conditioning for the future hydrothermal stockworks B and C. Through the incipient cooling as a consequence of uplift of the Aar Massif the ductile wedge was throughout the Oberaar phase brittley reactivated. This led to fracturing along former ductile shear zones and therefore an increase of the permeability promoting the subvertical ascent of geothermal paleofluids. Hence, there at least two generations of subvertical and subhorizontal ductile-brittle deformed (kfsp-) quartz veins, cross-cutting the aplitic rim facies` microgranites and aplites as evidences for the hydrothermal stockwork B. Strongly negative anomalies (54 cps) are connected with paleohydrothermal zones, which may attribute to the shallow hydrothermal stockwork C. These negative anomalies are based on the dissolution of radioactive minerals and therefore the “dilution” of the residual rest radioactivity. It exists at least four generations of subhorizontal macrocrystalline quartz veins, cross-cutting the hydrothermal breccias, at least one generation of microcrystalline vein quartz (chalcedony), as well as at least 11 generations of pore space cements. Within the pore space cements K, Si, Mg and Fe phases in terms of silicates and oxides can be identified. In addition to that Ca phases in terms of carbonates, as well as few and far between some S-phases as sulfides do arise in the geological older areas within the shallow hydrothermal stockwork C. In the geological younger areas of the shallow hydrothermal stockwork C Na and Mn phases in terms of carbonates exist. The CO_2-NaCl-H_20 fluid inclusion assemblages within the geological oldest generation of quartz veins show homogenization pressures of 304 bar and homogenization temperatures of 250 °C, as well as, salinities of 6.5 wt.% NaCl and densities of 0.77 g/cm^3. Furthermore, the H_2O-NaCl fluid inclusion assemblages arise with homogenization pressures of at least 44 bar and homogenization temperatures of at least 246 °C, as well as, salinities of 6.16 wt.% NaCl and densities of 0.85 g/cm^3. Therefore, in terms of the shallow hydrothermal stockwork C it concerns a K-Si-Mg-Fe-Ca-Na-Mn-S-CO_2-O_2-H_20-NaCl system with at least 18 paleofluid circulations. Within the shallow hydrothermal stockwork C the episodic fracturing is predominating. It exists strongly increased open fracture and matrix porosities in both relictic ductile-brittle quartz veins and the aplitic rim facies` microgranites and aplites. With increasing brittle strain gradient and with decreasing geological age of the hydrothermal units decreasing open porosities are denoted with values of 2.2 to 12.5 vol.%. At the Chli Furkahorn insights into the deep structure and the chronological evolution of a fault-linked orogenic hydrothermal system is opened up.

1.14
Mapping and modelling a developing magma-rich passive margin: the Western Afar Margin, East Africa

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This multidisciplinary research project (Zwaan et al. 2020, in review) focuses on the tectonics of the Western Afar Margin (WAM), which is situated between the Ethiopian Plateau and Afar Depression in East Africa. The WAM represents a developing passive margin in a highly volcanic setting, thus offering unique opportunities for the study of rifting and (magma-rich) continental break-up so that our results have both regional and global implications.

We show by means of earthquake analysis that the margin is still deforming under a ca. E-W extension regime (a result also obtained by analysis on fault measurements from recent field campaigns), whereas Afar itself undergoes a more SW-NE extension (Zwaan et al. 2020). Together with GPS data, we see Afar currently opening in a rotational fashion. This opening is however a relatively recent and local phenomenon, due to the rotation of the Danakil microcontinent modifying the regional stress field (since 11 Ma). Regional tectonics is otherwise dominated by the rotation of Arabia since 25 Ma and should cause SW-NE (oblique) extension along the WAM. This oblique motion is indeed recorded in the large-scale en echelon fault patterns along the margin, which were reactivated in the current E-W extension regime. We thus have good evidence of a multiphase rotational history of the WAM and Afar.

Furthermore, analysis of the margin’s structural architecture reveals large-scale flexure towards Afar, likely representing the developing seaward-dipping reflectors that are typical for magma-rich margins. Detailed fault mapping and earthquake analysis show that recent faulting is dominantly antithetic (dipping away from the rift), bounding remarkable marginal grabens, although a large but older synthetic escarpment fault system is present as well.

By means of analogue modelling efforts (Zwaan et al. in review) we find that marginal flexure indeed initially develops a large escarpment, whereas the currently active structures only form after significant flexure. Moreover, these models show that marginal grabens do not develop under oblique extension conditions. Instead, the latter model boundary conditions create the large-scale en echelon fault arrangement typical of the WAM. We derive that the recent structures of the margin could have developed only after a shift to local orthogonal extension. These modeling results support the multiphase extension scenario as described above.

Altogether, our findings are highly relevant for our understanding of the structural evolution of (magma-rich) passive margins. Indeed, seismic sections of such margins show very similar structures to those of the WAM. However, the general lack of marginal grabens, which are so obvious along the WAM, can be explained by the fact that most rift systems undergo or have undergone oblique extension, often in multiple phases during which structures from older phases control subsequent deformation.

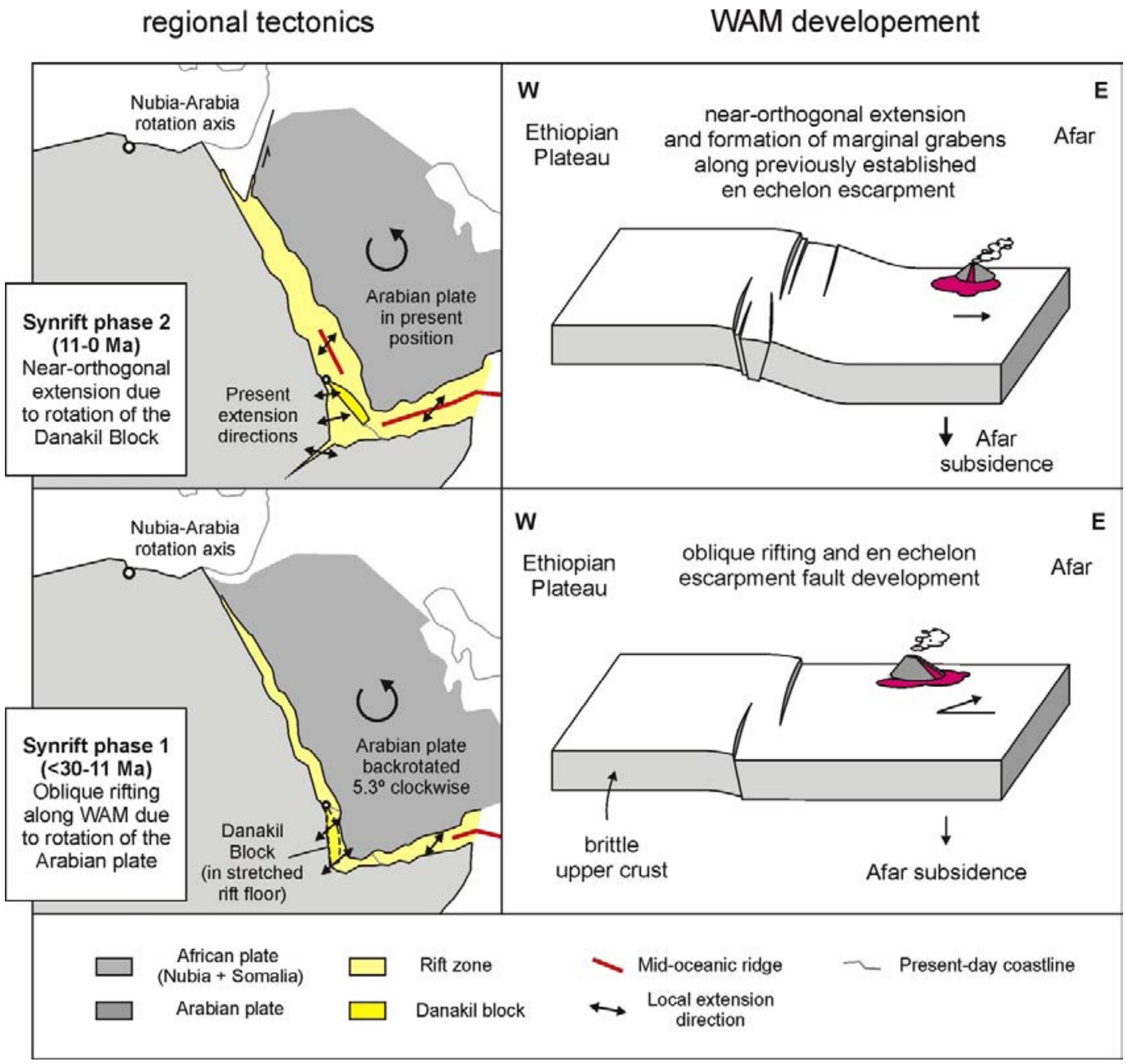

Figure 1. Multiphase rotational extension scenario for Afar (Zwaan et al. 2020).

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1.15
Interacting rifts in orthogonal vs. rotational extension experiments: implications for the East African Rift

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During extension of the continental lithosphere, rift basins develop. These are often initially offset, and must interact and connect in order to create a continuous rift system, that may ultimately achieve break-up. When simulating extensional tectonics and rift interaction structures, tectonic modellers often apply a continuous extension rate along the strike of a rift (system). Yet in nature, extension velocity variations occur along rifts and plate boundaries since plates move apart about a pole of rotation. This results in rotational extension, causing rift propagation and structural gradients (Fig. 1). Here we therefore present analogue experiments of rift interaction structures to compare the effects of orthogonal extension versus rotational extension conditions.

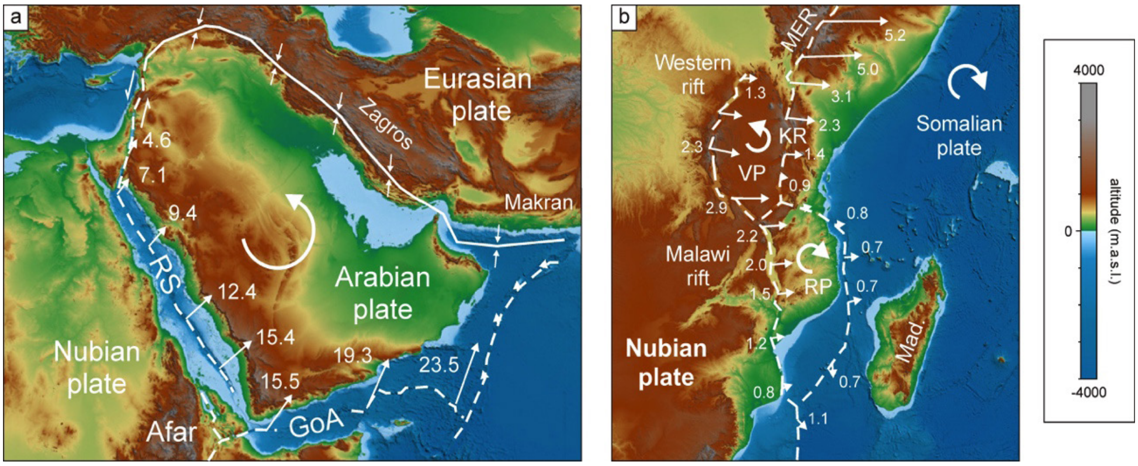

Figure 1. Rotational rifting in (a) the Red Sea/Gulf of Aden and (b) the East African Rift System. (Zwaan & Schreurs, 2020).

Our modelling efforts (Fig. 2) show that rotational extension and orthogonal extension produce significantly different large-scale structures. Rotational extension can cause significant changes in rift maturity between rift segments, delay rift interaction zone development, and make rift segments propagate in opposite directions (both towards and away from the rotation pole). Still local features in a rotational extension system can often be regarded as evolving in an orthogonal extension setting. Furthermore, we find that various degrees of rift underlap produce three basic modes of rift linkage structures. Low underlap distance (high angle φ) experiments develop rift pass structures. With increasing underlap distance (φ = ca. 40°), transfer zone basins develop. High degrees of underlap (φ ≤ 30°) tend to result in en echelon sub-basins. Our results match with data from previous modelling efforts and natural examples. We furthermore propose a large-scale tectonic scenario for the East African Rift System based on the effects of rotational extension and associated rift propagation observed in our models (Fig. 3). These insights may also be applicable when studying other large-scale rift systems (e.g. the South Atlantic).

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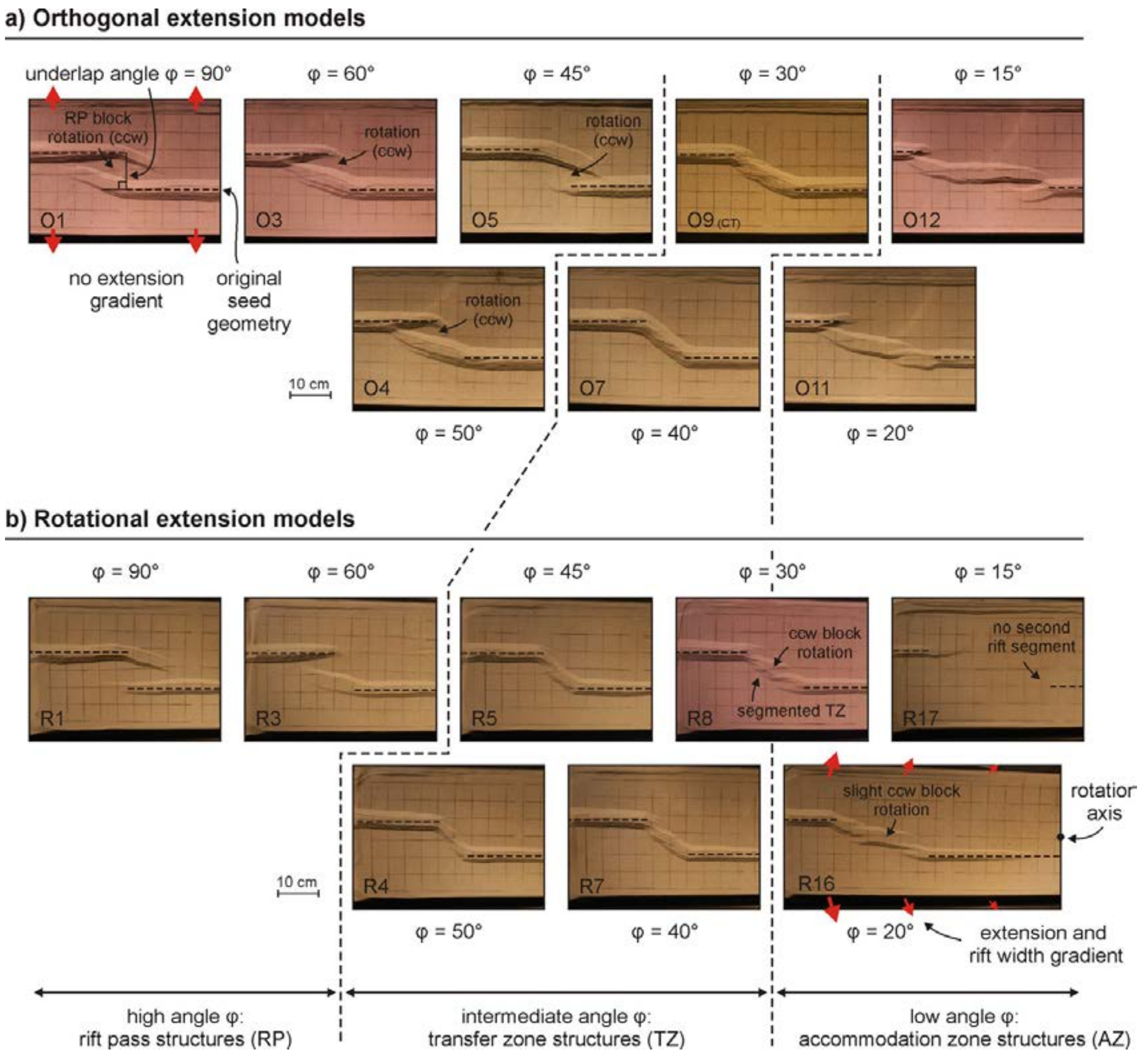

Fig. 2. Model results (final top views) of orthogonal- and rotational extension experiments (Zwaan & Schreurs, 2020).

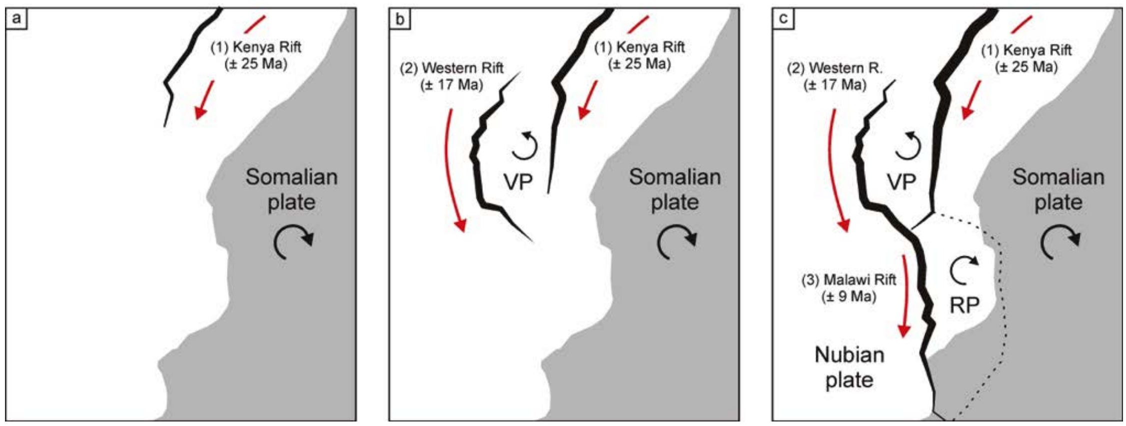

Figure 3. Evolution of the East African Rift System (Zwaan & Schreurs, 2020).

P 1.1
Dynamics of rotational rift systems: imaging, quantification and linkage of deep-seated flow and surface deformation

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Extension gradients in rift settings with a rotational component yield triangular basin structures with a laterally propagating rift tip. Compression-driven pressure gradients on the other side of the rotation axis induce along-strike lower crustal flow, which eventually influences the rift morphology and dynamics close to the rotation axis.

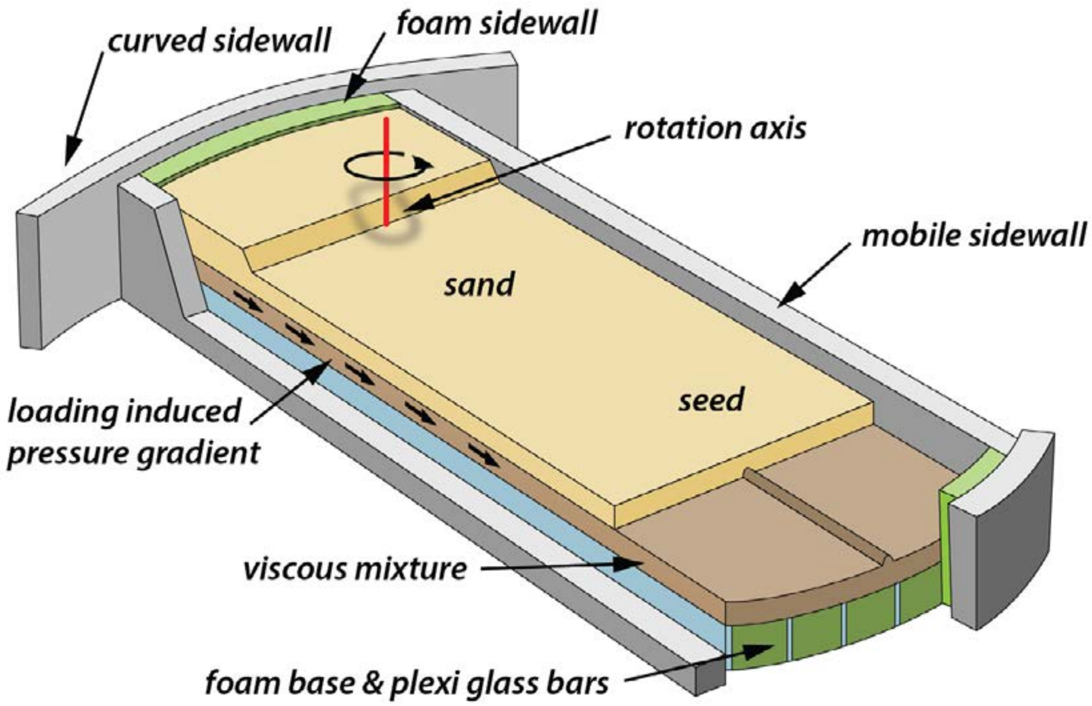

Figure 1 Cut-out view of the experimental apparatus. The model is confined by two curved short walls and long movable side walls. The laundry-peg like apparatus defines a compressional and an extensional domain separated by a rotation axis. The compressional domain is covered by an additional sand load for designated models to induce a pressure gradient driven flow within the viscous layer away from the compressional domain. To initiate rifting, a seed is placed on top of the viscous layer.

The aim of this study is to quantify dynamically scaled analogue experiments to investigate the influence of tectonic loading on rifting in a rotational setting where a rotation axis separates extensional and compressional domains. We monitor surface and internal deformation and focus on the interaction of surface rift propagation and internal flow. The surface topography evolution (DEM) and deformation (3D displacement field) is monitored and quantified using 3D Digital Image Correlation (3D stereo DIC) techniques and model internal deformation is investigated by digital volume correlation (DVC) techniques applied on X-ray computed tomography data of time-series experiment volumes.

Our models consist of a brittle-viscous setup overlying a foam base that expands and contracts homogeneously while applying extension and compression, respectively. A quartz sand layer represents a brittle upper part of the crust and sits on top of a viscous mixture that simulates a ductile lower part of the crust. An additional sand package on the compressional model part simulates tectonic loading and initiates rift-parallel flow (Fig. 1).

The conducted models show i) sequential rift propagation with transition from bidirectional to unidirectional fault growth in the upper crust, ii) enhanced rift-opposing horizontal flow in the lower crust and iii) a flow related topography close to the tectonic load (Fig. 2). These results highlight the importance of such out-of-plane motions in rift systems and are of great importance for the understanding of dynamics in rotational rift settings.

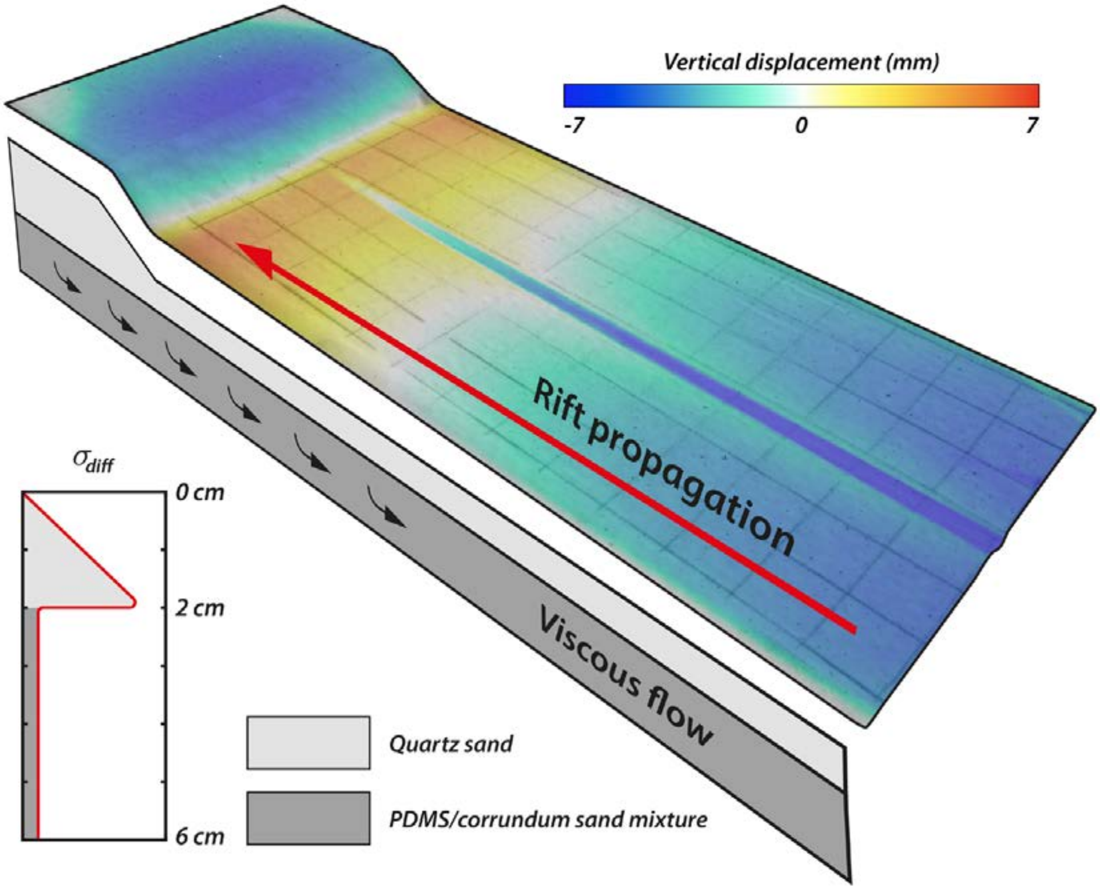

Figure 2. Conceptual analogue model showing the influence of pressure driven lower-crustal viscous flow on topography due to tectonic loading and indicated rift propagation for a crustal-scale two-layer model.

P 1.2
How different mantle and crustal weakness orientations affect rift systems: insights from 3D analogue models

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During extension of the continental lithosphere, deformation often localizes along pre-existing weaknesses originating from previous tectonic phases. When simulating such structures with analogue or numerical methods, modellers often focus on either crustal or mantle heterogeneities. By contrast, here we present results from 3D analogue models to test the combined effect (and relative impact) of (differently oriented) mantle and crustal weaknesses on rift systems.

Our model set-up involves a rigid base plate fixed to a mobile sidewall (Fig. 1). When this sidewall moves outward, the edge of the base plate induces a “velocity discontinuity” (VD) that acts as an upper mantle fault/shear zone in a strong upper mantle. The VD is either parallel to the model axis, or 30˚ oblique. On top of this base plate, we apply a viscous layer representing the ductile lower crust, followed by a sand cover that simulates the brittle upper crust. Crustal weaknesses were either imposed by implementing “seeds” (i.e. ridges of viscous material at the base of the sand layer), or by pre-cutting the sand. Similar to the basal plate edge, we apply different crustal weakness orientations as well.

Without weaknesses in the model crust, an axis-parallel base plate forms an axis-parallel rift basin above the VD (Fig. 1a). When adding (oblique) seeds, they strongly localize deformation, creating a series of obliquely oriented grabens. Yet the VD still induces faulting along the model axis, leading to the development of offset axial grabens as well (Fig. 1b). Pre-cut faults also localize deformation, but are less dominant than the seeds (Fig. 1c). As a result, the VD has more control and the axial rift structures are much more pronounced. In the oblique base plate case, the reference model develops a series of en echelon grabens along the VD (Fig. 1d). Axis-parallel seeds strongly localize faulting, to such a degree that the effect of the VD is very much overruled (Fig. 1e). Pre-cut faults allow more influence from the VD, but still dominate the system (Fig. 1f). Doubling the extension rate increases the strength of the viscous layer, enhancing coupling between the VD and sand cover, so that a series of en echelon grabens crosscutting the seed-induced structures develop (Fig. 1g). The above assessment is based on top view imagery. Further analysis of horizontal and vertical displacements and computer tomography analysis will provide additional insights in both internal and external model evolution (Fig. 2e-f).

So far we find that the orientation and relative weakness of inheritances in the mantle and crust, as well as extension rates control subsequent rift structures. These structures can be complex due to the interplay of the above factors, and importantly, all develop under the same pure shear extensional boundary condition. Our results show that very differently oriented rift structures can form during one phase of extension without the need to invoke multiple rift phases.

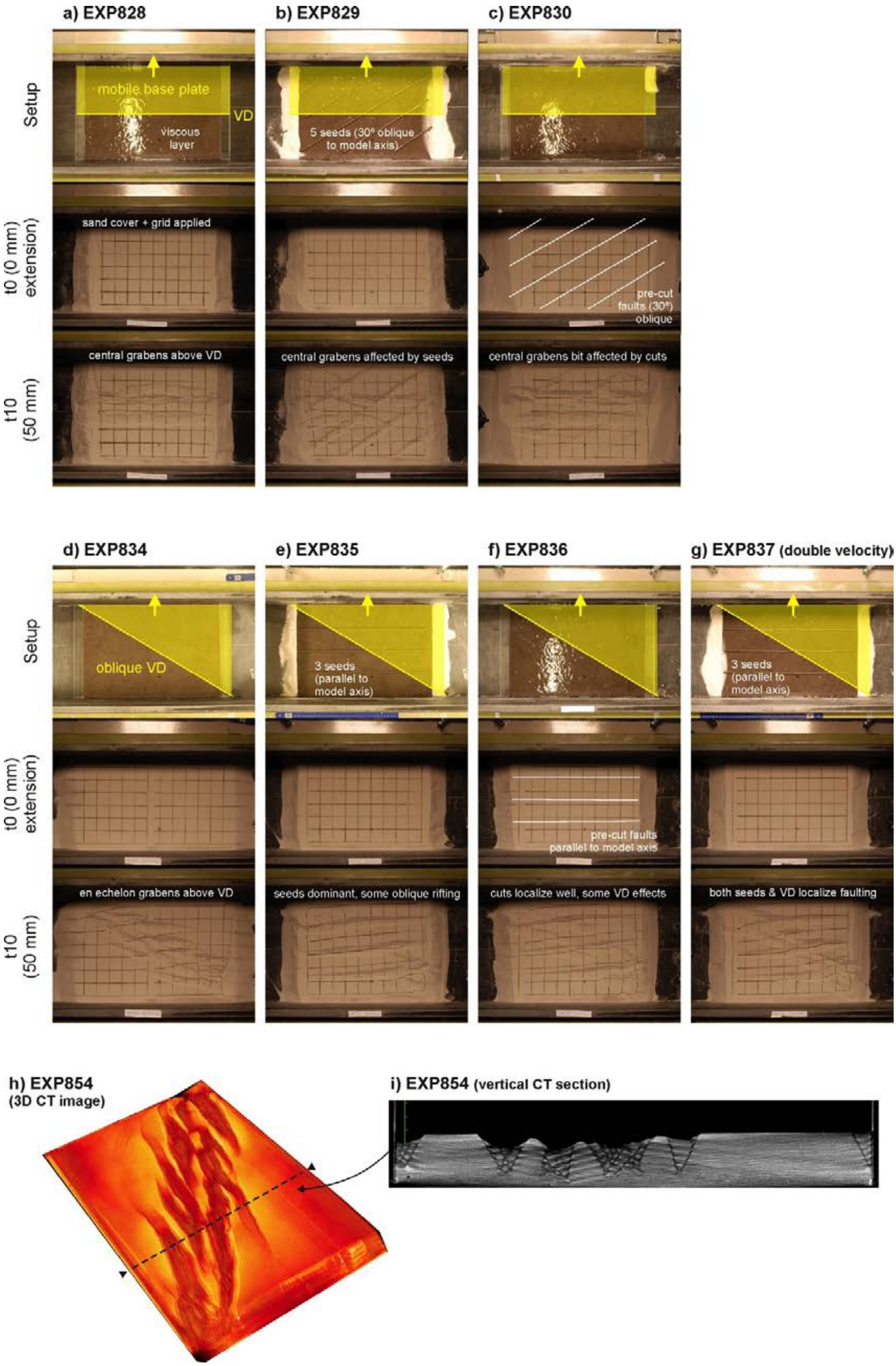

Figure 1. (a-c) Top view results of models with an axis-parallel base plate (yellow). (d-g) Top view results of models with an oblique base plate (yellow). (e-f) CT-scan results from EXP854 (rerun of EXP834).

P 1.3
Faulting and magma propagation interactions during volcano-tectonic events (Iceland): insights from structural data and analogue modelling.

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Volcano-tectonic events are found in various geological settings, included extensional environments. Understanding how magma propagates in the crust and eventually where it will erupt is one of the key challenges in volcanology research. Classical models of magma propagation assume Earth's upper crust as homogeneous and fully elastic and they do not account for pre-fractured medium. However, in volcano-tectonically active systems, inherited structures exist and may not be optimally oriented with the current stress field.

This study analyses the role of pre-existing crustal structure and their reactivation on the propagation of magma in extensional environments.

Iceland counts several recent rifting episodes in its volcanic systems, which involve reactivation of pre-existing structures. Literature on the Icelandic rifting events and their return periods suggest a cyclic nature of strain deficit loading and subsequent release. These cycles at divergent plates boundaries are expressed as a steady ~2cm/yr average extension rate in the far-field and as discrete, stepwise opening in the near-field.

Based on the strain deficit concept, we mapped representative structures in the North Volcanic Zone with a fixed-wing UAV. We surveyed the areas of Fjallagjá, Kollóttadyngja, Eggert, the 2014 landslide in Askja caldera, the monocline in Gríótagjá, and Námafjall.

The processing of the drone images resulted in a DEM (2-3 cm/px) and an orthomosaic (1-2 cm/px) of the fieldwork area. On this imagery, we performed a detailed morphological and structural analysis, looking at the shape of the overall graben structures and the effect of the topography on the faulting processes. Results highlight oblique interactions between two main sets of orientations: the main one, N-S, and a younger one, NE-SW. We will further look at fractures and potential kinematic indicators to reconstruct the paleostress history of this area of the plate boundary.

Parallel and based on the results of the field observations, we are building up an analogue experiment setup. The experiments will include extension, representing the long-term tectonic deformation, and injection tests, representing the short-term magmatic intrusions, to analyse the role of the structure's presence and reactivation during magma propagation.

P 1.4
A Thermo-Hydro-Chemical model for melt migration in the mantle

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The formation of alkaline magmas observed worldwide requires that low degree-melts, potentially formed in the asthenosphere, were able to cross the overlying lithosphere. Fracturing in the upper, brittle part of the lithosphere may help to extract such melts to the surface. However, the mechanism of melt migration in the lower, ductile part of the lithosphere is still contentious. Metasomatic enrichment of the lithospheric mantle demonstrates that such low-degree melts interact with the lithosphere, but the details of this interaction remain unclear. The aim of this study is to better understand the migration of melt in a porous medium at pressure (P) and temperature (T) conditions relevant for the base of the lithosphere and underlying asthenosphere. We investigate melt migration numerically with a newly-developed Thermo-Hydro-Chemical model of reactive transport using thermodynamic data obtained via Gibbs energy minimisation. We perform Gibbs energy minimisation with a self-developed MATLAB algorithm using a linear programming algorithm. We consider, first, a simple ternary system composition of MgO, FeO and SiO_2 based on the olivine phase diagram system, Forsterite (Mg_2SiO_4) – Fayalite (Fe_2SiO_4). The initial results show that at the employed P and T conditions, if we only use the olivine system, the melt density is larger than the solid density and the melt would sink downward. To reverse this effect, we extend the system by adding more SiO_2 using experimental data from Davis et al. (2011). The ternary system of MgO, FeO and SiO_2 mimics simple mantle rocks consisting of olivine and pyroxene for which the melt density is smaller than the solid density. All model variables (density, energy, chemical composition of the melt and the solid) are a function of T, P and chemical composition of the system (C). These variables are computed in both the thermodynamic data and in the reactive transport code, and can therefore evolve freely. This allows to quantify the impact of variations in the chemical composition on the migration velocity of the melt.

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P 1.5
Subduction channel vs. orogenic wedge model: numerical simulations, impact of serpentinites and application to the Alps

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The European Alpine orogen results from the closure of the Piemont-Liguria ocean and the subsequent collision of the Adriatic and European plate. Whether the Piemont-Liguria ocean was floored by significant volumes of a mature, 8-km thick Penrose-type oceanic crust, or only by minor volumes of embryonic oceanic crust is still subject to debate. Also, the plate tectonic processes leading to the formation of orogens, such as the European Alps, are often embedded in long-term (>150 Myrs) geodynamic cycles. The impact of plate deformation phases prior to the collisional phase on the orogeny is still incompletely understood.

In this study, we present state-of-the-art 2D thermo-mechanical numerical models of a geodynamic cycle modelled in a single and continuous simulation including the following stages. First, a ca. 360 km wide basin that is floored by exhumed mantle and bounded by two conjugate magma-poor hyper-extended passive margins is generated during a 50 Myrs rifting period. An absolute extension velocity of 1 cm/yr is applied. Second, no far-field plate deformation (extension velocity of 0 cm/yr) is applied to the evolved passive margin system during a subsequent period of 60 Myrs. At this stage, we parameterise a serpentinization front on top of the exhumed mantle by replacing the dry peridotitic mantle by serpentinized mantle in one series of simulations. Third, the evolved system is used as a self-consistently generated initial configuration for the subsequent period of convergence lasting for 70 Myrs applying an absolute convergence velocity of 1.5 cm/yr. Values for the duration of deformation periods and for deformation velocities are chosen to allow for comparison between simulation results and geological and petrological data from the Central and Western Alps.

We quantify (1) the impact of a serpentinization front of the exhumed mantle on the subduction dynamics by increasing systematically the strength of the serpentinites, (2) the peak pressure and temperature conditions of subducted crustal material from the passive margins of the overriding and subducting plate by tracking pressure (P)-temperature (T)-time (t)-depth (z) paths of selected particles and (3) the driving forces of the system. Last, (4) the impact of metamorphic phase transitions is investigated by parameterising densification of crustal material. We compare the results of simulations in which density is computed with a simple equation of state to results of simulations in which density is a more realistic function of P and T using precomputed thermodynamic look-up tables.

We discuss geometric similarities between the simulation results and 2D geodynamic reconstructions from field data, quantify the P-T-t-z-history of selected particles and compare it to P-T-t data obtained from natural rocks. First results indicate that the strength of the serpentinites controls whether the deformation within the orogenic core is driven by buoyancy forces (subduction channel model) or by far-field tectonic forces (orogenic wedge model). There is a transition from subduction channel to orogenic wedge model from low to intermediate strength of the serpentinites.

P 1.6
Full 3-D pseudo-transient finite difference modelling of stress distribution around continental plateaus

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Collisional environments can form continental plateaus, such as the Tibetan plateau, which are characterized by an unusually large crustal thickness. The crustal thickness and topography variations between the plateau and the neighboring lowlands generate lateral variations of gravitational potential energy per unit area (GPE). Although plateau and lowland are in isostatic equilibrium, the lateral GPE variations must be balanced by horizontal differential stresses, which prevent the plateau from flowing-apart instantaneously. These differential stresses have been quantified with analytical solutions and numerical simulations, but mainly for two-dimensional (2-D) and rectangular geometries. Stress magnitudes and distributions around plateau corners for 3-D geometries and for realistic spherical geometries of the Earth are largely unknown. Indeed, quantifying these stresses and their spatial variation in 3-D is computationally challenging.
Here, we present new 2-D and 3-D numerical algorithms, programmed in MATLAB (mathworks.com), to solve the Stokes equations under gravity. The algorithm is based on an Eulerian pseudo-transient finite difference method. The pseudo-transient method allows an explicit solution of the Stokes equations without the need of inverting a large stiffness matrix. When the pseudo-transient time derivatives approach zero, a steady-state solution for the velocity, strain rate and stress fields is obtained. The aim of developing these pseudo-transient algorithms is to eventually adapt them to GPU architectures, using the Julia language (julialang.org), in order to obtain highly-efficient high-resolution algorithms for 3-D numerical simulations. We present the current versions of the 2-D and 3-D algorithms for Cartesian, cylindrical and spherical geometries as well as numerical benchmarks and convergence tests.

P 1.7
The rheology and mechanical anisotropy of a foliated blueschist

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Blueschists are a major constituent rock type along the subduction zone interface and therefore critical to our understanding of subduction zone dynamics. Previous experimental work on natural blueschists focus on either seismic anisotropy or on the process of eclogization of a blueschist aggregate. We have begun an experimental investigation to constrain the rheology and mechanical anisotropy of a naturally foliated blueschist from the Condrey Mountain Window, CA. General shear experiments were performed in a Griggs apparatus using cores of the natural blueschist at 700°C, 1 GPa, and a shear strain rate of ~10-5 s-1. The starting material consists of ~55% glaucophane, ~40% epidote, <5% quartz and <5% mica where both glaucophane and epidote have strong crystallographic fabrics and shape-preferred orientations that define the foliation. Two types of experiments were performed: 1) with the foliation parallel to the shear plane and 2) with the foliation parallel to the sigma1 direction. Both experiments achieved a similar peak shear stress of ~250 MPa; however, the sample with the foliation parallel to the shear plane shows strain weakening while the sample with the foliation parallel to the sigma1 direction shows no strain weakening. We also observed several stress drops of ~20-30 MPa in the sample with the foliation parallel to the sigma1 direction prior to peak stress conditions. Additional experiments will be performed on these two deformation geometries at various stress and temperature conditions. A third type of deformation experiment will also be performed where the starting material has no foliation. A detailed microstructural analysis will accompany the mechanical results.

P 1.8
Experimental investigation of glaucophane rheology through shear and axial compression Griggs rig experiments on hot-pressed aggregates

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Constraining the rheological properties of glaucophane is critical to understanding subduction zone dynamics. Based on the rock record, glaucophane is a major constituent mineral associated with mafic oceanic crust at blueschist metamorphic facies. Previous experimental work on glaucophane focuses on the deformation of natural polyphase rocks with an emphasis on seismic anisotropy. Here we perform general shear and axial compression deformation experiments on synthetic glaucophane aggregates in a Griggs apparatus. The synthetic aggregates were produced through mineral separation of a natural blueschist from Syros, Greece. After mineral separation, the powders contain ~95% glaucophane with ~5% omphacite and epidote. We will present mechanical and microstructural data from constant displacement and strain-rate stepping experiments with the aim of developing a glaucophane flow law. Our results will also be compared to ongoing experiments focused on the viscous properties of experimentally deformed natural aggregates (see abstract in this conference by Tokle et al.).

P 1.9
Towards a model of the pre-Mesozoic basement beneath the Jura Mountains fold-and-thrust belt

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The Jura Mountains fold-and-thrust belt (JFTB) lies in the northern foreland of the European Alps, extending from eastern France to northern Switzerland. The JFTB formed as a result of Late Miocene to Pliocene northwest directed compression exerted by the orogenic wedge of the Alps and was sheared off its basement along a décollement in Triassic evaporites (Buxtorf, 1907; Laubscher, 1961). Prior to this, the pre-Mesozoic basement was intensely pre-structured, showing faults that had been active under changing stress fields during the Mesozoic and Cenozoic structural evolution of continental Europe. Main events were the opening of the Alpine Tethys in Early and Middle Jurassic, the formation of the Eocene to Oligocene European Continental Rift System (ECRIS, Dèzes et al., 2004) and the formation of a flexural foreland basin during the subduction of the European lithosphere underneath the African plate (Laubscher, 1992). In order to understand the connection between thin-skinned JFTB formation and pre-existing basement structures, we created a digital surface model of the top of the pre-Mesozoic basement in the area of the detached Northern Alpine Foreland (NAF), and we paid particular attention to include faults with notable vertical offsets (in excess of 50 m). Although the lateral extent of the JFTB is controlled by the distribution of Triassic evaporites, our model demonstrates that individual structural domains as well as the position of the thrust front are linked to structures in the pre-Mesozoic basement. In some cases, structural orientations of the JFTB are conclusively connected to known discrete fault zones in the basement. Fault zones in the pre-Mesozoic basement follow structural trends that suggest the reactivation of inherited fault systems originating from the Variscan orogeny and post-Variscan collapse, such as proposed for segments of the ECRIS in Illies (1962) or Dèzes et al.(2004). Our model of the pre-Mesozoic basement suggests that the fold and thrust geometry of the Jura Mountains was pre-determined and conditioned to a very high degree by structures in the pre-Mesozoic basement. This allows us to discuss varying structural elevations, the occurrence of oblique ramps or major strike-slip systems in the JFTB in a different light. We would like to encourage a holistic perspective on the JFTB and the detached NAF, which regards thin-skinned tectonics and basement tectonics neither as independent nor as strictly sequential.

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P 1.10
The anatomy of the basal shear zone of the High-Pressure Adula nappe and its repercussion on the Alpine regional geology

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Crustal shear zones commonly exhibit constrictional structures at all scales due to intense non-coaxial deformation. Within such deformational regime the lithological units are stretched and elongated along the shear direction, locally loosing their lateral continuity. The missing continuity of marker horizons or diagnostic rocktypes challenges the large-scale geological mapping and sometimes causes misleading regional interpretations.

Here, we present detailed geological maps and profiles (scale 1:10'000) along the shear zone of the lower boundary of Adula unit, the largest High-Pressure nappe of the Central Alps. Overall, the lithological units along this shear zone show a sub-horizontal penetrative foliation (at amphibolite metamorphic facies) parallel to the lithological contacts that dip gently E to the SE. On the foliation plane the mineral and stretching lineation and the fold axis are oriented almost N-S independently on the orientation of the schistosity. However, within this general trend, the lithological boundaries and the foliations may rotate steeply to the E or to the W shaping the gneissic bodies (mostly ortogneisses) as prolate ellipsoids, elongated parallel to the mineral and stretching lineation. Locally, folds with axis parallel to the prolate ellipsoids depict, on the plane orthogonal to the lineation, concentric- or Ω-shapes typical of sheath folds. Large-scale Ω-folds have been mapped in the Pontirone and in the Misox valleys, in the latter case the upright Ω-fold forms the controversial Lostallo tectonic window that exposes the lower unit of the Simano.

We conclude that the most complete explanation for these complex structural patterns is the progressive constrictional shear regime, without invoking polyphase deformation, during the emplacement of the Adula Nappe in the Eocene-Oligocene.

P 1.11
Ground displacement analysis of the 1975 Kalapana earthquake (south flank of Kīlauea volcano) using air photo correlation.

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The Kīlauea volcano is composed of several structural components, with the Kīlauea caldera, the East and Southwest Rift zones, the Koa'e and the Hilina fault systems and a deep detachment. Most of these structural components are related to the volcano flank instability. The origin, the relation and the evolution of the active fault systems on the south flank (e.g. Koa'e and Hilina) is still poorly understood, including its role in magma storage in the area and the overall flank instability evolution. Here we focus on the magnitude 7.7 earthquake (29 November 1975) that triggered ground displacement of several meters all over the south flank of Kilauea volcano. Ground displacement occurred along a 25 km long sector of the Hilina and Holei fault systems with vertical and horizontal displacement along preexisting fault scarps. Our aim is to extract and to quantify the displacement that occurred during the event using air photo correlation and geodetic data to better understand the overall volcano flank dynamics.

To quantify the coseismic ground displacement, we use an optical imagery correlation technique. We analysed the 1975 earthquake using 12 and 15 photos for the pre-event (October 1974 and July 1975, respectively) and 6 and 12 photos for the post-event time period (December 1976 and March 1977, respectively). Both aerial photo datasets allow investigating the entire sector of Hilina and Holei fault system. Results show ground displacements of several meters on Kilauea's south flank (Hilina fault system and Holei Pali), in agreement with EDM measurements of 8 meters horizontal displacement measured at the coastline. These data will later be integrated with leveling data to provide better quantification and constraints on ground deformation during the event.

P 1.12
Spatial and temporal characteristics of deep seismicity beneath the Himalayas

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The Himalayan orogen, formed by the continental collision between the Indian and Eurasian plates, is one of the most tectonically active regions in the world. A large number of geophysical data and previous studies have shed light on the mountain-building processes and lithospheric structure of the orogen. The temporal and spatial characteristics of the deep seismicity, however, is somewhat limited. Thus, compiling an extended catalog for the Himalayan deep earthquakes is of great importance.

To create this catalog, we collected all the available continuous seismic data that operated during the last two decades in the Himalayas region (networks mostly operated between the following periods: 2001-2005 and 2013-2016). We started with the earthquake origin times of all the available deep earthquakes (i.e., hypocentral depths >50 km) from data centers and previous studies. We applied a systematic processing routine (e.g., picking P- and S-wave phases), and we obtained absolute earthquake locations using a 1D velocity model. We have calculated 729 preliminary earthquake locations based on high-quality picks. We intend to refine these preliminary absolute earthquake locations and calculate local magnitudes. Using this catalog, we plan to examine the temporal evolution and characteristics of the Himalayan deep seismicity. This information may help provide a better understanding of the local processes and mechanisms controlling seismogenesis at the root of the orogen.

P 1.13
Tectonic structures and associated stress field in the Geneva Basin (Switzerland and France)

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The Northern Alpine foreland is divided in two domains: the Molasse Basin and the Jura FTB, both transported towards NNW. These domains are detached from the mechanical basement above a Triassic *décollement.* Thrusts and strike-slips faults affect the detached Mesozoic and Cenozoic sedimentary cover of the area. The Geneva Basin, located in western Switzerland, is part of the Plateau Molasse within the Molasse Basin and is limited to the NNW by the Jura FTB and to the SSE by the Subalpine Molasse. In the frame of the 2020 Geothermal project of the Canton Geneva, it is of major interest to constrain the subsurface geology of this area.

The aim of this project is to improve our knowledge on the geometry, the kinematics and the stress associated with the structures developed in the Geneva Basin and the adjacent Jura FTB.

Based on existing data and on new seismic interpretations, the first objective is to build a 3D geological model and balanced NW-SE cross-sections across the basin. In the Geneva Basin, the first results show that strike-slip faults are mainly oriented NW-SE and E-W and may be related to topographic differences of the top basement at the base of the Mesozoic series (“Vuache” or “Cruseilles” faults). Most of the anticlines and synclines show a NE-SW orientation, perpendicular to the general compressional direction. Along these anticlines, « shallow thrusts » in the Mesozoic cover appear to be rooted in intermediate detachment levels, possibly in the marls of the lower part of the Malm interval. A new detailed tectonic surface map makes it possible to better constrain the interpretation of structures even in the center of the Geneva Basin, and particularly in the area south of the E-W topographic lineament crossing the Mont-Sion pass. An important structure has also been observed close to the Humilly-02 well, and is interpreted as a NE-SW synsedimentary listric fault with possible salt flow. This structure has subsequently been reactivated and moderately inverted.

Numerical modelling will complement the structural and kinematic study, in order to better understand the structure development of the area and their related stress field. Based on existing and newly constructed cross-sections, a parametric analysis will be conducted to explore several hypothesis especially on the fault geometry of the area. Using a simplified geometry will subsequently allow us to constrain the mechanical context of the section. This will then help to generate hypothesis regarding structures that are poorly imaged, for instance the geometry of the footwall of the Salève Mount, or the nature of the faults in the Geneva Basin. A corresponding current stress field will be derived for each scenario.

Confronting results from the stress analysis and the kinematic/geometric model will allow us to address issues of strain partitioning as well as the sequence of fold and thrust development.

P 1.14
Seismotectonic evidence for active transtension along the Bodensee-Hegau Graben in the low-strain region of the northern Alpine Foreland

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The Hegau-Bodensee Graben (HGB), a major tectonic element in the northern foreland of the European Alps, is characterized by comparatively slow deformation rates (<1 mm/yr) and low seismicity. To understand the present-day deformation regime of this graben system, a seismotectonic study was performed, which builds on the seismological analysis of a series of recent earthquakes, recorded by an exceptionally dense, high-quality seismic monitoring network. The resulting high-precision absolute and relative hypocentre relocations, in combination with available focal-mechanisms, allow to identify geometry and kinematics of seismogenic structures in the upper crust, which can be related to the bounding faults of the NW-SE striking graben.

At its southwestern boundary, we associate micro-seismicity in the region of Schlattingen (northern Switzerland) with neotectonic activity along the Neuhausen Fault. Seismic velocities in the hypocentral area derived by recent tomographic studies, as well as structural models from seismic reflection surveys suggest that the seismically active part of the Neuhausen fault locates within the crystalline basement in a depth of about 5 to 6 km. Relative relocations and focal mechanisms image a NE-dipping normal fault, with indications for a listric geometry. On the opposite side of the graben, recent energetic earthquake swarms (magnitudes up to ML3.7) in the Hegau region near the town of Hilzingen and on the Bodman peninsula near Constance image graben-parallel faults. The earthquakes close to Hilzingen locate in depths of 5-6 km and are presumably located within the crystalline basement. The earthquake sequence near Constance locates shallower in about 3 km depth, indicating a source in the pre-Mesozoic basement. Associated focal mechanisms indicate normal to transtensional deformation in both cases.

Statistical analysis as well as stress inversion is performed for all available focal mechanism. Preliminary results indicate that today, an overall transtensional deformation regime prevails across the graben system. These results are in good agreement with the present-day stress field of the region, suggesting that the foreland of the Alpine collision zone is characterized by a present-day tectonic regime of strike-slip to normal faulting. Along preferentially oriented, pre-existing deformation zones, such as the NW-SE striking Hegau-Bodensee Graben oriented almost perpendicular to the regionally constrained minimum horizontal stress axis, this regime apparently allows for seismogenic dilatational faulting in an otherwise low strain region.

2. Mineralogy, Petrology, Geochemistry

Francesca Piccoli, Florence Begue, Julien Allaz

Swiss Society of Mineralogy and Petrology (SSMP)

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2.1
$^{53}Cr/^{52}Cr$ model ages of IIAB iron meteorites: implications for accretion and thermal evolution of their parent body

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The IIAB iron meteorites belong to the category of ''magmatic irons'', and are thought to sample the core of a distinct parent body that experienced large-scale chemical fractionation, most notably metal-silicate separation. The time of metal core formation in the IIAB parent body provides a key time marker for the evolution of early formed planetesimals including the accretion and cooling history of the parent body. The timing and duration of such early Solar System processes, including accretion, differentiation and subsequent cooling, can be investigated using the short-lived ^{53}Mn-^{53}Cr ($t_{1/2} \approx 3.7$ Ma) chronometer.

Chromite ($FeCr_2O_4$) and daubreelite ($FeCr_2S_4$) are the two main carrier phases of Cr in IIAB iron meteorites. Both these minerals have low Mn/Cr ratios (≈0.01) and thus, preserve the Cr isotope composition of their growth environment at the time of isotopic closure while the in-growth of radiogenic ^{53}Cr from in-situ decay of ^{53}Mn is negligible. Model ages for chromite and daubreelite in IIAB iron meteorites can be obtained by comparing their Cr-isotope composition with the Cr-isotope evolution of the chondritic reservoir, using the known[1] abundances of ^{53}Mn and ^{53}Cr at the beginning of the solar system or any point in time thereafter and an estimate[1] for the Mn/Cr in the relevant reservoir. In order to systematically resolve the ingrowth of ^{53}Cr over a time span of a very few Myrs, Cr isotope abundances need to be measured with high precision by TIMS.

The isotope ratios do not need any correction for the cosmic ray exposure due to the low Fe/Cr of the samples. Results for chromite from the meteorites Sikhote-Alin and Agoudal and daubreelite from NWA 11420 give an average model age of ~1 Ma after the formation of the Solar System. These ages are in good agreement with the core formation ages in IIAB iron meteorites parent body constrained with the short-lived ^{182}Hf-^{182}W chronometer[2]. Additionally, the agreement between Hf-W and Mn-Cr ages within uncertainties suggests that both systems closed approximately simultaneously.

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2.2
Mafic Dykes from Archean Singhbhum Craton: A Window into the Evolution of Sub-Continental Lithospheric Mantle

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Mafic dyke swarms constitute an important marker for reconstructing paleogeographic positions of Archean cratons. In addition, dykes of different ages from the same region can be used to track the temporal geochemical evolution of the subcontinental lithosphere. Of particular interest are dykes and dyke swarms of Archean age, penetrating older Archean crustal nuclei, because of their potential to provide a better understanding of the evolution of Archean mantle composition, mantle dynamics and subsequently the evolution of the continental crust above it. In continental setting, the question mostly revolves around whether the source was sub-continental lithospheric mantle (SCLM), or the upwelling plume or was a mixture of these different sources (e.g. Bartels et al., 2015). However, crustal assimilation during ascent of the magma or post-emplacement metamorphism may potentially alter the primary mantle signature.

The Singhbhum Craton in eastern India is host to at least seven distinct sets of mafic dyke swarms, collectively referred to as 'Newer Dolerite Dykes'. Present study focuses on four different dyke swarms emplaced between 2.80 and 1.76 Ga. These dykes range from basalt to basaltic-andesite to andesite and have transitional tholeiitic to calc-alkaline affinities. They show intra-swarm geochemical and isotopic (Sr-Nd) heterogeneity and have SiO_2 content mostly > 52 wt.%. The trace elements compositions of these dykes indicate the involvement of a crustal component in their petrogenesis. The dykes have variable but fairly radiogenic $^{87}Sr/^{86}Sr$ with gradual increase from oldest to the youngest swarm. They also have sub-chondritic initial ε_{Nd} ranging from -0.9 to -10, which shows gradual less radiogenic signatures in the younger swarms compared to the older ones. This indicates that older enriched material was involved in the petrogenesis of the Newer Dolerite Dykes of the Singhbhum Craton. These dykes have high concentrations of compatible trace elements, which indicate that the parent melts were in contact with mantle peridotite and they did not fractionate much olivine, pyroxene, and magnetite and were not modified by crustal assimilation during ascent and emplacement. The crust-like temporal trend of the Sr and Nd isotopic compositions suggests that the crustal material incubated in the mantle for a long time and was periodically tapped during the dyke emplacement, multiple times between 2.8 and 1.7 Ga.

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2.3 Systematic trends in the evolution of porphyry-related Zn-Pb-(Ag) deposits

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Zinc-Pb mineral deposits in a porphyry system include (i) deposits formed subsequently to a prograde skarn phase, and (ii) replacement bodies and veins that lack skarn assemblages and are best developed in the shallow part of the system, predominantly in the epithermal environment. The latter are frequently called Cordilleran polymetallic deposits, carbonate replacement deposits (CRD), or intermediate-sulfidation (IS) deposits. The term Cordilleran is preferred because these deposits are not restricted to carbonate replacement and often include also low- and/or high-sulfidation mineral assemblages (LS and/or HS).

Based on the study of multiple deposits, an updated model for the evolution of porphyry-related Zn-Pb-(Ag) deposits is presented. It points to a significant overlap between the retrograde stage of Zn-Pb skarns and Cordilleran Zn-Pb deposits. Both mineral deposit groups share characteristics and mineral assemblages that in the ideal case follow systematic trends from low to higher sulfidation state, to subsequently return to lower sulfidation conditions. In Cordilleran polymetallic deposits all or some of the following, frequently telescoped, stages are observed. Repeated events often complicate the picture.

Stage A (LS, Zn-Pb±Cu±Sn, ~350-220°C) is characterized by LS assemblages with pyrrhotite, magnetite, Fe-rich sphalerite (up to 30 mole % FeS), minor galena, chalcopyrite and arsenopyrite. Chalcopyrite and may be also abundant. In deposits with particularly reduced assemblages, siderite and the Sn-bearing minerals cassiterite, stannite, and herzenbergite occur too and sphalerite may have high In content. Main gangue minerals are quartz and chlorite. When well developed, stage A forms pervasive, massive bodies. In some deposits, stage A is absent or only represented by small pyrrhotite inclusions in stage B pyrite.

Stage B (IS, ~280-200°C) consists predominantly of pyrite, often idiomorphic and coarse-grained, and quartz. Minor wolframite and gold may occur too. Widespread sericitization indicates pH decrease compared to stage A. This stage frequently overprints stage A; diagnostic features include the formation of cubic, pyritohedral, and octaedric crystals of pyrite and/or replacement of stage A pyrrhotite and arsenopyrite by marcasite and pyrite.

Stage C (HS/IS, ~280-150°C) may reach up to HS conditions developing Cu-Zn±Au assemblages with enargite/famatinite, covellite, Fe-poor sphalerite, colusite, quartz, alunite and kaolinite that grade outwards to IS Zn-Pb-Ag assemblages with Fe-moderate to Fe-poor sphalerite, galena, tennantite-tetrahedrite, bismuthinite, other sulfosalts, chalcopyrite, rhodochrosite and other Mn-Fe (±Zn) carbonates as well as ± alabandite. Sericite is present mostly intergrown with Mn-Fe carbonates and quartz. In the outermost zone, barite and hematite are frequent, the later locally replaced by magnetite (mushketovite). Stage C mineral assemblages occur in veins that may extend laterally for kilometers in detrital, volcanic, and other poorly-reactive rocks, whereas in carbonate rocks stage C may form large replacement bodies and dissolution breccias. In distal parts of stage C veins, stibnite, realgar, orpiment and Ag-bearing minerals may occur. Late calcite ± sphalerite ±galena± arsenopyrite veinlets are common and indicative of further neutralization of the fluid. Anom- alous Mn and Fe contents in calcite veinlets are used in exploration as surface and distal expressions of hidden ore bodies. Stage C spans large mineralogical variations; assemblages rich in V, Bi, Ni, Co, In, Ga are also found.

Many Cordilleran Zn-Pb-Ag deposits consist only (or mainly) of stage C with IS mineral assemblages bearing rhodochrosite and other Mn-Fe carbonates. Therefore, in places, they have been termed “intermediate-sulfidation Zn-Pb deposits”. However, it has to be considered that these deposits originate by essentially the same processes forming Cordilleran deposits that also display stages A and B and/or those deposits that develop HS mineral assemblages in stage C. Thus, deposits with only IS assemblages in stage C may constitute the “tail” of larger zoned Cordilleran deposits and of porphyry systems.

In the retrograde stage of Zn-Pb skarns, an evolution that parallelizes that of Cordilleran deposits is often recognized. Most of the ore typically consists of Fe-rich sphalerite in LS assemblages with pyrrhotite and magnetite, siderite, and chlorite, formed at~ < 350°C that are comparable to the LS stage A described above. Occasionally, the LS stage in Zn-Pb skarns is preceded by chalcopyrite-bornite-pyrite assemblages. The LS assemblages are often overprinted by coarse-grained pyrite with a tendency to idiomorphy, like in the Cordilleran stage B. Subsequently, generally minor, veins with Fe-moderate and

-poor sphalerite, galena, Ag-bearing sulfosalts, and Mn-Fe carbonates can occur and are equivalent to IS stage C assemblages described above. When these mineral assemblages extend outside the skarn environment, they are indistinguishable from Cordilleran bodies. In other words, the evolution from low to higher sulfidation conditions is also observed in Zn-Pb skarns, although here the LS stage is more widespread than in most Cordilleran deposits.

At several Cordilleran deposits, a *"pre-A stage"* consisting of Mg exoskarn minerals like talc, serpentine, magnetite, siderite, quartz ± less easily recognizable actinolite and tremolite also supports the transition and overlapping between skarn and Cordilleran Zn-Pb deposits. These magnesium-rich assemblages in protoliths devoid of diagenetic dolomite point to previous hydrothermal dolomitization.

The ore stages of both groups of ore deposits have been formed by low- to moderate-salinity magmatic fluids resulting of the ascent, from the porphyry level, of intermediate-density fluids or of brines diluted by magmatic vapor. Direct ascent of magmatic vapor to the Zn-Pb deposition environment also happens and is probably responsible for the extreme acidic and oxidized conditions yielding the alunite-bearing HS mineral assemblages of certain Cordilleran deposits, in part flanking HS Au mineralization. The common tendency from low to higher sulfidation state is generally explained by decreasing temperature and interaction of the mineralizing fluids with host rock. This evolution, followed by buffering by the host rock, is reminiscent of the classical "looping path through time and space" in the porphyry deposit itself.

This summary is largely based on work in collaboration with members of the Mineral Resources and Geofluids Group of the University of Geneva and the geology staff of several mining companies.

2.4
Cenozoic magmatic evolution of the Lesser Caucasus and its link with Anatolian and Iranian tectonic belts: Insights from the South Armenian Block - a key witness of crustal growth during Arabia-Eurasia convergence and collision

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The South Armenian block (SAB) is located in a key location along the Central Tethyan belt, linking the Turkish and Iranian tectonic and magmatic belts. This study aims at tracking the geodynamic evolution during the convergence and collision of the Arabian plate with the Eurasian margin, and understanding how the SAB has evolved during the subduction of the southern Neotethys beneath Eastern Anatolia and NW Iran.

New geochemistry and geochronology results from this study are complementary to previous work (Rezeau et al., 2016, 2017; Moritz et al., 2016) and hence provide new insights into the regional magmatic evolution in the SAB. The Cenozoic magmatism in the SAB has evolved from calc-alkaline to shoshonitic, both in space and in time, linked to the evolution of the magmatic arc and back-arc . The high-K calc-alkaline to shoshonitic magmatism of the SAB was initiated in the NW and became younger toward the SE, as it migrated closer to the suture zone. Trace element geochemistry of these rocks consistently support an arc-related signature with an enrichment in LILE and depletion in HFSE (Nb, Ta, Ti). Trace element data also indicates that the most potassic magmas are the most metasomatized and were generated by a low degree of partial melting of depleted mantle. According to radiogenic isotopes, the high-K calc-alkaline magmas from the north were sourced by a very juvenile mantle component. It is attributed to asthenospheric mantle upwelling, either during slab retreat or slab tearing in the back-arc. Upwelling of the asthenospheric mantle-derived magma migrated to the SE during late Eocene-early Oligocene slab roll-back/retreat or slab tearing, and mixed with a magma with a higher crustal component. Finally, the late Oligocene-early Miocene period was characterized by adakitic-like magmatism in the SAB (Rezeau et al., 2017; this study) and is attributed to the initiation of the Arabian slab break-off (Rabayrol et al., 2019; this study).

When compared to contemporaneous magmatism in the adjacent tectonic regions, the early to mid-Eocene magmatism of the southern SAB can be linked to the Iranian subduction of the southern Neotethys along the same magmatic arc, especially based on their crustal $^{143}Nd/^{144}Nd(i)$ ratios. In contrast, during the mid- to late Eocene, the 143Nd/144Nd(i) ratios show that the NW SAB was already in a context of a back-arc setting and was connected to the Eastern Pontides geodynamic evolution, which was the back-arc domain of the Arabian subduction system.

The Oligocene was marked by a magmatic lull in Turkey, which can be attributed to the hard collision of the Arabian plate with the Eurasian margin (Schleiffarth et al., 2018). In Iran, the collision stage occured later, with a soft character, thought to be initiated at 36 Ma (Ballato et al., 2011). From mid Eocene to Oligocene, high-K calc-alkaline to shoshonitic magmatism in the NW SAB migrated towards the SE SAB and Alborz magmatic arc (AMA) as a result of slab retreat in a back-arc regime or tearing of the lithosphere.

Finally, the Miocene is characterized by widespread magmatic activity in the Tauride-Anatolian platform, as well as in the Urumieh-Dokhtar magmatic belt. In the SAB and in the northern AMA, this magmatism was restricted to early Miocene and tends to be adakitic in composition, matching in space and time with the start of the Arabian slab break-off underneath Turkey (Rabayrol et al., 2019), which is also reported in Iran (Omrani et al., 2008).

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2.5
In situ CO_2 quantification in apatite by FTIR: Opportunities and limitations

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CO_2 is a key agent for metamorphic and igneous processes, for example, driving metamorphic reactions, controlling mass transfer, and impacting the solidus. However, determining the CO_2 content in igneous and metamorphic systems is notoriously difficult due to the fugitive behavior of CO_2. While studying fluid inclusions can be a useful way to gain insights into fluid compositions, their complexity can be a limiting factor when interpreting fluid compositions in the crust. An alternative approach for determining crustal fluid compositions is the analysis of minerals that contain volatile fluid tracers. Although several minerals can incorporate the fluid tracers H_2O, Cl, and F, such as amphibole or biotite, the variety of minerals in silicic rocks that host CO_2 is limited. One exception is apatite. Apatite, a ubiquitously present mineral in crustal rocks, can incorporate CO_2 in its crystal structure via different (coupled) substitution (e.g., Pan and Fleet, 2002).

While it has been previously recognized that apatite can incorporate appreciable amounts of CO_2, its quantification on a micrometer-scale has remained difficult due to the lack of suitable techniques, challenging sample preparation methods, and the shortage of reliable standard reference material. Here we present preliminary data from our attempt to calibrate absolute CO_2 contents in apatite on a micro-meter scale using Fourier-Transform Infrared Spectroscopy (FTIR) using a microscope equipped with a Germanium-tip objective. This set up allows attenuated total reflectance measurements of apatites in polished thin sections, without the need for doubly polished samples. The absorbtion of C-related bands is calibrated with a set of independently measured apatite standard reference materials via nuclear reaction analyses. Limitations of the technique and new opportunities to better quantify CO_2 contents in igneous and metamorphic systems will be discussed.

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2.6
Melt inclusions and machine learning – a new approach to the curiosity that is Colli Albani

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Just 30 km away from Rome sits Colli Albani, a mafic-alkaline volcanic complex that repeatedly produced large volume explosive eruptions, producing up to 63 km^3 (DRE). It is uncommon for mafic and alkaline magmas to erupt large volumes in an explosive manner due to the rheological properties of the magma. It is thought that the unusual explosively is related to the addition of CO_2 resulting from the interaction with carbonates. However, location of the source carbonates is debated in the literature with some suggesting a shallow carbonate reservoir and others suggesting carbonatic material at the top of the subducted Adriatic plate (Conticelli et al., 2010; Freda et al., 2011). In order to gain insight into the eruptive parameters of this volcano we analyzed melt inclusions, major elements of the phenocrystic phases, and used thermobarometry derived from machine learning. Volatile content of several melt inclusions hosted in clinopyroxene contain >2 wt. % CO_2 with values as high as to 3.5 wt. % CO_2 and 3.9 wt. % H_2O. CO_2 solubility studies indicate that such values are not compatible with shallow magma storage. Additionally, clinopyroxene phenocrysts have high magnesium number (up to 0.93) and Cr_2O_3 content, which suggest equilibrium with the mantle. We used a random forest machine learning approach to determine crystallization conditions of the clinopyroxene phenocrysts and found pressures and temperatures of up to 16 kbar and 1250 °C. The highest pressure and temperature clinopyroxenes are particularly abundant at the base of the ignimbrite outcrop. Thus, we suggest that mafic and CO_2-rich magma rapidly ascends from the mantle, destabilizing a shallow crustal magma reservoir and triggering an eruption. We suggest that the high explosively of this system is primarily due to the addition of large amounts of CO_2 to the magma in the mantle, which allow for its fast ascent through the lithosphere.

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2.7
Accelerating reactive transport simulations in heterogeneous porous media with Reaktoro and Firedrake

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Modeling coupled physical and chemical processes is not only scientifically challenging but also computationally demanding due to the high computing costs of chemical reaction calculations. The importance of reactive transport modeling has significantly increased over the past years due to becoming essential for understanding the processes occurring in surface or subsurface systems as well as engineering and environmental problems for a wide variety of geochemical processes.

Geochemical reaction calculations in reactive transport modeling are costly in general. They become more expensive, the more complex the chemical system and the activity models, used to describe the non-ideal thermodynamic behavior of its phases, are considered. Accounting for many aqueous species, gases, and minerals also contributes to more expensive computations. This work investigates the performance of the on-demand machine learning (ODML) algorithm presented in Leal et al. (2020) when applied to different reactive transport problems in heterogeneous porous media. We demonstrate that the ODML algorithm enables faster chemical equilibrium calculations by one to three orders of magnitude. This, in turn, significantly accelerates the entire reactive transport simulations. The numerical experiments are carried out using the coupling of two open-source software packages: Firedrake (Rathgeber et al., 2016) and Reaktoro (Leal, 2015).

To highlight the critical performance characteristics of the ODML algorithm, we use Figures 1. Here, we summarize the overall number of learnings each simulation run required for different tolerances and activity models. We emphasize that the percentage of smart predictions remains greater than 99.8% with respect to the total number of chemical equilibrium problems in the entire simulation. We also include the lowest and highest speedups in chemical equilibrium calculations throughout all the time steps and the overall speedups in the reactive transport simulations achieved by using the ODML method.

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Case I: Dolomitization proccess

	HKF activity model			Pitzer activity model	
	$\varepsilon = 0.01$	$\varepsilon = 0.005$	$\varepsilon = 0.001$	$\varepsilon = 0.01$	$\varepsilon = 0.001$
# of learnings	1271	2449	11752	1003	6001
% of smart predictions	99.999%	99.998%	99.988%	99.999%	99.994%
Speedup in chemical equilibrium	7-22x	7-20x	5-15x	84-264x	25-200x
Total speedup in reactive transport	4.5x	4.5x	3.5x	53.6x	21.4x

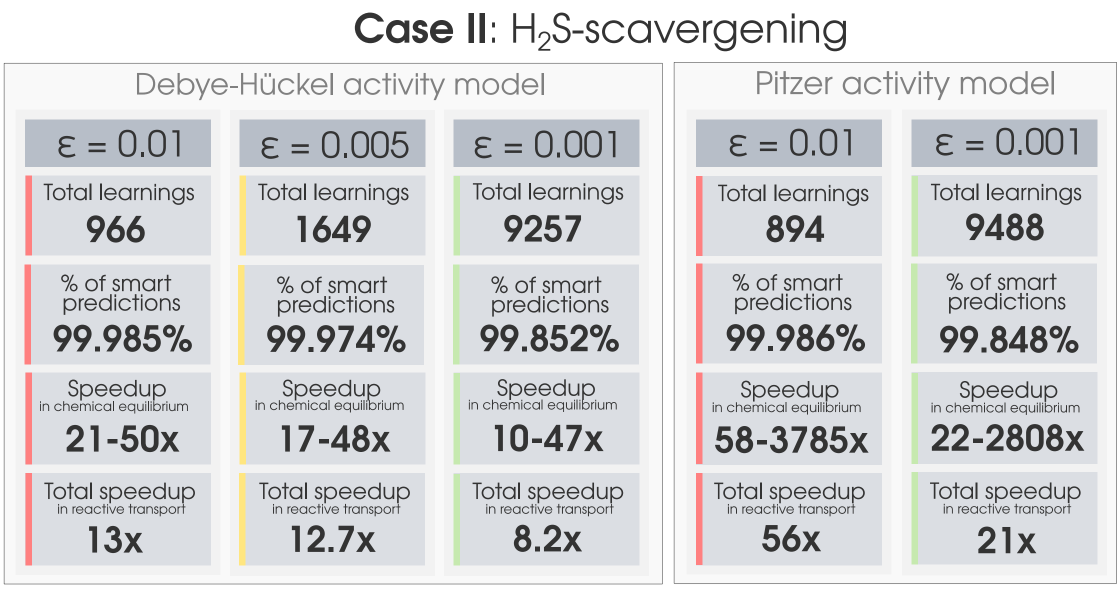

Figure 1. Summary of the total number of learning operations of the ODML algorithm, the percentage of the smart prediction with respect to the total number of chemical equilibrium calculations, the range of speedups in chemical equilibrium calculations throughout all time steps, and the overall speedups in reactive transport simulations for different tolerances ε. **Case I**: numerical modeling of a dolomitization process using the HKF and Pitzer activity models. **Case II**: simulation of the H_2S-scavenging process using the Debye-Hückel and the Pitzer activity models.

2.8
Investigating silicon isotope behaviour at small scale using melt inclusions.

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Melt inclusions are considered as representative of mantle derived primitive basaltic magmas when trapped in euhedral Mg-rich olivine crystals (Faure et Schiano, 2005). Despite some post-entrapment processes (e.g., Danyushevsky et al., 2000) the study of these melt inclusions leads to important insights (e.g., mantle source composition, magmatic processes (Schiano, 2003)). They can also be used to study isotopic heterogeneity in the mantle. In this study, we measure silicon isotope in olivine crystals and their hosted melt inclusions (OHMIs) in 3 samples from 2 different locations on the Mid-Atlantic Ridge: FAMOUS and 14° Triple Junction (Normal-MORB and Enriched-MORB respectively). Indeed, to date, only bulk δ^{30}Si have been reported for Mid-Ocean Ridge Basalt (MORB) samples, and they vary within -0.36 to -0.22‰ (Poitrasson et al., 2017). Measurements of δ^{30}Si in OHMIs and their host from MORB can be used to better understand the behaviour of silicon isotope at small scale in magmatic system.

Silicon isotope measurements were conducted with an ion microprobe (Cameca IMS1280HR, in Lausanne) using a set of 8 glass standards with compositions ranging from basaltic to rhyolitic. Calibration using optical basicity (Tissandier et al., 2017) revealed an average δ^{30}Si in OHMIs from the three samples of -0.48‰, associated with variability up to 2‰ in OHMIs from each samples, which is 4 times larger than in bulk MORB (<0.5‰; e.g., Poitrasson et al., 2017). In order to verify these values, silicon isotope were measured in the same OHMIs, as well as in 4 olivine crystals using laser-ablation-MC-ICP-MS following the protocol published in (Guitreau et al., 2020). Laser ablation data display average δ^{30}Si similar than measured by SIMS, but with a far smaller range (up to -0.5‰). The difference in variability measured between the two techniques implies that despite careful calibrations ($R^2 > 0.99$) SIMS instrumental mass fractionation for silicon isotope could be an analytical bias that still need to be identified for SIMS δ^{30}Si measurements in glasses. This requires further investigations.

OHMIs analysed with LA-MC-ICP-MS display consistent δ^{30}Si values between the 3 samples. For the N-MORB, δ^{30}Si values range from -0.32 ± 0.14‰ (2se) to -0.65 ± 0.14‰ (2se) for ARP73-10-03 and from -0.42 ± 0.11‰ (2se) to -0.65 ± 0.11‰ (2se) for CH31-DR8. For the E-MORB, values range from -0.25 ± 0.14‰ (2se) to -0.79 ± 0.12‰ (2se). For the 3 samples, OHMIs record homogeneous δ^{30}Si, but their average value (-0.47 ± 0.17‰ (2sd)) is lower than average MORB glasses from the Atlantic (-0.27 ± 0.06‰ (2sd)) (Savage et al., 2010). Since the 3 basaltic standards used during LA-MC-ICP-MS measurements (BHVO-2, BIR and BCR) gave consistent results with literature (e.g., obtained $\delta^{30}Si_{BHVO-2}$ = -0.29 ± 0.13‰ (2sd), literature $\delta^{30}Si_{BHVO-2}$ = -0.27 ± 0.08 ‰ (2sd) (Zambardi et Poitrasson, 2010)), we suggest that the lower δ^{30}Si measured in OHMIs compare to MORB glasses is real. The 4 host olivine crystals (Fo_{90}) returned an average δ^{30}Si of -0.34‰ ± 0.17‰ (2sd). Despite the apparent typical average δ^{30}Si measured in olivine and lower average δ^{30}Si in melt inclusions, melt inclusions seem to be in equilibrium with their host. Indeed, the Si isotope fractionation between olivine and its OHMI vary from -0.26 to 0.0‰, which is similar to theoretical equilibrium ($\Delta^{30}Si_{olivine-melt}$ = -0.15‰ (Savage et al., 2011)). This does not suggest boundary layer effect as a possible process for lower δ^{30}Si compare to bulk MORB values, even if there might be some variations of $\Delta^{30}Si_{olivine-OHMI}$. These results will be discussed as a possible tool to investigate silicon isotope fractionation between melt and minerals or during magmatic differentiation.

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2.9
The missing magmatic arc and the case for Ampferer-type subduction in the Alps and Pyrenees

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In the early 1900s, G. Steinmann and O. Ampferer identified two fundamental characteristics of the Alpine orogen, namely ophiolites (Steinmann Trinity, *Steinmann, 1905*) and the underthrusting of crustal material at depth ("*verschluckung*"), or "subduction" (e.g. *Ampferer and Hammer, 1911).* Ever since these discoveries, the evolution of the Alps, from rifting to ocean spreading, subduction and finally to continental collision has remained controversial.

The geophysical identification of subducting oceanic lithosphere at convergent margins and active mid-ocean ridge spreading in the mid-1900s (e.g. *Heezen and Tharp, 1966*) enabled the development of the conceptual framework of the motion of rigid oceanic plates as the key driver of *Plate Tectonics*, which was then implemented in the Alps (c.f. *Trümpy, 2001*). However, we highlight numerous characteristics of the Alpine and Pyrenean orogens that are fundamentally distinct from typical *Wadati-Benioff-type* of subduction. Benioff-type subductions have large oceanic slabs, a long term magmatic record and intra-oceanic subduction-initiation signatures during the first 20 Ma of subduction which include upper-plate extension and magmatism followed by either obduction or formation of arc system. Other characteristics include the minor abundances of high-pressure rocks in accretionary prism and near-absence of evidence of (ultra-)high pressure rocks. On the other hand, the Pyrenees and Alps are characterized by amagmatic subduction initiation at passive margins and a pre-collisional lithosphere comprised of rift basins characterized by thinned continental crust, exhumation of heterogeneous subcontinental mantle and oceanic core complexes (e.g. *Tricart and Lemoine, 1983*). The Pyrenees record no magmatism during convergence, whereas magmatism in the Alps is only recorded during collision (*McCarthy et al., 2018*). This leave a ca. 50-60 Ma gap in the Alps, from subduction initiation to collision, where the detrital zircon record shows no magmatism even though subduction of oceanic and continental fragments reaches ~2 GPa. Moreover, the Alpine orogen shows abundant high-pressure lithologies and coherent imbrication of high-pressure passive margins and oceanic core complexes (*Beltrando et al., 2014*).

These discrepancies can be resolved by reintroducing the term of Ampferer-type continental subduction. Convergence was controlled not by spontaneous subduction of rigid oceanic lithosphere but by the forced closure of hyper-extended basins along weakened, serpentinised passive margins. This allows us to distinguish Benioff-type oceanic subduction resulting from the efficient subduction of oceanic lithosphere, abundant magmatism and limited exhumation of metamorphic lithologies, from Ampferer-type continental subduction, derived from the closure of hyper-extended continental basins, inefficient deep subduction of hydrated (serpentinites and oceanic sediments) lithologies, preservation of high-pressure units and amagmatic characteristics.

Nearly 20 years ago, R. Trümpy published a fascinating paper entitled "*Why plate tectonics was not invented in the Alps*" which dealt with the evolution of geological thought in the Alpine realm since the inception of the nappe concept in the 19th century. We argue that the reason the Alps were not the prime location to develop a robust *Plate Tectonic Theory* is precisely because the Alps might be better understood in terms of continental tectonics (*Molnar, 1988*), namely extreme intracontinental extension, ultra-slow plate separation and compression of mainly hyper-extended continental domains (*McCarthy et al., 2020*).

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2.10
Mineralization stages at the Ayawilca Zn-Pb-In-Ag-Sn-Cu deposit, Pasco, Peru: new insights.

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The “Cordilleran” Ayawilca Zn-Pb-In-Ag-Sn-Cu deposit is part of the Miocene polymetallic belt of Central Peru (Fontboté, 2018), 40 km northwest of the world-class deposit of Cerro de Pasco. The blind Zn-Sn mineralization occurs mainly as 10 to 30 m-thick lenses (“mantos”) and up to dm-thick veins. Mineralization is largely hosted in limestones of the Upper Triassic to Lower Jurassic Pucará Group that in the deposit area overlie carbonaceous phyllites of the Excelsior Group (Devonian) and are overlain by Lower Cretaceous detrital sedimentary rocks of the Goyllarisquizga Group (Peralta et al., 2019). Zinc-(Ag) veins are also present in the western and eastern parts of the deposit. In the present work, we refine the previously defined paragenetic sequence (Benites et al., 2019) focusing on minerals appropriate for fluid inclusion studies (Fig. 1A). Fluid evolution in terms of sulfidation state is shown in Fig. 1B.

Stage Pre-A consists mainly of Mg-siderite, magnetite, prismatic quartz with undulose extinction (q_1 in Fig. 1A), and, frequently in voids, talc and chlorite. Local presence of actinolite-tremolite relicts suggests transition to skarn. This stage is identified in the lower part of the Pucará limestone close to the contact with Excelsior phyllites.

Stage A is the volumetrically most important and consists of a low-sulfidation assemblage with pyrrhotite, quartz, Fe-rich sphalerite (up to 30% FeS), arsenopyrite, chalcopyrite, cassiterite, stannite, herzenbergite and minor apatite (Figs. 1C-E). Several prismatic quartz generations are distinguished. Comb quartz, mainly pre-pyrrhotite, forms up to 10 mm crystals (q_2 in Figs. 1A; 1C) on which tips occur pyrrhotite and arsenopyrite inclusions. Milky quartz grains including apatite blebs postdate pyrrhotite (q_3 in Fig. 1A; 1E). It is followed by clear zoned quartz (q_4 in Fig. 1A). Fluid inclusion studies performed on quartz (q_4) from stage A (Harlaux, 2019) yield homogenization temperatures ranging from 341°C to 265°C and salinities between 2.4 and 9.1 wt.% NaCl equiv.-
Stage B consists of marcasite and pyrite altering stage A pyrrhotite and mainly of coarse-grained, partly euhedral pyrite. Unlikely at Cerro de Pasco (Rottier et al., 2018), no quartz suitable for fluid inclusion studies is observed in Stage B.
Stage C is poorly developed and made up of Mn-Fe carbonates (partly banded), intermediate- to low-Fe sphalerite (10-2% FeS), galena, chalcopyrite, bismuthinite, native bismuth, fahlore, Pb-Ag sulfosalts, kaolinite, dickite, and muscovite, outlining an intermediate sulfidation state. Minor arsenopyrite occur too. Small (up to 15 μm) negative crystal-shaped two-phase (liquid-vapor) fluid inclusions have been observed in growth zones of the Mn-Fe carbonates.

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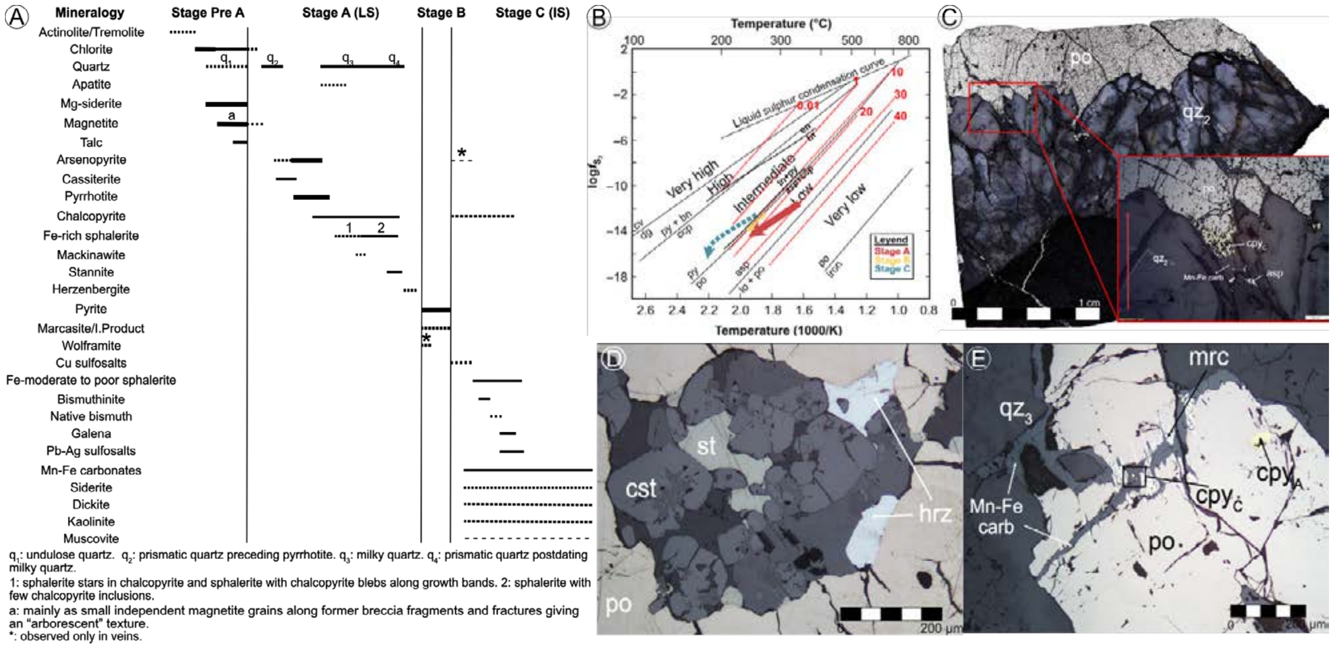

Figure 1. A) Paragenetic sequence of the Ayawilca deposit modified from Benites et al. (2019). B) Schematic representation of stages A, B, and C in a modified log fS2 vs temperature diagram of Einaudi et al. (2003) based on stable sulfide mineral assemblages; red lines indicate FeS (mol%) contents of sphalerite (Barton & Toulmin, 1966); starting temperature of stage A based on Harlaux (2019). C) Stage A vein, red arrow indicates quartz growth direction. D) Cavity in pyrrhotite filled with cassiterite, stannite, and arsenopyrite. E) Stage A pyrrhotite altered to marcasite (stage B) and crosscut by stage C Mn-Fe carbonate. asp: arsenopyrite; cst: cassiterite; cpy: chalcopyrite; hrz: herzenbergite; mrc: marcasite; po: pyrrhotite; qz: quartz; st: stannite.

2.11
Assessing the state and size of subvolcanic magma reservoirs by thermo-chemical inversion of zircon

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Determining the current state and size of magma reservoirs is crucial to mitigate volcanic hazards. However, the spatial resolution of geophysical imaging techniques is often too low to fully assess the volume of eruptible magma stored in the system, and the eruptive history of a volcano through geological and geochemical records does not resolve the present day state of the subvolcanic plumbing system. We developed and applied a new technique based on zircon geochronology, trace element geochemistry and thermal modelling to Nevado de Toluca volcano in Mexico to estimate the rate of magma input and accumulation of potentially eruptible magma in the subvolcanic reservoir. Our calculations constrain the average rate of upper crustal magma recharge to values between 5.8×10^{-6} and 7.5×10^{-6} km^3 km^{-2} yr^{-1}. We also show that only a few percent of the supplied magma erupted and that a maximum melt volume of $\sim$350 km^3 is potentially stored within the upper crustal plumbing system of the volcano today. The presence of eruptible magma at Nevado de Toluca is transiently associated with recharge events over timescales of years to centuries. We emphasize that dormant stratovolcanoes, such as Nevado de Toluca, may transition into unrest and eruption over short periods of time potentially without geophysical evidences for melt-rich magma bodies in the shallow crustal storage region. This calls for the need to extend monitoring networks and to combine multiparametric monitoring with petrology and modelling to gather a quantitative understating of the current status of dormant volcanoes. Our approach can be widely applied and provides vital quantitative information to better assess the potential magnitude of future volcanic eruptions.

P 2.1
Cluster analysis of crystal zoning: Application to pyroxene megacrystals from the 1669 eruption of Mount Etna

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Chemical zoning of minerals provides information on the magmatic processes preceding volcanic eruptions (Caricchi et al. 2020). Here we use cluster analysis to objectively and quantitatively study chemical zoning and identify the processes responsible for one of the large and disruptive eruptions of Mt Etna. We analysed 31 pyroxene megacrystals from the 1669 eruption of Mount Etna (Monti Rossi). The crystals have been cut perpendicular to the c-axis, polished, mounted in epoxy and then scanned with an electron microprobe at the University of Geneva. Compositional maps for silicon, calcium, magnesium, aluminium and chromium were collected. These crystals present both concentric and sector zoning. We use the intensity of the signals for each element to identify chemical clusters using cluster analysis. This is an unsupervised learning technique and consequently no prescribed number of clusters exists. Thus choosing the correct number of clusters is one of the most important challenges to apply this method. The initial target of the study is to identify the best methods to obtain compositional clusters which make petrographic and geochemical sense. To reach our goal, different algorithms have been applied using the R programming language. The two principal methods are the K-means (Hartigan-Wong) algorithm and the Ward's minimum variance method for hierarchical clustering. Both are working and widely applied techniques but need to be adapted to perform better with overlapping chemical data from a single mineral. The choice of the number of clusters remains a problem since none of the many tested indexes give satisfying results for each crystal. Therefore, we will design a new method or a combination of methods that gives the best results. To estimate the performance of the algorithms we will design a statistical test with elemental maps that will be visually assessed by geology and mathematics students.
We will present the preliminary results of our study and some applications to the Monti Rossi eruption.

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P 2.2
Quantitative chemical mapping of plagioclase as a tool for the interpretation of volcanic stratigraphy: an example from St Kitts, Lesser Antilles

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Establishing a quantitative link between magmatic processes operating at depth and volcanic eruption dynamics is essential to forecast the future behaviour of volcanoes, and to correctly interpret monitoring signals in active systems. The study of chemical zoning in minerals can be exploited for such a purpose due to its ability to fingerprint successive events or states within a magmatic system as the crystals grow. However, to move beyond a qualitative understanding of a magmatic system an unbiased quantification of a large number of zoned crystals is required. We apply an image segmentation approach to thin section scale chemical maps to segment textural zones in plagioclase and correlate these zones between crystals from a stratigraphic sequence from St Kitts, Lesser Antilles. Mapping crystals at the thin section scale allows us to assess chemical and textural complexity within an individual sample and between different samples. By working on a stratigraphic sequence with this methodology we can quantify chemical and textural complexity in time, in this case specifically on a millennial timescale.

Furthermore, recurring zoning patterns observed from this “crystals-eye view” of the magmatic system have the potential to show temporally repetitive processes experienced by the magma at depth. When coupled with textural quantification, these data show that variations in whole-rock geochemistry are more likely due to subtle variations in the assemblage of recycled phenocrysts, rather than long-term variations in chemistry of the juvenile magma. The evolution of microlite chemistry unveils a temporal trend towards less chemically evolved magma.

P 2.3
Mildly-explosive to effusive eruptions of Colli Albani (Italy)

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The Colli Albani volcano is located about 30 km SE of Rome and is part of the Roman Magmatic Province along the NW-SE extensional Tyrrhenian margin of Italy (Marra et al. 2004). Colli Albani has been active since c. 600 ka displaying a range of eruptive styles from caldera-forming to plinian explosive paroxysms and mildly explosive-effusive eruptions. All erupted products are mafic and potassic (Giordano & CARG Team 2010).

This project focus on the understanding of the processes that lead to such a variety of eruptive behaviours involving mafic-alkaline magmas. We combine physical volcanology, petrology, and geochemistry and focus on one of the mild-explosive to effusive units: the Fontana Centogocce formation.

The Fontana Centogocce formation (SLV) is constituted of fall deposits, lava flows and pyroclastic deposits that are located stratigraphically between the Pozzolane Nere (407 ± 4 ka)(Karner et al. 2001) and the Villa Senni ignimbrites (351-357 ±3 ka) (Karner et al. 2001) (Giordano & CARG Team 2010).

We are collecting whole rock analyses, mineral chemistry analyses and performing a detailed petrographic study to compare the units constituting the Fontana Centogocce formation and an existing dataset for the Villa Senni ignimbrites. We will use unsupervised and supervised learning approaches to identify similarities and differences between large caldera-forming eruptions and mild-explosive to effusive activity of the Colli Albani volcano and attempt to constrain the processes responsible for these different eruptive dynamics.

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P 2.4
Investigation of the thermo-chemical evolution of magma reservoirs through the growth and the analysis of experimentally zoned crystals

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Magma reservoirs are characterized by thermo-chemical gradients that lead to large variations of the physical properties of the magma they contain. Magmatic minerals can record this physico-chemical variability within a magma reservoir, recording variations of intensive parameters as chemical signals. To better understand these chemical signals, we use an experimental approach to grow chemically zoned minerals under controlled conditions. This allows us to study the role of intensive parameters, element diffusion and mineral growth on the chemical zoning.The starting materials for our experiments are natural samples of tephra collected from 2002-03 Mt. Etna eruption. Chemical zonation is forced by oscillating the temperature inside a high-temperature furnace under three different regimes: static conditions, using a controlled deformation gradient (concentric cylinder apparatus) and using a chaotic mixing regime (Chaotic Magma Mixing Device – CMMD).

We measure both major and trace elements distribution maps on a large number of crystals using Electron Probe Micro Analyzer (EPMA) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS), respectively. Using a series of custom-built machine learning algorithms we disentangle zoning patterns related to variations of the thermodynamic conditions of crystal growth from those produced by the competition between diffusion and growth. Backscattered Electron (BSE) images of the sample are also analyzed for Crystal Size Distribution (CSD). The main aims of this project are to provide experiments that will help deciphering the chemical signals recorded in magmatic minerals and to improve our understanding of magma reservoir dynamics.

P 2.5
Mineralizing fluids in the Catalina Huanca carbonate-replacement Zn-Pb-Ag deposit, southern Peru

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Catalina Huanca is a medium-sized carbonate-replacement (Zn-Pb-Ag) deposit located in the Andean Cordillera of southern Peru, 400 km southeast of Lima, and 100 km south of Ayacucho (unpublished company reports; Dávila et al., 2012). The Catalina Huanca mineralization is located at the base of a major Tertiary eastward thrust and consists of veins and replacement bodies. It is controlled by a NE trending horsetail fault structure cutting the foreland Tertiary red beds (previously attributed to the Permo-triassic Mitu Group; Davila et al., 2012) and the overthrusted Pucara Group limestones. Spacially associated pre-ore igneous rocks include rhyolitic and trachytic dikes.

Mineralization at Catalina Huanca comprises seven stages with contrasting mineralogy. Stage I corresponds to the high-temperature skarn replacement, with biotite and subordinate diopside, pyroxmangite, andradite, and ilvaite. It is followed by stage II, with high-temperature hematite replaced and overgrown by magnetite (mushketovite). Stage III consists of adularia, and abundant euhedral pyrite and quartz with minor arsenopyrite, while stage IV is dominated by Fe-rich sphalerite with chalcopyrite disease in part replacing the early pyrite. Stage V is characterized by early fluorite associated with hematite, quartz, Fe-poor sphalerite, fahlore, enargite, chalcopyrite, and galena. Stage VI corresponds to the epithermal evolution of the system, with abundant siderite-rhodochrosite as replacement and open space fillings, followed by kaolinite. Finally, stage VII is characterized by the presence of carbonates (subhedral or muddy facies) and minor apatite.

The goal of the present study is to characterize the mineralizing fluids and their evolution. A large number of samples (>50) has been used to define the paragenetic sequence of the mineralization. Of these, about fifteen key mineralized samples were selected from Stages III and IV for fluid inclusion analyses in ore and gangue minerals, combining traditional microscopy with near-infrared (NIR) microscopy and microthermometry. This approach allows tracing the hydrothermal fluid evolution and the P-T-X conditions of ore formation.

The paragenetic sequence is presented in Figure 1, and the ongoing work includes fluid inclusion analysis in different generations of sphalerite and fluorite (Fig. 2). Abundant primary and secondary L-V inclusions are found in sphalerite (early and late), but only secondary inclusions in fluorite. First results on fluorite show Th ranging from 150° to 250°C and salinities from 8 to 11 wt% NaCl eq. Further studies will include microthermometry measurements on sphalerite-hosted inclusions, cathodoluminescence petrography, electron microprobe analyses of sphalerite, Raman spectroscopy and LA-ICP-MS analyses of individual fluid inclusions in gangue and ore minerals.

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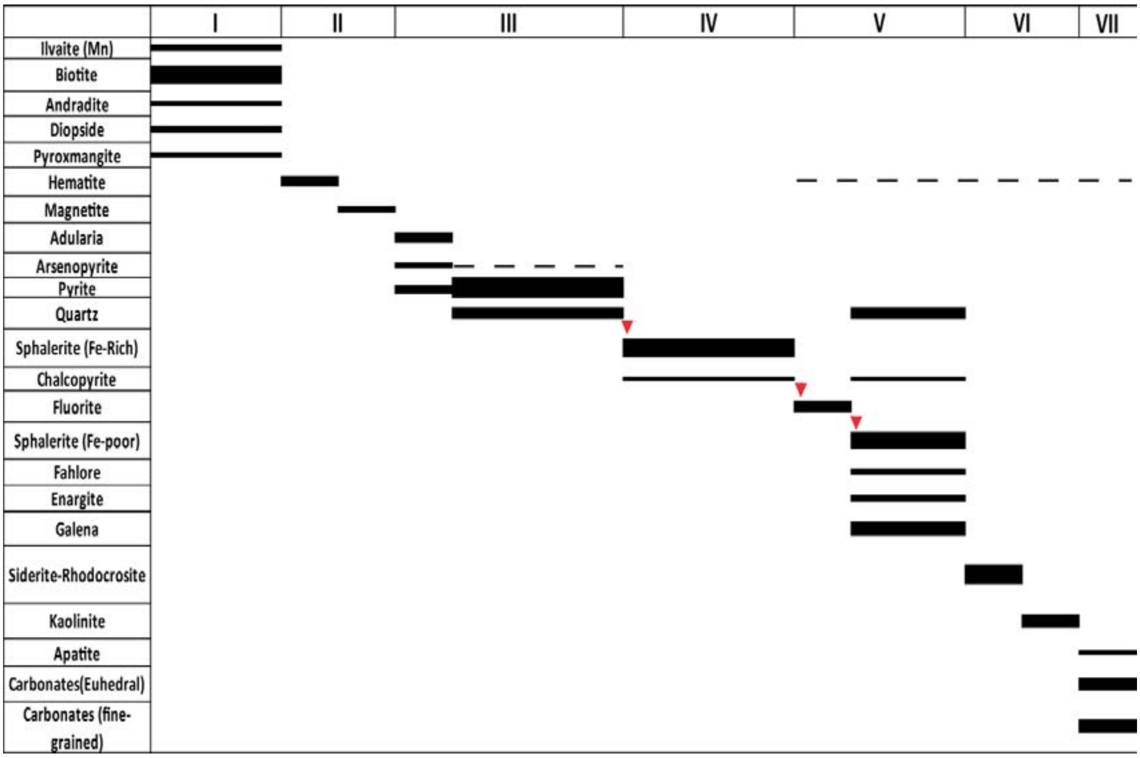

Figure 1. Paragenetic sequence of the Catalina Huanca deposit. Red arrows indicate minerals used for the fluid inclusion study.

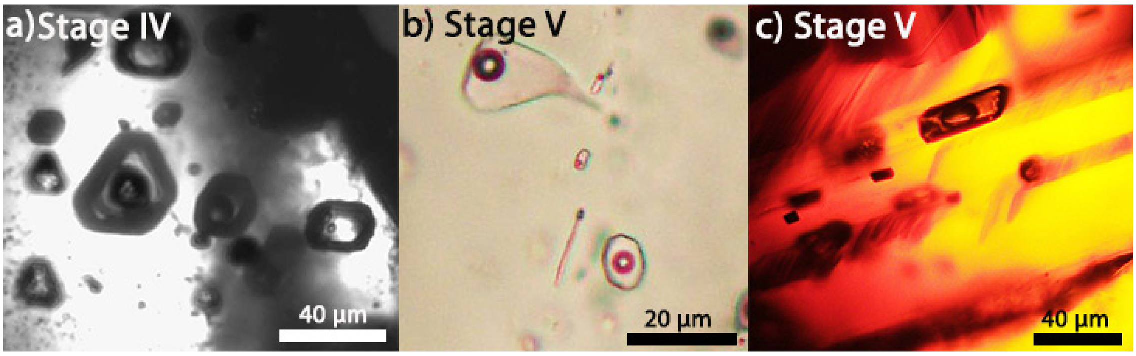

Figure 2. a) Negative crystal-shaped primary fluid inclusions in Fe-rich sphalerite (NIR light); b) Secondary fluid inclusions on fluorite.c) Primary fluid inclusions in Fe-poor sphalerite trapped along a twin plane.

P 2.6
Seafloor hydrothermal alteration along the downflow pathway: insights from the Semail ophiolite, Oman

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Hydrothermal alteration is ubiquitous throughout oceanic crust. Induced by subseafloor seawater circulation near mid-ocean ridge (MOR) spreading centres, alteration influences ocean chemistry and it leads to formation of Volcanogenic Massive Sulfide (VMS) deposits at black smoker vents. Our current understanding of seafloor alteration has largely been obtained from ocean drilling of in-situ oceanic crust, experimental fluid–rock studies, and examination of oceanic crust in ophiolites. Comparisons between ancient ophiolite and 'modern' MOR settings can be made as they share similar crustal stratigraphy, the hydrothermal agent is seawater, and the presence of disequilibrium assemblages is common (Lippard et al., 1986).

While research on subseafloor processes has begun to understand the evolution of the hydrothermal system over space and time, and to clarify the recharge and discharge pathways, the absolute timing of mineral formation and the element budgets and fluxes for each of the alteration stages/processes remain unclear.

Our ongoing study aims to unravel the complex hydrothermal alteration history of the Semail ophiolite and reconstruct the water–rock interaction along the downflow pathway by analysing representative stratigraphic transects across the Semail crust. With petrographic analysis, including optical microscopy, Raman spectroscopy and scanning electron microscopy, we show the changes in mineralogy and geochemistry across each transect, the paragenetic sequences of alteration reactions, and compare these observations with the hydrothermal alteration histories of the modern ocean crust and other ophiolites.

Generally, hydrothermal alteration along the downwelling zone of modern oceanic crust and ophiolites is similar; both the upper sheeted dykes and the volcanic sequence are pervasively altered to various intensities, and alteration 'grade' increases with increasing stratigraphic depth. However, many differences exist between ophiolites and oceanic crust, and between ophiolites themselves (Fig. 1). These differences may be a result of single versus multiple periods of magmatic activity, superimposition of regional metamorphic effects in the ophiolites, and/or longer lived hydrothermal circulation in certain ophiolites due to sediment capping (Alt, 1996; Alabaster & Pearce, 1985).

The Semail ophiolite ranks as one of the most intensely altered examples of oceanic crust anywhere, as testified by its rarity of fresh glass, its complete or near-complete alteration of the extrusive section to sub-greenschist to greenschist facies spilites, and its lack of very low temperature alteration assemblages, which are common in in-situ oceanic crust (Alabaster & Pearce, 1985; Pflumio, 1991). A remarkable feature is the stability of hydrothermal chlorite through to the very top of the Semail crust. Thus, the secondary mineralogies along the downflow pathway of the Semail ophiolite presumably reflect a complex, multistage hydrothermal alteration history. Nevertheless, the density of known VMS deposits in the ophiolite is no higher than in other more weakly altered ophiolites, such as Troodos.

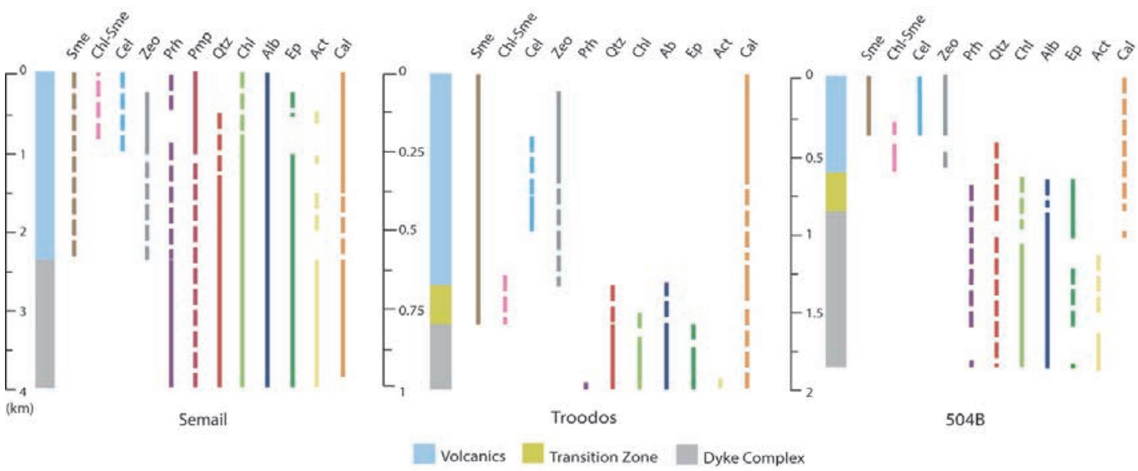

Figure 1. Distribution of secondary minerals in the Semail and Troodos (Cyprus) ophiolites, and Integrated Ocean Drilling Program (IODP) drill hole 504B. Scale indicates depth (km) below sediments. Vertical lines indicate occurrence of the mineral (solid = ubiquitous, dashed = locally present). Sme = Smectite; Chl-Sme = Chlorite-Smectite; Cel = Celadonite; Zeo = Zeolite; Prh = Prehnite, Pmp = Pumpellyite; Qtz = Quartz; Chl = Chlorite; Alb = Albite; Ep = Epidote; Act = Actinolite; Cal = Calcite. Modified from Alt et al. (1996), Pflumio (1991), Gillis & Robinson (1990), and Alabaster & Pearce (1985).

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P 2.7
Simulation of chemically driven convection in porous media using a charge-balanced multicomponent diffusion model

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Reactive transport in porous media typically comprises multiply charged ionic aqueous species. According to Joekar-Niasar et al. (2019), the effect of charged transport in porous media is often neglected in reactive-transport models even though it may be relevant. Tournassat et al. (2020) investigated numerical methods of solving the Nernst-Planck equation, including the chemical activity terms, and mentioned that only PHREEQC (Parkhurst and Appelo, 2013) could model such effects. The effect of chemical activity cannot be neglected at high ionic strengths. Such concentrated solutions are common in natural environments such as karstic aquifers or geothermal reservoirs. Therefore, we implement a charge-balanced multicomponent diffusion model using FEniCS (Alnæs et al., 2015) and Reaktoro (Leal et al., 2017) to better understand natural porous systems.

We benchmark our code implementation using an experiment of chemically driven convection in a Hele-Shaw cell (Almarcha et al. 2010). The experiment's initial conditions consist of an aqueous HCl solution placed on top of an equimolar aqueous NaOH solution. When the barrier between the acid and base is removed, the species starts diffusing, triggering an acid-base reaction, then convecting due to density differences brought about by the reaction. This experiment showcases how complicated coupled transport and reactive processes can be. We model the system using the disassociated ionic species (H+, Cl-, Na+, OH-). Concentration-dependent diffusion fluxes are calculated using the Nernst-Planck model under charge-balanced conditions (Steefel et al., 2015; Alt-Epping et al., 2018). No parameter fitting is necessary. Only measured (well-known) diffusion coefficients at infinite dilution are used. We use Darcy's law to model density-driven flow in the Hele-Shaw cell. Our simulations are capable of reproducing the complex flow and transport mechanisms seen in the experiments; mechanisms that are triggered by the differences in diffusivity of the various ions.

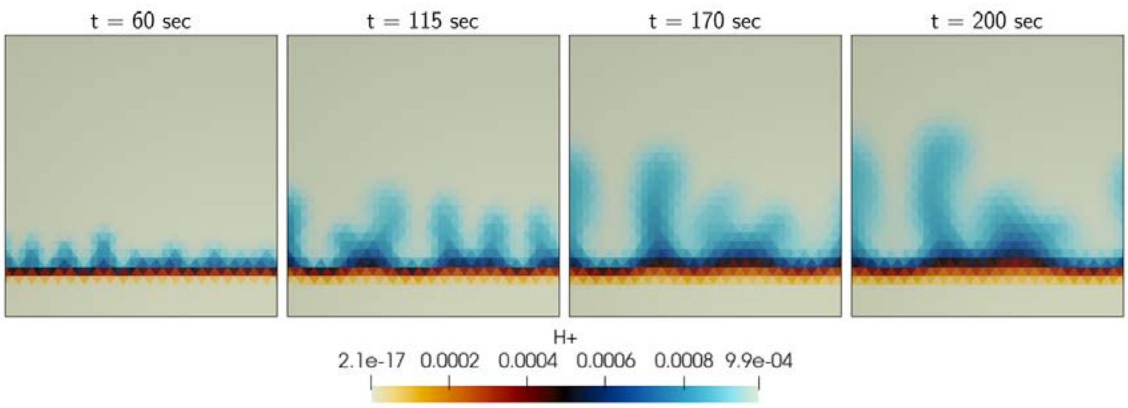

Figure 1. Simulation of chemically-driven convection. The colors represent the mass fraction of hydrogen ion.

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P 2.8
Metasomatic signatures revealed from trace element concentrations of clinopyroxene

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Periodic CO_2 outgassing from volcanoes along the Cameroon Volcanic Line is poorly understood.

The CO_2 could be mantle derieved through ancient subduction-related metasomatism during the Pan-African orogeny or be realted to more recent plume-related carbonatite metasomatism. In order to understand these processes, major and trace element concentrations of three representative clinopyroxene-bearing spinel xenoliths (Ka1, Ka2 and Ka7) from the Kapsiki plateau were measured. The Kapsiki plateau shows the oldest volcanism (35-27 Ma) along the line, and also bears the northermost known occurrence of mantle xenoliths. These xenoliths are quite peculiar because they show records of an ancient depleted mantle which has so far only been reported in the oceanic part of the line. However, with extended volcanism during the Cenozoic and a speculated juvenile state of the lithospheric mantle such features are not expected to be preserved. In this context, these xenoliths are a key to understanding and deciphering the evolution of the SCLM below the rest of the line.

The Kapsiki xenoliths show evidence of melt depletion along with a complex metasomatic history. The Mg# of olivine (0.91-0.92) and orthopyroxene (0.92-0.93), low Al_2O_3 (0.02-2.31 wt.%) contents in orthopyroxene and low incompatible trace elements point to a mantle composition with highly refractory components. Additionally, modal proportions and REE concentrations show that the SCLM has experienced modal and cryptic metasomatism. Modal metasomatism is indicated by the presence of two groups of clinopyroxenes; a low (18.65-18.92 wt. %) CaO groupin Ka1 and high (20.62-22.57 wt.%) CaO group which occurs in all samples.

Primitive mantle normalised trace element patterns of ortho- and clinopyroxenes show strong progressive enrichments in LREEs and to a lesser extent MREEs and HREEs in sample Ka1. Clinopyroxene patterns show negative Ti and Nb anomalies and a positive Sr anomaly but Pb anomaly which indicates the absence of subduction-related metasomatism. Negative Ba and Nb anomalies are inconsistent with metasomatism by alkaline melts. Instead, such features combined with strong enrichments in U and Th indicate the involvement of a carbonatite fluid component. The Kapsiki xenoliths thus show evidence for multiple metasomatic events since the trace element patterns do not show any distinctive features which could be attributed to a single melt/fluid type. Furthermore, the composition of the fluid/melt that metasomatised sample Ka1 is different from the others and shows three groups of compositions.

Different systematics were developed to discriminate between different types of metasomatism. Ti/Eu vs $(La/Yb)_N$ ratios are used to discriminate silicate and carbonatite metasomatism and show that the low Ca group of Ka1 clinopyroxene with high $(La/Yb)_N$ ratios and low Ti/Eu was affected by carbonatite metasomatism. However, the high Ca group along with most of the Ka2 and Ka7 clinopyroxenes with high $(La/Yb)_N$ and high Ti/Eu do not show well defined trends and could be a result of the presence of both fluids in varying proportions or a gradual overprinting of one fluid type by another. A few Ka2 and Ka7 grains which show low $(La/Yb)_N$ and high Ti/Eu ratios are indicative of interactions with basaltic melts. Zr/Hf vs Ti/Eu, data show that the Kapsiki xenoliths have been metasomatised by carbonated silicate melts and silicate melts which correlates quiet well with results from the Ti/Eu and $(La/Yb)_N$ ratios. Ti/Sr ratios of Ka1 samples range from 1-11, Ka2 and Ka7 ratios are much higher in the range of 9-18. Clinopyroxenes with low values (1-5) in sample Ka1 are identical to other clinopyroxenes that have been metasomatised by carbonatite melts with equally low Ti/Sr ratios. Most of the Kapsiki samples also show Ca/Al values of 4-7 which, is consistent with metasomatism induced by volatile rich melts.

Temperatures calculated using the two-pyroxene thermometry gives higher temperatures (1150 °C) for the low CaO clinopyroxene which show carbonatite metasomatism and lower temperatures (880 °C) for the high CaO clinopyroxenes. Our study shows that the SCLM below the kapsiki underwent partial melting with the extraction of basaltic melts, the lower temperatures clinopyroxene records the earliest metasomatism which was of silicate to silicate-carbonatite type and could be could be a precursor of the eruption. Clinopyroxenes with the higher temperatures show evidence for carbonatite metasomatism, which could be a potential source of the CO_2 released along the CVL.

P 2.9
A re-assessment of the equilibrium constant and aqueous activity ratios for the Albite – K-Feldspar – $NaCl_{(aq)}$ – $KCl_{(aq)}$

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Thermodynamic properties of solutes in water at temperatures higher than the critical point and at low to moderate densities are crucial to understand chemical fluid-rock interaction in important environments such as mid-ocean ridge, hydrothermal systems, superhot geothermal systems, magmatic-hydrothermal ore-deposits and others. However, at present, we are still lacking sufficient experimental data and a comprehensive thermodynamic formalism to be able to perform accurate geochemical modeling under these conditions.

Among the most important reactions are those between feldspars and aqueous chloride solutions. Accordingly, the reaction

Albite + KCl_{aq} = Kfeldspar + $NaCl_{aq}$

has repeatedly been studied (e.g., Lagache & Weisbrod 1977; Hemley 1967; Orville 1963).

In preparation for a new experimental campaign, we re-assessed those existing data and found that in the derivation of equilibrium constants from the raw experimental data some important effects were not properly taken into account. Namely, the re-assessment shows a significant density-/pressure-dependence of the equilibrium constant and highlights that the activity coefficient ratio of the aqueous species varies strongly with concentration from dilute conditions through the liquid+vapor (L+V) coexistence field into highly saline brine.

The re-assessment is primarily based on the data of Lagache & Weisbrod (1977) and we found that most of their experimental data points were obtained in the L+V region with >90% of the aqueous chloride residing in the liquid phase (Fig.1). This means that the post-quench measured fluid KCl/NaCl ratios were entirely dominated by the high-salinity liquid phase. The nearly constant KCl/NaCl ratio at a given temperature and pressure is, therefore, an artifact of repeatedly measuring the liquid phase composition at L+V conditions although the bulk chloride concentration in the experiments varied of wide ranges.

We re-derived KCl/NaCl ratios for the liquid and vapor phases and found that the vapor phase KCl/NaCl ratio is always significantly lower than that in the liquid phase. The difference may reach a factor of 4 to 5 (albeit with significant uncertainty) at the lowest experimental pressure and diminishes at higher pressures. Taking the vapor KCl/NaCl ratio as the closest proxy to the true equilibrium constant, we could derive the activity coefficient ratio for the two aqueous chlorides as a function of concentration (Fig.2).

We conclude (1) that the currently accepted, pressure-independent equilibrium constant is only valid for highly saline solutions and when ignoring activity coefficients, (2) that the currently accepted equilibrium constants may be in significant error when more dilute solutions are encountered, such as in porphyry-copper style magmatic-hydrothermal systems, and (3) that the assumption of similar or even equal activity coefficients for different electrolytes under the conditions of interest is not valid.

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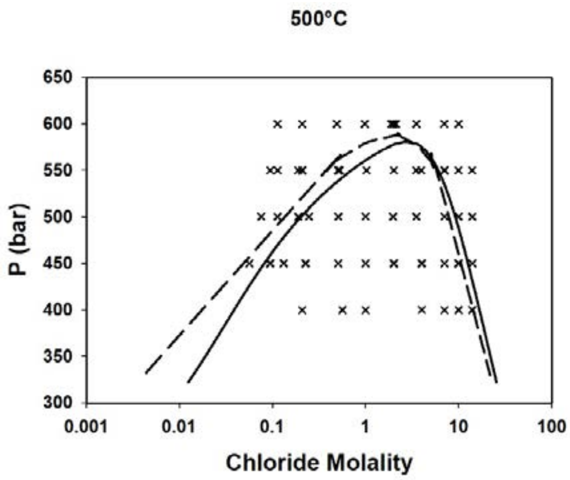

Figure 1. The most comprehensive experimental dataset is available from the study of Lagache & Weisbrod (1977). The plot illustrates that the data are mostly in the two-phase liquid+vapor region and there is a lack of data in very dilute solutions (=vapor); the dashed and solid curves are representing the L+V coexistance curve, according to Sourirajan & Kennedy (1962) and Driesner & Heinrich (2007), respectively.

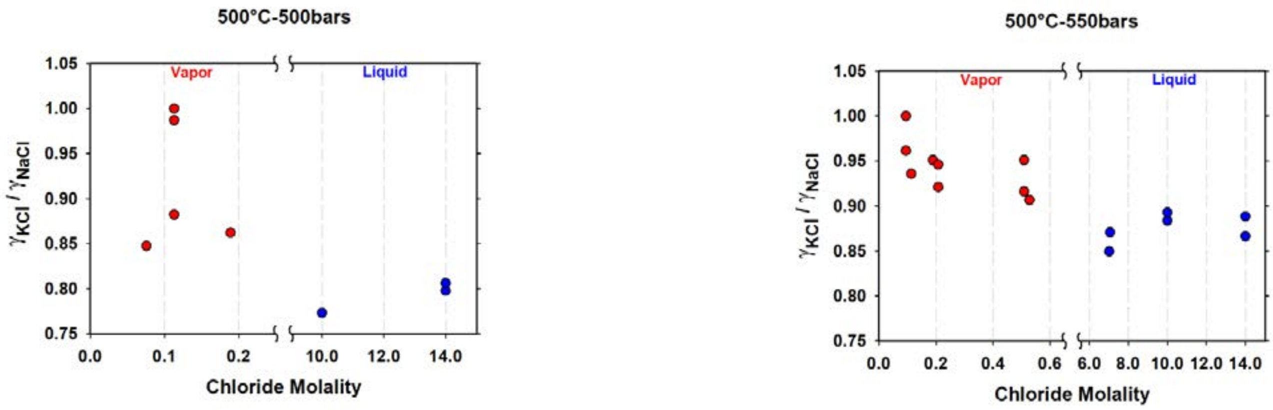

Figure 2. The activity coefficient ratios of alkali chlorides, calculated from Lagache & Weisbrod (1977) experimental data, plotted versus the corresponding total chloride molality to show the deviation from unity.

P 2.10
A global comparison of quartz-in-garnet barometery and conventional thermobarometry

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In recent years, elastic thermobarometry has gained wider acceptance and utility within the petrologic community and beyond. In particular, quartz-in-garnet (qtz-in-grt) elastic barometry is widely used because of the ubiquity of garnet in metamorphic rocks. The technique is based on measuring strain recorded by inclusions, and modeling the elastic evolution of the inclusion-host pair to constrain the initial conditions of inclusion entrapment. Recent studies have experimentally validated the technique by comparing pressures from the qtz-in-grt barometer with experimental conditions of garnet growth and entrapment of quartz, and have shown that the barometer can provide reliable pressure conditions of garnet growth. However, current experimental studies fail to capture the reliability of the technique under disparate pressure (P), temperature (T) and deformation conditions, and studies that systematically compare qtz-in-grt barometry and conventional thermobarometry are sorely lacking.

In this work, we compare P conditions from qtz-in-grt barometry and conventional thermobarometry from the following locations: spatially and temporally variant high P/T subduction zone eclogite blocks from the Franciscan Complex in California, high P/T subduction zone rocks of varying compositions from Syros, Greece, high P/T and low P/T rocks of varying compositions from the Betics system in Spain, and low P/T schists from the Jajarkot and Karnali klippen in the Himalaya. Qtz-in-grt barometry constraints from the Franciscan and Syros show good agreement with some reference P-T conditions, but often disagree with thermodynamic equilibria constraints and subsets of multi-mineral thermobarometry calibrations. Measurements of samples from other localities are currently in progress. This set of quartz inclusion analyses further allows us to evaluate the effects of inclusion geometry, anisotropy, P and T conditions of garnet growth, and P and T paths on the ultimate P conditions recorded by the qtz-in-grt barometer. The data-set also provides insights into the possible limitations of other techniques (e.g., conventional thermobarometry).

P 2.11
Origin and chemical evolution of eclogites and metagabbros in the Münchberg Massif, Germany

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The Münchberg Massif (German Bohemian Massif) is an allochthonous nappe pile within the Saxothuringian zone of the Variscan orogen. Its uppermost nappe (Hangendserie) contains eclogites and paragneisses which were both affected by early Variscan high-pressure metamorphism. A dark, kyanite-free eclogite (Mg# ~45–70, Al_2O_3 ~13–16 wt.%) can be distinguished from a light, Ky-bearing eclogite (Mg# ~70–85, Al_2O_3 ~18–21 wt.%, usually higher Cr and lower HFSE contents, positive Eu/Eu*). Amphibolite facies metagabbros in the underlying nappe (Liegendserie) were commonly considered as potential lower-pressure equivalent of the light eclogites due to chemical similarities and similar late Cambrian/early Ordovician protolith ages. However, the interrelation and geodynamic interpretation of dark eclogites, light eclogites and metagabbros remained uncertain.

For many major and immobile trace elements (e.g., HFSE, REE), most of the dark and light eclogites form a continuous, linear array when plotted against Zr contents. Immobile-element discrimination diagrams classify them between E-MORB and N-MORB. Due to their high Th contents, the light eclogites are in an array with values of the dark eclogites and arc basalts. The metagabbros also show a moderate arc basalt component, but have more within-plate character than the eclogites due to high Nb/Yb, Nb/Zr and Ta/Hf ratios. Most eclogites have elevated $\delta^{18}O$ values (+5 to +11‰) that correlate with Li, B, Bi and Sb contents. The metagabbros ($\delta^{18}O$ ~+10‰) are similarly enriched in these elements.

Based on major and trace elements, the light eclogites are identified as plagioclase-rich cumulates, similar to the metagabbros. The dark eclogites behave as a chemical counterpart of the light eclogites and are thus likely derived from the same parental magma. A few samples have a more depleted signature, indicating either a different magmatic origin or a strong fluid-induced metasomatic overprint. Thorium enrichment in the light eclogites can be explained by crustal contamination, which also affected the metagabbros (see Stosch & Lugmair, 1990; Bosbach et al., 1991). But crustal contamination cannot explain the high Nb/Yb, Nb/Zr and Ta/Hf ratios of the metagabbros, the protoliths of which appear to be derived from a more enriched mantle source than those of the light eclogites. Nevertheless, for both units, crustal contamination indicates a continental rather than oceanic origin, and seafloor alteration is evident from $\delta^{18}O$ correlation with Li, B and Sb. The Hangendserie and the Liegendserie therefore appear to be parauthochthonous to each other, suggesting that the protoliths of the eclogites and metagabbros have formed within the same large-scale extensional tectonic setting in the peri-Gondwanan realm that accompanied the opening of the Rheic Ocean.

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P 2.12
Unravelling the tectono-metamorphic history of the Monte Rosa nappe: cirque du Véraz, upper Ayas valley, Italy

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The Monte Rosa tectonic unit is a prominent nappe in the Western Alps, it consists of pre-Variscan paragneisses, intruded by Permian-age granitic bodies, later incorporated into the Alpine orogeny. The current position of the basement complex resides within the collisional Austroalpine-Penninic wedge, between the ophiolite units of the overriding Zermatt-Saas and the underlying Antrona. The basement complex derives originally from the upper crust of the pre-Alpine distal European passive margin, prior to Alpine continental collision. A spectacular area to observe the exposed Monte Rosa nappe complex as well as the overriding ophiolite units of the Zermatt-Saas is at the head of the Ayas valley branching from Aosta valley (northern Italy), in an area named “cirque du Véraz”. Recent glacial retreat has enabled detailed mapping, structural analysis and the collection of a wide range of lithologies in order to piece together the (poly-)tectono-metamorphic history of the Monte Rosa nappe. We will present the key findings of our investigations as well as newly documented outcrops.

As well as the lithological variability of the Monte Rosa basement exposed at the cirque du Véraz, continued attention has been focused here regarding its metamorphic variability, specifically during peak Alpine metamorphism, namely in pressure. The ongoing discussion concerning metamorphically-recorded pressure variations in the Monte Rosa nappe has been prompted by a wide range of peak metamorphic conditions calculated; with pressure estimates ranging between 1.2 and 2.7 GPa and temperature estimates between 490 and 640 ºC. The highest pressure eclogite conditions recorded for the Monte Rosa nappe primarily involve minor volumes of unique assemblages termed ‘whiteschists’ at 2.2 GPa (chloritoid, talc, phengite, quartz ± kyanite/garnet). The cirque du Véraz field area, contains the largest concentrations of these unique high pressure mineral assemblages compared to anywhere else in the Monte Rosa nappe. Recent work, has highlighted large disparities in peak Alpine pressure between whiteschist (2.2 GPa) and metagranite (1.4 GPa) assemblages, as well as between whiteschist (2.2 GPa) and metapelitic (1.6 ± 0.2 GPa) assemblages, resulting in a P difference of 0.6 ± 0.2 GPa for the same metamorphic event (peak Alpine orogenesis). We present detailed petrological investigations and pseudo-section modelling of a newly exposed whiteschist body at the cirque du Véraz area.

Two whiteschist samples have been investigated with variable grainsize. A fine grained sample consist of perfectly preserved assemblage of <1mm sized chloritoid, as well as phengite + talc + quartz. These assemblages reveal peak metamorphic conditions (with a Mg-talc activity correction) at 2.1 GPa and 560 ± 10 ºC, for Alpine orogenesis. This sample also displays a schistosity that coincides with a ductile deformation event that closely post-dates peak Alpine metamorphic conditions associated with a top-N shear sense related to nappe emplacement. A second whiteschist sample contains a similar peak paragenesis but with coarse grained >1cm sized chloritoid, as well as phengite + talc + quartz. Chlorite is also observed in this sample reflecting minor retrogression, with metamorphic conditions (with a Mg-talc activity correction) at 1.95 GPa and 560 ± 20 ºC. Coarse grained chloritoids show significant zoning in Mg and Fe, with low XMg (~0.32) in the cores, increasing to high XMg values at the rims (~0.57). We interpret these zoning patterns to represent chloritoid growth during prograde Alpine metamorphism to eclogite conditions. We compare thermodynamically predicted Mg content of chloritoid for a range of prograde pathways, with measured Mg zoning from natural samples.

P 2.13
Triple oxygen isotope trend recorded by Precambrian cherts: A perspective from combined bulk and in situ secondary ion probe measurements

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There are large uncertainties associated with the current estimates of temperature and oxygen isotope composition of Precambrian oceans, largely due to preservation issues inherited by the sedimentary record. The advancing ability to measure triple oxygen isotope ratios at the precision of 0.01 ‰ or better provides an opportunity to distinguish between signals captured during deposition, early diagenesis and late alteration of marine sediments. Here we undertake a triple oxygen isotope study of marine cherts that formed at 3.5 and 1.9 Ga using a suite of samples from the Dresser (Australia), Kromberg, Mendon (S. Africa) and Gunflint (Canada) Formations. To disentangle the effects of recrystallization on a case-by-case basis, we combined: i) triple oxygen isotope measurements by bulk laser fluorination; ii) in situ secondary ion probe (SIMS) measurements; iii) Raman spectroscopy of organic matter. Within the studied here samples the $\delta^{30}Si$ and $\delta^{18}O$ values measured by SIMS span over several ‰ at the scale of 10-100 µm, informing us of mixing arrays that are expected in the triple oxygen isotope space. To draw parallels with the envisioned environments for Archean silica deposition, we use geothermal amorphous silica scale that precipitated at ~188 °C as a result of high temperature seawater-basalt reaction at Reykjanes system in Iceland. The triple oxygen isotope signature of our Archean samples with negative $\delta^{30}Si$ values is consistent with precipitation of microquartz at 150-170 °C. We suggest that at least some Archean cherts formed in equilibrium with fluids that are 1-2 ‰ higher in $\delta'^{18}O$ and ~20-30 per meg lower in $\Delta'^{17}O_{0.528}$ than the contemporaneous seawater due to the influence of submarine vent fluids. The 1.9 Ga Gunflint chert contains high-$\delta'^{18}O$ generation of microquartz (+24-26 ‰) that likely reflects early crystallization from marine siliceous sediment, which we assess using trace element concentrations and silicon isotope measurements. The $\delta'^{18}O$ – $\Delta'^{17}O$ of such quartz are consistent with the temperature of 60-80 °C, given that the pore water fluids had $\delta'^{18}O$ of around -2 ‰. The extrapolation of vent fluids and marine pore water fluids towards pristine seawater does not require a hydrosphere with $\delta'^{18}O$ outside of ± 2 ‰ of modern value. Instead, we propose that Archean cherts, at least partially, reflect mixing between marine and hydrothermal sources of silica, while the Paleoproterozoic Gunflint formation reflects maturation of siliceous sediment in presence of marine pore fluids.

03. Stable and radiogenic isotope geochemistry: development and applications

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Swiss Society of Mineralogy and Petrology (SSMP)

TALKS:

3.1 *Ahmad Q., Hensel A., Wille M., Rosca C., König S., Hermann J., Pettke T.*: Molybdenum isotope evidence for recycling of metasomatized forearc mantle at the Tonga subduction zone

3.2 *Anguelova M., Fehr M.A., Takazawa E., Schönbächler M.*: Titanium isotope heterogeneity in the Earth's mantle: a case study of the Horoman peridotite massif

3.3 *Decraene M.-N., Marin-Carbonne J., Bouvier A.-S., Bouden N., Villeneuve J., Deloule E.*: A new procedure to investigate in situ Fe isotope compositions in micro-pyrites using Hyperion Radio Frequency source on IMS 1280 HR2.

3.4 *Maltese A., Caro G., Pandey O.P., Upadhyay D., Mezger K.*: First constraints on the role of Hadean components during the formation of Paleoarchean TTGs from India

3.5 *Peverelli V., Wille M., Pettke T., Berger A., Herwegh M.*: Trace elements and Sr isotopes in hydrothermal vein epidote from the Albula area

3.6 *Shalev N., Tomaso R.R., Bontognali C., Wheat G., Vance D.*: New isotope constraints on the Mg oceanic budget point to cryptic modern dolomite formation

3.7 *Storck J.-C., Greber N.D., Pettke T.*: Mo isotope fractionation induced by magma differentiation along the Kos Plateau Tuff (Aegean arc)

3.8 *Wertnik M., Welte C., Wacker L., Koch J., Christl M., Fohlmeister J., Synal H.-A., Eglinton T.*: Rapid, continuous scans of radiocarbon archives by laser ablation

POSTERS:

P 3.1 *El Korh A., Pohlner J., Chiaradia M.*: Variations of Fe isotope compositions of ophiolite-derived rocks within the Variscan allochthonous domain

P 3.2 *Spikings R., Paul A., Popov D., Gaynor S.*: Mid-temperature (350 – 550°C) thermochronology using the apatite U-Pb method

P 3.3 *Vilela N., Greber N., Storck J.*: Constraints on the Double Spike method: Comparison of different calibration methods based on theoretical calculations and experimental Ti-Isotope analysis.

3.1
Molybdenum isotope evidence for recycling of metasomatized forearc mantle at the Tonga subduction zone

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Molybdenum isotopes have emerged as novel tracers of metal recycling in subduction zones. Open questions remain as to whether or to what extent different subducted lithologies, such as oceanic crust vs. marine sediments, contribute to the Mo isotope signature and hence exert different controls on the terrestrial Mo cycle. To address this, we investigate the Mo isotope signature of the input and output parameters at the Tonga subduction zone factory: basalts and basaltic andesites from the Tonga islands Late, Tofua, Kao and Ata together with pelagic sediments and altered oceanic crust (AOC) samples at DSDP site 595/596 from the subducting Pacific plate. These are accompanied by Mo isotope analyses of exhumed subducted sediments and mafic oceanic crust from the Western Alps and Alpine Corsica, which allow to study the fate of subduction input during prograde metamorphism.

Tonga arc lavas have higher Mo/Ce and extend to higher $\delta^{98/95}Mo_{SRM3134}$ compared to the mantle, which covariate with fluid indices, such as Ba/Th and Ce/Pb. This suggests the addition of an isotopically heavy, slab-derived fluid to the Tonga subarc mantle. DSDP site 595/596 samples show that manganese oxide control Mo concentrations (up to 100 ppm) and Mo isotope signature (lower and higher compared to mantle) of pelagic sediments. Pelagic Mn-rich metasediments, covering a wide range of peak metamorphic conditions, display extremely low Mo content and low $\delta^{98/95}Mo_{SRM3134}$ (down to -1.5 ‰) indicating a loss of isotopically heavy Mo already in the forearc. Also, Mo signatures in mafic eclogites are within the range of AOC, yet extending towards lower $\delta^{98/95}Mo_{SRM3134}$, likely due to isotope fractionation during fluid related Mo mobilization and incorporation of light Mo into residual rutile. Our data thus documents prominent loss of isotopically heavy Mo upon early subduction metamorphism. Moreover, when prograde rutile crystallizes, it fixes the largest fraction of Mo in subducting rocks. Consequently, it is very unlikely that slab Mo represents the fluid-mobile Mo source responsible for observed higher Mo/Ce and $\delta^{98/95}Mo_{SRM3134}$ in Tonga arc lavas compared to the mantle. We suggest that increasing Mo/Ce along with higher $\delta^{98/95}Mo_{SRM3134}$ in Tonga arc lavas is a result of fluid-induced Mo mobilization during the early stages of subduction into the forearc mantle. Subsequent erosion and subduction of this metasomatized forearc mantle into the subarc regions is a plausible alternative recycling process. This is supported by positive covariations of Mo/Ce and $\delta^{98/95}Mo_{SRM3134}$ with other fluid mobile elements that are commonly enriched in metasomatized forearc mantle, such as As, Sb and Cs. We propose that this kind of multi-stage recycling of metasomatized forearc mantle is an important process in Mo recycling.

3.2
Titanium isotope heterogeneity in the Earth's mantle: a case study of the Horoman peridotite massif

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Titanium isotopes provide a novel tool to trace igneous processes such as magmatic differentiation. The Ti isotope composition of terrestrial rocks varies by up to ~2.1 ‰ in δ^{49}Ti (the per mil deviation of ^{49}Ti/^{47}Ti from the OL-Ti standard) (Deng et al., 2019; Mandl, 2018). Primitive basalts and komatiites define a narrow δ^{49}Ti range (e.g. Greber et al., 2017; Millet et al., 2016), suggesting a homogeneous mantle source. While magmatic differentiation significantly fractionates Ti isotopes towards heavy compositions (e.g. Millet et al., 2016), so far, Ti isotope fractionation during partial melting of the mantle is considered to be negligible. In contrast to mantle-derived magmas, peridotites display more variable Ti isotope compositions (Mandl, 2018). To constrain the origin of the observed small-scale mantle heterogeneity, we measured the Ti isotope composition of orogenic peridotites from the Horoman massif (Japan) comprising i) fertile lherzolites, ii) depleted harzburgites and iii) metasomatically overprinted peridotites. In addition, we present Ti isotope data of magmatic derivatives of a metasomatised mantle, i.e. ultrapotassic rocks.

The Ti isotope compositions of the Horoman peridotites range from -1.523 ± 0.029 to 0.547 ± 0.015 ‰ (2SD), with a total variation of 2.07 ‰, and include values that are both lighter and heavier than basalts. Heavy Ti isotope compositions are akin to continental crust and likely result from metasomatism of the mantle wedge above the Hidaka subduction zone. In such a scenario, isotopically heavy Ti was inherited from the recycled sediments. In addition, Ti isotope fractionation during mobilisation from the slab may have further contributed to the heavy signature. High δ^{49}Ti values (0.114 ± 0.040 to 0.290 ± 0.030 ‰, 2SD) are also found in ultrapotassic rocks, which originate from a mantle source modified by recycled crustal material. Conversely, highly depleted peridotites have extremely light Ti isotope compositions, potentially due to fractionation during high-degree melting of the mantle

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3.3
A new procedure to investigate in situ Fe isotope compositions in micro-pyrites using Hyperion Radio Frequency source on IMS 1280 HR2.

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Iron isotope compositions of pyrites are considered as a good proxy for past global/local redox conditions and to track microbial activity (Johnson et al., 2020). In situ studies (laser ablation, LA-ICP-MS or secondary ion mass spectrometer, SIMS) of sedimentary pyrites have evidenced inter- and intra-grain Fe isotopic variabilities (e.g. Marin-Carbonne et al., 2014; Whitehouse et al., 2007; Yoshiya et al., 2015). However, the investigation of these micrometer scale variabilities in <20µm pyrites was restricted to the primary beam size. Since 2015, the emergence of a new plasma ion source (Hyperion Radio-Frequency source) enables high spatial resolution measurements by increasing 10 times the beam density compared to the previous $^{16}O^{-}$ Duoplasmotron source (Liu et al., 2018). We developed a new analytical protocol to measure high spatial resolution and high precision Fe isotope compositions applied on micro-pyrites in Archean and Permian-Triassic sediments. This method was calibrated on two SIMS-Cameca 1280HR2 instruments at CRPG-CNRS (France) and at SwissSIMS (Switzerland). A gaussian 3nA primary beam was focused in 3µm, which allows the analysis of micrometric minerals with an analytical precision between 0.25‰ and 0.30‰ (±2σ), similar to the one obtained with the Duoplasmatron for a beam size of 10 to 15 µm. We assessed possible analytical effects induced by either topography or crystal orientation and none of them were identified. This new method opens a robust analytical way for searching micrometer scale Fe isotopic variations in natural samples and for better understanding the oceanic cryptic Fe cycle.

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3.4 First constraints on the role of Hadean components during the formation of Paleoarchean TTGs from India

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Constraints on the chemical evolution of the early Earth are conventionally obtained using geochemical and isotopic compositions of Archean rocks. In the absence of a known rock record beyond ca. 4 Ga, insights into earlier differentiation processes can be obtained either from remnants of Hadean rocks (i.e., detrital zircons and their inclusions) or extinct radionuclides. Using the short-lived ^{146}Sm-^{142}Nd isotope system, signatures for the existence of both chemically enriched and depleted Hadean reservoirs have been identified from mantle-derived rocks in some of the oldest Archean cratons (e.g., Caro et al., 2003; O'Neil et al., 2008). Model ages based on these findings indicate that crust-mantle differentiation started as early as 4.4 Ga (Morino et al., 2017) and proceeded within a tectonic regime that allowed preservation of primordial heterogeneities until at least 2.7 Ga (Debaille et al., 2013). Apart from these insights, little is known about the exact role these primordial reservoirs played during the formation of the Archean continents, which are dominated by the tonalite-trondhjemite-granodiorite (TTG) suite.

In order to better constrain the proportion of reworked Hadean material in the Archean record, rocks from the well-characterized Paleoarchean Bastar and Singhbhum cratons in central and eastern India were investigated using coupled ^{146,147}Sm-^{142,143}Nd isotope systematics. A comparison of first results for TTGs from the two terranes reveals no ^{142}Nd anomalies in Bastar, while the TTGs from Singhbhum define a trend in μ^{142}Nd vs ε^{143}Nd (long-lived) isotope space that extends from the primitive mantle composition up to μ^{142}Nd ≈ +6 ppm and ε^{143}Nd = +5.

Despite the near-synchronous formation of the Paleoarchean TTG crust in the two cratons, between ca. 3.5 to 3.3 Ga, these results demonstrate that their protoliths sampled distinct reservoirs, which may be indicative of Archean mantle heterogeneity. The observed μ^{142}Nd vs ε^{143}Nd correlation among Singhbhum TTGs can be explained by a two-stage model in which a reservoir first differentiated from a primitive mantle at 4.2 ±0.1 Ga and evolved until differentiation of the granitoids. Alternatively, the Nd isotopic signatures may have been inherited from a pre-existing mafic/ultramafic crust extracted from a Hadean depleted reservoir. Consistent with this observation, Eo- to Paleoarchean enclaves of mafic and ultramafic composition from the Singhbhum craton yield clearly resolved positive anomalies (μ^{142}Nd up to ca. +6 ±3 ppm). Both scenarios thus require an additional crust-mantle differentiation event, postdating the one that produced the ^{142}Nd anomalies identified so far in studies of Eoarchean terranes by 200-300 Myr (Morino et al., 2017).

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3.5
Trace elements and Sr isotopes in hydrothermal vein epidote from the Albula area

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Hydrothermal veins can be used to investigate the hydration of the granitic continental crust. A common vein-filling mineral is epidote [$Ca_2Al_3Si_3O_{12}(OH)$ – $Ca_2Al_2Fe^{3+}Si_3O_{12}(OH)$], whose complex crystalline structure incorporates large amounts of a wide range of trace elements from the mineralizing fluid. While Rb concentrations are negligible in epidote, contents of the highly fluid-mobile Sr can reach a few wt%, allowing for the measurement of $^{87}Sr/^{86}Sr$ ratios. In combination with trace elements and U-Pb data, Sr isotopes can be used to determine the origin and pathways of the vein-forming fluid.

Epidote-bearing hydrothermal veins are widespread in the Albula area (eastern Swiss Alps). We distinguish epidote-bearing veins based on their host rock: 1) V1: veins related to the greenschist-facies Eo-alpine metamorphism hosted by gneissic meta-granodiorite and 2) V2: veins hosted by cataclastic meta-granodiorite. In both cases, the host rock – deformed to different extents – is the Albula Granite, a Variscan to post-Variscan granodiorite that intruded the basement of the Err nappe of the Lower Austroalpine domain at the present-day Albula Pass. A third type of epidote-bearing veins (V3) crosscuts the Triassic meta-sediments in the area.

We report LA-ICP-MS data of trace elements measured in epidote of all vein types recognized at Albula Pass. TIMS data of $^{87}Sr/^{86}Sr$ ratios are presented for epidote of V1 veins. All vein types consist of epidote ± quartz. Epidote in V1 veins is also locally associated with minor (< 1 %) chlorite and albite. Trace element data confirm the petrographic distinction into V1, V2 and V3 epidote-bearing veins, as highlighted by the respective data clusters in diagrams comparing light elements (B and Li), fluid-mobile (Sr and Pb) and immobile ones (Y and REE), and transition metals (Cr and V). This might be related to different sources of V1, V2 and V3 vein-forming fluids, and also reflect successive fluid pulses. REE patterns of all samples are clearly different than the LREE-enriched patterns typical of granitic rocks and of the REE-rich member of the epidote group (allanite). This suggests a source outside the Albula Granite for the epidote-forming fluids of all vein types.

The low $^{87}Sr/^{86}Sr$ ratios of 0.713086-0.713835 (± 0.003-0.005 ‰) suggest that the V1 fluid was not in equilibrium with the Rb-rich abundant feldspars and rare micas of the host granodiorite. The initial $^{207}Pb/^{206}Pb$ ratio of 0.8334 ± 0.0043 obtained from U-Pb dating indicates no enrichment of the V1 fluid in uranogenic Pb. Sr and Pb isotopic data from V1 epidote therefore support the hypothesis that the presented trace element and isotopic signatures were acquired by the V1 fluid outside the host Albula Granite from a Rb- and U-poor but Sr- and Pb-rich lithology, such as carbonatic or marly sediments.

3.6
New isotope constraints on the Mg oceanic budget point to cryptic modern dolomite formation

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The oceanic magnesium budget is important to our understanding of Earth's carbon cycle, because similar processes control both (e.g., weathering, volcanism, and carbonate precipitation). However, dolomite sedimentation and low-temperature hydrothermal circulation remain enigmatic oceanic Mg sinks. In recent years, magnesium isotopes (δ^{26}Mg) have provided new constraints on the Mg cycle, but the lack of data for the low-temperature hydrothermal isotope fractionation has hindered this approach. Here we present new δ^{26}Mg data for low-temperature hydrothermal fluids, demonstrating preferential ^{26}Mg incorporation into the oceanic crust, on average by $\varepsilon_{solid\text{-}fluid} \approx 1.6‰$. These new data, along with the constant seawater δ^{26}Mg over the past ~20 Myr, require a significant dolomitic sink (estimated to be 1.5–2.9 Tmol yr^{-1}; 40–60% of the oceanic Mg outputs). This estimate argues strongly against the conventional view that dolomite formation has been negligible in the Neogene and points to the existence of significant hidden dolomite formation.

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3.7
Mo isotope fractionation induced by magma differentiation along the Kos Plateau Tuff (Aegean arc)

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Differentiation of primitive basaltic magmas is a fundamental process contributing to the production of intermediate to silica-rich magmas. Changing pressure, temperature, and fO_2 conditions induce fractional crystallization of hydrous magmas on their pathway through the crust. As a consequence thereof magmatic cumulates derived from aggregation of exsolved mineral phases (e.g., amphiboles) segregate while the melt evolves along the liquid line of descent (LLD). Associated changes in bulk chemistry, bonding environments and shifts in coordination state cause mass-dependant isotope fractionation.

Modern arc crust formation records source contamination (e.g., slab derived fluids), as well as secondary mixing and assimilation processes that may blur geochemical fingerprints of the source magmas. Heavy stable isotopes are increasingly applied to investigate and distinguish between fluid dominated (source contamination) versus fractional crystallization dominated processes of the derivative magmas. Molybdenum isotopes have recently been explored to trace both, variable source components and magmatic isotope fractionation, in order to better constrain calc-alkaline magma genesis and element recycling in subduction zones.

We will present an extended Mo isotopic dataset on bulk rock samples and mineral separates of the magmatic differentiation suite of the Kos plateau Tuff along the Aegean volcanic arc. Our detailed dataset sheds light on key players that fractionate Mo isotopes as a consequence of magma differentiation prior to eruption and offers new insight into reported discrepancies between heavy and light $\delta^{98/95}Mo_{NIST}$ reservoir formation of emerging modern arc crust.

3.8
Rapid, continuous scans of radiocarbon archives by laser ablation

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While Accelerator Mass Spectrometry (AMS) enables rapid and high-precision measurements of radiocarbon (^{14}C) in carbonate archives (e.g. speleothems, corals), the conventional sampling techniques require labor-intensive and time-consuming sample preparation. Using laser ablation (LA) to liberate CO_2/CO directly from solid samples reduces not only the preparation time significantly, but allows data acquisition along a continuous path.

The LA-AMS setup installed in 2013 at ETH Zurich (Welte, et al. 2016) has recently been improved in order to achieve higher signal intensities and consequently higher measurement precision as well as simpler instrumental maintenance. By redesigning the sample cell and reducing the optical path length of the laser, the fluence on the sample could be increased from previously 1-2 J cm^{-2} to now 8-23 J cm^{-2}, leading to more efficient generation of gaseous carbon from $CaCO_3$. The laser spot size was reduced from 110 µm x 680 µm to 75 µm x 140 µm, improving the overall spatial resolution of the setup. The background level of the method has been determined to have a $F^{14}C$ of 0.009 ± 0.002 and reaches a precision of less than 1% for modern samples.

The capabilities of this world-wide unique system will be presented by means of several carbonate samples including stalagmites and corals. The suitability of the technique for other matrices, such as wood and oxalates will be discussed and first results of a novel data-evaluation scheme including the use of suitable smoothing filters will be presented.

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P 3.1
Variations of Fe isotope compositions of ophiolite-derived rocks within the Variscan allochthonous domain

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The Variscan belt results from the Devonian to Carboniferous collision of Laurussia (formed of Laurentia, Baltica and Avalonia) and Gondwana. The Variscan belt in Western and Central Europe is divided into different domains: (1) the Saxothuringian Zone (external domain; Gondwana zones with Cadomian imprint), (2) the Teplá-Barrandian Zone and Moldanubian Zone (internal domain; Allochthon), and (3) the Brunia-Moravo-Silesian Zone, localised at the margin of Baltica during the early Palaeozoic (e.g. Franke et al., 2017). The Allochthonous domain is mainly composed of superposed nappes derived from peri-Gondwanan regions.

Devonian ophiolite-derived rocks form a discontinuous structure within the Allochthonous domain and can be followed from the Sudetes to the Iberic Peninsula. The basic and ultrabasic magmatic precursors were emplaced along the northern Gondwana margin during the Cambro-Ordovician rifting associated with the opening of the Rheic Ocean (von Raumer et al., 2015). Different models explain the Cambro-ordovician ophiolite-derived rocks as the remnants of: 1) a narrow ocean between Gondwana and Armorica ("Galicia-South Brittany-Moldanubian" or "Medio-European" ocean; e.g. Matte, 2001); 2) an intra-continental back-arc basin related to a late-Cambrian active margin setting along the northern margin of Gondwana (von Raumer et al., 2015); or 3) the oriental branch of the Rheic ocean (Stephan et al., 2019).

This study compares the Fe isotope compositions of various Variscan localities, in order to investigate 1) if Fe isotopes can allow determining common magmatic signatures between the ultrabasic and basic rocks from various localities of the Allochthonous domain, and 2) if and how Fe isotopes have fractionated in basic rocks during the pre-Variscan Cambro-Ordovician magmatism, and during the Variscan subduction and collision.

Fe isotopes were analysed in a series of Alpine eclogites (Aiguilles Rouges Massif; Adula nappe: San Bernardino and Trescolmen) derived from a Variscan protolith. The first set of data shows MORB-like δ^{56}Fe values of +0.06 to +0.18‰ for most eclogites. Besides, two eclogite samples from the Adula nappe have δ^{56}Fe values of+0.20 and +0.32‰, that are heavier than MORB and typical for OIB (see El Korh et al., 2017 and references therein for a review).

These results are comparable to the data obtained for the high-pressure metabasites of the Ile de Groix (Armorican Massif; +0.16 to +0.33‰; El Korh et al., 2017) and for the low-pressure Limousin ophiolite-derived rocks (French Massif Central; +0.03 to +0.18‰; El Korh et al., submitted). By contrast, lighter δ^{56}Fe were measured in eclogites from the Münchberg Massif (Saxothuringian zone, Bohemian Massif Germany) (–0.068 to +0.014‰; Pohlner et al., 2019).

The heterogeneous iron isotope signatures within the Moldanubian zone and Bohemian Massif suggest: 1) different magmatic events along the northern margin of Gondwana during the Cambro-Ordovician rifting; 2) different tectonic settings and/or mantle sources for the magmatic emplacement of the basic and ultrabasic protoliths; and/or 3) different metamorphic overprints during the Varican and Alpine orogenies.

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P 3.2
Mid-temperature (350 – 550°C) thermochronology using the apatite U-Pb method

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Thermochronological measurements have been frequently used since the 1960's to provide a quantitative understanding of many geological processes, such as the exhumation of the crust, and the cooling histories and preservation potential of mineralised deposits. All thermochronological methods are foundered on the assumption that temperature is the dominant process that drives the open system behaviour of isotopes, which is exploited via the mathematics of diffusion to generate plausible time(t)-Temperature(T) solutions. The $^{40}Ar/^{39}Ar$ method was reported as a potential mid-temperature thermochronometer by Lovera et el. (1989), although numerous studies (e.g. Villa and Hanchar, 2013; Popov et al., 2020) have invalidated the initial assumptions, and have shown that Ar loss is dominantly a function of the fluid interaction history. Alternatively, analyses using the U-Pb system in accessory phases (apatite, titanite, rutile; e.g. Paul et al., 2018, 2019) suggest these have the potential to yield accurate and continuous t-T paths, and thus that the dominant process that drove Pb-loss was thermally driven diffusion, in some cases.

We present U-Pb bulk grain (ID-TIMS) and intra grain (LA-MC-ICP-MS) U-Pb data from apatites to evaluate the accuracy of thermal history solutions obtained from U and Pb isotopic data. Apatites have been extracted from Triassic, peraluminous leucosomes from the Andes of Ecuador and Colombia, where the geological history since 260 Ma has been tightly constrained (Spikings et al., 2015). Thermal history (t-T) solutions are obtained by inverting the U-Pb dates and grain sizes using the Pb-in-apatite diffusion parameters of Cherniak at al. (1991). The accuracy of the t-T solutions is assessed by comparison with the already well-established tectonic history of the Northern Andes. Inversion of bulk (ID-TIMS) U-Pb dates of single apatites with a range of grain sizes yields sensible t-T solutions in some cases, confirming the utility of U-Pb thermochronology (Cochrane et al., 2014; Paul et al., 2018). However, a majority of ID-TIMS dates yield scattered plots when compared to grain size, which is not predicted by volume diffusion with a constant set of diffusion parameters and a homogeneous parent isotope distribution (Paul et al., 2019). We investigate the cause of scatter by examining the effects of U zonation, compositional variation, metamictization and petrological boundary conditions. Element mapping using LA-ICPMS reveals a highly heterogeneous distribution of U, and the mode of zonation can be highly varied within a single leucosome (e.g. oscillatory, core enriched and rim enriched). Inversion of in-situ U-Pb dates acquired along core-rim transects yields accurate t-T solutions when U zonation is accounted for. We conclude that U zonation has a significant influence on bulk apatite U-Pb dates when the rocks reside for a significant amount of time in the Apatite Pb Partial Retention Zone (APbPRZ; Paul et al., 2019). Additional analyses of numerous igneous apatites suggest that U zonation is ubiquitous, and thus ID-TIMS dates are generally not amenable for accurate thermochronology, and an in-situ method is required. A majority of apatites also have zoned concentrations of Mn, Fe and REE, although their influence on the activation energy for Pb diffusion appears to be minor. Mn may be an exception, and preliminary data suggests that apatites with ~3000ppm Mn may have activation energies that are ~5% higher than Mn concentrations of ~500ppm. Metamictization appears to have no influence on Pb diffusion in apatite, presumably due to the high temperatures (550 – 350°C) of the Apatite Pb Partial Retention Zone. We created a MATLAB script to examine the influence of mineral boundary conditions by modelling the ingrowth and volume diffusion of Pb isotopes in apatite inclusions (nullifying the assumption of Dodson, 1973). Results show that Pb-in-apatite closure temperatures can be 100°C higher for partition coefficients of 1 between the apatite and host phase. These results indicate the importance of understanding the influence of the crystal petrological environment when constructing t-T solutions. Finally, we have applied computational inversion to synthetic apatite U-Pb dates obtained from common, natural thermal history paths, to assess the impact of accuracy of common Pb corrections on the accuracy of thermal history solutions.

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P 3.3
Constraints on the Double Spike method: Comparison of different calibration methods based on theoretical calculations and experimental Ti-Isotope analysis.

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For high-precision isotope analysis of elements with four or more stable isotopes, the double spike technique is the method of choice to accurately correct for mass fractionation induced by sample preparation and analyzes. It is therefore crucial to investigate the potential, accuracy and limitations of this powerful tool in Isotope Geochemistry. In order to produce accurate results this method strongly depends on the quallity of the Double spike callbration. In this study we compare different established calibration methods that use the direct measurements of the double spike composition (e.g. Millet & Dauphas, 2014; Nanne et al., 2017) or its substitution by a unit vector (Rudge et al., 2009) for the Ti isotope system. Furthermore, we investigate the potential use of several Ti standards with artificially fractionated isotope compositions via ion exchange chromatography as a calibration tool. With theoretical predictions based on a mathematica skript and complementary experimental data obtained by multicollector inductively coupled plasma mass spectrometery (MC-ICP-MS) analysis of Ti-Isotopes, we will examine which of the three methods yields the best results for the double spike calibration.

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04. Environmental Biogeochemistry of Trace Elements

Andreas Voegelin, Moritz Bigalke, Montserrat Filella, Adrien Mestrot, Lenny Winkel

TALKS:

4.1 *Barbosa N., Jaquet J.-M., Martignier A., Filella M.*: Barium biomineralization in freshwaters

4.2 *Biswakarma J., Borrelli P., Jiskra M.*: Land-use-change impacts on mercury cycling in the Amazon basin

4.3 *Breuninger E.S., Tolu J., Thurnherr I., Aemisegger F., Bouchet S., Sonke J.E., Wernli H., Winkel L.H.E.*: Ultratrace level speciation of Se, As and S in atmospheric deposition at a high altitude site

4.4 *Cossart T., Garcia-Calleja J., Worms I.A.M., Tessier E., Kavanagh K., Pedrero Z., Amouroux D., Slaveykova V.I.*: Implication of natural phytoplankton communities in biotic accumulation and transformations of mercury species by species-specific isotopes tracking

4.5 *Gfeller L., Weber A., Worms I., Slaveykova V., Mestrot A.*: Mercury (Hg) release and formation of colloidal Hg upon flooding-draining cycles of an agriculturally used fluvisol.

4.6 *Grigg A.R.C., Schulz K., Rothwell K.A., ThomasArrigo L.K., Kretzschmar R.*: Observing in-situ transformations of ferrihydrite in redox-active paddy soil microcosms

4.7 *Guan H., Caggìa V., Coll Crespi M., Liu X., Mestrot A., Schläppi K.B., Bigalke M.*: Soil microbiota-dependent effects on arsenic behaviour in the soil-plant system

4.8 *Hummel W.*: Solubility and speciation of mercury under anoxic conditions

4.9 *Le Bras Z., Christen E., Bouchet S., Winkel L.H.E*: Development of an analytical method for the determination of volatile organic selenium species in environmental systems

4.1› *Marques Fernandes M., Baeyens B., Daehn R., Scheinost A., Churakov S.V.*: Keynote: Fate of contaminants from repositories for radioactive waste based in clay-rock?

4.11 *Nenonen V., Mangold S., Göttlicher J., Winkel L.H.E., Voegelin A.*: Effects of aging on the transformation of fresh Fe(III)-precipitates and on the retention of co-precipitated P

4.12 *Notini L., ThomasArrigo L.K., Kretzschmar R.*: Transformation of Ferrihydrite and Goethite in Heterogeneous Systems

4.13 *Santos J.P., Cossarta T., Garcia-Galleja J., Tessier E., Amouroux D., Slaveykova V.I.*: Exploring the capacity of diatom *Cyclotella meneghiniana* in contributing to the aquatic Hg species transformations

4.14 *Tolu, J., Bouchet S., Rydberg J., Bindler R., Garcia-Bravo A., Winkel L.H.E.*: Keynote: The influence of organic matter composition on trace elements cycling: analytics and applications

4.15 *Weber A., Mestrot A., Jarosch K.A.*: Release of arsenic from soils upon organic and inorganic phosphorus addition

4.16 *Zelano I.O., Gonzalez Holguera J., Spangenberg J., Pena J.*: Oxidation of glucose by Mn oxide and change in carbon bioavailability for soil bacteria.

4.1
Barium biomineralization in freshwaters

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The behaviour of barium in both marine and freshwaters is still not fully understood. For decades, scientists have been questioning how barite can precipitate in widespread undersaturated conditions (Monnin et al., 1999) as in marine environments. No precise mechanism has been proposed. However, the low solubility of $BaSO_4$ and some biological processes might be linked as some algae and organisms biomineralize it (Chow and Goldberg, 1960).

In seawater, hypotheses on the formation of barite range from microbial activity in sediments and in mesopelagic and pelagic zones (Dehairs et al., 2008; Jacquet et al., 2011; Planchon et al., 2013) to sinking organic matter which creates supersaturated microenvironments when decomposing (Dehairs et al., 1980; Bishop, 1988). In freshwater, barite formation has not been much studied but the possible formation of microenvironments could also explain barium precipitation in even more undersaturated water as in Lake Superior (Horner et al. 2017).

In this study, we are interested in understanding the biomineralization of $BaSO_4$ in *Spirogyra*, its role in the barium cycle in freshwaters and the link between the presence of barium and *Spirogyra* proliferation. We have explored the presence of barite in *Spirogyra* collected in different surface waters and its response when exposed to increasing barium concentrations in cultures, mainly by SEM observations and EDX analysis. Recently mediatised for its invasion in Lake Baikal, this green filamentous alga is recognizable and known for its helical chloroplast's arrangement. Its ability of biomineralizing barite is rarely mentioned, despite microcrystals of barite having been identified in 1957 by Kreger. The biological purpose of these crystals is still unknown, but we suspect that they may play a role in graviperception, as in *Chara* statoliths, and not in detoxifying the cells as seen in *Closterium*.

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4.2
Land-use-change impacts on mercury cycling in the Amazon basin

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Mercury (Hg) is a ubiquitous global contaminant posing adverse effects to human and environmental health. Previous studies showed that land-use-change can have large impact on terrestrial-atmosphere exchange and transfer to aquatic ecosystems of Hg. However, in contrast to greenhouse gas inventories, the effect of land-use-change is not included in national Hg emission inventories. In this study, we assess the changes in Hg estimates induced by forest and agricultural soil losses in the Amazon basin. In forest ecosystems, Hg inputs are linked to dry and wet atmospheric depositions. Here we combine reported Hg deposition and (re)emission data with soil transfer rates derived from a soil erosion model in order to predict the net flux of Hg. We will present the Hg estimates under two different land use scenarios. The first scenario accounts for current land use management practices; the second scenario provides Hg estimates under best land-use management practices. By combining a soil erosion model with Hg deposition and re-emission data under these two scenarios, we aim to provide projections for Hg budget in the Amazon basin from 2020 to 2050, to estimate the risk of exposure, and to develop better understanding on terrestrial Hg cycling.

4.3
Ultratrace level speciation of Se, As and S in atmospheric deposition at a high altitude site

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The elements selenium (Se), sulfur (S) and arsenic (As) have global health impacts as they can be essential and/or toxic to humans. It has been hypothesized that atmospheric wet and dry deposition are important sources of these (trace) elements to agricultural soils and terrestrial food chains, as the atmosphere is an important reservoir for all three elements (emission fluxes: 29-36 $Gg \cdot Se \cdot year^{-1}$, 31 $Gg \cdot As \cdot year^{-1}$, 89 $Tg \cdot S \cdot year^{-1}$). Se, As and S are emitted by both natural and anthropogenic processes. However, the individual contributions of particular Se and As sources and how these change at different temporal and spatial-scales remain poorly understood. Specifically, natural sources such as biogenic and volcanic emissions have either not been considered or have been underestimated in previous global atmospheric models. Due to similarities in chemical properties, biogeochemical behaviour and atmospheric sources, the investigation of parallels and differences between processes offers unique insights into atmospheric cycling of the three elements. Previous studies have mostly quantified total elemental concentrations in atmospheric samples and did not analyse their chemical form (speciation). However, knowing the speciation is important to identify specific sources and/or atmospheric transport patterns as well as chemical transformation pathways. A major challenge for analysing trace elements in atmospheric samples are the generally low occurring concentrations, usually in the range of sub-$ng \cdot L^{-1}$ for precipitation and sub-$pg \cdot m^{-3}$ for cloud water and aerosols.

In this study, we developed a pre-concentration step and optimized various High-Pressure-Liquid-Chromatography hyphenated to Inductively-Coupled-Plasma-Tandem-Mass-Spectrometry (HPLC-ICP-MS/MS) methods to determine Se, As and S speciation in atmospheric samples. These methods were applied to precipitation, cloud water and aerosol samples that were collected at Pic du Midi Observatory (French Pyrenees; 2877 m a.s.l.) from Sept-Oct 2019. This site enables the investigation of long-range transport of both marine and continental sources. Sampling was carried out at high time resolution, i.e. precipitation and cloud water were collected on a sub-event basis and day- and night-time aerosol samples were collected over 2 days (9am/9pm, 24h in total). In addition, we analysed air parcel back trajectories and moisture sources to identify the dominant atmospheric transport patterns during the sampling period and the main contributing source areas to both trace elements and atmospheric water. Here, we report the precipitation chemistry of Se, As and S and other elements including speciation data, in combination with a detailed meteorological characterization. These results give new insights into sources and processes controlling Se, As and S cycling and deposition.

4.4
Implication of natural phytoplankton communities in biotic accumulation and transformations of mercury species by species-specific isotopes tracking

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Phytoplankton could influence the aquatic cycle of mercury directly through the uptake, accumulation and biotic transformation , and indirectly through the excretion of bioligands which impact biotic and abiotic transformations. Opposite to the focus on bacteria activity in mercury interactions, the role of phytoplankton remains poorly detailed.

The goal of this pilot study is to get insights on the role of natural phytoplankton community in biotic transformations in freshwater environment of an eutrophic lake, Soppensee (Switzerland). Since the biotic transformations are carried out at the intracellular level, the accumulation and the subcellular accumulation of inorganic (iHg) and monomethylmercury (MeHg) by the natural communities were also determined. Phytoplankton communities were sampled in-situ at 2 depths with biological and chemical contrasted environment with Niskin bottle and concentrated by centrifiguation. Concentrated communities were exposed to an isotopic mixture of 1nM of ^{199}iHg and 0.1nM of ^{201}MeHg during 24 hours. An experimental protocol has been developed to follow the uptake, the subcellular accumulation and biotic transformations in several fractions: whole-system, extracellular medium, whole-cell, cytosol and membranes. Mercury characterization and quantification were carried out by isotopic dilution analysis gas chromatography coupled to inductively mass spectrometry and the changes in the ratio between control isotopes and newly formed species were used to determined biotic Hg methylation and demethylation.

Results showed that phytoplankton community is heterogeneous at the first depth and dominated by diatom group at the second depth. Hg compounds were significatively accumulated by both communities especially in membrane fraction. The subcellular distribution seems to be species- and community-dependant. Under comparable conditions, results showed that community dominated by diatoms accumulated more Hg in the cytosol and less in membranes that the heterogeneous community. No significant differences have been found between uptake of both Hg species or both communities. All calculated ^{199}iHg methylation rates have been found below the detection limit (0.2%) excepted for whole-cell fraction at depth 2 (≈0.3%). The ^{201}MeHg demethylation have been found at both depths but higher for the community dominated by diatoms. The demethylation process has been found higher in membranes at depth 2. The statistical analysis revealed a positive correlation between demethylation and diatoms group showing a community dependency of this process.

4.5
Mercury (Hg) release and formation of colloidal Hg upon flooding-draining cycles of an agriculturally used fluvisol.

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Soil polluted with high levels of mercury (Hg) can be a point source to downstream eco-systems. Repeated flooding and agricultural activities may influence the fate of Hg by altering soil redox conditions, microbial activity, changes in soil organic matter (SOM) abundance.The complex interplay between these parameters on soil Hg release is still not well understood. The aim of this work was to better understand the effect of flooding and organic fertilizer addition on the release and/or sequestration of Hg in a Hg-polluted floodplain soil.

We conducted a flooding-draining incubation experiment on a highly Hg polluted fluvisol (44.8 ± 0.5 mg total Hg kg^{-1} soil). The soil originated from an agriculturally used floodplain situated in the Rhone Valley (Valais, Switzerland) and was exposed to Hg pollution by an acetaldehyde producing plant until the 1970's. It was either incubated as such (control) or after the addition of 0.6% (w/w) liquid manure (MNR) to study the effect of freshly added organic matter on soil Hg dynamics. Both treatments were incubated in triplicates in the dark at 22 °C. During 42 days the soils were alternately flooded and aerated in intervals of 14 days. For flooding, we used artificial rain water and a 1:1.5 soil:water ratio. During the flooded periods, we monitored the soil pore water for redox potential (Eh), pH, dissolved organic carbon, total Hg and relevant metals (Cu,Fe,Mn) on a daily basis. Further, the sampled soil solution was passed through filters with different mesh with (10µm / 5µm / 0.45µm / 0.02µm) at selected time points and analyzed for total Hg. Additionally, the 0.45µm fraction was used to study the evolution of colloidal Hg using AF4-ICP-MS.

Soil solution in microcosms (MCs) treated with MNR achieved the field of Mn reduction (Eh < 300mV) significantly faster (day 2) than control soils (day 6). As well, soil solution $Hg_{<0.02nm}$ peaked faster (day 5 at 8.78 µg Hg L^{-1}) compared to the control (day 9 at 17.1 µg Hg L^{-1}). Total Hg release went along with an increase in pore water Mn indicating reductive disolution of Mn-oxides. Further, MNR addition accelerated the subsequent decrease of Hg in soil solution that went along with the formation of black precipitates in the MCs. These are interpreted as sulfide minerals forming due to the onset of sulfate reduction during the course of the experiment. Simultanously, we observed the increase of inorganic colloidal Hg (in the range of 6-20 nm hydrodynamic diameter) in MCs treated with MNR during the first 2 to 10 days of incubation. As well, the control soils showed much higher proportions (up to 70%) of Hg passing a <1kDa membrane of the AF4-ICP-MS system compared to the MNR treated soils (up to 30%). These differences were likely caused by a higher microbial activity and higher concentrations of colloidal organic matter binding Hg in the MNR-treated soil, compared to the controls.
After the aerated phase, soil solution of controls showed an increase in redox potential and a re-release of Hg and Mn to the soil pore water. This contrasted with the MNR treatment which kept a low Eh and low Hg release.

Flooding of polluted fluvisols released Hg into the soil pore water only after few days upon continous soil flooding. Manure addition to soil significantly accelerated this process. However, addition of manure also seems to promote the subsequent decrease and sequestration of total Hg in the MCs and the sorption of Hg on colloids in the soil solution.

4.6
Observing in-situ transformations of ferrihydrite in redox-active paddy soil microcosms

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Iron minerals are abundant in soils, have a major influence on the cycling of trace elements and undergo transformations that have the potential to immobilise or remobilise trace elements in redox dynamic soils (Borch et al. 2010). Iron mineral transformations have been extensively studied in laboratory-based model studies. However, assessing the relevance of the observed pathways and transformation rates in soil environments can be experimentally challenging. Here, we studied ferrihydrite transformation in soil microcosms, and demonstrate that different soil environments influence the rate and nature of iron mineral transformations. Five rice paddy soils from south, east and south-east Asia were flooded in laboratory microcosms to simulate soil conditions at the start of a rice growing period. We introduced synthetic ferrihydrite samples to the soil in permeable polyethylene terephthalate fabric sachets (maximum interior dimensions approximately 30 mm × 12 mm × 3 mm, pore size 52 µm), and followed the changes in the mineral composition inside the mineral sachets over time using X-ray diffraction (bulk) and Raman spectroscopy (spatially resolved). Mineral transformations were then analysed in the context of the soil and pore water properties.

Within two weeks, lepidocrocite and goethite partially replaced ferrihydrite in all bulk samples, except ferrihydrite that was incubated an acid-sulfate sub-soil from Thailand. However, ferrihydrite transformation rates and product composition varied widely, reflecting variations in the concentrations of key parameters of the soil solution, including dissolved metal concentrations, oxyanion concentrations and pH. Despite very high concentrations of Fe(II) and sulfate in some soil pore water (>10 mM Fe(II) and >20 mM SO_4^{2-} after 2 weeks), and evidence of Fe and S reduction, neither magnetite nor sulphide minerals were observed, as might have been predicted from the results of laboratory-based ferrihydrite transformation experiments (e.g. Hansel et al. 2015; Troc et al. 1992). Still, higher iron and sulphate concentrations in solution were associated with faster transformation rates and higher ratios of lepidocrocite to goethite in the product, contradicting the findings of previous laboratory studies (Hansel et al. 2005). Local transformation is likely to have been much faster than bulk transformation rates, as observed in the colour distribution (Figure 1) and spatially resolved Raman spectroscopy of mineral identity across mineral sachet cross-sections. Mineral transformation kinetics and pathways are highly dependent on the location within the mesh bag with reference to the soil. The distribution of minerals in the mesh bags demonstrates the importance of the local environment to ferrihydrite transformation processes in soil, and contributes to understanding how to improve the in-situ investigation of soil mineral transformation processes.

Figure 1. Microscope image of a partial cross-section of transformed mineral once removed from the permeable sachet. Darker red patches (left of dotted line) correspond to regions with Raman spectra more consistent with ferrihydrite, while light orange regions (right of dotted line) correspond with Raman spectra more consistent with goethite.

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4.7
Soil microbiota-dependent effects on arsenic behaviour in the soil-plant system

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Arsenic (As) is a trace metalloid known as “the king of poisons”. As is also a class one carcinogen and its high toxicity correlates with a host of human diseases e.g. skin cancer. The speciation of As largely regulates its mobility, bioavailability and toxicity in the environment. As speciation is not only driven by abiotic parameters (pH, DOC), but also controlled by biotic interactions with plants and microbes. Soil microbiota can enzymatically transform As from inorganic to less-toxic organic forms. We performed an experiment to investigate the effects of plant and soil microbiota on As behavior in the soil-plant system as well as the physiological responses of maize plants to As exposure (Figure 1).

With this experiment we aim to address two main research questions: 1. How As concentrations and speciation change as a response to As treatment, soil microbiota effects and plant growth? 2. What are the interaction effects of As and soil and plant microbiota on plant health? In this experiment, we set nine experimental groups: three soil treatments (normal soil (NS), sterilized soil (SS) and first-sterilized soil reconditioned with microbes (RS)) intersecting with three As concentration groups (0, 100 and 200 ppm). In each treatment group, 10 pots with maize plants and three pots without maize were cultivated. For the As treatments we spiked soils with different levels of As. After soil incubation for two months allowing for the equilibration of As with soils, we grew 99 maize plants and regularly determined multi-element concentrations in soil water with ICPMS as well as As speciation by HPLC-ICPMS.

Primarily, soil microbiota effects showed not only on the abiotic parameters of soil water including DOC and pH values, but also on As concentrations and As speciation in soil water. For example, As 0 group exhibited a concentration trend of total As and organic As species in soil water: SS> RS> NS. And compared to other two soils, SS had the highest DOC content and the lowest pH values in soil water. Regarding plant health, the maize phenotyping data revealed the hazardous physiological effects of As, in line with the corresponding concentrations of total As and As species in maize tissues. With the increasing of As concentrations, plants experienced smaller plant height, lower chlorophyll content, greater scale of spot disease on leaves, and lower fresh and dry biomass. Moreover, soil microbiota do play a role in As effects on plant health. Plants from NS acquired the best health conditions even at high As levels due to the presence of native microbes; on the contrary, the health conditions of plants in SS were the worst. Thanks to recondition of the native microbes in RS, the health condition level of plants from RS was between NS and SS. Overall, this experiment gains us a better understanding of the interaction effects of As and microbiota in the soil-plant system as well as As bioavailability and toxicity along the food chain.

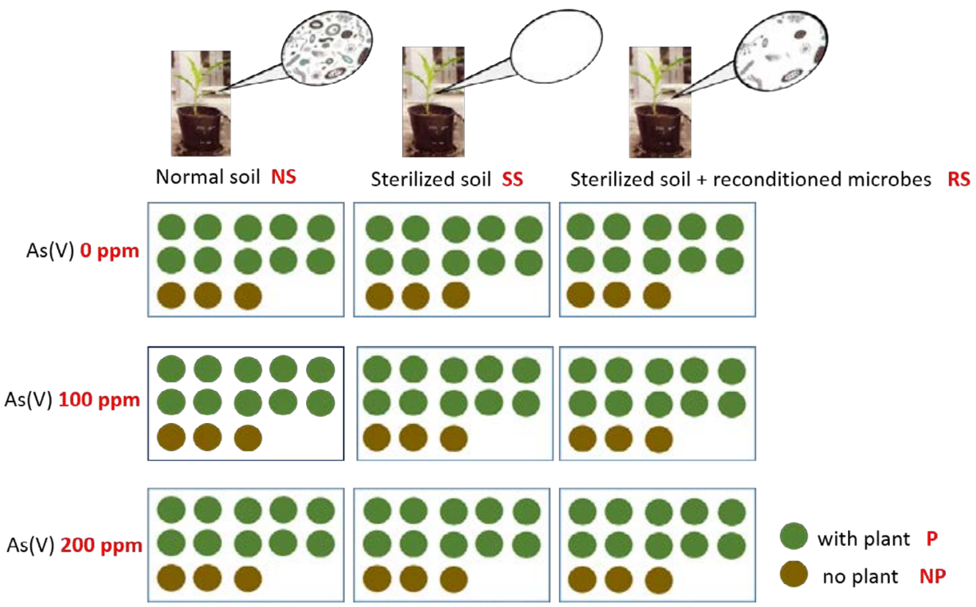

Figure 1. Experimental design overview.

4.8
Solubility and speciation of mercury under anoxic conditions

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Mercury is not only a chemotoxic element but also occurs as the isotope Hg-194 (with a half-life of 440 years) in radioactive waste originating from spallation facilities at PSI and CERN. Hence, a detailed review of published data for Hg has been carried out within the scope of the update of the PSI Chemical Thermodynamic Database, TDB 2020, which will be published in 2021.

A considerable number of experimental data has been published, and reviewed by Clever et al. (1985), concerning the solubility of metallic mercury, Hg(l), in the presence of dissolved mercury in redox state zero, Hg(aq). Under anoxic conditions, and in the absence of sulphide, the solubility of mercury is $3.0 \cdot 10^{-7}$ $mol \cdot kg^{-1}$ at 25°C but will increase significantly with increasing temperature (Fig. 1). As long as Hg(l) is the thermodynamically stable phase, the solubility of mercury will not change with varying pH or redox conditions, and Hg(aq) is the only aqueous species in solution.

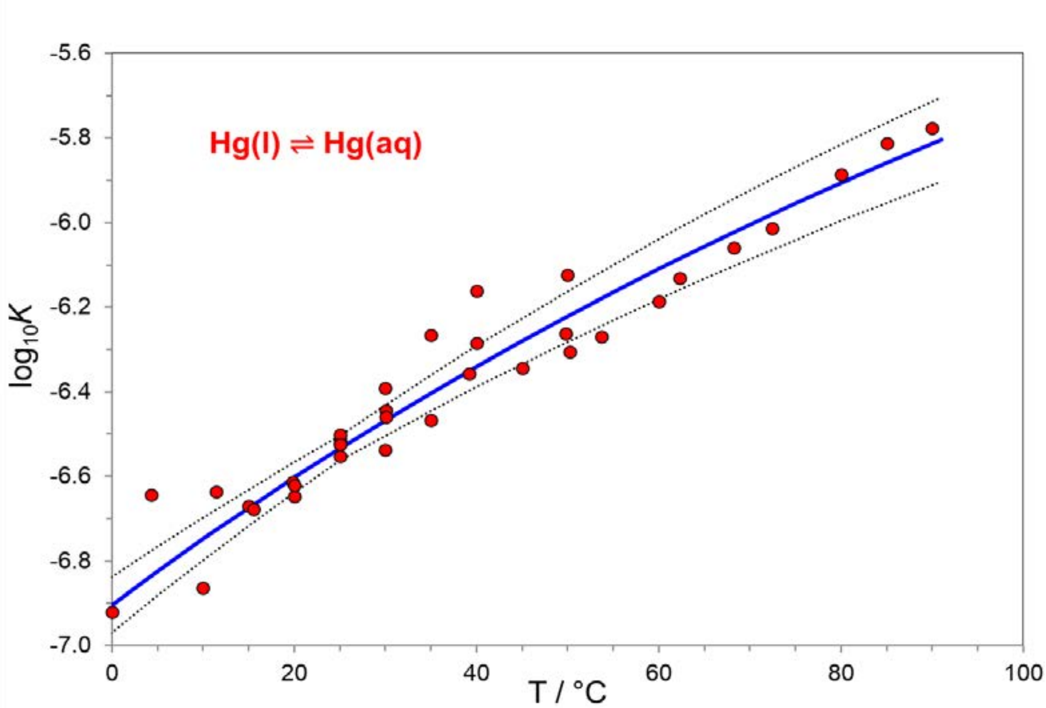

Figure 1. Temperature dependence of Hg(l) ⇌ Hg(aq). Data (circles) taken from Clever et al. (1985). Solid line: least squares regression with the integrated van't Hoff equation. Dotted lines: 95% uncertainty range extrapolated from 25°C to higher and lower temperatures.

In the presence of sulphide, red cinnabar or black metacinnabar, both HgS(s), may precipitate. Solubility product values for $HgS(s) + H^+ \rightleftharpoons Hg^{2+} + HS^-$ are reported in the old literature. Many times only this solubility product has been used to calculate absurdly low values for mercury solubility at neutral to alkaline conditions. This lead to the myth, perpetuated even in more recent textbooks, that HgS(s) is the most insoluble substance on earth. They all forgot to consider the formation of aqueous mercury-sulphide complexes.

In two PhD theses, published more than half a century ago, Widmer (1962) and Mehra (1968) measured the solubility of HgS(s) as a function of pH and total sulphide concentration using radiochemical methods. The results of both studies are consistent, revealing that the solubility of mercury increases in the neutral and alkaline region due to the formation of strong mercury – sulphide complexes (Fig. 2). However, at pH < 6 the experimental data seem to indicate that dissolved mercury is reduced to Hg(aq) in the presence of HgS(s). This new interpretation of HgS(s) solubility data needs experimental confirmation.

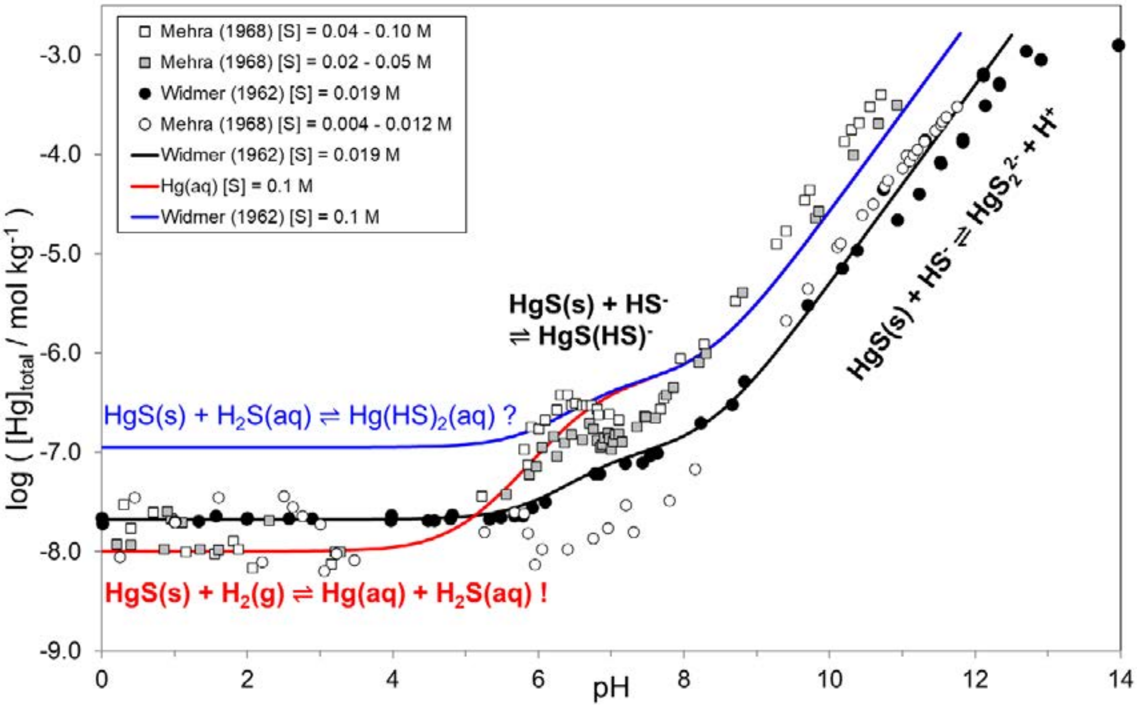

Figure 2. Solubility of HgS(s) in water as a function of pH at different total dissolved sulphide concentrations, [S]. Different symbols: experimental data of Widmer (1962) and Mehra (1968). Black line: solubility model according to Widmer (1962) comprising the species $Hg(HS)_2(aq)$, $HgS(HS)^-$ and HgS_2^{2-}, for [S] = 0.019 M. Blue line: the same solubility model for [S] = 0.1 M. Red line: the species Hg(aq) replaces the species $Hg(HS)_2(aq)$ in the solubility model; calculations done for 1 bar $H_2(g)$ pressure.

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4.9
Development of an analytical method for the determination of volatile organic selenium species in environmental systems.

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Selenium (Se) is an essential trace element for humans and animals. The atmosphere represents an important reservoir of Se, in which yearly around 29’000 – 36’000 tons of Se are cycled. Atmospheric Se, which is deposited to land and ocean surfaces via wet and dry deposition, functions as a source of this essential micronutrient to ecosystems and food chains. Marine and terrestrial biogenic emissions are responsible for around 60% and 20%, respectively, of natural selenium emissions (Feinberg *et al.*, 2020). The two combined represent between 35 to 70% of total selenium emissions, the rest being of anthropogenic origin e.g., fossil fuel combustion. The main biogenically-derived atmospheric Se species are the volatile methylated species dimethyl selenide (DMSe), dimethyl diselenide (DMDSe) and dimethyl selenyl sulphide (DMSeS) (Amouroux and Donard, 1996). Only a few studies have quantified volatile methylated Se compounds in aqueous phases (e.g., surface water) and air in marine and terrestrial environments via cryogenic or chemotrapping (Amouroux and Donard, 1996 ; Vriens *et al.*, 2014). Despite of the large contribution of natural emissions to atmospheric Se emissions and thus to the global biogeochemical Se cycle, spatio-temporal variations in Se emissions are still unknown. Furthermore, mechanistic knowledge on production pathways of these species and environmental sinks is very scarce.

To fill these gaps in data and knowledge, concentration trends in methylated species need to be studied over longer time-scales, which requires high- throughput analytical methods that are not only sensitive enough to detect trace Se species but also have a high sampling frequency. We present here the development of a novel analytical method (Fig. 1) for high-throughput trapping and analysis of volatile Se species. The method is based on trapping of volatile Se species onto specialized sorbents that are analyzed using a semi-automated thermal desorption unit coupled to gas chromatography-ICP-MS (GC-ICP-MS). This highly sensitive and selective technique allows the analyses of volatile Se species at ultra-trace levels with an absolute detection limit of 50-200 fg, depending on the species. Simultaneously, volatile sulfur (S) and bromine (Br) species can be detected at trace levels and quantified, allowing a comparison of fluxes and a better mechanistic understanding of Se species formation and pathways. In this presentation, we will exemplify the potential of the new method with first results obtained from its application on seawater samples (after purging with an inert gas) during marine cruises and direct air sampling at a grassland site in Switzerland.

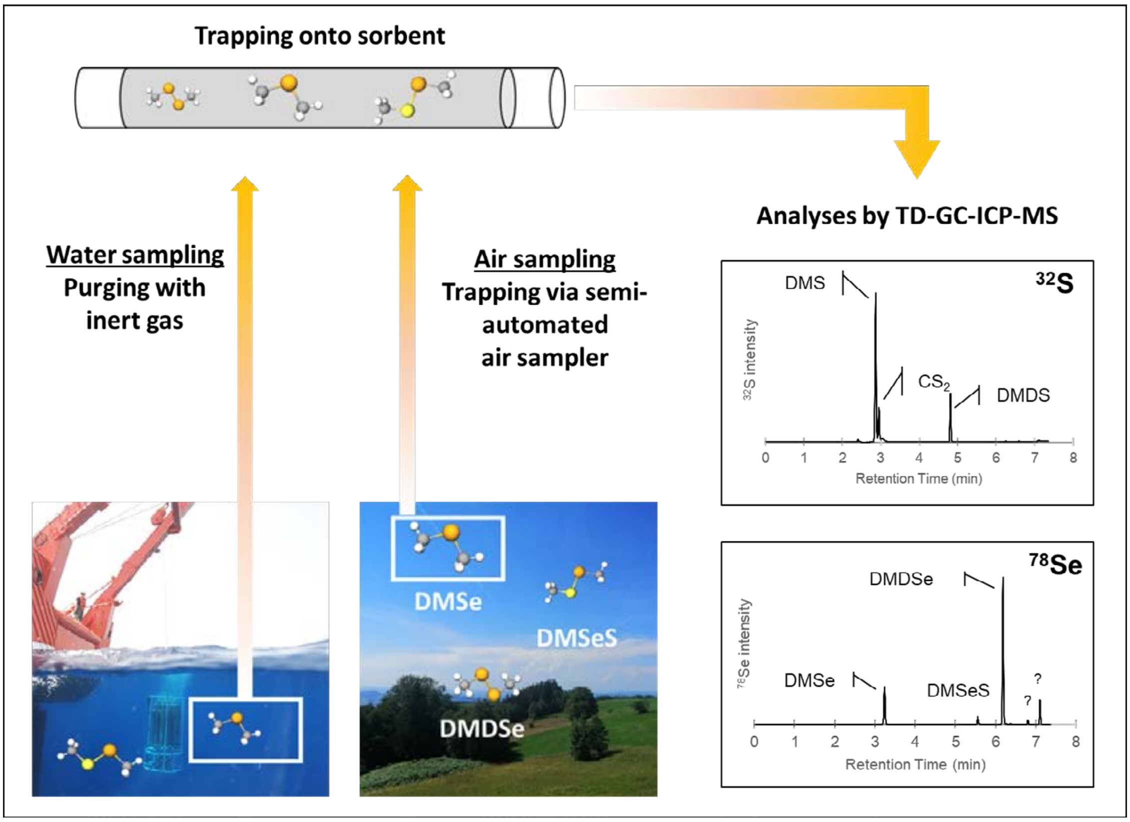

Figure 1. Schematic representation of the trapping methods and determination of volatile species in aqueous and air samples via thermal desorption-GC-ICP-MS (TD-GC-ICP-MS).

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4.10
Fate of contaminants from repositories for radioactive waste based in clay-rock?

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Safe disposal of high-level radioactive waste (HLW) is one of the key challenges of modern society. The concept of deep geological disposal has become internationally accepted as a means of safe waste management in order to isolate it from the biosphere for hundreds of thousands of years. Hence, the safety case has to demonstrate that transfer of radionuclides from the disposal site into the biosphere can be effectively prevented across this time span. The potential migration is primarily controlled by adsorption/desorption processes onto mineral surfaces along the migration path. Clay minerals are major constituents in both the engineered barrier and in the argillaceous host rock formation being considered for the deep HLW repository in Switzerland. Therefore, it is critically important that safety assessment of the repository is supported by a fundamental understanding of the uptake processes of radionuclides onto clay minerals and other minerals under a wide range of relevant geochemical conditions. An overview of the work performed at the Laboratory for Waste Management on the retention of radionuclides on clay minerals and clay rich materials will be presented.

4.11
Effects of aging on the transformation of fresh Fe(III)-precipitates and on the retention of co-precipitated P

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Fe(III)-precipitates formed by the oxidation of Fe(II) in natural waters critically influence the biogeochemical cycling of P and trace elements. In the framework of the EU project P-TRAP (https://h2020-p-trap.eu/) on the mitigation of diffuse P inputs into surface waters, we study the formation and transformation of Fe(III)-precipitates in the presence of inorganic and organic solutes and consequences for P and trace element (As, Cd) retention in soils and water filters.

Freshly-formed Fe(III)-precipitates are metastable and can transform over time. In extension of our earlier work (Senn et al., 2015, 2017, 2018), we perform time-resolved laboratory experiments on the structural transformation of fresh Fe(III)-precipitates as affected by Ca, Mg, silicate, and phosphate, and assess the consequences of structural transformations for the retention of co-precipitated P, As and Cd. Data on changes in dissolved element concentrations are combined with a detailed structural characterization of the solid phase using X-ray absorption spectroscopy (XAS), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and transmission electron microscopy (TEM).

First aging experiments have been performed in Si-free electrolytes at a molar P/Fe ratio of 0.3, i.e., with fresh Fe(III)-precipitates consisting of a mixture of amorphous Fe(III)-phosphate and poorly-crystalline lepidocrocite. The results show that increases in dissolved P and As during aging are linked to the transformation of the fresh solids into solids with a higher share of more crystalline lepidocrocite, and that this transformation is slowed down by Ca and (slightly less) Mg. In ongoing experiments, we further assess the coupled effects of Si with Ca or Mg on precipitate formation, transformation and P retention.

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4.12
Transformation of Ferrihydrite and Goethite in Heterogeneous Systems

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In soils and sediments, ferrous and ferric iron comprise one of the most abundant redox couples. Electron transfer between these two oxidation states controls the biogeochemical cycling of Fe and influences redox reactions with important elements such as carbon, nitrogen, and sulfur. In sub- or anoxic conditions, reactions between ferric minerals with aqueous Fe(II) tend to transform minerals with lower crystallinity, such as ferrihydrite, into more crystalline phases while thermodynamically stable minerals like goethite tend to undergo recrystallization rather than transformation. However, we still lack understanding of how co-existing minerals could influence transformation or recrystallization pathways in a heterogeneous system.

To learn how ferrihydrite (Fh) and goethite (Gt) interact with Fe(II) in a heterogeneous system, we worked with a synthetic mixture of ferrihydrite (30%) and goethite (70%). As a comparison, we also included a natural mineral sample from Hestur (Iceland) composed of ferrihydrite and goethite in similar proportions. Such an approach allowed us (i) to test each of the minerals individually and as a mixture and (ii) to compare the results of the natural sample with a laboratory synthesized mixture. The solids were reacted with an isotope-labeled ^{57}Fe(II) (1 mM) for up to four weeks. Solid and aqueous samples were periodically taken to investigate mineral transformations and the isotopic composition in each phase.

Pure ferrihydrite reacted with 1 mM Fe(II) rapidly (<1 day) transformed into lepidocrocite and goethite (Figure 1A and 1B). After four weeks, ferrihydrite was almost entirely transformed into goethite (85%), lepidocrocite (1%), and magnetite (8%) and underwent complete isotope mixing (Figure 1C), which is consistent with previous reports (ThomasArrigo 2018). Goethite reacted with 1 mM Fe(II) did not transform into new minerals, but it underwent substantial isotope mixing, which was also expected (Latta, 2012). Surprisingly though, when our mixture of ferrihydrite and goethite reacted together with Fe(II), it transformed almost entirely into goethite (final composition 97% goethite, 0.01% lepidocrocite and 3% magnetite). The overall transformation of Fh was much faster than in the pure ferrihydrite system, with almost all Fh transformed in one day and mostly skipping the initial formation into lepidocrocite.

Our results from the laboratory synthesized mixture suggest that the co-existence of ferrihydrite and goethite might lead to a synergistic effect towards the transformation of ferrihydrite into goethite. We hypothesize that the presence of goethite might serve as a template and lead to a faster and more direct route into the transformation to goethite. However, more experiments are necessary to understand if the preferred and faster transformation into goethite is maintained in mixed systems with different proportions of ferrihydrite and goethite.

In contrast to the synthetic mixtures, the reaction of the natural mineral sample with Fe(II) lead to no significant change in composition over four weeks. Interestingly, though, besides no changes in composition, there was substantial isotope mixing between the solid and the aqueous phase. Atom exchange without mineral transformation has been reported for ferrihydrite in the presence of organic matter (ThomasArrigo 2018). Therefore, we hypothesize that the presence of carbon (5.2%) and silica (2.9%) in the natural sample might have hindered ferrihydrite transformation.

Our results suggest that more studies are needed on mixed systems, and natural and synthesized samples' comparison requires caution since natural samples might contain elements or compounds other than the iron oxides that could hinder or affect mineral transformation. Nonetheless, the study of the laboratory synthesized mixtures sheds light on why we do not find lepidocrocite in the natural mixtures of ferrihydrite and goethite collected in Iceland.

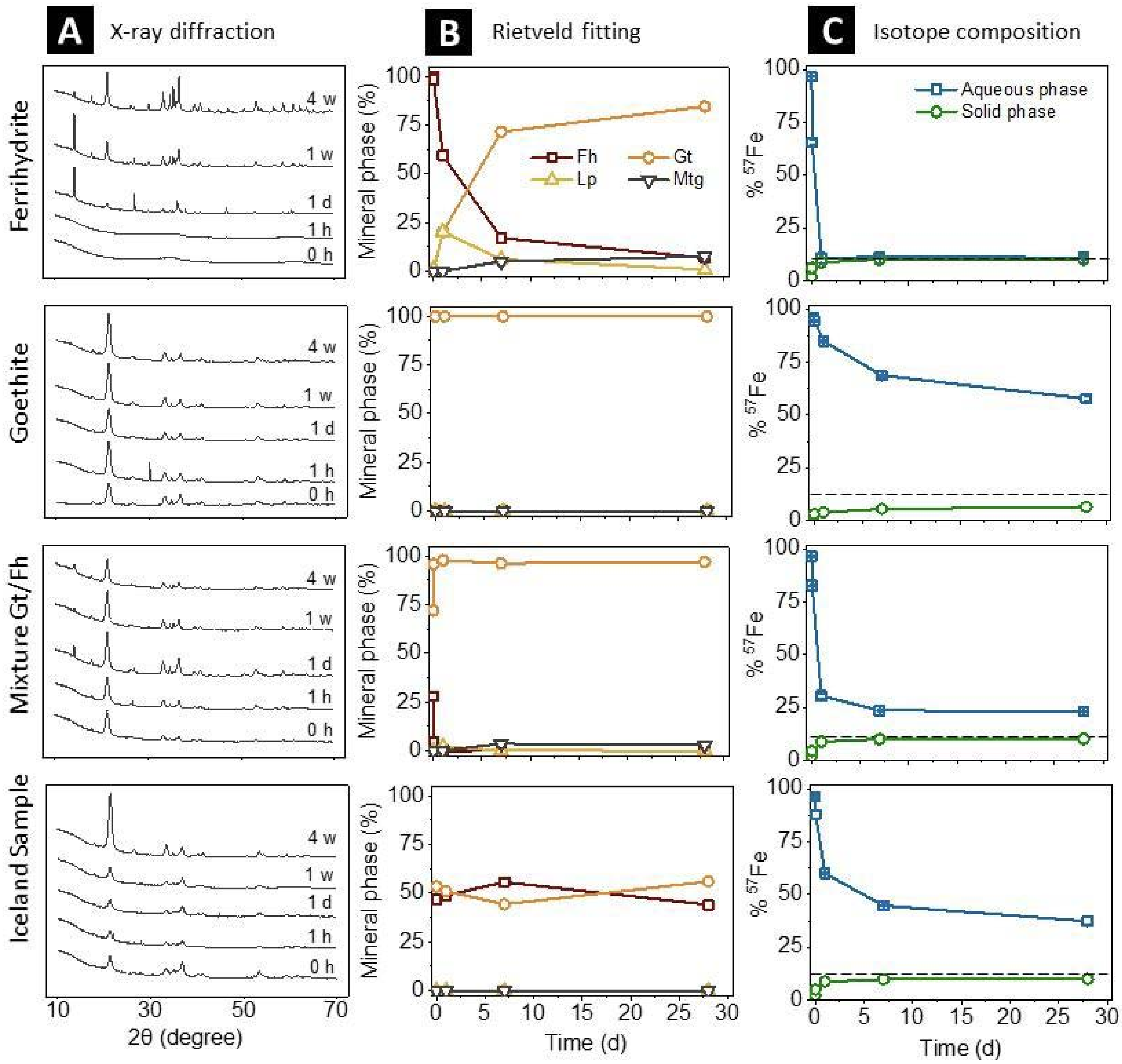

Figure 1. (A) X-ray diffraction patterns,(B) corresponding mineral phase contributions determined with Rietveld fitting and (C) isotope composition in aqueous and solids before and during reaction with 1.0 mM $^{57}Fe(II)$. Dashed lines represent complete isotope mixing.

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4.13
Exploring the capacity of diatom *Cyclotella meneghiniana* in contributing to the aquatic Hg species transformations

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Mercury is a persistent contaminant that can cause serious damage to human and environmental health.

Despite the low concentration levels, mercury can bioaccumulate in the aquatic organisms, and in the case of organic mercury organic, it can be biomagnified through the aquatic food web posing serious health issues to fish consumers.

Primary producers such as phytoplankton species are at the base of the food web, therefore playing a crucial role in the Hg transfer. The aim of the present study is to explore mercury species bioaccumulation and biotransformation capability of diatoms, as representative phytoplankton species. Species-specific isotope tracers technique was used to quantify the uptake, methylation and demethylation by diatom *Cyclotella meneghiniana*. The changes in the $^{199}Hg(II)$ and/or $^{201}CH_3Hg$ concentrations over exposure time were followed by gas chromatography coupled with inductively coupled plasma mass spectrometry (GC-ICP MS). To account for the contribution of the abiotic transformation, a comparison was made with the system in the absence of diatoms.

Results demonstrated a significant accumulation of both Hg(II) and CH_3Hg by *C. meneghiniana,* and CH_3Hg demethylation.

Additionally, $^{199}Hg(II)$ loss due to Hg(II) reduction to Hg0, ultimately released into the atmosphere (via volatilization process) was detected. The implications of the results are discussed with respect to the mercury incorporation at the base of the food-webs and possible contribution of diatoms in Hg cycling.

4.14
The influence of organic matter composition on trace elements cycling: analytics and applications

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The influence of organic matter (OM) in the biogeochemical cycling of trace elements has been recognized for a long time. In terrestrial and aquatic ecosystems, trace elements can be associated to various OM compounds via either complexation or covalent binding. The association of trace elements to OM thus affects their partitioning between the dissolved and solid phases and consequently controls their fate and behavior, such as their transport in watersheds but also their uptake by aquatic organisms. Moreover, OM influences the cycling of trace elements by exerting a strong control on bacterial activities involved in their chemical transformations, e.g. redox or alkylation/dealkylation.

It is now widely recognized that not only the quantity but also the composition of OM plays a crucial role in the fate of toxic (e.g., Hg, As) and/or essential trace elements (e.g., Se, Zn). Unraveling the effects of OM composition on trace elements cycle in natural systems remains however an analytical challenge due to i) the complex nature of OM, which is an heterogeneous mixture of molecules derived from biotic and abiotic transformations of organic compounds coming from various organisms (e.g., plants, algae, or bacteria) and ii) the low concentrations of trace elements (especially, Se and Hg), that are furthermore distributed among multiple organic and/or inorganic species, making the detection of individual chemical species difficult.

In this talk, I will present new analytical methods that provide either a high-throughput characterization of OM molecular composition (e.g., pyrolysis-gas chromatography/mass spectrometry) or a characterization of OM-trace elements associations (methods based on liquid chromatography coupled to inductively coupled plasma mass spectrometry). Each technique will be exemplified with a field study designed to investigate a specific aspect of trace element dynamic in an environmental system.

4.15
Release of arsenic from soils upon organic and inorganic phosphorus addition

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Arsenic (As) is a toxic metalloid for plants and humans. Switzerland has several naturally As contaminated sites due to bedrock weathering and few anthropogenic polluted old mining areas, potentially being a risk for releasing As to other environmental compartments. In soil, As can be bound by different mechanisms, yet, biding on iron oxides is often prevalent. Since phosphorus (P) is potentially occupying the same binding sites as As, the mobility of As in soil is potentially influenced by the addition of P to soil. Indeed, several studies have demonstrated that As was mobilized in soils by the addition of inorganic P fertilizer. However, up to now there is no understanding how the addition of organic P, a significant fraction of total soil P and present in many organic fertilizers, can alter the mobility of As in soil. For that reason, we performed a sequence of batch experiments to determine the effect of inorganic and organic P addition on the extractability of As from soil.

We selected soils of both calcareous and silicate parent material and with elevated As concentrations, either because of geogenic reasons or as a result of former mining activities in the area. In a desorption batch experiment different P solution treatments were added to the soils and subsequently shaken to equilibrate for 24 hours. P solution treatments consisted of the same amount of total P added to soil, but with changing ratios of inorganic and organic P. Orthophosphate was used as inorganic P, while phytate, an organic P compound most abundant in many soils, was used as an organic P compound.

Preliminary results on a Calcisol from the Jura mountains demonstrated that the addition of inorganic P caused an increase in the release of As with increasing amounts of inorganic P in the treatement solution. However, increasing concentrations of organic P did not result in a release of As. This was likely due to the precipitation of the organic P compound with calcium ions in solution. Further experiments on soils that developped from silicate parent material are currently ongoing.

This work will contribute to a better understanding of the release of As by both inorganic and organic P addition by e.g. fertilization with inorganic or organic fertilizerson soils with different properties.

4.16
Oxidation of glucose by Mn oxide and change in carbon bioavailability for soil bacteria.

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The interaction of organic carbon substrates with microorganisms and mineral phases is a key factor regulating its fate. While carbon substrates can be transformed into biomass or mineralized to CO_2 through microbial metabolism, mineral phases can stabilize organic compounds through sorption processes or induce their oxidation through redox reactions. Manganese oxides (MnOx), which are among the strongest natural oxidants in soils, are thought to play a central role in soil organic matter (SOM) decomposition. While promoting depolymerisation and hydrolysis of complex molecules, e.g. lignin ad cellulose, generating smaller bioavailable carbon substrates, the presence of MnOx can also drive the oxidation of a broad range of small organic molecules and carbohydrates through successive decarboxylation steps (Wang & Stone, 2006), altering the bioavailability of carbon sources for soil microorganisms.

To investigate whether the high redox reactivity of manganese oxides impacts carbon consumption of soil microbial communities, we compared the kinetics and mechanism of glucose oxidation by synthetic birnessite (δ-MnO2) to the consumption of glucose by *Pseudomonas putida* KT2440 and *P. putida* KT2440- δ-MnO2 composites. We performed batch kinetic experiments at pH 5 and 7, by adding 5.5 mM glucose solution to 1 mM δ-MnO_2, to biomass-only and to composite system suspensions. We monitored the evolution of dissolved organic carbon (DOC), the formation of intermediate oxidation products and the release of CO_2. In parallel, we followed the reduction of δ-MnO_2 by determining the Mn(III) accumulation in the mineral and the $Mn(II)_{aq}$ in solution.

Our data showed that under abiotic conditions, Mn(III) accumulated rapidly (up to 35 % in 20 minutes) in the solid phase prior to significant MnO_2 dissolution to Mn(II). This accumulation of Mn(III) prevented the complete oxidation of glucose to CO_2(g) by lowering the reduction potential of the oxide. Instead of CO_2(g), formate was the main product of glucose oxidation by MnO_2. In the *biomass*-only system, while DOC remained constant over time at pH 5, carbon was depleted entirely after 4 days of incubation at pH 7 with about 20 % of the added glucose respired to CO_2 and no formate measured in solution. Conversely, in composite systems at pH 7, we found that the bacteria consumed the abiotically produced formate, despite the large excess of glucose. The consumption of formate promoted biamass respiration, with a higher conversion of glucose to CO_2 (up to 30 %), but lowered the glucose consumption (50% DOC decrease after 4 days in the composite systems compared to 100% DOC decrease in the biomass only system).

Our results show that, even at low concentration, the presence of mangnaese oxides changes the extent of carbon consumption, as well as the pathway of substrate utilization upon the production of small bioavailable carbon substrates.

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05. Palaeontology

Torsten Scheyer, Christian Klug, Lionel Cavin, Allison Daley

Schweizerische Paläontologische Gesellschaft,
Kommission des Swiss Journal of Palaeontology (KSJP)

TALKS:

POSTERS:

P 5.1 *Veine-Tonizzo L., Tissier J., Becker D.*: Cranio-dental anatomy and phylogenetic analysis of Amynodontidae (Perissodactyla, Rhinocerotoidea)

P 5.2 *Plateau O., Foth C.*: Avian cranial suture closure: an interspecific indicator for age

P 5.3 *Ferrante C., Cavin L.*: A new coelacanth from the lower Jurassic of Switzerland

P 5.4 *El Hossny T., Cavin L., Samankassou E.*: Evolutionary history of the tselfatiiforms – weird ray-finned fishes from the Cretaceous – with a focus on Lebanese taxa

P 5.5 *Weinkauf M.F.G., Siccha M., Weiner A.K.M.*: Reproduction strategies in a marine protist: A modelling approach

P 5.6 *Luz Z., Leu M., Bucher H., Vennemann T.*: Evaluation of sea surface temperature gradient during the Smithian-Spathian (Early Triassic) using oxygen isotopes in conodont bioapatite

5.1
The Pleistocene Camelid Brain

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The Camelidae, a clade including living llamas, alpacas, and camels, first appeared in the fossil record around 40 million years ago. Their brain evolution has been traced with snapshots of change, based on fossilized brains, or endocranial casts, from several consecutive epochs. There are changes in size and complexity that took place throughout this time. Documented are the Eocene camelid, *Protylopus occidentalis*, followed by the Oligocene *Poebrotherium* and several examples of Miocene to late Pleistocene *Procamelus* and *Camelops* taxa. Comparison between these fossil forms and living camelid brains suggests that the increase in size and complexity occurred mostly in the last quarter of the Cenozoic. We describe the first known camelid brain endocast from the early Pleistocene, dated to ~1.2 Mya, a stage of camelid brain evolution not previously known. The brain belongs to a yet-unnamed specimen, catalog number PIMUZ A/V 4165, and is the sister taxon to modern llamas and alpacas, based on the most recent systematic work for camelids. It has been confirmed as a derived member of the Lamini clade that lived during a time when camelid generic diversity was dwindling. The outstanding preservation of the brain cast allows identification of multiple sulci and major compartments of the organ. Along with other details made available through X-ray computed tomography scanning, we provide a detailed description of cerebral complexity significantly higher than that in Pliocene forms. Thus, PIMUZ A/V 4165 represents one of the most derived camelid brains from the fossil record. We hypothesize about the sensory capabilities of this fossil taxon. One particularity is the reduced size of its olfactory bulbs compared to modern camelids, suggesting the importance of smell in modern forms, and reflecting a recent shift in sensory allocation.

5.2
Re-fleshing fossils: cranial reconstructions of Thalattosauriformes.

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3D-visualisation techniques have revolutionised the field of palaeontology. These new techniques allow for the possibility of revisiting old descriptions of problematic taxa or clades in unprecedented detail.

Thalattosauriformes are a cosmopolitan group of secondarily aquatic Triassic marine reptiles that inhabited mainly low-latitude nearshore environments. Their remains represent rare occurrences in North American and European fossil records while being one of the most common faunal components of the Late Triassic ecosystems of China. This enigmatic clade is characterized by a low taxonomic diversity but high morphological disparity, especially illustrated by a wide variation of body sizes, rostral shapes and dentition types. Currently there is little understanding of their phylogenetic affinity within the Diapsida and even the interrelationships within Thalattosauria are contested. The large degree of cranial variation has raised numerous questions about their feeding mechanics and ecological niche fill that have yet to be adequately studied.

Here we provide updated cranial reconstructions of various thalattosaur genera using state-of-art tomographic approaches including a combination of traditional Computer Tomography (CT) and Computer Laminography (CL), termed Augmented Laminography (AL). The main focus lies on specimens from the UNESCO world heritage site of Monte San Giorgio (Middle Triassic, Besano Formation, Switzerland/Italy) supplemented by new finds from the Middle and Late Triassic of China and North America. Segmentations of osteological elements extracted from these scans will be re-positioned into their anatomical context and retrodeformed to provide complete 3D cranial models. This approach not only offers detailed morphological information for phylogenetic purposes, but also provides 3D data to be used in quantitative shape analyses (e.g. 3D morphometrics) and detailed biomechanical studies (e.g. MDA + FEA). In this manner, the functional ecology and niche differentiation of the thalattosaurs and other marine reptiles of the Monte San Giorgio region and other Triassic ecosystems can be further studied.

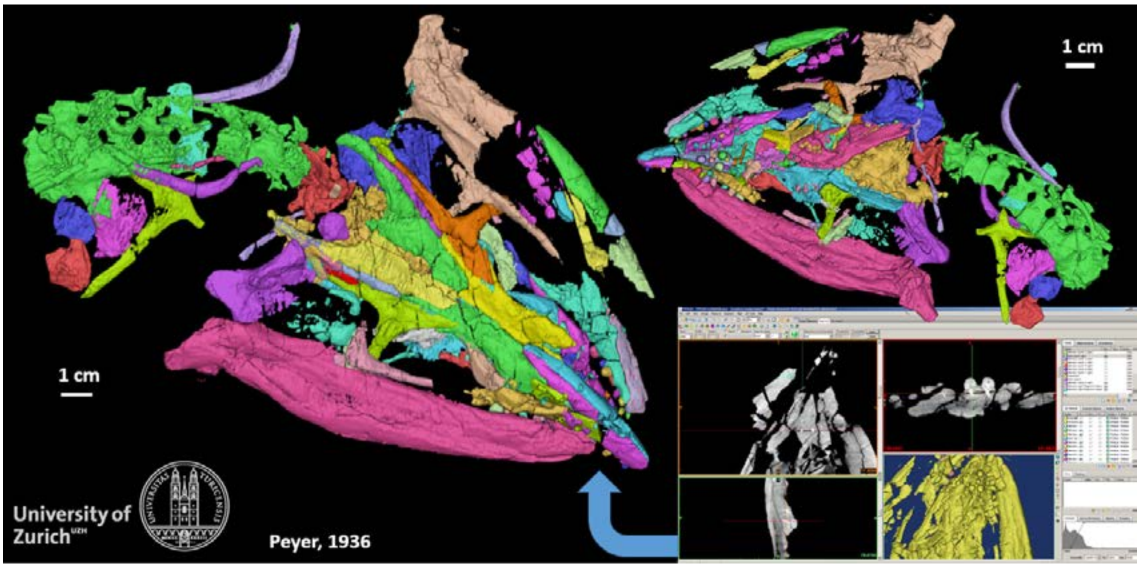

Figure 1. Three-dimensional segmentation of the holotype of *Clarazia schinzi* (PIMUZ T4778).

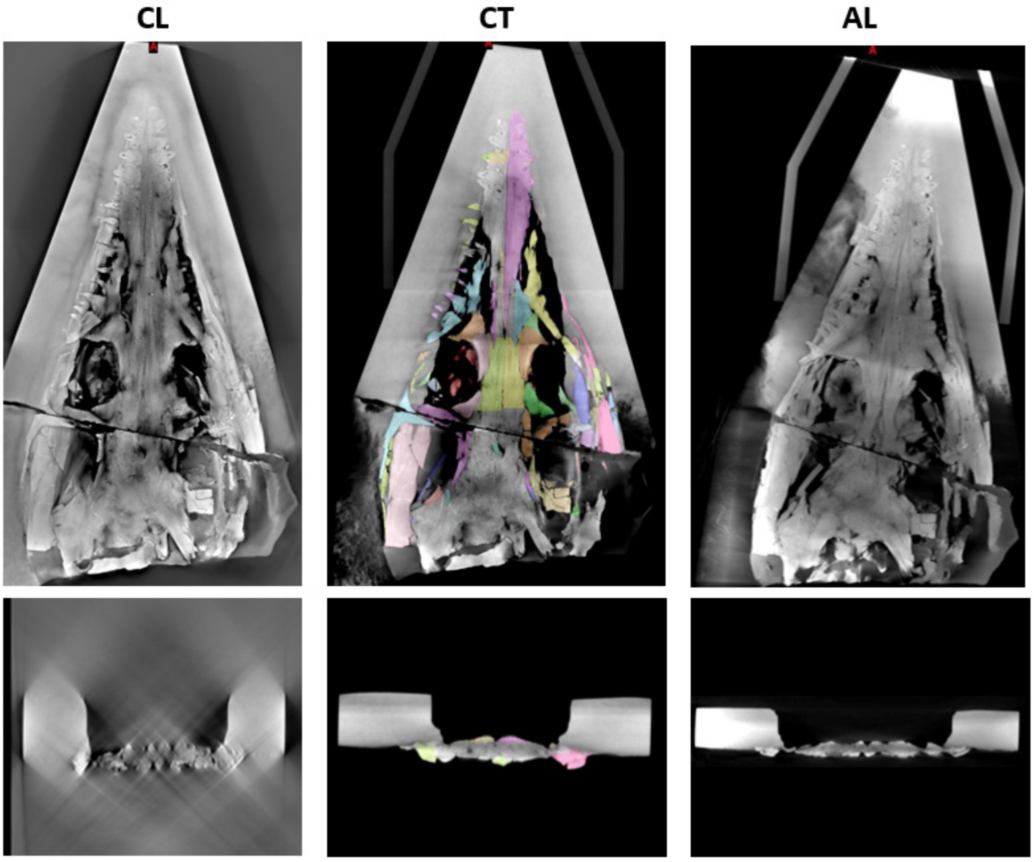

Figure 2. The application of Augmented Laminography (AL) to facilitate high resolution scanning for traditionally problematic slab specimens like this *Askeptosaurus italicus* (KO2-D-67 K 26/06 Number 2). Note that the Computer Laminography (CL) shows strong external artefacts, while the Computer Tomography (CT) shows a lack of internal resolution. Augmented Laminography uses the external resolution of CT combined with the internal resolution of CL to provide optimal results.

5.3 A doomed expedition? Investigating the concept of doomed pioneers using an annular flume and the polychaete, *Alitta virens*

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Trace fossils provide *in situ* evidence for organisms and their activities and are widely applied as palaeoenvironmental indicators. But what if the organisms are allochthonous to the depositional environment? This is the concept behind the “doomed pioneers” hypothesis (Föllmi and Grimm, 1990); that organisms living in a well-oxygenated environment could be caught up in a turbulent flow and transported to a different, oxygen deficient, environment. These organisms are then able to colonize and create trace fossils in anoxic sediment, at least for a short time, before eventually succumbing (Figure 1). The feasibility of this occurring has important implications for interpreting trace-fossil material in deep-marine settings.

Through a series of systematic experiments, we establish i) the mortality/survivorship potential of *Alitta virens* after undergoing transport; ii) the difference in burrowing rates of *Alitta virens*, from those that had been transported and those that had not; and iii) the adaptation of *Alitta virens* to environmental changes in temperature and oxygen conditions after significant transport. These experiments show how careful consideration must be employed when using trace fossils associated with event deposits to reconstruct benthic marine communities, oxygen availability, and their trophic structures.

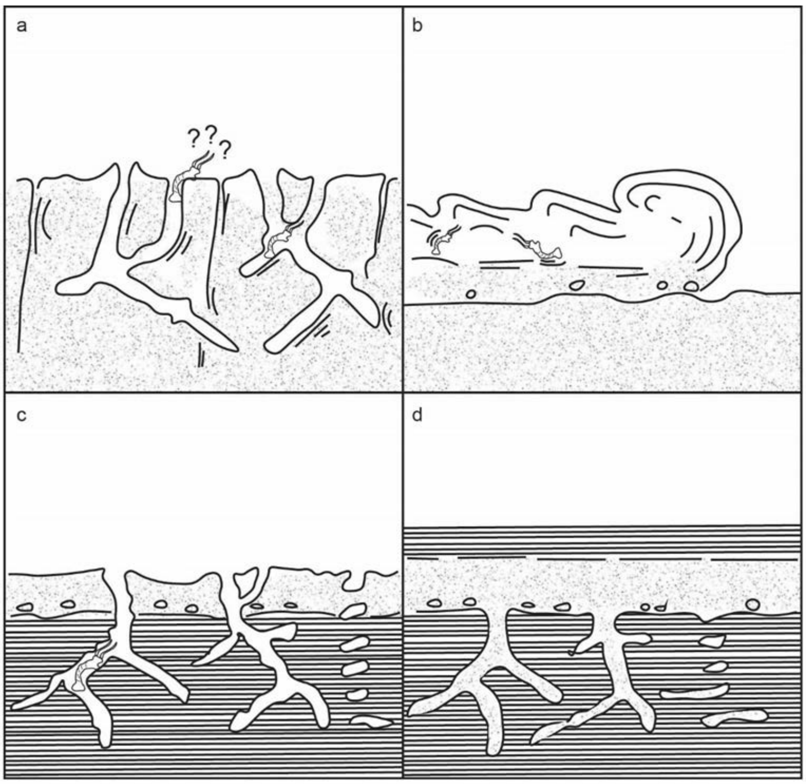

Figure 1. Schematic illustration of the doomed pioneer hypothesis (after Föllmi and Grimm, 1990).

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5.4
New Miocene aquatic mammal remains from Northern South America

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The tropical region of Northern South America (Colombia, Venezuela) is a global hotspot of biodiversity and the result of complex biogeographical and geographical processes. Between 16-11 million years ago, this region was heavily influenced by the Pebas mega wetland system that flooded much of the north-central part of South America (Jaramillo et al., 2017). These conditions greatly benefited animal diversification, as evidenced by fish, turtle, crocodilian, mollusc and terrestrial mammal assemblages (Hoorn et al., 2010). The record of aquatic mammals is, in contrast, poorly known. New remains from the localities of La Venta, Colombia (La Victoria Formation) and Falcón, Venezuela (Socorro, Caujarao and Coro formations) indicate that these animals were already fairly diverse during the Miocene. Fossils from La Venta (an isolated periotic and some rostral fragments) belong to the Platanistidae, a group whose only extant survivor is the Ganges river dolphin. They indicate that in South America relatives of extant *Platanista* invaded freshwater environments much earlier than those of the extant pink dolphin *Inia*, as previosly suggested by Bianucci et al. (2013) based on fossils from coeval layers of the Fitzcarrald Arc, Peru. Furthermore, direct comparisons of both La Venta and Fitzcarrald morphotypes indicate that at least two different *Platanista* relatives were present on South America. The isolated partial skull (Caujarao Formation, middle Miocene) displays a combination of features mostly found on stem Delphinida. A preliminary phylogenetic analysis based on Lambert et al. (2020) places this animal as sister taxon to *Hadrodelphis*, a genus characterized by its robust teeth and mostly symmetrical skull. This indicates that stem delphinidans (also known as “kentriodontids”) were also present on the proto-Caribbean, during a time where its productivity was much higher than today. In the case of sirenians, two species are known from the Pebas mega wetland system: *Potamosiren magdalenensis* from La Venta and *Nanosiren sanchezi* from Urumaco, both ranging from small to medium size. A third new morphotype from de Coro Formation (Venezuela), currently under study, displays some affinities with already known species from the Caribbean region, but also with *Metaxytherium* sp. from the Parana Formation in Argentina. Overall, the diversity of aquatic mammals in Tropical America is expanded with the additions of these new materials, indicating that their evolutionary history in this part of the world might have been more complex than once thought.

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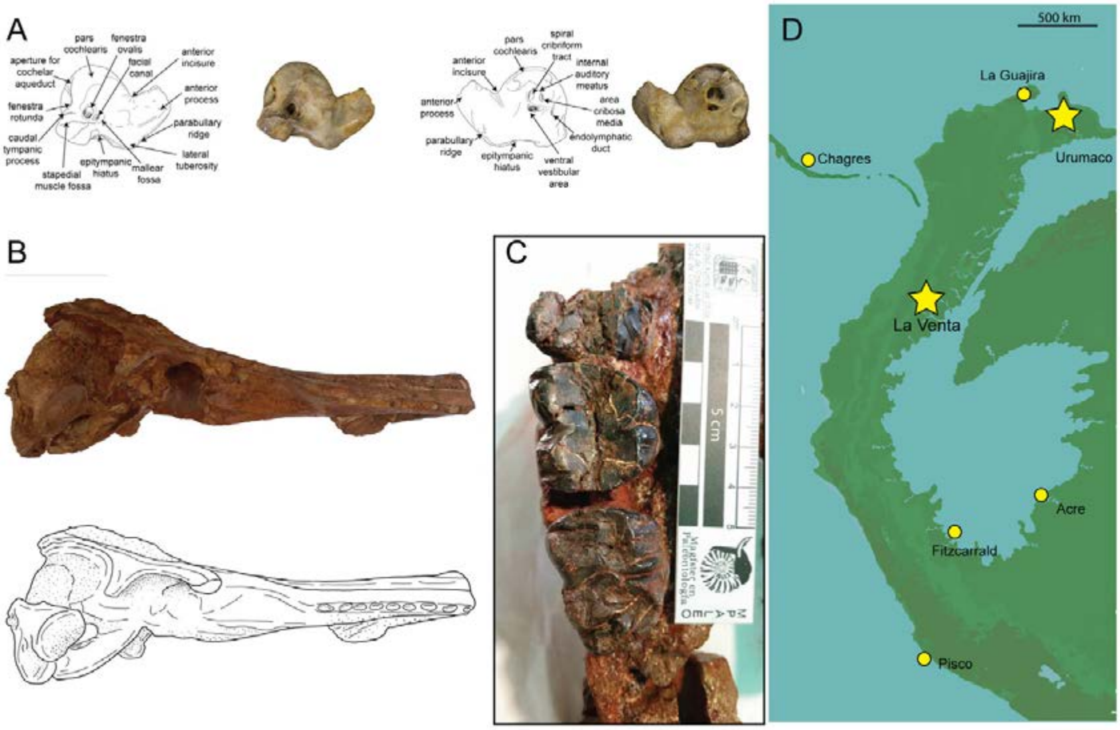

Figure 1. Aquatic mammal remains from Tropical America: A, isolated periotic from La Venta in ventral and dorsal views; B, skull in lateral view of the Caujarao Fm. dolphin; C, mandible fragment of the Coro Fm. sirenian. Map (D) showing the position of the main localities of northern South America.

5.5
Benthic foraminifera and facies of the Albian-Cenomanian platform limestones in the Geyik Dağı area, Central Taurides, Turkey

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The Cretaceous carbonate successions outcropping in the Geyik Dağı area, which is located at the Central Taurides in southern Turkey, are represented by two successions with different paleoenvironmental successions. These are open shelf to slope (Cenomanian to Maastrichtian) and inner (restricted) platform (Albian to Maastrichtian) successions (e.g., Solak & Taslı, 2020). This study focuses on the lower part of the Albian-Maastrichtian platform succession exposed in the Göbekçal Hill approximately 11 km northwest of the Geyik Dağı (2877 m) and aims to report benthic foraminifera and facies of them. The Cretaceous outcrop section is composed of Albian-Cenomanian limestones that frequently contain macrofossils represented by gastropod, rudist and larger bivalve shells. The section begins with the Albian limestones that have a rich benthic foraminiferal taxa such as *Mesorbitolina* gr. *texana, Nezzazata isabellae*, *Nezzazatinella* sp., *Vercorsella arenata*, *Vercorsella scarsellai*, *Cuneolina parva*, *Cuneolina sliteri*, *Akcaya minuta, Akcaya auruncensis, Cribellopsis moulladei, Glomospira urgoniana*, *Haplophragmoides globosus*, *Protochrysalidina elongata*, *Pseudonummoloculina aurigerica, Pseudonummoloculina heimi*, *Mayncina bulgarica* and a recently introduced taxon *Phenacophragma oezeri* by Solak & Taslı (2020). Lamination, birdseyes/fenestrae and karst infillings are common. The Albian limestones are conformably overlain by the Cenomanian limestones with *Sellialveolina viallii*, *Cuneolina pavonia*, *Biplanata peneropliformis*, *Spiroloculina cretacea* and *Pseudorhapydionina dubia*. The Cenomanian limestones covered by a major disconformable surface are characterized by frequently occurrence of emersion breccia interlayers that contain frequently mm to cm sized black pebbles. The Albian-Cenomanian limestones are composed of mainly alternation of mud-rich microfacies (wackestone to mudstone and packstone) containing mainly algae-foraminifera, intraclast/peloid, ostracod-miliolid and bioclast (bivalve and gastropod) grains, respectively. The bioclasts concentrate mostly in the uppermost part of the section. The mud-rich microfacies, common lamination and birdseyes/fenestrae indicate peritidal environments of an inner platform. The breccia layers that are widespread throughout the Cenomanian indicate frequently exposure of the platform to supratidal depositional environment with a short-lasting emersion phase.

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5.6
Diversity and Evolution of Radiodonta during the Early Paleozoic

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Radiodonta is an early Paleozoic group of stem lineage arthropods that includes *Anomalocaris* and over 25 other taxa. These animals are reknown amongst Cambrian Explosion taxa owing to their large body size, inferred predatory lifestyle, and complicated history of description. Radiodonts have been described from every major Cambrian and Ordovician Burgess Shale-type (BST) lagerstätten, showing that they were globally distributed and relatively abundant. They most commonly preserve as isolated cuticularised frontal appendages, oral cones, and cephalic carapaces of the head region, but rare complete specimens show the body trunk was segmented and consisted of swim flaps associated with setal blades. Study of these morphlogical features in radiodonts has helped clarify the evolutionary pathway of key anatomical structures in Arthropoda, for example the biramous limbs, compound eyes, and cephalic structures (Daley et al. 2009; 2018; Van Roy et al. 2015).

As the name suggests, Radiodonta was originally described as a clade uniting taxa with a radially-arranged oral structure of 32 plates with a central opening, which was thought to be a highly conserved element of radiodont anatomy (Collins 1996). More recent work has shown that the oral structures are more diverse, with some taxa possesing a variable number of radially-arranged plates (Daley & Bergstrom 2012), and others showing a series of gnathobase-like plates that do not form a solid oral cone (Cong et al. 2017). Likewise, the frontal appendages show a great diversity of feeding ecologies, including adaptations for active predation, sediment-sifting, and even suspension feeding (Van Roy et al. 2015). Cephalic carapaces range from small dorsal carapaces to elaborate carapace complexes that make up nearly half the total body length (Daley et al. 2009; Van Roy et al. 2015). We can trace the evolution of these structures and use their functional morphology to make inferences about how ecological function changed in response to evolutionary pressures.

Here I review the recent work revealing the diversity of radiodont taxa in major fossil lagerstätten. Four major families of Radiodonta have been established, with the relationships between them coming into focus and revealing the evolutionary history of the major anatomical features, specifically the frontal appendages and oral structures (Pates et al. 2019; Pates & Daley 2019). During the early stage of their evolution, radiodont diversity was dominated by members of the Anomalocarididae and Amplectobeluidae, all of whom were active predators. Later stages of radiodont evolution were dominated by Hurdiidae, most of which are interpreted as generalised predators and sediment-sifters. Suspension feeding evolved multiple times during their evolution, presumably in response to increasing levels of competition in the ecosystem. This work highlights that radiodonts were important components of early animal ecosystems.

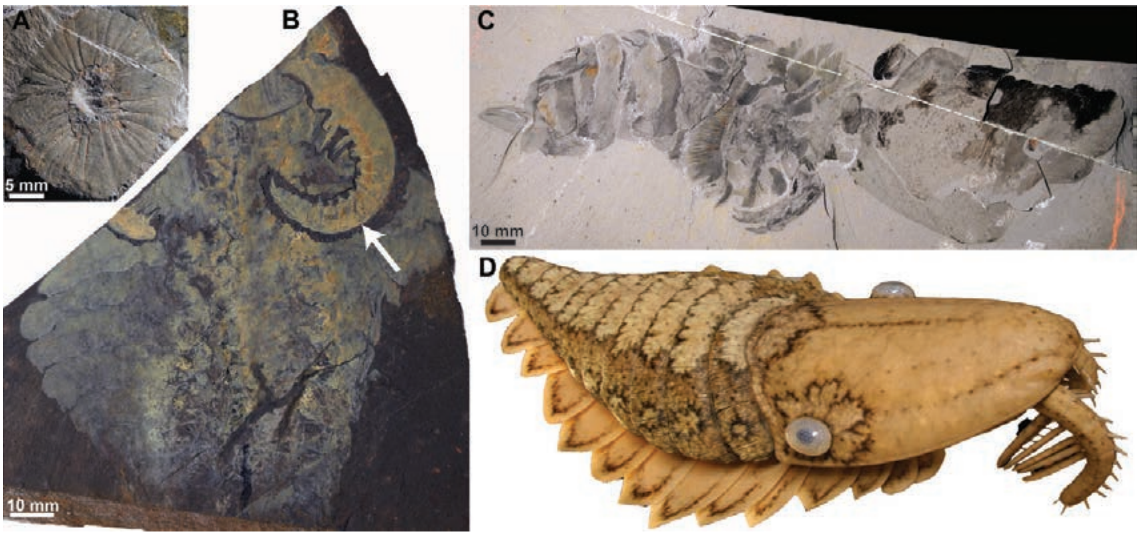

Figure 1. Cambrian radiodonts from the Burgess Shale, Canada. A: Oral cone showing 32-plate morphology of *Peytoia nathorsti*. B: Whole body specimen of *Anomalocaris canadensis*, with a raptorial frontal appendage indicated with white arrow. C: Whole body specimen of *Hurdia victoria*, showing large frontal carapace. D: Model of *Peytoia nathorsti* by E. Horn. Modified from Daley (2013).

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5.7
Do Tethyan mercury anomalies reflect a global volcanic trigger for the Smithian/Spathian boundary climatic and biotic crisis?

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The aftermath of the Permian-Triassic Boundary Mass Extinction witnessed cycles of extinction/origination for the marine nekton alternating with recurrent ecological setbacks of land plant communities. The most drastic extinction of the nekton (ammonoids and conodonts) occurred at the Smithian/Spathian boundary (SSB) *ca*. 249.2 Ma ago (Widmann et al. 2020). It was accompanied by climatic upheavals impacting the carbon cycle as evidenced by positive excursions in the global carbon isotope compositions (Baud et al.,1996, Galfetti et al., 2007), cooling of sea surface temperature (Romano et al., 2013), and a migration of cold water conodonts to low latitudes shallow waters (Leu et al. 2019). The long held hypothesis for a causal relationship between Early Triassic volcanism and the SSB crisis (e.g. Galfetti et al. 2007) was subsequently thought to correspond to anomalies in the Hg concentration of some sections but the validity of this proxy has also been questioned for the SSB (Hammer et al., 2019).

This study further investigates Hg concentrations as a proxy for volcanism leading to the SSB extinction in parallel with C (from organic and inorganic phases) and Sr isotope, elemental, and mineralogical compositions, in two biostratigraphically well-constrained carbonate SSB sections from the Tethyan Gondwana margin of Oman and one section from the shelf record of the Nanpanjiang pull apart basin, south China. In one of the two Oman sections and in the Nanpanjiang basin, Hg anomalies coincide with relatively low $^{87}Sr/^{86}Sr$, whereas Hg concentrations in the other Oman section approach detection limits. TOC measurements were possible in the shelf records of the Nanpanjiang basin, whereas the two offshore sections do not contain any detectible organic matter.

In addition, mineralogical and trace element compositions provide no evidence for the presence of sulfides, and potential Hg-hosting clay minerals are only present in the Nanpanjiang shelf section. Furthermore, the observed spikes in Hg concentration also vary in age and magnitude. As organic matter (OM) is the main sedimentary host of mercury under oxic conditions, its paucity in the studied sections might be related to the studied sites representing rather low bioproductivity marine environments and hence very limited organic matter accumulation and/or subsequent diagenetic loss of organic matter. Alternatively, there simply was no single volcanic event of global impact that triggered the SSB crisis (*cf* Hammer et al., 2019). Taken together, the temporal disparity, variable magnitude and spatial inconsistency of the Hg anomalies recorded in the studied carbonate SSB sections can be interpreted as pulses of increased regional deep-sea volcanic activity, and do not suggest a large-scale atmospheric input of Hg as would be expected from a continental, subaerial volcanic event with a global impact.

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5.8
The marine and terrestrial response during the Lower Jurassic: A multi-proxy approach to reconstruct the depositional environment

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The Toarcian oceanic anoxic event (T-OAE, ~183 Ma) is associated with oceanic anoxia, rapid seawater temperature increase and a marine mass extinction event. This is reflected in the widespread deposition of organic-rich black shales and a characteristic negative excursion in bulk organic carbon isotopes.

The underlying biotic and environmental upheavals are linked to the emplacement of the Karoo-Ferrar large igneous province (LIP) and associated volcanism. The Dotternhausen section (Larfarge-Holcim quarry, SW Germany) is considered one of the key sections of the T-OAE with comprehensive data including carbon isotope analyses, total organic and inorganic carbon content and Rock-Eval analysis. The quarry is not accessible anymore but a new open pit in Dormettingen (~2km, NW Dotternhausen) offers excellent outcrop conditions. Comparison between these two German sections showed that sedimentology, geochemistry and faunal data are laterally constant. Palynological analysis of 59 outcrop samples yielded an excellent quantitative data set of the early Toarcian, Posidonia shale sediments. Here we provide a high-resolution, multi-proxy study including chemostratigraphy ($\delta^{13}C_{org}$), particulate organic matter (POM), and palynology in order to reconstruct the depositional environment during the T-OAE. At the *falciferum* Zone a negative carbon isotope excursion was recorded that coincided with a biotic turnover with dinoflagellate and calcareous nannofossils being replaced by prasinophytes indicating long-term photic zone anoxia. The negative isotopic signal, the marine dinoflagellate “blackout” and the changes in terrestrial vegetation imply major palaeoenvironmental upheavals in both realms. The distribution and growth of dinocysts (planktonic organism) is influenced by environmental factors such as oxygen levels, salinity, temperature, nutrient availability, light, and water depth. Changes in dominance structure of terrestrial ecosystems as reflected in spore- pollen assemblages can be indicative of ecological disturbance.

Hence, a multiproxy approach incorporating both terrestrial and marine microfossils was necessary to understand the major environmental perturbations during the T-OAE.

5.9
Evolutionary ecology of benthic marine communities in the wake of the end-Permian mass extinction

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The end-Permian mass extinction eliminated the majority of species on Earth and thereby disrupted interactions between species by removing competitors, predators, prey species, mutualists, and ecosystem engineers. This paper reviews effects from this disruption on benthic marine communities in the wake of the crisis and explores how the re-establishment of ecological interactions affected ecological and evolutionary transformations of post-extinction communities. Elimination of competitors had a profound impact on the species composition of marine shelf habitats, because it allowed many surviving species the invasion of habitats from which they were previously excluded due to the presence of better-adapted competitors (Hofmann et al. 2013, 2014; Hautmann 2014). This effect manifests in a broader habitat range of many species, which has commonly been misinterpreted as the result of preferential survival of generalistic species. A macroevolutionary effect of the reduced number of competing species is low speciation rates, because the stimulating effect of interspecific competition on niche partitioning was reduced (Hautmann et al. 2015). Evolutionary consequences of increasing predation on hard-shelled prey (durophagy) became evident from the Middle Triassic onward and manifested in the evolution of antipredatory features such as cementation, improved armour, infaunalisation, and options for active escape (Hautmann 2004; Harper 2006). The effects from the removal of ecosystem engineers are exemplified by the disappearance of Permian reefs and carbonate platforms including the species that they harboured. Although smaller reefs sparsely re-appeared in the Early Triassic (Brayard et al. 2011), the main resurgence of carbonate build-ups took place in the Middle Triassic (Fig. 1), simultaneously with the main re-diversification of many benthic clades (Friesenbichler et al. 2019; unpublished data). During the Middle Triassic, positive effects on biodiversity due to habitat structuring by carbonate-producing organisms combined with those from increasing intensity of interspecific competition to produce a hyperbolic increase in benthic biodiversity (Hautmann et al. 2015), which continued until niche-pre-emption caused dampening of diversification in the Late Triassic.

Figure 1. Example for the re-establishment of large reefs during the Middle Triassic: Langkofel-group (South Tyrol), with spectacularly preserved reef-slope of the Plattkofel (right).

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5.10
Was the early tetrapod *Eryops* capable of a salamander-like walk? Developing new methods to test paleontological hypotheses about posture and gait

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The evolution of terrestrial locomotion in early tetrapods was one of the most significant events in vertebrate evolutionary history. However, we still do not know how these early tetrapods walked on land. Salamanders are often used as modern analogues for how early tetrapods moved, but few studies have tested this. Here, we tested *in vivo* and *ex vivo* knee and hip range of motion of *Salamandra salamandra* using rotoscoping and a new motion-capture experimental setup. We conclude that *in vivo* datasets offer data for comparisons to fossil taxa that are not available from *ex vivo* manipulation alone. With these *in vivo* data in hand, despite the lack of soft tissue preservation in fossils, we can use an exclusion-based approach to determine if the osteological joint range of motion in the fossil permitted certain gaits.

We developed a new method to investigate how the hip and knee joints interact to produce limb orientations, and to test paleontological hypothese about posture and gait. With this method, we oriented the hindlimb of the early tetrapod *Eryops megacephalus* to replicate four key limb poses employed by the salamander throughout its terrestrial stride cycle. We then tested *Eryops*' osteological joint range of motion to determine whether these poses could be achieved without reaching bony stops at both the hip and the knee. We conclude that, based on the bone morphology, *Eryops* was not incapable of a salamander-like lateral sequence walking gait. Future studies that incorporate other lines of evidence, such as soft tissue reconstructions and kinetic constraints, will help to further test this hypothesis.

5.11
A Devonian ctenophore from Canada

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Fossils of invertebrates lacking mineralized hard parts are generally rare. The likelihood of being preserved is lower when the content of water in the body is high and when the body parts are not or hardly sclerotized. Correspondingly, fossil remains of worms, jellyfish, slugs and the like can be found only in conservation deposits, where soft tissues were mineralized quickly or where imprints of bodies are buried quickly enough. Here, we present an invertebrate fossil, which displays an unusual symmetry. It was found in silty sandstones of the famous conservation deposit Miguasha (Canada), where Late Devonian sediments yield abundant fish fossils (e.g., Cloutier 2013; Cloutier et al. 2020). The disc-shaped fossil bears 18 radii, which fuse to groups of three towards its center. This means that only six radii can be seen around the centre. This symmetry is known only from some Cambrian dinomischids of the Burgess Shale and the Chengjiang Fauna. However, the disc- to sphere-shape is reminiscent of *Ctenorhabdotus*, another ctenophore from the Burgess Shale. By contrast, the 18 radii show a peculiar zigzag pattern, which resembles the cushion plates on tentacle rods of the Chinese genus *Daihua* (Zhao et al. 2019). We assessed its systematic position using parsimony analyses and Bayesian analysis using two different character matcrices (based on Zhao et al. 2019), where we coded missing characters following the two Cambrian ctenophores *Ctenorhabdotus* and *Daihua*. Depending on the matrix, the new taxon plots close to or at the base of the crown group of the Ctenophora. This new finding shows how little is known about this group.

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5.12 A new Euchelicerate (Synziphosurina) from the early Ordovician Fezouata Biota

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The Fezouata Formation in southeastern Morocco is an Early Ordovician Lagerstätte that preserves a wide variety of non-biomineralized taxa and anatomical features (Van Roy et al. 2015). This site is noteworthy because it preserves a mix of Cambrian Explosion fauna and more typical Paleozoic marine taxa, as exemplified by the arthropods from this site, which include radiodonts and other stem lineage taxa as well as a wide variety of euchelicerates. Two different undescribed euchelicerates are particularly abundant, one of them being the oldest occurrence of horseshoe crabs in the fossil record, and the other having been ascribed to a closely related clade known as the “synziphosurines”, characterised by the lack of a fused opisthosoma.

Synziphosurina is a paraphyletic clade of taxa of various affinities, including stem members of Euchelicerata and of the lineages leading to Eurypterida, Xiphosura and Arachnida. Here we described a new synziphosurine taxon characterized by the presence of a semi-circular prosoma with an apical carapace spine, a prosomal rim, and doublure. A first pair of uniramous appendages is present anterior to four pairs of biramous appendages and one pair of uniramous exopods in the prosoma. There are eleven post-cephalic targites, lacking fusion, and the first of them is not reduced to a ring like articulation, as seen in many synziphosurines, but instead is fully developed. The second to sixth targites possess a highly developed axis with pleura present from the first to the eighth segments. On the ventral side of the pre-abdomen uniramous appendages (exopods) have been found from the first to the seventh targites. The last four targites do not bear appendages and are fused with sternites forming a circular shaped segment. The pre-telson segment is often associated with a possibly membranous structure, interpreted as an anal pouch.

Only three taxa of Synziphosura have been found with preserved appendages and two of them shows strong similarities with the new taxon described here: *Offacolus kingi* (Orr et al 2000) and *Dibasterium durgae* (Briggs et al 2012) from the Silurian Lagerstätte of Herefordshire. Both of them are at least 50 Ma younger than our taxon. The new Fezouata Biota taxon possesses some characters in common with these taxa, such as biramous prosomal appendages similar in morphology to those of the Offacolus *kingi*, but also shares characters with crown euchelicerates, like a prosomal rim. Cambrian arthropods such as *Habelia optata* shares with the new taxon here described the number of targites, a squared margin of the axis, and an anal pouch. We undertook a phylogenetic analysis to clarify the phylogenetic position of the group. Two different datasets (Jago et al 2016; Aria et al 2019) have been used and compared, using both parsimony and Bayesian methods to increase the reliability of our result. The new taxon resolves as a stem-euchelicerate, and provides new information for understanding early euchelicerate evolution.

An in-depth study of the Fezouata shale material clarifies the evolution and phylogeny of early xiphosurids and synziphosurines, and the relationships between them and other euchelicerates. Linking our new findings on euchelicerate diversity during the Great Ordovician Biodiversification Event to the earliest origin of the phylum, as recorded in Cambrian Burgess Shale-type biotas, provides a more complete picture of euarthropod evolution during these major events.

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5.13
A new Lower Ordovician nektaspid euarthropod from Morocco

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Nektaspids are non-biomineralized euarthropods that were at the peak of their diversity during the Cambrian Period. Post-Cambrian nektaspids are a low-diversity group with only a few species described so far. Tariccoia tazagurtensis is a new species of small-bodied nektaspid (of the family Liwiidae) from the Lower Ordovician Fezouata Shale of Morocco. This species is characterized by a sub-circular cephalon with pointed genal angles and with a marginal rim; a thorax consisting of four tergites, the 1st and 2nd of which are overlapped by the cephalic shield; and by a pygidium with its anterior margin curved forwards, a rounded posterior margin and a long medial keel that does not reach the posterior pygidial border. T. tazagurtensis differs from the type (and only other known) species from the Ordovician strata of Sardinia (Italy), Tariccoia arrusensis, mainly in its cephalon and pygidial morphologies. The two specimens of T. tazagurtensis preserve remains of the anterior part of the digestive tract, which are comparable to the ramified digestive glands seen in in the Cambrian nektaspids Naraoia and Misszhouia canadiensis. The rare occurrence of T. tazagurtensis in the Fezouata Shale and the distribution of other liwiids suggest that these liwiids were originally minor members of open-marine communities during the Cambrian, and migrated into colder brackish or restricted seas during the Ordovician.

5.14
The false gharial *Tomistoma schlegelii* and its implications for phylogeny and character assessment of extant and extinct crocodylians

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Diversity and distribution of extant crocodylians is, with just over 25 species, quite depleted, with many species being prone to extinction and showing restricted and/or fragmented habitats. Considering the whole of crown-group Crocodylia including the extinct closest relatives of alligators and caimans, crocodiles, gharials, a different, more diverse picture emerges, in which, even in the recent geological past, these amphibious ambush predators were much more common in non-marine, and potentially even in nearshore marine ecosystems (e.g., Salas-Gismondi et al. 2019). Unfortunately, relationships between the extant and extinct crocodylians are still largely under debate, with molecular, mrophological, or total-evidence approaches often providing contradicting results. Furthermore, there is also a bias when using osteological descriptions for comparison with fossils: crania are more abundantly collected and more thoroughly described compared to postcrania. Here we use the description of a complete adult skeleton of the extant false gharial *Tomistoma schlegelii* from the collections of the Zoological Museum of the University of Zurich as starting point to explore the phylogentic value of the often less studied axial and appendicular skeletal parts. This serves as basis for the establishment of the first postcranial character-only matrix on extant and extinct Crocodylia. Surprisingly, even completely taking out cranial data, our phylogenetic analyses mostly retrieve the same topology as previous morphological studies (that are to a large degree based on cranial data instead), except for a few taxa that were recovered in unexpected positions. This might be resolved in the future by acquiring more comparative data on the postcranial skeleton of crocodylians in general, especially of extant species. Nevertheless, our study shows that crocodylian postcranial data does carry a phylogenetic signal, and as such, should be used more widely in morphological datasets. Furthermore, the use of continuous data instead of using discrete characters also often proved to be the more efficient approach, a result that ought to be further studied in future analyses as well.

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5.15 Phylogenetic analysis of Cambrian-Ordovician nautiloid cephalopods

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Cephalopods are important components of many modern and past marine ecosystems. In addition, externally shelled representatives provide an excellent fossil record dating back to the late Cambrian. In the Early Ordovician, cephalopods underwent a rapid diversification with most of the major groups informally referred to as "nautiloids" appearing for the first time. Nevertheless, the early evolutionary history and the relationships between those groups remain poorly understood and partly controversial. There exist a number of classification schemes that are sometimes incompatible with each other (e.g. Dzik 1984; Mutvei 2015; King & Evans 2019). This incongruency is explained by profound differences in the underlying phylogenetic hypotheses, which commonly reflect the author's opinions on the importance of certain characters, rather than being based on a thorough cladistic analysis. To date, cladistics have been scarcely used in nautiloid research and based on rather limited datasets.

Here, we present the first comprehensive phylogenetic analysis of Cambrian and Ordovician nautiloid cephalopods based on a large, newly compiled character matrix. We defined 137 characters and scored them for 163 species from all major groups spanning a time interval of about 50 million years from the Jiangshanian (late Cambrian) to the Hirnantian (Late Ordovician). The species were partly scored first hand and from a thorough survey and critical assessment of the existing literature. In some cases, we replaced missing data with data from congeneric species to maximise the information content of the data set. We analysed the data using both parsimony and Bayesian approaches, with an emphasis on the latter. Bayesian methods are widely applied to molecular data, but they have also gained more attention for morphological data recently, with a rapid development of new methods (Wright 2019). We used the fossilized birth-death model, which incorporates stratigraphic ages sampled through time (Heath et al. 2014). In addition, we applied a relaxed clock model to adjust for rate heterogeneities. This approach enabled us to reconstruct a timeline of nautiloid evolution.
The results recover many of the previously recognized groups, indicating that the application of phylogenetic methods on fossil nautiloids is well justified. They may serve as a robust base for a modern phylogenetic classification. Where uncertainties persist, future studies with additional data or refined models may increase accuracy.

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5.16
Fossil and modern microbialites from where everything starts : lake de Los Cisnes (southernmost Chile)

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Microbialites are organo-sedimentary deposits formed by the activity of most often a microbial consortium (Burne et Moore 1987). Appeared more than 3.5 billion years ago, they represent the oldest evidence of life on Earth discovered to date (Riding 2011). Currently, these structures are developing all over the world in both lacustrine and marine settings (e.g., Australia, Brazil, The Bahamas). However, after nearly 100 years of research on the taxonomy, sedimentological characteristics, and distribution of microbialites through time and space (Riding 2011), the origin and significance of these particular deposits is still a matter of debate. Little is known about microbialite formation, in particular the relative roles of microbial versus environmental factors ruling their accretion. Lake de Los Cisnes located at 53 ° 25’ S and 70 ° 40’ W in Chilean Tierra del Fuego, Patagonia, provides us with a unique site to fill this gap. This basin is part of a set of lakes formed during the retreat of the ice following the last glaciation about 10,000 years ago. Subsequently, Lake de Los Cisnes was densely colonized by microbial mats that developed the presently living and fossil microbialites. We present here the preliminary results obtained during a field campaign carried out in early February 2020, exploring the relative contributions of environmental (extrinsic) versus biological (intrinsic) factors that control microbialite morphogenesis across scales (Fig.1A).

Macroscopically, those organo-sedimentary deposits have an extension of almost 8 km^2 encompassing several morphologies exceptionally large with maximum heights and widths of 1.5 m and 5.0 m, respectively. Crater-like shapes are dominant, displaying a spherical to elongated character most frequently unfilled. Both spatial distribution and temporal succession of morphotypes suggest that physico-chemical settings are critical in the localisation as well as in the style of the microbial carbonate factory, which in turn is reflected in the gross morphology of the subsequent deposit (Fig.1A and B). On a smaller scale, the microbialite meso-structure reveals a pattern of three mineralogically and chemically distinct stacked layers (Fig.1C). This fabric reflects a multiphase history of formation, link with the ecological temporal succession of bacterial communities (Fig.1D), still under influence of environmental conditions (Fig.1A). Interestingly, the simultaneous occurrence of various living bacterial mats showing several stages of mineralization (both intra and extra-cellular), provides insights regarding the microscale complex interactions between the different compounds of the bacterial ecosystem (cyanobacteria, sulfate-reducing bacteria, green algae and diatoms) (Fig.1D).
Finally, the presence of extraordinary well-preserved fossil outcrops along with living microbialites gives a temporal dimension to this study, laying the foundations for a new formation model. By applying this model to other microbialites outcropping at different geographical and temporal scales, the microbial carbonates of Lake de Los Cisnes could represent a key to understand the early evolution of life in connection with the environment of the past.

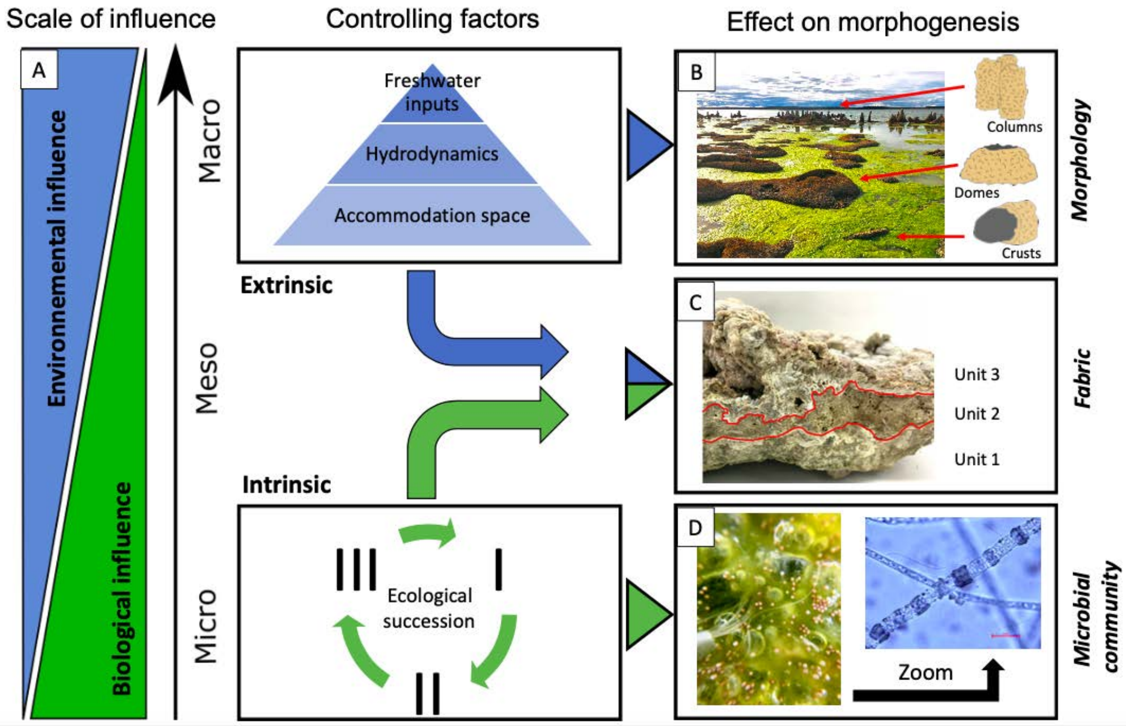

Fig. 1 : Conceptual model illustrating the traditional view of the relative influence of environmental versus biological factors on stromatolite morphogenesis at macro (morphology), meso (fabric) and micro (microbial community) scales. Original Trompette (1982) model (A) shows that microbes controls microscale microbial community whereas environment controls macroscale morphology. Modifications based on recent research from Lake de Los Cisnes have revised the model showing : (B) At the macroscale, microbialites are shape by a continuum of environmental factors with different orders of importance ; (B) At the mesoscale, the dual influence predicted by Trompette (1982) is supported by current research, showing fabrics are controlled equally by environment and biology; (C) at the microscale, microbial mats reflect a cycling of three different communities : (I) a floating filamentous phototrophic community which traps and binds sediments; (II) a benthic mixotrophic biofilm community, which precipitates microcrystalline calcium carbonates; (III) an endolithic community, which forms cemented layers. Based on Trompette (1982).

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5.17
Oligocene rhinoceroses from Switzerland untangle the phylogeny of the early Rhinocerotidae

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We describe two new Oligocene species of rhinoceroses, *Mesaceratherium tschani* and *Ronzotherium* sp. nov., that were both found in the Swiss locality of Bumbach, Bern Canton (MP25 reference level, "middle" Oligocene). In addition, we identify the only known complete mandible of *Epiaceratherium magnum*, that was found in a locality near Basel. *Epiaceratherium* and *Ronzotherium* were the earliest rhinoceroses in Western Europe and appeared just after the Eocene-Oligocene transition (Grande Coupure). *Mesaceratherium* is mostly known from the late Oligocene of Western Europe, and *M. tschani* from Bumbach is thus the earliest known species of this genus.
We computed a parsimony analysis based on morpho-anatomical characters to assess their phylogenetic position and elucidate the early evolution of the Rhinocerotidae. The reduction of the anterior dentition (i.e. incisors and canines) is a major adaptative trait of this group but the corresponding evolutionary sequence was lacking a robust phylogenetic frame to support it thus far. The results we found allow to propose a new scenario for the reduction of the anterior dentition and show that upper and lower anterior dentitions have undergone distinct evolutionary trajectories.

Figure 1. Mandibles of *Epiaceratherium magnum* from Rheinbetts (top-left), of *Mesaceratherium tschani* (top right) from Bumbach and of *Ronzotherium* sp. nov. (bottom) from Bumbach. Scale bar equals 2cm.

5.18 The evolutionary–phylogenetic pathway of *Aegocrioceras* spp.: Revisiting a Cretaceous ammonoid

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The Cretaceous ammonite genus *Aegocrioceras* from the Boreal of northern Europe is an enigmatic ammonite taxon. The last systematic description of this endemic genus dates back to Rawson's (1975) work on the English Speeton clays. Both, the systematic validity of its species (Hoffmann et al. 2019) as well as the origin of the genus—either descending from the Boreal *Juddiceras* (Rawson 1975) or Tethyan *Crioceratites* (Rawson 1995)—are still a matter of debate.

Here, we use an assemblage consisting of the *Aegocrioceras*-species *A. bicarinatum* [m], *A. quadratum*, *A. raricostatum*, *A. semicinctum* [M], and *A. spathi* from the clay pit Resse north of Hannover (NW Germany). A total of 320 specimens have been analysed for their conch morphology using univariate measurements, and their ontogenetic growth trajectories have been predicted. These morphometric measurements were then used for a systematic analysis within the *Aegocrioceras* genus and its relationship to the potential sister taxa *Crioceratites seeleyi*, *Emericiceras wermbteri*, and *Juddiceras curvicosta*.

We observe a clear systematic distinction of *A. raricostatum*, *A. spathi*, and the *A. bicarinatum*/*semicinctum*/*quadratum* complex (Fig. 1A). This supports earlier results from Hoffmann et al. (2019), which imply that *A. bicarinatum* [m] and *A. semicinctum* [M] are two antidimorphs of the same morphospecies. Potentially this complex also includes *A. quadratum*, but with only two usable specimens of that species in our final dataset this is impossible to verify. The species *A. raricostatum* and *A. spathi* are retained as separate morphospecies, however. A phenetic analysis puts all *Aegocrioceras*-species firmly within one clade, suggesting their monophyletic origin (Fig. 1B). The *Aegocrioceras bicarinatum*/*semicinctum* complex would be the phylogenetically oldest, with *A. spathi* being the youngest species and potentially a sister taxon to the boreal *Crioceratites seeleyi*. This is supported by the stratigraphic range and strato-phylogram developed by Rawson (1975) for the Speeton clay, as well as observations of the stratigraphic distribution of species in the clay pit Resse.
Our study thus confirms the monophyly of *Aegocrioceras* spp. as an endemic ammonoid genus from the Boreal. A derivation from both the Boreal *Juddiceras* and Tethyan *Crioceratites* leads to nearly identical phylogenies which are coherent with the observed stratigraphic distribution of the species, so that a decision for either one of the derivation hypotheses cannot be made based on our data. We hypothesize, though, that at least some of the later (i.e. Hauterivian) *Crioceratites* in the Boreal may indeed be descendants of local *Aegocrioceras*-species, instead of newly invading Tethyan forms. Further studies incorporating more Boreal *Crioceratites*-species are needed to verify this hypothesis.

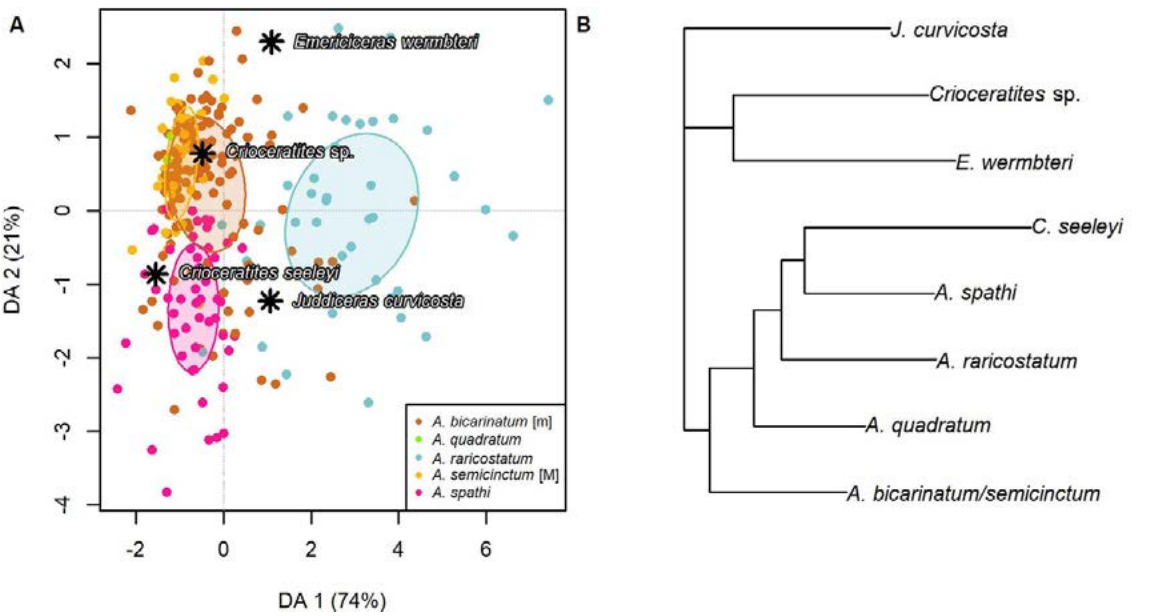

Figure 1. A: Flexible discriminant analysis of *Aegocrioceras* spp. from the clay pit Resse, including position of closely related species from the same region. B: Potential phylogram of *Aegocrioceras* spp. and related species with *Juddiceras curvicosta* as outgroup.

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P 5.1
Cranio-dental anatomy and phylogenetic analysis of Amynodontidae (Perissodactyla, Rhinocerotoidea)

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Amynodontidae are an extinct family of Rhinocerotoidea known from the Middle Eocene to the latest Oligocene. Amynodontidae had an important diversification during the Middle and Late Eocene in North America, in Asia and in Eastern Europe. Their presence in Western Europe is dated from the Oligocene and is related to the the “Grande Coupure” event.

We describe here unpublished specimens of Amynodontidae, a skull and a mandible, of *Zaisanamynodon borisovi* (Fig.1A-B) from the Late Eocene/Early Oligocene of the Zaysan Basin (Kazakhstan) and a skull of *Metamynodon planifrons* (Fig. 1C-D), from the Early Oligocene of the Big Badlands (United States). We included this new cranio-dental material in a morphological characters matrix (Tissier et al. 2018). It was completed with cranial specimens of the Amynodontidae *Amynodontopsis jiyuanensis*, *Cadurcotherium cayluxi* and *Cadurcotherium minus*.

We computed a parsimony analysis based on this matrix, including taxa of Rhinocerotidae, “Hyracodontidae” and Amynodontidae. We propose here a new phylogenetic hypothesis which allows to discuss the phylogenetic positions of the new referred specimens within the Amynodontidae and the position of the Amynodontidae within the Rhinocerotoidea. The new fossil occurrences described here expand the understanding of the geographical distribution of Amynodontidae.

Our phylogenetic results mostly display the same topology as previous morphological studies (e.g., Averianov et al. 2016; Tissier et al. 2018). Our cladistic analysis includes a more complete taxonomic sampling of Amynodontidae which permits to clarify the generic composition of the amynodontid tribes Metamynodontini and Cadurcodontini. The presence of several cranial characters such as the nasal incision above P4-M1 suggests an adaptation of the nasal area related to the presence of a proboscis in Cadurcodontini. These characters explain the split of the two tribes.

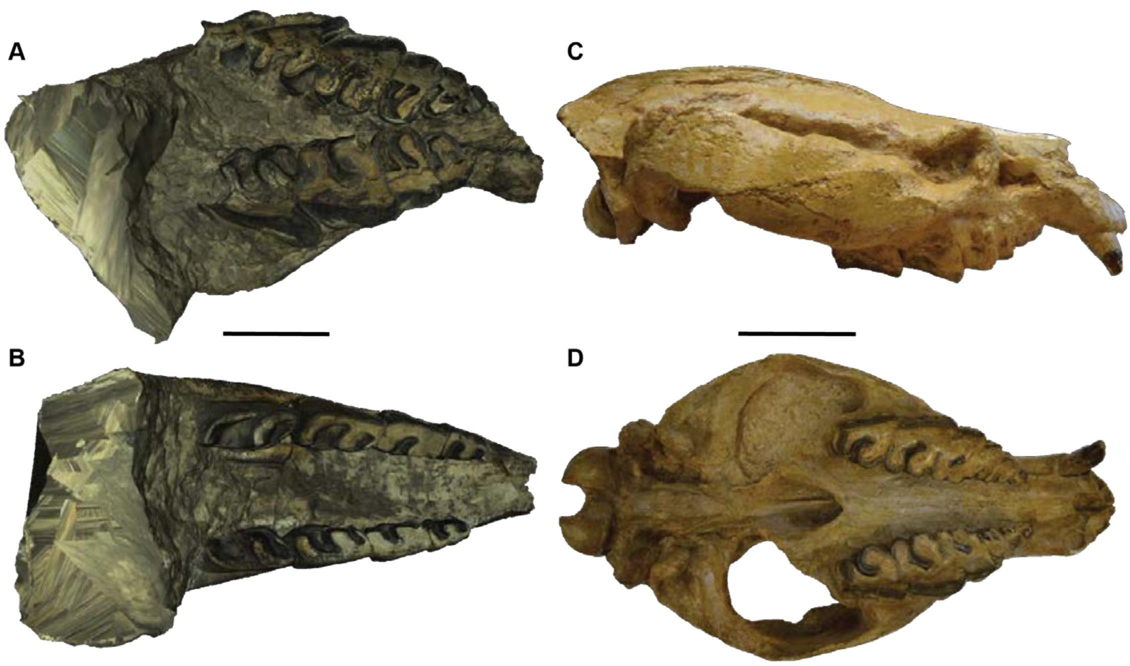

Figure 1. A-B: Skull and mandible of *Zaisanamynodon borisovi* from Kazakhstan; C-D: Skull of *Metamynodon planifrons* from The United States of America. Scale bars equal 10 cm.

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P 5.2
Avian cranial suture closure: an interspecific indicator for age

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The ontogeny of various vertebrate groups is characterized by a successive sutural closure between different skull bones during growth, which can be used as an osteological proxy for skeleton maturity. Bone sutures in juvenile vertebrates are usually open or incompletely connected, while those of adults are closed or even fused. The sutural closure has been essentially studied in mammals showing that the timing of cranial closure is very similar in all of the major placental clades (Rager *et al.* 2013). Sutural closure has been further studied for alligators and emus, but a detailed comparison revealed that the mammalian model cannot be adapted to archosaurs (Bailleul *et al.* 2015, 2016). This indicates a greater disparity in this ontogenetic process within vertebrates that need to be studied in more detail.

The goal of our study is to investigate if a general pattern of sutural closure (similar to that of mammals) can be determine for birds through ontogeny. To do so, we collected skull suture information for the ontogenetic series of ten bird species following the protocol of Bailleul *et al* (2016). We created an ontogenetic matrix of 39 suture characters and calculated the average of the sutural closures (ontogenetic ratio) for each specimen. Finally, we tested the correlation between sutural closure and log-transformed geometric mean (see Claude 2008) for each species.

Our analyses reveal that the degree of suture closure correlates significantly with the log-transformed geometric mean (Figure 1) and can be used to assess skull maturity, supporting the findings of the case study by Bailleul et al. (2016). However, the slope between the ontogenetic ratio and size differs from species to species, indicating interspecific variation that probably results from species-specific skeletal growth rates (Botelho and Faunes, 2015).

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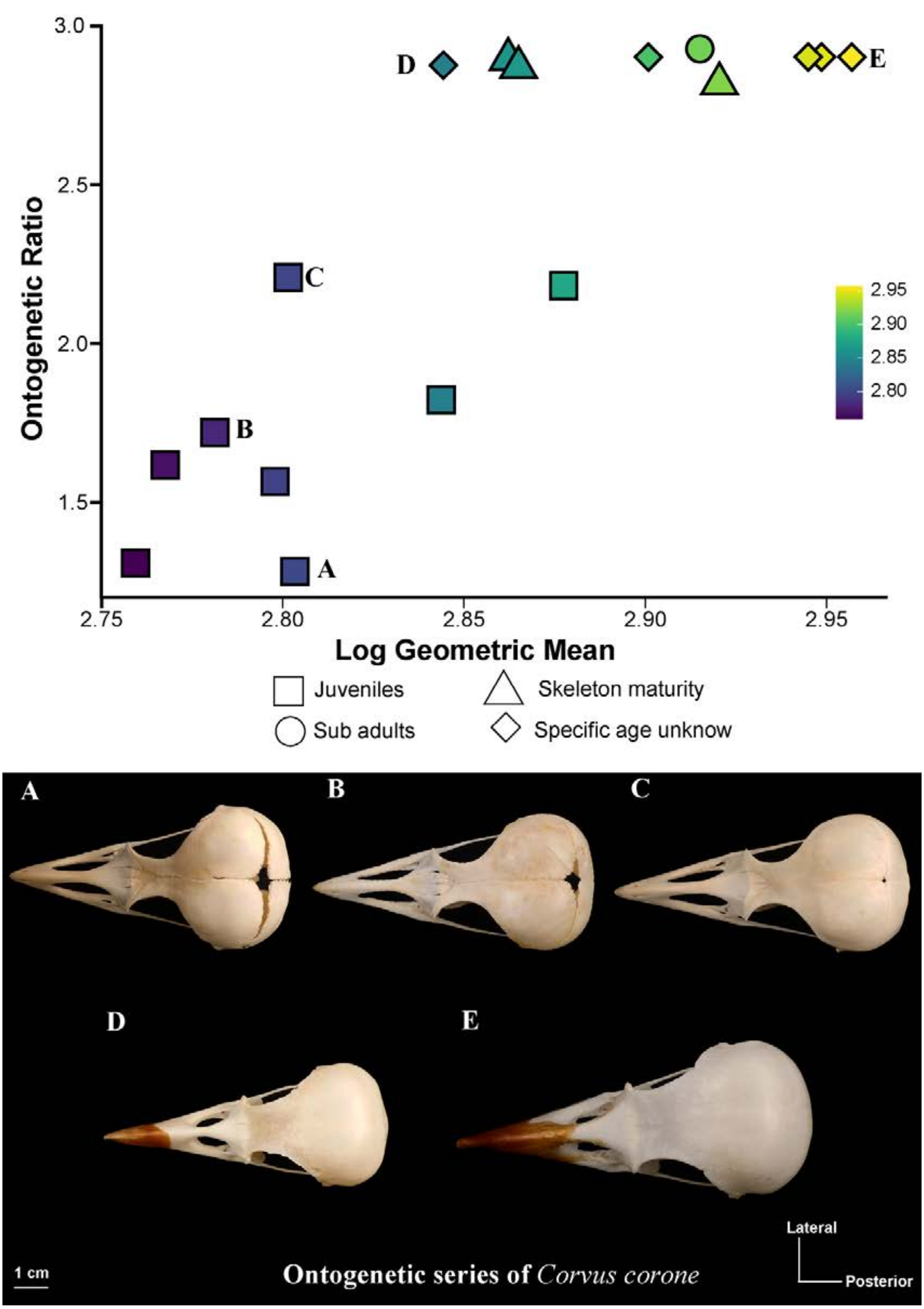

Figure 1. Ontogenetic serie of *Corvus corone*. The bivariate plot shows a significant relation between the log-transformed geometric mean and ontogenetic ratio (R2= 0.71, pvalue < 0.0001). A-B-C-D-E correspond to different ontogenetic stage showing the major modification on the skull in dorsal view.

P 5.3
A new coelacanth from the lower Jurassic of Switzerland

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The Middle Triassic of Switzerland has yielded four taxa of actinistians including Ticinepomis peyeri (Rieppel, 1980), Heptanema cf. paradoxum (Renesto & Stockar, 2018) and a new genus from Monte San Giorgio (Ferrante et al., 2017), Canton Ticino, and Foreyia Maxkhuni and Ticinepomis cf. peyeri, both from the Ducan–Landwasser mountains, Canton Graubünden (Cavin et al., 2017). Except this relatively high diversity of coelacanths found in the Triassic, few occurrences have been discovered in younger rocks.

One of the rare exception, and probably one of the first coelacanth fossil found in Switzerland, is a specimen collected in 1873-1874 in the lower Jurassic of the “Préalpes Médianes Plastiques”, near Teysachaux, a summit close to the iconic Moléson, Canton Fribourg. The identity of the collector is unknown. Potentially it is Joseph Cardinaux, a fossil collector and dealer who found and sold many other fossils, notably the first ichthyosaur in Switzerland (Mennecart & Havran, 2013), originating from this area to Fischer-Ooster, a paleontologist at the Museum of Bern.

The section at Teysachaux in a locality named “Creux de l’Ours” has yielded many marine fossils, including many bivalves, gastropods, ammonites, belemnites and some rare vertebrates such fishes and ichthyosaurs (Mennecart & Havran, 2013). It is composed of grey thin-bedded hemipelagic marls and marly limestones. The deposit was accumulated during the lower Toarcian in a deep and distal part of the Sub-Briançonnais basin of the Alpine Tethys under a warm and humid climat (Fantasia et al., 2018).

Fischer-Ooster wrote on the label of the specimen *Macropoma heeri*, corresponding to a new species of this genus, but he did not publish a diagnosis, a description and an illustration of the specimen. Consequently, this species should be regarded as a *nomen nudum* according to the International Code of Zoological Nomenclature. This mostly complete specimen (Fig. 1), lacking cheek and jaw bones, share characters with the type species of *Macropoma*, *M. lewesiensis* from the early Late Cretaceous of Europe, e.g the ventral swelling of the pterygoid, but it also differs by some characters, such the supraorbital sensory canal opening through a large, continuous groove crossed by pillars similar to *Libys polypterus* (Cavin et al., 2017), from the Upper Jurassic of Germany. If the generic identity of the specimen of Teysachaux is confirmed, this would increase considerably the stratigraphic range of the genus *Macropoma*, extending it by 80 million years in the past. Moreover, *Macropoma* is one of the closest relative of the extant *Latimeria*, except the Upper Jurassic *Swenzia*. The long stratigraphical range of this genera, and its morphological proximity with *Latimeria*, reinforce the idea that this coelacanth lineage has evolved morphologically slowly, which earned to the last living coelacanth *Latimeria* the nickname of “living fossil”.

Figure 1. The nearly complete specimen of coelacanth from the lower Jurassic found at Teysachaux, Switzerland.

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P 5.4
Evolutionary history of the tselfatiiforms - weird ray-finned fishes from the Cretaceous - with a focus on Lebanese taxa

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Tselfatiiformes, or Bananogmiiformes (banana-fishes), is an extinct order of actinopterygian fishes from the Cretaceous, extending over a short stratigraphical range from the Albian to the Campanian. It includes around 20 genera distributed around the world. The phylogenetic position of this order within the Teleosts as well as the intrarelationships within the clade are far from being resolved (Cavin 2001 vs Taverne & Gayet 2004). Therefore, previously studied material from various localities (Europe, Morocco, USA) housed at different institutions will be reviewed and new material, mainly from the Lagerstätte of Lebanon, will be investigated by tackling osteological, phylogenetic, palaeobiogeographical and paleoecological approaches.

The study of two specimens, one originating from the Lebanese deposits of Hjoula (Fig. 1 A and B) and the other from Haqel (Fig.1 C), allowed us to assign the first to the Lebanese endemic family Protobramidae, and the second was found to be closer to to the North-American genus *Martinichthys*.

With most tselfatiiforms having highly derived cranial and postcranial features, in particular characters related to the jaws and the dentition, these fishes likely occupied a peculiar position in the trophic web. They also display a positive correlation of body size with time (Cope's rule) (Guinot & Cavin 2018), along with a positive correlation of their taxic diversity with sea temperature (Cavin et al. 2007).

A hypothesis to be tested is that these fishes were pelagic fast swimmers feeding on soft bodied invertebrate, including jellyfish. The peculiar environmental conditions in the mid Cretaceous may have fostered this adaptation, in particular exceptionally high sea level and high sea temperature overreaching 30°C in the Tethys (Gale 2000).

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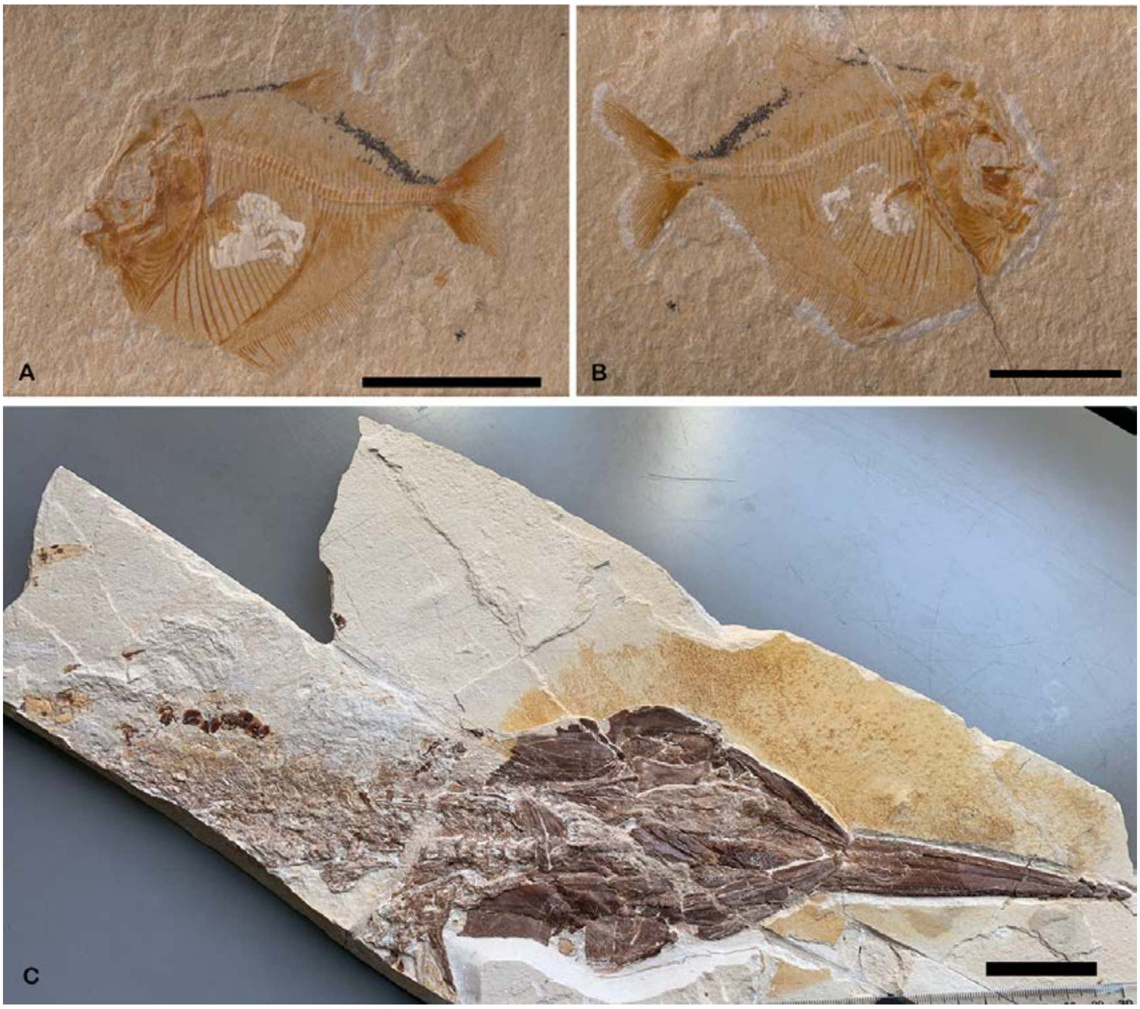

Figure 1. A, B, Part and counterpart of a complete specimen preserved in lateral view, originating from Hjoula, Lebanon. Scale bar equals 2 cm; C, Incomplete specimen preserved in ventero-lateral view, originating from Haqel, Lebanon. Scale bar equals 4 cm.

P 5.5
Reproduction strategies in a marine protist: A modelling approach

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Understanding the biology of reproduction is important for retracing key evolutionary processes (e.g. speciation and adaptation) in any group of organisms, yet gaining detailed insights often poses a major challenge. Planktonic Foraminifera are a group of globally distributed marine microbial eukaryotes that are important contributors to the global carbon cycle and, due to their fossil record, are widely used as model organisms to investigate the responses of plankton to past environmental changes (Kučera 2007). The extant biodiversity of planktonic Foraminifera shows restricted distribution patterns and local adaptations of some species, whereas others are cosmopolitan in the world ocean. Hypotheses on their diversification and population dynamics so far entirely rely on the assumption of a nearly exclusively sexual reproduction (Bé & Anderson 1976, Takagi et al. 2020).

So far, reproduction in culture has not been successful under laboratory conditions, and thus details on their life cycle and its influence on the evolution of the group remain unknown. Only the production of flagellated gametes has been observed and is taken as an indication for sexual reproduction. Yet, sexual reproduction by spawning of gametes in the open ocean relies on sufficient gamete encounters to maintain viable populations. This represents a problem especially for unflagellated protists like planktonic Foraminifera, which lack the means of active propulsion and are characterized by low population densities in large areas of the world ocean (Bé 1977).

To increase the sparse knowledge on the reproductive biology of planktonic Foraminifera, we applied a dynamic, individual-based modelling approach with parameters based on laboratory and field observations (Fig. 1). We tested if random gamete encounters under commonly observed population densities are sufficient for maintaining viable populations or if alternative strategies, such as asexual reproduction or synchronization in depth and time, are indispensable to achieve reproduction success. Our results show that a strict synchronization of gamete release in time and/or space seems inevitable for a successful maintenance of populations. We further argue that planktonic Foraminifera optimized their individual reproductive success at the expense of community-wide gene flow, which may explain their high degree of diversity as well as hampered evolvability. Our modelling approach helps to illuminate the ecology and evolution of this important marine calcifier and to predict the existence of necessary reproduction strategies, which may be detectable in future field experiments.

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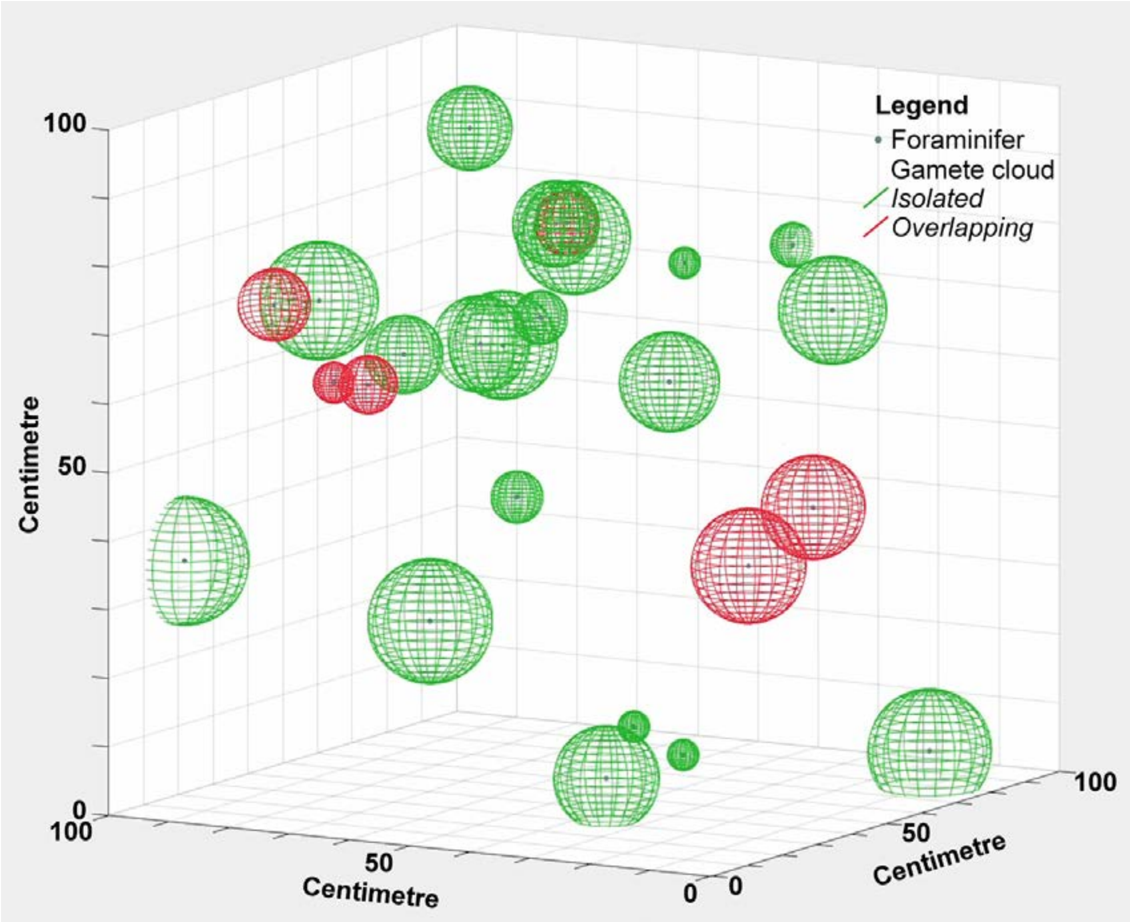

Figure 1. Representative depiction of the modelling approach within on cubic metre of sea water under laminar flow. Individual Foraminifera release gametes within a certain time frame (varying degrees of synchronization). The gametes disperse, following Brownian motion and a prescribed speed, to create a spherical gamete cloud around foraminiferal shells. Whenever the gamete clouds of two individuals overlap (red spheres) there is a chance for fusion of two gametes into a zygote based on estimates of the local gamete density.

P 5.6
Evaluation of sea surface temperature gradient during the Smithian-Spathian (Early Triassic) using oxygen isotopes in conodont bioapatite

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In the aftermath of the greatest extinction event in Earth's history (end–Permian mass extinction), the Early Triassic was a period with major environmental perturbations that required consecutive adaptations of living organisms. Early interpretations suggested lethally hot sea surface temperatures (in excess of 40 °C) and harsh environmental conditions (persisting for ca. 5 Myr) as the main explanation for the delayed recovery of marine ecosystems (e.g., Joachismki et al., 2012; Sun et al., 2012). In contrast, more recent studies with higher data density characterized the Early Triassic as a succession of short term cycles of extinctions and recovery periods. These cycles were likely controlled by climatic oscillations with locally variable environmental impacts (Song et al., 2011; Leu et al., 2019; Goudemand et al., 2019). To further constrain these climatic cycles, we selectively analyzed conodont bioapatite for its oxygen isotope composition from a number of high paleolatitude profiles that sadly have a low abundance of conodonts only, and hence where where bulk sampling geochemical techniques cannot be used. This required the use of secondary ion mass spectrometry (SIMS), which we calibrated using a more conventional method of using bulk sampling and high temperature reduction (HTR) analysis (e.g., Mine et al., 2017). The analyses focused on specimens from the 'Smithian–Spathian boundary' (SSB), as this represents a crucial interval with the biggest intra–Triassic extinction in the nekton, following the end-Permian main extinction phase by ca. 2.5 Ma (Widmann et al., 2020). 26 conodont elements from the *Scythogondollella* taxon were analysed so far: 13 from Timor (Noe Tobe) and 6 from the United States (Crittenden Springs, Georgetown, Schneebeli-Hermann et al., 2020) that geochronologically represent the *Wasatchites* ammonoid zone (Late Smithian); and another 7 from Spitsbergen (Stensiöfjellet), representing three stratigraphic horizons from the Middle Smithian up to the Late Smithian (*Arctoceras*, *Arctoceras*/*Euflemingites* and *Wasatchites* beds). Samples of *Sc*. ex gr. *milleri* from the Late Smithian of USA have a mean $d^{18}O_{PO4}$ value of 15.4 ±0.3 ‰ (*n* = 6, 20 spots), somewhat higher than the average $d^{18}O_{PO4}$ of samples from the Middle/Late Smithian of Spitsbergen (14.4 ±0.1 ‰, *n* = 7, 18 spots). The mean value of *Sc*. ex gr. *milleri* from Timor was highest (TM_{scm}: 17.1 ±0.2 ‰, *n* = 13). We performed statistical tests (Student's t-test, One-way ANOVA, Tukey's pairwise) among the three datasets (Timor *vs* USA *vs* Spitsbergen) and the results have significant differences in their average isotopic compositions. Two factors control the $d^{18}O$ value from a given bioapatite during its formation: temperature and the $d^{18}O$ of the water. Rather than representing differences in the temperatures of biomineralization, these differences in $d^{18}O_{PO4}$ averages may be related to distinct depositional and/or latitudanal settings within which the bioapatite crystallized. Conodonts from the western and northern Pangea (USA and Spitsbergen) are from geological sections that may have had a coastal influence, while conodonts from the Tethyan realm (Timor) were sampled from sites predominantly deposited under offshore, tropical conditions. Assuming similar habitats and hence water temperatures for the same conodont species sampled from high paleolatitudes (*Sc*. ex gr. *milleri*) their $d^{18}O_{PO4}$ values correspond to $d^{18}O_{water}$ values of about –3.5 ‰. Given the conventional value of –1 ‰ for an open ocean in an ice-free world, a paleolatitudinal offset of about –2.5 ‰ can be estimated (–1 vs –3.5 ‰), similar to that noted for modern seawater $d^{18}O$ values between low and high latitudinal waters (e.g., LeGrande & Schmidt, 2006). Within the errors of the methods used, these results support Early Triassic offshore seawater temperatures that were biologically feasible. Additional analyses in other conodont specimens/species from the northern Pangea and from the Panthalassic realm can help to estimate paleotemperatures and to understand the paleoclimatic context of these localities.

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06. Stratigraphy and Sedimentology: processes and deposits through time

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Swiss Committee for Stratigraphy (SKS/CSS)
Swiss Palaeontological Society (SPG/SPS)
Swiss Geological Survey – swisstopo

TALKS:

POSTERS:

P 6.1 *Watkins S.E., Simpson G., Guerit L., Sharma N., Tremblin M., Valero L., Zaki A.S., Arlaud F., Castelltort S.*: Understanding the differences in aggradation styles in fluvial stratigraphy between upstream climate-driven processes (i.e., water discharge and sediment supply variations) and downstream sea-level changes: insights from physical modelling

P 6.2 *Garefalakis P., Schlunegger F.*: Possible relation between sediment flux and grain size extracted from coarse-grained Swiss Molasse deposits

P 6.3 *Harlet D., Douillet G.A., Ghienne J.-F., Razin P., Dietrich P., Schlunegger F., Bouscary C.*: Stratigraphic architecture and depositional processes across lower Paleozoic siliciclastic shallow-marine platfomes: insights from the Late Ordovician of the Anti-Atlas (Southern Morocco)

P 6.4 *Blattmann F.R., Bucher H., Adatte T., Schneebeli-Hermann E., Bagherpour B., Vennemann T.*: Early Triassic Organic Carbon Cycle Perturbations in High Latitudes

P 6.5 *Lorenzo V., Baumgartner C., Baumgartner P.O., Escuder-Viruete J.*: Emergence and carbonate platform formation on the Caribbean Large Igneous Province – Exposures of the Bahoruco Peninsula (Dominican Republic)

P 6.6 *Peyrotty G., Brigaud B., Martini R.*: $\delta^{18}O$, $\delta^{13}C$, trace elements and REE in situ measurements coupled with U–Pb ages to reconstruct the diagenesis of Upper Triassic atoll-type carbonates from the Panthalassa Ocean

P 6.7 *Fucelli A., Martini R.*: Sedimentology and stratigraphy of the Upper Triassic carbonates from Hosselkus Limestone and Luning Formation (Western USA)

P 6.8 *Saitoh M., Olivier N., Garçon M., Boyet M., Thomazo C., Ueno Y., Moyen, J.-F., Marin-Carbonne J.*: Petrological and geochemical characteristics of the 3.47 Ga Middle Marker horizon in the Barberton Greenstone Belt, South Africa

6.1
The Role Of Deccan Traps On The Environment And Faunas: Evidences From Central Anatolia, Turkey

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Arguably no mass extinction boundary has ever hosted such a highly debate and dispute like the end-Cretaceous event. It has been 40 years since the postulation of extraterrestial source as the prime suspect of this mass killing at the K-Pg boundary (Alvarez et al. 1980). It is unique among the other big five phenomena as no other event accommodates an impact (the Chicxulub impact) and LIP activity (the Deccan Traps). Specifically, the role of the Deccan volcanism on the environment and the ecosystem is crucial to gain better insight into the latest Maastrichtian world. To do so, we performed high resolution biostratigraphy, stable isotope and geochemical analysis on two basins (Haymana and Mudurnu-Goynuk) in Central Anatolia, Turkey.

In both basins the K-Pg boundary is sharp and characterized by 2-3 mm thick reddish oxidized layer. Moreover, measurements in the Haymana Basin shows an Ir anomaly (3,5 ppb in contrast to average 0,5 ppb background level). This layer also corresponds to sudden annihilation of large, ornamented ecological specialists (e.g., *Globotruncana, Rugoglobigerina, Racemiguembelina*) with minor survivors from ecological generalists (e.g., *Heterohelix, Globigerinelloides, Guembelitria*). We also detected surges of opportunistic planktonic foraminifera *Guembelitria cretacea* and calcareous dinoflagellate *Thoracosphaera* indicating the ecosystem collapse right after the impact. Molybdenum (Mo) measurements also peaks at the K-Pg boundary representing bottom water deoxygenation in the earliest Danian. However, detailed quantitative planktonic foraminifera analysis in Haymana Basin shows that there has been ongoing reduction in species in the Late Maastrichtian *Plummerita hantkeninoides* Zone. In fact, this total richness drops by 46% within the final 3.75 m before the K-Pg boundary. Proliferations of the *Guembelitria cretacea* through the Late Maastrichtian represents high terrigenous influx and hence enhanced food resources. High sedimentation rates observed in all sections might be linked to increased greenhouse conditions due to Deccan volcanism leading to enhanced weathering.

Overall, our multiproxy approach including quantitative biostratigraphy and geochemical analyses highlights the influence of the Deccan volcanism by releasing high amounts of atmospheric CO_2 and SO_2, leading to the climatic changes and associated biotic stress, which predisposed faunas to eventual extinction at the K-Pg boundary.

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6.2
Geomorphology of the coastal alluvial deposits of Asia (peruvian Atacama Desert)

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Due to their sensitivity to both tectonic activity and climatic variations, alluvial deposits along the coastal part of the Atacama Desert (western Peru) are important archives for understanding Quaternary environmental change.

Our study focuses on alluvial deposits of an exceptionnal fan complex located at nest to the city of Asia (Peru, 12°4) along the coastal zone of the Atacama. Despite being one of the driest desert in the world, the western side of the Peruvian Andes has experienced multiple pluvial periods since the Pleistocene, inducing phases of erosion and the formation of large alluvial deposits at the outlet of the main valleys. Our goal is to understand if and to what extend the peruvian coastal Atacama was affected by humid episodes that were until now only evidenced for the Altiplano.

Because the valley of Asia is relativelly small and do not reach the Altiplano, the study of this deposits succession is bringing insight on the localisation of the precipitations.
For that, a detailed geomorphological analysis of the coastal alluvial fan complex has been made to understand the fan's morphogenesis. This analysis was based on a digital elevation model with a resolution of 1 m generated from Pleiades stereo satellite imagery. Despite the loss of the northern part of the deposits, the top flat surface of an ancient terrace remains visible allowing the reconstruction of the paleo slope of the river.
Additionally, during field work, the size of the pebbles of the alluvial deposits have been mesured in multiple locations of the fan complex to reconstruct the paleo hydrology and the transport dynamics.

Previous studies have shown that during the humid phases, precipitations and subsequent erosion have mainly been located in the uppermost reaches of the rivers. However, this study shows the alluvial sediments of coastal Asia have been deposited during one humid phase for which precipitations occurred not only on the Altiplano but also in the closer to the Pacific fringe providing new insight for paleo climate reconstructions.

6.3
Offshore tsunami deposits in Lake Lucerne: insights from combined analysis of numerical tsunami modelling and sediment cores

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The 1601 AD earthquake (Mw 6.2) with epicenter in Unterwalden triggered multiple subaqueous mass-movements in Lake Lucerne and a subaerial rockfall from the Bürgenstock Mountain (Schwarz-Zanetti et al., 2003; Schnellmann et al., 2006). The seismically induced secondary effects are reported in the historical chronicles written by Lucerne's city clerk Renward Cysat, which is based on eyewitness reports and observations made by the author (Cysat, 1969). Immediately after the earthquake was felt, the lake was agitated, became wild and foamy. Further, it is mentioned that the water raised in the middle of the lake and resembled a mountain, while the coastal plain in Ennetbürgen was inundated by several hundred meters and repeated draining of the River Reuss was observed at the lake outlet in Lucerne. Last but not least, it is reported that fisher boats, boulders and wooden debris were washed ashore up to 4 m above the lake level and several casualties occurred.

To better understand tsunami evolution, inundation and hazard associated with the 1601 earthquake event, we combine numerical tsunami modelling and sediment-core analysis. A thick package of fining upwards sand dated with the radiocarbon method to around 1400 cal. AD. was recovered in sediment cores from the Lucerne Bay area. Based on our sedimentological investigations and radiocarbon dating results, we have high confidence that the observed sandy sequence was deposited during the AD 1601 Lake Lucerne tsunami event.

With the numerical software BASEMENT we simulate the tsunami propagation caused by a subaqueous mass-movement close to the village of Weggis. Performed numerical tsunami modelling provide further estimates on the bed shear stress, wave velocity and amplitude in the Lucerne Bay, which are some of the governing parameters defining sediment erosion as well as transport and depositional processes.

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6.4
A numerical modelling approach to study sediment erosion, transport and deposition in a fluvial system

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Numerical modelling has become an important tool to study landscape evolution of a variety of processes such as fluvial and glacial erosion, hillslope, sediment transport and aeolian processes. The most common objective of these models is to simulate the generation of stratal geometries in response to secular variations of parameters. Modelling techniques in the field of sedimentology and/or geomorphology have gained relevance over the past years for their ability to possibly predict the impact of tectonic and climatic changes on sediment generation, transport and deposition. We present our model developed using the FastScape to examine how fluvial systems react to upstream (water discharge and sediment supply) and downstream (rise and fall of sea-level) changes. The FastScape consists of a set of subroutines that allow us to model landscape evolution by river incision, sediment transport and deposition in continental and marine environments. FastScape routines solve (a) the stream power law (SPL) that has been enriched by a sediment transport and depostion term, (b) hillslope diffusion and (c) marine transport and diffusion. Earth surface process models are often computationally demanding in order to achieve a higher spatial resolution over large domains such as at the scale of a sedimentary basin (i.e., 10-1000 km). In order to overcome this problem, the assumption that sediment transport is linearly proportional to slope, the resulting transport equation can be solved using a set of algorithms that solve these equations such that the computational time increases linearly with the number of nodes N used to discretize the problem (i.e., *O(N)* method) along with using implicit time integration to ensure numerical stability independent of time steps. Here we explore the response of our fluvial landscape to variations in factors such as uplift rate, subsidence rate, precipitation rate and coefficient of sediment erodibility.

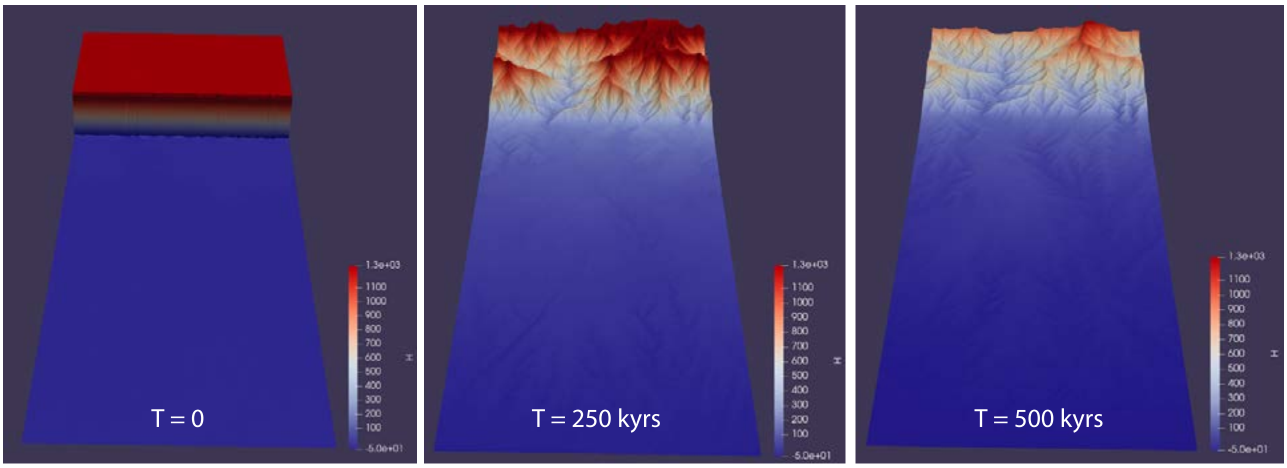

Figure 1. Landscape evolution in our model over time. Model consists of an initial plateau where sediment is generated and deposited downstream in the foreland basin. Each time step is 10^3 years. Color bar represents elevation in meters.

6.5
Mercury signals in Pyrenean Paleocene-Eocene foreland sections as evidence of enhanced volcanism across the Paleocene-Eocene Thermal Maximum

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The Paleocene-Eocene thermal maximum (PETM; ~56 Ma) was an abrupt and transient global warming coincident with a massive realease of carbon to the oceans and the atmosphere. This event is identified in the geological record by a prominent negative carbon isotope excursion (NCIE) in both carbonates and organic matter. The sequence of events triggering this disturbance, as well as the source of the ^{13}C-depleted carbon causing the NCIE remains controversial. External perturbation such as volcanism, associated with the setup of large igneous provinces (LIPs), is suspected to be one of the mechanisms responsible of this abrupt climate perturbation. Mercury (Hg) anomalies are now commonly used as a marker of volcanism and can therefore provide hints on the possible relationship between the LIPs development and the PETM or other major environmental disruptions.

In this study, we present Hg and stable isotope records from several peripheral basins of the Pyrenean orogen across the PETM. The high sedimentation rates which characterize these environments, in comparison to the oceanic realm, make them ideally suited to provide a high-resolution record of carbon and Hg cycle perturbations during the PETM.
Our data reveal the occurrence of two main NCIEs at each study sites. Based on biostratigraphy and similarity of shape and amplitude of the isotope excursions with global records, the largest NCIE is interpreted as major global NCIE characteristic of the PETM. This main excursion is immediately preceded by another, smaller one, that we interpret as the Pre-Onset Excursion (POE), also found in a few other sections worldwide. We find that these two major perturbations of the carbon cycle are systematically associated with important Hg anomalies without significant change in the total organic carbon content. These results show that important pulses of volcanism, probably associated to the emplacement of the North Atlantic Igneous Province, contributed to the onset and the long duration of the PETM. In addition, our study highlights the possibility to get reliable information about past extreme climate events from sedimentary successions even if deposited within active tectonic domains. Finally, our geochemical record allows to define robust isochronous lines and thus to propose a stratigraphic correlation between sections of the Pyrenean orogenic chain deposited in different palaeogeographical domains during the Paleogene.

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6.6
Orbital origin of the stratigraphic sequences in South-Pyrenean syn-kinematic sediments.

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Understanding the relative weight of allogenic drivers in the geological record still constitutes an unsolved problem in stratigraphy. Extracting the stratigraphic signature of orbital cycles may help to disentangle the complex causal relationship among the different drivers. Here, we study the role of orbital cycles in active tectonic emplacements in the South-Pyrenean Foreland Basin. In particular, we focus in the syn-kinematic delta to prodelta sediments of the Middle to Late Eocene Pico del Aguila anticline. Growth strata geometries evidence tectonic uplift and a shallowing upward stratigraphy. Superposed to that general trend, sedimentary sequences reveal shifts in the Accommodation/Sediment supply ratio forced by allogenic factors. A new *ca* 1000 m magnetostratigraphy combined with other regional magnetostratigraphic provides a high-resolution age model that permits to date the formations and also allows testing the role of orbital cyclicity. Based on facies description we built a clastic index depicting changes in either distality and depth of the facies. We conducted spectral analyses (Redfit, MTM) and Evolutive Harmonic Analyses to understand the correspondence of sequence duration with Milankovitch target frequencies.

Our results provide ages for the Guara, Arguis, Belsue formations and the base of Campodarbe formation for this sector of the basin. The contact between Guara and Arguis is very close of the top of Chron C19n. The Belsue and Arguis formations interfinger up to the chron C16n, leading to a major progradation marked by the obliteration of the Arguis marls by the Belsué formation, and subsequently the complete marine restriction occurs towards the top of C16n. This confirms the continentalization of the South Pyrenean Foreland basin-Ebro as an isochronous event.

Spectral analysis and evolutive spectra reveal significant frequencies throughout the stratigraphic column, in spite of the effects of the growing anticline. Constrained by our magnetostratigraphic model we show that these peaks fit well with Earth's eccentricity. In particular, the sequential stratigraphy division responds to the beat of 400-kyr eccentricity. In addition, it is also relevant the imprint of the minima of 2.4 Myr as well as the nodes of obliquity (1.2 Myr). Eccentricity minima is related to progradational trends, whilst eccentricity maxima are linked to transgressive, and-or high-stand conditions. We discuss the upstream or downstream forcing in the setting, and finally we suggest that accommodation driven cycles are the more likely scenario.

6.7
Formation calcified roots in terrestrial sediments and their implications for paleoenvironmental research - revisited

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Calcified roots, also known as rhizoliths, are widely distributed in Holocene soils and sediments of many different climates, which enables their use in environmental research. While one can frequently observe carbonate coatings on living and sub-recent root surfaces, it remains questionable, how rhizoliths of larger diameter (>10 mm) are formed and what their implications are for the paleoenvironmental information of the surrounding soil and sediment. Often one or a few dark colored channels can be observed within large rhizoliths, which suggested that organic matter from former tree or shrub roots was preserved in these areas. However, the internal structure of the rhizoliths commonly does not look similar like the internal structure of living roots, which led to the questions: 1) Which was the source vegetation of rhizoliths?; 2) How can large rhizoliths be formed?; 3) Where in the profile is the carbonate used for formation of rhizoliths originating from?; 4) What are paleoenvironmental implications of rhizoliths?
1) Stable carbon isotope and lipid molecular analyses analyses confirmed that frequently rhizoliths are formed by C3-vegetation.
2) A combination of micro-computed tomorgaphy (CT) and scanning electron microscopy (SEM) was applied to decipher the formation mechanisms of rhizoliths. The CT measurements of intact soil and sediment cores clearly confirmed that the calcification was related to former root growth. This was underpinned by side roots, some of which being calcified, whereas others remained visible in the CT scans as unfilled biopores. Surprisingly, SEM analyses showed that all investigated rhizoliths had a very similar internal structure, irrespective of their origin (Serbia, Hungary, or Germany). The large rhizoliths (>10 mm diameter) consist of an agglomeration of many microrhizoliths (<2 mm), which were formed by fine roots, showing the same internal structure like living roots. The SEM analyses suggest that calcification of roots starts at the surface, followed by coating of cortex cells of the roots and subsequent coating of internal cells. Finally, carbonate can be precipitated even within the root cells, the latter most likely after the death of the individual cell. However, the question remains, why one can find so many microrhizoliths in large rhizoliths? The answer is, that large biopores were formed by trees and shrubs. But during degradation of the large roots, smaller roots colonized the decaying root and used it as a source of nutrients. Such scenario is frequently observed for living fine roots. With ongoing degradation, more and more fine roots of different generations filled the pore space of the former root channel and started to calcify. Finally, the organic matter and nutrients entrapped in the primary large root are entirely consumed and one can find only the microrhizoliths that have the potential to persist for millennia.
3) Stable calcium and strontium isotope as well as radiogenic Sr isotope analyses suggest that Ca and Sr originate from a mixture of the leached fraction of the loess from the same stratigraphic level of the respective rhizoliths and from overlying soils or paleosols. However, we still lack of a detailed understanding of related leaching and transport processes in very deep subsoils, which requires further investigations.
4) The impact of rhizoliths on organic matter in soils and sediments depends on rhizolith frequency and organic matter concentration in the archive. On the other hand, rhizoliths themselves can provide valuable data on rooting plants and thus can contribute useful paleoenvironmental information.
In our presentation, we will explain the latest findings on the nature of rhizoliths and implications of these for their environmental interpretation.

P 6.1
Understanding the differences in aggradation styles in fluvial stratigraphy between upstream climate-driven processes (i.e., water discharge and sediment supply variations) and downstream sea-level changes: insights from physical modelling

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Fluvial deposits have the potential to record both changes in accommodation generated by upstream drivers (i.e., water and/or sediment discharge changes associated with tectonics and climate in the source area) and-or downstream drivers (i.e., sea-level change). Thus, the hypothesis is that upstream or downstream changes can potentially cause rivers to respond and adjust to a new equilibrium river profile by aggradation or degradation. Fluvial stratigraphy is a major record of past environmental changes, yet still we lack the capability to differentiate the expression of upstream and downstream driven changes when faced with fluvial stratigraphic successions. Here we explore this major challenge of sedimentary geology and geomorphology using physical modelling, which has the advantage of being able to independently control both upstream and downstream parameters.

In the Surface Dynamics Lab at the University of Geneva, we have designed and manufactured a long (2.25 m) and narrow (0.05 m) flume with an initial gradient of zero. The narrow width of the flume allows us to have a quasi 1-D system and additionally decreases experimental running time. We have developed an algorithm that captures the profile of the resultant sand wedge from side-profile photos and allows us to fit both linear regressions and polynomial ones to investigate slope changes through time. In addition, we are able to observe how volume changes and if sediment supply remains constant in the experiment. Finally, we have positioned a camera so that the wedge top is also captured and changes in channel width can be measured.

In our experiments we: (i) investigate the role of changes in upstream drivers, such as water discharge and sediment supply on equilibrium river profiles, and (ii) carry out a series of perturbation experiments varying downstream drivers (i.e., sea-level) which theoretically produce the same amount of aggradation as the upstream parameters we have used. This enables us to compare any similarities or differences in morphology that could then be used as diagnostic for upstream or downstream control. Our preliminary findings suggest that changes in sediment concentration are a major factor in controlling slope (when using a single grain-size distribution for all). Ultimately, we will migrate these experiments to a fully unconfined flume which will allow us to compare the changes we have seen in the ‘1-D’ to the 3-D.

P 6.2
Possible relation between sediment flux and grain size extracted from coarse-grained Swiss Molasse deposits

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Pioneer studies in fluvial hydraulics revealed already in the 1950's a general relationship between sediment loads (sediment discharge and grain size) and stream power conditions (water discharge and river slope) (Lane, 1955). In this context, changes in hydrological conditions (sediment and water discharge) have been commonly related to shifts in tectonic, climatic or source-rock conditions (Heller and Paola, 1992), which changes affect the dynamics of alluvial systems, such as megafans. These dynamics are thus largely mirrored by shifts in temporal and spatial grain size trends where related changes are to some extent self-similar (Brooke et al., 2018). Trends in grain size thus bear crucial information on the hydrological conditions of these systems. In addtion, as proposed by Lane (1955), there might exist an explicit relationship between discharge rates (or sediment flux) and grain size. In this project, we test the hypothesis whether trends in grain size are directly related to shifts in sediment flux at the scale of an entire basin.

To this extent, we focus on the Oligo-Miocene strata of the Swiss Molasse basin consisting of km-thick conglomerate sequences. From these, we extract information on grain size using state-of-the-art techniques in grain size analysis and compare the data to published patterns on sediment flux to the Molasse basin (e.g. Kuhlemann et al., 2001). The study area includes three major depositional systems that were active between c. 31 and at least 13 Ma and that are situated in western, central and eastern Switzerland along the Alpine thrust front. Sediments of these megafans (i.e. the Thun-Napf, Rigi-Höhronen and Speer-Hörnli systems) resulted in the construction of three composite sections consisting of Lower- and Upper Freshwater Molasse deposits (Schlunegger et al., 1997, Kempf et al., 1999). The composite sections have been logged and dated with magnetostratigraphy at a temporal resolution of c. 0.5 Ma by the same authors. While this temporal resolution provides us ideal conditions to test our hypothesis, we need to consider three major sources of uncertainties before interpreting possilbe relationships to grain size trends:

I) We collect grain size data directly in the field by taking photographs of the target rock units from which we then measure the grain size on the digital photos. We measure the longest visible axes of individual clasts because the random orientation of various outcrops hinders us from a proper identification of a specific axis. However, relationships between the streams' hydrological conditions and grain size are commonly calibrated to the length of the intermediate (*b*-) axis of individual grains (e.g. Bunte and Abt, 2001). We thus propose to apply corrections to our grain size data through a probabilistic approach that considers (i) data on ratios between *a*- and *b*-axes, and (ii) a random orientation of clasts and how this is influences a grain size dataset measaured on photos.

II) The volumetric budget, from which the sediment flux to the Molasse basin has been calculated (Kuhlemann et al., 2001), involves the entire range of sediments including mud, sand and pebbles that was supplied to the Molasse basin. However, we are only capable of measuring grains c. > 3mm due to the resolution of our digital camera. This adds a possible bias to our dataset, as a large portion of the fine-grained material is excluded from our bulk grain size distribution. We propose to correct this bias by estimating the proportion of fine-grained material through sieving. We will conduct this task in gravel pits because a large proportion of this mateiral has been reworked from Molasse deposits, and since the unconsolidated material can easily be excavated for sieving. This yields in a proxy for the fine-grained fraction within the material in the Molasse conglomerates.

III) Sediments experience a decrease in grain size from proximal to distal positions on alluvial megafans upon transport (e.g. Brooke et al., 2018). Because within Molasse sections, the lowermost exposed sediments were deposited at farther positions in relation to the palaeo-apex than material exposed at the top of the same section, this distal-proximal relationships could add a bias. We propose to solve this spatial problem by defining a grain-fining factor by collecting data along sections with isochronous proximal-distal relationships. Such conditions are found at the Rigi, in the Hörnli area and in the conglomerates near Thun.

The resulting uncertainties will be used to correct the dataset extracted from the digital photos The resulting grain size trends will then be compared to data on sediment flux to the Swiss Molasse basin. We will then explore whether trends in grain size reflect either regional conditions as considered by Schlunegger and Castelltort (2016) or if shifts thereof reflect changes at the scale of the entire Swiss Molasse basin.

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P 6.3
Stratigraphic architecture and depositional processes across lower Paleozoic siliciclastic shallow-marine platfomes: insights from the Late Ordovician of the Anti-Atlas (Southern Morocco)

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During Cambrian-Ordovician times (542-444 Ma), the Anti-Atlas (Southern Morocco) was part of the Gondwana supercontinent and drifted from mid- to subpolar latitudes. The area was part of a shallow marine platform on the so-called northern passive margin of the continent. The stratigraphic succession records a long-term flooding of the platform from the Cambrian to the Silurian. Above Lower Cambrian fluvial to estuarine deposits, an essentially shallow-marine succession (from offshore shales to tidal sandstones) is punctuated by major flooding events in the Middle Cambrian, the lowermost Ordovician, the middle Ordovician and the lower Upper Ordovician. A superimposed eustatic sea-level drop due to the Late Ordovician glaciation marks the last transgressive-regressive cycle that includes the Ktaoua group (mid-Sandbian to Upper Katian) and the glaciation-related Second Bani Group (Hirnantian).

In spite of well-known stratigraphy, details of the depositional processes, the overall geometry of the clinoforms (shelf vs. ramp) and resulting stacking patterns of the high-frequency units remain poorly understood in the platform domain. Here, we present a stratigraphic correlation made through a field-based logging of seven sections along a 50 km long, well-exposed cliff located in the Central Anti-Atlas. The Ktaoua to Second Bani groups, part of the Jbel Bani Mountain, are investigated between the villages of Tissint and Foum Zguid. The Ktaoua succession is dominated by high-order regressive parasequences grading from shales into fine to coarse-grained bioturbated sandstones, presenting paraconformable contacts. Incursions of sandstones showing hummocky-cross-stratifications (HCS) are common and considered to represent offshore-transition storm deposits. In the Second Bani Group, which includes glacially-related depositional facies (diamictites), fine to coarse-grained sandstones are dominant as well, though HCS are virtually absent. In the study area, the upper Second Bani Group forms an unconformable unit, severly truncating the Ktaoua succession and emphasizing a regressive sequence initiated within the Ktaoua deposition.

These archives enable to constrain the basin geometry in the Upper Ordovician. Indeed, whereas offshore shales in the region of Zagora (Central Anti-Atlas) characterize the depocenter of the basin (eastward from the study area), the studied succession is surrounded by a belt of coarser-grained deposits to the north-east (Alnif, Eastern Anti-Atlas) and west (Tissint/Foum Zguid, Western Central Anti-Atlas). The stratigraphic correlation of the Ktaoua parasequences will be used to reconstruct the orientation, direction, and dip of platform clinoforms, which will allow to dissociate a scheme based on chronostratigraphic units from the usual lithostratigraphy. Besides, we aim to further characterize the geometry, shape, and stratigraphic position of HCS bodies in order to advance our understanding of the setting (e.g., paleobathymetry, position relative to regressive vs. transgressive trends) and hydrodynamic processes generating sandstones bodied with prevailing HCS beds.

P 6.4
Early Triassic Organic Carbon Cycle Perturbations in High Latitudes

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The Permian-Triassic mass extinction (PTME) is considered to be the severest extinction in Earth's history with an approximate loss of 90 % of all marine species (Raup, 1979). Global carbon cycle fluctuations, which are associated with radiation and extinction pulses characterize the Early Triassic following the PTME (Payne et al., 2004; Galfetti et al., 2007). Despite the well-documented global carbon isotope oscillations and changes in fossil assemblages (e.g. ammonoids and conodonts), little is known regarding relevant changes in marine primary productivity. The aim of the present work is to gain a better understanding of the fluctuations of marine primary productivity and to distinguish the influences of terrestrial controls on this cycle. This is essential for understanding long-term shifts in atmospheric CO_2 concentrations and to distinguish local from global effects on the carbon cycle. First results for the Smithian-Spathian boundary (SSB) from Svalbard show a positive carbon isotope excursion of about 5 ‰. This has also been observed at other localities in Svalbard (Hammer et al. 2019). Here, this excursion is contemporaneous with an an increase in total organic carbon, nitrogen and phosphorous concentrations. A gradual increase in redox sensitive elements is also noted for the Spathian. Such changes are best explained by an increased amount of weathering from the SSB onward, which may lead to a high nutrient flux to the oceans. This may subsequently cause an increase in marine primary productivity, leading also locally to exceptional preservation of organic matter under anoxic conditions. This newly aquired dataset and increased marine primary productivity interpretation is in contradiction to other highlatitude studies done in the Sverdrup Basin and Svalbard (e.g. Grasby et al 2020).

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P 6.5
Emergence and carbonate platform formation on the Caribbean Large Igneous Province – Exposures of the Bahoruco Peninsula (Dominican Republic)

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The Caribbean Large Igneous Province (CLIP) is characterized by a discontinuous >5km thick basaltic plateau, largely of Late Cretaceous age, resting on an (originally Pacific) Jurassic ocean crust. The CLIP is thought to have formed far below the photic zone in large areas of the Caribbean Plate, and has remained deep oceanic, except for convergent settings, where it eventually became tectonically uplifted and exposed. More recently, Late Cretaceous subaerial development of the CLIP was documented by Buchs et al. (2018) in accreted sequences of W-Colombia.
Emergence of the CLIP and onset of shallow carbonates during the latest Cretaceous – Paleogene is also documented along the northern edge of the Caribbean Plate in the Lower Nicaragua Rise, the Beata Ridge and its onshore exposures in Hispaniola. Volcanic edifices of a depleted “second stage” CLIP volcanism (Dürkefälden et al., 2019) and/or a post-CLIP intraplate volcanism, may constitute the shallow substrate for carbonate buildups.
The aim of our study in the Bahoruco Peninsula (S-Dominican Republic) is to precisely date and better understand the establishment of subaerial/paralic conditions and the onset of shallow carbonate systems along the N-edge of the CLIP. Our first field campaign (Nov. 2019) focused on the eastern Bahoruco mountains, where the volcanic basement (Dumisseau Formation, regarded as Upper Cretaceous CLIP and associated pelagic sediments) and the overlying carbonates are well exposed. In the studied outcrops, the first carbonates, mapped as Polo Formation (Joubert, 2010), are shallow, lagoonal to upper ramp rhodophycaean limestones that contain upper Paleocene (not middle Eocene as previously reported) larger benthic foraminifera.
This formation is overlain by the Upper Neiba Formation (s.l.), made of well-bedded, mostly micritic, sometimes cherty limestones containing planktonic microfossils. Dm-bedded turbidites occur occasionally and are made of reworked and displaced shallow benthic organisms. The peri-platform accumulations of the Neiba Formation cover the largest area of E-Bahoruco.

Hydrothermal activity and evidence of sub-aerial CLIP exposure have been largely debated in the Los Cheseses mining area (Espi & Pérez-Puig Obieta, 2017), where larimar, a hydrothermal blue pectiolite (gemstone) is mined. The mining area is one of our targets to understand the interaction of volcanic, hydrothermal and sedimentary processes. The hydrothermal activity has not been directly dated, but is considered to be of Late Cretaceous age. However, the overlying Paleocene-Eocene shallow carbonates show frequent silicification that we analyze to reveal their hydrothermal vs. biogenic origin. An 40Ar/39Ar plateau age of 52.8±1.7 Ma (Early Eocene) was obtained from a dolerite dyke (whole rock) by Escuder-Viruete et al. (2016), in the basaltic (CLIP) basement of a coastal outcrop in the study area. Hence, volcanic/hydrothermal activity may have co-existed with carbonate sedimentation and may have affected Paleogene sediments. The origin of this silicification could be of major importance for the paleoenvironmental and paleogeographic interpretation of the Bahoruco carbonates.
To achieve our objectives, we analyze the sedimentology in the outcrops and in thin sections, determine micro- and biofacies, and establish a detailed biostratigraphy. Diagenetic and/or hydrothermal events will be studied using Rahman microscopy, microprobe and La-ICPMS analyses, as well as stable isotope analyses and ^{40}Ar/^{39}Ar radiochronology of selected minerals, such as larimar.

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P 6.6
$\delta^{18}O$, $\delta^{13}C$, trace elements and REE in situ measurements coupled with U–Pb ages to reconstruct the diagenesis of Upper Triassic atoll-type carbonates from the Panthalassa Ocean

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Owing to their isolated oceanic setting, atoll-type carbonates are well suited for documenting carbonate deposition and diagenesis in oceanic environments away from continental influence. The atoll-type Dalnegorsk limestone (Taukha Terrane, Russian Far East), deposited in the gigantic but poorly-documented Panthalassa Ocean, preserves a complete record of the diagenetic evolution of an Upper Triassic system, out of the Tethyan domain. To study the diagenesis of this carbonate system, we developed a novel analytical workflow, combining cathodoluminescence petrography with high-resolution analyses of environmental proxies in calcitic cements ($\delta^{18}O$, $\delta^{13}C$, REEY, trace and minor/major elements) and in situ U–Pb dating of calcite cements to precisely reconstruct the chronology of the diagenetic events. We combined these lines of evidence to establish a model of atoll evolution, from deposition to dismantling, based on 10 identified diagenetic episodes. The Dalnegorsk limestone records emergence at the Norian-Rhaetian transition, marked by meteoric and evaporitic cements, followed by dismantling of the atoll edges after drawning in the Early Jurassic. Neomorphism of calcitic shells occurred at the onset of calcitic sea conditions during the Toarcian-Bajocian. The limestone was thoroughly cemented during the Middle/Late Jurassic, and accreted within the Taukha Terrane during the Late Jurassic/ Early Cretaceous. Accretion resulted in fracturing, brecciation, and recrystallisation of the Dalnegorsk limestone. This model is potentially applicable to any similar atoll system, irrespective of age. The evidence presented here extends our knowledge of Late Triassic environments in the Panthalassa Ocean, and more generally, our understanding of mid-oceanic limestone formation and evolution.

P 6.7
Sedimentology and stratigraphy of the Upper Triassic carbonates from Hosselkus Limestone and Luning Formation (Western USA)

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Although the significant research carried out during the last years, knowledge about Panthalassan shallow-water carbonates remains distinctly minor than their Tethyan counterparts. Considering the broad diffusion of these limestones, the comprehension of their depositional environment, ecologic conditions and geographic extent, represents a unique way to better assess life evolution and recovery after the main Permo-Triassic biological crisis. Hosselkus Limestone and Luning Formation, respectively located in Northern California and Western Nevada, represent two completely different scenarios of limestone deposition during Upper Triassic. The first, deposited on a volcanic arc far from the coast of the American craton, shows a rapid change from shallow water facies to deep marine deposits, offering a wide spectrum of calcareous and siliceous organisms. The second, deposited in a large embayment attached to the continent, represents a much wider and homogeneous environment, where calcareous organisms thrive for a long period. Paleontological studies, started at the beginning of the last century and exclusively counting on large-dimension fauna, already proved strong similarities with both Panthalassan and Tethyan carbonates. Now, for the first time, the two formations are described in terms of microfacies and microorganisms, allowing a more exhaustive picture of the depositional environments and a sharper comparison of biological contents. Ages have been revised too, thanks to numerous Conodonts specimens, allowing a high temporal resolution and possibly providing new information about paleotemperature and water geochemistry.

P 6.8
Petrological and geochemical characteristics of the 3.47 Ga Middle Marker horizon in the Barberton Greenstone Belt, South Africa

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The Middle Marker (MM) horizon, the bottom horizon H1 of the Hooggenoeg Formation in the Onverwacht Group, is the oldest sedimentary unit in the Barberton Greenstone Belt (BGB), South Africa. A previous study suggested that the MM rocks accumulated originally as volcaniclastics (Lanier & Lowe, 1982). However, another study found microbial mat-like structures in the rocks and proposed a thriving microbial ecosystem on the original sediments (Hickman-Lewis et al., 2018). The petrological origin and depositional setting of the MM horizon is still controversial. To constrain them, we report petrology and geochemistry of the MM rocks. Rocks samples were collected from two outcrops on the western limb of the Onverwacht Anticline in the central BGB. In both sections, the ~10 m thick MM succession is composed of the black chert, characteristic lapilli beds, light gray chert, and uppermost black chert, in ascending order. The petrological and geochemical characteristics of the black and gray cherts are systematically different from each other. The black cherts are characterized by horizontal/cross lamination, high total organic carbon (TOC) contents, low sulfide contents, large mass-independent isotopic fractionation of sulfur (S-MIF), and flat chondrite-normalized REE patterns. In contrast, the gray cherts are characterized by their massive texture, low TOC contents, high sulfide contents, small S-MIF, and LREE-enriched patterns. The black cherts were likely deposited on shallow shelves with low accumulation rate, whereas the gray cherts accumulated rapidly as volcaniclastics during episodic volcanisms. Especially, the slow accumulation of the black cherts may have been favorable to proliferation of microbes and biofilm formation on the sediment-water interface.

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07. Seismic Hazard and Risk in Switzerland: From Science to Mitigation

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TALKS:

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7.2 *Alber S., Anastasopoulos I.*: On the development of a Bio-Inspired Self-Drilling Probe

7.3 *Anastasopoulos I., Marin A., Sakellariadis L.*: Optimized retrofit design of bridge pile groups

7.4 *Antoniou M., Gelagoti F., Kourkoulis R., Anastasopoulos I.*: Performance-based assessment of Suction Bucket Jackets supporting OWTs: a simplified approach

7.5 *Bergamo P., Hammer C., Faeh D.*: Progress in the compilation of multi-frequency seismic site amplification maps for the Earthquake Risk Model Switzerland project

7.6 *Bodenmann L., Reuland Y., Stojadinovic B.*: Towards dynamically improving predictions of post-earthquake damage, loss and recovery for residential buildings

7.7 *Božulić I., Vanin F., Beyer K.*: Modelling of Strengthening in the Equivalent Element Approach

7.8 *Del Giudice L., Wrobel R., Leinenbach C., Vassiliou M.F.*: Testing of Additively Manufactured Small Scale RC Specimens for Statistical Validation of Structural Models in Earthquake Engineering

7.9 *Glueer F., Häusler M., Gischig V., Fäh D.*: Former ammunition depot Mitholz: seismic response of a rock mass damaged by accidental explosions

7.10 *Hallo M., Bergamo P., Fäh D.*: An approach to characterize high-frequency ground motion at depth

7.11 *Häusler M., Glüer F., Fäh D.*: Earthquake-induced mass movements in Switzerland: overview on past and ongoing projects

7.12 *Imperatori W., Mai P.M., Faeh D.*: SCARF3D: a scalable library to efficiently generate large-scale, three-dimensional random fields

7.13 *Imtiaz A., Panzera F., Dresmann H., Steiner B., Fäh D.*: Developing an Integrated 3D Geological-Seismological Model at Urban Scale in Basel, Switzerland

7.14 *Janusz P., Perron V., Knellwolf C., Imperatori W., Bonilla L.F., Fäh D.*: Evaluation of the variability of soil response in urban environment using reference-site methods: the case of Lucerne, Switzerland

7.15 *Jones L., Anastasopoulos I.*: Physical modelling of interaction between earthquake-induced Tsunamis and geotechnical structures

7.16 *Kassas K., Adamidis O., Gerolymos N., Anastasopoulos I.*: Seismic response of a structure on liquefiable soil

7.17 *Khodaverdian A., Lestuzzi P.*: A Scenario-based fragility model for Swiss buildings

7.18 *Lontsi A.M., Shynkarenko A., Kremer K., Hobiger M., Bergamo P., Fabbri S., Fäh D.*: A seismological survey on Lake Lucerne (Switzerland)

7.19 *Marin A., Anastasopoulos I.*: In-situ estimation of rocking stiffness of pile groups

7.20 *Martakis P., Reuland P., Chatzi E.*: Towards building-typology formulations that are adapted for structural health monitoring applications

7.21 *Mizrahi L., Nandan S., Wiemer S.*: The effect of declustering on the size distribution of mainshocks

7.22 *Panzera F., Bergamo P., Fäh D.*: Reconstruction of site amplification functions through canonical correlation with site proxies

7.23 *Papadopoulos A., Roth P., Danciu L.*: Exposure aggregation strategies for efficient assessment of seismic risk in Switzerland

7.24 *Perron V., Bergamo P., Panzera F., Hammer C., Fäh D.*: Empirical earthquake's site response assessment in the Sion area, Switzerland

7.25 *Psychari A., Agaianos A., Sakellariadis L., Anastasopoulos I.*: Modelling of RC pilegroups under seismic loads

7.26 *Råman Vinnå L., Bouffard D., Wüest A., Girardclos S., Dubois N.*: A first step to assess subaquatic mass movement hazards in lakes

7.27 *Rossi Y., Tatsis K., Arbogast K., Awadaljeed M., Chatzi E., Rothacher M., Clinton J.*: Assessing a 6C Kalman filter using experimental datasets from an industrial robot

7.28 *Sakellariadis L., Alig D., Anastasopoulos I.*: Numerical study on the moment capacity of typical bridge pile groups on sand

7.29 *Shynkarenko A., Lontsi A.M., Kremer K., Bergamo P., Hobiger M., Hallo M., Fäh D.*: Revealing the structure of submerged slopes in Lake Lucerne using ambient vibration techniques

7.30 *Sieber M., Anastasopoulos I.*: Simplified analysis for nonlinear foundation response

7.31 *Tomić I., Penna A., DeJong M., Butenweg C., Correia A., Candeias P., Senaldi I., Guerrini G., Malomo D., Beyer K.*: Shake table testing of aggregate masonry buildings

7.32 *Weifeng Wu, Shiping Ge, Yong Yuan, Wenqi Ding, Anastasopoulos I.*: Seismic Response of Underground Metro Station: Shake Table Testing and Numerical Simulation

POSTERS:

P 7.1 *Galvez P., Pethukin A., Somerville P., Miyakoshi K., Peter D.*: Physics-based Earthquake Source Models for Seismic Engineering: Analysis and Validation for Dip-slip faults .

P 7.2 *Lanza F., Diehl T., Herwegh M., Wiemer S.*: Crustal Structure imaged by 3-D Seismic Attenuation for the Central Alps and their Foreland

P 7.3 *Kremer K., Grolimund R., Fäh D.*: Using the Swiss database of potential earthquake evidence to develop paleo-earthquake scenarios

P 7.4 *Strupler M., Anselmetti F.S., Bacigaluppi P., Boes R.M., Kremer K., Vetsch D.F., Wiemer S.*: Designing a probabilistic workflow for the assessment of the earthquake-triggered landslide-tsunami hazard along the shores of perialpine lakes

7.1
Simplified analysis method for bridges subjected to strike-slip faulting

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Strike-slip faulting refers to fractures of the bedrock outcrop, where the predominantly horizontal tectonic movement takes place along the fault strike. During a seismic event, such fault ruptures propagate through the overlying soil layers, and may emerge at the ground surface, thus affecting the structures in their immediate vicinity. Focusing on bridges, several past case histories have demonstrated their vulnerability to such large tectonic deformations (e.g., Yang & Mavroeidis 2018). The bridge structural system significantly influences the deck distress, with statically indeterminate systems being vulnerable to the imposed deformation. On the contrary, statically determinate systems can accommodate differential displacements and rotations without significant distress, constituting a successful strategy for faulting-hazard mitigation (Anastasopoulos et al. 2008).

Aiming to bridge the existing gap in the literature, the present work examines the performance of a symmetric 3-span overpass bridge subjected to strike-slip faulting. The bridge is founded on shallow footings, resting on a 20 m deep dense sand layer. A detailed 3D Finite Element (FE) model of the entire bridge–foundation–abutment–soil system is developed in ABAQUS, accounting for both soil and superstructure nonlinearities (Figure 1). The soil behaviour is simulated with a thoroughly validated Mohr-Coulomb constitutive model with strain softening (Anastasopoulos et al. 2007), an essential feature to correctly simulate shear localization problems. Regarding nonlinear pier response, the concrete damaged plasticity (CDP) model of ABAQUS is implemented after thorough validation. The fault offset is applied in a quasi-static manner at the model base (representing the rock outcrop) in the transverse bridge direction. Its performance is parametrically analysed for various fault locations, accounting for the uncertainty with respect to its outcropping location.

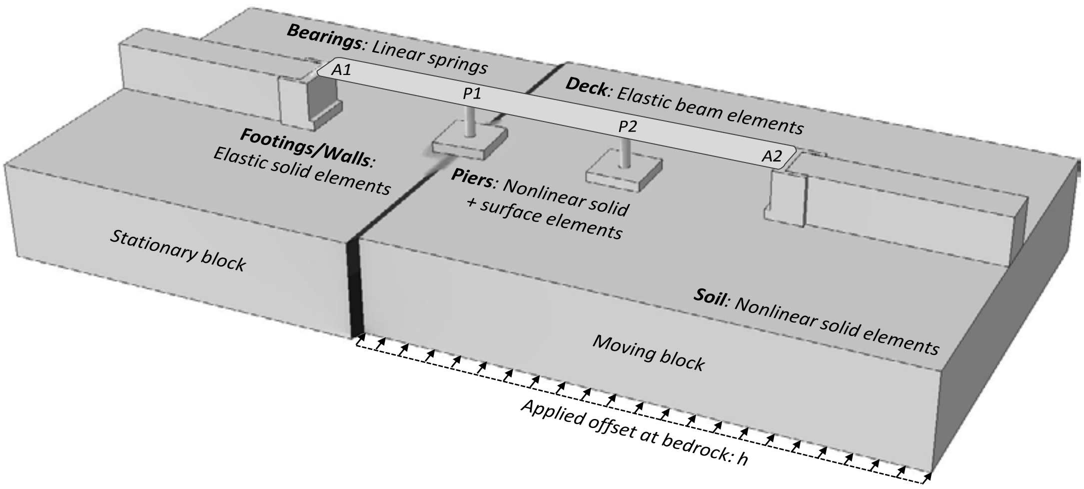

Figure 1. Detailed 3D Finite Element model of the examined problem.

The analyses confirm the susceptibility of the examined bridge structural system (continuous deck, monolithic pier-deck connections) to fault-induced differential settlements, which lead to axial load redistribution between the 2 piers and the abutments. Moreover, due to the monolithic pier-deck connections and the deck continuity, both the bridge deck and the piers are subjected during faulting to significant biaxial bending, shear and torsion. The system response highly depends on the exact fault outcrop location, emphasizing the need to develop simplified analysis techniques to perform series of parametric analyses.

Such a simplified analysis technique is described herein, including detailed modelling of the superstructure, similarly to the detailed model, while the soil-foundation system is modelled rigorously only for the pier directly affected by the fault. The soil-foundation interaction of the remaining piers is considered through properly calibrated nonlinear springs (Figure 2a).The proposed simplified method compares quite well to the detailed analyses, as indicatively depicted in Figure 2b in terms of deck out-of-plane bending moment M_z for fault offset h = 2 m underneath pier P1. Its main limitation, leading to the observed discrepancies, is identified as its inability to account for the fault-induced axial load redistribution by employing nonlinear springs. Overall, it constitutes a computationally efficient means to parametrically analyse long multi–span bridges subjected to strike-slip faulting for design purposes.

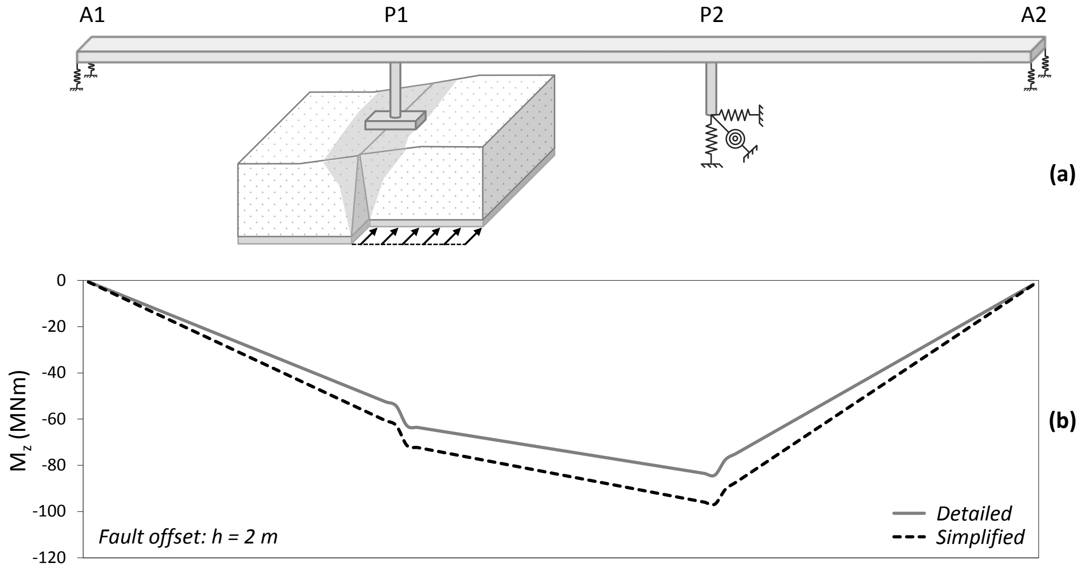

Figure 2. (a) Schematic illustration of the proposed simplified analysis technique and (b) example comparison between detailed and simplified analysis for fault offset h = 2 m underneath pier P1 in terms of deck bending moment M_z.

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7.2
On the development of a Bio-Inspired Self-Drilling Probe

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The seismic design of new and the retrofit of existing structures call for careful site investigation for the acquisition of soil properties. Especially in the case of seismic retrofit of existing structures, project sites are not easily accessible for conventional drill or penetration rigs, rendering soil investigation difficult (if not impossible) in close proximity to the examined structure. Efforts are dedicated to the development of an advanced, self-drilling probe for in-situ soil assessment, which will be able to perform an autonomous subsurface movement without the necessity of the reaction force by drilling rigs. Self-driven probes that are designed for planetary exploration to access subsurface sites on Mars or Moon are often based on the underground locomotion mechanisms found in nature (e.g. Nagaoka et al. 2010; Omori et al. 2013). The self-drilling probe described herein is bio-inspired, following the locomotion mechanism of inchworms. Figure 1 illustrates the subsurface inchworm locomotion sequence of the self-drilling probe.

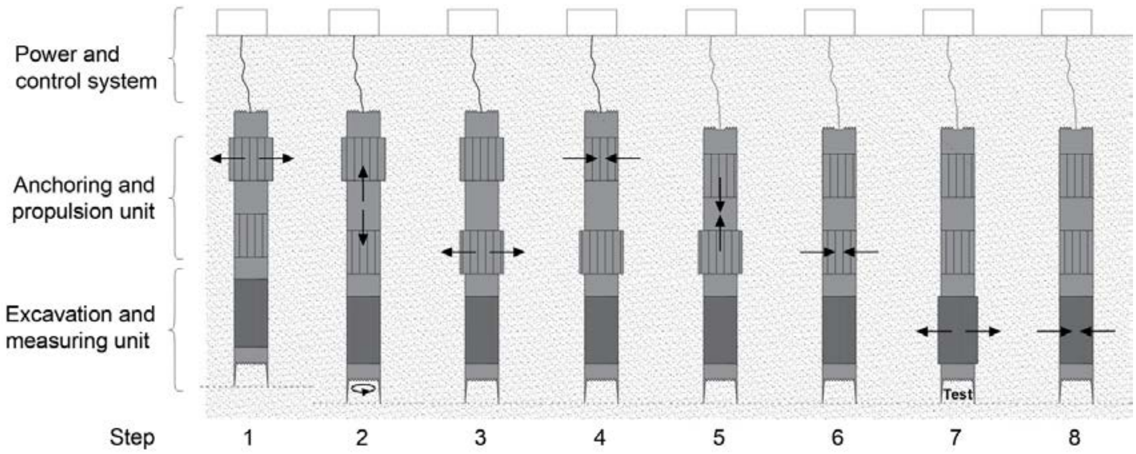

Figure 1. Penetration sequence of the underground self-drilling probe.

The device includes forward and rearward anchors for the generation of reaction force on the borehole wall, which allows the propulsion unit of the device to push forward the front or rear part. The self-drilling probe is excavating at the front through a rotating cutting edge, which is connected to a central tube and conveys the excavated soil through the probe to the back by means of a discharging mechanism using an auger. After advancement, the forward anchors are expanded to secure the device to the borehole wall and the rearward anchors are retracted, as well as the propulsion unit, to pull the rear end of the device towards the front. Because of its ability to advance in the soil and simultaneously excavate material without the generation of lateral pressure or rotation at the frontal bit, the device offers minimal soil disturbance at the front and therefore undisturbed soil conditions. The frontal bit can be considered as a measurement “cell”, where pressuremeter testing or shear-wave velocity measurements with bender elements can be conducted under “undisturbed” conditions. After this step, the device goes back in the original position. The prototype of the propulsion unit during advancement in a Plexiglas tube is shown in Figure 2. The anchoring system is currently in the construction phase and the front unit with the excavating bit and the measuring part are in the design phase. Especially the conception of the excavating unit is challenging, as gravelly material or dense soil are most likely to pose a challenge in producing a self-drilling probe with its own insertion reaction (Khosravi et al. 2018). However, the generation of sufficient reaction force in-situ within the device offers a decisive advantage over conventional instruments The autonomous advancement of the self-drilling probe can yield valuable information of in-situ soil parameters close to the future or existing structure of interest or even below it, while avoiding empiricism. This allows for more accuracy and reliability in the design of geotechnical structures.

Figure 2. Prototype of the propulsion unit in a Plexiglas tube (Simone Alber).

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7.3
Optimized retrofit design of bridge pile groups

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Pile groups are often over-designed due to excessive conservatism of current design practice, which tends to underestimate vertical bearing capacity of single piles. Such inaccuracies lead to substantial underestimations of moment capacity of pile groups. Consequently, road and rail infrastructure projects are associated with unjustified increased costs and construction time, and low levels of sustainability. The ASTRA project AGB2017/001, funded by the Federal Road Office (FEDRO), proposes three main directions of research in the attempt to deal with the above mentioned design issues.

Firstly, the possibility of introducing concepts of ductility in geotechnical design (Anastasopoulos et al., 2010) is explored, with the aim of reducing excessive levels of conservatism and rationalizing design practice. The full moment capacity of pile groups can be utilized and the design conservatism can be decreased by allowing progressive full mobilization of vertical pile bearing capacity and load redistribution from the edge towards the inner rows of piles. Preliminary numerical investigations (Fig. 1) indicate that the resulting increased moment capacity obtained by implementing such concepts in engineering practice can exceed by up to 400% the values suggested by current design codes . Moreover, a ductile energy dissipation mechanism develops through progressive bearing capacity mobilization during earthquakes and the seismic performance of pile groups improves at the cost of residual deformations that can be accounted for in design.

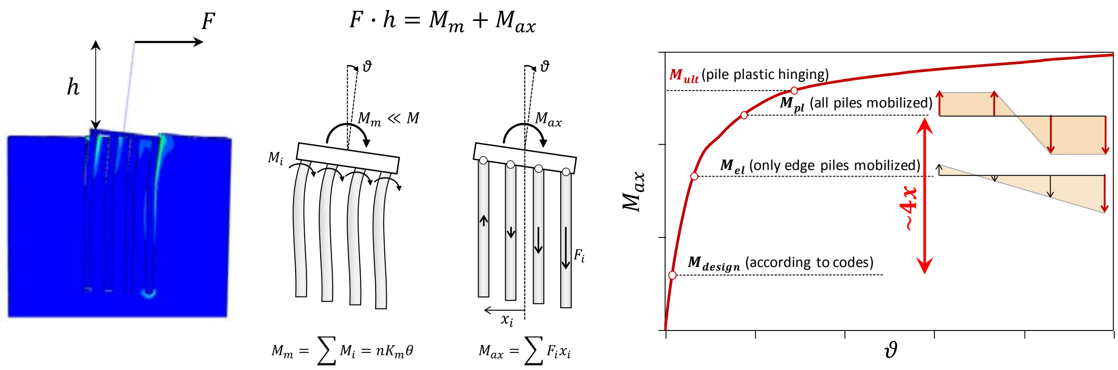

Figure 1. Moment resistance mechanisms of pile groups and qualitative evaluation of preliminary numerical investigations (Sakellariadis et al., 2019).

Secondly, existing methods for the estimation of the bearing capacity of piles are refined for more accurate results. Only in this way, ductile geotechnical design concepts can be implemented. Available data (e.g., CPT, pile-load tests) is used in conjunction with centrifuge tests and numerical analyses (Fig. 2), aiming to understand the concepts behind correlations of in-situ tests and corresponding bearing capacity estimates of piles. Moreover, most appropriate in-situ investigations and correlations are identified based on their capability to produce accurate estimates of vertical bearing capacity of single piles.

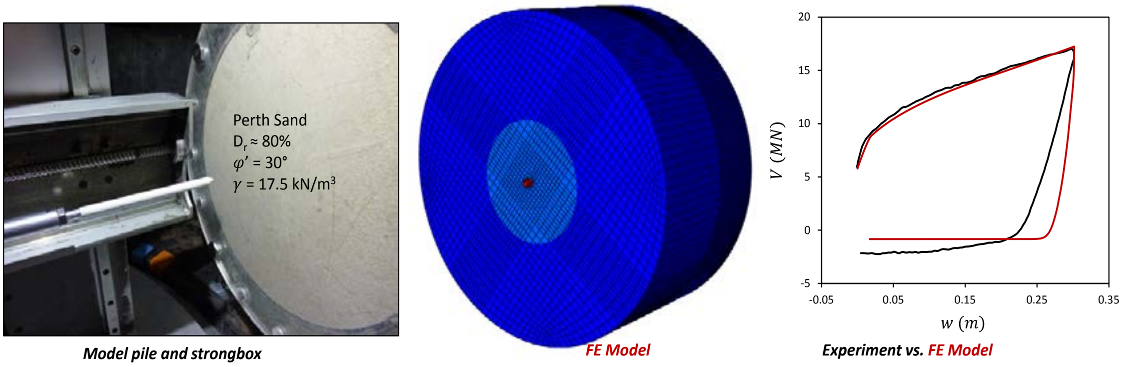

Figure 2. Comparison of experimental and numerical data related to vertical bearing capacity of piles.

Last but not least, an innovative technique for the measurement of the rocking stiffness of existing pile groups is developed (Fig. 3). A low-amplitude non-destructive testing method is envisaged, with a dynamic load applied at the top of the bridge pier. The vibration response (i.e., lateral drift of pier and rotations of pile cap) is measured, and the stiffness parameters of the pier and pile group estimated.

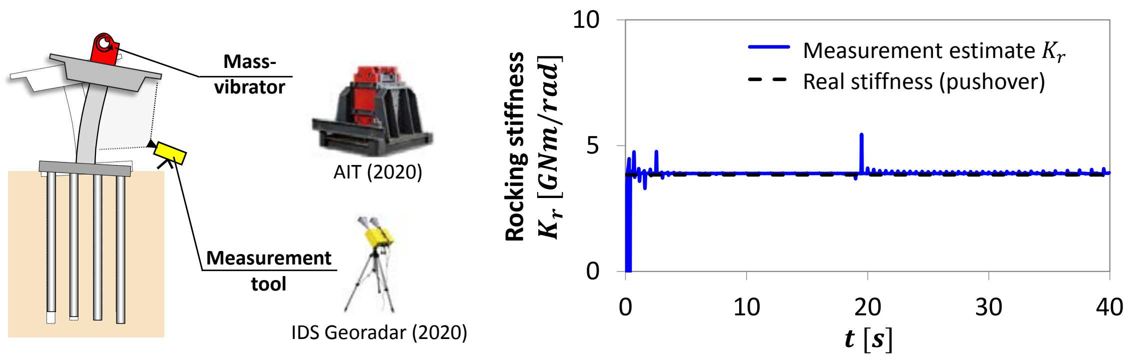

Figure 3. In-situ measurement technique for the estimation of stiffness parameters of bridge piers and pile groups.

The possibility of correlating the real stiffness with the actual moment capacity of pile groups is explored numerically and experimentally. To this end, simplified models based on beam-and-springs assemblies able to capture the monotonic lateral response of bridge piers and their foundations are developed. Parametric analyses can be performed and useful correlations can be developed with the help of such models.

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7.4
Performance-based assessment of Suction Bucket Jackets supporting OWTs: a simplified approach

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Following the ambitious energy targets set by countries worldwide, the offshore wind sector has seen impressive growth over the past decade, transforming from niche technology to a global industry. The vast spread of offshore wind turbine (OWT) installations has apparently broadened the hazardous sources that threaten this kind of infrastructure (Katsanos et al, 2016). In recent years, an extensive number of wind turbines has been or is planned to be installed in high-seismicity areas, such as China, Taiwan, India and South Korea, as well as in the USA, Mexico and several seismic active zones of Southern Europe, thus raising demanding concerns on the structural robustness of OWTs against a seismic environment.

At the same time, the industry's favorite monopile becomes financially inefficient for transitional water depths of 30 – 60m, while the offshore construction industry struggles to comply with the strict federal policies of limiting noise emissions during pile driving. On the other hand, jacket structures are gaining ground, with the industry making substantial progress towards standardized manufacturing and mass production of tubular joints using automatic welding procedures. Although hardly a new concept, jackets are gradually establishing their position in the offshore market (Wagner et al., 2011), being at the moment the second most installed OWT foundation in Europe (WindEurope, 2020).

Since 2018, suction caissons have been commercially deployed to support jacket structures in intermediate water depths, with installations taking place at the Borkum Riffgrund 1 (2014; one position), Borkum Riffgrund 2 (2018; 20 positions) and Aberdeen Bay (2018; 11 positions) offshore windfarms. Operating as the foundation system of jacket OWTs, suction caissons are primarily called to withstand vertical loading; the jacket structure assumes the environmental actions through rigid frame action, which is subsequently translated at the foundation level as a pair of axial forces. Despite the rise of this foundation solution within the offshore market, investigations of the dynamic axial response of Suction Bucket Jackets (SBJs) has received much less attention in the recent literature (e.g., Skau et al., 2018).

Motivated by the recent advancements in the use of SBJs for the support of OWTs, this study applies a rigorous FE analysis methodology to study their response under concurrent wind and seismic loading, proposing a novel intensity-measures-based methodology for performance-based seismic assessment of SBJs founded in clay. A dimensional analysis of axially-loaded suction caissons in clay is used as a means of generalizing the results of an extensive numerical analyses campaign, where the performance of SBJs in terms of caisson residual settlements is critically assessed against a number of selected Intensity Measures (IMs). In an effort to reduce variability in performance and guide design decisions, the study concludes on a unique correlation of permanent caisson settlement with a single IM, the Arias Intensity, and presents results in the form of easy-to-use caisson settlement charts (Fig.1.). The latter may serve as a simplified method to estimate foundation settlement under various seismic design load combinations, without the need to analyze the entire soil-foundation-structure-interaction problem.

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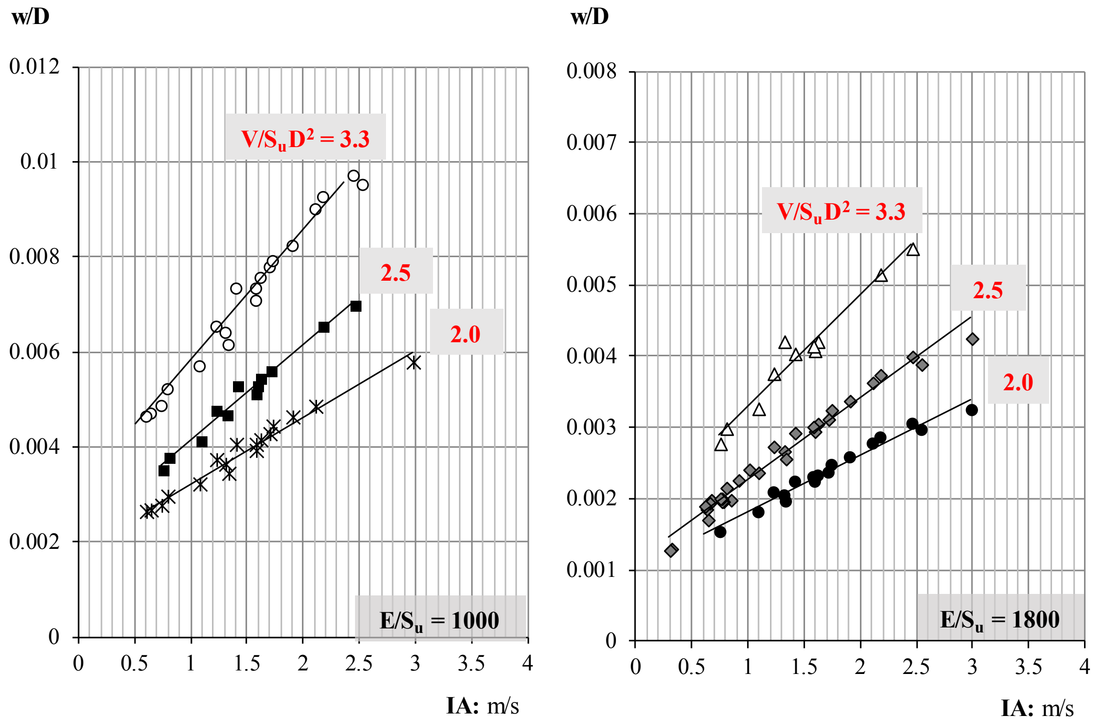

Figure 1. Example correlation of dimensionless caisson settlement (w/D) with Arias Intensity (IA), for different values of soil rigidity ratio (E/S$_u$) and vertical capacity ratio (V/S$_u$D^2).

7.5
Progress in the compilation of multi-frequency seismic site amplification maps for the Earthquake Risk Model Switzerland project

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The site response module of the Earthquake Risk Model Switzerland project articulates its development at three scales of investigation: national, regional and local scale. At each level, the final target is producing a layer representing the spatial variability of the site amplification term of ground motion, originating from the seismic response of the local geology. As for the national scale, the intended final product is a set of frequency-dependent amplification maps covering the Swiss territory. The strategy devised for this purpose involves resorting to the empirical amplification functions obtained with spectral modeling technique (Edwards et al., 2013) at all free-field seismic stations (~250) of the Swiss networks. These empirical amplification functions are then to be “spread” with the help of auxiliary variables (site condition indicators, such as parameters derived from DEM or geological thematic maps; or geophysical measurements, such as H/V_{noise} surveys, available at more than 6000 locations). The preferred extrapolation method was identified as the neural network (NN) technique (Bergamo et al. 2019a). However, numerous tests performed in the framework of the project (Bergamo et al., 2019b) have evidenced that i) the Swiss database of amplification and site condition information is not large enough to robustly constrain the NN parameters, and ii) that it is not possible to integrate the Swiss dataset with data from other regions (e.g. Japan), as far as indirect site condition indicators (topographical, geological parameters) are concerned. Therefore, we have been forced to explore the possibility to replace the NN with a Bayesian Network (BN), able to handle smaller and/or partly incomplete training datasets. While waiting for the first results from the BN, we have prepared a set of provisional site amplification maps where the local amplification is extrapolated by means of regressions on three support variables, identified as the most significant:

1. Coarse lithological classification of the Swiss territory, based on the 1:500000 geological map of Switzerland (Figure 1, top). The classification was cross-referenced with ~225 velocity profiles from the SED site characterization database (http://stations.seismo.ethz.ch) to ensure its significance in terms of geophysical properties;
2. Topographical slope. The amplification factors at each frequency ordinate were correlated with the slope evaluated at the spatial scale for which the correlation is maximized: 525 m for 0.5 – 1 Hz (Figure 1, bottom right), 225 m for 2.5 – 3.33 Hz, 125 m for 4 Hz, 75 m for 5 Hz;
3. Map of the depth of the quaternary sediments-bedrock horizon (Swisstopo, 2019). This model was collated with ~225 velocity profiles from the SED site characterization database, evidencing a fair agreement between the two datasets for depths > 5 m.

We produced 7 maps for as many frequency ordinates in the range 0.5 – 5 Hz, and additionally a PGV amplification map (Figure 1, bottom left); these maps are to be integrated in the first global test of the Risk Model project.
The reliability of the produced maps was positively tested with a comparison between predicted and empirically-measured amplification at 11 recently installed stations not included in the training dataset.
Next steps in our work include, in the short term, a further refinement of the maps by forcing the predicted amplification at and around instrumented sites to comply with the measured one, with a regression-kriging algorithm. In the medium term, we intend to pursue the Bayesian network strategy that will allegedly offer a more flexible tool for the correlation between site condition information and amplification.

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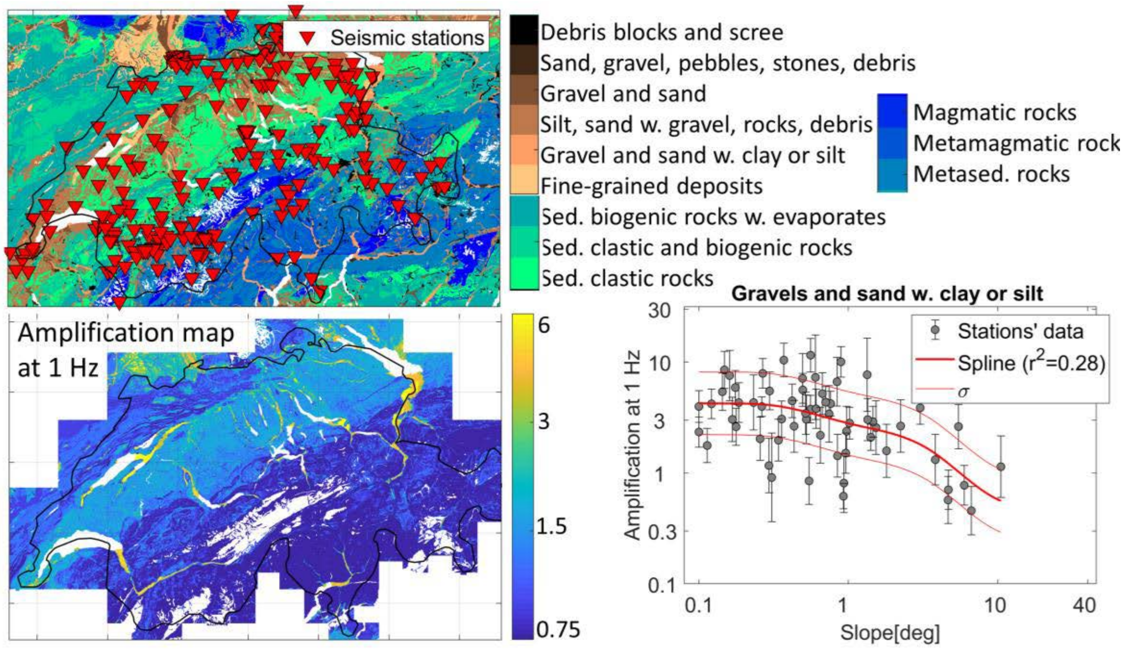

Figure 1. Top: map of the adopted geological classification for Switzerland and locations of the seismic stations. Bottom left: produced amplification map at 1 Hz. Bottom right: example of correlation between slope (525 m scale) and amplification factors (at 1 Hz) from the stations deployed on 'gravel and sand, with clay or silt' formations.

7.6
Towards dynamically improving predictions of post-earthquake damage, loss and recovery for residential buildings

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Earthquake disasters manifest in widespread damage to the built environment. This damage induces numerous direct and indirect consequences that often plague the affected communities long after an earthquake. Damage limitation via adequate design of new buildings and strengthening of existing buildings is one crucial pillar in earthquake risk mitigation. Because only small fractions of the existing building stock are renewed every year and because modern, code-conforming buildings may also suffer damage in rare events, planning and practicing disaster response and recovery actions is key to reducing negative impacts from earthquake-damaged buildings on the stricken community. However, an ex-ante development of optimal strategies for every possible scenario is not feasible. Instead, public and private stakeholders will have to shape the recovery path ex-post, in a decision environment characterized by high stakes and time pressure using scarce and uncertain data on the consequences inflicted by the event. For example, rapid safety screenings of all affected buildings might take from a few days to several weeks, depending on the severity of the event, the available engineering inspection resources and the accessibility of the affected region.

Hence, consequence models play a crucial role in offering first rapid impact predictions to decision-makers and the general public in the immediate aftermath of an earthquake event. However, the uncertainties inherent to every step of such models (such as shaking characteristics, building response, fragility of components, cost and duration of repairs) lead to wide ranges of possible outcomes. On the other hand the amount and the spatial coverage of event-specific consequence data increases during the response and recovery processes. This includes, amongst others, information from completed visual safety screenings, measurement-based structural health monitoring and post-processed aerial imageries. To provide stakeholders with up-to-date information for their post-earthquake decision-making, a framework is developed that continuously integrates and combines event-specific data, gathered ex-post, with consequence models, developed ex-ante. The transparent propagation of uncertainties present in the models and the data, enables dynamic updates and refinements of post-earthquake predictions on the spatial distribution of damage, loss and recovery.

A preliminary version of this dynamic framework is demonstrated using a small-scale simulated case study focused on residential buildings, which allows to discuss key aspects of ex-post data availability and to compare the proposed framework with existing methods for similar purposes (e.g., Loos et al. 2020; Kovačević et al. 2018, Marinković et al. 2018). A sucessful tailoring of such a framework to Switzerland requires not only discussions on the type and resolution of the desired information gathering, processing and output, but also on data availability and quality, planned procedures for rapid safety screenings and recovery (Gunzenhauser et al. 2018), as well as on the type and scope of models developed within the Swiss national earthquake risk model (Roth et al. 2018).

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7.7
Modelling of Strengthening in the Equivalent Element Approach

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The seismic vulnerability of existing masonry buildings can be reduced by applying various strengthening solutions. A recently developed 3D macroelement for modeling both in-plane and out-of-plane response
allows analysing masonry buildings in a computational efficient manner considering all relevant failure modes. The objective of this paper is to investigate the use of this macroelement for modeling the effect of FRP strengthening on the in-plane and out-of-plane response of masonry walls.

The increase in flexural in-plane and out-of-plane strength due to FRP strengthening is accounted for by defining the flexural capacity through a fibre section, which includes the vertical FRP strips. The effect of the FRP strengthening on shear strength and deformation capacity is modifying the corresponding parameters in the phenomenological marco-element equations. In this paper, in-plane monotonic and cyclic shear-compression tests, in-plane dynamic test, as well as four-point out-of-plane bending tests with and without FRP strengthening, which are documented in the literature, are modelled and the numerical simulations compared to the experimental results.

The comparisons shows that the proposed modelling approach for FRP strengthened masonry walls yields good predictions of their in-plane and out-of-plane response. Equivalent frame models can therefore be used to model the system response of masonry buildings with FRP strengthened walls.

7.8
Testing of additively manufactured small scale RC specimens for statistical validation of structural models in earthquake engineering

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This paper claims that a major source of error in Seismic Analysis of Structures is the assumptions used to scale up from component- to system-level behavior. It also claims that validation of numerical models should be performed statistically. As a statistical validation requires multiple virgin specimens, the paper suggests the use of a 3D printer to construct the reinforcement of microRC specimens (1:40) to be tested in a geotechnical centrifuge. It presents some first tests on gypsum-based microconcrete, additively manufactured rebars with diameters as low as 0.35mm, and small scale RC beams. The properties observed seem to resemble the ones of full scale RC components. Given the material properties, Opensees is able to accurately capture the behavior of the microbeam.

7.9
Former ammunition depot Mitholz: seismic response of a rock mass damaged by accidental explosions

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In 1947, an uncontrolled explosion of the subsurface ammunition storage Mitholz in the Swiss Kander Valley caused several fatalities, the partly destruction of the ammunition storage and the adjacent village of Mitholz – and a leftover of 3'500 t of unrecovered ammunition remnants. In 2018, a risk analysis of the site, which until then was used for military purposes and was planned to host a computer server centre, revealed unacceptable risks for the surroundings of the depot.

Especially rock falls and earthquake-induced ignition of the ammunition were considered high (10^{-3} to 10^{-2} per year, estimated by Risk&Safety AG (2018)). In the course of a more detailed investigation on seismic stability (a.o. with CSD Ingenieure AG) ambient vibration measurements at Mitholz were performed to support the further assessment of the rock characteristics. A combination of the field measurements with numerical simulations aimed to understand the seismic stability of the damaged cavern.

For an array measurement 21 seismic sensors (LE-3D 5-s and LE-3Dlite 1-s) were located both inside the tunnel system and outside at the surface above the cavern (Figure 1). The seismic response was analyzed with all state-of-the-art methods (amplification, polarization and normal mode behaviour) as described e.g.in Burjanek et al. (2014), Kleinbrod et al. (2019) and Häusler et al. (2019). Amplification factors are highest in the area just above the destroyed cavern and fracturing of the rock mass decreases the further away stations were located from the centre of the detonation (Figure 1c). Polarization direction is east-west – in line with the predominant geological fracturing and faulting of the underlying early createaceous limestone (Oehrlikalk).

Results of these measurements were used to calibrate the elastic properties of a 2D model to analyze the earthquake stability of the underground structure. Earthquake-induced displacement patterns of the rockmass involve rockfall of instable blocks at the outside (Dreispitz), rockfall and breakdowns within the caverns, and even a complete collaps of the tunnel system along the pre-existing fault-system of the Mitholz-fault seems possible. This study shows, that ambient vibration measurements and their analysis can be succesfully applied to characterize the subsurface not only for mass movements, but also to special cases of superficial mass displacements like underground explosions.

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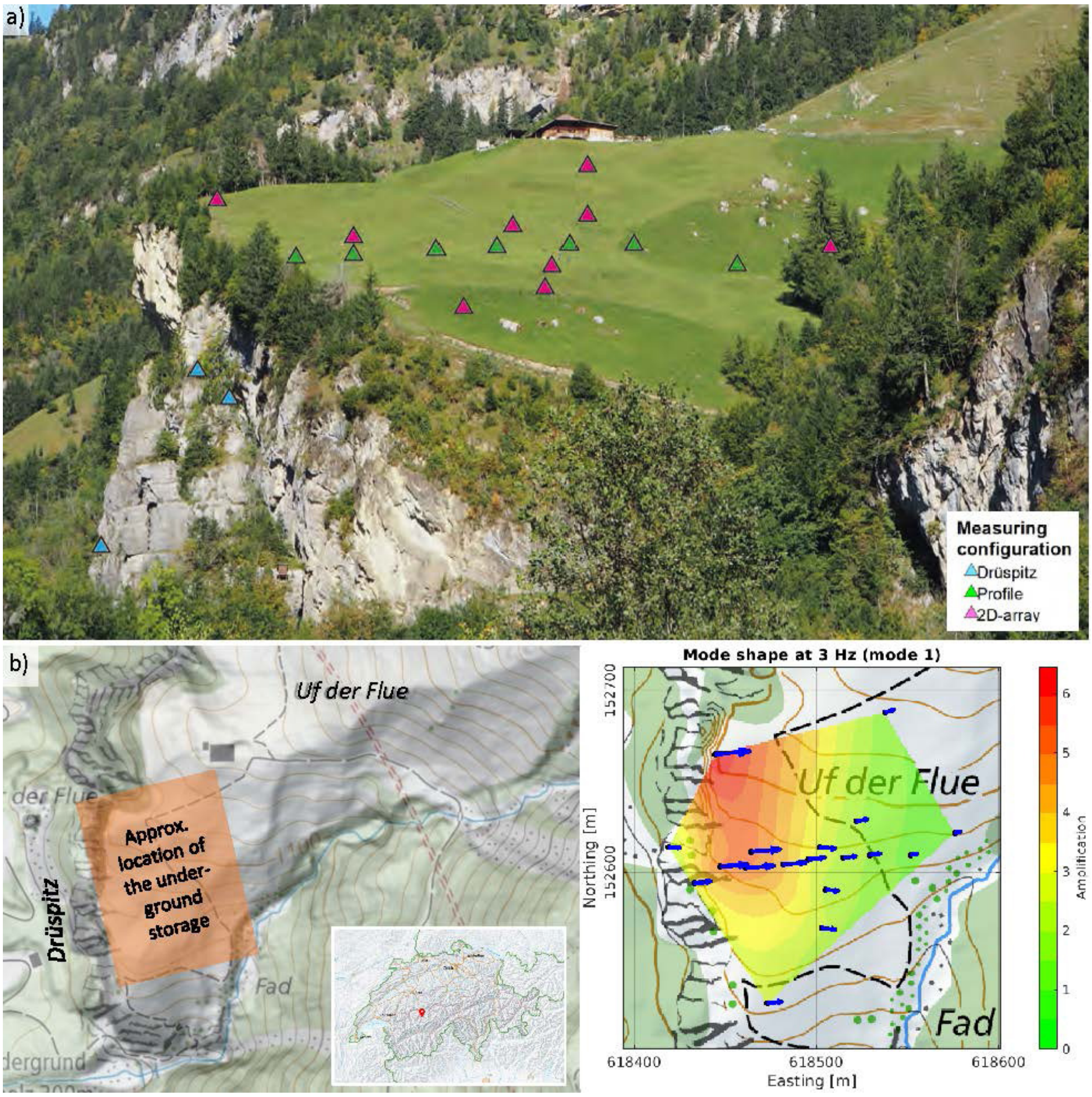

Figure 1. Location of the 1947 detonated underground ammunition storage chamber at Mitholz and results of the ambient vibration measurements. a) Measuring configuration of the passive seismic array at the Drüspitz peaks and the plateau Uf der Flue; b) Location of the site in Switzerland between Kandersteg and Kanderground and the topography and naming of the area; c) Amplification map of the mode shape at 3 Hz with the arrows indicating the normal mode vector (polarization).

7.10
An approach to characterize high-frequency ground motion at depth

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The site-specific high-frequency (>1Hz) attenuation and amplification are essential for the prediction of the ground-motions on a local scale. Amplification is generally modeled using Vs30 adjustments on classical ground-motion prediction equations while attenuation is usually concisely described with parameter kappa; however, these approximations are subject to high epistemic uncertainties. Furthermore, there is a need to characterize ground motion at depth in the seismic hazard assessment of deep geological disposals (e.g. nuclear waste repositories), with a particular need to characterize high-frequency ground motion for seismic design purpose.

In this research, we aim to develop a physical-based approach to construct stochastic depth-to-surface amplification models. We first derive a set of 1D velocity profiles based on geophysical measurements and considering various possible random effects of the near-surface geology on ground motions. These random models are then used for computation of an ensemble of the depth-to-surface SH-wave transfer functions. The ensemble of such transfer functions is used for the construction of the stochastic model shown in Fig. 1 through statistics in the power spectral density (amplification term) and the envelope delay (temporal term). Finally, we compare theoretical predictions with empirical depth-to-surface amplifications and durations as retrieved from borehole installations of the Japanese KiK-net network.

Our approach has many various applications, such as: the inversion on the high-frequency ground motion at depth from surface recordings, the site-specific stochastic adjustments on classical ground-motion prediction equations, the evaluation of the systematic bias in the representation of the local site response intrinsic to downhole seismometer arrays (e.g. interaction of up- and down-going waves, etc.

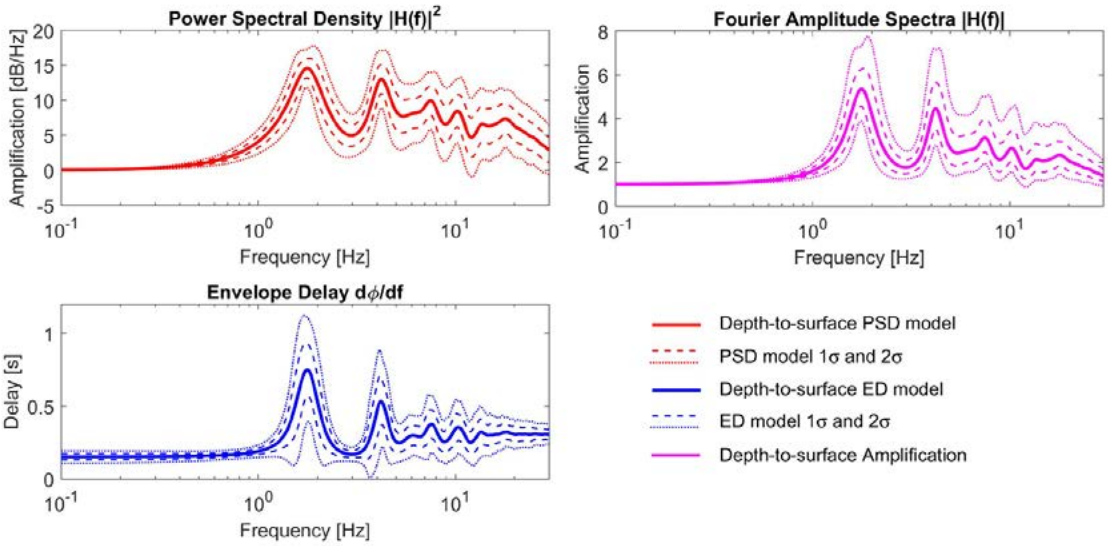

Figure 1. The model to characterize the ground motion at depth with respect to the surface. The model represents statistical properties from an ensemble of depth-to-surface SH-wave transfer functions in randomly perturbed velocity models.

7.11
Earthquake-induced mass movements in Switzerland: overview on past and ongoing projects

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Earthquake-induced landslides and rockfalls are common during and after seismic events with ~PGA 0.18 g (EMS macroseismic intensity VI to VII) and larger. In the Swiss alps, the probability of such an intensity generally exceeds 10 % in 50 years and reaches values up to 75 % in southwestern Switzerland (Wiemer et al., 2016). Testimonials of earthquake induced landslides are the destruction of the villages Corbeyrier and Yvornaz following the Mw 5.9 Aigle earthquake in 1584, the rockfall from Bürgenstock during the Mw 5.9 event 1601 in Unterwalden, and the 5 million m^3 rock avalanche at Rawilhorn during the largest aftershock of the 1946 Mw 5.8 Sierre earthquake (Figure 1).

Detailed studies on seismic site response of unstable slopes in Switzerland started with the COGEAR (Coupled Seismogenic Geohazards in Alpine Regions) project in 2009 (Fäh et al., 2012). Key findings include the observation of high seismic amplification factors (>7) and wavefield directivity perpendicular to complient fractures (e.g. Burjánek et al., 2012). Geospatial susceptibility proxies, such as topography, and ground motion prediction models allow for estimating the probability of coseismic landsdlides on a regional scale (Cauzzi et al., 2018). However, extensive field experiments on more than 25 slope instabilities in Switzerland revealed a great variety in dynamic response, including wavefield amplification factors larger than 35, normal mode resonance behavior and slopes exhibiting surface wave propagation (Kleinbrod et al., 2019). Therefore, site-specific analysis of a slope remains crucial to assess the hazard of coseismic mass movements on a particular location.

We present an overview on past and ongoing projects in the field of earthquake-induced mass movements in Switzerland and demonstrate how the methodology, which was developped to assess seismic site response, can be applied in environmental seismology to characterize rock slope instabilities in general, independent of potential triggering by earthquakes.

Figure 1. Deposits of the earthquake-induced rock avalanche at Rawilhorn (Valais) after an aftershock of the 1946 Mw 5.8 earthquake.

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7.12
SCARF3D: a scalable library to efficiently generate large-scale, three-dimensional random fields

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Numerical modelling of strong ground motion requires realistic structural models that allow simulation of all wave propagation phenomena. One dominant process is wave scattering due to small heterogeneities, associated to strong effects in terms of ground motion attenuation and duration. Starting point are realistic 3D models derived from extensive geological and geophysical field investigation. However, small scale changes in properties of geologic units can be characterized only by random variations. We present a new numerical package to efficiently generate large-scale, three-dimensional random fields with prescribed power spectrum. Our software can be used either as a stand-alone program or as a library and it can be therefore invoked by other computer programs to generate random perturbations directly on the nodes of structured and unstructured meshes, thus avoiding costly intermediate input-output operations. The code is highly flexible and allows the user to easily generate continuous multi-resolution random fields across mesh refinement interfaces. It implements two different algorithms that can be selected depending on the available hardware resources. The package relies on the popular MPI and FFTW libraries and it has been tested from desktop machines up to hybrid CPU/GPU supercomputers, showing very good scaling properties. The simulated random fields closely follow the desired auto-correlation function.

7.13 Developing an Integrated 3D Geological-Seismological Model at Urban Scale in Basel, Switzerland

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Assessment of seismic risk at a local scale is fundamental to the adoption of efficient risk mitigation strategies for urban areas with spatially distributed building portfolios and infrastructure systems. An important component of such a study is to estimate the spatial distribution of the expected seismic ground motion induced by site response.

The current work presents a prototype of seismic site response study at urban scale, performed in the context of developing an earthquake risk model for the canton of Basel-City in Switzerland. Different studies undertaken over last two decades in the area concluded that unconsolidated sediments were responsible for inducing fundamental resonance and large amplification of seismic waves over a range of frequencies pertinent to engineering interest. They also highlighted the necessity of better characterizing complex geological domains (the Upper Rhine Graben and the Tabular Jura) and tectonic setting (the master-fault system of the Graben) of the area. Therefore, we make a step forward in this study by attempting to develop a three-dimensional (3D) integrated geological-seismological model of Basel, which will explicitly account for the complex geological conditions at the surface and at depth.

Thanks to the past projects (see Michel & Fäh 2016 for a review), there is an abundance of geological, geophysical and seismological data for Basel. Earthquake recordings are available from an operating network of more than 20 permanent stations as well as from several former temporary stations. Single station ambient noise measurements are available from several hundred sites. Shear-wave velocity profiles have been obtained from more than 25 passive seismic arrays. In addition, a number of active seismic measurements and borehole logs are also available. This database will be complemented by 6 additional temporary stations (2020-2023) along with new passive seismic measurements. An updated and detailed 3D model of subsurface geological structure of the area has been provided by the team of Applied and Environmental Geology (AUG) of University of Basel.

The ongoing analysis of the available information will (1) better identify the composition, geometry, thickness and topography of the surficial unconsolidated sediments as well as the underlying more consolidated layers, and (2) characterize them by means of geophysical parameters (e.g. resonance frequency, shear-wave velocity). The results will then be compiled into the aforementioned 3D model. Ground motion simulation and 1D site response study will be performed in order to validate the developed model with respect to seismic observations. This model will be used to simulate 3D amplification effects and risk scenarios for Basel city.

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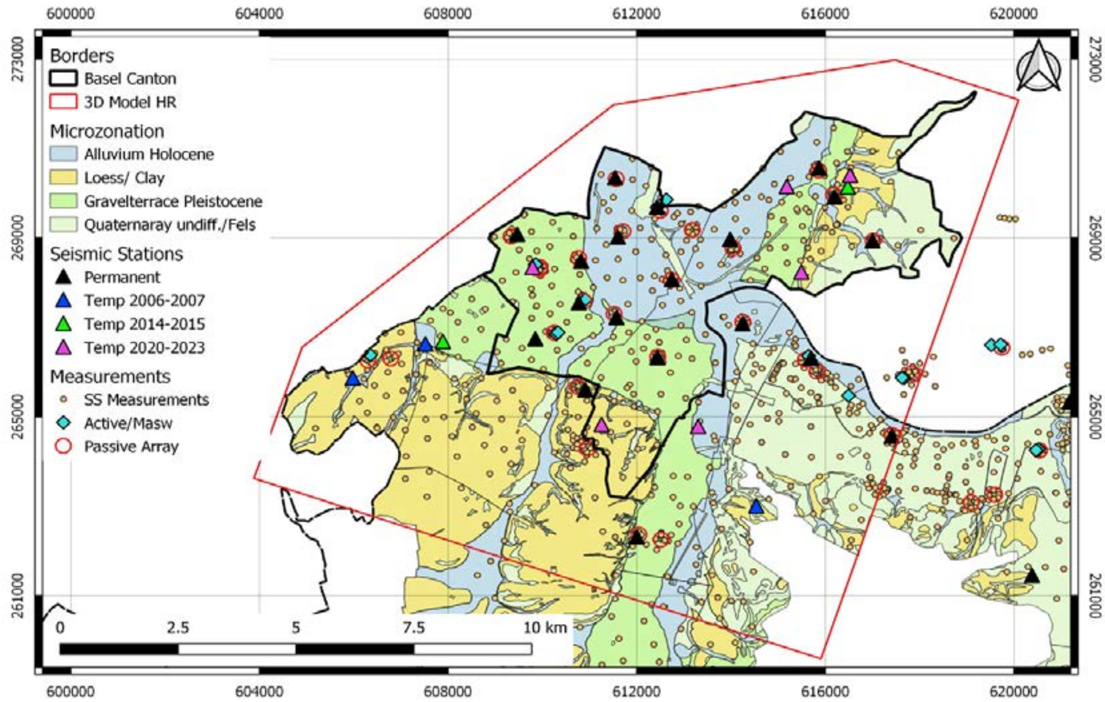

Figure 1. Locations of available geophysical and seismological data for Basel. A high resolution (HR) 3D geological-seismological model will be developed for the area bounded by the red polygon.

7.14
Evaluation of the variability of soil response in urban environment using reference-site methods: the case of Lucerne, Switzerland

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The long-term seismic risk cannot be neglected even in low-to-moderate seismicity countries like Switzerland, especially in densely populated urban areas. Site effects evaluation is a crucial part of local seismic hazard and risk assessment. The focus of this study is the city of Lucerne, located in a basin filled with unconsolidated deposits and struck by strong earthquakes in the past (i.e. Mw 5.9 in 1601). Our aim is the estimation of the site response in different parts of the city and a better characterization of the influence and variability of the local geological structure. This work is in the framework of the European URBASIS project concentrated on seismic hazard and risk in urban areas.

In the presented analysis, we used the weak motion observations from low-magnitude or distant earthquakes recorded by a temporary seismic network installed for half a year at selected urban sites. The dataset was supplemented by earthquake recordings at 3 permanent accelerometric stations belonging to the Swiss Strong Motion Network (SSMNet). We show the comparison of relative amplification factors evaluated using standard spectral ratio method applied to earthquakes (SSR - Borcherdt, 1970) and ambient noise (SSRn – Kagami, 1982) recordings, as well as a hybrid approach (SSRh) combining these two techniques (Perron et al., 2018). While amplification estimated with SSRn is usually overestimated in comparison to the SSR, matching results were obtained using the SSRh method. Another presented approach based on regional earthquake recordings is Empirical Spectral Modelling (ESM - Edwards et al., 2013). ESM shows consistent results with the SSR method due to similarities between the outcropping rock in Lucerne with the Swiss reference rock used in ESM.
In the next step, we applied the SSRh technique to estimate the spatial variability of basin response in a test area. A survey including several dozens densely distributed single-station noise measurements was performed in June 2020. Moreover, we combined our dataset and recordings from the past 20 years in the Lucerne city center to map the fundamental resonance frequency (f0) across the area.

This work represents the first step in a detailed site response analysis study for the Lucerne area, considering 2D and 3D effects and potential non-linear soil behaviour as well. We present the current status of the ongoing site effects assessment, highlighting the limitations and specifics of the site characterization in urban areas.

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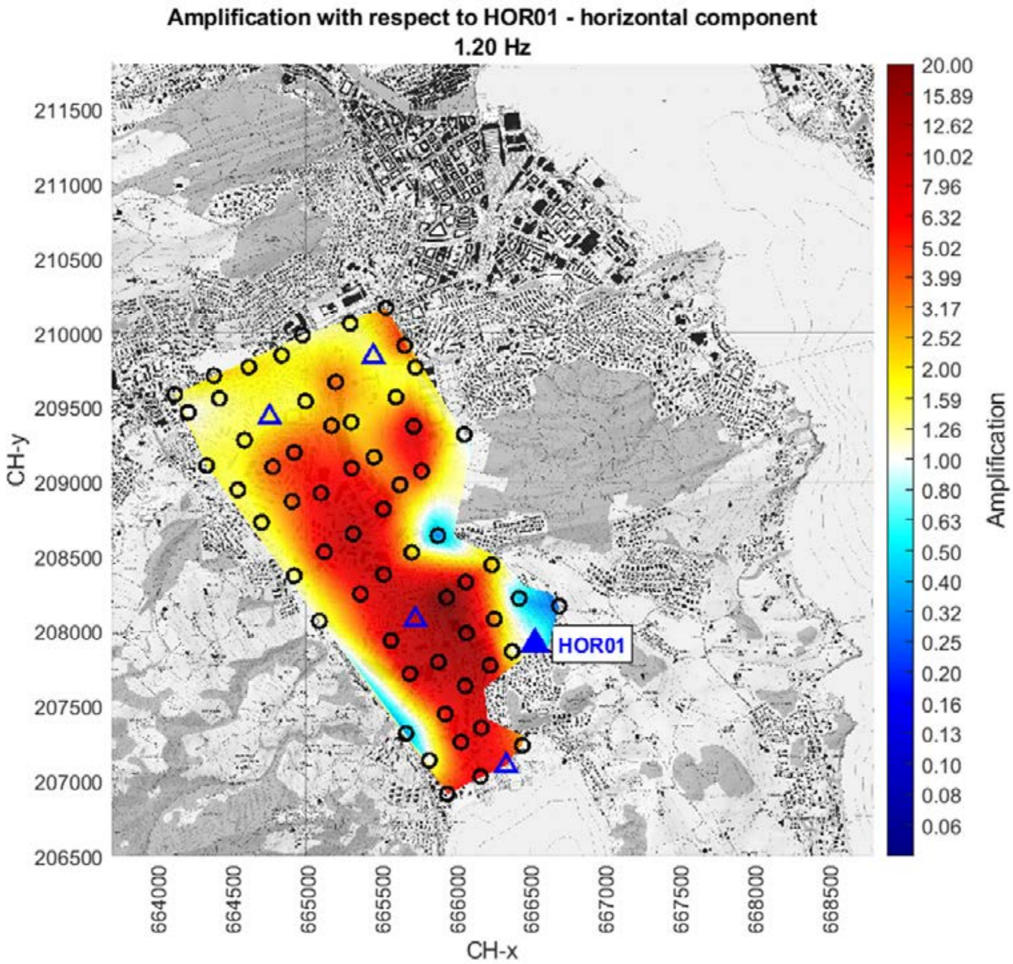

Figure 1. Amplification factors with respect to the rock station HOR01 estimated using the SSRh method. Blue triangles represent sites where earthquake recordings are available, black circles are ambient noise measurements.

7.15
Physical modelling of interaction between earthquake-induced Tsunamis and geotechnical structures

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Catastrophic hydrodynamic events, such as earthquake-induced Tsunamis can devastate society and the built environment. A good deal of this destruction is a result of a combination of scouring, the loss of support material, and hydraulic loading (Bricker *et al.*, 2015). Modelling such systems numerically is generally beyond our current abilities for all but the most simplistic scenarios and the difficulty in predicting the behaviour of these structures under these loads makes designing new structures, or assessing old ones, extremely difficult.

To bridge this gap, the problem is investigated through physical modelling, with particular emphasis on the complex geotechnical aspects of the problem which are often neglected in hydraulic models. Using scaled models, with an innovative “Miniaturised Tidal Generator” (Fig. 1) in combination with advanced non-intrusive sensing techniques, we are able to see subtle (but critical) changes in soil systems throughout the scour process. These include both complex changes in system geometry and changes in soil state. Such observations are critical to guiding the research, and ultimately design of coastal or near-water infrastructure.

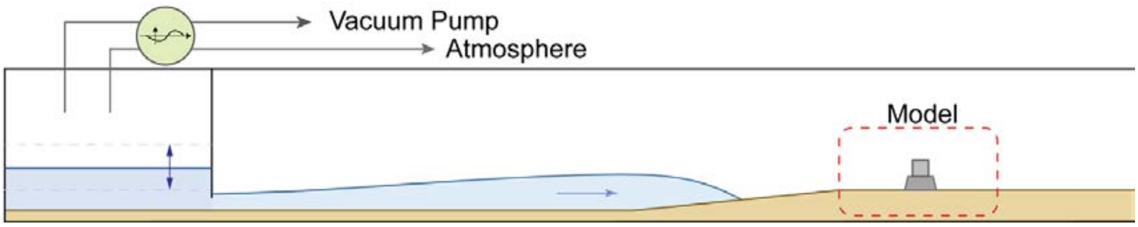

Figure 1. Schematic function of the “Tidal Generator” System, where air pressure is used to generate large length and amplitude waves.

The model is a 1:100 scale “composite” breakwater, based on a prototype 5x5m concrete structure lying on a conhesionless fine marine sand submerged to a depth of 4m. The prototype represents a typical marine structure, as well as a strong resemlence to a common geotechnical system (strip footing) and is assumed to constitute a 2D (plane-strain) problem. The model is subjected to an impact by long-period large amplitude wave (100s, 2m at prototype scale), based on a “Tsunami-like” waveform. This wave is generated by an innovative “Miniaturised Tidal Generator” (MTG) which was specially designed with geotechnical modelling in mind (Jones & Anastasopoulos, 2020). The structure is monitored through a combination of ultrasonic sensing and high-speed photography. Using the “Partical Image Velocimitry” (PIV) method (Stanier *et al.*, 2016), movements of the structure as well as detailed strain fields within the soil can be calculated (Figure 2). Further image analysis allows the computation of the deformed surface profile of the soil.

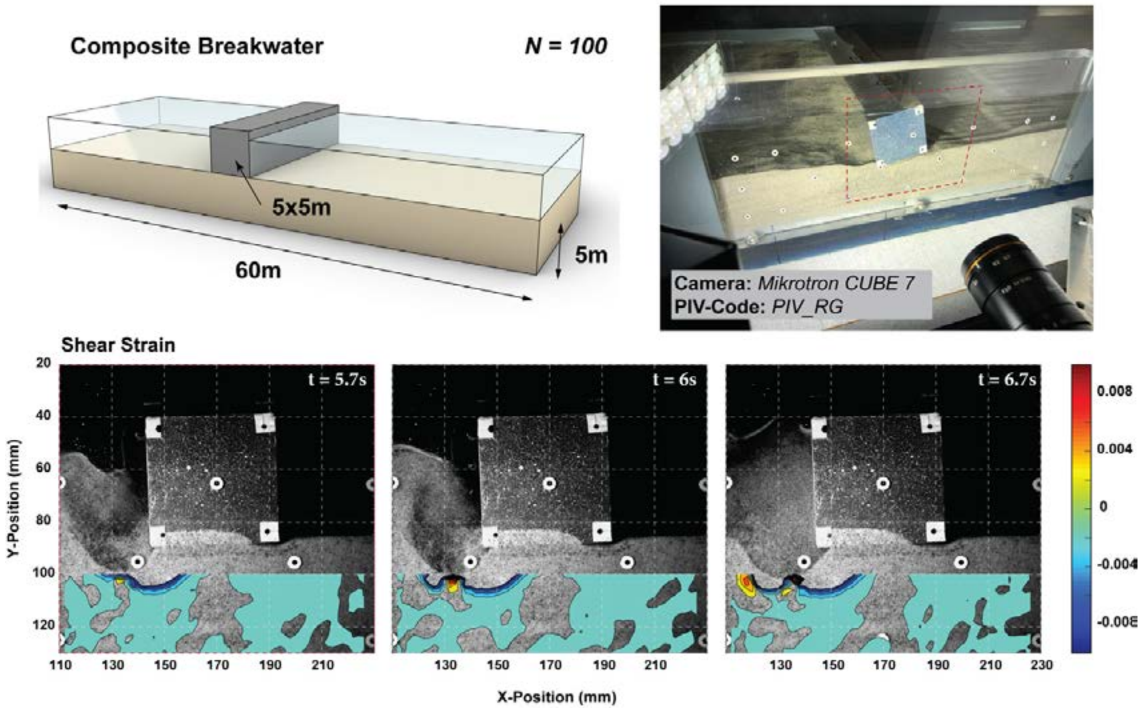

Figure 2. Prototype breakwater (top-left) and experimental model (top-right) showing high speed camera and targets used for image analysis with PIV. Computed shear strains within the soil (Bottom) are shown for 3 time instances.

Upon impact and overtopping by the wave, the development of a large scour hole is observed, along with some small rotation of the breakwater. Large shear strains develop in the soil before a rapid “failure” of the breakwater, where the concrete system rotates into to the newly developed scour hole. In addition, we see changes in volumentric strains within the soil, pre-failure, which indicate a signifant change in the state (and therefore mechanical behaviour) of the soil. Both of these phenomena are not accounted for in current design techniques and represent a significant paradigim shift in the way we understand the behaviour of such structures.

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7.16
Seismic response of a structure on liquefiable soil

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Buildings founded on shallow foundations on liquefiable soil layers may experience significant settlement and tilt, and can even suffer complete bearing capacity failure. Although such structures are the most common, they are not sufficiently protected, as showcased during a recent major earthquake in Indonesia (Sassa & Takagawa, 2019). The state of practice for the prediction of liquefaction-induced settlement typically relies on free-field methods. Such methods focus on consolidation in the absence of the structure, ignoring the shear strains in the vicinity of the foundation (due to the dead load of the structure) and soil–structure interaction (Dashti et al., 2010). However, experimental evidence from centrifuge model tests has shown that the settlement of such structures is primarily due to shear strains, while sedimentation and consolidation are of minor significance (Adamidis & Madabhushi, 2018).

Despite the valuable insights gained from such centrifuge experiments, a comprehensive study of the problem through centrifuge modelling is resource-demanding due to the large number of parameters that need to be investigated. A more viable option is the use of nonlinear numerical deformation analyses (NDAs), employing advanced constitutive models that can capture the nonlinear stress–strain response of liquefiable soil.

This study employs nonlinear, coupled hydromechanical, effective stress, dynamic, time history analysis to study the seismic response of a structure on a shallow mat foundation, resting on a shallow layer of loose Hostun HN31 sand. The analysis is performed employing the advanced constitutive model PM4Sand (Boulanger & Ziotopoulou, 2017), as implemented in the finite-difference (FD) code FLAC. The constitutive model is thoroughly calibrated versus an extensive set of element tests, which were performed at the ETH Zurich geotechnical laboratory (Kassas et al., 2020). The calibrated model is then validated using one of the centrifuge experiments of Adamidis & Madabhushi (2018) as benchmark.

In Fig. 1, the computed total displacement and shear strain contours at the end of shaking are compared to those of the centrifuge model test, calculated using image analysis (Adamidis & Madabhushi, 2018). The numerical simulation predicts the mobilisation of a bearing capacity failure mechanism, which mainly forms directly below the edges of the foundation, while the magnitude of shearing in the soil bellow the centre of the foundation remains low. The comparison between the total co-seismic displacements developed in the liquefiable layer is also favourable. Both the amplitude and the geometry of the displacement field are well predicted.
The thoroughly validated numerical analysis method (against several centrifuge model tests) is consequently employed to conduct a study, exploring the influence of the container type (rigid, laminar container) on the response. It is also determined the necessary distance of the lateral boundaries to minimize the boundary effects.

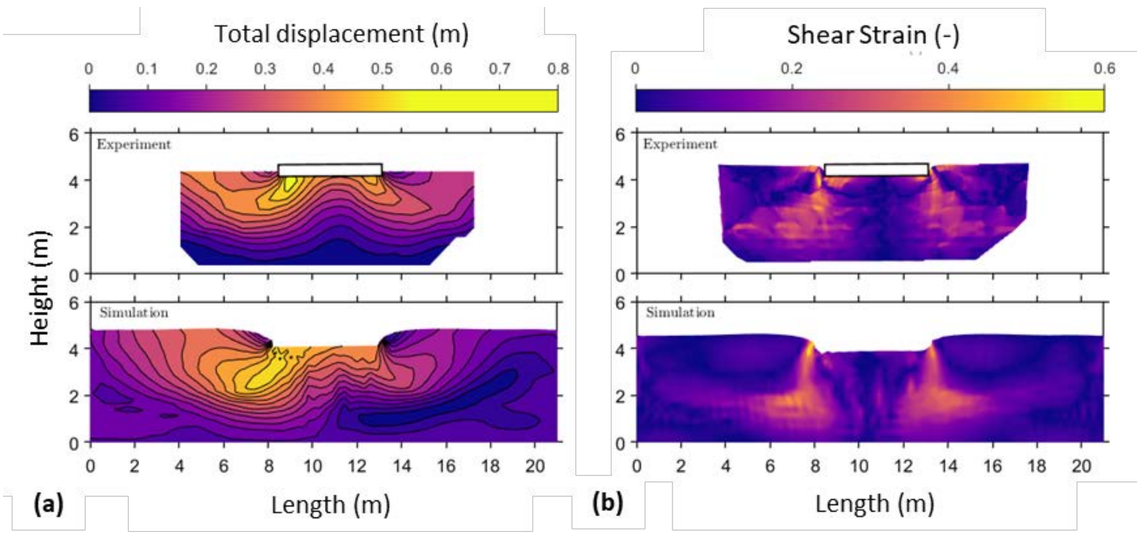

Figure 1. Comparison between numerical analysis and centrifuge experiment at the end of the seismic excitation: (a) accumulated total displacement contours; (b) accumulated shear strain contours

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7.17
A Scenario-based fragility model for Swiss buildings

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Seismic risk assessment at a regional/urban scale is of worldwide concern as the related human or financial losses due to a catastrophic event have a significant societal impact. Although large-magnitude earthquakes are not frequent in Switzerland, several studies (e.g., Lestuzzi *et al*., 2016) showed buildings, especially ones located in the areas with relatively high seismic hazard, are vulnerable to earthquakes. A fragility model, which covers different building classes with Swiss-specific characteristics, plays a major role in a realistic estimate of damages/losses. In this context, we here focus on Swiss building classes with different load bearing systems and heights; the corresponding fragility curves, which link the different damage grades to spectral ordinates, are generated using the conditional spectrum (Michel *et al*., 2018) for different scenarios. The obtained results showed that damages are dependant to earthquake magnitude. Considering a large variety of expected earthquake magnitude in Switzerland, the proposed scenario-based fragility model, hence, provides us with a better picture of consequences for each individual possible event and public authorities could benefit from that for real-time loss assessment.

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7.18
A Seismological Survey on Lake Lucerne (Switzerland)

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We present our experience in site selection and inspection, array design and deployment of Ocean Bottom Seismometers (OBS) in Lake Lucerne (Switzerland). The challenges related to the OBS localization offshore were addressed by combining multibeam bathymetry and differential GPS coordinates of the OBS at recovery. Two data pre-processing algorithms were developped. The first one was used to correct for the clock drift of the instrument and the second to correct the instrument misorientation. In total, OBS were deployed at over 160 locations on selected subaqueous slopes.
The power spectral density curves are estimated and interpreted to derive the Low and High Noise Model for the entire lake. The performance of the array to detect seismic events was assessed by comparing local (Figure 1) and teleseismic events recorded by onshore permanent Swiss Strong Motion stations and offshore OBS. The power power spectra and Peak Ground Velocity (PGV) for recorded earthquakes were also compared and show high values offshore.
By processing earthquake recordings using empirical spectral modelling (Edwards et al.,2013), the site amplification functions offshore are obtained and indicate large values compared to observations onshore. Furthermore, the orientation-corrected data were used to perform wavefield polarization analyses from local events using the receiver function principle. By analyzing microtremor data, the spatio-temporal variation of the horizontal-to-vertical (H/V) spectral ratio is assessed. Results show a sensitivity to changes in the local structure and the H/V curves are stable for a 24 hour-record. Finally high quality phase velocity dispersion curves for Scholte and Love waves are estimated.

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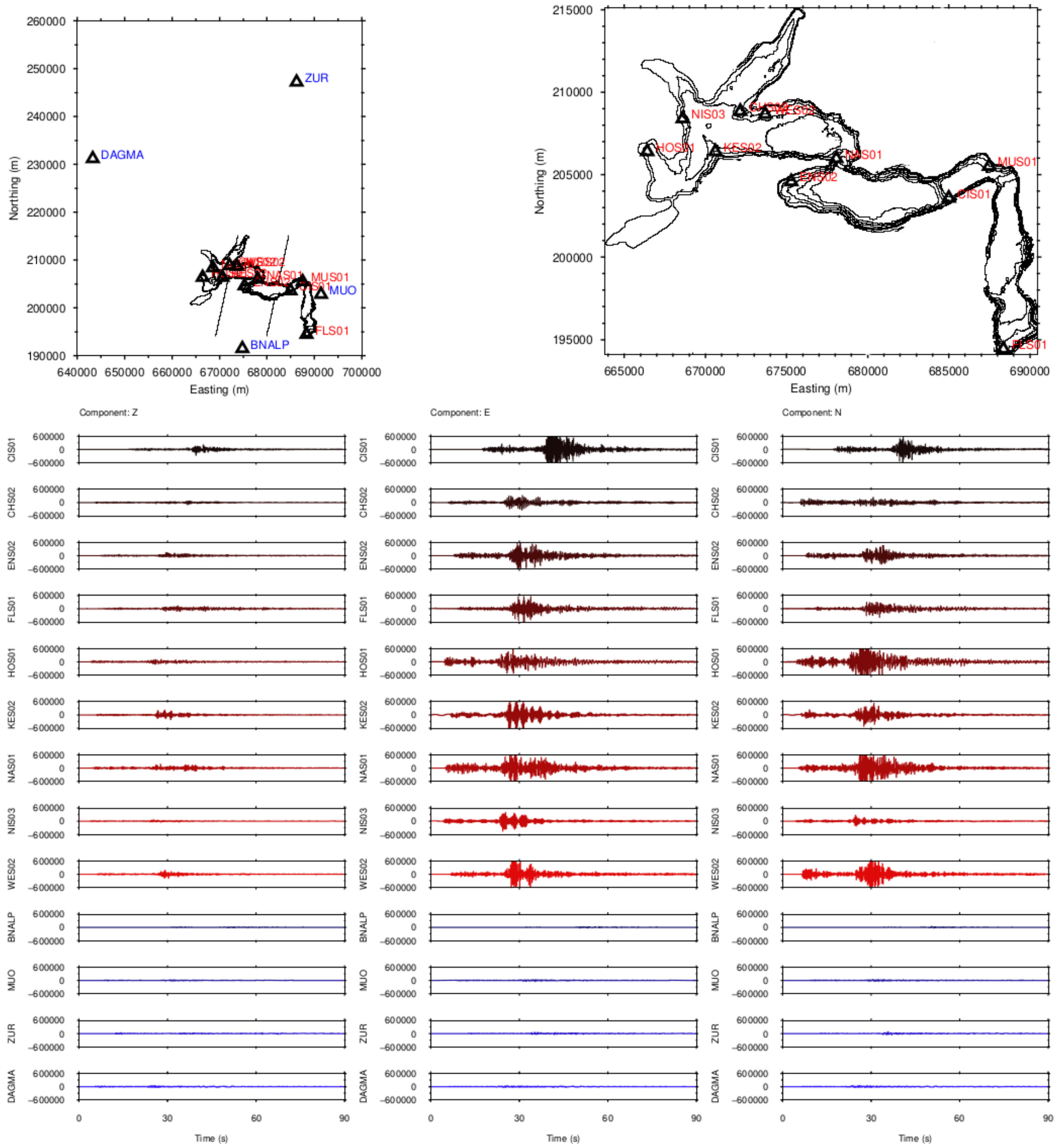

Figure 1. Seismograms of the Montreux M4.2 local earthquake that shook Switzerland on 28.05.2019 with over 600 citizen responses (Marti, 2020). The event was recorded on nine (09) OBS offshore four (04) stations onshore (CH network). The station locations are indicated. The data are corrected for both the sensitivity and the instrument response. The represented ground motion is in nm/s.

7.19

In-situ estimation of rocking stiffness of pile groups

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An in-situ method for the estimation of rocking stiffness of existing pile groups is highly desirable in the framework of performance-based design and improved evaluation of seismic performance of existing structures. This numerical study explores the possibility of developing such a method based on measurements of lateral vibration induced by low-amplitude non-destructive dynamic loading. The testing equipment required for real-scale applications consists of a mass vibrator at the top of the bridge pier and a measurement tool to record the lateral vibration response of the pier and the rotation of the cap (Fig. 1a).

The proposed measurement estimation method is based on a simplified model of the general problem (Fig. 1c): a series of three spring-dashpot-mass assemblies, representing equivalently the three main lateral motion components of the bridge pier illustrated in Fig. 1b (i.e., swaying δ_h, rocking δ_r, and bending δ_f). The stiffness parameters of interest K_f and K_r can be estimated using Eq. 1, derived from the equations of motion of the simplified model.

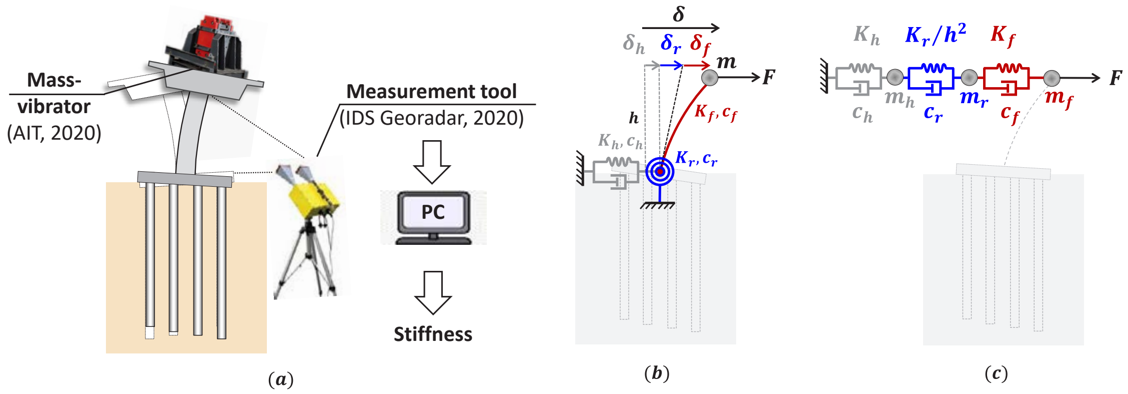

Figure 1. (a) General problem simplified to (b) a SDOF system and (c) a series of three spring-dashpot-mass assemblies.

$$K_f = \frac{F(t) - m_f\ddot{\delta} - c_f\dot{\delta}_f}{\delta_f} \qquad K_r = \frac{F(t) - m_f\ddot{\delta} - m_r(\ddot{\delta_r + \delta_h}) - c_r\dot{\delta}_r}{\delta_r} h^2 \qquad (1)$$

The accuracy of the stiffness estimation equations is evaluated using a three-dimensional numerical model (Fig. 2) of an idealized, yet representative system: a 2x1 pile group ($L_{pile} = 15\ m$; $D_{pile} = 1\ m$) connected with a rigid pile cap, supporting an $8\ m$ high bridge pier ($D_{pier} = 1.5\ m$). The response of the reinforced concrete elements is considered elastic ($E = 30\ GPa$), taking into account the low amplitude of the dynamic load (non-destructive testing). The soil profile assumed is a uniform clay of $s_u = 100\ kPa$, modelled with a kinematic hardening model with Von Mises failure criterion and associated flow rule (Anastasopoulos et al., 2011).

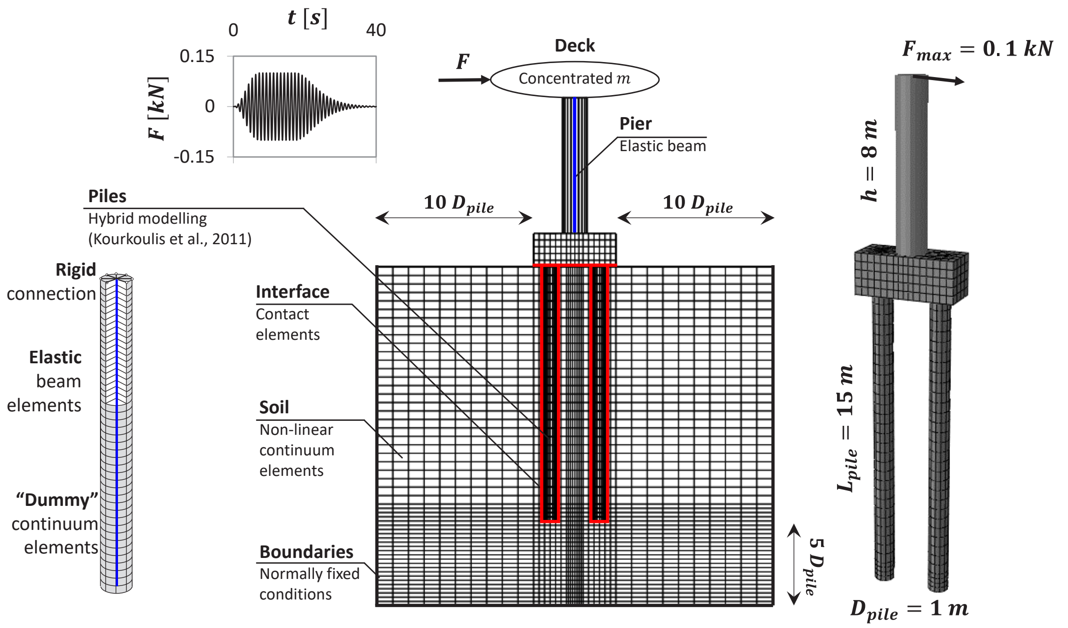

Figure 1. Details of the three dimensional model of the analysed problem.

The measurement estimates of the flexural and rocking stiffness parameters K_f and K_r, obtained by introducing in Eq. 1 the numerically simulated motion parameters, are compared with their real values, obtained from lateral pushover tests performed with the same FE model. The comparison indicates that the estimated values coincide with the real ones, and the proposed method can be used to evaluate the structural health (i.e., K_f of existing piers) and to estimate the real rocking stiffness (i.e. K_r) of existing pile groups. Nevertheless, further numerical and experimental investigations are required to generalize the results of this study and implement the estimation method to real-scale applications.

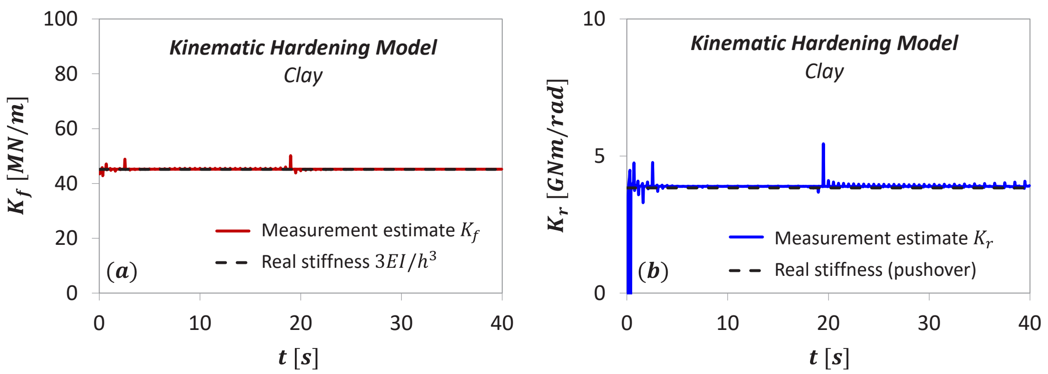

Figure 2. Three dimensional model of the analysed problem with the adopted loading function.

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7.20
Towards building-typology formulations that are adapted for structural health monitoring applications

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Earthquakes are disruptive events that cause widespread damages to the built environment and carry a high societal loss potential. In addition to direct losses, unavailable buildings and other infrastructure components undermine normal functioning for an extended period after the earthquake and ultimately hinder recovery. While enforcing modern building codes is a cornerstone of risk reduction, knowledge of the vulnerability of the building stock at large scale is key to enable optimal planning of retrofitting before earthquake events and emergency interventions immediately after the event. When coping with thousands of buildings, taxonomies of building types (Brzev et al. 2012) are an essential tool. However, classical taxonomy formulations and vulnerability curves of building types are based on highly simplified behavior models and very rudimental building characteristics, such as year of construction, building material and number of floors above ground (Lestuzzi et al. 2016). Although such data sources have the advantage of being well-documented in national databases (at least in developped countries), they are often not compatible with the degree of precision offered by modern tools, such as measurement devices and image-processing algorithms.

Another drawback of existing typological formuations (such as capacity curves or fragility curves) is related to missing out on key contributors to seismic deficiency. For instance, irregularities in plan and elevation, amount of openings, type of roof and foundations, are rarely part of simplified vulnerability classes. In addition, modal properties, such as natural periods and mode shapes, carry a lot of information regarding building responses to earthquake loads. With improved availability of efficient sensing solutions, modal properties can be retrieved with relative ease and speed.

Therefore, in this contribution, authors study the influence of characteristics of the Swiss building stock on the seismic capacity. With the help of parametrized physics-based models, clusters of behavior are analysed in order to discuss the most important properties that influence predicted seismic behavior (namely yield displacement, ultimate displacement and the safety coefficient described in Swiss codes (SIA 266, SIA269/8). As permanent installation of sensors is unlikely to be achieved systematically in all buildings, especially in regions with low-to-moderate seismic hazard, a performance-based building categorisation is key to chose indicator buildings for efficient and large-scale implementation of structural-health monitoring for rapid post-earthquake assessment. Through improvements of preparedness and rapid disaster response, such large-scale structural health monitoring tools can improve societal resilience with respect to earthquakes and, within the Swiss context, could refine the seismic risk model currently under preparation (Roth et al, 2018).

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7.21
The effect of declustering on the size distribution of mainshocks

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Declustering algorithms aim to divide earthquake catalogs into mainshocks and dependent (clustered) events such as fore- or aftershocks. Many seismicity studies, including seismic hazard assessment for Switzerland, are based on declustered catalogs. They consist solely of mainshocks to avoid spatial biases due to seismicity clustering.
Several declustering algorithms have been proposed and used, and, as earthquakes do not come with labels, there is no objective criterion with which to evaluate the performance of the different methods.

We assess the effect of declustering on the frequency-magnitude distribution of mainshocks, described by the empirical Gutenberg-Richter (GR) law (Gutenberg and Richter, 1944). In particular, we examine the dependence of the -value of declustered catalogs on the choice of declustering approach and algorithm-specific parameters. Using the catalog of earthquakes in California since 1980, we show that the -value decreases by up to 30% due to declustering with respect to the undeclustered catalog. The extent of the reduction is highly dependent on the declustering method and parameters applied. Window methods (Gardner and Knopoff, 1974), in particular with Gruenthal window parameters (Gruenthal, 1985) which are used for the 2015 Swiss seismic hazard model, induce a relatively large -value reduction among the methods considered.
In the second part of this study, all the above-described effects are reproduced in synthetic data by declustering simulated earthquake catalogs with known -value, which have been generated using an Epidemic-Type Aftershock Sequence (ETAS) model.

Our analysis suggests that the observed decrease in -value must, at least partially, arise from the application of the declustering algorithm on the catalog, rather than from differences in the nature of mainshocks versus fore- or aftershocks. Thus, -values of declustered catalogs are biased to a somewhat arbitrary and not immediately apparent extent. This bias can lead to an overestimation of seismic hazard. We conclude that declustering should be considered as a potential source of bias in seismicity and hazard studies, which could be avoided for example by using ETAS based long-term forecasts.

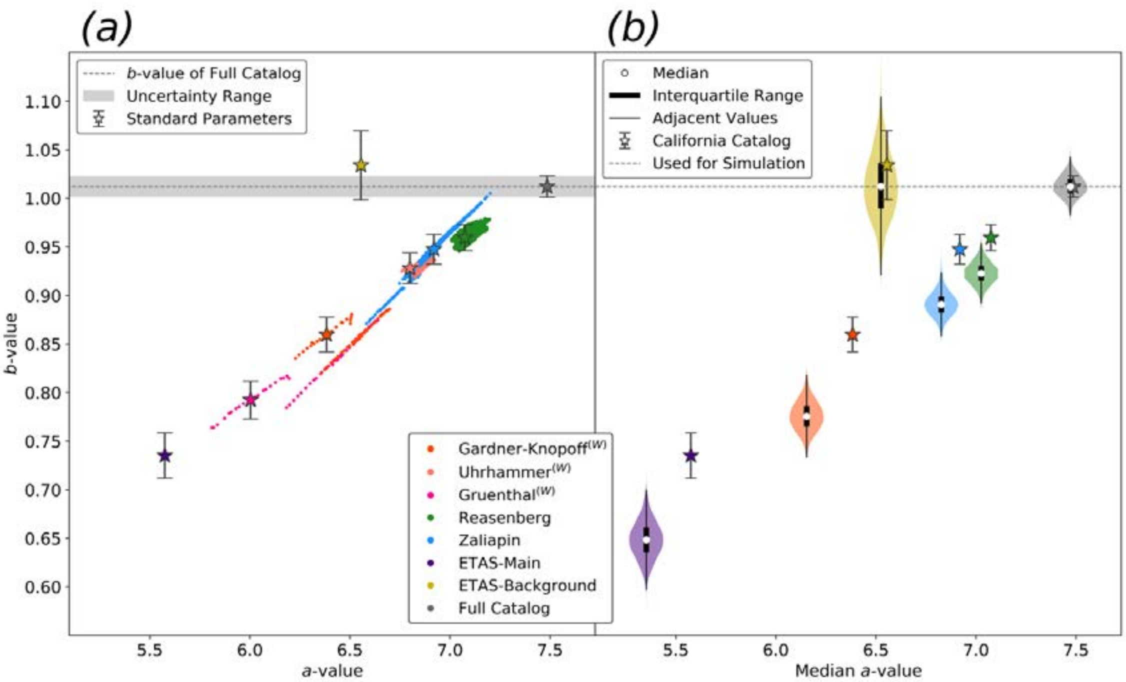

Figure 1: (a) -value versus -value of the declustered California catalog depending on declustering method and parameters. Each dot represents one variation of parameter settings, stars with error bars represent standard parameter settings. Marked with (W) are window methods. The dotted grey line and grey area indicate the -value of the non-declustered catalog and its uncertainty. (b) Distribution of mainshock -values of 2000 simulated catalogs, depending on declustering method (with standard parameter settings and standard (Gardner-Knopoff) window), plotted against median -value per method. Stars with error bars represent the - and -value of the regional earthquake catalog from (a) for the respective methods. The dotted line displays the -value used for catalog generation, which corresponds to the full-catalog b-value observed in the Californian primary catalog.

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7.22
Reconstruction of site amplification functions through canonical correlation with site proxies

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Site specific seismic hazard assessment needs a ground motion amplification model of the investigated region. This models allows to highlight areas that can be strongly affected by earthquake ground motion, which is a crucial information for earthquake mitigation.
Empirical site response can be investigated by using technique such as standard spectral ratio (SSR; Borcherdt, 1970), empirical spectral modelling (EAF; Field and Jacob, 1995; Edwards et al., 2013) or indirectly through analysis of horizontals-to-vertical spectral ratio (HVSR; Nakamura, 1989). The first two techniques SSR and EAF are the most powerful, because they allow to retrieve the amplification function of the investigated site by using earthquake recordings, but they require a long observation time to record a sufficient number of earthquakes. The HVSR method is instead a simplified method based on the ambient vibration recordings. It allows to retrieve information on fundamental frequency and amplitudes of HVSR as a function of frequency in a first step, and to estimate ground motion amplification in a second step. We propose such method to retrieve amplification information based on the correlation of geological, topographical and geophysical proxies (HVSR and Vs30 from measured shear-wave velocity profiles) with EAF measured at a set of instrumented sites. We apply canonical correlation (cc) as suggested by Cultrera et al. (2014). The cc technique investigates the correlation between two sets of variables by identifying their linear combinations having maximum correlation (Davis, 2002). For this purpose 172 free-field and urban free-field seismic station sites with available EAF, HVSR, and velocity profiles were used. The estimated cc coefficients are then used to reconstruct the expected EAF at sites where site proxies are available (see example in Fig. 1).

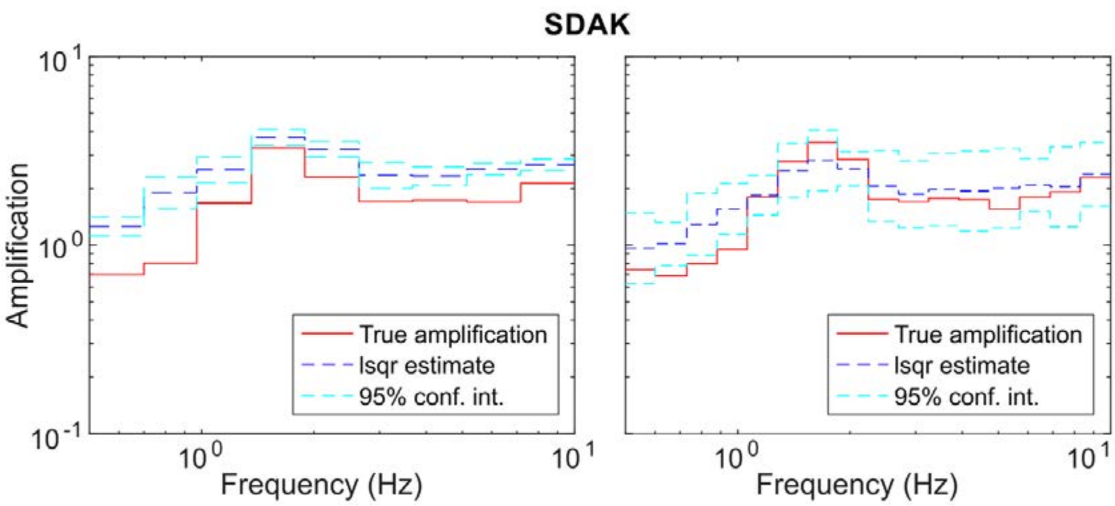

Figure 1. Comparison between observed amplification (red) and the predicted amplification (blue) obtained using cc coefficients for the SSMNet station SDAK. Left panel shows the predicted amplification in 9 frequency bins, whereas right panel displays results for 16 bins.

The results of our analysis highlighted the ability of the method to provide an estimate of the site amplification over a chosen set of frequency bins starting from simple geological, topographical and geophysical proxies (e.g. HVSR and V_{S30}). Finally, the method can be used to estimate amplification information at sites where ground motion amplification is not measured. We present an application for the site Visp in the Rhone valley.

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7.23 Exposure aggregation strategies for efficient assessment of seismic risk in Switzerland

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Exposure models for regional seismic risk assessment are typically defined at a rather crude resolution. In most cases, precise exposure locations are difficult to determine and model developers have to work with data available at administrative unit or ZIP-code levels. At best, these data are then disaggregated, leveraging upon proxy datasets such as the distribution of population or the density of night-time lights (Silva et al. 2020). The final resolution of the exposure model is either dictated by the resolution of the proxy dataset, or chosen by the modeler in line with the available computational resources. To build the exposure model of the 2022 ERM-CH model, the workflow is reversed, given the availability of an extensive building-by-building database for the Swiss territory, which however needs to be aggregated to ensure plausible risk calculation runtimes. The objective is thus to minimize the number of exposure locations, while achieving the best possible trade-off between accuracy and computational efficiency.

Exposure aggregation might introduce error in different ways (Bal et al. 2010; Bazzurro & Park 2007). For instance, the relocation of assets might move them further away or closer to seismogenic sources capable of inducing significant or frequent losses. Similarly, it can place them at locations with different site conditions, where they will be modelled to experience smaller or larger amplification of ground motion or macroseismic intensity. The latter is particularly relevant for the ERM-CH model for which high-resolution site amplification maps are developed. For large exposure datasets, such errors are often averaged out, yet they might still be pronounced depending on factors such as the size and spatial distribution of the exposure, the resolution of the aggregation, and the granularity of the source and site effect models. Aggregation can also introduce an artificial correlation on the input intensity of the assets aggregated together, which might result in a decrease of loss estimates at low return periods and an increase at larger return periods.

Herein, we present a preliminary investigation using a subset of the ERM-CH building database comprising 1,754,875 buildings distributed across the country. The building database was aggregated on three alternative grids with resolutions of 2 km x 2 km, 1 km x 1 km, and 0.5 km x 0.5 km. Moreover, three alternative strategies were explored: (a) aggregation at the centroid of each grid cell, (b) aggregation at the centroid of each grid cell but assigning to that location the intensity amplification factor that is the most prevalent across the real locations of the buildings, and (c) aggregation like in (b) but without aggregating the buildings comprising the top 5% of the exposure model in replacement cost. Comparisons of average annual loss (AAL) estimates obtained using each of these strategies and a non-aggregated exposure are reported for the cantons of Zurich and Valais. At the cantonal level, the effect of aggregation on risk estimates seems to be limited due to the averaging out of errors at individual grid cells. However, at ZIP-code level, our results indicate that an aggregation resolution of 2 km x 2 km should probably be avoided (see Figure 1).

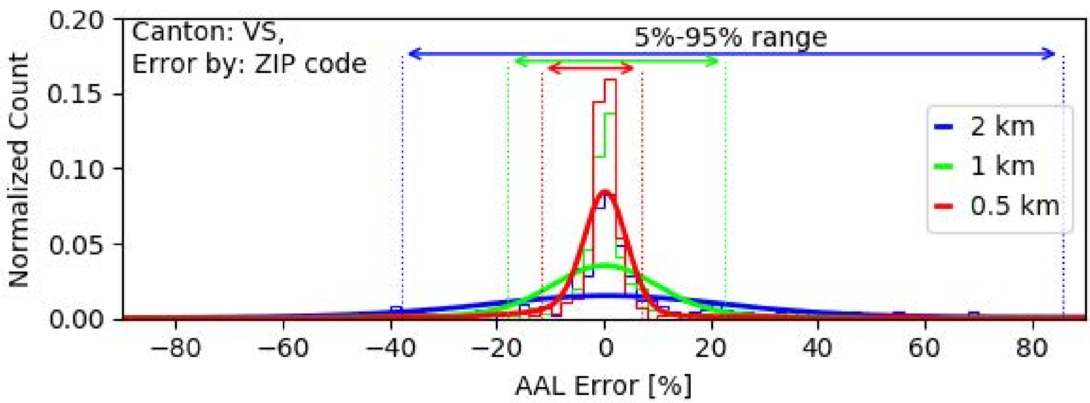

Figure 1. Distribution of AAL error across different ZIP codes in the canton of Valais for different aggregation resolutions and using aggregation strategy (b) .

Moreover, as shown in Figure 2, assigning to each location an amplification factor that best reflects the real locations of the buildings aggregated therein, i.e. strategy (b), seems to yield a substantial error reduction. On the other hand, not aggregating the most valuable buildings, i.e. strategy (c), results in just modest gains for the considered exposure dataset.

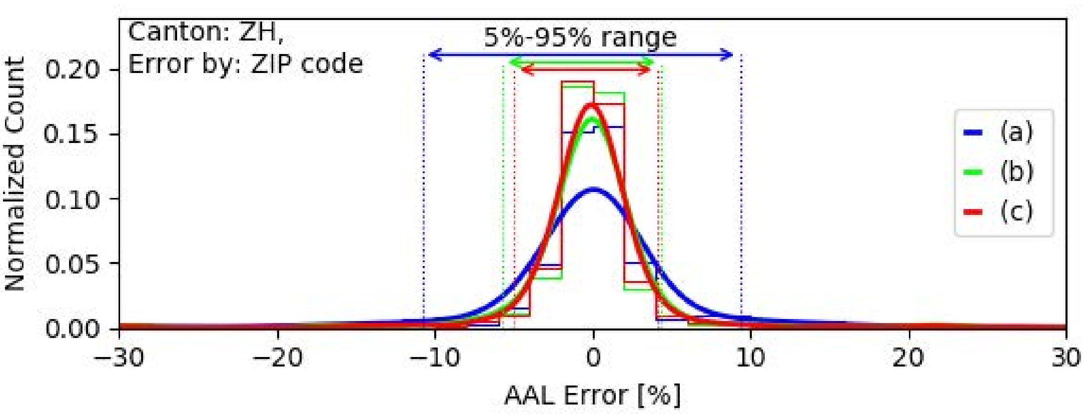

Figure 2. Distribution of AAL error across different ZIP codes in the canton of Zurich for different aggregation strategies and using a 0.5 km x 0.5 km grid.

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7.24
Empirical Earthquake's Site Response Assessment In The Sion Area, Switzerland

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The Sion area in Canton Valais is one of the most seismically active areas of Switzerland. Moreover, the thick and soft sedimentary deposits of the Rhône valley are prone to increase significantly both the amplitude and the duration of the seismic signal. This study aims to evaluate the so-called "site effects" in Sion area in order to better define the seismic hazard locally. It is carried out in the framework of the "Site Response" module of the "Earthquake Risk Model for Switzerland".
Five long-term seismic stations were deployed in addition to four permanent stations of the Swiss Strong Motion Network (SSMNet) already present in the area of Sion. Several tens of mostly local and small magnitude earthquakes were recorded successfully at these nine stations, including those of the 2019 seismic cluster north of Sion. This allows the use of the Empirical Spectral Modelling (ESM) approach of Edwards et al. (2013) at these nine stations. This approach accounts for the source and for the propagation term of the ground motion in order to provide amplification values with respect to the Swiss rock reference (Poggi et al., 2011). The site response is also estimated locally at seven stations by performing Standard Spectral Ratios (SSR - Borcherdt, 1970) with respect to two of the stations located on rock that are used as references, assuming that the source and the propagation term are similar for close stations.
In order to estimate site effects with high spatial resolution, a very dense measurement campaign was performed in 2019 in the area of Sion, along the Rhône valley from Vétroz to Saint-Leonard. Ambient vibrations were recorded for about 1h at around 300 points of a 250 m side grid. A detailed map of the fundamental frequency of resonance of the soil can be deduced from these measurements using the Horizontal-to-Vertical Spectral Ratio method (HVSR, Nakamura 1989). It helps addressing the spatial distribution of the seismic-wave resonance in the Rhône valley, and it is used to improve the resolution of the geological model locally. Moreover, we attempt to assess the site amplification with high spatial resolution at every frequency by applying the hybrid SSR techniques (SSRh - Perron et al., 2018). This approach uses the spectral ratio of ambient vibration recorded between stations located inside the sedimentary valley to estimate the spatial variation of the site response, and the classical SSR based on earthquakes recorded at few stations only to make the rock referencing.
For sites where both the SSR and the SSRh could be computed, a good agreement is found between the two approaches. Moreover, the fundamental resonance frequency model, and the amplification model are consistent with the geological model proposed by Swisstopo for the area of Sion. This is confirming the validity of analysing ambient vibration to determine both the fundamental resonance frequency and the amplification function of the sites. Amplification factor up to 12 are observed for frequency higher than 0.5 Hz along the Rhône valley in the area of Sion. Such amplification of the seismic waves drastically increase the seismic hazard in some parts of the city of Sion. From the measurements, we also propose a site for a new permanent seismic station in the SSMNet renewal project, which shows high amplifications due to shallow layers with very soft sediments, which can be found at some sites in the region of interest.

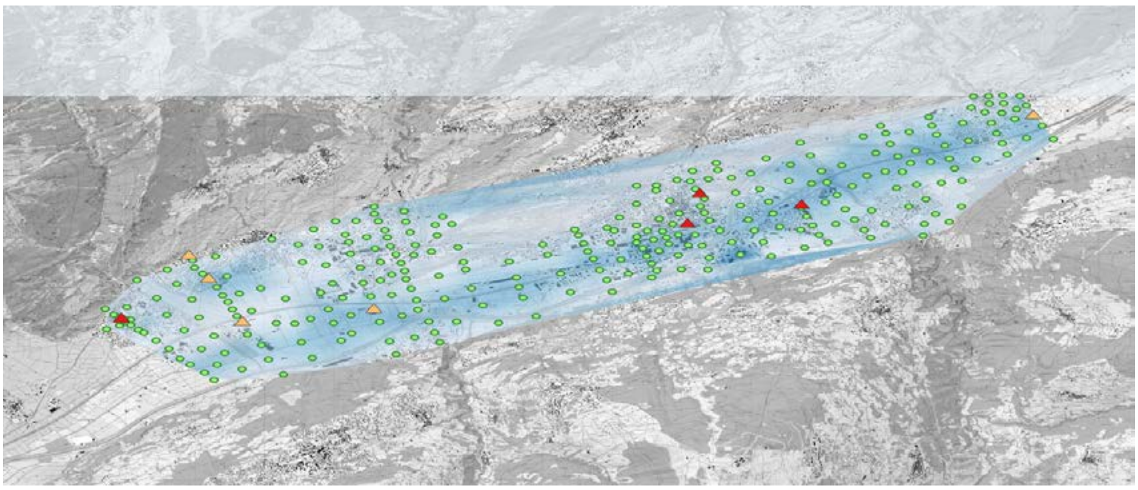

Figure 1 Map of the Sion area. The red triangles are the permanent stations of the SSMNet, the orange triangles long-term stations and the green dots represent the location of the 1h ambient vibration recording. The colormap represent the amplitude of the HVSR at 0.5 Hz which is the fundamental resonance frequency at the centre of the Rhône valley (the deeper the blue the higher the amplitude).

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7.25
Modelling of RC pilegroups under seismic loads

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Realistic finite element (FE) modelling of the dynamic response of pilegroups calls for reasonably accurate modelling of reinforced concrete (RC) nonlinear response. In practise, RC piles are commonly modelled with nonlinear beam elements, approximating their nonlinear response with moment-curvature relations (M-c model), according to section analysis for an assumed axial load. A hybrid modelling technique (Kourkoulis et al. 2011) combines nonlinear beam elements, positioned along the pile axis, with dummy contiuum elements (of zero stiffness) modelling the pile periphery. Appropriate kinematic constraints ensure the deformation of each pile section as a disk.

In the case of pilegroups, the main resisting mechanism to the applied seismic loads is through axial loading of the piles. As a result, the level of axial loading of each pile varries significantly during a seismic event and the aforementioned M-c model constitutes an approximation, as it assumes a constant axial load, neglecting the interaction between axial load (*N*) and moment capacity (*M*).

In the current study, the piles are modelled in a more rigorous manner with 3D nonlinear continuum elements, employing the Concrete Damage Plasticity (CDP) model, which is readily available in Abaqus (ABAQUS 2012). Appropriate material properties are defined to account for the confined concrete core and the unconfined cover concrete (Mander et al. 1988; Chang & Mander 1994). The longitudinal reinforcement of the piles is modelled with shell elements. In addition, damage parameters per level of inelastic response are defined to capture the crashing or cracking of elements within the pile cross section. The model is capable of caprturing not only the *N*-*M*-interaction, but also the cumulative damage of the plastic hinge during consecutive load cycles.

In order to comparatively asses the two modelling techiques, two simple 2x1 pilegroups are considered, varying the pile length from 10 m to 20 m (Fig. 1a), assuming a pile diameter of 1 m, pile spacing of 3 m, concrete C25/30 and 1% reinforcement ratio. The pilegroups are modelled employing both techniques (M-c and CDP). The pilecap is assumed elastic and a rigid pier of 9 m height is considered. In both cases, the soil is assumed to be homogeneous clay with undrained shear strength S_u = 100 kPa, modelled with a thoroughly validated kinematic hardening model, with a Von Mises failure criterion and associated flow rule (Anastasopoulos et al. 2011). Tensionless, frictional interfaces are introduced between the soil and the foundation members. The assumed static load acting on the pilegroup (superstructure dead load) corresponds to 50% of its vertical bearing capacity (corresponding to a factor of safety of 2). The pilegroups are subjected to displacement controlled horizontal pushover analysis, with the displacement applied at the pier top.

The two modelling techniques are compared in terms of moment-rotation (M-θ) response (Fig. 1b). The performance of the short pilegroup is almost insensitive to the employed modelling technique, as the response is dominated by the exterenal (soil) axial bearing capacity of the piles (Fig. 1c). This is not the case for the longer pilegroup, where the axial capacity of the leading pile (under tension) is dominated by its internal capacity (RC failure). Since the M-c model does not account for *N*-*M*-interaction, the RC failure of the leading pile is not captured, leading to 20% overestimation of pilegroup capacity (Fig. 1b). This confirms the need for realistic modelling of RC nonlinear response.

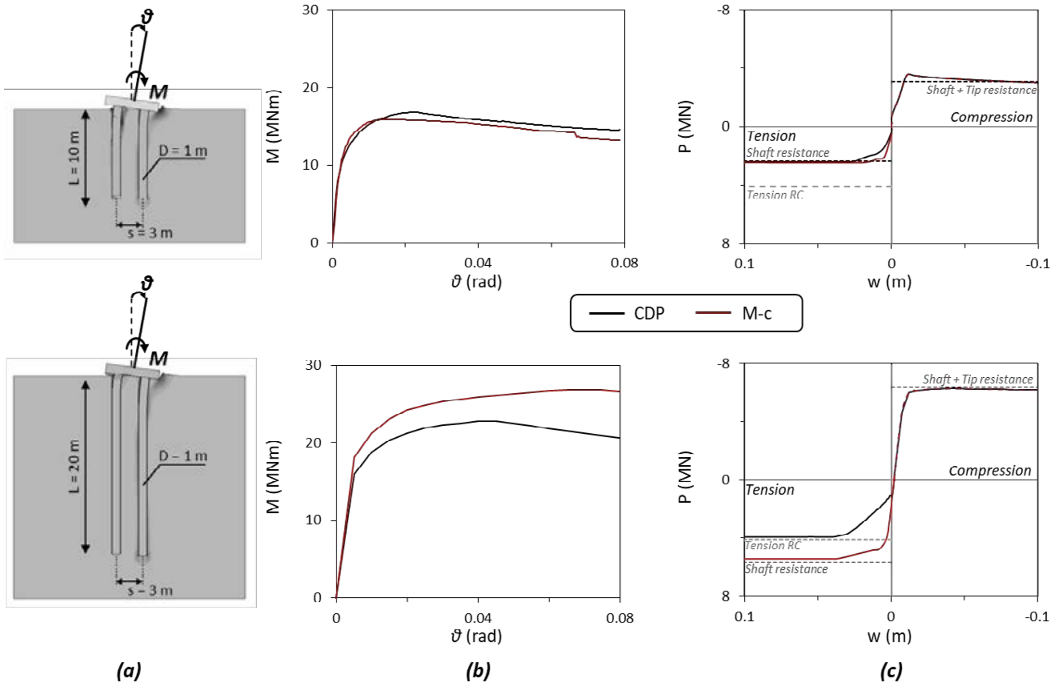

Figure 1. Monotonic pushover response of short (top) and long (bottom) pilegroup: (a) FE model; (b) moment-rotation (M-θ) response; and (c) pile axial response (and comparison with analytical solutions: dashed lines).

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7.26
A first step to assess subaquatic mass movement hazards in lakes

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Shorelines of both inland and coastal waters are often highly altered geomorphological environments that accommodate major infrastructure including harbors, roads, railways, underwater pipelines, transmission cables and water intakes. Slope failures resulting in massive, rapid downslope movement of sediment, also known as subaquatic mass movements, can damage this infrastructure and disrupt lake ecosystems. Subaquatic mass movements can also cause major property damage around lakes. Examples are plentiful and include the destruction of multiple houses and quays around Lake Geneva during the 18th and 19th centuries (Forel 1892, p.148-151). Subaquatic mass movements are known to have disrupted settlements surrounding Lake Geneva even during prehistoric times. A tsunami caused by a mass movement may have caused a gap in occupation around the lake during the early bronze age (~1700 BC; Kremer et al. 2014). In early medieval time, a rock fall caused a Rhône delta collapse resulting in a tsunami which passed over the city walls of Geneva (*563 AD*; Kremer et al. 2012). More recent examples include construction induced slides in Lake Lugano, which damaged the Lugano city port in 1992 (Hofmann & Filella 1999), and the Horgen slide of 1875 (Kelts & Hsü 1980), which swept a newly constructed railway into Lake Zürich.

Assessing risk associated with subaquatic mass movements is difficult and depends on accurate prediction of mechanisms that trigger slope failure and likely locations of failure (Harbitz et al. 2014). Recent advances in bathymetric sensing (e.g. multi-beam and LIDAR surveys) have enabled more detailed imaging of high-risk areas. Basin scale evaluation can include methods for estimating risk areas and damages of different risk factors (Strasser et al. 2011; Strupler et al. 2019). Surveys however can usually only gather a limited number of high quality samples. This research used an interdisciplinary hydrodynamic and sedimentological approach to identify areas at risk for subaquatic mass movement in Lake Biel. This was accomplished with both hydrological and Sedimentological in-situ samples combined with 3D hydrological modeling (Delft3D-Flow). The combined datasets revealed both processes driving lake sedimentation and areas at risk for future subaquatic mass movements.

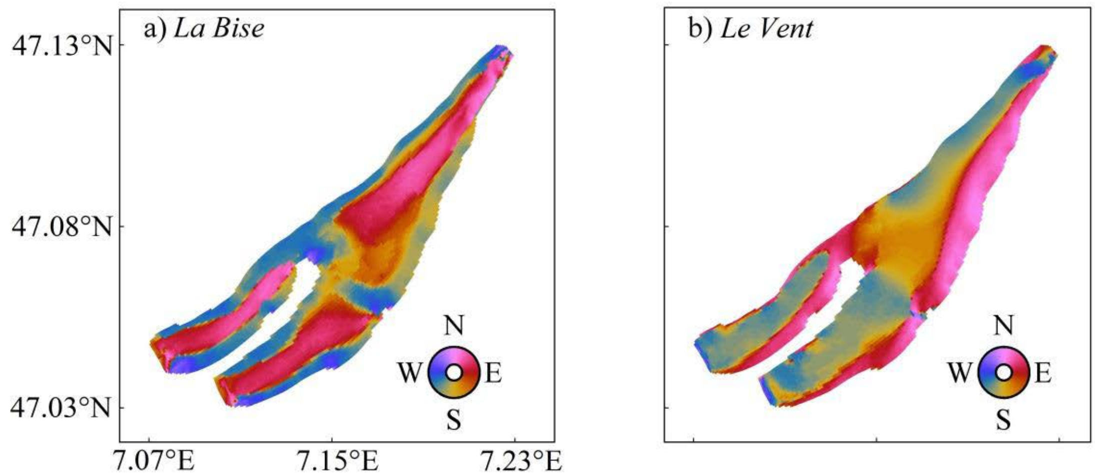

Figure 1. Epilimnion circulation inside Lake Biel for prevailing winds *La Bise* (a) and *Le Vent* (b).

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7.27
Assessing a 6C Kalman filter using experimental datasets from an industrial robot

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Shaking from earthquakes is a complex set of six components (6C) that make up the ground motion, containing both translations and rotations. Nonetheless, state-of-the-art earthquake monitoring stations only include accelerometers and GNSS to record the strong ground motion. The inertial accelerometer sensors directly measure the translational part of the motion, though rotations contaminate this output and are difficult to quantify. GNSS is less sensitive to rotations and can only resolve large amplitudes and long period ground motion. Therefore, the future design of monitoring stations should include a rotational sensor to allow a complete reconstruction of the ground motion. These monitoring stations do not only benefit the reconstruction of the ground motion resulting from earthquakes, but also the reconstruction of the dynamics of large engineered structures due to natural and anthropogenic sources. Switzerland has an abundance of bridges and dams that could largely benefit from a more complete motion sequence.

We have built a monitoring station that combines an accelerometer and rotational sensor, both sampling at 250 Hz, with a GNSS receiver and antenna determining coordinates with a lower sampling rate of 100 Hz. The three instruments have been fixed to a platform attached to the top of an industrial six-axis robot arm, while the arm performs simulated ground motions with high accuracy and repeatability. The robot has its own feedback loop recording position and orientation of the platform. This serves as the ground truth for the performed trajectory. It allows us to compare all the results obtained to the actually performed trajectory of the robot.

We designed a 6C Kalman filter that combines the three instrument records using an optimal equation design and optimal tuning of the parameters. It includes time domain tilt corrections of the acceleration and subsequent estimation and correction of the instrument records to get the state vector consisting of displacement, velocity and rotation. The developed framework and sensing scheme is able to output rotation-free, broadband and precise 3C translations as well as drift-free and precise 3C rotations.

7.28

Numerical study on the moment capacity of typical bridge pile groups on sand

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This study investigates the behavior of a simple pile group on sand under pushover loading, employing the Finite Element (FE) method. A parametric study is conducted, exploring the role of vertical safety factor (FSv), piles reinforcement ratio (ρ), and pier height (h). The contribution of the pile cap is also quantified.

ANALYSIS METHODOLOGY: CALIBRATION & VERIFICATION

After evaluation of data of Swiss bridges provided by ASTRA, a 2x1 pile group is studied, consisting of bored piles of length $L = 15m$, diameter $D = 1m$ and spacing $s/D = 3$ on Perth Sand. Figure 1 gives an overview of the FE model in Abaqus. The superstructure is modelled as rigid, while the mass and pier height are varied to study different FSv (1÷3) and moment to horizontal loading ratios (6÷20). “Heavily” and “lightly“ reinforced piles are studied (ρ = 0,6% - 1%). The Hypoplastic model (Von Wolffersdorff, 1996), calibrated against triaxial tests, is used to model sand, while the piles are modelled with the Concrete Damaged Plasticity (CDP) model.

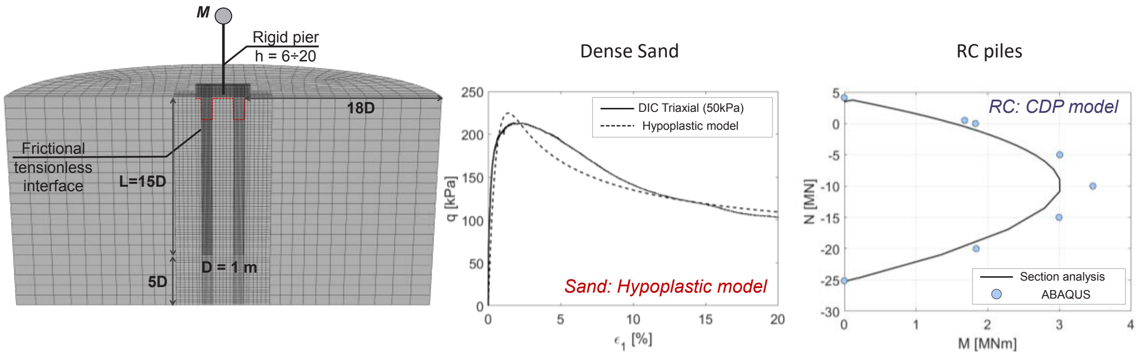

Figure 1. Overview and calibration of the FE model in Abaqus.

Initially, a single pile was examined. The load-settlement behavior under axial loading was validated against centrifuge test results and further compared to bearing capacity theory (Fleming et al., 2008). Subsequently, the behavior under lateral loading was verified against the solution of Broms (1964).

PARAMETRIC NUMERICAL STUDY

Example results of the initial study, where the pile cap contribution is ignored, are summarized in Fig. 2. The moment capacity of the pile group is slightly increased with h, while the reinforcement ratio ρ has limited effects. The reduction of FS_v (i.e., more heavily-loaded foundation) increases the capacity. The contribution of different resisting mechanisms is quantified, showing that the axial loading of the piles is dominant (Fig. 3). In all cases examined, the pullout resistance of the trailing pile is critical, and hence the more heavily loaded system mobilised increased capacity. On the contrary, the role of the “bending” mechanism is limited.

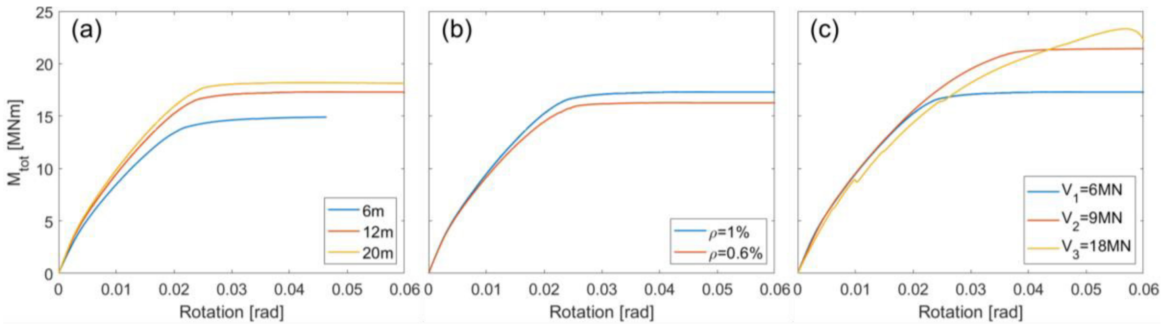

Figure 2. The effect of: (a) pier height h; (b) pile reinforcement ratio ρ; and (c) safety factor FSv, on the moment resistance of a 2x1 pile group.

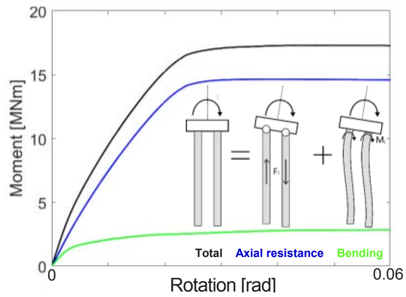

Figure 3. Mobilised resistance mechanisms.

The contribution of the pilecap is quantified, activating its interface (Fig. 4a). Its engagement increases both capacity and stiffness. Focusing on the effect of FSv, the more heavily-loaded pile group mobilises higher resistance (Fig.4b), while the structural behavior with and without the cap is similar.

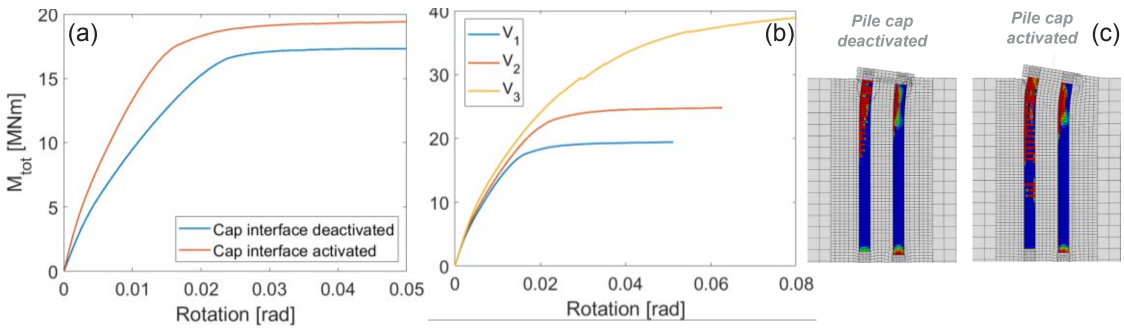

Figure 4. (a) contribution of the cap, (b) effect of FSv (c) structural performance of the piles with and without the engagement of the cap

CONCLUSIONS

The commonly used FSv is not representative of the seismic capacity: heavily-loaded systems mobilise larger moment capacity. The effect of ρ, and h is limited when the moment capacity is critical.

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7.29
Revealing the structure of submerged slopes in Lake Lucerne using ambient vibration techniques

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Seismically and aseismically triggered submerged slope failures in a lake environment can potentially cause a tsunami. Such a phenomenon would pose a significant hazard to the population and infrastructure of quite extensively used lake shores.

To better understand the tsunami hazard related to the submerged slopes in the lakes, we need to know their internal structure and sediment properties. As a study site for such an investigation, we selected Lake Lucerne in Central Switzerland. Tsunamis have occurred repeatedly in Lake Lucerne, for example, in 1601 AD a tsunami was triggered by the Mw 5.9 Unterwalden earthquake. Wave heights of at least 4 m and a subsequent seiche lasting several days are mentioned in historical reports. A repetition of such an event nowadays could cause significant casualties and financial losses.

In this work, we apply non-invasive passive seismic techniques based on the recording of ambient seismic noise to reveal the structure and material properties of the sediment-charged submerged slopes. For this purpose, we deploy arrays of 9 Ocean Bottom Seismometers (OBS) and single OBS stations at potentially unstable slopes (Fig.1a) for periods between 2 days and 9 months. Based on the analysis of recorded ambient seismic noise and earthquake signals, we evaluate the fundamental frequency of resonance and seismic amplifications at the study sites and estimate the Scholte wave ellipticity and the phase velocity dispersion curves of the propagating surface waves. A combined inversion of the ellipticity and dispersion curves allows us to derive the 1D shear wave velocity profiles at the investigated sites (Fig. 1b). Based on the obtained information, we define the sediment-lithological units of the slopes and estimate their thickness and elastic properties.

As the next step of this work, we aim at creating 3D slope models with defined sediment properties for the selected sites in Lake Lucerne.

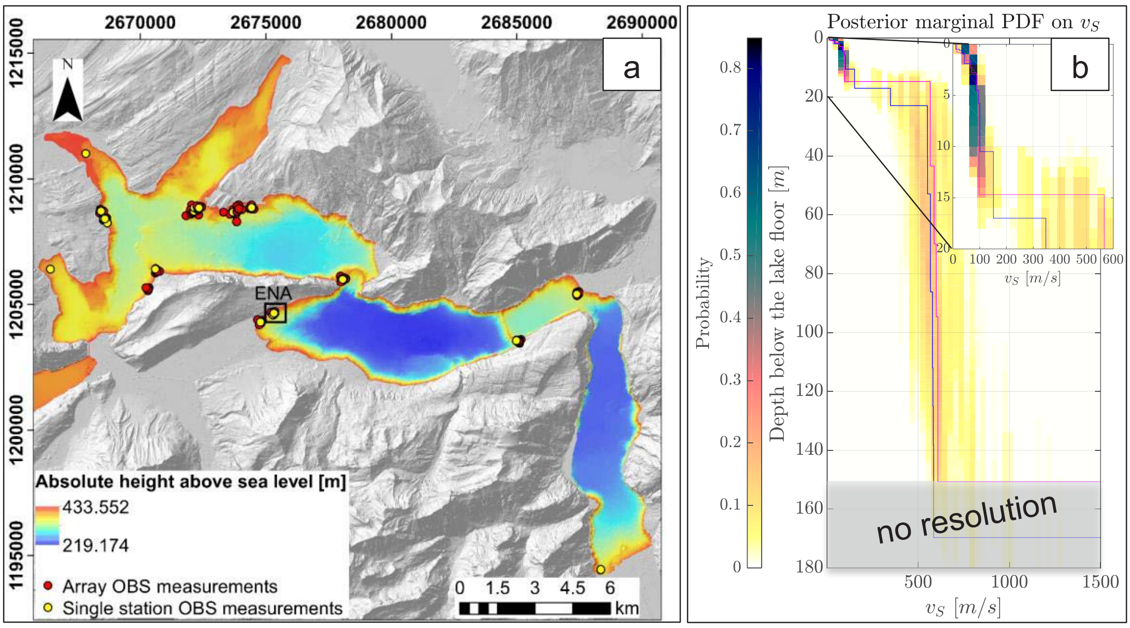

Fig. 1. a) map of conducted single station (yellow circles) and array (red circles) OBS measurements in Lake Lucerne. The black rectangle marks the location of the array ENA at Ennetbürgen; b) an example of derived shear wave velocity profile below the array ENA with zoom to the upper 20 m: purple and blue lines represent soil models with the maximum probability and minimum misfit, respectively; grey-shaded area marks part of the profile with no data resolution.

no resolution

7.30
Simplified analysis for nonlinear foundation response

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Recent research on soil-structure interaction of structures subjected to seismic loading led to the recognition that stongly nonlinear soil-foundation response may have a beneficial effect on structural integrity. Such strongly nonlinear soil-foundation response can be used for seismic protection of structures, leading to the development of a novel design concept, termed “rocking isolation” (Anastasopoulos et al., 2010 & 2013; Gajan et al., 2005; Gajan & Kutter, 2008; Mergos & Kawashima, 2005). Unlike conventional design, where failure is guided to the superstructure, rocking isolation guides failure to the soil (Fig. 1). Rocking isolation simply implies allowing a surface foundation to uplift and fully mobilize its bearing capacity (soil failure). Both effects limit the inertia loading of the superstructure and therefore act as a safety valve protecting the superstructure. Particularly for large intensity earthquakes, that clearly exceed the design limits, this novel design concept shows excellent performance. In practise, rocking isolation can be applied simply by reducing the foundation dimensions.

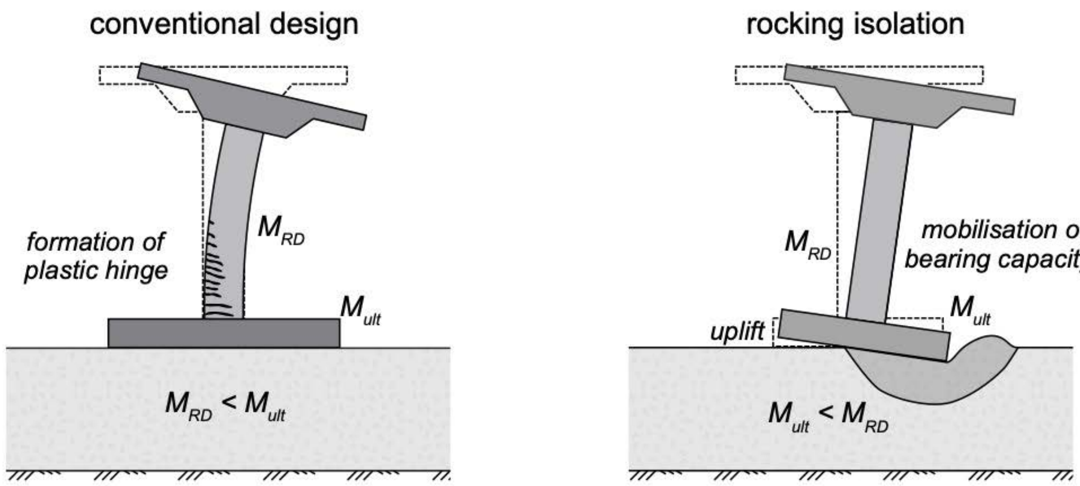

Figure 1. Comparison of conventional design (left hand side) and rocking isolation (right hand side) (Anastasopoulos et al., 2010)

However, the performance assessment of such rocking–isolated structures (needed for their design) can be challenging, since it requires nonlinear dynamic time history analysis. Therefore, there is a need for simplified analysis methods that are computationally efficient, simple in application and capable of predicting with reasonable accuracy the nonlinear foundation response. The present study investigates the robustness of three simplified analysis methods that differ in complexity and idealization. The methods are assessed by comparison with nonlinear finite element (FE) time history analysis of a single bridge pier supported on a shallow square foundation, lying on a stiff undrained clay stratum. The FE model encompasses the entire soil-foundation-structure interaction.

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7.31
Shake table testing of aggregate masonry buildings

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Masonry building aggregates can be found throughout historical city centers of Europe. Adjacent buildings have often developed during the long densification process, without consistent planning or engineering. It is common for neighboring units to share a structural wall with the connection between the units ensured through interlocking stones or a dry joint. Another consequence of the gradual development through the years are the different material properties, distributions of openings, and different roof and floor heights of the neighboring units. The difference in properties and the uncertainty related to the connection between the units leads to difficulties when modelling the seismic response. For that reason, units of an aggregate are often modelled as separate or perfectly connected. Both simplifications can lead to an incorrect estimation of the aggregate response. One of the principal reasons impeding the advancements in this area is the lack of large-scale experimental campaigns, due to the size and the cost of such campaigns. For that reason, the project AIMS (Seismic Testing of Adjacent Interacting Masonry Structures), included in the H2020 project SERA has the objective to provide the experimental data on the behaviour of an aggregate of two stone masonry buildings under bi-directional horizontal acceleration. The test unit is constructed at half scale, with one storey building and a two-storey building. The buildings share one common wall and the façade walls are connected by dry joints. Units have different floor heights and floor beam orientations, leading to a complex dynamic response. The shake table test is conducted at the LNEC seismic testing facility. Extensive instrumentation, including an optical displacement measurement system, displacement transducers, and accelerometers are used to provide information on the force-displacement response. Special attention is devoted to the interface opening and the global behaviour in relation to the interface separation.

Figure 1. Test unit

7.32
Seismic Response of Underground Metro Station: Shake Table Testing and Numerical Simulation

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The seismic response of underground structures has lately received increased attention, due to their severe damage or even collapse in recent major seismic events. This study investigates the seismic performance of a representative 2-storey, 3-span Shanghai Metro station in soft soil, combining 1g shaking table testing and numerical analysis. To remedy the problem of scale effects in 1g testing, synthetic model soil (a mixture of sand and sawdust) is used, along with similitude relations derived considering dynamic equilibrium. The properties of the synthetic model soil are adjusted to satisfy similitude, including stiffness and density. The structure is modelled using granular concrete and galvanized steel wires (Wu et al. 2020). As shown in Figure 1, acceerometers, wire displacement transducers and earth pressure transducers were installed to measure the seismic response of the tunnel and soil. To quantify the transferability of the results to prototype scale, the experiments are simulated with nonlinear finite elements (FE), modelling the synthetic model soil with an extended kinematic hardening constitutive model. The model was calibrated for the model soil using the results of resonant column and direct shear tests. In this way, the 1g shaking table tests served as a benchmark for model validation. The FE model was shown to compare well with the shaking table tests in terms of acceleration time histories and amplification. Larger discrepancies were observed when examining soil pressures on the station sidewall, which, however, may be due to measurement errors rather than modelling inaccuracies.

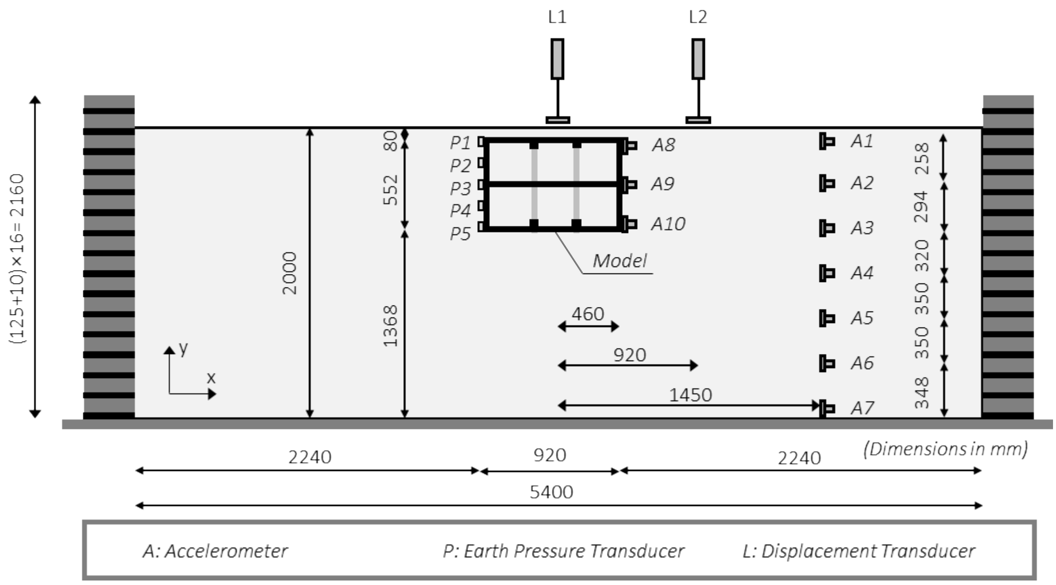

Figure 1. Shaking table model layout, showing geometry and instrumentation (detailed scheme of strain gauges on the tunnel is not included.

The validated FE model is subsequently used to predict the seismic response of the prototype, allowing indirect transfer of the results from model to prototype scale. As shown in Fig. 2, moving from model to prototype scale, the inter-storey drift remains qualitatively similar, but reduces by 50%. This is partly due to scale effects, but also related to differences between the idealized soil of the experiments and the multiple soil layers of reality. The maximum bending moment reduces by 30% going to prototype scale. The base of lower-storey columns is proven to be the most vulnerable, as was the case for the collapse of the Daikai Metro station during the 1995 Kobe earthquake (An et al., 1997).

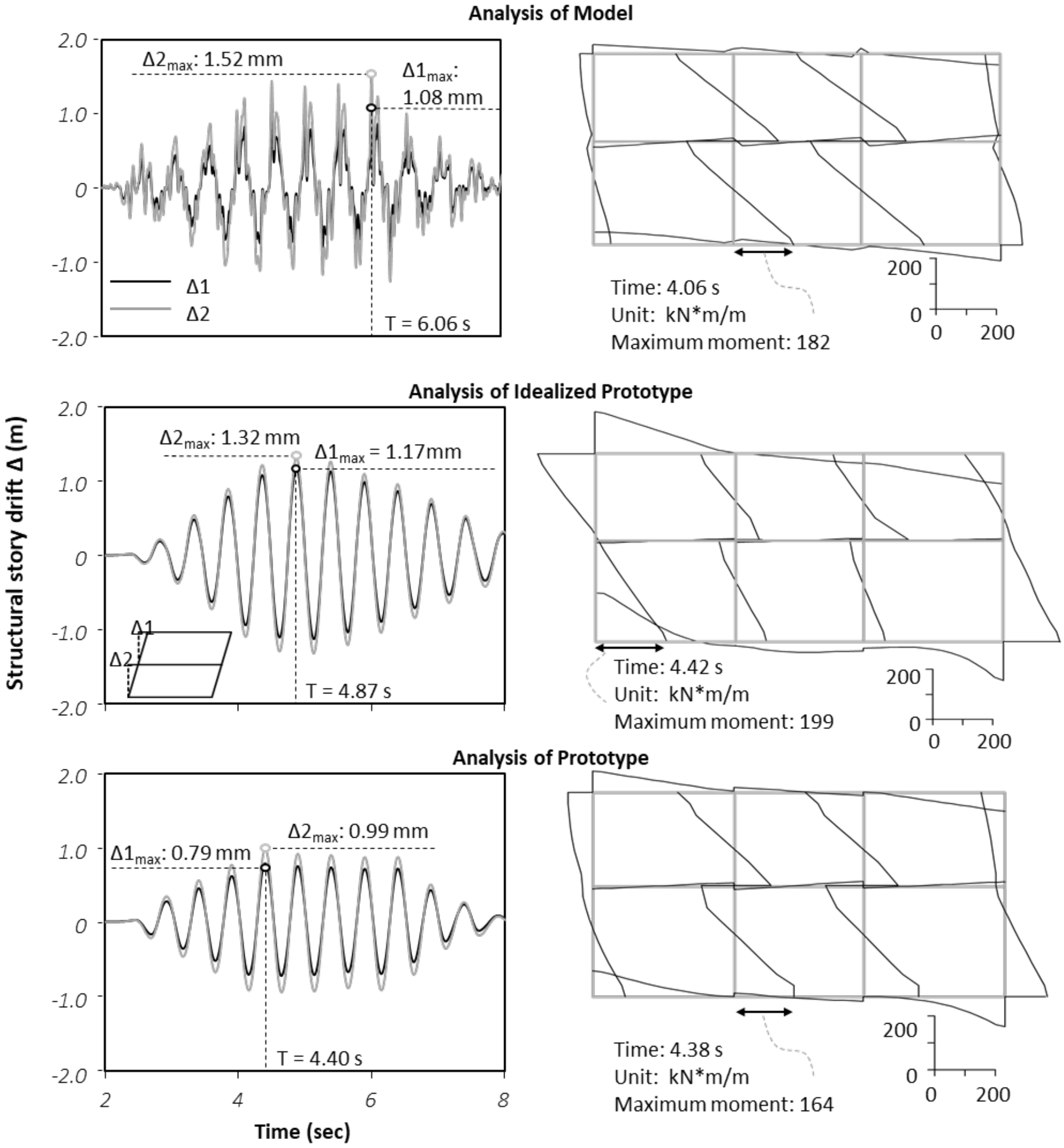

Figure 2. Numerical results of maximum racking deformation (drift) and bending moments: (a) shake table test; (b) idealized prototype; and (c) prototype.

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P 7.1
Physics-based Earthquake Source Models for Seismic Engineering: Analysis and Validation for Dip-slip faults

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Physics-based dynamic rupture modelling is necessary for estimating parameters such as rupture velocity and slip rate function that are important for ground motion simulation, but poorly resolved by observations, e.g. by seismic source inversion. In order to generate a large number of physically self-consistent rupture models, whose rupture process is consistent with the spatio-temporal heterogeneity of past earthquakes, we use multicycle simulations under the heterogeneous rate-and-state (RS) friction law for a 45deg dip-slip fault. We performed a parametrization study by fully dynamic rupture modeling, and then, a set of spontaneous source models was generated in a large magnitude range (*Mw* > 7.0).

In order to validate rupture models, we compare the source scaling relations vs. seismic moment *Mo* for the modeled rupture area *S*, as well as average slip *Dave* and the slip asperity area *Sa*, with similar scaling relations from the source inversions. Ground motions were also computed from our models. Their peak ground velocities (*PGV*) agree well with the GMPE values. We obtained good agreement of the permanent surface offset values with empirical relations.
From the heterogeneous rupture models, we analyzed parameters, which are critical for ground motion simulations, i.e. distributions of slip, slip rate, rupture initiation points, rupture velocities, and source time functions. We studied cross-correlations between them and with the friction weakening distance *Dc* value, the only initial heterogeneity parameter in our modeling. The main findings are: (1) high slip-rate areas coincide with or are located on an outer edge of the large slip areas, (2) ruptures have a tendency to initiate in small *Dc* areas, and (3) high slip-rate areas correlate with areas of small *Dc*, large rupture velocity and short rise-time.

P 7.2
Crustal Structure imaged by 3-D Seismic Attenuation for the Central Alps and their Foreland

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In the framework of the SeismoTeCH project, which aims at advancing our understanding of seismotectonic processes in Switzerland, seismic velocity
models of the Central-Alpine crust are improved and extended on different scales by various tomographic methods. In this study, we present a first 3-D attenuation model of the upper crust. The 3-D inversions derive the quality factor Q (1/attenuation) using path attenuation t* observations for 4192 distributed earthquakes recorded on permanent and temporary stations, including both velocity and acceleration records for the period 2002-2019. The preliminary Qs and Qp results show large-scale features in the upper crust, which are consistent with the recently improved high-resolution velocity models and serve to refine the interpretations of crustal structures from Vp and Vp/Vs. For example, the foreland region of southern Germany and northern Switzerland show a low Q crustal block bounded by high Q regions. This markedly correlates with the overlying surface geology, where low Q areas coincide with the Molasse Basin, and high Q regions outline the geological boundary between the Molasse and the Mesozoic sediments towards north and the Alpine front to the south. At depths ranging between 2 - 6.5 km, low Q is imaged along the Valais where the presently seismically most active fault zones are located. As the attenuation of fractured areas is enhanced by fluids, low Q values may relate here to distributed microfractures that produce greater fracture connectivity and permeability in a relatively higher strain-rate zone. On the other hand, high Q are found in the Black Forest Massif and in the external Aar Massif which is consistent with crystalline basement rocks. In combination with recently developed Vp and Vs velocity models, the 3-D attenuation models of the uppermost crust will provide crucial input for next generation seismic hazard models in Switzerland, allowing for a more realistic prediction of earthquake related ground motions.

P 7.3
Using the Swiss database of potential earthquake evidence to develop paleo-earthquake scenarios

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Information on prehistoric earthquakes are needed to extend the instrumental and historical earthquake catalogues for large damaging events (Magnitude Mw > 6). This allows to better constrain return periods of such very rare events, which is of interest in particular for areas of moderate seismicity such as Switzerland. Moreover, paleo-seismological methods might provide information to better constrain the maximum magnitudes to be expected for a probabilistic seismic hazard assessment.

Traces of prehistoric earthquakes can be found in the geological record. These are traces from primary effects such as fault ruptures or from secondary effects such as landslides, sediment liquefaction, tsunami deposits and broken speleothems in caves. A reliable compilation of dated traces can be used to reconstruct paleo-earthquakes.

Therefore, a database of potential paleo-seismic evidence in Switzerland has been compiled including information from limnogeology, sedimentology, geomorphology, archaeology and speleology (Kremer et al., 2020). At present, the database includes ~700 datapoints covering the period of the last 20,000 years. These datapoints have different levels of dating quality and uncertainty, as well as source reliability. These differences have been taken into account and categorized.
Our database allows to define clusters of increased occurrence of such traces in time and space, and to determine periods of potentially enhanced earthquake activity. However, not yet included in our analysis are the locations and magnitudes of these potential earthquakes that could have been responsible to generate the traces found. Thus, a further step is to analyse possible prehistoric earthquakes through scenario modelling, and to assess epicenter locations and magnitudes with their uncertainties. In this contribution, we propose a workflow that will allow us to compute paleo-earthquake scenarios based on the existing potential paleo-seismic evidence database for Switzerland.

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P 7.4
Designing a probabilistic workflow for the assessment of the earthquake-triggered landslide-tsunami hazard along the shores of perialpine lakes

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It has been documented that since deglaciation, landslide-tsunamis have occurred on multiple Swiss perialpine lakes (e.g. Cysat 1969; Bussmann & Anselmetti 2010; Kremer et al. 2012). However, on most lakes, the landslide-tsunami hazard is not well understood, due to sparse information from historical events on the hazard metrics (e.g. flow depth, flow velocity, run-up and inundation). In the absence of detailed historical data, models that simulate the hazard can be useful. The main steps in the assessment of tsunamis comprise the modelling of (1) the tsunami generation, (2) the tsunami propagation, and (3) the tsunami run-up and inundation. Each of these steps of the process chain adds uncertainty to the expected results. To consider the effects of the many uncertainties involved, a probabilistic tsunami hazard assessment (PTHA) is necessary. Due to the complexity of the process chain and related computational limitations, many existing studies focus on only one of these main steps of the tsunami assessment.

Here we present a first design of a workflow for the earthquake-triggered landslide-PTHA on perialpine lakes, that includes uncertainty quantification for each part of the process chain. Properties of past and hypothetical landslides are sampled based on available information from previous studies with “R” software , and numerical modelling of the tsunami wave is conducted using BASEMENT (Vetsch et al. 2019). The final outputs of the workflow will be distributions of flow depths, flow velocities, and the inundation area.

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08. Deep geothermal energy, CO_2-storage and energy-related exploration of the subsurface

Larryn Diamond, Christophe Nussbaum, Benoît Valley, Marie Violay

TALKS:

8.1 *Adams B.M., Saar M.O.*: Generating Electricity from Sequestered CO_2: CO_2 Plume Geothermal (CPG)

8.2 *Birdsell D., Adams B., Saar M.O.*: Determination of minimum transmissivity for high-temperature aquifer thermal energy storage from reservoir-engineering and economic constraints

8.3 *Bröker K., van Limborgh R., Ma X.*: In-situ stress characterisation at the Bedretto Underground Laboratory, Swiss Alps

8.4 *Dutler N.O., Valley B.*: Observations of shear dislocation and fracture opening during in-situ hydraulic stimulation

8.5 *Eruteya O.E., Moscariello A.*: A proposed workflow for screening and selecting a potential site for CCS in Switzerland

8.6 *Ezekiel J., Adams B.M., Saar M.O., Ebigbo A.*: Performance optimization of CO_2-Plume Geothermal (CPG) production wells and implications for electric power generation

8.7 *Fryer B., Giorgetti C., Violay M.*: Velocity steps across four orders of magnitude to investigate the effect of fault roughness on the stability of slip

8.8 *Grimm Lima M., Kong X.-Z., Saar M.O.*: Evolution of fracture permeability with thermal and mechanical stresses

8.9 *Hau K.P., Saar M.O.*: About the suitability of the Aquistore CCS-site for an CPG-system

8.10 *Javanmard H., Ebigbo A., Walsh S.D.C., Saar M.O., Vogler D.*: Impact of Contact Area on Hydraulic Behaviour of Rough Fractures under Normal Stress

8.11 *Kong X.-Z., Ma J., Lima M., Saar M.O.*: Carbonate dissolution in tight sandstones and flow-through drying in fractured granites: The role of stress

8.12 *Leal A.M.M., Kyas S., Kulik D.A., Saar M.O.*: Accelerating reactive transport simulations with on-demand machine learning

8.13 *Liu D., Lecampion B.*: Laboratory studies of hydraulic fracture growth in quasi-brittle rocks with different grain sizes

8.14 *Moreau A., Violay M., Schlaepfer R., Adatte T., Turberg P.*: X-ray Micro-CT Contribution to the Geological Identification of Rock Cuttings

8.15 *Moscariello A., Guglielmetti L.*: The GeoT-Play project: an innovative workflow to assist the exploration and development of geothermal resources.

8.16 *Niederau J., Friedemann S., Saar M.O.*: Multi-step conditioning of geological models for constraining heat transport simulations in the subsurface of the Canton Aargau, Switzerland

8.17 *Ogland-Hand J., Cohen S., Middleton R., Kammer R., Saar M*: Representing Geologic CO_2 Storage in Energy System Models

8.18 *Perret M., Gasparrini M., Teles V., Omodeo-Salé S., Guglielmetti L., Mondino F., Moscariello A.*: Fracture diagenesis and fluid paleocirculations in a fossil geothermal system – Geneva Basin, Switzerland

8.19 *Rossi E., Adams B.M., Vogler D., Kammermann B., Schiegg H.-O., von Rohr P.R., Saar M.O.*: Enhancing deep geo-resource utilization by advanced drilling technologies: CTMD and PPGD

8.20 *Rybach L.*: How to Calculate Heat Flow from Geothermal Heat Pump Data for Geothermal Exploration

8.21 *Saar M.O.*: An overview of current research in the Geothermal Energy and Geofluids (GEG) Group at ETH Zurich and a call for further collaborations

8.22 *Schädle P., Saar M.O., Ebigbo A.*: Numerical investigations of thermal attenuation and lag time in rough fractures: comparison of joint solute and heat tracer tests

8.23 *Vogler D., Walsh S.D.C., von Rohr P.R., Saar M.O.*: Numerical Modeling Approaches to Contact-less Drilling Techniques

POSTERS:

P 8.1 *Schneeberger R., Lanyon B., Herbert A., Habermüller M., Madritsch H.*: Predictive DFN modelling for the Trigonodus Dolomite aquifer in the northernmost Swiss Molasse Basin based on vertical and horizontal borehole records

P 8.2 *Ezzat M., Vogler D., Saar M.O., Adams B.M.*: Simulating plasma formation in pores to investigate key parameters governing Plasma Pulse Geo-Drilling (PPGD)

P 8.3 *Houlie N., Martin F., Guglielmetti L., Valley B., Meyer M.*: Monitoring geothermal field for heat production and storage in the context of the Jura tectonics.

P 8.4 *Alt-Epping P., Diamond L.W., Wanner C.*: Impact of recharge conditions on fluid flow in deep orogenic faults: implications for the hydrothermal system at Grimsel Pass, Switzerland

P 8.5 *Dambly L., Samrock F., Grayver A., Saar M.O.*: Magnetotelluric Exploration of Geothermal Systems in the Main Ethiopian Rift

P 8.6 *Erdenechimeg B., Samrock F., Grayver A.V., Kuvshinov A., Saar M.O., Sodnomsambuu D., Battuulai T., Shoovdor T., Dorj P., Oyuntsetseg D.*: 3-D imaging of mid-enthalpy geothermal systems in central Mongolia within the context of a Swiss r4d programme

P 8.7 *Hefny M., Ebigbo A., Qin C.-Z., Saar M.O.*: Characterisation of Nubian Sandstone for CO_2 storage using pore-network modeling

P 8.8 *Kumbhat D., Hefny M., Ebigbo A., Saar M.*: Estimation of CO_2-Plume Geothermal Potential in depleted Nubian Sandstone

P 8.9 *Lissa S., Ruf M., Steeb H., Quintal B.*: Digital rock physics applied to squirt flow

P 8.10 *Pimienta L., Quintal B., Sandrone F., Gastaldo F., Violay M.*: From elastic to anelastic properties in rocks: Role of strain amplitudes

P 8.11 *Pimienta L., Quintal B., Caspari E.*: From hydraulic and mechanical properties to hydromechanical coupling in rocks: Role of hidden microstructure?

P 8.12 *Solazzi S.G., Lissa S., Germán Rubino J., Holliger K.*: Squirt flow in rocks containing partially saturated penny-shaped cracks: Simple analytical solution

8.1
Generating Electricity from Sequestered CO_2: CO_2 Plume Geothermal (CPG)

Benjamin M. Adams[1], Martin O. Saar[1]

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The mitigation of climate change will likely result in the geologic sequestration of carbon dioxide in porous, sedimentary basins. This CO_2, once sequestered, has a use beyond permanent storage. It can additionally be circulated to the surface to extract geologic heat and generate geothermal electricity. This utilization of sequestered CO_2 provides value to otherwise expensive carbon sequestration activities, providing definite utilization to Carbon Capture, Utilization, and Storage (CCUS) activities. Here, sequestered CO_2 is used as the geologic working fluid in geothermal electricity generation, called CO_2 Plume Geothermal (CPG).

CO_2 Plume Geothermal is a carbon-neutral geothermal process that generates electricity by circulating hot sequestered CO_2 from a deep sedimentary reservoir (>2 km, >100 °C) to the surface. CO_2 has lower viscosity and similar specific heat to water, allowing it to remove geothermal heat at lower energy cost than water geothermal. In CPG, high-pressure CO_2 is produced to the surface, where it is directly expanded in turbomachinery to generate power, is cooled, and reinjected. Unlike water-based geothermal, the hot CO_2 maintains its pressure as it reaches the surface, due to its decreased density. As CO_2 is compressible, the injected CO_2 density is greater than the produced density which generates a self-circulating thermosiphon. Thus, CPG can generate power from sequestered CO_2, providing return on investment.

In this presentation, we will discuss the current state of the art for CO_2 Plume Geothermal (CPG). We find that CPG power generation in porous reservoirs is primarily a function of reservoir depth and transmissivity. Transmissivity is the product of reservoir thickness and permeability. We also find that CO_2 is an advantageous working fluid at moderate depths and transmissivities, while brine generates more power at greater depths and large transmissivities.

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8.2
Determination of minimum transmissivity for high-temperature aquifer thermal energy storage from reservoir-engineering and economic constraints

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Seasonal storage of waste heat can reduce carbon emissions and HVAC costs. Low-temperature (LT) (<25 °C) aquifer thermal energy storage (ATES) is already widely-deployed in central and northern Europe, and there is renewed interest in high-temperature (HT) (>50 °C) ATES. However, it is unclear if recommendations about well spacing, flow rate, and minimum transmissivity from LT-ATES will apply to HT-ATES. To assess the minimum transmissivity, we develop an analytical framework to balance reservoir-engineering (i.e. aquifer thermal capacity and avoidance of hydraulic fracturing) and economic constraints for a HT-ATES doublet that is connected to a district heating network. The framework uses conservative assumptions so that aquifers are not unduly removed from consideration.

We find that optimal well spacing and flow rate are dictated by reservoir-engineering constraints at shallow depths and/or low permeability. In contrast, optimal well spacing and flow rate are dictated by economic constraints at greater depth and/or higher permeability, because operating costs can become large at high flow rates. We find the optimal well spacing is 1.8 times the thermal radius, which is in line with recommendations for LT-ATES. We find the levelized heat cost is minimized at an intermediate depth, because for shallow and deep aquifers, the capital costs and the operating costs, respectively, are large compared to the heat recovery. This suggests that installation of intermediate-depth HT-ATES could relieve shallow congestion from LT-ATES systems. We define the minimum economically-viable transmissivity as the break-even transmissivity wherein levelized heat cost equals the cost of electricity. We find the minimum economically-viable transmissivity is relatively insensitive to depth and aquifer thickness, and we therefore propose that a single value (m^3) could be used in a pre-assessment step for HT-ATES. This minimum economically-viable transmissivity could be used to estimate an upper bound on HT-ATES potential at a regional, national, or global scale.

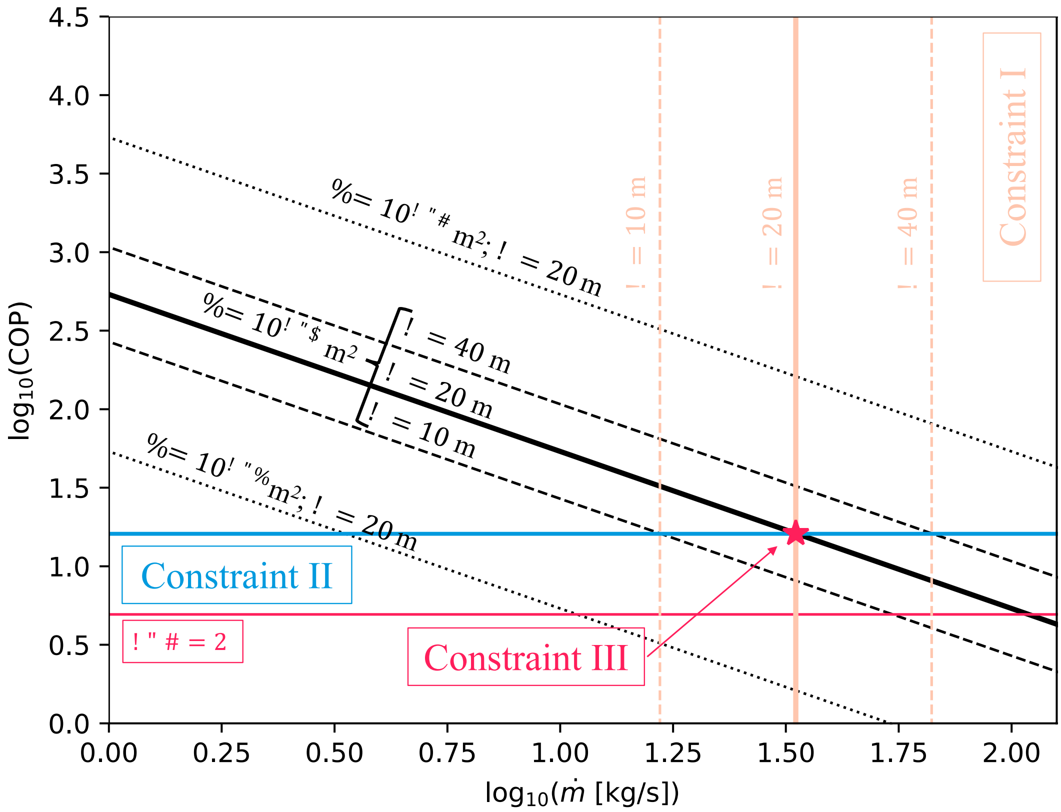

Figure 1. Illustration of the logarithm of the coefficient of performance versus the logarithm of the mass flow rate (black curves) plotted with reservoir-engineering and economic constraints. Constraint I (yellow) ensures the aquifer is large enough to hold the heat provided, Constraint II (blue) ensures hydraulic fracuturing does not occur, and Constraint III (red area and red star) ensures that the cost of heat provided is less than the cost of electricity. Operating conditions must fall outside of the color-shaded areas. Permeability and aquifer

thickness are denoted with and , respectively.

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8.3
In-situ stress characterisation at the Bedretto Underground Laboratory, Swiss Alps

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The Bedretto Underground Laboratory for Geoenergies (BULG) in the Swiss Central Alps (http://www.bedrettolab.ethz.ch) provides a unique environment to study processes related to enhanced geothermal systems (EGS), such as hydraulic stimulation techniques and associated induced seismicity. The laboratory is located in a 100 m long enlarged section of the Bedretto tunnel, about 2 km from its southern entrance. The overburden of around 1000 m and the relatively homogeneous granite as reservoir rock provide conditions close to realistic EGS systems in Switzerland.

One of the most important parameters to investigate prior to planning the reservoir stimulation is the in-situ stress field. For this purpose, six 30 m to 40 m long stress measurement boreholes were drilled. A measurement campaign with small scale hydraulic fracturing tests, so called mini-frac tests, in overall 30 intervals was conducted between December 2018 and July 2019. Subsequently, three long (190 m to 300 m), deviated boreholes were drilled perpendicular to the tunnel axis and in one of them additional mini-frac tests were performed.

The mini-frac measurement protocols included fracture initiation and propagation over several injection cycles, shut-in pressure decline and step-rate injection tests. The shut-in times were varied between a few minutes up to one hour and occasionally overnight (12 to 14 hours), to observe effects on different time scales and obtain the local pore pressure. Pre- and post-fracturing the boreholes were logged with acoustic and optical televiewers to identify natural and newly induces hydraulic fractures and their orientations.

The results of the mini-frac tests in the short boreholes reveal a heterogeneity of the estimates minimum principal stress magnitude on the scale of meters to tens of meters. The stress regime lies between normal- to strike-slip faulting conditions ($S_{hmin} < S_{Hmax} \leq S_v$) with S_{Hmax} around N100°E (Ma et al. 2019). Close to the laboratory S_{hmin} lies between 13-16 MPa and S_{Hmax} between 0.8-1·S_v, with S_v being equal to the overburden stress (Fig. 1). As the induced tensile fractures propagate further away from the borehole with every injection cycle, it is likely that they intersect natural fractures. This can be seen as multiple closure signature on several of the used diagnostic plots (e.g. G-function plots), where it is beneficial to have extended observation times (≥ 1 h) to fully characterise the different fracture closure behaviours. Inferred pore pressures ($P_p \approx$ 3-6 MPa) are mostly below the hydrostatic case due to tunnel drainage.

In the longer boreholes, extensive fractures/fault zones have been mapped from the cores and image logs. Another feature is the appearance of breakouts, which were mapped and analysed to have a second estimate of the in-situ stress field. Based on breakout presence, the azimuth of S_{Hmax} and the inferred stress regime are confirmed. The breakout azimuths in both boreholes show a rotation of 40° with a wavelength of 40 m (Fig. 1). This rotation is an indicator that the stress field is perturbed by the presence of fractures in this zone.

In general, the deeper mini-frac tests show comparable breakdown pressures as close to the BULG, but the derived minimum horizontal stress magnitude follows a higher gradient than that of the short boreholes (Fig. 1). We attribute such discrepancies to stress perturbations in the vicinity of the tunnel and compartmentalized hydro-structures connected to major fault zones.

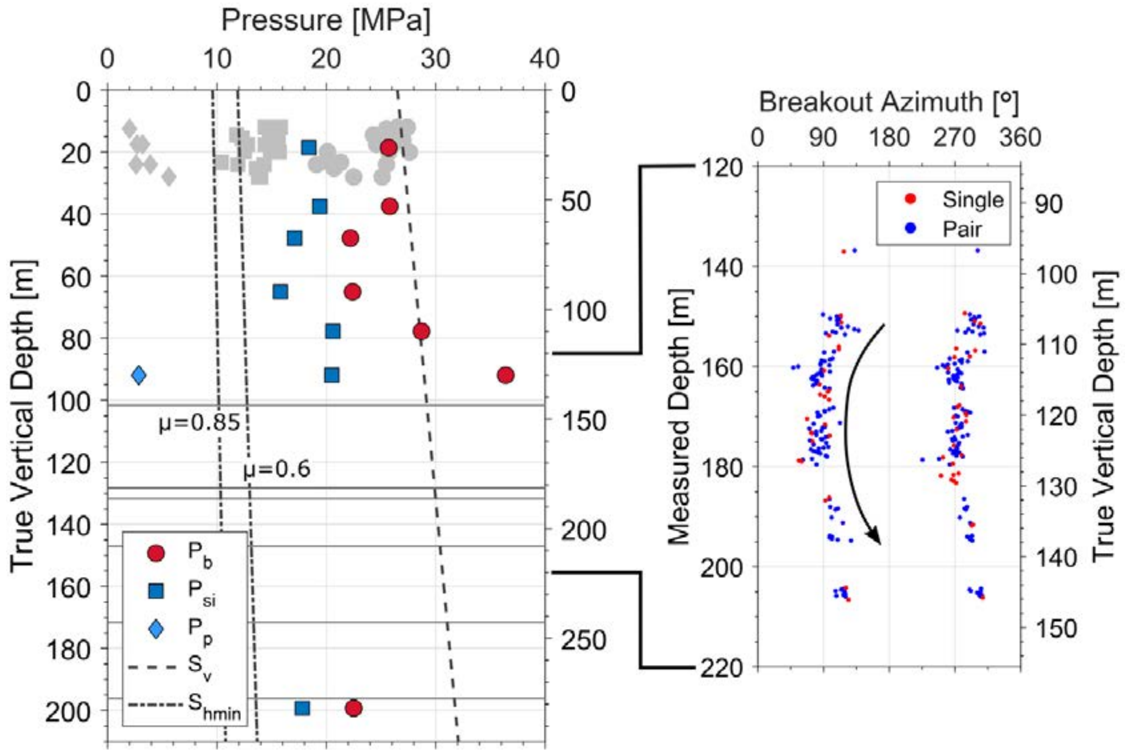

Figure 1. (left) Preliminary results of the mini-frac stress measurements conducted in the BULG. The P_{si} (instantaneous shut-in pressure) gives an upper bound of the minimum horizontal stress magnitude. P_b denotes the breakdown pressure and P_p the measured pore pressures. The coloured symbols are derived from measurements in one long deviated borehole. Grey symbols represent measurements in the short vertical borehole in and close to the BULG. The vertical stress magnitude is calculated from the overburden and the lower limit of the minimum horizontal stress from frictional equilibrium theory (assuming P_p = 5 MPa everywhere and a frictional coefficient of 0.6 or 0.85). Horizontal grey lines correspond to major mapped fracture zones. (right) Zoomed in section to the zone where breakouts occur. Single breakouts and breakout pairs are indicated with respect to the top of the borehole (high side).

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8.4
Observations of shear dislocation and fracture opening during in-situ hydraulic stimulation

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Six in-situ hydraulic fracturing experiments were conducted at the Grimsel Test Site in two inclined boreholes drilled through a sparsly fractured crystalline rock mass (Dutler et al., 2019).

Diagnostic analysis of the shut-in phases were used to determine the the fracture closure, which is equivalent with the minimum principal stress magnitude. In addition, the pressure-controlled step tests were conducted to measure the jacking pressure. This is the point, where the fracture walls jacked open and, in theory, the result should correspond to the minimum principal stress magnitude. We will show that shear dislocation and fracture opening can occur almost synchronously during the fracture opening process. This impacts the analysis of pressure-controlled step tests. With this contribution, we present the interval pressure record and the uniaxial Fibre-Bragg Grating strain records to give insights of the complicated mixed-mode deformation process during hydraulic stimulation (Dutler et al., 2020).

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8.5 A proposed workflow for screening and selecting a potential site for CCS in Switzerland

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Carbon dioxide (CO_2) capture and storage operations (CCS), is now a widespread practice and a viable path for reducing atmospheric carbon dioxide (CO_2) concentrations with implications on global warming and climate change (Metz et al., 2005). Successful sequestration of CO_2 requires a suitable geological formation usually at depth greater than 800 m below ground level for sedimentary basins such as the Swiss Molasse Basin and importantly an anthropogenic CO_2 emitter such as medium to large-scale industrial sources (see Figure 1).

In Switzerland, despite the promising theoretical storage capacity potential of 2670 million tons of CO_2 for the Swiss Molasse Basin (Chevalier et al., 2010), the possibility for suitable large-scale underground storage for CO_2 still needs to be assessed accurately. Hence the need for a site screening and selection operation. Switzerland is unique considering its subsurface geological framework, underground usage (in terms of existing, on-going and future geo-energy, nuclear waste repository projects), subsurface manifestation of geofluids (water, hydrocarbons) and regulatory framework (cantonal and federal laws). Therefore, these factors must all be considered during the screening of sites suitable for CO_2 storage which have now been developed for a candidate site in Switzerland (Figure 2).

Overall, the process involves quantifying the important properties necessary for CO_2 injection and storage in particularly assessing and understanding/reducing the risk and associated uncertainties and possible mitigation. Also addressed is the critical question regarding any envisaged decarbonization projects in achieving a net zero future as to whether the subsurface data available is (a) suitable and (b) enough in order to access the potential contribution and impact of such projects (Ireland et al., 2020). We tested these proposed workflow on two sites characterized by (a) a deep saline aquifer and (b) a depleted hydrocabon reservoir in the Swiss Molasse Basin. Our work highlights some challenges related to the subsurface aquifer/reservoir quality and likewise socio-economic and environment constaints as major factors that need to be well defined for any successful CCS operation in the study area.

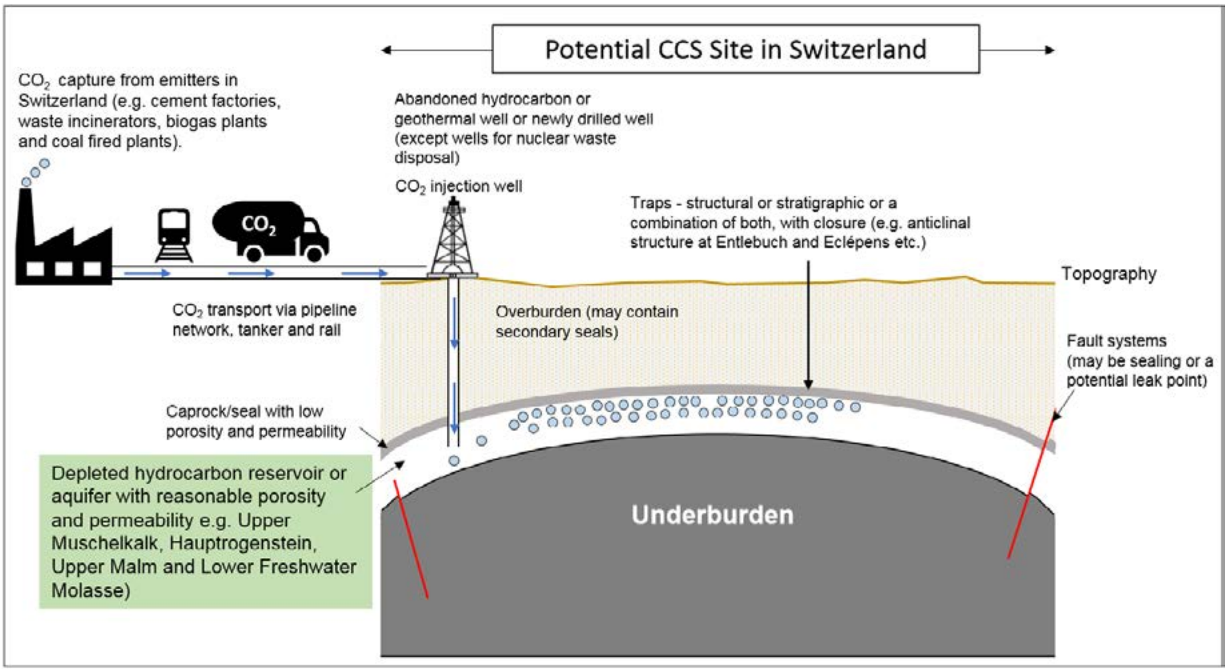

Figure 1. Schematic diagram for CO_2 storage at a potential site in Switzerland.

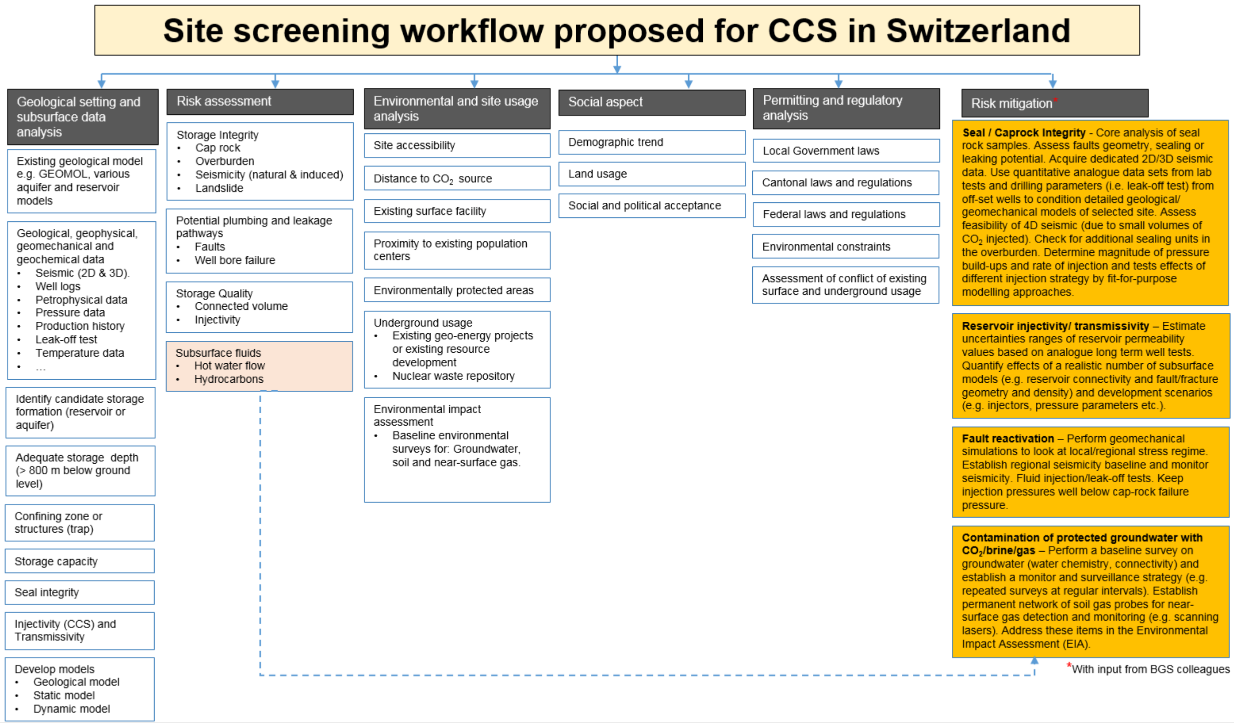

Figure 2. Site screening of a potential CO_2 storage site in Switzerland.

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8.6
Performance optimization of CO_2-Plume Geothermal (CPG) production wells and implications for electric power generation

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CO_2-Plume Geothermal (CPG) power plants can produce heat and/or electric power. One of the most important parameters for the design of a CPG system is the CO_2 mass flowrate. Firstly, the flowrate determines the power generated. Secondly, the flowrate has a significant effect on the fluid pressure drawdown in the geologic reservoir at the production well inlet. This pressure drawdown is important because it can lead to water flow in the reservoir towards, and into, the borehole. Thirdly, the CO_2 flowrate directly affects the two-phase (CO_2 and water/brine) flow regime within the production well. An annular flow regime, dominated by the flow of the CO_2 phase in the well, is favourable to increase CPG efficiency. Thus, flowrate optimizations of CPG systems need to honor all of the above processes. We investigate the effects of various operational parameters (maximum flowrate, admissible reservoir-pressure drawdown, borehole diameter) and reservoir parameters (permeability anisotropy and relative permeability curves) on the CO_2 and water flow regime in the production well and on the power generation of a CPG system. We use a numerical modeling approach that couples the reservoir processes with the well and power plant systems. Our results show that water accumulation in the CPG vertical production well can occur. However, with proper CPG system design, it should be possible to prevent such water accumulation in the production well and to maximize CPG electric power output.

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8.7
Velocity steps across four orders of magnitude to investigate the effect of fault roughness on the stability of slip

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The conditions that lead to stick slip as opposed to aseismic sliding are of great interest both in the realms of natural as well as induced seismicity. With this in mind, tectonic faults have been shown to have rougher patches that are stronger, and control earthquake nucleation and co-seismic slip. Indeed, in general, rougher faults seem to have a greater tendency to slip aseismically. However, while the influence of roughness on earthquake nucleation has been recognized, it has not yet been well explored and characterized. Using the High Strain TEmperature Pressure Speed (HighSTEPS) low to high velocity biaxial friction apparatus located at the EPFL in Switzerland, the effect of fault roughness on the stability of slip during velocity steps has been investigated.

The investigation concerns gabbro samples with customized roughness and Hrms ranging from 3 to 115 microns under normal stresses ranging from 10 to 40 MPa. Velocity steps from 10 microns/sec to 100, 1000, and 10000 microns/sec were performed, reaching higher velocities in comparison to previous related studies. Rate and state friction parameters have also been identified along with their trends in relation to relevant variables. It is generally found that increasing roughness and decreasing normal stress both stabilize slip. Additional velocity stepping experiments are also performed on Westerly Granite, lending support to previous investigations in the literature as well as to the fidelity of the novel HighSTEPS apparatus.

8.8 Evolution of fracture permeability with thermal and mechanical stresses

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Numerical simulations and laboratory experiments are conducted to study the impact of effective normal stress and thermal stress on fracture absolute permeability of fractured granodiorite specimens from the Grimsel Test Site in Switzerland. Aperture fields of six naturally fractured specimens were obtained under zero-stress conditions, via photogrammetric scans. The scanned aperture fields were numerically subjected to effective normal stress conditions of 2-30 MPa and temperatures of 25-400°C, utilizing a contact mechanics model, yielding computed aperture fields under the applied mechanical and thermal stresses. The hydraulic aperture of each computed aperture field is then determined after performing additional asynchronous steady-state, single-phase Darcy flow simulations using a finite-element method-based numerical simulator. The numerical results are then compared to the experimental results from laboratory flow-through tests of consecutive cycles of increasing effective normal stress.

The numerical results show that increases in both temperature and effective normal stress change the hydraulic and mechanical apertures in a similar trend, suggesting that similar effects and impacts on fracture closure can be caused by both thermal and mechanical stresses. Additionally, two compression regimes can be clearly identified, namely the “oceanic” and “archipelagic” compression regimes. These regimes seem to depend not only on the applied mechanical stress and temperature levels, but also on the initial fracture aperture distributions of the specimens. Specimens of larger mechanical apertures and lower contact area show more significant decreases in mechanical apertures with increases of effective normal stress. Moreover, the hydraulic apertures of specimens of smaller initial mechanical apertures tend to converge to a plateau value with the increase in effective normal stress, while more compliant specimens reveal less of this tendency. Finally, the laboratory experiments show a hysteretic behaviour of changes in hydraulic aperture with the change of effective normal stresses, which can be associated with a laboratory artifact caused by unmated fracture surfaces.

Our findings highlight the importance of characterizing fractures in order to better understand fracture closure due to changes of in-situ reservoir stresses or temperatures. These changes can directly impact the injectivity of fractured formations, thereby affecting the operation performance of subsurface reservoirs that depend strongly on the transmissivity of fractures.

8.9
About the suitability of the Aquistore CCS-site for an CPG-system

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The idea of utilizing the omnipresent greenhouse gas carbon dioxide (CO_2) at supercritical conditions in so-called CO_2 Plume Geothermal (CPG) systems is a promising concept to counteract the accelerating climate change. Large-scale CPG systems have the potential to provide a reliable, economical, and carbon neutral (or even carbon negative) energy source to the world's growing energy demand.

This study investigates the feasibility of implementing a CPG pilot test at the Aquistore CO_2 sequestration site in Canada, one of the world's first commercial-scale CO_2 capture and (geologic) storage (CCS) operations. In doing so, this feasibility study reviews the consequences of adding CPG operations to the existing CCS operations at Aquistore. A crucial aspect towards implementing CPG power generation successfully is to ensure continued CO_2 production, i.e. minimize the amount of back-produced liquid (here brine). In fact, for successful CPG (pilot test) operations, it is essential to increase the CO_2-brine-ratio over time, starting from when fluid production commences.

By performing reservoir simulations with a simplified model of the site, we are investigating the reservoir's response to different injection and production rates.

In the course of these investigations, the reservoir and well saturation of CO_2 is calculated. Finally the expected flow regime in the production well is estimated with the method of Ezekiel et al. (2020).

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8.10
Imapct of Contact Area on Hydraulic Behaviour of Rough Fractures under Normal Stress

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Fractures are the main pathway of fluids in the subsurface. Therefore, accurate estimation of the permeability of fractures is required when planing and implementing projects, such as geothermal energy extraction, oil and gas exploitation and geological carbon storage. Permeability of natural fractures is commonly estimated using the Cubic law (Witherspoon et al. 1980). Roughness of the fracture surfaces and the presence of contact points are identified as sources of error during permeability estimations using the Cubic law (Zimmerman and Bodvarsson 1996). While several corrections, to account for the effect of fracture roughness in the Cubic law, are suggested in the literature, the impact of contact area is not yet thoroughly quantified (Zhang and Chai 2020).

In this study, we investigate how the fractional contact area in rough fractures develops under normal stress and how it affects the permeability of the fracture. Rough fracture apertures, with a wide range of correlation lengths and two distinct aperture roughnesses, are synthesized. The aperture fields are then numerically deformed under ten successive normal stresses up to 50 MPa. Fluid flow through each aperture, at each stress level, is simulated and the permeability of the fracture is computed. The results demonstrate that the extent and pattern of contact area development strongly depend on the geometrical properties of the unloaded fracture. Moreover, the geometry of the unloaded fracture also determines the extent of the flow field obstruction caused by a specific fractional contact area. In conclusion, the fractional contact area alone is not an adequate parameter to quantify the effect of contact area on the permeability of rough fractures under normal stress.

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8.11
Carbonate dissolution in tight sandstones and flow-through drying in fractured granites: The role of stress

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Variation of formation stress promotes complex features of the coupled hydromechanical and chemical processes. Here we present these complexities with two sets of experiments: (1) carbonate dissolution induced by injection of CO_2-charged brine into a tight sandstone, and (2) flow-through drying induced by injection of supercritical CO_2 ($scCO_2$) into a brine-filled fractured granodiorite.

For Exp. (1), three consecutive experimental stages have been implemented: (i) pre-acid stimulation, (ii) acid stimulation, and (iii) post-acid stimulation. At Stages (i) and (iii), the confining and pore pressures were varied to determine the effective stress law for the permeability of the sandstone sample. At Stage (ii), the pore pressure was varied as a rectangular function during a 3-week reactive flow-through experiment at reservoir conditions, using CO_2-charged brine as the acid fluid, to examine the stress effects on geochemical reactions. X-ray CT imaging reveals two dissolution passages, formed near the injection inlet, due to carbonate mineral dissolution. The resulting passages significantly increase the post-reaction specimen permeability and lower the permeability sensitivity to effective stresses. SEM imaging suggests dissolution-induced exposure of previously covered clay minerals to the pore fluid, resulting in a higher sensitivity of pore fluid pressure changes to the bulk permeability.

For Exp. (2), $scCO_2$ was injected into a brine-filled, naturally-fractured granodiorite specimen at a constant temperature, to induce flow-through drying in the fracture under three different effective normal stresses. A novel approach was developed to delineate the evolution of brine saturation and relative permeability from measurements of fluid production and pressure drop across the specimen. Under higher compressive stresses, the derived relative permeability curves indicate lower mobility of brine and higher mobility of the $scCO_2$ phase. The derived fractional flow curves also suggest an increase in channelling and a decrease in brine displacement efficiencies under higher compressive stresses. Moreover, lowering compressive stresses seems to hinder water evaporation into the $scCO_2$ stream.

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8.12
Accelerating reactive transport simulations with on-demand machine learning

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Reactive transport simulations involve many coupled physical and chemical processes. Modeling chemical processes requires millions to billions of multiphase and multicomponent geochemical reaction calculations (i.e., chemical equilibrium and kinetics calculations). These are often the most expensive computations in the simulation (they can account for more than 99.9% of all computing costs). However, it turns out that many such geochemical calculations, during the reactive transport simulation, have similar (but not identical!) input conditions; and these similar conditions might occur at different points in space and time (at distinct mesh cells and time-steps).

Our on-demand machine learning algorithm
can accelerate reactive transport simulations
by one to three orders of magnitude.

It does so by *learning key geochemical equilibrium/kinetics calculations* ***during the simulation*** (rather than in advance, before the simulation started, when there is no clear idea of the possible chemical states that may develop over time and through space). These relatively few key calculations are then able to predict the subsequent millions to billions of geochemical computations (Leal et al. 2020). *The predictions are computationally cheap and accurate. As a result, the acceleration strategy causes significant simulation performance increases.*

In this presentation, we demonstrate the main advantages of the on-demand machine learning algorithm (Figure 1) and discuss its potential to substantially accelerate simulations of geologic carbon dioxide storage in deep saline aquifers or depleted oil/gas reservoirs, deep geothermal energy systems, radioactive waste management, and of oil/gas flow in reservoirs.

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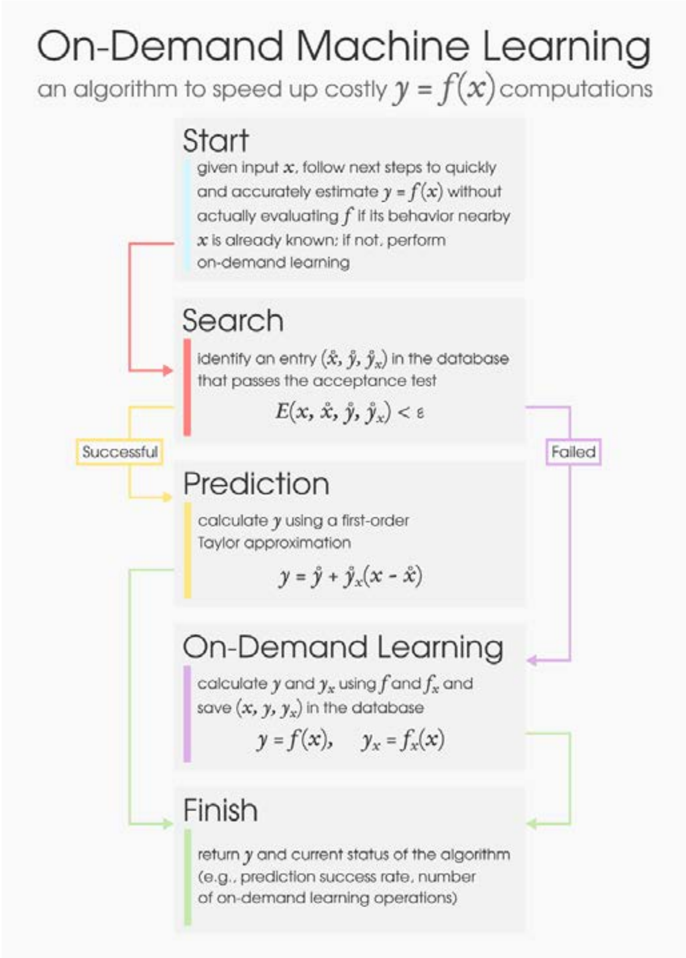

Figure 1. The on-demand machine learning strategy to speed up expensive computations encapsulated in a function *f(x)*, which can be a function that performs multiphase chemical equilibrium/kinetics computations, a function that computes thermodynamic properties of phases and chemical species, or a function that computes physical properties of materials, etc. **This acceleration strategy can be applied to a wide range of applications.**

8.13
Laboratory studies of hydraulic fracture growth in quasi-brittle rocks with different grain sizes

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Well completion for oil and gas, geothermal energy as well as CO2 storage sometimes require stimulation to achieve economical fluid flow rates (for both injector and producer wells). Predicting the growth of fluid-driven fractures in geological systems is essential for the sustainable and efficient engineering of those reservoirs. The quasi-brittle nature of rocks complexifies the coupling between fluid flow and fracture growth – especially in the fracture process zone.

To better understand the impact of the non-linear fracture in such materials, we perform different laboratory hydraulic fracturing experiments under controlled stresses and fluid injection conditions in a cubic block of 250*250*250 millimeter in size. We choose two different rocks (marble and gabbro) with an order of difference in grain sizes (and as a result most likely different process zone size) but both with very low permeability. We report a series of experiments performed under different regimes of propagation (lag-viscosity as well as toughness dominated) in these two rocks under different levels of confining stress.

We use active acoustic monitoring to reconstruct the evolution of the fracture front with time with a spatial resolution of a few millimeters every 4 seconds in time (see Liu et al 2020 for details). We show that the fracture growth is also consistent with other measurements such as fluid injection pressure and displacement measured. Attenuation of the transmitted acoustic energy also indicates the existence of a damage zone (often denoted as a process zone) ahead of the fracture. This process zone grows differently inside these two rocks during fracture propagation. Its final size appears limited by the specimen dimensions with a decrease of the fracture apparent toughness at later time.

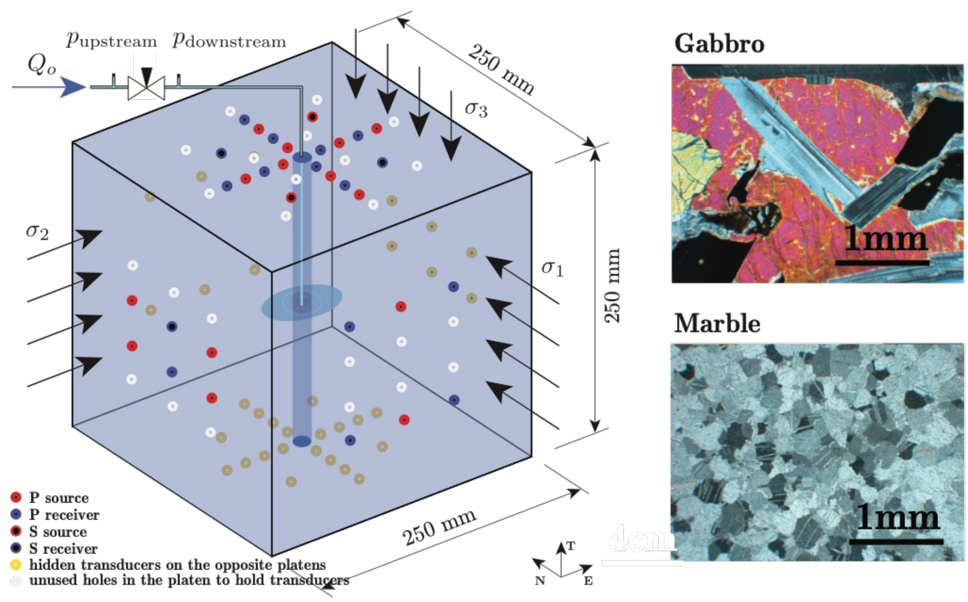

Figure 1. Schematic illustration of the rock sample showing the transducers' disposition (left). Additional holes are available in the platens allowing the use of various transducer dispositions. Two facing platens share the same transducers disposition and source/receivers transducers are alternately located on opposite platens for robustness. Thin sections of Zimbabwe gabbro and Carrara marble (right).

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8.14
X-ray Micro-CT Contribution to the Geological Identification of Rock Cuttings

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Investigation of the Earth subsurface with destructive boreholes is increasing in several domains such as geothermal engineering. It represents a rapid and cost-efficient method to characterize geological rock formations. However, the main drawback of this drilling method is the production of small rock fragments (cuttings) instead of full rock cores. These rock fragments provide only discontinuous and partial information which makes petrographic interpretation less precise than with rock cores. Most of the time, these rock cuttings are analysed under a binocular loupe to determine their petrographic nature and establish their relationship to the facies intersected by the borehole.

In this work, we develop a unique method based on X-ray micro-CT to better characterize the rock cuttings. Morphological (shape), dimensional (surface, volume) and intrinsic indicators (tomo-porosity, tomo-density) were analysed on selected rock cuttings from five different rock types.

Real cuttings from well documented borehole (DB-cuttings) and lab made cuttings (DL-cuttings) were compared to evaluate the influence of the rock type on the micro-CT based selected indicators. An example of micro-CT data on cuttings from two different rock types (micritic limestone and molassic sandstone) is presented in the figure below.

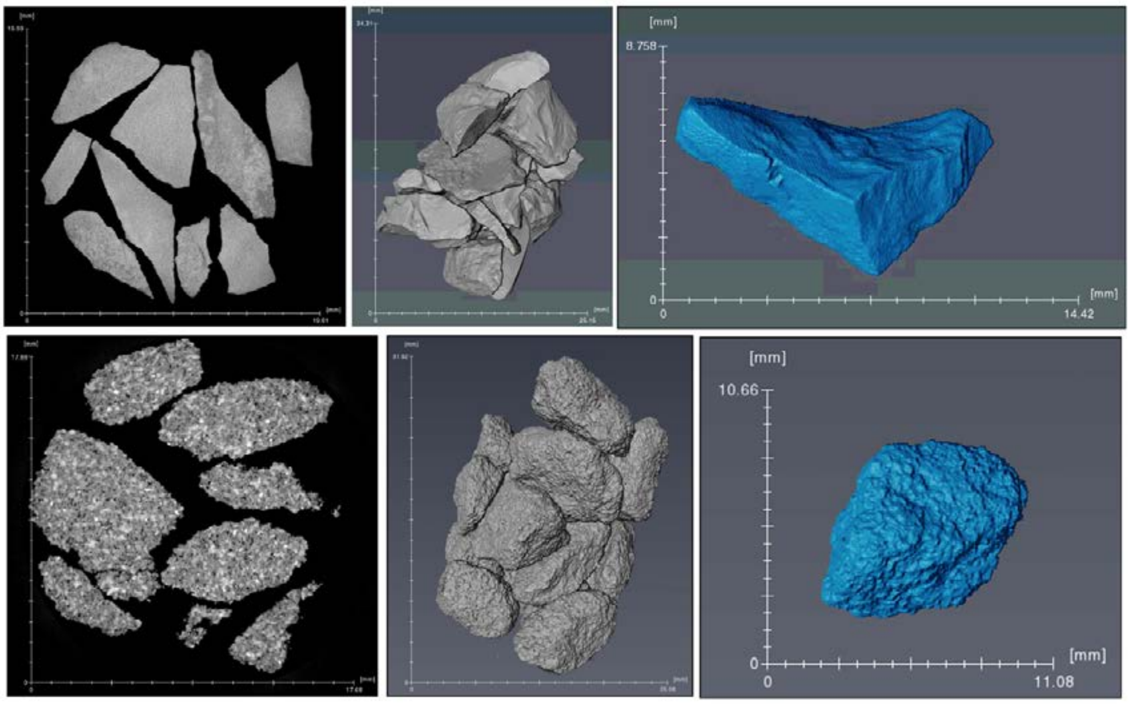

Figure: Example of X-ray micro-CT data for DL-cuttings from micritic limestone (top) and from molassic sandstone (bottom). 2D imaging of a cuttings set (left), 3D reconstruction of a cuttings set (middle) and volume rendering of a single cuttings (right).

Results show that most of the micro-CT based indicators are statistically different according to the rock type. Also multivariate analysis indicates that the rock types can be significantly differentiated by considering groups of selected indicators. As expected, the comparison of results between DB-cuttings (from borehole origin) and DL-cuttings (from lab origin) shows that the dispersion of values is higher in the cuttings from the borehole for various reasons (blend of different rock types, drilling method, facies changes,…).

This pilot study overall highlights that the micro-CT analysis could be advantageously used for detailed rock cuttings characterization. With some developments, it could probably be generalized to other rock types. The sensitivity of this method to detect smaller facies variations or fractures zones within a rock type remains to be evaluated.

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8.15
The GeoT-Play project: an innovative workflow to assist the exploration and development of geothermal resources.

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Reliable screening of both technical and economic feasibility of geothermal projects can assist government and industry players when investment decisions need to be taken on a single or portfolio of opportunities. In this context the GeoT-Play project aims at developing an innovative workflow combining i) the well-consolidated best-practices developed over the past 60 years by the hydrocarbon E&P (Exploration and Production) industry in assessing and quantifying the hydrocarbon potential of sedimentary basins (play-based evaluation) with the ii) specific needs of geothermal energy projects aimed at direct use of heat, power generation and heat storage.

The economic attractiveness of any geo-energy E&P project relies on effective and cost-efficient exploration and development. This is even more critical for projects with generally low economic margins like geothermal energy compared to hydrocarbon E&P projects. Differently from the latter, the success of geothermal E&P projects depends heavily on the detailed understanding of the energy demand portfolio and consumption distribution over time (i.e. current and future customers, seasonal variations etc) and type of users (i.e. industry, agriculture, buildings) who are generally located geographically close to the geothermal energy source.

In this perspective, the GeoT-Play project offers a 'source-to-sink" focused approach where the evaluation of the subsurface geothermal potential (the "source"), by means of rigorous integrated analysis and modelling of geophysical, geological and fluid dynamic data is carried out in parallel to the analysis of the energy demand (the "sink"), in a holistic understanding of actual and future efficient usage of renewable and non-renewable energy sources, including their economics.

This combined approach allows the identification of key success drivers which will determine the potential value of a specific geothermal project while identifying and quantifying the associated uncertainties, risks and mitigation actions. One of the key products of the GeoT-Play project are the Favorability Maps which summarizes a large and critical number of aspects including both the subsurface and surface, thus representing a key useful tool to assist the decision-makers.

The GeoT-Play project is part of the continued commitment of the GE-RGBA group at UNIGE to bridge the knowledge-gap between the well consolidated hydrocarbon industry know-how and the wannabe-successful geothermal industry and thus contribute to accelerate the overall energy-transition journey.

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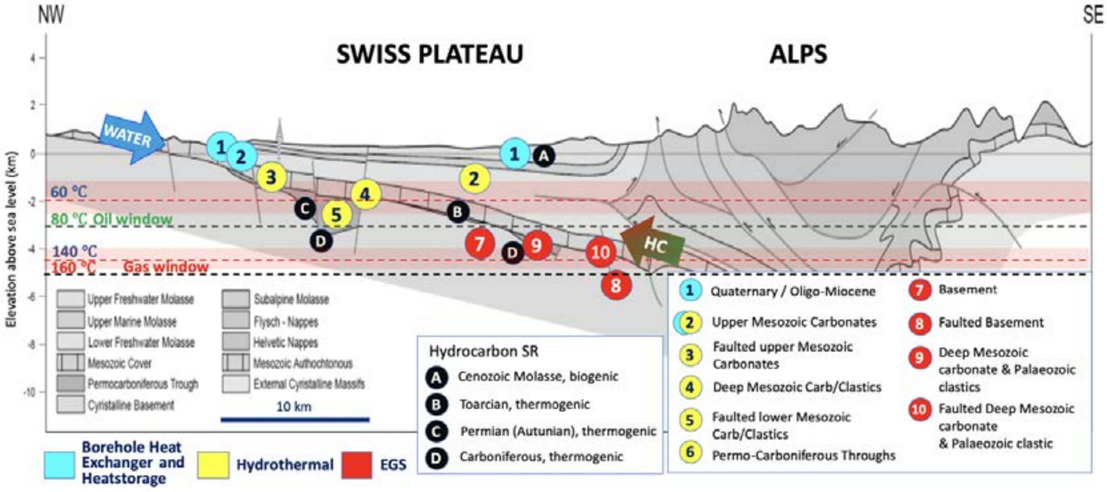

Figure 1. Summary of geothermal and hydrocarbon plays on an ideal section across the Swiss Plateau. The circles with numbers indicate the different geothermal plays and the type of geothermal energy utilization (borehole heat exchange, heat-storage, hydrothermal and enhanced/engineered geothermal systems). The arrows indicate the main direction of water circulation in the subsurface which is primarily opposite to the up-dip migration of hydrocarbons (from Moscariello, 2019).

8.16
Multi-step conditioning of geological models for constraining heat transport simulations in the subsurface of the Canton Aargau, Switzerland

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A known surface heat-flow anomaly exists in the Canton Aargau in Northern Switzerland. With specific heat-flow values of up to 140 mW m^{-2}, it is an interesting area for deep geothermal energy exploration. In this pilot study, which started in late 2018, we want to better understand the nature of this heat-flow anomaly by heat transport simulations, which consider uncertainties of the geology in this area. To achieve a complete characterization of the heat-flow values, as well as their spatial uncertainty, we developed a workflow comprising: (i) integration and homogenization of different types of geologic data, (ii) development of conceptual geological models with focus on parameters controling heat transport and (iii) numerical simulations of the dominant heat-transport processes in the area.

The models focus on an accurate representation of the Permocarboniferous trough, a roughly E-W striking structural feature in the sub-Jura basement in the study area. Considering the hypothesis, that advective heat transport along the graben faults (Griesser and Rybach, 1989) can yield increased heat flows, we assess how significant spatial uncertainties of these graben faults affect the overall heat flow rates. Previous potential studies in the area (Kohl et al., 2003) found that in addition to faults, hydraulic conductivity of the upper part of the crystalline basement has a strong influence on the spatial heat flow. For the aforementioned step (ii), we therefore vary graben-fault location and thickness of the weathered basement in a MonteCarlo approach, creating an ensemble of geological models. To represent different conceptual models, wie utilize the concept of model topology and topological graphs, an abstract representation of adjacency of geological units within a geological model.

Using existing geophysical data, such as gravity and temperature data, we condition the ensemble step-wise to fit the observations, yielding a posterior ensemble of geological structures fitting both gravity and temperature data. This workflow is schematically shown in Figure 1.

Due to its nature as a pilot study, the developed workflow has to be adaptable and accessible, so that new data at the same location can be integrated seamlessly and that the developed methods can later be applied to other cantons in Switzerland and worldwide. This means that the type and form of the input data have to be standardized, so that it can easily be integrated into the modeling and simulation process. Thus, only open-source software is used in this study to ensure maximum reproducibility.

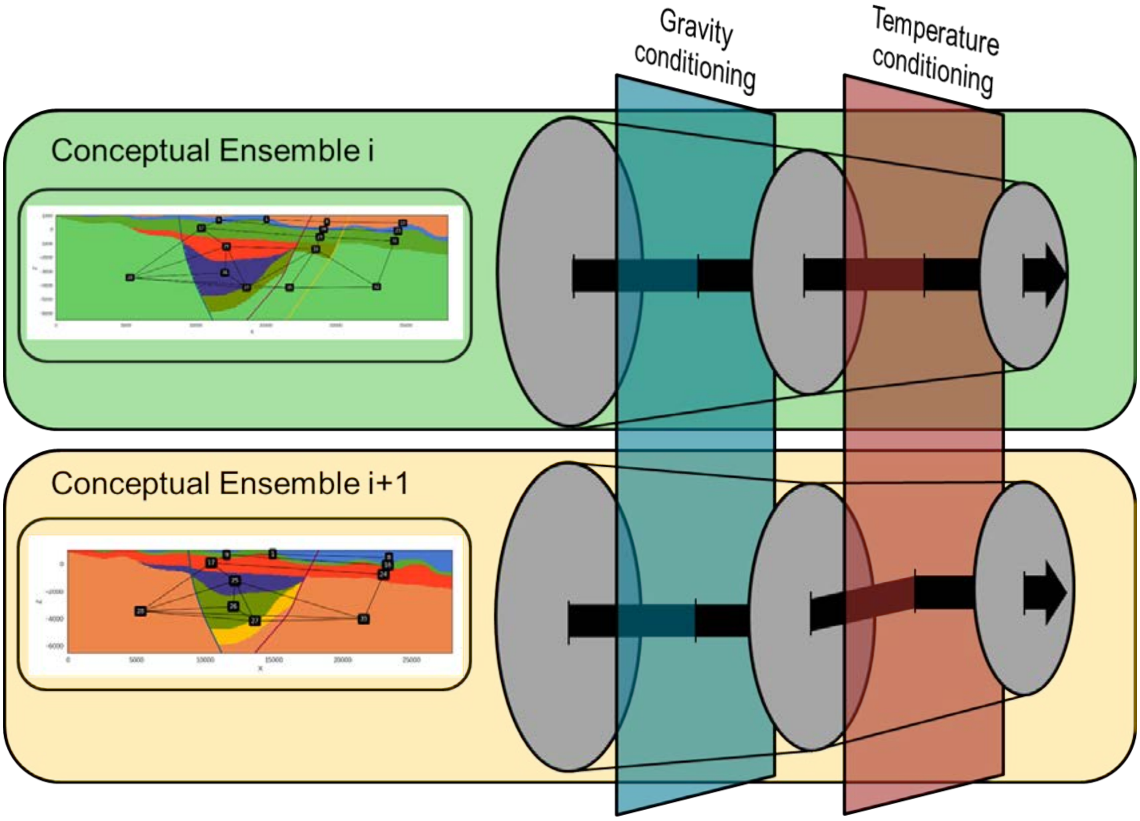

Figure 1. Schematic workflow procedure. Starting from different conceptual models (green and yellow colored boxes) with unique model topologies, the prior ensembles (left grey circles) are conditioned by gravity and temperature data, i.e. "likelihoods". Ideally, posterior ensembles will then comprise realisations of the respective conceptual model which fit geophysical observations.

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8.17
Representing Geologic CO_2 Storage in Energy System Models

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Carbon dioxide (CO_2) capture and storage (CCS) processes are critical components of least cost decarbonized energy systems and these processes rely on geologic formations to store captured CO_2. Despite this reliance, the representation of geologic CO_2 storage in optimization-based energy system models is lacking, in part due to challenges that the geospatial heterogeneity of the subsurface presents. In this talk, we present the Sequestration of CO_2 Tool (SCO$_2$T) and accompanying database, a reduced-order modeling framework that can address these challenges by generating physics-based supply curves for geologic CO_2 storage. As a case study, we use SCO$_2$T supply curves to characterize the geologic CO_2 storage resource in the Regional Energy Deployment System (ReEDS) model, which is an electric sector capacity expansion model. By comparing scenario combinations of wind turbine, solar photovoltaic, and battery energy storage technology costs, natural gas prices, CO_2 transportation costs, CO_2 emission taxes, CO_2 storage compensation rates, and geologic CO_2 storage supply curves, we demonstrate the effect that representing geologic CO_2 storage in energy system models has on future low-carbon electricity system investment decisions.

8.18
Fracture diagenesis and fluid paleocirculations in a fossil geothermal system – Geneva Basin, Switzerland

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The global rise of energy demand and the search for a less carbonated energy mix, makes geothermal energy production at the heart of new stakes. In this context of new explorations for low and medium enthalpy geothermal energy production, sedimentary basins appear as promising but challenging targets. Hence, several exploration programmes are currently developing around the globe (e.g. MEET (EU), Paris Basin (FR), GEothermie 2020 (CH) & Energeô (CH)). Exploration of geothermal resources faces several challenges, including the prediction of temperature distribution in potential aquifers and the connectivity of fracture networks. The connectivity of fracture influences fluid circulation efficiency (permeability) whereas the temperature repartition is crucial to evaluate potential plays. Understanding reservoir parameters and assessing the occurrence of matrix and fracture cementation in potential geothermal reservoirs reveals crucial to predict reservoir productivity.

The joint characterization of fossil geothermal systems with current active systems, combined with numerical modelling, is an innovative and promising approach to constrain reservoir parameters (e.g. Liotta et al., 2015; Bianco et al., 2015). The reconstruction of paleo-fluid flows in the Greater Geneva Basin (GGB; Switzerland – France) and in analogues may play a key role to predict the occurrence of cementation in natural conduits such as fractures or karsts.

A large prospection campaign is underway in the GGB, the westernmost sector of the Swiss Molasse Basin, under the supervision of the SIG and Canton of Geneva (GEothermie2020). Several potential reservoirs are identified within the 5 km thick sedimentary infill. The first targets are located in the Mesozoic formations, mainly composed of marls and carbonates. The structural depressions of the Permo-Carboniferous are also considered as potential targets. A large database of published seismic and well data is available as well as current fluid geochemistry and a basin-wide 3D geological model. Exhumed analogues of potential reservoirs outcrop in the surrounding massifs and reveal the presence of paleo-circulation of fluids through cemented fractures. Yet, despite numerous past studies conducted in the GGB, few efforts were directed to understand effective connectivity of the fractures affecting the potential reservoirs and the role played by diagenesis towards fluid circulation.

The current project capitalizes on the application of a multidisciplinary approach combining:

1) The description of geometric characteristics of faults and fractures by studying fossil geothermal systems (Mont Vuache), which are presumably analogous to currently active systems.
2) The characterization of the origin of paleo-fluids (relative and absolute timing, temperature, pressure, composition) by studying the diagenesis of fractures (cementation, dissolutions, etc.) both from outcrop analogues and core samples which represent fossil evidence of paleo-fluid circulation in the sedimentary basin.
3) Simulations of fluid-rock interactions to verify the thermodynamic validity of conceptual models related to diagenetic processes at the origin of cements, and to evaluate the volumes and spatial distribution of cementation.

This ongoing study has already provided insight into the complex structure of the Vuache fossil geothermal system and the vein-filling phases. Scanline analyses on the Mont Vuache outcrops revealed the complex structural framework of the Vuache Fault crossing the southwestern boundary of the basin. The field data processing will better constrain the existing fracture networks present in this analogue. This study focuses on mineralized fractures (veins) sampled in cores at depths between 300 and 3050 metres, as well as in outcrops in the Mont Vuache. Samples were recovered from reefal limestones and other marine limestones from Lower Triassic to Lower Cretaceous.

Petrographic analyses (by optical microscopy and cathodoluminescence), coupled with O-C isotope and fluid-inclusion microthermometry (FIM) analyses have been accomplished in samples from 3 wells: 1) Humilly-2 in the GGB; 2) Savoie 109 on the Vuache fault zone; 3) Savoie 107 in the south. The analysed veins consist of several cement, including calcite and dolomite and locally post-dated by sulphate cements. The preliminary petrographic results show a significant variation in the textures of mineralized veins and different generations of carbonate phases. The samples are mostly composed of “blocky”, “elongated blocky” and “fibrous” calcite (Bons et al. 2000) but the different phases observed in cathodoluminescence show a compositional evolution of the mineralizing fluids. O-C isotope results also indicate an evolution of fluids that have circulated in the fracture conduits ($\delta^{18}O$ between -9,57‰ and -3,41‰; $\delta^{13}C$ between -4.27 and 2.21‰).

The first results of fluid inclusions microthermometry revealed low salinity of mineralizing fluids (0.1 - 2.4 eq. wt% NaCl), indicating a significant contribution of fluids of meteoric origin possibly mixed with connate waters.

Further work using the mentioned methods as well as other analytical techniques (clumped isotopes; U/Pb geochronology) will enable the acquisition of more information on the paleogeothermal systems.

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8.19
Enhancing deep geo-resource utilization by advanced drilling technologies: CTMD and PPGD

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To meet the increasing worldwide energy demand in the next decades, the access to oil, gas and geothermal heat from deep reservoirs will play a fundamental role in the global energy supply (BFE 2019). Wells to extract deep geo-resources (deep geothermal, oil or gas) in more challenging and deeper environments, require major costs, mainly related to the involved drilling operations. Drilling costs increase exponentially with depth and, furthermore, they occur in an early, considerably high-risk phase of the project (Tester 2016). Thus, with the aim of improving the overall economics to access deep geo-resources in hard rocks, in this work, we propose two advanced drilling technologies being investigated at ETH Zürich (GEG-group), namely, Combined Thermo-Mechanical Drilling (CTMD) (Rossi 2018a, 2018b, 2020a, 2020b), and Plasma Pulse Geo-Drilling (PPGD) (Vogler 2020; Walsh 2020). Here, we present the two novel drilling technologies and we focus on the process efficiency and drilling performance of these methods towards an effective reduction of the drilling efforts to facilitate the utilization of deep geo-resources in hard rocks.

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8.20
How to Calculate Heat Flow from Geothermal Heat Pump Data for Geothermal Exploration

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Heat flow mapping is standard technique in geothermal exploration. The basic, indispensable ingredients to calculate heat flow are temperature gradient and thermal conductivity (λ). Such data can be obtained from boreholes.

Geothermal heat pump systems are now installed more and more in many countries for space heating and cooling, most of them with borehole heat exchangers (BHE). The higher λ of the surrounding ground, the higher the heat exchange efficiency (W per m borehole length). Therefore, special borehole measuring set-ups and procedures are commonly used in construction areas to determine the average thermal conductivity λ (TRT method) or the thermal conductivity profile ($\lambda(z)$, ETRT method). These data are needed for design calculations (BHE number, depth, spacing for a given object to be heated and/or cooled). At the same time, the borehole temperature profile T(z) is also measured. From such data, heat flow can be calculated.

Data from several BHE sites have been acquired, analyzed, and processed. First, the borehole temperature data for z > 100 are plotted to display the T(z) trends, and then average λ or $\lambda(z)$ are taken from the TRT or ETRT records and reports at a given site. Finally, the local heat flow is calculated either with the average λ and the average gradient or with the Bullard plot technique, which uses $\lambda(z)$. In the latter, layer-wise integrated thermal resistivities ($\Delta z_i/\lambda_i$) are plotted against measured temperatures at corresponding depths (details in Rybach, 2020).

The method is demonstrated by examples from BHE sites in the Zurich region/Switzerland. The “shallow” heat flow values elaborated by these means are in the range 80 to 100 mW/m^2 and fit reasonably well with the general Swiss heat flow trends, determined from deep (> 1 km) borehole data.

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8.21 An overview of current research in the Geothermal Energy and Geofluids (GEG) Group at ETH Zurich and a call for further collaborations

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The Geothermal Energy and Geofluids (GEG.ethz.ch) Group at ETH Zurich was founded in 2015. This presentation provides an overview of the diverse research topics covered by the group, the methods employed, the people who conduct the research, and the results/publications achieved thus far since the group's inception about 5 years ago. Several other presentations by GEG researchers during this 18th Swiss Geoscience Meeting (2020) provide actual research results. It is also hoped that this overview presentation will initiate further collaborations with additional researchers in Switzerland and beyond.

The GEG group conducts subsurface fluid dynamics research of multiscale, multiphase, multicomponent, reactive fluid (groundwater, CO_2, hydrocarbon) and heat energy transport during processes such as water- and CO_2-based geothermal energy extraction and use/conversion, geologic CO_2 storage, subsurface energy storage, enhanced oil/gas recovery, groundwater flow, and nuclear waste storage. The group also investigates and develops new, so-called contactless, drilling methods and conducts field work in the form of geothermal exploration, employing, for example, Magnetotellurics (MT) methods and tracer tests. The group also develops/improves MT methods. Research methods (https://geg.ethz.ch/methods-labs/) employed by the GEG group include computer simulations (50%), laboratory experiments (30%), and field analyses (20%) to gain fundamental scientific insights and to address a wide range of societal goals and concerns related to 1) renewable/sustainable geothermal energy supply, 2) geofluid (groundwater, CO_2, oil/gas) transfer, and 3) subsurface mass (CO_2, methane, hydrogen, nuclear waste, etc.) and energy (heat, pressure) storage. The group also develops new computational methods (e.g. Reaktoro.org) and modifies and couples existing codes. Reactive transport experiments (now inside the group's new X-Ray Computed Tomography (XRCT) scanner), coupled with 3D-printing and Particle Image Velocimetry (PIV) and Laser-Induced Fluorescence (LIF) in the group's GREAT Visualization Lab (https://geg.ethz.ch/methods-labs-laboratory-investigations/), mainly serve to test and calibrate numerical simulators, which can then be used for reservoir-scale simulations with heightened confidence in the results. The GREAT Visualization Lab can also be used by other researchers and in general, we are very happy to collaborate with a wide range of colleagues from different fields.

The GEG group currently works on 14 research projects (https://geg.ethz.ch/projects/), grouped into 5 main categories: 1) Reactive Transport, 2) MT and Heatflow, 3) Rock Mechanics, Fluid Flow, Poroelasticity, Induced Seismicity, 4) CO_2-Plume Geothermal (CPG), and 5) Drilling, currently (August 2020) resulting in 94 peer-reviewed journal publications since the beginning of the GEG group in 2015 (https://geg.ethz.ch/publications/). The GEG researchers come from several different fields of expertise, including the geosciences as well as engineering, math, physics, chemistry, and computer science.

8.22
Numerical investigations of thermal attenuation and lag time in rough fractures: comparison of joint solute and heat tracer tests

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Characterizing fracture-dominated reservoirs poses a key challenge in the context of many subsurface applications. Tracer tests are commonly used to obtain hydraulic properties, and specifically, heat tracers can provide information about the flow geometry. Due to the strong interaction of heat with the surrounding rock matrix, its transport characteristics differ from solute tracers. Generally, heat tracers lag behind solute tracers and are subject to large attenuation of the initial signal. This attenuation and lag time are characteristic for different flow geometries. De LaBernardie et al. (2018) presented analytical expressions for various fracture geometries to describe the thermal attenuation and lag time in relation to the advection time of conservative tracers. The developed expressions are described for a parallel plate and channel(s) with a linear flow field and a parallel plate with a dipole flow field. Generally, fractures are characterized by two opposite rock surfaces with variable surface roughness which results in a heterogeneous aperture distribution and hence the potential for the formation of preferential flow paths within the fracture planes. These preferential flow paths might be described by the above mentioned analytical expression for channel(s) with a linear flow field. However, it is unclear to which extent these preferential flow paths, in combination with a dipole setup, influence thermal attenuation and lag time.

In this study, we investigate the influence of fracture-aperture variability on thermal attenuation and lag time. To this end, numerical simulations of a single circular fracture, embedded in a low-permeability rock matrix, are performed. Various heterogeneous aperture fields with different correlation lengths are considered by applying the local cubic law. In the fracture, flow and transport of heat and a solute tracer occur between an injection and production borehole. In the rock matrix, only heat conduction is considered. The simulation results for different injection rates are used to characterize the thermal attenuation and lag time behavior for each aperture field. We show how heat-tracer breakthrough relates to solute-tracer breakthrough in a fracture with a heterogeneous aperture distribution. Our findings show that the thermal attenuation in rough fractures ranges between the analytical expression for a dipole flow field and the expression for channel(s) with a linear flow field. However, an increased heat exchange between the fracture and the rock matrix, which is typical for flow channeling, is not observed for the considered realizations. Our findings contribute to the improvement of reservoir characterizations by tracer tests.

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8.23
Numerical Modeling Approaches to Contact-less Drilling Techniques

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Contact-less drilling techniques, such as plasma pulse geo-drilling or thermal spallation drilling are among a range of novel drilling techniques that do not rely on mechanical abrasion like conventional rotary head drilling. This promises lower material abrasion and damage and therefore significantly reduced tripping times and overall cost associated with the multiple kilometer deep boreholes required for enhanced geothermal systems. Due to harsh monitoring environments in borehole drilling operations, the physical mechanisms dominating rock damage and thereby drilling progress are difficult to study, especially on the microscale. Additionally, observing the occurring processes of these drilling techniques at depths of multiple kilometers becomes yet more complicated and testing at similar conditions in the laboratory requires prohibitively expensive experimental equipment.

For reasons mentioned above, we rely on numerical simulations that can accurately capture the underlying processes of our drilling operations and shed light on the expected shifts in performance once realistic reservoir depths are reached. With this aim, we employ a finite-element framework to model rock damage and fragmentation in both thermal spallation and plasma pulse geo-drilling. This allows us to identify the key parameters dominating drilling success at such depths and helps us to further optimize our drilling techniques.

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P 8.1
Predictive DFN modelling for the Trigonodus Dolomite aquifer in the northernmost Swiss Molasse Basin based on vertical and horizontal borehole records

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A major challenge in geothermal exploration relates to the identification of fractures in the sub-surface as potential fluid pathways. The distribution of small-scale brittle structures below the resolution of reflection seismics is commonly modelled stochastically. Discrete Fracture Network (DFN) modelling is one possible technique for extrapolating related observations into an unknown volume. The results of such stochastic models require critical verification to determine resulting uncertainties and model robustness as they represent extrapolations.

We present a case-study from the village of Schlattingen, located the northernmost Molasse Basin in Switzerland, that is devoted to such a verification aimed at improvement of the DFN modelling workflows. Two boreholes were drilled at this location, a vertical cored borehole reaching into the crystalline basement and a deviated borehole running sub-horizontally for 464 m in the Schinznach Formation (Upper Muschelkalk), a potential geothermal reservoir (Frieg et al. 2015). This borehole layout allows testing the workflow for discrete fracture network modelling from a single borehole and the assessment of the added value of a deviated borehole (and vice versa).

The modelling workflow used borehole data and outcrop descriptions from a range of locations as input data. The spatial distribution of features was simulated using a Poisson distribution, assuming random distribution of the fractures. The aims of the study were to investigate the workflow's ability to account for the different orientation biases in the two boreholes and develop understanding of spatial variability in fracture orientation and frequency.

It was found that reasonable consistency in orientation and overall frequency could be achieved using the borehole orientation distributions but that the spatial variability in fracture frequency and clustering of fractures were significant. It was also necessary to critically evaluate the borehole imagery from the deviated borehole.

Current efforts are focused on better constrain the spatial fracture distribution along the deviated borehole using correlation analysis (Marett et al. 2018, Gale at al. 2018) and assess its influence on the discrete fracture network model.

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P 8.2
Simulating plasma formation in pores to investigate key parameters governing Plasma Pulse Geo-Drilling (PPGD)

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Plasma Pulse Geo-Drilling (PPGD), a novel, contactless drilling technique, offers a cost-effective and rapid alternative to conventional mechanical rotary drilling; and therefore it has the potential to enable deep-geothermal projects for economic electricity-generation (Anders et al., 2017; Rodland, 2012; Schiegg et al., 2015)everybody is enabled to generate autonomously clean and renewable energy, ample electricity and heat. The economical exploration and exploitation of this superdeep geothermal heat deposit requires a novel drilling technique, because the currently only deep drilling method (Rotary. Even though several experimental studies investigated the process, the underlying fundamental physics is still poorly understood (Anders et al., 2017; Inoue et al., 1999; Lisitsyn et al., 1998; Vazhov et al., n.d., 2010). The lack of understanding of the process increases the difficulty of optimizing the tools and limit its range of applicability.

Both thermomechanical breakdown and the internal breakdown mechanisms are dominant in the process (Lehr & Ron, 2017)the circuit may consist of a high-voltage generator and a pulse forming transmission line (PFL. Walsh and Vogler (2020)it has the potential to confer significant advantages to mining and drilling operations for mineral and energy resources. Nevertheless, before these benefits can be realized, a better understanding of these processes is required to improve their deployment in the field. In this paper, we employ a recently developed model of the grain-scale processes involved in electropulse stimulation to examine excavation of hard rock under realistic operating conditions. To that end, we investigate the maximum applied voltage within ranges of 120–600 kV, to observe the onset of rock fragmentation. We further study the effect of grain size on rock breakage, by comparing fine (granodiorite and Vogler et al. (2020) developed a model to investigate specifically the thermomechanical breakdown mechanism, while our study here is designed to investigate the internal breakdown mechanism, thereby improving on the previously developed plasma modelling approach. We investigate numerically the role of critical parameters that likely control the internal breakdown process, including the electric pulse voltage peak, the pulse rise time, the pore size, the rock mineral composition, and the pore fluid type.

Our study uses the ZAPDOS simulator to numerically model plasma formation (Lindsay et al., 2016)biological and chemical disinfection, agriculture, and other areas. Optimizing these applications requires a fundamental understanding of the coupling between phases. Though much progress has been made in this regard, there is still more to be done. One area that requires more research is the transport of electrons across the plasma-liquid interface. Some pioneering works (Rumbach et al 2015 Nat. Commun. 6, Rumbach et al 2015 J. Phys. D: Appl. Phys. 48 424001. We simulate plasma formation in rock pores/microcracks that exhibit different sizes/apertures of 10, 50, 100, and 500 µm, that are filled with air or water, and calculate the plasma pressure. Simulations investigate electric pulses with maximum peaks ranging from 200 to 600 kV and rise times ranging from 30 to 500 ns. The calculated plasma pressures for those parameter combinations are then compared to the tensile strength of the investigated rock to determine if rock fragmentation and, thereby, drilling operations, can be achieved.

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P 8.3
Monitoring geothermal field for heat production and storage in the context of the Jura tectonics.

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Geothermal production from deep reservoirs allows delivering energy in the form of heat and/or power to final users. Additionally, one application that is recently emerging is seasonal storage of excess heat from industrial and civil processes into the subsurface such as deep aquifers. Stored heat can then be delivered in high heat demand periods according and has the potentially to contribute decarbonizing the energy system by partially replacing fossil fuels that are commonly used for heat production in winter. The potential of storage of excess heat in deep aquifers in Geneva is under investigation in the framework of the European ERA-Net GEOTHERMICA HEATSTORE project.

Heat production and storage are the main applications that are investigated in the framework of the GEOTHERMIES program developed by the Services Industriels de Geneve (SIG) and the Canton of Geneva. The GEo-1 exploration well is the first deep wells drilled by SIG in the Geneva area, it is 744m deep, produces 50l/s of thermal water at 34˚C with 8-10 bars wellhead pressure. One of the environmental effects associated with geothermal production is ground deformations which usually occurs due to reservoir depletion because of excessive withdrawn of fluid with respect to the recharge. This effect has been observed in several industrial geothermal fields (Bromley et al. 2010, Mossop and Segall,1997) but has never been investigated for heat storage applications where rather frequent production and injection cycles are operated seasonally. The GEo-01 well is providing a great opportunity to assess the effects of fluid extraction from the reservoir as production tests are planned to be performed in the near future. Therefore, to establish the background noise that can and use it to establish a quiet baseline, before production tests, the GEo-01 well has been monitored using a wide range of geophysical instruments and the combination of truly collocated instruments (inclinometer, gravimeter, GPS and seismometer) allowing for the monitoring of ground motion and local vibration. This study presents the results from the data collection over 4 months, for all parameters of the local context at two locations close to GEo-1. The data time series are discussed in the context of regional tectonics.

P 8.4
Impact of recharge conditions on fluid flow in deep orogenic faults: implications for the hydrothermal system at Grimsel Pass, Switzerland

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The orogenic geothermal system at Grimsel Pass (2164 m a.s.l.) in the Swiss Alps constitutes a deep, fault-bound single pass flow system driven by the regional topography (Diamond et al., 2018). Meteoric water recharges at high altitude west of the pass, infiltrates the fault to depths exceeding 10 km and discharges at the Grimsel mountain pass at temperatures of around 28 ºC.

Numerical simulations with PFLOTRAN (www.pflotran.com) show that such topography-driven single pass flow through the fault implies conditions at or below the critical Rayleigh number. At the same time, fault permeabilities have to be high enough to produce the fluxes and thermal output observed at the springs. These constraints impose lower and upper limits to the range of average fault permeabilities. Simulations show these limits are 1e-15 m^2 and 1e-14 m^2, respectively. During the Pleistocene, several major glaciation events occurred, leading to the formation of thick sheets of ice covering the Alps and protruding far into the alpine foreland. During periods of peak glaciation, meteoric infiltration into the Grimsel fault was at a minimum as precipitation fell predominantly as snow. These cold periods alternated with warm, interglacial periods during which the recharge zone of the Grimsel fault was exposed to rainfall and seasonal meltwater infiltration. Meteoric infiltration was at a maximum.

Thus, during cold periods inflow into the fault was below the infiltration capacity as defined by the permeability and cross-sectional area of the recharge zone. During warm periods, recharge was at or near the infiltration capacity of the fault. As a consequence, the depth of the water table in the recharge zone and hence the hydraulic gradient between recharge and discharge zones changed over time in response to climatic conditions.

We have constructed a generic numerical model using PFLOTRAN, loosely patterned after the Grimsel system, to assess whether these changing recharge conditions and the ensuing water table fluctuations could have had an impact on the deep flow system in the fault. The top boundary of the model is a smooth surface with a linear slope of 6.4%, constituting an idealized representation of the surface topography of the Grimsel region (Figure 1A). A new type of boundary condition was implemented into PFLOTRAN and assigned to the top boundary, allowing for an explicit control of the rate of meteoric recharge into the fault and a dynamic response of the depth of the water table.

Results show that if meteoric recharge becomes the bottleneck for flow through the fault during periods of glaciation, a layered flow system evolves confining single pass flow to shallow depths and establishing non-Rayleigh convection in the deep fault (Figure 1B). Non-Rayleigh convection is driven by lateral temperature gradients induced by the surface topography under conduction dominated (i.e. sub-critical Rayleigh) conditions. By increasing the recharge rate, the deep single pass flow pattern is re-established. The flow system is very responsive to recharge conditions and can switch between mixed (convection and single pass flow) to pure single pass flow and vice versa within less than 1000 years.

The results suggest that during the last glaciation, which began some 30000 years ago, meteoric water penetrated the fault to much shallower depth than it does today. Fluids in the deep fault were isolated from shallow through-flow, moving slowly as a result of weak lateral temperature differences. Recharge rates increased again when the ice-sheet melted some 15000 years ago and deep single pass flow was re-established. Given the slow flow rates in the fault, it is possible that the water discharging at Grimsel Pass today is the water trapped at depth during the last ice age. This would be in agreement with the estimated residence time of the water of at least 30000 years (Waber et al., 2017) and its chemical signature of high temperature rock-water interaction.

Mixed flow systems with deep convection and shallow single pass flow also arise by lowering the aspect ratio (length/depth) of the fault plane. This is because by reducing the aspect ratio, the available recharge area limits the flux into and through the fault. This indicates that in the Grimsel system the depth of infiltration correlates with the distance between the recharge and the discharge zone. Simulations suggest that to achieve an infiltration depth of 10 km, the fault plane has to extent at least 10 km into higher terrain towards the west.

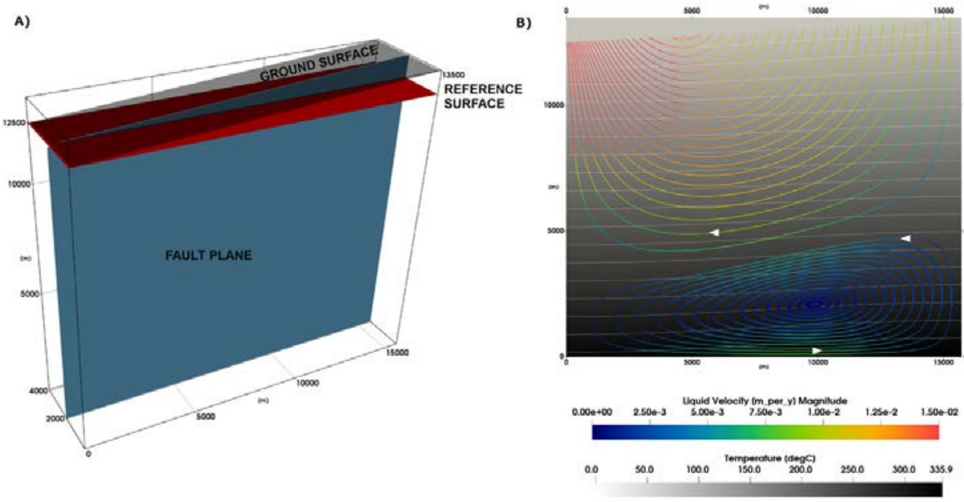

Figure 1. A) The model domain without topography (with flat "reference surface" shown in red) is a block of dimensions 15.7 x 4.1 x 12.5 km. A linear increase in the surface elevation with a slope of 6.4% along strike of the fault is stacked onto the reference surface to represent the general trend of the surface topography of the Grimsel region. B) Flow pattern under recharge-limited conditions (0.01 m/yr). Fault permeability is 1e-15 m^2. Infiltrating meteoric water no longer penetrates to the bottom of the fault resulting in a mixed flow system with single pass flow overlying deep non-Rayleigh convective circulation.

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P 8.5
Magnetotelluric Exploration of Geothermal Systems in the Main Ethiopian Rift

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Rifting and rift related magmatism in the Main Ethiopian Rift (MER) have endowed Ethiopia with abundant geothermal resources. Their estimated potential for renewable energy production exceeds 10.000 MWe, thus bearing the potential to support sustainable development of the country. The most attractive candidates for geothermal energy production are high-enthalpy geothermal systems which form over shallow crustal magmatic intrusions that drive massive convective hydrothermal reservoirs. Such geothermal systems can often be found in the direct vicinity of volcanoes. Local-scale magnetotelluric (MT) soundings at volcanoes in the central part of the MER played a key role in imaging the magmatic reservoirs and delineating their associated hydrothermal systems. MT is a powerful geophysical exploration method in geothermal areas, as it is sensitive to zones of high electrical conductivity, such as magma chambers, hydrothermal fluids and associated alteration minerals.

Two examples for such surveys are the geothermal fields of the volcanos Aluto and Tulu Moye, where MT investigations led to the successful siting of productive geothermal wells (Samrock et al., 2018 and 2020). We present 3-D local MT models from the two geothermal prospects and detail how they helped to image and interpret their associated magmatic-hydrothermal system. In the search for more geothermal fields, it is now necessary to extend the investigation area and integrate the existing local high-resolution MT models with regional scale models, covering the entire width of the rift.

In a new study, we reanalyse MT data from the only existing cross-rift profile (Hübert et al., 2018) together with a subset of local high-resolution data from Aluto (Samrock et al., 2020). By combining both datasets the study aims to overcome their specific limitations, which are sparse site distribution for the regional profile and limited aperture of the local dataset from Aluto. So far, these limitations have prevented to fully model the extent of the feeding zone of Aluto's magmatic system and the question has been raised if it is connected to a strong electrical conductor in a western fault zone. With this study, we expect to get an improved multi-scale model that can lead to a better understanding of the melt distribution across the rift and its main fault zones.

The study is a first contribution to the newly funded ETH project MIRIGE. With MIRIGE we plan to measure around 180 new MT stations across the rift in addition to the existing 600 local stations from the volcanoes (Gíslasson et al., 2015, Samrock et al. 2018, Samrock et al. 2020). The aim of this study is to recover a regional-scale electrical conductivity model of the Main Ethiopian Rift. From the new model we expect to get a better understanding about how melt is distributed in the rift on scales from the upper mantle to the shallow hydrothermal systems and how rifting-related magmatism leads to the formation of prospective geothermal resources. The overarching incentive is to enhance knowledge for future successful geothermal energy development and contribute to the risk assessment of volcanic hazards.

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P 8.6
3-D imaging of mid-enthalpy geothermal systems in central Mongolia within the context of a Swiss r4d programme

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The Hangai dome in central Mongolia is an intra-continental mountain range, located far from tectonic plate boundaries, with a high topography including several peaks that exceed 3000m in elevation. Numerous small-volume volcanic cones and alkali basaltic lava flows formed since ca. 30 Ma, with a focused volcanic activity in the uplifted Hangai dome region. There are more than 40 natural hot springs in the Hangai with temperatures of up to 90˚C. The most prominent one is Tsenkher hot spring with a high temperature of 87°C at the surface at a water flow rate of 10l/s, which is located in 25km south-east of Arkhangai province center Tsetserleg at an elevation of >1800 m.a.s.l. Being the largest hot spring, and due to its proximity to Tsetserleg, the Tsenkher geothermal site is the place, where geothermal energy utilization and studies, regarding the realization of a combined heat and power (CHP) geothermal plant, are most advanced. Currently the hot fluids are only used locally in the hot spring area for some limited greenhouse and house heating and in a spa.

Previous geothermal exploration surveys in Mongolia were conducted at most geothermal manifestations but they focused on geological and geochemical studies. Only near-surface (upper 150m) geophysical prospecting was performed around the hot springs of Tsenkher and Shivert, thereby missing the deeper geothermal reservoir and source region. Exploration wells drilled around Tsenkher, to find the geothermal reservoir, did not succeed. During 2016-2019, a regional magnetotelluric study of the Hangai dome was conducted by Käufl et al. (2020) in an area spanning 400km by 600km. The results of this work revealed an electrically conductive crustal anomaly beneath the Tsenkher geothermal area. The anomaly was interpreted in terms of small fractions of melt indicating the existence of a deep-rooted and lasting geothermal heat source.

With our project, which is supported by the Swiss Research for Development Programme (SNF r4d), we establish and deploy methods and tools for geothermal exploration in Mongolia. Our study region is located at the Tsenkher geothermal field near Tsetserleg, where we conduct electrical conductivity surveys, using the magnetotelluric (MT) method. MT is a geophysical technique to probe the electrical conductivity distribution of the Earth's subsurface down to depths of tens of kilometers. In geothermal exploration, MT is often used, since electrical conductivity is closely linked to important geothermal reservoir parameters, such as porosity, fluid fraction, permeability and temperature.

During summer 2019, we collected MT data at 184 sites in an area spanning 20 by 30 km, with an average site spacing of 2km. For the MT survey, we make use of the so-called telluric-magnetotelluric (TMT) approach, which enables increasing the amount of acquired data, while keeping equipment costs and survey duration low.

To obtain the electrical conductivity model, we use a 3-D finite element code GoFEM (Grayver, 2015) with locally refined unstructured hexahedral meshes that allow us to accurately model topography and account for the irregular site distribution. To recover a 3-D electrical conductivity model, we invert the full impedance tensor rotated into geoelectric strike direction. The best fitting model provides important new insights into the subsurface structure of the Tsenkher geothermal region.

A dominant feature in the model is a crustal resistor at a depth from 2 to 15km, which can be interpreted as highly resisitive pre-Cambrian cratonic basement rock (Cunningham, 2001; Käufl et al., 2020). At the near-surface, Permian, clastic sediments are imaged as a moderately conductive layer that reaches a depth of about 2km. A prominent feature in the model is a conductive channel in the upper crust beneath the hot springs that rises from depths greater than 10km to the surface. The nature of this conductor is not entirely clear. However, it is likely related to late-Cenozoic volcanic activity. Its high conductivity can be interpreted in terms of high permeabilities and magmatic or meteoric fluid saturations. Its orientation follows major fault zones identified in the study region. Thus, the channel likely acts as an up-flow zone of heated fluids from the lower crust and partial melt region, resulting in the formation of the hot springs at the surface. Our future study will concentrate on installing more measurement stations in the region of the identified heat source to better image how the channel-like conductor is connected to the hot springs at the surface and whether it might be a promising target zone for future geothermal drilling.

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P 8.7
Characterisation of Nubian Sandstone for CO_2 storage using pore-network modeling

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Depleted oil fields in the Gulf of Suez (Egypt) can serve as geothermal reservoirs for power generation using a CO_2-Plume Geothermal (CPG) system, while geologically sequestering CO_2. This entails the injection of a substantial amount of CO_2 into the highly permeable brine-saturated Nubian Sandstone. Numerical models of two-phase flow processes are indispensable for predicting the CO_2-plume migration at a representative geological scale. Such models require reliable constitutive relationships, including relative permeability and capillary pressure curves. In this study, quasi-static pore-network modelling has been used to simulate the equilibrium positions of fluid-fluid interfaces, and thus determine the capillary pressure and relative permeability curves. Three-dimensional images with a voxel size of 0.65 m^3 of a Nubian Sandstone rock sample have been obtained using Synchrotron Radiation X-ray Tomographic Microscopy. From the images, topological properties of pores/throats were constructed. Using a pore-network model, we performed a sequential primary drainage-main imbibition cycle of quasi-static invasion in order to quantify (1) the CO_2 and brine relative permeability curves, (2) the effect of initial wetting-phase saturation (i.e. the saturation at the point of reversal from drainage to imbibition) on the residual–trapping potential, and (3) study the relative permeability–saturation hysteresis. The results improve our understanding of the potential magnitude of capillary trapping in Nubian Sandstone, essential for future field-scale simulations. Further, an initial basin-scale assessment of CO_2 storage capacity, which incorporates capillary trapping, yields a range of 14-49 $GtCO_2$ in Nubian Sandstone, Gulf of Suez Basin.

P 8.8
Estimation of CO_2-Plume Geothermal Potential in depleted Nubian Sandstone

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The Nubian Sandstone formation is a highly permeable unit in the Gulf of Suez with a geothermal gradient of 35.7 ^{o}C/km (i.e. medium enthalpy); a system that cannot optimally be upscaled for power generation using a water-based geothermal approach. Due to its strong thermosiphon and high injectivity, we use CO_2 instead of water in a so-called CO_2-Plume Geothermal (CPG) technology. In CPG, the captured CO_2 is circulated underground into 3.5 km deep Nubian sandstone (a depleted oil/gas reservoir in the Gulf of Suez basin, Egypt). In these reservoirs, the CO_2 is naturally geothermally heated, produced to the surface, where it is expanded in a turbine to generate electricity, cooled, compressed, and then combined with any CO_2 stream, from a CO_2 emitter, before it is reinjected into the subsurface reservoir.

In this study, the geothermal potential and possible electric output by using CPG is estimated. The thermophysical properties of CO_2 at the depth of the formation is based on the equation of state. The well spacing is optimised to geological constraints in each fault block. The reservoir impedance is found for each of the compartmentalised blocks and is used to find the Net Power. An upper value of 4.3 MWe of net power can be generated using CPG for the investigated Nubian Sandstone formation.

P 8.9
Digital rock physics applied to squirt flow

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The characterisation of fluid-saturated rocks plays a fundamental role in several activities such as exploration and production of oil and gas, monitoring of CO2 geological sequestration, geothermal production (Metz et al., 2005; Tester et al., 2007). Seismic waves are known to be affected by rock heterogeneities, as well as, by the fluid in the pore space and, therefore, seismic methods are an important tool for indirectly inferring those rock properties. At the micro-scale, pores and cracks are examples of rock heterogeneities. In fluid saturated rocks, and considering seismic wavelengths much bigger than the pore sizes, a physical phenomenon, known as squirt flow, results in seismic attenuation and velocity dispersion. In this process, the deformation of flat pores (such as cracks and grain contacts), produced by a passing seismic wave, creates a fluid pressure gradient between the compressed pore and another stiffer pore provided that they are hydraulically connected. Then, with the fluid pressure diffusion, friction within the viscous fluid dissipates energy. The frequency-dependent seismic response of squirt flow has been studied analytically (e.g., Dvorkin et al., 1995), numerically (e.g., Quintal et al., 2019), and experimentally (e.g., Chapman et al., 2019).

We present a workflow for numerically obtaining seismic wave moduli dispersion and attenuation caused by squirt flow based on μXRCT rock images. A sample of Carrara marble is thermally treated, which initiates cracks at the grain boundaries as a consequence of the anisotropic thermal expansion of the grains, and subsequently a three-dimensional (3d) μXRCT image of the sample is obtained (Ruf and Steeb, 2020). Filtering, segmentation and meshing procedures are applied on a sub-volume of the rock image to create the numerical models. We solve the coupled equations in the solid and the fluid domains, in the frequency domain, using the finite element method (Quintal et al., 2019). An upscaling procedure, based on the fact that the heterogeneous medium behaves as a homogeneous viscoelastic medium is applied to obtain the P- and S-wave moduli dispersion and attenuation in all directions.

We first numerically computed the effective P- and S-wave velocities in all directions for two models of different sizes, the small model being a sub-volume of the big one, in dry conditions (Figure 1A). Although the P-wave velocity in the z-direction shows a big discrepancy, all the other velocities present small reduction when increasing 8 times the model size (Figure 1B). Additionally, the model velocities present a moderately isotropic behaviour. Nevertheless, the numerically estimated velocities are considerably higher than the ones estimated by laboratory measurements. The small model was also analysed under fully-saturated conditions. The P- and S-wave moduli exhibit significant attenuation above 10^6 Hz caused by squirt flow (Figure 1C). Moreover, the attenuation were higher for the shear tests. The variability of the P- and S-wave moduli, as well as their corresponding attenuation, with respect to the incidence direction were lower in the case of the P-wave.

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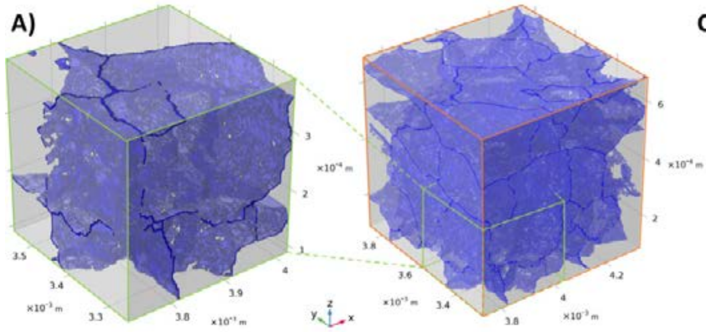
A)



B)

Velocity $[\frac{m}{s}]$	Small model	Big model	Laboratory
V_P^x	4175	3830	
V_P^y	4310	4170	1825
V_P^z	3700	2675	
V_S^{xy}	2420	2430	
V_S^{xz}	2205	1970	1283
V_S^{yz}	2230	2005	

C)

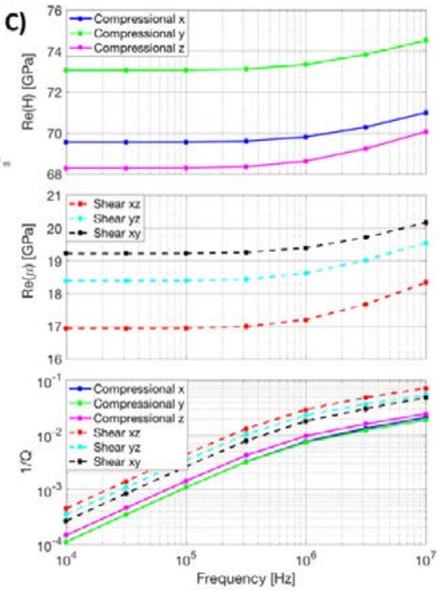


Figure 1. (A) Cubes derived from the µXRCT images with dimensions of 300 µm side (left) and 600 µm side (right) showing the two segmented phases: pore space (blue) and solid grain (grey). (B) Velocities of the models in dry conditions. (C) Real part of the P- and S-wave moduli and attenuation 1/Q in x-,y-, and z-direction for the small model.

P 8.10
From elastic to anelastic properties in rocks: Role of strain amplitudes

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For any geo-engineering application, the precise knowledge of reservoir rocks mechanical properties is of importance. For the purpose of characterising these properties, applied geophysics is a powerful tool that allows inferring the mechanical properties of subsurface rocks from the recorded seismic waves. To apply this method, however, one needs to precisely characterise rocks elastic and anelastic properties in the laboratory. When aiming at reconciling laboratory and field measurements, two main constrains need to be understood: (i) the frequency of measurement, known to induce strong dispersions and attenuations in fluid saturated rocks (e.g. Müller et al., 2010); and (ii) the strain amplitude, which could induce a departure from linear elasticity in some cases.

This work aims to investigate the role of the strain amplitudes on the measured elastic and anelastic properties of a variety of rocks, varying in mineral contants, porosities and porosity types.

This study uses the stress-strain method, by applying axial stress oscillations and recording axial and radial strain oscillations of the rock sample. Young's modulus and Poisson's ratio, as well as their quality factors (i.e. proxy for attenuations), are inferred from the recorded oscillations (e.g. Pimienta et al., 2015). A uniaxial cell allowing to apply large ranges in oscillating amplitudes, equipped with high-precision stress and strain sensors, is used. No confining pressure can be applied on the rock sample so that, assuming the properties ruled by Terzaghi effective pressure, the properties would be that expected in case of near-lithostatic fluid pressures. A standard automatic procedure is set-up, of stress oscillations at different values of mean axial stress (Fig. 1a).

The cell is tested and calibrated with three different samples: a plexiglass sample (Fig. 1b), a plastic sample and a non-porous and non-cracked diorite sample (Pimienta et al., 2019). While the plexiglas sample allows testing the precision of the cell to measure dispersion and attenuation, the diorite sample should not exhibit any frequency dependence. The two allow testing that no dependence to both mean stress and oscillating one are intrinsic to the cell, for a temperature range of up to 80°C. For the plexiglass sample, the values and frequency dependence are convincingly similar to that found in the litterature (Pimienta et al., 2015 & 2016). For temperatures below 60°C, little dependence to the strain amplitude is observed. At higher temperatures, viscoelasticity might be enhanced.

The rocks are measured over the amplitude range under either dry or water-saturated conditions, at different temperatures. In the case of a gabbro rock sample (Fig. 1c), as well as what will be shown for other rocks, large dependences to the amplitude are observed for Young's modulus at low mean stresses only. Poisson's ratio does not seem affected.

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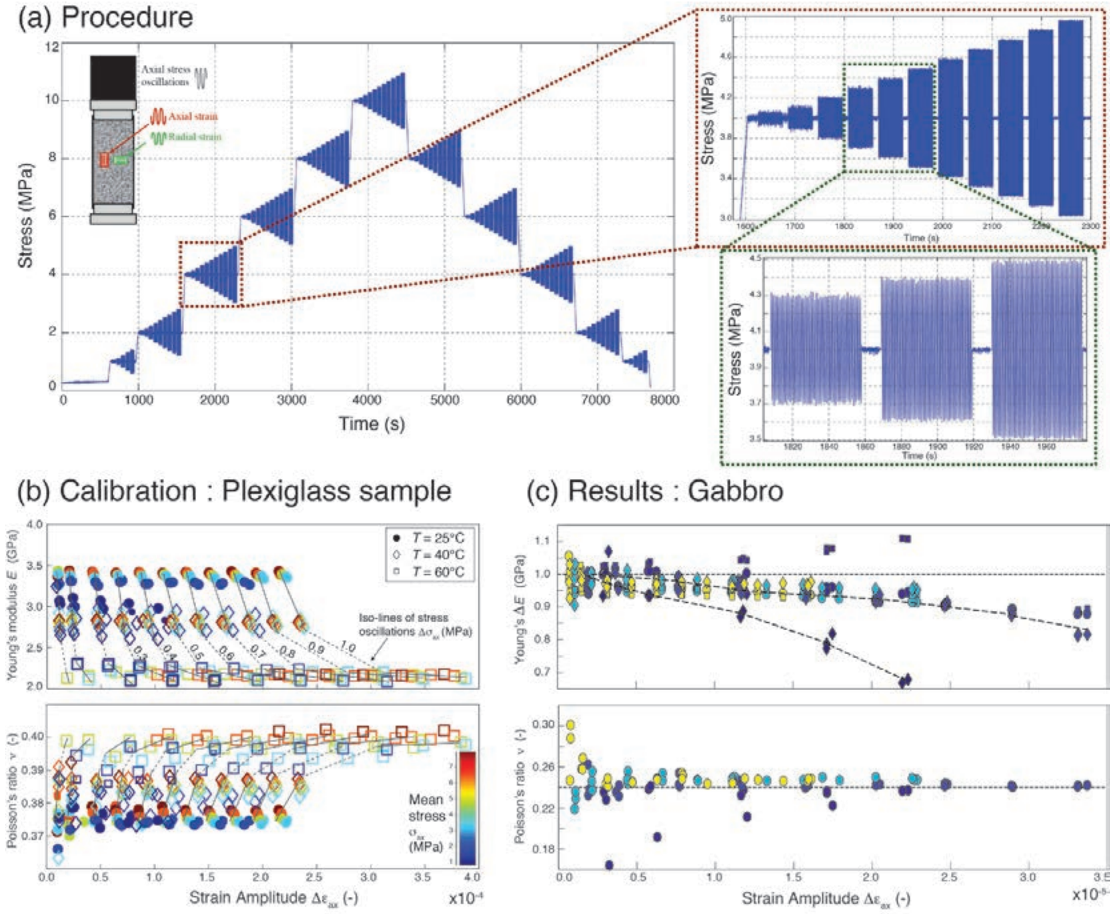

Figure 1. (a) Principle of axial stress oscillations of varying amplitudes as a function of time, for different values of mean axial stress; (b) Exemple of calibrations using a Plexiglasss sample (e.g. Pimienta et al., 2015), in terms of Young's modulus and Poisson's ratio as a function of oscillations amplitudes of up to 1 MPa. Temperatures and mean axial stress are varied, and the frequency for the measurement is here of 1 Hz; and (c) Variation in Young's modulus and Poisson's ratio as a function of the strain amplitude for a sample of Gabbro (e.g. Liu et al., 2020). The colour code represents also the different mean axial streses, the same in (b) and (c).

P 8.11
From hydraulic and mechanical properties to hydromechanical coupling in rocks: Role of hidden microstructure?

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When injecting fluids at depth in geological reservoir rocks, whichever the geo-engineering application, one needs to account for the poromechanical deformation and stresses induced by the anthropic action. Similarly, when investigating in the laboratory poromechanical coupling in rocks, assumptions have to be made about how and at which time scale the rock will be affected by pressures variations. Usually poromechanical coupling is inferred from the known hydraulic and mechanical properties: Hydraulic properties determine the time scale at which deformation occurs, which magnitude is in turn determined by the mechanical properties.

As a first approximation, because poroelasticity deals with effective properties, at the scale of the Representative Elementary Volume, it seems logical to directly combine the apparent hydraulic and mechanical properties.

Studies from the past decades seemed to confirm the applicability of such an approach. However, many applied the investigation to rocks bearing one type of microstructure only, such as the crack density for granites. For such cases, the two properties depend in a similar way on the microstructure. This work aims to question such an approach and the resulting hydromechanical coupling for the case of rocks bearing two families of microstructure: sperical – low compressibility – pores and tubes, and elongated spheroidal – compressible – microcracks.

Compiling data from the litterature of hydraulic and mechanical properties measured on sandstones of varying porosities (Pimienta et al., 2017), one observes that the same rocks measured under the same pressure conditions exhibit opposite pressure dependences of permeability (Fig. 1a) and bulk modulus (Fig. 1b). While both hydraulic and mechanical properties of low porosity rocks have similar pressure dependence, the ones of higher porosity rocks differ. Their mechanical properties have a similarly strong dependence to pressure as the low-porosity rocks, yet its hydraulic properties are independent of the pressure condition. Because the pressure dependence of properties has been linked to the crack family network (e.g. Walsh, 1965), this implies that in such rocks the two properties depend in a different way on the two pore families of the microstructure.

Applying the simplest existing, largely used, models of pore families acting in parallel on the hydraulic (e.g. David et al., 1993) or mechanical (e.g. Fortin et al., 2015) properties, we show the very same behaviour as that observed from experiments. While of the exact same family of microcracks, depending on the porosity content and the linked existence of tube networks, very different behaviours and pressure-dependent properties are inferred for either low or high porosity rocks.

This result confirms the qualitative applicability of the concept of parallel networks for the two properties, and further hilgihts using the exact same assumption that the two properties depend differently on the pore families. As this simple concept of parallel networks applies for the prediction of either hydraulic or mechanical properties, we try applying it to the prediction of hydromechanical coupling. It is shown that different behaviour is expected than that typically found. This is because the time scale for fluid pressure equilibration in the crack network is much larger than that in the network of pores/tubes, yet most mechanical effects originate from the presence of cracks.

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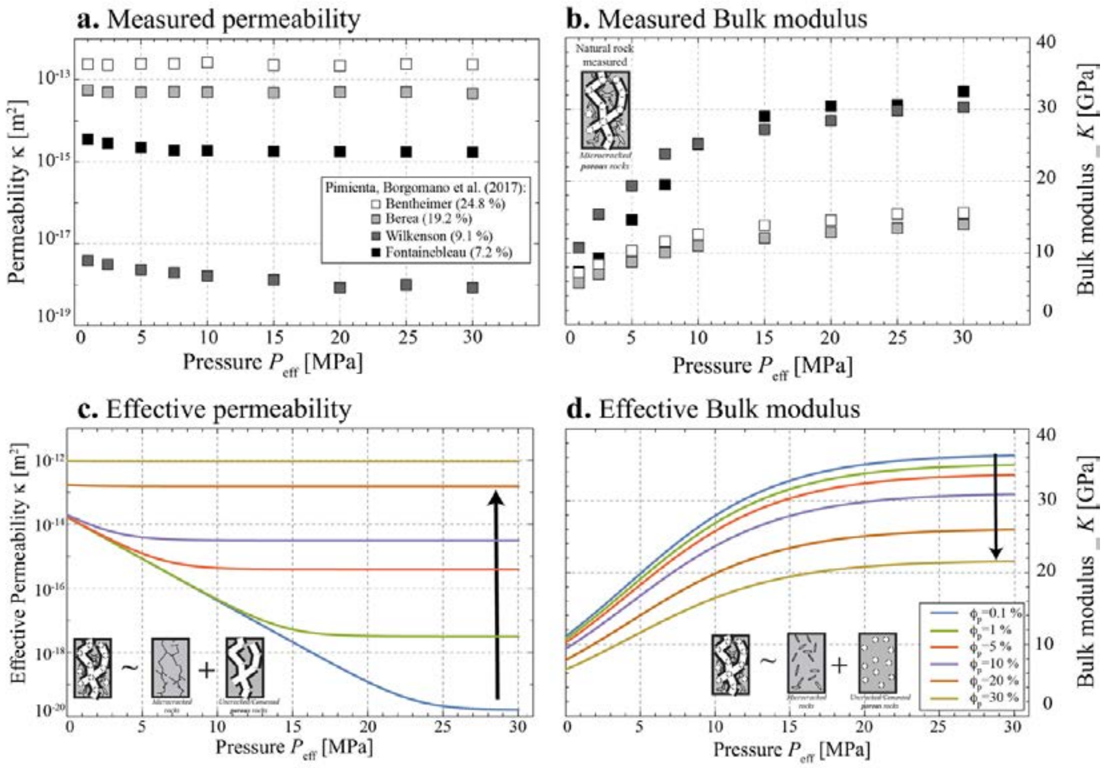

Figure 1. Compiled dataset from Pimienta et al. (2017) of pressure-dependent (a) permeability and (b) bulk modulus of four sandstone samples ranging in porosity. Prediction from the model of networks acting in parallel, for rocks bearing two families of porosity (i.e. pores/ tubes and cracks/sheets), of (c) permeability and (d) bulk modulus.

P 8.12
Squirt flow in rocks containing partially saturated penny-shaped cracks: Simple analytical solution

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Determining fluid content in partially saturated rocks using seismic data is a complex task of great importance in a number of pertinent scenarios, such as geothermal energy exploitation and CO_2 geosequestration, among many others. The distribution of pore fluids within a geological formation is conditioned by rock frame heterogeneities. In particular, cracks can significantly affect the fluid distribution and the corresponding seismic signatures. If we wish to correctly estimate pore fluid distributions from seismic data, models that address the complex interrelationships existing between frame heterogeneities, pore fluid content, and seismic attributes are needed.

The problem of obtaining the seismic response of a rock containing a concentration of cracks whose scales are much smaller than the seismic wavelengths is a classic one in the rock physics literature. Notably, analytical solutions are broadly employed for this purpose, as they constitute a simple and computationally inexpensive way to interpret the seismic data using inversion techniques (e.g., Hudson, 1981). However, to date, analytical models that consider squirt flow effects in the presence of partially saturated cracks present some limitations: (i) they do not consider fluid pressure diffusion processes occurring within the partially saturated cracks due to heterogeneous ditributions of immisicle fluid phases (e.g., Gurevich et al., 2010); (ii) their validity is restricted to low frequencies and/or low saturations (e.g., Hudson, 1988); (iii) they operate under the assumtion that the non-wetting fluid phase does not play a significant role in the dissipation process (e.g., Murphy et al., 1986). Furthermore, all squirt flow models disregard the effects of capillary forces, which is not an obviously valid assumption.

In this work, we present a new analytical model to account for fluid pressure diffusion effects in rocks containing aligned partially saturated cracks embedded in an impervious background (Figure 1a). For this, we consider a penny-shaped crack geometry under oscillatory compression. The center of the crack is saturated with a non-wetting phase (e.g., gas, oil), which is surrounded by a wetting phase fluid (e.g., water). The analysis contemplates the effects of capillary forces on the crack walls and on the flow conditions, and it considers the compresibilities of both immiscible pore fluid phases. We derive an expression for the complex-valued and frequency-dependent bulk modulus of an effective fluid, which permits to reproduce the stiffness variations of the saturated crack with frequency due to internal fluid pressure diffusion processes. We then combine Hudson's (1981) model and the anisotropic version of Gassmann's (1951) equations to derive the properties of the rock permeated by aligned cracks saturated with such an effective frequency-dependent fluid. In this way, we obtain the complete complex-valued frequency-dependent effective compliance tensor of the vertical transversely isotropic (VTI) medium. The latter allows to compute the angle-, saturation-, and frequency-dependent seismic response of the partially saturated cracked rock. The proposed analytical solution is validated by comparing the resulting seismic signatures with corresponding numerical simulations (Figure 1b), which are obtained by solving the fluid pressure diffusion problem using the quasi-static and linealized coupled version of Lamé-Navier and Navier-Stokes equations in a 3D cracked analog.

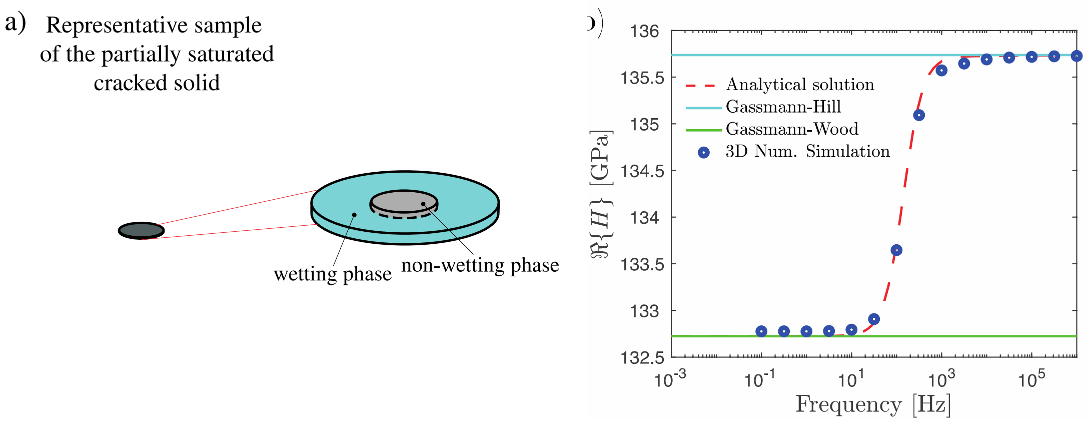

Figure 1. (a) Sketch of a representative rock sample of a medium containing aligned cracks and blowup of a corresponding partially saturated crack. (b) Real part of the plane-wave modulus R{H} for a vertically propagating wave as a function of frequency for a granite rock sample (L=12 mm) comprising a crack saturated with glycerin (99%) and air (1%). The crack has a 10 µm aperture and a 2 mm radius. We display the proposed analytical solution (dashed red line) and the 3D numerical simulation (blue circles). Gassmann-Hill (light blue line) and Gassmann-Wood (green line) represent the unrelaxed and relaxed regimes, respectively.

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09. Quaternary environments: landscapes, climate, ecosystems and human activity during the past 2.6 million years

Stefanie Wirth, Marc Luetscher, Loren Eggenschwiler, Gaudenz Deplazes, Jean Nicolas Haas, René Löpfe, Bigna Steiner and Catharina Dieleman

Swiss Society for Quaternary Research (CH-QUAT)

TALKS:

9.1 *Beccari V., Almogi-Labin A., Spezzaferri S., Basso D., Rueggeberg A., Makovsky Y.*: An overview on macro- and micro- fauna assemblages and seepage-related features in the Palmahim Disturbance (offshore Israel) as indirect proxies of seepage activity

9.2 *Dieleman C., Christl M., Vockenhuber C., Akçar N.*: The Timing of the Most Extensive Glaciation in the Northern Swiss Alpine Foreland

9.3 *Kamleitner S., Ivy-Ochs S., Monegato G., Gianotti F., Martin S., Christl M.*: New insights into timing and extent of the LGM Ticino-Toce glacier, Swiss-Italian Alps

9.4 *Luyao Tu, Grosjean M.*: Late-glacial and Holocene sedimentary phosphorus dynamics in response to climatic variability, productivity, anoxia and early anthropogenic impact recorded in a varved lake in central Switzerland

9.5 *Rowan S., Berg J., Vogel H., De Jonge C.*: Using brGDGT lipids to determine Holocene climate variations in Swiss alpine Lake Cadagno

9.6 *Schwenk M.A., Bandou D., Schläfli P., Douillet G.A., Gribenski N., Schlunegger F.*: The Bümpliz trough: Insights into the sedimentary fill of the Aare Valley overdeepening

9.7 *Tielidze L., Eaves S., Norton K., Mackintosh A.*: Evolution of the Ahuriri Glacier during the Last Glacial Maximum, Southern Alps, New Zealand

9.8 *Zander P.D., Żarczyński M., Vogel H., Tylmann W., Wacnik A., Sanchini A., Grosjean M.*: High-resolution Holocene multi-proxy reconstruction of aquatic productivity and lake mixing regime, Lake Żabińskie, Poland

POSTERS:

P 9.1 *Dziomber L., Schwörer C.*: New insights into the paleoecology of mountain forests during the Holocene: A case study in Eastern Switzerland (Lai da Vons, GR)

P 9.2 *Gajendra N., Berg J.S., Schubert C.J., Zhu R., Lever M.A.*: The degradation controls of carbohydrates in Quaternary sediments of Lake Cadagno

P 9.3 *Gegg L., Keller L., Buechi M.W., Spillmann T., Deplazes G., Madritsch H., Anselmetti F.S.*: The subsurface geometry of the overdeepened Lower Aare Valley revealed by seismic surface waves

P 9.4 *Martin C., Richter N., Schubert C., Dubois N.*: Searching for the alkenone paleothermometer in Swiss lakes

P 9.5 *Temoltzin-Loranca Y., Gobet E., Szidat S., Wienhues G., Grosjean M., Tinner W.*: Chronology of Vegetation and Fire Changes in the Lake Victoria area, Eastern Africa

P 9.6 *Wienhues G., Temoltzin-Loranca Y., Vogel H., Grosjean M.*: Multiproxy paleolimnological reconstruction of Lake Victoria's environmental history, East Africa

P 9.7 *Faurschou Knudsen M., Nørgaard J., Grischott R., Kober F., Lundbek Egholm D., Mejer Hansen T., Jansen J.D.*: New cosmogenic nuclide burial-dating model indicates onset of major glaciations in the Alps during Middle Pleistocene Transition

P 9.8 *Heusser C., Welte C., Hattendorf B., Montluçon D., Günther D., Eglinton T.I.*: Purification of Organic Compounds Using Microsublimation for ^{14}C Analysis

P 9.9 *Russo E., Buzan J., Raible C.*: High Resolution Modeling of the Quaternary Climate of the Alps

P 9.10 *Steinemann O., Ivy-Ochs S., Hippe K., Christl M., Synal H.-A.*: In the forbidden field: how glacial erosion influences the ^{10}Be/in-situ ^{14}C ratio

P 9.11 *Tomonaga Y., Horstmann E., Deplazes G., Kipfer R.*: ^{4}He/U-Th dating of pore waters from Quaternary sediments of the Swiss Midland

P 9.12 *Zappa D., Bomou B., Adatte T., Spangenberg J., Bichet V.*: Paleoenvironmental and paleoclimatic reconstruction of the Lake Val (France) during Late Glacial and early Holocene

9.1
An overview on macro- and micro- fauna assemblages and seepage-related features in the Palmahim Disturbance (offshore Israel) as indirect proxies of seepage activity

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The presence of seepage-related features and chemosymbiotic faunal assemblages have been documented in the framework of the EU Eurofleets SEMSEEP 2016 cruise onboard RV Aegaeo in 2016 in the Palmahim Disturbance (offshore Israel) (Makovsky et al., 2017; Basso et al., 2020; Beccari et al., 2020).

The analysis of box-core and core samples showed the presence of chemosymbiotic macrofauna including bivalves (e.g. *Isorropodon perplexum, Waisiuconcha corsellii),* gastropods (e.g. *Taranis moerchii*) and crustacean decapod claws. These organisms are often associated to microfauna assemblages consisting of low-oxygen tolerant benthic foraminifera such as *Globobulimina pseudospinescens* and *Chilostomella oolina* (Basso et al., 2020).

In the present work, three cores from representative environments of the Palmahim Disturbance have been selected (AG16-20-BC1b in the “Coral” area, AG16-23-BC2 in the “Pockmark” area, AG16-25-BC1a sampled as a “Reference” site).

These cores have been preliminary analyzed for benthic molluscs (bivalves and gastropods) holoplanktonic molluscs (pteropods and heteropods) and benthic and planktonic foraminifera. In the same samples analized for the fauna, small fragments of authigenic carbonate, small black concretions and remains of bioturbation were observed. Their co-occurrence may represent the influence of past gas seepage through the sediments.

An on-going investigation focuses on the *Limacina* Dissolution Index (LDX) based on pteropod shells. As suggested by Almogi-Labin et al. (1986) and Gerhardt et al. (2000), the degree of preservation of the pteropod *Heliconoides (Limacina) inflatus* can be used to assess the degree of aragonite dissolution in the sediment and the potential presence of CO_2-excess due to bacterial activity. The latter may be related to chemosynthetic processes, thus possibly giving an indirect evidence of past seepage through the sediments.

Interestingly, the established categories of the LDX cannot be completely used because not all the individuals of *H.inflatus* observed in the samples have the typical transparent or withish color described by Gerhardt et al. (2000), but they display yellowish shells. Understanding the origin of this change in color of pteropods shells, previously observed also in others Mediterranean regions, may provide additional insights about potential seepage activity in the region.

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9.2
The Timing of the Most Extensive Glaciation in the Northern Swiss Alpine Foreland

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During the Middle Pleistocene, Alpine glaciers are considered to reach their most extensive position in the northern Swiss Foreland (Schlüchter, 2004; Keller and Krayss, 2010). The extent of the Most Extensive Glaciation (MEG) is reconstructed based on the distribution of erratic boulders and few preserved glacial deposits, because the Last Glacial Maximum eroded evidences of previous glaciations (Schlüchter, 2004; Graf, 2009). For example, relict tills and associated glaciofluvial deposits that are attributed to the MEG are found in the Basel region (Penck and Brückner, 1909; Schlüchter, 1988, 2004; Dick et al. 1996). These sediments have been for a long time correlated with the Riss glaciation and morphostratigraphically classified into the Higher Terrace deposits (Penck and Brückner, 1909; Dick et al., 1996; Preusser et al., 2011).

Although the timing of the MEG glaciation were gaged between the Brunhes/Matuyama transition (780 ka; Spell and McDougall, 1992) and the Marine Isotope Stage 6 (191 ka; Lisiecki and Raymo, 2005) by previous studies, it still remains to be revealed. Schlüchter (2004) proposed that the MEG is younger than the Deckenschotter glaciations and occurred just after the Brunhes/Matuyama transition. Recently, the loess layer overlying the glacial and glaciofluvial deposits in Möhlin (Canton of Aargau) were dated with the optically simulated luminescence technique (Gaar et al., 2017). Based on these results, the MEG is attributed to occur prior to the Marine Isotope Stage 6. With the aim of shedding light on the timing of the MEG, we focus, in this study, on the glacial deposits in Möhlin. We apply the isochron-burial dating with cosmogenic ^{10}Be and ^{26}Al to the till layer in the Bünten gravel pit near Möhlin. For the isochron-burial dating, we collected one sample composed of quartz pebbles and more than nine clast samples of different lithology, shape and size. After extracting and purifying the quartz from these samples, we measured total Al concentrations. Samples having low total Al-concentrations were further processed for the accelerator mass spectrometry analysis of cosmogenic ^{10}Be and ^{26}Al. Analysis of six samples are succesfully completed. The first absolute timing of the MEG will be presented.

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9.3
New insights into timing and extent of the LGM Ticino-Toce glacier, Swiss-Italian Alps

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Multiple advances of the Ticino-Toce glacier during the Pleistocene have led to the formation of the Verbano moraine amphitheatre spanning from the southern tip of today's Lago Maggiore over to the city of Varese. For more than a century, its parallel moraine ridges have fostered discussion on the extent of the last episode of foreland glaciation. As a consequence, various Last Glacial Maximum ice margins have been suggested based on geomorphological observations. In light of missing chronological constraints, the size of 'true' LGM as well as LGM glacier timing remain unresolved.
To overcome this knowledge, gap our study addresses spatial and temporal dimensions of the LGM Ticino-Toce glacier system.
We present the first erratic boulder exposure ages from the Verbano lobe. New chronological data combined with geomorphological mapping on the basis of digital elevation models points towards an LGM ice extent greater than lately thought. First results from glacier modelling and petrographic analysis of erratic boulders provide additional insight into glacier geometry and flow pattern.

9.4
Late-glacial and Holocene sedimentary phosphorus dynamics in response to climatic variability, productivity, anoxia and early anthropogenic impact recorded in a varved lake in central Switzerland

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Cultural eutrophication caused by excessive phosphorus (P) inputs in freshwater lakes is a global problem (Smith and Schindler, 2009). In seasonally stratified temperate lakes, eutrophication-induced hypolimnetic anoxia tends to stimulate redox-mediated P release from sediments and largely diminish the sediment-binding capacity for P (Tu et al., 2019). However, little is known about the influence of lake eutrophication and anoxia on net burial rates of different sedimentary P fractions in the past under pre-anthropogenic or weaker human impact, different climate conditions and vegetation cover in the catchment. In this study, we present a long-term perspective on late-glacial and Holocene P-fraction net burial rates in sediments from Soppensee (central Switzerland; Lotter 1999). Soppensee is a very interesting case because a high-quality diatom-inferred reconstruction of TP (Lotter, 2001) is available which, in combination with net burial rates of sedimentary P allows estimates of P recycling from sediments (internal P loads) in the past under different trophic, mixing and oxygenation states of the lake. A high-resolution hyperspectral imaging record allows the reconstruction of lake paleo-productivity (green pigments proxy) and seasonally anoxia or meromictic events (bacteriopheophytin proxy) in the last 15,000 years.

The first results show that Soppensee probably remained in the meso- to eutrophic status over the last 14,000 years, with rising primary productivity since the early Holocene. Persistent meromixis was developed at the onset of the Bölling/Alleröd (B/A) warm period and from the early Holocene until ca. 2 ka BP. During the Younger Dryas (YD) cold period, meromixis vanished and the lake water was well-mixed. In contrast to climate-induced changes of the lake mixing regime, however, the cease of Holocene meromixis events after 2 ka BP is related to massive anthropogenic deforestation in the catchment, which increased wind exposure of the water column. We observed relatively high sediment burial rates of total P (TP) and labile P fraction (primarily Fe-P and organic P) during the last ca. 6,000 years. Enhanced TP and labile P-fraction burials in sediments also occurred with increased lake productivity caused by climate warming during the early Holocene and B/A, despite of persisting anoxia in bottom waters. Interestingly, considerably low TP and Fe-P burial rates were found in sediments with calcareous biogenic varves during the early to mid-Holocene. This phenomenon might reflect an increase in internal P loading from Fe-P fraction, which is further supported by the predomination of Ca-P fraction.

In conclusion, we present an unusual case of synergistic interaction between eutrophication, anoxia and high sedimentary P burials in a small deep Swiss lake.

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9.5
Using brGDGT lipids to determine Holocene climate variations in Swiss alpine Lake Cadagno.

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Lake Cadagno (Ct. Ticino) was cored in 2018 in the framework of an interdisciplinary research project, collecting sediments deposited during the last 13.5 ka. Here, we present continuous XRF, bulk organic matter proxies (C/N, $\delta^{13}C$) and selected biomarker lipids (brGDGTs) analysed at discrete depths (n=90) to reconstruct changes in hydrology, sediment source and climate through time. To allow for a reliable climate reconstruction, the sedimentary brGDGT biomarker lipid distributions are compared with the signal produced throughout the water column (n=5) and in surrounding soils (n=16). After constraining the source of the brGDGT compounds as lake-derived, changes in their distribution through time (summarized as the MBT'_{5ME} and the CBT' ratios) are used to reconstruct changes in lake temperature and pH. The Russell et al. (2018) calibration (RSME = 2.4 °C) is used to reconstruct a low-resolution (n=20) increase in lake temperature from 1 to 6 °C between 13 ka and 6 ka. Between 6 ka and 0.5 ka a higher resolution reconstruction is possible (n=70). Here, reconstructed lake temperature fluctuates between 4 and 7 °C, with short-lived warmer (8-9 °C) episodes at 3400, 1900 and 1225 BP.

Although the provenance of brGDGTs was constrained to be lake-derived, short-term changes in their distribution indicate that environmental variables other than temperature influence their downcore variation. By comparing core lipid and intact polar lipid signals, degradation and production of brGDGT lipids (specifically, brGDGT IIIa') within the sediments was shown to occur both in the upper 40 cm and also at deeper depths.

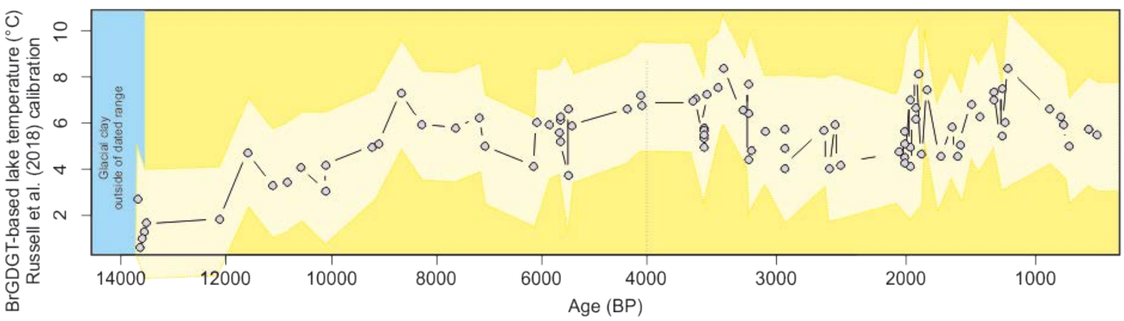

Figure 1. BrGDGT-based lake temperature reconstruction. The range of the RSME of the calibration is plotted as the light yellow background.

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9.6 The Bümpliz trough: Insights into the sedimentary fill of the Aare Valley overdeepening

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We present the results of a scientific drilling that was conducted in the Bümpliz trough (i.e. the Rehhag drilling), a lateral branch of the main Aare Valley overdeepening. The drilling disclosed thick and most probably solely glacial to periglacial deposits. These sediments can be divided in two sedimentary sequences A (lower) and B (upper), both starting with a till that is overlain by dominantly sandy subaqueous, most probably lacustrine deposits. The Rehhag sedimentary succession does not comprise thick, lacustrine and pollen bearing silt layers which is a contrast to the nearby Meikirch and Thalgut sites, where scientific drillings in the Aare Valley overdeepening were conducted as early as in the 1980s. This was unexpected. Furthermore, feldspar luminescence dating of the topmost unit of sequence B at the Rehhag yielded signals close to saturation, thus resulting in an age range between 250–300 ka, which is at the method's upper limit. Additionally, 16 total organic carbon (TOC) readings from silt layers in the Rehhag sediments revealed a low mean TOC of 0.27±0.08 wt.%. We interpret the lack of pollen and the low TOC values as indicators of a periglacial environment with limited supply of organic material into the lake. We are positive that the Rehhag sequence B is related to the glaciation, which occurred in the region during the marine isotope stage 8 (300–243 ka). In the same sense, generally low, yet slightly higher TOC readings (max. 0.41 wt.%) in the lower sequence A are considered to point to a periglacial environment where the local vegetation cover was low. Hence, we relate the deposition of the stratigraphically lower and older sequence A to a glaciation prior to MIS 8 (e.g. MIS 10, 374–337 ka). Accordingly, we tentatively assign a minimum age of ~340 ka for the erosional carving of the Bümpliz trough and possibly the Aare Valley overdeepening.

9.7
Evolution of the Ahuriri Glacier during the Last Glacial Maximum, Southern Alps, New Zealand

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Mountain glaciers are sensitive to variations in temperature and precipitation – thus records of their past changes yield important data concerning the timing and magnitude of past climate change. After the peak of the last glaciation (about 20,000 years ago), mountain glaciers began to retreat significantly with slight advancement phases from time to time. On the scale of several millennia, we have only very indirect observations of glacier retreat and advance based on the positions of glacial moraines. Well preserved moraines provide a good opportunity to develop an improved understanding of ice ages and glacial-interglacial transitions. Dating of the moraines using cosmogenic exposure techniques such as ^{10}Be is providing exciting and important information on the duration, timing, and scale of the Late Quaternary glaciation (Last Glacial Maximum in particular), as well as providing additional information about the past climate.

Some valleys in South Island, New Zealand already have a number of well-dated glacier records. However, understanding of the precise timing of old glacial events in many valleys still remains poor.

We used field observation and geomorphological mapping to investigate the extent and drivers of glaciation in the Ahuriri River valley, Southern Alps, New Zealand. Cosmogenic ^{10}Be surface exposure dating technique was also used to constrain the timing and extent of late Quaternary glaciation in this valley. Numerical glacier modelling will be used later in order to investigate palaeo climatic implications for the study area.

9.8
High-resolution Holocene multi-proxy reconstruction of aquatic productivity and lake mixing regime, Lake Żabińskie, Poland

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Human activities have led to increased eutrophication and anoxia in lakes worldwide. Long-term records of primary production and anoxia are valuable to understand the natural variability of lake ecosystems, and to improve our understanding of drivers of productivity and anoxia. In this study, we use the varved sediment record of Lake Żabińskie, Poland to answer the following research questions: 1) How have primary production and water oxygenation varied during the past 10,800 years 2) What role did natural and anthropogenic forces have in driving changes in primary production or lake mixing regime? We applied recently developed hyperspectral imaging techniques to quantify sedimentary chloropigments and bacteriopheopigments (Bphe) at sub-annual resolution. These data, combined with micro X-ray fluorescence (μ-XRF) measures of elements and high-performance liquid chromatography (HPLC) measures of pigments, were used to reconstruct paleolimnological conditions. We use Bphe as an indicator of anoxia in the hypolimnion, and find that anoxic conditions were persistent for the majority of the Holocene. Prior to 2.8 ka cal BP forest cover (reconstructed from pollen counts) was little affected by humans, and this closed forest cover limited wind driven mixing, leading to anoxia. After 2.8 ka BP, human impacts to forest cover lead to intermittent periods of water column oxygenation. However, the period from 610-1470 CE stands out as a period of prolonged anoxic conditions due to reforestation processes. After 1610 CE, large-scale deforestation caused major increases in erosion rates, algal production, and water column oxygenation. Pigment assemblages indicate that the algal community in the lake during the past 150 years was distinctly different than natural conditions during the Holocene. We observe that decadal scale variations in plant cover (naturally caused or anthropogenic) affected oxygenation of the lake, as indicated by Bphe. Our results demonstrate a clear link between plant cover and lake mixing regime. This study demonstrates the potential of hyperspectral measures of pigments to produce extremely high resolution records of productivity and redox conditions from varved lake sediments.

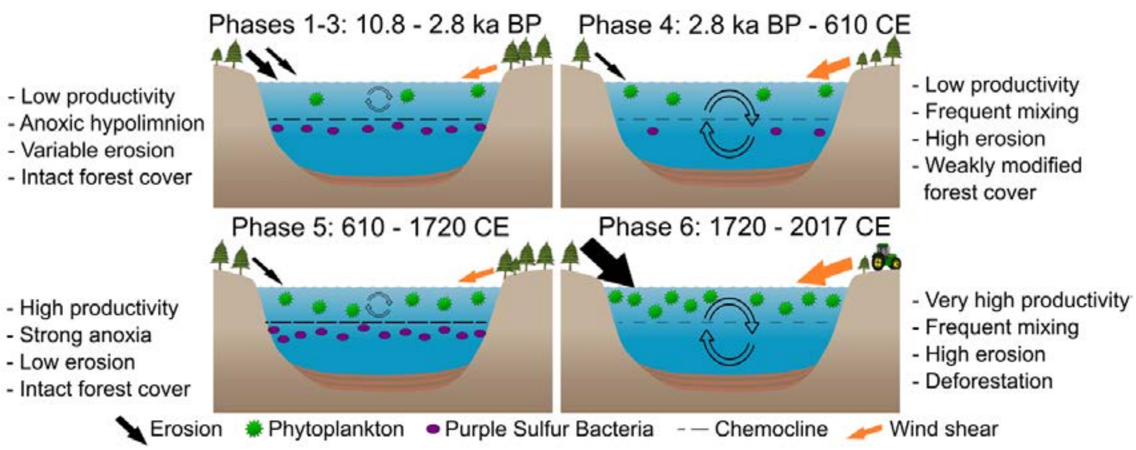

Figure 1. Lake phases with a summary of lake mixing regime, productivity, and land cover.

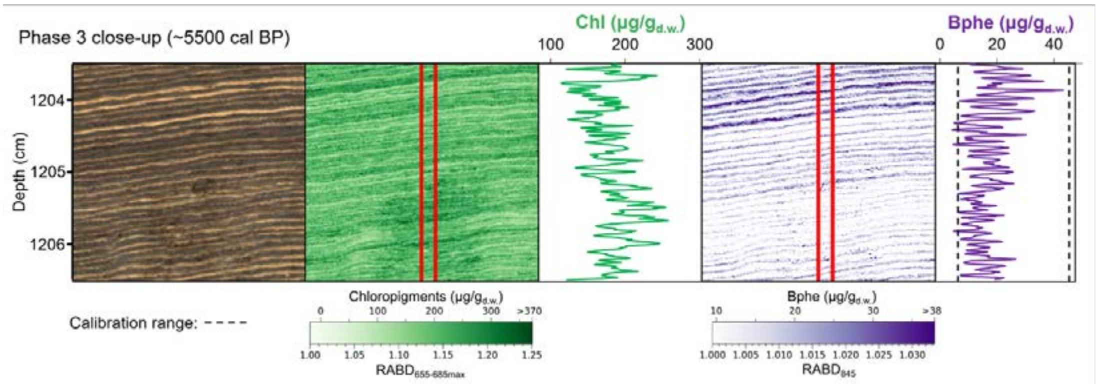

Figure 2. Close-up of varved sediments from ~5500 cal BP showing seasonal pattern of calibrated hyperspectral imaging indices of chloropigments (Chl) and bacteriopheopigments (Bphe).

P 9.1
New insights into the paleoecology of mountain forests during the Holocene: A case study in Eastern Switzerland (Lai da Vons, GR).

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The human-driven global change currently occurring during the Anthropocene impacts mountain vegetation in many aspects, such as climate warming, habitat destruction, pollution, and excessive exploitation of resources. Large temperature changes force organisms to produce adaptive responses, such as migration or adaptation, or face decline. With a rapid increase of global temperatures by 1.5°C since the pre-industrial period and a projected warming of 1.5-4°C by the end of this century, the consequence of the current and future climate change is a serious threat to biodiversity and ecosystems stability.

There is in general an insufficient use of greater time scales in conservation biology despite growing databases concerning biotic reactions to climate changes during the Anthropocene. The last climate change of a similar magnitude and rate as projected for this century is the transition between the last Ice Age and the Holocene interglacial (ca. 11’700 years ago). Studying this time period will provide new insights into vegetation changes resulting from climatic drivers based on paleoecological data, since it represents a potential analogue to the present-day and future climate change. Understanding the response of organisms to rapid temperature increase is a fundamental prerequisite to produce accurate and reliable predictions.

We are currently investigating a new palaeoecological archive from a high-altitude mountain lake, Lai da Vons (1991m a.s.l), situated in Eastern Switzerland. Macrofossils, pollen and charcoal are commonly used in order to reconstruct local to regional vegetation and fire dynamics with high chronological precision and resolution. We are presenting preliminary results for macrofossils, charcoal deposition and lake sediment composition. In a next step, we will combine traditional palaeoecological approaches with novel molecular methods, in order to track adaptive and neutral genetic diversity through the Holocene by analyzing ancient DNA (aDNA). The overarching goal of this large scale, multiproxy study is to better understand past vegetation dynamics and the impact of future climate change on plant communities.

P 9.2
The degradation controls of carbohydrates in Quaternary sediments of Lake Cadagno

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Carbohydrates represent one of the largest fractions of sedimentary organic matter on Earth. However, their compositions, pool sizes and degradation controls are poorly constrained in lake sediments. To shed light into the factors that determine the microbial degradation of carbohydrates in lake sediments through time, we investigated the distribution and composition of carbohydrates across the 12,000-year sediment sequence from the stratified, high-altitude alpine lake, Lake Cadagno (Ticino, Switzerland). This sedimentary sequence includes distinct intervals that are dominated by lacustrine and terrestrial organic matter, and thus differ fundamentally in carbohydrate sources. Free and polymer-derived neutral sugars and amino sugars were analyzed by gas chromatography with a flame ionization detector (GC-FID) (Zhu et al., 2020) using a new extraction method and GC-FID protocol that increases carbohydrate extraction yields and further improves analytical resolution. Based on this optimized assay, we generated a high-resolution carbohydrate depth profile of the produces new insights into the role of time and carbohydrate sources in determining the long-term preservation of carbohydrates in lake sediments.

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P 9.3
The subsurface geometry of the overdeepened Lower Aare Valley revealed by seismic surface waves

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The confluence area of the rivers Aare, Reuss, and Limmat (“Wasserschloss”) is a key region of Alpine Quaternary geology. Below the confluence, the Lower Aare Valley hosts a narrow, S-N trending overdeepened bedrock trough (Gebenstorf-Stilli Trough) with a depth of >100 m below surface. On its ~10 km-long course, it cuts through the Jura fold-and-thrust belt, a wedge of the Molasse basin, as well as the southeastern margin of the Tabular Jura. These units consist of contrasting lithologies and are characterized by different degrees of tectonic overprint, and thus by presumably very different erodibilities. The geometry of the Gebenstorf-Stilli Trough is therefore an essential study case for the understanding of lithological and structural controls and processes of subglacial overdeepening.

We investigate the Gebenstorf-Stilli Trough with three scientific boreholes located along the trough axis as well as a with a set of eight seismic cross-sections acquired by analysing surface waves. The chosen methodology combines active and passive as well as point and array measurements, and is well capable of imaging the base of the overdeepening. We combine our data with surface and borehole information as well as models of the subsurface geology in order to better constrain the geometry and morphology of the Gebenstorf-Stilli Trough. We thereby aim to discern how different bedrock lithologies and structures influence subglacial overdeepening erosion.

P 9.4
Searching for the alkenone paleothermometer in Swiss lakes

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Understanding and predicting short-term and long-term changes in temperature is crucial for informing climate adaptation and management strategies in the coming decades to centuries. Quantitative temperature records from the past are needed to improve our understanding of climate mechanisms and test model predictions of future climate changes. Unfortunately, the few existing tools to reconstruct past temperatures on the continents have limits: they are often biased towards the warm season (e.g., tree rings- or insects-based reconstructions), are subject to confounding environmental factors (e.g., glaciers, speleothems) or are limited to the historical period (e.g., written testimonials). In this project we will survey Swiss Lakes for a promising sedimentary paleothermometer, the alkenone biomarker. Alkenones are temperature-sensitive lipids produced by different groups of haptophyte algae, which have been used for decades to reconstruct quantitative changes in sea-surface temperatures. Increased reporting of alkenones in both saline and freshwater lakes worldwide suggests that there is great potential for alkenone-based paleotemperature reconstructions in lacustrine settings. In particular, recent work has identified a group of lacustrine alkenone producers that bloom during the spring season and produce alkenones that are well correlated with changes in winter-spring temperatures. Winter-spring temperatures are crucial for understanding lacustrine ecosystems as they control how long lakes remain frozen and how rapidly they warm up during the spring season. Our goal is to find one (or several) lake(s) where this group of alkenone-producing haptophyte algae is present and develop the first winter-spring lake temperature reconstruction in Switzerland that extends beyond existing historical records.

P 9.5
Chronology of Vegetation and Fire Changes in the Lake Victoria area, Eastern Africa

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Lake Victoria is the largest tropical lake on the planet by surface. Located in East Africa at an altitude of 1135 m asl (meters above the sea level), it lies across the limits between two major climatic zones with a strong moisture gradient and associated biomes, the rain forest and the savannah. This lake has demonstrated to be highly sensitive to changes in climate, for instance, it has been hypothesized that it dried up completely twice over the last 20,000 years

In this work, we will focus on the past ca. 14,000 years. A core of 720 cm was drilled in October 2018 for which a 14C chronology is established, and land cover and regional fire intensity during this time span is assessed.

Small samples of macroscopic charcoal were dated with 14C AMS (Accelerator Mass Spectrometry), by making use of the gas ion source on the MICADAS system of LARA at the University of Bern.

Vegetation and land use dynamics is reconstructed with pollen, and regional fire intensity is assessed performing macroscopic charcoal analyses as a first approach. On the basis of recent continental-scale calibration efforts and given the size of the lake, it is assumed that these fires must have regional sources (ca. 100 km radius).

This work, is part of a SINERGIA project funded by the Swiss National Foundation which seeks to unravel the long-term causes and consequences of Lake Victoria’s ecosystem dynamics with a special focus on the evolution of its biota from the late Pleistocene to the present.

P 9.6
Multiproxy paleolimnological reconstruction of Lake Victoria's environmental history, East Africa

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Lake Victoria (LV) is the largest lake in Africa and the Tropics and is situated within an elevated plateau in the western part of the African Great Rift Valley. In contrast to other African Great Lakes, LV's shallowness (max. 68 m; mean. 40 m), limited river inflow, and large surface area relative to its volume make it sensitive to climate changes and fluctuations of the water level. As a result LV has undergone periods of low stands, or even desiccation with profound effects on the aquatic ecosystem. For instance, a unique biodiversity of endemic cichlids species following LV's re-emergence ~15,000 years ago after its complete desiccation during the last glacial.

In an interdisciplinary project we aim to reconstruct these linkages between major ecosystem transitions and disturbances and evolution of biota in LV by combining approaches from paleogenomics, paleoecology and paleolimnology. For this purpose, four sediment cores along a transect (near-shore to offshore), covering ca. the past 14,000 years, are analysed.

We present first paleolimnological results from long-term changes of aquatic and sedimentological parameters. We use high-resolution hyperspectral imaging (HSI), sedimentary pigments and biogenic silica to infer aquatic productivity. Additionally, XRF scanning data, ^{13}C and ^{15}N and extracted phosphorus fractions provide information on changes in sediment composition and cycling of nutrients.

Preliminary analyses reveal that past environmental signals are best preserved at the deepest site, but are present as well in the two shallower sites of the transect. The aquatic productivity (BSi and chloropigments) increased rapidly after refilling of the lake basin in the Late-Glacial. Simultaneously, elevated and variable Ti, Zr and K signals indicate increased lithogenic influx due to a wetter climate and infilling of the lake prior to a stabilization of the signal in the early and mid-Holocene.

P 9.7
New cosmogenic nuclide burial-dating model indicates onset of major glaciations in the Alps during Middle Pleistocene Transition

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The landscape in the northern Alpine Foreland is the combined result of tectonic and climatic processes and particularly of numerous glaciations. Aggradation of glaciofluvial sediments and the subsequent fluvial incision led to the development of terraces comprised of thick gravel units. The oldest terraces/gravel units preserved in the Foreland – the so-called Deckenschotter – are morphostratigraphically divided into the Höhere (HDS) and Tiefere Deckenschotter (TDS) units which are separated mostly by a significant altitude difference of ~100-150 m. Both gravel terraces/gravel units represent spatially extensive paleosurfaces and can form plateaus up to 200-300 m above the modern valley bottom. Absolute ages of former fluvial systems are crucial to establish landscape evolution scenarios and to reconstruct past river drainage patterns and related (local/regional) base-levels.

Deriving absolute ages for glaciofluvial gravels which are much older than the age range of radiocarbon methods has been a challenge. Alternatively, the use of the cosmogenic burial dating method can be employed. This method makes use of the differential decay of an in-situ produced nuclide pair in a mineral target (here: ^{26}Al and ^{10}Be in quartz) and the facts that pebbles in the initial fluvial sediment have different nuclide signatures due to varying origin and erosion histories (Balco and Rovey, 2008; Erlanger et al., 2012). The method is based on the fundamental assumption, that the initial production ratio of ^{10}Be:^{26}Al at the source is known (commonly used 6.8:1 at/g/yr at the surface) and that erosion is steady. However, applying the method to glaciogenic samples derived from the Swiss Alps with deep and unsteady erosional patterns during the ice ages might challenge this.

To support the current efforts of absolute age dating of Swiss Deckenschotter deposits (Akcar et al. 2017, Claude et al. 2019, Grischott et al. 2020), we devised a new burial-dating model tailored to glaciogenic sediments: P-PINI (Particle Pathway Inversion of Nuclide Inventories). The method applies a source-to-sink framework to a cosmogenic ^{10}Be-^{26}Al inversion model accounting for variable cosmic-ray exposure and non-steady erosion. Taking published ^{10}Be-^{26}Al data from five HDS sites (Feusi and Tromsberg (Grischott et al. 2020), Siglistorf (Akcar et al., 2017), Irchel Steig, and Irchel Hütz (Claude et al., 2019)) and one TDS site at Iberig (Grischott et al. 2020), we obtain age distributions (±1σ) that are especially well constrained for Feusi (0.93 ±0.13 Ma), Iberig (0.93 ±0.17 Ma), and Tromsberg (0.88 ±0.14 Ma), less well-constrained for Irchel Steig (0.69 ±0.25 Ma) and Siglistorf (0.94 ±0.27 Ma), and very poorly constrained for Irchel Hütz (1.39 ±0.56 Ma)(Knudsen et al. 2020). Consistent with the morphostratigraphy, which dictates that the TDS postdates the HDS, we implemented a Bayesian modelling framework, yielding an age of 0.69 ±0.12 Ma for Iberig (TDS) and a combined age of 0.95 ±0.07 Ma for the HDS sites. Based on the P-PINI burial ages as well as the combined, Bayesian burial age, we propose an age around 1.0–0.9 Ma for the onset of the large Alpine glaciations that triggered the accumulation of the HDS outwash sediments. This roughly accords with the first long glaciation of the Pleistocene (MIS 24–22), identified as a step-change to colder climate and larger glaciations towards the end of the Middle Pleistocene Transition. While our results challenge previously reported ages of ~2 Ma or more for the HDS in Switzerland, they corroborate evidence from the southern Alpine retroforeland and provide quantitative support for the early hypothesis by G.J. Kukla, who ascribed the oldest glacial deposits in the northern Alpine Foreland to around MIS 22. Finally, we suggest that the source-to-sink approach of P-PINI offers a viable alternative to the established isochron burial-dating method in cases involving non-steady exposure and erosion.

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P 9.8
Purification of Organic Compounds Using Microsublimation for ^{14}C Analysis

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The decrease in required sample sizes for radiocarbon (^{14}C) analysis by accelerator mass spectrometry (AMS), which now is on the order of ten micrograms carbon or less provides the opportunity for precise dating of single specific compounds. However, background contamination associated with sample purification presents a major limitation to precise ^{14}C dating at these low sample sizes. Many key target compounds are amenable to isolation using preparative chromatographic methods. Using preparative GC, for example, column bleed has been reported as the main contamination source. Although this contamination may be at sub-microgram levels (Casanova et al. 2017), removal is favorable for accurate dating of ultra-small samples. In synthetic and analytical chemistry, sublimation is a well-established approach for purification of semi-volatile compounds, and here we test it as an approach for purification of selected compounds for microgram-level ^{14}C analysis. As commercial sublimation equipment usually is not designed for such small sample sizes, a custom-built micro-sublimation apparatus has been developed and tested for the purification of organic compounds in the sub-milligram range. The design of the microsublimation apparatus, which has been optimized to enable a streamlined protocol that minimizes contamination risks, will be presented. Experiments were performed with a range of different compound types, including fatty alcohols, alkanes and vanillin. Reproducibility with yields of up to 90% have been achieved. Stability of isotopic measurements and contamination sources will be discussed along with possible other application areas in the future.

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P 9.9
High Resolution Modeling of the Quaternary Climate of the Alps

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For determining an ideal location for a nuclear waste storage repository that could endure the effects of future glaciations, we aim to assess the risk of different areas of Switzerland to glaciers development during the Quaternary. For this purpose we produce physically plausible climate information of the Alpine region during the Quaternary using a set of atmospheric dynamical models at different spatial resolution, from the global to regional scale. This information can successively be used for driving an ice sheet and glacier model for the same period of time.

Here we present the first results of the project for selected time-slices of the Quaternary, highliting the challenges encountered in setting up the high resolution climate simulations at a spatial resolution of 2km over the Alpine region. In particular we focus on the solutions adopted for the characterization of changes in surface features such as glaciers extension, sea level height and vegetation distribution.

P 9.10
In the forbidden field: how glacial erosion influences the ^{10}Be/in-situ ^{14}C ratio

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Direct measurements of glacial erosion are challenging due to difficulties accessing the ice-bedrock interface to place measurement equipment and therefore only few measured values exist (e.g. Boulton 1996). Recent studies have shown that cosmogenic nuclide concentrations measured on glacially abraded bedrock surfaces allow quantification of how much rock was removed by the glacier (Briner & Swanson, 1998; Fabel & Harbor 1999; Wirsig et al., 2017; Steinemann et al., 2020). However, to determine the rate of glacial erosion it has to be known how long the glacier was covering the site. Theoretically, measuring two nuclides, e.g. ^{10}Be and in-situ ^{14}C, can provide additional information about the duration of glacier coverage, taking advantage of their different half-lives (^{10}Be: 1.4 Ma, ^{14}C: 5.7 ka) and depth profiles (Hippe, 2017).

From a glacially polished bedrock riegel in front of the Trift glacier in the central Alps (Bern, Switzerland), ten samples were analysed for both ^{10}Be and in-situ ^{14}C to determine glacial erosion depths and rates. Evaluation of the nuclide concentration revealed that in areas with rather high glacial erosion rates the $^{10}Be/^{14}C$ ratio can be significantly influenced. The ratio can even be altered in a way that the ratio reaches values that should be impossible, as they plot in the so-called forbidden field.

With a numerical model developed at Ion Beam Physics ETH (MECED-model, Wirsig et al., 2017) we were able to show the complexity of how glacial erosion influences the $^{10}Be/^{14}C$ ratio by implementing various glacial erosion rates on a defined glacier fluctuation history.

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P 9.11
^{4}He/U-Th dating of pore waters from Quaternary sediments of the Swiss Midland

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Dating based on the ^{4}He/U-Th method can be used to estimate the residence time of pore waters in very low-permeable rocks and consolidated sediments. The residence time is inferred from the time necessary to accumulate radiogenic ^{4}He measured in the pore water being produced by the decay of U and Th in the sediment matrix [1].

In the Jurassic Opalinus Clay, the pore water still contains the signature of the original marine formation water that was entrapped during sediment deposition. The pore water composition was altered only by diffusive processes [2,3]. The fact that even ~100-Ma-old water signatures can be preserved in their original pore space suggests that such preservation might also be possible in much younger dense glacial deposits. The ^{4}He concentrations measured in the pore waters of glacial tills were translated into mean residence times of 15-25 kyrs [4] that agree rather well with the expected depositional ages of 25-31 kyrs [5]. These observations, as well as evidence from lacustrine sediments [6,7], suggest that, if the solute transport in the pore space is sufficiently attenuated, even unconsolidated sediments can “store” and host “old” pore waters.

In the present work we investigate if the ^{4}He/U-Th dating of pore waters can be used as a novel tool to complement other dating tools (e.g., optically-stimulated luminescence) for unconsolidated Quaternary sediments. We applied the ^{4}He/U-Th method to date pore waters in the time range of 10 to 100 thousands of years which covers the age range of the sedimentary depositions targeted by the Quaternary drillings (QBO) managed by the National Cooperative for the Disposal of Radioactive Waste (Nagra) in Switzerland. In particular, we focus on fine-grained lacustrine sediment layers that might provide low-permeability conditions suitable for the preservation of radiogenic ^{4}He concentrations in the pore space.
We report the preliminary results of the ^{4}He/U-Th dating based on the measurements conducted in sediment samples from selected QBO, highlighting potential and challenges of the method with respect to the studied glaciofluvial sediments of the Swiss Midland.

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P 9.12
Paleoenvironmental and paleoclimatic reconstruction of the Lake Val (France) during Late Glacial and early Holocene

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Research on the earth's surface dynamics and processes includes the study of Quaternary geological formations linked to erosion or sedimentation processes, directly or indirectly dependent on climatic phases. The study of lacustrine deposits is one most useful approach to understand the bioclimatic cycles mechanisms. In a climatic change context and uncertainties regarding future environmental issues, the analysis of the evolution of sedimentary deposits is crucial for understanding the environmental changes within these ecosystems, Lacustrine deposits represent important archives for the study of the Late Glacial and the Holocene.

The main aim of this study is to characterize the paleoenvironmental and paleoclimatic evolution recorded in the Lake Val, in the French Jura Mountains during the Allerød and the beginning of Holocene. We use a multiproxy approach including sedimentology, mineralogy (XRD) and geochemistry ($\delta^{13}C$, $\delta^{18}O$, TOC, C/N, HI, OI, and P). These data suggest that the Younger Dryas period is characterized by an increase of lacustrine primary productivity linked to high Phosphorus inputs. The nutrient intake is a consequence of the increased detrital sediment supply, which seems to be the related to a colder and more humid climate.

The study of tephras is frequently used in Quaternary stratigraphic research in particular as a chrono-stratigraphic tool such as the Lacher See Tephra (LST). The Analysis of mercury concentrations in sediments was used in order to identify recent volcanic episodes, but the obtained results are unsatisfactory. Mercury contents are too low, and even after normalization by TOC, no significant trends or correlation with other methods such as magnetic susceptibility are observed.

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10. Geomorphology or Shaping Earth Surface

Cristian Scapozza, Nikolaus Kuhn, Dorota Czerski, Caroline Bolliger, Reynald Delaloye, Isabelle Gärtner-Roer, Elisa Giaccone, Christoph Graf, Margreth Keiler, Julia Krawielicki, Isabelle Kull, Mario Kummert, Christophe Lambiel, Géraldine Regolini, Julie Wee

Swiss Geomorphological Society

TALKS:

10.1 *Bandou D., Schläfli P., Schwenk M., Douillet G.A., Kissling E., Marti U., Schlunegger F.*: 3-D models of the overdeepenings in the Aare and Gürbe valleys using gravimetry

10.2 *Battista G., Schlunegger F., Burlando P., Molnar P.*: Combining numerical modelling and geomorphic mapping to study sediment provenance in a pre-Alpine river basin

10.3 *Raab G.*: The Tor Exhumation Approach (TEA) – Dealing with continuous and reversed exhumation patterns to determine surface denudation rates

10.4 *Vos H., Eckardt F., Fister W., Kuhn N*: Surface boundary conditions for dusts emission from the agricultural lands in the Free State, South Africa

10.5 *Wicki A., Jansson P.-E., Lehmann P., Hauck C., Stähli M.*: Performance analysis of simulated vs. measured soil moisture dynamics for regional landslide early warning in Switzerland

10.6 *Zaki A.S., Edgett K.S., Gupta S., Maurizio P., Davis J., Hughes C.M., Watkins S.E., Valero L., Grindrod P., Thomas N., Cremonese G., Castelltort S.*: Fluvial landforms in Antoniadi crater: Evidence for two intervals of water-generating landscapes on Mars

POSTERS:

P 10.1 *Mair D., Lechmann A., Delunel R., Yeşilyurt S., Tikhomirov D., Vockenhuber C., Christl M., Akçar N., Schlunegger F.*: Millenial scale denudation of the steep Eiger headwalls through thermo-cryogenic pre-conditioned rockfall

10.1
3-D models of the overdeepenings in the Aare and Gürbe valleys using gravimetry

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Interpretations of the processes leading to the formation of overdeepened valleys, where the bedrock lies well below sea level today, are contested as the overdeepenings have been filled by sediments or host lakes making observations difficult (Cook and Swift, 2012). Here, we combine gravimetric, GNSS (Global Navigation Satellite System) and borehole data within a 3D forward modelling framework, Gravi3D, to assess the subsurface geometry of such overdeepenings in 3D. We particularly aim at reconstructing the geometry of overdeepened valleys' walls, which bears information on the erosional mechanism leading to the formation of these features. We focus on two valleys, the Aare valley and the Gürbe valley.
In this region, the occurrence of overdeepenings, or alternatively tunnel valleys, has already been disclosed through drilling (Reber and Schlunegger, 2016), but the details about the geometry have not been elaborated yet. The study region is characterized by three low ranges made up of Burdigalian Upper Marine Molasse bedrock with c. 300 m-deep and c. 1 km-wide valleys in-between, where overdeepenings with a >100 m-thick Quaternary fill have already been identified by drilling. The gravity data, which we collected, along an 8km long profile with stations spaced between 100 and 300 m yield a Bouguer anomaly that ranges from c. -99 to -106 mGal. We infer this anomaly to the regional trend (c. 2 mGal over 8 km) and to the effect of the overdeepenings sedimentary fillings (2-4 mGal over 1 km), disclosing a sharp anomaly pattern over the inferred tunnel valleys. The removal of the signal related to the regional trend results in a residual Bouguer anomaly of c. 1 mGal for the Belpberg hill in-between the valleys that is made up of Molasse bedrock, and 2.6 and 3.8 mGal for the Gürbe and Aare valley overdeepenings, respectively. Furthermore, preliminary interpretations of the residual gravity anomaly of the Belpberg bedrock hill suggest a density of 2.4 kg/m^3 for the Molasse bedrock. This value will be better constrained with the Nettleton method for the quantification of an accurate density contrast between the Molasse bedrock and the Quaternary fill.
Finally, and most important, we prepare a forward modeling program written in Python, Gravi3D, which allows to calculate a theoretical gravity effect of a geological body with variable geometries and densities to detail the geometry of the overdeepenings on the lateral flanks of the bedrock hills (Kissling and Schwendener, 1990). This program is designed such as it can be employed by the larger scientific community. It has two components referred to as PRISMA and BGPoly, where analytical solutions for the gravity effect of prisms and of polygons by Nagy (1966) and Talwani & Ewing (1960) are implemented. PRISMA allows first order estimates of the spatial extent and density of a simple structure, while BGPoly is intended to fit complex 3-D geometries with a series of horizontal polygons similar to lines of equal height in topographic maps. The results will be integrated within a GIS environment for comparison purposes. We then use published information on the near-surface bedrock geometry of the target area together with information on the densities of the geological units as initial constraints for the calculation of the gravity effect, which will be compared with the Bouguer gravity survey's results. We iteratively improve on the model geometry and the densities until we reach a best fit between the observed and the modeled Bouguer anomaly. The goal is to refine the 3-D geometrical details of the target overdeepenings.

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10.2
Combining numerical modelling and geomorphic mapping to study sediment provenance in a pre-Alpine river basin

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Sediment mobilization in a river basin takes place by means of multiple processes and from a variety of sources, such as landslides, hillslopes, riverbed and banks. Next, the transport processes in the river network allow for mixing, deposition and further erosion (e.g. Jerolmack and Paola, 2010). The complexity of these mechanisms makes the provenance of the sediment load at the outlet very difficult to predict (e.g. Roering et al., 1999). However, such information is key to identify areas of excessive soil erosion and the main sources of sediment. The information about sediment provenance is also essential for denudation rate studies that are based on cosmogenic radionuclide (CRN) dating. CRN-based estimates of catchment-average denudation rates rely on the assumptions that a riverbed sediment sample at the basin outlet is representative of the long-term erosion rates of the basin, and that all the basin areas contribute material proportionally to their erosion rates (Von Blanckenburg, 2005).

The aim of this work is to use a physically-based and spatially-explicit modelling framework where we simulate the sediment production from localized sediment sources and track the material flux from the sources to the outlet. To do so, we combined the hydrology-sediment model Topkapi-ETH presented in Battista et al. (2020) with geomorphic mapping of potential localized sediment sources at the scale of the entire basin. This allows us to account for the periodic activation of incised areas and landslides by the combined action of hillslope runoff and river discharge (see Figure 1). Furthermore, in the presented framework the sediment mobilized from different sediment sources is routed in parallel, thus allowing us to keep track of the sediment load, its provenance and its variability in time at the outlet. We apply this modelling framework to the pre-Alpine Kleine Emme river basin (Switzerland), where we quantified the relative contribution of sedimentary material derived from localized sources and overland flow erosion to the suspended load at the basin outlet.

We found that the modelling of suspended sediment fluxes in the study basin substantially improves when localized sediment sources are considered, and that accounting for overland flow erosion only fails to explain the pattern of suspended loads of sediment at the basin outlet. We therefore introduced a parameter for the competence of gullies on landslide surfaces to produce sediment, which allowed us to simulate two extreme behaviours of the catchment: from a scenario where channel-processes dominated sediment production to a mechanism where hillslope-processes exert the strongest control. We tested these two scenarios with two independent model validations. The first one bases on the surface roughness analysis of the landslides, whereas the second validation uses observed ^{10}Be concentrations as a sediment tracer. Both validations suggest that channel processes are likely to be the dominant sediment production process in the study basin.

The modelled temporal dynamics allows to draw two main recommendations for cosmogenic sampling: (a) sampling during low flow conditions should be preferred, while sampling during and immediately after extreme events should be avoided; (b) sediment should be sampled as close as possible to the low flow channel, in order to reduce the risk of collecting high-flow deposits. Finally, we propose that the presented framework can be used to complement fingerprinting techniques, because it allows to extrapolate the measured sediment apportionment to other flow conditions, by linking it to climatic variables and hydrological conditions.

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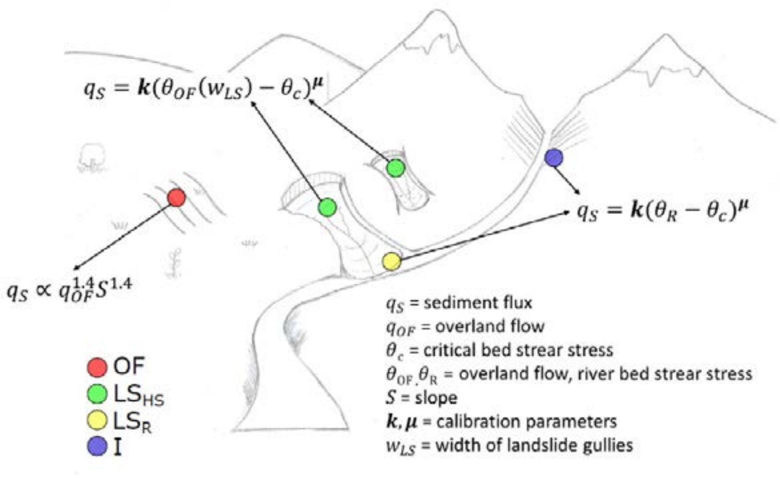

Figure 1. Schematic description of the model. Four processes can generate sediment mobilization: overland flow erosion on hillslopes (OF), overland flow erosion on the body of landslides (LS_{HS}), river flow erosion of landslide toes (LS_R) and of incised areas (I). Figure from Battista et al., 2020b.

10.3
The Tor Exhumation Approach (TEA) – Dealing with continuous and reversed exhumation patterns to determine surface denudation rates.

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Landscapes are subjected to changing environmental conditions. Yet, capturing the surface denudation variations over geological time-scales remains challenging due to the lack of suitable archives. Therefore, the Tor Exhumation Approach (TEA) was developed in recent years (Raab, 2019), unlocking a new in-situ archive with continuous surface denudation records. It uses the exhumation pattern of tors (i.e. large residual rocks) and surface exposure dating paired with numerical modelling. So far, the TEA has successfully provided continuous surface denudation histories in magmatic (granite; Raab et al., 2018, 2019) and metamorphic (schist) landscapes (Raab et al., under review).

Here a summary of the diverse results and achievements of these new investigation technique is presented. In example, rates in a granitic upland of southern Italy (Sila, Calabria) have clear exhumation pattern also in dependency of their landscape exposition. There, the variations of the surface denudation rates range about 0.06 to > 0.30 [mm year^{-1}] for the last 100 ka. An investigation at the meta-sedimentary Otago upland (New Zealand), revealed (Raab et al., 2018, 2019) similar exhumation and consequently surface denudation speeds in the range of about 0.02 to 0.22 [mm year^{-1}] over period of 200 ka (Raab et al., under review).

In addition, the process on how to deal with outliers and reversed exhumation patterns, as found at Otago, is discussed. There it is considered that some exposure patterns are the result of mushroom-like exhumation by undercutting and repeated rock breakoffs.

In summary, the applicable of the TEA in geomorphological and tectonic studies for surface evolution reconstructions from Pleistocene age and younger is disclosed.

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10.4
Surface boundary conditions for dusts emission from the agricultural lands in the Free State, South Africa

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The Free State has been identified as a dust emission hotspot, whereby the agricultural fields are expected to be the main emitters of dust. Besides the direct soil degrading effect of dust emission, the transported fines can also have detrimental effects on human health, regional and global climate, and global bio-chemical cycles. Depending on the crop type and the agricultural management, which in some cases include measures against wind erosion, a great variability in dust emissions from fields can be observed on the ground and in satellite images, even at times of constant high winds. A Swiss National Science Foundation (SNSF) and South African National Research Foundation (NRF) co-funded project tried to gain insight in the factors controlling wind erosion on these fields, as well as the relationship between these factors and the agricultural practices. We will present data from field measurements that address the erodibility on several temporal scales: from decimetre scale variation, to within field variation, to large-scale variation between fields.

Small-scale measurements were done using a Portable In-Situ Wind Erosion Laboratory (PI-SWERL), which assesses the potential PM10 emission of a surface of 30 cm diameter. These measurements were performed on different adjacent surface types that are created by agricultural activities, such as track rows, disturbed soils, and undisturbed, crusted areas. Together with the dust emission, other soil characteristics were measured, such as the surface strength, soil texture, carbon and moisture content. Gradient Boosting Machine (GBM) models were used to gain insight in the relative influence of these surface characteristics on the overall dust erodibility and spatial variability of the potential PM10 emissions. In addition, field-scale measurements were performed by monitoring the sediment flux during wind events using Big Spring Number Eight (BSNE) poles, and by measuring the threshold velocity of grain saltation.

Our data shows a juxtaposition of the factors that control the emission on these different scales. On a small scale, for example, on average areas with freshly broken up tracks emit 2.6 times more PM10 than crusted areas (1.263 mg m^{-2} s^{-1} and 0.488 mg m^{-2} s^{-1} respectively). Emission from both surface types are strongly affected by the presence of saltating sand grains which abrade the surface. However, the influence of other factos differ greatly per surface types, such as the silt and clay content that only has a protective effect on tracks. For the erosion of particles on a field scale, surface roughness appears to be of additional importance. Peanut fields are the main emitters of suspended particles. These fields have a horizontal sediment mass flux that is approximately 100 times higher than that of a harvested maize field with some stubble and straw cover.

These results indicate that the interaction between soil cohesion, abrasion by the presence of moving sand, and the surface form and cover controlling the threshold wind velocities, determines the occurrence of dust emissions in the Free State. Consequently, to predict and control the emission of dust in the Free State, all these different factors need to be integrated in modelling and management approaches.

10.5
Performance analysis of simulated vs. measured soil moisture dynamics for regional landslide early warning in Switzerland

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In mountainous regions, rainfall-triggered landslides pose a risk to people and infrastructure due to the widespread occurrence and the short time interval between activation and failure. Landslide early warning systems (LEWS) have demonstrated to be a valuable tool to inform decision makers about the imminent landslide danger and to move people or goods at risk to safety. While most existing LEWS are based on empirically derived rainfall-exceedence thresholds, recent studies have shown improvement of the forecast goodness by including in-situ soil moisture measurements.

The use of soil moisture sensor networks bears specific limitations such as the sensitivity to local conditions, data quality issues, and costly installation and maintenance, which could be overcome by the application of numerical models. However, soil moisture models are demanding both dynamic input data and details on soil, plant and atmospheric conditions to provide a realistic representation of various environments. Ultimately, this rises questions about the reliability and representativeness of simulation-based early warnings compared to using measurements.

To assess the reliability of simulation-based LEWS, a one-dimensional heat and mass transfer model (CoupModel; Jansson, 2012) was applied at 35 sites in Switzerland to calculate soil moisture during the period of 2008 to 2019. For that purpose, soil hydraulic properties were estimated using different types of pedotransfer functions. By applying a statistical framework (Wicki et al., 2020), the temporal variation of simulated soil moisture was quantified and the forecast goodness for rainfall-triggered landslides was analysed through the comparison with a national landslide database. Next, the forecast goodness was compared to a measurement-based model by applying the same statistical framework to measured soil moisture available at the same sites and time period. Finally, the model was applied to additional 120 sites without measured soil moisture (using meteorological data and estimates of soil hydraulic properties) to assess the effect of increasing the network density on landslide prediction.

First results show that (i) a similar forecast goodness is achieved for both simulation- and measurement-derived early warnings and that (ii) the forecast goodness could be increased for short distances between modelling site and landslide location if more modelled sites are included. These findings encourage the use of a combination of modelled and measured soil moisture to improve current LEWS.

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10.6
Fluvial landforms in Antoniadi crater: Evidence for two intervals of water-generating landscapes on Mars

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Studies of remotely sensed data have been used extensively to suggest that hundreds of water bodies formed under wet climate conditions that occurred on early Mars. However, theoretical climate models propose that the early climate on Mars was wet, but they also suggest that there might not have been enough water to feed and sustain large bodies of water (e.g., Haberle et al., 2015). Here, we examine fluvial landforms in one of the largest putative paleolake basins on Mars, Antoniadi (Fassett and Head, 2008), to assess the amplitude, scale, and frequency of fluvial activity using paleo-morphological reconstructions of a wide range of paleo-hydrological processes. Our reconstructions are primarily based on study of high spatial resolution images (0.25 to 6 m/pixel) from the Context Camera (CTX), High-Resolution Imaging Science Experiment (HiRISE), and Color and Stereo Surface Imaging System (CaSSIS).

Antoniadi exhibits diverse landforms that resulted from surface and subsurface processes. These landforms include valley networks, sediment fans at valley outlets, and short, stubby branched ridges (inverted paleo-stream forms). The valley networks, coupled with the fan-shaped deposits, occur in terrain on the western rim of the crate; they display well-preserved, short distance, source-to-sink fluvial systems, suggesting precipitation-fed runoff (Figure 1A). One of the fans is composed of three lobes aggraded at different elevations. These lobes might have formed as a result of changing water levels. Using crater counting, we have estimated the crater retention age of the valley networks and the fan-shaped deposits to be 3.7 ± 0.1 Ga.

In the central part of Antoniadi, a deflated surface yielded a crater retention age of 2.4 ± 0.1 Ga. This surface covers an area of 700 km^2 and hosts short, stubby drainage networks that today stand as ridges (Figure B and C). The inferred paleo-streams debouched into low-relief terrain via a 0.6 – 2 km-wide, 30-km-long trunk. The morphology of these branches supports episodic groundwater release as the primary driver of this later, second interval of fluvial activity, as they originated near a set of faults that might have served as conduits that brought the water to the Martian surface. An example site of sappping valley networks on Earth that exhibits a drainage network of similar scale and form occurs in Florida Panhandle (Figure 1 D; Schumm et al., 1995). This analog suggests that the formation of such drainage networks on Mars requires highly permeable soil, coupled with existing, abundant groundwater.

In conclusion, the modeled ages, coupled with morphological reconstruction, suggest fluvial erosion and deposition triggered by precipitation-fed runoff during the Noachian, followed by groundwater processes during early Amazonian. Once the period of fluvial activity declined, erosion inside Antoniadi was dominated by aeolian processes, which exposed paleo-stream ridges.

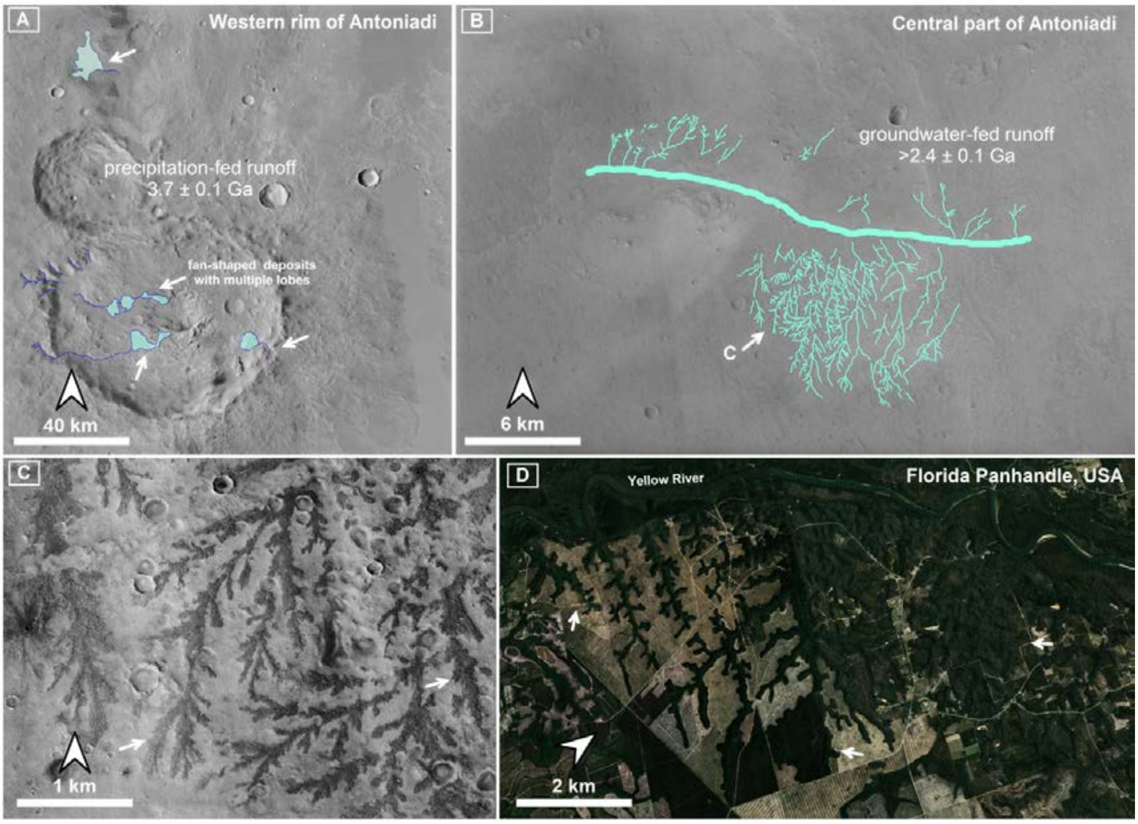

Figure 1: (A) CTX mosaic shows the distribution of the valley networks (blue) and the fan-shaped deposits (light blue) on landforms at the western rim of Antoniadi. (B) CTX mosaic showing the short, stubby, branched ridges in central Antoniadi. These ridges record former streams that drained into a main trunk that debouched into low-relief terrain. (C) HiRISE image shows a portion of the short and stubby branches (ESP_012435_2015). (D) Satellite image of a drainage network on Earth that is similar to the example in Antoniadi (image credit: Google Earth; 30°34›0.48»N, 84°51›30.48»W).

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P 10.1
Millennial scale denudation of the steep Eiger headwalls through thermo-cryogenic pre-conditioned rock fall

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Denudation of steep, alpine rockwalls is driven by rock fall processes of various sizes and magnitudes. These rockwalls are sensitive to temperature changes because thermo-cryogenic processes weaken the bedrock through fracturing, which preconditions the occurrence of rock fall. However, it is still unclear how and at which rate the fracturing of rock from cryogenic processes impacts the denudation processes operating on these steep rockwalls. Here, we present data on long-term rockwall denudation rates at the Eiger from concentrations of cosmogenic ^{36}Cl and ^{10}Be along bedrock depth profiles (Mair et al., 2019). We link these with the local bedrock fabric and the reconstructed temperature conditions at the cosmogenic nuclide study sites. We then estimate the probability of bedrock for failure (Mair et al., 2020) through the employment of a theoretical frost cracking model. Results indicate that denudation rates are low in the higher region of the NW rockwall, in contrast to both the lower part of the NW rockwall and the SE face, where rates are high, despite similar bedrock fabric conditions. Furthermore, the cosmogenic nuclide inventory allows to infer rock fall events on a small scale as main denudation agent. Additionally, the frost cracking model predicts a difference in cracking intensity from ice segregation where the inferred efficiency is low in the higher region of the NW rockwall, but relatively high in the lower section of the NW wall and on the SE rock face of the Eiger. Throughout the last millennium, temperature conditions for all studied sites have been similar to the present. These data thus suggest the occurrence of large contrasts in microclimate between the NW and SE walls of the Eiger, conditioned by locally varying insolation. These would explain the relatively low denudation rates in the upper part of the NW rockwall and the rapid denudation in the SW face and in the lower part of the NW rock face.

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11. Soil: Formation, Processes, and Conservation

Tobias Sprafke, Klaus Jarosch, Stéphanie Grand, Tatenda Lemann, Volker Prasuhn

TALKS:

POSTERS:

P 11.1 *Herrmann C., Steffens M., Oberholzer S., Mestrot A., Jarosch K.A.*: Do effective microorganisms (EM) affect the decomposition of organic matter?

P 11.2 *Jarosch K., Kandeler E., Bünemann E.*: Soil organic phosphorus characterisation in soils at early stages of pedogenesis

P 11.3 *Moser M., Griepentrog M., Dötterl S.*: Influence of parent material and weathering on soil organic matter stabilization in alpine ecosystems

P 11.4 *Ofiti N.O.E., Zosso C.U., Solly E.F., Hanson P.J., Wiesenberg G.L.B., Schmidt M.W.I.*: Rapid transformation of plant-derived soil organic matter in response to elevated CO2 and warming in a spruce-dominated ombrotrophic bog

P 11.5 *Semeraro S., Rasmann S., Le Bayon C.*: Swiss Mountain Soil Ecology Project

P 11.6 *Simon C, Petras D., Roth V.-N., Dührkop K., Dorrestein P.C., Gleixner G.*: Understanding dissolved organic matter by destroying it

P 11.7 *Speckert T.C., Wiesenberg G.L.B.*: Changes in soil organic matter composition after afforestation

P 11.8 *Sprafke T., Sawakuchi A.O., Vidal-Torrado P., Lauer F., Rodrigues L., Almeida Santos T., Calegari M.R., Veit H.*: Luminescence dating to unravel Ferralsol evolution in SE Brazil

P 11.9 *Thomas C.L., Jansen B., van Loon E.E., Wiesenberg G.L.B.*: Potential for inverse modeling to assist in source apportionment of organic matter in soil and peat using molecular biomarkers

11.1
Field Verification of Remote Sensing-based UN Land Degradation Neutrality baseline produced using Geospatial cloud computing and machine learning

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Achieving land degradation neutrality (LDN) has been proposed as a way to stem the continued loss of land resources globally. LDN baselines are being set and the corresponding UN Sustainable Development Goal 15.3.1 indicator to estimate the proportion of degraded land over total land area between 2000 and 2015. LDN baseline is based on estimate of these three sub-indicators, i) land cover (LC) change computed– as a proxy for land use change, ii) land productivity dynamics (LPD) in vegetation productivity, iii) soil organic carbon stocks (SOCs). United Nations Convention to Combat Desertification (UNCCD) recommended the use of Remote Sensing-based (RS) global datasets (DD), particularly in data scarce contexts. For the first round of LDN reporting in 2018, many countries estimated the LDN and SDG 15.3.1 but reported with low levels of confidence because estimates were made with global datasets in the absence of national and/or local datasets without field verification.

Contributing to the scientific basis for operationalizing LDN and leveraging the availability of freely available satellite images, we developed procedures for generating national level metrics (NM) using geospatial cloud computing and machine learning (Fig. 1) [1]. Landsat 30m images were processed for land cover classification (2015) in Google Earth Engine using Random Forest. LPD was measured in terms of the state, trend, and performance of vegetation productivity using MODIS vegetation time series (250m). State captures recent changes to vegetation productivity and is computed by comparing the initial biomass (2000-2012 mean) to the final biomass (2013-2015 mean) in the time series. For trends in vegetation conditions, we used the Mann-Kendall test in R. Performance compares local levels of productivity with that of similar areas in the region [2]. SoilGrid250m data (~2000) was used for computing SOCs (t/ha), whereas SOCs (2015) uses the carbon conversion coefficients (tropical dry) in relation to LC transitions.

We validated LDN and SDG 15.3.1 estimates based on field datasets over Palapye, eastern Botswana using the Composite Land Degradation Index (CLDI). CLDI incorporates physical, chemical, biological degradation indicators [2]. Differences in the NM, DD and CLDI classes do not permit direct matching. Instead, based on the spatial intersection of land degradation classes, the modal class (most frequently occurring class) was adopted per unit (Fig 2a). A matching scheme of the possible combinations of classes between the maps was then developed using the one-in-one-out rule ([3], Fig 2b). NM and DD underestimated the 'Improved' class by 12% and 88% respectively (Fig 2c).

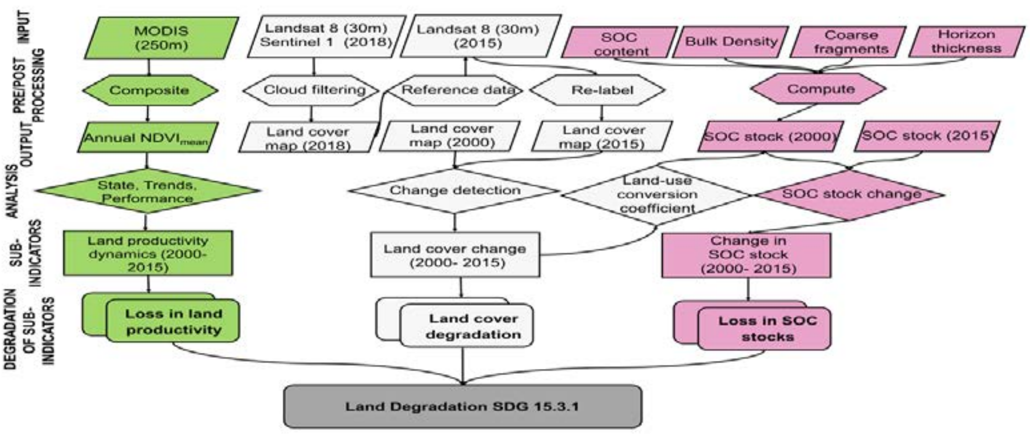
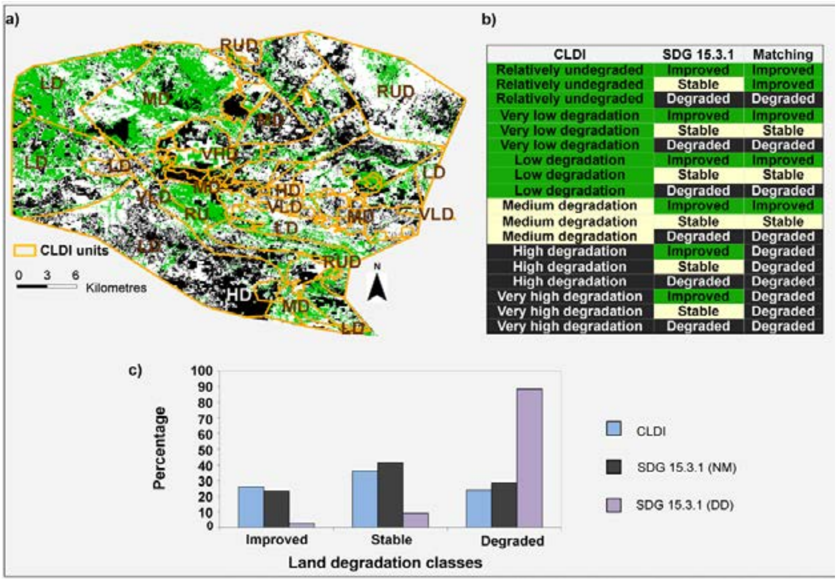


Fig. 1 The workflow followed in this study



CLDI	SDG 15.3.1	Matching
Relatively undegraded	Improved	Improved
Relatively undegraded	Stable	Improved
Relatively undegraded	Degraded	Degraded
Very low degradation	Improved	Improved
Very low degradation	Stable	Stable
Very low degradation	Degraded	Degraded
Low degradation	Improved	Improved
Low degradation	Stable	Stable
Low degradation	Degraded	Degraded
Medium degradation	Improved	Improved
Medium degradation	Stable	Stable
Medium degradation	Degraded	Degraded
High degradation	Improved	Degraded
High degradation	Stable	Degraded
High degradation	Degraded	Degraded
Very high degradation	Improved	Degraded
Very high degradation	Stable	Degraded
Very high degradation	Degraded	Degraded

Fig. 2 Validating land degradation with CLDI data in Palapye (a) SDG 15.3.1 (NM) map with the CLDI unit boundaries superimposed

NM overestimated the ‘Stable’ class by 17%, whereas DD underestimated ‘Stable’ by 75%. NM and DD overestimated the “Degraded” class by 21% and 267% respectively. Thus, NM estimates better match the CLDI than does the DD. Overall, SDG 15.3.1 estimate using the DD (51.4%, 296,717 sq/km) improved with the use of the NM (32.6%, 182,985 sq/km). The study demonstrates conducting LDN validation with field-based data.

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11.2
Global phosphorus shortage will be aggravated by soil erosion

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Soil phosphorus (P) loss from agricultural systems will limit food and feed production in the future. Here, we combine spatially distributed global soil erosion estimates (only considering sheet and rill erosion by water) with spatially distributed global P content for cropland soils to assess global soil P loss. The world's soils are currently being depleted in P in spite of high chemical fertilizer input. Africa (not being able to afford the high costs of chemical fertilizer) as well as South America (due to non-efficient organic P management) and Eastern Europe (for a combination of the two previous reasons) have the highest P depletion rates. In a future world, with an assumed absolute shortage of mineral P fertilizer, agricultural soils worldwide will be depleted by between 4 – 19 kg ha^{-1} yr^{-1}, with average losses of P due to erosion by water contributing over 50% of total P losses.

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11.3 Geochemistry and Paleopedology of a Paleosol Carbonate Sequence from the Okavango Delta, Northern Botswana: Implications for Environmental Change

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The Okavango delta is home to the biggest wetland ecosystem in southern Africa. Charaterised by hot semi-arid climates, evapotranspiration exceeds precipitation in the Okavango and this leads to the deposition of soluble salts, mainly alkali carbonates, as surface crusts which are subsequently leached into the subsoil during rainy season (McCarthy and Metcalfe, 1990). In consequence, the area has active carbonate and silica accumulation. Paleosol carbonates are important source of information on terrestrial environmental and climate variations over a long temporal scale (Sheldon and Tabor, 2009; Eze and Meadows 2014, 2015). Our study seeks, for the first time, to: (i) delineate and characterise the soils and paleosol carbonates from an Okavango palustrine sequence using their morphological, physico-chemical, geochemical composition and clay mineral content; and (ii) interpret the paleoenvironments and paleoclimates of the area using geochemical indicators of weathering and pedogenesis

Standard pedological parameters including structure, colour, pH, electrical conductivity and carbonate contents were determined using routine laboratory procedures. Mineralogical composition of the fine-earth fractions (<2 mm) were determined by x-ray diffraction. Total elemental composition of the soils were determined using XRF. Weathering and pedogenic intensities were assessed using selected geochemical molecular ratios.

Results of the study shows the palustrine carbonate sequence (Fig. 1) consists of two distinct units: an older paleosol unit and recent alluvial topsoil unit. An abrupt and irregular soil horizon boundary separates the two units. Horizons “A” and “Bkm” developed weak granular and hard sub-angular blocky structures respectively. Based on paleosol maturity and drainage classification indices, the paleosol carbonates of the Okavango Delta are moderately developed and poorly drained. Soil pH ranged from 8.1 to 10.0 in the sequence. Electrical conductivity also increased consistently from 10 dS/cm in the topsoil to 55 dS/cm in the 2Bkm3. The total elemental compositions of the units show SiO_2 as the dominant major oxide (56.6 – 94.1 wt. %) followed by CaO (0.19 – 16 wt. %), Al_2O_3 (1.76 – 4.20 wt. %), Fe_2O_3 (1.02 – 3.09 wt. %), and MgO (0.44 – 2.98 wt. %). Loss on ignition was lowest (1.9 wt. %) for A horizon and highest (17.36 wt. %) for the 2Bkm3 horizon. Molecular weathering and pedogenic ratios derived from geochemical signatures of the samples varied across the section.

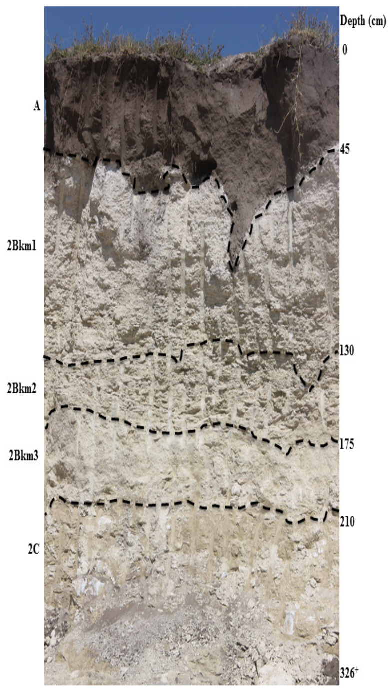

Figure 1. The studied sequence from the Okavango delta.

The index of chemical variability (ICV) ranges from 1.39 to 5.26, while chemical index of alteration (CIA) of the samples falls between 19.04 and 72.43. In the paleosol unit, the 2C horizon is quite outstanding for having the highest ICV and the lowest CIA values. On the contrary, the topsoil (A horizon) has the lowest ICV and the highest CIA values. Quartz and calcite are the dominant minerals in the <2 microns fractions. With the exception of hydrolysis, i.e. the loss of common rock forming alkaline and alkaline earth elements relative to Al during pedogenesis, other pedogenic processes (leaching, clayeyness, calcification and acidification) were quantitatively below the threshold.

A combination of evidence from the geochemistry and pedological properties points to incipient (weak) weathering and pedogenesis under cool and dry arid climates in the Okavango Delta. Calcification, a medium term pedogenic process, is predominant in the area. The paleoenvironments have been predominantly alkaline, had intermittent wetting and drying soil conditions and low leaching intensity. This study validates the efficacy of paleosols in understanding climate change in depositional settings, and gives the possibilities of connecting the paleosols to regional stratigraphic markers

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11.4
A novel in-situ sensor for soil enzymatic activity

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Sustainable soil management requires good indicators for soil health and ways to monitor them. Microbial activity is a particularly good indicator for healthy, non-degraded, and resilient soils and reacts sensitively to management practices. A good proxy for microbial activity in the soil is the activity of extracellular enzymes, which reflects both the long-term microbial activity and the activity of the currently viable microbial population. As such, it directly affects the ability of soil to fulfil its numerous functions.

Most commonly, soil enzyme activities are assessed using destructive biochemical laboratory incubations that involve the dispersion of soil in an aqueous solution of a suitable chromogenic or fluorogenic substrate at a relatively high solution to soil ratio. However, due to these artificial measurement conditions and the influence of transportation and storage on the samples, such assays might not represent the true in-situ activity at the time of sampling but rather a “maximum potential activity”. A recent alternative, operating at more natural conditions, is zymography. Here, enzyme-specific fluorogenic substrates are attached to membranes, which are then applied directly to soil surfaces. The method is particularly suited to map the distribution of enzyme activities around roots or earthworm burrows exposed on the surface of mesocosms in the laboratory. However, the potential application of substrate loaded membranes to assess enzyme activities as an indicator of soil health in-situ in the field has been prevented so far by difficulties in preparing and employ all the materials under field conditions.

Here, we present the design of a novel easy-to-use tool (Digit Soil; www.digit-soil.com) based on zymography methodology that allows both researchers and practitioners to reliably, reproducibly and comparably measure a suite of soil enzyme activities to assess soil health and better understand enzyme-driven ecosystem processes. It combines soil incubation unit and camera detection in one small hand-held device capable of measuring the activity of main soil enzymes in-situ in a wide variety of soils within minutes. Apart from time-saving, this also minimizes the problem of changes in conditions, in particular moisture, during membrane application. Data can be transferred to a hand-held device such as a tablet computer and be analyzed, thus allowing immediate management decisions based on the measured enzymatic activities.

11.5
Soil carbon sequestration potential in Swiss agricultural mineral topsoils

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Soil carbon sequestration is one of the cheapest and technically least demanding carbon dioxide removal (CDR) technologies. Several recent studies have estimated the potential to sequester carbon (C) in soils, incorporating the concept of soil organic carbon (SOC) saturation as a limiting factor. In Switzerland, biomass availability is most likely limiting rather than the soil's capacity to store C. We therefore use an opposite approach and ask the question: How much C could additionally be stored in Swiss agricultural soils, given the organic material sustainably available within the country? More specifically, we determine how much additional C can be sequestered by, e.g. maximising the use of cover crops, maximising residue retention, increasing organic amendments (fertilizer, compost), and applying biochar produced with domestic material, without compromising food production and soil fertility.

To estimate SOC stocks in mineral topsoils for Switzerland under these different management options, we use a modelling system that we have developed for national greenhouse gas reporting. It is based on the soil-C model RothC. For the present study, we modified RothC to dynamically simulate biochar applications. Simulations are run until 2100 using regionally downscaled climate change scenarios. A critical requirement for the simulations is that agricultural productivity of Switzerland should be sustained and that shares under different land-use types such as cropland, grassland and forest will remain the same. We estimate the C sequestration potential as the difference to a baseline scenario, where current practices are maintained.

11.6
Quantitative soil erosion assessment based on imagery acquired by Unmanned Aerial Vehicles

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Measuring and mapping actual erosion across agricultural land remains a challenging task even after more than 100 years of research in the topic. While the occurrence of erosion is easy to spot and mark on a map, assessing the actual amount of soil lost on cropland affected by erosion is more difficult. There are several reasons for this difficulty of measuring soil loss. Soil erosion by sheetwash and shallow raindrop-impacted flow is widespread, but moves only a millimetre-thin layer of soil. In addition, rainfall and wetting smoothen and compact the surface soil, so a lowering of the soil surface does not necessarily translate into an equivalent loss of soil. For rill erosion, the change in surface features is more prominent, but the shape of the rills is complex so that simple measurements of width and depth offer only a rough estimate of the volume of soil that is lost. Furthermore, the mapping of rills in the field is time consuming. To a certain extent these problems have been overcome in an indirect way by establishing erosion monitoring plots where a qualitative assessement of rills being present or not can be combined with the amount of sediment caught at the plot outlet. However, plot data are associated with several problems, most notably their size and artifical boundaries, which often interfere with the actual surface hydrology and erosion and depostion patterns on an agricultural landscape (Fig. 1). Furthermore, in the case of the standard plot size introduced for the Universal Soil Loss Equation in the 1950s (22.13 m long, 1.83 m wide, 9% slope) modern farm mashinery does not fit on a plot anymore. Finally, plots are expensive to install and deliver erosion only for the site where they are built, which may not correspond to the sites with the greatest erosion problem in a particular agro-ecosystem.

Erosion mapping using Unmanned Aerial Vehicles has been explored for some time, but only during the last decade the fast development of both, drones capturing images and their processing into Digital Elevation Models (DEMs) has opened their use for widespread application. In most studies and applications, imagery of eroding sites was captured either just after the erosion event, or at some point before and after. In the former case, erosion features, mostly rills, have been separated by an algorithm from the surrounding soil surface. The volume of soil below the perimeter of the rill has been calculated from the DEM. When before and after erosion imagery is available, the net reduction in surface height between two DEMs has been considered as corresponding to the actual soil loss. The accuracy of these approaches has been tested by comparing DEM derived from UAV imagery and independently construchted DEMs using a terrestrial laser scanner. The results show that UAVs can offer a good approximation of the actual amount of soil eroded by rill erosion. However, it became also clear that each soil management and tillage system requires a specific quality of the imagery in terms of resolution and time of acquisition. In addition, the DEM generated by laser scanning for comparison has inaccuracies itself, e.g. as a result of the shadowing by steep and overhanging rill walls or deep furrows from tillage. In this study we therefore aimed at comparing a direct meaurement of rill volume with the change of volume estimated from UAV imagery, both through a before and after comparision, as well as the mapping of rills from an after event image.

The rill erosion mapping was carried out on a cropfield on the Heshan Farm (125° 20′ 10.5″ E, 49° 00′ 23.1″ N) in Nenjiang County, Heilongjiang Province, Northeast China. The field experiences rill erosion regularly, often due to snowmelt in spring. For this study, rills were created artificially by generating runoff in furrows with a downslope orientation. UAV imagery was captured using a DJI Mavic 2 pro. Rill volume was measured by filling 29 one-metre sections of rills with sand. The volume of the sand filled into the rills was assumed to correspond to the amount of soil that had been washed away by erosion. UAV images were taken before rill erosion was initiated, after the erosion, and after the rill sections had been filled with sand. From the DEMs, the rill volume was calculated in two ways: first by the volume of soil below the rill edge delineated by the sand, and second by calculating the difference between the DEMs for the test sections captured before and after the rill erosion.

The results show that the commonly used difference between DEMs capturing the soil surface before and after an erosion event are within 20% of the volume of sand filled into the rills. Matching the sand volume with the DEM generated after filling proofed difficult because of the limited quality of the elevation of the sand surface. This is attributed to their uniform colour, lacking matching points for constructing a DEM. Overall, the comparison between the direct measurement of the volume of eroded soil with the DEM showed that the imagery has the potential to improve and replace current approaches to quantitative erosion measurements. Apart from an acceptable variability, UAVs can measure erosion where it happens rather than on plots with disturbed hydrology and erosion and deposition patterns. They can also be applied in a far more widespread way by capturing images of sites where erosion actually happened which enables an improved quantitative identification of the boundary conditions that cause erosion compared to just qualitative mapping or few plot studies.

Figure 1. Erosion and deposition caused by runon slope and tillage direction

11.7
Rapid decrease of soil erosion rates with soil formation and vegetation development in periglacial areas

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High mountainous areas are are strongly shaped by redistribution processes of sediments and soils. Due to the projected climate warming and the continued retreat of glaciers in the 21st century, we can expect the area of newly exposed, highly erodible sediments and soils to increase. It is therefore important that we improve our understanding of erosion processes in young, mountainous soils and that we quantify them. An increase in soil erodibility could threaten human infrastructure (i.e. hydroelectric power, touristic installations and settlements) as well as the livelihood of mountain farmers due to the resulting soil degradation.

While soil development is increasingly well understood and quantified, it has rarely been coupled to soil erosion. The aim of this study was, therefore, to assess how soil erosion rates change with surface age. We investigated two moraine chronosequences in the Swiss Alps: Firstly, the periglacial area of Steingletscher (Sustenpass), with siliceous soils ranging from 30 a to 10 ka, and secondly, in the periglacial area of Griessgletscher (Klausenpass) with calcareous soils ranging from an age of 110 a to 13.5 ka. We used $^{239+240}Pu$ fallout radionuclides to quantify erosion rates and compared them to physical and chemical soil properties and the vegetation coverage. At both chronosequences, the erosion rates were highest in the young soils (on average 5−10 t $ha^{-1}a^{-1}$ soil loss). Erosion rates decreased markedly after 3−5 ka of soil development (on average 1−2.5 t $ha^{-1}a^{-1}$ soil loss) to reach a more or less stable situation after 10−14 ka (on average 0.3–2 t $ha^{-1}a^{-1}$). We conclude that climate change does not only cause glacier retreat, but also increases sediment dynamics. Depending on the relief and vegetational development, it seems to take up to at least 10 ka to reach soil stability. The establishment of a closed vegetation cover with dense root networks seems to be the controlling factor in the reduction of soil erodibility.

11.8
Effects of shallow incorporation of cover crop mixtures on short-term soil organic matter cycling in agricultural soils – An on-farm field trial

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Short term soil organic matter (SOM) cycling is an important part of soil fertility, soil health and crop performance. In an agricultural system the habitat for soil microbiology is constantly altered by farmer’s management. Within a single crop rotation there are periods of SOM formation and periods of SOM mineralization. Compared to the total amount of SOM, the quantities of these short-term changes are rather small. Therefore, it is challenging to measure these short-term SOM dynamics and accordingly current knowledge is quite limited. However, according to the state of research, cover crops are considered to play a major role in short-term SOM formation. The standard treatment to terminate green cover crops is either ploughing or herbicide application. A new and spreading method in agricultural praxis is to incorporate green cover crops into the first 0-5 cm of topsoil. Thereby, plant biomass is brought into the biologically most active soil layer and can serve as high quality energy source for soil microbiology which leads to a rapid decomposition. By this method farmers expect i) stimulation of soil microbiology ii) efficient formation of soil organic matter, iii) improvement of soil structure and iv) constant nutrient supply for the following crop. In this on-farm trial the direct influence of shallow incorporation of green plant biomass is assessed by taking soil samples in high density. The trial comprises the period of nine months between cereal harvest and sowing of spring crop. In this period two cover crops are sown and shallowly incorporated. The summer cover crop mixture consists of 12 species and the winter cover crop mixture of four species. Soil samples are taken right before cover crop incorporation and about one month after which leads to four sampling time points. At each time point samples are taken at 39 GPS referenced points and three soil depths (0-5, 5-10, 10-20 cm) resulting in 117 samples per time point. The trial is conducted on six fields in Eastern Switzerland. All samples are analyzed for total C, total N and permanganate oxidizable carbon (POXC, also referred to as active C). Additionally, soil microbial biomass is measured per field in a mixed sample with four replications. To analyze the 2600 GPS-referenced samples near infrared spectroscopy is used. The calibration of the spectral models is done for each field separately to achieve a high prediction accuracy. The presentation in the session will discuss the first results of the trial and the suitability of spectral measurements for high density sampling to detect small changes in SOM.

11.9
Aeolian soil erosion assessment ($^{239+240}$Pu) within a dry-oceanic area (Otago, New Zealand)

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New Zealand is characterised by high uplift rates and strong erosion. Currently only a few studies have investigated the local soil redistribution and degradation processes at the largest semi-arid area in New Zealand. Here we present the elemental redistributions results of our comparative study between small hills at an intraterrain valley and an adjacent ridge. On average the Plutonium based soil erosion rates in the valley are typically lower (86–435 [t km^{-2} yr^{-1}], PDM), compared to the ridge (193–1,108 [t km-^{2} yr^{-1}], PDM), confirming past ^{137}Cs-based rates. We estimated that about 400 to 660 [t km^{-2} yr^{-1}] are eroded by wind in the Otago upland through mass balances with local river sediment yields.

We found, that higher wind erosion is attributed to the exposed ridge which contains as much as 31% aeolian dust. In addition, the wind erosion effect on the landscape is evident in deep abrasion of the rock tors (large residual rocks). A variety of chemical weathering indices of the local soils have shown a faster mineral removal on the ridge and lesser degree of soil weathering in the valley. Further, a continuous soil surface rejuvenation is found to be present at the ridge, as the mineral decomposition is up to 25 % lower compared to the valley. Soils at both hilltops have the lowest weathering degree. We consider that fresh rock material from adjacent tors (large residual rocks) is causing a rejuvenated chemical weathering signature. The Otago upland is therefore characterised by strongly active geomorphodynamics (soil denudation and subsequently soil production), which are amongst the most intense and fastest in New Zealand.

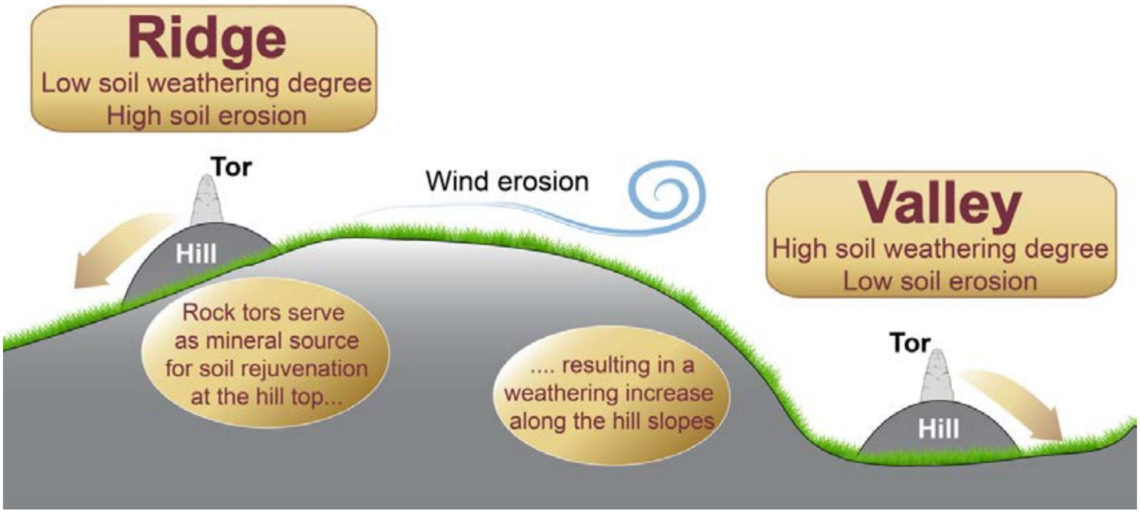

Figure 1: Graphical Abstract by Raab et al. (submitted).

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Raab G., Egli M., Martin A.P., Norton K., Lukens C., Ketterer M.E., Wanner R., Scarciglia F. (submitted). Assessing aeolian soil erosion with $^{239+240}$Pu within a dry-oceanic area of the southern hemisphere (Otago, New Zealand).

11.10
European Joint Programme 'Soil' (H2020 EJP Soil): Stocktaking on estimates of achievable soil carbon sequestration on agricultural land in Europe

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Soils are the largest terrestrial pool of organic carbon and can act both as a source and a sink for CO_2. Since agricultural practices have been endorsed as an option to remove CO_2 from the atmosphere to mitigate climate change, scientist worldwide are concentrating their research to answer questions such as: How and for how long can carbon be stored in soils? What are the potentials of agricultural measures to sequester carbon? As part of the project EJP Soil, we collected information on the available knowledge of achievable carbon sequestration in mineral soils in agricultural land, including pasture/grassland for 21 European countries, under different farming systems, soil types and pedo-climatic conditions as well as on GHGs mitigation measures for managed organic soils. The objective is to prepare an inventory as basis for the efforts to be taken by the EJP SOIL consortium members to estimate these potentials under different conditions, including the inventory of past and current studies on the topic and methodology used, and to identify potential gaps. First results indicate that the available knowledge is unevenly distributed across the continent (Fig. 1)

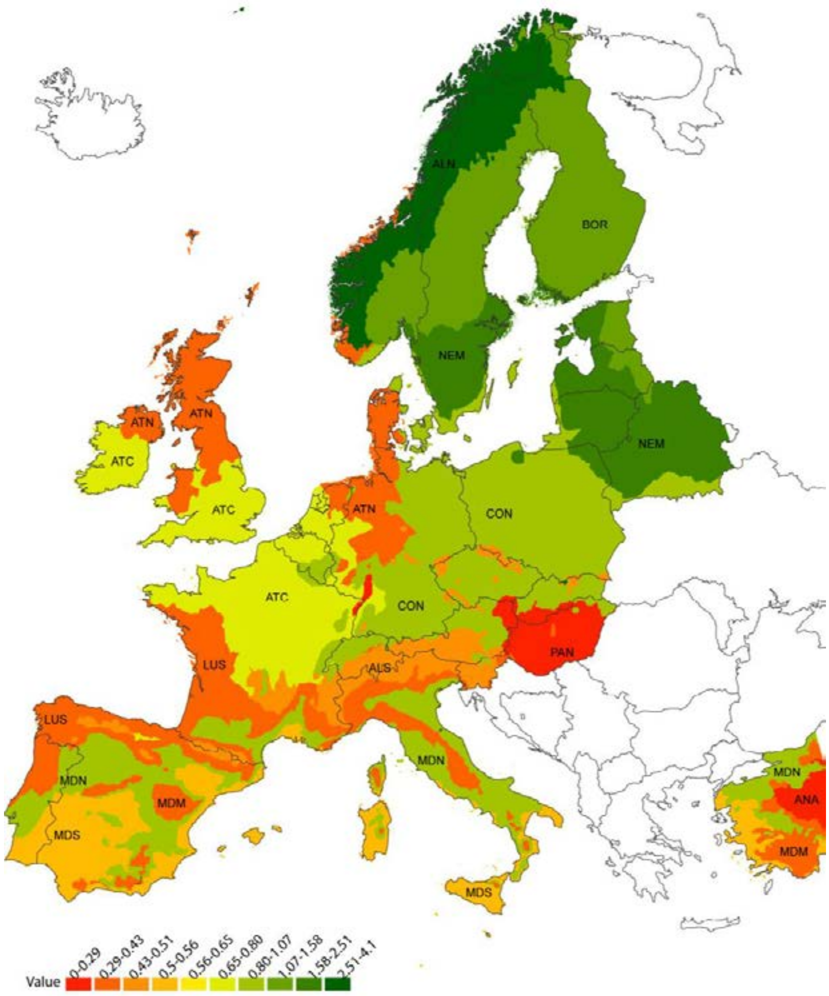

Figure 1: Data density (Studies per 10'000 km2) for each environmental zone (EZ) across Europe, normalized by its agricultural area. Value unit: Alpine North (ALN), Boral (BOR), Nemoral (NEM), Atlantic North (ATN), Alpine South (ALS), Continental (CON), Atlantic Central (ATC), Panonian (PAN), Lusitanian (LUS) Anatolian (ANA), Mediterranean mountains (MDM), Mediterranean North (MDN), Mediterranean South (MDS). EZ according to Metzger et al., 2005.

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11.11
Large clay contents in arable land do not limit soil structure quality and vulnerability

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High clay contents are often considered an obstacle for keeping good soil structure quality and large soil organic carbon (SOC) contents in arable land. This is particularly a concern since the soil structure vulnerability was shown to depend on SOC:clay ratio threshold values, with 1:10 being the structure vulnerability index (SVI) lower acceptable limit (Fell et al., 2018; Johannes et al., 2017). In this study, we sampled 96 fields from 58 farms in the Jura region with clay content up to 51.5%. Undisturbed soil samples were collected and measured for their physical properties, namely bulk density at -100 hPa, gravimetric water content at -100 hPa, gravimetric air content at -100 hPa. The soil structural degradation index (SDI) was calculated as the the ratio of air to water gravimetric content at -100 hPa as proposed by Johannes et al. (2019)such as food production, carbon and nutrient cycling or water regulation and filtration strongly depend on soil structure quality (SSQ. The samples were then visually scored with the CoreVESS method. Although the SVI was low in this study, the relationship between SOC and clay was linear on the whole clay content range (Figure 1). Physical properties were not impacted by clay content and were explained by SOC, suggesting that SOC is the main driver of the soil physical properties. The SDI structural quality classes and the CoreVESS observations did not show significantly different clay contents. We conclude that large clay contents are neither an obstacle for soil structure quality and vulnerability, nor for SOC content management. The characterization of the associated cropping systems was also discussed according to clay content.

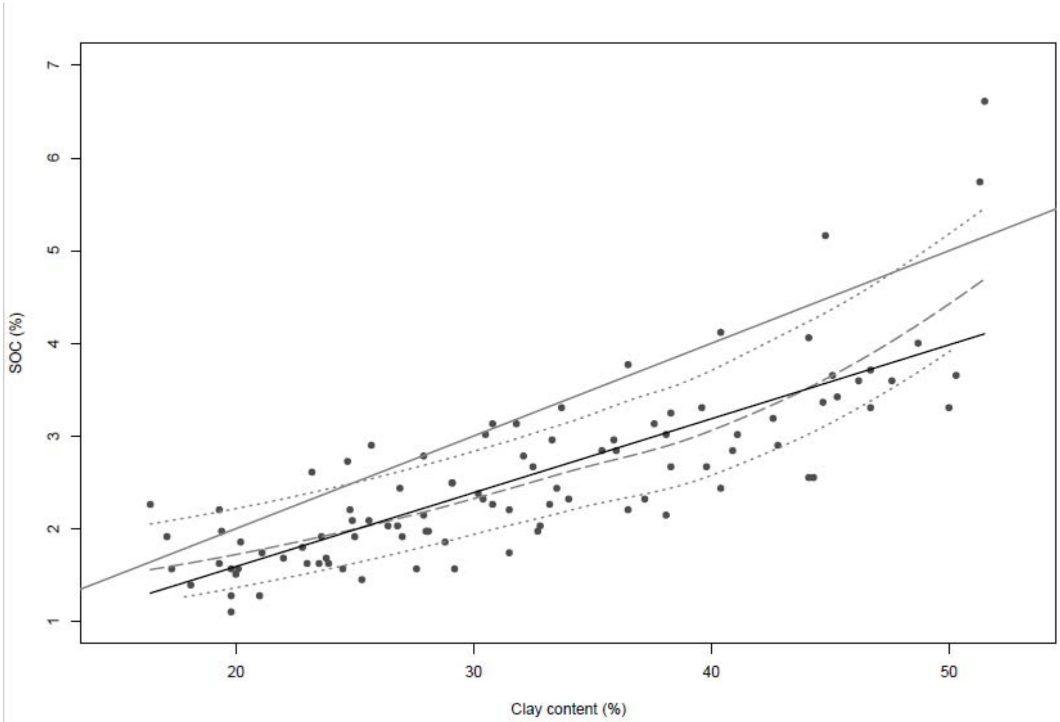

Figure 1: Linear model and "lowess" non-parametric local regressions between soil organic carbon (SOC) and clay content; black solid line: linear regression line ; light grey dashed line: lowess smooth curve (polynomial degree 2); light grey dotted lines: 95% confidence interval ; grey solid line: 10% SOC:clay ratio.

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11.12
Termites as soil engineers

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Fungus-growing termites (FGT) have long been considered as ecosystem engineers (Dangerfield et al., 1998) for the modifications they bring to the soil, their ability to concentrate nutrients, and their capacity to create patches of fertile land. Only a few studies have highlighted the ability of FGT to modify the grain-size distributions of the sediments and soils that are forming the environment where they develop (Jouquet et al., 2002). The aim of this talk is to present new data on soil textures affected by FGT and collected in a semiarid subtropical region of southern Africa. The key questions of the study relies on the capacity of fungus-growing termites (i) to adapt to any kind of parent material to build their mounds, (ii) and to enrich or deplete this parent soil to meet their texture requirements in terms of mound stability and appropriate settings to insure the success of the colony. In order to assess the sedimentary modifications carried out by termites on parent materials and their associated constructed mounds, the used techniques were mostly based on grain size distributions and soil micromorphology. Only a few studies have combined both methods to highlight the role FGT play in the selection of grain sizes to build their epigeal mounds (Abe et al., 2009). The study targeted the evaluation of the potential impact of FGT on texture modifications in an environment of contrasted grain sizes: (i) in soils dominated by sands and (ii) in soils dominated by fine material, in this case diatomites. Moreover and for the first time in this context, Electrical Resistivity Tomography (ERT) was used to investigate a fullsize underground fungus-growing termite mound. The 2D resistivity inversion ERT data emphasized the FGT amendments to the parent soil material, as expected. Consequently, from the above-mentioned results, it can be concluded that the FGT built mound converges to a required optimum, whatever a given parent material. Indeed, by selecting, transporting, and mixing at will the various grain sizes at disposition from the surrounding environment, FGT reach the mandatory texture adapted to the functions and properties for their mounds. Over time, these mounds will be flattened by erosion and will become a new soil/sediment. These results clearly recognize the role of fungus-growing termites not only as soil engineers, but also as biogeological agents able to modify the grain size distribution of the sediments in their environment

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11.13
Subsoil warming decreases abundance and modifies community structure of microorganisms

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Global warming is predicted to increase soil temperatures in near-synchrony with air temperatures at all soil depths. How microbial communities of the subsoil (below 30 cm) will respond to the predicted warming remains largely unknown. This knowledge gap causes uncertainty in predictions of future carbon fluxes from the enormous subsoil carbon pool (>50 % of the soil organic carbon [SOC] stocks are below 30 cm soil depth) to the atmosphere.

The Blodgett forest field warming experiment (California, USA) warms whole soil profiles to 100 cm soil depth by +4°C compared to control soils. Samples were taken after 4.5 years of continuous warming. We investigated how warming affects the abundance and community structure of microoganisms using proxies for bulk microbial biomass carbon and specific lipid biomarkers, such as phospholipid fatty acids (PLFAs) and branched glycerol dialkyl glycerol tetraethers.

After 4.5 years of warming microbial abundance was 28% lower in warmed subsoils compared to the control plots. In contrast, warming did not affect topsoil microbial abundance. The microbial community composition only changed in the subsoil: the relative abundance of Actinobacteria increased in the warmed plots below 50 cm soil depth and Gram+ bacteria in the subsoil adapted their cell-membrane structure to warming induced stress. Our results show for the first time that subsoil microorganisms are differently affected by uniform soil warming compared to topsoil microorganisms. The decrease in microbial abundance in subsoils was strongly correlated with lower soil organic carbon concentrations. We hypothesize that the microbial responses in subsoils could be related to changes in carbon availability. If easily available SOC becomes depleted and forces subsoil microorganisms to feed on previously stable SOC, these stable SOC pools might become more vulnerable to decomposition under global warming.

P 11.1
Do effective microorganisms (EM) affect the decomposition of organic matter?

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The shallow incorporation of cover crops with the intention to improve soil fertility has become increasingly popular in the recent years. Often, effective microorganisms (EM) are applied during green manure incorporation into soil with the aim to facilitate the decomposition process. Through EM application, the mineralization of the recently incorporated plant material is expected to be facilitated, increasing the nutrient availability for the subsequent crop. However, empirical evidence on the effectiveness of EM application on soils and their subsequent effect on soil parameters, including the availability of nutrients or even detrimental effects, such as mobilisation of toxic trace metals, is scarce.

For that reason, we performed a soil incubation experiment on a Swiss loamy Cambisol, simulating a cover crop decomposition procedure. Fresh topsoil (0-10cm) was passed through a 2mm sieve and amended by eight different treatments: Addition of a commercially available EM solution either 1) equal to vendor-recommendation 2) 100-times the vendor-recommendation 3) 100-times the vendor-recommendation past repeated heat-sterilization and 4) no EM addition. Each of the treatments were either incubated alone or with plant material, simulating fresh organic matter input. During a 28-day soil incubation at 12°C, soil pH, labile organic carbon (permanganate oxidizable carbon “POX-C”), respiration, water-extractable ions as well as trace metals were regularly assessed.

Addition of EM to soils amended with plant material decreased soil pH from 7.1 to 6.8 during the first three days after addition, yet the effect was reduced at later time points. Soil respiration, an indicator on soil microbial activity, was strongly enhanced by plant material addition, while the addition of EM showed no detectable difference compared to the non-amended control. Interestingly, labile carbon did not show any differences between treatments with and without plant material addition, indicating that POX-C is insensitive to recently added plant material. Yet, also EM addition did not alter labile organic C.

While the effects on water extractable ions and trace metals are currently analysed, we in the meantime conclude that neither the recommended nor the excessive addition of EM during green manure decomposition has detectable effects on soil organic matter decomposition or the utilization of added organic matter by microorganisms. The data set will be further corroborated with analyses whether or not added EM were able to establish in the soil over the period of soil incubation, using genetic tools.

P 11.2
Soil organic phosphorus characterisation in soils at early stages of pedogenesis

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Phosphorus (P) is an essential nutrient and can be found in organic and inorganic form in soil. During soil development, the relative proportion of soil organic P is commonly considered to increase with time. However, information on the occurrence of specific organic P compounds during the early stages of pedogenesis is scarce.

We characterised the organic P fraction of a young soil chronosequence to better understand which organic P compounds accumulate over a period of 136 years of soil development. Topsoil (0-5cm) samples of 21 sites in the forefield of the Damma glacier (Switzerland) were sampled. Soils were classified as Leptosols developed on granitic bedrock. Soil organic P compounds were determined in alkaline (NaOH-EDTA) soil extracts by using an enzyme addition assay: By the addition of substrate-specific phosphatase enzymes, specific organic P compounds were hydrolysed, causing an increase of inorganic orthophosphate in the extract and indicating the presence of specific organic P compounds. Four organic P classes were determined: phytate-like P, monoester-like P, diester-like P and enzyme-stable P (i.e. total organic P minus sum of the three enzyme-labile P classes). Obtained organic P classes were correlated with biotic and abiotic soil properties.

Total extractable organic P (i.e. sum of the four organic P classes) generally increased with soil development, but reached a plateau after 110 years of soil development. Between 60% and 100% of extractable organic P was hydrolysed by the added substrate specific phosphatase enzymes, indicating a potentially high lability of organic P during the early stages of soil development. Phytate-like P was the most abundant organic P compound (5 – 24 mg kg^{-1}), followed by monoester-like P (0 – 23 mg kg^{-1}) and diester-like P (0 – 11 mg kg^{-1}). These three enzyme-labile P classes increased linearly with time, but reached a plateau at the later stages of soil development.

Strong linear correlations of phytate-like P and monoester-like P with P bound in the microbial biomass as well as plant aboveground biomass in the first 78 years of soil development support the idea that both of these two sources were involved in the formation of these organic P classes. Interestingly, no such correlation was observed with the occurrence of Al- or Fe-oxides, which are potential binding sites for these organic P compounds in soil. Therefore, the occurrence of these compounds was more driven by the continuous and increasing input from different sources with time, rather than their stabilisation and protection from degradation on the soil solid phase.

This study thus contributes to an improved understanding on the factors driving the accumulation of specific organic P compounds in soil during early pedogenesis considering different formation, stabilization and degradation mechanisms.

P 11.3
Influence of parent material and weathering on soil organic matter stabilization in alpine ecosystems

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In the global carbon cycle, organic matter (OM) in soils represents the major terrestrial pool of carbon, storing roughly twice the amount of carbon as do the atmosphere and vegetation combined (Ciais et al., 2013). However, under changing environmental conditions, it remains unclear whether soils act as sources or sinks of carbon. Recent research has shown that the persistence of soil organic matter (SOM) is not only controlled by its molecular structure, but rather by the properties of its surrounding environment. The accumulation or loss of OM in soils is regulated by the interplay of climate, soil matrix development, nutrient availability as well as belowground vegetation inputs and microbial community structure (Doetterl et al., 2018). Nevertheless, there exists a lack of a more comprehensive understanding as to what extent these factors affect SOM stabilization. Especially the impact of parent material has remained an understudied control of organic matter cycling in soils. Although recent studies have shown the importance of soil physicochemical properties (which depend on parent material and soil weathering stage) on SOM persistence (e.g. Griepentrog et al., 2018; Rowley et al., 2018), current models of SOM cycling mostly do not include soil geochemical parameters (such as parent material). For example, soils developed on mafic parent materials exhibit relatively lower potential for decomposition of SOM compared to those developed on felsic parent materials, because of relatively higher mineral reactivity (and thus development of essential sites for OM stabilization). Furthermore, soils developed on marl with relatively higher potential to develop soil matrices that are able to stabilize SOM are expected to exhibit relatively lower potential for decomposition of SOM compared to soil developed on dolomite with relatively low development potential for soil matrices that are able to effectively stabilize OM. Additionally, soils at higher elevations are more vulnerable to decomposition compared to those at lower elevations, as they undergo less weathering and therefore have relatively lower potential for SOM stabilization. Taking all these expected effects into account, the hypotheses of this Master’s thesis are the following:

SOM stabilization will be highest in soils that provide a developed soil matrix and reactive mineral surfaces, which leads to large fractions of OM being stored in aggregate or mineral soil fractions where SOM is protected from degradation via physico-chemical interactions. Furthermore, SOM stabilization will be highest in soils that provide nutrients for plant growth through weathering of parent materials.

Hence, the objective of this Master’s thesis is to develop a mechanistic understanding of the impact of parent material on SOM stabilization through its influence on geochemistry and thus potential for soil matrix development and nutrient supply. The thesis will therefore address the following questions: What is the geochemical composition in soils developed on different parent material and what is its influence on (i) SOM stabilization, (ii) soil matrix development, and (iii) nutrient supply. Investigations will be carried out on soils which were sampled at elevations between 2000 – 2400 m.a.s.l. within five different geologies exhibiting varying geochemistry (i.e. greenschist, gneiss, marl, dolomite, and flysch). In order to get more insight into geochemical dynamics of the aformentioned parent material, weathering indices will be analyzed using Ti/Zr and Fe/Si ratios as well as contents of iron and aluminum oxides. Furthermore, the elemental composition, pH, soil texture and cation exchange capacity will be determined, as potentially major geochemical drivers of SOM stabilization.

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P 11.4
Rapid transformation of plant-derived soil organic matter in response to elevated CO_2 and warming in a spruce-dominated ombrotrophic bog

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Northern peatlands store approximately one-third of global terrestrial soil carbon, despite occupying less than 3% of the land surface. Rising atmospheric CO_2 concentration and temperature (6–10 °C by the end of the 21st century) are predicted to stimulate the decomposition of the stored carbon, contributing disproportionate amounts of greenhouse gases to the atmosphere (Hanson et al., 2020). Thus, peatlands could turn from net carbon sinks to net carbon sources and cause positive feedbacks to future climate. Peatlands are key ecosystem and their warming responses and underlying mechanisms need to be better understood.

In this study we assessed how 0–9°C of deep peat warming (0-200 cm) with ambient or elevated CO_2 (+500 ppm) affect the quantity and quality of soil organic matter (SOM) in the climate change manipulation experiment SPRUCE (Spruce and Peatland Responses Under Changing Environments) in Minnesota USA. We assessed how warming and elevated CO_2 affected the degradation of plant and microbial residues as well as the incorporation of these compounds into SOM. Specifically, we analysed free extractable *n*-alkanes and fatty acids combined with compound-specific stable carbon isotope ($\delta^{13}C$) analysis.

We observed a 6‰ offset in $\delta^{13}C$ between bulk SOM and *n*-alkanes, which were uniformly depleted in $\delta^{13}C$ when compared to bulk organic matter, confirming previous findings. Surprisingly, already after 4 years of deep peat warming and 2 years of elevated CO_2 a strong depth-specific response became visible with changes in SOM quantity and quality. In the upper 0-30 cm depth, the $\delta^{13}C$ values of bulk organic matter and of individual *n*-alkanes increase concurrently with increasing temperatures in both temperature and temperature x elevated CO_2 treatments, but not below 40 cm depth. Our results suggest that *n*-alkanes, which typically turn over slower than bulk SOM, undergo a fast transformation under relatively short period of simulated warming.

It remains to be seen how fast the deep (>40cm) peat will respond to rising temperatures and atmospheric CO_2 concentrations, and how this large carbon reservoir will respond to the changing environmental conditions.

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P 11.5
Swiss Mountain Soil Ecology Project

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Currently, undergoing significant climatic changes, terrestrial ecosystems are disturbed or even disordered. Because Swiss mountain ranges are concerned, it is crucial to look at the functioning of alpine environments to understand what the major issues for this natural environment are. In this way, the concerned authorities will be able to take adequate measures for the protection and conservation of these environments, and thus, maintain the ecosystem services supported by alpine environments such as the stability of the terrain, the regulation of water and hosting many animal and plant species. This diversity of landscapes in such a small and diversified territory (especially regarding the topography and rocky substrate) makes all Swiss soil profiles indexed in the Pedolibrary - a soil database - at the University of Neuchâtel , all the more valuable and very interesting. This collection includes more than 4'000 samples referenced by profiles and soil horizons. So far, several people have been involved in updating the database to be able to use it for research. The aim of this project is to gain knowledge in the field of science regarding soil-vegetation interactions while conducting feasible field and laboratory experiments.

Using a diachronic and synchronic approach, we will deepen our research questions working at different scales:

MACRO How do soil and vegetation properties correlate across spatial and temporal scales?

MESO What is the interdependence of soil and vegetation within a homogenous climatic zone?

MICRO What is the relative contribution of vegetation traits and climatic conditions for explaining soil organic matter formation and pedogenesis?

P 11.6
Understanding dissolved organic matter by destroying it

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Dissolved organic matter (DOM) is a ubiquitous complex mixture that resists usual attempts of identification due to its high chemical diversity (Hawkes et al. 2020, Roth et al. 2019). Even state-of the-art techniques such as liquid and gas chromatography, coupled to high resolution (tandem) mass spectrometry, are often hampered by characteristic chimeric mass spectra that are difficult to interpret and thus limit our understanding of molecular-level processes in the environment (Hertkorn et al. 2008, Petras et al. 2017). Ecosystem information encrypted within these mixtures thus remains largely elusive and descriptive. Tandem mass spectrometry (MS²) can reveal unknown imprints of isomers and isobars due to exact mass determination (Figure 1). We present an approach to decipher complex chimeric mass spectra of soil dissolved organic matter obtained by direct-infusion electrospray ionization tandem mass spectrometry (DI-ESI MS/MS). Pairwise alignment of all precursor and product ions revealed an exact mass difference (delta mass) matrix that was subsequently matched against two lists of known delta masses: 1) literature-known but non-indicative delta masses and 2) highly indicative delta masses derived from tandem MS experiments using a set of 14 phenolic standard compounds. Additionally, we fragmented four isobaric precursor ion mixtures (m/z 241 301, 361 and 417) at three normalized collision energies (15, 20, 25%) to analyze DOM fragmentation patterns and sensitivity. Our results reveal that full exploitation of MS fragmentation experiments produces valid biogeochemical data and helps to identify novel ecosystem process markers in DOM. Furthermore, our approach resolved the contribution of particular delta masses on the single precursor (molecular formula) level, which added a novel information layer to the frequently used Van Krevelen plot. The identity and number of matched delta masses agreed well with ion abundance and the number of distinct organic species in structure databases. The delta mass matching thus yielded new insight into the underlying patterns of DOM chemodiversity. Altogether, the results open up new avenues to access structural information encrypted within complex mixtures and study their link to ecosystem processes.

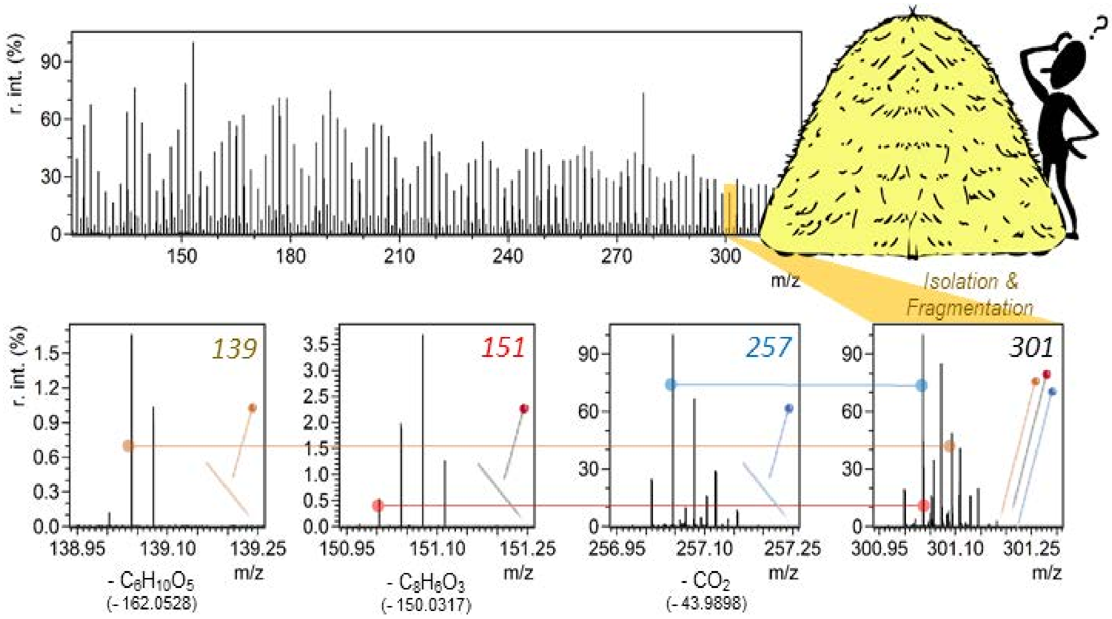

Figure 1. Typical non-targeted direct-injection mass spectra of dissolved organic matter resemble a haystack of metabolites, hampering the true identification of unknowns (upper panel). Lower panel: By isolation and fragmentation, certain “needles” (here, at m/z 301) can be “pulled out of the haystack” for MS fragmentation, yielding structural information. Thanks to ultrahigh resolution and exact mass determination, these chimeric tandem MS spectra can be dissected to obtain information on specific “needles”. Three exact mass differences are highlighted: neutral loss of CO_2, which is a common and non-indicative mass loss (m/z 257); neutral loss of $C_8H_6O_3$, which is also observed in flavonoids (m/z 151); and a neutral loss of $C_6H_{10}O_5$ (m/z 139), which could represent the loss of a sugar moiety.

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P 11.7
Changes In Soil Organic Matter Composition After Afforestation

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Ongoing climate change and specifically the increasing atmospheric CO2 concentration has led to a great interest in an improved understanding of the carbon cycle in terrestrial ecosystems. The increasing atmospheric CO2 concentration can accelerate soil organic matter (SOM) decomposition, which creates an imbalance between carbon input and output into the soil (Bradford et al., 2008). This rapid carbon loss causes soils to move from a carbon sink to a carbon source (Jones et al., 2003)

Following the Kyoto Protocol, afforestation has been acknowledged as a promising strategy for SOM conservation and to mitigate anthropogenic CO2 emissions. The establishment of forests on land that was not forested before leads to an increased carbon pool at the ecosystem scale due to the increase in aboveground tree biomass (Huang et al., 2011). However, the effect of carbon sequestration in soils depends on ecosystem properties, the former land use and on type of trees planted. Some studies show a decline in soil carbon concentration after afforestation of former pastures due to reduced root litter input (Hiltbrunner et al., 2013). Other studies, however, show an increase in soil carbon concentration 30 to 40 years after afforestation (Thuille & Schulze, 2006). Thus, there is a need for well-designed and site-specific experiments over several decades to investigate changes in the dynamics of SOM following afforestation to predict the behaviour of carbon sequestration under changing environmental conditions.

One approach to trace the sources of organic matter (OM) is the application of molecular proxies like phospholipid fatty acids (PLFA; Gunina et al., 2017) or cutin and suberin monomers (Huang et al., 2011). Though, focusing only on one compound class may lead to flawed conclusions due to missing information offered by other compound classes. One way to obtain more solid information on SOM dynamics is the combination of multiple compound classes (Li et al., 2018). The aim of this project is to identify possible sources of OM in soils in a subalpine afforestation sequence (40-130 years) with Norway spruce (Picea abies L.) on a former pasture in Jaun, Switzerland, by combining molecular proxies from several compound classes originating from various plant and microbial sources. This allows a more precise determination of the sources of OM and a better understanding of its transformation.

Root frequencies of living roots counted during field work revealed a larger quantity (+70%) of fine roots (< 2mm) in pasture compared to forest soils ($P < 0.001$). However, there was no significant age effect ($P = 0.09$) in terms of root quantities between the different forest stand ages. Nevertheless, the number of fine roots in the topsoil (0-10cm) exceeds the number of fine roots in the subsoil (20-40cm) by a factor of three, both under pasture and in forest stands of all ages. The lower root frequency and the changes in litter composition under spruce compared to pasture affects the quality of the SOM. As shown by Hiltbrunner et al. (2013), who observed changes in SOM dynamic through changes in quality and quantity of litter input following afforestation of former pastures as fine roots of grass have a lower lignin content (240 mg g-1) compared to fine roots of spruce (310 mg g-1). Further, they observed a decline of the SOM stock of the mineral soil after 30 years, with a minimum 40-45 years after afforestation. In contrast, mineral SOM stocks in the old forest (120yr) are equal to that in the original pasture. This is explained as older forests typically produce more biomass than younger forests, which leads to the accumulation of a forest floor with a large C amount originated from needle fall (Hiltbrunner et al., 2013). In our project, we further want to identify a precise rate of SOM input into soil, e.g. plant- and microbial-derived, decomposition and losses of old SOM following afforestation by combining molecular compound classes originated from various sources.

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P 11.8
Luminescence dating to unravel Ferralsol evolution in SE Brazil

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Thick and deeply weathered tropical soils are the basis for the most diverse ecosystems worldwide and an important pillar of global food production. Under today's increasing pressure on soils, the understanding of soil formation and its rate are essential. There is remaining debate if in-situ processes sufficiently explain the genesis and distribution of thick tropical soils, or if additionally, allochtonous components transported by e.g. water or wind have to be taken into account.

Luminescence dating is a promising tool of Quaternary research and increasingly recognized in soil science. Mainly regarded as tool to date sedimentation, it can also be used to evaluate rates of soil turnover by bioturbation. In this presentation, we present first luminescence ages from > 3 m thick Ferralsols near Piracicaba, SP, southeastern Brazil. Our data indicate Late Pleistocene to Holocene reworking. We discuss the significance of these ages to understand the formation of these soils and the implications for the paleoenvironmental development and present land-use.

P 11.9
Potential for inverse modeling to assist in source apportionment of organic matter in soil and peat using molecular biomarkers

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To study past environmental conditions, such as climate and vegetation, molecular biomarkers stored in soil and sedimentary archives have been used across a variety of studies. These biomarkers originate primarily from plants and include straight-chain lipids (particularly n-alkanes), suberin, cutin, and lignin monomers. While molecular markers can provide a wealth of information, their use can lead to problematic interpretations. It is often assumed that following deposition, there is little to no change in the concentration or distribution pattern of biomarkers, such as n-alkanes. A systematic literature review regarding the fate of n-alkanes in soil has indicated that this is an overly simplistic view. Preservation can vary based off of a variety of factors including climate and soil conditions. Additionally, most studies focus on only one or two compound classes of biomarkers, which can lead to an incomplete or incorrect understanding of results. To improve the use of molecular markers to reconstruct palaeoenvironments or identify sources of organic matter, we propose an inverse modeling approach to enable simultaneous analysis of multiple compound classes and increase the quantitative nature of results. Preliminary analyses show great promise for the use of our model in soil and peat archives. We will show findings gleaned from our literature review that will be used to determine essential parameters necessary for further improved source quantitation.

12. Cryospheric Sciences

Matthias Huss, Theo Jenk, Kathrin Naegeli, Nadine Salzmann, Andreas Vieli

Swiss Snow, Ice and Permafrost Society

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12.2 *Clerx N., Machguth H., Tedstone A.*: Hydrological processes at the runoff limit on the Greenland Ice Sheet

12.3 *Frey L., Frey H., Allen S., Farinotti D., Huss M., Grab M., Huggel C.*: Future glacial lakes of the world – characteristics, risks and opportunities

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12.10 *Mollaret C., Hilbich C., Pellet C., Hauck C.*: Towards a geoeletrical database for permafrost monitoring to enable the processing and repetition of historical measurements

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P 12.17 *Wicky J., Hauck C.*: The thermal behaviour of a low elevation cold talus slope: Insights through numerical modeling

12.1
Towards a global assessment of glacier change – A focus on satellite based geodetic mass changes in polar regions

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Glaciers all over the world are shrinking and are expected to continue doing so, with or without further temperature increase, as current glacier extents are out of balance with the current climatic conditions. For larger scale purposes, the geodetic method comes in place, which enables to assess the global sea-level rise contribution of glaciers. The Fluctuations of Glaciers (FoG) database at the WGMS collects datasets derived from remote sensing platforms (i.e. geodetic glacier elevation change data). The Copernicus Climate Change Service (C3S) aims and is in progress to extend the FoG database in space, time and to improve its regional representativeness. This work, as part of the C3S project, contributes to this aim by (A) improving estimates of glacier loss and sea-level rise by enhancing data coverage temporally and spatially, and (B) tackling the challenges associated with the application of DEMs for geodetic mass balance assessments (i.e. data voids, radar penetration).

We will present the basic concept of the C3S, what has been achieved since its launch in 2017, challenges we are facing as well as what we plan to tackle in the future. By doing so, the previously published study about glacier elevation changes of Greenlandic glaciers from 1980 to 2012 will be discussed. This study presents for the first time glacier-wide elevation changes for a large sample of Greenland peripheral glaciers and improved the assessments of the contribution of glaciers to sea-level rise.

12.2
Hydrological processes at the runoff limit on the Greenland Ice Sheet

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Surface meltwater runoff is responsible for roughly 60% of the current mass loss of the Greenland ice sheet. The runoff limit is the highest elevation from which meltwater finds its way off the ice sheet; above the runoff meltwater is captured by refreezing in the snow and firn. The location of the runoff limit therefore plays an important role in the mass balance of the Greenland ice sheet. Recent findings have shown that widespread ice slabs have developed on the Greenland ice sheet close to the runoff limit (Machguth et al., 2016). These ice slabs might impede meltwater from percolation and refreezing and accelerate surface runoff.
Hydrological processes in snow have been studied extensively, but little is known about meltwater flow through snow and firn on the Greenland ice sheet, and no direct evidence exists on how runoff is affected by the ice slabs.

In July 2020 we carried out a field campaign at 1760 m a.s.l. around the runoff limit on the Greenland ice sheet, near the KAN_U weather station in south-west Greenland. We did *in situ* measurements to study hydrological processes in relation to the location of the runoff limit and its evolution in time and space. We carried out snow pit and borehole measurements to assess firn stratigraphy, crystal structure, porosity and height of the meltwater table. Salt dilution and dye tracing experiments were performed to measure meltwater flow velocity and direction. Here we present first results from these measurements.

Substantial amounts of liquid water were encountered. The water flows towards intermittent supraglacial drainage systems through snow and firn overlying the ice slab. Measured flow velocities inside the snow matrix range from 3-15 m/hr. Meltwater flow behaviour and -direction is primarily controlled by regional surface slope but modified by local stratigraphic features such as ice lenses, ice slab surface undulations and the presence of supraglacial river beds from previous melt seasons.
These results show that significant quantities of meltwater flow at relatively high velocities atop the ice slab towards supraglacial discharge networks, allowing the water to leave the ice sheet through these systems. We conclude that the presence of ice slabs increases meltwater runoff. The relevance of this process to ice sheet mass balance remains to be quantified in future research.

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12.3 Future glacial lakes of the world – characteristics, risks and opportunities

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Accelerated retreat of glaciers is observed all around the world and is seen as an icon of climate change. This retreat is often accompanied by the formation of new glacial lakes, with remarkable and far-reaching impacts on the downstream population. These impacts include exposure to potential hazards such as glacier lake outburst floods (GLOFs), but such new lakes also provide potential opportunities, such as for hydropower exploitation or irrigation. To anticipate the formation of such glacial lakes and related phenomena for the future at global scale, we produce an inventory of all potential future glacial lakes of the world.

To do so, we draw on data produced by Farinotti et al. (2019), who provided digital elevation models (DEMs) of the glacier surfaces and an ensemble of associated ice thickness distributions for all glaciers on earth, based on up to four different models and a composite.

Using standard GIS procedures (ice thickness subtraction from the surface DEM, sink-filling, and raster to polygon conversion), and assuming complete melting of all glaciers and ignoring possible filling of sinks with sediment, we were able to derive an inventory of all future glacial lakes of the world. A special challenge was related to handling the large amount of data that was required for the analysis. With around 215'000 glaciers and up to five realisations of the ice thickness for each glacier, a highly automated processing approach using parallelization in a high-performance computing environment was applied. Processing of the ensemble of ice thickness realisations allows for a first-order quantification of uncertainties. Additionally, a validation of the ensemble of derived bedrock distributions against GPR measurements from Swiss glaciers with regard to reproduction of future glacier lakes was performed. We further plan to compute the topographic potential of each future lake for ice/rock avalanches (as potential GLOF triggers) (Romstad et al. 2009; Allen et al. 2019), and simulate GLOF trajectories and formation period for each lake (results pending).

Our results indicate that the total number of future glacial lakes in the world can reach 400,000, with a total lake volume of about 4000 km^3, a total lake surface area of around 70,000 km^2 (i.e. close to twice the area of Switzerland). The single largest future glacial lake, located at the Barnes Ice Cap in Baffin Island, Canada, will likely have a volume of about 150 km^3. At Konkordiaplatz on Grosser Aletschgletscher, models predict a potential future lake with a volume beteween 33 and 220 Mio m^3. The validation procedure indicated qualitative agreement between models and high accuracies (around 0.9) in reproducing future glacial lakes (binary: lake / no lake), yet no clearly best model emerged and quantitative performance indicators are realtively poor. This result, together with the uncertainties represented by the spread of the ensemble, demands caution in interpreting our results.

Nevertheless, our results allow for a global assessment of hazards, risks and opportunities related to future glacial lakes at regional scales.

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12.4
Improving temporal and spatial estimates of solid precipitation and snow accumulation in high mountain regions with statistically-based models

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The scarcity and the considerable uncertainties of precipitation observation and estimation in high mountain regions are a major drawback for enhancing our understanding of climatic-cryospheric processes and limits the reduction of uncertainties in related climate impact studies.
We are tackling the scientific challenge of improving precipitation estimates in high mountain regions by combining methods and data from atmospheric and cryospheric sciences. Here, we present a study in the Swiss Alps, which aims to produce temporally and spatially highly resolved estimates of Snow Water Equivalent (SWE) by applying statistical methods.
Firstly, a Multiple Linear Regression (MLR) combining weather radar composites (Rad4Alp network of MeteoSwiss) and specifically, the CombiPrecip product with COSMO-1 precipitation estimates and COSMO-1 10 m wind speed estimates is applied to produce temporally highly resolved estimate of solid precipitation. The MLR is trained with SWE from a Cosmic Ray Sensor (CRS) deployed on the glacier de la Plaine Morte. SWE estimates of another CRS located on the Findelgletscher are used to test the MLR estimates.
Secondly, the MLR is applied to the whole glacier area of eight Swiss glaciers. In order to evaluate our results on these glaciers, we compare them with the scattered end of season SWE measurements provided by GLAMOS (Glacier Monitoring Switzerland). The cumulated sums of our MLR estimates show a good agreement with end of season measurements. The difference between ground measurements and the cumulated winter precipitation is partially explainable by the radar visibility, melting and snow drift processes, which depend on the topography and local meteorological conditions.
Thus, we derived several high-resolution topographical indicators from a 25m resolution digital elevation model (DHM25, swisstopo) in order to explain the differences between GLAMOS measurements and our MLR precipitation estimates. The obtained model shows an increase of the correlation and a reduction of the mean bias error with respect to GLAMOS measurements. An example of the cumulated precipitation of the different products and models over the Findelgletscher is reported in figure 1. The final model is further validated with bi-weekly manual SWE measurements of SLF, in order to evaluate the model generalization for high mountain sites without glaciers.

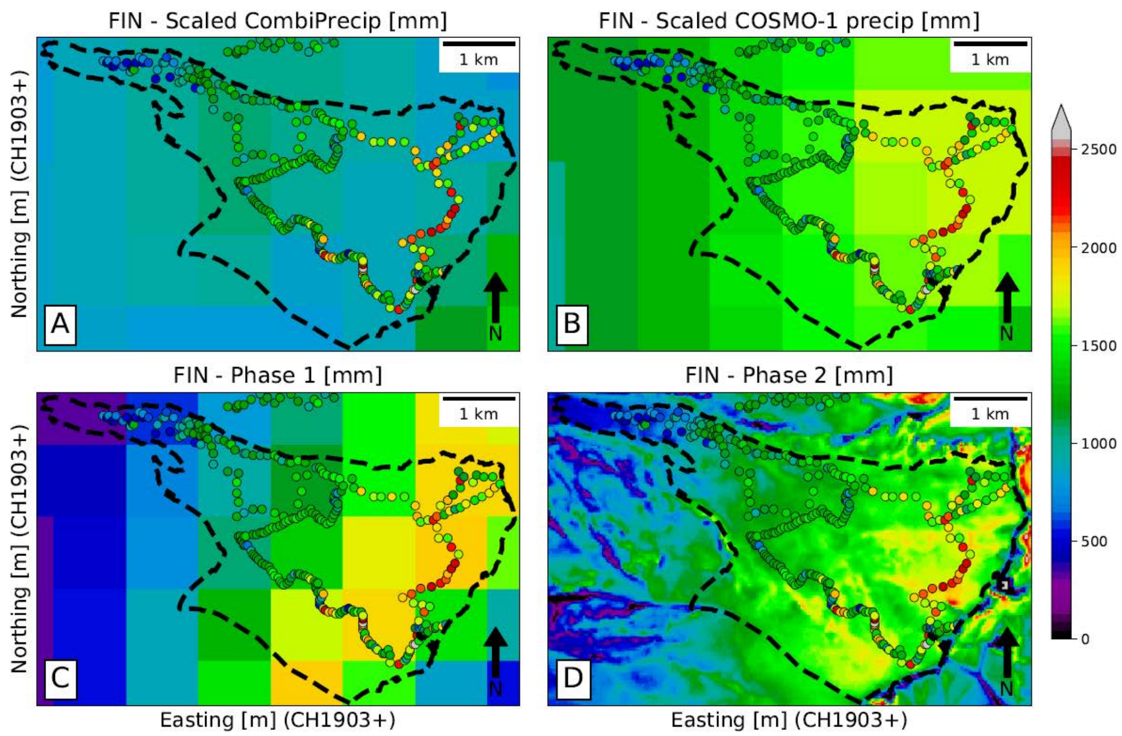

Figure 1. Maps of cumulated precipitation and GLAMOS observations over the Findelgletscher at the end of the winter season 18/19. (A): Scaled CombiPrecip, (B): Scaled COSMO-1, (C): Phase 1 MLR, based only on Plaine Morte site, (D): Phase 2 MLR, involving topographical parameters.

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12.5
Experiments on wind-driven heat exchange processes over melting snow

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Snowmelt runoff predictions in alpine catchments are challenging because of the high spatial variability of the snow cover driven by various snow accumulation and ablation processes. In spring, the coexistence of bare and snow-covered ground engages a number of processes such as the enhanced lateral advection of heat over partial snow cover, the development of internal boundary layers, and atmospheric decoupling effects due to increasing stability at the snow cover. The interdependency of atmospheric conditions, topographic settings and snow coverage remains a challenge to accurately account for these processes in snow melt models.

In this experimental study, we used an Infrared Camera (VarioCam) pointing at thin synthetic projection screens with negligible heat capacity. Using the surface temperature of the screen as a proxy for the air temperature, we obtained a two-dimensional instantaneous measurement. Screens were installed across the transition between snow-free and snow-covered areas for various topographic settings. With measurements taken at 10Hz, we were able to capture the dynamics of turbulent temperature fluctuations over the patchy snow cover at high spatial and temporal resolution. Combined with an ultrasonic anemometer and an eddy covariance sensor, heat advection and turbulent heat fluxes along the projection screens are investigated.

Preliminary results show the formation of a stable internal boundary layer (SIBL), which was temporally highly variable. Our data suggest that the SIBL height is strongly sensitive to the mean near-surface wind speed. Only strong gusts were capable of penetrating through this SIBL leading to an enhanced energy input to the snow surface.
With these type of results from our experiments we aim to better understand small scale energy transfer processes over patch snow cover, enabling to improve parameterizations of these processes in coarser-resolution snow melt models.

12.6
Detecting the crystal orientation fabrics of an ice core with non-invasive ultrasonic measurements

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The orientation of the hexagonal ice crystals provides valuable information about the history of the ice of glaciers and ice sheets. The stresses and strain rates force a development of typical crystal orientation fabric (COF) patterns. Typical COF patterns are a single maximum, a girdle structure or multi-maxima patterns. For single maxima, the ice grains and their c-axes are aligned in a certain direction and thus the basal planes are suitably oriented for simple shear stresses and a girdle is most likely the result of extensional forces. Multi-maxima pattern have been repeatedly observed in the ablation zone of temperate valley glaciers. This is a clear indication of a more complex stress regime.

Up to today, the COF is analysed under cross-polarised light. The ice grains divert the porlarised light according to their orientation. For this measurement, 0.3 mm thin ice core sections need to be cut out from the ice core. This is time consuming and requires some preparation. Furthermore, the valuable ice core needs to be fragmented and these samples are lost for further analyses.

Non-destructive seismic methods can be suitable to support the state-of-the-art fabric analysis. We developed a setup to analyse the COF of ice with ultrasonic measurements. By using point contact transducers, which can easily attached to the ice, we induce a high frequent acoustic wave into the ice and measure the travel times of the signals for different azimuths. With the known ice core diameter and the recorded travel times, we are able to calculate the seismic p-wave velocities for different azimuthal directions and determine the velocity differences as function of azimuth. We show and discuss the resulting velocity variations for such ultrasonic experiments compare them with theoretically derived acoustic velocities from the classical fabric analysis. Here, we found a considerable effect of large grain sizes, which are typically present in temperate ice. The large grain size together with the limited ice core sample size result in unbalanced and not representative measurement statistics. On this basis, we propose further improvements of the methodology.

12.7
Improving the representation of ice cliffs and supraglacial ponds in distributed glacier melt models

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Ice cliffs and supraglacial ponds play a major role in the mass balance of debris-covered glaciers by dramatically enhancing melt, but have only been represented in simplistic ways in distributed glacier melt models by adding a constant melt enhancement to the entire glacier. This representation ignores the dynamics of the ice cliff and pond population, as well as the inter- and intra-annual variability of their distribution and contribution to melt. Physically based melt models of ice cliffs and ponds have been developed at the scale of single features but are currently too computationally expensive to be run over long time-periods for more than a few cliffs or ponds. We have explored two promising avenues to improve the representation of these supraglacial features in distributed melt models. First, we designed two robust and efficient mapping schemes to delineate ice cliffs and ponds from multispectral satellite images. These approaches can be applied to both commercial and freely available, fine (1-5 m) and coarse (up to 10 m) resolution products, and perform overall better than the other existing approaches based on slope, brightness or object based image analysis (Fig. 1). Second, we implemented an automated tracking tool to understand the inter-annual birth and death rates, area changes and backwasting rates of ice cliffs and the filling and draining rates of supraglacial ponds. We ultimately use this data to build a stochastic model to represent the evolution of the cliff and pond population and its total contribution to melt at the glacier scale. This model is computationally efficient and can be easily implemented in future distributed glacier melt models.

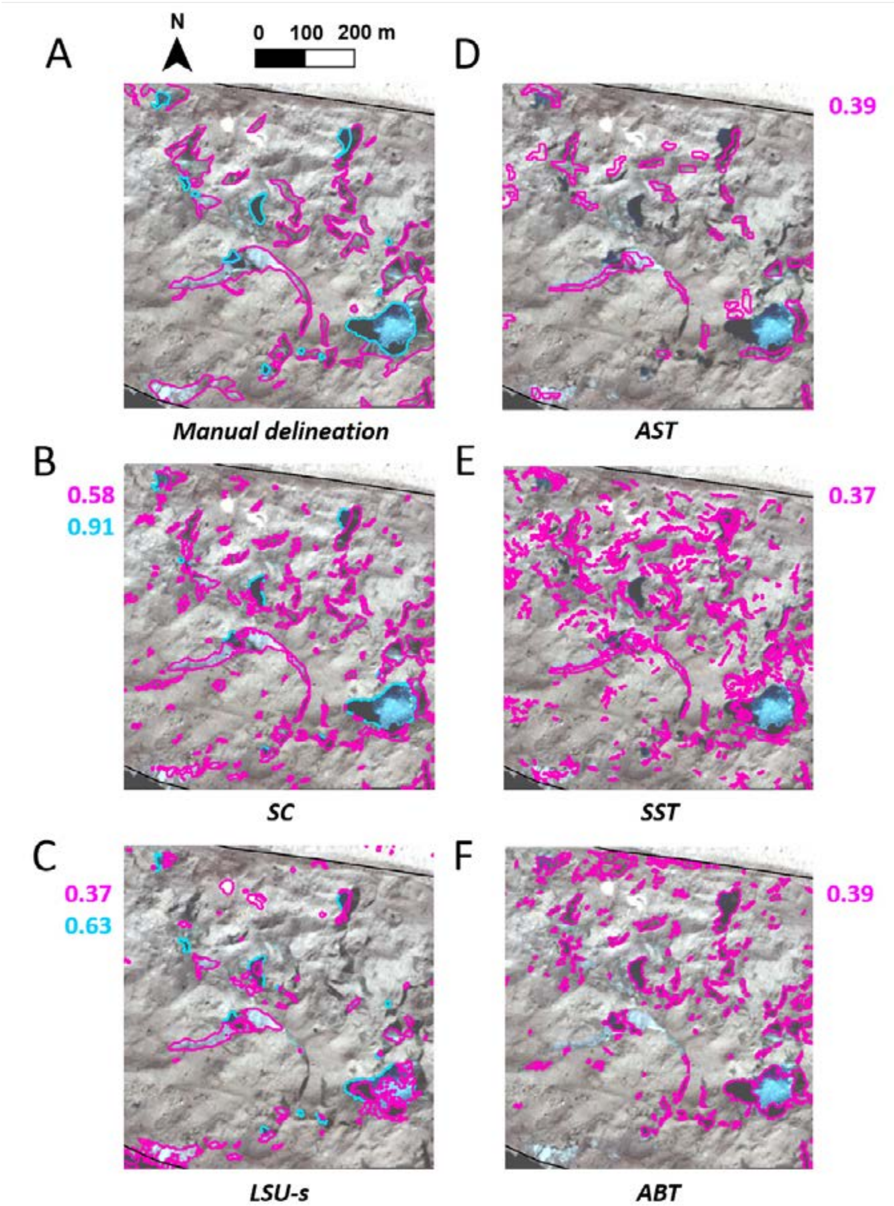

Figure 1. Comparison of the cliffs and ponds outlines obtained from the manual delineation (A), Spectral Curvature (B), Linear Spectral Unmixing with scale (C), Adaptive Slope Threshold (D), Simple Slope Threshold (E) and Adaptive Binary Threshold (F) approaches for a section of Bhagirati Kharak glacier (2 m resolution Pléiades scene from September 2018). The values in pink (resp. light blue) correspond to the Dice coefficient of the cliffs (resp. ponds) relative to the manually delineated outlines in this small domain. The background corresponds to the Pléiades false color composite.

12.8
Accessing forest snow cover dynamics in steep mountain terrain using UAV-based Lidar data

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The spatial and temporal dynamics of accumulation and melt of snow under forest canopy is of key interest for hydrology. However, mountain forests in Switzerland are typically located in steep terrain which is difficult to access, particularly during winter. Data concerning snow cover dynamics in mountain forests is therefore limited. Modern remote sensing technology, particularly airborne laser scanning, is a very promising technology for snow depth mapping in such environments. Here we use a Yellowscan Mapper II Lidar mounted on a multicopter, for mapping the snow depth in two opposite facing forested slopes in Davos, Switzerland. Consecutive snow-on campaigns took place from December to April 2020 with a high temporal resolution in both slopes, along with snow-off flights early spring. The flights covered a 200*200 m area incuding dense larch trees forests and forest gaps. A flight plan with interlaced patterns yielded very high point densities. Our validation of the resulting snow maps revealed RMSEs of only ~10cm.

Our data show interesting patterns on the distribution of snow under variable canopy cover, both in terms of small scale physiographic controls and canopy density. Also, the temporal dynamics is fundamentally different between snow cover from the two opposing slopes. Exploratory data analysis shows which factors at which length scale are correlated with the observed snow distribution. Such information can support the development of subgrid parameterizations within coarser-scale snow models.

12.9 Specific mass balance and health of glaciers in High Mountain Asia derived from the continuity equation

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Glaciers in High Mountain Asia have experienced intense scientific scrutiny in the past decade due to their hydrological and societal importance. The explosion of freely-available satellite observations has greatly advanced our understanding of their thinning, motion, and overall mass losses, yet our understanding of glacier accumulation and ablation rates is limited to a few individual sites. We combine recent assessments of ice thickness (Farinotti et al, 2019) and surface velocity (Dehecq et al, 2019) within the framework of the continuity equation to adjust observed glacier thinning rates (Brun et al, 2017) for mass redistribution and estimate specific mass balance across the region's glaciers. We evaluate our results at the glacier scale with field measurements of surface mass balance (35 glaciers sourced from WGMS and individual studies, e.g. Figure 1), then analyze 5527 glaciers comprising 58% of mass for glaciers larger than 2 km^2.

The specific mass balance results allow us to assess the health of High Mountain Asia's glaciers for the period 2000-2016 by determining the equilibrium line altitude, accumulation area ratio, committed loss, and ablation balance for each individual glacier. We find that 40% of glaciers accumulate mass over less than 20% of their area (Figure 2). These unhealthy glaciers are concentrated in Nyainqentanglha, whereas accumulation area ratios of 70%-90% are common in the Karakoram and Kunlun Shan regions. We find that surface debris extent explains up to 1000 m of ELA variability, reflecting the importance of avalanching as an accumulation mechanism for debris-covered glaciers.

Overall, 29% +/- 8% of regional ice volume cannot be sustained by current mass inputs, and 35% of glaciers are committed to lose at least half of their volume. In the Ganges-Brahmaputra basin, 41% +/- 6% of ice volume is unsustainable in current climatic conditions. However, we find that the most important and vulnerable glacier-fed river basins (Amu Darya, Indus, Syr Darya, Tarim Interior) are currently supplied with >50% sustainable glacier ablation due to the extensive accumulation areas of the Karakoram Anomaly glaciers. These results provide a comprehensive baseline for the health of the High Asian ice reservoirs in the early 21st Century, and highlight the potential synthesis of distinct remote-sensing observations to understand patterns of recent glacier change.

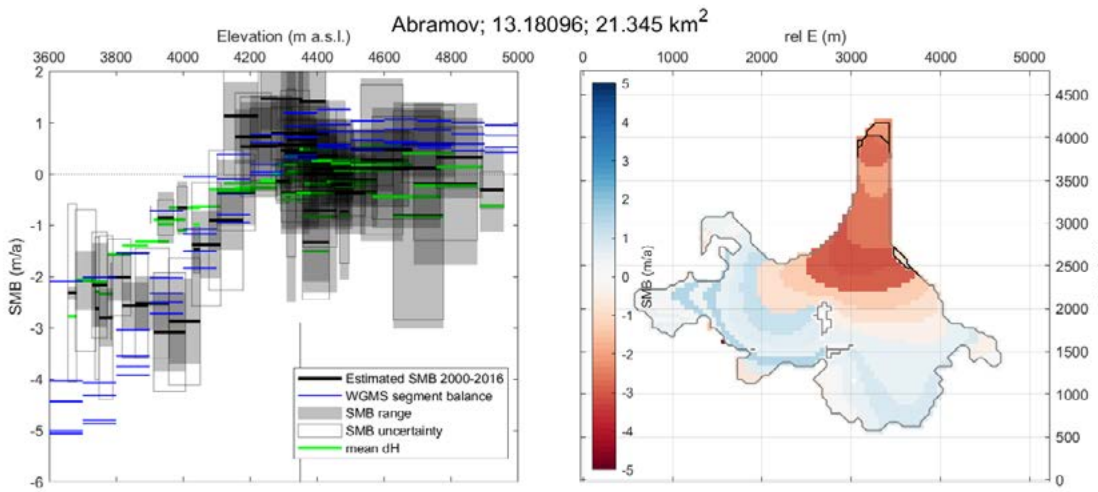

Figure 1. Continuity-based reconstruction of specific mass balance for Abramov Glacier, showing comparison to WGMS (2019) database of surface mass balance measurements (left), and spatial distribution of specific mass balance (right).

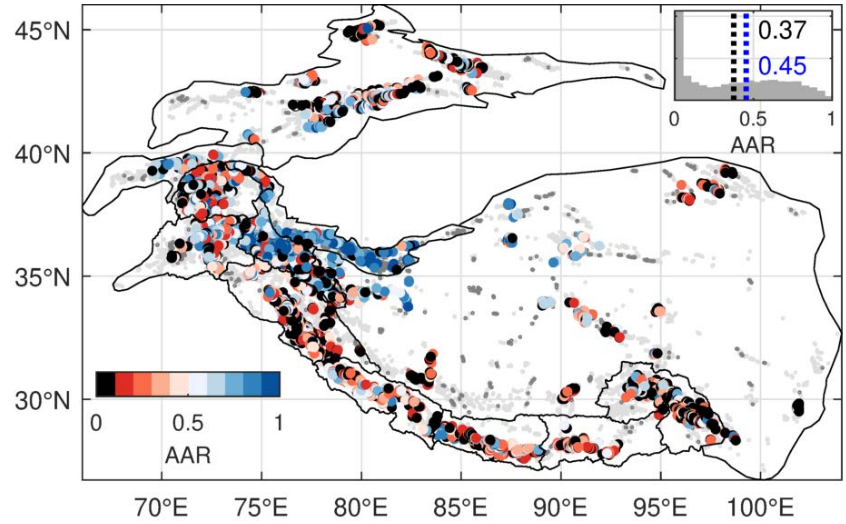

Figure 2. Regional distribution of Accumulation Area Ratios (AARs) for each glacier derived by the continuity approach, along with a histogram of AARs (inset) showing the regional mean (blue) and median (black) values.

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12.10
Towards a geoeletrical database for permafrost monitoring to enable the processing and repetition of historical measurements

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Electrical imaging has been widely applied for permafrost detection and monitoring over different spatial scales. Only very few permafrost sites worldwide are continuously monitored with ERT as part of national monitoring programmes (~10). On the contrary, a much larger number number of individual ERT surveys from the past exist (estimated to be >200 alone in the Swiss Alps). These data sets are neither included in a joint database nor have they been analysed in an integrated way. Within a GCOS Switzerland-funded project we address this important historical data source.

In a first step, historical data on permafrost terrain from UniFR groups and their collaborating national and international partners were collected and metadata archived (> 150 profiles). Based on this data collection, we will present a protocol of measurements repetition for summer 2021. Some of the historical measurements were already repeated in summers 2019 and 2020 (e.g. Etzelmüller et al. 2020, Hilbich et al. 2019). The resulting resistivity changes on time scales of 10 to 20 years are presented and analysed according to several sites characteristics such as geomorphology, elevation and surface type. These results are analysed in the context of climate change, showing the value of repeated ERT measurements to detect the climate signal of permafrost change after time spans up to 20 years.

In a second methodological step, the Reproducible Electrical Data Analysis (REDA) scientific Python library (Weigand and Wagner, 2017) will be used for the homogenisation of processed ERT data. It is aimed to reprocess the historical data in an integrative and reproducible manner. Technical challenges for reprocessing a large number of data sets in an integrative way will be discussed. Furthermore, the structure and the ongoing implementation of the international open-access database for ERT surveys is described.

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12.11
Permafrost warming in the Swiss Alps – 20 years of measurement in the framework of PERMOS

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The Swiss permafrost monitoring network PERMOS documents the state and changes of permafrost in the Swiss Alps. It started in the year 2000 as the first national network for long-term permafrost observation. Today it includes the longest and most diverse collection of mountain permafrost data. After 20 years of operation the results based on three main observation elements show a consistent picture of permafrost changes (Figure 1, PERMOS 2019): permafrost is warming, containing less ice but more water, and is flowing faster. The period covers the two decades with the highest air temperatures ever measured in Switzerland and changes were more pronounced in the past decade. Ground ice content and the temporal and spatial snow distribution are the most important factors influencing the change patterns: temperature changes in warm and ice-rich permafrost approaching 0 °C are minimal due to latent heat effects, highest warming rates are measured in cold permafrost in steep bedrock sites at high elevation, and the timing of the snow cover can accelerate or interrupt warming trends.

The PERMOS observation strategy was evaluated repeatedly over the past decades and adapted to new findings and technology. Today, it builds on direct measurements of permafrost temperatures in boreholes, which are complemented by geophysical surveys to detect changes in ground ice content and terrestrial geodetic surveys for the observation of rock glacier creep velocities. These three elements allow for a comprehensive view on permafrost changes. The PERMOS network includes a total of 27 study sites, which are spread throughout the Swiss Alps and are maintained by six academic partner institutions. The network is financially supported by MeteoSwiss in the framework of GCOS Switzerland, the Federal Office for the Environment (FOEN), and the Swiss Academy of Sciences (SCNAT).

All PERMOS data is available open source at the PERMOS Data Portal: http://newshinypermos.geo.uzh.ch/app/DataBrowser/

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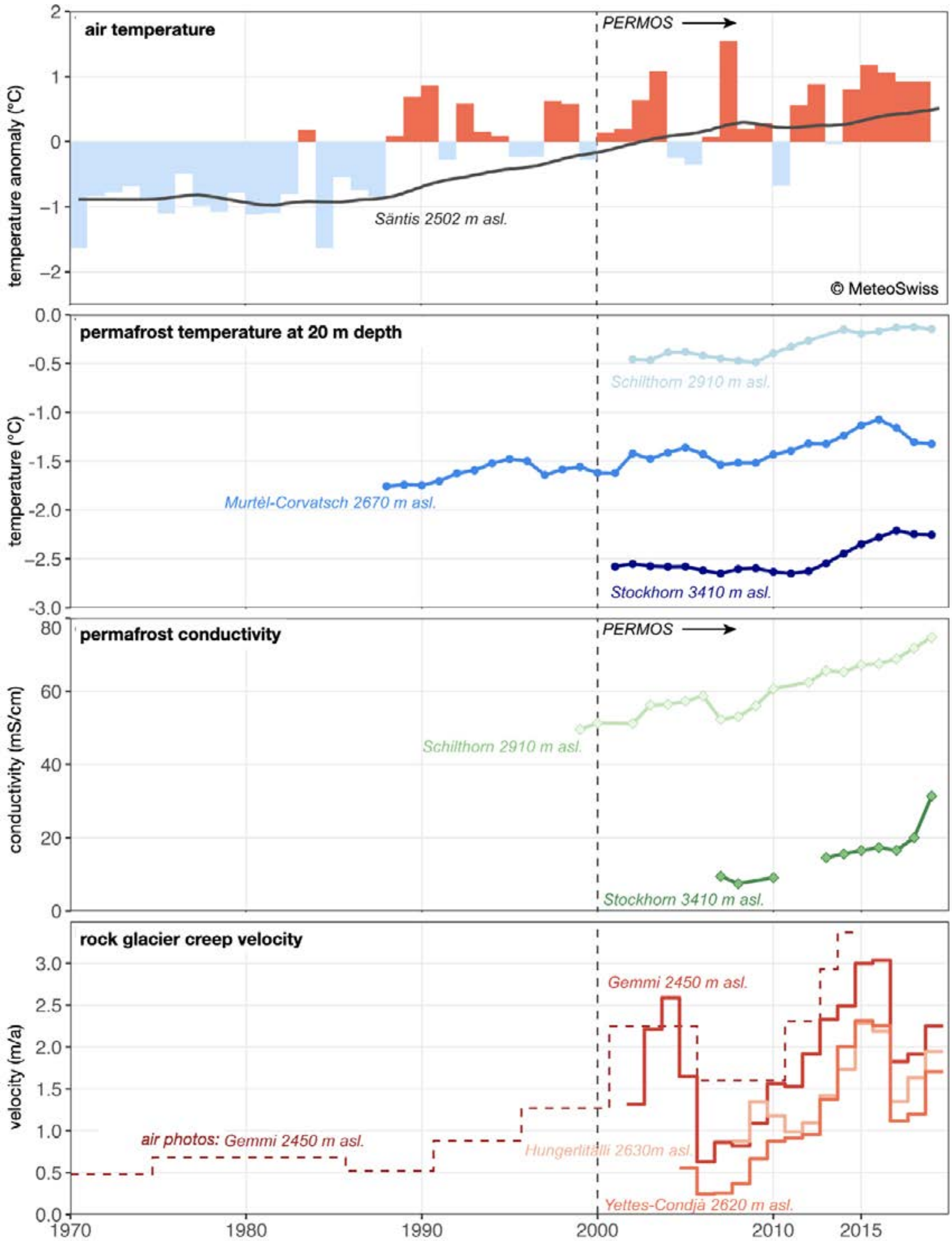

Figure 1. Permafrost evolution based on twenty years of measurements in the framework of PERMOS compared to air temperature anomalies based on data from MeteoSwiss.

12.12
Characterising englacial R-channels using artificial moulins

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The theory of channelised en- and subglacial waterflow through so-called R-channels was established by Röthlisberger (1972). This theory has now been widely used for almost 50 years, however, its parameters are still not well constrained. In order to obtain the hydraulic friction parameter and the evolution of the cross-sectional area of an englacial R-channel over time, we conducted experiments in two artificial moulins on Rhonegletscher.

To create artificial moulins we drilled to the glacier bed with a hot water drill and diverted water from a nearby stream down into the boreholes. By installing Conductivity Temperature Depth sensors (CTDs) at different depths in the boreholes and by injecting salt tracers regularly over a time period of two weeks we obtained the hydraulic gradient, the flow speed and the water discharge through the artificial channels. This information then allowed us to compute the cross-sectional area and the hydraulic friction parameter.

This is the first time that the hydraulic friction parameter and the time evolution of the cross-sectional area of an R-channel were directly determined from field experiments. Constraining the parameters of R-channel theory will help improving the predictions of glacial drainage models.

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12.13
Observations of Coherent Backscatter Enhancement in Dry Snow Using Bistatic Radar.

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The coherent backscatter opposition effect (CBOE) is a phenomenon which causes increased backscatter intensity of coherent radiation at small bistatic angles (less than 1 degree) in random disordered media, due to constructive interference of each EM wave scattered in the volume with its time-reversed counterpart. The exact angular width and height of the intensity peak depend on the properties of the incident radiation (wavelength, polarization), the random medium (grain size, mean free path, reflectivity), as well as measurement geometry (local incidence angle, layer thickness). It has been previously investigated in order to better characterize surfaces of various Solar System bodies (Hapke et al. 1998, Black et al. 2001), however it has received comparatively little attention in Earth-focused observations, despite the well known occurrence of significant volume scattering within snow and ice.

In this submission, we report on observation of the intensity peak in a snow layer on top of the peak Rinerhorn in Davos, Switzerland (Figures 1 & 2), using an experimental bistatic, fully-polarimetric, real-aperture, Ku-band radar – KAPRI (Baffelli et al. 2017). We also report on observation of backscatter enhancement in the accumulation zone of Aletsch glacier in space-borne observatios with the bistatic synthetic aperture radar mission TanDEM-X.

The measured parameters of the enhancement peak (height, width) can further be connected to physical parameters of the scattering medium. For example, the half-width at half-maximum of the peak can be related to the mean free path between scattering events within the medium (Hapke et al. 1998, eq. 1). Using this model, for KAPRI measurements we can estimate the mean free path within the snow layer to be approx. 53 cm.

We believe that further study of CBOE in the context of Earth-focused observations of snow and ice opens new opportunities for development of quantitative models aiming to derive snow properties from bistatic radar observations.

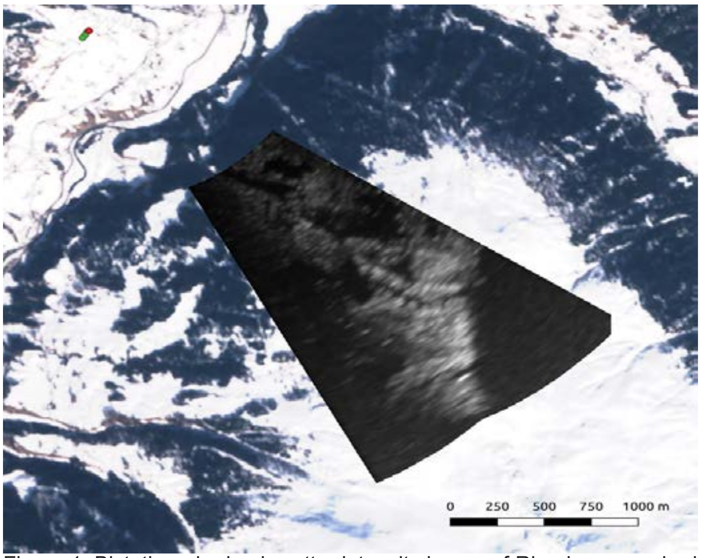

Figure 1. Bistatic radar backscatter intensity image of Rinerhorn acquired by KAPRI. Map underlay source: Modified Copernicus Sentinel data 2020/Sentinel Hub.

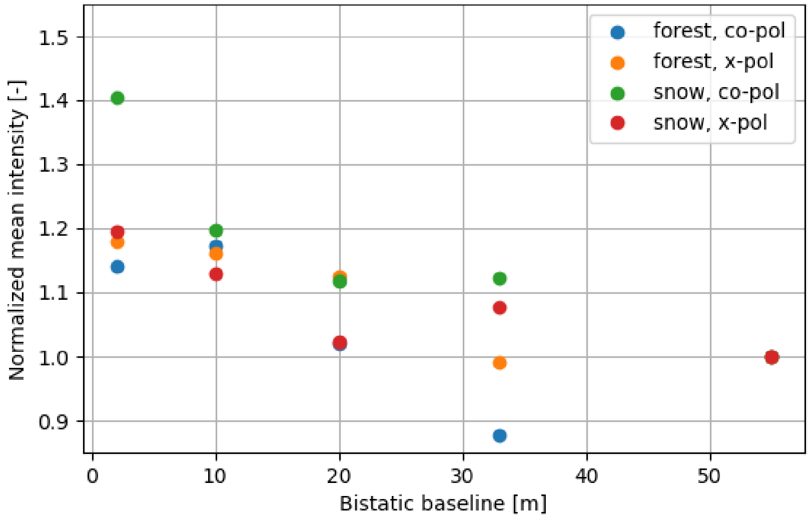

Figure 2. Measured mean backscatter intensity dependence on bistatic baseline between transmitter and receiver (KAPRI data). Range distance to observed area is approx. 3km. In snow, significant enhancement is observed in the co-polarized polarimetric channels in the monostatic direction. Enhancement of smaller magnitude is also observed in the cross-polarized polarimetric channel, and also in forest ROI. All measured intensity values were normalized to the value at 55m baseline.

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12.14
The history of glacier study of the Greater Caucasus and current state of observation

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The Greater Caucasus is one of the major mountain systems in Eurasia, stretching ~1,300 km from the Black Sea in the west to the Caspian Sea in the east with glaciers covering about 1200 km^2. As the Greater Caucasus Range is located on the boundary between temperate and subtropical climatic zones, the orientation and height of the range determines the contrasts between the northern and southern macroslopes, with generally larger glaciers in the north than in the south.

In the first part of this work I briefly present the history of the glacier research in the Caucasus Mountains. The second part is more about the current state of glacier observation. I will also present the percentage and quantitative changes in the number and area of Caucasus glaciers over the last half century. Some results of the supra-glacial debris cover assessment will also be provided.

Changes in glacier extent between 1960 and 2014 were determined through analysis of large-scale topographic maps (1:50 000 scale) from several hundreds of aerial photographs taken between 1950-1960 and images from Landsat 8 Operational Land Imager (OLI), and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The 30 m resolution ASTER Global DEM (GDEM, 17/11/2011) was used to determine the aspect, slope and height distribution of glaciers.

P 12.1
A 'subsurface weather station' to measure boulder-mantle heat fluxes on Murtèl rock glacier

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The debris cover of rock glaciers partially decouples the underlying ice-rich permafrost from the atmosphere, retarding permafrost degradation and making rock glaciers locally important water storages in future deglacierized arid mountain ranges. Heat exchange between atmosphere and permafrost table mainly governs seasonal active layer thawing and long-term permafrost ice melt. However, in the open-framework boulder mantle, heat exchange processes are complex. Numerical modelling and laboratory experiments showed that long-wave radiation between boulders (Lebeau & Konrad, 2016) and convection by air circulation (Wicky & Hauck, 2020) are not negligible with respect to simple conduction.

We attempt to quantify the relative importance of the different energy fluxes by measuring heat-flux components in the boulder mantle of the rock glacier Murtèl (Upper Engadine). This intensively studied rock glacier is an ideal test site because the internal stratigraphy (active-layer thickness, ice content) is known from boreholes and the surface meteorological conditions are continuosly measured (Fig. 1, boreholes and meteo station).

We augment the decade-long (surface) meteorological time series and borehole temperature data of the Murtèl rock glacier with a three-part array of sensors:
First, we place microclimate sensors in a natural cavity within the open-framework boulder mantle (Fig. 1, boulder-mantle sensors). They capture conduction in boulders, radiation, and air and moisture flow in the active layer. The upper boundary condition (BC) is resolved by additional sensors for eddy-correlation based turbulent heat flux calculations and sensors for snow-cover characterization (Fig. 1, atmospheric and snow sensors). Ground heat flux from the underlying rock-glacier core (lower BC) is calculated via existing borehole temperature data. Second, this point measurement is complemented with temperature and wind-speed loggers distributed over the rock glacier to capture large-scale air circulation patterns. Time-lapse images in the visible light and thermal infrared ranges monitor seasonal snow-cover and surface temperature evolution (Fig. 1, cameras). Third, hydrological measurements in the rock-glacier forefield consisting of electrical conductivity, water temperature and water column height serve to track water provenance and to estimate discharge (Fig. 1, hydrological sensors).

The project focuses on understanding the temporal evolution of water resources in periglacial catchments and more reliable ice-rich permafrost runoff forecasts. This process understanding will also improve predictions on downwasting rates of debris-covered glaciers.

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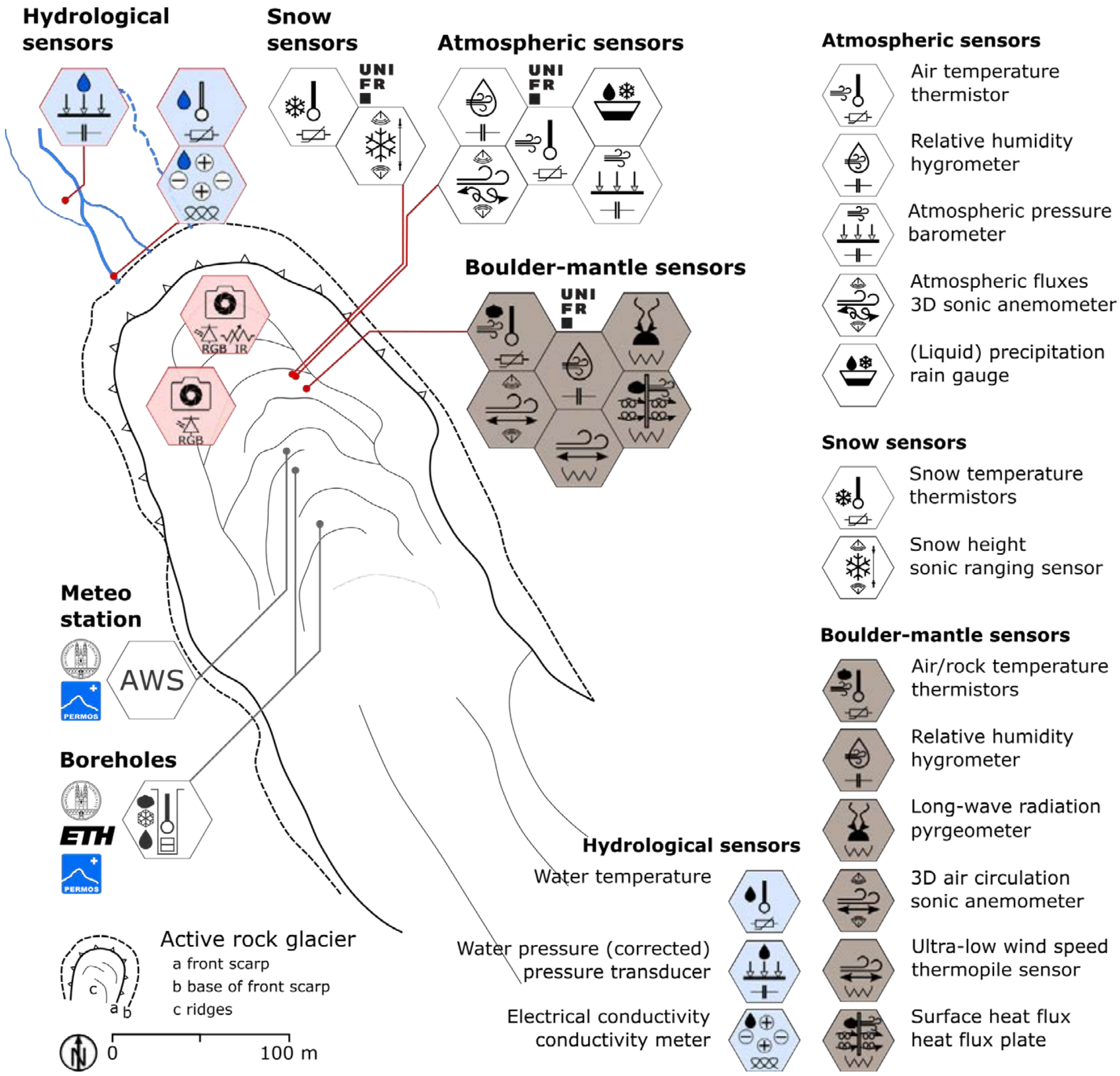

Figure 1. Sketch map of the Murtèl rock glacier with existing sensors (meteo station and boreholes) and newly deployed sensors (cameras, hydrological, snow, atmospheric and boulder-mantle sensors).

P 12.2
Unveiling the secrets of the debris cover of the Zmutt Glacier (Valais – CH)

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Supraglacial debris strongly influences the morphology, dynamics and mass balance of debris-covered glaciers. When debris-laden ice melts, a surface debris layer is left behind which insulates the glacier and thereby reduces the ablation rate. Therefore, a better understanding of the processes controlling the evolution of debris-covered glaciers and their mass balance requires detailed information about the debris cover (Mölg et al., 2019).

For this purpose, we investigated the debris cover and the energy balance of the Zmutt Glacier (Valais - CH) by means of in-situ and remotely sensed observations. During two field campaigns in summer 2020, we surveyed a small area on the glacier characterized by large spatial variability in debris thickness.
We performed nine repeated flights with an unmanned aerial vehicle equipped with an infrared sensor under different weather and radiation conditions at different times of the day. The resulting temperature maps are constrained by calibration measurements of ground surface temperature within the debris cover and at the location of supraglacial water ponds.

Additionally, two meteorological stations monitoring liquid precipitation, wind speed and direction, short and long wave radiation (incoming and outgoing) as well as air temperature have been installed on the glacier tongue; one within the surveyed area and the other one two hundred meters of elevation lower.
On the basis of this unique dataset, a numerical inversion of the thermal imagery using energy mass balance modelling allows to recover the debris thickness over the surveyed area.
The modelling is validated by comparing the calculated values with numerous direct measurements performed in the field.

First results from this method are promising, showing a clear relationship between the temperature field and corresponding debris thickness inversion. Further work is required to quantifiy the uncertainties due to spatial inhomogeneities and to better understand process feedbacks.

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P12.3
Impact of debris cover on future evolution of HMA glaciers

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Knowing the future evolution with accuracy of glaciers is extremely important, so that appropriate measures can be taken to mitigate negative impacts on sea level change, hydropower production and water availability. However, to date, the majority of regional- to global-scale glacier models (Marzeion et al., 2020) do not explicitly model ice flow, do not take debris cover evolution into account, and were not forced with the latest climate projections from the Model Intercomparison Project Phase 6 (CMIP6).

In this study, we extend the capability of GloGEMflow – a combined mass-balance ice-flow model (Zekollari et al., 2019) – with a newly developed debris evolution component, and applied it to all glaciers in High Mountain Asia (HMA). The model was initialized with the ERA5 re-analysis product, while the future forcing was provided by CMIP6 climate projections. The model was calibrated with glacier specific geodetic volume changes covering more than 98% of HMA's glaciers (Hugonnet et al., in review). Contemporary debris cover was classified using Landsat scenes, and debris thickness was determined by using an energy-balance model to constrain altitudinal Ostrem curves, combined with sub-debris specific mass balance estimated through the continuity equation. In GloGEMflow, debris cover and its thickness evolve in the future as a function of mass balance and ELA change, and are calibrated through satellite observations spanning the last 30 years.

First results from model runs with and without the debris-evolution component showed significant discrepancy in the projected future glacier evolution. Indeed, the reduced (enhanced) ice melt beneath debris thicker (thinner) than a few centimeters, does not only impact the local mass balance (Fig. 1c, 1d) and therefore the future glacier geometry (Fig. 1a, 1b), but also the total future volume evolution. Constraining debris accumulation on glaciers is key to understand future glacier evolution.

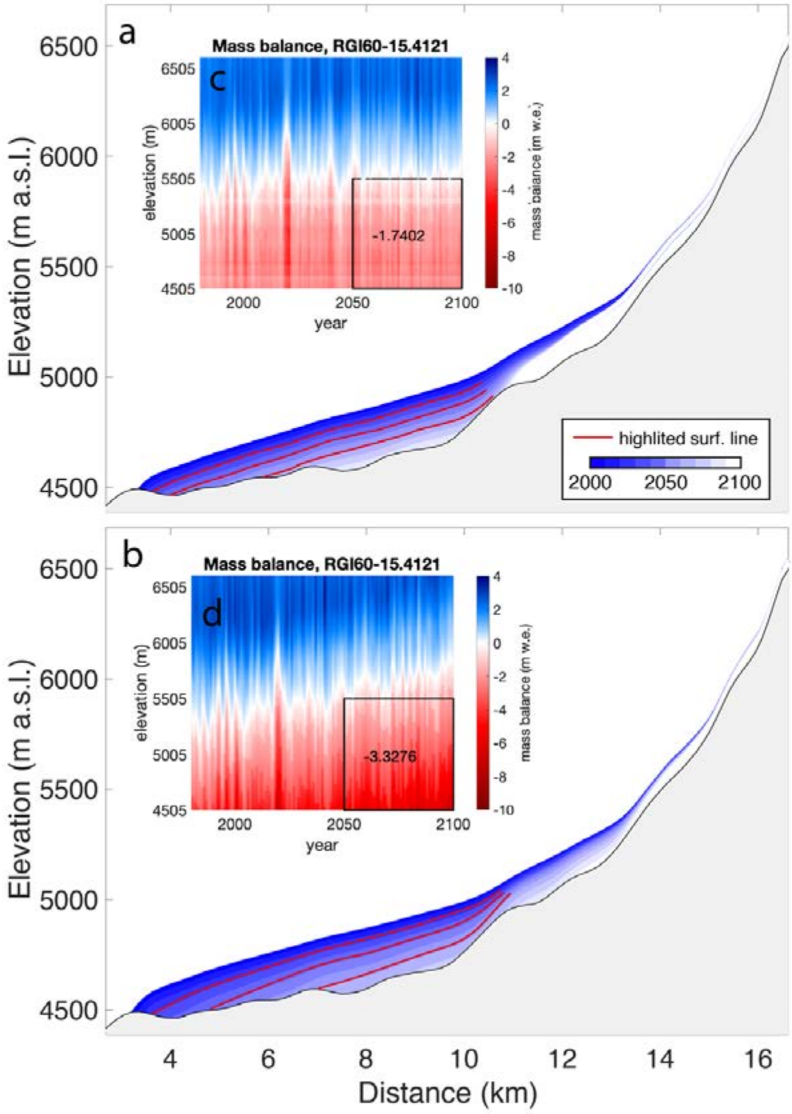

Figure 1. Future evolution of Langtang Glacier in scenarios (a) with debris cover and (b) without debris cover. Panels (c) and (d) show the corresponding mass balance evolution. The red highlited surface lines in (a) and (b) show how the glacier geometry evolves differently.

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P 12.4
Nonlinear feedbacks driving pattern formation on debris-covered glaciers

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Debris-covered glaciers are commonly found in most glaciated regions of the world. When debris mixes with the ice in the accumulation zone, primarily due to avalanching, it eventually melts out in the ablation zone and remains on the surface of the glacier where it reduces the surface melt rate once it becomes thick enough. The mean debris layer thickness increases down-glacier but the local surface morphology tends to be highly irregular and typically exhibits a range of patterns from individual humps to lengthy medial moraines.

In this study, we examine the evolution of surface patterning on debris-covered glaciers by developing a numerical model that captures the coupled effects of ice transport, debris transport, melt out, debris redistribution due to topographical effects, and shading effects due to feedbacks between aspect and surface roughness. We perform a sensitivity analysis to determine which feedbacks are most important for surface pattern evolution and we compare our model results with field observations from Zmuttgletscher, Valais.

P 12.5
Rescue, documentation and re-analysis of Swiss glacier monitoring data

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Long-term glacier monitoring in Switzerland has resulted in some of the longest and most complete data series globally. Point mass balance observations, starting in the 19th century, are the backbone of the monitoring as they represent the raw and original data demonstrating the response of surface accumulation and melt to changes in climate forcing. However, little attention has so far been devoted to the careful documentation of the raw point mass balance measurements, including an assessment of their sources and an estimate of their quality. Yet accurate metadata are highly important for homogenisation of the in-situ measurements and subsequent analysis of the long-term series.

For compiling and documenting raw point mass balance data acquired in Switzerland, a complete re-assessment of all measurements from pre-existing digital sources, published reports, unpublished documents, field notes, as well as meta-knowledge of the observers has been performed. A newly developed system of indicators allows attributing quality measures and further information on data acquisition, sources and observers for single measurements.
At this stage, data series for about 60 individual glaciers are available, corresponding to almost 60.000 point observations. The data comprise three types of point measurements: 55 series of annual mass balance, 46 series for winter snow accumulation, and 46 series with intermediate observations (daily to sub-seasonal). All previously available point mass balance observations have been re-assessed and documented, but a significant amount of additional data has been discovered and digitized summing up to 68 new data series, adding more than 20.000 point measurements.

Many of the previous observations were not traceable, and their quality was mostly unknown. The quality-checked and updated original data permits the re-analysis of consistent time series of glacier-wide mass balance allowing further interpretation of the climate change impacts on Swiss glaciers.

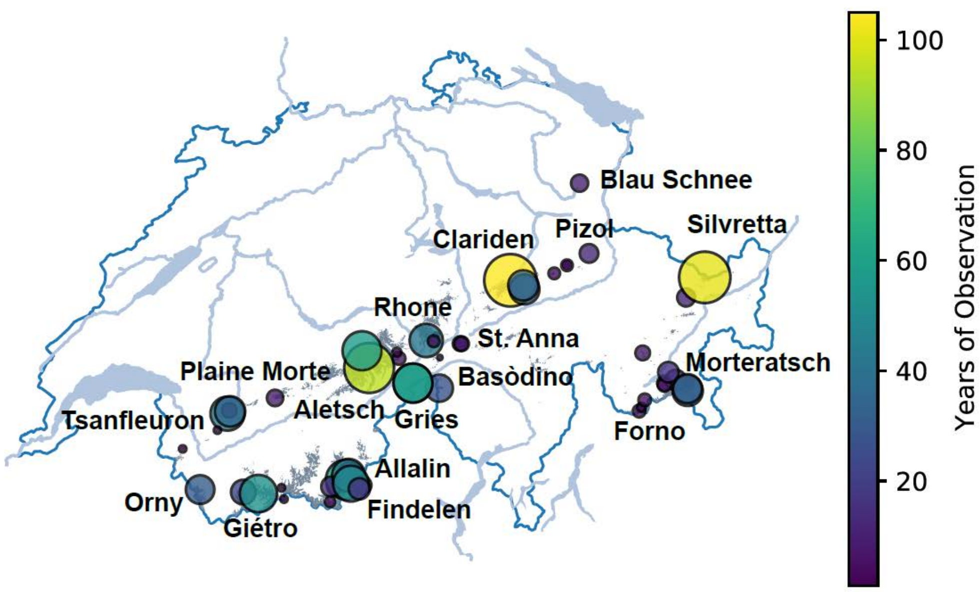

Figure 1. Coverage of annual point mass balance data series in Switzerland. The size of the dots and their colour indicate the length of the observational period. Important sites are labelled.

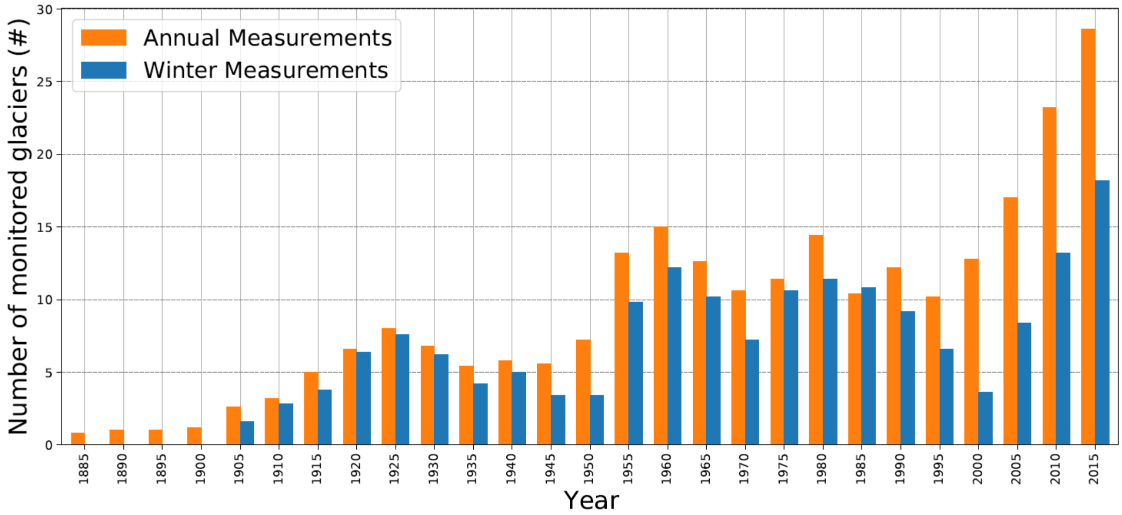

Figure 2. Number of glaciers with annual and winter point mass balance observations between 1884 and 2020 averaged in 5-year periods.

P 12.6
Using age-layer modelling for interpreting borehole age-profiles of rock glaciers

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The genesis of rock glaciers differs fundamentally from 'normal' glaciers and results in much older landforms that are often reaching ages of several millennia. Recent datings of rock glacier material from boreholes indicate early Holocene ages for rock glaciers and allow the derivation of age-depth profiles at the borehole location. We use here a 2-dimensional numerical modelling approach that calculates age-layers (isochrones) within the rock glacier body and that considers the accretion, melt and flow-advection of rock glacier material. We apply this model to the case of Lazaun rock glacier (Southern Ötztal Alps) for which a well dated profile from a borehole exists, with ages at the bottom older than 9000 years (Krainer et al. 2015). With our modelling we are able to reproduce the observed age-depth profiles well and are able to infer a long-term accumulation rate that is around 1 cm/yr which is an order of magnitude higher than a previous estimate that does not account for deformation. The modelling is further consistent with the classic rock glacier genesis of material accretion in the upstream talus slope and confirms the dominance of deformation in the shear-zone at the bottom layer of the rock glacier. We conclude that combining age-layer modelling with dated depth-profiles of rock glaciers allows for important new insights into our understanding of rock glacier evolution and dynamics.

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P 12.7
Multispectral and thermal mapping of the polythermal Gorner-/Grenzgletscher terminus

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Gorner-/Grenzgletscher is the only large polythermal glacier of the Alps. Even in the terminus area at 2500 m a.s.l. the glacier ice is at subfreezing temperatures, with cold ice discernible by its bright white color. The impermeable cold ice leads to the formation of deeply incised streams and lakes on the glacier surface which are unique in the Alps.

With drones carrying thermal, multispectral and optical cameras, we mapped structures on the ice surface. These thermal images reveal an intricate pattern of high- and low-emission areas on the glacier surface, linked to streams, lakes, water-filled cyroconite holes within the ice, and further patterns that are not easily attributable to surface features. First results of the analysis of these images with neural-network based classification algorithms elucidate several classes ice properties with different characteristics.

P 12.8
The snow microstructure on sea ice - first results from the MOSAiC expedition

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Snow on sea ice governs much of the heat exchange during winter, and its melting during summer. The microstructure has a key role in the thermal heat resistance and in the albedo. We installed a micro-CT on board of the research icebreaker Polarstern during the MOSAiC-expedition. The MOSAiC expedition drifted for a full year in the Arctic Ocean. We could measure every week 1-2 full snow profiles between 0.1-0.3 m deep. We extracted, mostly in-situ, cores of 48-78 mm diameter and of about 0.1 m length, and scanned with 18-28 µm resolution. The goal of these measurements was to understand the formation and metamorphism of the snowpack in detail, and to derive detailed geometrical and physical properties from the samples. We will present first examples and overview of characteristic snow profiles from leg 1 - 4, spanning the winter, spring and melt season, and the evolution of the sea ice from solid ice towards the formation of the surface scattering layer, a snow-like ice cover. We could also observe the inclusion of brine in some snow samples, especially in first year ice. Until know it was not known how brine is included in the ice structure of snow.

P 12.9
Swiss-wide post-Little Ice Age glacial lake evolution

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During the currently accelerating glacier retreat, number and size of glacial lakes in most mountain regions of the world are rising. Knowledge about the location and size of new (post-Little Ice Age, LIA) glacial lakes allows (1) analysing their environmental conditions to better understand formation processes, and (2) deriving information regarding their hazard potential.

In this study we present the first complete multi-temporal glacial lake inventory for Switzerland spanning ~the end of the LIA to present. The availability of historical orthophoto mosaics, existing lake boundaries for the 2000s and 2010s (Swisstopo TLM3D), and glacier boundaries from the end of the Little Ice Age (LIA, ~1850s) and several dates thereafter, facilitated the generation of a time series of glacial lake datasets for seven points in time between the end of the LIA and 2016.

Altogether 1276 natural glacial lakes formed in this period, 1212 still existing in 2016, with a total area of 6.5 km² (Figure 1). The lakes are homogeneously distributed over the deglaciated terrain without a clear spatial hotspot, but are predominantly in the most glaciated Cantons of Valais (2.8 km²), Graubuenden (1.8 km²), and Bern (1.3 km²). Periods of strong lake area/ number increase alternate with periods of attenuated increase, corresponding well with the temperature evolution that strongly drives glacier changes. We also extracted several parameters relevant for lake hazard assessment, e.g. dam material and topographic potential.

In a next step we want to discuss lake monitoring and management strategies, also with regard to a future with a continuously increasing number of lakes located inmidst of a geomorphologically young, dynamic and unstable alpine environment.

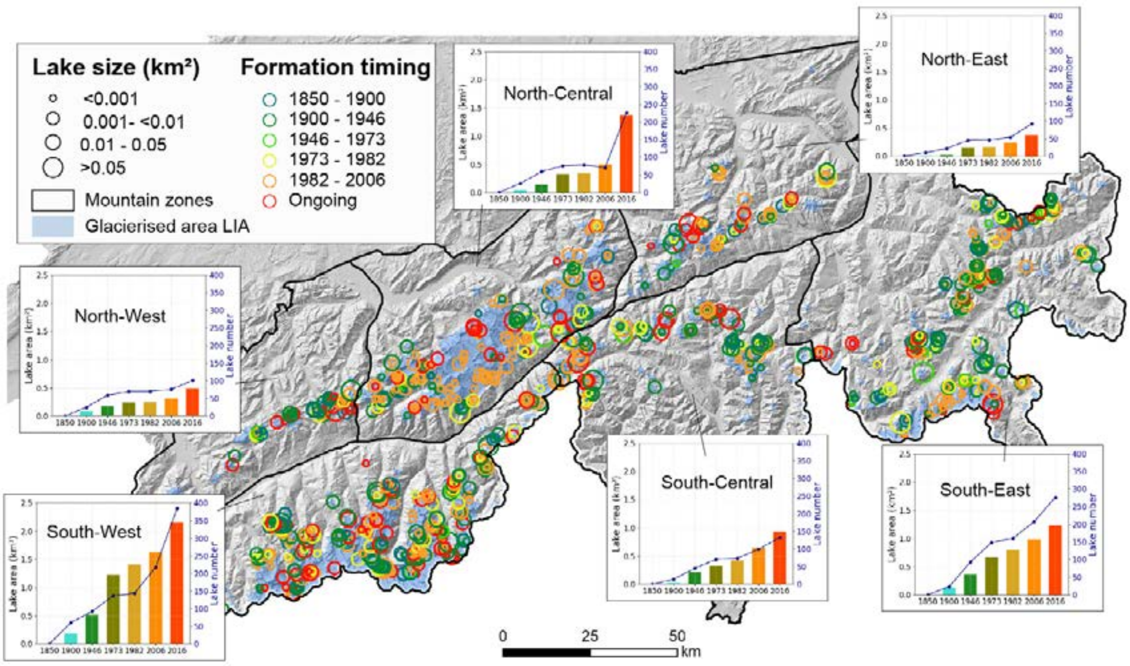

Figure 1. Distribution of glacial lakes over the Swiss Alps.

P 12.10
A framework for modelling rock glaciers and permafrost at the basin-scale in high Alpine catchments

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Water stores in rock glaciers may become important water reservoirs in future, since rock glaciers are thought to be more resilient to climate change than clean-ice glaciers (Brighenti et al. 2019). In particular, regions which currently rely on glacial runoff may need to find alternative water resources. In order to project future runoff potential from rock glaciers, distributed runoff models suitable for high Alpine catchemnts are needed.

In this work, the distributed Glacier Evolution and Runoff Model (GERM; Huss et al., 2008; Farinotti et al., 2012) is extended by a permafrost module, which allows for the modelling of rock glaciers in Alpine catchments.The permafrost module treats permafrost as discreet depth layers in a one-dimensional column for all grid cells. Thermal properties are calculated from the layer's constituents (ice, water, air and solid component). The temperature evolution is computed using heat conduction and latent heat exchanges, modified by ventilation effects. The contribution the the runoff is inferred from permafrost degradation.

First results for the Schafberg catchment are presented here.

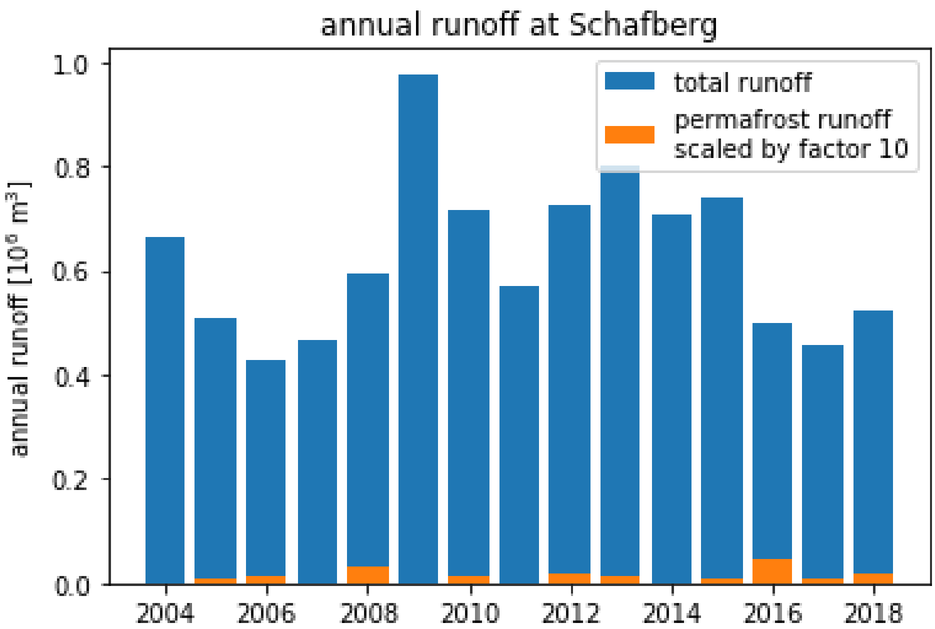

Figure 1. Annual modelled runoff at Schafberg. Total runoff is summed over all catchment grid cells and the runoff contribution from permafrost is also summed over all depths and grid cells containing permafrost.

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P 12.11
Challenges of estimating the snow-rain transition zone in the semi-arid Andes

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The height of the snow-rain transition, closely related to the 0°C-isotherm, is a crucial variable for snow cover extent and natural hazards. In semi-arid northern Chile, it plays a fundamental role in high discharge flows. A high snow-rain transition above 3000 m leads to a strong increase in the pluvial area of Andean basins (Garreaud, 2013). Estimations of past and future changes in the snow/rain transition zone and its relation to large-scale climate oscillations, such as El-Niño Southern Oscillation (ENSO) are therefore fundamental for water availability assessment and adaptation strategies and might eventually serve to develop landslide, debris flow and mudflow early warning systems in this region (Vergara del Pont, 2018; Palma, 2019). However, there are important challenges that hinder the assessment of the snow-rain transition zone in semi-arid environments and little is known about future changes under different global warming scenarios. For example, it is difficult to identify statistically significant trends for the snow-rain transition in a region where on average 90% of the precipitation depends on five or fewer events per year. Additionally, most weather stations in the Andes are located in valley bottoms, influenced by local conditions and the assumption of free-air temperature lapse rates contributes to the uncertainty. Also, satellite observations (e.g. bright band information) are limited over mountainous areas.

The main questions driving our work are therefore:

i) What is the elevation band of the snow-rain transition zone for the past decades (1979-2020)?
ii) What is the role of large-scale climate modes such as ENSO and PDO in the interannual and interdecadal variability of the snow-rain transition height?

We combine different data sets to estimate the past snow-rain transition zone the semi-arid Chilean Andes. Meteorological station data are used to vertically extrapolate temperature with free-atmosphere lapse rates. Results are then compared to radiosonde records, MODIS snow cover products, ERA5 atmospheric reanalysis, and a Regional Climate Model (Aladin-Climate, 12km resolution, 1979-2018). First results from radiosonde data indicate a relationship between the snow-rain transition height and ENSO and PDO variability. The new findings will enable us to model future spatially-distributed precipitation phase probabilities along the semi-arid Andes.

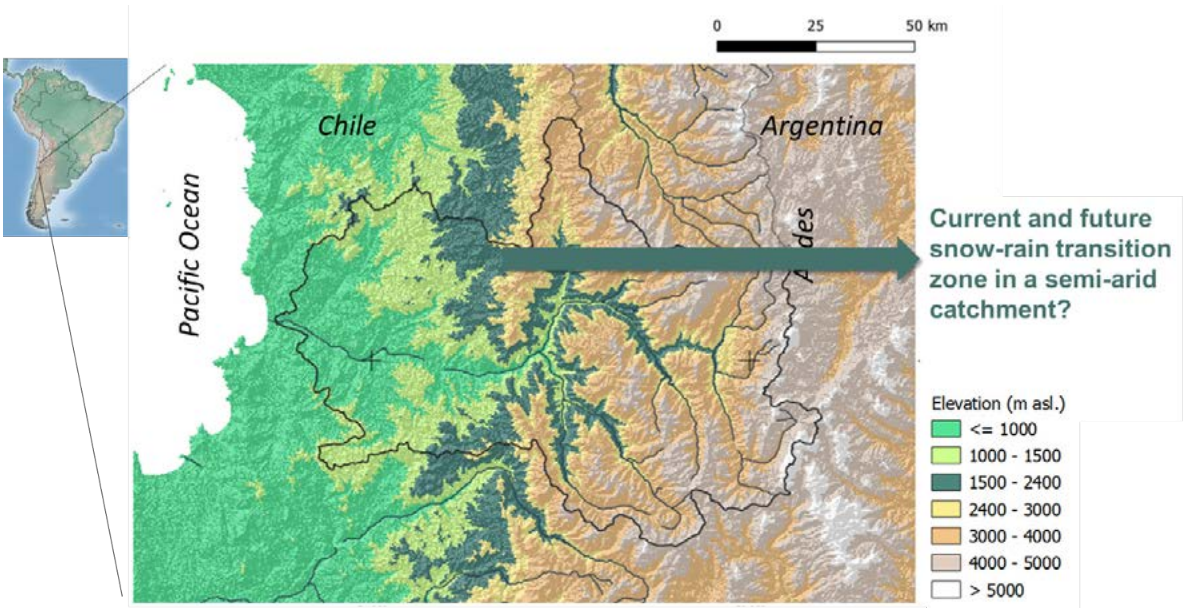

Figure 1. Map of the Elqui River catchment. A rise of the snow-rain transition altitude leads to an important increase of the pluvial area for many large foothill catchments along the Andes – increasing the risk for natural hazards.

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P 12.12
Calving styles and patterns vary strongly for different front geometries

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Glacier calving is an important process for the mass loss of tidewater outlet glaciers in Greenland. At the same time the calving process causes significant uncertainties in currently used glacier flow models and thus projections of the future evolution of the Greenland glaciers and ice sheet. These uncertainties are also due to a lack of observations. This study contributes with a very detailed and unique dataset of calving activity and front characteristics to fill this gap.
Two tidewater outlet glaciers in Greenland, Eqip Sermia and Bowdoin Glacier, were observed during six and two field campaigns, respectively, with a terrestrial radar interferometer (TRI). From the TRI measurements the ice flow field, the front position, crevasse patterns, strain rates and calving activity were extracted. Since the two glaciers are characterised by different geometries and velocity fields, the influence of those parameters on the calving process is investigated. The results highlight that both glaciers show highly variable calving activities along the front and over time. The calving style also differs significantly between the individual front geometries. At Bowdoin glacier the mass loss is dominated by a few large-scale calving events, while Eqip Sermia is characterised by frequent smaller events and for the front section ending in deeper water subaqueous mass loss. In a further step we use this unique dataset to investigate the driving forces on the calving process and the comparison with results from state-of-the-art calving models. This will allow us to understand the suitability of different calving implementations in the models and to optimise parameters to better reproduce the observed calving rates.

P 12.13
The Role of Local Resolution Weighting in Automatic Avalanche Mapping with Sentinel-1

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The documentation and statistical analysis of snow avalanche events is an important factor to improve avalanche predictions. So far, reports are based on human observations and therefore are sparse in bad weather conditions or remote areas. Sentinel-1 (S1) synthetic aperture radar (SAR) images provide a weather-independent coverage of the Swiss Alps all six days and have proven to be an effective basis for detecting avalanche deposition zones by experts. The manual mapping of avalanches on pixel level (here called segmentation) is extremely laborious, which makes an automation indispensable. The steep terrain of the Swiss Alps combined with the slant view angle of the SAR complicate this process. In areas of layover and shadow, avalanches are not visible and the spatial resolution varies strongly with the local radar incidence angle .

Local resolution weighting (LRW) merges images of different satellite orbits by weighting them by their local spatial resolution. This creates an image of very extensive coverage and overall high spatial resolution with only little loss of temporal resolution. We present a processing pipeline which automatically downloads, processes and merges S1 images with LRW before segmenting the avalanches with a deep neural U-Net from a backscatter difference image. We created a dataset of 914 manually drawn avalanche outlines from the 4th of January 2018. It was used to evaluate the avalanche backscatter characteristics with respect to the incidence angle and the polarization, to quantify the effect of merging images with LRW on the brightness and segmentation of avalanches and to train and test the U-Net.

We show that avalanches appear brighter when imaged with a large local radar incidence angle. This motivates the use of LRW as it weights these parts stronger. Furthermore, the merging of images with LRW has proven to be very beneficial to a segmentation with a threshold. Our preprocessing pipeline with LRW followed by a segmentation with our U-Net achieved high precision, recall and F1 scores of 0.88, 0.76 and 0.81.

An automatic avalanche mapping in the Swiss Alps on the 4th of January is demonstrably feasible with a good accuracy. LRW and deep learning proved to be promising approaches to this task and especially deep learning techniques should further be developed. It remains to be studied to what extent our results can be generalized to other events with different snow conditions and avalanche visibility.

P 12.14
Modelling the long-term mass balance and firn evolution of Abramov glacier, Pamir Alay

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Glaciers located in Western High Mountain Asia have shown mass gain or limited mass losses compared to other mountain regions since 2000 (e.g. Brun et al. 2017; Shean et al. 2020). The reasons for this behaviour have not yet been satisfyingly resolved. An increase in accumulation is considered a potential cause for this situation. However, meteorological as well as glaciological in situ data are limited for the region impeding an analysis over longer periods. In this context, modelling energy and mass fluxes can enhance our understanding.

A distributed energy balance model coupled to a multi-layer firn model EBFM (van Pelt et al. 2012, 2019) is applied to study the mass balance evolution for a glacier in the region for which unique in situ data are available (Fig.1). Abramov glacier is located in the Pamir Alay at the northern margin of regions with anomalous mass balance behaviours. In a first step, we run the EBFM with meteorological in situ measurements from a weather station located next to the glacier for the period from 1967-99. Second, we use measurements from an automatic weather station installed in 2011 to run the model. In a third step, we evaluate gridded meteorological data products. Those products are then used to run the EBFM for periods without in situ measurements. Model parameters are calibrated with a subset of the mass balance point measurements available for the periods of 1969-99 (174 points, monthly resolution) and 2011 to present (20 points, annual resolution). Another subset of the mass balance point measurements as well as firn data from the 1970s and 2018 are used for model validation.

P 12.15
CRAMPON - a workflow for obtaining and assimilating near real-time glacier mass balance observations

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Switzerland is affected by shrinking glaciers in many ways, but the decrease in summer runoff form glaciers might be the most important one. This runoff decrease impacts the available water volume downstream of glaciers and thus reduces both drinking water availability and the possibility to produce electricity. This is why interest in the near real-time status of glacier mass balance is high. During the hot summer months, when public interest is highest, there are often no in situ mass balance observations available though. This makes it impossible to make accurate statements about the current state of a glacier. To tackle this issue, we have initiated CRAMPON – Cryospheric Monitoring and Prediction Online. In CRAMPON, we aim at two things: first, we want to reduce near real-time mass balance uncertainty by ensemble modelling with frequent assimilation of remote and in situ observations. The former are satellite acquisitions, for the latter we rely on automated camera observations. Second, we want to make the obtained near real-time mass balance available to the public on a web platform.

To establish frequent in situ observations, we mounted up to nine autonomous cameras on four Swiss glaciers during the summer ablation periods of 2019 and 2020: Rhonegletscher, Findelengletscher, Glacier de la Plaine Morte, and Aletschgletscher (see Fig. 1). These cameras take images of suitably-marked ablation stakes every 20 minutes, which allows aggregating the readings to daily mass balance estimates. Remote observations stem from Sentinel-2 acquisitions and comprise broadband albedo and derived snow lines. They are not as frequent as the camera observations (potential availability: every 2-3 days), but have a better spatial coverage. We assimilate these estimates in an ensemble of three temperature index melt models and one simplified energy balance melt model (Hock, 2003, for an overview). This model ensemble is driven with gridded uncertain meteorological input and uncertain parameters, since it should be run over all Switzerland in a next step. To perform the assimilation, we use a particle filter (Van Leeuwen et al., 2019, for an overview). Particle filters are flexible data assimilation methods that do not constrain the models and distributions used to linearity or Gaussianity. By adding a custom resamping method to the filter, we ensure that every model is always maintained in the ensemble, and that temporarily poorly performing models can recover at a later stage. This makes it possible to analyze model performance and parameter distributions over time.

The validation of the operational ensemble shows that the mass balance analysis follows the observations closely (Continuous Ranked Probability Score within 1cm of the stake reading on average) and can well reproduce also independent measurements. A cross-validation experiment between the glaciers with camera observations shows that the ensemble does not deviate more than 7% from the observed cumulative mass balance. A comparison to the autumn glacier-wide mass balance provided by the Glacier Monitoring Switzerland (GLAMOS; www.glamos.ch) initiative showes agreement within few centimeters, except for Findelengletscher, where the camera locations might not be representative for the entire glacier mass balance. In general, over 95% of the uncertainty in the cumulative ensemble mass balance stems from the period before summer observations are available. This shows that it is advantageous to start with observations as early as possible in the season.

Our contribution will provide insights into the processing pipelines, highlight the importance of frequent in situ and remote observations for near real-time glacier mass balance estimation, and present the status quo of the CRAMPON online platform.

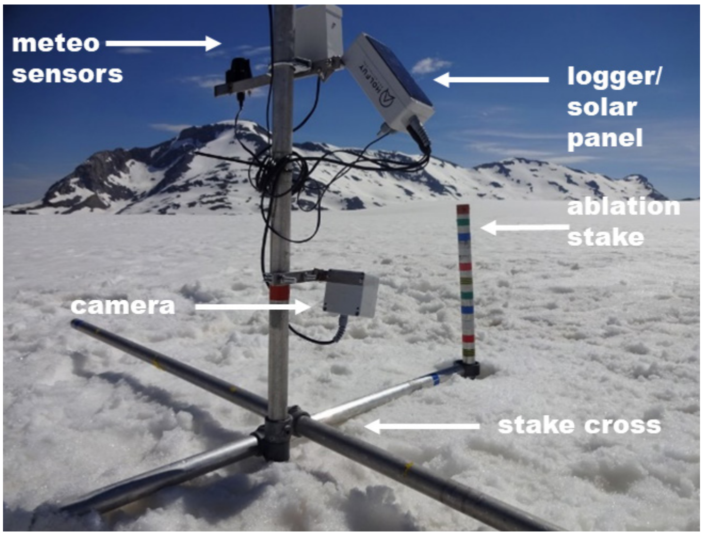

Figure 1. The setup of an in situ mass balance observation camera.

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P 12.16
Understanding monsoon controls on the energy- and mass-balance of glaciers in High Mountain Asia

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The South- and East-Asian Monsoons (AMs) shape the melt and accumulation patterns of glaciers in large parts of High Mountain Asia (HMA) in complex ways (Maussion et.al, 2014) due to the interaction of persistent cloud-cover, large temperature amplitudes, high atmospheric water content and high precipitation rates. While the AMs dominate in the southern and eastern regions, they progressively lose influence westward towards the Karakoram, where the influence of westerlies is predominant (Figure 1) (Yao et.al, 2012).

Previous applications of energy- and mass-balance models for glaciers in HMA have been limited to single study sites (e.g. in Khumbu, Langtang and Parlung) and a few attempted to link model results to large-scale weather patterns (Mölg et.al, 2013). While these studies have helped to understand glacier melt and accumulation in HMA under specific local climates, a regional perspective is still missing. In this study, we use a full energy- and mass-balance model together with eight on-glacier AWS datasets around HMA to investigate how AMs conditions influence the glacier-surface energy- and mass-balance. In particular, we look at how debris-covered and debris-free glaciers respond differently to the AMs, validating our results against independent in-situ measurements.

We identify combined effects of the AMs and debris-cover on the glacier mass-balance (Figure 2), seek for explanations in the surface energy-balance and discuss regional differences. We also discuss the important role of high-elevation monsoonal snow in controlling accumulation and ablation in HMA. This work is fundamental to the understanding of the present and future HMA cryosphere and water budget evolution and will inform long-term studies on HMA catchment hydrology.

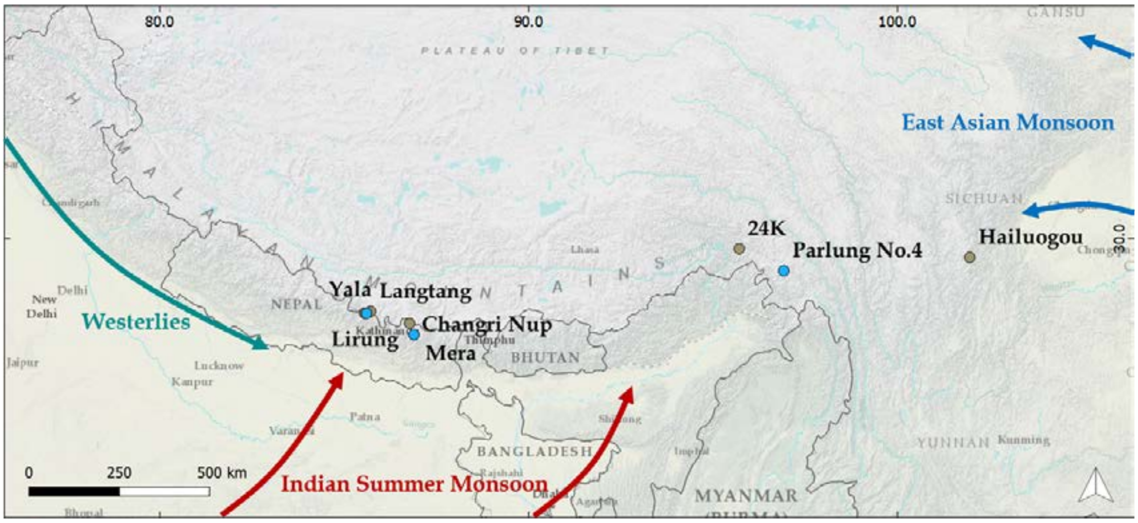

Figure 1. Study sites and large scale weather patterns

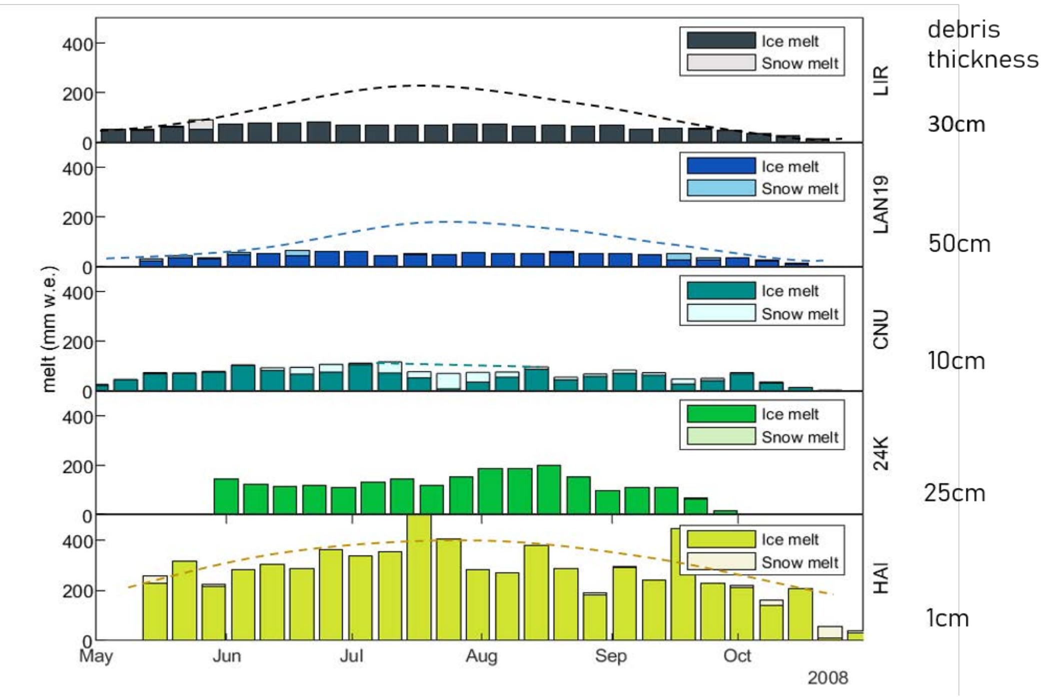

Figure 2. Seven-day sums of ice- and snow-melt at AWS sites on debris covered glaciers. Dashed lines indicate theoretical melt regime if there was neither monsoon, nor debris or snow cover.

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P 12.17
The thermal behaviour of a low elevation cold talus slope: Insights through numerical modeling

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Coarse blocky talus slopes are a characteristic geomorphic feature of the alpine high mountains, but can also be found at lower elevations. Their high permeability allows for air circulation within the ground leading to an increase in convective heat transfer. The convective heat transfer related to air, especially the seasonal cycle of natural convection, is known to have a cooling effect on the ground (Wicky and Hauck, 2020). At low elevations, this can lead to the occurrence of azonal permafrost (Morard et al., 2012). Dreveneuse, a well-studied former PERMOS site, is located at 1500 m a.s.l. and showed continuous subzero temperatures for some years (PERMOS, 2016). Research at Dreveneuse has already been done conducting ample field measurements (Morard et al., 2012) and geophysical monitoring (Mollaret et al., 2019), whereby the geophysical data are still ambiguous concerning the ground ice content. We try to analyze and re-model ground temperature measurements of the Dreveneuse low elevation talus slope in the Western Swiss Alps in order to understand to what extent convection is the explaining factor for the observed thermal anomalies. The 2D model is set up in COMSOL Multiphysics and solves for heat conduction coupled with a Darcy approach for the convective air flow within the ground (Wicky and Hauck, 2020) and is driven by temperature data measured on site.

Figure 1. Coarse debris deposits at the Dreveneuse low elevation talus slope in the Valais, Western Swiss Alps, at 1500 m a.s.l. (Photo: J. Wicky).

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13. Hydrology and Hydrogeology

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Swiss Hydrological Commission CHy,
Swiss Society for Hydrology and Limnology SGHL,
Swiss Hydrogeological Society SGH

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13.1
Quantification of fracture-matrix fluid exchange in fractured porous media PIV measurements

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Fluid exchange between fractures/free-flow and porous media is of crucial importance in various applications, such as geothermal energy, carbon dioxide sequestration, groundwater utilization, hydrometallurgical recovery, and infiltration/drying in fractured soil. However, it is still challenging to quantify fluid flow exchange between fractures/free-flow and porous media, particularly in fracture-dominated porous media.

Here, we use 3D-printing techniques to manufacture a well-structured, transparent porous medium, which consists of two low- and high-permeability matrices, each with one flow-through and one dead-end fracture. We conduct Particle Image Velocimetry (PIV) measurements in this 3D-printed medium (Ahkami et al., 2018) to determine the stress-jump (Saffman,1971) and velocity-slip (Beavers and Joseph, 1967) coefficients for characterizing fluid exchange at the fracture-matrix interfaces.

We further calculate the cross correlations between the aforementioned two coefficients and the velocities perpendicular to the fracture-matrix interface for all the interfaces of flow-through and dead-end fractures. The calculated correlation coefficients illustrate that the stress-jump and velocity-slip coefficients are incapable of quantifying fluid exchange across the current definition of physical fracture-matrix boundary. Using the PIV-measured velocities, we also discuss in detail the velocity-dependent boundary layer at the fracture-matrix interfaces for typical incoming and outgoing flow regions. Finally, we propose a new quantity to relate fluid shear rates inside the fractures and inside the matrices around the fracture-matrix interfaces. Our study provides insights into fluid exchange between fractures/free-flow and their surrounding matrix, which is crucial to characterize the associated mass and energy transport processes and to improve the efficiency and sustainability of the aforementioned applications.

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13.2
Improving hydrologic model realism by using stable water isotopes

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The last century of hydrological research has led to significant improvements in representing different hydrological processes in rainfall-runoff models. Despite this progress, most rainfall-runoff models are calibrated only against streamflow, which informs the celerity i.e. the fast response behavior of a catchment. Using environmental tracers such as stable water isotopes can help constrain the velocity aspect of the catchment. However, stable water isotopes have either been used qualitatively to learn more about the dominant hydrological processes or to calibrate a much more complex solute transport model, where the added benefit of using stable water isotope data is not entirely clear.

In this study, we use stable water isotopes to design a semi-distributed conceptual rainfall-runoff model for an Alpine catchment (Vallon de Nant), and incorporate information about pre-event water fraction in the stream within the rainfall-runoff model. Pre-event water fraction is estimated using stable water isotope data and a Bayesian mixing model, and is used to calibrate the rainfall-runoff model. This kind of a calibration scheme increases the representation of pre-event water fraction within the stream, thus making model simulations more realistic. We discuss the advantages and limitations of such a modeling approach and how it can be extended to other experimental catchments.

13.3
Modelling the impact of climate change on hydrological processes in the Volta river basin

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This study evaluates the impacts of climate change on water resources of the Volta River basin located in West Africa. In total, 43 combinations of global climate models (GCM) and five regional climate models (RCM) from CORDEX-Africa are considered under three representative concentration pathways (RCP2.6, RCP4.5 and RCP8.5). The R2D2 multivariate bias correction method is applied to the climate datasets before using them as input to the fully distributed Hydrologic Model (mHM) for hydrological projections over the twenty-first century. The mHM model is constrained with a novel multivariate calibration approach based on the spatial patterns of satellite remote sensing data (Dembélé et al., 2020).
Results reveal contrasting changes in the seasonality of precipitation depending on the RCPs and the future projection periods (2021-2050, 2051-2080 and 2071-2100) as compared to the historical period (1991-2020), while a clear increase in the seasonality of temperature is expected. A clear intensification of the hydrological cycle during the twenty-first century is expected only under the RCP8.5 scenario. In this case, an increase is foreseen for the long-term annual estimates of precipitation (+6.2%), average temperature (+9.5%) and potential evaporation (+5.0%). These changes in climatic variables will lead to changes in actual evaporation (+4.2%), surface runoff (+42%), streamflow (+84%), groundwater recharge (+37%), soil moisture (+2.3%) and terrestrial water storage (+3.2%). Consequently, recurrent floods and droughts could weaken the water-energy-food security nexus and amplify the vulnerability of the local population to climate change. These findings could serve as a guideline for decision makers, and contribute to the elaboration of adaptation and mitigation strategies to cope with dramatic consequences of climate change on various sectors including agriculture and hydroelectricity, and strengthen the regional socio-economic development.

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13.4
Climate change effects on groundwater recharge and temperatures - status and development for Swiss aquifers

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Climate change will have both quantitative and qualitative effects on groundwater resources. These impacts differ for aquifers in solid and unconsolidated rock, urban or rural locations and the principal processes of groundwater recharge. Knowledge of the intrinsic key parameters (aquifer geometries, storage properties, groundwater renewal rates, residence times, etc.) and the principal groundwater recharge processes as well as temperature imprinting enables a comparison and forecast of the sensitivity of individual aquifers to climate change.
The sensitivity of future groundwater temperature development for selected climate projections was investigated for representative Swiss unconsolidated rock groundwater resources on the Central Plateau, the Jura and the Alpine region. For non-urban and rural areas, climate change is expected to have a strong overall impact on groundwater temperatures. In urban areas, however, direct anthropogenic influences are likely to dominate. Increased thermal subsurface use and waste heat from underground structures as well as adaptation strategies to mitigate global warming result in increased groundwater temperatures. Likewise, measurements for the city of Basel show that groundwater temperatures increased by an average of 3.0 ± 0.7 °C in the period from 1993 to 2016 and can exceed 18 °C, especially in densely urbanized areas. Similarly, regarding shallow aquifers with low groundwater saturated zone thicknesses, such as in Davos (Canton Grisons), groundwater temperatures will strongly be influenced by changes in groundwater recharge regimes. In contrast, groundwater temperature changes within deep aquifers with large groundwater saturated zone thicknesses, such as in Biel (Canton Bern), or in some cases with large distances from the surface to the groundwater table and extended unsaturated zones, e.g. in Winterthur (Canton Zurich), are strongly attenuated and can only be expected over long time periods.
We show that seasonal shifts in groundwater recharge processes could be an important factor for the future development of groundwater temperatures. Moreover, the interaction with surface waters and increased groundwater recharge during high runoff periods are likely to have a strong influence on groundwater temperatures. Accordingly, a shift in precipitation and river flood events from summer to winter months is accompanied by an increase in groundwater recharge in comparatively cool seasons, which would be accompanied by a tendency for “cooling” groundwater.

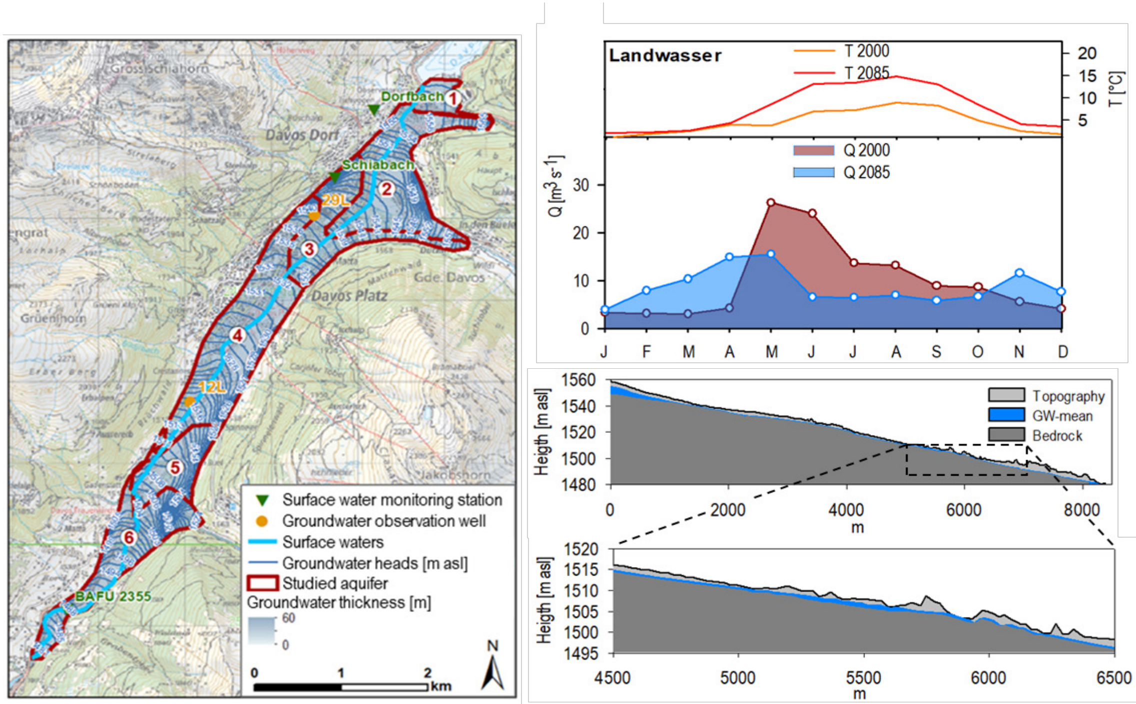

Figure 1. Left: Aquifer of Davos (Canton Grisons) illustrating groundwater head and thickness, including groundwater and surface water monitoring stations; for 6 subdomains groundwater flow length and times were evaluated. Upper right: Simulated emission scenario RCP85 and results for river discharge (Q) and temperature (T) for the reference state 2000 and for the year 2085. Lower right: Progression of the river Landwasser related to the bedrock and the surface topography for a mean groundwater head situation, including a zoom of the river section between 4500 and 6500 m where the river locally can be in contact with the groundwater table.

13.5
GRUN-ENSEMBLE: A multi-forcing observation-based global runoff reanalysis using machine learning

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Although river flow is the best-monitored variable of the terrestrial water cycle, the scarcity of available in situ observations in large portions of the world has until now hindered the development of consistent estimates with global coverage. Recently, fusing sparse in-situ river discharge observations with gridded precipitation and temperature using machine learning has shown great potential for developing continental (Gudmundsson & Seneviratne 2016) to global (Ghiggi et al., 2019) monthly runoff estimates. However, the accuracy of gridded precipitation and temperature products is variable and the corresponding uncertainty in the resulting runoff and river flow estimates is not yet quantified.

Here we present a multi-forcing global reanalysis of monthly runoff rates at a 0.5° resolution, named Global RUNoff ENSEMBLE (GRUN-ENSEMBLE) (Ghiggi et al., in preparation), composed of up to 525 runoff simulations. The GRUN-ENSEMBLE is based on 21 different atmospheric forcing datasets, overall spanning the period 1901-2019. The reconstructions are benchmarked against a comprehensive set of global-scale hydrological models (GHMs) simulations, using a large database of river discharge observations as a reference, which can serve as basis also for future GHMs intercomparison studies. Overall, the GRUN-ENSEMBLE shows higher accuracy than the GHMs, especially with respect to the reproduction of the dynamics and seasonality of monthly runoff rates. The accuracy of the reconstructions is dependent on the quality of the forcing data. However, we found the GRUN-ENSEMBLE to be less sensitive to forcing data compared to GHMs simulations. Potentially, this is because the employed ML algorithm is not impacted by the cumulative nature of errors and biases that affect dynamical models.
The uncertainty quantification related to the multi-forcing nature of the GRUN-ENSEMBLE paves the way for reliable and robust water resources assessments, hydro-climatic studies (Figure 1), climate change attribution, as well as evaluation, parameter calibration and refinement of GHMs.

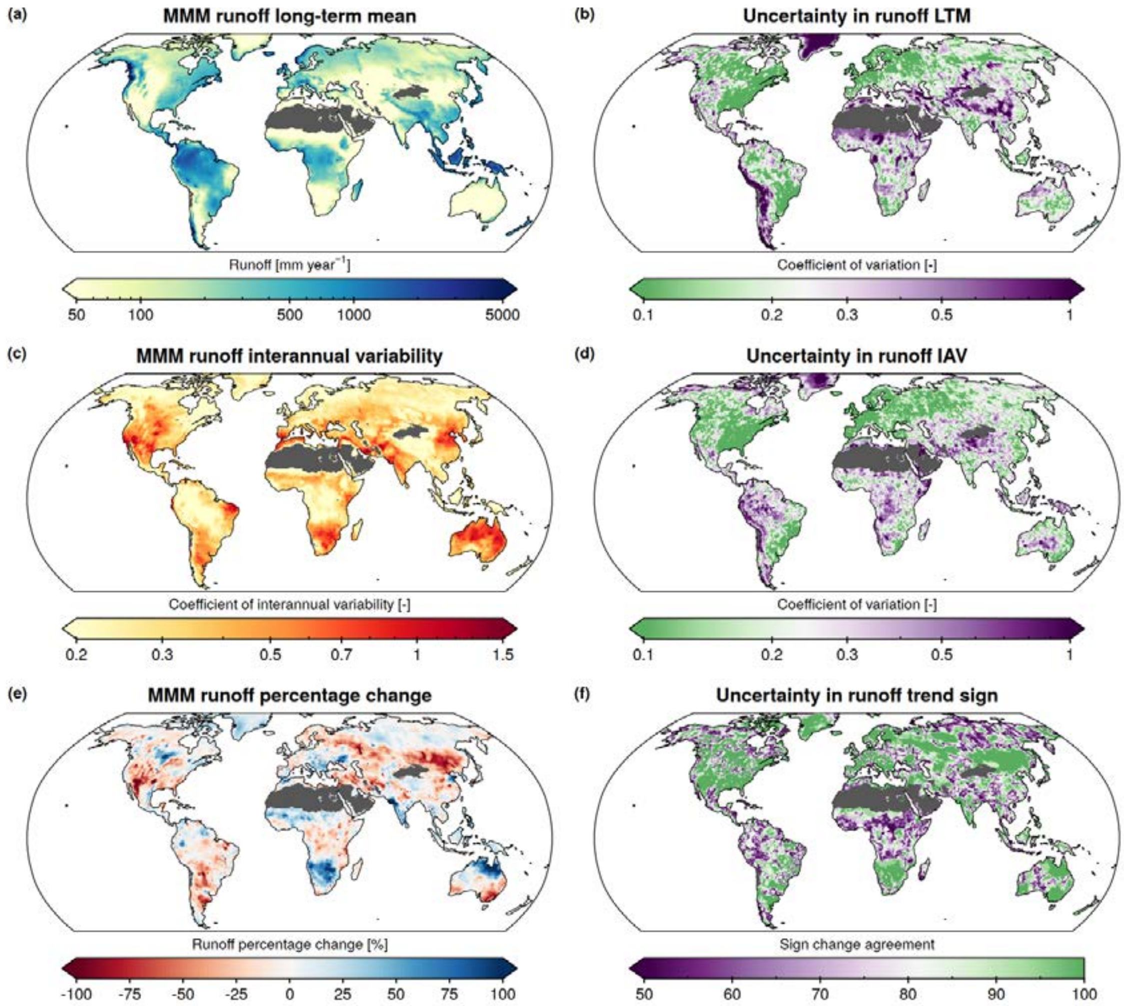

Figure 1. Climatological analysis based on the GRUN-ENSEMBLE for the period 1981-2010. Desert regions with long-term precipitation lower than 100 mm/year are masked. a) Multi-model median of the runoff long-term mean (LTM) computed for each GRUN-ENSEMBLE member. b) Coefficient of variation of the ensemble LTM statistics. c) Multi-model median of the runoff interannual variability (IAV) computed for each GRUN-ENSEMBLE member. d) Coefficient of variation of the ensemble IAV statistics e) Multi-model median (MMM) of changes in annual runoff rates, expressed in percentage change over the 30-year period, computed for each GRUN-ENSEMBLE member. f) Percentage agreement of the runoff trend sign across the 20 GRUN-ENSEMBLE members spanning the period 1981-2010.

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13.6
Assessment of methods to estimate bare soil evaporation based on lysimeter data

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Bare soil evaporation is a key component of the water balance and is influenced by numerous complex physical processes. While many empirical methods to estimate evaporation have been proposed, their performances under different hydrological conditions have not been assessed systematically. We evaluated four commonly used methods, namely the FAO-56 method with the skin evaporation enhancement (FAO-56 skin), the groundwater level fluctuation (GLF) method, Darcy's law method, as well as the Maximum Entropy Production (MEP) approach to estimate evaporation. The estimated evaporation rates were compared to evaporation rates measured by three lysimeters with different water table depths in the Guanzhong Basin, China. Our study includes conditions where the water table is above- as well as below the extinction depth of evaporation. The extinction depth is the critical depth below ground where groundwater no longer contributes to evaporation.

The results show that the position of the water table relative to the extinction depth is a useful first-order indicator of the performance of three methods (the Maximum Entropy Production method, the FAO-56 skin method, and the groundwater level fluctuation method). The MEP method provided the best results across all hydrogeological conditions. However, if the water table is below the extinction depth, significant biases can occur with the MEP approach. The FAO-56 skin method tended to overestimate the evaporation when the water table depth was larger than the extinction depth, and vice versa. The groundwater level fluctuation method, combined with the water balance method could reproduce the evaporation well. However, estimating evaporation using the groundwater level fluctuation method requires a falling water table in response to evaporation, which only can occur if the water table is above the extinction depth. In principle, Darcy's law can reproduce evaporation dynamics. A reliable estimation of the soil parameters is required and very difficult to obtain. The above results are significant to groundwater management and sustainable development in arid and semi-arid regions.

13.7 Sustainable Use of an Overpumped Aquifer: Example the North China Plain

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The overpumping of aquifers is a non-sustainable practice, by which on average more water is abstracted from an aquifer than is recharged by seepage of rainwater or from surface water bodies. It is seen in many arid and semi-arid areas all over the world. The aquifer system of the North China Plain (NCP) is one of the most prominent examples for over-pumping.

Due to the increase of food demand of a growing population the irrigation agriculture in NCP was expanded significantly over the last 50 years. It is responsible for about 80% of water use. The over-pumping showed in a decline of groundwater tables by about 1 m per year, with consequences such as increased pumping cost, soil subsidence, drying up of wetlands, and sea water intrusion at the coast. At the same time the aquifer is losing its function as long-term reservoir, capable of buffering weather extremes such as multi-year droughts, which are expected to occur more frequently under climate change.
A prerequisite to maintaining an aquifer's drought mitigation capacity is sustainable groundwater use, which implies a long-term balance between recharge and abstraction. Sustainability can be enhanced by conjunctive use of surface water and artificial groundwater with excess surface water available outside of the irrigation season. Sustainable use requires management, based on quota and the red line concept.

The Sino-Swiss project developed such a system. It consists of 3 elements, which can be implemented with the presently available sensors and transmission techniques: A monitoring module recording groundwater levels and pumping rates, a data platform and modeling module, computing the allowable pumping rates under given sustainability goals, and a policy module implementing the required reductions in pumping.

The pilot site is Guantao County in NCP. The measurement of pumped volumes has been implemented using the electricity consumption of each well as a proxy. Pumping tests allow to convert the energy consumed into the water volume pumped. The dominant double cropping of winter wheat and summer maize in the region is the reason for over-pumping. A solution involves three elements: the reduction of winter wheat planting, increased surface water imports from the south and advanced water saving irrigation. Both a 2D groundwater model and a simple box model water balance sheet are used in the assessment of suggested scenarios. A decision support system has been set up, which determines the water requirements of the cropping system, the expected reaction of the groundwater levels and the amounts of fallowing and water imports needed to reach a target groundwater level in the next season, on average over the county. On the field implementation side, water quota and a water price have been defined by a ladder scheme, with water within quota being free of charge. A dry run of fee calculation - without farmers actually paying up to now - has been performed according to electricity consumption in 2018. A subsidy for fallowing of winter wheat has been introduced, for which villages can apply up to a number of hectares determined by the provincial government. Water saving irrigation is also subsidized but its potential is low. It will only increase when small family farms are merged to larger units practicing precision agriculture. For grain security reasons the over-pumping problem cannot be solved by fallowing of winter wheat alone. It has to be combined with more imports of surface water from the south. While progress has been made over the last 6 years, a final solution will still take a few years' work.

The Swiss partners in the project are ETH Zurich, hydrosolutions Ltd., Geopraevent Ltd. and the Zurich University of the Arts. The Chinese partners are the Water Resources Ministry's General Institute of Water Resources and Hydropower Planning and Design (GIWP), the China Institute of Geo-Environment Monitoring, the China Center for Agricultural Policy at Peking University, the Key Laboratory of Agricultural Water Resources of the Chinese Academy of Sciences in Shijiazhuang and the local Departments of Water Resources in Handan and Guantao.

13.8
From hydrological forecasts to adapted water management

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Hydro-CH2018, a major FOEN research project to be completed in 2020, also included several targeted literature studies. One of them focused on the use and management of Swiss water resources, and how its objectives are challenged by a changing climate.

To assess current and future water management in Switzerland, the sector was clustered into nine societal demands (see table 1). Some are of predominantly public interest (drinking water supply, waste water management, flood management, river and lake ecology), others are mainly commercial activities (thermal use, irrigation, tourism, industrial water use) or a combination of both (hydropower).

Table 1. Societal demands concerning water

Drinking water supply
Wastewater management
Industrial water use
Agricultural irrigation
Thermal use of water resources
Tourism
Hydropower
Flood protection
River and lake ecology

The literature study shows, that water resources in Switzerland are under pressure due to abstraction, pollution, encroachment of riparian areas, and hydro-morphological deficits. Recently introduced legislation on water protection aims to alleviate some of these pressures in the decades to come. The remaining pressures and climate change will exert a combined effect on water resources, to which water management will have to react.

Generally, the impact of socioeconomic change on water management is at least as important as that of climate change. This finding is in tune with earlier research projects such as the Swiss national research program on sustainable water management (NRP 61, 2010-2014).

In some sectors, adaptation of water management to climate change is likely to increase conflicts and environmental problems. This will be particularly the case in summer and fall when demand for water in agriculture and for cooling is heightened. Also, groundwater use for climate-neutral heating systems has increased pressure on underground water resources.

Drinking water supply
Switzerland obtains ca. 80% of its drinking water from underground aquifers. Much of the groundwater is abstracted in heavily utilized river plains where its quality is under pressure from agricultural activities, transportation, industry, and expanding residential areas. In many regions, virtually all groundwater is influenced by societal activities preventing the appropriate protection of drinking water quality. Combined with climate-induced reductions in available quantity, the lack of adequately protected groundwater resources is becoming a major challenge for future drinking water supply. Lately, widespread exceedances of the legal drinking water limit for pesticide residues in large parts of the country have confirmed the vulnerability of the system.

Industrial water use
Industry and business are major users of water in Switzerland. Their consumption exceeds household use of water by a factor of 2.5. Some 73% are obtained from private wells, 27% from public water supply. Up-to-date information on industrial water use is lacking, the most recent figures concern the year 2006. Abstracted quantities are published only by one canton, most other cantons do not require abstractions to be measured and there is no fee on water consumption (other than concession fees independent of actual abstraction).

Most industries and businesses discharge their wastewater via public treatment plants. To date, information about the chemicals contained in industrial wastewater are scarce. Their quantity is however significant: Chemicals from industry and business make up about a quarter of anthropogenic substances in the Rhine river at the border in Basel.

Wastewater

Wastewater management is among the sectors requiring major adjustments due to climate change. Reduced run-off in summer and fall result in an increase of wastewater concentrations in rivers. To make up for this, Switzerland will upgrade at least 130 strategically selected wastewater treatment plants with ozonization and/or active carbon filtration technology. This will markedly increase the quality of drinking water abstracted downstream of WWTPs. However, large parts of the Swiss river system will still receive wastewater from treatment plants without advanced technology.

A second challenge is that increasingly heavy storm water events are exceeding the capacity of sewage systems. To prevent untreated wastewater from overspilling into rivers, rain water is to be kept away from sewers by local infiltration and retention systems.

Agricultural irrigation

Agricultural irrigation is likely to become a key issue of water management in Switzerland. The area of crops requiring irrigation is rapidly increasing (+26% vegetable hectares 2010-2016). Extended additional irrigation infrastructures are currently being planned or implemented, usually with substantial public support. However, the additional water demand of these new projects is unclear. There is no policy of recording water abstractions of agriculture in Switzerland. As a result, authorities are often unable to assess the impact of irrigation on water resources. Conflicts with other water users and aquatic ecology are likely to increase.

The emphasis of public policies for adapting irrigation to climate change is on water use efficiency and a shift to less water-consuming crops or varieties. In practice, such demand management policies find little resonance. Almost all current irrigation development aims at increasing water availability. Hence, irrigation is a typical example for effects of societal change overriding those of climate change. In most areas, the extension of irrigated crop area has a larger impact on water consumption than rising temperatures.

One obvious solution to avoid increasing conflicts in times of water scarcity is a drought insurance. As soon as meteorological drought prevails, farmers are reimbursed for crop losses. Drought insurances also improve protection of rivers and groundwater from over-abstraction, as insured farmers will be obliged to stop abstracting water in times of low water tables.

Hydropower

Hydropower is expected to benefit from the general shift of runoff from summer to winter, as more water will be available in times of highest electricity demand. However, the effect of prolonged droughts could affect hydropower production also during winter. International political decisions and economic developments haven proven to substantially affect the demand for hydropower. Building hydropower infrastructure is expensive and time-consuming, and the general economic circumstances are unfavorable for further extensions. On the other hand, hydro-electricity is an important renewable energy source. Clearly, societal influences are much more important for the future of Swiss hydropower than hydrological changes brought about by climate change.

Outlook

Most societal activities concerning water are affected by both climate change and pre-existing pressures (abstraction, pollution, encroachment, infrastructure). Adaptation to climate change can only be successful if these pressures are also addressed. Quick and thorough implementation of existing legislation will make rivers, lakes and groundwater more resilient to the hydrological fall-out of climate change. At the same time, current water protection legislation ought to be assessed to make sure it is sufficient to safeguard future river and lake ecology.

13.9
Overland flow evolution on moraines in silicate and carbonate proglacial areas of the Swiss Alps

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In many areas of the world, the surface of the earth is changing rapidly. Overland flow is one of the processes that can dramatically modify the shape of our landscapes but is also affected by the land surface characteristics. However, our understanding of the evolution of overland flow characteristics and the feedback mechanisms between hydrological, pedological, biological and geormorphological processes that affect overland flow is limited.
We used a space-for-time approach (e.g. Lohse & Dietrich, 2005) and studied 3 plots (4m x 6m each) on four different aged moraines (several decades to ~13.500 years) on the Sustenpass near the Steinglacier and in the karstic glacier foreland of the Griessfirn near Klausenpass (total of 24 plots) to determine how overland flow generation changes during landscape evolution. We used artificial rainfall experiments with three different intensities to determine the overland flow ratio, peak flow rate, timing and duration of overland flow. The addition of tracers (2H and salt) to the sprinkling water and sampling of soil water allowed identification of the mixing of the water within the slopes and the interaction of overland flow pathways with the subsurface. In addition, the runoff samples and sensor-based turbidity measurements provide an estimate of the erosion rates during extreme events. In order to link the differences in overland flow generation with the pedological and biological characteristics of the slopes, soil and vegetation samples were taken on each plot to determine soil texture and root characteristics and the saturated hydraulic conductivity was measured in situ at three different depths (Maier, 2020).
The results show that the overland flow amount and related erosion rates, response times and mixing of overland flow and soil water change during landscape development and can largely be explained by related changes in soil surface and near surface characteristics. However, the rate of these changes during landscape evolution depends on the geology.

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13.10
PIV examinations on the flow-path evolution induced by shear displacements in rough-wall fractures

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Preferential flow-paths are well-known features in fractured rock masses, often allowing rapid movement of fluid and early breakthrough of solute and heat/cold in a small fraction of void space, compared to normal (unfractured) porous media. These preferential flow-paths can change as the configuration of fractures varies, due to, for example, shearing (Kluge et al., 2017; Yeo et al., 1998). Such changes could become particularly imporant for reservoir enhancement, such as hydraulic shearing stimulations. Although numerical studies have shed some light on such changes in flow-paths, experimental visualization and, more importantly, quantification of the flow-path evolution in fractures with rough walls still remain a challenge.

Here, we report our experimental observations and quantitative analyses on flow-path evolution induced by fracture shearing. Fluid flow is introduced into a single rough-wall fracture, configured by the two inner surfaces of a base and a sliding cover. The two rough surfaces of the fracture are numerically generated using SynFrac. Both the base and the cover are 3D-printed with transparent materials. The sliding of the cover is precisely monitored by gauge meter to yield controllable shearing. A solution of mineral oil and anise oil is prepared to match the refractive index of the 3D-printed materials, and serves as the working fluid, seeded with nearly neutrally-buoyant fluorescent particles. Such an experimental setup allows us to implement the Particle Imaging Velocimetry (PIV) measurements, which still have rarely been applied in the geosciences (Ahkami et al., 2018; S.H. Lee et al., 2015). By acquiring the velocity fields of the fluid passing through the rough-wall fracture at different sheared positions, we are able to quantify the changes in the tortuosity and averaged flow rate of individual flow-paths. Our results provide important insights into the impact of shearing on fluid flow in fractures with rough walls.

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13.11
How many parameter sets are really needed for reliable simulation of extreme floods?

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Delivery of reliable extreme flood estimates with associated return periods along with uncertainties remains a major challenge in water resources management and safety-studies. In the absence of long discharge records, these estimates may be derived with a help of a hydrological model through a simulation-based study. Such a simulation-based approach is capable of generating very long pseudo-observed discharge time series based on meteorological inputs from a weather generator (Grimaldi et al. 2013). These pseudo-observed time series of discharge can be then used for frequency analysis. Yet, use of any hydrological model is linked with uncertainty that may arise from several sources and is often represented by the model parametric uncertainty (e.g. in a form of a probability distribution or multiple sets of equally probable parameters). To propagate this uncertainty on flood frequency estimates, multiple model runs are needed with these parameter sets. This increases however the computation requirements of model simulations, particularly if many different input scenarios or long time climatic series must be analysed.

An intelligent preselection of hydrologic model parameter sets is therefore desired. Sikorska-Senoner et al. (2020) have recently proposed a clustering of model parameter sets in frequency space to reduce the number of parameter sets to a smaller amount that could be easily dealt with within simulation frameworks. However, it is not clear how many parameter sets are really needed to reliable describe the full ensemble of hydrologic responses but with keeping the computational model efforts at a desired low level.

In this work, we analyse different number of parameter sets (between 1 and 1000) to describe the hydrologic responses ensemble in order to select an optimal number of parameter sets. Such an optimal number should maximize the information contained in the predictive intervals of flood frequency and minimize the computational efforts at the same time. A selection of these parameter sets is done through clustering of hydrological responses in flood frequency space. The approach is tested in a small Swiss catchment (Dünnern at Olten, 196 km^2) with 10’000 years of continuous daily pseudo-discharge simulations. These pseudo-observations are simulated with a hydrological model (HBV) fed with meteorological scenarios generated with the weather generator (Evin et al. 2018). The selection of the parameter sets is performed in the frequency space by analysing the variability of hydrologic responses through clustering of annual daily discharge maxima.

Our preliminary results illustrate that already 3 sets provide a good representation of the predictive intervals for flood flow frequency if only flow ranges are of interest. If one is interested in the inter-interval variability, 5 till 10 sets could be already sufficient to represent this variability of possible hydrological responses. Potential applications include different simulation studies of flow extremes or safety-studies for dams, bridges or hydropower.

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13.12 Dominant Factors Controlling Sub-Seasonal to Seasonal Hydrological Predictability in Switzerland

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Sub-seasonal to seasonal hydrological forecasts provide knowledge of hydrological variables (e.g. streamflow, soil moisture, snow depth, etc.) several weeks or months in advance (sub-seasonal to seasonal lead times, respectively), rendering them a powerful tool for decision-makers involved in early disaster recognition, management of hydropower plants and agriculture. The skill of such forecasts depends principally on two factors: knowledge of the land surface hydrological conditions (ICs) at the forecast start date and knowledge of the climate forcing (CF) during the forecast period. The common approach to the evaluation of the relative importance of the ICs and the CF is the Ensemble Streamflow Prediction (ESP)–reverse Ensemble Streamflow Prediction (revESP) framework (Wood & Lettenmaier, 2008) that contrasts the forecast skill originating from known ICs and an ensemble of historical climate traces with the forecast skill originating from an ensemble of historical ICs and known CF, respectively. Therefore, the skill of the ESP stems from perfect knowledge of antecedent moisture states (soil moisture, snow, groundwater), whereas the skill of the revESP stems from perfect knowledge of the meteorological variables (mainly temperature and precipitation). The impact of these two main predictability sources on sub-seasonal to seasonal hydrological predictions is highly dependent on the catchment location and elevation, the catchment properties and the season and lead time under consideration. This work aims at elucidating the role of ICs and CF for sub-seasonal to seasonal hydrological predictions in an ensemble of 307 catchments covering entire Switzerland. To this end, the hydrological model PREVAH was implemented to perform the ESP/revESP methodology for the period 2000–2018. The variable topographical, hydro-geological and meteorological characteristics of the catchments result in diverse hydrological regimes that lead to a different impact of the ICs and the CF on the (sub-) seasonal hydrological predictability and on the critical lead time (CLT), denoting the time after which the revESP skill surpasses the ESP skill.

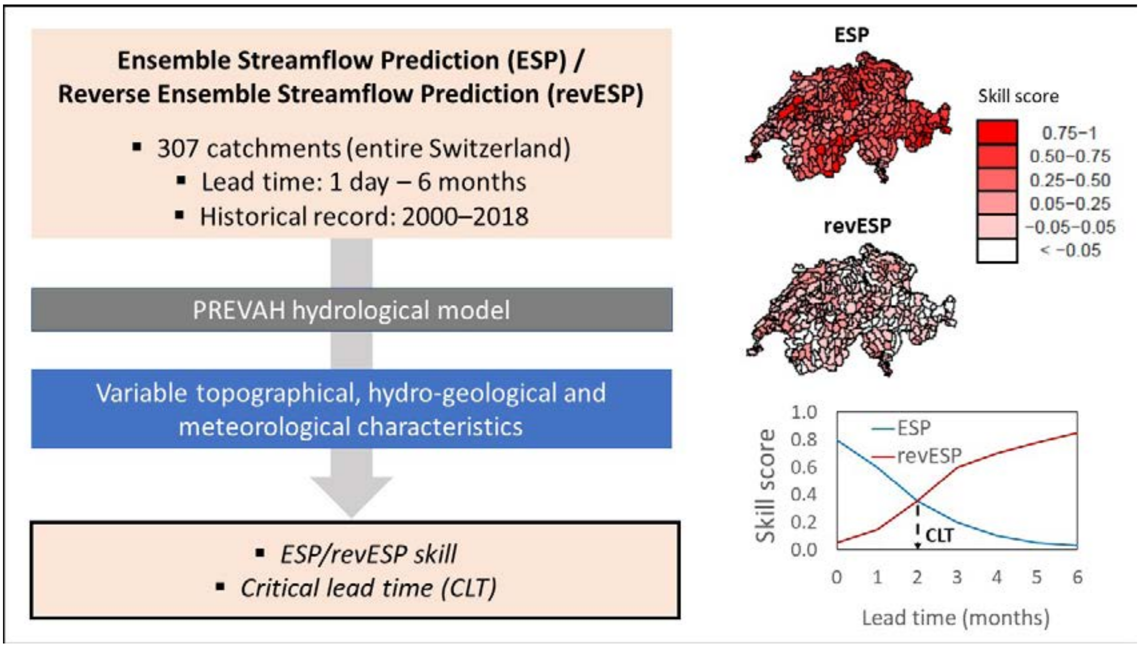

Figure 1. Graphical illustration of experimental procedure

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13.13
Fully-integrated surface-subsurface hydrological modelling in steep, snow-dominated, geologically complex Alpine terrain

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Most hydrological climate change impact assessments in Alpine areas continue to be underpinned by simple conceptual hydrological models. However, such models have numerous limitations that may ultimately affect the reliability of predictions generated using them. For instance, spatial variability in surface and subsurface material properties is often lumped together, empirical snow modelling approaches prevail, and the potential hydrological impacts of contemporaneous changes in other environmental system components such as vegetation and permafrost tend to be overlooked. Considerably more sophisticated physically-based, spatially explicit codes which are capable of simulating 2D surface flows, 3D variably-saturated subsurface flows, and evapotranspiration in a fully-integrated fashion appear to have great potential with respect to the simulation of mountainous hydrological processes. However, integrated models have not yet been applied in real steep, snow-dominated, geologically complex Alpine catchments. This presentation therefore describes the development, automated calibration, and application of a fully-integrated model of two adjacent headwaters in the western Swiss Alps under both historical and plausible future climatic, vegetation, and permafrost conditions. The model incorporates both a detailed representation of the 3D geological structures encountered in the study region and a sophisticated, energy balance-based snow modelling routine that additionally accounts for the gravitational redistribution of snow from steep slopes and was conditioned on two types of complementary snow observations. The results indicate that, for a moderate warming scenario towards the end of the century, "direct" climatic changes are found to dominate the impacts upon key hydrological variables such as streamflows and groundwater levels, whilst "indirect" forest expansion is likely to have a more modest modulating effect via enhanced evapotranspiration. Overall, the work attests to the potential of integrated models to provide a physically sound and internally coherent representation of hydrological dynamics in even the most complex of Alpine settings. That said, the amount and diversity of the data required, as well as long execution times, mean that such an approach is presently only recommendable in exceptionally important or ecologically sensitive catchments.

13.14
Elevated concentrations of toxic elements in high-alpine streams of the Eastern Alps: a manifestation of climate change?

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In the Eastern Alps, there are several high-alpine streams with distinctivley white-colored streambeds (Fig. 1). The white color originates from the precipitation of nanocrystalline basaluminite [$Al_4OH_{10}(SO_4)\cdot(H_2O)_3$] sticking to the bedload of the streams (Wanner et al., 2018). The phenomenon is triggered at the origin of the streams where the oxidation of pyrite leads to the production of sulfuric acid and the subsequent dissolution of aluminum from the host rock. Owing to its strong *pH*-dependent solubility, precipitation of basaluminite eventually occurs when the acidic and aluminum-rich streams are neutralized along their flow paths.

For this contribution, we present chemical water analyses for seven high-alpine streams with clearly visible basaluminite precipitates. The streams are all located in the canton of Grisons. Geologically, the catchments are located within the crystalline basement of the Australpine nappes and the exposed host-rock is dominated by pyrite-bearing mica-schists. All streams show low *pH* conditions (<5) and elevated total dissolved solid concentrations up to 2000 mg/L. The lowest *pH* and highest element concentrations are observed at the origin of the streams where streamwater temperatures are below 2 °C. Beside their low *pH*, the streamwaters do not meet Swiss drinking water quality with respect to their As, Ni, F, Al, and Mn concentrations. Moreover, in most streams the concentrations of As, Mn and F even exceed the Swiss regulatory limits for contaminated sites. The mobilization of toxic As is further manifested by elevated As concentrations in basaluminite precipitates collected along the streams, reaching values up to 1400 µg/g

In a preliminary study, we have shown that slow moving groundwater flow is required to promote pyrite oxidation and the subsequent mobilization of toxic elements in such high-alpine settings (Wanner et al., 2018). The observation that the minimum temperature of all seven acidic streams is very close to the melting point of ice now suggests that rock glaciers (i.e. permafrost) occurs at the origin of the streams and that these form little aquifers with sufficiently high groundwater residence times to produce sulfuric acid from pyrite oxidation. The presence of rock glaciers is also consistent with geomorphologic observations, the high altitude of the catchment origins (>2700 m a.s.l.), and their generally north-facing orientation.

The apparent importance of permafrost in generating low streamwater *pH* values and elevated toxic element concentrations implies that the impact of climate change on the water quality of such high-alpine streams should be assessed. A likely scenario is that the ongoing permafrost retreat will expose more pyrite-bearing bedrock to aerobic waters and that the production of sulfuric acid and mobilization of toxic elements will increase in the future. This scenario is supported by a long-term monitoring study performed in a smilar setting in the Rocky Mountains, demonstrating that the concentrations of sulfate and Zn strongly increased over the past 40 years (Todd et al., 2012). Moreover, the importance of climate change in adversely affecting the water quality of high-alpine streams is also demonstrated at one of the investigated catchments in the Eastern Alps. There, from aerial photographs it can be inferred that the onset of basaluminite formation only dates back to the year 2000, implying that the phenomonon is relatively new. In conclusion, we propose to initiate a long-term water quality monitoring of the affected high-alpine streams in the Eastern Alps to assess the future impact of climate change on these particular water ressources.

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Figure 1. Photograph of basaluminite precipitation occurring along “Ova Lavirun”, a high-alpine stream in the Engadin area. The white arrow marks the onset of precipitation, which is triggerd by the neutralization of Ova Lavirun by a circumneutral tributary merging from the upper left.

13.15
CH2018 projections for Run-of-River power production

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Around 57 % of electricity in Switzerland is generated by hydropower (HP), whereof around 25 % are produced by Run-of-River (RoR) power plants.
In the context of the Swiss energy strategy 2050, an attempt is made to increase this share by about 10 % (in total 38’600 GWh/a). But, growing energy demand coupled to growing ecological awareness is catapulting hydropower into a position of great expectation and responsibility. In this context, the present research proposes to compare climate change impact on RoR production with the potential increase by optimizing the design discharge or to losses due to environmental flow requirements.

To assess climate change impact, daily runoff until the end of the century was simulated with the hydrological model PREVAH, using a total of 26 climate model chains from the new Climate Change Scenarios CH2018, corresponding to the two different CO_2 emission scenarios RCP2.6 and RCP8.5. Changes in HP production under climate change are estimated for eleven RoR power plants based on differences in the flow duration curves (FDCs) between the reference period (1981-2010) and the future periods (2045–2074 and 2070–2099), assuming unchanged installed machinery and environmental flow requirements.

The changes in RoR power production are due to changes in precipitation, temperature and evaporation, which in turn have a strong impact on the dominant hydrological processes (snow accumulation and melt, glacier melt and runoff production), and show important spatial and temporal differences (Figure 1). By mid-century (2045–2074) and under concerted mitigation efforts (RCP2.6), annual production will remain roughly the same as during the reference period. Production will decrease slightly (about -3 %) without climate change mitigation (RCP8.5). Exceptions are power plants that are strongly influenced by melt processes. Due to reduced snowfall and increased winter precipitation and ensuing higher winter streamflows, winter production will increase at almost all RoR power plants considered in this study by mid-century, by about 5 % on average.
By the end of the century (2070–2099), a slight decline of the annual production (-1.5 %) is to be expected under RCP2.6. Without climate change mitigation (RCP8.5), annual production will fall further (-7 %). Winter production will increase at virtually all studied RoR power plants. Depending on the emission scenario, the average winter production increase will be between 5 % (RCP2.6) and 10 % (RCP8.5). However, this increase in winter production will not be sufficient to prevent annual production decline.

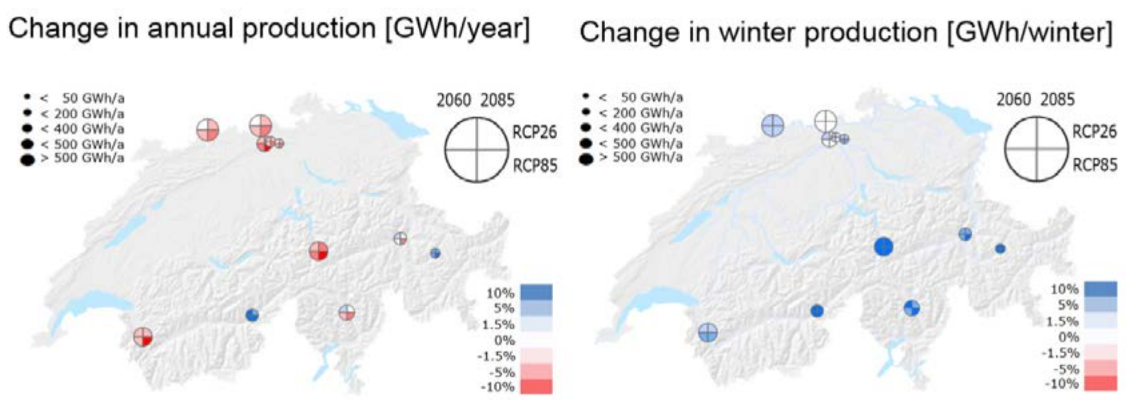

Figure 1. Expected changes in annual (left) and winter (right) production of eleven selected Swiss Run-of-River power plants for the periods 2060 (mid-century, 2045–2074) and 2085 (end of century, 2070–2099). The calculations are based on the most recent Climate Change Scenarios CH2018 established by MeteoSwiss (26 climate models; two emission scenarios: with concerted mitigation efforts RCP2.6 and no climate change mitigation RCP8.5) and a state-of-the-art hydrological model (PREVAH), taking into account unchanged installed machinery and environmental flow requirements (SCCER-SoE 2019).

These climate change induced reductions of annual HP can be put into context by comparing the potential production losses that result from environmental flow requirements or production increases through optimizing the design discharge. For the eleven RoR power plants under current hydrological conditions, the potential that could be achieved by optimizing the design discharge is an increase of 6% in production. Compliance with legal constraints on environmental flow rates, compared to no residual flow, means a decrease of 4% in production.

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14. Limnology in Switzerland and the new LéXPLORE infrastructure

Damien Bouffard, Natacha Tofield-Pasche, Michael Döring

Swiss Society for Hydrology and Limnology SGHL

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14.2 *Chmiel H.E., Férnandez-Castro B., Minaudo M., Krishna S., Perolo P., Rasconi S., Wüest A.*: Summer primary and ecosystem production in Lake Geneva diagnosed from high-resolution in situ oxygen measurements

14.3 *Cotte G., Vennemann T.*: Nutrient cycling at the LéXPLORE platform of Lake Geneva, Switzerland.

14.4 *dos Santos Correia F., Ray A., Fillion R., Spaak P., van de Waal D., Ibelings B.W.*: Trophic bottlenecks in Lake Geneva

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14.13 *Tardif M., Rey S., Ribi S., Arabadzhiev I., Ibelings B., Pomati F., Bellouard Y.*: Optofluidic sensor for in-situ monitoring of phytoplankton in Lake Geneva

14.14 *Worms I., Slaveykova V.*: Characterization of dissolved organic matter (DOM) by asymmetrical flow field-flow fractionation with multidetection (AF4-MD) and its potential applications to investigate dynamci of changes in DOM composition and properties occuring in the freshwater contiuum

POSTERS:

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P 14.2 *Råman Vinnå L., Wirth S.*: Assessing pockmark activity in lakes under influence of drainage area processes

P 14.3 *Doda T., Ramón C.L., Ulloa H.N., Brennwald M.S., Kipfer R., Schubert C., Wüest A., Bouffard D.*: Lateral transport of dissolved gases by cooling-driven density currents in a small temperate lake

P 14.4 *Scheidler S., Dresmann H., Huggenberger P., Auckenthaler A., Epting J.*: Regional groundwater flow systems in the context of karst development – an example from north-western Switzerland

P 14.5 *Escoffier N., Perolo P., Lambert T., Rüegg J., Odermatt D., Adatte T., Vennemann T., Perga M.-E.*: Triggers of whiting events in Lake Geneva

P 14.6 *Erdbrügger J., van Meerveld I., Seibert J., Bishop K.*: Flow directions of shallow groundwater in a boreal catchment

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P 14.8 *Martinetti S., Floriancic M., Fatichi S., Burlando P., Molnar P.*: Riparian vegetation controls transpiration as a function of the groundwater level: a field study with stomatal conductance and dendrometry measurements

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P 14.13 *Maner J., Drieschner C., Ebi C., Schönenberger R., Angst L., Bloem S., Solsona M., Renaud P., Schirmer K.*: RAINBOWflow CHIPonline: A fish cell-based impedance sensor to monitor water quality

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14.1
SIMILE: An integrated monitoring system to understand, protect and manage sub-alpine lakes and their ecosystem

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Lakes are a fundamental resource for the Insubric region (cross-border area that includes Ticino, North Lombardy and west Piedmont regions). Therefore the quality of their waters must be protected from the risks caused by the increased anthropogenic pressure and climate change. The main objective of the interreg project named SIMILE [1] is to support decision making in the definition of management policies through an advanced information system based on data obtained from innovative monitoring systems (automatic, diversified, cost-effective and with high spatial and temporal resolution). The information system will also facilitate the identification of possible critical issues understanding the specific causes in a timely manner by using a common methodology across Switzerland and Italy: specifically for Lake Lugano, Lake Maggiore and Lake Como. The project aims at capitalizing and sharing the experiences of the project partners in the field of monitoring and management of water resources in the project area, in particular in the context of the CIPAIS programs (IT-CH international water protection commission). The information system, fully open, is designed to offer an effective, low-cost and sustainable solution that can be maintained by the project partners beyond the end of the project. From a scientific and technical point of view the project is based on the combination of advanced automatic and continuous observation systems, high resolution remote sensing data processing, citizen science and ecological and physical models. The system architecture is illustrated in Figure 1.

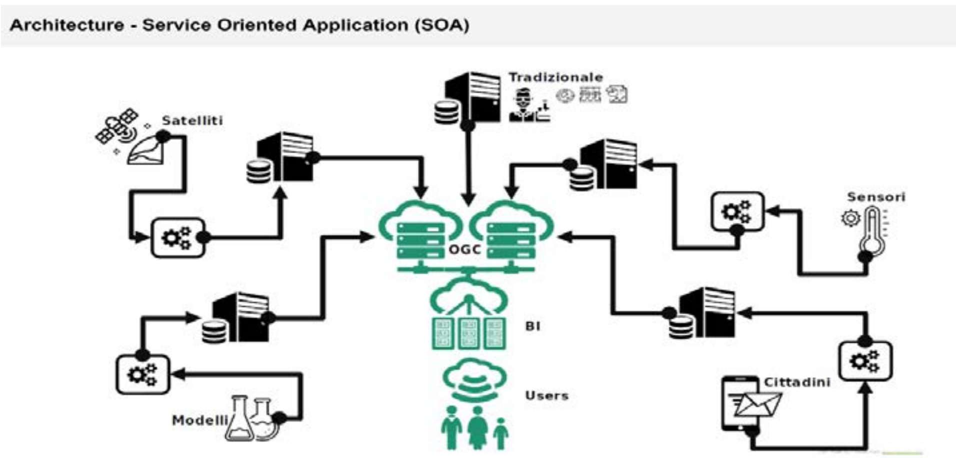

Figure 1. SIMILE's information system architecture. It includes the management of data obtained from Satellites, Numerical Models, Traditional laboratory analyses, real time in-situ sensors and citizens.

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14.2
Summer primary and ecosystem production in Lake Geneva diagnosed from high-resolution in situ oxygen measurements

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The dynamics of primary production (PP) in Lake Geneva remain a topic of debate. In spite of a significant reduction of the phosphorus load over the past decades, the algae biomass has not decreased as expected. However, the traditional quantification of PP from bottle incubations in the long-term monitoring at biweekly or monthly timescale might be insufficient for capturing primary production dynamics occurring on shorter timescales. Newly acquired free-water measurements of dissolved oxygen (DO) and temperature near the LéXPLORE platform allow now for resolving the rates of gross primary production (GPP), community respiration (R), and their balance term net ecosystem production (NEP) in this large lake at the daily scale and at different depths. Metabolic rates are traditionally derived from in situ DO measurements using the *diel oxygen method*. The application of this method to a large lake and over multiple depths poses unique challenges for the separation of the biological from the physical signal, namely the vertical dislocations caused by internal wave motions.

Here we investigate two different methods to tackle this problem in the frequency and in the time domain, using a 7-month depth-resolved (0-30 m) data record acquired in Apr-Oct 2019. (i) The first method generated fortnightly NEP estimates from filtered DO time-series and GPP and R were calculated from the diel amplitude using spectral techniques to remove the physical signal. (ii) The second method used the classical diel oxygen technique applied to a DO signal previously de-noised in the time domain by subtracting the fraction of daily DO variability correlated to temperature variations. We found that a large part of the DO variability at daily scale (up to 60-80% below 15 m, 40-50% above) was explained by physical processes alone. Despite this challenging situation, both methods produced consistent estimates of the metabolic rates and their temporal variability. From the spectral method, which seemed to produce more robust estimates, we obtained an average NEP of +1.8 gO_2 m^{-2} d^{-1} in the upper 30 m of Lake Geneva during summer 2019, with a mean GPP of 7.5 gO_2 m^{-2} d^{-1} partially balanced out by a mean R of 5.8 gO_2 m^{-2} d^{-1}. The diagnosed NEP is consistent with previous estimates of hypolimnetic oxygen consumption and nutrient budgets in the photic zone.

14.3
Nutrient cycling at the LéXPLORE platform of Lake Geneva, Switzerland.

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In the context of the re-oligotrophication scheme of Lake Geneva, the nutrient concentrations in its catchment have been considerably reduced (CIPEL, 2019). However, despite these restrictions, the primary production may still exceed those expected for generally oligotrophic Alpine lakes. Hence, it is still relevant to determine: (i) the origin of the nutrients (rivers as likely entry points), (ii) the distribution in space and time of the nutrients throughout the lake and, (iii) how they are metabolized.

This study focuses on a series of long-term, high density measurements of the principle anions and cations dissolved in water, the H- and O-isotope composition of water as well as of the dissolved inorganic carbon (DIC) in addition to standard temperature, pH, conductivity, and turbidity for a depth profile at the recently established research platform (LéXPLORE) situated close to Pully within Lake Geneva (Fig. 1).

The objectives are to study the temporal dynamics of nutrients and to determine the physical, geochemical and biological processes responsible for it.

To address these objectives, a submerged pump coupled to a refrigerated autosampler were installed on the platform during September and October 2019. Lake water was continuously pumped from 18 m then 22 m depth, where the Rhône River interflow was previously detected for this season (Cotte and Vennemann, 2020). Overall 120 samples were collected at regular intervals over this period.

The results present a high variability in nutrient concentrations with time. Vertical advection events (upwelling and downwelling) clearly have a strong impact on the nutrient dynamics and hence bioproductivity within the water column. The H- and O-isotope composition of the water, clearly demarcates the interflow of the Rhône River, the main tributary of the lake, and it is hypothesized that the Rhône has a potential fertilisation effect by introducing nutrients directly into the euphotic zone of the lake during the stratification period. The importance of autochthonous metabolisms is best ascertained by following the dissolved oxygen concentration within the water column. Depending on correlation between different measured parameters, hypotheses can be made on the processes responsible of the nutrient cycling.

Figure 1: Map of Lake Geneva showing the location of the LéXPLORE platform as a yellow cross. The Rhône River inflow is indicated by a blue arrow. The blue and green dots represent the locations of the two permanent monitoring stations within Lake Geneva. Insets : a. Image of the platform. b. Larger scale map of the area around the platform.

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14.4
Trophic bottlenecks in Lake Geneva?

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Lake Geneva, like other peri-alpine lakes in Switzerland is undergoing rapid environmental change, driven by amongst others re-oligotrophication, increasing levels of micropollutants and the dirct and indirect effects of climate change. The ca. 80 % reduction in phosphrous has not yet resulted in a decrase in chlorophyll-a levels of the lake. There are, however, indications that higher trophic levels, notably small crustaceans like *Daphnia* and their crustacean predators *Bythotrephes longima* - an important food source for coregonid fish in the lake – are declining. In this project (Trophic Bottlenecks in le Léman – TaBLe)we invstigate whether an increase in the carbon : phosphorous ratio may create trophic bottlenecks, where the quality of the seston as food for zooplankton is insufficient to sustain optimal population development. Seston that is high in C:P or C:N ratios has negative consequences for growth and reproduction of zooplankton that generally exhibit lower carbon:nutrient ratios due to their high nutrient demands (Van de Waal et al., 2009). This will reduce transfer of carbon to higher trophic levels (Sterner and Elser 2002). This is what has been referred to as a stoichiometric bottleneck. Van Donk et al. (2008) conclude that these bottlenecks may occur in lakes that undergo re-oligotrophication, but it is by no means an inescapable outcome. The occurrence and severity of stoichiometric bottlenecks is highly lake specific, depending on factors like lake-morphometry, water residence time, water temperature and food web structure. Therefore bottlenecks should be studied in each lake individually. Homeostasis of zooplankton is expected to dampen the effect of stoichiometric imbalance for the next trophic level (e.g. *Bythotrephes*), but studies indicate that the negative effects may find their way up the foodweb (Malzhan et al., 2010). TaBLe aims : (i) To verify the possible existence and strength of stoichiometric bottlenecks in the foodweb of Lake Geneva, (ii) To investigate long term trends in the sestons` C:N:P of Lake Geneva, what are typical values for the eu-, meso- and oligotrophic phases of lake restoration?, (iii) To assess to what extent an increase in Lake Geneva seston C:N.P affects local zooplankton growth; what are the so-called threshold-elementary ratio`s (*TER*) above which zooplankton life history starts to be negatively affected as result of reduced food quality?, (iv) To look for the dampening of stoichiometric imbalances through homeostasis in the primary consumers on secondary consumers of Lake Geneva (predatory zooplankton)? For this we apply the following methods : (i) Time series: compute - and validate - long term trends in seston C:N:P, (ii) Field sampling: seasonal changes C:N:P, (iii) Experiments: vary C:N:P of phytoplankton and test effects on life-history of zooplankton, both primary and secondary consumers (Sarpe, Ibelings et al., 2014). Initial results indicate that both the main effects of food quantity and food quality (C:P) have clear effects on life history of Daphnia from Lake Geneva. Full results will be presented at the conference. Also the opportunties for new instrumentation on LéXPLORE to study plankton and foodweb interactions will be explored.

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14.5
Seasonality of the mechanical energy budget in a large lake: Lake Geneva (Switzerland-France)

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Mechanical energy (potential + kinetic) is supplied to lakes at the atmosphere-lake interface in form of heat fluxes and wind stress, but also through river discharge. The interplay between these energy fluxes and the fate of mechanical energy (mixing *vs*. dissipation) in the interior of the waterbody determines the vertical stability and the magnitude of the vertical fluxes, influencing the ecosystem dynamics by promoting the exchange of nutrients, gases, etc.. Due to the extensive fieldwork required to close the ME budget, previous attempts based on *in situ* measurements are restricted to a few case studies, which focused exclusively on the summer season. However, seasonal changes in forcing and stratification certainly modify the energy pathways. For this study, we collected year-round measurements in Lake Geneva, between April 2019 and April 2020. Depth-resolved temperature, currents and turbulent kinetic energy dissipation rates were obtained with moored instruments and microstructure profiles (~400) from a newly built research platform LéXPLORE (https://lexplore.info/), located 600 m away from the northern shore of the lake.

During the study period, wind work at 10 m above the lake surface averaged 172 W m^{-2}. Correlation between wind stress and sub-surface velocities indicated that ~0.38% of this energy (0.66 mW m^{-2}) fed internal lake motions, which stored on average 175 J m^{-2}. On average, most of the energy was dissipated in the bottom boundary layer (0.33 mW m^{-2}, ~48%) by turbulent (0.22 mW m^{-2}, ~32%) and laminar (0.11 mW m^{-2}, ~16%) processes, and in the interior of the water column (0.27 mW m^{-2}, ~40%). Finally, ~12% of the energy supply (0.08 mW m^{-2}) was used to produce mixing in the stratified part of the water column.

This general picture showed significant seasonal variations. In winter, when the lake received more wind energy and was weakly stratified, bottom boundary dissipation was the dominant energy sink. On the other extreme, during the weakly energetic, stratified summer period, mixing represented an important sink of energy, while the bottom boundary layer contribution was relatively minor (~15%). The energy supply by the windseemed insufficient to account for all energy sinks during the summer period. The intrusion of the Rhône river in summer produced a large scale upwelling and was a source of potential energy available (yearly mean, 0.04 mW m^{-2}) for mixing within the stratified part of the water column, likely contributing to close the summer energy budget.

14.6
Can the bio-optical stratification in a large lake be estimated using temperature profiles and meteorological data?

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Lakes, as an essential part of the water cycle, play a vital role in supplying domestic water, as well as in agricultural and industrial applications. Today, several polar-orbiting earth observation satellites are used to monitor water quality parameters through measurements of reflected sunlight. The vast majority of remote sensing retrieval methods assume vertically uniform optical properties within the euphotic layer. However, deep Chlorophyll (CHL) maxima [*Odermatt et al.*, 2012] or river intrusions at the thermocline [*Doxaran et al.*, 2012] can add considerable complexity to Apparent Optical Properties (AOP; e.g. water-leaving radiance) used to retrieve water quality parameters from space. In this study, we aim to link the bio-optical stratification in a large lake to the vertical temperature profiles and surface meteorological forcing, e.g., wind speed and global radiation. The developed predictor model will serve as a critical step towards a bigger goal, namely obtaining stratification properties from remotely sensed optical signals. Lake Geneva is our primary study site because its euphotic depth is often larger than its stratification depth. Furthermore, automated measurements of optical and physical profiles by a Thetis profiler moored next to the LéXPLORE research platform provide a unique and precious dataset for the objectives of this work.
Preliminary investigation of Thetis data suggests that the relevant vertical non-uniformities of constituents, i.e. deep CHL and/or backscattering (as a proxy for the Total Suspended Matter; TSM) maxima, occur mainly during the April-September period. This is in agreement with the historical monthly measurements at the deepest point of the lake[*Nouchi, Odermatt, Wüest, & Bouffard*, 2018]. The results also indicate that the extent of CHL and backscattering maxima lies between the top and the bottom of the metalimnion layer for most of the studied period. The backscattering maxima are usually deeper than CHL peaks. We will employ more sophisticated models, e.g. machine learning approaches, to establish a reliable bio-optical stratification predictor based on water column thermal structure and dominant meteorological parameters.
The results of this study can be used to improve remote sensing retrieval algorithms, particularly by employing hyperspectral OCI sensors (e.g., future NASA's PACE satellite). The validated model can be also combined with the outputs of a 3D hydrodynamic model of the lake such as meteolakes [*Baracchini, Wüest, & Bouffard*, 2020], and Sentinel-3 OCI satellite products in order to enhance the estimation of water quality parameters at larger scales. The developed methodology can be also useful to study other inland water bodies and oceans, wherever there is similar datasets.

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14.7
Model-based data analysis of the effect of winter mixing on primary production in a lake under reoligotrophication

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Reduced nutrient loading, in combination with climate change are important drivers of primary productivity in lakes. Understanding and forecasting future changes in primary production (PP) in response to local and global forcing are major challenges for developing sustainable lake management. The objective of this study is to understand and characterise the mechanisms underlying the large differences in observed PP rates and nutrient concentrations between two consecutive years (2012 and 2013) in Lake Geneva. For this purpose, we apply a one-dimensional (1D) physical-biogeochemical model system. The Framework of aquatic biogeochemical models (FABM) interface is used to couple General Ocean Turbulence Model (GOTM) with a biogeochemical model, Ecological Regional Ocean Model (ERGOM). We calibrated GOTM, by adjusting physical parameters, with observed temperature profiles. A model calibration method is implemented to minimise model-data misfits and to optimise the biological parameters related to phytoplankton growth dynamics.

According to our results, the simulated surface mixed layer depth is deeper and heat loss from the lake and turbulent kinetic energy in the water column are much higher in winter 2012 than that of 2013, pointing to a cooling-driven, deep mixing in the lake in 2012. We found significant differences in internal phosphorus loads in the epilimnion between the two years, with estimates for 2012 being higher than those for 2013. ERGOM predicts weak nutrient limitation on phytoplankton and higher growth rates in 2012. Apparently, the deep mixing event lead to high turnover of nutrient (particularly dissolved inorganic phosphate) to the surface layers, and a massive algal bloom developed later in the productive season. In contrary, the turnover of nutrients in 2013 was weak and consequently the primary production was low. Our findings demonstrate the utility of a coupled physical-biological model framework for the investigation of the meteorological control of primary production dynamics in aquatic systems.

14.8
Diel patterns in water inherent optical properties of Lake Geneva and their physical and biogeochemical drivers

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To explore the interplay between biogeochemical and physical processes and how they are related to primary production (PP) in large lakes, we have deployed since October 2018 a sophisticated autonomous profiler in Lake Geneva, Switzerland, in the vicinity of the floating platform LéXPLORE (https://lexplore.info/). The so-called Wetlabs Thetis profiler measures with a centimeter resolution backscattering and fluorescence at discrete wavelengths, hyperspectral absorption and attenuation, along with temperature, dissolved oxygen and conductivity. The profiler was deployed over contrasted seasons and recorded these parameters every three hours over the top 50 m of the water column as long as batteries last, i.e. for approximately 3 weeks. Between October 2018 and May 2020, the Thetis has performed 1380 profiles, despite one large gap in the data collection between July 2019 and January 2020 due to telemetry issues. We extracted several metrics in the inherent optical properties (IOPs), serving as proxys for the concentration and nature of dissolved and suspended matter. We were interested in the vertical and temporal variability of these metrics, across the diurnal to the seasonal scale. Data revealed interesting diel patterns in the IOPs, in particular within the photic zone. For instance, absorption line height peak at 676nm, a good indicator for phytoplankton biomass, was synchronous with the diurnal cycle of solar radiation. Similarly, the spectral attenuation slope, indicative of average particle size, presented often a minimum by the end of the day, and a minimum before sunrise, as a result of phytoplankton cell growth during the day and cell division and loss during the night. There was a link between diel patterns in IOPs and diurnal O2 concentration, classically used to characterize the metabolism variations of the ecosystem. Moreover, the amplitude of diel IOPs was found to be the largest under low wind and high irradiance conditions, i.e. under conditions highly favorable for PP.

Our work demonstrates the great potential of using high-resolution IOPs measurements to characterize PP in freshwater. This in-situ data is now being combined with remotely sensed water quality parameters (OLCI products from Sentinel 3A and 3B) and a three-dimensional hydrodynamic model of Lake Geneva (www.meteolakes.ch) to upscale PP estimates from local to basin scale.

14.9
Satellite Earth observation products for lake research

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Lacustrine processes are subject to substantial sub-daily dynamics in all spatial dimensions. The Sentinel-3A and Sentinel-3B satellites' Ocean and Land Colour Instruments (OLCI) acquire daily optical remote sensing data suitable for water quality estimation in the horizontal domain. Since 2018, the automated Thetis profiler next to the LéXPLORE platform in Lake Geneva has acquired an unparalleled dataset of high temporal and vertical resolution optical data (pres. Minaudo et al., SGM 2020). We are developing purposeful, validated and easily accessible datasets from both data sources, with the ultimate aims to better characterize primary production and calcite precipitation in Lake Geneva, and to provide a comprehensive and diverse dataset to the wider lake research community. ¨

Calcite precipitation is often a subtle, and sometimes a visually striking ('whiting') process that occurs in Lake Geneva and many other water bodies usually during the summer months. Whitings in Lake Ontario, 2007 (Effler et al., 2013) and off the coast of Florida (Long et al., 2017) feature consistently steeper decreases in particle backscattering coefficients in contrast to reference samples. Specific absorption by calcite, on the contrary, is lower than for any other mineral (Babin and Stramski, 2004). Empirical algorithms relate these inherent optical properties to the 550 nm reflectance peak in Earth observation satellite data, which is void when the peak wavelength shifts to 510 nm for higher particle concentrations. We therefore evaluate year-round backscattering slopes measured by Thetis to indicate calcite abundance and validate semi-analytical retrievals from OLCI data.

We furthermore use Thetis measurements to validate OLCI-derived Secchi depth and chlorophyll-*a* as input into bio-optical primary production models. All validated products will be made available in https://www.datalakes-eawag.ch.

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14.10
LéXPLORE – the novel platform for Léman exploration

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The LéXPLORE platform is a novel and unique infrastructure floating on Lake Geneva since February 2019, with the goal to foster interdisciplinary research. Up to 16 researchers can work simultaneously in safe, dry and spacious conditions on the water. Its floating pontoon of 10 x 10 m^2 offers multiple accesses to the water column extending to a depth of 110 m. Around the platform, a protected area of 15’000 m^2 hosts scientific instrumentation in safe conditions, which can be directly connected to the platform infrastructure.

The LéXPLORE platform opens many opportunities for research, technology development and innovation. It allows testing nonsubmersible technologies in-situ, deploying autonomous multiparameter profilers and moored instrumentation to acquire data at high frequency. LéXPLORE opens new perspectives in remote sensing, as it provides a calibration point with measurements in real-time. In addition, a core dataset of background information is available openly for researchers and the public. This dataset is processed automatically in near real-time and products including in-situ data, lake simulations and remote sensing data are available in the DATALAKES web-portal.

The LéXPLORE platform is open to any researcher at the national or international levels. It is a unique partnership between 5 academic institutions: EPFL, Eawag, University of Geneva, University of Lausanne, and CARRTEL (INRAE-USMB, France). These collaborations ensure multi and inter-disciplinary studies using state of the art technologies. Currently, 20 research projects, which cover a wide range of topics, are or will use this novel infrastructure in parrallel. Some projects concentrate on the ecosystem functionning including bacteria, mussels, and phytoplankton to fishes. Other projects focus on physical and biogeochemical processes or on the development of new technologies. With the collected data, researchers will be able to model the evolution of the lake ecosystem and the interaction with the atmosphere.

This presentation will give a general overview of the LéXPLORE platform, the opportunites and current research projects. We invite any interested scientists to already visit lexplore.ch and join us by filling in the project application form.

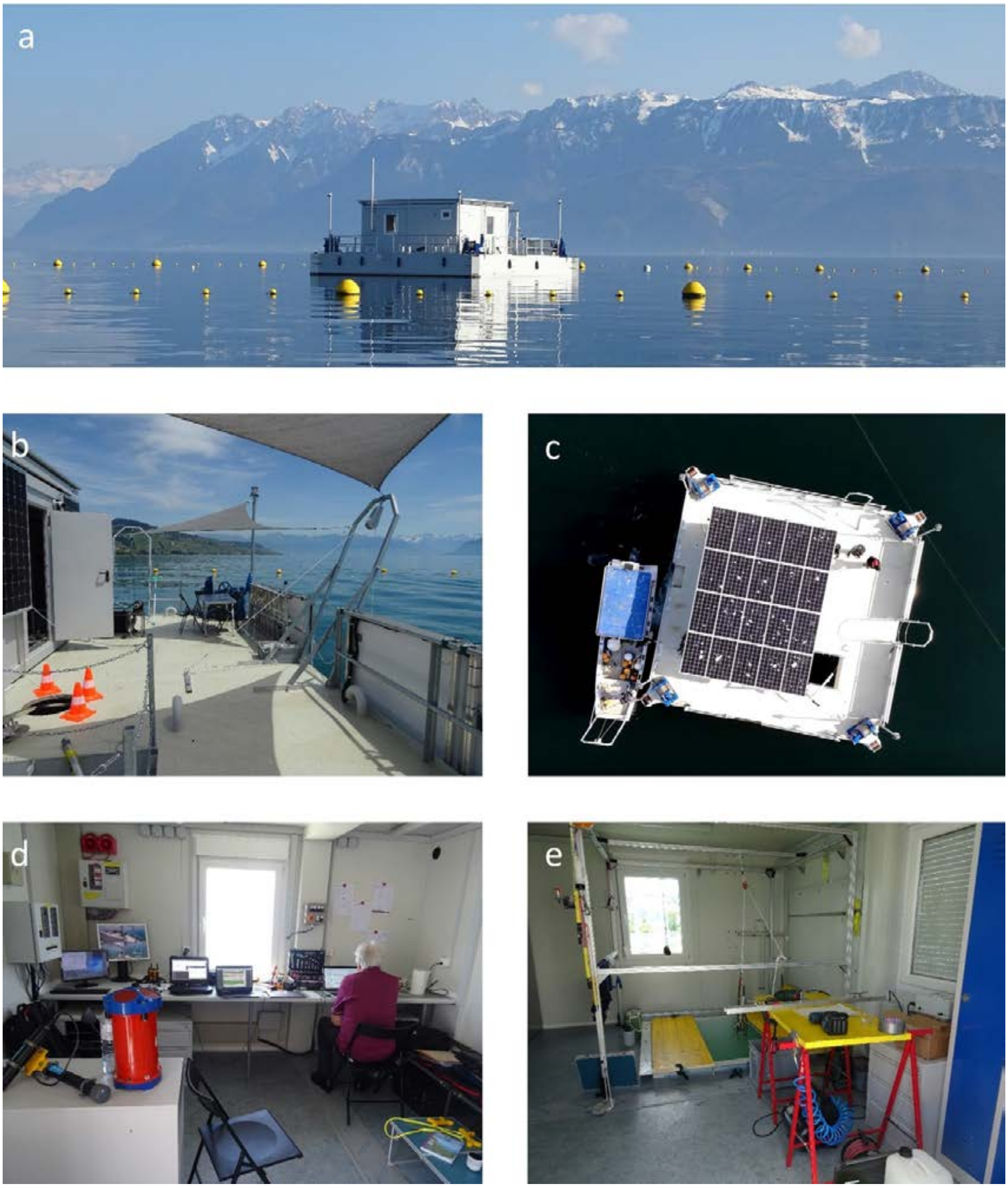

Figure 1.a) General view of the LéXPLORE platform with the protection perimeter, b) southern outside deck, c) top view of the platform, d) working area inside the cabin, and e) view on the moonpool inside the cabin

14.11
Does mixing of stream and lake water create mini-estuaries in lotic-lentic transition zones?

Janine Rüegg, Marie-Elodie Perga, Stuart Lane

Lakes and their streams are inherently linked by flowing water, but the lotic-lentic-lotic continuum and lotic-lentic transition zones are rarely studied. The lotic and lentic transition zone can be viewed as an ecotone similar to a mini-estuary where the mixing of lotic and lentic water may alleviate biological limitations and create hotspots. We hypothesized that the littoral area influenced by the inflowing stream would differ in physical, chemical, and biological characteristics from the remainder of the lake littoral. We measured physical (e.g., flow, temperature), chemical (e.g., nutrient concentrations) and biological (e.g., benthic biomass, benthic metabolism) properties of the littoral along the 50 cm depth line parallel to shore in the two inlets of the Alpine Lake Derborence (Switzerland). Sample locations were selected to begin the transect beyond the influence of the inflowing stream water, pass though the inflow, and end on the other side beyond the inflow influence, with sampling occurring monthly from July through October. The stream-lake connections were highly dynamic from the high snowmelt-related discharge reaching far into the lake in July to no surface flow connection in September, which was reflected in the flow velocity measured in the littoral. Flow velocity as an indicator of the transition zone mainly predicted physical variables, while benthic function was better described by nutrients and benthic biomass. Transition zones of Lac Derborence were thus neither easily identified nor well established, but rather spatially and temporally variable.

14.12
A comprehensive Bayesian data assimilation platform for a 3D hydrodynamic model of Lake Geneva

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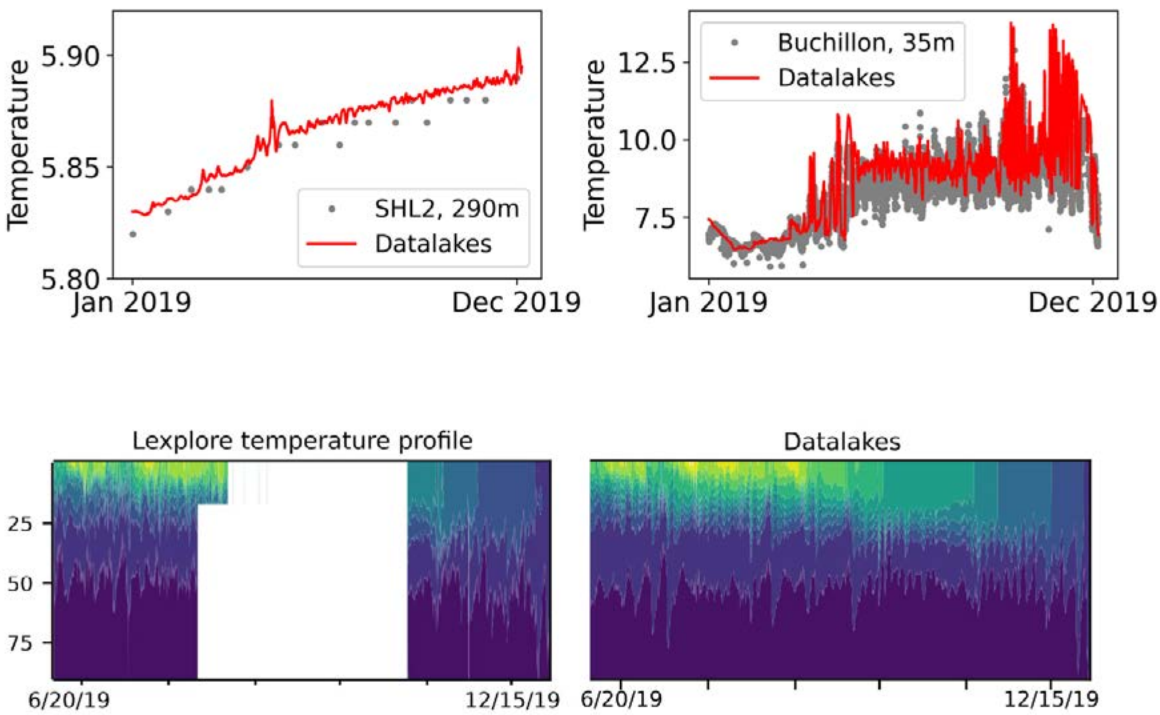
The steady expansion of computational resources has enabled the use of complex high-resolutions hydrodynamic models. In parallel, we observe a gradual increase in the number of high-resolution in-situ measurements and a rising use of remotely sensed observations to monitor the state of the Swiss lakes. While the data provides a rich spatio-temporally heterogeneous glimpse into the condition of a lake, its exact state remains largely uncertain. Therefore, the challenge is to combine the in-situ observation platforms, remote sensing and computational resources into a single framework capable of making accurate predictions. Of particular interest is the recently deployed LéXPLORE platform, which provides high-frequency dataset of vertical measurement profiles in real-time.

As part of the DATALAKES project, we develop a 3D hydrodynamic model capable of using heterogeneous observational measurements for data assimilation and forecasting purposes. Uncertainty quantification using Bayesian inference and modern Markov Chain Monte Carlo methods is implemented using the SPUX package, with the stochasticity provided by an ensemble of weather forecasts. We deploy a Bidirectional Long Short-Term Memory (Bi-LSTM) machine learning algorithm to perform bulk-to-skin temperature conversion, which enables the assimilation of remote sensing lake surface water temperature (LSWT) with an accurate error model.

We present calibration results based on a year-long data assimilation run, and compare the results to the observational data and previous hydrodynamic platform *meteolakes*. Aside from showing how the model manages to follow various datasets (see figure 1 for preliminary results), we also reflect on the challenge of balancing the significance of different data sources into a single assimilation model.



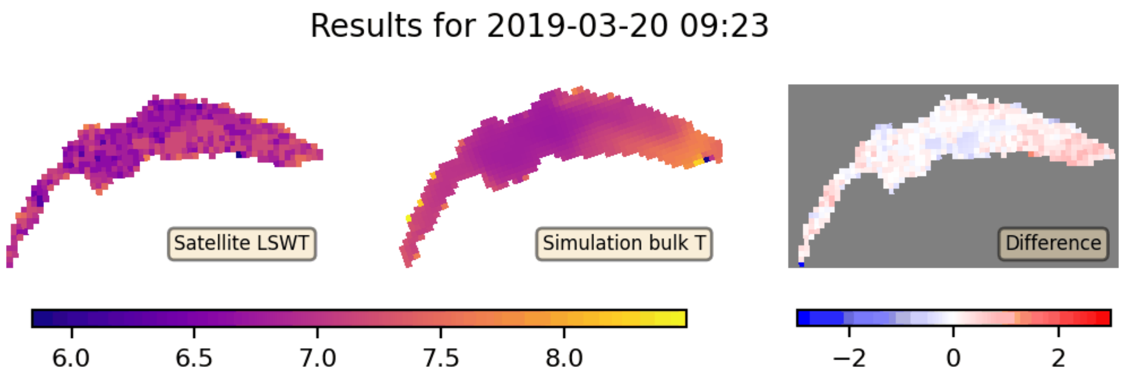


Figure 1. Preliminary comparison between observational data and DATALAKES hydrodynamic model prediction. Top: comparison for in-situ measurements of Buchillon (left) and SHL2 (right) data. Middle: LéXPLORE thermistor chain (white space indicates gaps in measurement). Bottom: a sample comparison of simulated bulk temperature versus remotely sensed LSWT.

14.13
Optofluidic sensor for in-situ monitoring of phytoplankton in Lake Geneva

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With climate change, the micro-algal populations of our lakes are changing [1]. Some species may become rare, while others may proliferate. These phenomena can have a strong impact on the environment, especially in the case of toxic algae [2,3]. Unfortunately, conventional laboratory-based techniques for monitoring phytoplankton are time-consuming, slow and costly, and, do not provide information on how different algae taxa develop and interact together, while sharing a same habitat.

Here, we investigate a concept of optofluidic device in the context of *in situ* and rapid monitoring of Lake Geneva microalgae diversity.

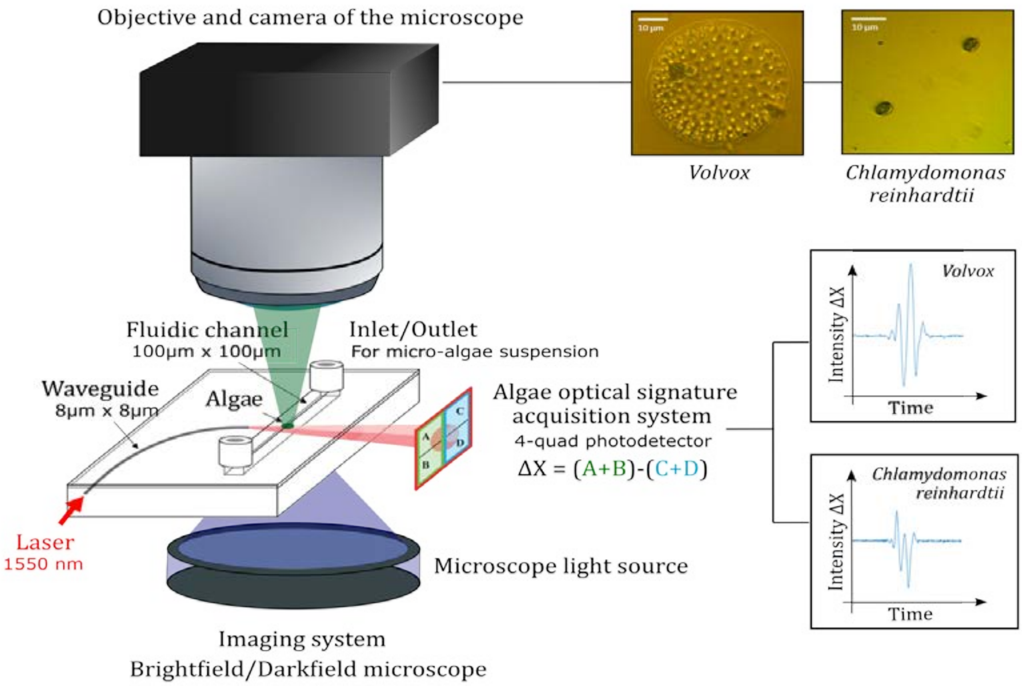

Figure 1. Schematic overview of the microalgae analysis device. Water containing phytoplankton circulates in a fluidic channel of a glass microchip. When a particule crosses an infrared light beam, it triggers an image snapshot taken from a microscope. Algae when passing through the light-beam produce characteristic wavelets which can later on be uniquely associated with a given species. The insets show two examples of microalgae species: *Volvox* and *Chlamydomonas reinhardtii* (pictures and corresponding wavelets).

An autonomous instrument featuring an optofluidic device is currently being deployed on the LéXPLORE platform off the coast of Pully. Identification and counting are performed within a glass biochip, in which filtered lake water circulates in a micro-fluidic channel. The principle is as follows: when a particle passes in front of a coherent infrared laser beam, a snapshot of the particle is taken with a camera and the changes in transmitted infrared light are recorded (see figure 1).

The images taken are used for training an artificial intelligence algorithm to decipher between wavelet-like infrared transmitted signals. In a continuous monitoring phase, only the infrared signal is used for identifying purpose, enabling high-speed monitoring of representative volumes of water.

In previous work, we have shown that such a principle can efficiently be used, not only for distinguishing algae from other particles, such as detritus, but also, for discriminating between different algae species [4]. The latter is particularly attractive for observing specific population fluctuations over an arbitrary period, in an autonomous manner, and without necessitating human intervention.

The proof-of-concept set-up allows for a preliminary analysis of microalgae found in Swiss lakes (namely, *Volvox*, *Chlamydomonas reinhardtii*, *tetrahedron minimum, staurastrum punctulatum, oocystis solitaria and scenedesmus obliquus*, some are shown in figure 2).

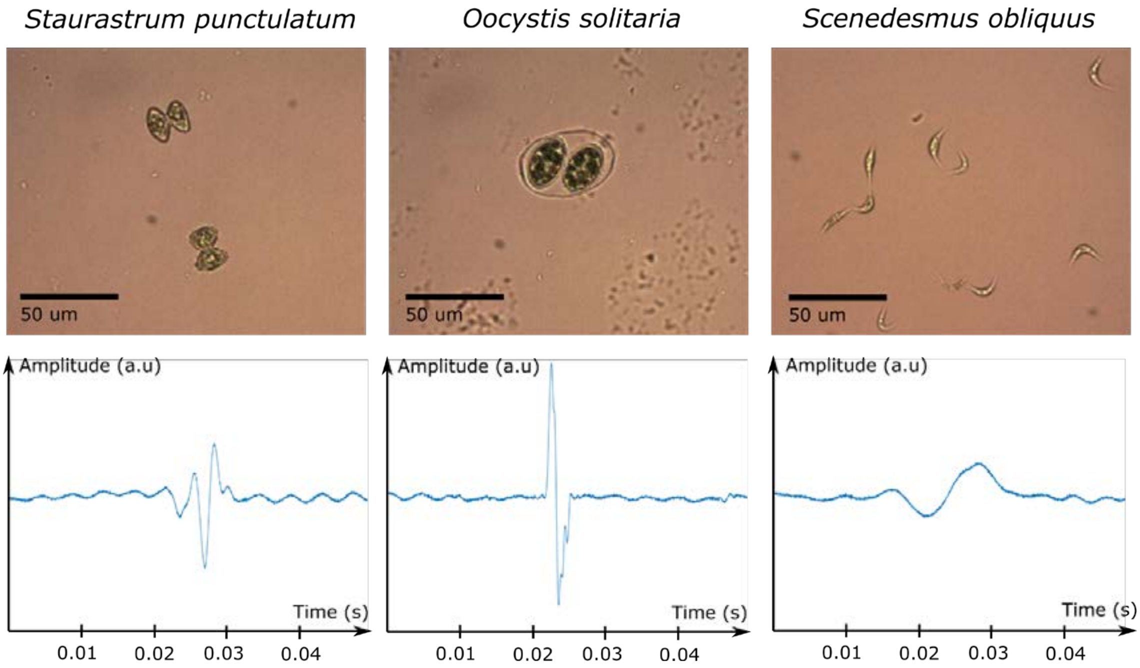

Figure 2. Example of wavelets, typical of three species of microalgae (*staurastrum punctulatum, oocystis solitaria and scenedesmus obliquus*), analyzed with the optofluidic set-up built in the laboratory. Each wavelet corresponds to the passage of one alga in front of the detector.

THE FULLY AUTOMATED IN-SITU ANALYSIS INSTRUMENT WILL BE DEPLOYED ON THE LÉXPLORE PLATFORM IN LATE OCTOBER OF THIS YEAR (2020) AND IS PLANNED TO BE OPERATIONAL OVER SEVERAL MONTHS OF CONTINUOUS MONITORING.

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14.14
Characterization of dissolved organic matter (DOM) by asymmetrical flow field-flow fractionation with multi-detection (AF4-MD) and its potential applications to investigate dynamic of changes in DOM composition and properties occurring in the freshwater continuum

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DOM is ubiquitous in aquatic environments and plays an essential role in regulating the water quality, the chemical speciation of many trace elements, and thus their fate. DOM is heterogeneous and occurs as a variable mixture of components. Their relative proportions depend on the sources (production sites) and on the transformations that occurred during their transport through the freshwater continuum. Among such transformations, preferential adsorption on inorganic colloids, preferential photo/bio-degradation and changes in agglomeration state can occur. Consequently, each water sample should be characterized by a distinct DOM composition, associated to a singular molecular size spectrum, leading to change in metal binding (among other) properties. Its ability to separate on a size-basis from components to colloidal assemblages, associate to the simultaneous on-line detection of several optical characteristics (UV-visible absorbance, Fluorescence) and elemental composition (ICP-MS), make AF4-MD one of the technique of choice to study in depth the mechanisms leading to changes in DOM composition when both inorganic and organic components co-exist.
To illustrate the great potential of AF4-MD for this purpose, the results from two different case studies related to the characterization of two main colloidal components of DOM are presented. The first set of samples were obtained from a transect sampling of the Petrozadovosk bay of the Lake Onego receiving the iron-rich humic-rich Shuya River as main tributary (Karelian region, RU), and thus focus on the dynamic of humic substances (HS) and their properties in "fresh-water" estuary. Our results suggested that the agglomeration state of pedogenic HS can be related to changes in metal binding capacity, although the AF4 was operated at the lower limit of its size separation capacity. The second study aimed to characterize and compare the production of DOM made by 3 different phytoplanktonic species in their respective culture media. Our results show that the 3 species differed by their relative capacity to produce aquagenic HS vs proteins and that AF4-MD, with the addition of a multi-angle-light scattering detector, was able to differentiate the protein size-patterns associated to each microorganism secretome and that some proteins are of globular nature although other should occur more as inorganic-co-agglomerates in the culture media.
AF4-MD had found applications in hydrology and limnology but more generally in processes regulating DOM cycling and metals dispersion and impact in freshwater during the 10 last years. An overall picture will be given based on our own expertise and examples taken from the literature to conclude.

P 14.1
Datalakes, a data platform for Swiss lakes

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Predicting the evolution of freshwater systems is the impetus of many limnologists. Technological developments have opened countless ways to investigate these systems, with the drawback that scientists are today overwhelmed by data. Efficiently utilizing the benefits of present-day data and technology requires optimizing the way data is shared and reused. The means of acquisition and computational processing of third-party data are often non transparent, and hence irreproducible after the end of the project's timeframe.

With the recent development of an operational interdisciplinary in-situ floating laboratory (LéXPLORE, https://lexplore.info/) on Lake Geneva, we identified the need for a user-friendly web based open access data platform to foster scientific data exchange: https://www.datalakes-eawag.ch/. The main objective was to provide a fully open access sensor-to-front end platform for scientific data in Swiss lakes. The Datalakes platform (Figure 1) incorporates continuous acquisition, storage, curation, patching, visualization, and extraction frameworks of environmental data and products (in-situ, remote sensing and models), together with an accessible online interface for visualization of historical data, future predictions, and user-friendly online processed data and products extraction.

We invite interested scientists to use Datalakes, and to visualize and download our initial datasets. We also welcome feedback and the inclusion of new data, products or models that will be of use to the Swiss freshwater community via this newly developed open access data infrastructure.

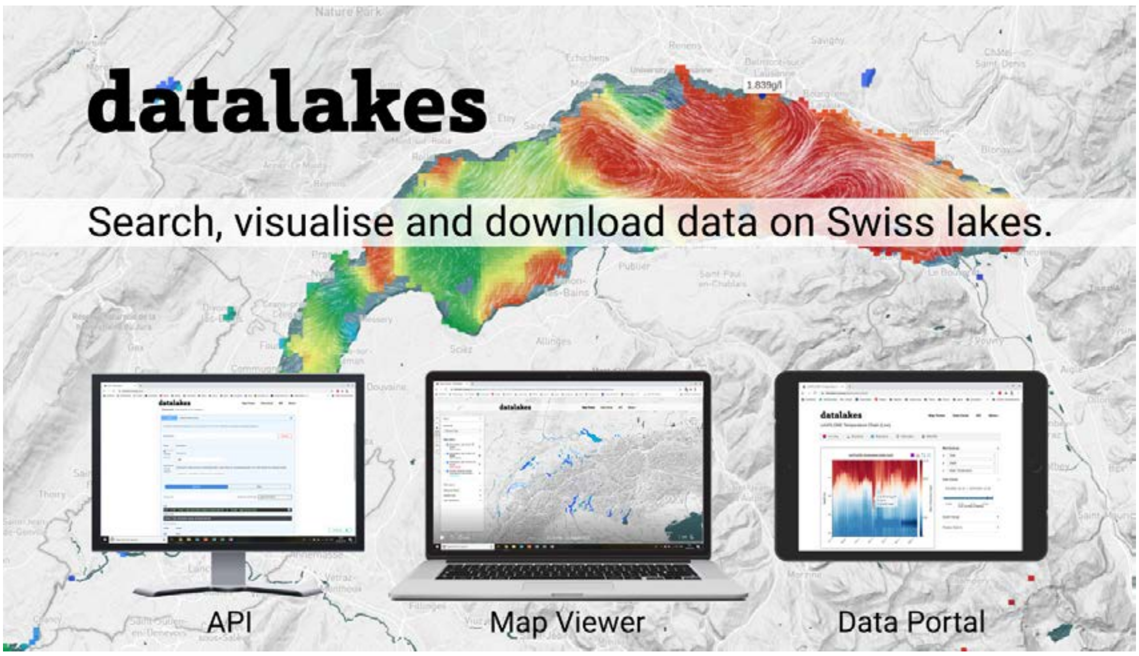

Figure 1: Overview of the Datalakes platform https://www.datalakes-eawag.ch . Heat map for Lake Geneva representing the total suspended matter estimated from Sentinel 3 satellite and white lines the lake surface current estimated from meteolakes.ch.

P 14.2
Assessing pockmark activity in lakes under influence of drainage area processes

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The water balance in enclosed aquatic systems are dependent on the amount of water entering into and leaving a body of water. Measuring inflows and outflows require good knowledge of local conditions as well as high quality instruments in sufficient quantity to measure each source and sink. The nature of this problem usually result in ample quality of outflow measurements compared to incomplete assessment of inflows at temperate latitudes. The result is usually a negative water balance, where sources and sinks do not add up to water level observations in lakes or reservoirs. Measurements in the drainage area of Lake Neuchâtel from 2015 to 2016 of known sources and sinks compared to water level observations obtained inside this lake showed a volume deficit between the two methods of ~20 m^3 s^{-1}.

High-resolution bathymetric surveys (multi-beam and Lidar) have in recent years resolved both oceans and inland waters such as lakes and reservoirs to an unprecedented detail. This has been used to pinpoint key geological features such as underwater canyons, sediment slides and pockmarks. Pockmarks, i.e. crater-like depressions, are common morphological features on the floor created by the focused upwards migration of fluids (gas and water) through the unconsolidated sediment column. A variety of fluids may form pockmarks: escaping interstitial gases (Solheim and Elverhøi, 1993), pore water seepage due to compression and overpressure (Harrington, 1985), and meteoric groundwater discharge (Morellón et al., 2014). While marine pockmarks have been recognized as a usual component of the oceans, the importance of pockmarks in lakes as element of the hydrological, chemical and sedimentological system has been less well researched. Recent bathymetric surveys in Lake Neuchâtel reviled multiple pockmarks, the largest Chez-le-Bart spanning 160 m across containing suspended sediment (Loher et al., 2016; Reusch et al., 2015). Through a bi-annual measurement campaign, we were able to investigate the long-term development of pockmarks in lake Neuchâtel. We find multiple functional types of pockmarks, either actively emitting water or being in a semi dormant stage with liquefied sediments. We investigate the long-term variability of the lithosphere in Chez-le-Bart pockmark and link this to hydraulic activity in the surrounding catchment.

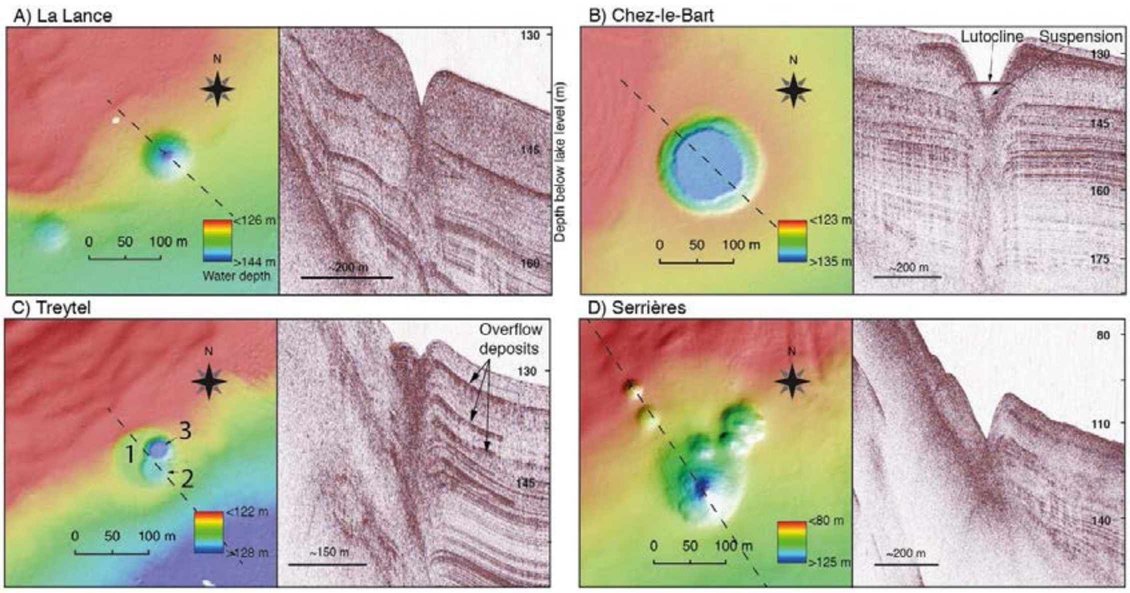

Figure 1. Morphological details and reflection seismic profiles (3.5 kHz pinger) of the four giant pockmarks. Dashed lines show position of seismic profile.

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P 14.3
Lateral transport of dissolved gases by cooling-driven density currents in a small temperate lake

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The distribution of dissolved gases in lakes varies spatially, with strong differences between the littoral and pelagic zones. The shallower littoral region is characterized by enhanced biological activity and primary production which can lead to higher concentrations of dissolved oxygen (O_2) during the day, carbon dioxide (CO_2) and methane (CH_4) compared to the same depth offshore (Brothers et al. 2017; Encinas Fernández et al. 2016; Wetzel 1990).

However, nearshore waters are not isolated, lateral flows are able to connect littoral and pelagic regions. A common example of such lateral flows are density currents driven by differential cooling, known as thermal siphons. At night, shallower regions of lakes cool faster than deeper regions, leading to horizontal density gradients. The denser nearshore waters plunge and create a cold downslope flow that can flush the littoral region in a few hours only (MacIntyre & Melack 1995).

Thermal siphons have the potential to transport dissolved gases from the littoral to the pelagic region. In particular, several studies mentioned a possible effect of thermal siphons on the estimation of metabolic rates from O_2 (Brothers et al. 2017), the calculation of CO_2 budget in the mixed layer (Czikowsky et al. 2018) and the presence of CH_4 in oxic surface waters, known as the “methane paradox” (e.g., Encinas Fernández et al. 2016). However, the effective contribution of thermal siphons to the lateral transport of dissolved gases remains to be established with in-situ observations.

To address this question, we performed in-situ measurements in Rotsee, a small (0.5 km^2) eutrophic lake located near Lucerne (Switzerland). This wind sheltered lake is highly influenced by thermal siphons from July to December. To monitor the cold density currents, we deployed six thermistor chains along a cross-shore transect, between the littoral region (1.5 m depth) and the deepest point (16 m depth). The termistor chains were coupled with upward-looking Acoustic Doppler Current Profilers (ADCPs) to collect velocity data. Dissolved gases concentration (O_2, CH_4, CO_2, N_2, Ar) were measured simultaneously in the littoral region (two depths sampled) and in the sloping zone where thermal siphons are flowing (4 m depth, three depths sampled) using two portable mass spectrometers (miniRUEDI). The gases concentrations were recorded continuously over several days to capture the diurnal cycle potentially associated with the presence of thermal siphons. In addition, Conductivity-Temperature-Depth-Oxygen (CTDO) profiles and water samples (CH_4 analysis) were collected. Finally, meteorological forcing was obtained from a nearshore weather station. Here we present preliminary results from this field campaign with a focus on assessing the effect of the established thermal siphon on the biogeochemistry.

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P 14.4
Regional groundwater flow systems in the context of karst development - an example from north-western Switzerland

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Based on geological and hydraulic 3D models, the groundwater circulation for regional-scale aquifers within the Rhine Valley within the Tabular Jura east of Basel (Switzerland) was investigated. The main aquifers comprise the Quaternary aquifer of the unconsolidated gravel deposits along the river Rhine and its tributaries as well as the regional-scale karst aquifer within the upper part of the Muschelkalk. Land subsidence indicates further subordinate groundwater bearing segments and complex groundwater interactions between deeper and higher groundwater along fault zones.
The current state of regional-scale groundwater regimes within the investigated aquifer systems could be simulated and visualized in relation to the geology, including lithostratigraphic units and fault structures and their parameterization with hydraulic properties as well as the definition of the most important hydraulic boundaries.

Scenario calculations were used to investigate the sensitivity of the aquifer systems to hydraulic parameter changes, the change of regional groundwater flow systems during Quaternary aggradation and degradation in the main valley, as well as the base-level changes of the rivers Rhine and Birs, including anthropogenic changes such as the influence of dam and power plants and the reasons for large-scale land subsidence. For this purpose, probable historical base levels before river regulation were considered. Focus was also placed on scenarios considering increased groundwater recharge rates, e.g. due to low frequency, long-lasting precipitation or heavy rainfall events in the catchment area. The results indicate that increased groundwater recharge rates in the catchment areas during low frequency precipitation events (or periods) are associated with orders of magnitude increases of the regional inflow into the karst aquifer of the Upper Muschelkalk. Furthermore, the range of groundwater fluctuations and groundwater saturated regions within the karst aquifer shift in the model calculations to locations where high densities of sinkholes are documented. Adaptation of the surface water base-levels to probable historical levels leads to increased hydraulic gradients (local lowering of the groundwater level by up to 7 m), which are associated with increased groundwater flow within some aquifer regions that are particularly vulnerable to karst development.

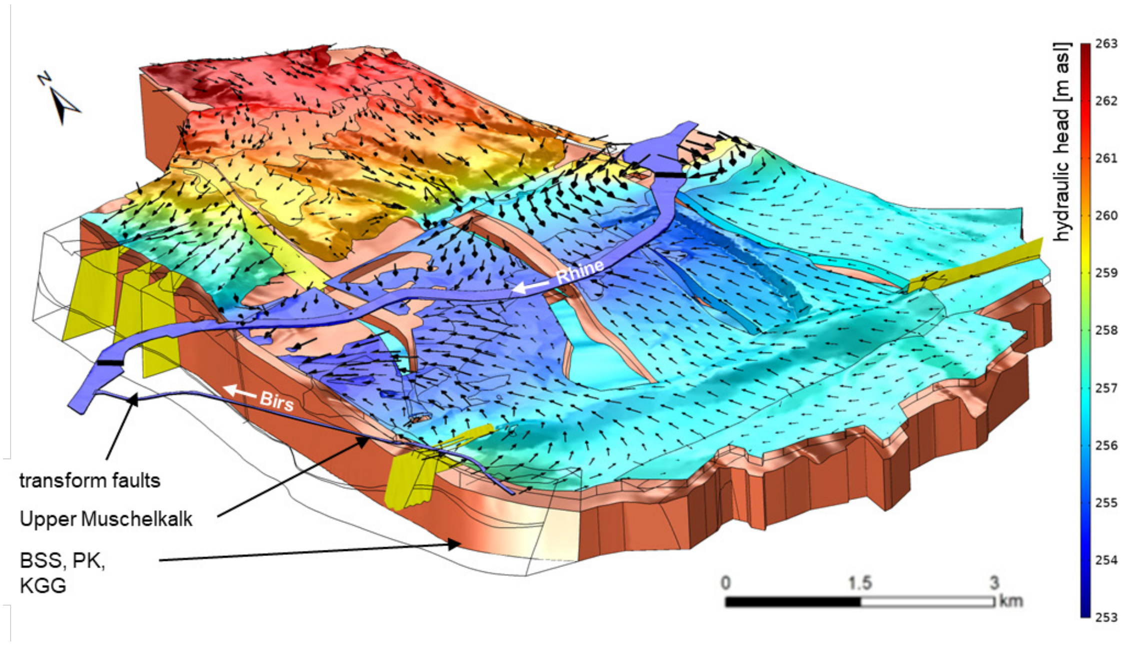

Figure 1. Groundwater flow regime in the Upper Muschelkalk. The color scale shows the hydraulic pressure in the Upper Muschelkalk in absolute height, the arrows show the logarithmic distribution of Darcy flow velocities (BSS: Buntsandstein Group, PK: Permo-Carboniferous, KGG: Crystalline basement).

P 14.5
Triggers of whiting events in Lake Geneva

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Whiting events are transient phenomena commonly occurring in alkaline and hardwater lakes that manifest as a chalky blue coloration of surface waters due to massive calcium carbonate precipitation. Although the bio-physical drivers of carbonate precipitation are theoretically known, their relative contributions in controlling the spatial and temporal extent of whiting events remain poorly understood. In Lake Geneva, conditions for calcite precipitation are usually met during summer while whiting events are only reported for restricted time-periods at the interface between lake waters and the Rhône River. In this study, we aim at identifying the mechanisms responsible for a specific whiting event that started in June 2019 at the river inflow and spread along the northern lake shore during four weeks, as observed from satellite images. Based on spatially-resolved data collected from the river delta to the LéXPLORE platform, isotopic analyses and geochemical modeling, we show that authigenic calcite precipitation during whiting conditions is triggered by the mixing of cold snowmelt-diluted sediment-rich river water with warmer lake surface layers. Moreover, scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy analyses confirm the advection of the fine-grained sediment fraction by river interflow through the metalimnion and an enrichment in authigenic carbonates due to settling of heavier detrital particles during transport and potential biologically-induced precipitation. Altogether, these results help refining the conditions controlling the dynamics of whiting events in Lake Geneva and their contribution to the seasonal carbonate precipitation, as additionally constrained from LéXPLORE high-frequency sensor measurements.

P 14.6
Flow directions of shallow groundwater in a boreal catchment

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There is usually insufficient data to determine the location of the groundwater surface. In humid climates, it is used assumed that the groundwater surface follows the surface topography. This allows the use of digital elevation models (DEMs) of the surface to estimate flow directions and catchment boundaries. However, high-resolution elevation data also include many small-scale features that are unlikely to affect the direction of groundwater flow or only affect it during specific conditions. The optimal resolution of the DEM for determining flow directions is not known yet. We determine how much DEM derived flow directions and catchment boundaries depend on the resolution or smoothing of the elevation data for the Krycklan catchment in northern Sweden. We also measured the groundwater levels in two small sub-catchments to determine what DEM resolution bests describes the groundwater surface and flow directions.

For the topographic analyses, the LiDAR based elevation data were first smoothed with various filters (e.g., Gaussian filters) and resampled to obtain lower resolution elevation data. We then determined the flow directions for these different DEMs. The aim was to determine where in the catchment the calculated flow directions are most sensitive to the resolution of the topographic data and how the catchment boundaries change when different resolution topography data are used for the calculations. The results of the topographic analyses show that for some areas the calculated flow directions depend strongly on the resolution and smoothing of the elevation data. The smoothing of the topographic data also affected the calculated catchment areas. These analyses help to estimate uncertainties in the topography-based groundwater flow directions and thus indicate where groundwater level measurements are particularly valuable to determine the flow direction.

To test how well the DEM based groundwater flow directions represent actual flow directions, we installed a dense (5-20 m spacing) network of shallow (1 to 6 m deep) groundwater wells (75 wells in total) in a 1 ha and a 2 ha sub-catchment. The triangular nested design of the groundwater well network allowed us to determine smaller (5 m) and larger scale (20 m) groundwater gradients within the study area. We measured the groundwater levels with water level loggers. During the summers of 2018 and 2019, we additionally measured the water level manually. The high spatial and temporal resolution groundwater level data allowed us to study the response of the groundwater to different meteorological situations (e.g., large precipitation events after dry and wet conditions and during the very dry period in summer 2018). These observations indicate that the degree to which the groundwater-surface is a subdued copy of the surface topography, and thus which DEM resolution best represents the groundwater flow directions, varies throughout the year.

P 14.7
Signatures of coherent flow structures in the atmospheric surface layer over Lake Geneva

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Reliable estimates of air-water exchange of momentum, heat, and gas are vital for understanding boundary layer dynamics and for developing accurate global and regional climate and weather forecasting models. Spatiotemporal variability of physical processes, below and above the water surface and at the interface, contribute to the uncertainty of these estimates. Air-side exchange processes are closely related to various phenomena in the Atmospheric Boundary Layer (ABL), which frequently manifest themselves as coherent structures in turbulent flow fields. The identification of such structures and their dynamics is essential for determining their role in the variability of air-water fluxes.

A Doppler wind LiDAR (Light Detection And Ranging) was deployed on the south side of the LéXPLORE platform in Lake Geneva, two meters above the lake surface water. It provided the line-of-sight (radial) component of wind velocity (spatial resolution of 18 m, Fig.1). The LiDAR was configured for both horizontal arc sector and staring scans, i.e., sequential sweeps and a fixed direction of the laser, respectively, aligned with the mean wind direction. The results presented here are from measurements taken during a *Bise* event, a regularly occurring strong wind (U_{10} > 5 m s^{-1}), blowing from the northeast over most of the lake surface (Lemmin & D'Adamo, 1996). Empirical Orthogonal Function and Continuous Wavelet Transform analyses were used for data post-processing. These techniques allowed decomposition of the time series of radial wind data into modes of spatial variability of the fluctuations and temporal variations of the different time-scales embedded in the flow field, thereby providing the dimensions of structures coexisting in the wind field and their corresponding time-scales.

It was found that the horizontal radial wind field over Lake Geneva is “patchy” and can be decomposed into large-scale horizontal coherent structures (Fig. 1). In particular, coherent structures of high velocity are evident. They were always elongated in the wind direction, extending several hundred meters in length. The shape and the spatial distribution of these structures changed continuously in time. The radial velocity magnitude in any scan varied by a factor of two or more. This indicates that macro turbulence in the ABL, as documented by these coherent structures, is well developed and is the dominant feature of the near-surface boundary layer of the wind field. Even though the three-dimensional nature of the ABL wind vector cannot be determined from these measurements, it is clear that the strong spatio-temporal variability observed here will have important consequences for the dynamics of the air-water exchange of momentum, heat and gas. This variability will affect surface shear stress and thus surface renewal and the production of turbulence in the near-surface water boundary layer. Furthermore, it will affect the surfactant distribution in the surface micro layer, which in turn will again modify the exchange processes.

Our results agree with similar studies on coherent structures in the atmospheric surface layer under near-neutral stability conditions (Hutchins & Marusic, 2007). However, here we document for the first time in the open lake the presence of large-scale near-surface wind structures whose shape and pattern continuously change in time and space. This was not reported in a previous near-shore LiDAR study on Lake Geneva (Calaf et al., 2013).

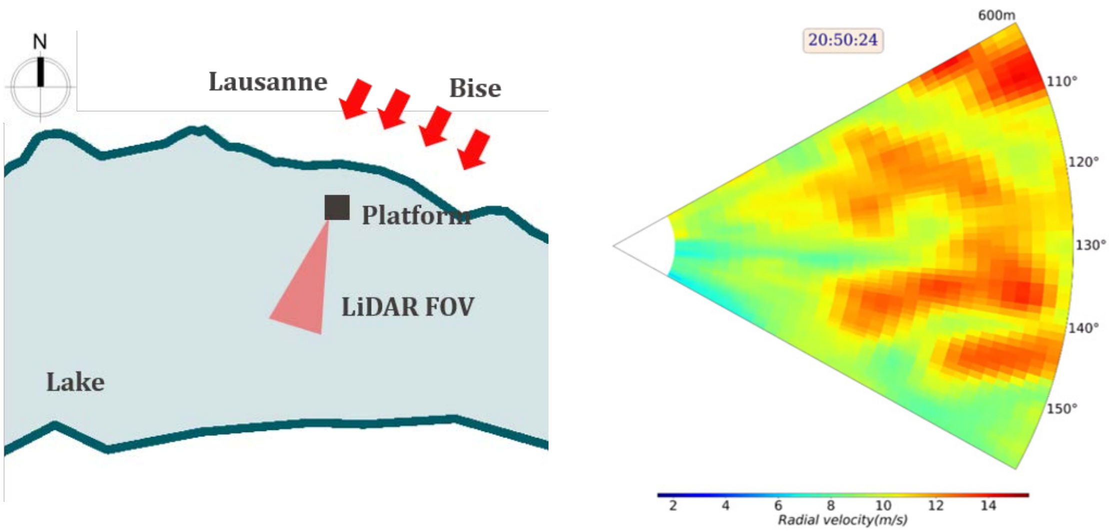

Figure 1. (left panel) A schematic of the LiDAR configuration on the LéXPLORE platform showing the Field Of View (FOV; red triangle), Red arrows indicate the Bise wind. (right panel) An example of the 600-m horizontal arc sector LiDAR measurements of the wind field (taken at 20:50:24 on 14.04.2020) degrees are measured from the East). The color bar indicates the range of the velocities.

Acknowledgement
We would like to sincerely thank Peter Brugger from the WIRE Laboratory EPFL, for making available the LiDAR and teaching us how to operate the instrument.

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P 14.8
Riparian vegetation controls transpiration as a function of the groundwater level: a field study with stomatal conductance and dendrometry measurements

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Vegetation establishment, growth, and succession in riparian ecosystems are linked to river and groundwater dynamics. This is especially true in Alpine gravel bed rivers with wide floodplains and a strong river-aquifer exchange. Here we provide data evidence of riparian plant response to short-term groundwater table fluctuations in a braided gravel bed river (Maggia). We used indirect physiological variables for photosynthesis and transpiration – stomatal conductance g_s and amplitude of daily tree diameter change ΔD_d – which we measured at six mature riparian trees of the *Salicaceae* family, one *Populus nigra* and one *Alnus incana* at two sites during two growing seasons. The site where g_s measurements were conducted showed a greater depth to groundwater with higher variability compared to the site were dendrometers were placed.

We analyzed the data by means of two different random forest regression algorithms for the two study sites. One with the daily tree diameter amplitude of the growing season 2017 as the dependent variable, and one with the raw g_s measurement sequence, which was conducted on 10 days throughout the growing season 2019, as the dependent variable. In both algorithms the independent variables consisted of meterological measures (locally measured and at valley scale) and of groundwater and river stages near the individual plants. We also separated the g_s measurements into low and high groundwater stage conditions observed during the g_s field campaign and applied traditional regression analysis of g_s on vapor pressure deficit VPD and global radiation r_g for the 2 groups.

The data analyses demonstrate that:

(a) short-term variation of the groundwater table affects riparian vegetation: at the site with deeper groundwater, the water table depth was the best predictor of g_s variability, while in the site with shallower groundwater, temperature and vapor pressure deficit were the best predictors of ΔD_d variability;

(b) instantaneous stomatal conductance is related to vapor pressure deficit (VPD), but conditioned by groundwater levels, with higher stomatal conductance for the same radiative input and VPD when the water table was higher for all trees (Figure 1);

(c) local micro-climate measured at tree locations had a stronger predictive power for g_s than valley scale climate, suggesting local climate may be an important control on vegetated stands on gravel bars.

Even though the considered plants are located in close proximity to the river and could be considered to be unaffected by water stress, our analysis provides evidence of riparian trees undertaking physiological adjustments to transpiration in response to groundwater stage, depending on their riparian floodplain settings. In the Maggia River which is heavily regulated by hydropower, this has implications on the minimum flow release by dams, as prolonged periods of low water stage in the river will lead to a decrease in groundwater stage, and subsequently in reduced growth of phreatophytic riparian plants on the floodplain. We argue such plant-scale measurements should be helpful for the optimisation of flow release levels in regulated riparian systems.

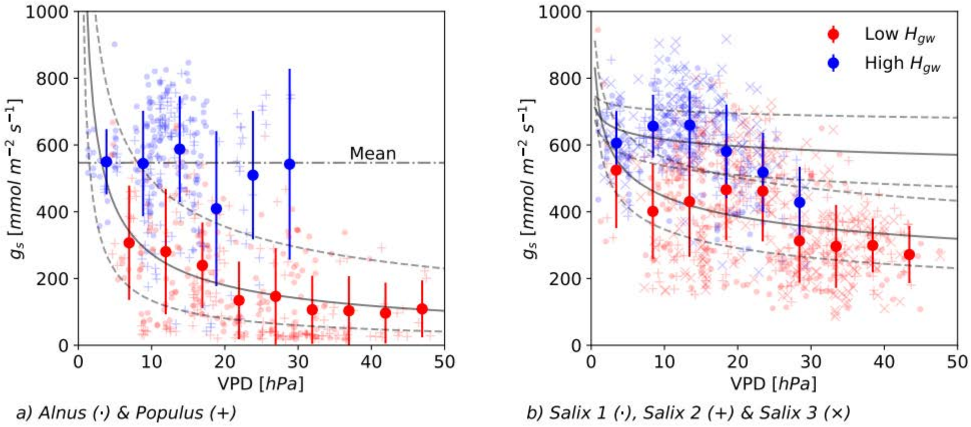

Figure 1. Relationship between stomatal conductance g_s and vapor pressure deficit VPD for two periods of low (red) and high (blue) groundwater levels for (a) *Alnus i.* and *Populus n.*, and (b) three *Salix e*. The data was fitted with a power-law model . The dotted line shows the 95%-confidence interval of the fitted parameters A and b. The filled circles show the mean, whiskers the standard deviation of measurements in bins with equal width 5 hPa VPD (from Martinetti et al., 2020).

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P 14.9
MetOxiC: Methylmercury in Oxic water Column

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Methylmercury (MeHg) is a potent neurotoxin and the most dangerous species of Hg for both wild and human life. MeHg is mainly produced in anoxic environments of aquatic ecosystems but increasing evidence is uncovering the importance of MeHg production in oxic layers of both marine and lake systems. This is believed to be mediated by anoxic micro-environments present inside and around suspended and settling particles, where microbial methylation can take place. The MetOxiC project aims to demonstrate this MeHg production using Lake Geneva as a case study. We collected particles at various depths in the water column to obtain concentrations of both organic and inorganic mercury and, coupling these results with other parameters (e.g. dissolved oxygen), to determine where the production zones are located. Preliminary results from three different depth (15 m, 30 m and 100 m) indicate a clear presence of MeHg in suspended particles, with concentrations ranging from 1.70 ± 0.39 ng/g to 7.41 ± 1.20 ng/g in May and from 2.53 ± 0.51 ng/g to 4.66 ± 0.16 ng/g in June. While at 100 m MeHg concentrations are higher and more stable, MeHg concentrations slightly decreased at 15 m depth from May to June and increased at 30 m. This could be explained by the migration of the likely main production zone from 15 to 30 m in June probably due to the effect of the summer stratification of the lake. A previous work conducted on the bottom sediments of Lake Geneva shows lower concentrations of MeHg in the same periods (1.91 ng/g ± 0.047 ng/g in May and 2.51 ng/g ± 0.46 ng/g in June), highlighting the fact that bottom sediments and setting particles represent most probably two different MeHg production hotspots. Another important aim of the project is to investigate the internal structure of the settling particles to link the methylmercury production with anoxic micro-niches inside these particles. To this end, we deployed twice in July-September 2020, from the LéXPLORE platform in Lake Geneva, a sampling setup composed of sediment traps at 3 different depths (15 m, 25 m and 100 m), to collect undisturbed particles in a 0.5 cm polyacrylamide film on the bottom of the trap. This transparent and viscous medium helps maintaining the particles isolated from the others, preserving their shape, structure, and chemical conditions. Image analysis and microchemical techniques were applied to characterize the particle nature and internal chemical conditions, to support the hypothesis of anoxic micro-niches favourable of MeHg production. Preliminary results are presented. These results are important to better understand the cycle and pathways of Hg and MeHg in the environment.

P 14.10
Mapping karst conduits in a heterogeneous aquifer using hydraulic tomography: The first 2D sandbox validation

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Hydraulic tomography (HT) is a well-established approach to yield the spatial distribution of hydraulic conductivity of an aquifer. This work explores the potential of HT for the characterization of the distribution and connectivity of karst conduits in a two-dimentional (2D) sandbox. Two types of HT techniques were implemented and compared: the simultaneous successive linear estimator (SimSLE) algorithm, which utilizes transient hydraulic heads, and the simultaneous iterative reconstruction technique (SIRT) algorithm, which uses hydraulic travel times. Four aritifical karst conduits in different geometries were placed in a layered sandy aquifer, which consists of nine types of sand with various grain sizes. In this sandbox, we conducted six pumping tests at six different locations, and the pressure fluctuations were recorded at 42 observation points. The measured data were then used for the inversion of hydraulic diffusivity by the SimSLE and SIRT algorithms, respectively. Our results show that both algorithms are able to approximately reveal the structures of the embedded karst conduits. Moreover, although both HT algorithms yield similar hydraulic diffusivities at the patch and sandbox scales, regions of high permeabilities, obtained by the SimSLE algorithm, are in better agreement with the positions of the embedded karst structures, compared to those obtained by the SIRT algorithm. Uncertainties and limitations of our results are also discussed in this work, followed by recommendations on hydraulic tests in karst aquifers.

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P 14.11
Life in the deep: colonisation by Dreissena along a dept gradient

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Several invasive freshwater species have invaded Swiss lakes in the past. Especially Quagga mussels, *Dreissena bugensis*, are challenging our ecosystem by affecting the food web through their high abundance, filtration rate, quick spread within and between waterbodies and the ability to colonise various substrates in the lake at greater depths.

In this project, the aim is to understand how Quagga mussels cope with deep lake conditions, such as low temperature, no light and high water pressure. We want to know A) how fast Quagga mussels colonize and grow on new substrates on varying depths and B) whether they adapt to different depths. Thus, we installed the same experiments in Lake Geneva and Lake Constance, consisting of three replicated ropes in the perimeter of the LéXPLORE platform in Lake Geneva and on a buoy in the Überlingersee of Lake Constance. We measure colonisation of Quagga mussels on PVC plates every three months between 0-100m depth.

Adaptation to different depths is tested with a reciprocal transplant experiment, within both lakes, in which mussels are collected from two depths. In time intervals of 2-4 weeks, we measure growth and survival. Both experiments are still ongoing, therefore we present preliminary results.

P 14.12
Elevation-dependent impacts of climate change on Alpine Hydrology: High-resolution modelling and uncertainty estimation

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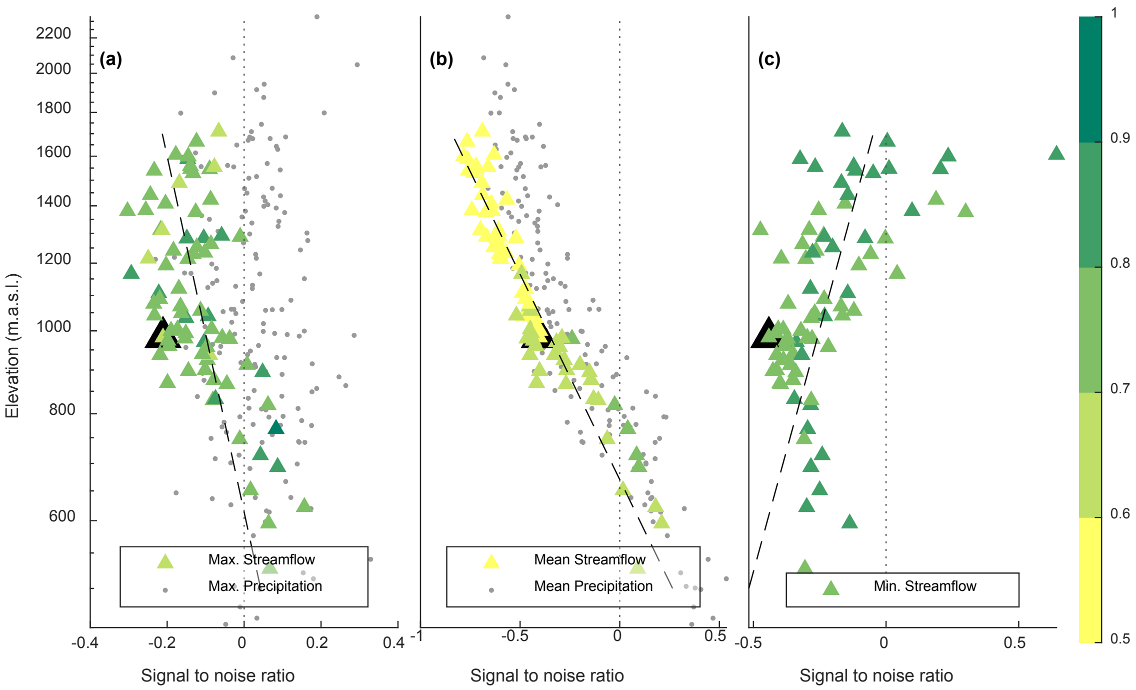
Global warming will impact hydrological processes across multiple scales and climates, including the European Alps. Owing to their highly heterogeneous nature, the responses of Alpine catchments to the effects of climate change are expected to show large spatial variability. Typical hydrological studies, which use coarse climate data inputs obtained from General Circulation Models (GCM) and Regional Climate Models (RCM), focus mostly on statistics at the outlet of relatively large catchments, overlooking the effects on small sub-catchments. Furthermore, uncertainty, especially originated from natural climate variability, is rarely analyzed. In this study, we focused on the the small-scale climate change impacts on mountain hydrology and the sources of uncertainties in the projections for two mostly natural Swiss catchments: Kleine Emme and Thur. Using a two-dimensional weather generator, AWE-GEN-2d, and based on nine different GCM-RCM model chains, we generated high-resolution (2 km, 1 hour) ensembles of gridded climate inputs until the end of the 21st century. Temperature increases uniformly by up to 5 °C toward the end of the century under and RCP.8.5 emission scenario, while precipitation shows increases in the valleys and decreases in the higher parts of the catchments, although the patterns vary according to the driving cliamate model. The high-resolution climate ensembles were subsequently used as inputs into the fully distributed hydrological model Topkapi-ETH to estimate the changes in hydrological statistics at 100-m and hourly resolutions. Results show an increase in evapotranspiration, while the snow melt contribution to the streamflow is expected to decrease up to 50% by the end of the century. Consequently, streamflow at the catchments' outlets will experience an important shift in streamflow seasonality, with a stark increase during the winter months and a reduction during the summer. Analysis at the scale of small sub-catchments reveals elevation-dependent hydrological responses: mean annual streamflow, as well as high and low flow extremes, are projected to decrease in the uppermost sub-catchments and increase in the lower ones. Furthermore, we computed the uncertainty of the estimations and compared them to the magnitude of the change signal (Figure 1). Although the signal-to-noise-ratio of extreme streamflow for most sub-catchments is low (below 0.5) there is a clear elevation dependency. In every case, internal climate variability (as opposed to climate model uncertainty) explains most of the uncertainty, averaging 85% for maximum and minimum flows, and 60% for mean flows. The results highlight the diversity of hydrological response to climate change throughout the catchments with different level of uncertainties, emphasizing the importance of investigating the distributed impacts of climate change in mountainous catchments.



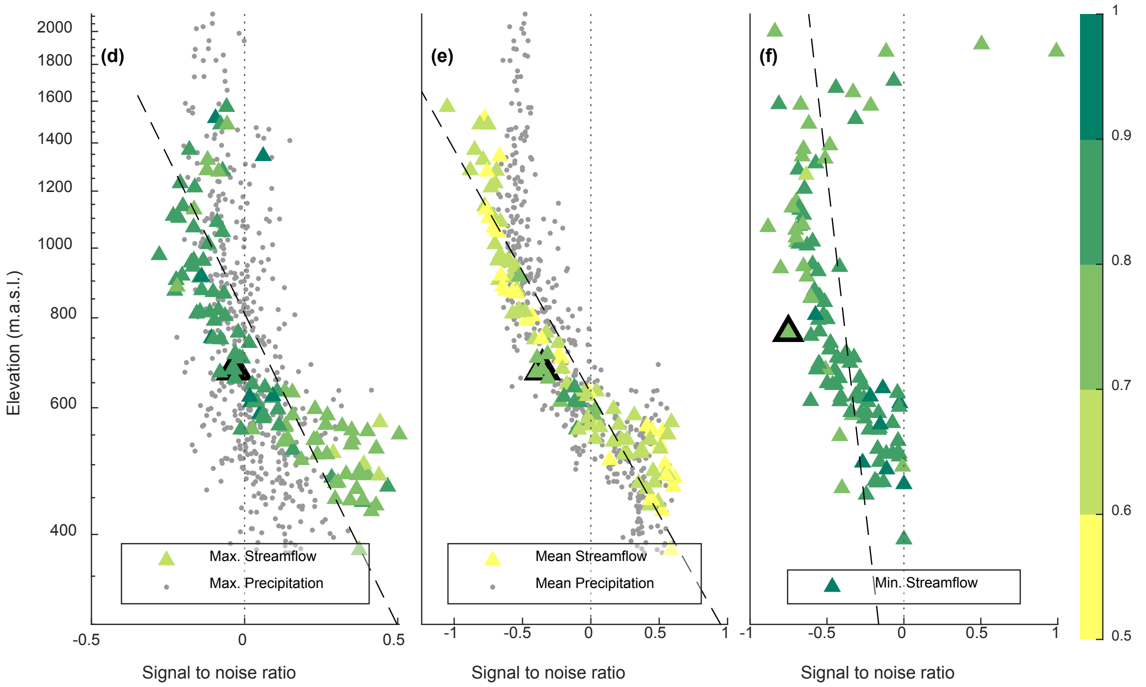


Figure 1. Signal-to-noise ratio (STNR) in the Kleine Emme (a-c) and Thur (d-f) catchments for hourly maximum (a, d), mean (b, e), and low flows (c, f) compared to the median elevation of the sub-catchment. A fitted semi-logarithmic regression is superposed to the plot. The STNR of maximum and mean precipitation averaged over the sub-catchments is also shown as gray dots for comparison. The colors in the triangular markers show the fraction of uncertainty attributed to the natural climate variability.

P 14.13
RAINBOWFLOW CHIPONLINE: A fish cell-based impedance sensor to monitor water quality

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Fish form an integral part of aquatic ecosystems and as such are an important indicator species for the health of their environment, e.g. for the impact of chemical contamination. However, measuring toxic effects in live fish is costly, time-consuming, and ethically questionable. Fish cells have been shown to be able to predict toxic effects on whole fish (Tanneberger et al. 2013, Stadnicka-Michalak et al. 2015). In the $\mathrm{RAINBOW_{FLOW}}$ $\mathrm{CHIP_{ONLINE}}$ project, we therefore use an intestinal cell line of the rainbow trout (*Oncorhynchus mykiss*), RTgutGC, to develop a biosensor for automated water quality testing by impedance sensing. For this, cells are seeded on a microfluidic chip where their adherence to the electrodes creates a resistance to an applied electric current flow. This resistance reflects the health status of the cells; a decrease in resistance is an indicator for loss of cell viability, as can be elicited, for example, by exposure to chemicals in the water (Tan & Schirmer, 2017). Impedance sensing is non-invasive and can be measured in real-time, allowing for time-resolved monitoring. Our aim is to design a portable and compact system for use in the field, with the data being accessible online to inform about the current water quality. An embedded computer will control the automated measurement process. A miniature version of the impedance analyser is being constructed, and the system is programmed for automation and remote access. For the measurement of the complex impedance an integrated network analyzer module is being designed in. A syringe pump will be used to aspirate a water sample and enrich it with a small volume of salt solutions to establish favourable osmotic conditions for the cells before pumping the water sample through the channel containing the cells in a temperature-controlled environment. We create a semi-continuous flow-through, using medium flow rates, which generate a shear stress reflective of physiological conditions in the fish intestine. As the chip contains six channels, two replicates are measured in parallel in addtion to a positive and a negative control (likewise in duplicate). We are currently establishing this biosensor in the laboratory, and a first prototype will be tested on the LéXPLORE platform in Lake Geneva.

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P 14.14
Changing Groundwater Dynamics in Urbanizing Catchments: A Swiss Case Study

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Land development and urbanization have significant impacts on groundwater – surface water interactions and groundwater availability, both in terms of water quantity and water quality. As the populations towns and cities in Switzerland and across the globe are ever-increasing, it is important to understand exactly how these changes occur.
Much of the infrastructure inherent to cities – impervious surfaces, storm drains, sewer mains, among others – has particular significance in the surface runoff – groundwater recharge relationship during storm events. Observed increases in surface runoff from storm events have been observed in many urbanized areas, which can constitute a major loss factor in the groundwater balance, and also acts as a conduit of pollutants from the surface into aquifers.

We have investigated the relationship between urbanization, groundwater – surface water interactions, in a small, urbanizing catchment within the Canton of Zürich. This area is undergoing active growth, which is expected to continue due to its proximity to the city of Zürich. With this study site, we have begun an observation network that may be used to monitor changes in groundwater dynamics as the urban areas continue to expand. We explore these impacts using two approaches: first with a conceptual water balance, and second by making use of chemical tracers.

For our conceptual water balance, we have estimated storm runoff, using two empirical approaches: comparing hydrograph separation against an improved version of the widely used Curve Number approach. These runoff estimates are in turn used to estimate groundwater recharge. This groundwater recharge estimate is then compared to results from the conceptual HBV-Light model and to literature estimates in order to assess its performance.

Following this, we applied chemical tracers to groundwater and surface water samples. We used these data to identify localized areas of groundwater – surface water interactions, and to identify areas vulnerable to pollution from storm runoff. We first carried out a multivariate statistical cluster analysis using data from stable water isotopes combined with dissolved ions, which allowed us to identify the respective signature of both water types, and areas of interaction. We then made use of organic micropollutants including pesticides, industrial compounds, and the lifestyle product caffeine – which are unequivocal evidence of human impacts – in order to identify the magnitude of these imacts, and to validate zones of interaction obtained from our cluster analysis.

These analyses have offered insight on the current conditions of the study area, and have allowed us to identify zones of vulnerability, which helps to direct future monitoring efforts.

P 14.15
Wave breaking integration for predicting air-water gas exchange in large lake

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Although there is a crucial need to assess lakes CO_2 emissions at a global scale, these fluxes are almost never directly measured. Instead, fluxes are often estimated from a restricted number of CO_2 concentration measurements in water (mostly during daytime) combined with modeled piston velocity using forcing data averaged by day, week or month. Yet, in large lakes, the short-term variability in surface CO_2 can be substantial enough to generate major inaccuracies in estimated fluxes. Besides, models for piston velocity integrate only a limited number of the physical and chemical mechanisms that drive the air/water gas exchanges. Their performance, although rarely tested, might vary depending on the seasonal contribution of wind shear, convection and wave breaking.

Here, we compared direct measurements of CO_2 fluxes in Lake Geneva, a large hardwater lake, from an automated (forced diffusion) flux chamber to computed values based on high frequency CO_2 measures and different models of piston velocity (*k*) of increased complexity (progressive integration of wind shear stress, convective mixing and wave breaking). Surveys were conducted at different time periods of the year on the new LéXPLORE platform in order to cover distinct weather conditions and surface CO_2 concentrations. We evaluated the performance of the different models, and identified the importance of considering wave breaking during wind event to improve the CO_2 flux estimation in large lake. Altogether, we show how crucial the choice of *k*-models and the high-frequency of data are for CO_2 fluxes computations.

P 14.16
Using CH2018 climate scenarios to predict sediment yield and debris-flow activity in the Illgraben

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Sediment production and transfer processes in catchments are driven by climatic factors like precipitation, runoff and temperature, and land surface properties like erodibility, topography and geomorphological connectivity. Sediment production and transfer can present a significant natural hazard in the form of landslides, debris flows, etc. Changes in the hydrological and geomorphological processes driving such events are especially difficult to predict in temperature-sensitive environments such as the Alps. In this study, we use a chain of climate-hydrology-geomorphology models to quantify possible impacts on sediment fluxes in the Illgraben, a catchment usually producing at least three debris flows every year. To this end, we combine the AWE-GEN weather generator (Fatichi et al., 2011) with CH2018 climate scenarios (CH2018, 2018). These climate simulations are fed to the SedCas hillslope-channel sediment cascade model (Bennett et al., 2014), which is calibrated against observed debris-flow magnitudes estimated from force plate measurements (McArdell et al., 2007).

The results highlight the role of hillslope landslides supplying sediments to the channel, where they can be re-mobilized if sufficient surface runoff is generated. In supply-unlimited conditions, a rather uncertain future rise in precipitation, combined with a certain rise in air temperature, leads to an increase in sediment yield by about ~50% by the end of the 21st century. In contrast, if sediment production is considered with a simplified frost-weathering mechanism, future sediment supply is reduced and sediment storage is exhausted already in early summer (Figure 1). As a consequence, sediment yield and the annual number of debris flows decrease by about ~-50% and ~-25%, respectively. Similar to hydrological climate change impact studies, predicted changes in sediment fluxes contain large uncertainties. An important feature is that when uncertainties are partitioned, irreducible internal climate variability contributes large parts to the total uncertainty. Therefore, our findings have important implications for the assessment of natural hazards and risks in mountain environments.

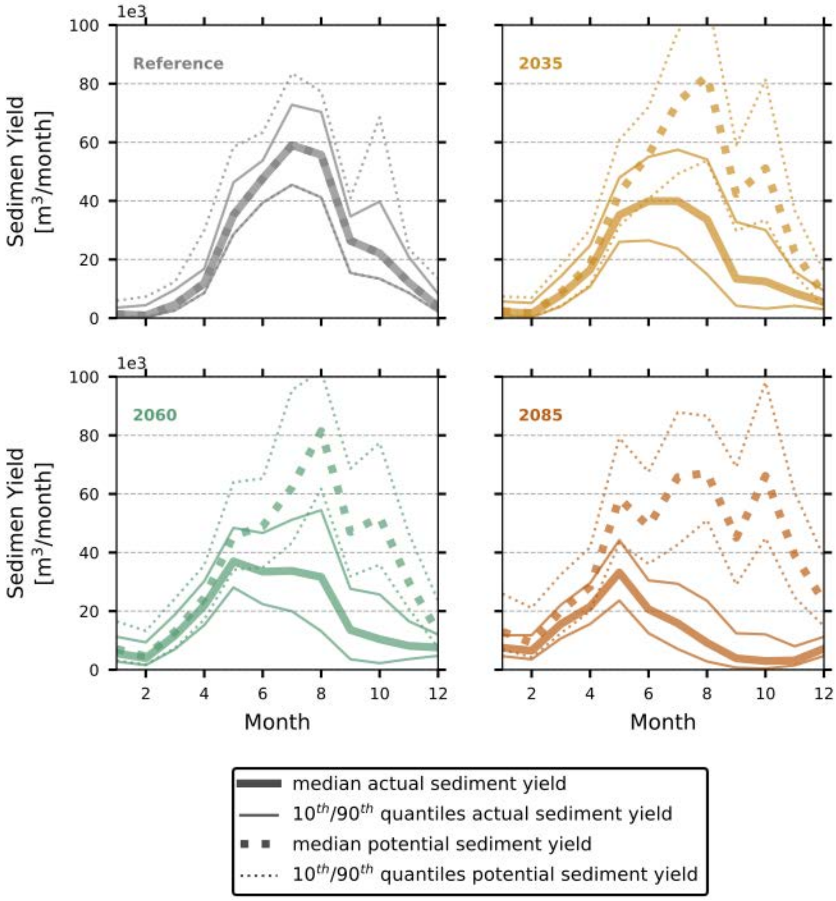

Figure 1. Mean monthly sediment yield at the Illgraben computed with SedCas and AWE-GEN for the reference and three future periods. Solid and dahsed lines show the actual sediment yield in sediment supply-limited and supply-unlimited conditions (i.e. potential), respectively. Thicker lines are medians and thinner mark the 10th and 90th percentiles.

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P 14.17
Lake-atmosphere CO_2 fluxes in Lake Geneva: disentangling the role of physical and biological processes in affecting diel and seasonal patterns

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The importance of carbon dioxide (CO_2) fluxes between water bodies and atmosphere is of fundamental importance for the global carbon budget and specifically for the atmospheric CO_2 content, which influences our climate. In recent decades, large efforts have been made in the direct measurement of CO_2 fluxes, and different approaches have been proposed to quantify the gas transfer velocity. Empirical parameterizations based on wind speed have long been used for flux quantification, but recently surface renewal models based on turbulent kinetic energy (TKE) dissipation rate have been proposed to account for other relevant processes such as cooling-induced convection at night. Despite the significant advancements on the topic, direct measurements are still limited and not always fully explained by empirical parameterizations, making this subject open to further investigation.

In this context, we exploit the floating platform LéXPLORE (https://lexplore.info/) on Lake Geneva (Switzerland-France) to simultaneously measure CO_2 fluxes at the lake-atmosphere interface and near-surface TKE dissipation rates. A first set of measurements acquired in spring-autumn 2019 will be complemented with a second set started in summer 2020 and relying on a revised operational procedure. In particular: three low-cost CO_2 chambers equipped with a CO_2, temperature, relative humidity sensor are employed for the measurement of the fluxes; the same sensor is installed above the lake to measure CO_2 concentration in air; a precise CO_2 sensor (MiniCO2, produced by ProOceanus) is installed in the lake at about 20-30 cm depth; and a microstructure profiler (MicroCTD produced by Rockland Scientific International) is used to measure turbulence quantities in the upper 30 m of the lake. The monitoring activity are scheduled under different stratification and forcing conditions with the main objective of disentangling the interplay between physical and biological (e.g., photosynthesis and respiration rates) processes in affecting CO_2 patterns at diel, synoptic and seasonal time scales.

P 14.18
Classification of groundwater ecosystem services based on expert judgement elicitation.

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Humanity is completely reliant on services of primary types of ecosystems (freshwater, ocean and terrestrial). Humankind's wellbeing is completely dependent on these natural assets which are available through the ecosystem functions. The present research is intended to enrich the approach to natural resource management and human wellbeing economic valuation through the suggested groundwater ecosystem services classification system.

Several studies have provided frameworks for the description and valuation of ecosystem services (Costanza 1997; De Groot 2002)but all too often the aquifer system have been considered as a.subcategory of wetland, lake, river and b.by merging its main ecosystem services categories.

The baseline data for the systematic literature review qualitative analysis were retrieved through an over 60 publications database by using SALSA (searching, appraisal, synthesis and analysis) framework application between 1985 and 2020. The 80% of the publications which were used for analysis present a groundwater ecosystem services classification following the MEA (Millenium Ecosystems Assessment 2005) Ecosystem Services Classification System and the CICES (Common International Classification of Ecosystem Services 2013).

The analysis was mainly highlighted: a. the existence of conceptually gaps which mix final and intermediate ecosystem services b.the risk of double-counting of groundwater supporting and regulating ecosystem services. To counteract these shortcomings, a structured expert judgement elicitation of a group of seven experts assessed the framework analysis results in order to structure the suggested groundwater ecosystem services classification system which constitute a supporting foundation stone to further resarch on the economic services assessment.

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P 14.19
Lake temperature monitoring – temporal and vertical resolutions required for observing climate change impacts

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The most direct impact of climate change on lakes is a modification of their thermal structure, including changes in surface and deepwater temperature, the duration of summer stratification and the intensity and frequency of vertical mixing. Early detection of these changes requires an accurate monitoring of lake temperatures. Here we assess, based on an analysis of 33 years of simulated water temperatures for Lake Zurich (Schmid & Köster, 2016), what temporal and spatial resolutions are required to be able to accurately detect trends in the thermal structure of lakes. As exemplified in Figure 1 for lake surface temperatures, the current monthly montoring frequency can result in large uncertainties, especially for seasonal trends. Continuous temperature measurements are therefore recommended for monitoring climate change impacts in lakes.

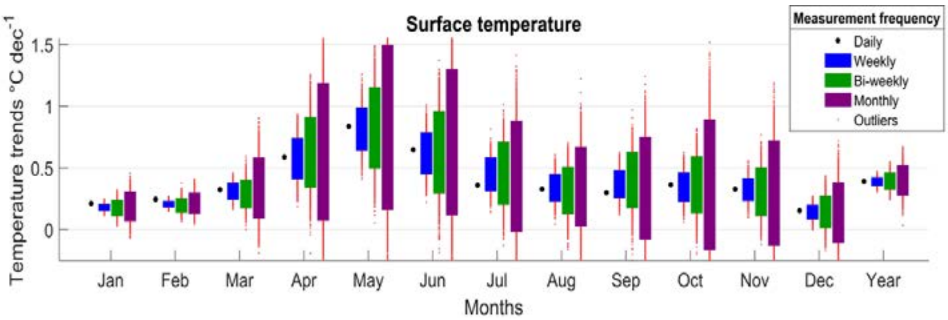

Figure 1. Monthly trends of lake surface temperature (°C decade^{-1}) calculated from 33 years of simulated temperatures for Lake Zurich sampled at different temporal resolutions. Black dots represent trends calculated from daily measurements. Every coloured box represents the 90 % spread of Monte Carlo simulation results (from quantile 0.05 to 0.95) for different measurement resolutions. Blue represents weekly measurements, green bi-monthly measurements and purple monthly measurements (Figure modified from Bouffard et al. 2019).

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15. Scientific Ocean Drilling: Driving Questions from a Swiss Prospective

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TALKS:

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15.2 *Hernández-Almeida I., Diz P., Peñalver-Clavel I., Cobelo-García A, Corbí H., Bernasconi S.M.* : Export production and oxygen bottom conditions in the Eastern Equatorial Pacific during the Mid-Pleistocene Transition

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P 15.1 *Knappertsbusch, M.*: Insights from the study of morphological evolution of menardiform globorotalids at Western Pacific Warm Pool ODP Hole 806C (Ontong-Java Plateau)

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15.1
Global size evolution of the planktonic foraminifera *Globorotalia menardii* during the last 8Ma: Synthesis of 23 years of research

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In 23 years of evolutionary prospection of menardiform planktonic foraminifera, morphometric data of more than 35,000 specimens were collected from 192 deep sea sediment samples (Knappertsbusch, 2007, 2011, 2016, manuscript in preparation; Friesenhagen, in preparation a and in preparation b). They allow an unprecedented insight into the tempo and mode of evolution of our model lineage *Globorotalia menardii* since the late Miocene. Speciation and evolutionary trends are investigated by comparing changes in the test morphology for the last eight million years and between the Atlantic Ocean (DSDP Site 502, ODP Site 667A, ODP Site 925B), the Pacific Ocean (DSDP Site 503, ODP Site 806C), and Indian Ocean (IODP Site U1476A).

Intact tests were picked from the >63µm fraction and standardly mounted on Plummer Cells in keel position. Specifically for this enterprise two automated orientation, imaging and measurement systems (AMOR 1 & 2) were developed over the years (Knappertsbusch et al., 2009 and manuscript in preparation). Based on the collected images, measurements of different morphometric parameters were performed employing own-developed software programmed in *Fortran* and LabView (Knappertsbusch, 2015).
Evolution in menardiform globorotaliids is strongly manifested in size evolution of the shell. The speciation mode of cladogenesis (splitting) and subsequent morphological divergence could be observed in the menardiform lineage, but despite the large number of specimens investigated it is visibly expressed to a less prominent degree than it was originally expected for a speciation event.

The comparison of the test size evolution between the sites shows striking differences. While an almost gradual test size evolution is observed in the Pacific and the Indian Ocean sites, the Atlantic Ocean reveals several phases of size fluctuations. A distinct event is developed at the time interval between 3.2-2Ma. In the eastern tropical Atlantic Site 667A the axial length (max δY) significantly decreases from 875µm during the Mid-Pliocene Warmth period (3.2Ma) to 520µm at end of Pliocene (ca. 2.6Ma). This time interval coincides with the onset of the Northern Hemisphere Glaciation. It is followed by an interval of test size increase. Until ca. 2Ma, the size more than doubles (ca. 1200µm) to a size which has never been observed before. The occurrence of giant menardiforms was also observed in the western tropical Atlantic Site 925B and the Caribbean Sea (Site 502), although 0.1Ma and 0.4Ma later, respectively. The comparison with Indian Ocean specimens suggests episodic dispersal of a giant form from the Indian Ocean into the Atlantic Ocean, which we tentatively explain by an episodic phase of strengthening of Agulhas Faunal Leakage.
This "new" giant *G. menardii* form occurs at almost all sites within this time interval. Its predominant coiling direction is sinistral, while the ancient, smaller morphotype occurred in predominantly dextral coiling. This observation suggests that a new morphotype/subspecies replaced the old incumbent type between 2.5 and 1.7Ma at the six investigated sites.

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15.2
Export production and oxygen bottom conditions in the Eastern Equatorial Pacific during the Mid-Pleistocene Transition

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We present new high-resolution microfossil and geochemical records at Ocean Drilling Program Site 1242 located in the deep East Equatorial Pacific (EEP). We reconstruct the export production and the oxygen conditions in the deep ocean between 760 and 1040 ka using benthic foraminifera assemblages and redox-sensition elements (see Diz et al 2020a; 2020b for details). Benthic fauna two major shifts related to changes the nature of the organic carbon arriving at the seafloor. During marine isotopic (MIS) 23 the increased influence the open ocean upwelling of the Costa Rica Dome caused an increase in the seasonality of the organic carbon flux. Another change occurred at MIS 19 coinciding with the disappearance of mainly elongated benthic foraminifera (Extinction Group) suggesting a link between both events.. Geochemical and microfossil data indicate the development of suboxic bottom conditions during MIS 23 and 22, suggesting capture and storage of respired carbon. Re-oxygenation of the deep ocean started during the MIS 22/21 deglaciation, and it was accomplished during full interglacial conditions at MIS 21. This pattern pattern, describe as “less complete deglacial ventilation”, differs from the Mid-to-Late Pleistocene Pacific deep ocean ventilation patterns, dominated by 100kyr climate cyclicity. We suggest that deep-ocean carbon sequestration beyond deglaciation might have contributed to the development of the 100kyr variability.

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15.3
Microbial alkalinity production and clay mineral alteration in marine methanogenic zones: implications for carbonate diagenesis

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Methanogenic zones in marine sediments are commonly attributed with very high alkalinity and local production of diagenetic carbonates. It is not clear whether these effects are mainly a result of microbial metabolic activity or of interaction with silicate minerals. A numerical reaction transport model was developed to simulate the effects of microbial activity and mineral reactions on the composition of the porewater in a 150-m-thick sedimentary interval drilled in the Peruvian deep-sea trench (Ocean Drilling Program, Site 1230). This site shows a zone of intense methanogenesis below 10 m sediment depth. The simulation shows that microbial activity accounts for most alkalinity production of up to 150 mmol/l, while the excess of CO_2 produced during methanogenesis causes a strong acidification of the porewater. Ammonium production from organic matter degradation significantly contributes to alkalinity production, whereby ion exchange was simulated to compensate for hidden ammonium production not otherwise accounted for. Although clay minerals are reacting far too slowly to equilibrate with the porewater over millions of years, additional alkalinity is provided by slow alteration of chlorite, illite, and presumably volcanic glass. Overall, alkalinity production in methanogenic zones is sufficient to prevent dissolution of carbonates and to induce carbonate formation either continuously as disseminated (cryptic) dolomite or episodically as hard lithified beds along a supersaturation front. The simulation presented here provides fundamental insight into the diagenetic effects of the deep biosphere and may also be applicable for the long-term prediction of the stability and safety of deep CO_2 storage reservoirs.

15.4
The Maldivian archipelago: Past, present and future climatic and oceanographic insights using foraminiferal proxies

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Coral reefs are sensitive to climatic perturbations, and as such, a major concern for the Maldivian archipelago, in the equatorial Indian Ocean, is the future response of the seasonally reversing South Asian Monsoon (SAM) to increasing global temperatures. The SAM governs the climate across the entire northern Indian Ocean and furthermore, drives the regional surface ocean currents. This work uses planktonic and benthic foraminiferal geochemical measurements (n = 5067) to better understand past SAM processes and forcing mechanisms, and its influence on the physicochemical properties and thermocline of the Maldives Inner Sea. Particular emphasis is given to the interval encompassing Marine Isotope Stage (MIS) 11 (ca 410 kyr BP), a recognised analogue for the current Holocene. Insight gained from the warmer MIS11 allows a better comprehension of possible future SAM scenarios, in a world with rapidly increasing sea surface temperatures (SSTs), and the associated impacts on the shallow, tropical Maldivian ecosystems.

To reconstruct past SAM dynamics, high-resolution geochemical records ($\delta^{18}O$, $\delta^{13}C$, Mg/Ca) are compiled for multiple foraminiferal species (n = 15) for the top ~1800 kyrs (60 mcd) of International Ocean Discovery Program (IODP) Expedition 359 Site U1467, drilled within the drift deposits of the Maldives Inner Sea. Notwithstanding the apparent diagenetic influences on the foraminiferal geochemistry within this shallow carbonate setting, absolute reconstructions of seawater temperatures, salinity and $\delta^{18}O_{sw}$ are still deemed viable for at least the top ~627.4 - 790.0 kyr (24.7 - 28.7 mcd) of the records. Multi-species geochemical data across the MIS10-13 interval, together with data from the modern core-top and extremes of the Last Glacial Maximum (LGM), MIS11 and MIS12 all confirm discrete glacial-interglacial thermocline and SAM dynamics. Overall, the summer SAM is found to be in-phase with insolation and atmospheric CO_2. Similar to present observations there was a strong summer SAM during the interglacials, which resulted in large basin-wide salinity gradients whereas; at the glacial maxima, it was weaker with subsequently more homogenous basin-wide surface waters. A deeper, warmer SML together with a stronger thermocline and more stratified water column is observed for the interglacial maxima with a cooler, shallower SML and comparatively weak thermocline during the glacial maxima. Overall, based on the assumption that future conditions could present with similarities to the warmer MIS11 maximum (+0.30 - 0.41 °C from modern SSTs), it is shown that in comparison to the present, there was a stronger summer SAM control with a more prominent Arabian Sea Oxygen Minimum Zone extent in the Maldives region.

As opposed to the traditional 'pooled' foraminiferal geochemical measurements, which provide a mean signal from the measured population, supplementary individual foraminiferal analysis (IFA) datasets allow insight into the relative frequency (skewness) and magnitude of periodic warm events. In this respect, our IFA datasets, of the shallow-dwelling species *Globigerinoides ruber* (white) and *Trilobatus sacculifer,* show that in conjunction with elevated SSTs during MIS11 the respective IFA datasets are skewed towards higher temperatures with coral bleaching thresholds exceeded more frequently (two-fold). Alarmingly, this region has already experienced three El Niño related mass-bleaching events over recent years. All of these events led to widespread mortality of corals and symbiont-bearing larger benthic foraminifera (e.g., *Amphistegina*), both of which represent important reef constituents. Based on the reality that current warming (anthropogenically driven) is much faster than seen during MIS11, more extreme as well as more frequent El Niño events are anticipated in the future which would place the world's coral reef ecosystems under increasing strain.

This research confirms the strength of an integrated multi-species foraminiferal geochemical study to link both present and past oceanographic and SAM processes, which is particularly important in light of the current anthropogenic warming trends. A future increase in SSTs together with a stronger summer SAM control and more prominent low oxygen/high nutrient intermediate waters might push the tropical Maldivian coral and benthic shoal ecosystems closer or even beyond their ecological and thermal limits. Importantly, these ecosystems have proven to be resilient in the past and thus, it remains to be seen if they can continue to recover and adapt to future climatic perturbations.

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15.5
Distribution and sources of carbon at the Atlantis Massif (IODP Expedition 357)

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Serpentinization is a fundamental process that has significant consequences for geochemical cycles and microbial activity in a variety of environments. IODP Expedition 357 used seabed drills to core 17 shallow holes at nine sites across the Atlantis Massif (30°N, MAR) to better understand the role of serpentinization in driving hydrothermal systems, in sustaining microbiological communities, and in the sequestration of carbon in ultramafic rocks. On-going active serpentinization is evident by in-situ gas release and elevated concentrations CH_4 and H_2 over several sites. Our study aims to evaluate abiotic vs biotic carbon in this serpentinizing environment. Petrological and stable isotope studies allow us to track abiotic vs biotic carbon and to characterize the speciation and source of carbon as well as the distribution of carbonates in the drill cores.

Serpentinites from the central part of the massif closest to the Lost City hydrothermal field have higher total carbon concentrations, in general, related to higher carbonate contents. Total organic carbon contents range between 46 ppm and 800 ppm with isotopic composition between -28 ‰ to -20 ‰. The carbonate phases at the southern wall of the Atlantis Massif record multiple episodes of fluid movement through the detachment fault and secondary faults that cut the detachment. Total inorganic carbon isotopic composition varies over a broad range from -14.1 ‰ to +2.4 ‰. The carbon isotopic signature of carbonate veins lies on a mixing line between the Lost City hydrothermal fluid and seawater ($d^{13}C_{veins}$ = -3.0 ‰ to +2.3 ‰). The measurements of multiply substituted carbonate isotopologues (clumped isotopes) allow us to reconstruct formation temperatures of the carbonates without considering the isotopic composition of the related fluid; instead, it even allows us, using different calibrations, to calculate $d^{18}O_{fluid}$. Carbonate phases at the AM include aragonite, calcite, dolomite, and magnesite, whereas the latter two are restricted to high-temperature phases with up to 188°C. Based on carbon and oxygen isotopic composition, two types of carbonates can be distinguished. Type I carbonates show a more rock dominated signatures ($d^{13}C$ < -2.1 ‰, T_{d18O} > 50°C) and type II resemble formation from a seawater dominated endmember hydrothermal fluid ($d^{13}C$ > -0.5 ‰; $T_{clumped\ isotopes}$ = 4 - 7°C). Carbonates in general, occur in the basement as interstitial carbonates, carbonates replacing fully serpentinized olivine cores and as carbonate veins. Until today magnesite within oceanic peridotites have only been reported in a few studies (Gablina *et al.*, 2006), even though magnesite is a ubiquitous phase in ultramafic outcrops on land, and thermodynamic studies predict that magnesite should form during the reaction of oceanic serpentinite and CO_2-bearing aqueous fluids (e.g., Grozeva et al., 2017; Klein and Garrido, 2011)the underlying mechanisms controlling the transformation of CO_2 to carbonates in ultramafic-hosted hydrothermal systems remain incompletely understood. A long-term laboratory experiment was conducted at 300 °C and 35 MPa to investigate serpentinization and carbonate formation pathways during hydrothermal alteration of peridotite. Powdered harzburgite was initially reacted with a Ca-rich aqueous fluid for 14,592 h (608 days.

Our data indicate that carbonate precipitation in the footwall of the oceanic detachment fault at the Atlantis Massif depends on multiple geochemical mechanisms including fluid flux intensity, the concentration of $SiO_{2(aq)}$ and $CO_{2(aq)}$, the location relative to mafic intrusions, and temperature. Based on our results, we argue that three primary carbon sources affect the system: (i) reduced carbon from hydrothermal degradation of organic matter; (ii) mantle carbon trapped as volatiles in fluid inclusions; and (iii) dissolved inorganic carbon from the seawater.

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15.6
Morphological and geochemical characterisation of seep carbonates in the southeastern Mediterranean Sea (Palmahim Disturbance and Levant Basin)

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Seep carbonates were recently discovered in the Levant Basin and Palmachim Disturbance (SE Mediterranean Sea) during the EUROFLEETS 2 SEMSEEP expedition aboard the RV AEGEO in September 2016 offshore Israel. Methane-derived authigenic carbonates are often used to identify the methane source and the timing of the seepage. Here, we try to reconstruct the past seepage activity in the Eastern Mediterranean Sea using sediment petrography, XRD and stable isotope analysis of different seep carbonate morphologies.
Three different seep carbonate morphologies (chimneys, crusts and pavements) were found in the Palmachim Disturbance (PD), the Levant Channel (LC) and the Nile Fan (NF). The combination of X-ray computed tomography and sedimentary petrography highlight recurrent cements. X-Ray Diffraction analyses indicate the presence of high-magnesium calcite, as well as aragonite, dolomite and low-magnesium calcite.

The chimneys consist mostly of high-Mg calcite and botryoidal and fan-shaped growing aragonite. Furthermore, Fe-Mn phases were often found at the boundaries of the aragonitic cements and barite crystals within the high-Mg calcite and aragonite.
The carbonate crusts show a high amount of high-Mg calcite with low content of aragonite. The carbonate pavements evidence in contrast to the crusts and chimneys high amounts of micritic dolomite within a low-Mg calcitic matrix. The aragonite content in the carbonate pavements change throughout the sample, but is always less than ~10%.
Stable carbon isotope data reveal three different clusters, resp. (1) one highly depleted cluster (~35 to – 50‰), (2) one cluster with values around 0‰ and (3) one mixing phase respectively.
The occurrence of different cement generations indicate changing seep activity conditions through time in the Eastern Mediterranean Sea.

P 15.1
Insights from the study of morphological evolution of menardiform globorotalids at Western Pacific Warm Pool ODP Hole 806C (Ontong-Java Plateau)

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The morphological evolution was investigated in the tropical Neogene planktonic foraminiferal lineage *Globorotalia menardii*, *G. limbata* and *G. multicamerata* during the past 8 million years at ODP Hole 806C (Ontong-Java Plateau, Western Pacific Warm Pool WPWP). This research is an extension of a series of previous studies about the morphological evolution in this group from the Caribbean Sea, the tropical Atlantic and the Eastern Equatorial Pacific (Knappertsbusch, 2007; Mary and Knappertsbusch 2015; Knappertsbusch, 2016; Friesenhagen and Knappertsbusch, 2020). The goal is to find empirical and quantitative confirmation for morphological speciation – splitting or phyletic gradualism – in planktonic foraminifera with the above lineage as model objects. A major question was wether a conspicous time-transgressive shell size-increase of menardiforms, that was observed in several tropical Atlantic sites during the Late Pliocene, is also present in the tropical Pacific Ocean. The Atlantic size evolution pattern is currently thought to reflect a peripheral influence from Agulhas Current Faunal Leakage of Indian Ocean or even remote Pacific menardiform faunas into the South Atlantic (Knappertsbusch, 2016), but accelerated evolution may come as an alternative explanation as well. The present study from ODP Hole 806C, which is outside the reach of the Agulhas Current System, thus serves as a test to discriminate between these scenarios.

In the WPWP, stable tropical environments prevailed back to Pliocene times, and potential influences of Northern Hemisphere Glaciation are thought to bear less severely on shell size evolution than in the Atlantic Ocean. Hence, a slow and gradual pattern of shell size increase is expected in the western tropical Pacific, in contrast to the intermittent rapid menardiform shell size increase during periods of intensified formation of warm water eddies in the southern to tropical Atlantic.

For this study >5250 specimens comprising *G. menardii*, *G. limbata* and *G. multicamerata* from 33 stratigraphic levels extending over the past 8 million years were morphometrically investigated using imaging- and microfossil orientation robots *AMOR* and *System AMOR2*, that were both especially developed for such purposes (Knappertsbusch et al, 2009, Knappertsbusch et al. 2019). Special attention was given to trends of spiral height (dX) versus axial length (dY) in keel view, for which bivariate contour- and volume density diagrams were constructed to visualize speciation and evolutionary trends.

The investigation at Hole 806C showed, that *G. menardii* evolved in a more gradual manner than in the Atlantic. Plots of dX versus dY reveal bimodality between 3.18 Ma – 2.55 Ma with a dominant branch consisting of smaller *G. menardii* (dX<~300 μm) persisting until the Late Quaternary, and a less dominant branch of larger *G. menardii* (dX>~300 μm) until 2.63 Ma. There is evidence for cladogenesis – splitting with subsequent morphological divergence in the Late Pliocene *G. menardii-limbata-multicamerata* lineage, albeit the divergence was less clearly expressed than originally expected for such a speciation event. Up-section, bimodality vanished but *G. menardii* populations shifted towards extra large shells between 2.19-1.95 Ma supporting the possibility of long-distance inter-oceanic dispersal of giant menardiforms.

In summary, the morphological evolution of Pacific menardiform globorotalids contrasts the one observed in the Atlantic realm. Seen together this inter-oceanic asymmetry is indication of possible long-distance dispersal of *G. menardii, at least during intermittent phases*. Implications for biostratigraphic applications are, that in plankton biostratigraphy correlation events may be based more often than previously thought on large scale environmental perturbations with local morphological ecophenotypic adaptations and nuances.

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P 15.2
Looking to the Future of Scientific Ocean Drilling from a Swiss Prospective

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In 2018, the Earth science community celebrated the 50th anniversary of scientific ocean drilling. From the early beginnings of the Deep Sea Drilling Program (DSDP) to the current International Discovery Program (IODP), numerous Swiss scientists have been actively involved and have contributed to the success of this ongoing and evolving program. Now, 52 years after the first official expedition was conducted, organized scientific ocean drilling is still going strong with continued Swiss participation to many drilling programs, e.g., from drilling the Atlantis Massif to study serpentinization and associated microbial life (IODP Exp. 357) to probing into “Iceberg Alley” to study Subantarctic ice and ocean dynamics (IODP Exp. 382). Looking to define the challenging directions of the post-2023 drilling program, a large and diverse international multi-disciplinary science community has compiled an extensive document entitled “Exploring Earth by Scientific Ocean Drilling”, which aims to provide a 2050 Science Framework to make new discoveries about Earth’s past, present, and future. In presenting the content of this new document from a Swiss prospective, we ask *Quo Vadis*?

16. Biosphere-Atmosphere Interactions and Greenhouse Gases
+
17. Atmospheric Chemistry and Physics

Christof Ammann, Stefan Brönnimann, Mana Gharun, Martin Steinbacher, Werner Eugster + Ulrich Krieger

ACP – Swiss Commission on Atmospheric Chemistry and Physics
ProClim (SCNAT)

TALKS:

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16.2 *dos Reis Martins M., Keel S.G.* : New steps towards a model-based estimation of N_2O emissions from agricultural soils in Switzerland

16.3 *Feinberg A., Stenke A., Peter T., Winkel L.H.E.* : Modelling current and future atmospheric selenium deposition using available observational constraints

16.4 *Guangyu Li, Wieder J., Pasquier J., Henneberger J., Paglione M., Licina D., Nenes A., Lohmann U., Kanji Z.A.* : Investigation of the Nature and Variability of Ice Nucleating Particles to Understand Ice Formation in Arctic Mixed-phase Clouds

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16.11 *Van de Broek M., Riley W.J., Frey S.D., Schmidt M.W.I.* : Simulating the effect of decadal soil warming on CO_2 losses from a temperate forests soil

16.12 *Wang Y., Paul S., Jocher M., Alewell C., Leifeld J.* : The impact of mineral soil coverage on N_2O emissions from organic soil drained for agriculture

16.1
Quantification of methane emissions from a waste water treatment plant in Switzerland

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Quantification of gaseous emissions from waste water treatment plants (WWTPs) is challenging due to the heterogeneity of the emissions in space and time. The inverse dispersion method (IDM) using concentration and turbulence measurements in combination with a backward Lagrangian stochastic (bLS) dispersion model based on Flesch et al. (2004) is a promising option to quantify such emissions. It is increasingly used to determine gaseous emissions from confined sources (Flesch et al., 2009; VanderZaag et al., 2014), as it offers high flexibility at reasonable costs. For the application on WWTPs the bLS model assumption of spatially homogeneous turbulence, which implies absence of obstacles as buildings and trees that disturb the flow, is often not fulfilled. However, studies showed that with the correct instrument setup and data filtering the bLS can be used for emission estimates. In this study methane emissions from a WWTP in Switzerland were quantified using the IDM with the bLS model. Methane concentrations were analysed with open-path tunable diode laser spectrometers (GasFinder3-OP, Boreal Laser Inc., Edmonton, Canada) placed up- and downwind of the source. Here we present WWTP emission estimates from the 20 day measuring campaign.

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16.2
New steps towards a model-based estimation of N_2O emissions from agricultural soils in Switzerland

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The agriculture sector is responsible for almost 13 per cent of all greenhouse gas emissions in Switzerland (FOEN 2020), with a significant contribution of nitrous oxide (N_2O)-emissions from agricultural soils. The amount of nitrogen converted to N_2O remains highly uncertain due to the very dynamic nature of soil processes that lead to N_2O production. Because of the complexity and the need of detailed databases covering the whole territory of a country, including reliable weather and farming data, so far only few countries have been able to use modelling for their national N_2O-inventories of the agricultural sector.

In the present study, we evaluate the process-oriented model DayCent for estimating soil-based N_2O emissions from agricultural soils in Switzerland as a first step towards implementing a more detailed methodology for national greenhouse gas reporting. To test the model performance, we are comparing the model outputs with soil N_2O fluxes measured in field experiments. A selection of field studies from the literature was performed considering the following criteria: (i) the measurements of N_2O emissions were performed under pedoclimatic conditions and agricultural management representative for Switzerland; (ii) studies with a reliable strategy of N_2O monitoring (e.g., number of measurements over time); (iii) with measurements performed for at least one year; (iv) at least one important auxiliary variable related to N_2O emission was analysed, including soil water-filled pore space (WFPS) and soil mineral N content.

After a preliminary tuning of the model parameters, the results of the simulations showed, in general, a proper capability of the model in predicting the management-induced effects on soil N_2O fluxes. DayCent simulated quite well the tillage-generated mineralization of SOM resulting in production of mineral N and soluble C and triggered, consequently, the N_2O production from soil indigenous N due to denitrification. The soil WFPS, which indicates the soil aeration status and so the potential for denitrification-induced N_2O emissions, was in acceptable agreement with the measured values.

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16.3
Modelling current and future atmospheric selenium deposition using available observational constraints

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Selenium (Se) is a trace element that is essential for humans and animals to have in their diet for proper physiological functioning. Between 0.5 to 1 billion people are estimated to have inadequate dietary Se intakes. The concentration of Se in crops depends on the amount of bioavailable Se in agricultural soils, which in turn depends on the amount of atmospheric Se depositing on these soils. However, until now, very little was known about the atmospheric Se cycle in general, and past quantitative estimates of global atmospheric Se fluxes were highly uncertain. Therefore, we implemented the Se cycle in a three-dimensional aerosol-chemistry-climate model, SOCOL-AER, to simulate the transport and deposition of Se. This model can be used to identify areas where atmospheric inputs to soil Se are low and predict future trends in Se deposition.

The Se cycle in SOCOL-AER is based on the existing sulfur (S) cycle in the model, because these two elements have similar atmospheric sources and chemical properties. Gas phase Se species (DMSe, H_2Se, CSSe, CSe_2, OCSe, and SeO_2) are emitted by natural processes — including volcanic degassing, the marine biosphere, and terrestrial biosphere — and anthropogenic activities — including coal combustion, metal smelting, and biomass burning. Once in the atmosphere, the volatile Se species are quickly oxidized (on timescales of minutes to hours), forming low volatility compounds that partition to the particulate phase. Particulate-bound Se is transported on average for around 4.5 days in the atmosphere and is ultimately removed through wet and dry deposition.

In order to constrain the atmospheric fluxes of Se, we compare the new Se model with a compiled database of more than 2000 aerosol Se measurements using Bayesian inference methods. When optimized emission parameters are used, SOCOL-AER shows reasonable agreement with the aerosol Se measurements included in the optimization (R^2 = 0.66), as well as with independent aerosol (R^2 = 0.59) and wet deposition measurements (R^2 = 0.57). We find that 29 and 36 Gg of Se cycle through the atmosphere every year, which is around double previous estimates. Atmospheric inputs of Se to agricultural soils and the marine environment may therefore be larger than previously expected. Currently, anthropogenic emissions contribute around 35% of total Se emissions. However, anthropogenic emissions of Se have decreased over the last three decades in North America and Europe, due to changes in technology and energy policy.

In the future, anthropogenic S and Se emissions are expected to decrease further because of improved pollution control technology and shifts away from coal power generation. To investigate the impact of these changes on agriculture, we model the changes in S and Se deposition between the 1980s and the 2090s in SOCOL-AER under two socioeconomic scenarios. Sulfur and Se inputs to soil in the Northern Hemisphere are significantly reduced (–55 to –90%) by the end of the 21st century. Climate change will alter precipitation patterns in the future, though this effect on Se deposition is minor compared to projected emission changes. While the decrease in coal combustion is a success for environmental protection and climate change mitigation, it may lead to consequences for industrial agriculture. Due to reduced S and Se supply from the atmosphere, fertilization and biofortification strategies will need to be developed to prevent S deficiencies in agricultural crops and Se deficiencies in humans and animals.

16.4
Investigation of the Nature and Variability of Ice Nucleating Particles to Understand Ice Formation in Arctic Mixed-phase Clouds

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As climate change has an amplified effect in the Arctic regions, it is crucial to better understand the properties of Arctic clouds. Aerosol particles significantly influence cloud properties such as lifetime, optical thickness and cloud phase, by acting as cloud condensation nuclei and ice nucleating particles (INPs). These properties are instrumental to understand the radiation budget and hydrological cycle, which are key for climate projections. The concentration of ambient INPs in clouds, responsible for the initiation of atmospheric ice formation at temperature > -38 °C is highly uncertain and variable. So far, the understanding of the origin and nature of INPs in the Arctic remains unclear owing to the scarcity of data and the low overall aerosol concentrations that challenge INP measurements.

In this study, we performed two field campaigns in autumn 2019 and spring 2020 in Ny-Ålesund, Svalbard (78.92°N, 11.91°E), where we monitored ambient INP concentrations continuously at -30 °C in the immersion freezing mode using an online continuous flow diffusion chamber (HINC, Lacher et al., 2017) at a temporal resolution of 20 minutes. Additionally, we deployed a PM_{10} filter collector at a sampling interval of 8 hours to perform offline analysis of INP concentrations at temperature > -22 °C via an offline drop-freezing technique (DRINCZ, David et al., 2019). Aerosol properties including size distributions and the contribution of flourescent particles as a proxy for biological aerosol were also monitored for determining the source of aerosol particles throughout the measurement period. We will report the results combining the above measurements, which allows determining the INP concentrations, their variability, nature, and contributions to primary ice formation in Arctic mixed-phase clouds. In particular, we will present our findings on the role and conncection between biological sources and INPs in the Arctic.

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16.5
Top-down Estimation of Swiss non-CO_2 Greenhouse Gas Emissions in Support of National Inventory Reporting to UNFCCC

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Globally, emissions of long-lived non-CO_2 greenhouse gases (GHG; methane, nitrous oxide and halogenated compounds) account for approximately 30 % of the radiative forcing of all anthropogenic GHG emissions. In industrialised countries, ‘bottom-up’ emission estimates are provided with relatively large uncertainties for non-CO_2 GHGs when compared with those of anthropogenic CO_2. ‘Top-down’ methods based on the observation of atmospheric concentrations and applied on the country scale offer an independent tool to reduce these uncertainties and detect biases in emissions reported to the UNFCCC. Hence, they provide additional support for policy makers to control the effectiveness of initiated emission reduction measures and build mutual trust between goverments.

Since 2012, the Swiss national inventory reporting (NIR) contains an appendix on ‘top-down’ studies for selected halogenated compound. More recently, this appendix was extended to include methane and nitrous oxide. Here, we present these updated (FOEN, 2020) regional-scale (~300 x 200 km^2) atmospheric inversion studies for non-CO_2 GHG emission estimates in Switzerland, making use of observations on the Swiss Plateau (Beromünster tall tower) as well as the neighbouring mountain-top sites Jungfraujoch and Schauinsland.

We report spatially and temporally resolved Swiss emissions for CH_4 (2013-2019), N_2O (2017-2019), and total Swiss emissions for hydrofluorocarbons (HFCs) and SF_6 (2009-2019) based on a Bayesian inversion system and a tracer ratio method. Both approaches make use of transport simulations applying the regional-scale (7 x 7 km^2) Lagrangian particle dispersion model (FLEXPART-COSMO). We compare these ‘top-down’ estimates to the ‘bottom-up’ results reported by Switzerland to the UNFCCC. Although we find good agreement between the two estimates for some species (CH_4, N_2O, Figure 1), emissions of other compounds (e.g., HFC-134a) show larger discrepancies. Potential reasons for the disagreements are discussed. Currently, our ‘top-down’ information is only used for comparative purposes and does not directly feed back into the revision of emisison factors in the ‘bottom-up’ inventory. However, as a result of our long and fruitful collaboration with the national inventory group and similar such efforts in other countries (e.g., UK, Australia, New Zealand) the value of “top-down” methods on a country scale is now being accepted by a broader community. As such, “top-down” methods have recently been recommend in the “2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories” (Volume 1, section 6.10.2, Comparisons with atmospheric measurements), which is part of the legal framework of the UNFCCC emission reporting procedure.

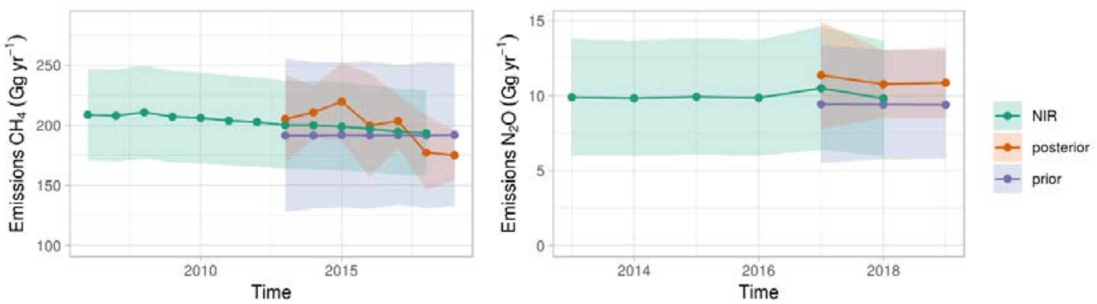

Figure 1. Swiss annual mean anthropogenic emissions of CH_4 (left) and N_2O (right) based on the National Inventory Report (NIR, green line) and based on top-down estimation from atmospheric observations at Beromünster, Jungfraujoch and other sites (posterior, orange line). The shaded areas denote the 1σ uncertainties ranges. Figures from Swiss NIR report (FOEN, 2020).

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16.6 Metrology for climate relevant volatile organic compounds − MetClimVOC

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Volatile organic compounds (VOCs) play an important role in the atmospheric chemistry, especially in the oxidative capacity of the lower atmosphere (Atkinson & Arey 2003). VOCs are direct and indirect greenhouse gases and precursors of ozone and aerosols, which both contribute to the radiative forcing (Chameides & Walker 1976; Taipale et al. 2008). Accordingly, long-term, accurate and traceable measurements of VOCs are needed to produce comparable datasets at regional and temporal scales, which are essential to identify climate trends.

VOCs are emitted into the atmosphere from natural and anthropogenic sources. Vegetation is the main source of VOCs emitting biogenic VOCs (BVOCs) such as isoprene and monoterpenes (Guenther et al., 1995; Sindelarova et al. 2014). The chemical degradation of BVOCs and the resulting intermediate products are relevant to air quality and climate. A better understanding of BVOC chemistry and quantification of the emissions are essential to predict BVOC feedbacks in the biosphere−atmosphere−climate system. The lack of stable and traceable standards to the international system of unit for some terpenes, together with effects linked to BVOC reactivity with surfaces (i.e. memory effects, decomposition artefacts) and to ozone and humidity interferences are common issues for sites monitoring BVOCs in the atmosphere and BVOC emissions. Similar problems occur for other compounds like oxygenated and halogenated VOCs.

The project “Metrology for Climate Relevant Volatile Organic Compounds” (MetClimVOC, 2020-2023) pursues to minimise these limitations by generating gas standars of oxygenated VOCs, terpenes and halogenated VOCs that are considered priority by stakeholders (WMO-GAW, AGAGE, ACTRIS, EMEP). These gas standards will be produced at amtospheric amount fraction level with an accuracy and temporal stability fulfilling the Data Quality Objectives of the monitoring networks (amount fraction between 1 nmol/mol and 1 µmol/mol with expanded uncertainty < 5% for oxy-VOCs and terpenes and < 1 nmol/mol with expanded uncertainty < 3% for halogenated VOCs; minimum 2 years of temporal stability for gravimetric standards). Moreover, the project aims to optimize the sampling and analytical methods used in monitorign stations and to develop fit-for-purpose working standards.

The project MetClimVOC is part of the European Metrology Programme for Innovation and Research (EMPIR) of the European Association of Metrology Institutes (EURAMET), involves 13 partners from metrological and atmospheric monitoring communities and is coordinated by the Federal Institute of Metrology METAS. Here, we present the project and its first outputs, such as a priority list of VOCs relevant for climate research and their metrological requirements elaborated by active collaboration with stakeholders.

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16.7
The impact of turbulence parameterization in high resolution inverse modelling with FLEXPART-COSMO

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Regional-scale atmospheric inverse modelling can provide observation-based estimates of greenhouse gas emissions at a country scale and, hence, makes valuable information available to policy makers when reviewing emission mitigation strategies and confirming the countries› pledges for emission reduction. Considering that inverse modelling relies on accurate atmospheric transport modelling, any advances to the latter are of key importance. Within the SNSF project IHALOME (Innovation in Halocarbon Measurements and Emission Validation) we characterize and improve the Lagrangian particle dispersion model (LPDM) FLEXPART-COSMO at kilometer-scale resolution and to provide estimates of Swiss halocarbon emissions by integrating newly available halocarbon observations from the Swiss Plateau at the Beromünster tall tower. The transport model is offline coupled with the analysis fields generated by the regional numerical weather prediction model (NWP) COSMO run at MeteoSwiss. Previous inverse modelling results for Swiss greenhouse gases are based on a model resolution of 7 km x 7 km (ref 1). Here, we utilize higher resolution (1 km x 1 km) fields to drive FLEXPART and compare these to previous results.

The higher resolution simulations exhibit increased three-dimensional dispersion, leading to a general underestimation of observed tracer concentrations at the tall tower site Beromünster and when compared to the coarse model results. Because the TKE (Turbulent Kinetic Energy) values do not differ significantly between the two model versions head-to-head comparisons of parameterized turbulence cannot fully explain the concentration discrepancies. Comparisons of variability (turbulence) resolved on the grid-scale suggest that the dispersion differences may originate from a duplication of turbulent transport, on the one hand, covered by the high resolution grid of the Eulerian model and, on the other hand, diagnosed by FLEXPART›s turbulence scheme. In an attempt to tune FLEXPART-COSMO's turbulence scheme at high resolution, we scale FLEXPART›s parameterized turbulence so it matches the TKE computed in COSMO. Test simulations with the scaled FLEXPART turbulence show remarkable improvements in the high resolution model›s ability to predict the observed tracer concentrations at the Beromünster tall tower.

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16.8 Particulate Matter on Honeybee Body Surfaces

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An unconventional method to get an overlook on aerosol particles deposited in the environment is to analyze particles attached on the bodies of honeybees (Apis mellifera, L.). During foraging, other particles than pollen accumulate on the bee surface. Based on the chemistry and the morphology of these particles obtained by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS), a rough source appointment can be made (Negri et al., 2015).

To get an overview over the particles collected by foraging bees, specimens were sampled around beehives in autumn 2019 at four sites in the Canton of Fribourg with different background settings (rural, urban, close to a highway and close to a shooting range). All particles found at the surfaces are in a size range between 1 and 100 μm. Due to carbon coating and the bee's body composition, organic particles like pollen or carbon particles (soot) are difficult to analyze chemically, but in most cases can be distinguished based on morphology. In addition to pollen and soil-derived (dust) particles, which were always present, the particle population contained site specific components.
Heavy metal rich particles containing Pb, Ba, Cu, Hg, Zn and Sn, typical for the composition of gunshot residue, were found on bees from the beehive close to the shooting range. A second sampling campaign has been undertaken at this site in spring/summer 2020.

The results show that the analysis of particles found on the surface of bees are a quick and convenient tool to monitor the predominant sources of aerosol in the vicinity of beehives.

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16.9
Carbon budget of a drained organic agricultural soil with mineral soil coverage

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The agricultural use of organic soils usually requires drainage that leads to high Greenhouse Gas (GHG) emissions and soil subsidence. A proposed strategy to maintain productivity of these soils is to cover them with mineral soil. To quantify the climatic impact of this practice, the net ecosystem carbon balance (NECB) was determined for a pair of covered (Cov) and uncovered reference (Ref) organic soil. Our experimental field site is located in the Rhine Valley, Switzerland, and the grassland is intensively managed. The NECB was determined for two full years (1.3.2018-29.2.2020) by accounting for all relevant carbon fluxes entering and leaving the soil-vegetation system. For this purpose, the net ecosystem exchange of CO_2 (NEE), CH_4 exchange fluxes, carbon removal by harvest, and carbon import by organic fertilizers were measured. The gas exchange for CO_2 and CH_4 was determined by eddy co-variance (EC). In both years, NEE was positive indicating an upward net flux of CO_2 to the atmosphere. However, the magnitude of CO_2 fluxes differed considerably between the two years for both sites. For the first year, NEE was around 600 g C m^{-2} yr^{-1}, about 3 to 4 times higher as insecond year. Annual CH_4 emissions were marginal at both sites. Considering the NECB the reference site was found to be a net carbon source with higher emissions in the first year. The NECP of the covered site was similar, indicating a marginal effect of the soil coverage on the NECB in both years. We found the groundwater to be an important driving factor for the observed loss of soil carbon at our site. Based on the two year measurement period, we preliminary conclude that covering organic soils with minerals soil might not be an effective climate mitigation option at the Rüthi site.

16.10
First halogenated greenhouse gas measurements at the Beromünster tall tower in Switzerland and emission estimation

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Synthetic halocarbons reach the atmosphere due to a wide range of anthropogenic activities. Once in the atmosphere, long-lived halocarbons act as strong greenhouse gases, and in addition, chlorinated or brominated halocarbons contribute to stratospheric ozone depletion. To monitor abundances and trends of halocarbons, global measurement networks, such as the Advanced Global Atmospheric Gases Experiment (AGAGE), have been put in place. However, to capture regional pollution sources and to validate country-specific bottom-up emission estimates by atmospheric observations, additional measurements, focusing on smaller scales, are required. For this purpose, we already carried out devoted multi-month field campaigns in the Eastern Mediterranean and Eastern Europe. However, halocarbon emissions from many European regions remain largely unexplored in terms of atmospheric observations.

In the frame of the SNF-project IHALOME we present the first continuous halocarbon measurements covering the most industrialized and densely populated area of Switzerland, the Swiss Plateau. The data obtained during a one-year measurement campaign at the Beromünster tall tower in the canton of Lucerne complement the long-term measurements at the high altitude research station Jungfraujoch. High precision, high accuracy measurements of >60 halogenated substances were performed via the analytical setup of the AGAGE network (Miller et al. 2008): Air samples are pre-concentrated in a two-trap process at low temperatures before the analytes are separated by gas chromatography (GC) and detected by quadrupole mass spectrometry (MS). All halogens compound classes of the Montreal and Kyoto Protocols are represented in our measurements, the chlorofluorocarbons (CFCs), the hydrochlorofluorocarbons (HCFCs), the hydrochfluorocarbons (HFCs) and perfluorocarbons (PFCs) and the youngest generation of unregulated hydrochfluoroolefins (HFOs). The obtained results improve our understanding of halocarbon abundances and source allocation in Switzerland, and, for the first time, they offer the possibility to robustly quantify Swiss national halocarbon emissions with top-down methods (tracer ratio and Bayesian inverse modeling).

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16.11
Simulating the effect of decadal soil warming on CO2 losses from a temperate forests soil

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As a consequence of the predicted warming of the atmosphere over the coming decades, soils are expected to warm at similar rates. This warming might have profound consequences for the rate at which biogeochemical processes take place in soils, such as an enhanced rate of soil organic carbon mineralization to CO2. Making reliable predictions of the response of soil organic carbon to soil warming is therefore necessary to assess the extent to which this process might constitute a positive feedback to global climatic change over the coming decades.

Therefore, we applied a state-of-the-art soil biogeochemical model (ReSOM, Tang and Riley (2015)) to two long-term soil warming experiments (+ 5 °C) at Harvard Forest (Massachusetts, USA), which have been running for 17 and 29 years. Our aims are to (1) assess the extent to which ReSOM is able to correctly simulate the effect of long-term soil warming on soil organic carbon stocks and temporal patterns of CO2 fluxes, (2) assess the importance of including thermal adaptation of soil microbes (using macromolecular rate theory) and temporal patterns in soil moisture content in ReSOM to correctly simulate intra- and inter-annual soil organic carbon dynamics, and (3) check the reliability of model predictions to make forecasts on decadal timescales when calibrated using data from a decade of soil warming.

Our results show that including thermal adaptation of soil microbes is necessary to reliably predict the effect of decadal soil warming on intra- and inter-annual CO2 fluxes. In addition, the limiting effect of soil moisture on microbial decomposition of soil organic carbon needs to be simulated in order to correctly simulate the effect of soil warming at different forest sites in the same region. Last, we assessed the effect of including or excluding the effect of (1) soil moisture and (2) thermal adaptation of soil microbes on simulated changes in soil organic carbon stocks over the next century. We found diverging predictions of soil organic carbon losses under these different scenarios, showing the importance of correctly including and parameterizing these processes.

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16.12
The impact of mineral soil coverage on N_2O emissions from organic soil drained for agriculture

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Peatland store 12 – 21 % of the total soil organic nitrogen (N), which accumulated over millennia. However, long - term drainage of peatland for agricultural use leads to a strong release of carbon and nitrogen and subsidence of peatland through aerobic peat decomposition. In order to improve the sustainability of peatland management in agriculture, and to counteract soil subsidence, mineral soil coverage is becoming an increasingly used practice in Switzerland. Mineral soil coverage may affect the N balance from the corresponding organic soil, owning to the eventual change of surface soil characteristics. However, the effect of mineral soil coverage on nitrous oxide (N_2O) emission has not been studied yet. Here, we report on a field experiment carried out to explore the impact of mineral soil coverage on the N_2O emission from drained organic soil.

The experimental site, a drained peatland with a peat thickness of around 10 m, is located in the Swiss Rhine Valley. In 1973, an integral drainage system was built. Since then, an intensivly managed meadow was established, with mineral and slurry fertilization and 5 to 6 grass cuts per year. In 2006, one part of the field (1.7 ha) was covered with mineral soil material (thickness 30 – 40 cm). We established our field experiement on this mineral soil coverage site (DC) and used the adjacent drained organic soil without mineral soil coverage as reference (DN). Both sites have the identical management and vegetation. In our experiment, an automatic chamber system is used for collecting the N_2O at an interval of 3 h. After one and a half year's (03.2019 to 08.2020) continuous measurement, the data reveals that: the average N_2O emissions from DN (10.66 ± 1.28 mg N_2O-N m^{-2} day^{-1}) exceeds the one from DC (1.14 ± 0.08 mg N_2O-N m^{-2} day^{-1}) by a factor of 10. The more details analysis shows that this difference between DC and DN is mainly driven by the different reaction to fertilizer inputs. In general, the N_2O peaks occur shortly after N application and last for 2 to 3 weeks before returning to background emission. The N_2O peaks after fertilization account for 80 % and 70 % of the total N_2O emissions for DN and DC, respectively. However, significantly higher peak N_2O emisisons were found in DN than DC, whereas the background N_2O emissions show no difference. To further explore the impact of mineral soil coverage on the N balance of drained organic soil, extra $^{15}NH_4{}^{15}NO_3$ labelled fertilizer will be applied in September 2020 to trace the N transformation at DC and DN. In summary, our data suggest that mineral soil coverage could strongly reduce N_2O emission from drained organic soil, and may therefore be an interesting GHG mitigation measure in agriculture.

18. Climatology

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18.2 *Buchmann M., Brönnimann S., Begert M., Marty C.*: Evaluating the seasonal robustness of snow climate indicators using a unique set of parallel snow data

18.3 *Burgdorf A.-M., Arblaster J.*: Precipitation response to ozone depletion in the Southern Hemisphere

18.4 *Comte V., Schneider L., Rebetez M.*: Trends in bioclimatic indices for the coming decades in the Neuchatel vineyard

18.5 *Gudmundsson L., Gädeke A., Grant L., Kirchner J., Padron R., Thiery W., Seneviratne S.I.*: Detecting and attributing climate change impacts in terrestrial systems

18.6 *Scheen J., Pöppelmeier F., Lippold J., Stocker T.F.*: Reconstructing AMOC strength by simulating the transport of Pa/Th isotopes in the ocean

18.7 *Valler V., Franke J., Brugnara Y., Brönnimann S.*: A monthly paleo-reanalysis of the atmosphere between 1603-2005

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P 18.4 *Pappert D.*: Unlocking weather data of the Societas Meteorologica Palatina: a daily reconstruction of the severe winter 1788/89.

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P 18.6 *Schneider L., Comte V., Sneiders B., Rebetez M.*: Climate change in the vineyard: perspectives for pest species in the region of Neuchatel

18.1
Atmospheric Contribution to Multidecadal Flood Variability in Europe

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Analyses of historical streamflow records and documentary data indicate clear multidecadal changes of flood frequency in Europe. Floods were more frequent in Central Europe in the 19th century than during the mid-20th century, and an increase is also noted since the 1970s. The causes for these multidecadal variations are not well understood. In this contribution I will focus on the atmospheric contribution to multidecadal flood variability, such as changes in atmospheric circulation. Long streamflow records are analysed together with daily weather data from reanalyses and from weather type classifications, with monthly data from climate reconstructions and with atmospheric model simulations. Results show that atmospheric circulation variations as well as climate change contribute to multidecadal flood variability and change.

18.2
Evaluating the seasonal robustness of snow climate indicators using a unique set of parallel snow data

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It is well known that measurements of snow can heavily depend on the measurement location and can differ even over short distances. A data set of 25 station pairs with parallel manual snow measurements, gathered by two separate institutes in Switzerland, provides a unique opportunity to analyse the local-scale variability of typical snow climate indicators. The independent daily measurements date back several decades and cover at least 25 years and an altitude range from 490 to 1800m a.s.l. The parallel locations are usually separated by less than 2 km in terms of distance and less than 100 metres in terms of elevation. In contrast to many other meteorological variables, the manual snow measurement instruments have not changed over time. However, the data series almost certainly encountered one or several changes in the exact measurement location or observer, which may have not been documented in the metadata.
A sensitivity analysis was carried out to look for snow climate indicators, such as mean snow depth, sum of new snow, maximum snow depth or number of days with snowfall, with the smallest variations among the station pairs.
Results show that there are only small differences in the sensitivity of the various snow climate indicators with regards to, usually unknown, local changes. However, the indicators number of days with snow on the ground as well as the maximum snow depth and the sum of new snow are least affected by local influences and changes at station level. Median values of all station pairs reveal relative differences of about 7% for the number of days with snow cover and 11-16% for all other indicators. However, there are clear seasonal differences, which can be much larger in extremes cases.
These experiences will help to define application-dependent robust snow climate indicators and will also help to interpret suspicious snow data series from locations without parallel measurements and without documented changes in the metadata and thus contribute to the generation of homogenous snow climatological time series.

18.3
Precipitation response to ozone depletion in the Southern Hemisphere

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A mature body of research examines the influence of stratospheric ozone changes on Southern Hemisphere climate and circulation. Stratospheric ozone depletion, which has its strongest signal over Antarctica in austral spring, is believed to be the dominant driver of austral summer atmospheric circulation changes in recent decades. These changes include a poleward shift of the lower-tropospheric midlatitude jet, the poleward expansion of the subtropical edge of the Hadley Cell, as well as a shift of the Southern Annular Mode (SAM) into its positive phase.

In terms of surface impacts associated with these circulation changes, the Ozone Assessment (2014) suggested that observed changes in extratropical and subtropical austral rainfall may be linked to ozone depletion. However, only a few studies have investigated this link and mostly on regional scales. Moreover, most have not been able to clearly isolate the effect of the ozone forcing from other anthropogenic forcings and internal climate variability, due to a lack of appropriate experiments and/or model output.

This study focuses on the isolation of the ozone forcing from other forcings using individual forcing simulations of the CESM1-CAM5 Large Ensemble (CESM-LE) and tries to further identify its impact on austral summer precipitation in the Southern Hemisphere as well as the influence of/on changes in the SAM. The additivity of the precipitation response to individual forcings is explored within this large ensemble, which allows for better quantification of the role of internal variability.

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18.4
Trends in bioclimatic indices for the coming decades in the Neuchatel vineyard

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Weather conditions are known to be the most important factor for vitiviniculture (Jones and Davis 2000, van Leeuwen et al. 2004). Numerous studies have shown that climate change influences the phenological development stages of grapes (e.g. Duchêne and Schneider 2005, Cook and Wolkovich 2016) and of the wine composition (Spayd et al. 2002, Jones and Webb 2010). Thus, wines tend to have more sugar and alcohol levels and less acidity in connexion with warmer temperatures. RCPs scenarios provide an essential tool to anticipate future climatic conditions and their impacts on wine production. They help to develop long-term adaptation strategies to climate change. These strategies may consist in an altitudinal shift of the traditional cultivated varieties and/or in the introduction of new varieties (Jones et al. 2005).

In this study, we analysed present and future climatic conditions in the wine region of Neuchatel. We used temperature data from 1980 to 2019 and two RCPs scenarios. We focused on two bioclimatic indices, which are critical for viticulture: the Huglin heliothermal index and the growing season temperature average. We also analysed the frequency and intensity of heat waves occurrences during the summer season and the trend in night temperature during the period prior to harvest. The results should help winegrowers to develop their own strategies to adapt to climate change.

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18.5
Detecting and attributing climate change impacts in terrestrial systems

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Monitoring and understanding the impacts of climate change on terrestrial systems is essential for adapting our societies to the changing world we live in. In contrast to many other drivers of environmental impacts, which can be pin-pointed at local scales (e.g. land management), the influence of climate change is often masked by high degrees of internal climate variability, the complexity of terrestrial systems and the interplay with socio-economic changes. Assessing climate change impacts in the observational records therefore requires a continental to global perspective that offers a more favorable signal to noise ratio. Recent advances in assembling international collections of in situ observations (e.g. of river flow) together with ongoing progress in using data-driven and model based approaches for reconstructing large-scale dynamics of essential environmental variables (e.g. terrestrial water storage) allow now for detecting ongoing environmental change at the global scale. Here we provide an overview on shifts in several components of the global terrestrial system that include indicators of freshwater resources, lake ice dynamics and permafrost. Subsequently, we use approaches that combine observational evidence with process knowledge encoded in global models to uncover the degree to which observed shifts in terrestrial systems can be attributed to anthropogenic climate change. Our results highlight that rivers, lakes and permafrost across the globe are already deeply impacted by historical climate change, calling for careful scruteny of their evolution in the coming decades.

18.6
Reconstructing AMOC strength by simulating the transport of Pa/Th isotopes in the ocean

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The Atlantic Meridional Overturning Circulation (AMOC) is a critical component of the climate system due to its large capacity to redistribute heat, nutrients, and carbon between the hemispheres. Reconstructions indicate that the strength of the AMOC is tightly coupled to climate and it experienced major perturbations in the past during northern hemispheric cold periods. Studies predict that the AMOC may also slow down under future anthropogenic warming.

In order to infer past AMOC strength, the ratio between the radionuclides protactinium-231 and thorium-230 (hereafter Pa/Th ratio) is used as a proxy. These rare metals are naturally formed in the ocean from uranium decay and are preserved in ocean sediments. Pa typically binds less than Th to particles that sink to the ocean bottom and therefore Pa is transported away if ocean circulation is strong. Due to the complex behaviours of Pa and Th in the ocean, models can be of great value to assess possible interpretations of the Pa/Th ratio as a proxy for AMOC strength by simulating secondary processes and disentangling them from the presumed AMOC strength signal. We simulate Pa and Th in the ocean following previous work by Rempfer et al. 2017 with an updated version of the Bern3D earth system model.

A prevailing open question is the contradicting relation between Pa/Th and AMOC strength in different regions. Both sediment measurements and models show a Pa/Th ratio that is anti-correlated with AMOC strength in the deep Northwest Atlantic (Bermuda Rise), but positively correlated in other regions, e.g., shallower regions or regions further north (Rempfer et al. 2017, Süfke et al. 2020). Whereas the former behaviour confirms the classical idea of this proxy, our goal is to investigate why many other regions show an 'inverted behaviour'. Answering this question would improve the interpretation of Pa/Th and therefore provide a better understanding of how changes in AMOC are coupled to changes in climate.

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18.7
A monthly paleo-reanalysis of the atmosphere between 1603-2005

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Data assimilation techniques are becoming increasingly popular for climate reconstruction. They benefit from estimating past climate states both from observation information and from model simulations.

The atmospheric paleo-reanalysis (EKF400v2) is generated by blending observations into model simulations via an offline data assimilation technique. EKF400v2 builds on its predecessor (EKF400v1) which utilized the ensemble Kalman fitting (EKF) paleoclimate data assimilation technique.

Here, in the production of EKF400v2 the EKF technique was further developed by implementing methodological improvements such as better estimation of the background-error covariance matrix and a better localization scheme.

Furthermore, new observational sources were added to the assimilation process contributing to an extended observational network and helping to obtain a more skillful reconstruction both in space and time.

The EKF400v2 paleo-reanalysis can be used to study the dynamics associated with past extreme events and to analyze large-scale circulation changes on time scales raining from monthly to multidecadel.

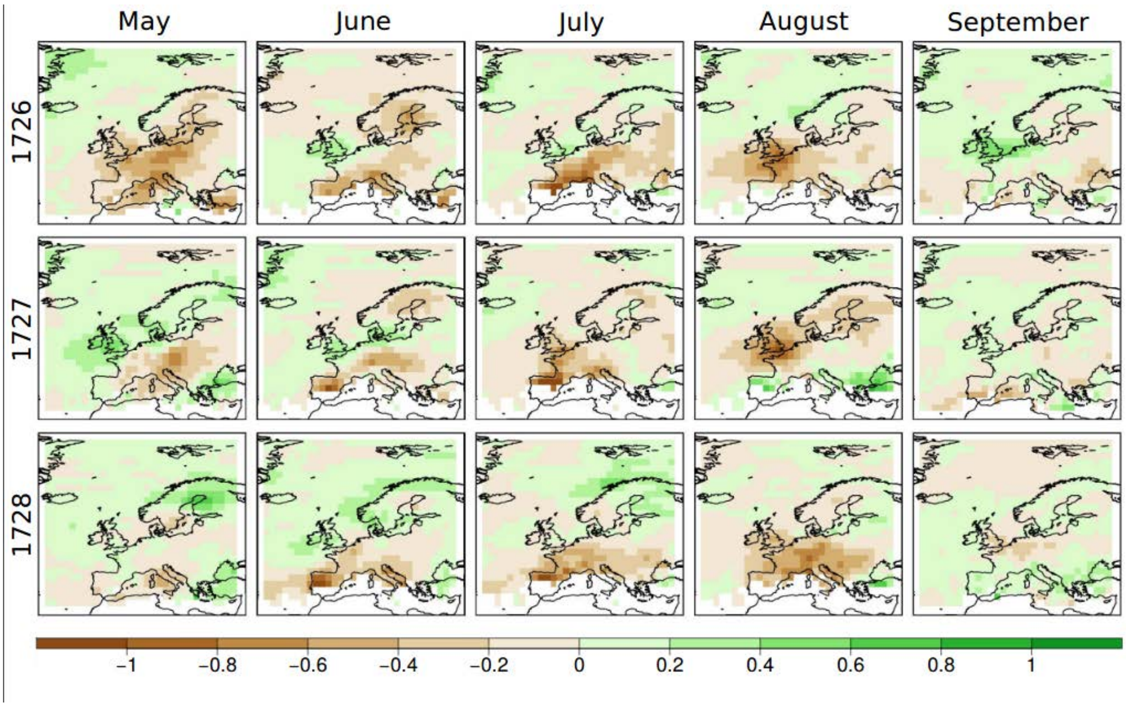

Figure 1. Monthly relative anomalies of precipitation from May to September over Europe for the dry summer years between 1726-1728 in EKF400v2. The areas left blank in the Mediterranean are regions where monthly precipitation amount is less than 10 mm in the climatology.

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18.8
Towards a conditional representation of heat wave probability in large ensemble climate model data

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Single-model initial condition large ensembles provide novel opportunities to study the physical drivers and risks of large-scale climate extremes in a changing climate. The probability of extremes such as weekly heatwaves, here quantified as seven-day maximum temperature (Tx7d), are usually approximated with a general extreme value distribution that is stationary or accounts for non-stationarity of a warming climate. However, estimating the occurrence probability of very rare climate extremes in the presence of large internal variability further benefits from the integration of process-based covariates characterising the preceding and concurrent climate conditions both at global and local scale.

We use more than 6000 years of stationary pre-industrial and 2xCO_2 control simulations and an ensemble of 84 transient historical and RCP8.5 simulations performed with the Community Earth System Model CESM1.2 to develop and robustly test methods of quantifying extreme events under a broad range of climatic conditions. The generalised extreme value distribution is parametrised such that it can account for changing environmental circumstances, ranging from large-scale thermodynamic non-stationarity due to climate change, regional-scale dynamic forcing such as atmospheric blocking, or local land-surface conditions such as soil moisture deficits. Fields of covariates are integrated using approaches from statistical learning theory, accounting for the spatio-temporal correlation inherent in climate data. How well the respective statistical model generalises is tested with respect to further simulations of the US CLIVAR Working Group on Large Ensembles. The relevance of different covariates can inform both detection and attribution as well as risk assessment how their respective statistical models can be further refined to account for the influence of physical drivers under present and future climate conditions.

P 18.1
Global monthly sea surface temperature and sea ice reconstruction for historical simulations

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Variability in Sea Surface Temperature (SST) is one of the prime sources of intra-annual variability, and also an important boundary condition for Atmospheric General Circulation Models (AGCMs). In many AGCM simulations, SST and Sea Ice Concentration (SIC) are prescribed. While SSTs are specified according to observations available in recent period of instrumental records (1850 – present), SIC depends on climatological averages with less variability prior to the inception of satellite measurements. This limits our understanding of large-scale climate variations in the past.
In this study, we augment multi-proxy reconstructed annual mean temperature of Neukom et al. (2019) with intra-annual variability from HadISST (v2.0), for 850 years (1000 – 1849). Intra-seasonal variability, such as the phase-locking of El-Nino Southern Oscillation, Indian Ocean Dipole and Tropical Atlantic SST indices to annual-cycle, are utilized. The intra-annual component of HadISST and SST indices estimated from the multi-proxy reconstructed annual mean, are used to develop grid- based multivariate linear regression models using the Frisch-Waugh-Lovell theorem, in a monthly stratified approach. Furthermore, we introduce a scaling technique to ensure homogeneous mean and variance, similar to that of the target. SST observations obtained from ship measurements by ICOADS before 1850, will be integrated in an off-line data assimilation approach.
Similarly, we reconstruct SIC via analogue resampling of HadISST SIC (1941 – 2000), for both hemispheres. We pool our analogues in four seasons, comprising of 3 months each, such that for each month within a season, there are 180 possible analogues. The best analogues are selected based on correlation coefficients between reconstructed SST and its target.

P 18.2
The overlooked hot summer of 1947

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During the summer of 1947, western Europe experienced several heat-waves and severe drought conditions, which led to considerable socio-economic impacts on a society that was only recovering from the second world war. Despite this, the summer of 1947 has only received little attention regarding its temperature records and atmospheric conditions. Between June and September 1947, in total, five hot periods were registered, which show a remarkable spatial consistency in their onsets and ends. A comparison of indices for maximum temperature based on station data for western Europe in the period 1930-2015 shows that the year 1947 ranks among the top three warmest summers for most of the indices (e.g. mean temperature anomaly, number of days above the 95th percentile, daily heat-wave magnitude index) together with the years 2003 and 2015. However, regarding indices based on minimum temperature, the summer of 1947 appears less extreme. Meteorological conditions were very conducive to the development of hot periods throughout the summer. All five hot periods were related to blocking situations, which occurred during June- September 1947 by a factor of two more frequently than during a usual summer. A heat budget analysis of the levels 1000hPa to 500hPa shows, that the high temperatures of the first four hot periods were rather related to diabatic processes than to advection of warm air. This is however not the case for the last hot period in September. Further, we put the summer of 1947 into a climatological perspective regarding drought conditions.

P 18.3
Can we build 260-year-long instrumental climate records for Bern and Zurich?

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Long climate records are fundamental to understand past multidecadal variability. In Europe, regular meteorological measurements of temperature and pressure (and less commonly, precipitation and humidity) began in the 18th century in most countries and allow climatologists to build climate series spanning over two centuries. Switzerland is no exception and such series were published in the past for Basel and Geneva for daily temperature means.

There exist, however, records for numerous other Swiss cities (e.g., Aarau, Bern, Schaffhausen, St. Gall, Zurich) that span back to the 18th or early 19th century and that have not been used by modern researchers. In the past years these records were collected and digitised at the University of Bern in the framework of multiple projects, involving a considerable amount of time-consuming archive and transcription work.

Here we show the details and the progresses made for the temperature records of Bern and Zurich, both starting around the year 1760, and describe the challenges involved in building homogeneous 260-year-long climate series, i.e. 100 years longer than currently available for those cities.

P 18.4
Unlocking weather data of the Societas Meteorologica Palatina: a daily reconstruction of the severe winter 1788/89.

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For some decades now, early instrumental observations have increasingly played an important role in climate research. Not only have they shown enormous potential in reconstructing past changes in temperature, pressure, and precipitation, but they also allow for daily-to-decadal variability and extremes to be studied in great detail, particularly for 17th- and 18th-century Europe. The *Societas Meteorologica Palatina* (SMP), or Palatine Meteorological Society, stood out as one of those few networks that efficiently managed to control its members, integrating, refining and publishing measurements taken from numerous stations around Europe and beyond (Kington, 1974). According to T.S. Feldman, the work performed by the SMP "was not surpassed for three-quarters of a century" (Feldman, 1990: p. 154).

A comprehensive understanding and rescue of this early instrumental weather data has great potential for today's climate scientists who wish to explore pre-industrial climatic variations and extreme weather events. The aim of this study is therefore, in a first part, to create an inventory listing the availability and extent of data coverage by the stations that belonged to the SMP's network. The data in the printed records is then digitised; with the help of the Copernicus Climate Change Service (C3S) for Data Rescue (Brönnimann, 2018) raw temperature and pressure observations from a selection of stations are converted and quality-controlled; finally, the time series are homogenised. With these steps the observations are now ready for scientific use.

The second part of the study aims to reconstruct daily temperature and pressure fields for Europe for the extreme winter 1788/89 on a 0.1x0.1 grid using the historical station observations from the SMP and an analogue resampling method (ARM) (see Pfister, 2018). Evaluation experiments will show the skill of the reconstructions, which in turn will give insight into the dynamics that led to the extreme winter.

This statistical reconstruction is one of many ways early instrumental data can be used to explore past climate and weather changes. From the inventory, the generation of time series, to the reconstructed spatial fields, the present study illustrates the full process and potential of climate data rescue. From raw historical measurements to informative statistical reconstructions.

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P 18.5
Past Climate Variations in Early Instrumental Data

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There is a growing need for past weather and climate data to support science and decision-making. This poster or presentation will describe the compilation of global instrumental climate data, with a focus on the 18th and early 19th centuries. In addition to available repositories (GHCN, ISTI, CRUTEM, Berkeley Earth, HISTALP) many of the older series have been digitized within the project. The product will form the most comprehensive global monthly climate data set, encompassing temperature, pressure, and precipitation. These data will be homogenized and analyzed with respect to climate variability and they be assimilated into global climate model simulations to provide monthly global reconstructions.

This is a contribution to the ERC PALAEO-RA-project (https://www.palaeo-ra.unibe.ch/)

P 18.6
Climate change in the vineyard: perspectives for pest species in the region of Neuchatel

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Global warming increases the need for local climatic studies in wine-producing areas. Winegrowers have to develop strategies to adapt their activities to new climatic conditions and to their various effects on vine culture. Among them, distribution and population dynamics of pest species are likely to change. New species could reach the temperate regions, and some native species could create more damages than previously in the vineyards. In Western Europe, the distribution of the American grapevine leafhopper *Scaphoideus titanus* has been observed to shift northwards during the last decades (Boudon and Maixner 2007). Plurivoltin species such as the European grapevine moth *Lobesia botrana* could produce more generations per year (Gutierrez et al. 2018), creating potentially more damages on grapes. To help winegrowers, it is crucial to lead research at local scale, taking into account microclimatic specificities of the vineyards (Mozell and Thach 2014).

In this study, we examine temperature trends during the growing season in the region of Neuchatel and their potential impacts on major vine pest species. We focus on the American grapevine leafhopper and on the European grapevine moth. The American grapevine leafhopper is already established in the Lake Geneva area and could soon reach the Neuchatel area, while the European grapevine moth is already present in the Neuchatel vineyard. We use temperature data over the last 40 years (1980-2019) and two climatic scenarios to assess present suitability for pest development and the perspectives for the next decades.

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19. Tackling the Climate Crisis: Interdisciplinary Perspectives on Climate Change Education and Communication

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Swiss Association for Geographic Education (VGDch)

TALKS:

19.1 *Bättig-Frey P., Jäger M.U.*: Using impact orientation for effective climate communication

19.2 *Breitenmoser P., Keller-Schneider M.*: Why prospective elementary school teachers (don't) intend to teach Climate Change?

19.3 *Chatterjee S., Suess S., Sobecka K., Allen J., Brönnimann S.*: Visualizing climate science: the poster between science and politics

19.4 *Colberg C.*: Climate Scenarios for Switzerland CH2018 as a starting point for knowledge-based learning experiences in teacher training

19.5 *Cologna V., Kreissel A.L., Siegrist M.*: Techno-optimism as a moral hazard and its implications for climate-friendly behaviour

19.6 *Fritz L., Brenner-Fliesser M., Schneeberger A., Seebauer S.*: Youth and Behavioural Spillover: Fundamentals, Competencies and Learning Programme for Lowering the Personal Carbon Footprint

19.7 *Gubler M., Brügger A., Probst M., Eyer M.*: About the effectiveness of localized climate change education: Insights from an intervention study

19.8 *Mahl D., Hase V., Schäfer M.S., Keller T.*: A “societal turn” in climate change coverage? How the media portray climate change as a threat affecting all parts of society

19.9 *Perga M.-E., Reynard E., Swaton S., Clivaz C., Schaefli B.*: MOUNTAINCRAFT: Gaming the future of mountain environments to foster climate adaptation initiatives

19.10 *Van Eck C.W., Mulder B.C., Van der Linden S.*: Climate Change Risk Perceptions in the Climate Change Blogosphere

POSTER:

P 19.1 *Barathieu S., Clerc M., Heinzen S., Scherrer P., Varone S., Vouillamoz J., Vouillamoz N.*: PhilTheGap: Feel the Gap to Fill the Gap – Philosophy to Trigger Climate Action

19.1
Using impact orientation for effective climate communication

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Communication on climate change usually goes beyond the mere transfer of factual knowledge: sustainable climate communication motivates the audience to reflect their own lifestyle and to adapt it to make more climate-friendly choices in everyday life. The research group Sustainability Communication and Environmental Education presents a selection of four vivid project examples, which communicate knowledge more effectively, efficiently, and sustainably. Each presented project illustrates an innovative communication strategy to foster an engaged, informed, and long-lasting relationship to climate-related topics such as nutrition, CO_2-footprint, landscape, and soil.

The starting point of each project is a precise impact orientation, defining the key messages and recommendations for action. Based on the impact orientation, an analysis of the relevant target groups is conducted, before defining the means for communication. This method results in specific approaches for targeting different groups. The first example uses a scientainment approach. The 'Zombie Mission', a digital outdoor game, attempts to communicate facts about sustainable nutrition to a young adult target group that is not environmentally aware. The second example is an interactive exhibition which provides personalized tips for reducing the individual footprint based on a lifestyle analysis. The third project uses targeted storytelling and immersion to achieve long-term and reproducible storage of knowledge (Dahlstrom 2014) The educational panorama trail "Zwischenhalt Zukunft", is a multi-media interpretive environment (Paraizo 2011) where scientific visions of the future are brought to life with images overlaying the existing landscape and with audio installations. The last example is the narrative environment "Erdreich" (Bättig-Frey et al 2018). It operates with the same methodology as "Zwischenhalt Zukunft" but focuses on soil. By using this more tangible subject, information on climate change can be communicated without overwhelming – and putting off - visitors with the complexity of the politically charged debate around climate change.

All these projects are developed in an interdisciplinary team, where natural and social scientists, communication experts, artists, landscape architects and graphic designers work together during the whole project. The team creates outdoor spaces with interactive exhibits and garden elements, that invite visitors to immerse themselves in a landscape of visual impressions, sounds and stories. Instead of a purely factual information transfer, these "narrative environments" tell a story that convey scientific content in a playful, affective way. Facts and complex correlations become meaningful and tangible, and visitors create their individual relationship with the topics. Attractive settings and immersive experiences create positive emotions that make visitors more receptive (Friedman 2013). They absorb information and are more motivated to think about changes in their own lives. Using these tools thus can help improve the transfer of knowledge from scientists to the public, resulting in a more meaningful debate and ultimately help to establish new sustainable habits, leading to a more resilient society.

Figure 1 (left). Stairs leading down into the "Erdreich", Photo by Monica Ursina Jäger
Figure 2 (right). Images overlaying the existing landscape in "Zwischenhalt Zukunft", Photo by Monica Ursina Jäger

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19.2
Why prospective elementary school teachers (don't) intend to teach Climate Change?

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Climate change is a defining issue of our time. To achieve the global sustainability goals, a space-related responsible decision-making expertise is fundamental which is based on understanding environmental, economic, and social networks in space and time. It is thus the responsibility of schools to help pupils building up knowledge and basic expertise on climate change (Lüschen 2015). Pizmony-Levy & Pallas (2019) found in an online survey conducted in the year 2017 with 3117 adults, that 77% of the participants believe it is important for primary and secondary school students to learn about climate change. However, climate change education at primary schools in Switzerland is largely omitted even though pupils and student teachers likewise are interested in this topic (Adamina et al. 2018).

It is the aim of this pilot study, to investigate on the expertise and intentions of prospective primary school teachers to implement climate change at primary school level. It is of interest to find out which requirements subjectively perceived as challenges by the students require an intensive consideration during the training and to what extent context factors are important. To do so, different aspects of pedagogical-/ content knowledge on climate change, system competence, and other individual resources such as beliefs are examined. This study evaluates these aspects, explores how they change during an intervention and analyses how they influence the intention of the student teachers to teach climate change. To reach this goal, a mixed-methods approach is useddrawing on a pre-/post-intervention questionnaire (N=20) and interviews with student teachers (N=9) after completing an online-based intervention on climate change and system thinking in spring 2020. First results will be presented at the meeting.

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19.3
Visualizing climate science: the poster between science and politics

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The geosciences play a role outside of the natural, research sciences as agents responding to geopolitical crises like climate change and corporate and military interests that seek strategic advantage in planetary repair and control. The notion of the neutrality of science has increasingly eroded with researchers more frequently becoming embroiled in public deliberation and policy. Geoscientists are being asked to project the future of physical earth systems as well as evaluate the performance of policies (Beck and Mahony 2018) contributing to solutions and providing metrics for “climate services” (Daly and Dilling 2019). *How* the story of the earth, its climate and ecology, are told, is developed in specific ways, evoking different kinds of value and purpose for different communities.

Climate denial think tanks exploit the authority of science by intentionally using the languages and forms of scientific communication to sow confusion by presenting contradictory conclusions and arguing against climate action (Oreskes & Conway 2011). Pointing to colonial and extractive histories of geology and climate science, there are communities who urge scientific communities to acknowledge and counter the apolitical stance of neutrality. Scientists are more explicitly engaging on the representational, ethical and political dimensions of their science, pulling into question the dominant ideology of scientific neutrality which still structures much of its institutions’ protocols.

Research into the ways that discourse can change behaviour is central to the dilemma of the commons, and how the mobilization of nomenclature and information are best transferred to actionable knowledge (Nerlich 2010). In addition to language, the visualization of data, the distribution of images and iconography, and the rendering of time-based media (audio and video) all impact the ways in which we treat ecosystems and imagine their modulation and adjustment. There are even those who pronounce a “spectacle of nature” that has been created through the circulation of overabundant images of destroyed and protected ecologies (Igoe 2010).

Climatology & Climatography of Care, a project by University of Bern’s mLab + Critical Media Lab is interested in histories and futures of climatology and climatography, not only as scientific trajectories and disciplines, but as means of producing and *practicing* knowledge that are always and increasingly entrenched in economic, political and necessarily public debates. An objective of this project is a critical rethinking of data visualization and communication through the creation of a public poster campaign that references and questions the visual forms that both *scientific* and *political* posters take. The overall aim is to further investigate the future of climate change communication.

For the Swiss 18th Geosciences Meeting (2020), we will present a critical history and contemporary analysis of geosciences relevant communications, outlining how such visualization explicitly renders information as both scientific, public and therefore political. Showing examples of histories, stories and impacts of how both scientific and public campaign aesthetics are mobilized in contexts of scientific publication, conferences, public events and debate, we aim to articulate discussion as to the ways in which communications can of this kind can help to make explicit the goals and intentions of the geosciences *vis a vis* urgent topics like anthropogenic climate change, environmental racism, ecological justice, extractive industries. As an interdisciplinary group we hope to encourage discussion, questions, inconsistencies and unquestioned assumptions at the intersections of exchange within interdisciplinary communities, and with publics.

Image: Left: Lester Beall posters promoting the Rural Electrification Administration, U.S. Department of Agriculture (1930) Right: Alexandria Ocasio-Cortez's office's posters promoting the Green New Deal (2019).

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19.4
Climate Scenarios for Switzerland CH2018 as a starting point for knowledge-based learning experiences in teacher training

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The idea of this sympsium illustrates that interdisciplinary perspectives and approaches for Climate Change Education and Communication are needed to tackle the Climate Crisis. Scientists from the fields of climate change, education and communication as well as teachers need to communicate and cooperate.
The young generation organises itself independently of educational opportunities and makes its voice heard through the worldwide “Fridays for Future” movement. This can and should be explicitly taken up as an educational opportunity in the sense of participation.
Therefore student teachers and in service teachers need to be enabled to implement climate change issues effectively in their classrooms.
As a starting point the Climate Scenarios for Switzerland (NCCS, 2018) are used in different settings at the Teacher Training University of Thurgau (PHTG) as well as at the Swiss Federal Institute of Technology (ETH) in order to address three different target groups. The scenarios address scientific understanding of Climate Change and expected consequences for Switzerland on the basis of the four stories *dry summers, heavy precipitation, more hot day* and *snow-scarce winters* (NCCS, 2018). The scientific facts are well communicated, attractively presented and therefore aimed at a broad audience.
Three examples of its educational implementation are described below:

(1) Pedagocical content knowledge (PCK) course *Weather Observation and Climate Change (2 ECTS)* as a compulsory elective at PHTG for future primary school teachers:
As a warm up the students read the Climate Scenarios for Switzerland (NCCS, 2018) before the course starts. Additionally they focuss on one of the four characters/stories and do a content based in-depth preparation.
During the course different climate change education aspects like PCK findings and the serious implementation of Education for Sustainable Development (ESD) (e.g. CCESO, 2020) are being discussed. As an action orientated element a two day excursion to the Morteratsch Glacier in Engiadina in the Canton of Grisons is conducted as well.
As an outcome a comprehensive study unit for primary school students on the basis of the Climate Scenarios for Switzerland (NCCS, 2018) and taking into account general planning aspects (Colberg, 2019) is designed by the student group and published on an internal platform at PHTG.

(2) International project *Teaching and Learning for a Globalized and Sustainable World* for teacher students (13 ECTS), teachers and primary school students under the lead of PHTG for primary level.
The PHTG and the University of Hawaii (UHM) offer a joint specialization elective for teacher candidates in the field of ESD. This enables an ongoing intercultural dialogue and a multi-perspective approach to teaching and learning.
Mutual study visits are a central element of the project. Due to the actual global pandemic virtual exchanges have developed as the most important tool.
Local phenomena which have the same cause (climate change) but different effects are studied, exchanged and compared. The idea is to explore the two phenomena glaciers and coral reefs which are typical for the two regions and ecologically extremely important, to introduce them to each other, to compare and consider the implications for future teaching. The Climate Scenarios for Switzerland (NCCS, 2018) are the essential case study on the Swiss side. With a common (real or virtual) excursion to the alps the melting of the Swiss Glaciers is observed closely and compared to the bleeching of corals in Hawaii.
Therefore the students first learn facts about climate change and sustainable development. Afterwards they should be enabled to teach the topic in the context of ESD.
As an overall result enduring effects are observed for stakeholders of different levels of both education system, namely teacher trainers, teacher candidates, in-service teachers and school students. Their action competence is increased and thus the main goal of ESD achieved.

(3) Implementation of a scientific case study (*Climate and Weather Risks*) with a pedagogical focus in a *Mentored Assignment (2 ECTS)* as a compulsory elective at ETH Zurich within didactical certificate course for environmental scientists:
As a prerequisite the teacher students read the Climate Scenarios for Switzerland (NCCS, 2018). On the basis of an existing curricula a teaching sequence is developed and integrated into a semester plan either for a vocational training school (Berufsfachschule or Höhere Fachschule) or a higher education institution (e.g. Fachhochschule). As an outcome a

comprehensive study unit in the field of adult education on the basis of the Climate Scenarios for Switzerland (NCCS, 2018) is designed by the student group. This is published on an internal platform at ETH Zurich.

The Climate Scenarios for Switzerland (NCCS, 2018) are the main scientific content of all three examples and show the fruitful cooperation of scientists from the fields of climate change, education and communication.
In this context accompanying research projects which examine the options of teaching in general (qualitative) up to the point of effectiveness (quantitative) are reconsidered and planed to be developed. This will be discussed in detail during the symposium.

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19.5
Techno-optimism as a moral hazard and its implications for climate-friendly behaviour

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Narratives of “green technologies” as panaceas for mitigating global climate change are dominant in the media. Such narratives can advance and consolidate sociotechnical imaginaries and potentially create moral hazards, whereby increased optimism about green technologies reduces the perceived obligation to act climate-friendly. The impact of optimistic sociotechnical imaginaries on personal mitigation efforts has only recently begun to be studied and findings remain controversial. In this study, we develop a novel scale to measure attitudes towards technologies and analyse the effect of techno-optimism on both private and public climate-friendly behaviours. We further investigate the determinants of techno-optimism. With a survey of N = 552 Swiss respondents, we find that more techno-optimistic individuals engage in significantly fewer private climate-friendly behaviours, while we find no effect for public climate-friendly behaviours. Techno-optimism is significantly predicted by being male, less religious, less worried about climate change and by trusting stakeholders to effectively manage technologies. We thus confirm previous results that techno-optimism poses a moral hazard. Our findings indicate that optimistic narratives about green technologies can potentially have negative effects on the uptake of climate-friendly behaviours.

19.6
Youth and Behavioural Spillover: Fundamentals, Competencies and Learning Programme for Lowering the Personal Carbon Footprint

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Despite the fact that worldwide greenhouse gas emissions increased more than fifteen-fold in the last century (Ritchie & Roser 2017), the global assessment report on biodiversity and ecosystem services stated that nature still “can be conserved, restored and used sustainably […] through urgent and concentrated efforts fostering transformative change” (IPBES 2019). Therefore, academia and political decision makers should firmly go from observing and setting targets to initiating individual and collective climate action. But pro-environmental behaviours are not independent but interact, influence, trade off against and give rise to each other, which is called spillover.

Positive or negative spillover effects can occur within and between different consumption domains (Nilsson et al. 2017). Thus, consumers and learners need to acquire the awareness and skill sets to put cross-domain considerations into everyday practice in order to allow today’s society to still meet the 1.5°C (or 2°C) target. Accordingly, in SPILLOVER, an interdisciplinary research project funded by the Austrian Climate Research Programme 2019-2021), the main research questions are:

- What are scientifically acceptable conceptions of spillover effects, and of climate-friendly behaviours, which may significantly lower the individual carbon footprint?
- How has a learning programme to be designed in order to increase climate-relevant competencies among students?

By applying a learning programme which consists of three self-chosen, problem- and/or inquiry-based (Pascal & Stanszus 2019) learning modules, students are enabled to develop key competencies for realising climate-friendly behaviour. The learning modules target consumption choices in settings under the students’ decision and control, e.g. concerning sustainable fashion or mobility. It is assumed that positive spillover may stem from acquiring factual knowledge, practical skills and self-efficacy beliefs during engaging in a particular consumption activity, and then transferring these insights to other activities (Crompton & Thogersen 2009).

Given the fact that self-efficacy is a key component for pro-environmental engagement among young people (Corner et al. 2015), a critical constructivist learning setting is applied, which provides an autonomous learning environment (Ahmad et al. 2015). Furthermore, participation encourages young people to develop action-related knowledge about concrete options in climate protection and to reflect upon these options (Mochizuki & Bryan 2015). The urgent call for youth participation is underlined by the creation and implementation of so-called real-world projects which facilitate not only the vital significant behavioural change but also the development and integration of knowledge, ideas and perspectives (Rieckmann & Stoltenberg 2011).

At the conference, the learning programme will be presented in detail, and experiences and difficulties encountered will be discussed.

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19.7
About the effectiveness of localized climate change education: Insights from an intervention study

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Education about local, present, and perceptible impacts of anthropogenic climate change is often promoted as an effective strategy to increase students' willingness to act against global change (e.g. Monroe et al. 2017). Although the hereby intended reduction of perceived psychological distance to climate change and its effect on risk perceptions, concerns, and behavioural intentions have been intensively studied in social and environmental psychology (McDonald et al. 2015; Brügger 2020), the hypothesis of a closer perception of climate change risks leading to increased levels of concerns and even stronger willingness to do something about it lacks of empirical evidence from educational contexts.

Here, we report the findings of a recent educational intervention (pre-post-post-design) that evaluated the short- and long-term effects of proximising climate change on personal risk perceptions, worry about climate change, and intentions to act in a climate-friendly manner. We tested the hypothesis of localized education about climate change leading to increased levels of worry and motivation for climate action by using a sample of 630 high-school students aged between 14 – 18 years and originating from the city and surroundings of Bern, Switzerland. The two experimental groups were either thaught about climate change impacts on (urban) heat stress and human health within the city of Bern in record summer 2018, or within the city of Singapore by the end of the century. In order to get a more differentiated picture of the study's outcome, the currently on-going analysis of the data aims at revealing potential interaction effects of the intervention with socio-demographic variables, pre-knowledge about climate change, and value orientations.

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19.8
A "societal turn" in climate change coverage? How the media portray climate change as a threat affecting all parts of society

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Climate change is considered a global crisis affecting people across the world. Underlining the issue's imminence, studies indicate that the media discuss climate change not only in terms of scientific knowledge (e.g., Boykoff 2008; Kirilenko & Stepchenkova 2014), but that there might be what this study introduces as the concept of a "societal turn" in media coverage on climate change. This "societal turn" implies a shift characterized by (a) increased media attention towards climate change and (b) an increased focus on societal topics in coverage (e.g., problem awareness, climate politics, economic impacts, impacts on humans). However, content analyses of climate change coverage often neglect countries most affect by climate change, for example in Africa or Asia, and temporal patterns (Schäfer & Schlichting 2014). To analyze a potential "societal turn" in media coverage, we conducted a longitudinal, cross-national content analysis guided by two main research questions:

RQ1: How prevalent is climate change coverage compared to other news issues?
RQ2: Which topics contribute to a "societal turn" in media coverage on climate change?

Method.
The study analyzes coverage from 20 news outlets in ten countries (Australia, Canada, Germany, India, Namibia, New Zealand, South Africa, Thailand, UK, United States) over 13 years (2006-2018). Our manually validated sample of climate change coverage (F1 = .91) consists of N = 71,674 articles. We use a combination of manual and automated content analysis, primarily structural topic modeling estimating K = 85 topics. We use time as an independent variable and vulnerability to climate change according to the Climate Risk Index (Eckstein et al., 2020) as a control variable to estimate the prevalence of topics in coverage.

Results.
The analysis indicates that issue attention towards climate change varies strongly by national context: While focusing events such as the United Nations Climate Change Conferences (COPs) explain cross-national peaks in coverage, both the baseline of issue prevalence as well as changes over time differ by country. While issue attention rose in some countries (e.g., the UK), it decreased in others (e.g., Australia). According to RQ1, we thus replicate findings from previous studies arguing that issue attention is bound to focusing events, but also national contexts (Schmidt et al. 2013). Turning towards the content of coverage, the study finds seven overarching themes, including frequently analyzed themes in the news, such as "Climate Science" and "Climate Change & Environmental Impacts". However, news also discusses the societal impacts of and responses to climate change based on the themes "Awareness & Education", "Causes of and Solutions to Climate Change", "Climate Politics", "Economic Impact & Energy Industry" and "Impacts of Climate Change on Humans". Themes for example illuminate shared societal consciousness about climate change and report on events where one may get further educated ("Awareness & Education"). News also sheds light on human-made causes for and solutions to climate change, for example changes in eating habits or efficient energy use ("Causes of and Solutions to Climate Change"). As a more threating example, coverage underlines how climate change affects humankind, for example through diseases or water scarcity ("Impacts of Climate Change on Humans"). Societal themes did not increase over time. However, we find strong differences in themes' prevalence between countries (see Figure 1). According to RQ2, the study indicates support for a "societal turn" in climate change coverage. However, the prevalence of this societal perspective is less a product of temporal patterns but more a consequence of national contexts.

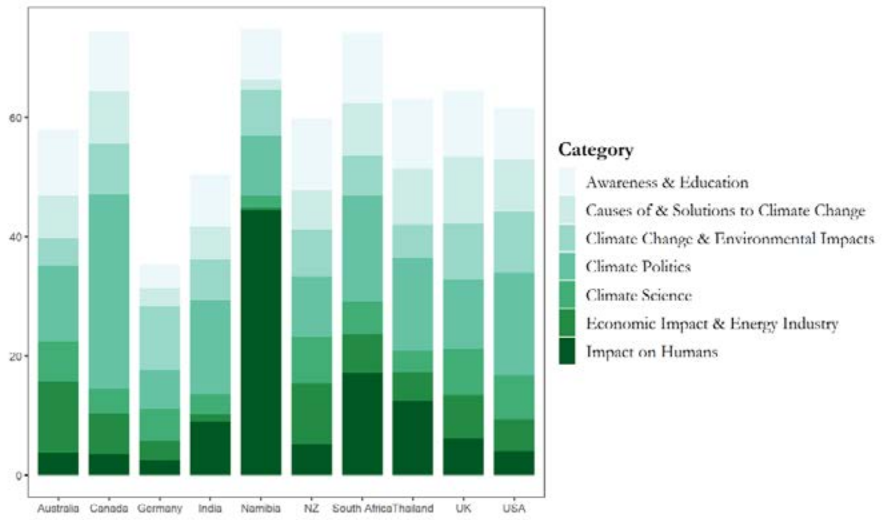

Figure 1. Changes in themes' prevalence between countries.

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19.9
MOUNTAINCRAFT: Gaming the future of mountain environments to foster climate adaptation initiatives

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Environmental consequences of climate change (CC) challenge the business-as-usual operations of many mountain-dependent sectors for an expected total cost over 1 billion CHF/year by 2050 for Switzerland. Undertaking actions and developing policies to minimize the adverse consequences and to make the most of the opportunities that arise from CC, i.e. adaptation, has been raised as a national concern. Yet, in Switzerland, as in most countries, implementations of adaptive strategies have been limited.

Engaging in effective adaptation poses a huge challenge for our mental models. Proactive adaptation involves decision making in a changing world with many intertwined ecological and societal stakes, with continuing uncertainties about the severity, magnitudes and manifestations of climate change. There are pressing calls to develop scientific approaches to foster the engagement of decision-makers in adaptation, and guide them within alternative policy and management options. Designing adaptation actions requires a holistic view of complex socio-ecological systems, which can be embraced through modelling. Yet, if models are at the core of adaptation science, their direct outcomes might be hardly palatable by and transferable to the stakeholders. Improvements of adaptation modelling would be of low impacts on adaptation initiative without the implementation of innovative communication means to make them available to the stakeholders' community. However, serious gaming, especially when supported by digital interfaces, is regarded as an emerging way to bring complex systems and models to a hands-on level.

MOUNTAINCRAFT's objective is to develop serious video-game grounded in scientific models to foster adaptation initiatives for Swiss mountain territories. The project considers that :

- (i) There is a wealth of data and predictive models on the different typical features of Swiss mountain environment that allows a landscape-wide social-ecological modelling, acting at time and space scales that are relevant for local management (valley scale, <30 years)
- (ii) Such a social-ecological model could be used for testing how different climate and social-economic adaptation scenarios will affect both the environmental and human futures at the local scale (watershed, commune).
- (iii) The digital interface of video games is a media by which those models could be exported out of academia, and handled by a larger public.
- (iv) If rooted in scientific modelling, digital interfaces can allow the gamer to make an empirical but realistic experience of potential futures, while fostering empowerment.

19.10
Climate Change Risk Perceptions of Audiences in the Climate Change Blogosphere

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The Climate Change Risk Perception Model (CCRPM, Van der Linden, 2015) has been used to characterize public risk perceptions; however, little is known about the model's explanatory power in (other) online contexts. In this study, we extend the model and investigate the risk perceptions of a unique audience: the polarized climate change blogosphere. In total, our model explained 84% of the variance in risk perceptions by integrating socio-demographic characteristics, cognitive factors, experiential processes, socio-cultural influences and an additional dimension: trust in scientists and blogs. Althrough trust and the scientific consensus are useful additions to the model, affect remains the most important predictor of climate change risk perceptions. Surprisingly, the relative importance of social norms and value orientations is minimal. Implications for risk and science communication are discussed.

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P 9.1
PhilTheGap: Feel the Gap to Fill the Gap – Philosophy to Trigger Climate Action

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97% of climate scientists agree about the basics of anthropogenic climate change (Cook et al. 2016). There is a general understanding that climate change will have dramatic consequences on our environment, which are in turn expected to contribute to major social problems such as resources conflicts, migration and health issues and political instability in the 21st century. At current emission rates, the remaining carbon budget for a global warming of 1.5-2°C ranges within one or two decades from now (CarbonBrief, 2018) and fossil fuels are consumed in such quantities that replacing oil, gas and coal with nuclear (i.e. the highest-density low-carbon known energy solution) would take some 42 years by building each day a 1 GW reactor (based on BP 2019)! On the renewable side, the largest solar farm ever built in the world spreads over 57 km^2 in the Rajasthan desert for a capacity of about 2.2 GW.

Hence, it appears that the currently proposed energy transition by most governments as the way towards carbon neutrality simply cannot be a substitution of the current fossil fuel-based system by a renewable-based one. What is required is a paradigm shift and democracy will be at risk in the transformation process! Moreover, the necessary behavioral changes towards sustainable lifestyle are occurring far too slowly in the population. This might be explained by the abstract nature of climate change which poses a significant challenge to human perceptual, cognitive and affective processing mechanisms (Brosch 2020).

New educational and pedagogical avenues are needed (Heinzen 2017). The practices of philosophy (PP) implement a pedagogy using co-inquiry focused on oral discussion. PP are recognized by UNESCO as contributing to strengthen democracy. PP provide tools to educate individuals in critical and autonomous thinking, to empower their own-opinion formation and to reinforce self-determination in a collaborative manner. As such, PP can be used to develop integrative 'transition' proposals based on a common shared argumentation, to trigger and motivate climate action and behavioral change at the individual and community levels.

We launch a consortium, PhilTheGap, aiming at (1) developing a database of scientific factsheets, addressing Swiss specific thematic at the energy-climate nexus that will provide (2) triggering resources for PP workshops, animated by PP trainers and supported by an interactive digital application (*abb - around the ballot box*, developed by ValAct Foundation) to monitor and handle discussions outputs; and (3) the conception of a serious game (role-playing game, RPG) implementing methodologies of PP in an attractive environment emphasizing contextualized effectiveness of selected 'transition' scenarios.

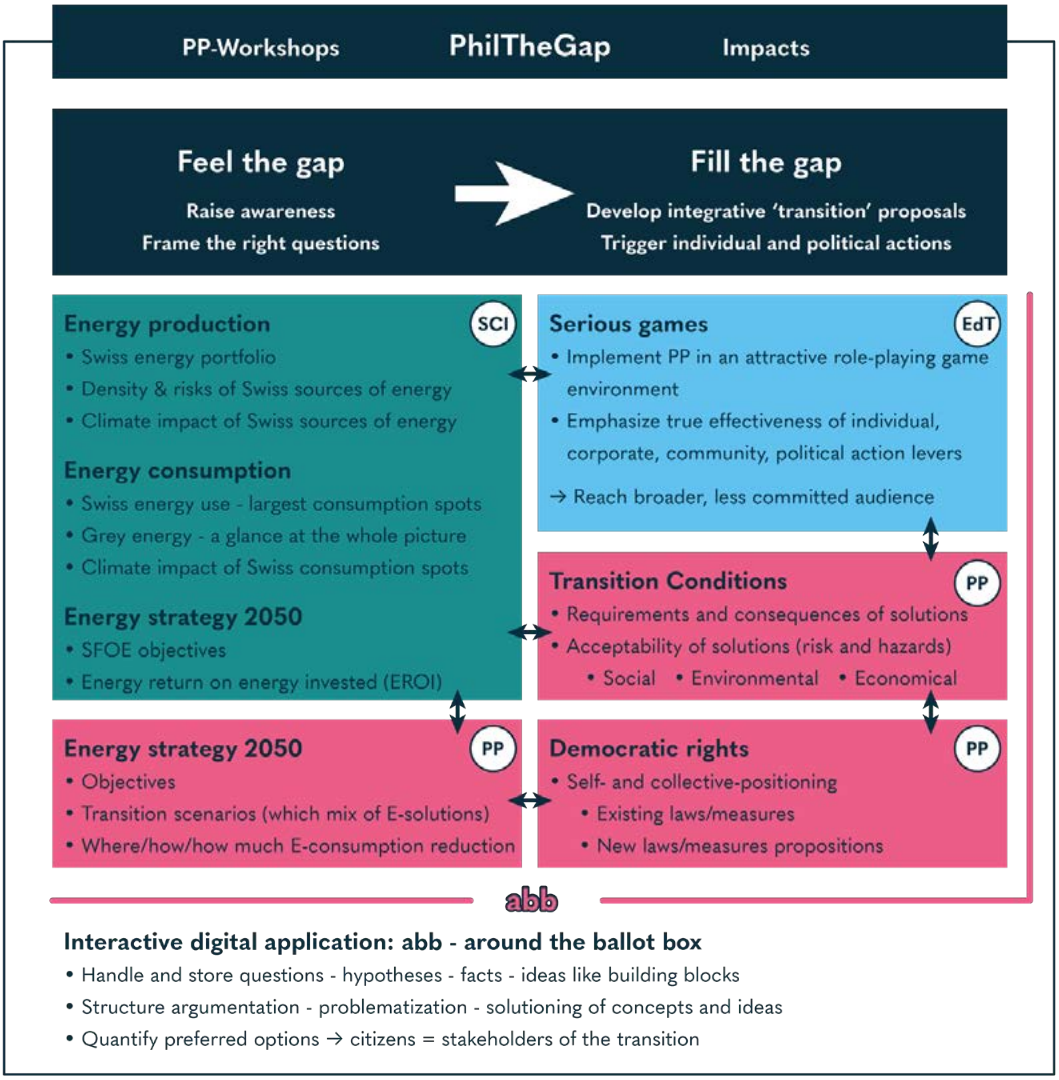

Figure 1. PhilTheGap avenues. SCI: Scientific resources; PP: Practices of Philosophy workshops; EdT: Educational Technologies.

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20. Remote Sensing of the Spheres

Stefan Wunderle, Mathias Kneubühler, Dominik Brunner, Alain Geiger

Swiss Commission for Remote Sensing,
Swiss Geodetic Commission

TALKS:

20.1 *Ahmed K.R., Paul-Limoges E., Rascher U., Damm A.*: Impact of the 2018 European drought on ecosystem evapotranspiration: A remote sensing perspective

20.2 *Augustin H., Sudmanns M., Tiede D., Weber H., Neuhaus C., Wunderle S., Hummer P., Reichel S., van der Meer L., Baraldi A.*: SemantiX: a cross-sensor semantic EO data cube to open and leverage AVHRR time-series and essential climate variables with scientists and the public

20.3 *Eruteya O.E., Niyazi Y., Omosanya K.O., Ierodiaconou D., Moscariello A.*: Morphology of rafted blocks in a buried landslide: A case study from the Exmouth Plateau, offshore NW Australia

20.4 *Frey O., Werner C.L., Manconi A., Coscione R.*: Measing surface displacements using a novel UAV/car-borne radar interferometer: including a case study on a fast-moving landslide in Brinzauls

20.5 *Gupana R., Odermatt D., Damm-Reiser A.*: Remote sensing of sun-induced fluorescence in inland and coastal waters: current state and future prospects

20.6 *Hadjipetrou S., Kyriakidis P., Mariethoz G.*: Geostatistical downscaling of offshore coarse spatial resolution wind speed data using satellite-derived wind information

20.7 *Hohensinn R., Rothacher M.*: How small can ground movements be in order to be detected with GNSS?

20.8 *Kellenberger B., Veen T., Folmer E., Tuia D.*: Efficient high-density bird colony censuses using drones and convolutional neural networks

20.9 *Manconi A., Caduff R., Strozzi T., Frey O., Werner C., Wegmuller U.*: Monitoring displacements of complex landslide scenarios with broadband multiplatform radar techniques

20.10 *Moeller G., Ao C.O.*: Atmospheric tomography – a valuable asset for future CubeSat missions

20.11 *Müller L., Chen K., Rothacher M.*: Refinement of CubeSat orbit determination using on-board velocity solutions

20.12 *Odermatt D., Runnalls J., Sturm J., Damm A.*: SenCast: Instant Copernicus satellite data and analysis

20.13 *Petibon F., Czyz E., Ghielmetti G.,* Hueni H., Kneubühler M., Schaepman M.E. , Schuman M.C.: Typical Uncertainties in Measurements of Leaf Optical Properties Still Permit Detection of Fine-Scale Biological Variation

20.14 *Sauvageat E., Hagen J., Kotiranta M., Hocke K., Gomez M., Neduloha G., Murk A.*: Comparison of three high resolution real-time spectrometers for microwave ozone profiling instruments

20.15 *Shehaj E., Moeller G., Geiger A., Frey O., Rothacher M.*: Mapping 3D tropospheric variables in an Alpine Region by collocation of tropospheric delays in spaceborne microwave signals

20.16 *Sturm J., Damm A.*: Drought-induced Impacts on Forest Health in Switzerland: A Remote Sensing Perspective

POSTERS:

P 20.1 *Prakash N., Manconi A., Loew S.*: Mapping Event Landslides from Satellite Images Using Convolutional Neural Networks

P 20.2 *Jing Xie*: Both urbanization and elevation constrict forest greening in the Pearl River Delta, China

20.1
Impact of the 2018 European drought on ecosystem evapotranspiration: A remote sensing perspective

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The combined drought and heat-wave affecting Europe in 2018 was one of the most extreme events in the last decades. Recent studies already assessed and confirmed the severity of this extreme event on ecosystems using greenness proxies with remote sensing data (Buras et al., 2020; Schuldt et al., 2020). Droughts and heat-waves compose a complex set of abiotic driver that determine ecosystem water fluxes, i.e., evapotranspiration (ET), by affecting plant water availability (e.g., soil moisture) and atmospheric water demand (e.g., vapor pressure deficit, relative humidity, air temperature) (Orth and Destouni, 2018; Sippel et al., 2018). Assessing ET, therefore, provides an additional strategy to evaluate the impact of droughts and heat-waves on ecosystem integrity via a complementary functional perspective. Besides, ET is considered an essential environmental process to determine the state of ecosystem functioning in response to extreme climate events (Bonan, 2008; Lawrence et al., 2007). Recent studies demonstrated, for example, the feasibility of ET to study the impact of droughts on ecosystem water deficit (Dang et al., 2019; Hanel et al., 2018; Orth and Destouni, 2018; Sippel et al., 2018; Teuling, 2018).

In this study, we aim to evaluate the effect of the combined drought and heat-wave in 2018 on ET across European ecosystems and to unravel causality to underlying abiotic drivers. We used the established and globally available 8-day ET composite obtained from the MODerate Resolution Imaging Spectroradiometer (MODIS) and investigated monthly ET anomalies in 2018 compared to a monthly reference period from 2007-2017. The MODIS ET product is based on the Penman-Monteith (PM) equation (Monteith, 1965; Penman, 1948, Mu et al., 2009), one of the most frequently used mechanistic frameworks to model ET across ecosystems. PM based ET estimates are particularly suited for our analysis since considering atmospheric and energy constraints and the biological control (e.g., canopy resistance) on ET fluxes (Allen, 2005; Langensiepen et al., 2009; Mu et al., 2011, 2007; Schymanski and Or, 2016). We additionally investigated three meteorological variables to understand causality ecosystem responses to extreme events, particularly subsurface soil moisture (NASA-USDA SMAP Global Soil Moisture Data (NASA GSFC, 2020)), total precipitation and air temperature (both from the European Centre for Medium-Range Weather Forecasts (ECMWF) (C3S, 2018)).

Our results revealed that ET in specific regions across Europe was reduced by up to 70% during the peak of the extreme event. Particularly agricultural areas (mean reduction of 15% to 20% from April to October) and non-irrigated arable land (mean reduction of 16% to 24% from April to October) in Northern Europe where affected, while forest ecosystems in Southern Europe were almost unaffected. We confronted calculated ET anomalies against anomalies of abiotic drivers (temperature, total precipitation, soil moisture) and found that particularly ecosystems with soil moisture and precipitation as dominant abiotic drivers showed the largest reductions in ET compared to ecosystems dominated by the air temperature. Our results give a first comprehensive insight into the 2018 European drought impact on ecosystem ET. Ideas on the interdependency between ecosystem functioning and driver dynamics will advance understanding of ecosystem responses and integrity and can become essential to improve ecosystem management for future environmental change.

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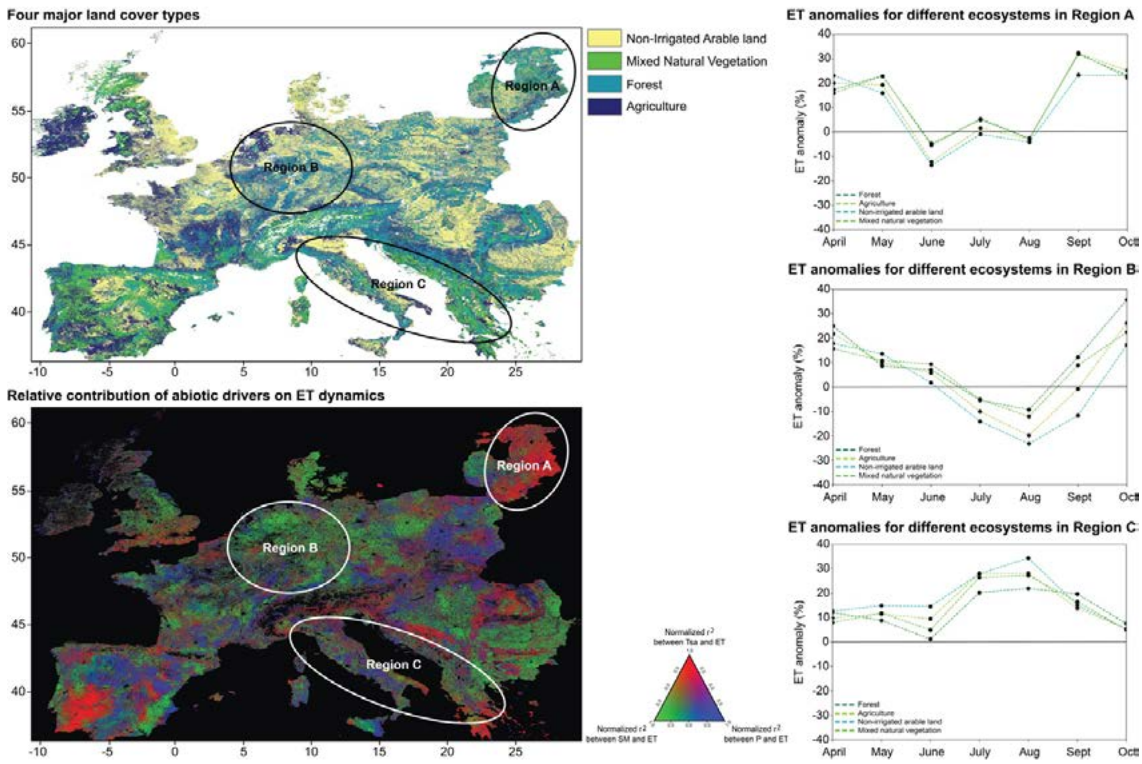

Figure 1. The graphical abstract of the study. The upper left image showing the four major land cover types. The lower left image showing the relative contribution of abiotic drivers (air temperature, precipitation, and subsurface soil moisture) on ET dynamics. The images on the right side showing the anomalies of ET for Region A, B, and C, accordingly.

20.2
SemantiX: a cross-sensor semantic EO data cube to open and leverage AVHRR time-series and essential climate variables with scientists and the public

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Long time series of essential climate variables (ECVs) derived from satellite data are key to climate research. ECVs comprise a representative set of physical, chemical, or biological variables or a group of linked variables that critically contribute to the characterisation of Earth's climate system's state, interactions and developments (Bojinski et al. 2014). They are a critical, independent source of information to compare with climate model results and can also be used to directly detect and monitor changes in our environment. One of the longest European time series (1981-now) of Advanced Very High Resolution Radiometer (AVHRR) imagery will be compiled and archived by the Remote Sensing Research Group at University of Bern. Until now, AVHRR imagery has only been accessible via sequential access, requiring a significant time investment and expert knowledge to find relevant data for analysis.
SemantiX is a new project to establish, complement and expand AVHRR time series using Copernicus Sentinel-3 A/B imagery and make them and derived ECVs accessible using a semantic Earth observation (EO) data cube. To the best of our knowledge, SemantiX will establish the first EO data cube based on semantically-enriched AVHRR imagery and has the potential to open the AVHRR archive and derived ECVs to a wider audience. Data cube technologies are a game changer for how EO imagery are stored and accessed, but more importantly in how they establish reproducible analytical environments for queries and information production and in how they can better represent multi-dimensional systems. A semantic EO data cube is a spatio-temporal data cube containing EO data, where for each observation at least one nominal (i.e., categorical) interpretation is available and can be queried in the same instance. (Augustin et al. 2019). Such a tool facilitates easier data access for scientists and, in this case, will join the backend of a smartphone application providing visualisation targeted to non-expert users. Offering analysis ready data (i.e., calibrated and orthorectified AVHRR data) in a data cube along with semantic enrichment reduces barriers to conducting spatial analysis through time based on user-defined AOIs and improves data access by enabling queries of image content instead of being limited to querying imagery based on when images were acquired and the area covered. The proposed data cube of AVHRR and Sentinel-3 imagery, and derived-information including selected ECVs (i.e., snow cover extent, lake surface water temperature, vegetation dynamics) will be linked to a mobile citizen science smartphone application. For the first time, various target groups will have a new, direct and interactive access point and simplified access to EO imagery and derived information, including ECVs. Scientists from disciplines unrelated to remote sensing, students (i.e., the next generation of scientists) as well as interested members of the public will have direct access to long EO data time series for a variety of applications and location-based access through the mobile citizen science application. SemantiX runs from August 2020-2022 funded by the Austrian Research Promotion Agency (FFG) under the Austrian Space Applications Programme (ASAP 16) (project # 878939) in collaboration with the Swiss Space Office (SSO).
This contribution presents a prototypical semantic EO data cube containing a short, temporal subset of AVHRR imagery (updated after Hüsler et al. 2011). The AVHRR time-series has been semantically-enriched using the Satellite Image Automatic Mapper (SIAM). SIAM applies a fully automated, spectral rule-based routine based on a physical-model to assign spectral profiles to colour names with known semantic associations; no user parameters are required, and the result is application-independent (Baraldi et al. 2010). Existing probabilistic cloud masks generated by the Remote Sensing Research Group (Musial et al. 2014) are also included in the semantic EO data cube as additional data-derived information to support spatio-temporal semantic queries. This prototypical implementation is a very first step towards the overall objective of combining climate-relevant AVHRR time series with Sentinel-3 imagery for the Austrian-Swiss alpine region, a European region that is currently experiencing serious changes due to climate change that will continue to create challenges well into the future.

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20.3
Morphology of rafted blocks in a buried landslide: A case study from the Exmouth Plateau, offshore NW Australia

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Submarine mass wasting plays a vital role in remobilizing substantial volumes of sediments basinward including massive slide blocks from the continental shelves and/or upper slope into deeper water. Landslides are notorious for damaging vital subsea infrastructure, triggering tsunamis and problematic during offshore drilling operations for hydrocarbon exploration. Yet, the understanding of the evolution of slide blocks and their associated deformations during downslope transportation remains limited, particularly in data-starved deep-water settings. In this study, we investigated the morphology of large blocks preserved in a buried landslide in the Exmouth Plateau, offshore NW Australia using a 2D and 3D seismic reflection data (Figure 1).

Analysis of the dataset revealed a buried landslide, termed MTC-BDF spanning ~75 km by ~35 km and containing at least 32 blocks (inside the 3D seismic coverage) surrounded by a well-deformed debrite background (Figure 1 and 2a and c). The evolution of this paleo-landslide is related to instability along the slope and flanks of an underlying Miocene submarine canyon (Figure 1). These blocks construed as rafted blocks have lengths ranging from 0.48 km to 3.40 km with thicknesses reaching up to 165 m (Figure 2a, c-g). Interestingly, these blocks are more abundant in a region characterized by moderate-high amplitude debrites (Figure 2c). Erosional morphologies encompassing a unique groove and other circular to irregular-shaped depressions mapped along the basal shear surface provide evidence for the erosive nature of the flow (Figure 2b). The origin of the groove is related to transported blocks gouging the basal shear surface. Importantly, intra block deformations are recorded within these blocks as fault and fold systems (Figure 2d-e). This suggest a complex flow regime within MTC-BDF, with the deformations arising either during block translation or also possibly upon the arrest of the failed mass in interaction with bathymetric elements. Our findings suggest inherent deformations within these blocks may serve as high-permeability conduits with implications for deep-water drilling operations within this segment of the Exmouth Plateau and elsewhere in other hydrocarbon-rich deep-water settings.

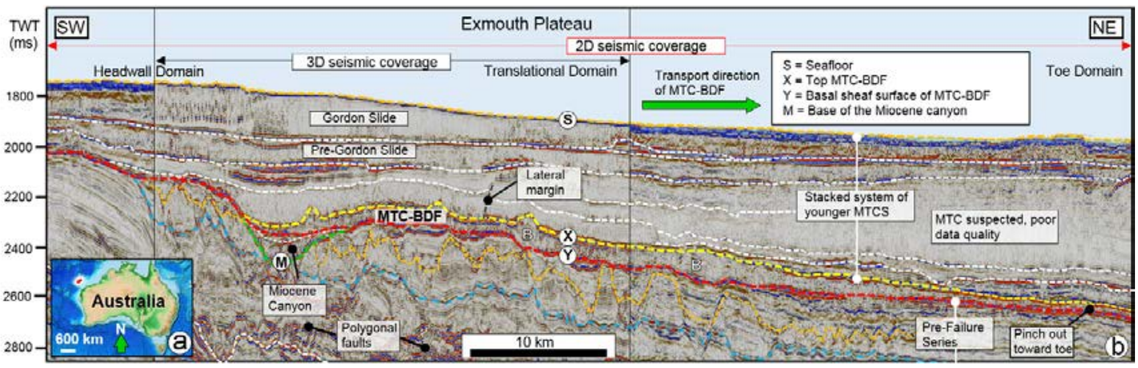

Figure 1. Study area. (a) Location map of the study area in context of offshore NW Australia. Study area is denoted by the red rectangle (b) Structure of the study area in the Exmouth Plateau. The interpreted seismic line shows the Neogene successions of Exmouth Plateau is characterized by the emplacement of stacked system of mass transport complexes from Miocene to recent. The focus of this study is the buried MTC-BDF bounded by Horizon X and Y. B denote slide block.

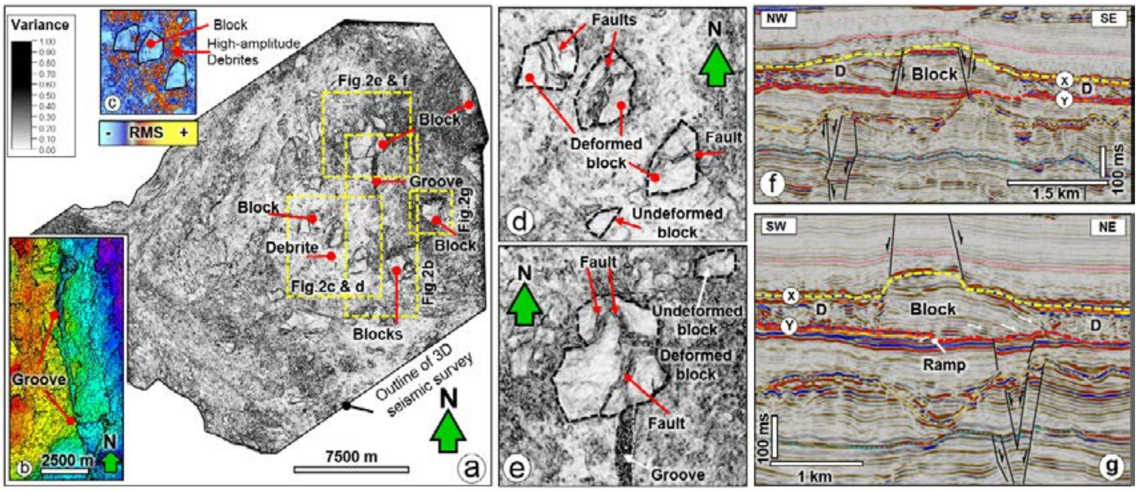

Figure 2. Internal architecture of MTC-BDF (a) Variance attribute slice generated from 3D seismic data flattened along the BSS (Horizon Y) at -2320 ms TWT. The blocks within MTC-BDF are well imaged within the debritic matrix background. (b) A unique erosional groove along the basal shear surface developed by tooling activities of block fragments (see figure 2a for location). (c) RMS attribute of parts of MTC-BDF showing blocks surrounded by high-amplitude debrites. (d-e) Enlarged deformed and undeformed blocks within MTC-BDF as shown in the variance slice (see figure 2a for location). Remnant of the groove is likewise visible (see figure 2b). (f-g) Rafted blocks in MTC-BDF. Seismic sections showing the internal configuration of MTC-BDF comprising of blocks and debrites. Some of these blocks show internal deformation characterized by faults and discordant relationships with the BSS where ramps are present. Location of seismic profiles is shown in figure 2a. In all figures D denote debrites within MTC-BDF.

20.4
Measing surface displacements using a novel UAV/car-borne radar interferometer: including a case study on a fast-moving landslide in Brinzauls

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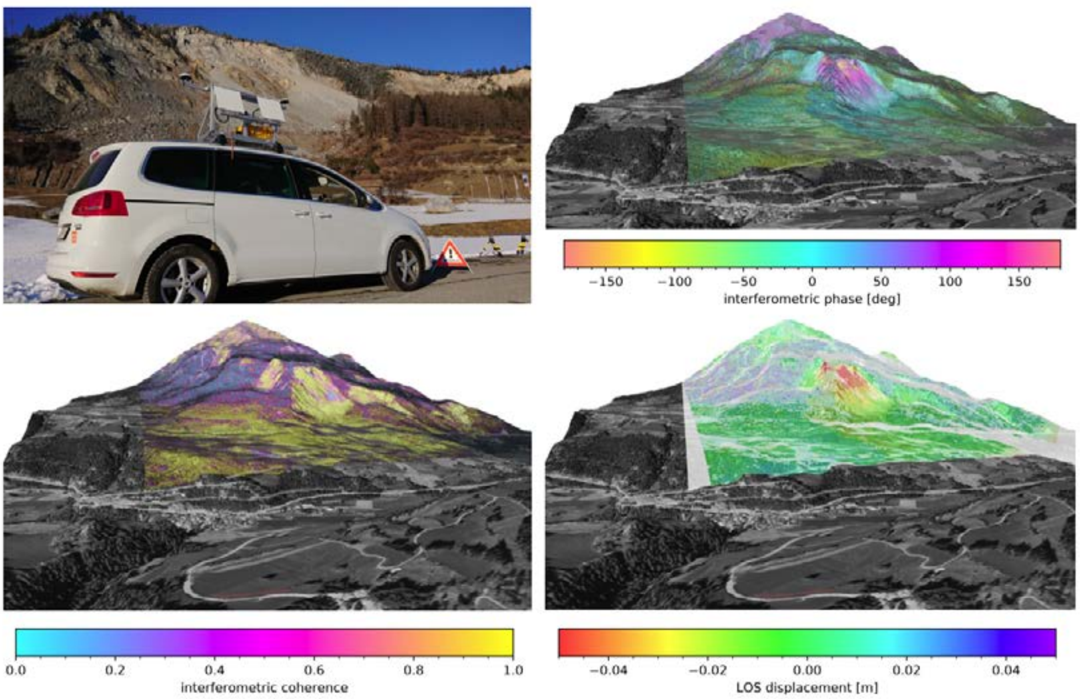
Synthetic aperture radar (SAR) interferometry based mobile mapping of ground surface displacements from moving sensor platforms such as cars and UAVs has been a rather unexplored field. In our contribution we address this topic comprehensively and, particularly, we demonstrate InSAR-based measurement of surface displacements with our newly developed car-borne and UAV-borne L-band SAR system at different test sites in Switzerland.

The reduced temporal decorrelation at L-band is an important advantage and a complementary property as compared to high-frequency (quasi-)stationary systems. While the sensitivity to line-of-sight displacements is lower, the longer wavelength permits to acquire longer interferometric time intervals also in natural terrain and even in adverse conditions (rain, snowfall), in which the decorrelation time at X- or Ku-band (the frequencies of many stationary terrestrial radar interferometers) can be in the order of minutes or less.

Terrestrial SAR data acquisitions from a car driving on a road or imaging from a UAV allow synthetic aperture lengths of 100m and longer, which means that high-resolution SAR imagery can also be obtained at lower frequencies such as L-band. In addition, view geometries (line-of-sight views to landslides) complementary to those available from spaceborne SAR systems can be selected. A flexible SAR imaging approach (time-domain back-projection) allows that even for curvilinear sensor trajectories (e.g. a car driving along a curved road) high-quality SAR images and repeat-pass interferograms with good spatial resolution are obtained.

We show based on a few test sites that such a mobile InSAR system fills a current gap in terms of available InSAR systems for displacement monitoring. A particular focus is laid on a case study carried out on a fast moving landslide in Brinzauls (GR), Switzerland, for which the entire processing approach/chain including mitigation of the tropospheric phase variations is discussed (see also Fig. on next page). We highlight the potential and discuss the challenges and the limitations of this novel InSAR-based mobile mapping system.



Top left: Car-borne SAR setup with the novel compact L-band FMCW SAR system at test site Brinzauls, Switzerland, where a fast-moving land slide was observed. 4-day repeat-pass interferogram (top right), coherence (lower left), and relative line-of-sight (LOS) displacement (lower right) after unwrapping, atmospheric phase detrending, and coherence & shadow masking (whitish blend). The track of the car-borne SAR acquisitions is indicated with a red line close to the view point.

20.5
Remote sensing of sun-induced fluorescence in inland and coastal waters: current state and future prospects

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Sun-induced fluorescence (SIF) emission can be used as a proxy for chlorophyll-a concentration and as indicator of phytoplankton physiological status. The traditionally used fluorescence line height algorithm to measure SIF shows various limitations to adequately account for the low magnitude and dynamic characteristic of this naturally occurring signal. Besides physiological factors, optical properties of the atmosphere and the water body, instrumental effects, and assumptions inherent to retrieval schemes complicate the retrieval and interpretation of SIF. Thus, the complexity of factors determining SIF occurrence and measurement causes SIF to be under-exploited, particularly in inland and coastal waters.

In this study, we address the need to examine the current state of SIF remote sensing in optically complex waters, where the gaps are and how future missions can advance this field of research. We review the theory behind SIF occurrence, available instrumentation to measure water leaving radiance, retrieval schemes to disentangle SIF from other non-SIF contribution to upwelling radiance, and how the subsequent results can be applied in lacustrine and coastal waters.

The Fluorescence Explorer (FLEX) is an upcoming satellite mission dedicated to measure terrestrial SIF globally. FLEX, currently under development by the European Space Agency, will fly in tandem with Sentinel-3 and is planned to be launched in 2023. This tandem mission offers a new generation of data which can advance SIF research in inland and coastal waters. We confront challenges identified in our review with the capacity of this new mission. We particularly evaluate possibilities to better constrain SIF retrievals and how FLEX data can improve interpretation of retrieved SIF. Moving forward, we can conduct further investigation on how to fine-tune SIF estimation knowing the characteristics of the FLEX payload. We can also assess how improved SIF emission estimates can advance applications in biomass estimation, phytoplankton taxonomic discrimination and primary productivity modelling.

20.6
Geostatistical downscaling of offshore coarse spatial resolution wind speed data using satellite-derived wind information

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Researchers from multiple disciplines rely on routine forecasts from Numerical Weather Prediction (NWP) models to conduct wind resource assessments for wind energy projects. These forecasts are often corrected on the basis of observations via data assimilation methods. The model output products, however, are usually provided at a coarse spatial resolution which in several cases affects the estimation and interpretation process regarding regional or local-scale natural phenomena. Indeed, detailed resource or impact assessment studies often call for higher spatial resolution data products. Remote sensing data e.g. Synthetic Aperture Radar (SAR) on the other hand are typically exploited to retrieve the spatial distribution of wind fields over the sea surface at a high spatial resolution. Sentinel-1A & 1B C-band SAR instruments, in particular, provide detailed information on the spatial variability of offshore wind. Despite the satellite's low repeat frequency, Sentinel-1 data are a valuable source of information for conducting offshore wind resource assessment as well as for the long-term validation of wind speed measurements from various sources.

Downscaling techniques can be performed on spatial and temporal aspects of climate projections in order to obtain higher resolution wind images that could be used for more detailed trend recognition and projection of future phenomena. The methodology of this work is based on a novel geostatistical approach for downscaling the Uncertainties in Ensembles of Regional Reanalyses (UERRA) data using Sentinel-1A & 1B SAR data in order to spatially enhance the coarse information of the former. More precisely, Ocean Wind Fields (OWI) geophysical component data from Sentinel-1 Level-2 Ocean (OCN) products are used primarily with a spatial resolution of 1km to refine the coarse wind information (11km) derived from the UERRA-HARMONIE 3-dimensional variational data assimilation system thus contributing in a more detailed offshore wind speed assessment for Cyprus. Sentinel-1 data have been validated against in-situ data from Cyprus' coastal meteorological stations.

The proposed methodology is showcased via the estimation of offshore wind speed values at a spatial resolution of 1km for the offshore area of Cyprus and at specific dates around the year. Results indicate that the geostatistically downscaled predictions can provide the basis for finely resolved offshore wind resource assessments. The methodology can also be further developed to predict the spatial distribution of wind speed values at a fine spatial resolution for time periods where Sentinel-1 data are not available. Lastly, unlike traditionally employed methods where the uncertainty is based on a per-pixel analysis, our method quantifies the uncertainty of the gridded estimates collectively.

20.7
How small can ground movements be in order to be detected with GNSS?

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High-precision GNSS (Global Navigation Satellite System) positioning can reach an accuracy down to the millimeter level, and typically ground motions down to tenths of millimeters per year can be resolved. This paper addresses the sensitivity of GNSS for the resolution of medium and long-term movements, as observed for plate motions, postglacial uplift, or the motions of rock glaciers, for example. For our analysis, the data comes from the GNSS stations of the EPN (European Permanent Network) – the GNSS station coordinates are obtained at a daily sampling rate, with almost 25 years of data available for some stations. Based on these time series data, we use a common mathematical model, that accounts for long-term station drift, annual- and semiannual variations, as well as for discontinuities (sudden jumps). Together with a statistical description of the GNSS observation noise we set up an a-priori adjustment model, based on which we are deriving the parameters of target, namely minimum detectable displacements for the long-term drift, the periodic seasonal variations and the discontinuities.
We see that the minimum detectable displacements depend strongly on the length of the time series and on the noise characteristics. Furthermore, an important quantity is the number of discontinuities that result, e.g., from GNSS equipment changes or earthquakes. For GNSS stations with good performance, the displacements that can be detected are at the level of few millimeters or even below.
We conclude that such an analysis can be useful for global change monitoring with GNSS, and it can be used to determine how long one has to observe in order to detect critical phenomena. Furthermore, the methodology can be applied not only in the field of GNSS but also to any other remote sensing technique.

20.8
Efficient high-density bird colony censuses using drones and convolutional neural networks

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[4] SkyPilot UAS

The West-African coastline offers suitable breeding conditions for colonial breeding bird species like the African Royal Tern (*Thalasseus maximus albididorsalis*), Caspian Tern (*Hydroprogne caspia*), Slender-billed gull (*Chroicocephalus genei*), and Gray-headed gull (*Chroicocephalus cirrocephalus*). To evade predation and disturbance they breed on sandy islands where they form large breeding colonies. However, the number of undisturbed breeding islands is limited and the four species thus highly sensitive to changes such coastal erosion and disturbance (Veen et al., 2019). Mapping and counting bird colonies is a vital necessity for conservation purposes. However, manual counting is a complex task, due to high population densities in the limitedly sized breeding spots.

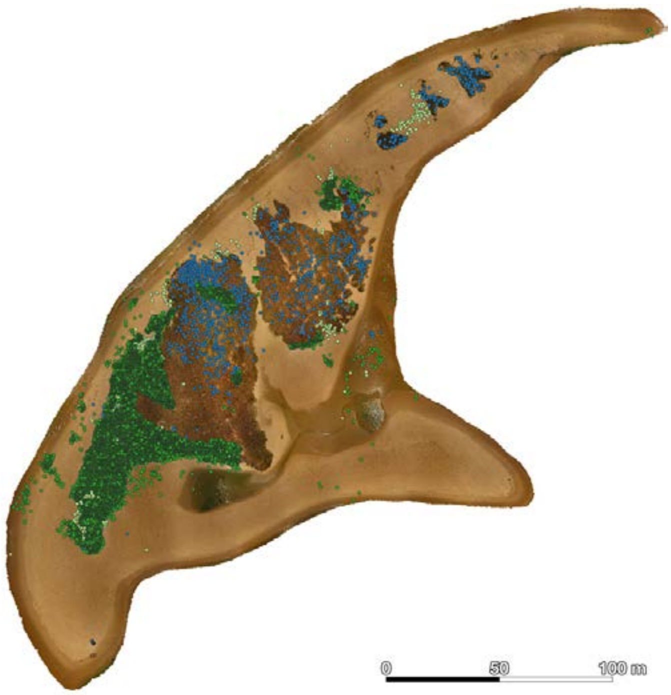

Figure 1: High-resolution test orthomosaic with 21›066 manually annotated bird individuals.

In this work, we aim at automatically identifying, classifying, and counting colonies of birds using drone imagery and Convolutional Neural Networks (CNNs; Zhu et al., 2017). In a first instance, we acquired six high-resolution (1cm) orthomosaics along the West African coast in May 2019, using a DJI Phantom 4 drone[1]. These were then labeled with point annotations and species information in a locally complete manner, *i.e.*, all individuals were annotated in small regions, but not necessarily across the entire images. We deliberately allowed incomplete annotations that did not include all individuals present in an image to facilitate the manual labeling task as much as possible. One orthomosaic was fully annotated and served for accuracy evaluation only (Figure 1). The open source software AIDE was used to create the annotations[2].
We then trained a CNN based on a ResNet-18 (He et al., 2015) that predicts a patch-wise grid of bird species probabilities as described in Kellenberger et al. (2018). A Markov Random Field was further employed to improve prediction quality in terms of spatial patterns (Li, 2012).

1 https://www.dji.com/ch/phantom-4
2 https://github.com/microsoft/aerial_wildlife_detection

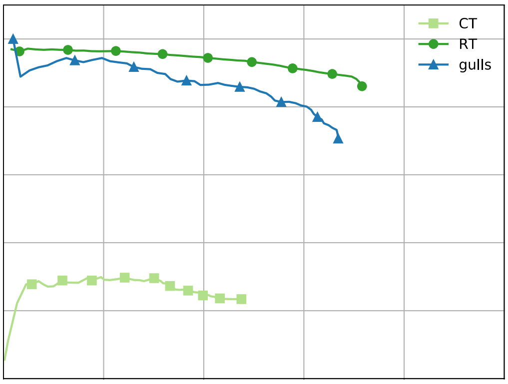

Figure 2: Our CNN detects birds with high precision and recall, but only requires 200 training points per species and three hours for training.

Our test orthomosaic contains 21’066 point annotations, which were created by five experts in three working hours spread across several weeks. In contrast, our CNN only required 200 point annotations per species and a low number of drawn background polygons for training and predicted 23’288 birds with a high precision and recall (Figure 2). In sum, our model reduces the required analysis time for bird censuses by orders of magnitude, and relieves operators from the tedious manual labeling of high-density bird colonies.

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20.9
Monitoring displacements of complex landslide scenarios with broadband multiplatform radar techniques

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The evolution of slope instabilities towards catastrophic failure events is accompanied by the progressive increase of ground displacements. For this reason, accurate data of surface deformation in space and time is important for the analysis and the interpretation of the associated hazard and risk potential. Remote sensing techniques have demonstrated to be a valid complement to standard in-situ monitoring. In particular, Differential Synthetic Aperture Radar Interferometry (DInSAR) from satellite-based imagery as well as from ground-based platforms allowed great advances in the identification and monitoring of surface deformation processes. However, the results obtained with currently available DInSAR methods might be hindered by insufficient spatial or temporal resolutions and/or due to intrinsic limitations of the methods used. For example, satellite based DInSAR provides great advantages to cover large areas, identify and map landslide displacements, and to monitor their spatial and temporal evolution in periods ranging from days to years. Despite, when the scenario evolves towards a potential failure, revisit times in the order of several days are not sufficient anymore. Phase aliasing, decorrelation, geometrical distortions, and layover/shadowing effects typical of satellite acquisitions may additionally hamper the possibility of accurate interpretations. On the other end, terrestrial based radar systems provide higher sensitivity to very small movements and are generally used when the landslide scenario requires continuous monitoring. These devices can obtain representative information over the area of interest, however, their spatial coverage is often limited and, since they exploit Ku- or X-band wavelengths, may suffer when large surface displacements occur. For this reason, comprehensive analyses of surface displacements should imply the use of multiple interferometric radar datasets. Here we present the results of an integrated investigation performed in Brienz/Brinzauls, GR, Switzerland. There, an area of 3 km2 is affected by a large and complex compound landslide with surface velocities locally exceeding values of 1 m/year. The scenario poses high concerns to the community, first for the village directly affected by extensive damage to the buildings (some of them already evacuated for safety), and more in general for the transportation network lines that would be affected in case of catastrophic failure. We selected analyzed SAR data acquired from: (i) satellite platforms, Sentinel-1 (C-Band) and ALOS-2 (L-Band); (ii) ground-based GAMMA Portable Radar Interferometer (GPRI, Ku-Band) from different locations; (iii) Car-borne SAR L-Band imagery, acquired from similar locations as the GPRI. We explore the results of interferometric analyses considering different observation periods and weather conditions.

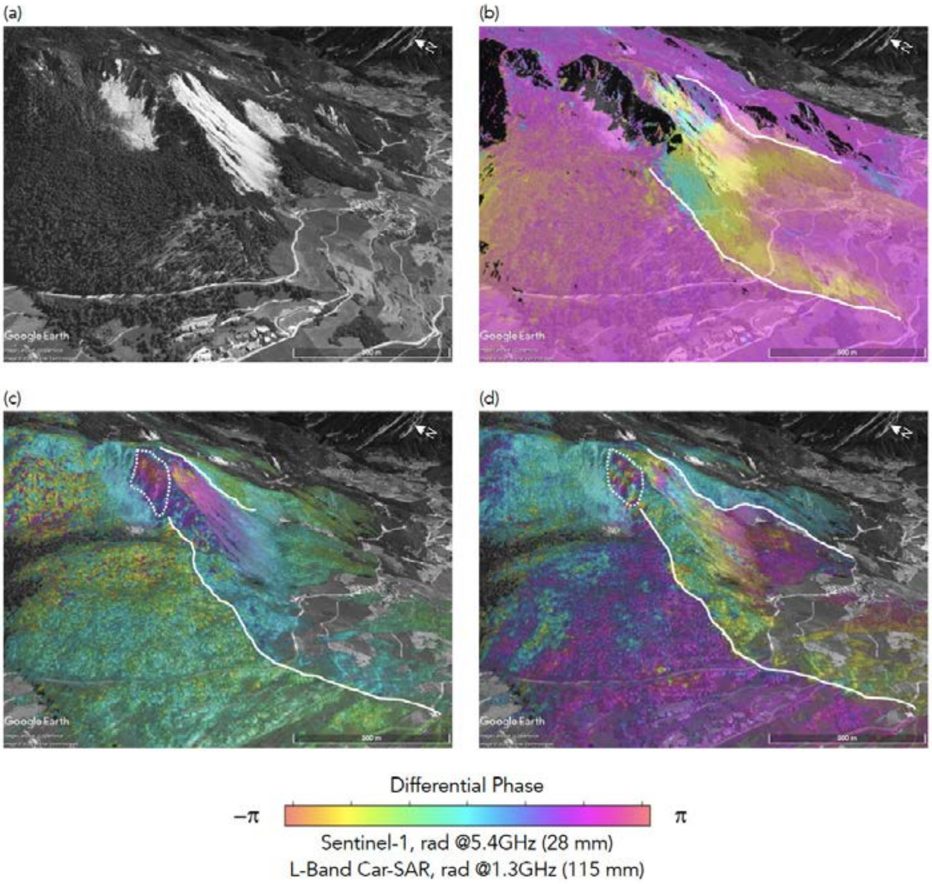

Figure 1. Comparison between the results obtained from car-borne and Satellite radar interferometry. (a) Background reference (Google Earth); (b) Sentinel-1 interferogram between January 08 and January 14, 2020, ascending orbit; (c) Car-borne interferogram between 20 and 24 January, 2020, both acquisitions in clear weather conditions; (d) Car-borne interferogram between 20 January and 3 February, 2020, with the second acquisition performed in rainfall conditions. Note that the area bounded with white dashed lines in (c) and (d) is not visible in (b) because of layover/shadowing effects due to the Sentinel-1 acquisition geometry.

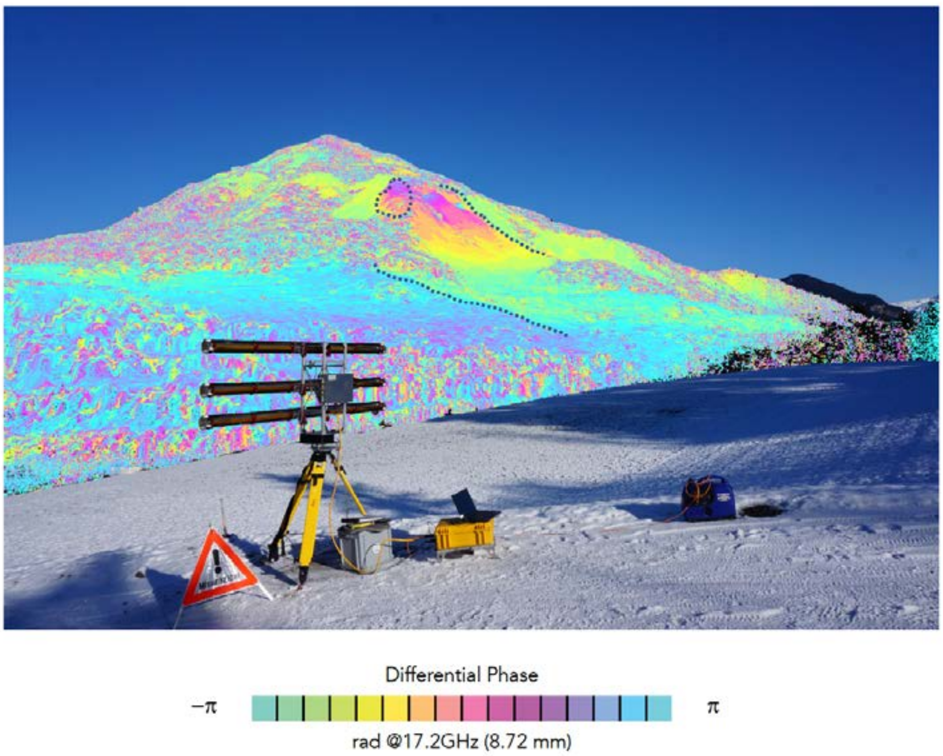

Figure 2. Results obtained with the GPRI system on January 22, 2020 between 10:46 and 18:19 overlain on a picture of the Brienz/Brinzauls slope. Black dashed lines mark the zones of phase gradients associated with areas having different displacement behavior. These areas match well with the results obtained with the space-borne and the car-borne interferometric results.

20.10
Atmospheric tomography – a valuable asset for future CubeSat missions

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Recent developments in small-satellite technology open up new possibilities for Earth observation. We expect that in the next decade large CubeSat constellations will arise with hundred, up to thousand satellites in low Earth orbit. While most constellations will be dedicated to internet of things and global communication, a larger number of satellites might be also equipped with rather low-cost sensors – suited for monitoring of the Earth's atmosphere. In this context, the GNSS radio occultation (RO) technique has been identified as a promising tool for remote sensing of the atmospheric state. For processing of the RO signals, a new analysis method has been developed, which is based on tomographic principles.

In this presentation, we will highlight the basic principles of the developed approach and will show a series of closed-loop validations to demonstrate the potential of tomographic techniques for analysis of dense CubeSat constellations. Applied to GNSS signal delays it will allow for a detailed reconstruction of the water vapour distribution inside and outside convective systems and therefore, will contribute to a better understanding of convective storms, heavy precipitation and related weather events.

20.11
Refinement of CubeSat orbit determination using on-board velocity solutions

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In December 2018 and April 2019, two 3-unit cube satellites of the company Astrocast were launched into space. Both satellites are equipped with our low-cost single-frequency multi-GNSS payload board, which can provide continuous on-board navigation solutions containing position, velocity and time. By fitting a dynamic orbit to these on-board solutions using the Bernese GNSS Software, we can evaluate the quality of the on-board solutions. Usually, only the receiver positions of the satellite are used to fit a dynamic orbit without considering the receiver velocity information that is also available. In this study, we develop and analyse an extension and refinement of the dynamic orbit determination by using not only the satellite positions but also the satellite velocities of the on-board solution in the orbit fit.

To study the use of velocity observations in the determination of a precise dynamic orbit, we consider three different approaches: fitting the equation of motion of the satellite orbit (1) to the positions only, (2) to the velocities only and (3) to both positions and velocities. For the combined orbit estimation with positions and velocities, we apply an appropriate relative weighting of the two observation types based on the RMS of the residuals from the orbit fits.

After removing a few outliers, the standard deviation of the position residuals from the position-only approach is about 5 m, the standard deviation of the velocity residuals from the velocity-only approach is about 15 cm/s. However, when looking at the positions computed from the velocity-only approach they deviate by much more than a few meters from the orbit obtained by the position-only fitting. These deviations show a periodicity of one revolution with an amplitude of up to 60 m. In the differences between the velocity-only and position-only orbit fit we see an offset of about -0.01 m/s in the radial component of the velocities and an offset of about 15 m in the along-track component of the positions. Additionally, a periodicity of one revolution with an amplitude of 0.03 m/s to 0.05 m/s is detected in the differences of all velocity components.

These discrepancies between the different approaches indicate that considerable systematic effects must be present in the receiver solutions. Apart from the ionospheric refraction that leads to a radial position bias in the satellite orbit, we also expect systematic effects from the receiver tracking loops under the high dynamics and from the deficiencies in the modelling of the perturbing forces acting on the satellite. With a detailed analysis of the three approaches over a long time span, we quantify these inconsistencies and identify their causes.

20.12
SenCast: Instant Copernicus satellite data and analysis

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This contribution was recently published in Geomatik Schweiz as: 'SenCast: Copernicus Satellitendaten auf Knopfdruck' [in German].

The Sentinel satellites by the European Copernicus program have provided standardized data for environmental monitoring since 2014. For example, Sentinel-3 and Sentinel-2 acquire spatially and spectro-radiometrically detailed imagery with global coverage within one and five days, respectively. Access to this data is open and free of charge via conventional archives of the European Space Agency (ESA) and EUMETSAT, via five Data and Information Access Services (DIAS) commissioned by the European Union, or via third-party providers. The availability of these extensive datasets requires however dedicated tools and analysis strategies for automated and harmonized processing. Availability of such tailored tools is, still limited and their use is often complicated.

With the financial support of the Federal Office for the Environment, we developed the open source software package SenCast. SenCast is a versatile tool that can be used in all fields of environmental Earth observation (Odermatt et al., 2020; https://gitlab.com/eawag-rs/sencast). It is implemented in Python, and independent of operating systems. SenCast is entirely based on open source software and on processors from the Sentinel Application Platform (SNAP, https://step.esa.int), an open source toolbox from ESA. SenCast is developed to automatically process historical data, or new data as soon as they become available in archives (e.g. ESA, EUMETSAT, various DIAS).

In this study, we outline the functioning and structure of SenCast and we demonstrate its applicability for environmental research on aquatic and terrestrial ecosystems. Exemplarily, we show how SenCast enables assessments of primary production and summer calcite precipitation (Nouchi et al., 2019) using chlorophyll-a, Secchi depth and turbidity estimates from Sentinel-3 data. Another example relates to a recently reported forest damage due to extreme weather conditions in the summer of 2018 (Schuldt et al., 2020). We use SenCast to calculate proxies sensitive to dynamics in plant water content from Sentinel-2 data, and use these proxies to evaluate the severity and extent of damages across Switzerland. SenCast can be installed on desktop computers, DIAS platforms or other servers. It is configured using simple text-based parameter definitions, and it can be extended by users who have basic knowledge of Python and SNAP or XML. We also show how products generated with SenCast will be made accessible in a new information portal on the state of Swiss waters (https://www.datalakes-eawag.ch).

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20.13
Typical Uncertainties in Measurements of Leaf Optical Properties Still Permit Detection of Fine-Scale Biological Variation

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The measurement of leaf optical properties (LOP) supports continuous, time-resolved, and rapid characterization of an increasing amount of ecophysiological information from plant communities. Field spectrometers are widely used to calibrate measurements from airborne optical sensors (Hueni, 2017) or to directly monitor biological variation at the leaf level (Jacquemoud and Ustin, 2019). Coupled with a contact probe and a standardized light source, they allow LOP measurements to be taken independently of environmental conditions and with an expected high accuracy and repeatability. However, to our knowledge, neither standardized nor systematic characterizations exist for the measurement uncertainties associated with commonly used contact probes, i.e., leaf clips and integrating spheres.

In this study we investigate what level of uncertainty can be tolerated in LOP measurements while ensuring reliable information about biological phenomena of interest. We first identify and quantify the uncertainty of measurements from standard materials with different optical properties. We show that although our integrating sphere yields more repeatable measurements on materials with a high specular reflectance component, measurements tend to be more repeatable using our leaf clip on materials with a low specular component. In a series of experiments on the common European beech Fagus sylvatica, we quantify the amount of variation in LOP associated with biologically distinct groups, i.e., leaves sampled at different times of the season from one individual, or standardized leaves measured within a short time frame from different individuals in a set of monitored Swiss forest stands and in a French forest reserve. Spectral variance in LOP among sun-exposed and fully developed leaves of a single individual, approximated by the coefficient of variation, reaches up to 32% in the visible region, representing more than 90% of the observed coefficient of variation between individuals at corresponding wavelengths (Figure 1). Therefore, taking into account biological variation at smaller scales (i.e., individual) appears essential to be able to draw conclusions and confidence intervals at larger scales (i.e., population). We suggest measures towards a standardized protocol to allow rigorous quantification of biological differences via LOP.

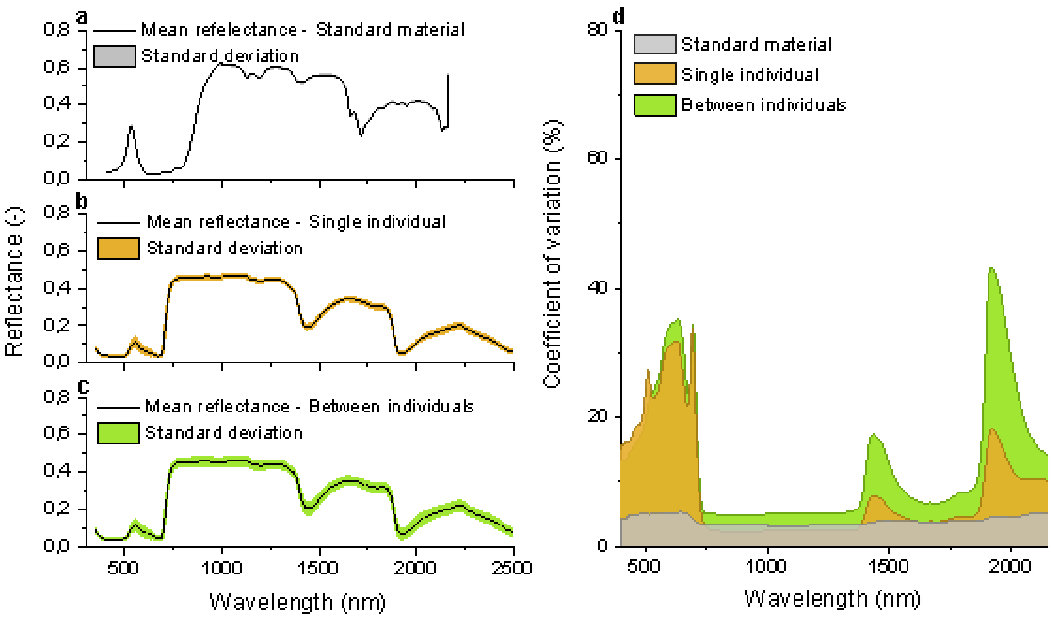

Figure 1. Mean reflectance and standard deviation of a standard material (a), sun-exposed and fully developed leaves of a single individual (b), as well as several individuals (c). The measurement uncertainty is estimated from the coefficient of variation of the standard material and compared to the coefficients of variation of different biological groups to estimate the biological variation (d).

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20.14
Comparison of three high resolution real-time spectrometers for microwave ozone profiling instruments

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Passive microwave ground based radiometry is a remote sensing tool used for the sounding of atmospheric temperatures and the profiling of trace gases such as ozone, water vapor or carbon monoxide. In the case of ozone, this technology provides continuous, all-weather observation capabilities in the middle atmosphere (~25-70km) and is important for estimating long-term trends and cross-validating satellites measurement in this scarce data altitude region.

Today, most atmospheric remote sensing radiometers are using high resolution real-time spectrometers as back-end. While the spectroscopic performance of such back-ends influences the retrieval of atmospheric profiles, their exact contributions are often unknown.

To investigate the performance of different spectrometers for ozone observations, we connect three state-of-the-art spectrometers to the same radiometer front-end for simultaneous operation. We use a single sideband heterodyne receiver with an uncooled low noise amplifier as radiometer front-end (Kotiranta et al., 2019) and the Acquiris AC240, Acquiris U5303 and Ettus USRP X310 as spectrometers (Murk & Kotiranta, 2019). With that instrument, we observe successively a hot and a cold calibration target as well as the atmospheric ozone emission line at 110.8 GHz.

Between January and June 2019, the Microwave Ozone Profiling Instrument (MOPI 5) operated continuously on the roof of the University of Bern (47 °N) in Switzerland and provided parallel observations from the three spectrometers covering a broad band of atmospheric conditions. This setup allows to characterize and compare the radiometric noise performance, channel response, binning artifacts and linearity of the different spectrometers over an extended period of time. We find that the calibrated spectra of the ozone emission line from the AC240 show a systematic bias leading to scaling errors of the observed emission lines. In particular, the spectrum has a systematically smaller line amplitude while its slope, caused by the strong line wing of the oxygen line at 118 GHz, has a different inclination compared to the spectra from the more recent spectrometers U5303 and USRP X310 (Figure 1.). To understand the origin of the observed behavior and characterize this systematic bias, we investigate the influence of these discrepancies to the ozone profile retrieval while taking into account different atmospheric conditions.

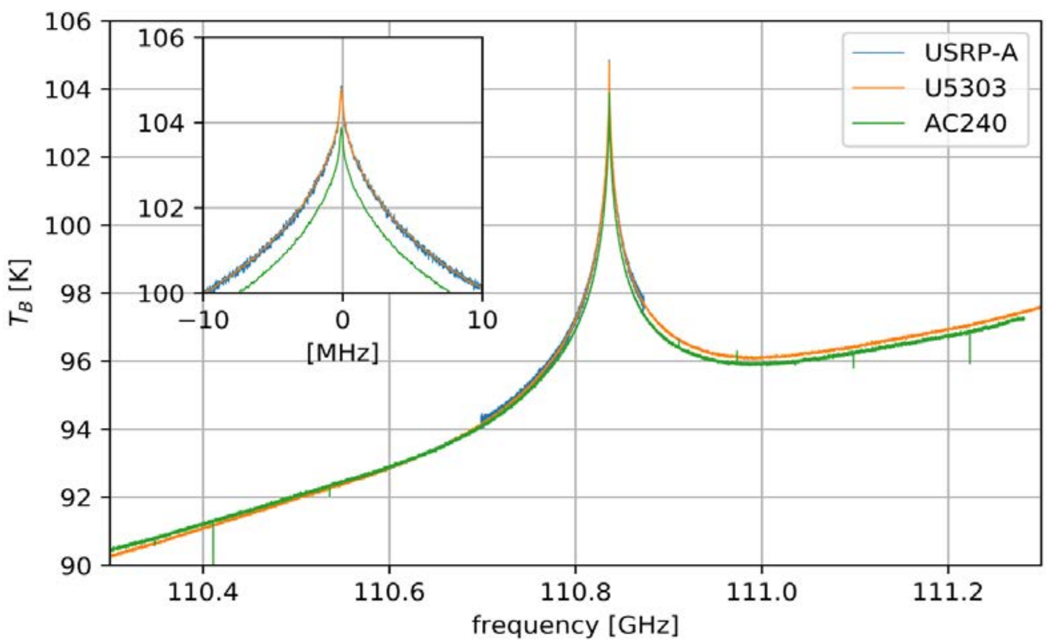

Figure 1. Comparison of a daily calibrated spectra recorded simultaneously on the 4th of January 2019 from the three different spectrometers of the MOPI 5 instrument.

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20.15 Mapping 3D tropospheric variables in an Alpine Region by collocation of tropospheric delays in spaceborne microwave Signals

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Microwave signals experience delays when traveling through the Earth's atmosphere as a function of the integrated refractivity along the path from the transmitter to the receiver. High spatio-temporal variations in the refractivity index in the troposphere are mainly caused by rapid 4D changes of atmospheric water vapor. These delays affect the output of space geodetic techniques such as Global Navigation Satellite Systems (GNSS) and spaceborne radar interferometry. Consequently, these delays need to be estimated during the processing of the observations, together with the other parametres of interest. Considered a noise in geodetic applications, these estimated delays contain additional information about the tropospheric state, thus tropospheric variables like GNSS Zenith Total Delays (ZTDs) are nowadays routinely assimilated in weather models together with other meteorological parameters. While tropospheric delays are integrated quantities, advanced mathematical methods, such as tomography, are applied to model 3D refractivity fields from tropospheric delays, which can be converted into 3D water vapor or temperature fields.

In this work, we use a collocation framework to model 3D tropospheric quantities. Collocation is an enhancement of traditional parameter estimation and adjustment theory; therefore, we separate the problem into a deterministic and stochastic part and estimate 3D refractivity fields. The used deterministic and stochastic models have been proven accurate in several test campaigns performed by the Institute of Geodesy and Photogrammetry of ETH Zürich.

For validation of the model performance, we focus on an alpine region in Valais, Switzerland, where a relatively dense GNSS network exists, as well as an interferometric time series of Synthetic Aperture Radar (SAR) images is available for several years. After showing the use-case and the available observations, we perform a comparison of our retrieved refractivity fields with a typical tomography approach with the aim to provide a quantitative and qualitative comparison. Furthermore, we investigate the impact of network densification and we display the collocated fields for another region (Upper Rhine Graben) with a very different topography. Finally, we convert our refractivity fields into water vapor and temperature 3D fields, which are Essential Climate Variables (ECVs) directly characterizing the Earth's climate.

20.16
Drought-induced Impacts on Forest Health in Switzerland: A Remote Sensing Perspective

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The ongoing warming of Earth's climate has been accompanied by an intensified frequency of extreme events, e.g. droughts, that heavily affect land-atmospheric feedback mechanisms and cycles (Miralles et al. 2019). In Switzerland, the summer of 2018 was the driest summer since 1962 and among the five warmest summers since measurements started (MeteoSchweiz 2019). This combination of low precipitation and high temperatures caused early leaf and needle discoloration, premature leaf-shedding, canopy die-back and tree mortality among many forests (Schuldt et al. 2020).
This study aims to assess the impact and causality of this exceptional event on health and damages in forests across Switzerland. We particularly applied the normalised difference water index (NDWI) (Gao 1996), a topography robust index sensitive for the liquid water content of vegetation canopies and respective changes. The NDWI was parameterized with the Sentinel-2 bands 8 (near infrared) and 11 (shortwave infrared) observed on August 2017, 2018, and 2019. We calculated the normalised difference between the NDWI images over the years to detect the locations and intensities of drought-induced forest changes.
Considering the biogeographic regions of Switzerland, the Jura featured the biggest proportion of negatively affected forest areas, whereas the Central Plateau was least affected (Figure 1). Drought-induced impacts mostly appeared as small isolated patches that as represented by a serious NDWI decrease.

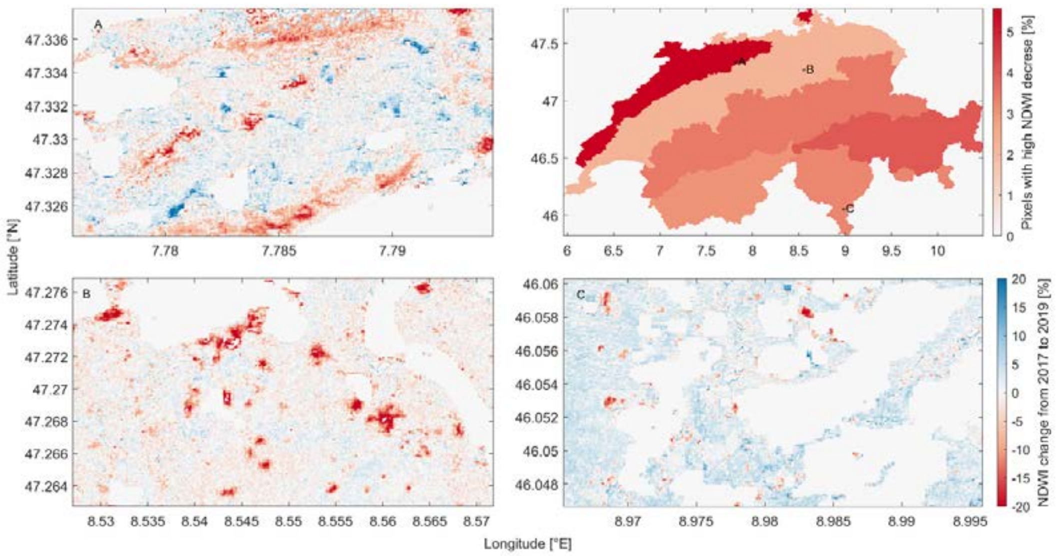

Figure 1. Choropleth map of the biogeographic regions of Switzerland coloured according to their proportion of heavily affected forest areas. Three sites reveal different patterns of change of NDWI values from 2017 to 2019.

A pixel-based analysis was conducted to gain further insight into the causality of forest damage by investigating various environmental parameters. We found a large effect of topographic variables representing the exposition and location of forest. Parts of forests located along ridges suffered more from drought-related damages than forest parts in sheltered locations. Additionally, the mixture and dominant tree species played a crucial role with coniferous trees being more affected than broadleaf trees.

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P 20.1
Mapping Event Landslides from Satellite Images Using Convolutional Neural Networks

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An earthquake or an extreme meteorological occurrence in mountainous regions can trigger hundreds of landslides. These event landslides can cause widespread destruction to infrastructure and human lives. Hence, an inventory of landslides triggered by such an event is required to plan a quick disaster response. These event landslides are mapped by identifying characteristic changes in surface features that are associated with ground movements. A pair of satellite images acquired before and after the trigger event is an ideal data source for mapping over large areas. Fully automated machine learning strategies have been studied in this context, as using manual effort is a slow and time-consuming process.

In this work, we develop a new convolutional neural network (CNN) method to map landslides from a pair of satellite images. A modified U-Net architecture was used for the semantic segmentation of EO data. We achieved F1 scores from 0.58 to 0.82 for experiments conducted on multiple earthquakes and metrological triggering events. Figure 1 shows one such mapping result from the 2018 Hokkaido earthquake in Japan. We also explore the option of combining the landslide inventories from multiple events for training. The CNN trained with combined inventories was observed to have better generalization ability, and this eliminates the need of training of a new model after every future events.

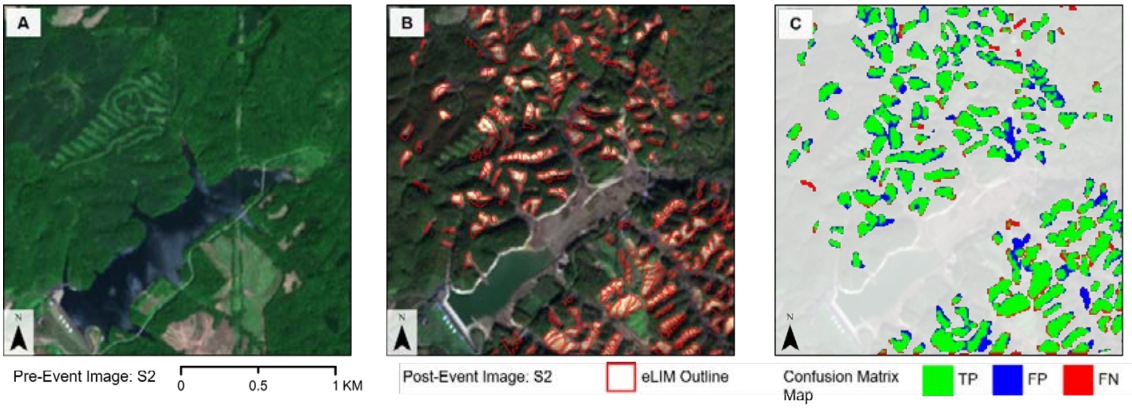

Figure 1. Mapping of landslides triggred by a earthquake in Hokkaido, Japan using the trained CNN. The images from left to right are: (A) pre-event Sentinel-2 image, (B) post-event Sentinel-2 image with landslides inventory from Wang et al. (2019) shown as red polygons, and (C) map of confusion matrix values generated from the output of the CNN. The output from the CNN is compared with the ground truth inventory to generate the confusion matrix map, which shows the true positive (TP), false positive (FP), and false negatives (FN) detections.

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P 20.2
Both urbanization and elevation constrict forest greening in the Pearl River Delta, China

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Environmental gradients of build-up areas in urban domains and suburban regions as well as of topography in rural and natural regions can affect and shape the behavior of forest growth in various ways. However, our understanding of the combined impacts of both urbanization and elevation on forest greening based on spatial variation of local climate zone (LCZ) is limited. A more in-depth investigation and evaluation hence is needed.

In this study, we tested the spatial variations and temporal changes of satellite-derived time-series greenness of forested regions, combined with LCZ and digital elevation model (DEM) in subtropical highly urbanized Pearl River Delta region for the period of 2000–2019. Average values and inter-annual trends were analyzed for time-series forest greenness in order to clarify the variation of these spatial and temporal values with distances to patterns from urban centers (LCZ 1: Compact and high-rise) between 0–55,250 meter and with elevation ranging from 0 to 1,556 meter above sea level.

It is found that the average value of peak greenness is lower in urban domains (< 2,000 meters from urban centers) than in suburban (between 2,000–5,000 meters from urban centers) and rural (> 5,000 meters from urban centers). The average value is also lower at high elevations than at low elevations in rural regions. Also, the forest peak greenness in urban domains shows a more slanted inter-annual increasing trend than in suburban and rural regions. Moreover, drastic volatility in inter-annual dynamics are more pronounced at forested areas adjoining compact and high-rise LCZ types than that adjoining open, mid- and lower-rise LCZ types. The effects of built-up LCZ types on forest greenness are stronger in strength and higher in magnitude than effects of elevation in urban and suburban regions. However, the situation is vice-versa in rural regions, with the effects of elevation on forest greening in rural regions are more pronounced than the built-up LCZ types.

We conclude that both urbanization and topography affect forest greening, and these effects are especially pronounced in urban domains and rural high-elevation zones. The results suggest that forest ecosystems adjoining urban centers (i.e. compact and high-rise built-up types) and high elevation above 1,000 meters above sea level are especially sensitive to the variation of environmental factors and projected climate change scenarios in the Pearl River Delta region.

21. Geoscience and Geoinformation – From data acquisition to modelling and visualisation

Nils Oesterling, Massimiliano Cannata, Michael Sinreich, Elmar Brockmann

Swiss Geological Survey
Swiss Geodetic Commission
Swiss Geophysical Commission
Swiss Hydrogeological Society

TALKS:

21.1 *Araya D., Kumi M., Podgorski J., Berg M.*: Exploring geographically weighted logistic regression to predict groundwater fluoride contamination in Ghana

21.2 *Cannata M., Antonovic M., Oesterling N., Brodhag S.*: Borehole Data Management System v1.0

21.3 *Iosifescu E.I., Hanimann D., Karger D.N., Plattner G.K., Haas-Artho D., Kurup Buchholz R., Espona L, Zimmermann N.E., Pellissier L., Hägeli M.*: Challenges for Integrating Web-EGIS Functionalities in the Environmental Research Data Portal EnviDat

21.4 *Oriani F., Mariethoz G.*: Missing data imputation for incomplete multisite time series: a data pattern-based approach

21.5 *Podgorski J., Berg M.*: Second-generation global risk map of groundwater arsenic contamination

POSTER:

P 21.1 *Zakeri F., Mariethoz G.*: Multiple-Point Geostatistical Simulation Models in Remote Sensing Applications

21.1
Exploring geographically weighted logistic regression to predict groundwater fluoride contamination in Ghana

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About 25% of Ghana's population lacks access to essential drinking water services, and 73% have no access to reliable and clean water sources (Safe Water Network 2017). The population, especially in rural areas, is dependent on groundwater for drinking. However, dental and skeletal fluorosis related to groundwater fluoride contamination is well documented across the north of the country (Figure 1), where the majority of the population lives in rural areas (Apambire et al. 1997). The World Health Organization (WHO) has set a maximum concentration guideline of 1.5 mg/L for drinking water. Different geological, topographical and climatic characteristics throughout Ghana are responsible for the distribution of fluoride contamination in groundwater.

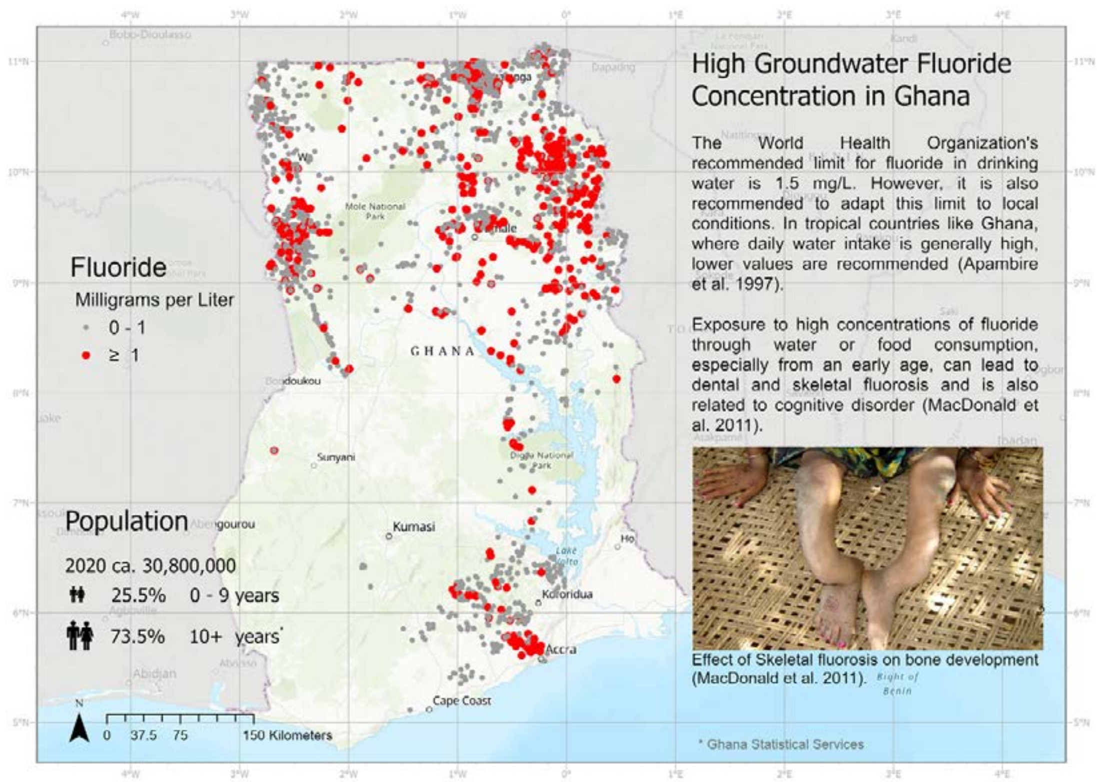

Figure 1. High concentration of fluoride in groundwater in Ghana, the red dots show a concentration greater than 1 mg/L.

Logistic regression (LR) has been used to study the relationship between geogenic groundwater contamination and various environmental variables. However, this type of modelling method applies a global approach to regression, i.e., it assumes that relationships between variables do not vary across space. Therefore, LR runs the risk of not addressing the heterogeneous and complex characteristics of aquifer environments.

The first law of geography states that closer things tend to be more related than things that are farther apart, thus recognizing spatial dependence and self-correlation. Geographically weighted regression (GWR) attributes weights to models according to location and distance (Brunsdon et al. 1996). It adapts the structure of the model over space to address the local statistical associations among environmental variables. Therefore, the closer a point is to an observation location, the higher the probability to be related to this observation. Hence, GWRs allow heterogeneity in spatial relationships to be addressed through local rather than global regression models.

The present study explores GWLR for probability modelling of groundwater fluoride contamination throughout Ghana. Data of 3150 groundwater wells were collected to map and model the occurrence of fluoride exceeding 1.0 and 1.5 mg/L. The GWLR and LR models were created using geospatial predictor variables of topography, geology, soil, hydrology, climate, and ecology. Preliminary model validation results indicate that GWLR performs better than LR. Fluoride hotspots were identified in the Upper East and Northern Region with over 95% confidence using Getis Ord Gi* statistic. Geological and soil variables were identified as positive predictors of groundwater fluoride contamination. The derived prediction map of groundwater fluoride contamination throughout Ghana highlights high-risk areas. This map could be used to rise awareness and understanding, and to inform actions of local scope in order to avoid or mitigate fluoride water contamination-related risks.

This study is part of the Groundwater Assessment Project GAP where other geospatial statistical methods such as multivariate logistic regression (Rodriǵuez-Lado et al. 2013) and machine learning (Podgorski and Berg 2020) have been used to assess and predict geogenic groundwater contamination.

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21.2
Borehole Data Management System: feature

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Most of the time boreholes data, particularly those collected in the past, are in the form of static data reports that describe the stratigraphy and the related characteristics; these data types are generally available as paper documents, or static files like .pdf of images (.ai). While very informative, these documents are not searchable, not interoperable nor easily reusable, since they require a non negligible time for data integration. Sometime, data are archived into database. This certainly improve the find-ability of the data and its accessibility but still do not address the interoperability requirement and therefore, combining data from different sources remain a problematic task. To enable FAIR borehole data and facilitate the different entities (public or private) management Swisstopo (www.swisstopo.ch) has funded the development of a Web application named Borehole Data Management System (BDMS) [1] that adopt the borehole data model () [2] implemented by the Swiss Geological Survey. From the first beta release (2019) several improvements to the platform has been implemented leading to the first official release of the platform (v1.0) officially available on www.swissforages.ch. The latest released features includes:

- Borehole document storage
- Interface customization
- Improved access & authorization managemnt
- External WMS/WMTS background map support
- Added user feedbacks form
- Handling of personalized and versioned terms of service
- Enhanced bulk data import
- Minor enhancements and bug fixes

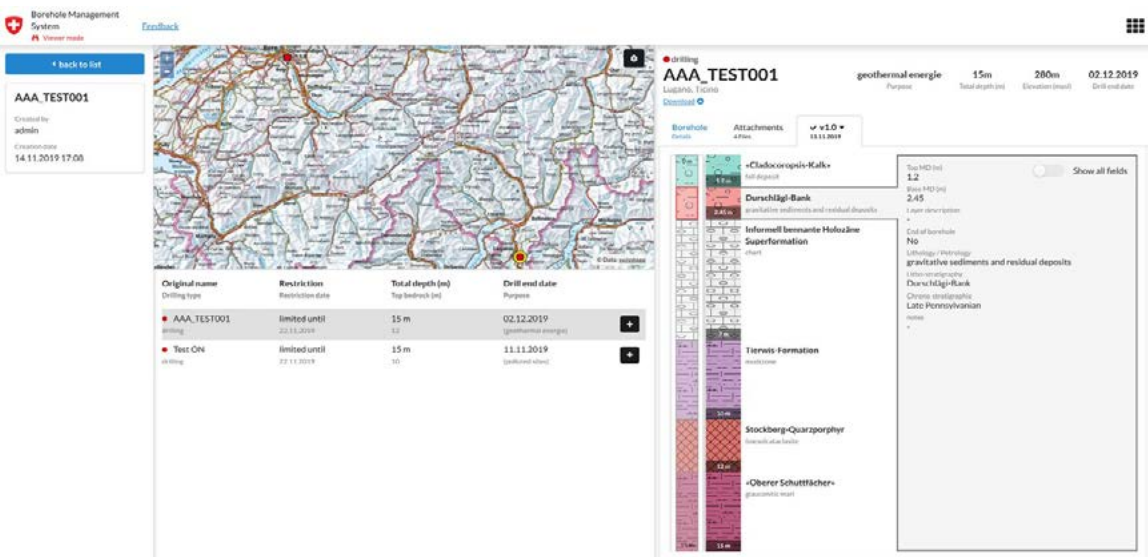

Figure 1. Screenshoot of Web interface of the swissforages platform with a test data input.

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21.3
Challenges for Integrating Web-EGIS Functionalities in the Environmental Research Data Portal EnviDat

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EnviDat is the environmental data portal of the Swiss Federal Research Institute WSL covering datasets from forest, landscape, biodiversity, natural hazards, and snow and ice research. EnviDat offers a wide range of services that support Research Data Management (RDM) and Open Science. For example, EnviDat actively implements the FAIR (Findability, Accessibility, Interoperability and Reusability) principles by offering formal publication of research data with proper citation information and Document Object Identifiers (DOIs) [Iosifescu et al. 2018, 2019].

Recently EnviDat evolved beyond the set of core features expected from a research data management portal with a new, built-in repository. This evolution is driven by the diversity of researchers' requirements for a specialized environmental data portal. Examples include (i) immediate access to data collected by automatic measurements stations and (ii) environmental data visualization on charts and maps, with geoservices for large geodatasets. The latter is highly relevant for the topic "Geoscience and Geoinformation – From data acquisition to modelling and visualization".

The environmental research data published in EnviDat is georeferenced and thus inherently spatial. Consequently, there are several user requirements related to mapping and visualization of heterogeneous environmental data in vector and raster form directly in the publishing portal. In this context we first review the concept of a Web-based Environmental Geospatial Information Systems (Web-EGIS). A Web-EGIS is a special case of Web-GIS, which is designed to integrate the functionalities of geospatial information systems with "environmental geo-referenced data and services" based on a generic hypercube-based data organization and visualization [Iosifescu et al. 2015]. This concept can guide the extension of the existing EnviDat portal with geoportal components, such as the online mapping of geospatial data.

The mapping requirements also pose, however, several important challenges. First, a hypercube-based architecture cannot be applied directly because it requires a common geospatial database with a unified schema for all data sets. In EnviDat, the data deposited by researchers is heterogeneous in file formats which were produced with highly different schemata, workflows and software. Although geospatial databases and technologies such as PostgreSQL and PostGIS are already an integral part of EnviDat's architecture, harmonizing and inserting user-uploaded data into a single geospatial database is not possible at this time. Migrating the data into a common database would require both a significant amount of labor and a harmonized schema that allows to organize the data from various environmental research fields in a unified manner. Consequently, the hypercube-based concept needs to be simplified and adapted to the realities of an existing data repository.

Second, the envisioned mapping capabilities must be supported by an extensible Spatial Data Infrastructure (SDI). Implementing and managing an SDI requires substantial computing and storage resources that are significantly larger than what is available for running a research data management repository such as EnviDat. Beside dedicated servers for providing the necessary mapping and geoprocessing services, additional storage is needed for optimizing data for GIS display. According to our tests, the additional pyramids and multi-band raster GeoTIFFs increase the total data storage size from 1.3 to 2.5 times, despite using raster compression algorithms such as LZW or Packbits for the data files, and the JPEG lossy compression for the associated pyramids.

Third, some environmental data sets are quite large and can contain a complex directory structure. Relevant examples in this context are the "High resolution climate data for Europe" (https://www.envidat.ch/#/metadata/eur11) or the "Climatologies at high resolution for the Earth's land surface areas (CHELSA)" (https://www.envidat.ch/#/metadata/chelsa-climatologies). Terabytes of georeferenced raster data are produced by climate models, and their size is expected to increase in the petabytes range with a complex directory structure containing a large number of individual files. Obviously, raster time-series with up to 10'000 layers for a single data set pose quite a performance challenge: such vast number of layers can not be configured and served interactively by traditional SDI map services. Subsetting or clipping smaller spatial areas from a global dataset would also take a significant amount of time with standard geoprocessing services, which is no longer adequate for real-time interactions with many users. Moreover, well-known mapping frameworks are not adapted for providing user-friendly temporal navigation for a huge number of layers.

The above challenges were uncovered during an early proof-of-concept for the integration of selected Web-EGIS functionalities for raster data in EnviDat and shown in Figure 1. Nevertheless, this proof-of-concept demonstrates some of the possible features that could become part of EnviDat in the future, once these challenges are resolved. Some features are (i) automatic creation of the necessary geoservices based on a user-provided configuration file, (ii) automatic display of the data in the data-set map (as a 2D map or on a globe), (iii) temporal navigation for a large number of layers of a time series, (iv) split view and difference map for visually comparing layers at different times, and (v) querying and displaying point data on charts for the entire time series. The mock-up implementation of these features in the proof-of-concept allows us to precisely test and refine the generic user requirements, thus improving the estimates of the necessary implementation effort and overall costs. These estimates also help us taking better informed decisions about which features to keep or drop in any future prototype and release phases.

The many challenges mentioned above also represent opportunities for further improving the exchange of scientific information in the environmental domain. Geospatial technologies have the potential to become a central element for any specialized environmental data portal, triggering the convergence between publishing repositories and geoportals. Ultimately these new requirements demonstrate the increased expectations that institutions and researchers have towards the future capabilities of research data portals and repositories in the environmental domain. With EnviDat, we are ready to take up these challenges over the years to come.

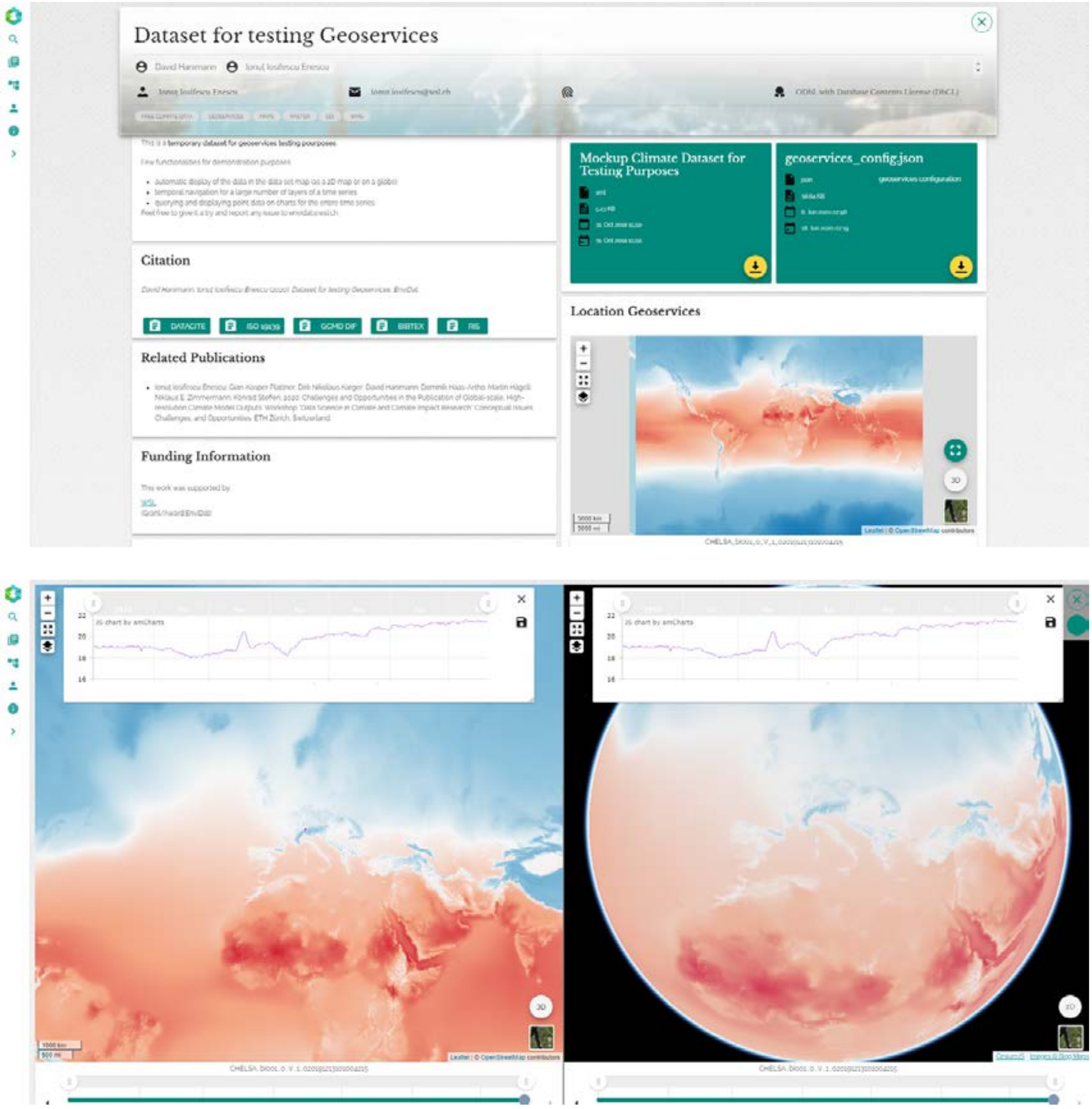

Figure 1. Proof-of-concept for integrating Web-EGIS functionalities in EnviDat

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21.4 Missing data imputation for incomplete multisite time series: a data pattern-based approach

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In the era of big data, missing data imputation (gap filling) remains a task of primary importance to obtain homogeneously informed and representative datasets for environmental studies, monitoring, and numerical modelling. We propose here a data reconstruction algorithm, called Vector Sampling (VS), for missing data imputation in multisite measurement networks.

Based on a multiple-point resampling scheme, VS first retrieves the pattern of data present for a given day from multiple stations. Then it looks for the *k* most similar patterns in the historical record from the same stations. Finally, it draws an estimate of the missing data by applying a weighted mean on the *k* historical data for the target stations. The process is repeated for all missing days to complete all the dataset. The VS algorithm presents three main advantages with respect to usual imputation approaches:

I) Unlike traditional *k*-nearest neighbor (*k*-nn) algorithms, it can handle incomplete training datasets robustly: this means it can use the available dataset as both historical (training) and target dataset. The user can simply input an incomplete dataset to obtain the complete version, with the estimations based on its own data patterns.

II) It does not require building statistical models, only having the parameter *k* which can be manually setup, taking typical values between 10 and 20.

III) Unlike most machine-learning techniques, it does not require computationally intensive training procedures, drawing on-the-fly estimations based on simple matrix operations.

VS has been applied to daily rainfall networks from Denmark, Australia, and Switzerland, and compared with inverse-distance, kriging, and *k*-nn interpolations [1]. On flat terrains, with spatially uniform rain events, kringing interpolation tends to minimize the error, while, in mountainous regions with non-stationary rainfall statistics, VS can better recover the complex rainfall patterns. VS turns out to be a convenient option for routine or automatic applications, which can be applied to continuous environmental variables with the only requirement of a representative historical dataset.

VS for Python3 is open-source and freely available at: https://bitbucket.org/orianif/vs/src/master/

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21.5
Second-generation global risk map of groundwater arsenic contamination

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Naturally occurring arsenic in groundwater affects millions of people around the world. Odorless and tasteless, arsenic can present significant hazards to human health in the concentrations frequently found in nature. Due to generally not being measured in groundwater quality analyses and the fact that its health effects can be similar to those stemming from other causes, its presence can go undetected for a long time. In order to assess the extent of this problem, we have used machine learning to create an up-to-date global prediction map of groundwater arsenic concentrations exceeding the WHO drinking water guideline of 10 µg/L.

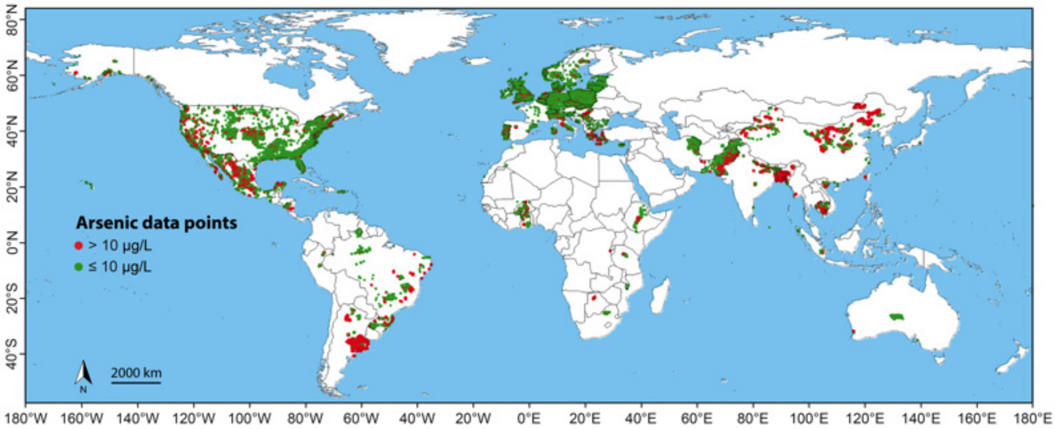

Figure 1. Arsenic concentration measurements excluding those known to originate from a depth greater than 100 m, averaged to 1-km square pixels (n=58,555).

Over 200,000 measurements of arsenic concentration in groundwater were compiled from a wide variety of sources while excluding measurements known to have originated from a depth greater than 100 m. These were aggregated into 58,555 data points by taking the geometric mean of concentrations falling within 1-km square pixels (Fig. 1), which corresponds to the resolution of the predictor variables used. A collection of 52 spatially continuous predictor variables with global coverage representing various climatic, geologic, soil and other parameters related to the dissolution and accumulation of arsenic in groundwater was assembled. Recursive feature elimination was employed to identify a subset of 11 variables, which were then used in a random forest model grown with 10,001 trees.

The model was then validated against a test dataset. Despite a prevalence of high values (>10 µg/L) of only 0.22 in the data, the model performs well in predicting both high values (sensitivity: 0.79) and low values (specificity: 0.85) at a probability cutoff of 0.50. Likewise, the model's Area Under the Curve (AUC), which considers the full range of possible cutoffs and generally ranges from 0 to 1, has the very high value of 0.89 with the test dataset

The resulting model predicts areas with high arsenic concentrations in groundwater on all continents. Known areas of groundwater arsenic contamination are identified as are new areas of potential geogenic arsenic contamination, including large sections of Central Asia, the Sahel region and Okavango Delta in Africa, and parts of the Arctic. Combining the global arsenic prediction model with household groundwater-usage statistics, we estimate that 94-220 million people are potentially exposed to high arsenic concentrations in groundwater. As groundwater is increasingly utilized to support a growing population and buffer against increasing water scarcity due to a changing climate, this model will help raise awareness, identify suitable areas for safe wells and guide where testing for arsenic should be prioritized.

P 21.1
Multiple-Point Geostatistical Simulation Models in Remote Sensing Applications

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Multiple-point geostatistical simulation (MPS) aims at generating realizations of a spatial phenomenon based on training images (TIs) while preserving complex patterns [1]. These methods have been increasingly used for analyzing remotely sensed data over the past few decades. This presentation will review some uses of MPS to remote sensing and summarize the main concepts. Common applications include downscaling, improving land use/land cover classifications, and gap-filling.

The resolution of satellite imagery is often insufficient in geoscience applications. The sub-pixel information is typically not uniquely determined, making a case for using geostatistical approaches to quantify uncertainty [2]. The most widely used MPS methods in downscaling are Direct Sampling (DS), Single Normal Equation Simulation (SNESIM), and Filter-based Simulation (FILTERSIM). For instance, DS, which is suited for both categorical and continuous variables, performs downscaling by sampling small-scale patterns based on a pair of high-resolution and low-resolution TIs that provides a correspondence between resolutions.

One of the main issues affecting classification accuracy is “salt-and-pepper” noise (i.e., isolated pixels) or spatially discontinuous appearance, which usually occurs in classification results. MPS models have been used to improve the accuracy of classification maps, often as a post-processing step. These methods usually incorporate the spatial and spectral information or apply the MPS to the obtained classified images directly to improve the accuracy of them.

Gap-free satellite data are often unavailable due to obstructions, such as clouds or clouds shadows [3]. MPS methods have been used to fill these gaps with realistic patterns. The general approach is to use a training image presenting a similar structure as the gaps to be filled, such as the same scene taken at a different date, or an image of another texturally similar area. Using multivariate MPS simulation allows the inclusion of covariates in the gap-filling process, such as elevation or land cover classes.

Our review shows that MPS approaches have a strong potential for applications that need to derive spatial information. However, more research is required to apply different MPS methods in new domains, such as detecting changes or information fusion. Moreover, future studies need to tailor the existing MPS algorithms to specific remote sensing applications.

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22. Human Geographies: Bodies, Cultures, Societies

Karine Duplan, Elisabeth Militz

Swiss Association for Geography (ASG)

TALKS:

22.1 *Adomako K.*: Backlash or reverb? What undoing binary understandings of ‘opposing movements’ tell us about heteroactivism in Ghana

22.2 *Boulila S.C.*: Sexual Politics in Post-Racial Europe

22.3 *Calderaro C.*: Feminism and street prostitution policies: comparing abolitionisms in France and the United Kingdom

22.4 *Duplan K.*: Geneva: A queer city?

22.5 *Hilbrandt H.*: Housing in the Margins: Urban Order and the State in Berlin’s Allotment Gardens

22.6 *Komposch N.*: Worker Cooperatives’ Potential to Transform Migrant Women’s Social Position and Agency: A Case Study in New York City

22.7 *Mayer H., Schwiter K., Vorbrugg A.*: Slow Scholarship, Better Science: Political horizons and practical steps to remake the university

22.8 *Militz E.*: Emotional geographies of virginal blood

22.9 *Mittmasser C., Stingl I.*: Migrant counterspaces: Challenging labour market exclusion through collective action

22.10 *Oechslen A.*: Shooting in the dark: Dealing with uncertainty in a digital work environment

22.11 *Steiner J.*: Contested Care: Organising and Negotiation Practices in Transnational Live-in Care Arrangements in Swiss Private Households

22.1
Backlash or reverb? What undoing binary understandings of ‘opposing movements’ can tell us about heteroactivism in Ghana

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In September 2019, the Ghanaian public caught wind of Ministry of Education guidelines on how to include comprehensive sexual education (CSE) in the national school curricula. This sparked a media firestorm. At the height of the controversy, political and religious leaders held that year’s Africa regional conference of the International Organization of the Family’s World Congress of Families in Accra, 31 October and 1 November 2019.

In light of these events, I wrote this piece to contribute to the growing literature on ‘heteroactivism,’ as new forms of ‘pro-family’ and ‘LGBT’ activism proliferate, shifting sociosexual landscapes across the globe. I study how Ghanaian political and religious elites use heteroactivism to shore up political capital, while tying post-colonial and anti-imperial nationalism to ‘compulsory heterosexuality’ (Gosine, 2009). The majority of work done on heteroactivism has concentrated on Australia, Canada, Ireland, the U.K. and the United States (Browne et al., 2018; Nash et al., 2019). Extending the focus to Ghana is an attempt to reveal how the call to substitute ‘homophobia’ with the new imperative of ‘inclusion’ is also observable in the heteroactivism seen in non-Western contexts, albeit shaped by national realities. As these shifting landscapes act as vectors for competing sexual politics, in this article I ask, *what are the roles of religious (inter)national organizations that promote ‘religious freedoms’ on the one end, and (inter)national NGOs that promote ‘sexual/LGBTI rights’ on the other, in shaping debates about changing norms?*

I offer up the notion of ‘reverb’ to draw attention to two sets of observable conundrums, as actors attempt to facilitate, resist and/or endure these rapid social changes: the first set is the apparent similarities between practices and political framings of both LGBT advocates and heteroactivists, who seek to achieve different political outcomes. The second are how seemingly diametrically opposed worlds can exist at the same time, and in close proximity: where in one milieu, actors vehemently present LGBT as a category which jeopardizes the country, and in another, actors curate safe and highly visible digital spaces that accommodate queer representations. My exploration of these themes is an attempt to move beyond common notions of ‘Africa’ as a ‘singular place’ (Williams, 2011) that is uniformly homophobic, while offering a more complex alternative to the binarity of the ‘opposing movements’ framing.

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22.2
Sexual Politics in Post-Racial Europe

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Postfeminist discourses surrounding sexuality operate significantly through race and the post-racial agenda. Women of colour take on particular roles in postfeminist sexual cultures. They serve as an embodied ‘prefeminist’ projection. For example, in male supremacist discourses, women in non-Western contexts are considered desirable for (allegedly) being in touch with their natural (hetero-)femininity, as they are deemed unaffected by feminism. Moreover, racialized women are represented as providers of passion and excess. This paper speaks to the way bodies play into intersectional dynamics of inequality and marginalization by including the analytical category of race in examinations of postfeminist sexual cultures. It will do so by arguing that the postfeminist script of female sexual freedom entails unexamined racial underpinnings. Through a discourse analysis of media representations from the UK, Italy and Switzerland, I will illustrate how racialized femininity is valued as a particular commodity in European postfeminist discourse. I will examine how through exoticization and hypersexualization of racialized femininity, women of colour become liminal figures that signal the limits of desirability. The aim of the paper is to demonstrate the value of supplementing the analytical category of postfeminism with the category of race when analyzing ‘sexualization’ in Europe.

22.3

Swiss Geoscience Meeting, Zurich
November 7th 2020

Charlène Calderaro, University of Lausanne
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Title:

Feminism and street prostitution policies: comparing neo-abolitionisms in France and the United Kingdom

Abstract:

Since the adoption of the so-called Nordic model in various Western countries, abolitionism has shifted its focus from the abolition of all forms of legal regulation of prostitution to the abolition of prostitution itself, considered as a harm done to all women. 'Neo-abolitionism' refers to this new form of abolitionism, which also involves feminists in the project of criminalising the clients of prostitution and not the seller, who is considered a victim. The relationship between feminists and prostitution abolitionism is not new; it has a long and variegated story with radical feminism. However, the recent renewal of public policies dealing with street prostitution in abolitionist contexts almost systematically involves institutional feminists. Prostitution policies have thus integrated the institutional feminist agenda in a lot of Western countries where gender equality public institutions have been established, often in contexts of a strong division between feminists on the issue of prostitution. Sex workers' rights activists strongly oppose these neo-abolitionist measures promoted by abolitionist feminists, who often are represented at the forefront of the institutional promotion of these policies. Hence, the institutionalisation of feminism and its forms seem to be at the heart of the questions raised by these neo-abolitionist reforms.
This communication will compare the different forms of abolitionism in France, where the 2016 law criminalising the clients of prostitutes was implemented, and in the United Kingdom, where two forms of abolitionism co-exist. Indeed, in Great-Britain (England, Wales and Scotland), prostitution is legal but related activities are crimes, whereas in Northern Ireland, paying for sex has become illegal since 2015, according to the Nordic end-demand model. Feminist abolitionist activists in Great-Britain claim for the application of the Nordic model throughout the country, taking the example of Sweden, France, or Northern-Ireland. The comparison of the French and British contexts allows for an analysis of the role of institutionalised women's and feminist agencies in the introduction and implementation of these neo-abolitionist reforms criminalising the clients of street sex workers. Indeed, the fieldwork results have shown that feminist public institutions have played a central role in the French adoption of the end-demand model enacted in 2016. The analysis draws on ongoing fieldwork in both contexts with institutional, associative and activist actors involved in these policies. It provides a comparative analysis of feminist public policies on street prostitution, that often resonates with urbanist projects of gentrification and 'genderfication' of the cities (Van den Berg, 2013).

22.4
Geneva – A queer city?

Karine Duplan – University of Geneva and University of Neuchâtel (CH)

While Geneva benefits from different public policies oriented towards LGBTQ+ rights along with a grounded activist milieu, one can ask to what extend this makes a city more inclusive towards LGBTQ+ people's and communities' needs and desires. Indeed, whereas most European/Western global cities have a designated gay neighbourhood, Geneva does not. Rather, LGBTQ+ venues are disseminated throughout the city, questioning the possibilities of queer space itself. Hence, in a context of critics towards pink washing neoliberal policies, the question remains on the ways in which the shapes of cities contribute to enhance intimate senses of belonging for LGBTQ+ people. This paper will offer preliminary reflections on the conceptualisation of queer spaces and queer cities applied to the Geneva case. Drawing on queer scholars who have pointed exclusionary effects of heteronormativity towards LGBTQ+ people and consequent marginalisation in terms of citizenship, this paper will complicate these ideas by questioning how sexuality takes part to senses of belonging and citizenship depending on the places within the city.

22.5
Housing in the Margins: Negotiating Urban Formalities in Berlin’s Allotment Gardens

Hanna Hilbrandt
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SwissGeoscience Meeting 2020

Critical shortages of affordable housing force people into housing precarity across the globe. Drawing from my forthcoming book, Housing in the Margins (Hilbrandt 2020), this presentation explores unruly housing practices and their regulation in the context of the German housing crisis. Through ethnographic research on the ways in which Berliners dwell in allotment gardens despite a law that prohibits housing at these sites, it illustrates how these gardeners negotiate the possibilities of residency with the local bureaucracy, gardening associations and amongst themselves. I pursue this project with empirical and theoretical objectives: studying empirically how people negotiate ways of staying put in allotment gardens and how boundaries around their dwelling practices are drawn, I aim at understanding the production and governance of housing precarity in a relatively rich European city. In theorizing these processes of governance, I seek to unveil the possibilities of conceptualizing informal housing in the context of bureaucracies that are commonly understood to regulate thoroughly, coherently, and according to fixed rules. This analysis highlights the contested terrain of enacting regulations and the exclusions that these negotiations entail. Building on postcolonial theory, anthropology of the state and critical legal geography, the presentation draws attention to the power of negotiations in the governance of urban space.

22.6
Worker cooperatives’ potential to transform migrant women’s social position and agency: a case study in New York City

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For many migrant women in New York City, structural discrimination and administrative hurdles complicate access to well-paid and safe labor. Worker cooperatives have been shown to reduce precariousness and economic exclusion of marginalized groups. However, while much is known about the worker cooperatives’ economic impact on workers’ lives, other social effects remain far less explored. The present research contributes to filling this gap by examining the change in the social position and agency of migrant women in their everyday lives after joining a worker cooperative. Combining an intersectional perspective with Bourdieu’s different forms of capital and the concept of self-empowerment, I analyze changes in everyday lives of migrant women who are members of nine different cleaning- or care-worker cooperatives in New York City. A participatory research approach gave access to data sources, including interviews, participant observations and a quantitative survey. The findings reveal that worker cooperatives have empowering effects on migrant women beyond the sphere of paid work. While the additional unpaid workload as co-owners of cooperatives represents an extra burden for many migrant women, they now have better wages, more flexibility and safer workplaces. Furthermore, they acquire different leadership skills, enlarge their social network beyond their ethnic communities and earn increased respect as co-owners of a business. Through worker-ownership, migrant women increase their economic, cultural, social and symbolic capital, which enables them to exercise more agency not only in their paid work life sphere, but also in their families and during leisure time.

22.7
Slow scholarship, better science: Political horizons and practical steps to remake the university

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The slow scholarship movement combines a general critique of current academic norms and institutions with concrete demands and practical suggestions to remake our universities. It emphasises reflexivity, positionality, intersectionality and care as part of our everyday practices in academia.
In the first part of this workshop, we briefly introduce the roots and principles of the slow scholarship movement, and the critique of the logic of competition, the precarisation of academic labour and mechanisms of exclusion it formulates. In the second part, we discuss strategies and initiatives towards slow scholarship (e.g. the Better Science Initiative) and invite participants to share their own experiences and suggestions in an open workshop format.

22.8
Emotional geographies of virginal blood

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Worldwide, a heteronormative understanding of femininity requires female bodies to perform virginity at one point in their lives (Abboud et al. 2015). In the cultural context of Kyrgyzstan, a compulsory performance of virginity is often tied to the heterosexual wedding night (Kim 2020) when many women meet the successful performance of the female virgin body, and thus bleeding body, with relief. The trauma of not bleeding, however, reveals the force of the emotional labour at stake in performing virginity and in dealing with one's sexuality in light of patriarchal ideas of a desirable and thus marriageable female body.

Drawing on ethnographic fieldwork on virginity and gendered and sexualized violence in Kyrgyzstan in 2017 and inspired by feminist geographic scholarship of the body (e.g. Longhurst 2001, Suyarkulova 2016, Tolia-Kelly 2010) and heteronormativity (e.g. Hubbard 2008), I unravel the emotional geographies of virginal blood. Ambivalent emotions of fear and pain and happiness and pride produce, accompany and normalize performances of virginity and illustrate the power of virginal blood to regulate female bodies mobility in and access to social spaces. Virginal blood, I argue, becomes a core element in normalizing a heteronormative cultural and social order in Kyrgyzstan.

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22.9

Migrant counterspaces – Challenging labour market exclusion through collective action

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Abstract

Recent debates within migration studies and labour geographies emphasise the need to acknowledge migrants' agency and its ability to challenge regulatory migration regimes and precarious work relations. Following this perspective, this paper examines how migrants in Switzerland create a collective "counterspace" in response to difficulties in accessing the labour market. Methodologically, the paper builds on qualitative ethnographic data from two research projects with a migrant organisation. Taking this organisation as an example, we analyse to what extent its members' collective strategies challenge labour market exclusions mobilized by the state, employers, and society at large. Furthermore, we explore ambivalences in the organization's strategies with regard to their immediate impact on migrants' professional lives and existing structural relations. Our findings highlight the important social and relational dimension of migrants' spatial agency.

Keywords: *Migration; Labour; Agency; Counterspaces; Switzerland*

22.10
Shooting in the dark – dealing with uncertainty in a digital work environment

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Graphic designers connecting to clients via online work platforms such as 99designs or Upwork spend a good deal of their time doing anything but creating designs. To get to a point where they can execute a paid gig and to do so successfully, they perform a great amount of unpaid work. This includes, for example, working on their online profile, structuring their schedule, and sorting through design briefs. What is more, emotional work goes into handling their own stress and managing relations with clients. In my presentation, I will reflect upon graphic designers' work using online platforms against the backdrop of invisible work (Star/Strauss 1999), emotional labour (Hochschild 1985), and free labour (Terranova 2000). I argue that the diverse challenges designers on online platforms face are all related to dealing with uncertainty and that this uncertainty is an integral part of working on an online platform. Uncertainty in this context stems from a highly volatile work rhythm, being confronted with an overwhelming amount of information, and platform mechanisms that are not transparent for workers. These insights are based on narratives by designers I interviewed in Bengaluru, India in February and March 2020 as well as an ethnographic analysis of several online work platforms.

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22.11
Contested care: Organising and negotiation practices in transnational live-in care arrangements in Swiss private households

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In Switzerland, live-in elderly care has become an increasingly common way to fill gaps in long-term care. Similar to other Western European countries, a market for home care services has emerged, with specialised agencies recruiting care workers from Central and Eastern European countries for temporary 'around-the-clock' care in private households. This labour market is highly segregated by gender, ethnicity, and class, and is shaped by complex power relations.
Despite the challenging conditions of their working arrangements, their isolation in the private home, and constrained labour rights, live-in carers in Switzerland have successfully managed to organise and to politicise commodified care work in recent years. Drawing on two empirical examples, this paper examines how care workers try to enact change on various levels – from publicly raising their concerns to everyday negotiations in the household. In doing so, it shows how the gendered geographies of the live-in model create specific spaces of negotiation and contestation and how the care workers challenge the arrangement by transcending previously firm boundaries: between the 'private' and the public sphere, between the conception of care as labour and care as social relation, and between traditional unionism and community organising.

23. Human Geographies: Cities, Regions, Economies

Sven Daniel Wolfe, Julio Paulos

Swiss Association for Geography (ASG)

TALKS:

23.1 *Alpermann H.*: Caring for place in times of uncertainty. Residential use for Halle-Neustadt's district center?

23.2 *Beverridge R., Koch P.*: Policies in and of the urban everyday

23.3 *Dagkouli-Kyriakoglou M.*: The vicious circle of familism in housing during Covid-19 in Greece.

23.4 *Delz S.*: Accessibility, Affordability, Adequacy: A Co-operative Response to Address the Chronic Urban Emergency of Housing

23.5 *Glaser M., Althaus E., Christensen L.*: Geographies of Age – Older people's access to housing and to urban life

23.6 *Hesse M.*: Relational cities as city-state formations: challenges for policy & planning

23.7 *Hilbrandt H.*: Housing in the Margins: Urban Order and the State in Berlin's Allotment Gardens

23.8 *Oesch L.*: What do you mean by planning? When urban planning in the refugee camp is rendered invisible

23.9 *Paschek, F.*: Promoting cycling with/without/against the state

23.10 *Sangermani C.*: Homes of refugees: A Human-Landscape Relationship

23.11 *Seabold A., Cocco-Beltrame D., Grimaldi A.*: COVID-19 Response in Self-Built Urban Communities: Lessons from the Global South

23.12 *Sewordor E.*: God Knows His Children': How Ghanaian Migrants in Italy are Sensing COVID-19, Mediating Rituals and Sociospatial Urban Practices

23.1
Caring for Place in Times of Uncertainty. Residential Use for Halle-Neustadt's district center?

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With crises such as the current global pandemic, short distances to supply facilities, but also the quality of one's neighborhood become more important and even existential for vulnerable groups.
Residential use was a central feature in socialist city centers (Dellenbaugh-Losse, 2020, p. 104). Thus, the high-rises *Hochhausscheiben A-E* in the district center of East German Halle-Neustadt were not only intended to provide a vertical frame to the otherwise rather flat functional buildings and facilities, but also to create a concentration by combining living and working (Bach, 1993:29-30).
The buildings, plannend and designed as dormitories for i.a. single workers of the local chemical industries and students, 'lost their function' after pricatization during the 1990s and four out of five buildings remained empty for more than 20 years by 2020.
Drawing on the example of the *Hochhausscheiben A-E*, this paper follows unrealized potentialities and traces controversies focusing on renewed residential use as a possible future for the high-rises.
It shows how questions of *care* became predominant in urban planning in Halle (Saale) after 1990 and how the challenging questions of "resposibility in what spaces, places, times and for which people?" (Metzger, 2014, p. 1007) have been enacted.
The relevance of the concept of 'care' in relation to issues of site and place has long been debated in human geography, urging for geographers and planners to think about their responsibilities and the consequences of their actions (Lawson, 2007). The article shows for Halle-Neustadt that (not) caring for the non-human is inseparable form the (not) caring for the human while the questions of "how to care?" is not easily answerable in times of uncertainty.

23.2
Abstract for the 18th Swiss Geoscience Meeting – Panel: urban planning and policy-making with/without/against national states

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Professor, Institute of Urban Landscape, Zurich University of Applied Sciences

Policies in and of the urban everyday

In this paper, we examine housing policies situated in and directed towards the urban everyday. We understand them as an urban form of policy building and contrast them to state form of policy making. This requires a fundamental shift in understandings of the agents, processes and institutional processes through which policy is made, even if the substantive objectives of these two policy types might be the same. Rather than focusing on governments and formal institutions we turn to activists (housing cooperative movements, squatters and insurgent planners) in European and US cities. What these activists do is an attempt to re-shape urban space and processes. These practices, we contend, share the generic features of a policy: intervention in socio-spatial practices, collective actions containing explicit goals and the means to achieve them. Through a close reading of urban housing policies we will delineate a particularly urban way of making policies. *First*, state and governmental actors and institutions (on different levels) do not lie at the center of these policy actions. Rather urban policy making often takes place in an "institutional void" (Hajer 2003) where the polity is emergent rather than fixed in advance. *Second,* the knowledge produced and used in these policies and the rules through which knowledge turns into action is grounded in the urban everyday and not based on scientific and/or political expertise. This means that knowledge and rules are developed in a circuit of formal and informal negotiations encompassing different actors and actions rather than implemented as a result of expert/political recommendations. *Third*, the interventions of urban policies target processes and outcomes of urbanization and not (parts of the) society as such. Urban policies, conceived here are socio-spatial and have a -radical – democratic intent to make urbanization self-governable. We conclude by discussing the scope and range of this understanding of urban policy in both practical and analytical terms.

23.3

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The vicious circle of familism in housing during Covid-19 in Greece.

The COVID-19 crisis already marked a pre- and post- era for economy and society worldwide. The pandemic and the related state actions impacted all aspects of personal and work life through the measures implemented nationally and internationally. Home was in the centre of official and informal campaigns that recommended strongly or ordered people to ‘stay home’ in order to stay safe. However, housing distress and overcrowding was already present in Greece which suffered more than a decade of severe financial crisis. As a new crisis is pilling up to the already precarious financial reality, housing situation will deteriorate and people will rely once again to the only persistent welfare agent, the family. However, the family support comes “with strings attached” and power relations that impact the wellbeing of all the members involved. This dependence reproduces also conservative notions of family and relations as older generations are usually “in charge” of an ‘assemblage of support’. For how long can and should the family act as a shock-absorber that solidifies intergenerational hierarchies and dependencies?

23.4 Accessibility, affordability, adequacy: A co-operative response to address the chronic urban emergency of housing

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The Coronavirus pandemic is laying bare one of the most prevalent challenges within the urban sphere: the lack of access to affordable and adequate housing. This scarcity is naturally exposed through instantaneous disasters – such as the current COVID-19 crisis, natural disasters, or military conflicts, etc. However, the crisis also magnifies the 'housing question' – to put it in Engels' words – in much more general terms, as it reveals many challenges of an underlying, long-lasting and chronic emergency of housing provision all around the globe. Being an essential pillar of our current economic system, many housing policies are intentionally designed to support the paradigm of perpetual economic growth and its speculative markets by mainly determining housing as a commodity. The proposed paper will address the chronic state of emergency produced by this system by outlining a fundamental shift in how housing – and land – could be valued, owned and managed in more inclusive, democratic and sustainable ways. Deriving from recently conducted research on collective forms of housing, the paper will focus on the potentials (and challenges) of the co-operative model to provide long-term accessibility, affordability and adequacy for housing production. While the co-operative model provides a global aspiration of building an economy on democratic and speculative-free enterprises, it is, simultaneously, a deeply contextual undertaking that has to be locally adapted through bottom-up processes in respective communities on the one hand, and ultimately supported at a policy level on and the other hand. The co-operative model therefore not only allows for envisioning alternative urban policies to alleviate social, economic and health-related crises on a general level, but also provides strategies for how – in this example through housing – local communities can become both more resilient to imminent emergencies, and be more directly included in how to address long-term challenges.

23.5
Abstract for the submission to

The panel “At home: the domestic city in times of crisis” at the 18th Swiss Geoscience Meeting

06-07.11.2020, ETH Zürich

Geographies of Age – Older people’s access to housing and to urban life

Eveline Althaus, Liv Christensen, Marie Glaser
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Not only the home itself, but also access to urban life plays a central role if ‘aging in place’ is to succeed, according to WHO policies (WHO 2007). In recent studies we show that the residential area is of great importance as the centre of life in old age and that informal encounters in various public and semi-public spaces from the entrance area to the local pub play a very important role for mental and physical well-being in late life (Christensen and Glaser, 2019; Althaus and Birrer, 2019). Taken on their own, the many spontaneous encounters in the immediate living environment and in the neighbourhood may seem insignificant, but it is precisely in the sum total that they unfold their potential. Accordingly, the possibility of participating in social urban life should be given high priority and guaranteed by low-threshold offers and barrier-free access in financial, physical and social terms. If spaces of encounter, but also social measures to promote neighborhood networking are missing, loneliness can potentially become the downside of self-determined living. Due to the lockdown and quarantine conditions during the COVID-19 pandemic older people’s access to urban life has been severely challenged, in some cases leading to precarious circumstances. The situation of many elderly people has worsened, and their social isolation has increased. We look into the impact of the crisis on the effectively lived everyday experiences in late life and discuss the necessary action strategies to improve the situation.

23.6 Relational cities as city-state formations: challenges for policy & planning

Markus Hesse[1]

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This paper explores urban governance against the background of small-but-global urbanisation processes, an economic transformation that has gained increasing importance recently. In this context, cities and city states have emerged that are of relatively limited size but became hot spots of the world economy, and of big politics. They function as financial market-places (some also as tax havens), political brokers, logistics hubs, or corporate headquarters and centres of the services industries, resulting from a dedicated path of internationalisation. Following Olds & Yeung, the ability of these places and their actors to extract “streams of profit from extraterritorial terrain” is essential for the successful practice of relationality (Olds & Yeung, 2004, 492).

The paper draws upon empirical evidence obtained from case studies in Geneva, Switzerland, Luxembourg City, Luxembourg, and Singapore (Hesse & Wong 2020). Despite significant differences in their historical trajectories, all three have some important features in common. Particularly, they share certain political-economic attitudes to governance: they became successful by combining a sort of extraverted economic orientation with practices of introverted urban governance. The paper will discuss some of the key characteristics and outcomes of these governance practices. Firstly, relational cities make particular use of the inflow of capital and workforce that are necessarily attracted from ‘out there’, while the governing capacity is mainly provided by and for the idiosyncratic milieu of decision makers. Secondly, they practice an unusual combination of state power and local politics which seems important to understand not only their economic success, but also the supporting policy frameworks. We interpret this model as a ‘city-state formation’, which appears as a variant of the developmental state (Hwang 2016).

Thirdly, and this will be the main focus of the paper, this governance practice brings specific challenges to urban development and policy. These challenges emerge from the mismatch between economic power, small size and partly limited governance capacity. While the provision of office space and related infrastructure for international services corporations was the main determination of political institutions (which may also explain the economic success of the three places), land use conflicts and particularly housing issues were not equally taken into account, at least in two of the three cases (Geneva and Luxembourg). This has caused major shortcomings in the urban settings of the two cases, where rocketing house prices render these places either increasingly inattractive for international staff, or create ever rising demand for cross-border commuting. The related consequence for policy and planning would be to pursue a more balanced development trajectory, both in sectoral and in spatial terms. However, this seems difficult to implement under the conditions of the cities’ economic policy focus and the primacy of the urban centres. Therefore, these problems pose a big challenge to the sustainability of the relational cities’ development model.

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23.7
Housing in the Margins: Negotiating Urban Formalities in Berlin's Allotment Gardens

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Critical shortages of affordable housing force people into housing precarity across the globe. Drawing from my forthcoming book, Housing in the Margins (Hilbrandt 2020), this presentation explores unruly housing practices and their regulation in the context of the German housing crisis. Through ethnographic research on the ways in which Berliners dwell in allotment gardens despite a law that prohibits housing at these sites, it illustrates how these gardeners negotiate the possibilities of residency with the local bureaucracy, gardening associations and amongst themselves. I pursue this project with empirical and theoretical objectives: studying empirically how people negotiate ways of staying put in allotment gardens and how boundaries around their dwelling practices are drawn, I aim at understanding the production and governance of housing precarity in a relatively rich European city. In theorizing these processes of governance, I seek to unveil the possibilities of conceptualizing informal housing in the context of bureaucracies that are commonly understood to regulate thoroughly, coherently, and according to fixed rules. This analysis highlights the contested terrain of enacting regulations and the exclusions that these negotiations entail. Building on postcolonial theory, anthropology of the state and critical legal geography, the presentation draws attention to the power of negotiations in the governance of urban space.

23.8
"What do you mean by planning?" When urban planning in the refugee camp is rendered invisible

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How does a refugee camp urbanize? Up to now, camps have been considered as either urban assemblages made by dwellers' improvised tactics or spaces governed by disjointed urban planning policies. I demonstrate that there is another side to the urbanism of the refugee camp. A form of coherent institutional urban planning exists as well. It takes the shape of an improvised dispositif. One of its main effects is to render the very process of urban planning invisible. I investigate this type of urbanism on the basis of fieldwork conducted in the Al-Hussein Palestinian refugee camp located within the city of Amman in Jordan. This improvised dispositif of urban planning is an ensemble made of the interventions of several levels of government, i.e. the municipality of Amman (local level), the Jordanian state (national level) and a UN agency (international level). This urbanism is the result of a balancing act that ensures the temporary character of the camp, while allowing the implementation of a form of urban development that leads toward a material homogenization between the camp and the surrounding urban space. It does this by rendering its own processes invisible and being officially referred to as mere 'improvement'. In this paper, I show the way the municipality of Amman, the Jordanian State and a UN agency have improvised away from more conventional urban planning.

23.9
Promoting cycling with/without/against the state: A strategic-relational perspective on innovation in urban transport planning and policymaking

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The proposed article presents an analysis of an empirical case study of the ongoing process of re-establishing utility cycling as a mainstream transport mode within the London transport system against the backdrop of local, national and supranational policymaking and planning.

Informed by the literatures on socio-technical innovation and transition studies (Geels, 2010), and cultural political economy (Sum & Jessop, 2013) the case study disentangles

- the different actors involved in the governance of transport policy and planning across multiple scales and levels, and
- their varying ability to exercise agency in the planning and policy-making processes

that govern transport at the local level in London with/without/against the state, as well as dynamics and processes at scales below and beyond the state.

In doing so, the article illustrates an example of how analysis of urban planning and policymaking can go beyond reified notions of 'city' and 'state' to draw out the multiplicities that constitute 'the city', 'the state', and their interwoven nature. The article does this by taking in the perspective of various actors and institutions from government, professional practice, civil society and social movements (via empirical data from 40 semi-structured interviews and the study of documents) to reconstruct how their actions and interactions at certain moments in time contrast, connect, combine and/or cancel out to produce what may at a distance come to be perceived as 'the city' variously acting with/without/against 'the state'.

This type of granular study does much to draw out spatio-temporal particularities of urban planning and policymaking, emphasising the dynamic and ambivalent nature of these processes. Despite this, it offers also a promising starting point for cross-case comparative study of urban policymaking and planning vis-à-vis the state within and across cities, as the paper argues.

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23.10
Homes of refugees: a human-landscape relationship

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Every year floods, earthquakes, climate conditions, and wars force millions of people to leave their homes. During the 2000s, migrations have been increasing year by year worldwide. Today, the field of emergency management is a crucial aspect of the professional and ethical scenario of architects and designers.
The emergency nature of these situations has a significant impact on the individual›s social and psychological attitudes, bringing forth irreversible life consequences and diseases. Migration is often related to the loss of a home, and the objects and territories migrants are familiar with. This psychological stress invades all the aspects of their lives: family, friends, memories. After migration, the social environment and urban context they are immersed in is determinant for the development of a new life.
Starting from the underlying meaning of the term «home» intended as «someone›s or something›s place of origin, or the place where a person feels they belong» (Cambridge Dictionary, 2020) we can understand the intrinsic connection of the word «home» with a personal feeling and sense of belonging. The research explores the role and significance of the concept of home in the context of migrations by analysing emergency scenarios and situations in different countries. Through interviews and data collection, a series of elements are catalogued as a result of the relationship human-home. This investigation aims to highlight the role of the natural landscape and urban context as a significant part of the integration process of migrants.

23.11
COVID-19 Response in Self-Built Urban Communities: Lessons from the Global South

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The origins of informal settlements across the globe can be traced to patterns of exclusion that force households into inadequate dwellings, usually on account of socio-economic needs. Initially conceived as a temporary state of exception, low-income informal dwelling, or slum dwelling, has become a permanent feature in the urban scene. Research shows that these patterns of exclusion become exacerbated in times of emergency or crisis, with profound socio-spatial impacts that (re)shape our city. Too frequently, international recommendations to face such challenges are disconnected with realities on the ground, and Government agencies, already struggling to provide basic services, face an added strain to generate responses in an adequate and timely manner. Their failure to do so, in turn, exacerbates existing urban inequality. The impact of COVID-19 on informal settlements provides a clear example. Lack of basic sanitation services, high-density living quarters, and economic insecurity make informal settlements especially vulnerable to COVID-19, turning some into hotspots. International guidelines for mitigating the spread of the virus include several actions, such as frequent handwashing and physical distancing, that are often not possible in these contexts. Through a trans-disciplinary approach, our work focuses on the politics and governance of the COVID-19 pandemic in informal settlements. It explores the gaps between top-down guidelines – from international organizations, National Governments, and Academia, and grassroots organizing in informal settlements.Through three case studies - namely Buenos Aires (Argentina), Freetown (Sierra Leone), and Ahmedabad (India) - we explore the tensions in the urban interfaces of the COVID-19 pandemic and the responses it engenders.

23.12
‘God Knows His Children’: How Ghanaian Migrants in Italy are Sensing COVID-19, Mediating Rituals and Sociospatial Urban Practices

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Abstract: This paper attempts to broadly evaluate the threats entangled with migrancy, and pointedly interrogate how Ghanaian migrants in Italy are making sense of COVID-19 associated uncertainties by dwelling on configurations of social mediation through re-activated faith-based practices aided by social media. Centrally, this essay intends to intersect some recent scholarly reflections about the politics and precarity of COVID-19 that draw on migrant ‘hotspots’ located along southern European border-scapes with theoretical insights by urbanists. At its core, this study dwells on lived experiences beyond ‘hotspots.’ Unpacked in two parts, the first thread reflections by Bilgin Ayata and Kenny Cupers, and adapts the analytical frame offered by AbdouMaliq Simone and Michele Lancione (i.e., ‘danger’ and ‘emergency’) to examine how layered and uneven degrees of danger (immanent and potential threats naturally associated with migrancy, and presently evoked by COVID-19) is being mediated while urban mobility is restricted by quarantine regulations in Italian cities. The second part adds empirical evidence to the preceding scholarly debates outlined, in order to make a twofold claim: (a) that while the danger of uncertain conditions faced in migrancy is not fully known, it is often rationally estimated by migrants; (b) that dangers associated with COVID-19 and its accompanying state of ‘emergency’ imposed by European governments (focus on Italy) may have restricted physical bodily movement, yet have engendered media spaces that extend the spatial ‘prison’ into which migrants (focus on Ghanaians in Italy) remain quarantined by reactivating (spi)ritual beliefs to mediate social relations and order the chaos surrounding them.

[wordcount: 250]

Keywords: COVID-19, Ghanaian migrants, Italy, danger, emergency, social mediation, ritual practices.

24. Human Geographies: Materials, Natures, Politics

Rony Emmenegger

Swiss Association for Geography (ASG)

TALKS:

24.1 *Andriamahefazafy M.*: A new wave for marine conservation? Doing conservation in the context of blue economies and sustainable development goals.

24.2 *Berndt C., Wiederkehr C.*: Chemicals as market agents: Argentina's articulation with the global pesticide complex. agribusiness in Argentina

24.3 *Castelblanco F.*: Cartographies of the unseen.

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24.14 *Sharma N.*: Urban aesthetics and creation of a clean and green post-colonial city: Whose Bhagidari, whose Zimmedari?

24.15 *Tola M.*: Decolonizing the commons in Latin America.

24.1
A new wave for marine conservation? Doing conservation in the context of blue economies and sustainable development goals

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In this research, Madagascar is used as a case study to analyse the evolution of marine conservation. As a biodiversity hotspot and with a vast coastline and exclusive economic zone, marine conservation in Madagascar has been booming. With only a few marine protected areas 10 years ago, it has now a network of locally managed marine areas, legislations that promotes management transfers of marine resources, national strategies that promotes sustainable use of marine resources and various collaborations that involve the government, NGOs, coastal communities and actors from the private sector. Globally, marine conservation has gained a lot of momentum in conservation practices and is not limited anymore to a few NGOs leading initiatives. This evolution of marine conservation stems from two phenomena, the adoption of the concept of blue economies by countries that make countries aspire to sustainably use their marine resources along with economic growth and the adoption of a specific United Nations Sustainable Development Goal regarding the ocean. This talk will then present the evolution of marine conservation in Madagascar in the past 10 years by looking at three aspects: the impacts of historical moments and the historical trajectory of the country in shaping the marine conservation movement; the role of knowledge production in defining priorities by conservation actors; and the involvement of different groups especially coastal communities in these processes.

24.2
Chemicals as market agents: Argentina's articulation with the global pesticide complex

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Industrial agriculture is unthinkable without agrochemicals. They are key drivers of our current global food system, making today's agriculture dependent on these chemical substances as never before. In the decisive herbicide sub-segment, there has been an unprecedent boom in the wake of far-reaching transformations (i.e. GMO seeds, generic pesticides). More recently, however, the GMO-herbicide sociotechnological package appears to have become a victim of its own success as herbicide trade and use is increasingly encountering limits, both with a view to human (e.g. risks to human health) and nonhuman nature (e.g. emerging herbicide-resistant weeds).

Putting critical market and commodity studies into dialogue with Science and Technology Studies, our paper is a first step to overcome the surprising silence within the critical social science literature on the topic. Choosing Argentina as our entry-point, we focus on herbicide assemblages as heterogeneous socionatural arrangements that entangle chemical substances, production technologies, agrochemical companies, and corporate strategies with crops, seed science, state regulation, and agricultural production methods. Such a perspective allows us to investigate how the wider transformative processes at the global scale articulate with the specific situations of agents in the global South. It is here that global processes – after being disentangled from established contexts of existence (e.g. manufacturing plants in the global North, patent protection, herbicide tolerance) – attach themselves to new environments and heterogeneous contexts (e.g. Southern agrochemical production sites, emerging weed resistance). We argue that the result of this translation process is contradictory: On the one hand, wider global processes format heterogeneous contexts in a way that make them amenable to a market rationality; on the other hand, these contexts maintain their own logics and rationalities that feed back and set limits.

24.3
Cartographies of the Unseen

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A map is a bifocal instrument: while seeking to represent objectively it simultaneously reveals the gaze of those who seek to know or grasp by seeing.
With a single line that joined together singularities of the landscape, the fence and walls that closed off the land emerged in Europe. After this, space was divided based on property codes and transformed into a territory through evolving acts of enclosure, measurement and representation. However, just like how some features of the landscape cannot be plotted on a map, there are cultures that have produced territories that cannot be reduced to measurement or fenced off. Contrary to the definition of territory common to the Anglo-speaking world -bounded space under the control of a group of people, usually a state (Elden 2010)in the sense of a single meaning; but rather to indicate the issues at stake in grasping how it has been understood in different historical and geographical contexts. It does so first by critically interrogating work on territoriality, suggesting that neither the biological nor the social uses of this term are particularly profitable ways to approach the historically more specific category of ‘territory’. Instead, ideas of ‘land’ and ‘terrain’ are examined, suggesting that these political-economic and political-strategic relations are essential to understanding ‘territory’, yet ultimately insufficient. Territory needs to be understood in terms of its relation to space, itself a calculative category that is dependent on the existence of a range of techniques. Ultimately this requires rethinking unproblematic definitions of territory as a ‘bounded space’ or the state as a ‘bordered power container’, because both presuppose the two things that should be most interrogated, space and boundaries. Rather than boundaries being the distinction between place and space, or land or terrain and territory, boundaries are a second-order problem founded upon a particular sense of calculation and concomitant grasp of space. Territory then can be understood as a political technology: it comprises techniques for measuring land and controlling terrain, and measure and control – the technical and the legal – must be thought alongside the economic and strategic.”,”DOI”:”10.1177/0309132510362603”,”journalAbbreviation”:”Progress in Human Geography”,”author”:[{“family”:”Elden”,”given”:”Stuart”}],”issued”:{“date-parts”:[[“2010”,12,10]]}}],”schema”:”https://github.com/citation-style-language/schema/raw/master/csl-citation.json”} - indigenous spatial-philosophies from Latin America consider the territory as a multi-scalar system of life or a web of life-sustaining relations that extend even across vertical layers of colonial and neo-colonial occupation.

Building on the findings of my current practice-based research project, this paper unpacks the epistemic singularities of territorial production among indigenous nations in the Colombian-Pan Amazon region. Through cinematic cartographies, collective action and enactments, this project challenges the notion of seeing as the only means of knowing the landscape. As a whole, this multi-layered investigation takes the cartographic task to the fringes of representation and opens up opportunities for inter-epistemic dialogue through a process of participatory research and co-creation with members from five indigenous nations. Throughout the process, documentary film, counter-mapping, storytelling, walking and community organizing become complementary tools used to explore these sub-visible, entangled and overlapping territories. Ultimately, this project aims to render the Pan-Amazon landscape not as an image but as an experience. It also offers concepts that can help to re-calibrate our own understanding of territory, moving from enclosure to a type of weaving, reciprocity and inter-existence.

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24.4
Donkeys, Deer, and Death around the Swiss National Park: Developing a relational values approach to align environmental values in conservation

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Environmental values are important for many nature conservation contexts—particularly in participatory decision making (Fish, 2011; see Gregory, Failing, Harstone, Long, & McDaniels, 2012) or ecosystem services assessments (Millennium Ecosystem Assessment, 2003) and implicitly in policies and programs for conservation (O›Neill, Holland, & Light, 2008; West, 2006). When values are included in nature conservation efforts, usually one of two approaches are used: instrumental values focus on the benefits from nature for people whereas intrinsic values reflect the idea of nature's value for its own sake.

Yet neither of these approaches effectively captures a wide range of values that motivate many people to care for land, ecosystems and species. For many people, relationships with nature and with other people via nature better characterize how they value and view their biophysical environment. Relational values include values such as stewardship and care, kinship and connection towards nature, concepts such as 'eudaemonia' which refers to living a good life in harmony with nature, as well as values around responsibility towards nature (Chan et al., 2016).

Our research project elaborates an approach to relational and furthers the conceptual foundations of this emerging research area via qualitative value-elicitation interviews with farmers in a Swiss alpine agro-ecosystem and philosophical analysis. We present a framework for understanding relational values and its application to interview results. We conclude with implications of how a relational values approach can inform more inclusive forms of nature conservation.

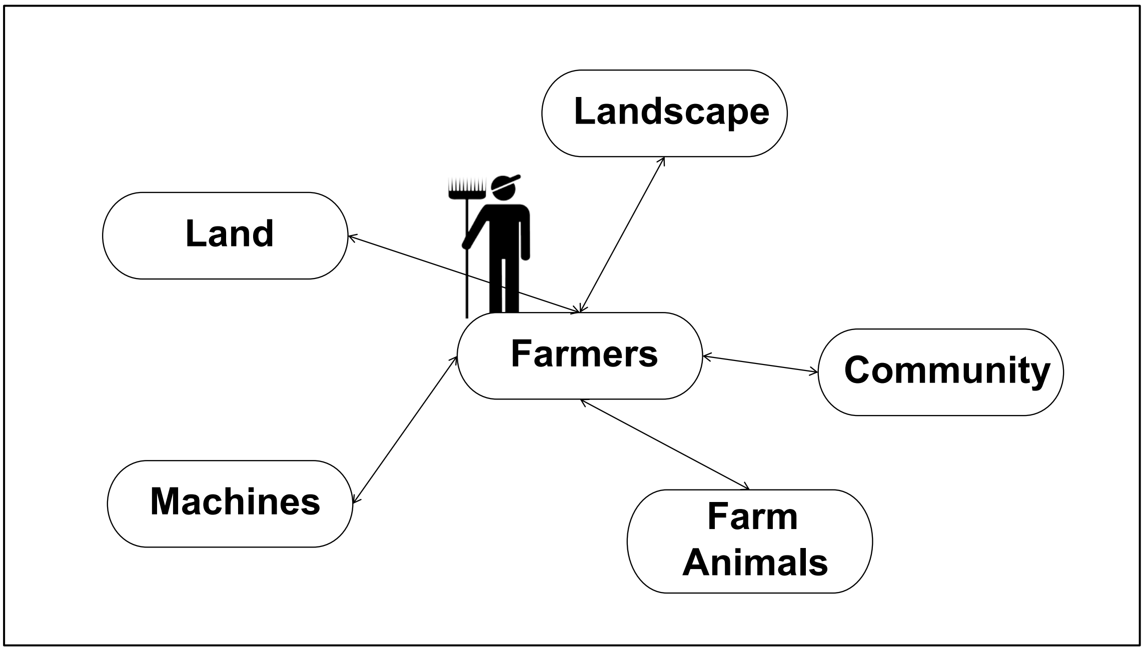

Figure 1. Relationships and Relational Values of Farmers (examples)
Farmers relate to different types of entities in their environment, such as those shown in the figure above. Qualitative interviews with farmers involved a dialogue and conversation guided by the researcher that provides participants with the opportunity to express and reflect upon their valued relationships and examine the limits and motivations for these values.

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24.5
Conserving agrobiodiversity: rare varieties promotion narratives of institutions and their volunteers in Swiss Romandie

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Over the last decades, conservation processes have been growing in agriculture, particularly through the rise of peasant, ancient and rare seeds preservation against the loss of agrobiodiversity and the dependence of producers on agro-industry (Peschard and Randeria 2020). This paper seeks to discuss the post-capitalist approach of “convivial conservation” (Büscher and Fletcher 2019) and in particular its incentive to promote and celebrate both human and nonhuman nature equally. I will do it in the light of agrobiodiversity conservation by confronting this approach to the case of a Swiss nonprofit foundation committed to preservation of rare varieties – i.e. which were not easily available or cultivated anymore for trade purpose in the past decades – through the collaboration of hundreds of voluntary seed growers. I will focus on rare food plants promotion narratives for and by humans (id. 2019) conveyed by this institution, its collaborators and volunteers. Drawing on a qualitative analysis of communication and promotional materials, I will emphasise the human-plant relationships and analyse these actors’ representations of rare varieties (e.g. everyday or spectacular nature; within or beyond the frame of nature-people dichotomy). This will enlighten the underlying values and objectives of conservation promotion narratives (celebration of diversity, collaborative work, free trade or exchange, etc.), and the convergences and possible collisions of interests between the volunteers and the institution (e.g. commoning vs. making rare varieties more available for trade). More broadly, this analysis will help to understand how agrobiodiversity promotion narratives foster rare varieties crop expansion.

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24.6
Housing in the Margins: Negotiating Urban Formalities in Berlin’s Allotment Gardens

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Critical shortages of affordable housing force people into housing precarity across the globe. Drawing from my forthcoming book, Housing in the Margins (Hilbrandt 2020), this presentation explores unruly housing practices and their regulation in the context of the German housing crisis. Through ethnographic research on the ways in which Berliners dwell in allotment gardens despite a law that prohibits housing at these sites, it illustrates how these gardeners negotiate the possibilities of residency with the local bureaucracy, gardening associations and amongst themselves. I pursue this project with empirical and theoretical objectives: studying empirically how people negotiate ways of staying put in allotment gardens and how boundaries around their dwelling practices are drawn, I aim at understanding the production and governance of housing precarity in a relatively rich European city. In theorizing these processes of governance, I seek to unveil the possibilities of conceptualizing informal housing in the context of bureaucracies that are commonly understood to regulate thoroughly, coherently, and according to fixed rules. This analysis highlights the contested terrain of enacting regulations and the exclusions that these negotiations entail. Building on postcolonial theory, anthropology of the state and critical legal geography, the presentation draws attention to the power of negotiations in the governance of urban space.

24.7
Challenges of non-dualist thinking for urban natures

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For a long time the traditional viewpoint of the human-nature relationship was based on the idea that humans and nature are separate. Non-dualist thinking arose in critic to this perspective and has gained popularity across academia and the wider public over the last decades. It is based on the idea that human and nature are always interconnected and has opened up new possibilities of research topics, especially regarding urban natures where the duality of urban and nature has always been a difficult one to uphold.

The wide acceptance of non-dualist ideas and concepts has lead to new ways of doing research, doing conservation, new natures and new ecosystems. Letting go of long-held beliefs of a dualist and essentialist separation of human and nature (or the inhuman) has opened up new possibilities to see the world as relational, processual, emergent and becoming (Mansfield & Doyle, 2017) but at the same time has introduced new challenges.

With dualist thinking, everything that is "natural" normally holds the position of highest value. But "natural" in the sense of a state free of human influence does no longer exist within non-dualist thinking. Therefore, removing the big categories of human and nature leads to new negotiations and new ecological and political struggles about what is "right" when interacting with the environment has become more and more difficult to decide on. The question of what belongs in post-dualist ecosystems and how to manage them is a matter of debates in conservation of protected areas and urban natures alike (Braverman, 2015; Castree, 2014; Lorimer, 2015).

This presentation explores the challenges of the non-dualism of urban natures through the example of the rat. The long shared history between rats and humans has created an abundance of reactions, narratives, symbolic meanings and practices regarding rats. In a time where "nature" is called back into the city in the form of greening and renaturalisation projects, rats are "removed" and cleansed from the city with new and bigger pest control campaigns (Poon, 2018; Willsher, 2018). Rats are a part of the city, that no one wants to have anywhere, yet who decides about who gets to thrive in our new non-dualist environments? Whether we want them to or not, they continue to exceed human efforts of managing and controlling them and thrive nevertheless. Following rats to the places they territorialise, continuously transgressing the material boundaries and social framings humans have established for them helps to understand how the politics of non-dualist natures in urban settings work and how post-dualistic urban ecosystems could look like.

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24.8
A social practice theory approach to farmers’ pest management

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Increasing societal pressure due to e.g. the ongoing biodiversity loss has led the European agricultural sector and policy to embark on a transition process towards low-pesticide agriculture (EC 2019; for Switzerland see e.g. Huber & Finger 2019). In Switzerland, public policy efforts to substantially reduce the use of chemical plant protection products are reflected in the number of agri-environmental schemes (AES) that address this issue (FOAG 2019; Mack et al. 2020). The AES promote, first, the further development of alternative pest management methods and second, farmers’ uptake of these using financial incentives. Studies on farmers’ behaviour change in this respect usually focus on either individual or structural aspects and neglect the interplay of these.

In this paper, we conceptualise pest management (PM), an important component of crop production, within a social practice theory (SPT) perspective. In applying SPT to farmers’ PM, practices as routinized activities instead of actors become the principal units of analysis (Shove et al. 2012). The aim of the paper is then to identify the different (parallel used) variants of PM practices on Swiss farms and to analyse how their elements (meanings, competencies, materials) are connected. In line with Shove et al.’s (2012) SPT concept, *meanings* here refer to the ways in which a practice is understood and include norms, symbols and affections. A typical meaning related to PM is that of ‘healthy plants’. *Materials* refer to all physical elements related to performing the practice; in the case of PM, these involve e.g. pesticides, machinery and fields. *Competencies* mean the skills and knowledge needed for performing the practice, such as knowing when and how to apply pesticides on particular crops. When performing the practice of PM, farmers thus connect their understanding of suitable PM to the properties of the field, the crops, the available products or techniques and to their skills and know-how.

Methodologically, the paper is based on a literature meta-analysis and on semi-structured interviews among 10 farmers and 5 agricultural experts, conducted between February and August 2020. This allows us to perform a microanalysis of farmers’ individual practices. Our preliminary results suggest that at least four types of PM practices can be described along the three elements. These were named according to the main logic of each practice and include: 1) “Old school” – maximizing yields, clean fields, 2) Optimizing direct payments (subsidies), 3) Integration and innovation and 4) “Ecology first” – regenerative cultivation. The results inform a framework for further research and may be relevant for the advancement towards more effective Swiss agri-environmental policy.

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24.9
“Mercury doesn’t bite”: the politics of toxicity governance in Colombian gold mining

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The most recent UNEP Global Mercury Assessment (2019) estimates that anthropogenic mercury releases are at approximately 2’220 tons per year and that a significant source of these releases is artisanal and small-scale gold mining. The ubiquity of mercury and its negative effects on human and non-human matter have prompted policymakers on different administrative scales to come up with mercury governance schemes, and Colombia prohibited the use of mercury in mining in 2018. This mercury-ban is depicted to serve a set of greater goods, most prominently the protection of the environment and human health, but it has been highly contested within artisanal and small-scale gold mining communities. This contribution will take the mercury-ban and its contestations as starting points to raise questions about emerging political mining subjectivities in a context of macro-political transition where state institutions and their corporate allies attempt to (re-)assert their control over the production networks of gold. It will show that the mercury-ban and its contestations are intrinsically related to the deeply political and representational qualities of mercury for different actors along and beyond the production networks of gold. This will contribute to a more nuanced and politicized understanding of mercury governance that moves beyond simplistic assumptions that legitimize the marginalization and criminalization of mercury users.

24.10
Earth Beings

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In her book *Earth Beings. Ecologies of Practice across Andean Worlds* (2015), anthropologist Marisol de la Cadena proposes to translate the Andean word *tirakuna* as “earth beings”. *Tirakuna* is the Quechua plural of earth, accordingly, earths would be the literal translation. *Tirakunas* are for these Andean indigenous populations what European colonial thought considered for centuries *guacas*, idols, pagan deities and animated beings. They are mountains and hillsides, ridges and ravines endowed with powers and genealogical relationships, and interacting in complex ways with *runakuna* (Quechua plural for *runa*, or person). These entities, often interpreted by non-indigenous people as sacred beings expressing local religious beliefs, are the target of neo-extractivist practices and the site of socio-environmental conflicts. As “environmental resources”, *tirakunas* in South America and across the Global South have become the object of land grabbing and expulsions, the cheap nature for climate mitigation, food security and export of raw materials. The talk will explore strategies of “uncommoning”, practices that recognize how earth beings challenge and exceed the neoliberal perception, management and exploitation of nature.

24.11 Stakeholder engagement for nature conservation: A conceptual design based on a comparative analysis of multi-stakeholder platforms

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Multi-stakeholder platforms (MSP) are increasingly recognized as key elements of environmental governance. In places where competing claims on land harm the environment and threaten to crowd our less privileged land-users, convening stakeholders from science, policy, the private sector and society is a promising approach to reframe complex problems and develop shared pathways to change. As spaces of interaction, mutual learning, and decision-making, MSPs can spur innovative formats of nature conservation and thus negotiate trade-offs in view of sustainability and environmental justice. Critical voices, however, point out the risk of powerful actors being offered, via MSPs, privileged access to governments and thus disproportionately expanding their influence.

The proposed contribution offers a systematic reflection based on well-documented experiences in multi-stakeholder process facilitation as a response to the supposed tension between success stories and emerging criticism. Based on a literature review, a comparative analysis of 15-20 multi-stakeholder platforms operating in various sustainable development projects across the globe, and in-depth expert interviews from the field, we propose conceptual guidelines and sketch out a practical design for making multi-stakeholder engagement functional in the context of nature conservation.

This is an initiative mandated by the recently founded Wyss Academy for Nature at the University of Bern whose mission is to develop, test, and scale up innovative pathways that strengthen and harmonize nature conservation, human well-being, and natural resource use in different landscapes around the world

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24.12
"Infrastructure, power, and people's labour": everyday waste politics in Mandalay, Myanmar

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Waste Management in Myanmar, like in many developing countries, is deprived of sufficient and proper physical infrastructure. Myanmar, also known as Asia's last frontier, is a country which has been experiencing rapid urbanization brought by the political and economic transformations that occurred since 2011. In this process, the major Myanmar cities, Yangon and Mandalay, are regarded as economic growth engines and their transformation is largely shaped as per the interests of a small group of people: political authorities and global elites (investors, development banks). Meanwhile, the everyday struggles of urbanites are often not understood and incorporated into contemporary urban development. Through the study of everyday waste management practices, this paper aims to unravel the everyday experiences of people in dealing with the present urban situation in Mandalay. Thanks to a situated ethnography of people's experiences, and the use of narrative methods, the paper aims to bring insight on how waste infrastructure deficiencies challenge people's daily lives and create unjust politics. Urban Political Ecology (UPE) will be used as an analytical and theoretical lens. UPE provides insights into how the urban cities are made through socio-ecological, and political processes, and in making so, how the inequality and unevenness are created. Two main contributions are to be made with this paper: first, to discuss the UPE of waste and infrastructure in a post-authoritarian context, and second to bridge the urban gap existing in Myanmar Studies literature.

24.13
“Recycling without recyclers is rubbish”: remapping geographies of waste in Cartagena, Colombia

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Colombia is considered a pioneer in inclusive recycling in Latin America, and municipalities across the country are legally obliged to integrate *recicladores* into their waste infrastructure. Nevertheless, as captured in the national recyclers' organisation's motto *“Recycling without recyclers is rubbish”,* this population is struggling to remain in place. In a context of top-down reshaping of the waste management policy, this paper explores the ongoing experiences of exclusion, displacement and dispossession experienced by *recicladores* in the city of Cartagena as well as the tactics they develop to navigate these threats. Through ethnographic work with recyclers in the city, the paper seeks to analyse waste workers' everyday spatial practices in the city in a context of a rapidly changing recycling economy. The paper shows how the formalisation process unexpectedly opened the door for a variety of actors to enter the recycling waste infrastructure, thus increasing the pressure to get waste materials and the competition between waste workers. As waste becomes scarce and less available on the streets, pressures grow to seize profitable collection routes, pushing the less well-off waste workers to the edges. This competition for waste driven by a ‘free market’ policy remaps the geographies of waste in the city. Thinking of waste as a politicized materiality, the paper considers what this case suggests about the understanding of the relation between everyday politics of waste and urban segregation.

24.14
Urban aesthetics and creation of a clean and green post-colonial city: Whose Bhagidari, whose Zimmedari?

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Abstract: Scholarship around inequalities in the post-colonial state explain how the gargantuan displacement of rural populations to the urban terrains causing an urban explosion represent less the demographic expansion of the post-colonial city and more the catastrophic human cost of unrestrained capitalist accumulation (Chandoke 1991).The spatiality or the socially constructed spaces in the city become a 'terrain for contestations' where the marginalized manifest their struggles and display their human agency as *political actors, mediators* and *social agents* and not just passive recipients of the structural forces in the 'unintended cities' that they now comprise (ibid, pp 2870-2871; Ghertner 2015).

Elite entitlements to public spaces, resources, and services, and hegemonic conception of pollution and purity, entail them to demand aesthetically pleasing cities where they use activism and *bourgeois environmentalism* as a tool to form alliance with the state in dislocating/demolishing anything that falls outside their imaginaries of a world-class city (Baviskar 2012). This aesthetic governmentality is a result of a process of *Bhagidari* (participation) between the state and the elites through a process of gentrified participation where demands of transparency, accountability and good governance are made. It is ironic that, and I present through my research how, the *Zimmedari* (responsibility) for attaining this vision of a world-class city, however, lies entirely on the labouring body of a certain section of this urban population who has no role in this process of *Bhagidari*. This labouring body, deemed polluted by the elites, comprises the section of society they want to keep close to hand for their labour but far away from their cities to create aesthetic value in it (Appadurai et al 2013). This is the section that cleans, maintains, and reproduces these urban spaces and prevents it from chocking on its own debris (Gill 2011). In this research, I look at the specific case of caste-ascribed waste-workers in India who risk life working with toxics to keep the city clean and functional.
Through this paper, I look at the inequalities experienced by waste-workers in India who have little bargaining power in their dealings with the state and the elite, yet practice agency in their everyday lives. I shall use Urban Political Ecology (UPE) as my framework for this research.

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24.15
Decolonizing the commons in Latin America

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This presentation interrogates the encounter between the commons and decolonial perspectives through the analysis of political movements in Latin America. Over the last two decades, facing environmental degradation and the increasing privatization of land, water, affects and ideas, scholars and activists have taken up the commons as a project for creating alternatives to extractive economies that impoverish both environments and populations. Once associated to medieval pastures and famously dismissed as “tragedy” by Garrett Hardin, the commons have been recently invoked in a wide range of activist practices, from protests laying claims to urban spaces in Turkey to digital currency initiatives in Canada. Scholars of the commons have often used this concept in the analysis of political movements in Latin America that are largely animated by indigenous groups. My paper interrogates the role of land in the Zapastista project of autonomy from the state and the market in Chiapas, Mexico, and that of water in the early 2000s Cochabamba Water War in Bolivia. It shows that, unlike Western approaches to the commons that cast land and water as part of ecosystems transformed through human action, indigenous movements in Latin America understand these other-than-human entities as part of political collectives. In so doing, these movements complicate prevalent understandings of the commons as a form of social cooperation that includes the care of natural resources. In dialogue with indigenous and decolonial studies, this presentation explores divergent modes of life in common and argues for the possibility of their intersection as a strategy for refusing forms of expanded extractivism. Such alliance across difference, however, can only arise from a radical reassessment of the commons’ aspirations to universalism.

27. Mountains as contexts for global change: interdisciplinary experiences, challenges and new perspectives across the natural and social sciences

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27.2 *Bassignana C.F., Rastorgueva N., Migliorini P.*: Agrobiocultural Resilience in Alpine Foodscapes: reshuffling of local and innovative food practices

27.3 *Bürgin R., Mayer H., Haug S., Kashev A.*: Digital multilocality: marginality as a strategy for novel work arrangements between center and periphery in Switzerland

27.4 *Castro E., Castro W., Cooper L., Garcia T.*: Convergence and divergence between ancestral and modern knowledge in the “sowing” and “harvesting” of water: the case of the Community of Chuschi, Ayacucho, Peru.

27.5 *Dominguez P.*: From a ‘Territory of Life’ to a ‘Territory of Death’? The Save Sinjajevina movement.

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27.1
Long-term social-natural monitoring in mountains: the case of Switzerland

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With its approximate 29'000 km^2 of mountains (>70% of the territory), Switzerland is a mountain country *par excellence*. Compared to the lowlands, the Swiss Alps include high numbers of habitats of national importance, including mires, alluvial zones, dry meadows and pastures, and an exceptional number of species, in particular in the alpine vegetation zone (Körner, 2004; Lachat et al., 2010). However, climate change, tourism activities, hydropower infrastructures, and the abandonment of the most remote meadows and pastures are some of the many drivers of global change putting mountain habitats and their biodiversity under increasing pressure in Switzerland (FOEN, 2017). In the face of these growing challenges, effective national and local policies and management approaches are needed to identify ongoing changes and safeguard the natural assets that underpin human wellbeing in Swiss mountains and surrounding lowlands. Some of the most critical data for understanding social-ecological systems, quantifying their changes and associated causes, predicting their trajectories, and ultimately informing environmental policies and agendas, are the time series provided by Long-Term (Social) Ecological Research (LT(S)ER) and other monitoring programs.

Here, we present the outcomes of a review of ongoing long-term monitoring in the mountains of Switzerland, performed as part of the BlueMount Project (https://www.gmba.unibe.ch/research/projects/bluemount) initiated within the Interdisciplinary Center for Mountain Research (ICMR) of the University of Lausanne. This inventory is based on a novel conceptual model of mountain social-natural systems. This model builds upon the conceptual framework of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) but explicitly identifies specific components and dynamics of the Earth System (Nature) and of what we call the Anthroposphere (i.e., direct anthropogenic drivers and indirect drivers), which we identify as necessary for the scientifically-sound and policy-relevant monitoring of mountain social-natural systems.

Our inventory along these individual components supports four main conclusions. First, with 11 networks and initiatives performing long-term data collection in a total of 38 individual sites in mountains, Switzerland is well off compared to other mountain countries, which often have very few if any monitoring programs for much larger mountain areas. Second, as is the case for most long-term research and monitoring programs in mountains and beyond, social dimensions are largely under-monitored. Of the 38 monitoring sites, 92% monitor the biosphere (biodiversity, ecosystems), 55% the hydropshere and/or cryopshere, and 95% the lithosphere and pedosphere, but no site explicitely and systematically monitors socio-economic variables. Third, Switzerland's mountain social-natural systems are not assessed within a holistic and integrated framework that considers the entire elevation gradient offered by the Alps as well as the social-ecological landscape continuum. For example, only six sites cover at least three bioclimatic belts (Körner et al., 2011), five of which range from the lower and/or upper montane to the lower and/or upper alpine. Last, the monitoring of the direct and indirect drivers of change identified as relevant both from a societal point of view and from an environmental policy and management point of view is essentially inexistent. No monitoring site has purposely been selected nor designed to specifically study, monitor, and inform about both the status of and trends in mountain social-natural systems as well as the pressures acting on them.

We conclude with our vision of an inter- and trans-disciplinary observatory of the Swiss mountains that would serve to coordinate long-term monitoring across sites, fill geographic and data gaps, and inform policy and management across scales with scientifically robust data and indicators.

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27.2
Agrobiocultural Resilience in Alpine Foodscapes: reshuffling of local and innovative food practices

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In the Western Alps, different social, political and demographic changes have been observed in the last three decades, such as a clear trend of repopulation, changes in the local food chains and in local community dynamics.
This study of new and local mountaineers involved in agriculture and food production highlights the reshuffling of local food practices, emerging new forms of agriculture, property and conviviality in mountain rural foodscapes.
Through multidisciplinary (agroecological and anthropological) lenses, our research draws an overview of the phenomena of new-ruralism in several valleys of the Western Alps. Each valley has undergone different processes and dynamics according to the socio-environmental-economic context, with various effects on the local food chains, on the local social systems and on the environment.
Our research points out the tools, occasions and dynamics that foster connectivity, participation, sharing and co-creation of knowledge and practices among native or new-comer farmers, producers and consumers in the local food networks.

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27.3
Digital multilocality: marginality as a strategy for novel work arrangements between center and periphery in Switzerland

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In recent decades, digital technologies have led to fundamental changes in work. Specifically, the use of the Internet and digital information and communication technologies (ICTs) allow to work in multiple locations. In this regard, economic activities of knowledge workers become increasingly detached from fixed workplaces and can be relocated from urban centers to peripheries such as, for example, mountain regions in Switzerland.

In terms of everyday work, a remarkable shift from location dependent work to more location independent digital multilocal work arrangements can be noted. From time to time, an increasing number of employees and entrepreneurs leave their workplace in the center and choose to spend some workdays in the Swiss mountain regions (e.g. in coworking spaces or second homes). They deliberately choose to work in such a digital multilocal setting in order to strategically make use of marginality in the periphery to enhance their work efficiency and productivity; far away from the mainstream in the center. However, the marginality used during workdays in the periphery may be beneficial or detrimental to the work of these digital multilocal workers.

The paper analyzes how marginality affects multilocal workers and their engagement with digital technologies during workdays in the center and in the periphery. Furthermore, we examine differing work tasks at both workplaces, how the change of scenery affects digital multilocal work, how marginality is related to distance and the reasons why digital multilocal workers temporary choose to work in the periphery using marginality.

We focus on the following research questions: To what extent and why does the use of applications on the laptop and smartphone for work differ between the workplace in the center and in the periphery? How do digital multilocal workers utilize marginality in their work? How do they benefit from using marginality for work, what are its limitations and why do they decide to work in a multilocal setting between center and periphery?

To answer these questions, we examined the work practices of six digital multilocal workers, who engage in such work arrangements between cities and mountain regions in Switzerland. In our exploratory study, we followed a novel digital mixed methods approach by combining geolocation data, digital work tracking data of laptops and smartphones (application tracking), personal digital diaries and ethnographic walk-along observations in combination with qualitative semi-structured interviews.

At the Swiss Geoscience Meeting 2020, we would like to present and discuss our results and methodological experiences from the field. Our study contributes to a more nuanced understanding of marginality in terms of self-chosen strategies (Grabher 2018), creative work (Hautala & Ibert 2018) and the radicalization of innovative and exotic ideas in the periphery (Sgourev 2019). Furthermore, we also provide novel insights for digital multilocal work practices between center and periphery (Vesala & Tuomivaara 2015; Simpson et al. 2003) as well as new methodological insights for discussion on the potential of digital mixed methods for social sciences and human geography.

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27.4
Convergence and divergence between ancestral and modern knowledge in the "sowing" and "harvesting" of water: the case of the Community of Chuschi, Ayacucho, Peru.

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In the Andes, indigenous communities have a long tradition of a unique relationship between humans and water, closely interconnected to their particular worldview. In Peru, the highland Andean communities put ample attention to water in their environments; partly due to the history of water scarcity in this eco-region, but also in new ways as communities directly experience the effects of climate change. In the higher altitude areas of the Chikllarazu, Ritipata and Portuguesa microbasins that together form the Apacheta basin of the Ayacucho region, the loss of glacial ice is evident, affecting the availability of water and putting at risk sustainability of the ecosystem and the local indigenous communities. A local collective strategy that allows the adaptation to these changes to water available in dry seasons is referred to as the "sowing" and "harvesting" of water in the Andean indigenous community of Chuschi.

This abstract aims to contribute to the understanding of the "sowing" and "harvesting" of water in Andean communities as a process where ancestral and modern knowledge comes together. The Centro de Desarrollo Agropecuario (CEDAP), an local Peruvian NGO, in the indigenous community of Chuschi located at 4074 m.a.s.l in the Ayacucho region, Peru has pioneered this work. The current initiative of the "sowing" and "harvesting" of water brings an opportunity to analyze convergences and divergences between ancestral and modern knowledge held by indigenous actors and technical professionals on ecological, technological, and social aspects related to conditioning of natural reservoirs called "qochas" in the rainy season and building of artificial dams (Figure 1).

Figure 1. Water "sowing" and "harvesting" in the headwaters of the Apacheta basin (Source: CEDAP)

The following methodology reflects both the analysis and interpretation of biophysical data including the presence of migratory birds, presence of water indicator plant species such as "Putacca" and "Sorahuayta", physiochemical and microbiological parameters of water quality, physical retention of water, soil permeability, inspection of the reservoir floor to identify the presence of heavy metals and water runoff, and dam design data, ethnographic data on the indigenous worldview of the Chuschi community about water, and the approach used by the engineers in dam building and other modern technology applications in the water "sowing" and "harvesting". Quantitative and qualitative data from 2003 to 2019 reflects participation of 47 community members, 3 agronomy engineers, and 7 social and health sciences professionals.

CEDAP's socio-technological intervention in the "sowing" and "harvesting" of water in the Community of Chuschi is part of an integral approach addressing the ecosystem, human health, and agro-ecosystem dimensions. In the community's indigenous worldview, water is "the mother" ("mamayaku"), and is both physical and symbolic. It is also associated as the "Amaru"; a powerful mythical being that inhabits some reservoirs ("qochas"), taking the appearance of different animals associated with water and "illas" – small stone sculptures with aspects of animals of the area (cows, sheep, alpacas or llamas). The qochas contain a vital and generating characteristic that provides people reproductive and protective attributes in the Chikllarazu microbasin. The building of dams in the qochas is meaningful for the community members. During the construction of dams, communities hold devotion and demonstrate respect for nature, requesting permission from their guardian mountains spirits ("apus").

The CEDAP approach, which included engagement with community families, was based on the ancestral social practice called “Atipanakuy” and ultimately allowed the construction of 42 dams with a particular effort to converge ancestral knowledge and low-cost technological innovations with local materials. Currently (2020) 21 qochas store double or triple their initial capacity, for example Cruz Qocha storage moved from 60,000 m^3 to 180,000 m^3; and others were even more dramatic from 20,000 m^3 to 120,000 m^3 of water (Figure 2). These efforts have provided positive ecological and social impacts in the Chuschi Community, located in the high altitude mountains, founded on trust-building, and inclusive engagement between indigenous people and technical professionals. Challenges that have been identified include a limited “openness” of technical professionals to value ancestral knowledge and a disconnect between local communal governance activity and municipality intervention. The establishment of inter-institutional platforms could contribute to the integration of ancestral and modern knowledge in “sowing” and “harvesting” of water for enhancing impacts in additional highland communities struggling to face a changing climate.

Figure 2. Artesaqucha small lake with artificial dam, in Pucruhuasi - Chaquiccocha area (Source: CEDAP)

27.5
From a 'Territory of Life' to a 'Territory of Death'? The Save Sinjajevina movement.

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There is a growing scientific and political awareness that commons are a positive management regime vis-à-vis human well-being and environmental conservation. Concretely, this paper focuses on the Sinjajevina-Durmitor massif mountain range in Montenegro, the second largest mountain pasture in Europe, an over 1,000 km2 limestone highland between 1.600 to 2.500 masl, which has numerous pastoral commons within it making a cluster of community-conserved areas as defined by the ICCA Consortium. The highland pastoral settlements (katuns) dispersed over the territory of Sinjajevina, belong to 8 tribal groups, and each katun more or less coordinates with the others but most importantly, they have their own rules of governance eachone, concerning timing of access to pastures and the ways of using them.

The Delegation of the EU to Montenegro co-funded a nearly 300.000€ study concluding that a Regional Natural Park for Sinjajevina should be created and that was expected by the end of 2020. Nevertheless, last September 2019, midway through the process, the Montenegrin right-wing nationalist Government officially inaugurated an artillery camp in the heart of these inhabited pastures and began military training in collaboration with important NATO allies (USA, Italy, Austria and Slovenia). Due to macro geopolitical reasons, still obscure to the public, an over 7.000 ha military ground within the Tara basin UNESCO Biosphere Reserve and surrounded by a multiplicity of other protected areas, has started to expel local farmers.

In such context, this paper will present how an initial ethnographic project of the most important pastoral commons of the Balkans has shifted into an engaged anthropology action-research project, and how this has opened many doors to the research itself at the same time as it has given full sense to it by contributing to the protection of these valuable highland living rural socio-ecosystems through its involvement in the local and global uprising against Sinajevina's militarization.

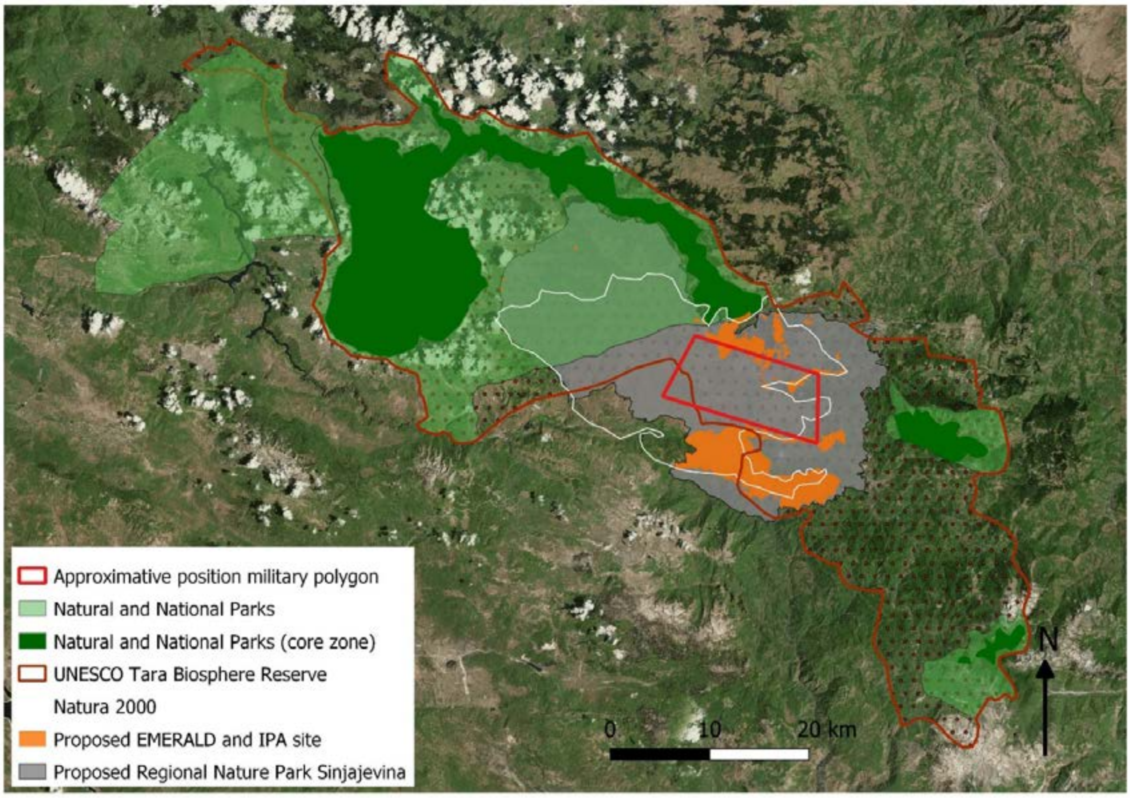

Figure 1. Approximate position of the military ground, and borders of the proposed and existing protected areas.

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27.6
« Cybercartographic Atlas on Naga customary land use: A participatory multimedia project. »

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Communities around the globe have had often ambivalent relationships with maps. But the importance of communities' mapping and representing their own territories and environment has been widely acknowledged. Beside countermapping, contrapuntal cartography, community mapping and participatory GIS, story mapping is increasingly used by communities as a tool for political and legal purposes. Furthermore, story maps are becoming popular as an interactive tool for communication and dissemination in Geography. Today a number of online cartographic applications for mapping stories are available. One of them is the Nunaliit Atlas Framework, a collaborative mapping platform designed for creating interactive online atlases following the principles of cybercartography (Taylor 2003, 2005; Taylor and Pyne 2010).

A primary critical concern is whether cartography is capable of meaningfully conveying experience, local perspectives and knowledge, and academic approaches critical to the status quo (Turnbull 2007). The multimedia, multi-sensory, multimodal, interactive, and interdisciplinary nature of the cybercartographic approach to atlas making positions it well to address concerns about misappropriations of knowledge, understandings, and perspectives (Caquard 2017).

The doctoral project "Cybercartographic Atlas on Naga customary land use" focuses on local perspectives on costumary land use systems of the Naga communities in Myanmar. It incorporates both qualitative and quantitative data in multi-modal and interactive presentations and envisages a participatory research process that situates the community at the centre of atlas production. The contribution reflects on the process of designing the atlas and emphasizes challenges and potentials of participatory multimedia methods. As a cybercartographic space for collaborative knowledge production, this research asks how multimedia methods can capture 'different knowledges' and 'different ontologies' in more creative ways than the conventional 'text-heavy' academic formats. In addition, it reflects on the changing circumstances of doing fieldwork due to COVID-19 and the search of innovative ideas for avoiding in-person interactions by using mediated forms that will achieve similar ends.

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27.7
Headwater-dependent systems for characterizing coupled socio-ecological adaptations to changing water resources

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Billions of people and critical ecosystems worldwide rely on water generated upslope. The temporal storage of atmospheric-sourced water provided by glaciers, seasonal snowpack, and upland groundwater, lakes, and wetlands -- together with a variety of constructed reservoirs -- plays a vital role in buffering hydrological variability for humans and ecosystems, from the highlands down the freshwater gradient to the ocean (Viviroli *et al.* 2007, 2020; Immerzeel *et al.* 2020). Changing climate, land use, and increasing demand for water increase the likelihood of irreversible ecological impacts, failure to water delivery and political conflicts (Wolf 2007). Headwater resources governance requires a coupled understanding of social and eco-hydrological processes and responses between source, storage and transfer of water, and the governance of the water resources system. Given the complex and diverse nature of the problems faced globally, a vast yet fragmented literature exists across locations, social-ecological systems, and academic disciplines.

Our project focuses on the headwaters and headwater-dependent systems (HDSs) across a longitudinal transect from Canada to southern Chile (the Transect of the Americas) to begin to help harmonize transdisciplinary understanding of the longer term, coupled and adaptive dynamics of HDSs.
Here, we review existing water resources management literature to synthesize HDS research across a breadth of research paradigms and disciplines, with a geographic focus on the Americas (a region exhibiting large economic, societal, ecosystemic, and climate differences). In doing so, we highlight the 1) dissimilar and diverse nomenclature used to describe HDSs in the academic literature, 2) common themes and issues being studied across a range of representative HDS storage systems, 3) range and degree of interdisciplinarity in the methodological approaches used for studying HDSs, and 4) future research needs of HDSs, including a focus not only on climate change, but ecosystem service management, green infrastructure, and environmental justice. Results from this review will be used to advance HDS research within our Transect of the Americas project, and across the academic and practitioner community more broadly.

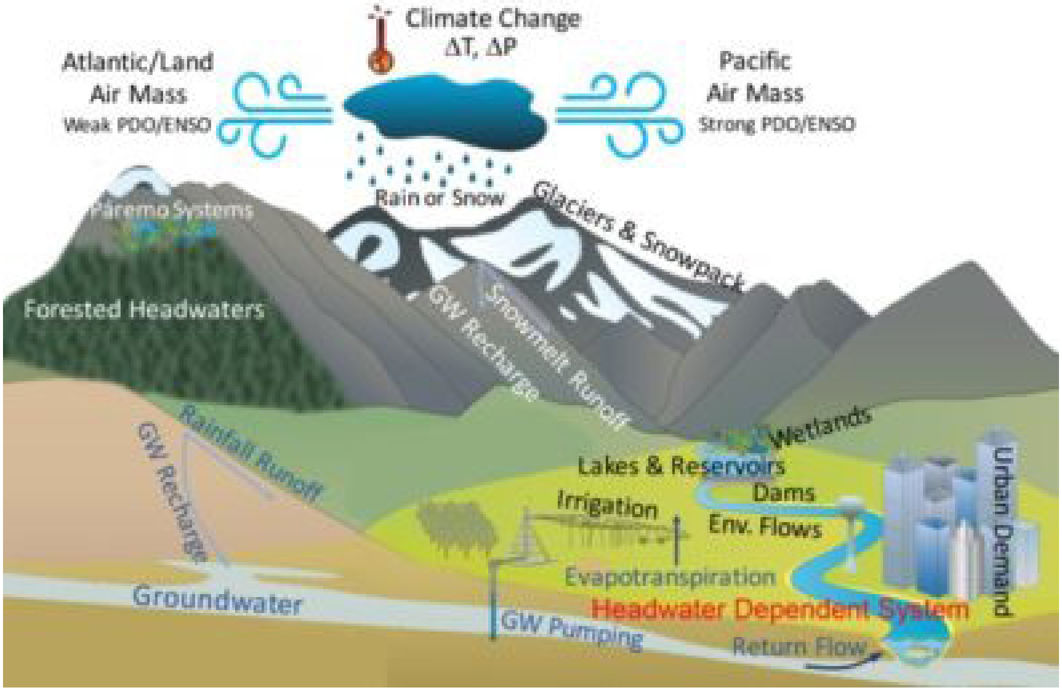

Figure 1. Headwater dependent systems are characterized by the downslope dependence of ecoystems and humans on water generated and temporarily stored in upslope ecosystems, such as glaciers, snow, wetlands, soils and lakes.

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27.8
Participatory Policy Review: “Supportive Tourism” Concept for Hand-in-hand Mountain Economic Development

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The role of tourism in the advancement of mountainous and rural settlements is significantly increasing day by day. However, its potential cannot be fully exploited because of its incomplete development. Owing to the empirical findings of the latest studies, such disjointed progress of tourism is mainly linked to the sporadic and unreasonable functioning of the local tourism supply chain (LTSC). Considering the imperative consequences of the effectiveness of tourism supply-side for the local community and destinations, in this paper, we examine whether policy development strategies also recognize disconnection of LTSC. The article presents an exhaustive review of the high mountain settlement development, rural development, and tourism development strategies. The study utilized a systematic review method for the analysis of different types of literature materials focusing on tourism supply chain management. Furthermore, participatory workshops with local stakeholders ensured their voices are heard and responded too. As a result, the analysis of thematic development strategies points to the fact that despite considering the vital role of tourism for mountain and rural settlement’s economic life, the development policies use a narrow approach. Particularly, strategies consider tourism impact is only through its direct effects. The recommendations presented in the article may facilitate improvements in the LTSC to strengthen the integration of agricultural and non-agricultural activities into the tourism industry. Based on the study, acknowledging the increasing dependency on such a sensitive economic branch as tourism, we suggest the new concept of tourism advancement - “supportive tourism”. Particularly, the paper suggests using tourism as i) starting point for other local innovative solutions, economic activities/startups; ii) the first option for the increased demand for services and products; iii) support of economic activities with the prospect of expansion; iv) to overcome dependence on the local tourism supply chain.

27.9 Climate change adaptation in Andean communities: insights into livelihoods tensions

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Climate change is known to be a major hazard for mountain regions and the people who live there or depend on its resources. In the Andes of Peru this is a topic of particular interest due to the vulnerability of extensive glacier ranges to global warming as they provide water and ecosystem services to a large population and support economic activities (Huggel et al., 2015). As a result, several initiatives were implemented in order to build and/or strengthen capacities of locals to adapt to climate change. In this context, multidisciplinary approaches are called to be best way to tackle a complex problem, but this is challenging on the field. However, most interventions are based mainly on the natural sciences (changes in weather, glacier retreat, etc.), while a comprenhensive understanding of people´s livelihood is usually assessed as a separate context. Some studies alreay provide insights about the effects of this when people have to chosse between livelihood issues and climate change issues (Motschmann et al., 2020).

Here we used the sustainable livelihoods approach (Scoones, 1998)to describe the interaction between people´s livelihoods and external factors like climate change and water governance. We carried out 150 interviews and surveys of members of local communities, selecting interviewees by age, gender, main economic activity and place of origin. The study was conducted at the Salcca (2334 km^2) and Pitumarca (685 km^2) catchments (ca. 4% glacier coverage), in the Cordillera Vilcanota - Cusco, the second largest glacier range in Peru. In both catchments (ranging from ca. 3400 to 6000 m a.s.l.) livestock production and agriculture are the main economic activities.

Our preliminary results show that even when climate change is recognized as a concern for locals, it is not the most important. The main concern is linked to livelihood issues, namely production of livestock, agriculture, grassland grow as feed for the livestock, issues related to infrastructure, roads, electricity and water rights, as well as market integration.

All interviewees recognized changes both in weather and in glaciers, but only in the last 10 to 15 years. This coincides with the period when different NGO´s and research groups started to implement climate change projects in the region. In addition, we found topics to be mixed up when discussing the reasons of such changes: pollution, mining activities, climate change and beliefs.

Although climate change is directly linked and will affect the concerns related to livelistock, feed and agricultural production, interviewees perceive that there are more urgent issues to solve. When people were asked about what are their priorities for capacity building, most interviewees identified production while climate change adaptation was rarely mentioned. Most interviewees indicated that they do not actively participate on climate change topics and even large fraction of interviewees did not remember recent initiatives, but reported even old interventions related to production (e.g. XXXX). Most interviewees consider that climate change is a problem for their children but without an inmediate impact. Instead, climate change seems to be used as a topic to ask for public or privete interventions.

Based on these preliminary findings, we propose that an early understanding of the perceptions, beliefs and priorities as well as promoting the involvement of local communities is fundamental for the success of any climate change adaptation policy or project. Interventions on climate change must include at their inception and design phases a proper knowledge of the society, otherwise compromising the sustainability and degree of success of investments once the intervention is finished.

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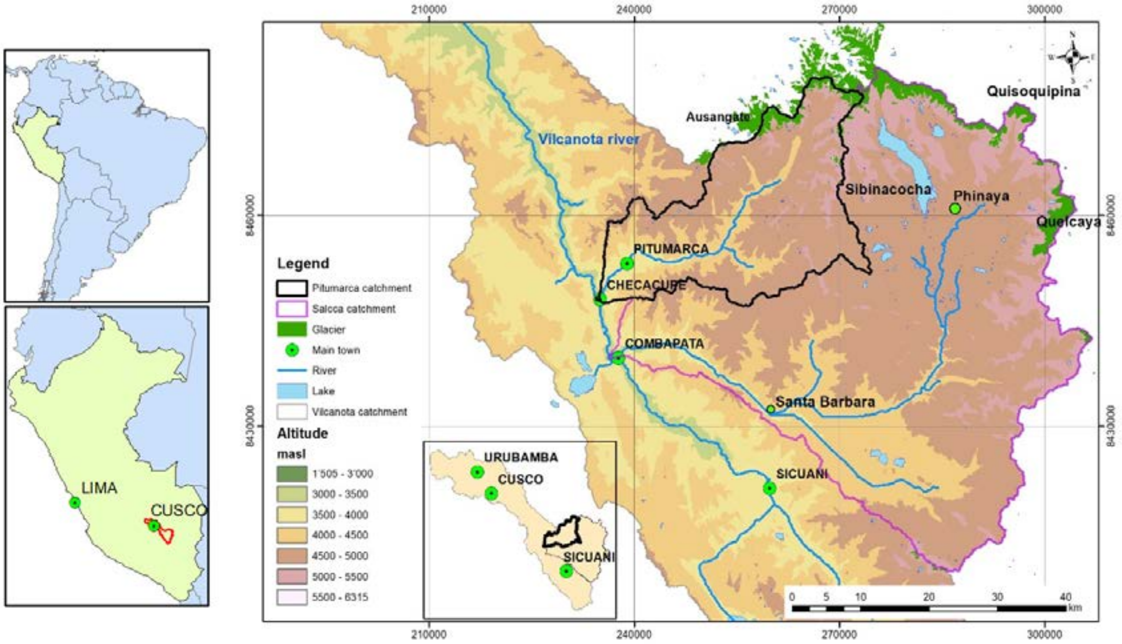

Figure 1. Location of the study site

27.10
State territorialzation and transition of forest frontier spaces in post-socialist Vietnam

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The paper examines substantive transition in forest spaces over the last three decades in one district of Upland Central, Vietnam. Using the well-known notion of state territorialization by Vandeergest and Peluso (1995) and political ecology analytical approach, the paper reveals that 30 years reform toward a socialist market-oriented economy model, the territorialization of forest spaces in Vietnam, has also transformed from a state-dominant to new polycentric process. From above, the state has been using new market-oriented conservation strategies, such as Payment for Forest Ecosystem Services to re-orient assemblages' actors engaged in forest governance but still can maintain control of forests and people. From below, through industrial tree plantation, the peasants have emerged as one important actor that engages actively in state forest territorial practices. Instead of resistance or be victims, they have made creative and resourceful use of whatever "materials" at hand, de facto and de jure - into a territorial strategy to secure their access to forest resources. These dynamics have gradually dissolving or altering existing social relations related to forests and distorting the current political forest territories and even creating new ones. It indeed is a dramatic structural reconfiguration of nature and society; and turns upland forest spaces become rupture frontier when the opportunities and risks multiply. This piece hopes to highlight the contribution to a fuller picture of state territorialization under the context of neoliberal environmentalism and call for more attention about its social-ecological implications from both academics and policymakers.
Keywords: State territorialization, Forest Frontier, Upland transformation, Central Vietnam

27.11
The hammer of extinction and the dance with wildland fire use; the new fire deal in Pyrenees to foster socioecological resilience to climate change challenges

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Episodes of extreme wildfires around the world show that firefighting policy only postpones the inevitable. Emergency organizations need to make a shift from suppression to resilience, including the ability to accept and manage some wildfires within pre-planned conditions. The particularities of the Pyrenees socio-ecological system, together with the need to adapt to the current emerging scenario of climate change lead to the creation of a new conceptual and operational framework. Our approach designs how to create a space-time window where fire experts can turn wildfires into prescribed burnings, and in such a contra-intuitive way emergency management can create landscape resilience at medium-long term. We use a transdisciplinary methodology approach offering a project for disruptive eco-innovation that we called the pyro-sustainability framework.

Pyro-sustainability is translated into practice by applying a pioneering methodology and developing a series of specific products with direct implications for emergency management organizations and landscape managers. Fire ecology, ecosystem services and the opportunity costs are recognized. The framework offers a technical solution tailored to the Aran that from the prioritization of the common good allows to find a conciliation of interests between the agents involved.

The proposal is based on the concepts of wildland fire use (WFU) and fire ecological flow (EF). WFU is the intervention aimed at monitoring the evolution of the fire to minimize its negative consequences and / or enhance the positive ones, deploying stabilization and fire support maneuvers to final anchors until the final extinction. EF is an analogy of the concept of water ecological flow and defines the quantity and quality of fire required to maintain essential processes in the self-organization and resilience of the forest ecosystem. Collaterally, EF reduces vulnerability to the collapse of the socio-ecological system, including emergency organizations.

In the event of a fire, this can only become a manageable fire if it is part of the emergency pre-planning, and only when conditions are compatible with the criteria set out in the prescription. Each proposed management sector has an operational file in which the EF parameter is specified through variables such as capacity, power, behavior, seasonality, and recurrence.

We also identify key environmental factors to assess potential impacts, based on modeling, wildfire community expertise, and bibliographic references. Potential benefits, vulnerabilities, and areas for improvement to mitigate adverse effects have been identified.

Although the project is in a specific valley of the Pyrenees, it may have a wider application in many valleys of this massif. At the same time, this transdisciplinary method could also be an interesting management tool beyond the Pyrenees since many other European mountain areas share similar challenges to deal with the management of common good and wildfire regimes in the context of global change.

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27.12
An operational framework for assessing transformative change through nature-based solutions in mountains

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Transformative change is the only way forward towards sustainability is one of the major conclusions of the IPCC and IPBES reports (Diaz et al., 2019; Hoegh-Guldberg et al., 2018). Research on transformative change has considerably increased in recent years (Köhler et al., 2019). However, few studies have assessed transformative change from an empirical social-ecological perspective (Colloff et al., 2020; Fazey et al., 2018). Given the urgency to undertake transformative changes, the study of on-ground examples with transformative change potential should be a core priority within sustainability science. Here, we provide a pragmatic operational framework to evaluate how Nature based Solutions (NbS) in mountains can contribute towards transformative change. Our framework allows to identify: (1) key elements that can catalyse transformative change; and (2) main characteristics to evaluate if transformative change has occurred. To operationalize our framework, we assessed 93 NbS from the PANORAMA platform. A bottom-up classification of NbS is presented to illustrate how the main components of our framework interact in practice. The evaluation of NbS with our framework allows for the necessary monitoring of NbS and tracking progress towards the sustainability of mounatin social-ecological systems.

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27.13
Relation between cryosphere and human activities: 280 years of adaptation of glacier tourism to glacier fluctuations.

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Alpine cryosphere has intimately been linked to human societies since centuries (Cruikshank, 2005). During the Little Ice Age (LIA), glacier tongues were used as “ice quarry” and ice was exported to the cities around. During the Medieval Climate Optimum, glacier shrinkage allows commercial ways through ice-free passes. Since 1741 and the discovery of the Mer de Glace by English tourists, societies have appropriated the glacier areas and developed a growing touristic activity throughout the different seasons of the year. However, this tourism niche is currently hardly affected by climate-related cryosphere changes all around the world, and adaptation strategies are developed to face this threat (Welling et al., 2015). To better understand the consequences of glacier shrinkage on glacier tourism today and assess resiliency changes undertaken by societies, we examine the way that cryosphere has affected the evolution of glacier tourism around the Mer de Glace since the end of LIA and how related stakeholders have adapted their activities. To answer this question, we use a methodology combining analysis of a series of hundred ancient pictures, comparison between different tourism guides edited since the early 19th century, review of the grey literature about this site, and conduct a series of semi-structured interviews with key informants from the Chamonix valley. First results show that glacier tourism around the Mer de Glace depends on glacier fluctuations since its beginning. On the one hand, touristic itineraries have changed or even disappeared due to glacier surface lowering and related geomorphological processes, some of tourism activities then became more dangerous or disappeared. For instance, the “Vallée Blanche’s” downhill skiing, which is an activity who have a wide reputation since decades, becomes more and more vulnerable since snow conditions are getting worse and glaciers are shrinking. On the other hand, the tourist attractors themselves have evolved in relation to the glacier shrinkage. For example, the famous “Montenvers-Chapeau” itinerary become possible because of the retreat of the glacier in the mid 19th century. Since the beginning of the 19th century, stakeholders have adapted their businesses: “cave watchers” became engraving sellers, or mountain guides adapted their practices to the evolution of paths due to the glacier dynamics. In the light of past evolutions of glacier tourism, the adaptation of stakeholders to the current glacial retreat is the result of a long process. However, the current rate of cryosphere changes (Bosson et al., 2019), the prominence of tourism in the concerned regions, and the complexity of today’s tourism system requires a new approach towards adaptation to ensure sustainability and resilience.

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27.14
Is tourism the beginning or the end? Livelihoods of Georgian mountain people at stake

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This study was an attempt to empirically understand the transformation of rooted livelihoods after tourism's arrival in mountainous Georgia. A case-specific methodology combining qualitative and geographical information methods facilitated the uncovering of four types of tourism-led livelihood changes; particularly i) New and/or expanded non-agricultural livelihoods; ii) Reduced and/or abandoned traditional livelihoods; iii) Tourism with agriculture; and iv) New and/or increased agricultural livelihoods. The broad spatial coverage ensured the collection of representative data, embodying remote residents' voices in the study. The findings indicate that although some residents tried to engage in tourism through economic fields other than agriculture, such precedents appear to be exceptional. We argue that the realm of beneficial opportunities from tourism, through the eyes of mountain residents, is narrow and mainly associated with agriculture and tourism itself. However, only a portion of the locals expanded agricultural activity along with tourism's increased demand for agri-products, as several barriers (lack of human capital, modern technology, and finances) impeded this opportunity for other residents. As the study revealed, households based on traditional livelihoods mostly replaced agriculture by directing all their resources to develop tourism-related livelihoods. Others created added value from their synthesized (agriculture – and tourism-based) livelihoods through providing visitors with locally made products. After looking behind the scenes of livelihood trend shifts, the study also aided in developing an understanding of households' imperative motifs of economic priorities reappraisal. We trust that the new insights surrounding tourism-provoked livelihood shifts will commence debate on how people in mountain regions cope with the swift spread of tourism.

27.15
Developing indicators for sustainable regional development in mountain areas

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Scientific studies show that park areas and world heritage sites can make a substantial contribution to regional value creation and development. A central role in these mechanisms is the guaranteed protection of important resources such as glaciers and water reservoirs or biodiversity due to a globally recognized protection status. Beyond the protection of biophysical resources, keeping alive traditional cultural landscapes, institutions and local forms of knowledge is an important feature of heritage sites too. This feature is crucial as it builds the bridges between natural and cultural resources in heritage sites within broader spatial contexts. The comprehensive view on heritage sites, therefore, opens up novel pathways for positioning heritage sites as social-ecological systems that play an important role in regional sustainable development. The contribution of these areas to sustainable regional delevopment is mainly evident in tourism through the creation of jobs in related sectors such as hotels, outdoor infrastructure, tourist services and visitor catering. In addition, these areas often have indirect effects on infrastructure, industrial sectors or agricultural structures. However, little is known about the potential of heritage sites and park areas as social-ecological systems to contribute to sustainable regional development. Often neglected but potentially strong elements, these areas should be integrated into sustainable regional development agendas.

This knowledge gap is closely related to the lack of globally comparable indicators for assessing sustainable regional development in mountain areas in general. Comparable indicators are a necessary prerequisite to monitor and analyze sustainable regional development and, where necessary, to intervene. Hence, a globally comparable set of indicators for sustainable regional development in mountain areas can present a basis for decision making in affected areas, particularly in the face of global changes such as climate and land use change, biodiversity loss, migration or changed social and cultural conditions for inhabitants of mountain areas.

Heritage sites and park areas offer themselves for the development of an indicator set for monitoring and evaluating sustainable regional development in mountain areas if they are treated as comprehensive social-ecological systems as mentioned before. Their development is an inter- and transdisciplinary endeavour that relies on the integration of different types of knowledge from social and natural sciences as well as from actors with a non-academic background. While the social and natural sciences can contribute their expert knowledge to questions of social wellbeing, economic development, environmental quality or the changes of physical parameters, the knowledge of non-academic actors is essential for defining desirable futures and environments they would like to live in. The process of defining desirable futures contains many normative aspects and has to rely on social negotations rather than drawing on scientific knowledge alone.

In this contribution we introduce a transdisciplinary approach for developing a set of indicators for sustainable regional development in mountain areas. This approach is being applied in several research projects on the sustainability of food systems, just transition within food systems, and sustainable regional food provision in mountain huts. We present some of the learnings of this approach and point to pitfalls when engaging in such processes.

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P 27.1
Factors that facilitate and hinder the development of inter and / or transdisciplinary projects for improving quality of live of smallholder integrated farming systems in the Peruvian Andes

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In Peru, the poorest of the poor live the arid Andean highlands (over 3,500 masl) where the majority of the indigenous Quechua and Aymara communities live below the poverty line are dependend on agriculture (IFAD, 2013). In this environment, livestock is produced by small-holders in complex agricultural systems that integrate livestock and crop production (integrated farming systems). However, existing integrated farming systems have a low productivity, high dependence on natural resources, and are volunerable to the impacts of climate change. Although climate-smart agircultural strategies exist to improve the productivity, adaptation to climate change and reduce greenhouse gas emissions of these sytems, their implementation is limited, because of lack of political suport, financial resources, materials, and training. This leaves smallholder livestock producer volunerable to climate change and food insecurity.

To better understand technical, economic, and socio-ecological dimensions that influence local decision-making regarding integrated farming systems in the Andes inter- and/or transdisciplinary research is needed. However, little is known about the factors that facilitate and hinder the formation of research collaborations. Heberlein (1988) suggested that visible and invisible barriers seem to keep natural and social sciences apart, which leaves the public is ill served as researchers will often just present pieces of the puzzle and rarely the whole picture. Hence, the aim of the present study was to (i) determine the perception about the importance of inter- and/or transdisciplinary research projects related to livestock production in the Andes among professionals, (ii) identify elements affecting the formation of collaborations of natural and social scienctist, and (iii) estimate existing capacity at professionals to conduct inter- and/or transdisciplinary research. For this purpose surveys were applied to thirty five profesionals coming from natural sciences (veterinarians, biologists, animal scientists, agronomists) and social sciences (sociologists, anthropologists, political scientists) with previous experience in conducting inter- and/or transdisciplinary research in the Peruvian Andes.

Results obtained are very interesting. First, there wasn't different perception between social and natural scientists. In relation to the importance of inter- and/or transdisciplinary research:

- 77% of the profesionals indicated that the institution to which they belong considers the execution of inter- and/or transdisciplinary research as important.
- 66% reported that they have observed in the last years an increased need for integrating natural and social sciences
- 63% agree that national and international funding available for research stimulate and provide conditions to implement projects that include inter and / or transdisciplinary teams.
- 63% think that the integration between the social and natural sciences can contribute to a better generation of results in terms of sustainable development, 23% in terms of socio-environment capacity transformation, and only 6% in terms of social justice.

In terms of factors affecting inter- and/or transdisciplinary research:

- 60% identified that adequate conformation of research teams is a main factor for facilitating the process of integration of natural and social sciences in inter and/or transdisciplinary research, 17% indicated regulations to promote this type of studies as the main factor and 14% the availability of funds for conducting research that way.
- 54% reported epistemological paradigms as the main one for limiting the process of integration of natural and social sciences in inter and/or transdisciplinary research, 26% suggested the nature of methods applied in natural vs social sciences as the main factor and 11% the presence of different research objectives.

In relation to capacity building:

- Only 40% think that training of profesionals in natural or social sciences at universities provides sufficient integral skills to professionals to ensure their effective participation in inter and / or transdisciplinary research work.
- 14% reported that their own university training gave them sufficient skills to develop inter and / or transdisciplinary research work, 49% some competences and 37% declared haven't received any training related to inter and/or transdisciplinary research during their bachelor studies.

The results of the present study highlight the importance of inter- and/or transdisciplinary research for professionals. Conformation of research teams was indentified as the most facilitating factor for conduct inter- and/or transdisciplinary research, while a lack of adequate training at university level and difference in epistemological paradigms was identified as one of the most hindering factors. Openess to transversal epistemological approaches and training of young professionals in inter- and/or transdisciplinary research approaches are suggested to improve the impact of future research project to improving quality of live of smallholder integrated farming systems in the Peruvian Andes.

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P 27.2
Glacier Tourism facing climate change, a research project across the Alps

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Glaciers througouht the Alps are receding quickly because of climate change (Sommer et al., 2020). This generalized receding of glaciers has consequences for human societies, whether in terms of water resources, hydroelectricity or even for the tourism activities that have been developed around. Glaciers are a touristic object that are bringing millions of visitors per years (Welling et al., 2015). The impact of climate change on glacier tourism is beginning to be well-knows around the world but are still lacking in the Europeans Alps. In this context, the aim of this research project is to understand how glacier tourism are impacted by glacier retreat in the European Alps. Furthermore, this poster aims to summarize the differents results achieved since 2018. The research project presented has been developed around three main research questions: How glacier tourism operators are impacted and adapt to climate change? How glacier retreat and associated process, including landscape evolution, are drinving changes in visitors' behaviour? How glacial fluctuations since the end of the Little Ice Age (LIA) are driving changes for glacier tourism? Different methodologies has been applied to answers those questions and differents glacier tourism places has been investigated in France, Switzerland and Austria. The different interviews conducted with glacier tourism stakeholders show that there are all impacted by the effect of climate change. The impacts can be varied including the degradation of the glacier's access, increase in the risk regarding glacier activities, changing in the activities timing, infrastructure destabilisation or also decrease in attractivness. Different adaptation strategies are developped including tourism planning, glacier shrinkage attenuation, access evolutions, internal reorganisation, enhancing of heritage dimension or also development of new infrastructures. The different quantitative and qualitative survey conducted with glacier tourism visitors show that the more they are aware about climate change, the more they decide to come to see the glacier before its disapear in a Last Chance Tourism (LCT; c.f. Lemelin & Whipp, 2019) perspective. LCT motivation in glacier tourism context is driving by four different dimensions including the desire to observe and understand the impacts of climate change,a willingness to come before its to late and a desire to witness environmental changes with others. The first results concerning landscape perception show that despite the tourism operator perception, visitors are mainly satisfied by their visits and had negative impression only on the glacier itself that its not negatively affect the overall appreciation. The glacier landscape also drive important emotions mainly related to sadness. In a historical perspective, results from different methods including grey literature review, analysis of historical documents and interviews show that glacial fluctuations have always had an impact on tourism activities. Sometimes the receding glacier allows glacier tourism actives to be developped, for example in the middle of the 19th century. However, such glacier retreat also drives negative changes including activities disapearance as it happened for the crossing of the Mer de Glace in the 20th century. Those differents results shows that European glacier tourism is impacted by glacier tourism in many ways and raise questions about the futur of glacier activities. First, most of the adaptation strategies developped by stakeholders are incremental (c.f. Fedele et al., 2019) and do not allowed to ensure future sustainability. Accordingly, academics could work with tourism stakeholders to develop long-term adaptation strategies to climate change. Second, glacier tourism often require large infrastructures, and visitors emit greenhouse gaz emissions by travelling to the site. View throught this lens, LCT visitor inderectly destroy what they come to see. In summarize, is glacier tourism can be sustainable and how to achieve it? One argument can be to consider that viewing glacier can enhance climate change awareness and be a vector of improving pro-environemental behaviours. Future studies could try to answer those questions. Some has be done to understand how European glacier tourism respond to climate change, but many has to be done to ensure sustainable futurs.

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P 27.3
Impacts of climate and land use on 12,000 years of vegetation dynamics in the Italian Alps

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Mountain ecosystems, and specifically the tree line ecotone, are very sensitive to changes in temperature and as a result extremely vulnerable to climate change. However, climate change is not the only factor driving vegetation change over time; human land use and other factors such as soil development/degradation or disturbance also play a major role in shaping ecosystem properties, vegetation composition and species distribution. Given the long-term processes involved, assessing past vegetation dynamics and the influence of the different forcing factors on the vegetation may decisively contribute to refine predictions of future vegetation change. We analysed lake sediments from Lago Sangiatto (1980 m a.s.l.), a small lake located close to the tree line, to study the interactions between climate, land use, fire and vegetation. We reconstructed the vegetation- and fire history around the lake for the past 12,000 years by using pollen, stomata, *seda*DNA, macrofossils and charcoal as our proxies. Lago Sangiatto is situated in Ossola in the Italian Alps (timberline at ca. 2050 m, treeline ca. 2250 m a.s.l.). This area has not been studied extensively yet, despite its ecological and historical importance.

The sediment record of Lago Sangiatto starts during the Younger Dryas and spans the entire Holocene. Our results show afforestation started at 10,900 cal. BP with *Larix decidua* and *Betula*, which formed open forests together with *Pinus cembra* and *Abies alba* from 10,600 cal. BP onwards. From 5,200 cal. BP the first human impact on the vegetation can be detected, with expansions of *Picea abies* and *Alnus viridis,* in connection to land use activities and disturbance. Redundancy analysis and GAM models show that livestock grazing and fire were major drivers of vegetation change at Lago Sangiatto. Increasing human impact, mainly livestock grazing, led to the formation of diverse larch meadows and alpine pastures during the Bronze and Iron Age.

This study is the first radiocarbon-dated multi-proxy study from Ossola that describes vegetation dynamics in response to climate change and disturbance. Our results suggest that under anticipated climate change and continuing land abandonment timberline will likely shift to higher altitudes, leading over the centuries to changes in species compositions and potentially biodiversity losses. Moderate grazing activity would likely maintain today's diverse alpine meadows. We can thus recommend it as an effective way to mitigate adverse climate change effects on alpine ecosystems.

P 27.4
How Indigenous Methodology can contribute to the Sustainable Mountains Development: A Case Study of Bamyan Province, Afghanistan

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Mountain ecosystems are significant for the sustainability of the global ecosystem. Baba Mountains which lie not far from the city of Bamyan province in Central Afghanistan have been identified as the greatest and most popular tourist spot in war-ridden Afghanistan. The people of Bamyan city are mainly engaged in agriculture and livestock. The paper argues how traditional and indigenous knowledge in agriculture has largely contributed to the sustainable development of the Baba Mountains in Central Afghanistan. A semi structured questionnaire was prepared. For the purpose of the paper, a group of experts mainly ecologist, agriculturist, regional development expert, academia and environmentalists and a group of indigenous people who are engaged in farming along the Baba Mountains were interviewed. The outcome of the paper shows how indigenous knowledge in sustainable agriculture has largely contributed to the sustainable development of the Baba Mountains ecosystem in Bamyan city, Afghanistan and how the usage of such methodology has economically benefited the farmers along the Baba Mountains. The authors of the paper argue that incorporating indigenous knowledge in agriculture in mountainous Afghanistan will lead to the sustainable development of the mountains ecosystem in Afghanistan.