Complex linkages between hydrologic dynamics & biogeo-chemical processes in the near-stream zone – new ways forward

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1 HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Outline

- Introduction: Why care about GW-SW interactions ?
- Characteristics of the GW-SW interface
- Case studies of three stream-aquifer systems
  - 1st order stream in a riparian wetland (Lehstenbach, South-East Germany)
  - monsoonal stream-aquifer dynamics (Haean Catchment, South Korea)
  - hyporheic dynamics (Selke River, North-East Germany)
- Conclusions
- Outlook – challenges and ways forward

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Introduction

Background

- EU WFD mandates „good status“ of GW and SW
- Management → fate of critical substances in aquatic systems
- Importance of GW-SW exchange for ecological functions
- Need to evalute water & solute fluxes between GW and SW

Hypotheses

- GW-SW interface as a reactive zone for solute transformations
- Hydrologic dynamics → biogeochemical space-time patterns
- Patterns affect solute export to rivers and streams

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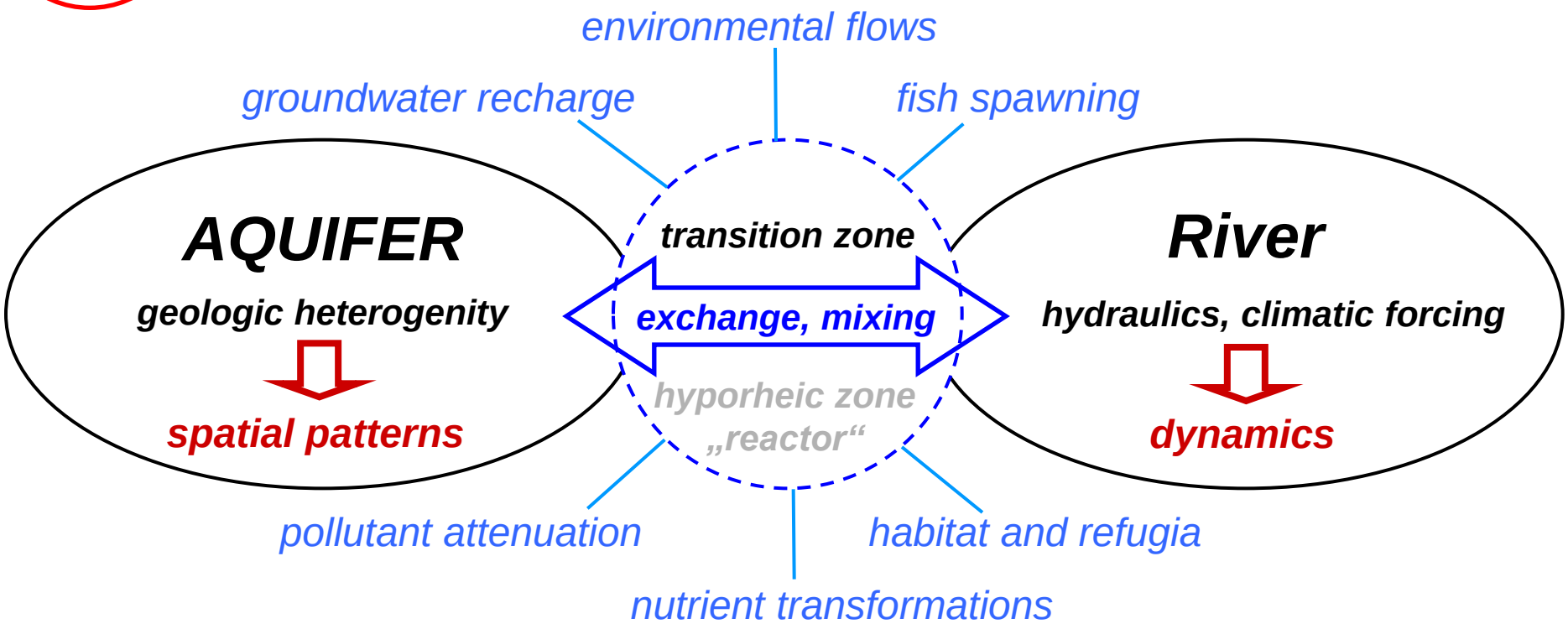
The GW-SW interface



Typically steep hydraulic, biogeochemical and thermal gradients

Spatial and temporal variability of fluxes → hot spots, hot moments

Mediates water and solute fluxes between GW and SW

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Hydrology ← → biogeochemistry

HYDROLOGY

o GW-SW exchange
o mixing → chemical, thermal
o flow paths → residence times
o flow velocities → exposure
o climatic forcing

BIOGEOCHEMISTRY

o oxygen content
o redox-reactions / sequences
o microbial activity
o thresholds
o kinetics

MOSAIC
of hydrologic
& biogeochemical
regimes

o transformation
o retention
o attenuation

export of nutrients and pollutants from aquatic systems

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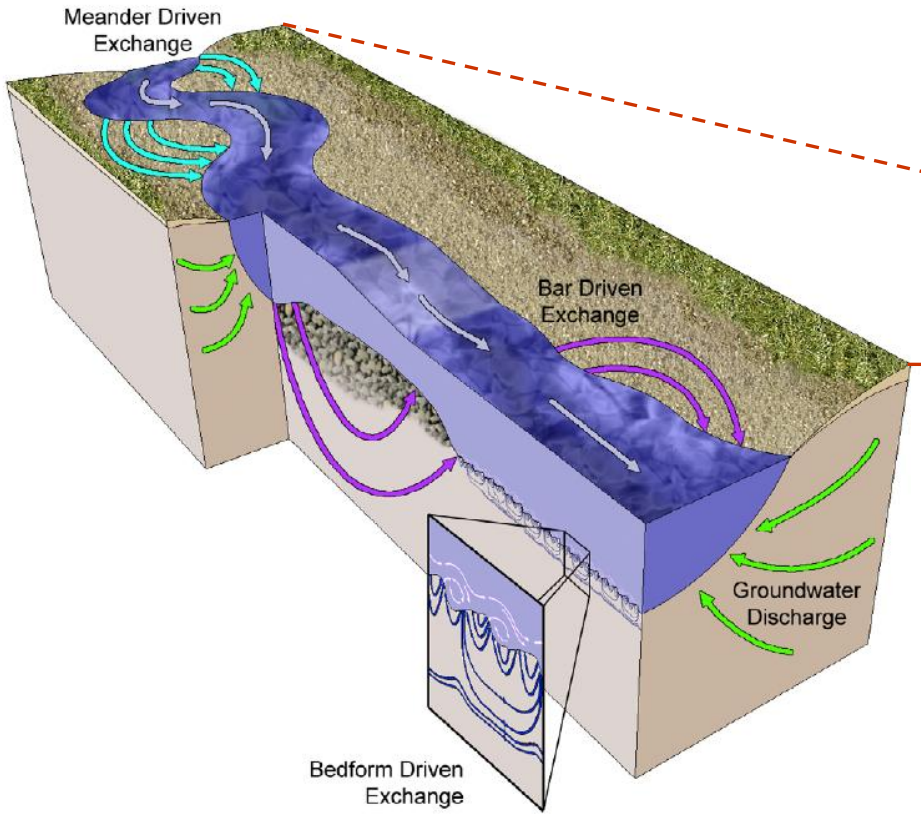
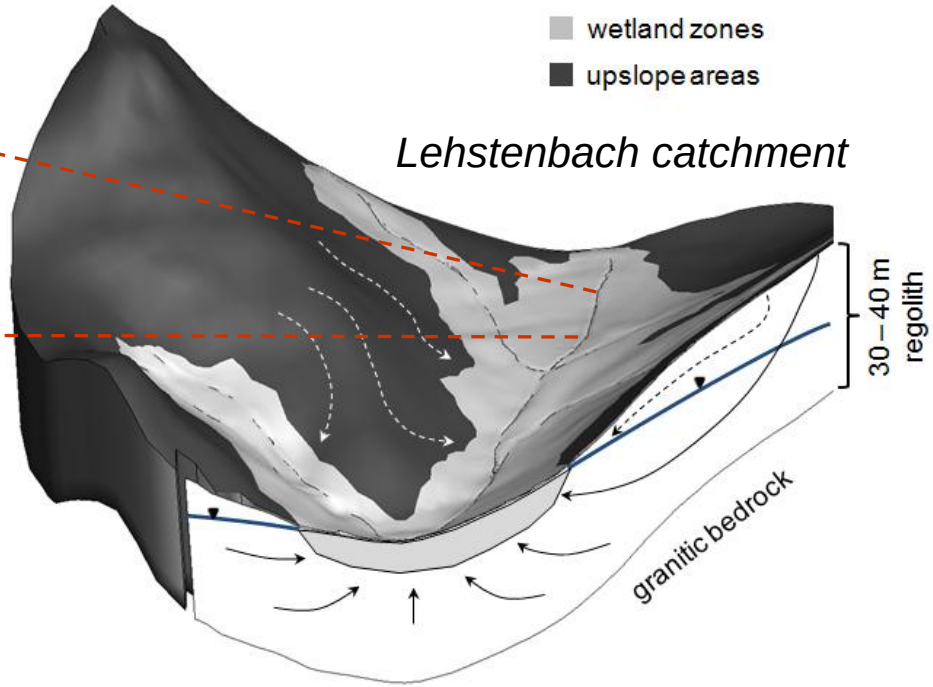
Complexity of GW-SW exchange – nested scales

hyporheic exchange



from: Stonedahl et al. 2010, WRR, 46:W12539

catchment-scale GW-SW exchange



from: Frei, Lischeid, Fleckenstein 2010, AWR, 33(11):1388-1401

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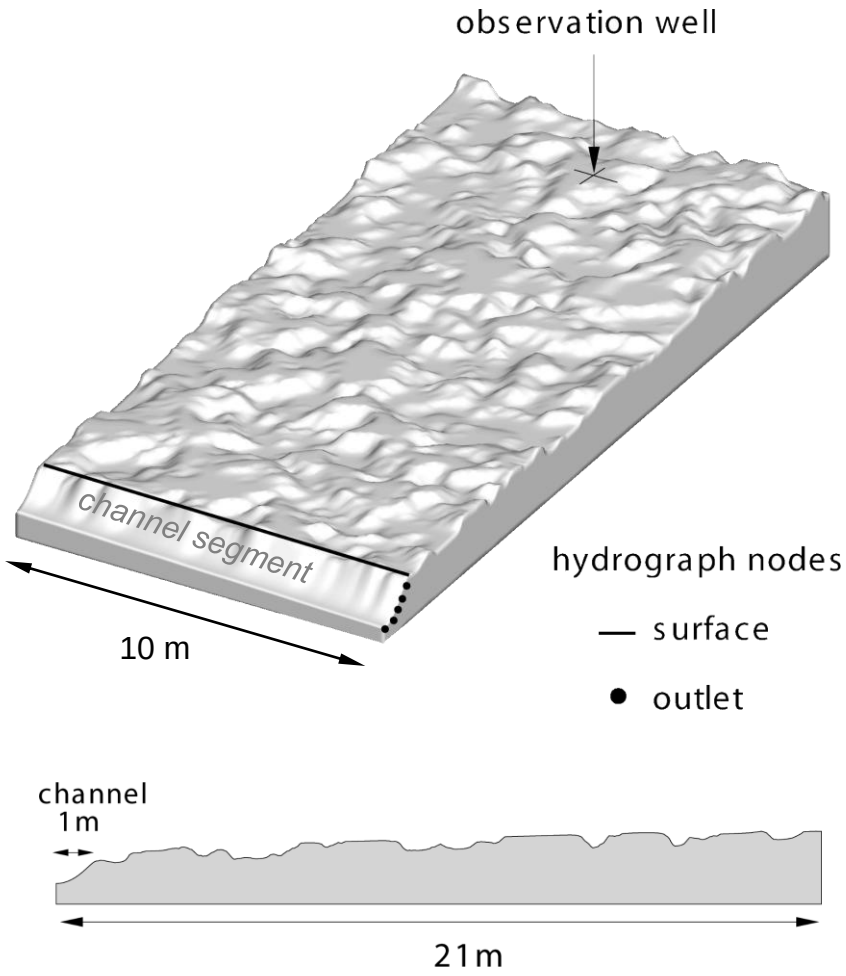
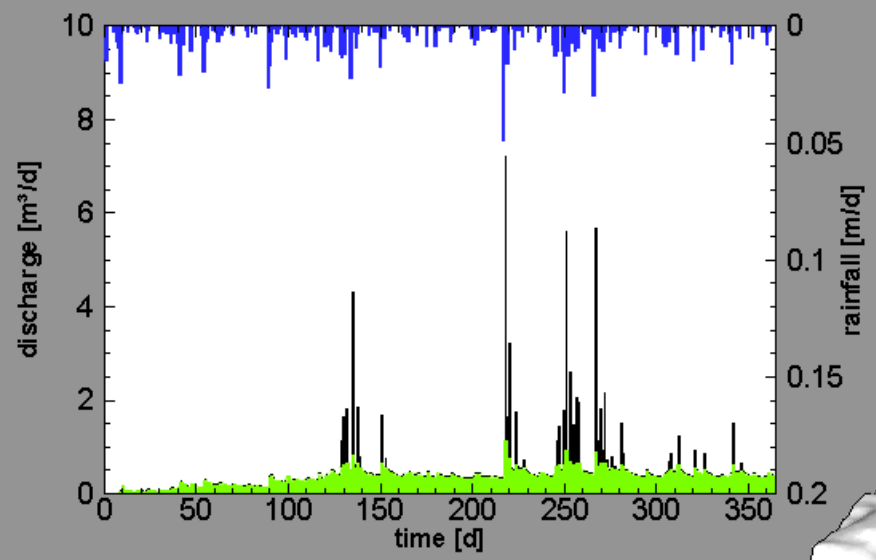
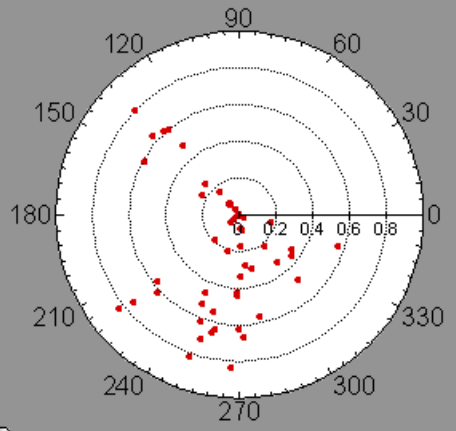
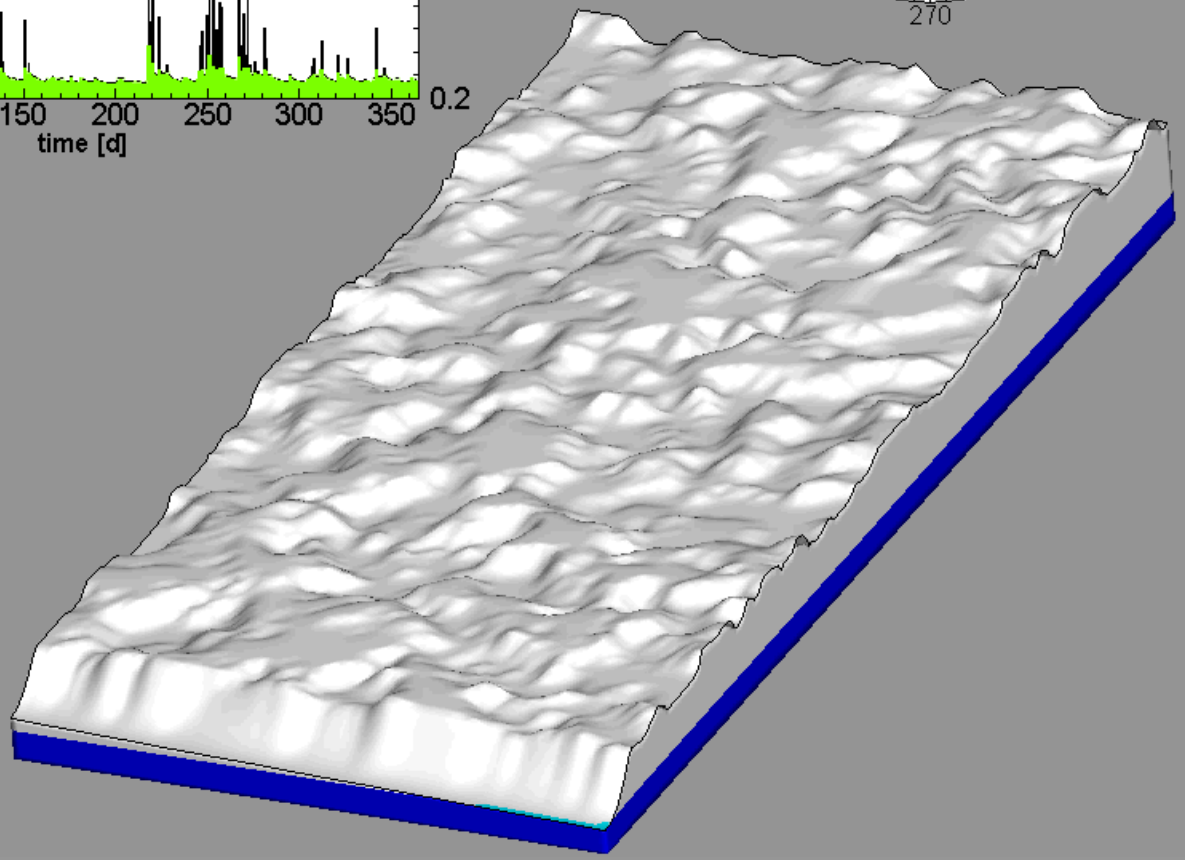
Lehstenbach – simulation of exchange dynamics



numerical code HydroGeoSphere







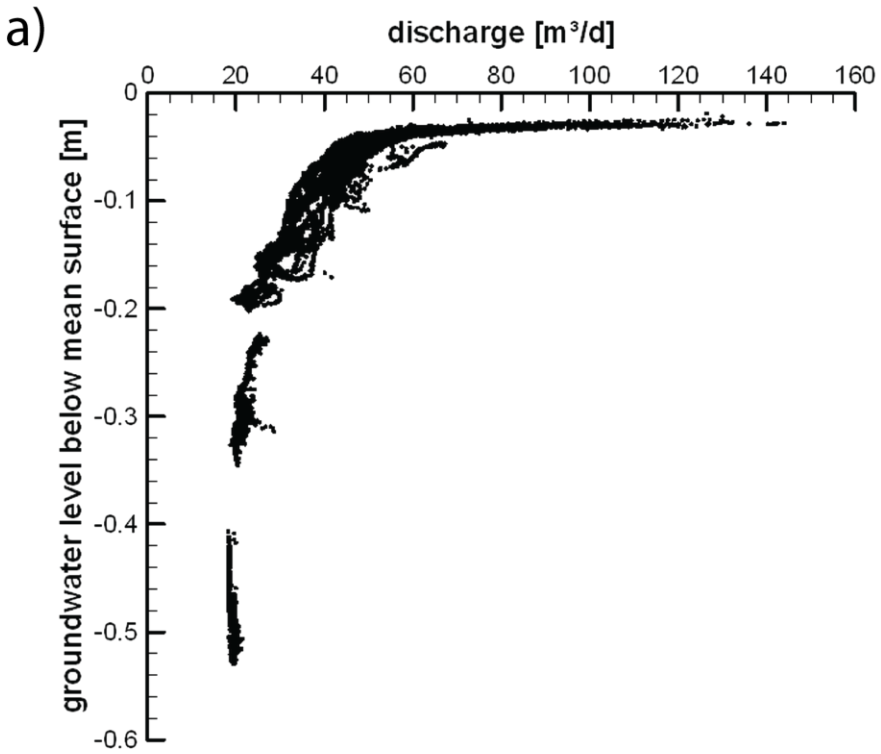
ponded water

groundwater

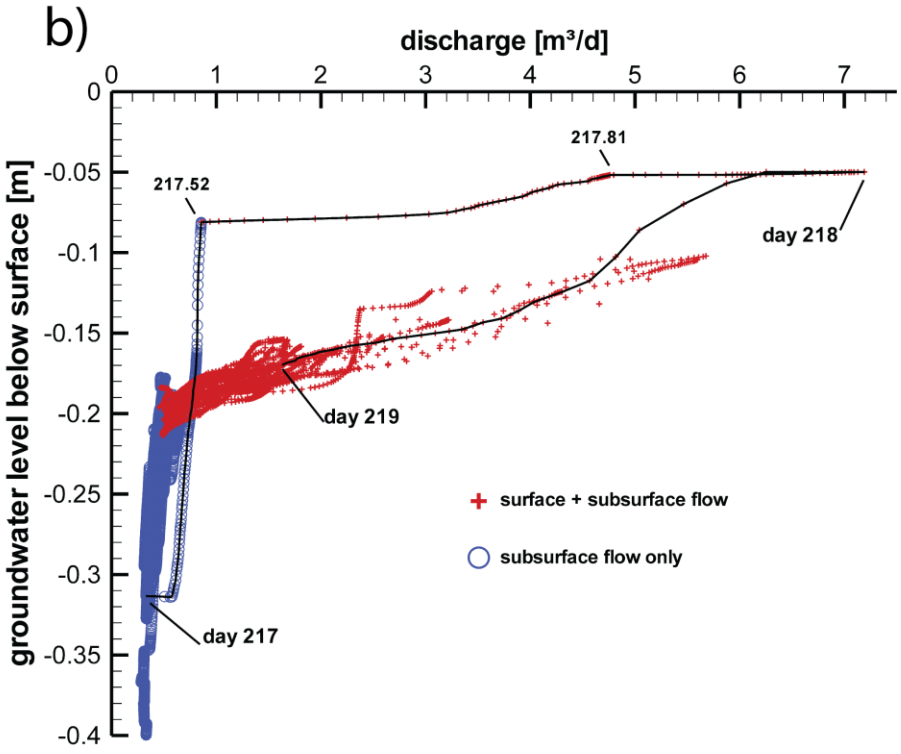
code HydroGeoSphere

Frei , Lischeid. & Fleckenstein (2010) Advances in Water Resources, 33(11):1388-1401

Non-linear, hysteretic discharge behavior



observed



simulated

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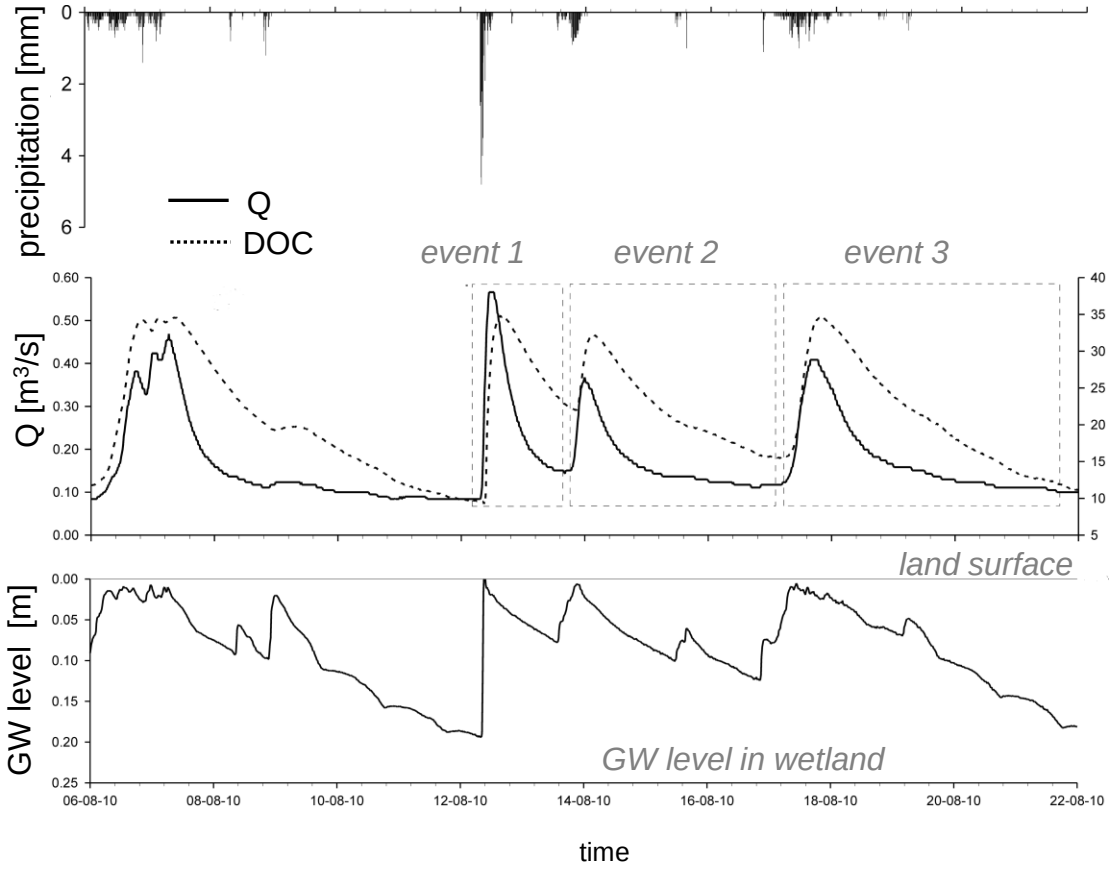
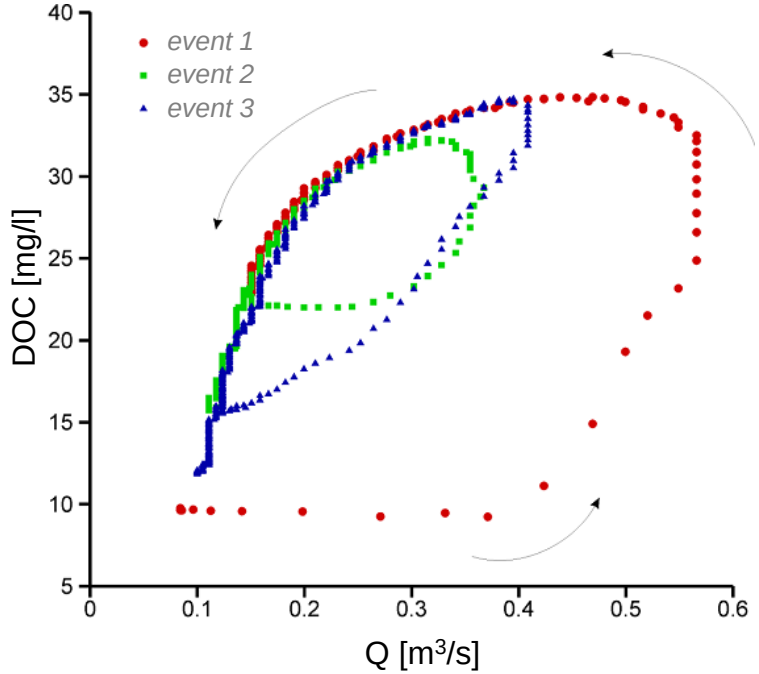
Non-linear, hysteretic solute dynamics

three rain events in the summer of 2010





dynamics in riparian wetland control DOC Export from catchment !

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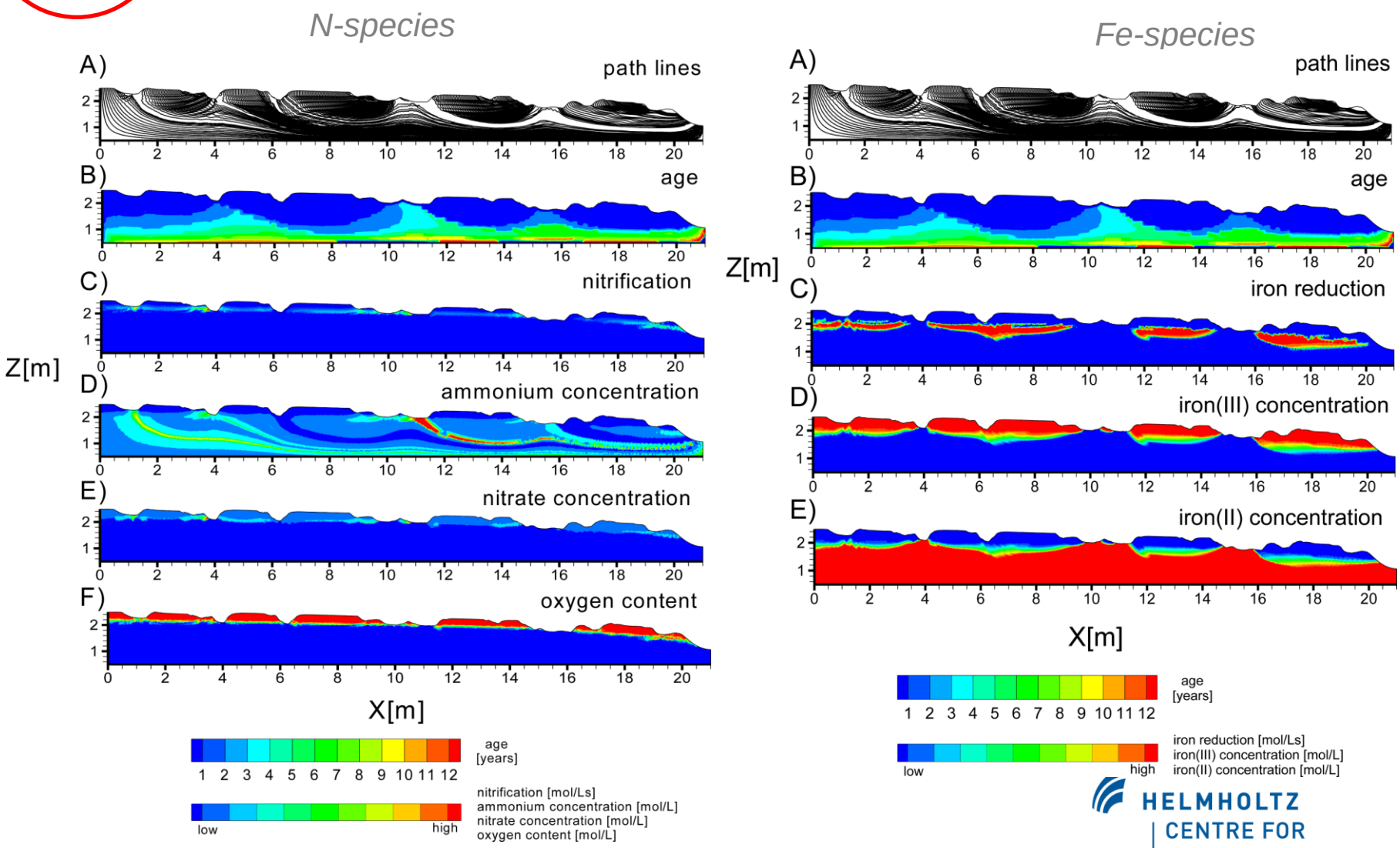
Simulated biogeochem. patterns – particle tracking + PHREEQC



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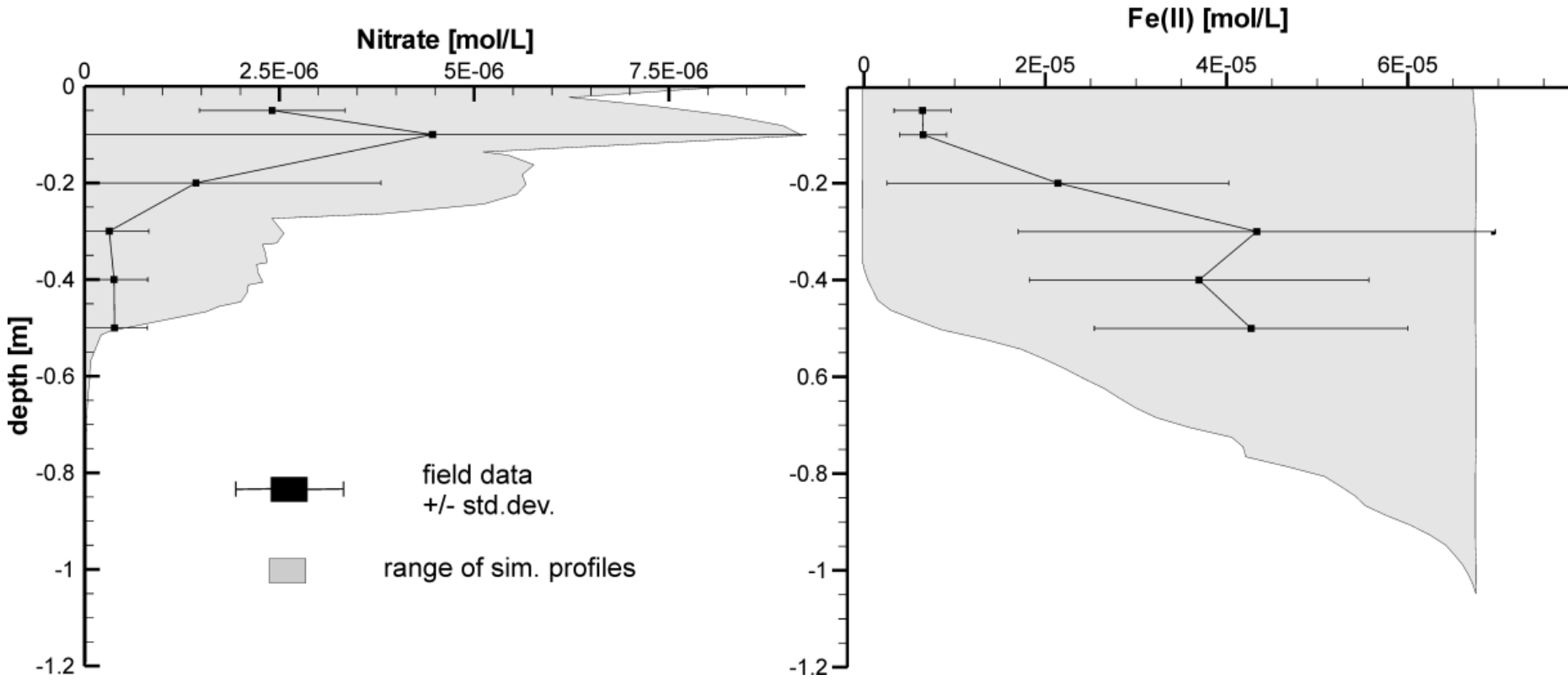
Observed vs. simulated concentration profiles



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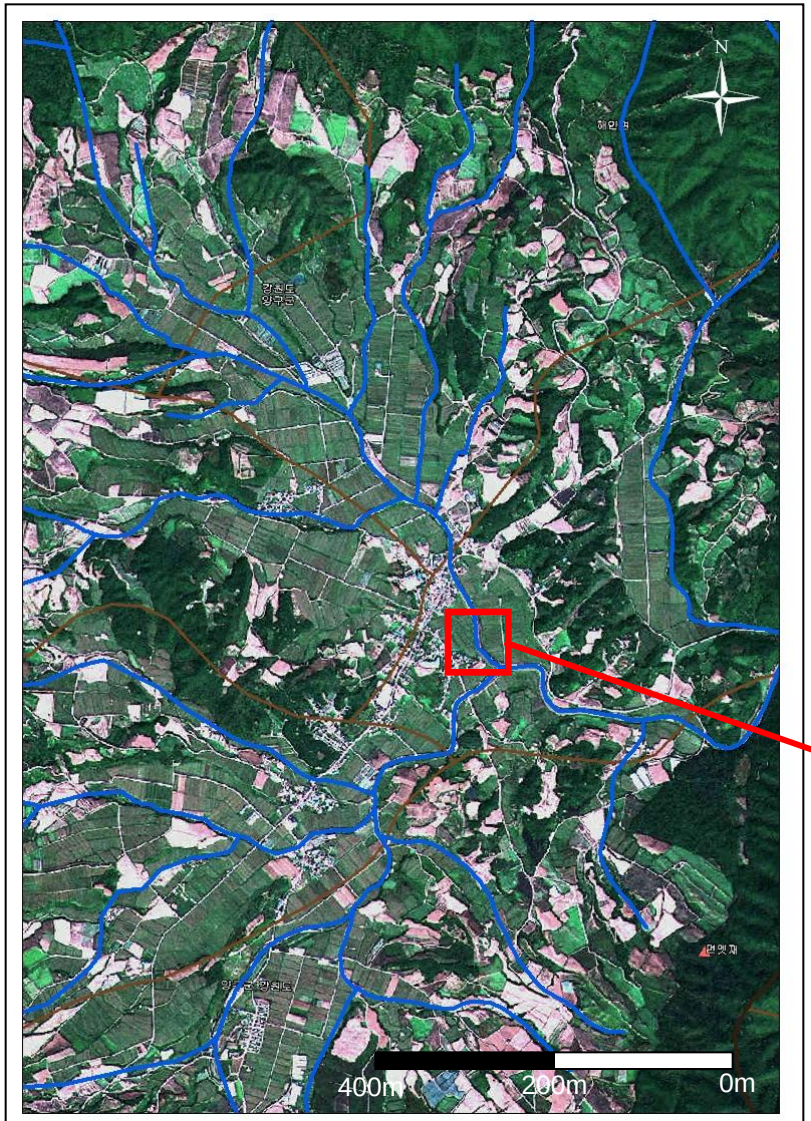
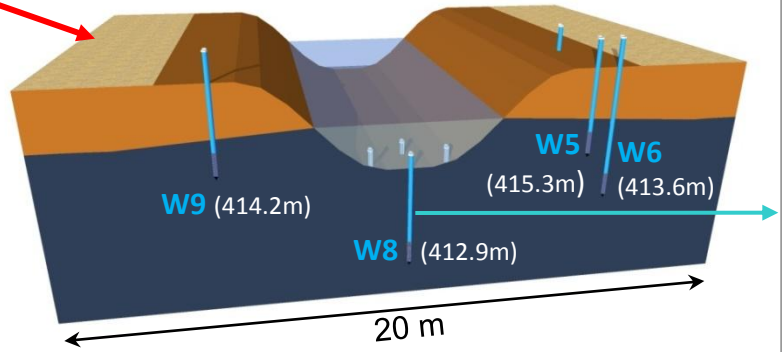
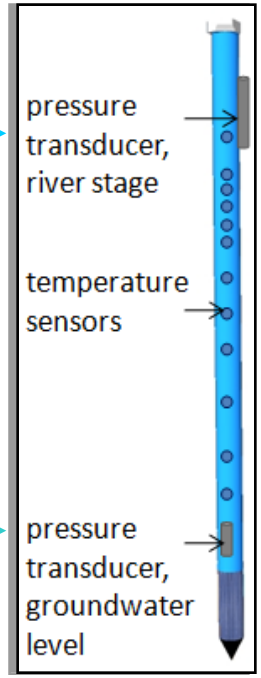
Haean catchment, South Korea



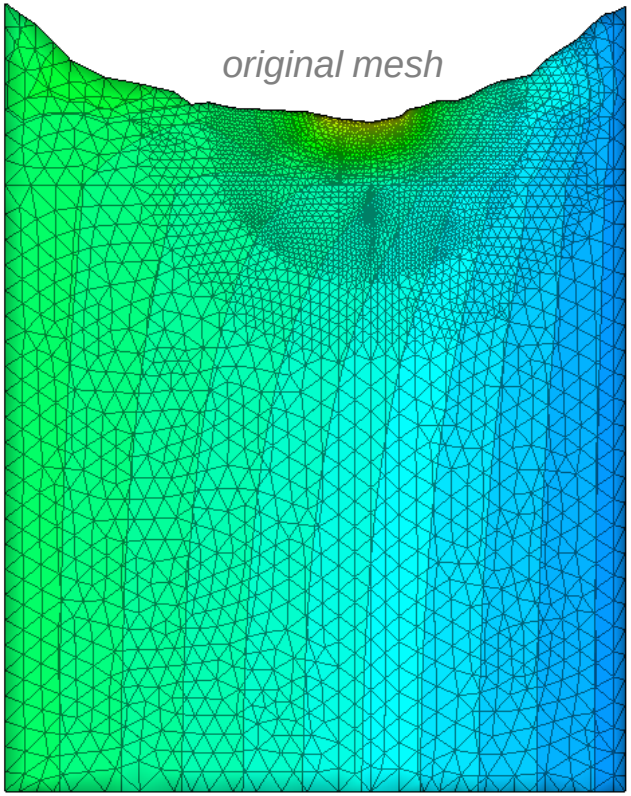


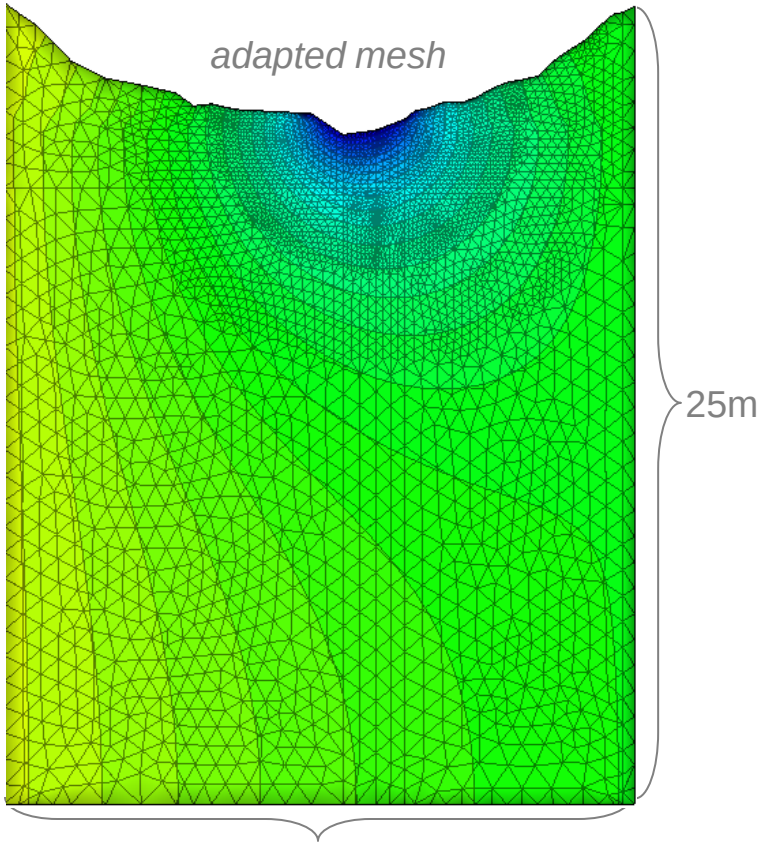


Monsoon events → scour in the channel

before July 2010 event (P = 15 mm in 70 min)

after July 2010 event

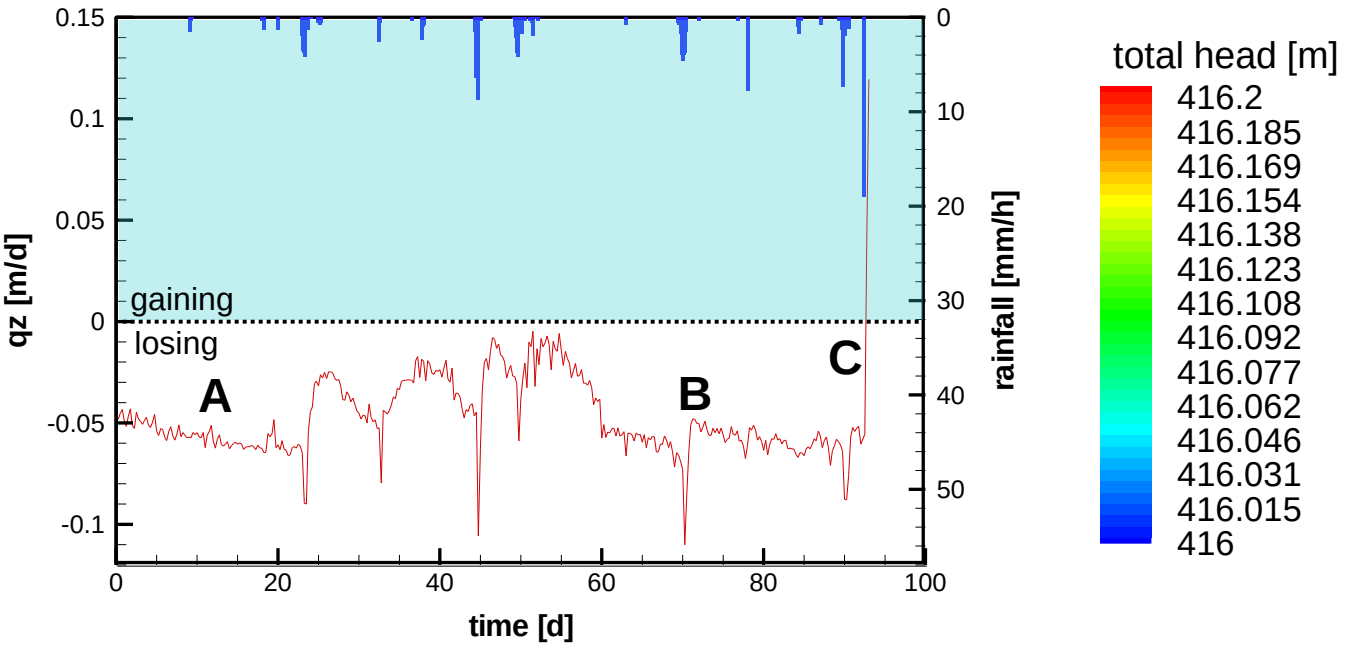


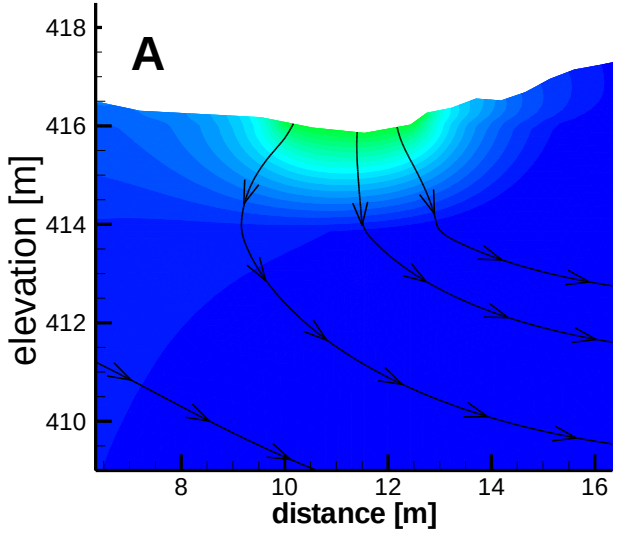


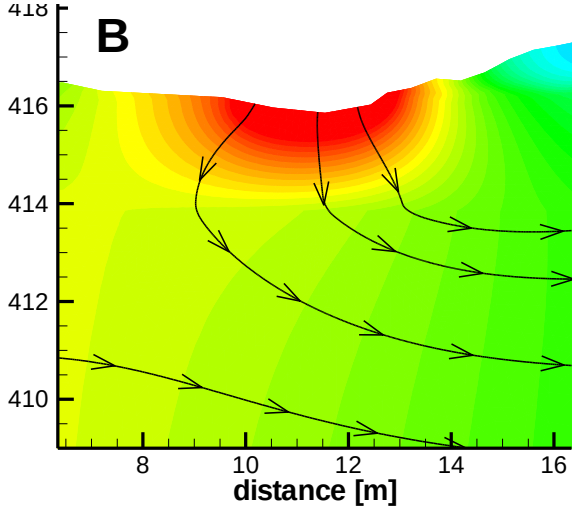
Monsoon events → shifts between losing & gaining

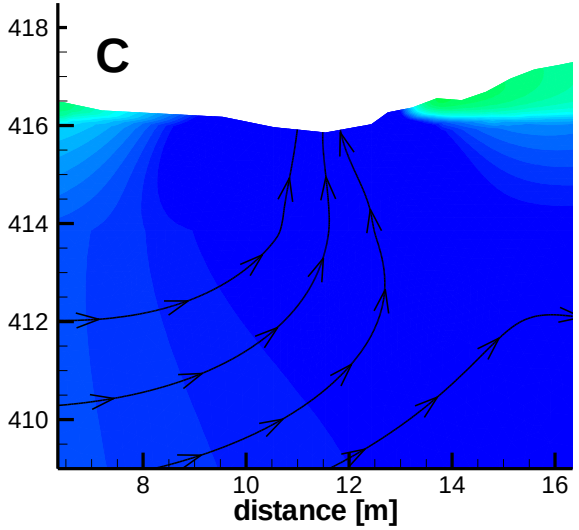
Period I → losing

April 3rd to July 5th, 2010





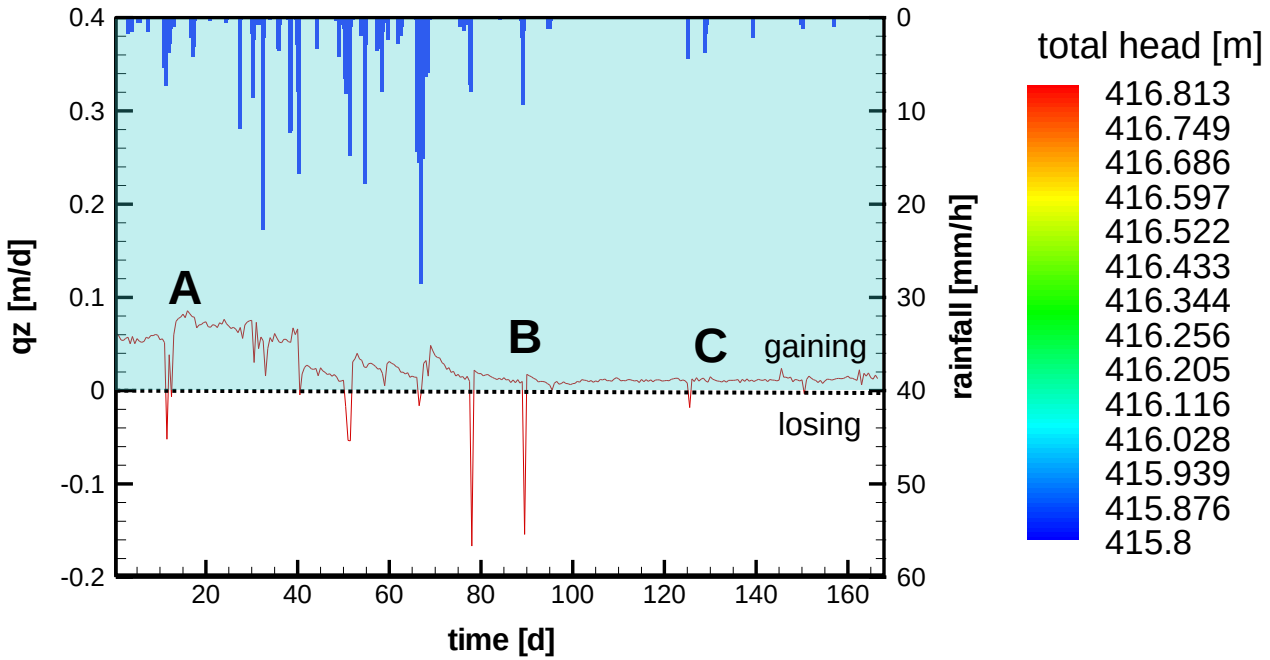


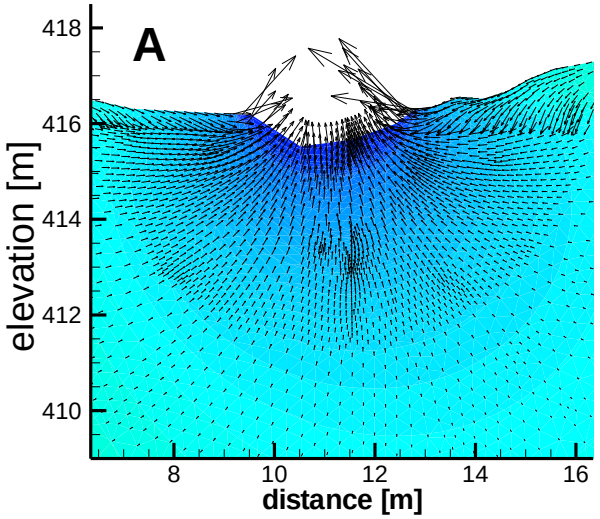


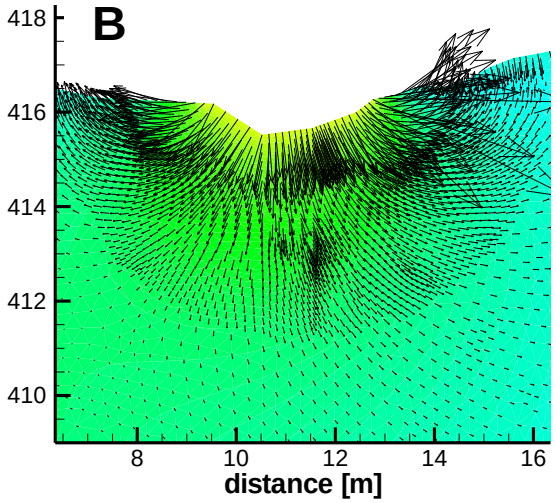
Monsoon events → shifts between losing & gaining

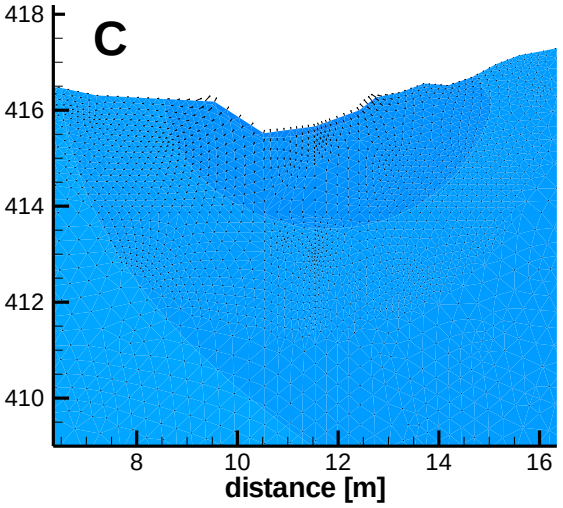
Period II → gaining

July 5th to Dec. 18th, 2010



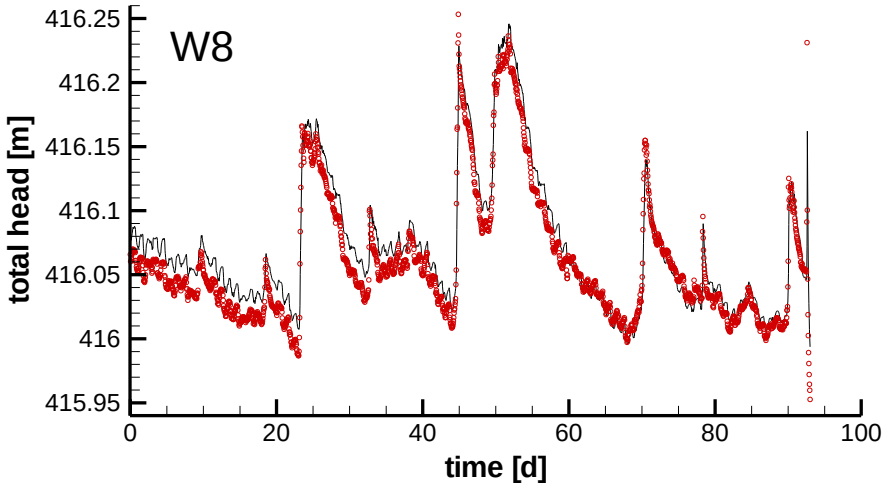




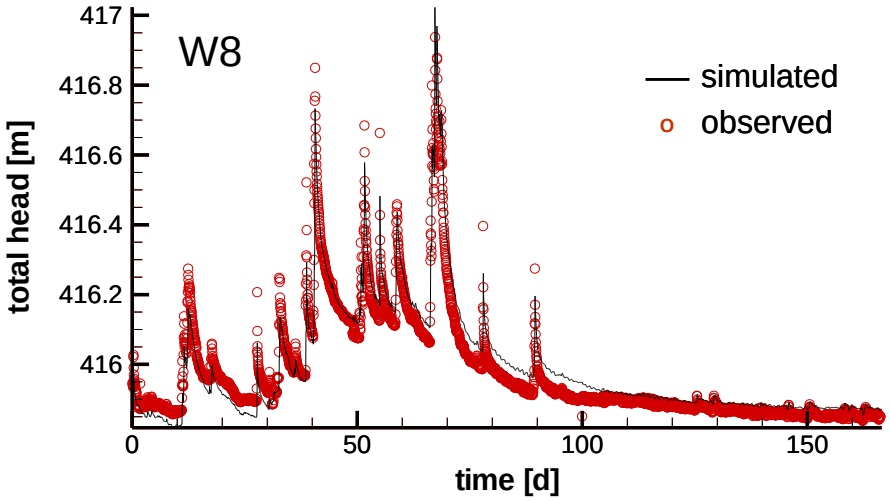


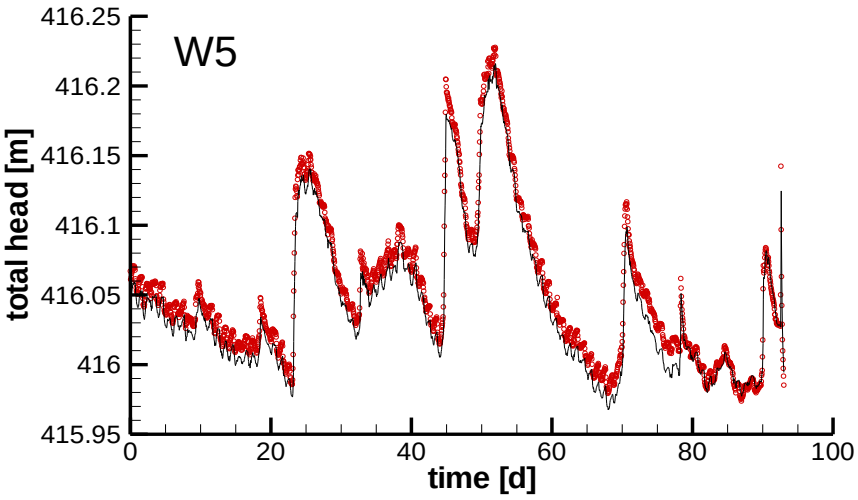
Simulated vs. observed heads

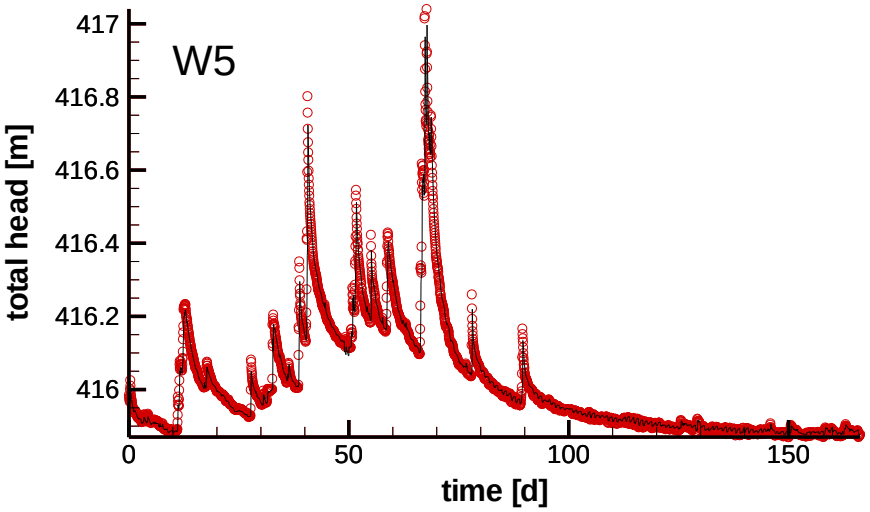
losing conditions



gaining conditions



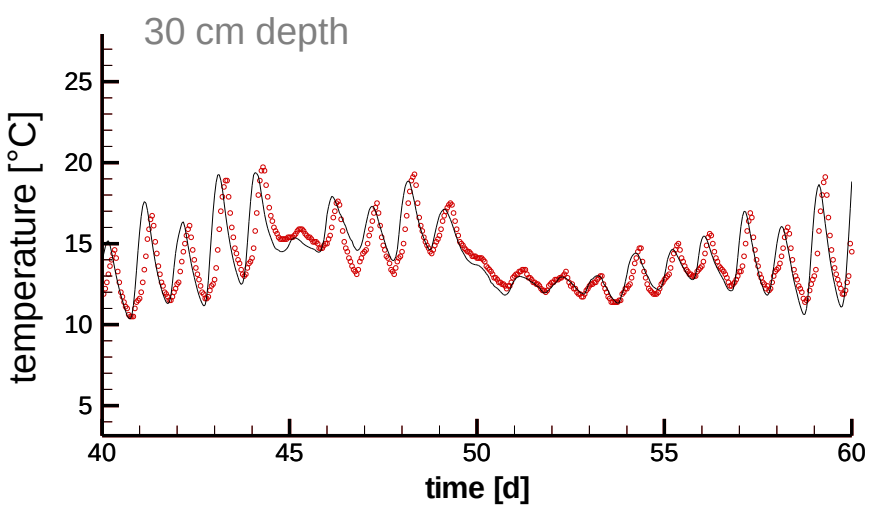


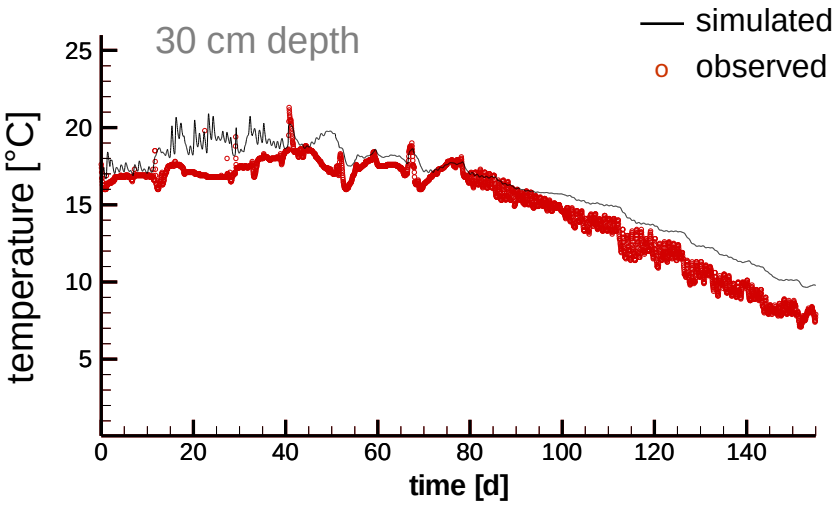


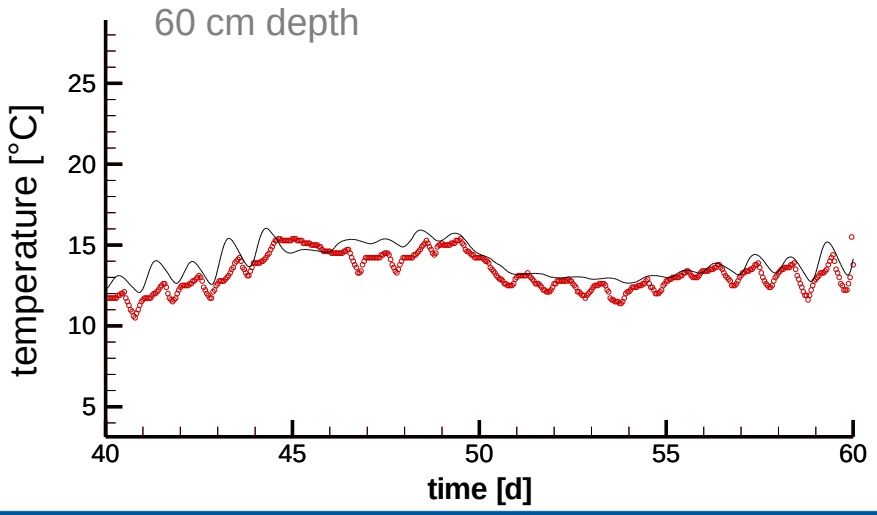
Simulated vs. observed temperatures at W8

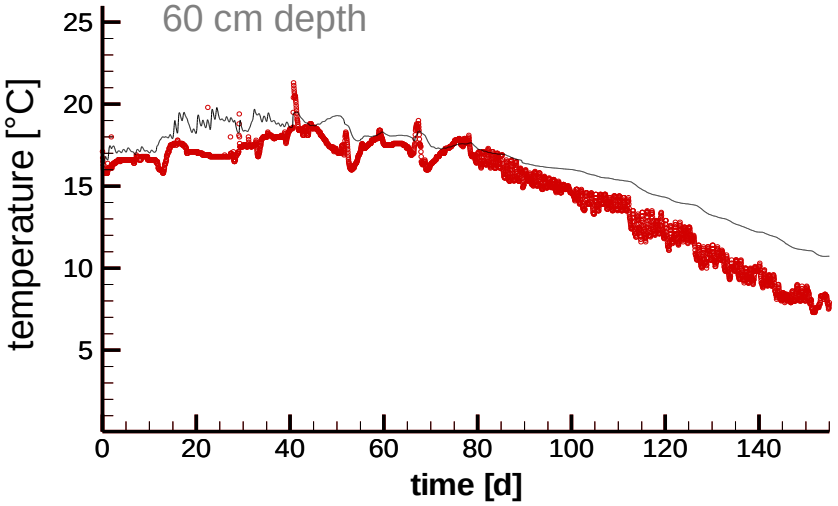
losing conditions

gaining conditions

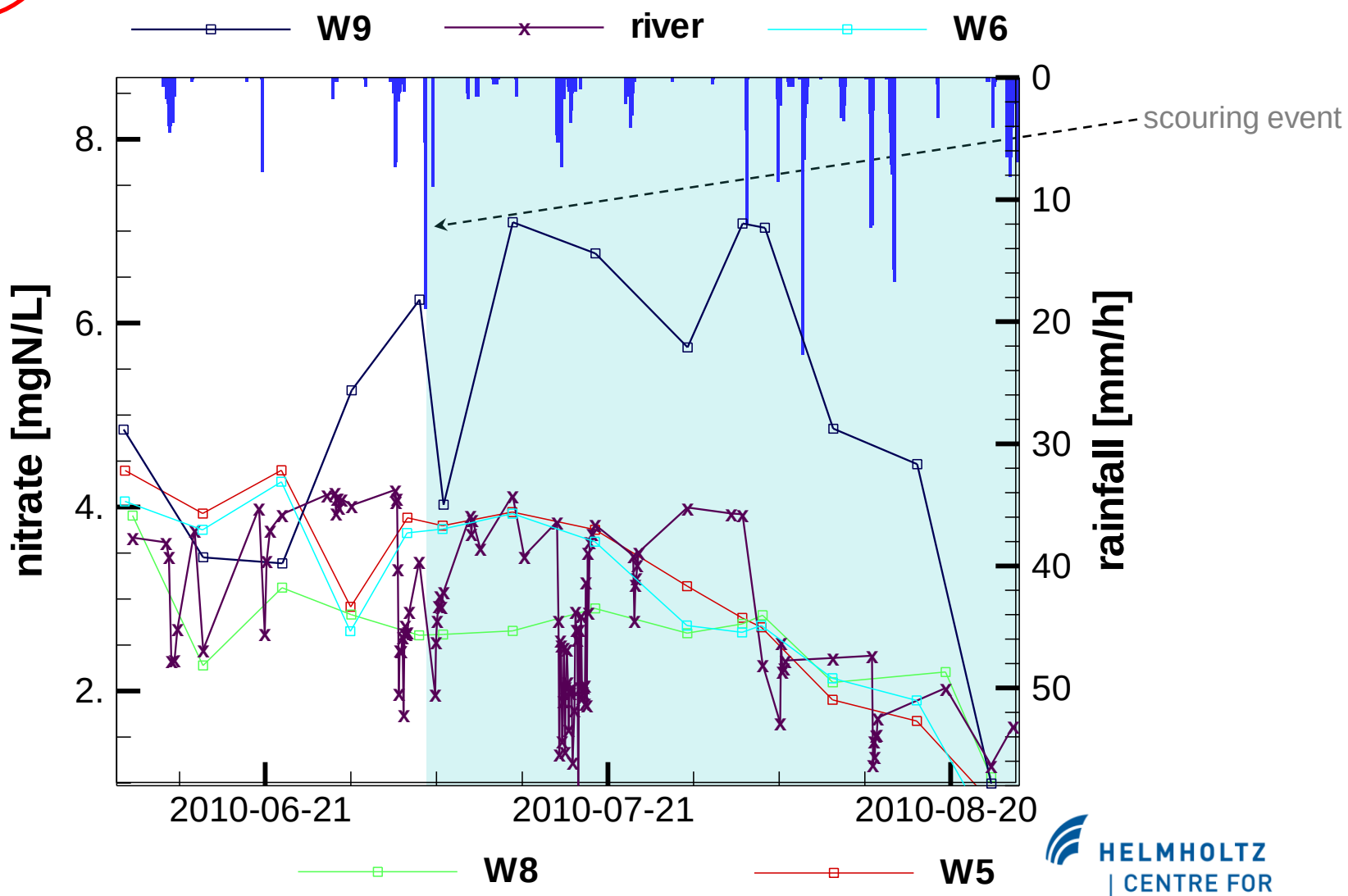








Dynamics of NO_3



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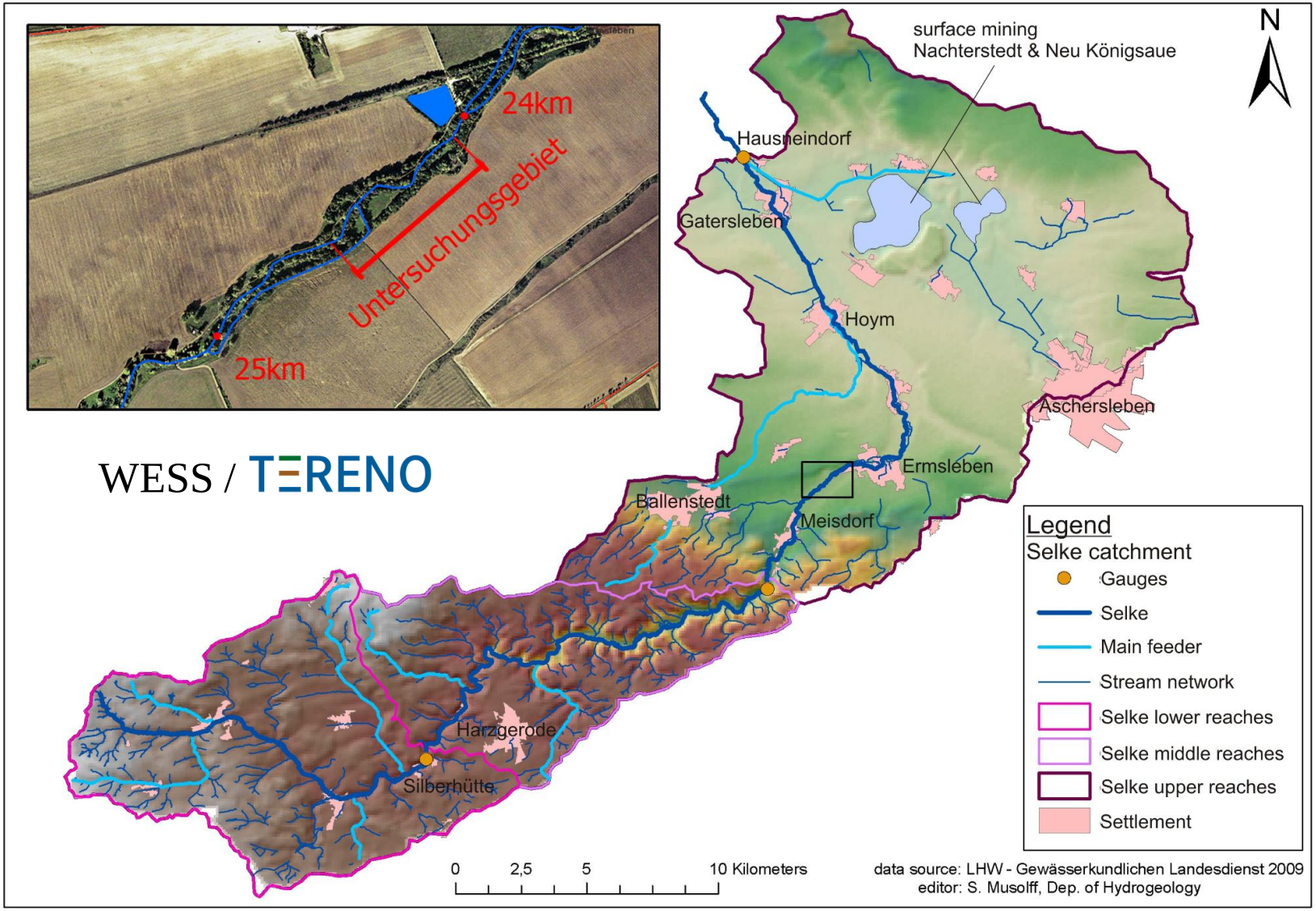
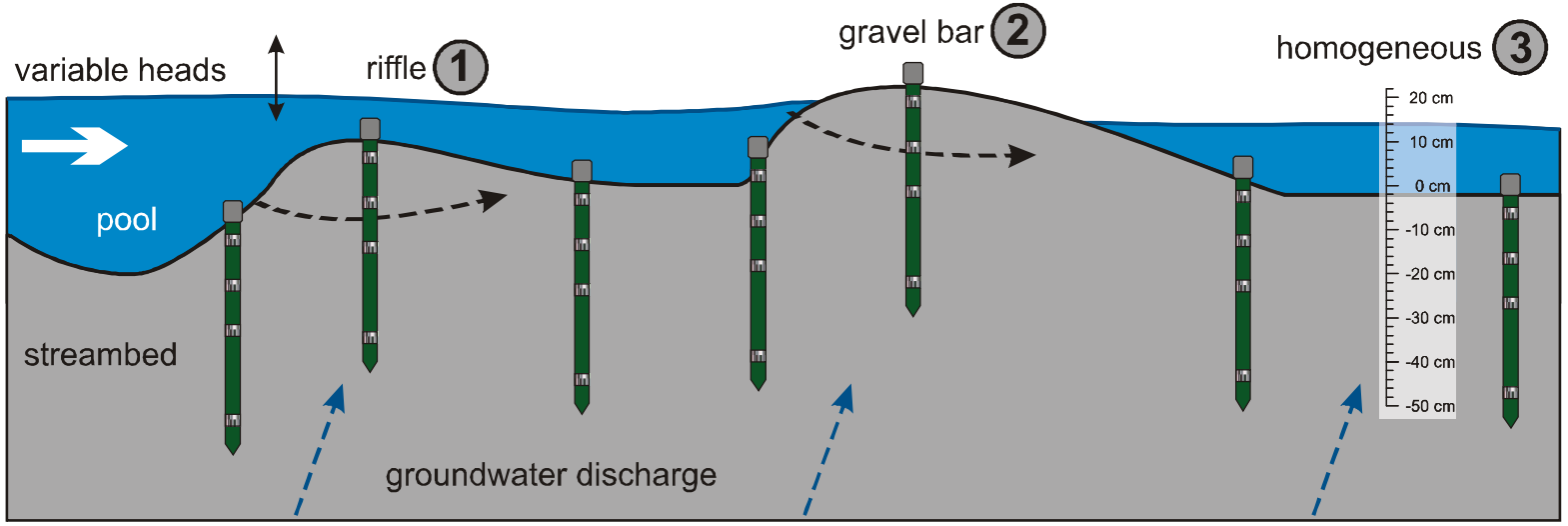
Hyporheic zone dynamics – Selke River, NE Germany

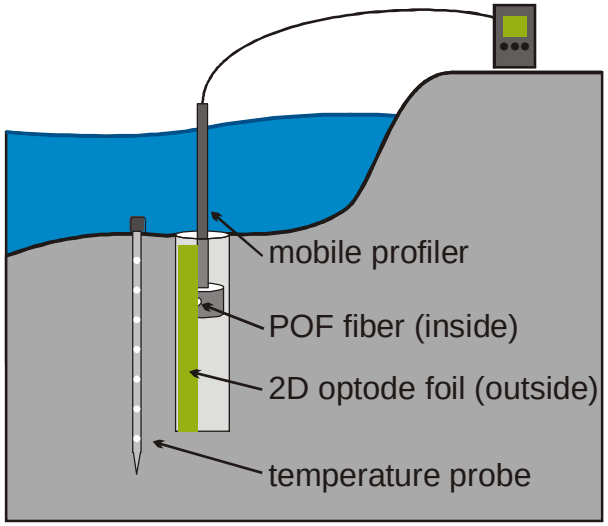


Field monitoring & field laboratory

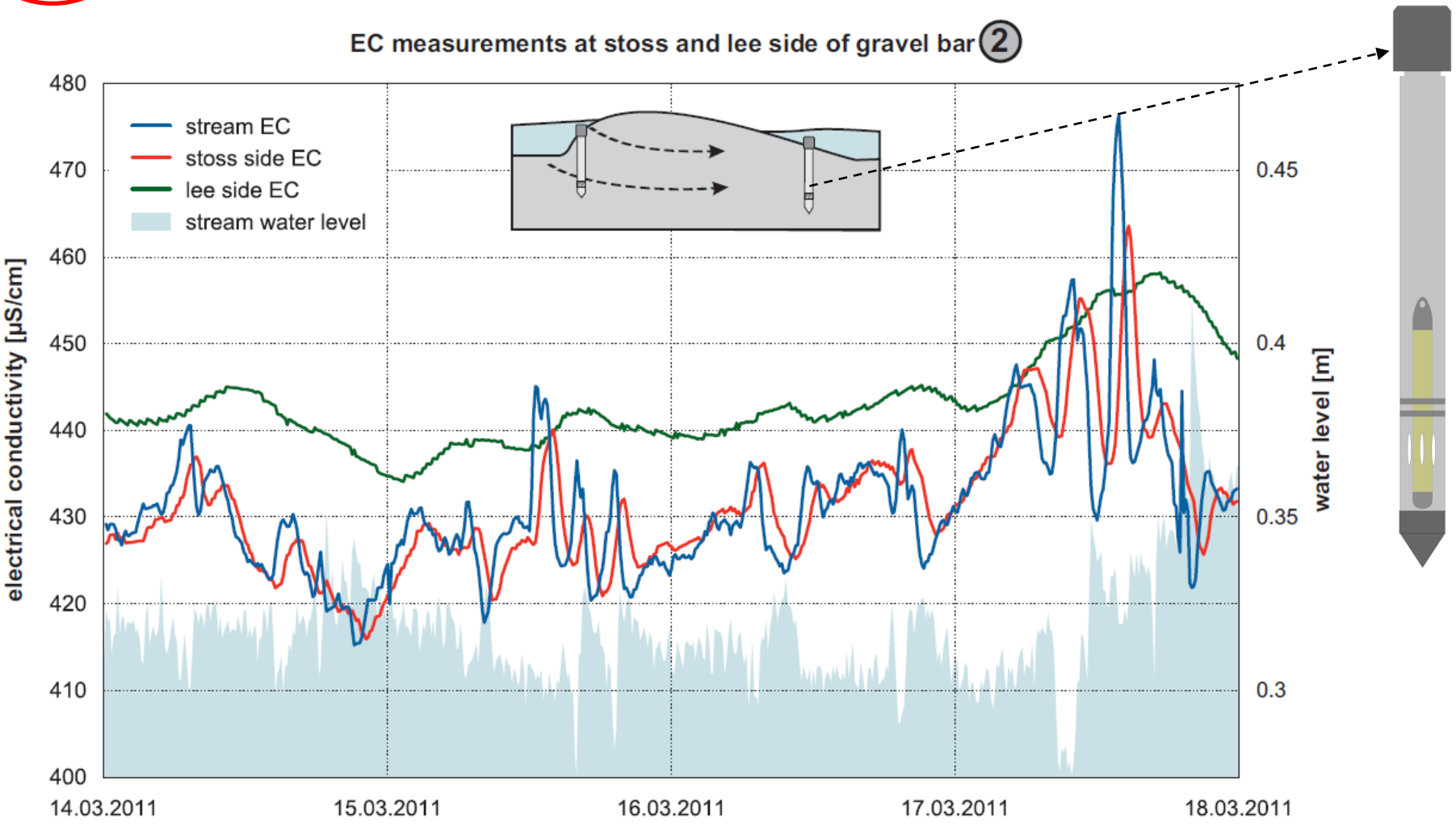


WESS / TERENO

high-resolution online oxygen profiling

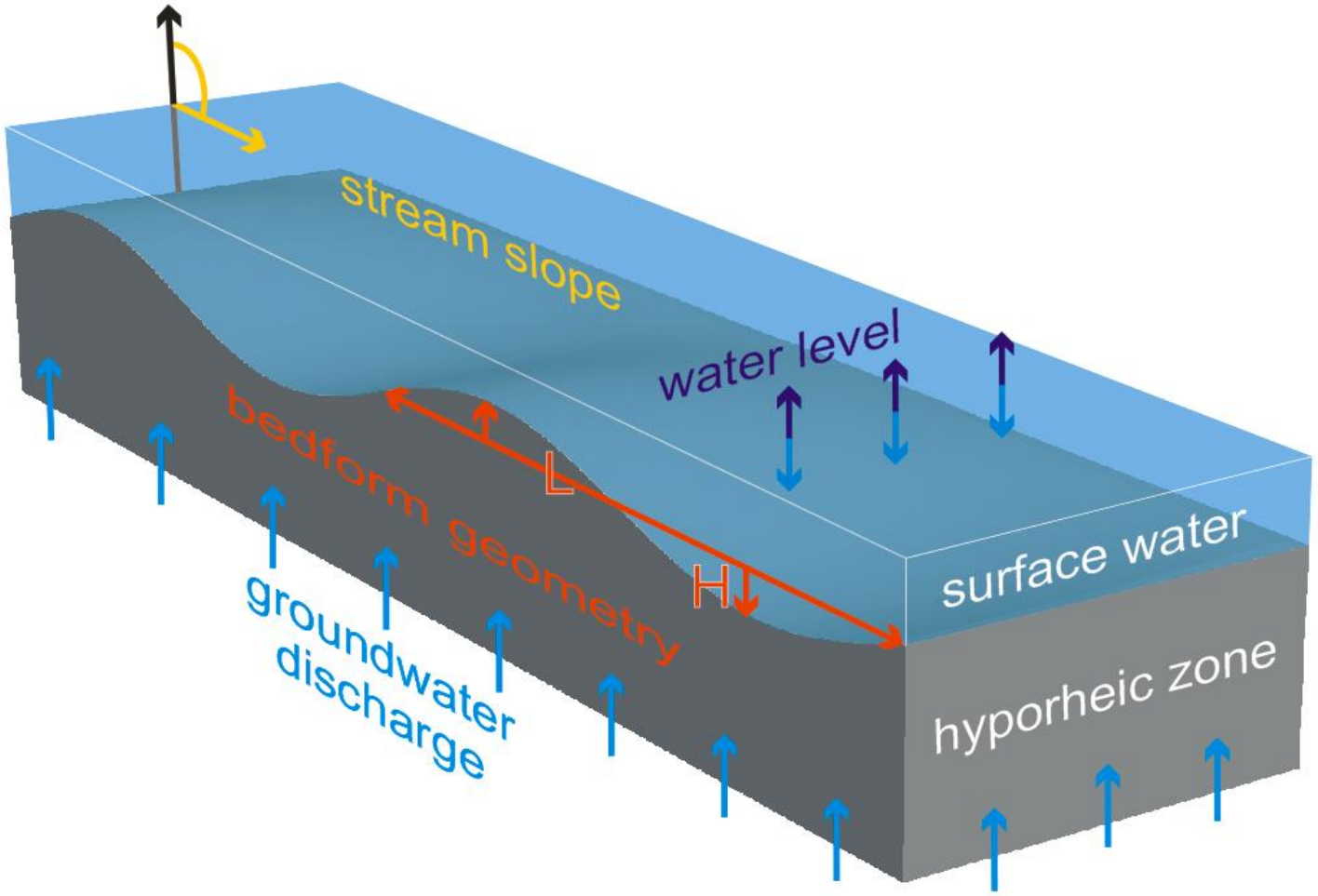


EC dynamics across gravel bar – *first results*



RTDs by non-parametric deconvolution of EC time series (Cirpka et al. GW 2007, Vogt et al. AWR 2010)

Explorative modeling – flow, transport & reactions



- CFD → turbulent flow in the channel (OpenFoam)
- flow & reactive transport in the hyporheic zone (MIN3P, HGS)

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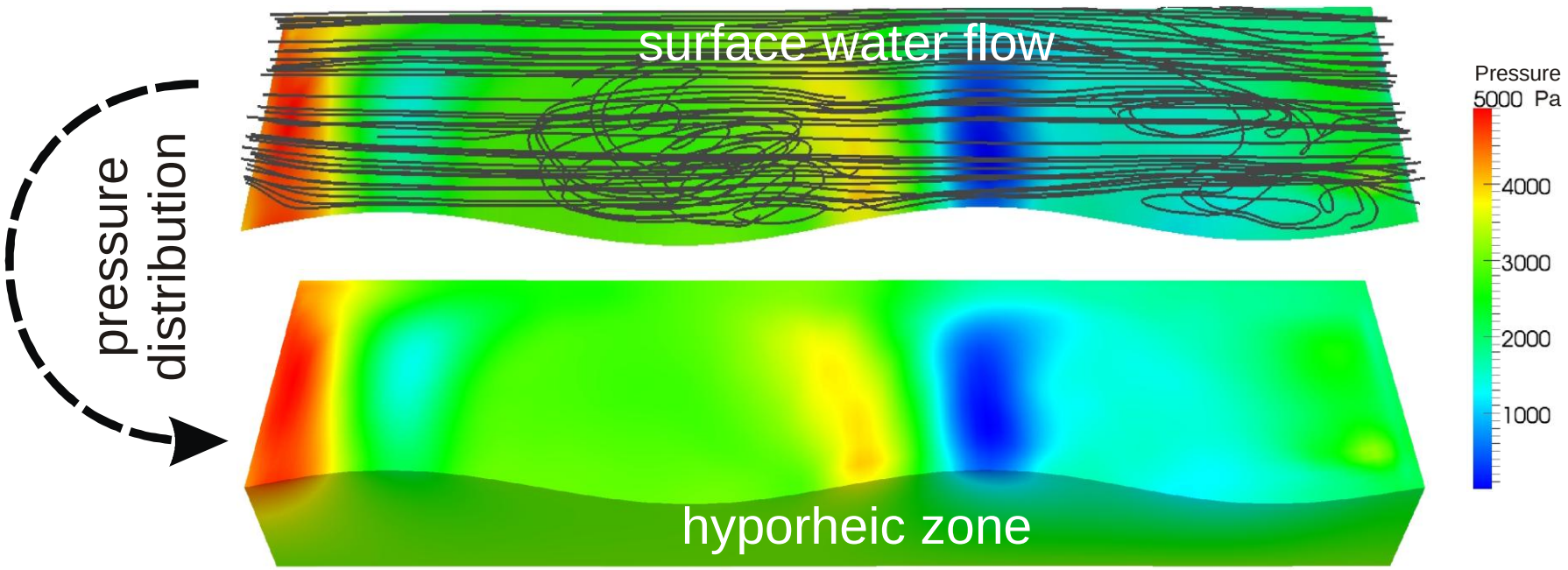
Pressure distribution at the interface



- CFD-generated pressure distribution as BC for HZ model
- variations in channel structures + inflow of ambient GW

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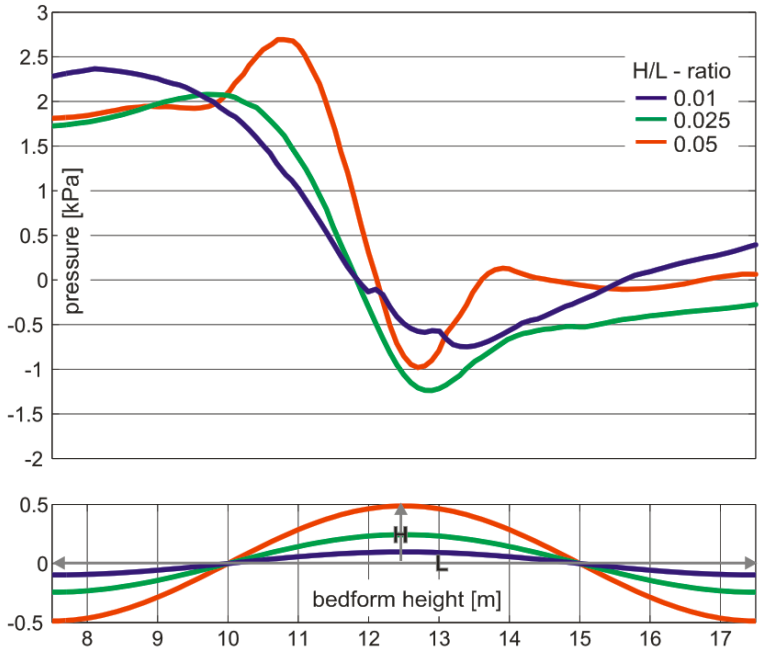
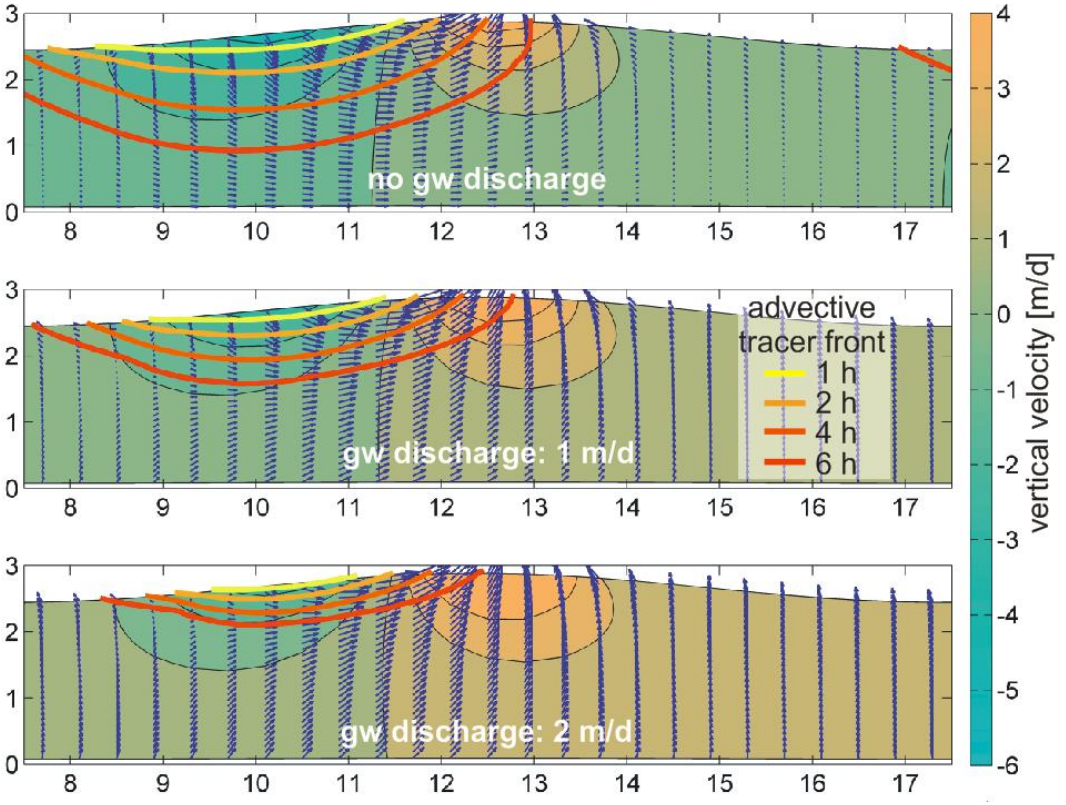
Modelling scenarios

pressure distributions for different H/L-ratios



tracer movement for different rates of GW upwelling



- shifting pressure minima & maxima for different bed forms
- GW inflow reduces extent of HZ

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Conclusions

- Complex dynamics of water & solute fluxes at GW-SW interface
- Hydrology as major control for biogeochemical process patterns
- Solute fluxes driven by event-based dynamics (e.g. thresholds)
- Specific times & locations may dominate solute flux response
- Solute fluxes not described well by average states & conditions
- Interface processes may drive solute dynamics at larger-scale
- High-frequency monitoring may reveal non-intuitive dynamics
- Explorative modeling helps to avoid pitfalls in data interpretation

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Outlook – challenges & ways forward

Challenges

- Knowing what to measure & monitor where & when
- How to identify dominant processes
- Model, parameter & predictive uncertainties
- How to assess process relevance at management scales

Ways forward

- Creatively utilize potential of new field technologies & methods
- Hypothesis-driven explorative research designs
- Combine „top-down“ with traditional „bottom-up“ approaches
- Iterative combination of monitoring & modeling → conceptual models of solute fluxes, classification schemes for GW-SW system types → WQ management strategies

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Thank you for your attention !