Field Evidence Model: A hierarchical hetero-geneous structure for subsurface transport modelling

Alraune Zech[1,2], Sabine Attinger[2], Peter Dietrich[2], and Georg Teutsch[2]

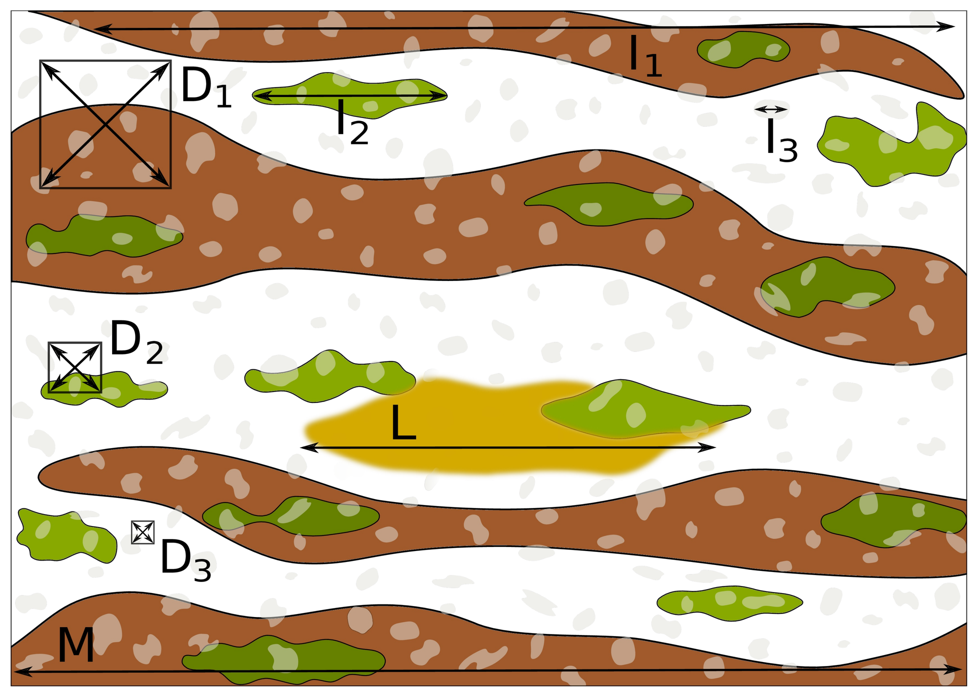
1 - Hydrogeology Group, Department of Earth Science, Utrecht University, Netherlands (contact: a.zech@uu.nl)
2 - Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany

Introduction & Objective

- prediction of solute behavior in groundwater valuable for risk assessment, remediation etc.
- solute mass distribution strongly influenced by unknown aquifer heterogeneity
- lack of data for parametrization and calibration
- novel hierarchical conductivity structure combining deterministic information and simple statistics
- incorporating aquifer features of different scales following field evidence
- implementation for MADE & sensitivity analysis

Approach: Concept & Scales

- modules capturing features of heterogeneity according to scales (large, intermediate, local)
- deterministic/stochastic representation depending on ergodic conditions
- structural parameters from characteristic investigation methods

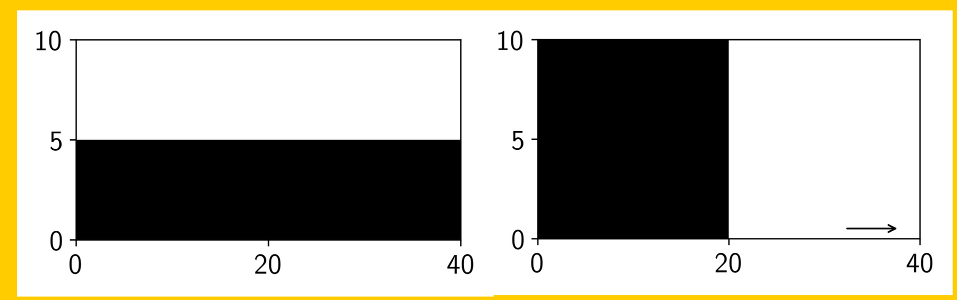


Relevant scales:
M - domain scale
L - plume scale
D - Detection scale (device specific)

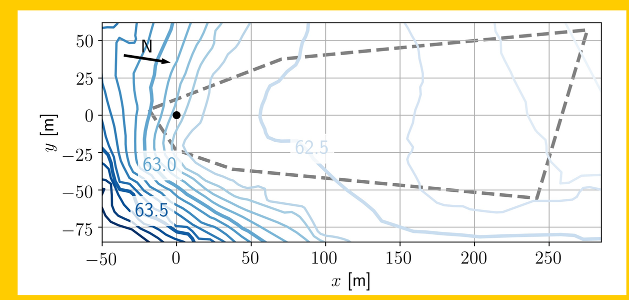
I - Heterogeneity scales:
- *Large scale: I_1 ~ M > L*
- *Intermediate: I_2 ~ L > M*
- *Local: I_3 > L >> M*

Approach: Conductivity Modules

A) Large Scale Structures
- character: regional trends, facies
- concept: deterministic zones
- observations: piezometric surface map, pumping tests

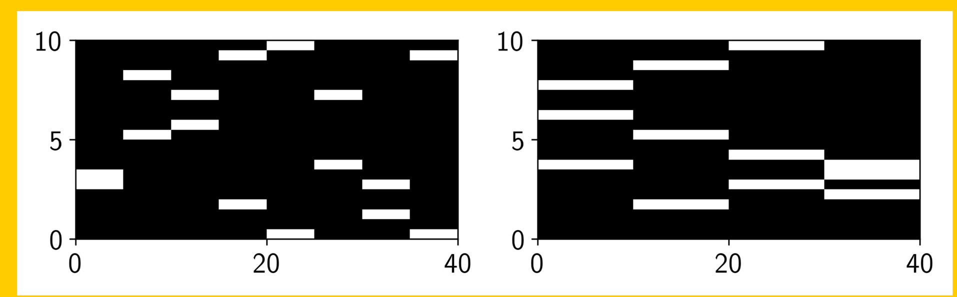


Concept deterministic zones: zone 1 with K_{Z1} (black), zone 2 with K_{Z2} (white). Left: vertical layering; right: horizontal blocks.

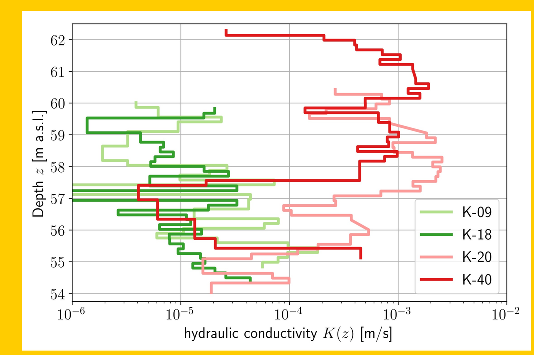


Piezometric surface map of MADE site

B) Intermediate Scale Heterogeneity
- character: preferential flow paths, stagnant areas
- concept: binary inclusion distribution (discrete, stochastic)
- observations: few borehole logs, e.g. flowmeter, DPIL

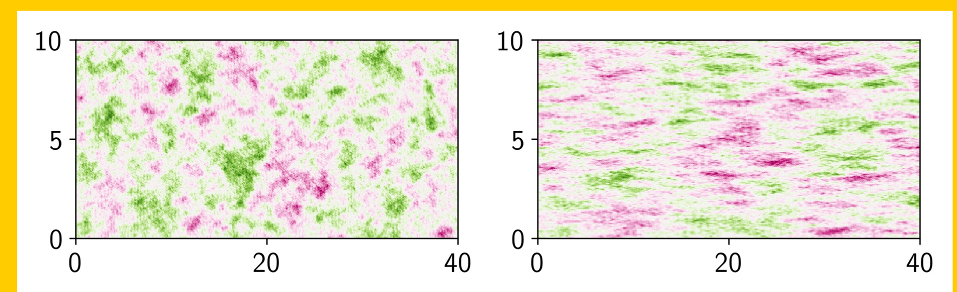


Concept inclusion structure: bulk of low K_1 (black), inclusions of high K_2 (white). Left p=15%, length I_h=5m, I_v=0.5-1m; right: p=10%, I_h=10m, I_v=0.5m

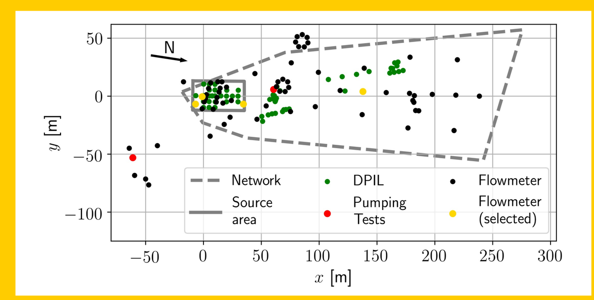


Borehole flowmeter logs at four selected locations

C) Small Scale Heterogeneity
- character: local fluctuations
- concept: log-normal spatial variable (continuous random)
- observations: geostatistics, e.g. flowmeter, DPIL

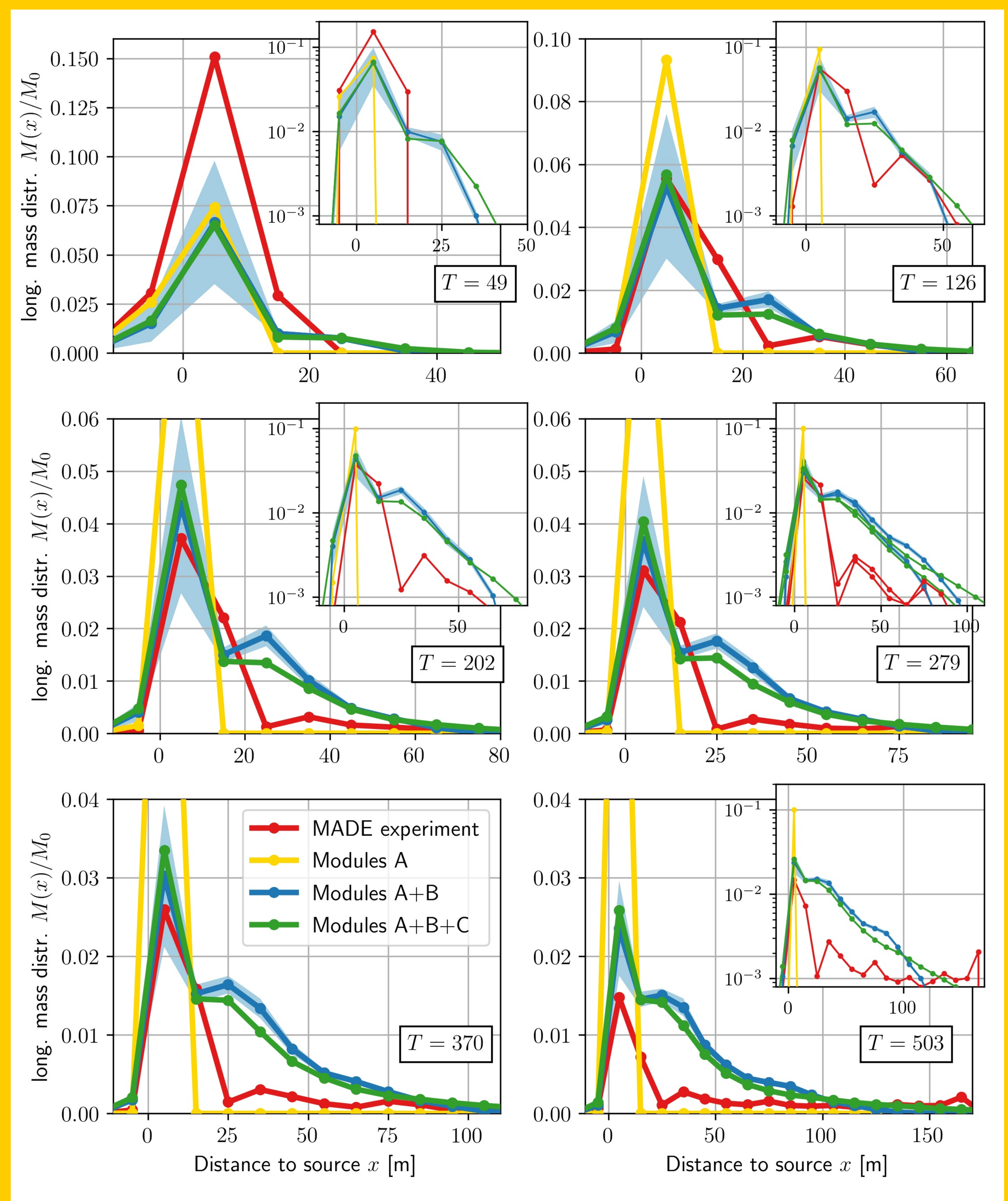


Concept fluctuations: Gaussian field with exponential covariance. Left: λ_l=2, λ_v=1 (e=0.5); Right: λ_l=5, λ_v=0.5 (e=0.1).



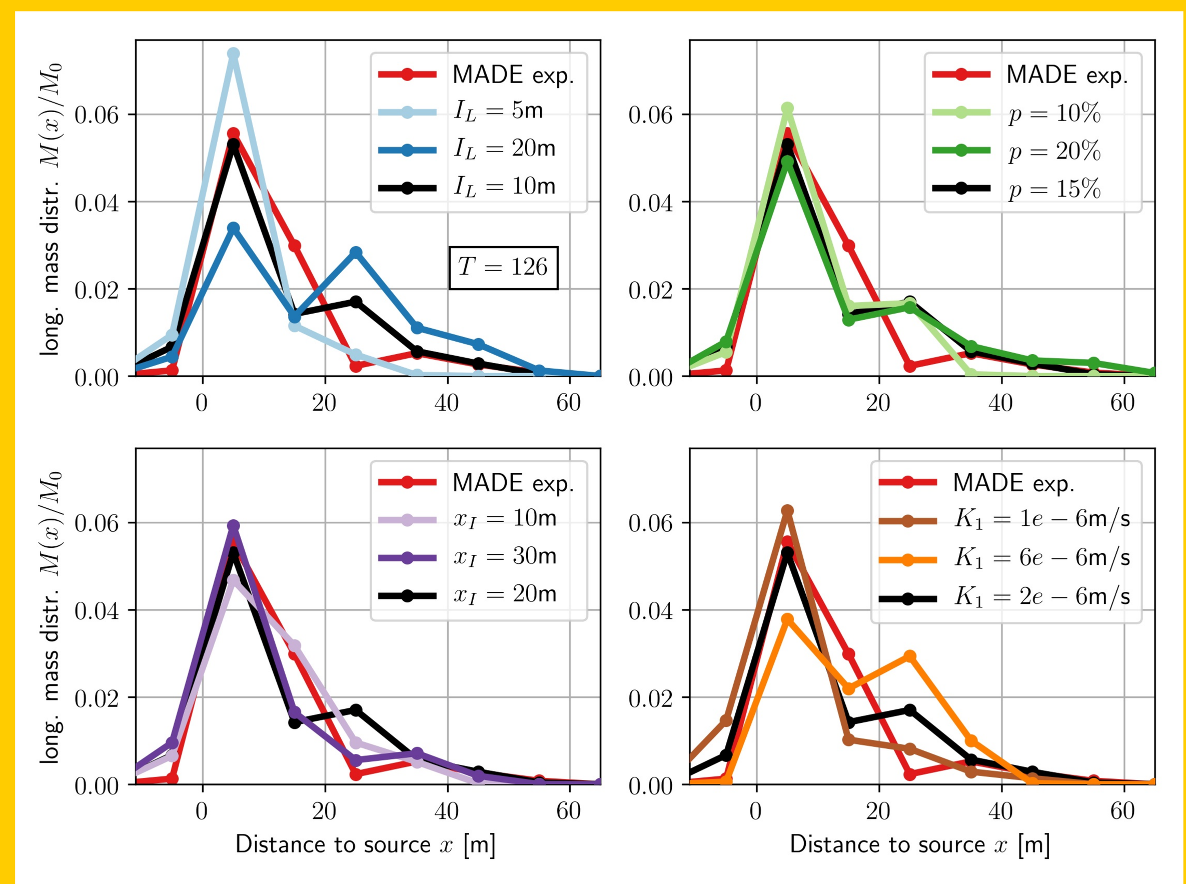
Observation locations at MADE site

Results: Mass Distribution

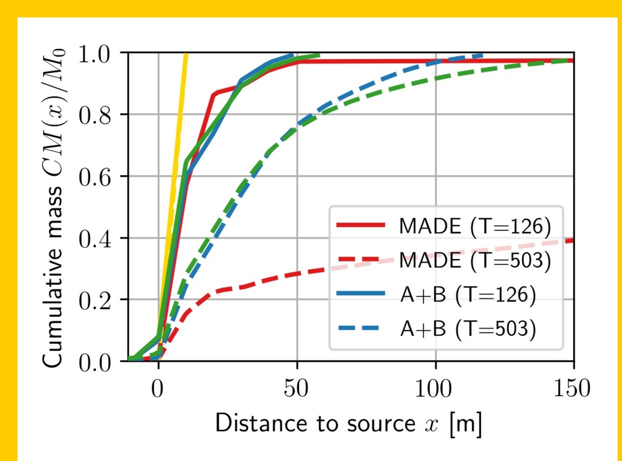


Longitudinal mass distributions M(x) for conductivity concepts (A = yellow), (A+B = blue), (A+B+C = green) of MADE aquifer versus tracer experiment observations (red): for 6 times (panels) in linear scale with subplot in log-scale. Data is aggregated over intervals of 10m distance as established for MADE experiment data.

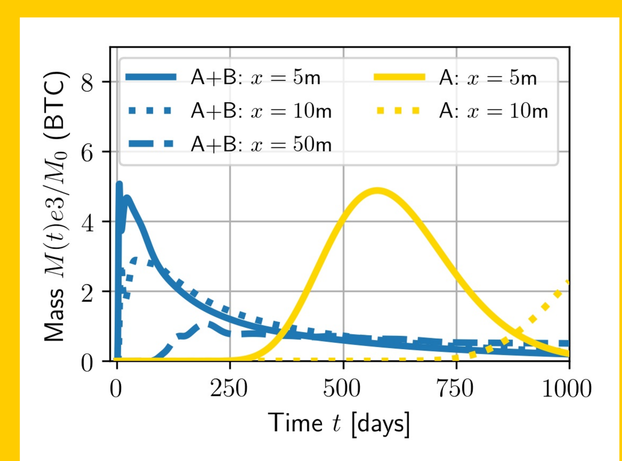
Results: Impact of Parameters



Longitudinal mass distributions M(x) at T=126 days of concept (A+B) for standard setting (black) and various input parameters (colors): inclusion length I_L, amount of inclusion p, distance of zone interface x_I to injection and mean conductivity K_1 of zone 1 (source area). MADE experiment in red.



Cumulative mass distributions: A = yellow, A+B = blue, A+B+C = green, MADE experiment = red.



Breakthrough curves M(t) for structures (A) and (A+B) at distances x from the injection.

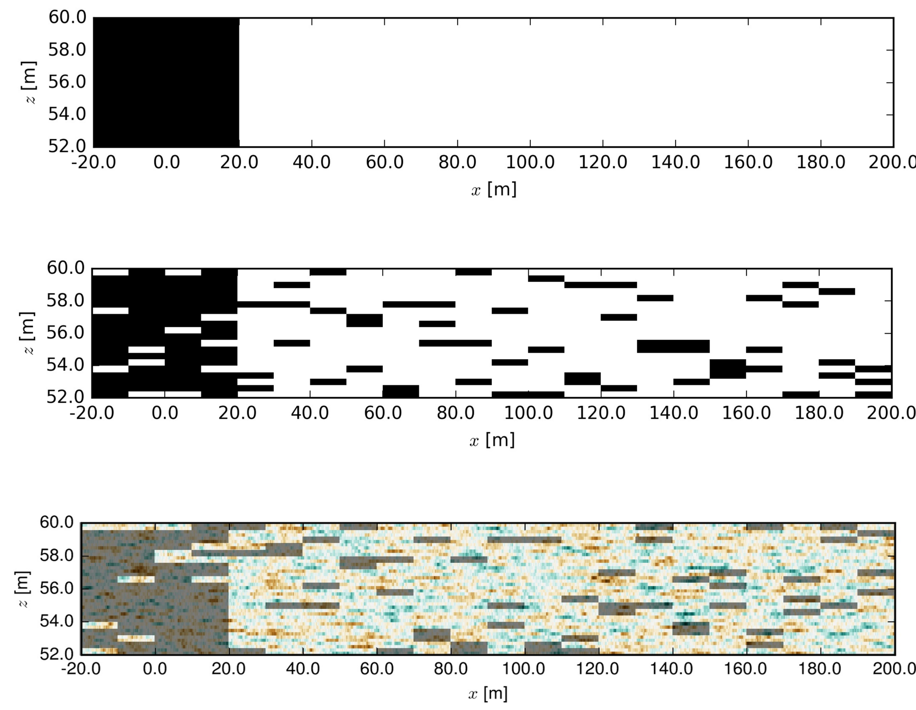
Example: Transport at MADE

The MADE Site (Columbus, Mississippi)
- field campaigns: *Boggs et al., Rehfeldt et al. 1992*
- transport experiment: natural gradient flow with forced pulse injection of bromide
- longitudinal mass distribution M(x) for 6 times: T=49,126,202,279,370,503 days after injection

A) Deterministic Zones
- 2 zones, locations from piezometric surface map
- zone's average K-values from pumping tests: K_{Z1}=2e-6 m/s; K_{Z2}=2e-4 m/s

B) Heterogeneous Inclusions
- binary distribution with low K_1 & high K_2 value
- inclusion's frequency: p =10-20% from flowmeter logs
- inclusions lengths: L_l =5-20m, L_V =0.5-1m

C) Small Scale Heterogeneity
- flowmeter (*Rehfeldt et al., 1992, Bohling et al., 2016*)
- log-K variance: σ_Y^2 = 4.5
- correlation lenghts: ℓ_h=10m, ℓ_v =1m



Conceptual Conductivity Structures:

(A) determi-nistic blocks

(A+B) inclu-sions in blocks

(A+B+C) inclusions in blocks and random fluctuations

Conclusions
- goal-oriented site specific transport analysis:
  - (i) Model parametrisation adapted to available measurements at field site
  - (ii) Representation of critical features of heterogeneity
  - (iii) Focus on minimal characterization requirements
- simple conductivity structures able to reproduce skewed mass plumes
- combining deterministic and stochastic approaches reduces required observation data
- binary structure is alternative to Gaussian distribution which needs geostatistical analysis

References

1 - Boggs, Young, Beard, Gelhar, Rehfeldt & Adams, 1992; Field study of dispersion in a heterogeneous aquifer: 1. Overview and site description; WRR 28; doi: 10.1029/92WR01756
2 - Rehfeldt, Boggs & Gelhar, 1992; Field Study of Dispersion in a Heterogeneous Aquifer: 3. Geostatistical Analysis of Hydraulic Conductivity; WRR 28; 10.1029/92WR01758
3 - Bohling, Liu, Dietrich & Butler, 2016; Reassessing the MADE direct-push hydraulic conductivity data using a revised calibration procedure; WRR 52; doi: 10.1002/2016WR019008