

14. Limnology in Switzerland and the new LéXPLORE infrastructure

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Swiss Society for Hydrology and Limnology SGHL

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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 CIP AIS 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.

Architecture - Service Oriented Application (SOA)

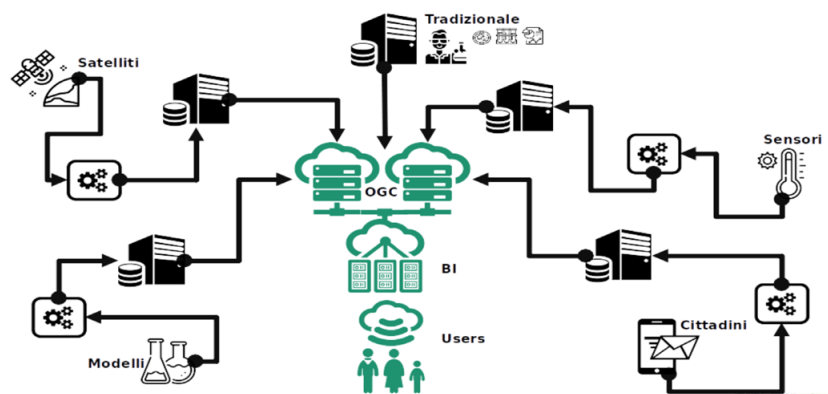


Figure 1. SIMILE's information system architecture. It includes the management of data obtained from Satellites, Numerical Models, Traditional laboratory analyses, real time in-situ sensors and citizens.

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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 $+1.8 \text{ gO}_2 \text{ m}^{-2} \text{ d}^{-1}$ in the upper 30 m of Lake Geneva during summer 2019, with a mean GPP of $7.5 \text{ gO}_2 \text{ m}^{-2} \text{ d}^{-1}$ partially balanced out by a mean R of $5.8 \text{ gO}_2 \text{ m}^{-2} \text{ d}^{-1}$. 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.

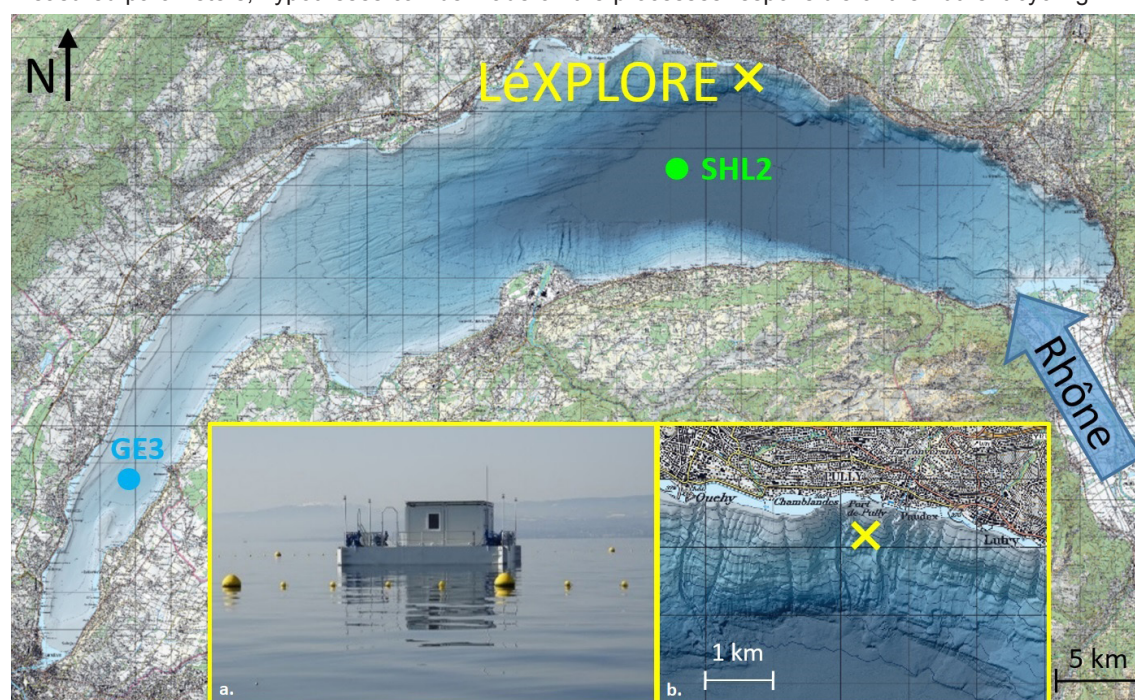


Figure 1: Map of Lake Geneva showing the location of the LéXPLORE platform as a yellow cross. The Rhône River inflow is indicated by a blue arrow. The blue and green dots represent the locations of the two permanent monitoring stations within Lake Geneva. Insets : a. Image of the platform. b. Larger 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 direct and indirect effects of climate change. The ca. 80 % reduction in phosphorus has not yet resulted in a decrease 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 longimanus* - an important food source for coregonid fish in the lake - are declining. In this project (Trophic Bottlenecks in le Léman – TaBLE) we investigate whether an increase in the carbon : phosphorus 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 (Malzhahn 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 seston's 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 opportunities 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 wind seemed 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 LEXPLORE (<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 proxies 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 m² offers multiple accesses to the water column extending to a depth of 110 m. Around the platform, a protected area of 15'000 m² 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 CARRETEL (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 parallel. Some projects concentrate on the ecosystem functioning 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 opportunities and current research projects. We invite any interested scientists to already visit lexplore.ch and join us by filling in the project application form.

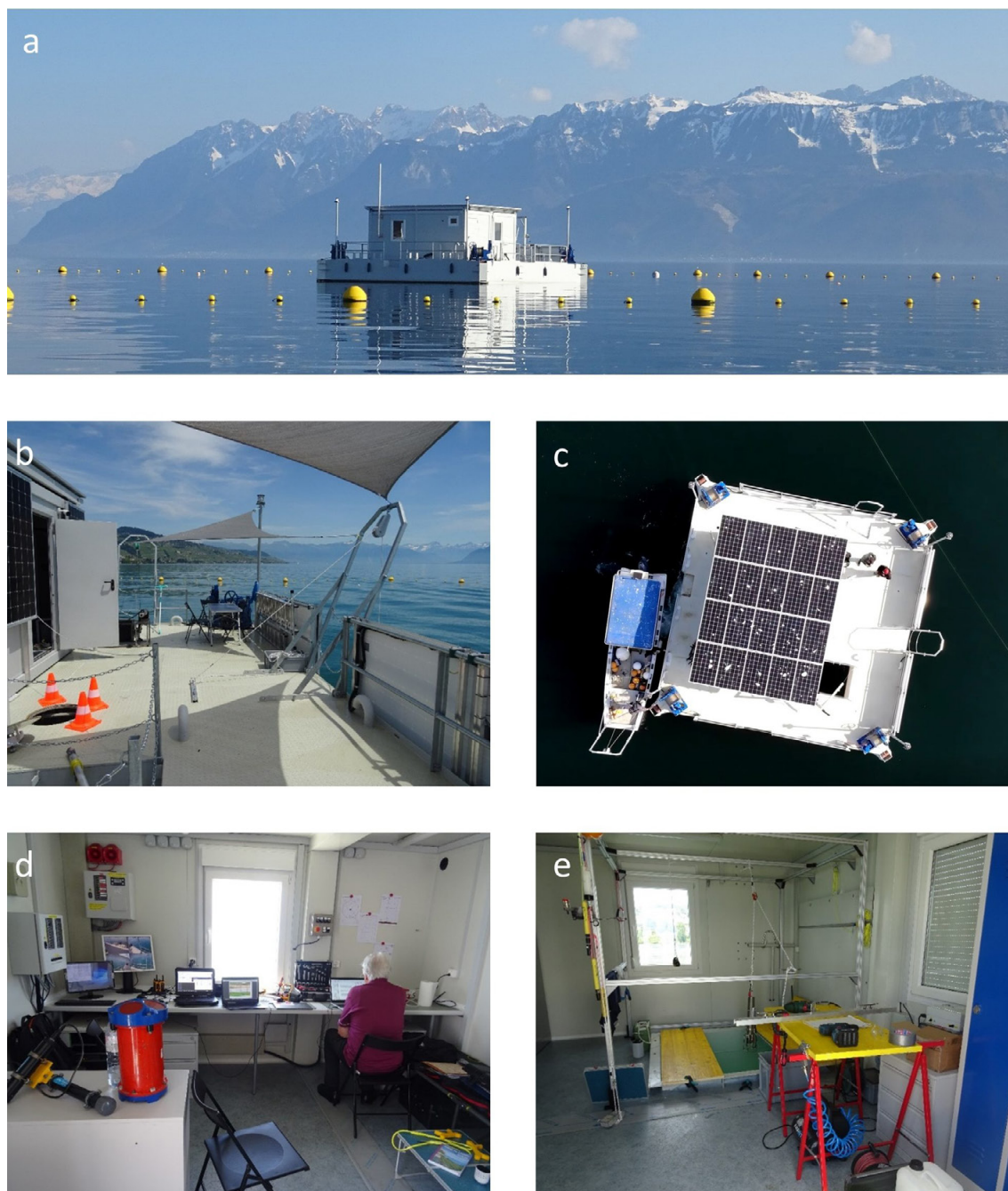


Figure 1. a) General view of the LéXPLORE platform with the protection perimeter, b) southern outside deck, c) top view of the platform, d) working area inside the cabin, and e) view on the moonpool inside the cabin

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 through 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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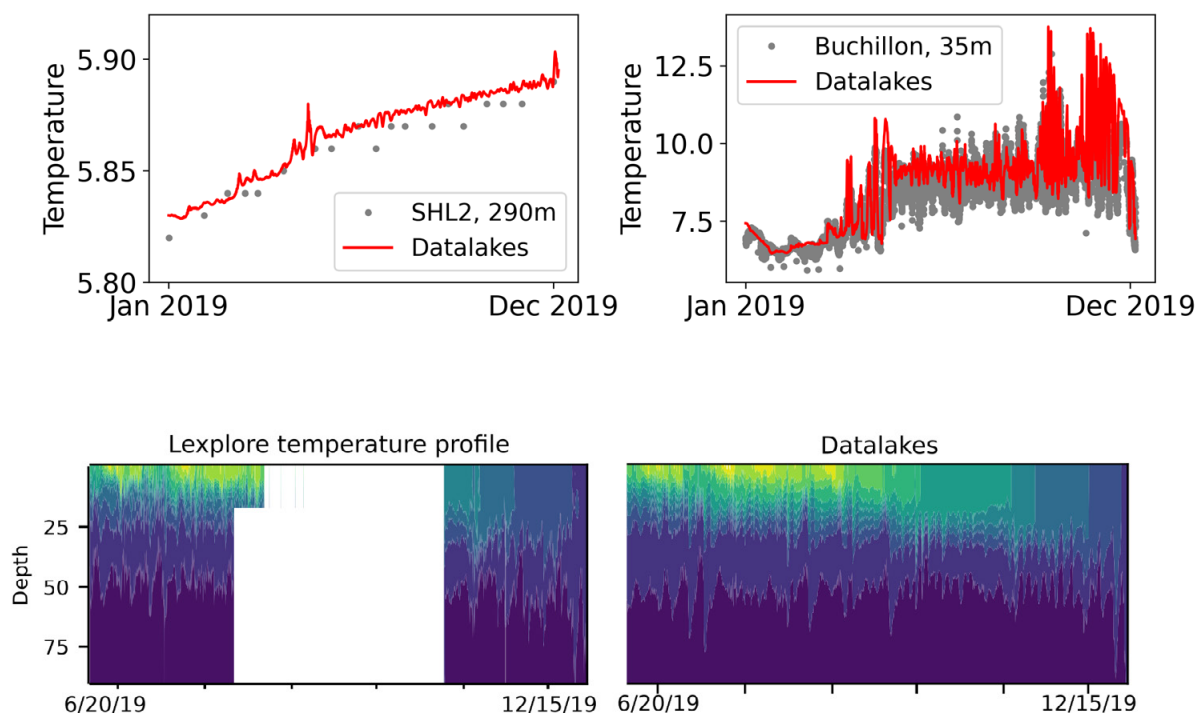
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The steady expansion of computational resources has enabled the use of complex high-resolutions hydrodynamic models. In parallel, we observe a gradual increase in the number of high-resolution in-situ measurements and a rising use of remotely sensed 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.



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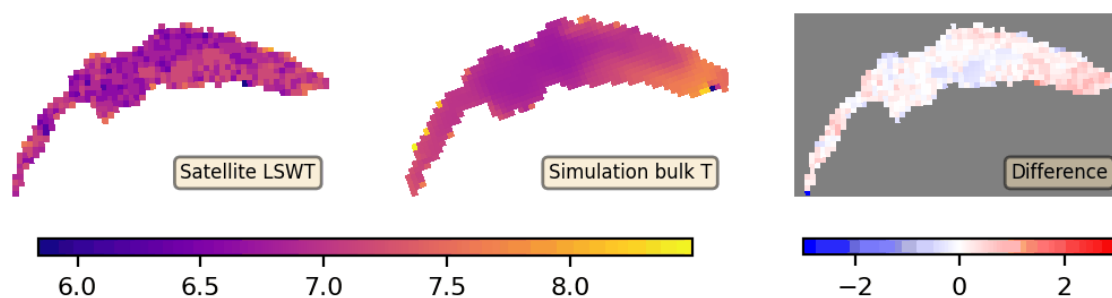


Figure 1. Preliminary comparison between observational data and DATALAKES hydrodynamic model prediction. Top: comparison for in-situ measurements of Buchillon (left) and SHL2 (right) data. Middle: LéXPLORE thermistor chain (white space indicates gaps in measurement). Bottom: a sample comparison of simulated 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.

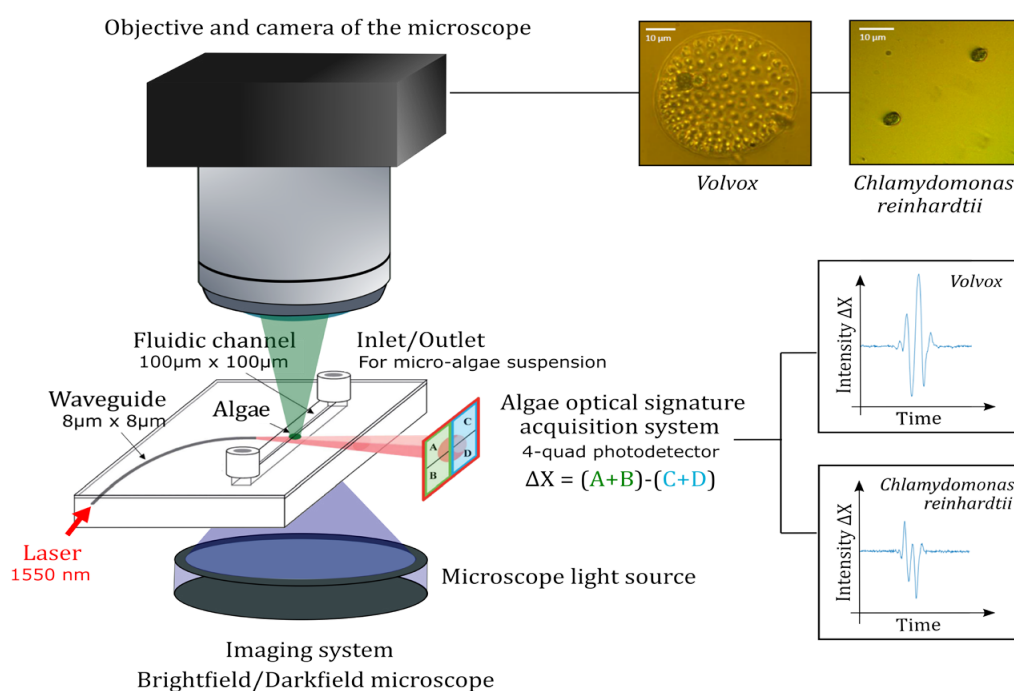


Figure 1. Schematic overview of the microalgae analysis device. Water containing phytoplankton circulates in a fluidic channel of a glass microchip. When a particle crosses an infrared light beam, it triggers an image snapshot taken from a microscope. Algae when passing through the light-beam produce 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).

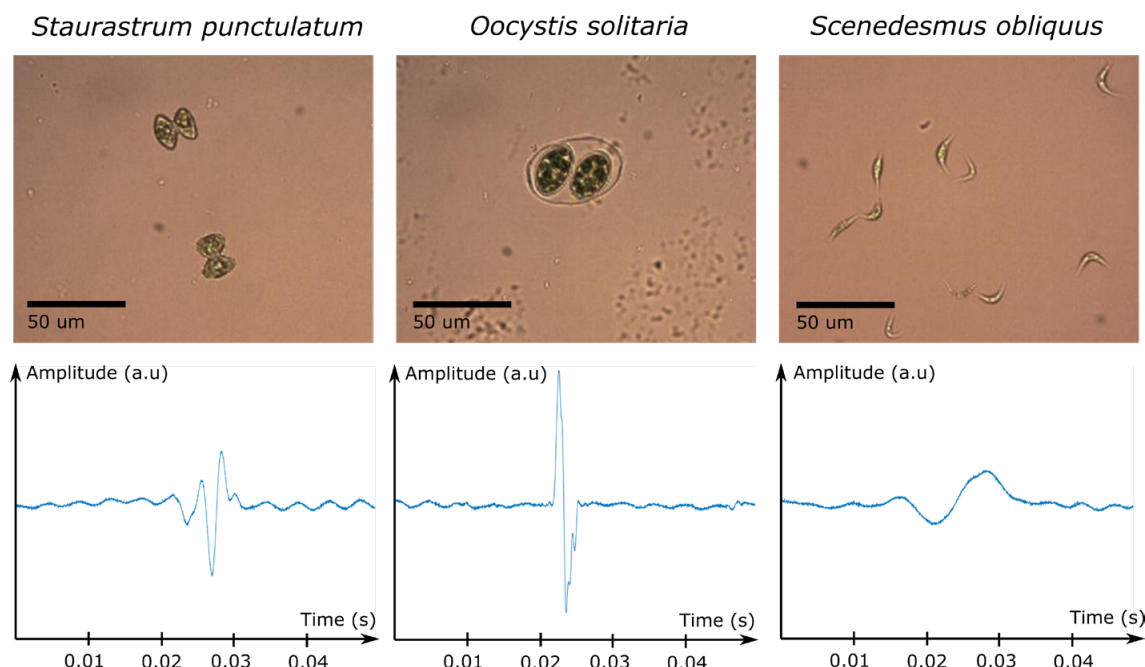


Figure 2. Example of wavelets, typical of three species of microalgae (*staurastrum punctulatum*, *oocystis solitaria* and *scenedesmus obliquus*), analyzed with the optofluidic set-up built in the laboratory. Each wavelet corresponds to the passage of one alga in front of the detector.

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.

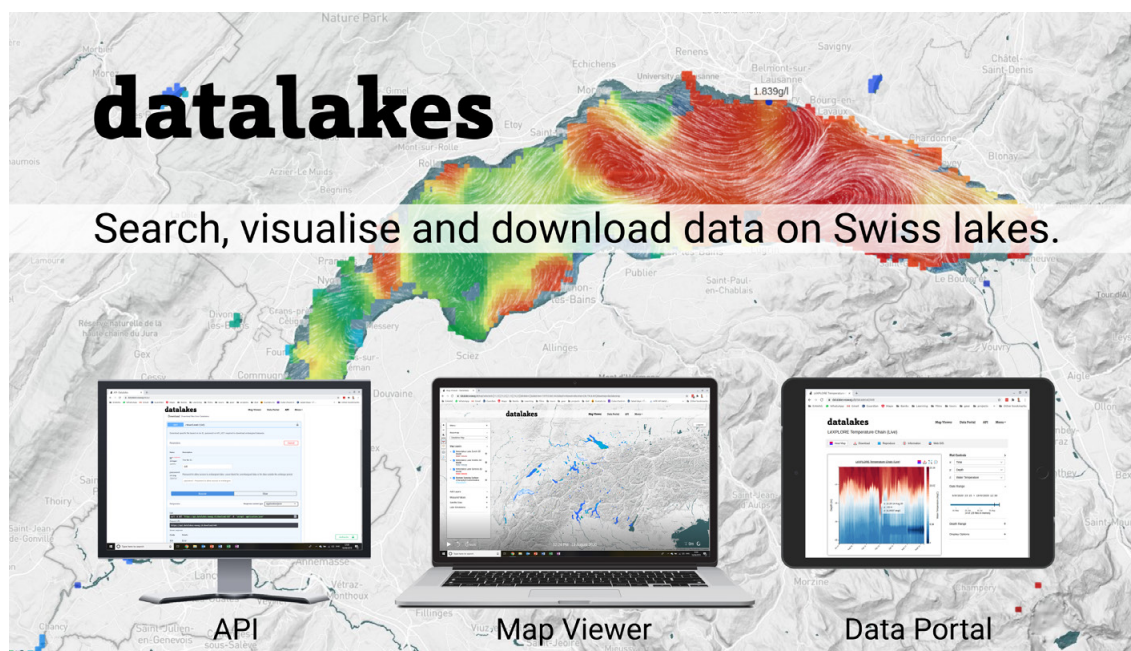


Figure 1: Overview of the Datalakes platform <https://www.datalakes-eawag.ch/> . Heat map for Lake Geneva representing the total suspended matter estimated from Sentinel 3 satellite and white lines the lake surface current estimated from meteolakes.ch.

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 $\sim 20 \text{ m}^3 \text{ s}^{-1}$.

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 revealed 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.

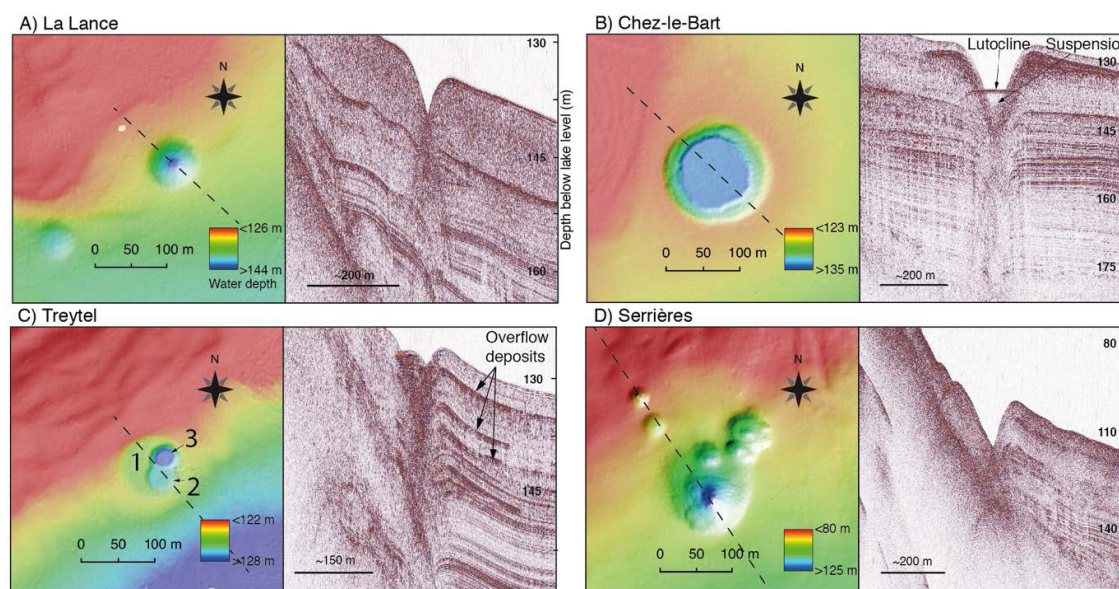


Figure 1. Morphological details and reflection seismic profiles (3.5 kHz pinger) of the four giant pockmarks. Dashed lines show position of seismic profile.

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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 (O₂) during the day, carbon dioxide (CO₂) and methane (CH₄) 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 O₂ (Brothers et al. 2017), the calculation of CO₂ budget in the mixed layer (Czikowsky et al. 2018) and the presence of CH₄ 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 km²) 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 thermistor chains were coupled with upward-looking Acoustic Doppler Current Profilers (ADCPs) to collect velocity data. Dissolved gases concentration (O₂, CH₄, CO₂, N₂, 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 (CH₄ 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.

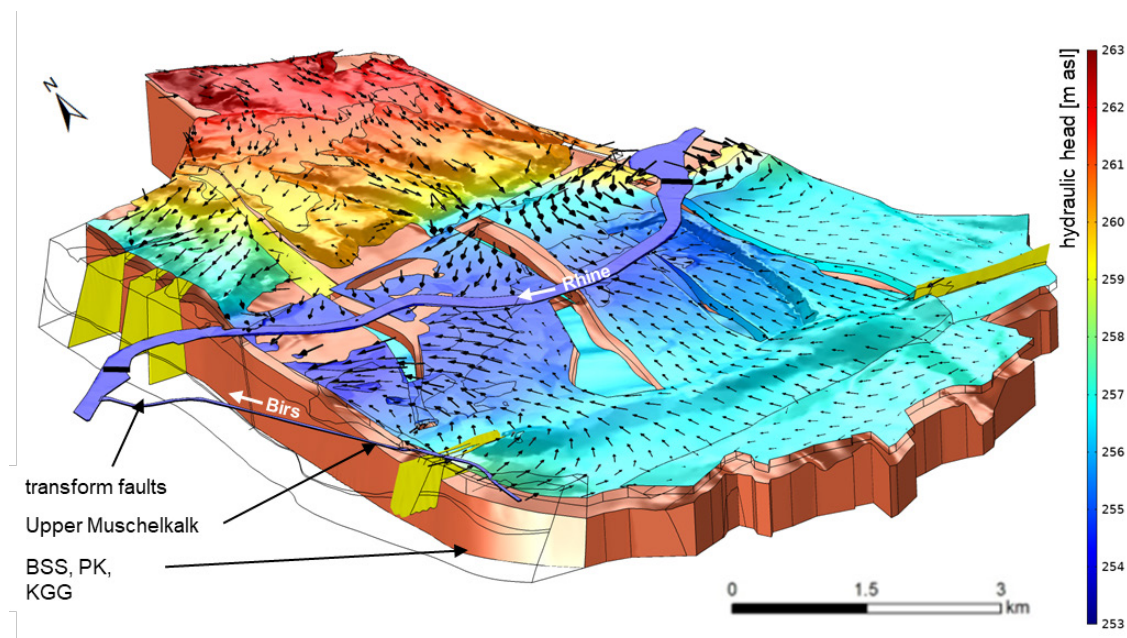


Figure 1. Groundwater flow regime in the Upper Muschelkalk. The color scale shows the hydraulic pressure in the Upper Muschelkalk in absolute height, the arrows show the logarithmic distribution of Darcy flow velocities (BSS: Buntsandstein Group, PK: Permo-Carboniferous, KGG: Crystalline basement).

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 best 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 ($U_{10} > 5 \text{ m s}^{-1}$), 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).

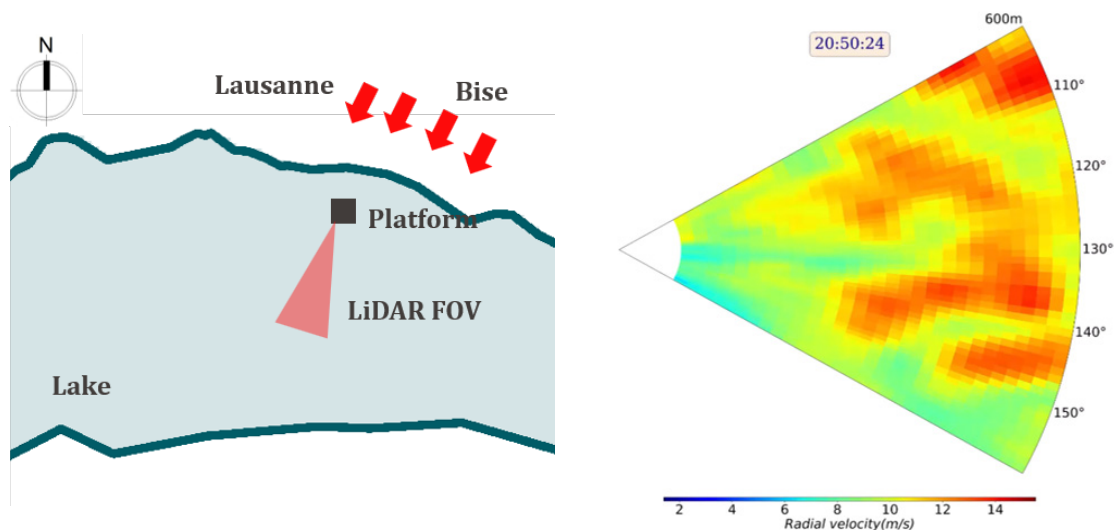


Figure 1. (left panel) A schematic of the LiDAR configuration on the LÉXPLORE platform showing the Field Of View (FOV; red triangle), Red arrows indicate the Bise wind. (right panel) An example of the 600-m horizontal arc sector LiDAR measurements of the wind field (taken at 20:50:24 on 14.04.2020) degrees 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 where 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 meteorological 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.

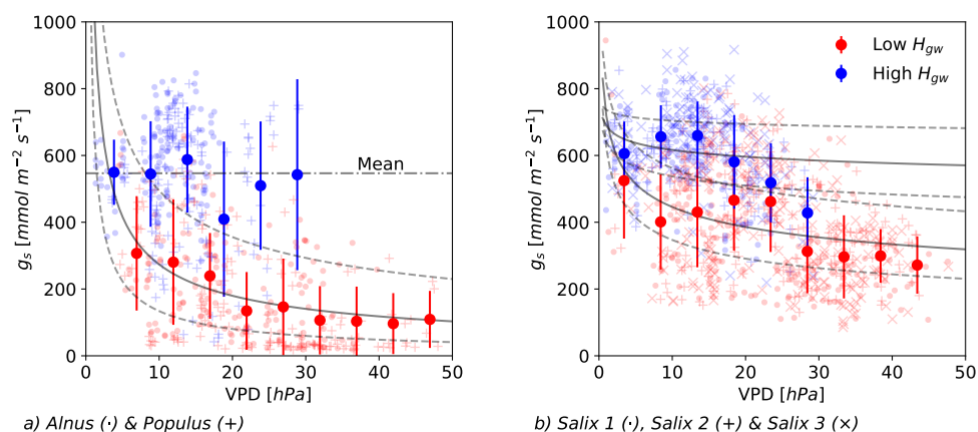


Figure 1. Relationship between stomatal conductance g_s and vapor pressure deficit VPD for two periods of low (red) and high (blue) groundwater levels for (a) *Alnus i.* and *Populus n.*, and (b) three *Salix e.* The data was fitted with a power-law model. The dotted line shows the 95%-confidence interval 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 Oxidic 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 depths (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 \pm 0.047 ng/g in May and 2.51 ng/g \pm 0.46 ng/g in June), highlighting the fact that bottom sediments and settling 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-dimensional (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 artificial 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

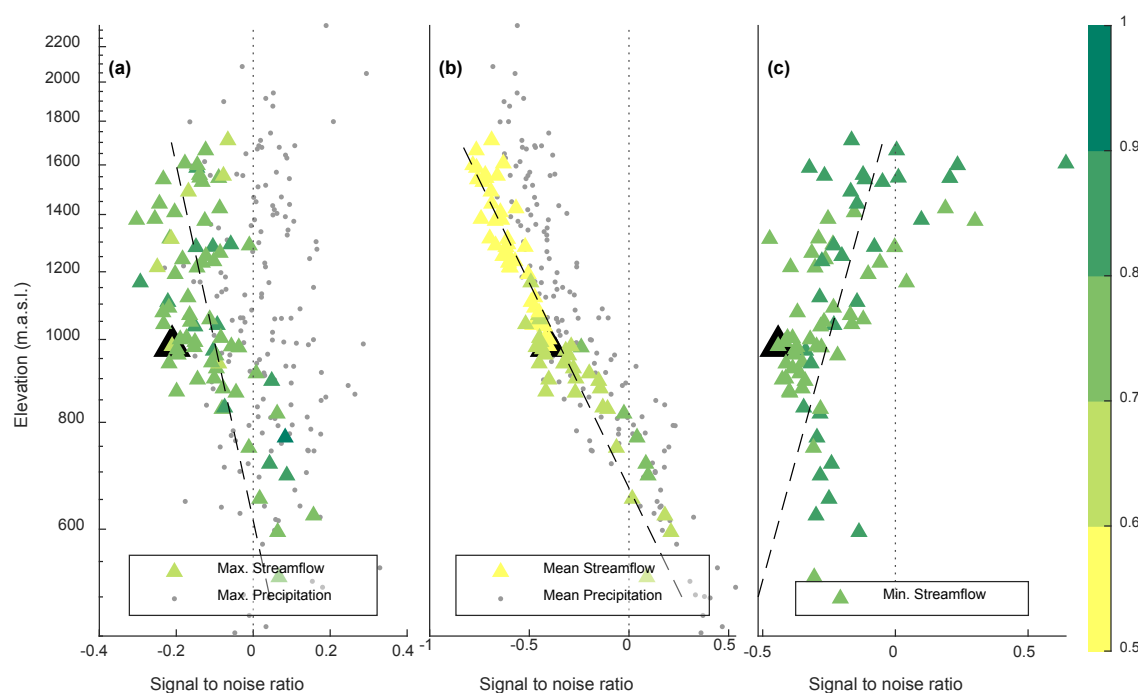
Elevation-dependent impacts of climate change on Alpine Hydrology: High-resolution modelling and uncertainty estimation

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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 climate 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.



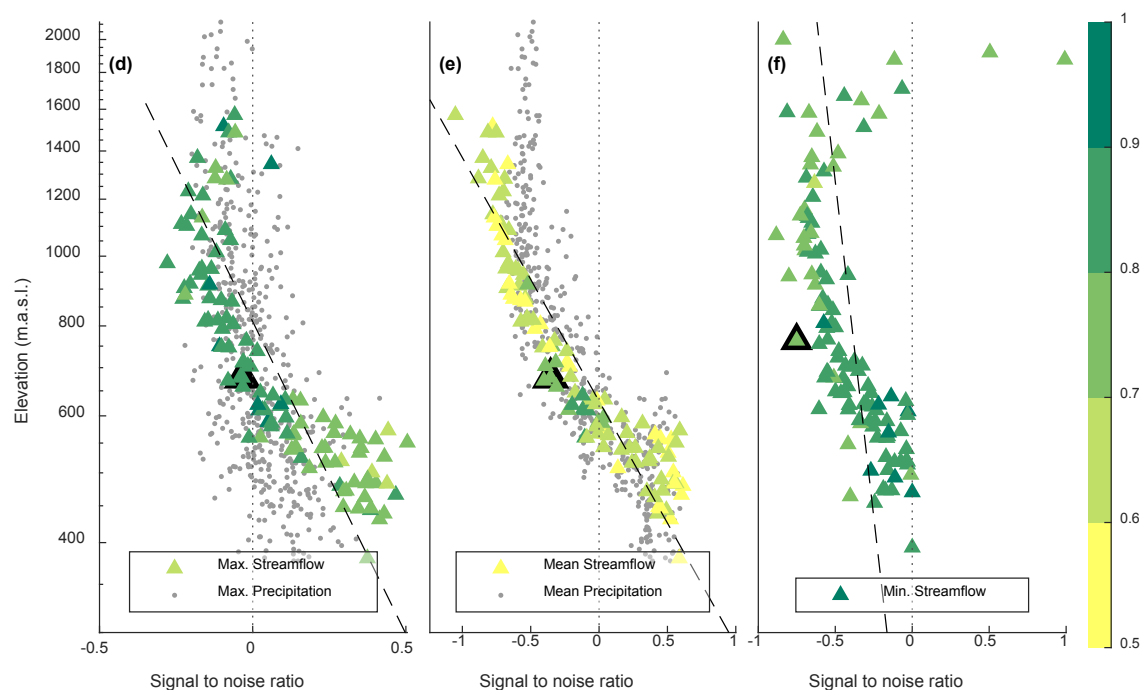


Figure 1. Signal-to-noise ratio (STNR) in the Kleine Emme (a-c) and Thur (d-f) catchments for hourly maximum (a, d), mean (b, e), and low flows (c, f) compared to the median elevation of the sub-catchment. A fitted semi-logarithmic regression is superposed to the plot. The STNR of maximum and mean precipitation 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 RAINBOW_{FLOW} 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 addition 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**Robin Weatherl^{1,2}, Maria Henao-Salgado, Mario Schirmer^{1,2}¹ EAWAG, Ueberlandstrasse 133, CH-8600 Dübendorf (robin.weatherl@eawag.ch)² Center for Hydrogeology and Geothermics, University of Neuchâtel, Avenue du Premier-Mars 26, CH-2000 Neuchâtel

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 impacts, 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 CO₂ emissions at a global scale, these fluxes are almost never directly measured. Instead, fluxes are often estimated from a restricted number of CO₂ 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 CO₂ 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 CO₂ fluxes in Lake Geneva, a large hardwater lake, from an automated (forced diffusion) flux chamber to computed values based on high frequency CO₂ 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 CO₂ concentrations. We evaluated the performance of the different models, and identified the importance of considering wave breaking during wind event to improve the CO₂ flux estimation in large lake. Altogether, we show how crucial the choice of k -models and the high-frequency of data are for CO₂ 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.

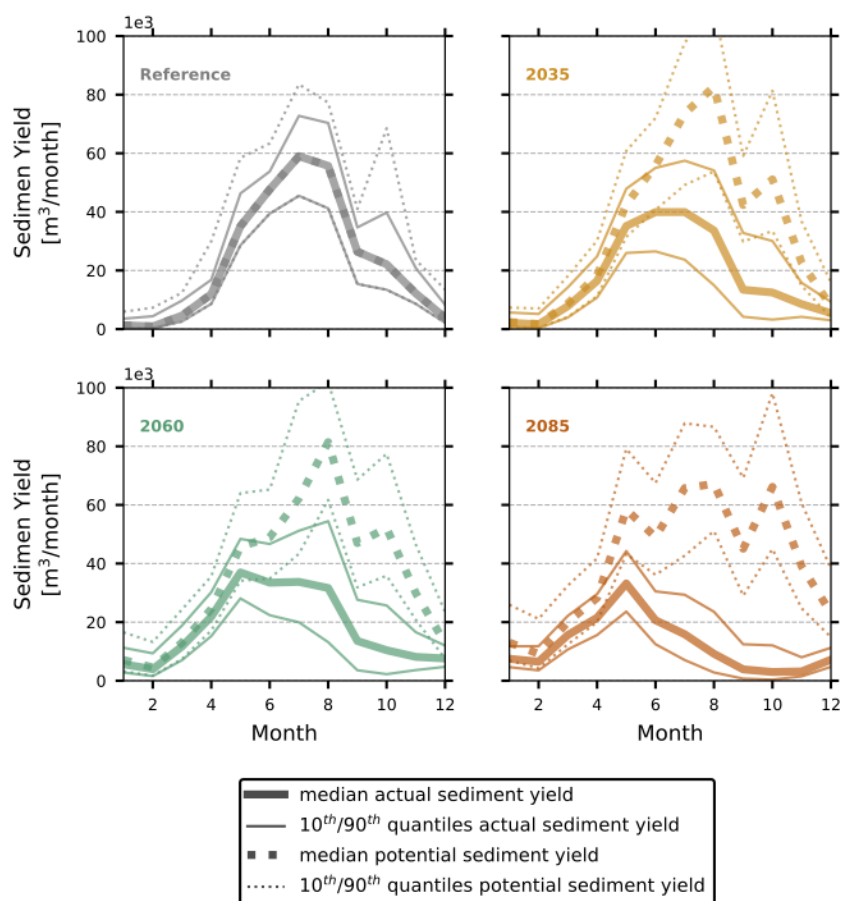


Figure 1. Mean monthly sediment yield at the Illgraben computed with SedCas and AWE-GEN for the reference and three future periods. Solid and dashed lines show the actual sediment yield in sediment supply-limited and supply-unlimited conditions (i.e. potential), respectively. Thicker lines are medians and thinner mark the 10th and 90th percentiles.

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P 14.17**Lake-atmosphere CO₂ 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 (CO₂) fluxes between water bodies and atmosphere is of fundamental importance for the global carbon budget and specifically for the atmospheric CO₂ content, which influences our climate. In recent decades, large efforts have been made in the direct measurement of CO₂ 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 CO₂ 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 CO₂ chambers equipped with a CO₂, temperature, relative humidity sensor are employed for the measurement of the fluxes; the same sensor is installed above the lake to measure CO₂ concentration in air; a precise CO₂ 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 CO₂ 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 research 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 monitoring frequency can result in large uncertainties, especially for seasonal trends. Continuous temperature measurements are therefore recommended for monitoring climate change impacts in lakes.

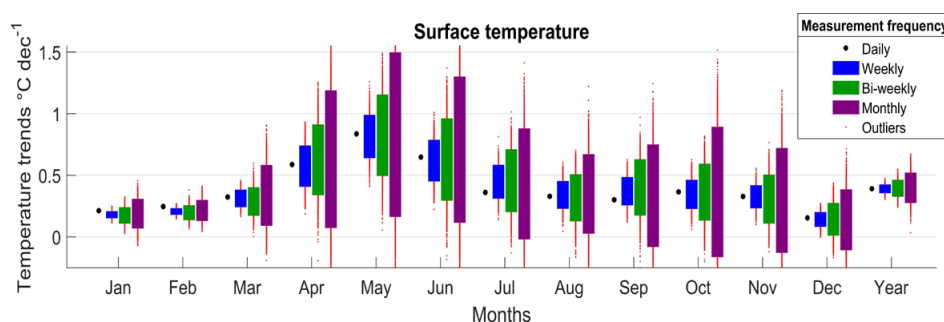


Figure 1. Monthly trends of lake surface temperature ($^{\circ}\text{C decade}^{-1}$) calculated from 33 years of simulated temperatures for Lake Zurich sampled at different temporal resolutions. Black dots represent trends calculated from daily measurements. Every coloured box represents the 90 % spread 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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