Multi scale transport modelling in heterogenous porous and fractured media

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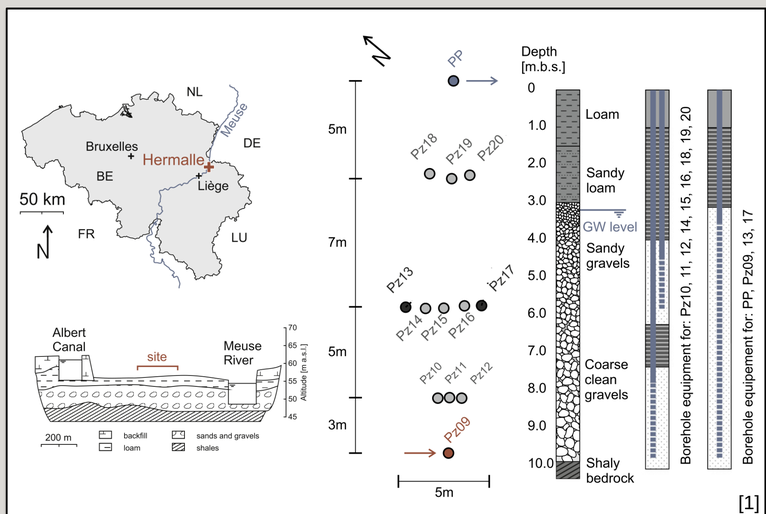
[*] For the poster purpose the PhD main supervisors are listed on top, while for Part A and/or B additional Co-workers are involved and mentioned with [a,b] below each part. They must be respected for a citation of poster Part A/B.

ENIGMA ITN PhD process presentation at the 4th Cargèse Summer School „Flow and Transport in Porous and Fractured Media" – (25/06-07/07/18)

Motivation for using complementary tracer behavior and performing joint tracer modelling/inversion

1. Characterize preferential flow paths using innovative heat, solute and dissolved gas tracer for advanced subsurface process imaging + multiple scale transport.
   - ➢ Compare multiple tracer injection tests in heterogenous media like alluvial sediments (A: Hermalle (on H+ website)) and fractured rocks (B: Chalk).
2. Assess the impact of preferential flow paths and quantify + reduce the associated uncertainty in model predictions using HydroGeoSphere for transport modelling.
   - ➢ Perform e.g. Bayesian Evidential Learning for porous media (A) and using a dual-domain modelling approach for a double porosity Chalk Aquifer (B).

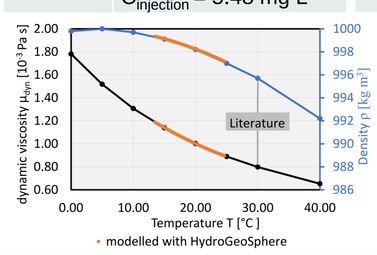
Part A - Porous media – 20 m – Hermalle-sous-Argenteau, Liege (BE)

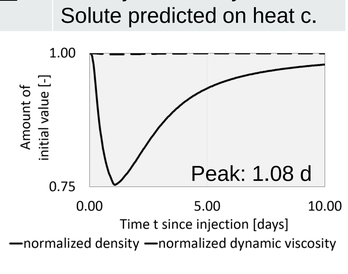


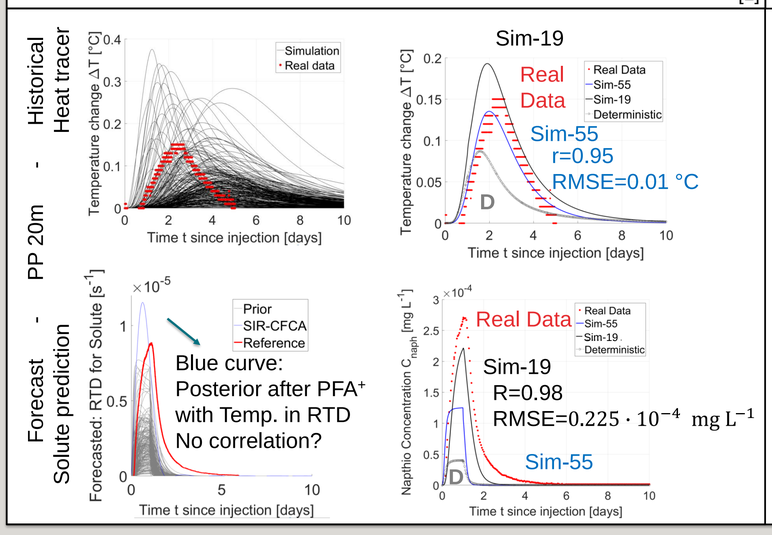
[1]

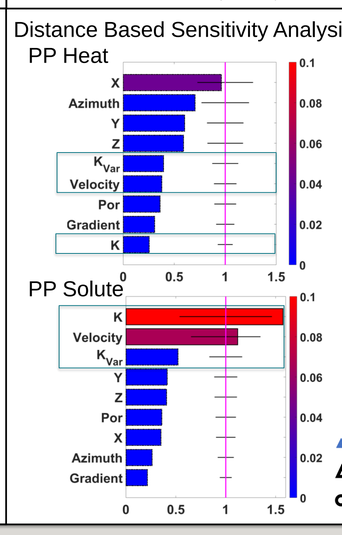
Joint Heat + Solute tracer [1]	
PP:	Q_{pump} = 30 m³ h⁻¹
	Heat + 1 Solute signal
Pz10-20:	Only heat monitored
Pz9	$Q_{Injection}$ = 3 m³ h⁻¹ $T_{injection}$ = 24.3 h $T_{injection}$ = 40 °C $C_{injection}$ = 5.48 mg L⁻¹

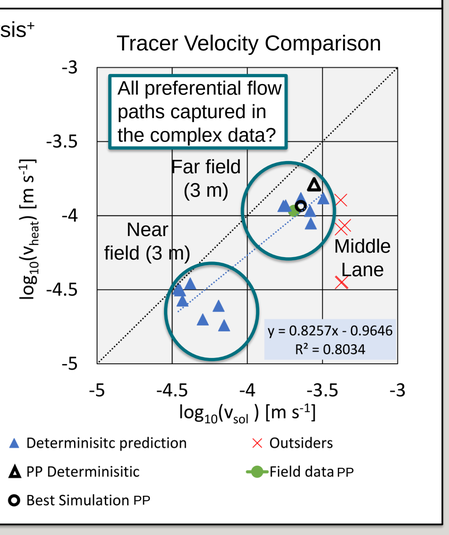
Numerical model (Basis [2])	
2 Layer	Pe(Up) = 300 Pe(Low) = 14000
Dim	20 m x 60 m
Old	Density d. + heat transport Against heat calibrated
New	Density + Viscosity d. + Heat Solute predicted on heat c.











⁺start scripts from Stanford GitHub

Additional Co-Workers: Part A: [a] T. Hermans (UGhent), F. Nguyen (ULiege)

A - Key-Results

A1 Solutes are, as expected for porous media systems with high advection, sensitive to hydraulic parameters.

A2 On the contrary, heat is less sensitive to a spatial variation of hydraulic conductivity as expected.

A3 So far there is no "one" best porous medium model allowing to fit both individual tracer behaviour…but individual best solutions exist.

A - Discussion

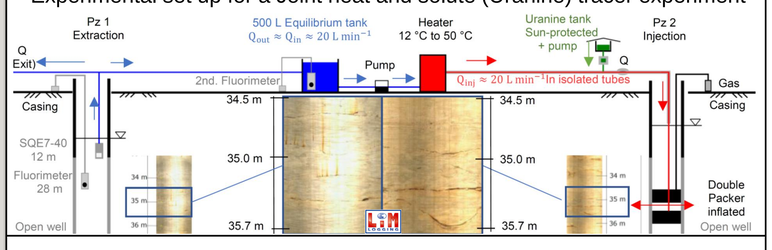
- ➢ Solute needs an accurate quantification of the flow preferential pathways caused by heterogeneity, while heat needs an accurate conduction parametrization acting as a "wave front movement".
- ➢ Models dominated by advection neglect too much the heat conduction
- ➢ Stacked overlaps of many simulations respecting the best simulation for each observation point by an individual weight, seems to be a possible integration of the different behavior with reduced uncertainty.

Part B - Single fracture in double porosity Chalk – 7.55 m – Mons (BE)

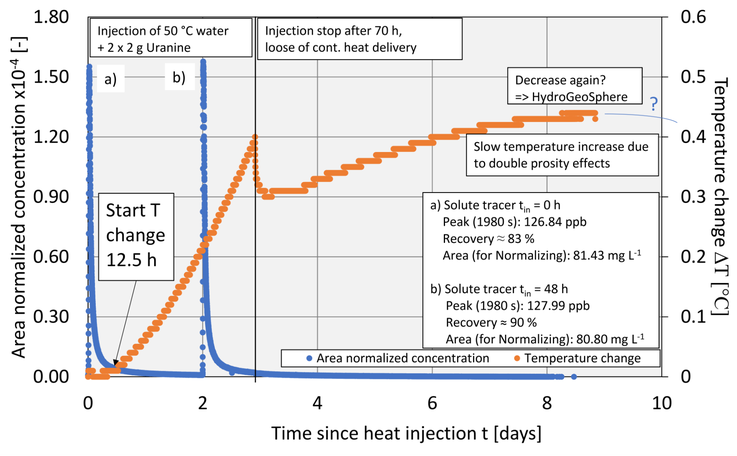
Multiple tracer tests between two adjacent 50 m-deep wells - distant 7.55 m

Called „Pic et Plat" test site - part of the Mons sedimentary basin (Belgium)

Experimental set up for a Joint heat and solute (Uranine) tracer experiment

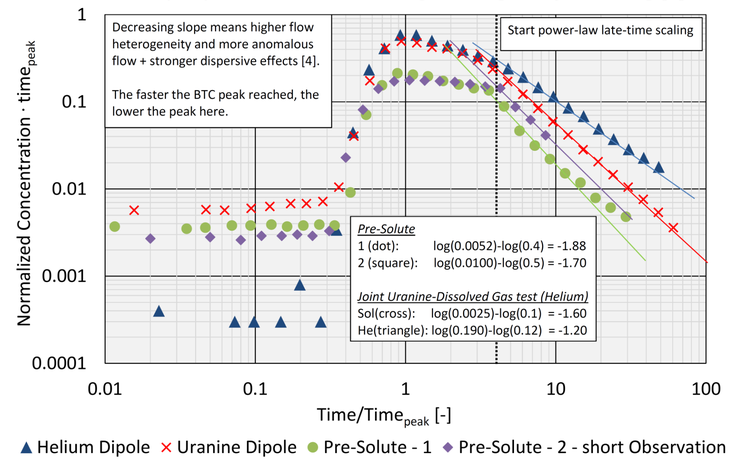


Observed data for a joint heat and solute dipole tracer test



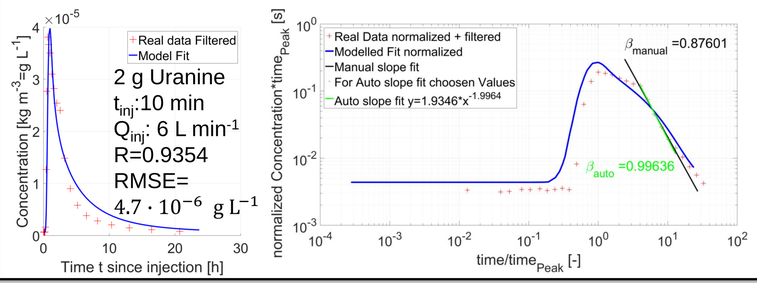
Observed data for a joint solute and dissolved gas (CF-MIMS [3]) dipole test

Focus on slope quantification describing heterogeneity following [4]



A first single fracture dual domain HydroGeoSphere model

Against Pre-Uranine test ([5]) calibrated – *in work for the new tests*



Additional Co-Workers: Part B: Heat: [b] P. Jamin (ULiege), Gas: [b] E. Chatton (URennes1), T. Labasque (URennes1,Critex), T. Le Borgne (URennes1)

B - Key-Results

B1 Heat in chalk is far more delayed compared to advective driven solute tracer and its distribution is more isotropic around the injection well.

B2 When heat injection is stopped, a fast temperature decrease is followed by a slow rebound.

B3 "Heterogeneity factors" [4] are derived for Uranine (≈ 0.7) and Helium (0.2), for a possible higher heterogeneity in chalk with increasing diffusivity.

B – Discussion

- ➢ Unlike solute tracer, heat is influenced by conduction in the chalk matrix and shows a temperature rebound cause by the release of heat from the matrix to the colder water drawn from the surroundings by pumping in the observation well Pz1.
- ➢ Helium prefers more "anomalous flow" then other solutes and is less influenced by double porosity effects then heat.

Over all conclusion + Outlook

- ➢ Heat + Solute tracer brings: complementary behaviors and added information on matrix properties
- ➢ Joint tracer tests have a high potential for advanced heterogeneity characterization + Uncertainty reduction
- ➢ 1st Secondment: Push-Pull tests at H+ Site Hyderabad (India) (BRGM: A. Selles + J.C. Maréchal, End 2018)
- ➢ 2nd Secondment: GPR Training for parallel tracer imaging (FZ Jülich: J. van der Kruk, probably End 2019)

Acknowledgements

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References

[1] Wildemeersch, S., Jamin, P., Orban, P., Hermans, T., Klepikova, M., Nguyen, F., Brouyère, S. & Dassargues, A. (2014): Coupling heat and chemical tracer experiments for estimating heat transfer parameters in shallow alluvial aquifers. Journal of Contaminant Hydrology, **169**, 90-99.
[2] Klepikova, M., Wildemeersch, S., Jamin, P., Orban, P., Hermans, T., Nguyen, F., Brouyère, S. & Dassargues, A. (2016): Heat tracer test in an alluvial aquifer: Field experiment and inverse modelling. Journal of Hydrology, **540**, 812-823.
[3] Chatton, E., Labasque, T, de la Bernardie, J., Guihéneuf, N, Bour, O. & Aquilina, L. (2015): Field Continuous Measurement of Dissolved Gas with a CF-MIMS: Applications to the Physics and Biogeochemistry of Groundwater Flow. Environmental Science & Technology, **51**, 846-854.
[4] Kang, P.K., Le Borgne, T., Dentz, M., Bour, O. & Juanes, R. (2015): Impact of velocity correlation and distribution on transport in fractured media: Field evidence and theoretical model. Water Resources Research, **51**, 940-959.
[5] Goderniaux, P., Beyek, A., Tchotchom, A, Poulain, A., Wattier, M-.L. & Vandycke, S. (2018): Study of the heterogeneity of hydraulic properties in a chalk aquifer unit, using sequential pumping and tracing experiments with packer systems. Conference paper for Engineering in Chalk 2018, London.