# Preliminary Program

## EGU Leonardo Conference

# Water stable isotopes in the hydrological cycle

**16.-18.10.2017 Hotel Saigerhöh, Black Forest, Germany**

## Monday, 16.10.2017

10:00-11:15 Registration

11:15-11:30 Opening and Welcome (Weiler/Stumpp)

**Session "Analytical developments and monitoring systems"**

11:30-12:00 **Keynote**

**Stumpp, Christine und Weiler, Markus:** Caveats, challenges and potentials in measuring and monitoring stable water isotopes

12:00-12:30 **Keynote**

**Orlowski, Natalie:** Critical Evaluation of Soil Pore Water Extraction Methods for Stable Isotope Analysis

12:30-14:00 **Lunch/ Check-in**

14:00-15:20

**Kraft, Philipp:** A multi-source "Water Analysis Trailer for Environmental Research" (WATER) for high frequency isotope and water quality measurements

**Welker, Jeffrey:** Arctic ocean seawater, water vapor and precipitation isotopes using in situ measurements from the icebreaker Healy and the Alaska Water Isotope Network

**Rücker, Andrea:** The quantification of snow meltwater in a snow-dominated catchment based on a spatially distributed isotope sampling network

**Böttcher, Michael:** Water isotopes as hydrological tracers for the Land-Ocean-Interface-Zone and in Paleohydrology

15:20-16:00 **Coffee break**

**Session "Ecohydrological Processes"**

16:00-16:30 **Keynote and Junior Leonardo Lecture**

**Dubbert, Maren:** Partitioning ecosystem water fluxes using stable isotopes – progress and challenges

16:30-17:10

**Sargeant, Christopher:** Trends in riparian tree source water use across a climatic gradient

**Keim, Richard:** Constraining effects of vegetation on isotopic composition of recharge

17:10-18:30 **Poster Session** "Analytical developments and monitoring systems", and "Ecohydrological Processes"

**Hissler, Christophe**: In situ observation of O and H isotopes in the soil microporosity

**Koeniger, Paul**: Event sampling campaigns of stable isotopes ($\delta^{2}H$, $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) indicating groundwater influence in the large scale Weser River Basin

**Michelsen, Nils**: A microcontroller-based automatic rain sampler for stable isotope studies

**Von Freyberg, Jana**: High-frequency analysis of isotopes and water quality in streamflow and precipitation at a snowmelt-dominated headwater catchment

**Wyhlidal, Stefan**: Preliminary results of water – isotope patterns in the Hydrological Open Air Laboratory (HOAL) at Petzenkirchen

**Cayuela, Carles**: Intra-event dynamics of stable isotopes in throughfall under Scots pine and Downy oak forest

**Hasselquist, Niles**: Using stable isotopes to quantify the important role trees play in the boreal hydrologic cycle

**Muñoz-Villers, Lyssette**: Reduced dry season transpiration is coupled with shallow soil water use in tropical montane forest trees

**Seeger, Stefan**: What can isotopes tell us about the influence of grassland diversity on plant water uptake?

**Rouholahnejad, Elham**: Eco-hydrological connectivity and groundwater contribution to transpiration

19:00 **Dinner**

## Tuesday, 17.10.2017

**Session “Ecohydrological Processes”**

9:00-9:30 **Keynote and Leonardo Lecture**

**McDonnell, Jeffrey**: Elements of an age-based theory of the water cycle

9:30-10:30

**Hervé-Fernández, Pedro**: Availability vs Mobility of water in soils, what is more popular among trees?

**Jeřábek, Jakub**: Investigating water and nutrient uptake by trees with in-situ measurements of water stable isotopes and phosphate in xylem

**Allen, Scott:** Soil and climate effects on the temporal origin of water in trees

10:30-11:10 **Coffee break**

11:10-12:30

**Tetzlaff, Dörthe:** Using stable isotopes to understand vegetation-water linkages across northern landscapes (VeWa)

**Latron, Jérôme:** Modification of stable isotopes input signal under forest. Should we take it into account for hydrograph separation?

**Llorens, Pilar:** What are the water sources for trees under humid Mediterranean conditions?

**De Wispelaere, Lien:** From precipitation to plants: Unrevealing East-African eco-hydrology using water isotope ratios along an elevation gradient on Mt. Kilimanjaro

12:30-14:30 **Lunch and Time for individual meetings/getting fresh air**

**Session “Climate models and water balance”**

14:30-15:00 **Keynote**

**Pfahl, Stephan:** Stable water isotopes in atmospheric circulation models

15:00-16:00

**Tuinenburg, Obbe:** Testing mixing assumption of atmospheric moisture tracking using stable water isotopes

**Arnault, Joel:** Precipitation tagging with the fully coupled atmospheric-hydrological modeling system WRF-hydro – Application to the Danube river basin

**Durán-Quesada, Ana María**: Understanding tropical rain producing systems through precipitation stable isotopic composition

16:00-16:30 **Coffee break**

16:30-17:50

**Dar, Shaakir Shabir:** Stable isotopic characterisation of event and monthly precipitation at Kashmir valley in the Western Himalayas

**Larsen, Joshua:** How much does snow contribute to groundwater recharge? A Bayesian approach to inverse estimation of source contributions

**Schaefli, Bettina:** Learning from regional isotopic lapse rates in rainfall and groundwater

**Harum, Till:** Interaction of lakes with local groundwater systems using environmental isotopes as tracer for detection and quantification

17:50-18:50 **Poster Session** (“Climate models and water balance”, “Water fluxes, transport and transit times”)

**He, Zhihua:** Quantifying the spatial contributions of runoff components in a glacierized basin using an isotopic-hydrological integrated modeling approach

**Juhlke, Tobias:** Integrating isotope hydrology, climatology, and tree rings: The CorsicArchive Project

**Malov, Alexander:** Study of radioactive and stable isotopes in travertine and thermal spring samples: implications for effects of changes in geochemical environment

**Malov, Alexander:** Evolution of groundwater fluxes in coastal aquifers of the south-eastern White Sea area (NW Russia) using radioactive and stable isotopes

**Merz, Christoph:** Quantifying the regional groundwater/surface water interaction based on 18O and Deuterium

**Schmieder, Jan:** Runoff and tracer response of a high-mountain stream in the Austrian Alps

**Guillon, Sophie:** Coupling water stable isotopes with hydrogeological models to improve constraints on surface-groundwater interactions at the watershed scale

**Heidbüchel, Ingo:** Catchment and state-dependent transfer function shapes for the determination of spatio-temporally variable transit times

**Rohini, Kumar:** Climatic and landscape controls on travel time distributions across Europe

**Lamine-Koningue, Jean-de-Dieu-Ulrich:** Current status and recharge of suburban groundwater of Dakar (Senegal)

**Lutz, Stefanie**: How young water fractions can delineate travel time distributions in contrasting catchments

**Rodriguez, Nicolas:** Modeling the uncertainty of time-varying travel times in neighboring catchments with different sampling frequencies of water stable isotopes

**Rouhiainen, Jarno**: Dynamic Transit time and residence time estimations by using lumped rainfall-runoff model with stable water isotope model at two adjacent catchments

**Winde, Vera:** Rhine river plume tracking with stable hydrogen and oxygen isotopes in Lake Constance

19:15 **Dinner**

## Wednesday, 18.10.2017

**Session "Water fluxes, transport and transit times"**

9:00-9:30 **Keynote**

**Kirchner, James:** Catchment storage and transport on timescales from minutes to months, traced by stable water isotopes

9:30-10:30

**Klaus, Julian:** The link between catchment storage and SAS functions in a Mediterranean climate

**Müller, Christin:** Tomography of anthropogenic nitrate contribution along a mesoscale river

**Groh, Jannis:** Which state variables matter to estimate water flow and transport parameters of layered soils?

10:30-11:00 **Coffee break**

11:00-11:30 **Keynote**

**Sprenger, Matthias:** Mobile and tightly bound soil water fluxes in northern environments

11:30-12:10

**Windhorst, David:** From source to sink: The stable water isotope story of a tropical mountain rainforest in south Ecuador

**Penna, Daniele:** Spatial variability in the isotopic composition of different water compartments is small catchments and its effect on mixing model results

12:10-12:30 **Closing**

12:30 **Lunch and end of conference**

# Abstracts

## Oral Session "Analytical developments and monitoring systems"

### Critical Evaluation of Soil Pore Water Extraction Methods for Stable Isotope Analysis

Orlowski, Natalie[1]; Pratt, Dyan L.; Breuer, Lutz; McDonnell, Jeffrey J.

[1]Institute for Landscape Ecology and Resources Management, Justus Liebig University Giessen, Giessen, Germany

Measurements of $\delta^2H$ and $\delta^{18}O$ composition of soil pore waters are an important component in ecohydrological studies. Various pore water extraction methods for isotope analysis now exist. Here we present an intercomparison on lab soils and a natural soil among five water extraction techniques: mechanical squeezing, centrifugation, direct vapour equilibration, microwave extraction, and cryogenic vacuum extraction. To test the isotopic performance of each method, we used spiking experiments for the lab soils, where we added water of known isotopic composition to the oven-dried soils. For the intercomparison on a natural soil, we sampled a summer-dry clayey soil. $\delta^2H$ and $\delta^{18}O$ compositions were analyzed via OA-ICOS and IRMS. Our results showed that the extraction method has significant effects on the isotopic composition also depending on the soil type and water content. Cryogenic vacuum extraction showed large deviations from the spiked water for the lab soils and was also different to the other methods for the natural soil. Mechanical squeezing and vapor equilibration techniques produced similar results for the field soil. Results closest to the spiked water for both lab soil types were provided by centrifugation and mechanical squeezing. We suggest that users of water extraction approaches carefully choose a technique that is suitable for the specific research question, scale of interest, dominant soil type, and water content.

### A multi-source "Water Analysis Trailer for Environmental Research" (WATER) for high frequency isotope and water quality measurements

Kraft, Philipp[1]; Windhorst, David; Sahraei, Amirhossein; Breuer, Lutz

[1]Justus Liebig University, Gießen, Germany

Event and intra-event dynamics of stable water isotope composition play a major role to understand spatiotemporal patterns of runoff generating processes. Despite the development of in situ, high frequency sampling devices such as laser spectroscopes, continuous high frequency time series from various sources (rain, soil and stream water or groundwater) remains challenging. We constructed an automated, mobile and self-sufficient system that samples and analyzes stable water isotopes (laser spectroscope with a continuous water sampler) and water quality parameters (UV spectrometer and multi-parameter sensor) from up to 12 sources in the field. Possible sources include streams, groundwater, rainfall or soil water near the trailer (<150 m). The continuous water sampler can provide a stable isotopic signal after approximately 15 min, the lower limit of sampling frequency. Up to 260 samples can stored frozen in a custom-made auto sampler. A soil moisture sensor network and climate station complement the fully remote controlled system. The system's mobile platform is a trailer powered by a diesel generator and solar panels. We will present the setup and configuration together with the first results from field deployment. We like to discuss extensions to the setup, like integrating stable water isotope measurements from gaseous sources.

**Arctic ocean seawater, water vapor and precipitation isotopes using in situ measurements from the icebreaker Healy and the Alaska Water Isotope Network**

Welker, Jeffrey[1,2]; Klein, Eric

[1]University of Oulu, Finland, [2]University of Alaska Anchorage, USA

The Arctic hydrological, atmospheric and cryosphere are all undergoing changes associated with global temperature increases. Central to understanding the dynamics of each major component and especially their interactions requires new approaches that quantify critical processes in situ and continuously; especially the water isotope cycle. We have been measuring the in situ Arctic seawater and water vapor onboard the US icebreaker Healy in conjunction with precipitation on land in Alaska developing a complete depiction of the water isotope cycle under a range of sea ice and from the Gulf of Alaska, into the Bering, Chukchi and Beaufort seas. We find that as sea ice density increases the associated reductions in kinetic fractionation lead to low d-excess values and that these in situ measurements are reflected in Greenland Ice Core records of d-excess. We also have quantified surface sea water at ultra-high resolution with a gradual depletion from -1 per mil in the Gulf of Alaska into the Bering and Chukchi Seas where the most depleted values reaching -3 per mil. These seawater isotope values are extended on shore as precipitation values that reflect condensation fractionation, continental, and altitudinal processes. Together, our Arctic Ocean ship based in situ seawater & water vapor isotope measurements and our complementary land-based precipitation measurements are transforming our understanding of the modern Arctic water isotope cycle.

**The quantification of snow meltwater in a snow-dominated catchment based on a spatially distributed isotope sampling network**

Rücker, Andrea[1]; Boss, Stefan; Von Freyberg, Jana; Zappa, Massimiliano; Kirchner, James;

[1]Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

The availability of water resources throughout the season is crucial and needs detailed process understanding for sustainable water management in the future. Knowledge about water flow pathways, residence times can be gained by isotopic ($\delta^{18}O$, $\delta^{2}H$) and geochemical tracers. For this reason, a spatially distributed isotopic sampling network was established in a snowmelt-dominated catchment (46.4 $km^2$) in Central-Switzerland. Regular sampling obtains results from precipitation, stream water, snowpack and snow meltwater at different sites. We capture the varying isotopic signature of snow meltwater in time and space by our snowmelt lysimeter system. It also facilitates real-time monitoring of the melt rates, system status and environmental conditions (air and soil temperature). Three lysimeter systems were installed within the catchment, in one forested site and two open field sites at different elevations. We will present the isotope time series from our regular sampling network, as well as the results from our three snowmelt lysimeter sites derived from the first operating season in winter 2016/17. Furthermore, our dataset will allow for detailed hydrograph separation based on stable water isotopes and geochemical components. We use these information to identify source areas with their difference in elevation and vegetation to quantify snowmelt contributions to streamflow in time and space.

**Water isotopes as hydrological tracers for the Land-Ocean-Interface-Zone and in Paleohydrology**

Böttcher, Michael E.[1]

[1]Leibniz Institute for Baltic Sea Research (IOW), Warnemünde, Germany

The hydrological cycle is reflected by specific water isotope signatures found in precipitation, surface, ground and seawater-derived waters. Since fresh waters of different ages and development may enter the coastal areas it is expected that they carry characteristic stable isotope signatures. Information about the specific composition of different fresh water sources allows for a use in mixing models for the origin of coastal waters and the deduction of benthic-pelagic coupling. Traditionally, investigations focused on the abundance of the isotopes H-1, H-2, O-16, and O-18. Nowadays, also the O-17 isotope is in the focus of interest. Using examples from the coastal and central North and Baltic Sea areas, I will demonstrate how the multi-isotope composition of different sources for fresh waters can be traced, with a focus on mixing processes due to submarine ground water discharge. Interstitial water from brackish-marine sediments provide quantitative information about temporal changes in the hydrological cycle associated, for instance, with changing connections between costal seas with the world ocean (sea level changes) or glacial-interglacial climatic phases. These vertical isotopic pore water trends are related to temporal dynamics that are superimposed by transport processes that can be interpreted by means of quantitative modeling. This is shown by excellent examples from the Black Sea and the Baltic Sea for changes since the late Pleistocene.

# Poster Session “Analytical developments and monitoring systems”

**In situ observation of O and H isotopes in the soil microporosity**

Hissler, Christophe[1]; Legout, Arnaud; Valle, Nathalie

[1]Catchment and Ecohydrology, Luxembourg Institute of Science and Technology, Belvaux, Luxembourg

O and H stable isotopes contribute to improve our understanding of soil-water-plant interactions. Many investigations have focused on the relationship between the various processes triggering isotope fractionation within soils. So far, the dominating perception is that the isotope profile of water observed in soils is solely due to evaporative fractionation and its shape is dependent on climate and soil parameters. Nevertheless, the established knowledge depends on some very controversial methodological and conceptual assumptions. As a consequence, we still ignore if only the water extraction conditions or also the soil properties can influence the O-H isotopic composition of the extracted water and no link with processes related to soil functioning could still be established as of today. However, the influence of biogeochemical processes on the spatio-temporal variability of $\delta^{18}O$ and $\delta^{2}H$ of the soil solutions has been rarely studied. At this stage, a detailed understanding of the interactions between the various soil components and the stored water still remains incomplete.

This could be achieved by in situ observation of O and H isotopic composition in soil micropores. In this contribution we combine high-resolution imaging techniques – Scanning Electron Microscopy + Nanoscale Secondary Ion Mass Spectrometry (SIMS) - to identify water-soil interactions based on elemental chemistry and O-H isotopic ratio analyses from micro- to nano-scale.

**Event sampling campaigns of stable isotopes ($\delta^2H$, $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) indicating groundwater influence in the large scale Weser River Basin**

Koeniger Paul[1], Stanley Kelly[2], Schüth Christoph[2], Himmelsbach Thomas[1]

[1]BGR Federal Institute for Geosciences and Natural Resources, Hannover, Germany, [2]IAG Institute of Applied Geosciences, Technical University Darmstadt, Germany

Hydro chemical and isotope hydrological investigations in large river basins are relatively rare most likely due to logistical reasons. Such comparative studies of high spatial and adequate temporal resolution gain multiple information on river basin influences and characteristics, such as geogenic background, possible pollutants, processes (runoff characterisation, residence times of runoff components, e.g., direct flow and groundwater). At the Weser river basin (42,000 km$^2$) several sampling campaigns have been conducted during 2008 (May), 2009 (January, August) (Koeniger et al. 2009) and 2017 (March, May, July) and surface water samples were collected at about 40 sites of the river basin. During the 2017s campaigns additionally hydro chemical parameters (major anion and cation concentrations, trace elements, total organic and inorganic carbon) and stable isotopes (beneath deuterium and oxygen-18 also nitrogen-15, and carbon-13) were investigated. Beneath seasonal and altitude patterns of the stable water isotopes, anthropogenic influences and potential sources derived from hydro chemistry and stable isotope characteristics will be discussed.

References:
Koeniger P., Leibundgut Ch., Stichler W. (2009): Spatial and temporal characterization of stable isotopes in river water as indicators of groundwater contribution and confirmation of modelling results; a study of the Weser river, Germany. Isotopes in Environmental and Health Studies, Vol. 45 (4), 289-302.

**A microcontroller-based automatic rain sampler for stable isotope studies**

Michelsen, Nils[1]; Laube, Gerrit[2]; Friesen, Jan[2]; Al-Mashaikhi, Khalid[3]; Müller, Thomas[2]

[1]Technische Universität Darmstadt, Institute of Applied Geosciences, Darmstadt, Germany; [2]Helmholtz-Centre for Environmental Research – UFZ, Leipzig, Germany; [3]Ministry of Regional Municipalities and Water Resources, Salalah, Sultanate of Oman

Although isotope analyzers have become field-deployable, enabling on-site rain analyses for $\delta^2H$ and $\delta^{18}O$, most samples are still gathered in traditional ways for subsequent lab analysis. They are collected manually (e.g. in intra-event studies), with cumulative rain collectors, or, more conveniently, with autosamplers. However, most commercial autosamplers are costly and often do not minimize evaporation sufficiently. Hence, we have developed a microcontroller-based sampler that allows timer-actuated collection of rain samples, with time intervals ranging from minutes to weeks. The low-cost device is robust, oil-free, and holds 17 HDPE bottles in its current version. Post-sampling evaporation is effectively reduced through a combination of design features. We provide a detailed description of the sampler and its components (commercially available as well as custom-made parts). Moreover, we present the results of an initial multi-week field test in a hot and arid desert environment in the Sultanate of Oman.

**High-frequency analysis of isotopes and water quality in streamflow and precipitation at a snowmelt-dominated headwater catchment**

Von Freyberg, Jana[1]; Studer, Björn; Kirchner, James W.

[1]ETH Zürich, Zürich, Switzerland

We present a data set from the pre-Alpine Erlenbach catchment in central Switzerland, where a sampling network was established to study the role of snowmelt on (summer) low flows. At the catchment outlet, we measured stable water isotopes ($\delta^{18}O$, $\delta^{2}H$) in precipitation and streamwater using Picarro, Inc.'s (Santa Clara, CA, USA) newly developed Continuous Water Sampler Module (CWS) coupled to their L2130-i Cavity Ring-Down Spectrometer, at 30 min temporal resolution. Water quality was monitored with a dual-channel ion chomatograph (Metrohm AG, Herisau, Switzerland) for analysis of major cations and anions, as well as with a UV-Vis spectroscopy system and electrochemical probes (s::can Messtechnik GmbH, Vienna, Austria) for characterization of nutrients and basic water quality parameters. In addition, a spatially distributed snowmelt lysimeter system as set up to measure melt rates (10min) and to collect melt water (daily) for subsequent stable isotope and chemical analysis in the laboratory. By combining the high-frequency isotope measurements with the spatially-variable snowmelt and precipitation rates, we are able to quantify the fractions of event water in streamflow at high temporal resolution. Initial results show that the event-water fractions in the Erlenbach catchment are generally high, indicating a very limited water storage capacity and a strong dependency of the discharge regime on the most recent snow pack.

**Preliminary results of water – isotope patterns in the Hydrological Open Air Laboratory (HOAL) at Petzenkirchen**

Wyhlidal, Stefan[1]; Oismüller, Markus[2]; Eder, Alexander[3]

[1]Center for Energy, Austrian Institute of Technology, Vienna, Austria; [2]Center for Water Resource Systems, TU Wien, Vienna, Austria; [3]Institute for Land and Water Management Research, Federal Agency for Water Management, Petzenkirchen; Austria

Hydrological flow path information at a catchment scale is critical to the preservation of public water supplies. Knowledge of the hydrological and environmental processes underlying discharge formation, discharge concentration and associated transport of nutrients and pollutants in catchment areas is essential in order to construct predictive models to effectively manage water resources sustainably. In the light of climate and land use change these models will be used predictively at a policy level to address issues of flood protection, flood prediction, groundwater pollution as well as soil erosion and losses to the environment. To construct hydrological models and effectively predict and control flooding, we need to understand water dynamics at a cascade of scales both temporally and spatially.

The Petzenkirchen Hydrological Open Air Laboratory (HOAL) is located 100 km west of Vienna, Austria. The 66 ha catchment is dominated by agricultural land use and well equipped with numerous climatological, hydrological and water quality measuring devices. The catchment is special in that many runoff generation processes (surface runoff, spring runoff, tile drainages, runoff from wetlands) can be observed simultaneously.

In this Poster we will present preliminary results of water - isotope patterns of precipitation as well as discharge-component analysis during hydrological events at high temporal and spatial resolution.

# Oral Session “Ecohydrological Processes”

### Partitioning ecosystem water fluxes using stable isotopes – progress and challenges

Maren Dubbert[1], Arndt Piayda[2], Angelika Kübert[1], Matthias Cuntz[3], Christiane Werner[1]

[1] University of Freiburg, Ecosystem Physiology, Germany

[2] Thünen Institute of Climate Smart Engeneering, Germany
[3] INRA, Department for Forest Ecology and Ecophysiology, France

Water is the main driver of ecosystem productivity in most terrestrial ecosystems worldwide. Given that extreme events such as floods and droughts are predicted to increase in frequency in many regions, dynamic responses in soil-vegetation-atmosphere feedbacks play a privotal role in understanding the ecosystem water balance and functioning. In this regard, more interdisciplinary approaches, bridging hydrology, ecophysiology and atmospheric sciences are needed. Water stable isotopes are a powerful tracer of water transfer in soils and at the soil–plant interface (Werner and Dubbert 2016). Here, we present observations from a grassland and a savannah type ecosystem. Ecosystem water fluxes, atmospheric concentrations and their isotopic compositions were measured using laser spectroscopy. Soil moisture and its isotopic composition in several depths as well as further water sources in the ecosystem (precipitation, groundwater, lake water) were monitored throughout the year. Using combined flux based and isotopic approaches we disentangled soil-plant-atmosphere feedback processes controlling the ecosystem water cycle including vegetation effects on soil water infiltration and distribution, event water use of vegetation and soil fluxes, plant soil water uptake depths plasticity and partitioning of ecosystem water fluxes. In this regard, we review current strategies of ET partitioning. We highlight pitfalls in the presented strategies (Dubbert et al. 2013, Dubbert et al. 2014a, Dubbert et al., 2017). We demonstrate that vegetation layers strongly influenced water cycling in the ecosystems and further alter infiltration and distribution of precipitation (Piayda & Dubbert et al., 2017). In conclusion, application of stable water isotope tracers delivers a process based understanding of interactions between soil, understorey and trees governing ecosystem water cycling necessary for prediction of climate change impact on ecosystem productivity and vulnerability.

References
Dubbert, M. et al. (2013): Partitioning evapotranspiration – Testing the Craig and Gordon model with field measurements of oxygen isotope ratios of evaporative fluxes. Journal of Hydrology
Dubbert, M. et al. (2014a): Oxygen isotope signatures of transpired water vapor: the role of isotopic non-steady-state transpiration under natural conditions. New Phytologist.
Dubbert, M. et al. (2014b): Stable oxygen isotope and flux partitioning demonstrates understory of an oak savannah contributes up to half of ecosystem carbon and water exchange. Frontiers in Plant Science.
Werner, C. and Dubbert, M. (2016): Resolving rapid dynamics of soil–plant–atmosphere interactions. New Phytologist.
Dubbert, M., Kübert, A., Werner, C. (2017): Impact of Leaf Traits on Temporal Dynamics of Transpired Oxygen Isotope Signatures and Its Impact on Atmospheric Vapor. Forntiers in Plant Science.
Piayda, A., Dubbert, M., Cuntz, M., Siegwolf, R.T.W., Werner, C. (2017): Quantification of dynamic soil – vegetation feedbacks following an isotopically labelled precipitation pulse. Biogeosciences.

**Trends in riparian tree source water use across a climatic gradient**

Sargeant, Christopher[1]; Singer, Michael

[1]University of St Andrews, St Andrews, UK

As climate change progresses we can expect shifts in water availability to forest trees. This problem is more challenging in lowland riparian forests, where water availability is controlled by local climate conditions (precipitation, evaporation, and infiltration) and by regional climate (e.g. streamflow, snowmelt, recharge), all of which may vary during a growing season. To determine how the seasonal water source use of riparian trees is controlled by local or regional changes in hydroclimatic regime, we reconstructed the seasonal $\delta^{18}O$ signature of water used by two riparian tree species with contrasting rooting depths along a strong climatic gradient within the Rhône River basin, SE France. We utilised over 800 $\delta^{18}O$ cellulose measurements which provided 12 tree-level decadal time-series, each with sub-annual resolution. Individual $\delta^{18}O$ cellulose values were deconvolved to obtain the isotopic signature of water utilised for growth via a bio-physiological fractionation model. We combined these results with $\delta^{18}O$ measurements made of local riverine waters, shallow phreatic and xylem waters as well as a reconstructed $\delta^{18}O$ precipitation time series. This enabled us to distinguish the seasonal evolution of water source use and how this responds to differences in climate. Our findings show that both local and regional climatic expressions are fundamental in determining the seasonal evolution of water source availability to riparian forests.

**Constraining effects of vegetation on isotopic composition of recharge**

Keim, Richard[1]

[1]Louisiana State University, Baton Rouge, USA

Fractionation and spatiotemporal reorganization of precipitation before infiltration generally have small but measurable effects on both mass and isotopic composition of recharge to depth and streamflow. Observations of above-ground vegetation fractionation are accumulating in the literature, but there is not yet any general theory to describe processes in a way integrated with the entire critical zone. This research used numerical experiments based on empirical data and a simplified soil model to constrain vegetation effects for use in models of rain-dominated, forested watersheds. The soil model partitions infiltration into either bypass flow or matrix exchange in a simple representation of isotopic separation of mobile and bound waters. Stochastic simulations of rainfall d18O and canopy fractionation, parameterized from the literature, show that temporal variability of isotopes in groundwater recharge is attenuated by soil storage proportionally to soil depth and dominance of matrix flow. Spatial variability of isotopic composition of throughfall is less than temporal variability, and lack of temporal stability of spatial patterns in fractionation by forest cover means that lateral redistribution within soils further contributes to temporal attenuation of variability in area-mean recharge. Parameterizing the model for some typical, macroporous forest soils reveals that temporal variability of the vegetation effect on groundwater recharge is likely larger than the mean.

**Elements of an age-based theory of the water cycle**

McDonnell, Jeffrey J [1]

[1] Global Institute for Water Security. University of Saskatchewan, Saskatoon SK , CANADA S7N 3H5

The terrestrial water cycle is the hallmark of hydrology. But closure of the water mass balance includes water (streamflow, soil water, transpiration water and groundwater) that can be years to thousands of years old. A grand challenge for watershed hydrology is how to understand what controls the time it takes the water molecule to transit a gauged research basins and how this differs (in time and space and in terms of physical controls) to the celerity of the hydraulic potentials that are transmitted through the basin. Here I present some new information on what we know and what we think we know of the characteristic water ages from diverse catchments in Oregon, China and New Zealand. I highlight some of the challenges in squaring this information with traditional water flux measures and outline some specific steps towards attacking what we need to know re: the characteristic space and time scales of water cycle components. I end with some thoughts on a community whole-watershed tracer experiment to begin to unpack water age distributions and to ultimately form the elements of a nascent 'age-based theory' of the water cycle.

**Availability vs Mobility of water in soils, what is more popular among trees?**

[1]Hervé-Fernández, Pedro; Verrot, Lucile; Oyarzún, Carlos; Geris, Josie; Steppe, Kathy; Boeckx, Pascal; Verhoest, Niko

[1]Laboratory of: Hydrology and Water Management; Isotope Bioscience; and Plant Ecology, Ghent, Belgium

Recent studies using bi-plots of water stable isotopes (∂H and ∂18O) in throughfall, stream, bulk soil and xylem water argue for an ecohydrological separation of water between streams and trees, known as the "two water world hypothesis". This hypothesis indicated that trees relied on water attached to soil particles (i.e. static compartment), while stream and groundwater recharge are fed by mobile water within the soil matrix. The separation of these distinct water pools has been challenging and there are still methodological limitations to unravel the amount of mobile and static isotope signatures in soils. In this study, we propose using the known Rayleigh equation and Bayesian mixing model to test the hypothesis and account for the mobile/static water fraction trees are withdrawing. Seasonal and ecohydrological connectivity effects are discussed.

## Investigating water and nutrient uptake by trees with in-situ measurements of water stable isotopes and phosphate in xylem

Jeřábek, Jakub[1,2]; Herbstritt, Barbara[1]; Rinderer, Michael[1]; Gessler, Arthur[3]; Weiler, Markus[1]

[1]University of Freiburg, Freiburg, Germany; [2]Czech technical university in Prague, Prague, Czech Republic; [3]Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

To quantify the sources of water and nutrient uptake by trees in forest ecosystems we developed an in-situ measuring technique for non-destructive, high temporal resolution sampling of the isotopic signature ($\delta^{18}O$, $\delta^{2}H$) in xylem sap and its phosphate concentration. We present a field-applicable sampling procedure to collect water vapor samples in equilibrium with the xylem water based on a modification of a technique by Volkmann et al. (2016). The samples of water vapor are collected in air-tight bags and analyzed in the lab for water stable isotopes. While other researches try to use isotope analyzers in the field this procedure is less dependent on power supply and handling expensive equipment in the field and avoids measuring errors due to non-lab measuring conditions. We show results from lab tests on the reliability of different sampling bags and valves/septa and the influence of in-bag storing time. In parallel we develop an in-situ-sampling procedure for xylem phosphate ($PO_4^{3-}$) using microdialysis (MD). We show the lab calibration procedure using stem segments of young beech trees. We also show the influence of perfusate concentration, xylem sap $PO_4^{3-}$ concentration, xylem flow rate and MD flow rate on the MD probe recovery rate of $PO_4^{3-}$. Using these methods for sprinkling experiments with deuterium-labeled water at three sites in Germany will allow studying spatial and temporal differences of tree water and nutrient sources and the recovery of nutrient supply after rainfall events.

References:

Volkmann, T., Kühnhammer, K., Herbstritt, B., Gessler, A., Weiler, M. (2016) A method for in situ monitoring of the isotope composition of tree xylem water using laser spectroscopy. Plant, Cell & Env. 39, p. 2055 – 2063.

## Soil and climate effects on the temporal origin of water in trees

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Investigations using xylem water isotopes to determine where trees take up water have generally focused on temporal variations; this perspective provides limited insights into how site characteristics control soil water transit and root uptake. We present results from an ongoing investigation of the spatial variation of water isotopes at 191 sites spanning the forests of Switzerland. The objective of this study is to test how species differ in where they access water and how those differences relate to climate, forest, and soil characteristics. Sites range in elevation from 260 to 1870 m asl, annual precipitation from 700 to 2060 mm, and canopy dominance by three different species. Xylem and soil water samples, collected by uniform methods at all sites within a 10-day period, were analyzed for $^{2}H$ and $^{18}O$ composition. Systematic variations in the temporal origin of xylem water across regions were more pronounced than differences among proximal trees. Xylem water in southern and alpine regions was similar to summer precipitation and xylem water in northern regions was similar to winter precipitation. Spruce xylem water was more like recent precipitation than for beech or oak, perhaps indicating shallower roots in spruce. However, species differences were small and, compared to other site characteristics, may be secondary controls over isotope patterns. Inter-site variations in water uptake reveal new insights into tree water uptake responses to site edaphic and climatic factors.

**Using stable isotopes to understand vegetation-water linkages across northern landscapes (VeWa)**

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Vegetation is fundamentally important to water partitioning and can mediate the hydrological response of catchments to climate forcing. Understanding how plants respond to environmental change and the hydrological impacts of such responses is critical for projecting future ecosystem dynamics and water availability. As part of the ERC funded "VeWa" project, we use stable isotopes of different waters (i.e precipitation (rain and snow), soil water, groundwater, streamwater, plant xylem water) to understand ecohydrological partitioning of precipitation by plants, and the subsequent implications for storage and release of water at 6 long-term experimental sites across the wider North (in Scotland, Sweden, Canada, US). Importantly, we integrate such isotope data into water and solute transp. models at different spatial scales to understand mixing and water fluxes to streams and ecohydrological feedbacks on hydrological partitioning. This tracer-aided modelling allows us to simulate stream and soil isotope responses very well and at some sites can account for the composition of xylem water. Water in top soils was kinetically fractionated compared to precipitation, which has implications for the water available for plant uptake in these northern latitudes. Our simulations showed contrasting time-variant age distributions of water exiting catchments as evapotranspiration and stream flow; these differences are strongly influenced by veg. cover and other landscape controls (topogr., soils, geology).

**Modification of stable isotopes input signal under forest. Should we take it into account for hydrograph separation?**

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This study aims to characterize water stable isotopes variability in rainfall, throughfall and stemflow to assess the relevance of observed differences for two-component hydrograph separation at the catchment scale. For this purpose, Oxygen-18 and deuterium were measured to determine more accurately "new water" inputs during storm events in a small Mediterranean research catchment (Vallcebre, NE Spain). Rainwater was sampled at 5mm rainfall intervals. In a Scots pine stand inside the catchment, throughfall was sampled with the same procedure as rainfall and also with 10 throughfall collectors; stemflow was sampled by means of 4 collectors associated to trees of different diameters. Stream water was sampled at the gauging station with two automatic water samplers. Comparison of rainfall, throughfall and stemflow isotopic signatures showed the complexity of rainfall partitioning process. Enrichment occurred for a majority of throughfall and stemflow samples and was higher for rainfall events of lower magnitude. Stemflow was more enriched than throughfall. Incorporating forest-induced isotopic modifications at the catchment scale changed the input signal used for hydrograph separation. However, in the Can Vila catchment, this modification had only marginal effects on hydrograph separation results because of the limited extension of forest cover, the low stemflow volumes generated by pine trees and the limited runoff response for rainfall events lower than 40mm.

**What are the water sources for trees under humid Mediterranean conditions?**

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A dual isotope-based approach was used to analyse the water pools used by Scots pine trees in a Mediterranean mountain catchment (Vallcebre Research Catchments, 42º 12'N, 1º 49'E). From May to December 2015 water-isotopes were monitored in rainfall, throughfall and stemflow in a pine stand and in stream water at the catchment outlet. Moreover, fortnightly soil samples, xylem samples and mobile soil water samples (low-suction lysimeters and piezometer) were collected at the same stand. Water from soil and xylem samples was extracted by cryogenic vacuum distillation and isotope analyses were obtained by infrared spectroscopy. All this information has been combined with continuous measurement of weather, soil moisture, piezometric levels and hydrological variables. Stable isotopes ratios of bulk soil water fell below the LMWL, with more enrichment in the shallow horizons, whereas, mobile soil water, groundwater and stream water fell along the LMWL. In contrast to what was observed for mobile waters, negative lc-excess values in bulk soil water as well as in trees water were observed along all the studied period, suggesting that these waters have undergone some evaporative enrichment. The fact that xylem water was, in some sampling days, even more evaporated than water in bulk soil evidenced however the complexity of the ecohydrological separation assessment, as well as the need to perform more detailed sampling to validate the two water worlds hypothesis in this environment.

**From precipitation to plants: Unrevealing East-African eco-hydrology using water isotope ratios along an elevation gradient on Mt. Kilimanjaro**

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Lake Challa is situated in equatorial East Africa, a semi-arid area with bimodal rainfall pattern. The $\delta^2H$ and $\delta^{18}O$ of rain, lake water, plant xylem and leaf water were measured across different plant species, seasons and plant habitats around Lake Challa during 2013-2014. During 2014-2015, similar sampling campaigns were set up along an altitudinal transect from lake Challa up to the SE slope of Mt. Kilimanjaro. This transect encompasses contrasting climates and vegetation belts that are representative for tropical Africa. Our observations have important implications for interpretations of paleohydrological records in the region. We found that plants surrounding the lake rely mostly on water from the NE monsoon (October- December) as these recharge the soil pores after the long dry season. Plant species and their associated leaf phenology are the primary factors influencing the enrichment in $\delta^2H$ from xylem to leaf water. Along the SE slopes of Mt. Kilimanjaro, we observed that plants in the savannah rely on one relatively constant water pool throughout the year, while plants in the subalpine zone mainly rely on source water from the SE monsoon (March-May). Large trees in the forest tap source water from a broad depth range as an efficient adaptation to seasonal variations in rainfall and nutrient resource acquisition. We observed robust correlations between both the isotopic composition of leaf water and the xylem-leaf isotopic enrichment, and the vapor pressure deficit.

# Poster Session "Ecohydrological Processes"

### Intra-event dynamics of stable isotopes in throughfall under Scots pine and Downy oak forest

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In forested ecosystems the isotopic composition of rainfall that reaches the soil is modified by processes taking place in tree canopies. Here, we present the results of the intra-event sampling of rainfall and throughfall isotopic composition. This information is complemented with spatial variability data of the isotopic composition of rainfall, throughfall and stemflow. The study was carried out between May 2015 and June 2016 in a Downy oak and a Scots pine forests located in the Vallcebre research catchments (NE Spain). The design for isotopic intra-event sampling consisted of two sequential samplers for rainfall and one sequential sampler in each stand. These instruments were complemented with 10 throughfall collectors spatially distributed and 4 stemflow collectors. Isotopic sampling was combined with hydrometric measurements and meteorological data from two towers located above canopies. Our results revealed a high temporal variability of the isotopic composition of the open rainfall during the studied period. Below forest, enrichment occurred for 55% of the throughfall samples and for 77% of the stemflow samples. Higher variability on the isotopic modification was produced at the onset of rainfall, later this variability was reduced. The analysis of intra-event scale rainfall and throughfall isotopic composition combined with detailed meteorological data offers new possibilities in understanding the role of the canopy in the interception processes.

### Using stable isotopes to quantify the important role trees play in the boreal hydrologic cycle

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One of the major challenges when trying to predict how the hydrologic cycle will respond to future climate change scenarios is the need to partition evapotranspiration water losses into evaporation and transpiration, which in the past have commonly been lumped together by hydrologists and treated as a black box. However, transpiration and evaporation represent two fundamentally different pathways of water loss from terrestrial ecosystems: (i) transpiration through stomata of plants and (ii) evaporation from wet surfaces. These pathways are controlled in different ways and to varying degrees by environmental factors and, thus, are likely to respond differently to climate change. In my presentation, I will present an experimental design that takes advantage of recent advances in stable isotope techniques to partition evapotranspiration into evaporation and transpiration across multiple spatial and temporal scales in a boreal forest watershed. This new approach will allow for a novel, mechanistic assessment of the interactions and feedbacks between vegetation and the terrestrial hydrologic cycle as well as evaluate how these interactions and feedbacks may response to a changing climate.

## Reduced dry season transpiration is coupled with shallow soil water use in tropical montane forest trees

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Tropical montane cloud forests (TMCF) are ecosystems particularly sensitive to climate change; however the effects of warmer and drier conditions on the ecohydrology of TMCF remain poorly understood. To investigate functional response of trees to reduced water availability, we conducted a study during the 2014 dry season in the lower limit of the TMCF belt in central Veracruz-Mexico. Temporal variations of transpiration, depth of water uptake and tree water sources were examined using micrometeorological, sapflow and soil moisture measurements, in combination with stable isotope analysis of rainfall, tree xylem, soil and stream water. Results showed that crown conductances decreased from the mid to late dry season, as temperature and vapor pressure deficit increased, and soil moisture decreased. Canopy species consistently showed more depleted isotope values compared to mid-story trees. MixSIAR Bayesian model results showed that the evaporated soil water pool was the main source for trees. Additionally, while the shift in the depth of tree water uptake from deeper (60-120 cm) to shallower soil water (0-30 cm) sources occurred, concomitant decreases in transpiration were observed as the dry season progressed. A larger reduction in deep soil water use was observed for canopy trees (from 79±19 to 24±20%) than for the mid-story species (from 12±17 to 10±12%). The shift to shallower soil water sources may reflect a trade-off between water and nutrient requirements in this forest.

## What can isotopes tell us about the influence of grassland diversity on plant water uptake?

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In this study we want to investigate the influence of plant-diversity on the plant's reaction to drought stress. While there are several studies explaining incerased drought-tolerance of more diverse ecosystems with complementary water use, the actual patterns of plant water uptake (PWU) are rather hard to observe. By combinbing in situ stable water isotope measurements with an artificial labeling approach, we want to compare PWU patterns for a set of study plots of varying plant-diversity. We planted our 1.3 m x 1.3 m study plots two years ago with varying mixtures of 16 selected plant species with different traits regarding rooting depths and leaf-biomass. By irrigating the study plots with three pulses of isotopically distinct labeling waters, we will obtain soil water isotope profiles that contain much more information than naturally occuring soil isotope profiles. After the irrigation, the plots will be shielded from natural precipitation and dry over the course of several weeks. During this time, we will repeatedly measure the isotopic signatures of soil water vapour(via a newly developed mobile profile probe) and plant transpiration (via chamber measurements). With the isotopic information of soil water and plant transpiration, we will be able to estimate the source depths of PWU for each of the study plots. Special focus will be put on the comparison of PWU patterns for the same species in different mixtures.

**Eco-hydrological connectivity and groundwater contribution to transpiration**

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There have been increasing attempts to integrate groundwater processes into Earth system models in recent years. Improving the representation of groundwater-surface interactions in such models requires reliably quantifying the contribution of groundwater and other water pools to transpiration. Many studies have reported on the use of groundwater by individual species at the plot scale, but these studies generally are based on individual point-scale samples. Thus, we currently lack a general model for the importance of groundwater at broad scales or a systematic approach for quantifying the temporal and spatial dynamic contributions of different water reservoirs, including groundwater, to plant water uptake across a range of geographical and climate conditions. This represents a critical knowledge gap in our understanding of the hydrological connectivity (passage of water from one pool to another in the subsurface) between groundwater, the vadose zone, and vegetation. Sporadic observations of water isotopes at the point scale have provided valuable insights into how isotopic signatures change through the vadose zone and plant xylem, but they have not enabled us to propose a clear physical model that links plants' water sources to land-surface processes. So far, the dynamic responses and strength of connectivity of the vegetation to water in the surface and subsurface (so-called "eco-hydrological connectivity") has not been systematically mapped at the watershed scale, and there appears to be no theory for predicting how this eco-hydrological connectivity will evolve as watersheds progressively dry in the changing climate. A well-characterized model, combined with spatiotemporal observations, will provide a new tool to predict the evolution of hydrological connectivity, and its link to vegetation and climate, under climate change. I will present the overall framework of the recently proposed study to explore the spatiotemporal dynamics of the eco-hydrological connectivity between groundwater and plant transpiration, taking into account climate seasonality, vadose zone properties, land cover, plant species, and landscape positioning (riparian zones, hill slopes, and hilltops), in three different sites representing a range of climate and geological conditions.

# Oral Session “Climate models and water balance”

### Testing mixing assumption of atmospheric moisture tracking using stable water isotopes

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The atmospheric part of the water cycle has been subject of study during extreme weather events. Knowing the location of the source evaporation of extreme precipitation can improve predictability of extreme events. Postprocessing models use atmospheric reanalysis (wind, precipitation and evaporation) as forcing data to determine the path of moisture from evaporation, via atmospheric transport and cloud-formation, to precipitation. By using the reanalysis as forcing data, the models are computationally cheap and the simulated moisture flows resemble reality due to the data assimilation. However, several assumptions are needed; (1) after evaporation, how does the moisture mix in the atmospheric column? (2) during transport, how strong is the vertical convective mixing? and (3) during precipitation, how does the likelihood of rainout depend on altitude? Stable water isotopes provide an excellent opportunity to validate these assumpions. We have forced an atmospheric moisture tracking model both with ERA-interim and IsoGSM2 stable water isotope reanalysis and made the moisture budgets over H2O, HDO and HDO18. This allows for further constraining the water cycle and testing above assumptions. Our results show that continental recycling ratios vary up to 20% with mixing assumptions. The isotopically constrained atmospheric moisture cycle and its recycling ratios and residence times will be presented.

### Precipitation tagging with the fully coupled atmospheric-hydrological modeling system WRF-hydro – Application to the Danube river basin

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Water resources management requires an accurate knowledge of the moisture pathways in the terrestrial and atmospheric branches of the hydrological cycle. A precipitation tagging method was recently developed in the fully coupled atmospheric-hydrological version of the Weather Research and Forecasting model WRF-Hydro, in order to quantify the partitioning of precipitation into water stored in the soil, runoff, evapotranspiration, and potentially subsequent precipitation through regional recycling. An application to a high precipitation event on 15 August 2008 in the upper Danube river basin, 94 000 km$^2$, Germany and Austria, is presented. Water precipitating during this day is tagged for the period 2008-2012. Its contribution to runoff and evapotranspiration decreases with time, but is still not negligible in the summer 2011. At the end of 2012, 3 % of the precipitating water on 15 August 2008 is recycled in the source region. Moisture pathways can also be investigated with measurements of stable water isotope, as well as with earth system models that describe the fate of these isotopes. This would also enable a more direct evaluation of the tagging results. A future implementation of fractionation processes into the tagging-enabled WRF-Hydro model is straightforward, however, appropriate isotope observation data are mandatory.

**Understanding tropical rain producing systems through precipitation stable isotopic composition**

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Costa Rica is known by its rich biodiversity which results from a rainfall distribution made up by the combination of locally forced processes and large scale dynamics. Determine the local versus large scale origin of rainfall is of relevance to improve weather and climate modeling and to better interpret rainfall changes under warming scenarios. The study aims to provide observational evidence on the processes that control local and large scale precipitation that can be either used as a proxy or directly incorporated in models. The relationship between the isotopic composition of rainfall and the main features of the rain producing systems affecting Costa Rica were analyzed based on a daily isotope record in rainfall provided by the Stable Isotope Research Group, a set of meteorological stations, MODIS cloud information and an objective analysis method for weather typing for the 2014-2016 time span. Precipitation from the meteorological stations network was used to classify rainfall regimes in the country whereas ERA-Interim Reanalysis and MODIS cloud products were used to identify the large scale conditions linked with the rainy conditions. The combination of independent meteorological data and the isotopic ratios at a daily resolution allows the identification of particular rainfall producing mechanisms during specific weather events. The results so far show a clear signal of enrichment associated with shear lines and low pressure systems linked rainfall during extreme events.

**Stable isotopic characterisation of event and monthly precipitation at Kashmir valley in the Western Himalayas**

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In this study, we investigate the sources of moisture contributing water vapor to precipitation over the Kashmir valley using a Lagrangian particle dispersion model(HYSPLIT) to track changes in atmospheric moisture along 8-day Backward Trajectories(BT). The change in the specific humidity along the BT indicates the Mediterranean Sea, the Arabian Sea, the Bay of Bengal and the land recycled component to be the contributing moisture sources. Stable isotopic analysis of precipitation collected at Srinagar located in the Kashmir valley, between March 2015 to March 2017 revealed variations documenting the role of local physical factors and transport process. Together with precipitation, surface water(SW) and ground water(GW) collected from within the valley were analyzed to understand the composition of local moisture. A large variation in isotopic composition of precipitation is observed with $\delta^{18}O$ and $\delta^{2}H$ ranging from -18.1‰ to 6.8‰ and -145‰ to 60‰ respectively. The d-excess values fall between -14‰ to 33.5‰. The meteoric water lines for precipitation, lakes and rivers, streams and GW are ($\delta^{2}H = 8.18\times \delta^{18}O + 8.17$ $R^2=0.96$ n=59),( $\delta^{2}H = 5.00\times \delta^{18}O - 15.96$ $R^2=0.36$ n=11),( $\delta^{2}H = 4.60\times \delta^{18}O - 21.88$ $R^2=0.42$ n=15) and ($\delta^{2}H = 11.97\times \delta^{18}O + 43.41$ $R^2=0.36$ n=9) respectively. In the presentation, we will quantify the contribution of moisture from different sources to the precipitation and discuss the significance in the reconstruction of precipitation patterns in paleo records from tree rings and sediments.

**How much does snow contribute to groundwater recharge? A Bayesian approach to inverse estimation of source contributions**

Beria, Harsh; Ceperly, Natalie; Michelon, Anthony; Larsen, Joshua[1]; Schaefli, Bettina

[1]University of Lausanne, Lausanne, Switzerland

Snowmelt-based groundwater recharge is a key component of high Alpine water balances. Stable isotopes can be useful tracers of these sources, with Bayesian mixing models routinely applied to estimate the source contributions. In the case of two sources (snowmelt and rainfall), these mixing models estimate the respective source contributions by solving two equations obtained from $\delta^{18}O$ and $\delta^{2}H$ concentrations observed in the sources and in the groundwater. Here we present a Bayesian method to estimate source proportions in groundwater using an inverse approach, i.e. by inferring the mixing model parameters that minimize the model residuals, which are the differences between observed and simulated model outputs. This method represents an advance over the commonly used linear Bayesian mixing models in that it allows a joint estimate of source proportions in combination with important governing parameters (in this case lapse rate, and isotopic distinctions between snowfall and snowmelt). This approach is applied to water stable isotopes observed for an intensively studied high Alpine catchment (Switzerland), and we compare the proportional contribution of snowmelt to estimates of the proportion of snow vs rain in total annual precipitation. The differences between the estimates are discussed i) in terms of the dominant hydrological processes and how they partition incoming water and ii) in terms of the key observational uncertainties.

**Learning from regional isotopic lapse rates in rainfall and groundwater**

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Alpine environments are important water resources for low lying areas and for hydropower production. These resources experience growing human pressure while being particularly sensitive to climate warming. In this context, new methods for water resources quantification are of prime interest for sustainable management. Water balance estimation in mountainous areas is, however, notoriously difficult due to the high heterogeneity of rain- and snowfall and related hydrological processes.

In this presentation, we discuss how new quantitative insights can be gained from the analysis of routinely analyzed stable water isotopes in groundwater, rainfall and streamflow in Switzerland. Isotopic lapse rates of deuterium and oxygene-18 are known to contain information about the catchment feeding the sampled ground water and in particular about the mean elevation. We analyze Swiss groundwater and rainfall lapse rates to infer new insights into elevation gradients of groundwater recharge. The used data includes stable water isotope data available from the national and international isotope observation networks along with the data from a national pilot study including 1102 observations from 50 groundwater wells for the period 2007-2013. The obtained results are compared to elevation gradients obtained from a regional analysis of river discharge.

**Interaction of lakes with local groundwater systems using environmental isotopes as tracer for detection and quantification**

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With the example of 2 alpine lakes with different hydrogeological boundary conditions and circulation it is demonstrated that the stable isotopes $^{18}O$ and $^{2}H$ deliver relevant information concerning evaporation processes, in- and outflow of groundwater and circulation behaviour. The meromictic lake Klopeiner See (catchment 2.4 km2, surface 1.14 km2, max. depth 48 m, slow circulation, connected with pore aquifer) was one of the test sites of the ETC-Alpine-Space-project SILMAS with the goal to investigate the impact of climate change on water balance and circulation of alpine lakes. On the basis of isotope monitoring data the connection between the lake and a spring is proved and the portion of lake water on spring discharge quantified. This relevant information is used for modelling of past and future changes of the lake water balance. The lake of Altaussee (located in the Northern Calcareous Alps) has an intensively karstified catchment (54.5 km2, surface 2.1 km2). It is mainly recharged by sublacustrine springs, circulation is fast. In the frame of soundings a karstic swallet has been detected being 73 m under the lake surface. Monitoring of the isotopes $^{18}O$ and $^{2}H$ is performed in different depths and of inflows and the outflow. Mixing calculations allow to quantify the discharge of the swallet with high fluctuations. The spring was verified by diving into the swallet. The interpolation of $^{18}O$ -signals on the lake ground enables the zoning of groundwater regimes in the lake.

# Poster Session "Climate models and water balance"

### Quantifying the spatial contributions of runoff components in a glacierized basin using an isotopic-hydrological integrated modeling approach

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Quantifying the contribution of individual runoff component to the entire streamflow is critical for the understanding of the dynamics in water resource. The contributions of runoff components significantly vary in spatial locations, e.g. elevation bands, leading to complex runoff response to climate change in glacierized basins. Estimating the contribution patterns of runoff components at elevation bands is key for the quantification of the climate change effects on runoff processes. This study developed an approach to simultaneously model the stable water isotope composition and runoff generation in a glacierized basin. The spatial variability of water isotope composition in precipitation was simulated in a Rayleigh fractionation procedure using spatial temperature and precipitation. The fractionation and mixing processes of water isotope compositions in various water sources were integrated in a glacio-hydrological model. Spatial contributions of runoff components were estimated by a tracer-mixing approach at each elevation band. Results shown that the proposed approach acceptably reproduced the isotope composition in streamflow, and was able to yield spatial contribution patterns of runoff components in the study basin. Our findings also demonstrated that integrating water isotope composition in hydrological model obviously helps to improve model internal consistency.

### Integrating isotope hydrology, climatology, and tree rings: The CorsicArchive Project

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Paleoclimate proxies such as tree rings use stable isotope ratios for the reconstruction of past climatic conditions. Such information then allows the calibration of models that evaluate and predict ongoing and future effects of global climate change. A region expected to be strongly affected is the Mediterranean. Therefore, the island of Corsica in the western Mediterranean was subject to isotope hydrology and dendroisotope studies in the recent past. Based on findings of these previous investigations, the new project "CorsicArchive" was launched in 2017.
The project integrates climate analysis and modeling, isotope hydrology, wood anatomy, and dendroisotopes for a better understanding of key aspects within the hydrologic cycle and for climate reconstruction efforts. The project aims to trace the stable isotope ratios of water along its pathway in the hydrologic cycle from vapor transport over precipitation formations to soil water until trees, where the information is eventually stored in the xylem cell walls.
For these purposes we placed 5 climate and dendroecological stations together with 10 rain collectors in an E-W transect over the islands central main mountain range. With this setup, we foresee high-resolution sampling to map spatial and temporal variations of precipitation stable isotope ratios and the fate of oxygen isotope along it's pathway in soil and plants. We will present preliminary results from this exciting study.

**Study of radioactive and stable isotopes in travertine and thermal spring samples: implications for effects of changes in geochemical environment**

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Data on modern radiocarbon activity in the old travertine formations of the Pymvashor hydrothermal system were used, in combination with 230Th/U dating of the travertine, to estimate the 14C contents of the TDIC in the ancient thermal water at the time of precipitation of the travertine (14Ccalc). With the known values of 14Ccalc and average age of the thermal water, and under the assumption that the residence time of the water in aquifer was constant over the last 13.9 ± 1.5 ka, the initial 14C contents (14C0) in the ancient thermal water were estimated. The findings in this study are that (1) both 14C0 and ?13? have decreased in young waters compared to the ancient waters; (2) although atmospheric 14C activity (14Catm) has also decreased in the same time, the decrease in 14C0 is faster than the decrease in 14Catm. Under certain assumptions, one could link changes in 14C0 and ?13C to climate change. Decrease in ?13? of soil CO2 and decrease in 14C0 was caused predominantly by warmer and wetter climate, decomposition of fossil organic matter, and decrease in 14Catm. There could be also increased dissolution of solid carbonate and increased carbon exchange between DIC and soil CO2, caused by thawing permafrost.

**Evolution of groundwater fluxes in coastal aquifers of the south-eastern White Sea area (NW Russia) using radioactive and stable isotopes**

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Investigation revealed that the main evolutionary trends are the following: (1) Mixing Late Pleistocene relict brackish water with residence time (t) in the aquifer of 33 ka and Mikulino sea water (t=130ka) with salty water formation (SW1), which has 18O from -5 to -10 ‰, 2H from -40 to -80 ‰. Recharge of the relict water could have occurred in MIS 3 – a period between 60 and 27 ka ago during the last glacial cycle, when there were several abrupt climatic warming phases events. The isotope composition of SW1 reflects the warm climate of the Mikulino interglacial and the impact of LGM. Relict brackish water has 18O from -14 to -15 ‰, 2H from -110 to -114 ‰, and reflects the coldest climate and the impact of LGM. (2) Mixing Late Pleistocene freshwater (LPW) with t=25-39 ka and SW1 with brackish water (BW) formation, which has 18O from -12 to -13 ‰, 2H from -90 to -100 ‰. Recharge of LPW could have occurred ~ in MIS 3 also. (3) Mixing Middle Pleistocene-Holocene freshwater (MPHW) from melting glaciers and deep brine with salty water formation (SW2), which has 18O from -11 to -13 ‰, 2H from -90 to -100 ‰. Recharge of MPHW could have occurred after MIS 12 and after LGM. As a result of intensive and rapid recharge after the glacial melting, glacial fluids have penetrated at depth to more than 200 m. The isotope composition of the last two types of water (BW and SW2) is close to modern, but reflects the impact of LGM.

**Quantifying the regional groundwater/surface water interaction based on 18O and Deuterium**

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Small, non-permanent ponds of glaciofluvial origin (kettle holes) are widely spread in the younger Pleistocene landscapes of the northern hemisphere. New investigations show that much more of the kettle holes in NE Germany are more closely connected to the groundwater than expected before. They are not isolated hydrological depressions and can be viewed as linked components of a hydrologic continuum. These kettle holes have a high informative value regarding changing behavior of the regional groundwater system functioning as a suitable indicator for changes of regional connected hydrological system. Measurements of the stable isotopes $^{18}O$ and $^{2}H$ enables the quantitative estimation of the individual water flux and evapotranspiration rates. An isotope-mass-balance model was used to quantify lake water balances. The approach after Skrzypek et al. 2015 based on the global relationship between the $^{18}O$ and $^{2}H$ values of the precipitation and the kinetic isotopic fractionation during evaporation. Assuming that the lake is hydrostatically connected to the groundwater the used isotope mass-balance model accounts for the quantification of the evapotranspiration rate considering the groundwater inflow. Results clearly show distinct patterns of the temporal dynamics of the groundwater/surface water interaction reflecting the regional system behavior. They provide the basis for anticipating the future development of the hydrological system under anthropogenic impacts.

**Runoff and tracer response of a high-mountain stream in the Austrian Alps**

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Mountain water availability is important for various concerns (e.g. energy production, irrigation, and tourism), and understanding its origin, as well as simulating future states of the hydrologic cycle is crucial for many regions worldwide. In this study we present runoff and tracer responses of a high-mountain stream, supplied by snowmelt, glacier melt, rain, and groundwater, at diurnal to seasonal scales. A perceptual model of streamflow generation is derived from a two year data set of isotopic and electrical conductivity tracer data. The model describes processes of runoff generation in a stream with a glacial flow regime during six typical system states (classified as i) winter baseflow, ii) early snowmelt, iii) peak snowmelt, iv) snow/glacier melt, v) peak glacier melt, and vi) glacier melt/rain). Those periods differ in snow cover extent, evolution of the glacier drainage system, discharge, tracer signature and its variability, air temperature, precipitation, and wetness condition. In a second step we estimated streamflow contributions of various components by means of a tracer-based mixing model at the event (1-day resolution) and the seasonal scale (monthly resolution). Maximum contributions at the daily scale were as high as 75, 69, 23, and 81% for snowmelt, glacier melt, rain, and groundwater, respectively. Seasonal estimates of snow and glacier melt were compared with the results derived from a distributed, energy balance-based hydroclimatologic model (AMUNDSEN).

# Oral Session “Water fluxes, transport and transit times”

### Catchment storage and transport on timescales from minutes to months, traced by stable water isotopes

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Landscapes store and transmit water and solutes over a wide spectrum of time scales, with important implications for contaminant transport, weathering rates, and runoff chemistry. In the past, stable isotopes of water (18O and 2H) have been widely used to separate event-scale hydrographs into "new" and "old" water, based on short-term intensive isotope sampling campaigns focused on individual storm events. More recently, long-term isotope time series have been collected in many research catchments, and new technologies have emerged that allow quasi-continuous measurements of isotopes in precipitation and streamflow. These new data streams create new opportunities to study how rainfall becomes streamflow on timescales of minutes to months following the onset of precipitation. Here I show that the conventional hydrograph separation formula can be converted into an equivalent linear regression equation that quantifies the fraction of current rainfall in streamflow across ensembles of precipitation events. This approach can be generalized to empirically determine the contributions of precipitation inputs to streamflow across a range of time lags. In this way, the short-term tail of the transit time distribution can be directly quantified for an ensemble of precipitation events. Applications using high-frequency tracer time series from several experimental catchments demonstrate the utility of the new approach outlined here

### The link between catchment storage and SAS functions in a Mediterranean climate

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Travel time (TT) distributions and StorAge Selection (SAS) functions fundamentally describe catchment behavior. Recent work using SAS functions showed for several catchments that young water is preferentially mobilized to contribute to discharge when catchment storage is high; the so-called Inverse Storage Effect (ISE). Until today, the range of climate conditions where the ISE has been observed was limited to climates with high precipitation throughout the year and rather low ET. Here, we investigate the link between storage and SAS functions in WS10 of the HJA Experimental. The HJA has a strong climate seasonality and related runoff behavior, with high flows during winter and spring and pronounced summer low flows. We used a model with two reservoirs combined in series-parallel. The model was calibrated to discharge and stable isotope data. The TTs were determined assuming randomly sampled conditions for each reservoir by solving the Master equation (that describes the dynamics of water ages in storage and in catchment outflows). The variability of SAS functions with catchment storage was consistent with the observations of the ISE in other climates, yet the link between variations of storage and age selection patterns was more complex during the transition periods between from high to low and low to high storage conditions. The SAS functions indicated that the pronounced seasonality of the climate at HJA control catchment mixing and travel time dynamics.

**Tomography of anthropogenic nitrate contribution along a mesoscale river**

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During the last decades, nitrate concentrations in surface and groundwater have increased due to land use change and accompanying application of agricultural fertilizer as well as increased atmospheric deposition. To mitigate nutrient impacts on downstream aquatic ecosystems, it is important to quantify potential nitrate sources, instream nitrate processing and its controls in a river system. The objective of this project was to characterize and quantify (regional) scale dynamics and trends in water and nitrogen fluxes of the entire Holtemme river catchment in central Germany making use of isotopic fingerprinting methods. We combined a spatially highly resolved assessment of nitrate concentration and fluxes along the catchment with four-year monitoring data at two representative sites. The investigated area was characterized by a strong land use gradient from pristine headwaters to lowland sub-catchments with intense agricultural land use and wastewater sources. While the nitrogen dynamics in the headwater region was controlled by hydrological conditions, nitrate loads further downstream stemmed from external anthropogenic sources like effluents from wastewater treatment plants (WWTP) and fertilization. Especially during extreme low flow, major inflows from WWTP's with high nitrate loads played a crucial role for the nitrate dynamics of the entire main stream. During normal base flow conditions river water nitrate was dominated by the inflow from agricultural sub-catchments.

**Which state variables matter to estimate water flow and transport parameters of layered soils?**

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To protect groundwater resources and model hydrological behavior at large scales, a better understanding of soil hydraulic properties and dispersivity is mandatory. Here we present an inverse modeling study in which we estimated soil hydraulic parameters and dispersivity in 4 lysimeters. We used different optimization strategies and a parameter optimization algorithm to investigate which observation types are necessary in the objective function (OF) to reproduce simultaneously the observed soil moisture, matric potential, and water stable isotope data with HYDRUS-1D simulations. A comparison of the different optimization strategies showed that a balanced compromise procedure, which used multiple observation types simultaneously during the inverse model calibration in the OF, reached the best agreements. This revealed the importance of using different observations data types in the OF during inverse model calibration. Using the identified parameter-sets to simulate a parallel conducted tracer experiment with bromide ($Br^-$) showed a much slower movement of $Br^-$. Prevailing geochemical conditions suggest that the negatively charged anion $Br^-$ was adsorbed onto clay minerals and amorphous oxides under low pH values. Accounting for anion adsorption in the simulation reached good agreements and confirmed our model parameterization strategy.

**Mobile and tightly bound soil water fluxes in northern environments**

Sprenger, Matthias[1]; Tetzlaff, Doerthe; Ala-Aho, Pertti; Buttle, Jim; Laudon, Hjalmar; Mitchell, Carl; Snelgrove, Jenna; Weiler, Markus; Soulsby, Chris

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Understanding water fluxes in the critical zone, the mixing of soil waters and the resulting transit times are crucial to assess hydrological dynamics in the soil-vegetation-atmosphere interface. To better understand how water flows and mixes in soils of northern environments with a strong seasonal climate, we studied the hydrometric conditions and soil water isotopic composition ($\delta^{18}O$ and $\delta^{2}H$) in the upper soil profile of six different land scape units in the long term experimental catchments: Bruntland Burn (Scotland), Dorset (Canada) and Krycklan (Sweden). The mobile water was sampled with suction lysimeter and the bulk soil water isotopic composition was sampled with the direct-equilibration method.

We used a numerical 1-D flow model, based on the Richards and the advection-dispersion equation and parameterized by soil textural and vegetation characteristics, to simulate the observed hydrometric and isotopic dynamics at each of the six study locations. The model includes evaporation fractionation and accounts for the differences in water flows of mobile and more tightly bound soil waters and the mixing between the two pore spaces.

We present how the assumption of a two-pore system (in contrast to a one-pore system) affects the isotope dynamics of the soil water. We further discuss the consequences of the modeled and observed differences of mobile and tightly bound waters for root water uptake studies and travel time estimates.

**From source to sink: The stable water isotope story of a tropical mountain rainforest in south Ecuador**

Windhorst, David[1]; Timbe, Edison[2]; Breuer, Lutz[1]

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Deciphering the information behind the spatial and temporal dynamics of stable water isotope signatures has advanced modern hydrology to a new level of process understanding. Here, we present the knowledge gained and lessons learned from the application of a variety of stable water isotope related methods to investigate the spatial and temporal dynamics of hydrological fluxes in a headwater catchment of a tropical mountain rainforest in south Ecuador. We also show ways forward to improve the application of existing methods and for the development of new modelling techniques to account for stable water isotopes in process based hydrological models beyond the 1d scale.

The applied methods and results include HYSPLIT backward trajectory modelling and spatial rainfall sampling, highlighting its strong spatiotemporal variability, and the seasonal importance of recycled moisture from the Amazon. Mean transit times (MTT) estimations where used to investigate the transition from source to sink, and revealed, regardless of flashy response of the hydrograph, surprisingly long MTTs? 2 yr for streams and a considerable contribution of old water (46%) prior to the release of new one (54 %). Finally, we show results of an early hillslope modelling study using stable water isotopes as a tracer. The results allow an in depth analysis of the flow processes (e.g. deep percolation accounting for almost 50%) and highlight the potential as well as the research needs of such model applications.

**Spatial variability in the isotopic composition of different water compartments is small catchments and its effect on mixing model results**

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Most catchment isotope studies focus on the temporal variability of the isotopic composition of surface or subsurface water. Usually few samples are taken at only a few locations and it is assumed that they are representative for that compartment. We reviewed 131 papers published in international peer-reviewed journals between 1970 and April 2017 that used the stable isotopes of water to infer hydrological processes at the small catchment scale (up to 10 km2) to determine the spatial variability in the isotopic composition of different hydrological compartments and how this affects isotope-based applications. The two most frequently sampled hydrological compartments were streamflow and precipitation, followed by soil water and shallow groundwater. The studies that characterized a hydrological compartment at more than three locations all revealed a large spatial variability, even at short distances. On average, the largest spatial variability in isotopic composition was observed for precipitation, throughfall and soil water. We used this information to determine for which compartment the average observed spatial variability in isotopic composition had the largest effect on mixing model results. This review highlights the need to consider the spatial variability in the isotopic composition of surface and subsurface water in isotope-based small catchment studies.

## Poster Session “Water fluxes, transport and transit times”

**Coupling water stable isotopes with hydrogeological models to improve constraints on surface-groundwater interactions at the watershed scale**

Guillon, Sophie[1]; Rivière, Agnès[1]; Flipo, Nicolas[1]

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The Orgeval watershed (70km East of Paris, France) is a temperate agricultural catchment within the Seine river basin, which has been highly instrumented and studied for more than 50 years, and is part of the French Critical Zone Observatories network. Coupled surface-groundwater models are currently developed for this watershed at MINES ParisTech, and, in addition to piezometer head and flow data, require other proxies for calibration and validation. Here we incorporate water stable isotopes data into these models in order to improve constraints on water flow paths and transit times.

Water stable isotopes are monitored at daily to hourly time scale in the river, upstream and downstream the watershed, as well as at the monthly time scale in the river, the nearby bank alluvial aquifer, the regional aquifer and in precipitation. First, the global agreement between isotope data and the hydrological functioning of the watershed is checked based on hydrograph separation. In such a temperate climate, the temporal and spatial variability of water stable isotopes in surface and groundwater is limited, requiring fine scale monitoring to calibrate the dynamics. Coupling water stable isotopes with dissolved radon data in surface and groundwater is thus proposed to better localize and quantify groundwater inflows in the river. Finally, high-frequency surface water isotope composition will be used to calibrate transport properties and transit time distributions of the models.

## Location and state-dependent transfer function shapes for the determination of spatio-temporally variable transit times

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Transfer function convolution models have long been used in combination with stable water isotope data to determine water transit times of catchments. One of the main problems of this approach is the time (and space) variability of the transfer function shape (i.e. the shape of the transit time distribution) - causing equifinality and therefore non-unique mean transit times. We conducted virtual experiments to relate the shape of transit time distributions to catchment properties, hydrologic state and precipitation event characteristics. The resulting location and state-dependent variable transfer functions help to make transit time determination via convolution models more accurate and reliable.

## Climatic and landscape controls on travel time distributions across Europe

Kumar, Rohini[1]; Rao, Suresh[2]; Hesse, Falk[1]; Borchardt, Dietrich[1]; Fleckenstein, Jan[1]; Jawitz, James[3]; Musolff, Andreas[1]; Rakovec, Oldrich[1]; Samaniego, Luis[1]; Schroen, Martin[1]; Zink[1], Matthias; Attinger, Sabine[1]

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Travel time distributions (TTDs) are fundamental descriptors to characterize the functioning of catchment storage and release of water and solutes. Identifying the relative importance of climate and landscape attributes on TDD descriptors is fundamental to improve our understanding of underlying mechanism controlling the spatial heterogeneity of TTD descriptors like mean TT. In this study, we use the spatially resolved water fluxes and states simulated by a mesoscale Hydrologic Model (mHM; *Samaniego et al, 2010; Kumar et al., 2013*) to characterize the stationary and non-stationary behaviors of water particles transported through the vadose zone across the European domain. The model is established at 25 km spatial resolution for the period 1955-2015. TTDs across EU are derived following the analytical expressions given by *Botter et al., 2010*. Results suggest a complex set of interaction between climate and landscape properties controlling the spatial heterogeneity of mean TT. The spatial variability in the mean TT across EU generally followed the climatic gradient with lower values in humid regions and higher in semi-arid regions. Results also signify the role of a landscape attribute like total soil-water-storage capacity, when taken together with climate attributes such as average storm depth forms a useful predictor for explaining the spatial heterogeneity of mean TTs. Finally, we highlight the time-varying behaviors of TTDs and discuss the seasonal variation in TT across EU.

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**Current status and recharge of suburban groundwater of Dakar (Senegal)**

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Thiaroye shallow and unconfined sandy aquifer is an important groundwater reservoir in the region of Senegal's capital Dakar. However, its quality is deteriorated due to anthropogenic activities. Despite the alarming situation, little is known about the transport and fate of contaminants in soils and groundwater. Therefore, the objective of the study was to use environmental tracers, including stable isotopes of water, to understand groundwater recharge processes and its impact on groundwater quality in the suburban area of Dakar. In two sampling campaigns (pre- and post-rainy season), soil and groundwater samples were taken and analyzed for water stable isotopes, physico-chemical and bacteriological parameters. Results from water isotope analysis plotted below the local meteoric water line emphasizing the importance of evaporation; particularly in soil water. Depth distributions of isotopes in soil water indicated variable spatial and temporal recharge. Due to higher groundwater recharge during the rainy season, elevated concentrations of $Cl^-$, $NO_3^-$, and $SO_4^{2-}$ and higher numbers of total coliforms/E. coli were found after rainy season. Groundwater quality assessment based on statistical analysis and kriging provided a better insight into the current groundwater status of the study area and showed the seasonal influence both on bacteriological and hydrochemical parameters. Poor groundwater status highlights the requirement of improved water management strategies in future.

**How young water fractions can delineate travel time distributions in contrasting catchments**

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Travel time distributions (TTDs) are crucial descriptors of flow and transport processes in catchments. Tracking fluxes of environmental tracers such as stable water isotopes offers a practicable method to determine TTDs. The mean transit time (MTT) is the most commonly reported statistic of TTDs. Recently, the young water fraction (Fyw) has been introduced as additional statistic that can be derived from seasonal tracer cycles. In this study, we first determined Fyw and TTDs in 24 contrasting sub-catchments in a meso-scale catchment (3300 km²) in Germany. Fyw derived from seasonal tracer cycles ranged from 0.01 to 0.27 (mean=0.12) and was mainly correlated with climatic factors. Second, assuming gamma-shaped TTDs, we determined time-invariant TTDs for each sub-catchment using the convolution integral method. Multiple optimization runs for the same sub-catchment showed a wide range of TTD parameters due to model equifinality. In contrast, the use of Fyw as additional information allowed constraining this range and thus improving the assessment of MTTs (mean of two years; ranging from eight months to 5.7 years). Hence, given that Fyw is a robust descriptor of fast-flow contribution, isotope models should aim at accurately describing both Fyw and the isotope time series in order to improve our understanding of flow and transport in catchments.

**Modeling the uncertainty of time-varying travel times in neighboring catchments with different sampling frequencies of water stable isotopes**

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Time-varying travel times (TT) are being increasingly used to understand water flow paths and the fate of solutes in catchments. Studies have highlighted the impact of tracer sampling frequency on TTs derived from convolution approaches or sine-wave fitting methods. Comparatively, little work has been done on the uncertainty of TTs derived using StorAge Selection functions in conceptual catchment models that need to be calibrated to streamflow and tracer data. In this contribution, we calibrate a conceptual model to four neighboring catchments of the HJA forest (Oregon, USA) that have different sampling frequencies of $^{18}O$ in streamflow. We use Bayesian Inference to derive model parameter uncertainty, which is propagated in the TT calculations. The resulting TTs and their uncertainties are compared between catchments to highlight the importance of tracer sampling frequency, and the influence of catchment properties, on the inferred age of streamflow.

**Dynamic Transit time and residence time estimations by using lumped rainfall-runoff model with stable water isotope model at two adjacent catchments**

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Knowledge of residence times of water in the catchment and water age at the river outlet is often required to better understand the catchment functioning. Stable isotopes of water are natural and ideal tracers to track water movement within catchments. In this study we use lumped HBV rainfall-runoff model coupled with modified isotope model of Klaus et. al 2015 (Water Resources Research 51(6) 4208-4223) to simulate river discharge isotope ratios. We use the model at two adjacent catchments in central Germany and compare the results. Two years data set of precipitation and river water isotope measurements with varying sampling intervals (daily to monthly) with ten years of daily climate and river discharge data is used as model input. As model output information of transient and residence times of water in different model compartments is received. Simultaneously the method reduces the amount of good parameter sets for the hydrological model and thus reduces the equifinality problem.

**Rhine river plume tracking with stable hydrogen and oxygen isotopes in Lake Constance**

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Lake Constance is an intensively used lake (e.g. fishing, drinking water reservoir). The main tributaries of the lake are the dominant influence on the physical and chemical properties of the lake and thus a potential source for pollutants. The BMBF–ReWaM Project “SEEZEICHEN” was established with one focus on the investigation of propagation paths of these river plumes (intrusion depth and mixing behaviour of the main river input) by isotopic signals and elemental composition. To identify river plumes at 20 Stations through the Lake Constance has been sampled 3 times by vertical profiles with a multi parameter probe were measured and in selected depths water samples were analysed for ion concentration and isotope signatures. Results showing interflow layer in different water depths depending on the season and river water discharge and can be tracked over the whole Lake. The isotopic compositions of the investigated water bodies indicate a vertical stratification of the isotopic signal in the metalimnion between a water depth of 15-30m during summer and fall, which is caused by the intrusion of lighter Rhine River water, caused by loading with isotopic light melt water in the summer months, which is mixing with the homogenous heavier isotope signal of the lake water body. The results show that stable isotopes are representing an “ideal” conservative tracer to detect and quantify river water plumes in Alpine lakes with input originating from high mountainous areas.