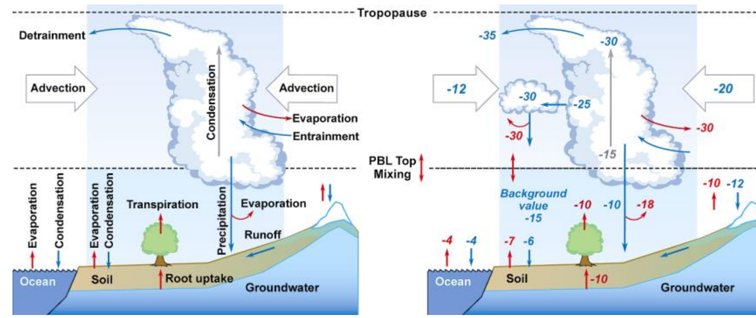
Tracer-aided ecohydrological modelling to quantify fluxes and ages in an upland agricultural headwater catchment

Xiaoqiang Yang[1,2], Doerthe Tetzlaff[1,3], Chris Soulsby[1,4], and Dietrich Borchardt[2]

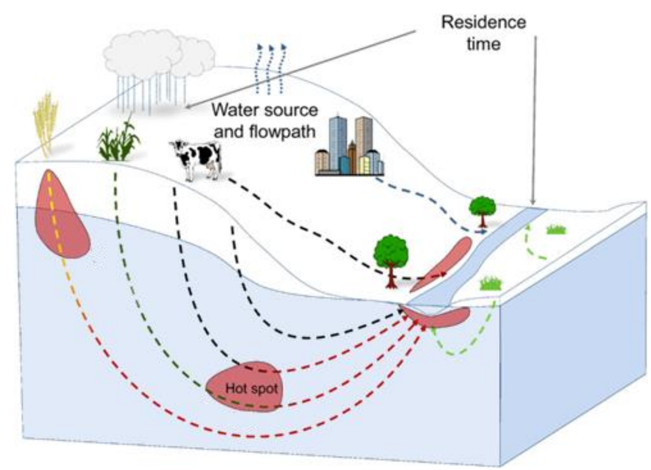
[1]Department of Ecohydrology, Leibniz – IGB, Berlin, Germany
[2]Department of Aquatic Ecosystem Analysis and Management, Helmholtz – UFZ, Magdeburg, Germany
[3]Department of Geography, Humboldt University of Berlin, Germany
[4]Northern Rivers Institute, University of Aberdeen, Aberdeen, UK

Introduction

- Stable isotope tracers provide insights in ecohydrology:
  - Storage-flux-age interactions
  - Mixing and partitioning (e.g., Evaporation vs. Transpiration)
- Tracer-aided ecohydrological modeling:
  - Capturing vegetation dynamics
  - Explicitly revealing flow paths and water ages
- Fully distributed, process-based modeling:
  - Representing heterogeneity of natural and anthropogenic controls
  - Benefiting from measurements at different scales



Water balance compartments are charaterized by specific isotopic signatures (source US Dept. of Energy)

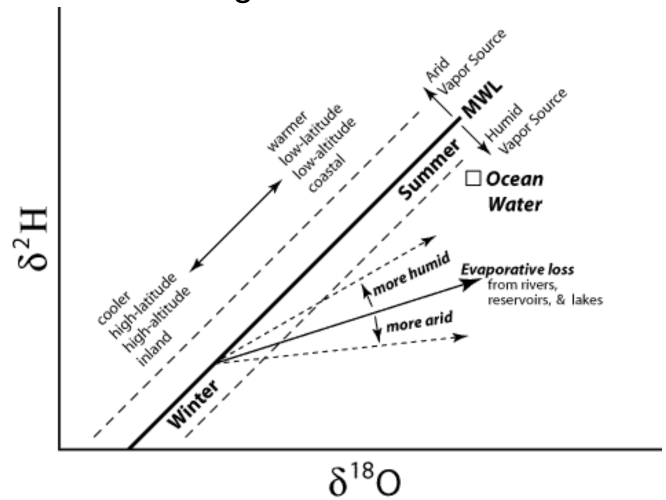


Heterogeneity of catchment functioing (Adjusted from Abbott et al., 2016 *Earth-Science Reviews)*

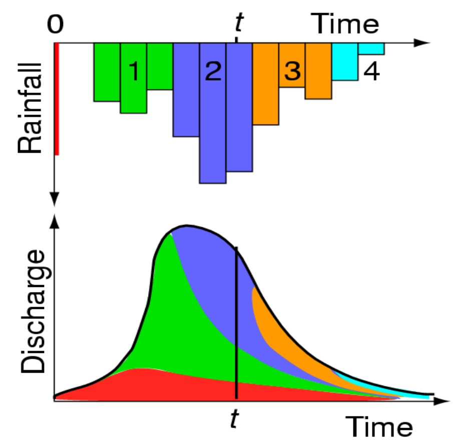
What do isotopes/tracers help us to understand?

- When is water coming from where and how old is that water

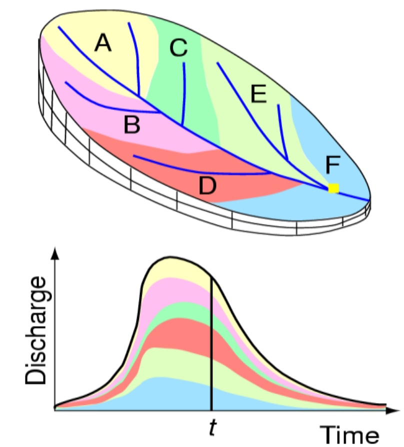
Characteristic signatures for water sources



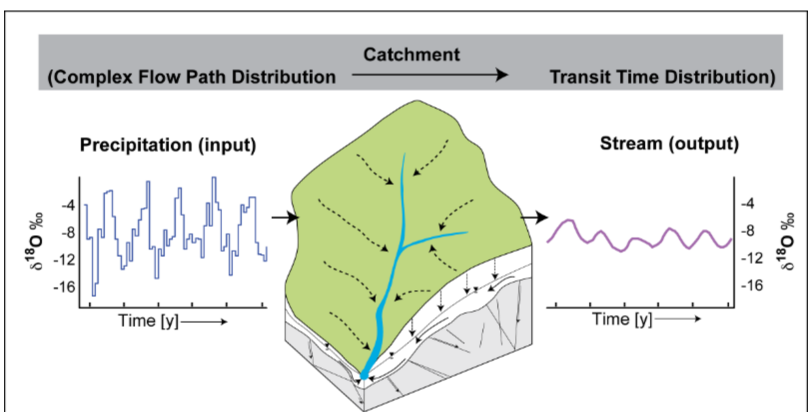
Temporal hydrograph separation

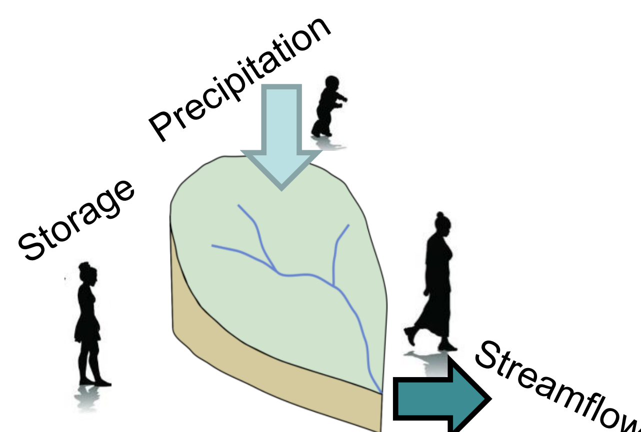


Spatial hydrograph separation



- Catchment functioning (tracked by water isotopes and age)





Sayama and McDonnell, 2009 WRR; Tetzlaff et al, Hydrol.Proc., 2015

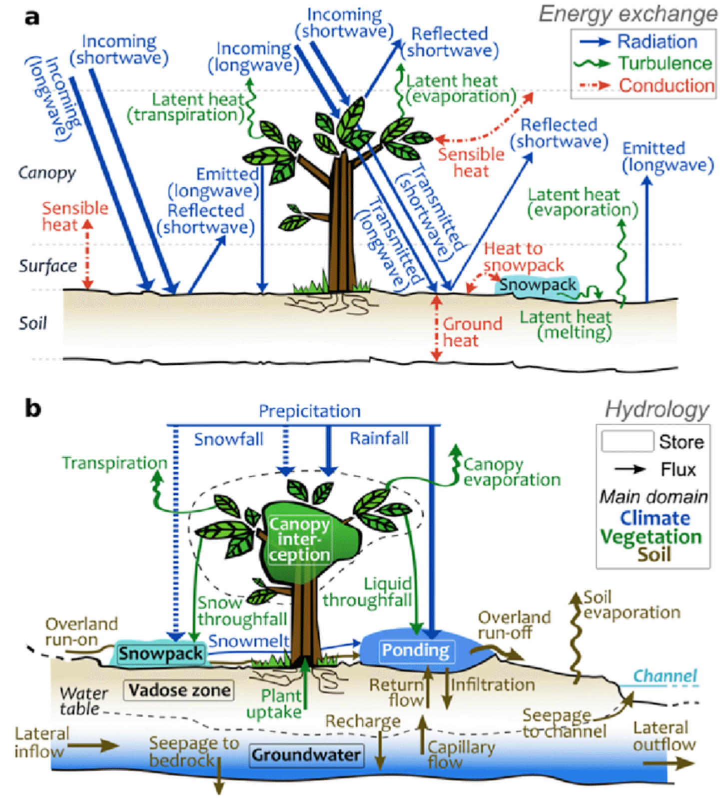
Objectives

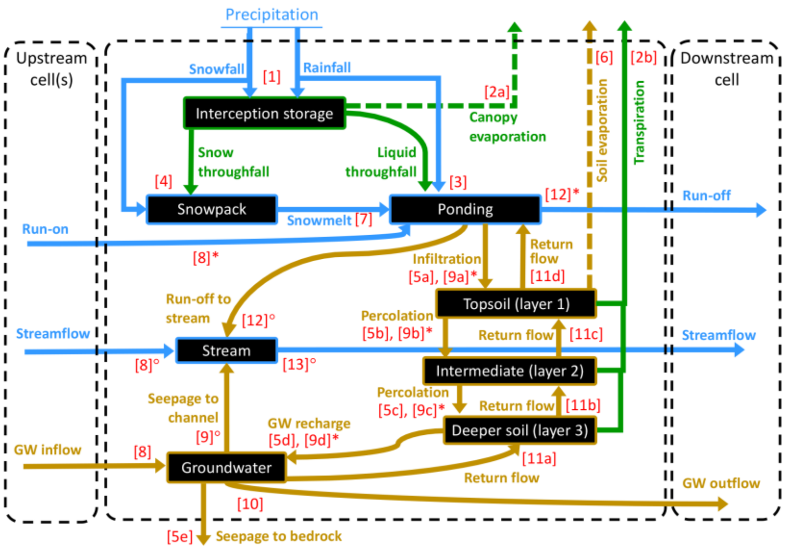
- Investigation of complex catchment functioning in an agricultural headwater catchment based on long-term intensive monitoring
- Isotope-aided ecohydrological modeling to track and reveal flow paths and precipitation partitioning
- Insights into impacts of extreme droughts on catchment functioning and implications for further model development

Ecohydrological Model – the EcH_2O-iso model

- Spatially distributed model
- Water, energy and vegetation dynamics (Maneta et al., 2013)
- Integration of isotopic tracers and water age (Kuppel et al., 2018, 2020)

EcH_2O model structure



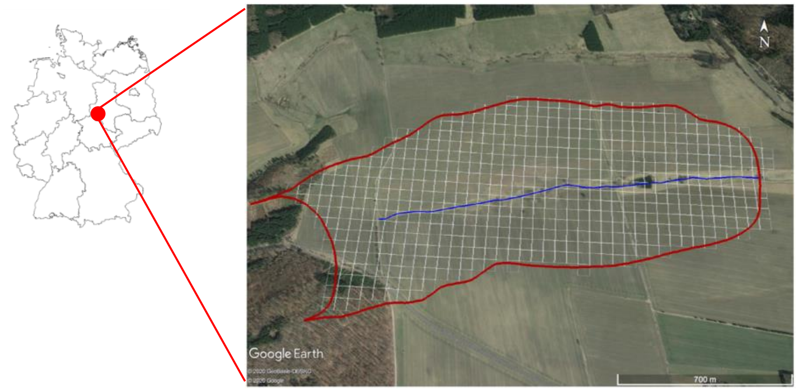


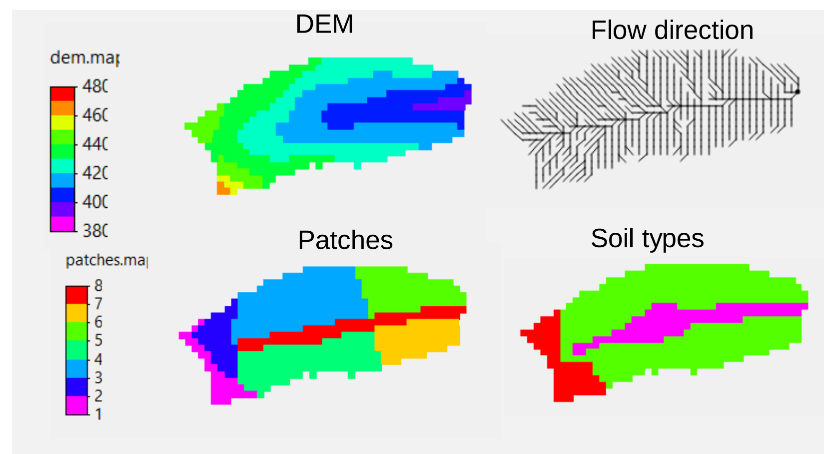
Fully integrated tracer module for tracking water isotopes and age

Maneta and Silverman, A spatially distributed model to simulate water, energy and vegetation dynamics using information from regional climate models, Earth Interact., 17,1-44,2013
Kuppel, Tetzlaff, Maneta & Soulsby, EcH2O-iso 1.0: water isotopes and age tracking in a process-based, distributed ecohydrological model, Geosci. Model Dev., 11,3045-3069, 2018
Kuppel, Tetzlaff, Maneta & Soulsby, Catchment storage control on the transit times of ecohydrological fluxes, 2020 (Accepted)

The Schäfertal catchment: an intensively monitored, upland agricultural catchment

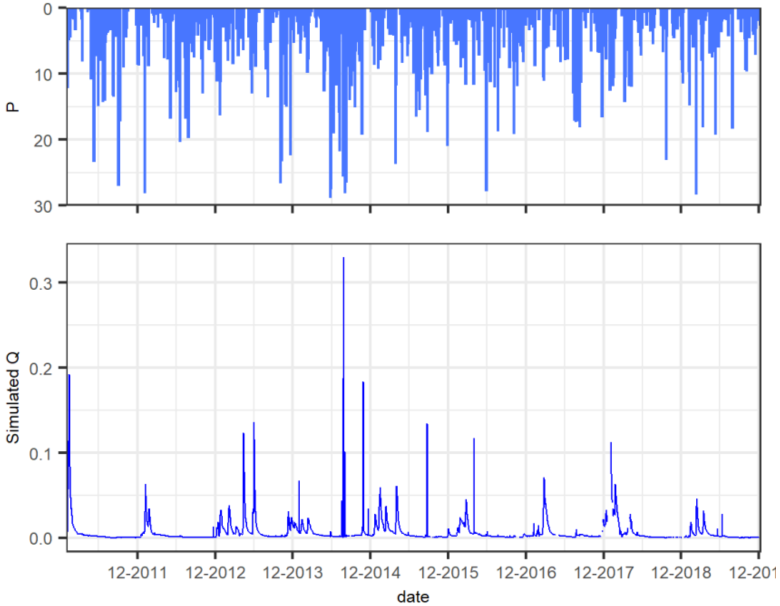
- Agricultural dominant headwater catchment (1.44 km^2) in the Harz mountain, Central Germany
- Multi-source Data:
  - Climatic, discharge, soil temperature
  - Soil moisture from the lysimeter station
  - Stable water isotopes (^{2}H and ^{18}O)
  - Detailed agricultural management information
- EcH2O-iso model configuration:
  - 50× 50 m grid size
  - **Three soil types**: arable hillslope, riparian floodplain and upland forest
  - **Seven patches**: grass, forest and five crop fields with different crop rotations
  - Daily simulation in 2010 - 2019



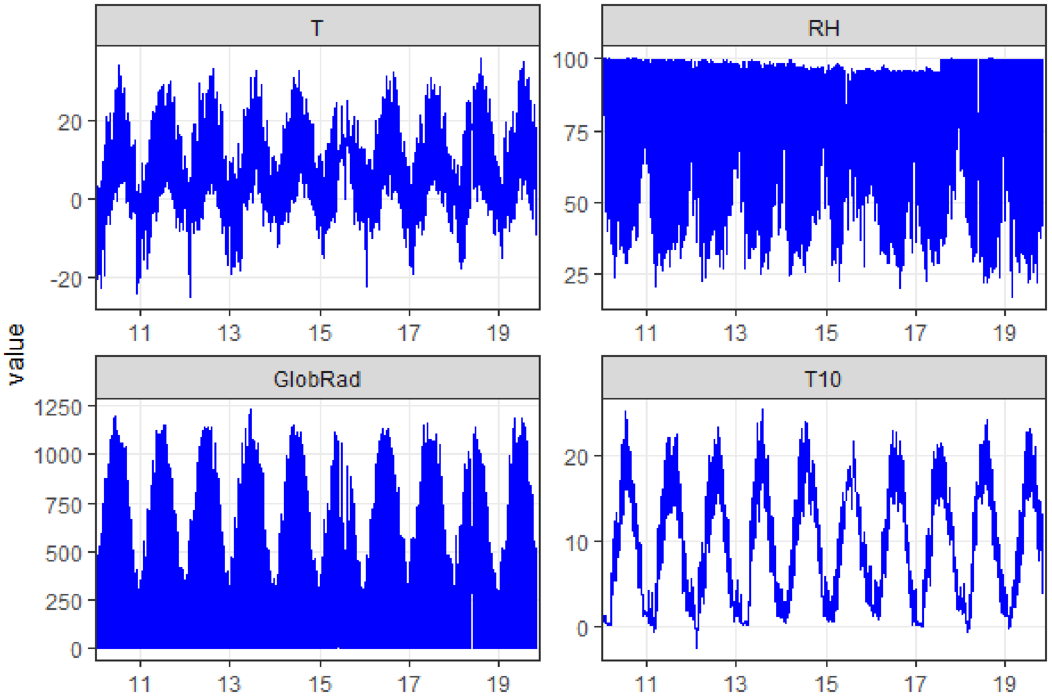


Complex catchment functioning

- Complex geomorphologic structures and soil profiles: High hydraulic conductivity and porosity in the top layer vs much less permeable deep layer (Graeff et al., *Hydrol.Process*., 2009)
- Complex catchment responses and precipitation partitioning
- Extreme drought summer in 2018 and 2019



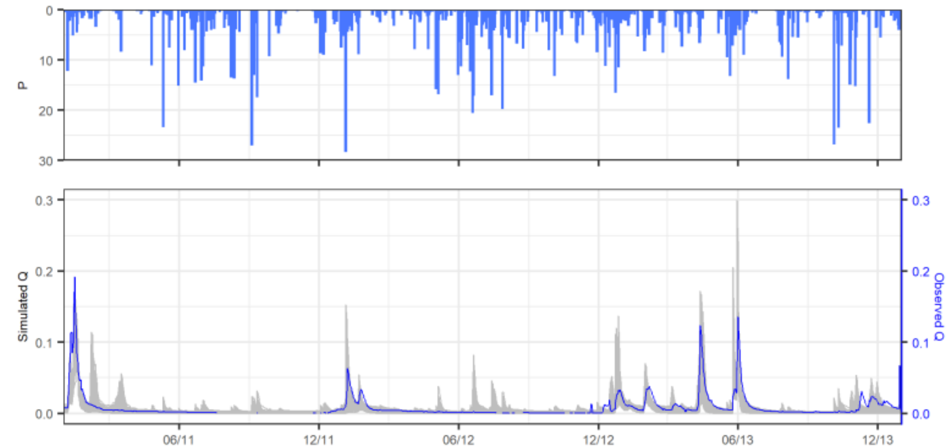
Distinct seasonal patterns of observed daily precipitation (upper) and daily discharge (lower)



Five-min high-frequency, continuous meteorological observations in 2010-2019
(**T**- air temperature (℃), **RH**- relative humidity (%), **GlobRad**-global radiation (W/m^2), **T10**-soil temperature at 10cm(℃))

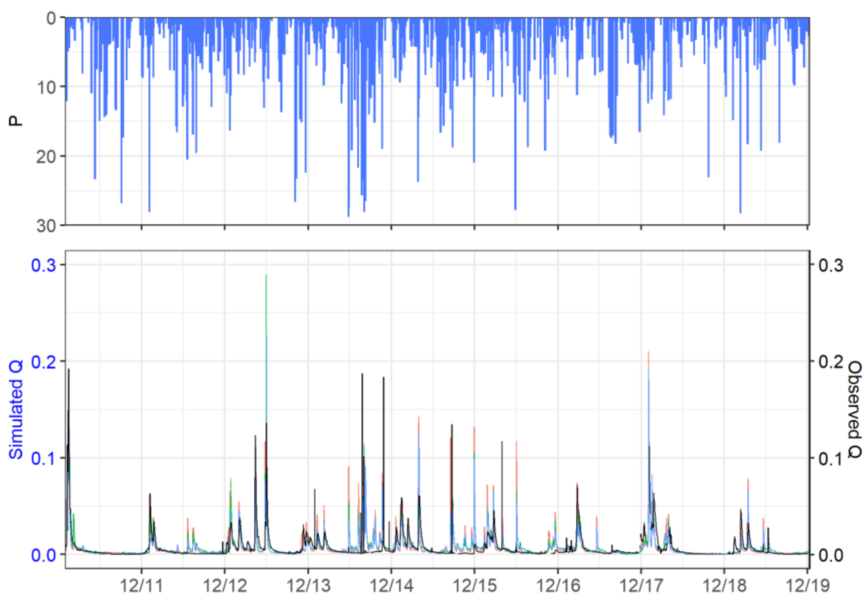
Preliminary results

- Initial model calibration based only on daily discharge data (2011-2013)

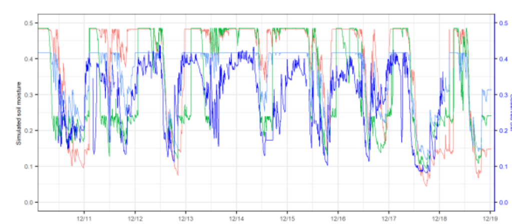


Discharge performance in calibration period
(grey lines: the best 100 simulations; blue line- observations)

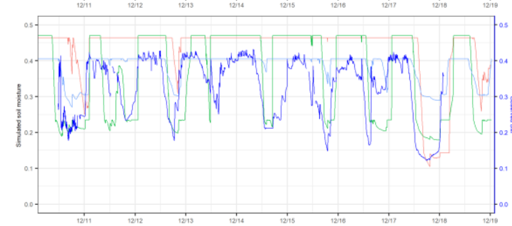
- Initial model validation I – discharge and soil moisture content (SMC) in 2010-2019



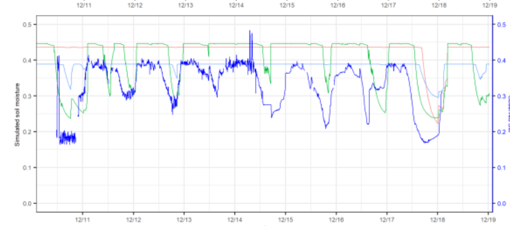
Best three runs of discharge simulations for the whole period
(colored lines-simulations, black line-observations)



SMC simulations in 1st soil layer (0-0.2m, blue line-observations at 10cm)



SMC simulations in 2nd soil layer(0.2-0.5m, blue line-observations at 30cm)

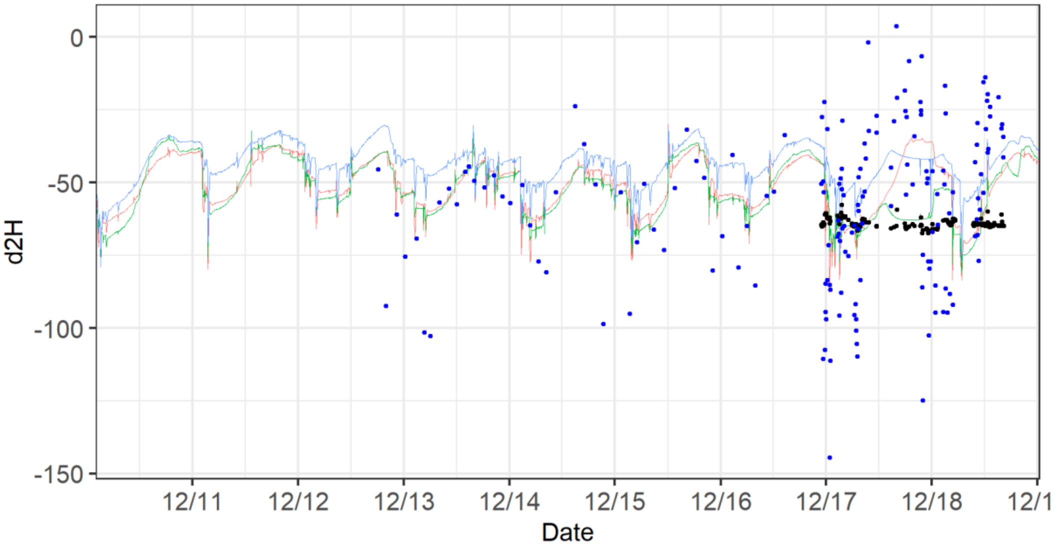


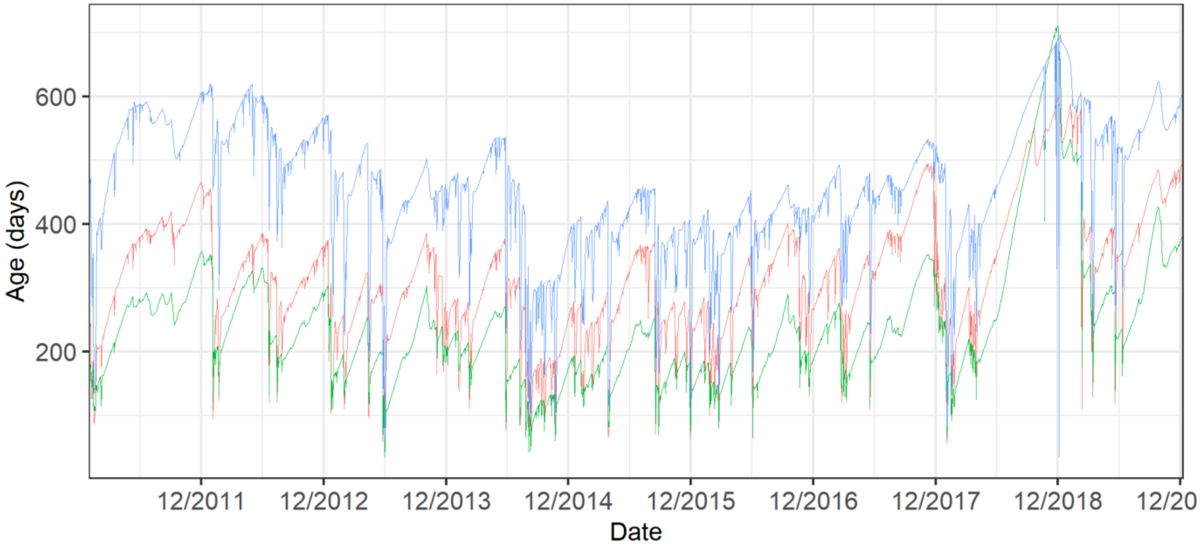
SMC simulations in 3rd soil layer(0.5-2m, blue line-observations at 50cm)

Preliminary results

- *Initial model validation* II – reasonable simulations of surface water isotopic and age signatures in 2010-2019

Water isotopic (^2H) simulations of best three discharge runs (colored lines-simulations, blue dots-measurements in Precipitation; black dots- measurements in the outlet surface water)

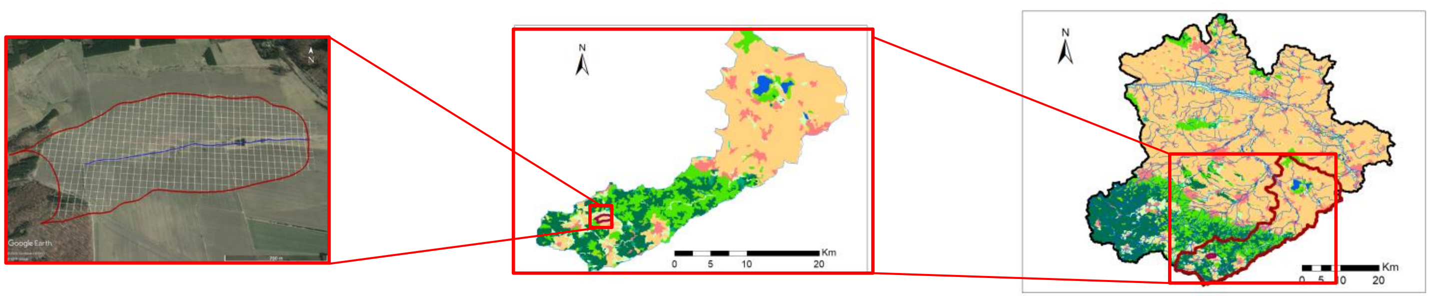




Water age simulations of best three discharge runs
Water age of the surface water at the outlet was younger (less than 100 days) in winter periods and much older (up to > 500 days) in summer periods

On-going and future work

- Model is capable of reproducing catchment functioning of well-managed Schäfertal catchment, as well as under extreme conditions in 2018 and 2019
- Comprehensive model calibration/validation based on multi-objective functions and multi-source data are needed
- Coupled ecohydrological and water quality modeling is critical for advanced understanding of ecohydrological and environmental impacts under the changing climate
- Coupled, tracer-aided model support targeted investigations of critical areas/moments across scales



The Schäfertal catchment (1.44 km²)

The Selke catchment (456 km²)

The Bode catchment (ca.3300 km²)

IGB
Leibniz-Institute of Freshwater Ecology and Inland Fisheries