UFZ HELMHOLTZ Zentrum für Umweltforschung

Combined Effects of Geological Heterogeneity and Discharge Events on Groundwater and Surface Water Mixing

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2nd TERENO-OZCAR Conference Bonn,
27.09.2023

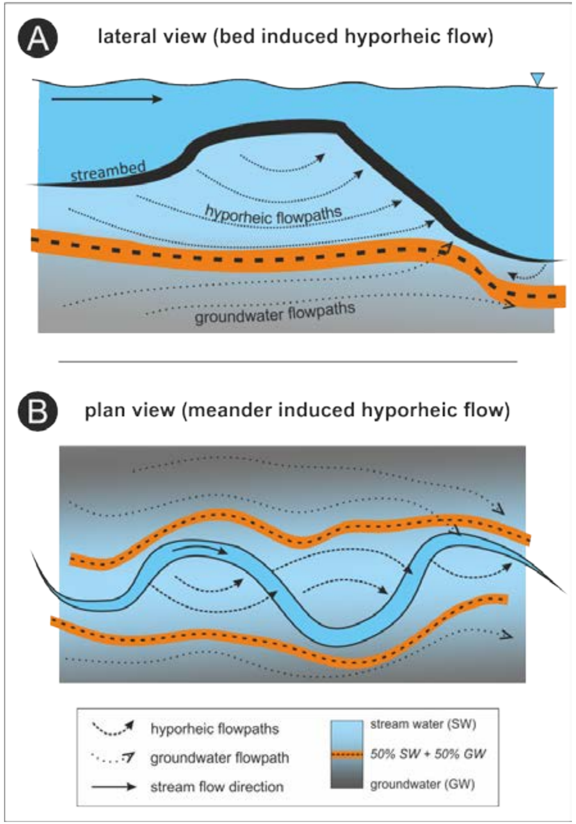
Introduction and Motivation

- Surface water (SW) and groundater (GW) mixing is relevant for biogeochemical processes affecting water quality around river corridors;
- SW-GW mixing has mainly been investigated in small-scale 2D domains, under the streambed, and mostly under steady-state conditions.

Our main objectives:

1) **Assess how SW-GW mixing develops through strongly contrasting geological units;**

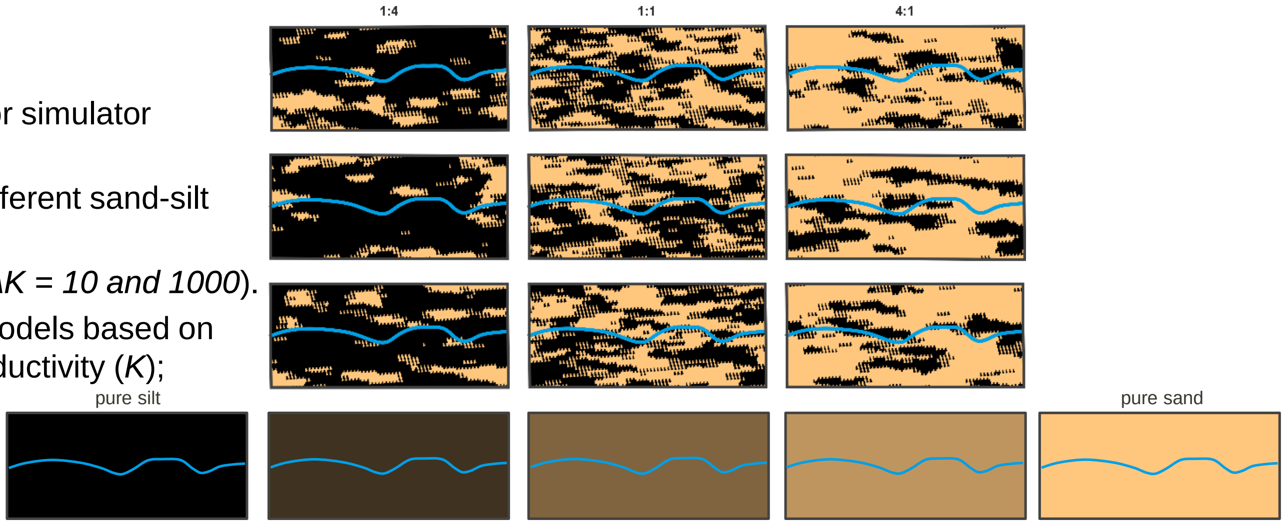
2) **Evaluate how mixing is affected by different discharge events (i.e., magnitudes and duration) within different geological scenarios.**



modified from Nogueira et al. (2022, HESS)

Methods and Virtual Experiments

- **Geological Scenarios**
  - Markov Chain model and indicator simulator (**TProGS**)
  - 30 different bimodal fields with different sand-silt ratio (*e.g., 1:4, 1:1, 4:1*);
  - Low and high *K* contrast cases (*ΔK = 10 and 1000*).
  - Equivalent pure-homogeneous models based on geometric mean of hydraulic conductivity (*K*);
  - = 70 geological scenarios



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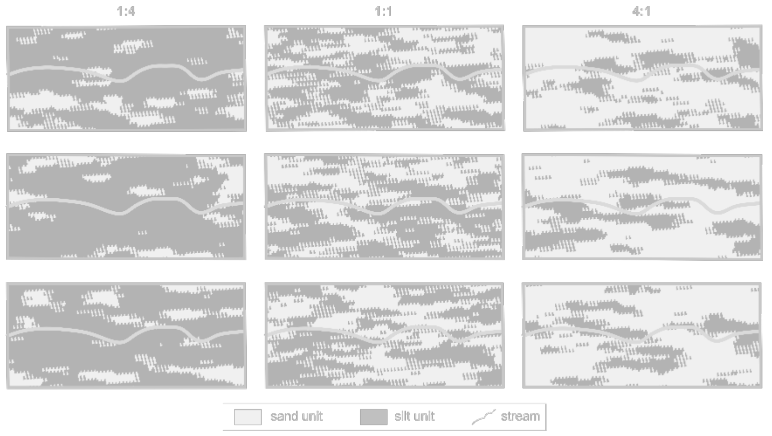
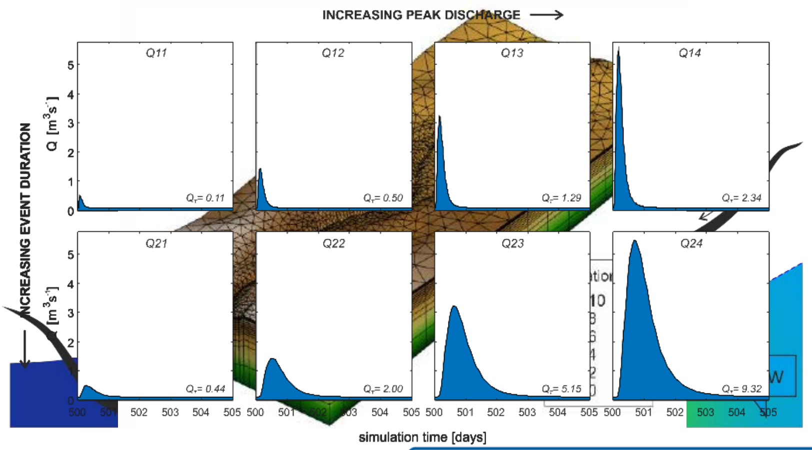


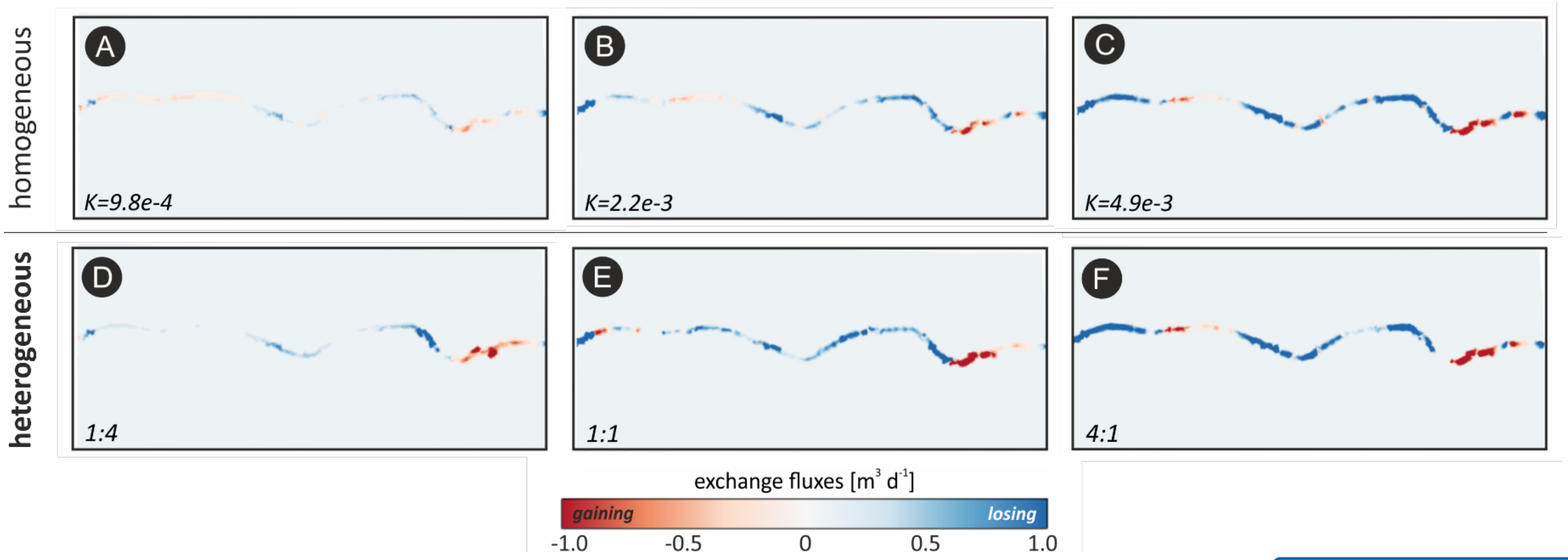
- **Fully Coupled 3D Numerical Model**
  - Transient simulations (**H**ydro**G**eo**S**phere);
  - Eight different discharge events with different durations and peak discharges (*total of 560 model runs*).



- **Mixing Analysis**
  - Hydraulic Mixing Cell (**HMC** – *Partington et al., 2011*);
  - Tracking of infiltrating SW and local flowing GW, and their fractions and mixing in different locations and times.

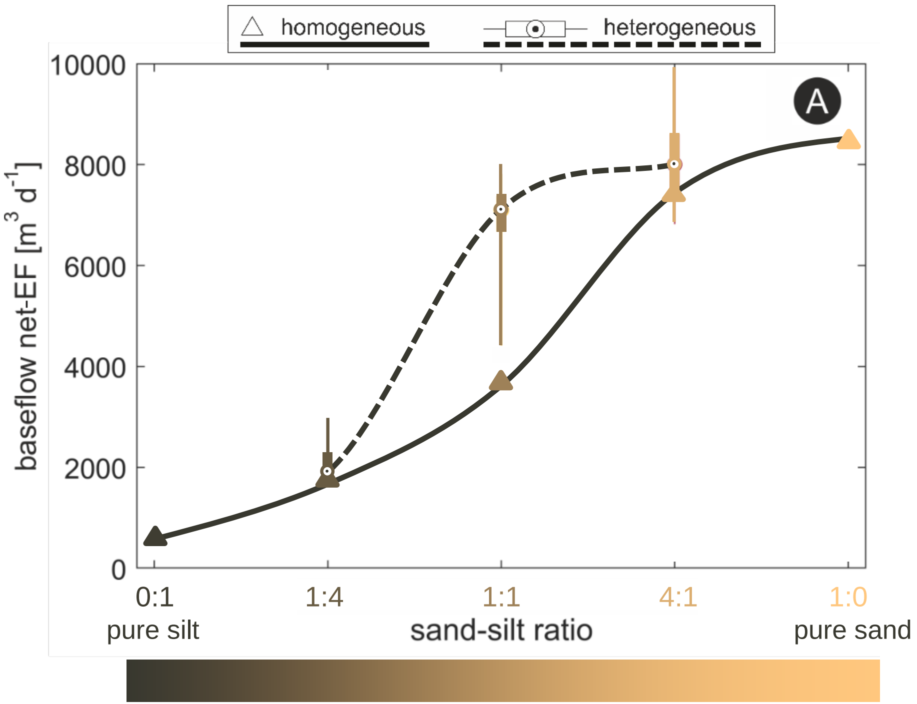
Results: *SW-GW Exchange*

- **SW-GW Exchange *Patterns***
  - Similar EF patterns among equivalent homogeneous and heterogeneous models;
  - Subordinate impact of geological heterogeneity on EF patterns;
  - Increasing EF magnitudes with average *K* values (and sand fraction).



Results: *SW-GW Exchange*

- **SW-GW Exchange *Fluxes***
  - Positive net-EF for all scenarios: net-losing conditions in the reach (with restricted gaining locations);
  - Increasing net-EF with sand fraction (i.e., increasing average *K*).
  - Larger increase of EF for heterogeneous models.
  - Overall larger EF magnitudes and net-EF for larger *K* contrast (inset plot);



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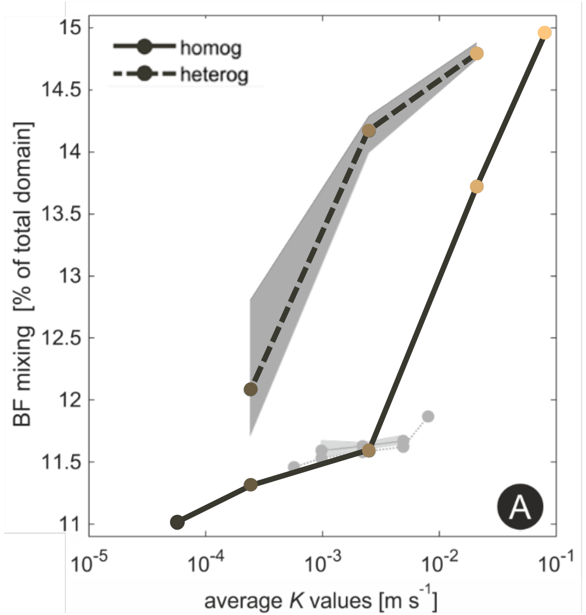
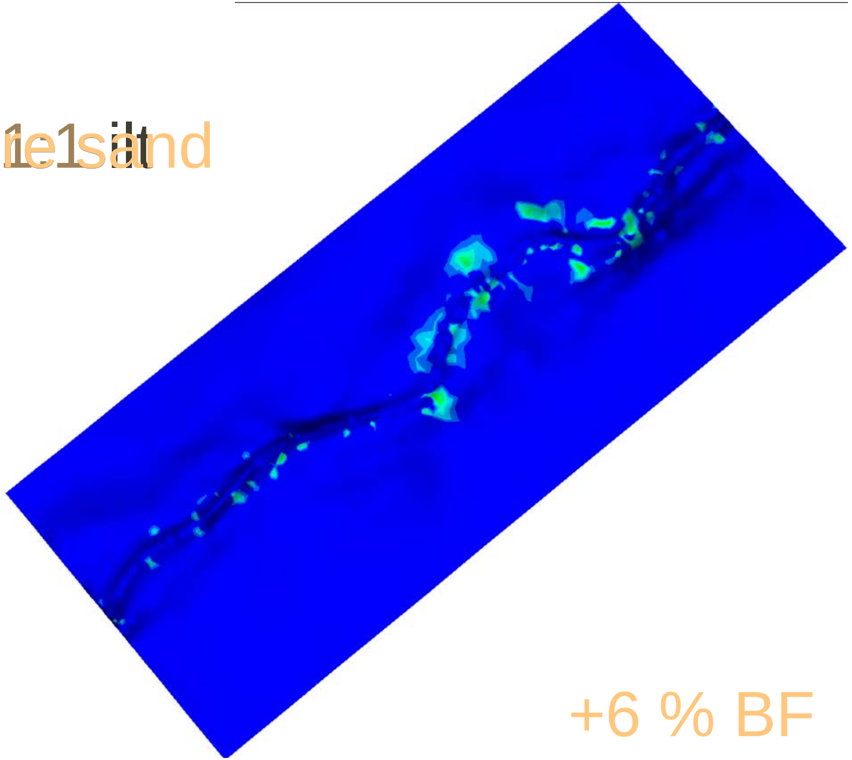
- **SW-GW Mixing *Extent***
  - SW-GW mixing increases spatially with average *K* values (i.e., EF magnitudes);
  - Larger mixing area for heterogeneous models (and for large *K* contrast).



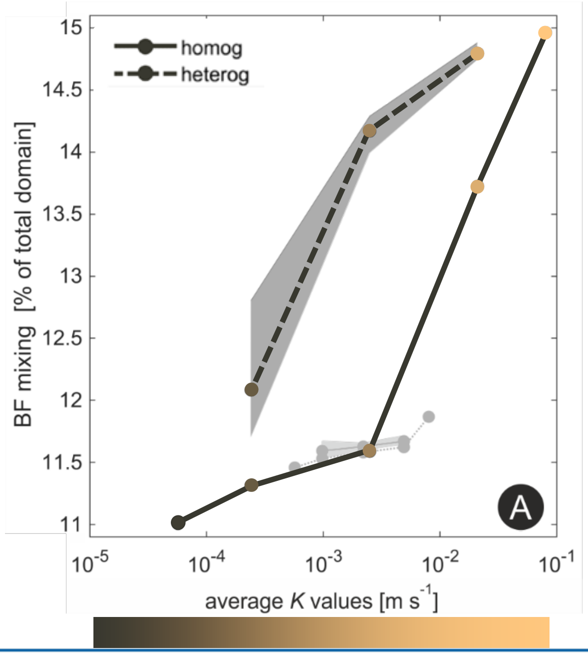
pure sand
1:1
silt

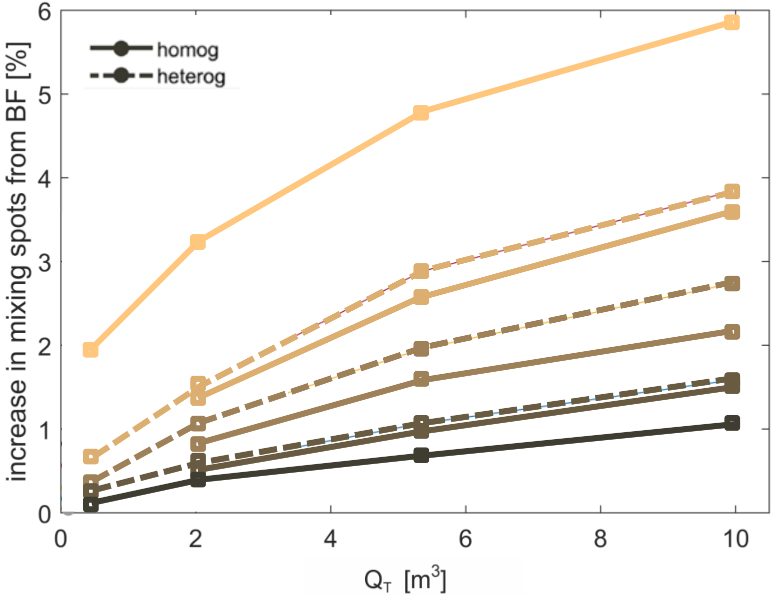


+6 % BF

Results: *Riparian SW-GW Mixing*

- **SW-GW Mixing *Extent***
  - SW-GW mixing increases spatially with average *K* values (i.e., EF magnitudes);
  - Larger mixing area for heterogeneous models (and for large *K* contrast).
  - Larger increase in mixing area for larger events
  - Larger increase in mixing area for heterogeneous models





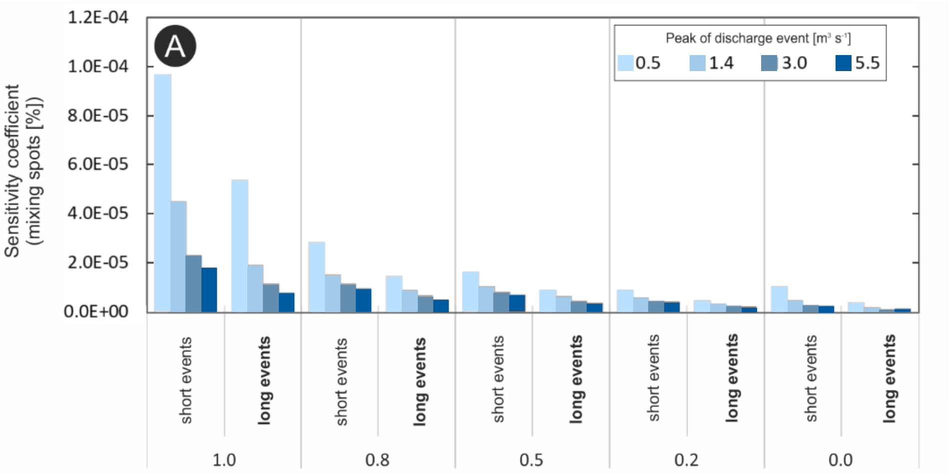
Results: *Riparian SW-GW Mixing*

- Sensitivity analysis for changes in SW-GW mixing extent from baseflow values (*Zheng and Bennett, 2002*):

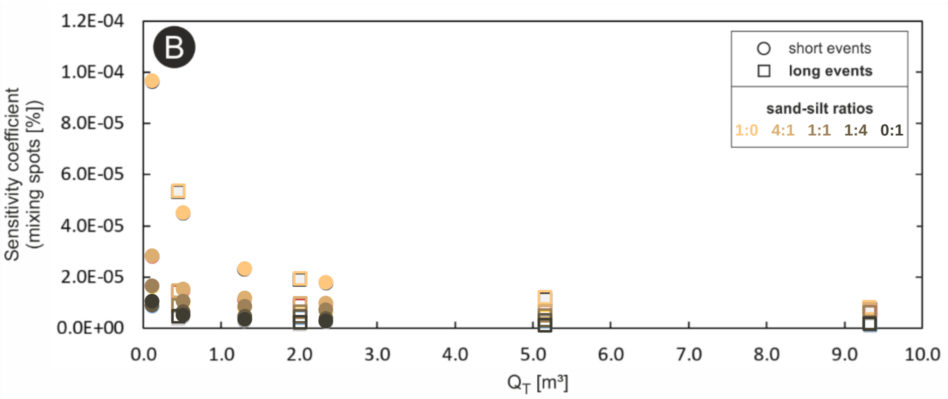
$$X_{m,n} = \frac{\gamma_m(\alpha_n + \Delta\alpha_n) - \gamma_m(\alpha_n)}{\Delta\alpha_n / \alpha_n}$$

- SW-GW mixing extent is more sensitive to hydrological variations than to changes in K values
    - Higher sensitivity at high conductivities
    - Higher sensitivity for short events with low peak discharge (low cumulative discharge)

SAND FRACTION



CUMULATIVE DISCHARGE



Conclusions

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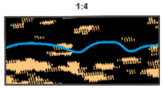
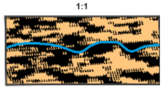
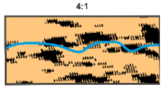
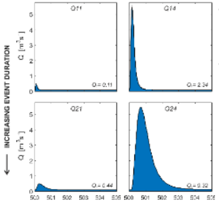
- Geological heterogeneity:
    - ***substantial*** effect on EF magnitudes
    - higher heterogeneity:
        - increases EF magnitude
        - increase is larger for higher sand fractions / higher K contrasts
    - ***subordinate*** effect on SW-GW mixing extent
    - higher heterogeneity:
        - increases SW-GW mixing extent
        - increase is larger for higher sand fractions / higher K contrasts

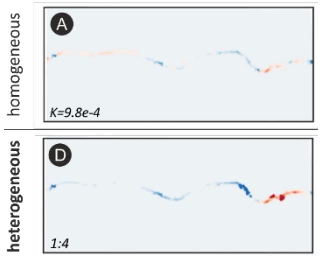


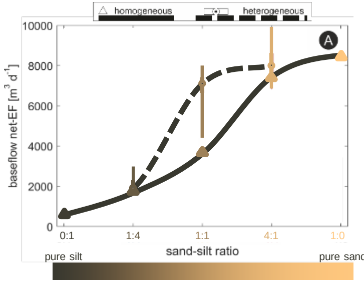


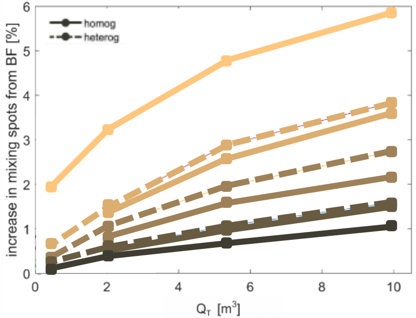


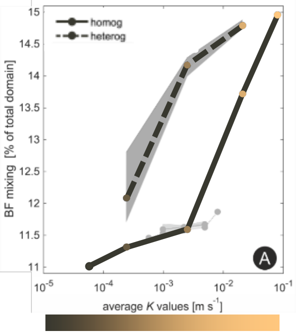
- Discharge event characteristics:
    - ***stronger*** effect on SW-GW mixing extent
    - long events with higher discharge:
        - cause larger increases in SW-GW mixing extent
        - increase is larger for heterogeneous scenarios / higher sand fractions / higher K contrasts
    - Sensitivity of mixing extent is highest for high conductivities and small discharge events

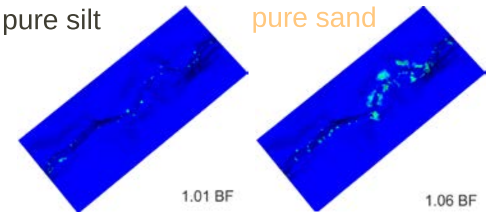












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- Nogueira GEH, Partington D, Heidbüchel I, Fleckenstein JH. "*Combined Effects of Geological Heterogeneity and Discharge Events on Groundwater and Surface Water Mixing*". Journal of Hydrology. **(*under review*)**

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- Partington D, Brunner P, Simmons CT, Therrien R, Werner AD, Dandy GC, Maier HR. **2011**. "*A hydraulic mixing-cell method to quantify the groundwater component of streamflow within spatially distributed fully integrated surface water-groundwater flow models*". Environmental Modelling and Software 26 (7): 886–898 ***DOI: 10.1016/j.envsoft.2011.02.007***

- Zheng C, Bennett G. **2002**. "*Applied Contaminant Transport Modeling*". Wiley-Interscience: New York.

Thank you for your attention!

Questions?