Comparison of temperature from DTS and ERT with direct measurements during heat tracer experiments in heterogeneous aquifers

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Overview

1. Context

2. A forced heat tracer experiment

3. ERT and DTS monitoring

4. Future challenges

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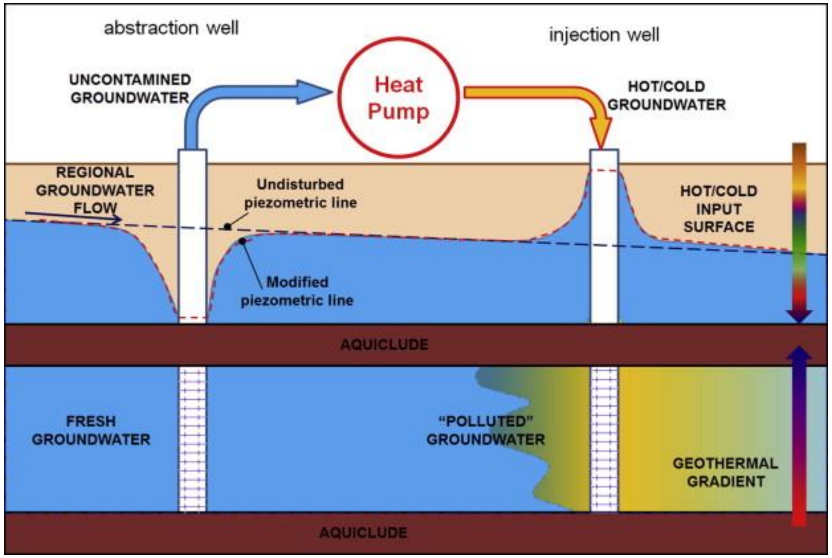
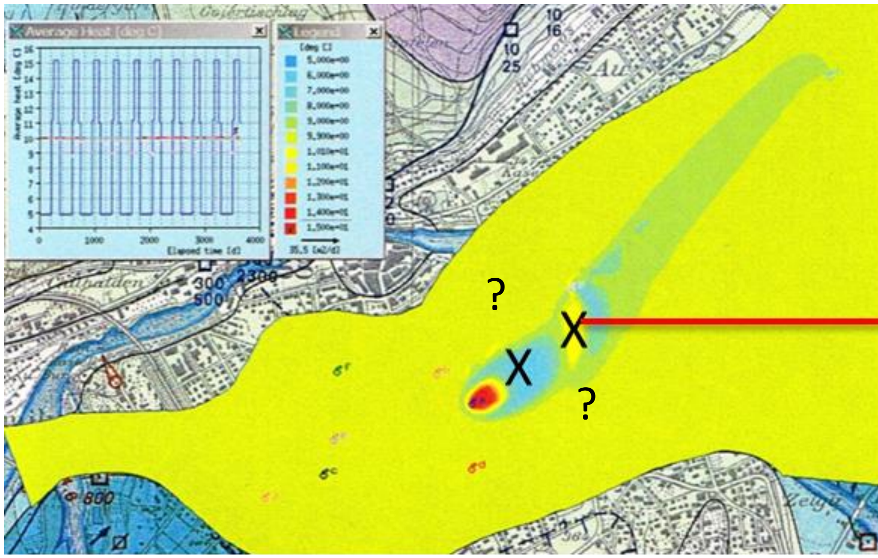
Context: a growing need of sustainable energy

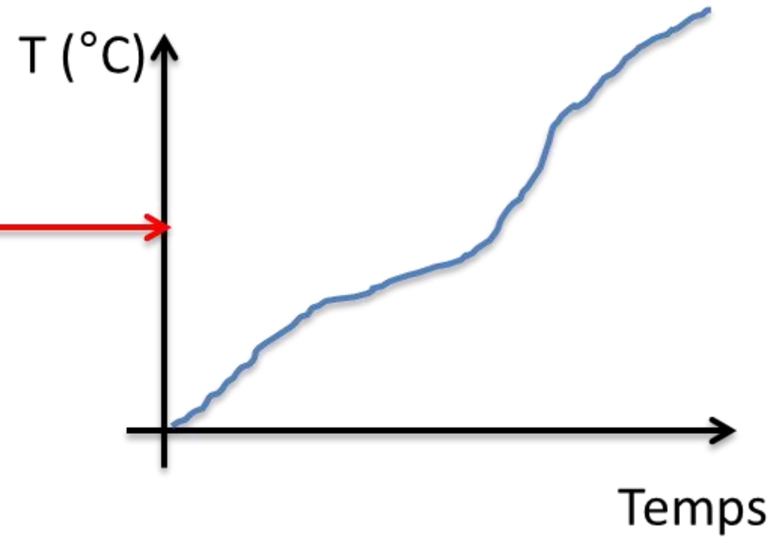


Sustainable heat and cold provider with high performance

Open loop systems are based on low energy exchanges
Groundwater provides the energy supply with stable T° < 30°C
Groundwater (ΔT~6°C)→ Heat pump → building
Ex. CAF Lyon 16 633m² 600kW heat 600 kW cold
37% saving compared to gaz heating and climatisation
Saves 70% of CO_2 emissions

Sustainable use requires forecasting spatiotemporal behaviour





We need to estimate the governing parameters for heat flow and transport models for the **design** and the **monitoring** of such systems

Temperature monitoring in aquifers and **heat tracing** remain challenging

Need for spatiotemporal **information**

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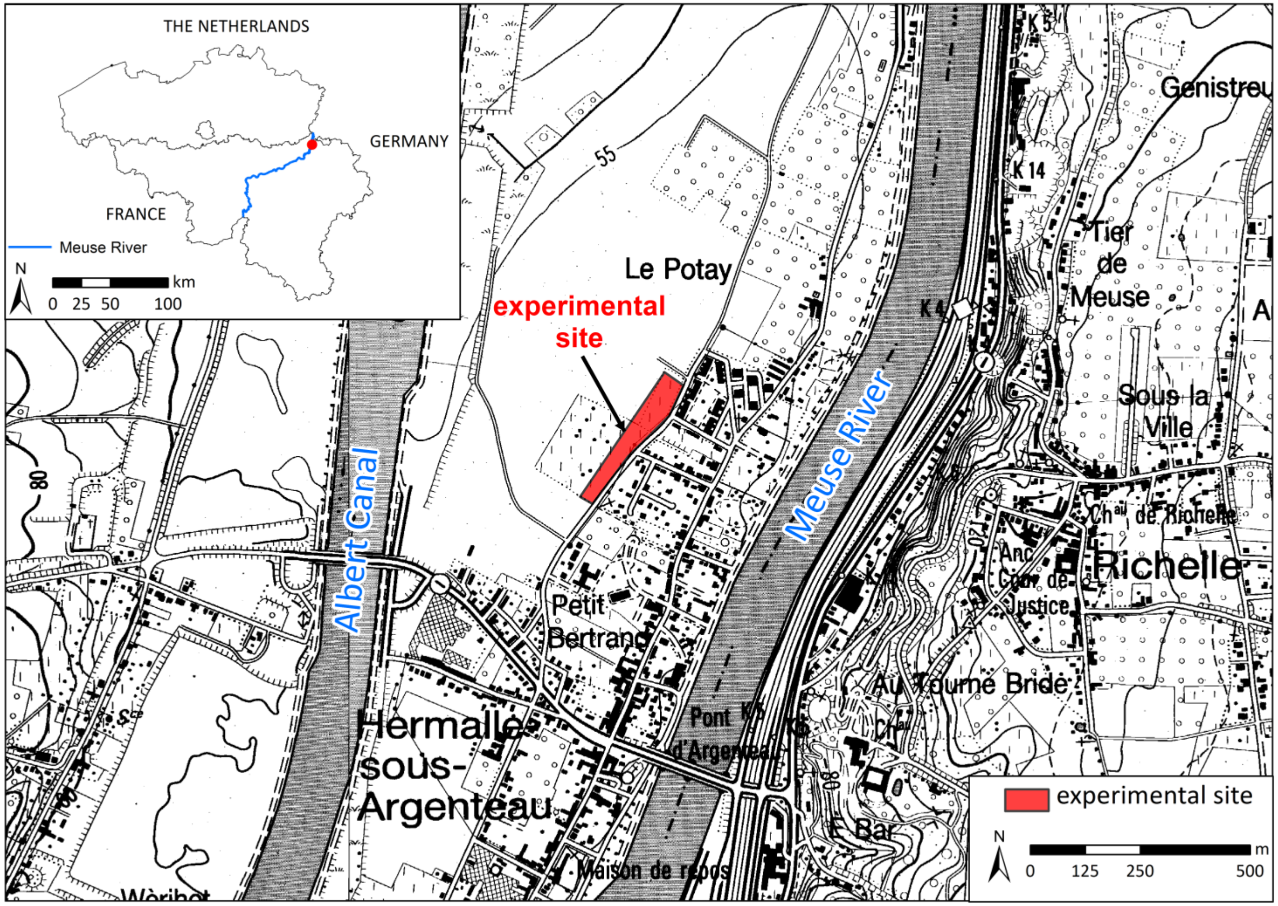
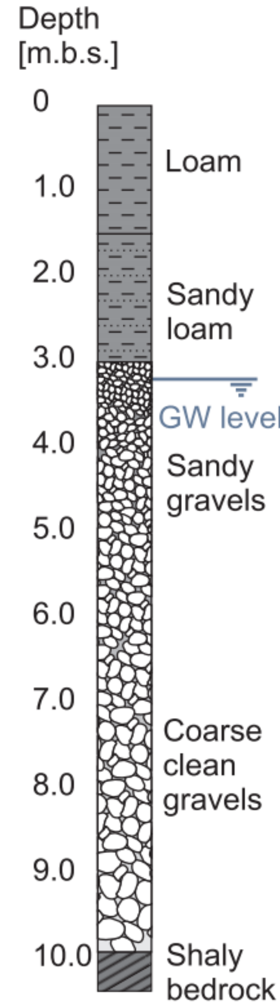
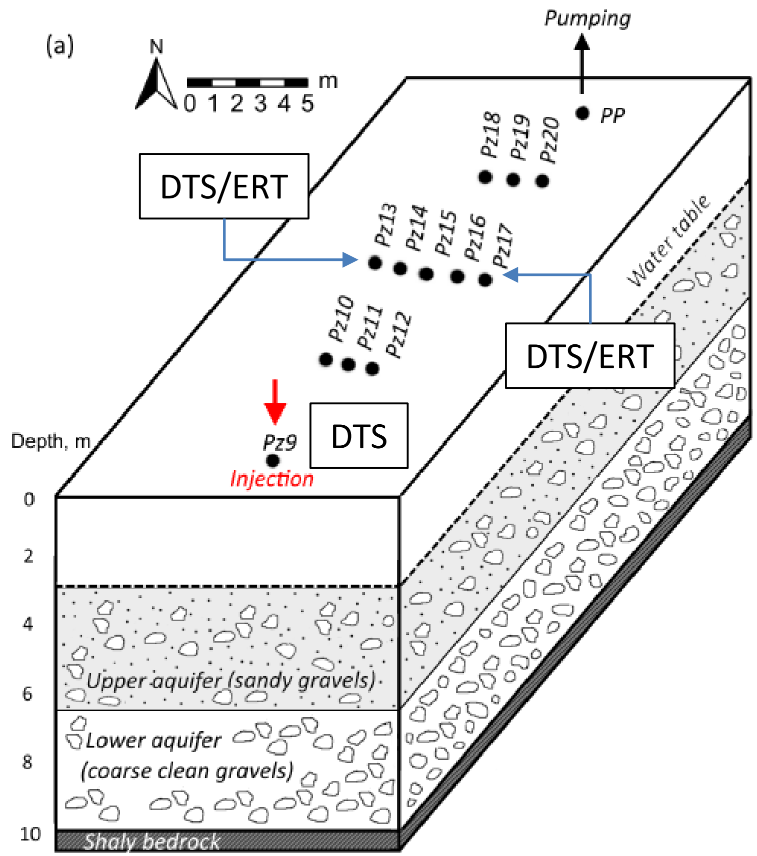
The study site is located in the alluvial aquifer of the Meuse River near Liege (Belgium)





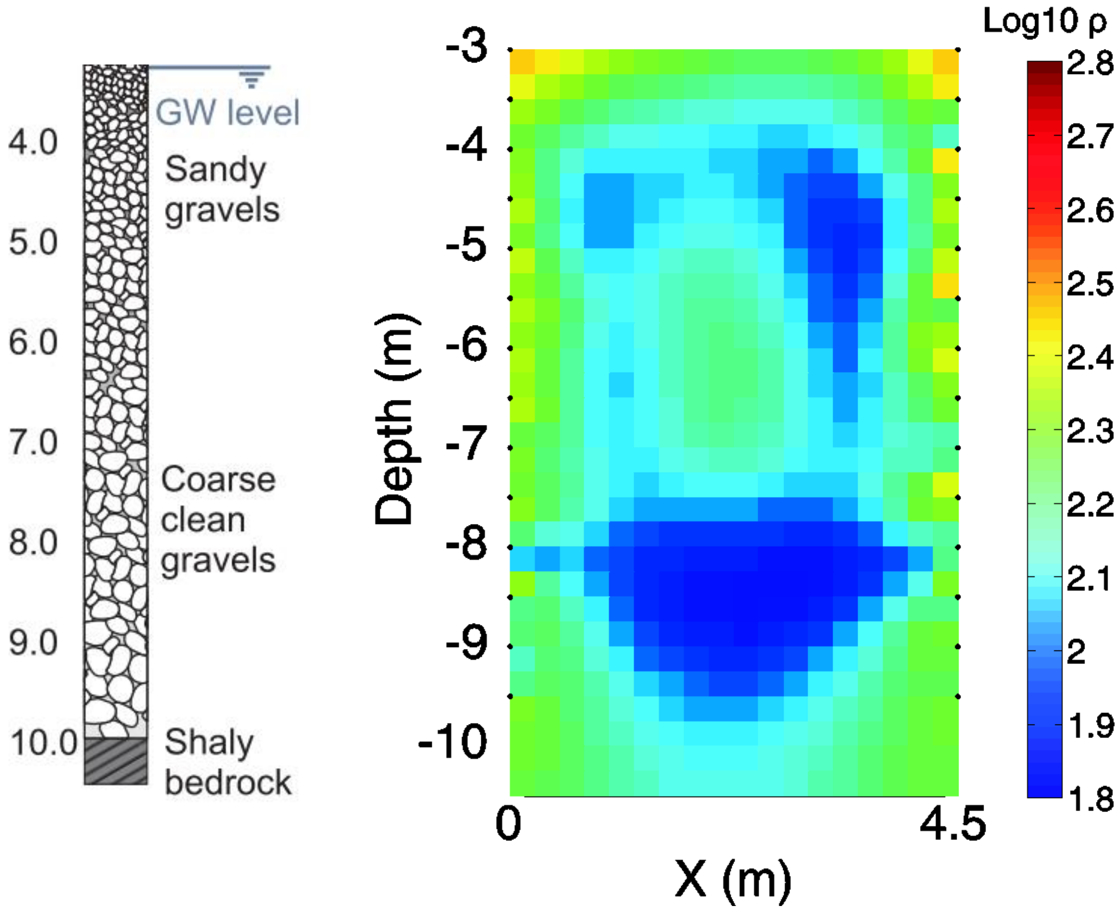
Lithological surveys have shown that below surface loams, the saturated part of the aquifer is composed of sandy gravel and clean gravel

The study site is equipped with 11 control piezometers, 1 injection well and 1 pumping well



Injection of heated water at 38°C (+25°C) during 24h at 3m³/h and pumping at 30 m³/h
ERT in the middle panel in 2 boreholes (4.5m apart) with 13 electrodes (0.5 m spacing)
Combined bipole-bipole and dipole-dipole configuration and DTS

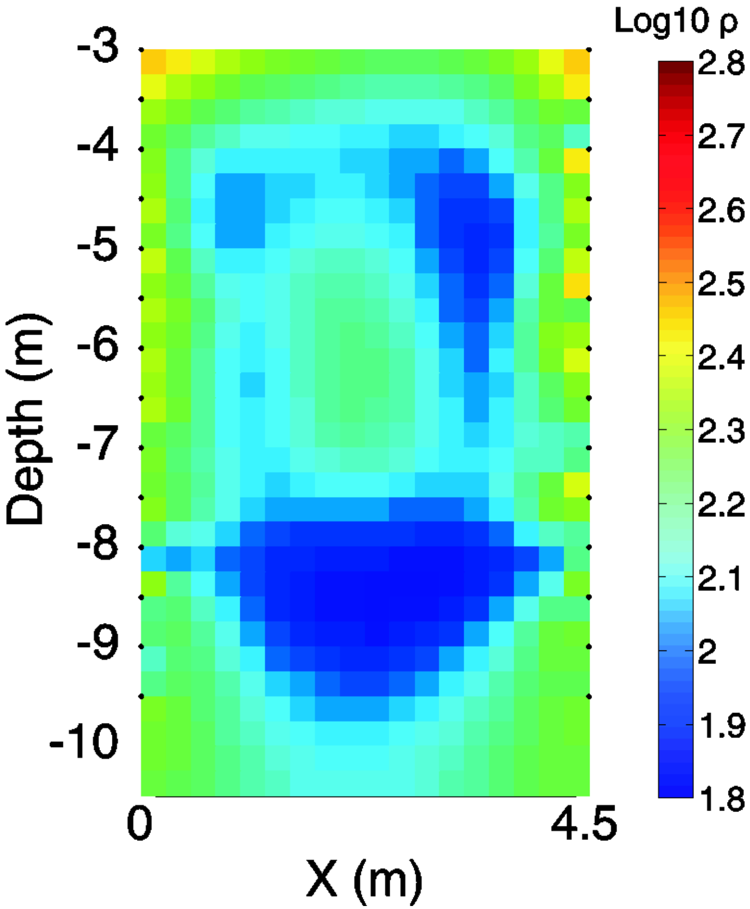
The background ERT image shows heterogeneities in the resistivity distribution with values between 100 and 200 Ohm.m

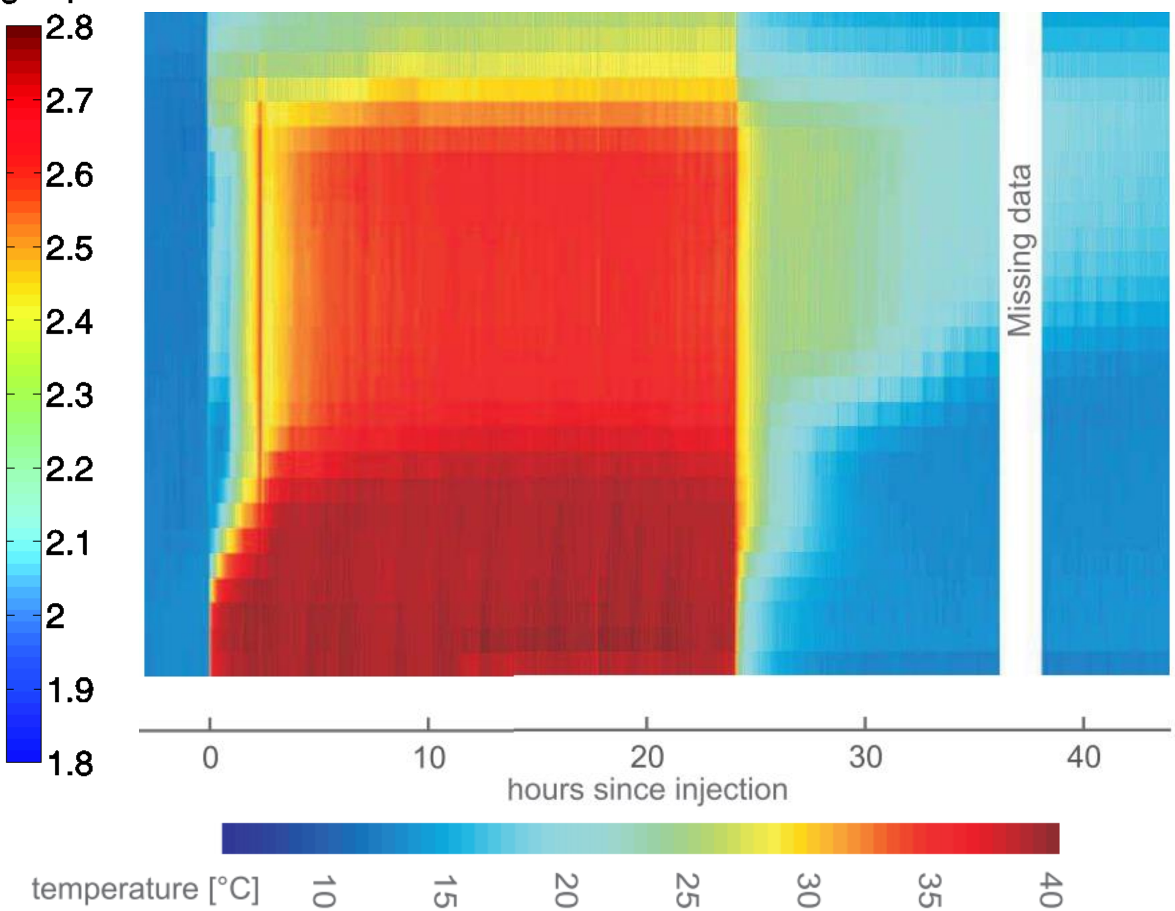


The aspect ratio is equal to 0.75, which is the limit to achieve a reasonable resolution in the middle of the section

Reciprocal were used to assess the error level of each data set during the study

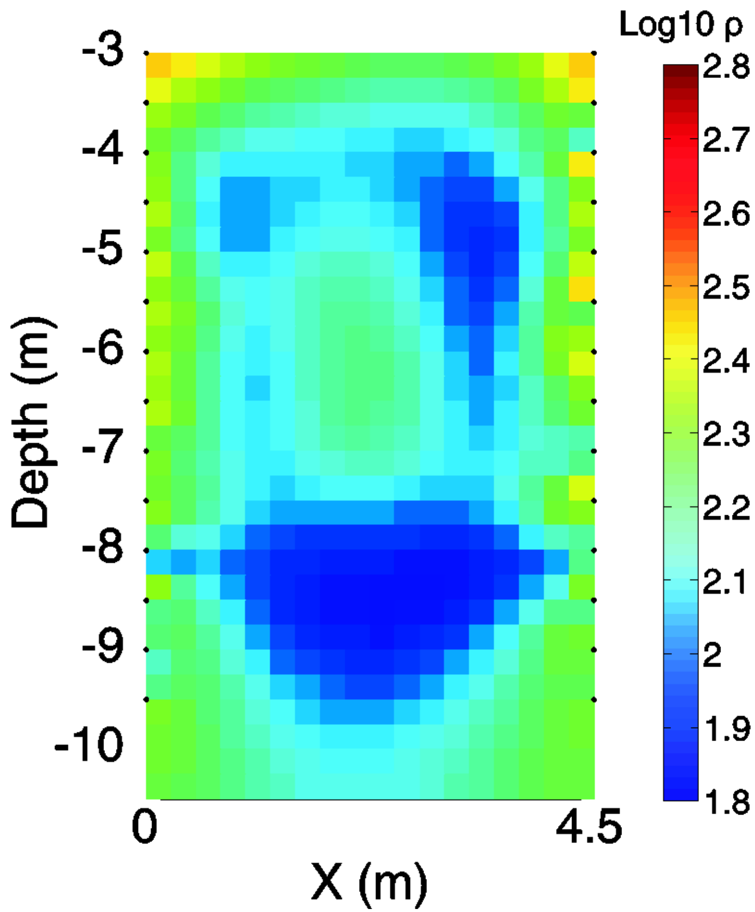
Injection of heated water at 38°C (+25°C) during 24h at 3m³/h (outlet installed at the bottom)

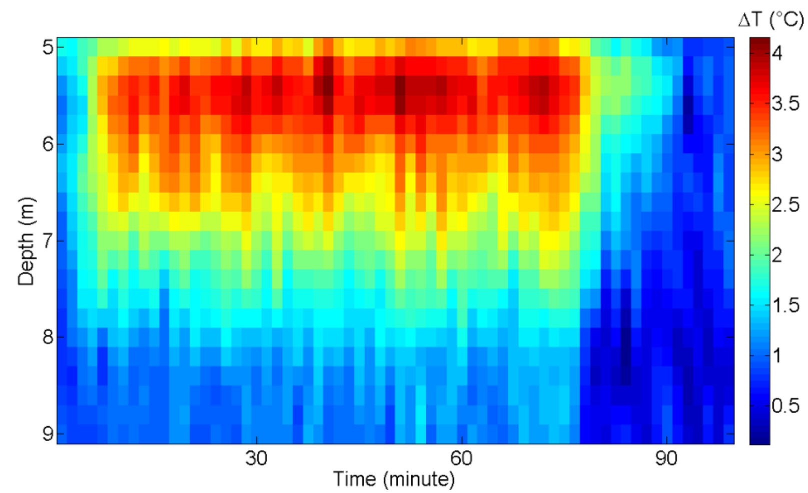




The DTS measurement in the injection well clearly shows the two-layer nature of the aquifer. After the end of injection, the temperature in the bottom part of the well decreases faster than in the upper part due to the higher water fluxes.

Heating wire heats uniformly over the entire depth of the well





The lower temperatures at the bottom are due to higher groundwater flow, confirming the previous results are confirmed by DTS measurements in natural flow conditions.

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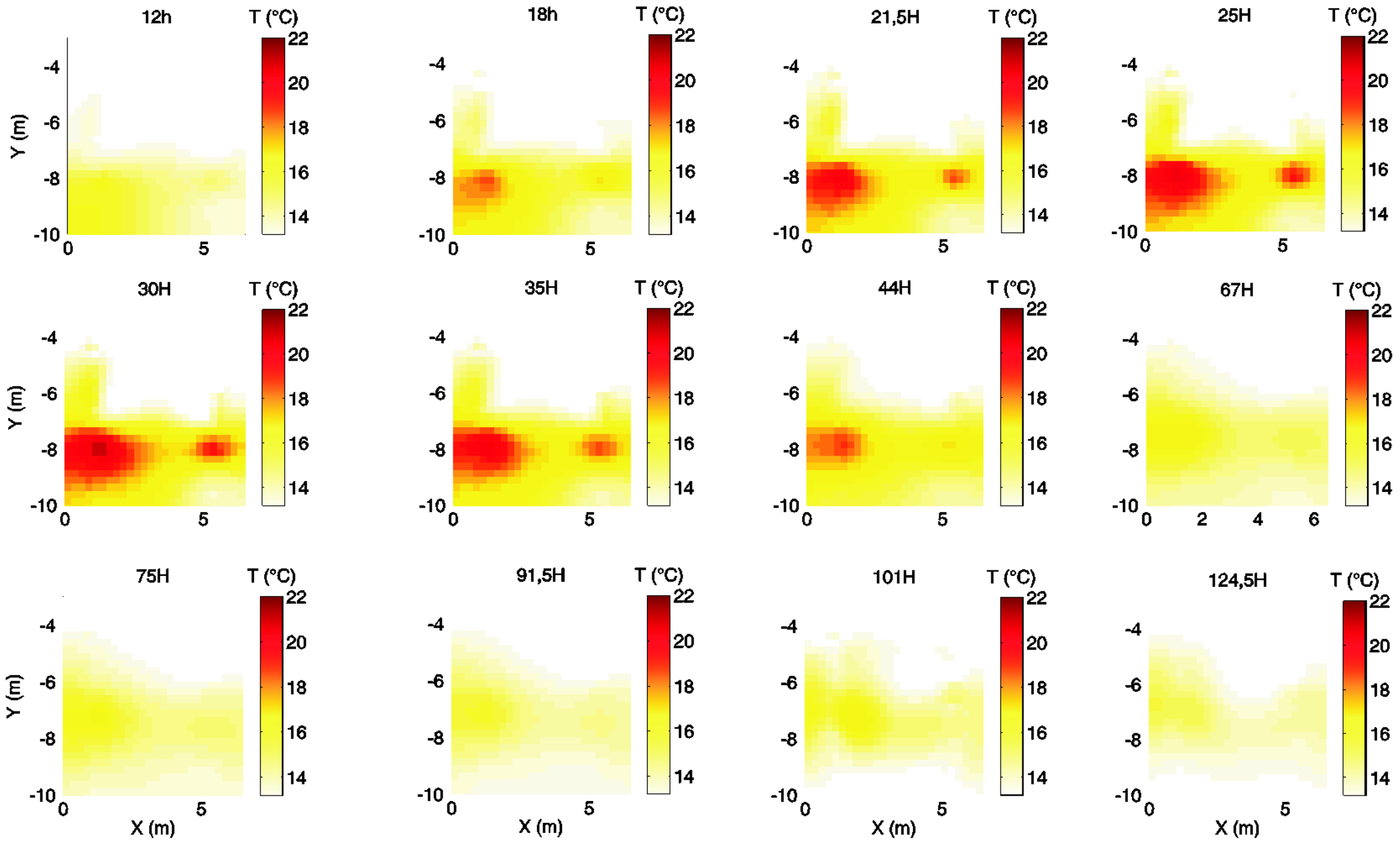
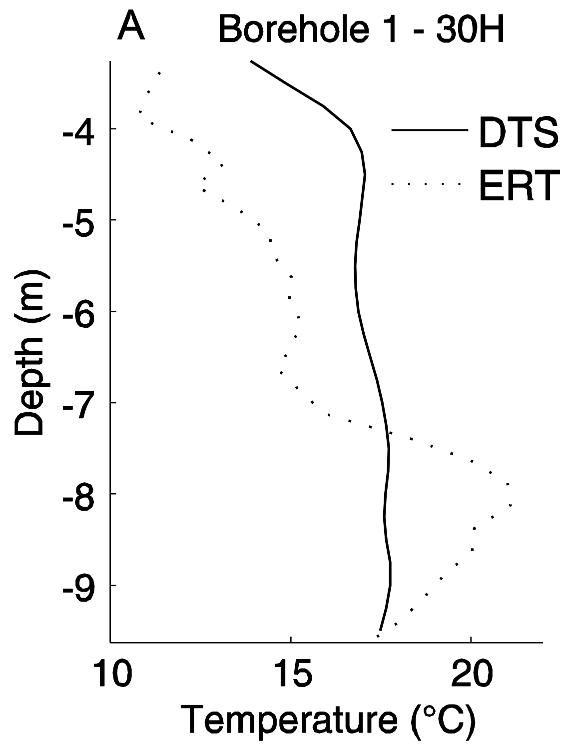
Standard inversion: Interpretation in terms of temperature is valid only in the saturated zone with a maximum temperature of 21°C (ΔT = +8 °C)



We used a mean temperature of 13.2°C to transform globally ERT into temperature (based on temperature measurements in the ERT borholes)

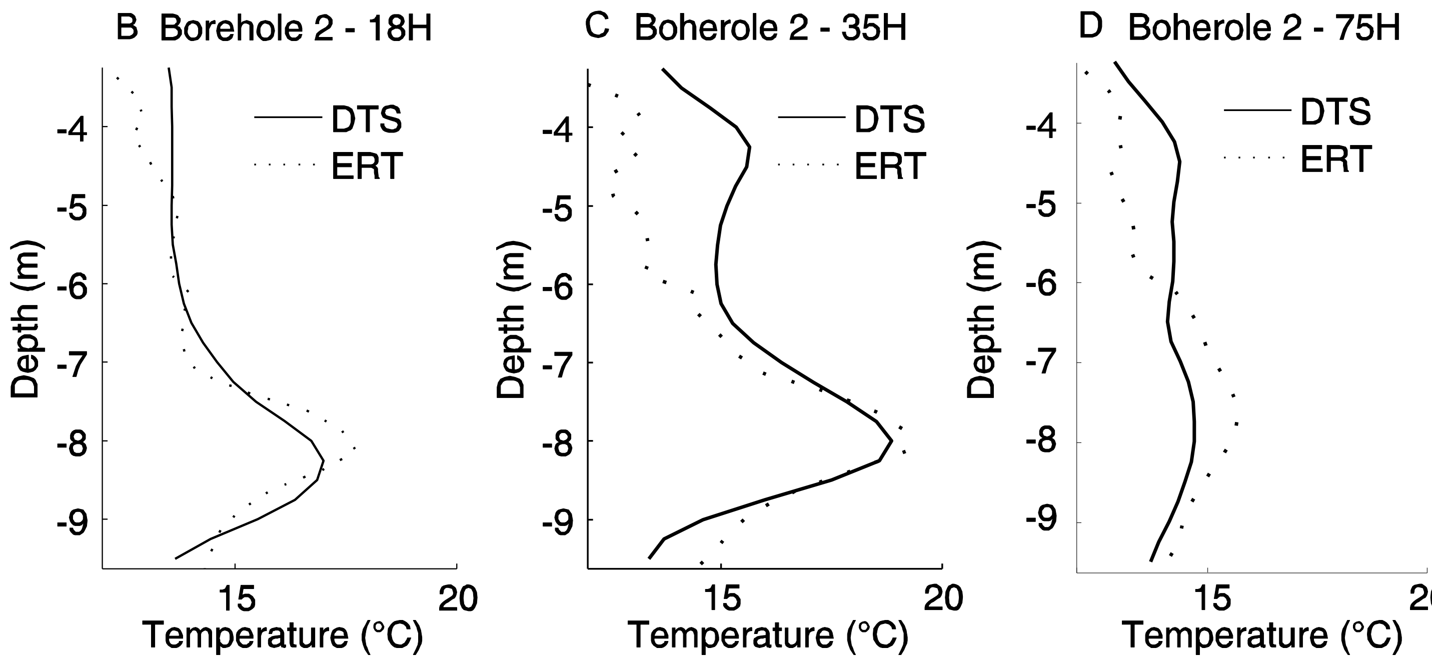
ERT-temperature were compared with direct temperature measurements (DTS) into ERT borehole 1 (DTS in the well)



The fitting is bad, certainly due to mixing effects in the borehole, DTS measurements are in contradiction with other data available on the site.

Multilevel sampling remains very challenging and here ERT is more robust

ERT-temperature were compared with direct temperature measurements (DTS) into ERT borehole 2

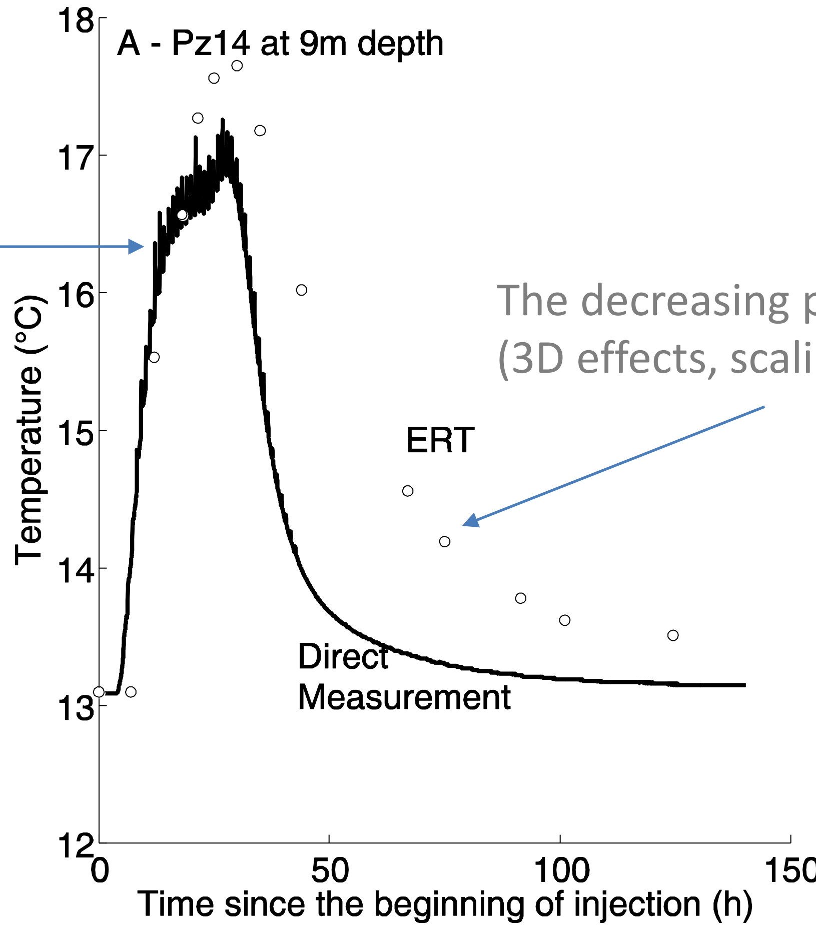


The correspondence is very good with the maximum temperature detected at the correct depth and a coherent range of values

Such a good vertical resolution was rarely shown for time-lapse studies given the difficulty to sample at different depth

Reality check with GW temperature loggers into control piezometers ; ERT is able to correctly retrieved within time-lapse series change of temperature smaller than 0.5°C

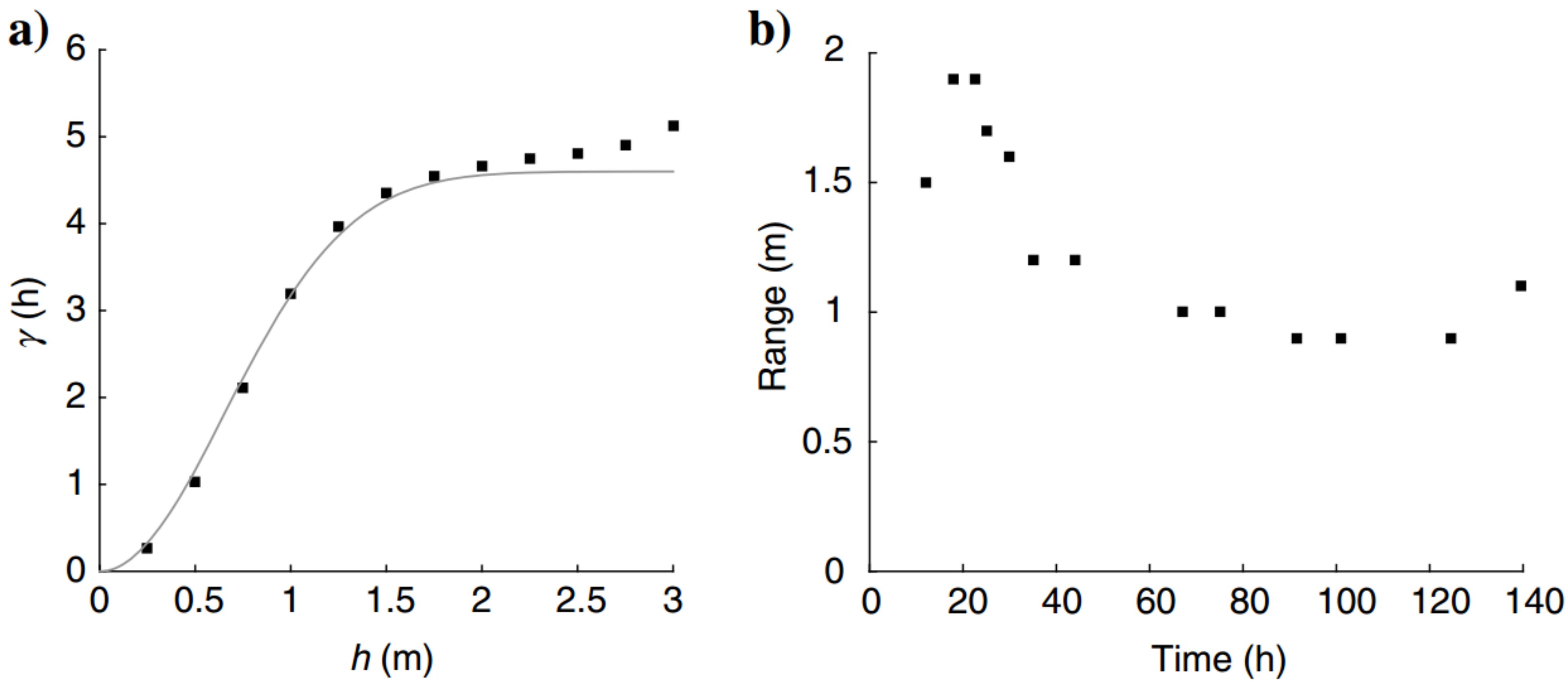
The initial part of the breakthrough curve is well retrieved



The decreasing part is overestimated (3D effects, scaling effect ?)

If the global limit of detection is about 1.5°C, the sensitivity of the method enables to image change smaller than 0.5°C.

Improving imaging: Using DTS information to constrain ERT



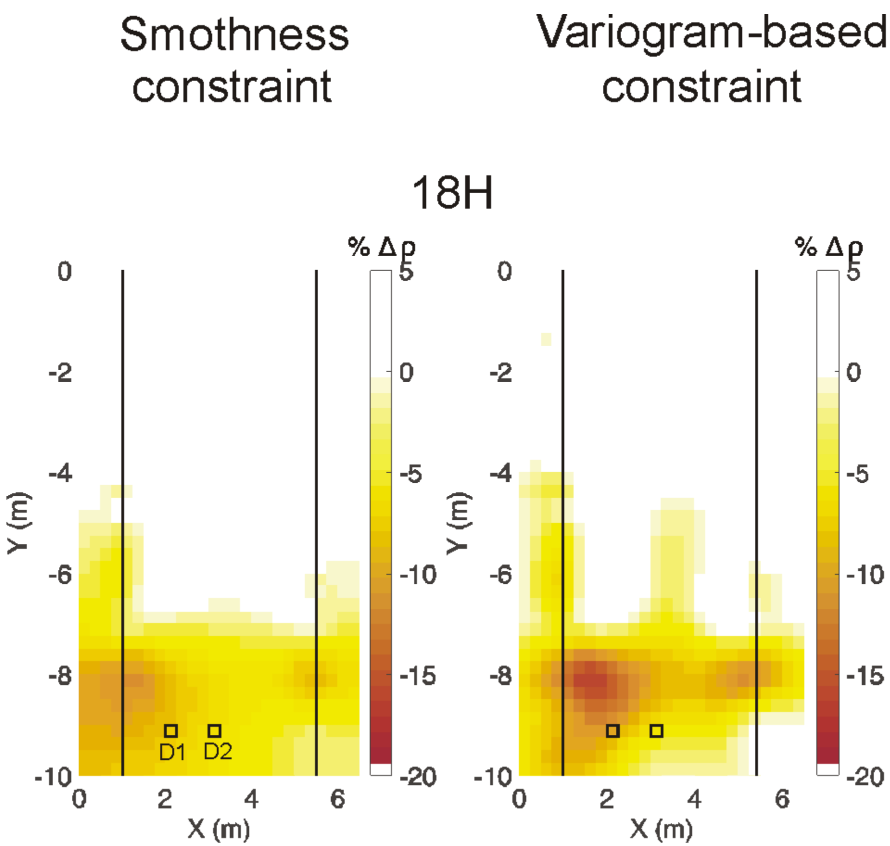
Experimental variogram (30 h)

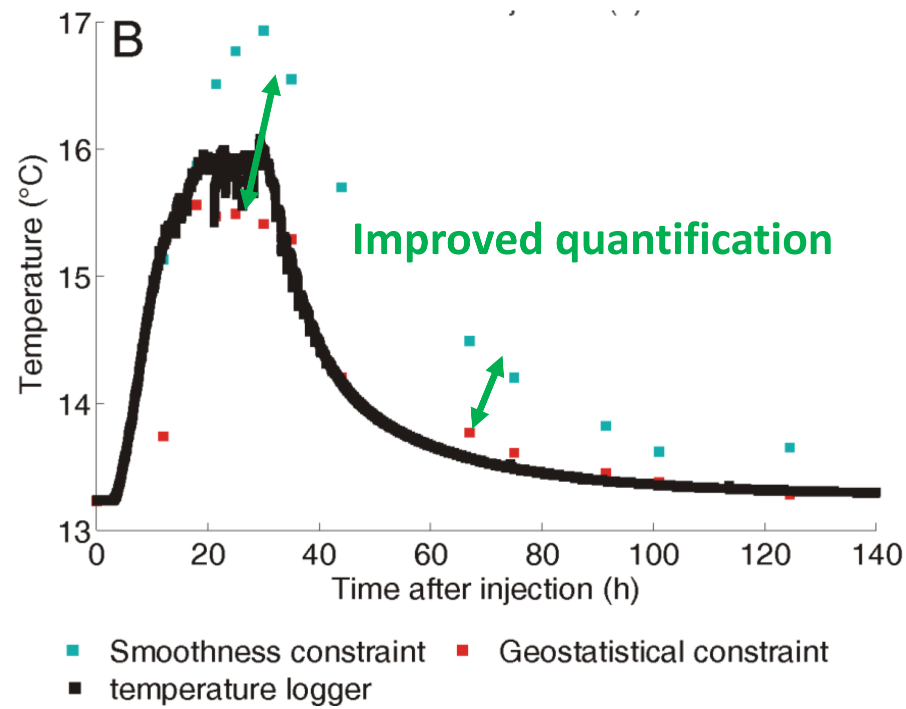
Range evolution

We used the spatially distributed temperature measurements from the DTS in one of the boreholes to derive the vertical correlation length of temperature changes (spatial resolution of 25 cm).

$$\phi_{\mathrm{diff}}(\mathbf{\Delta m}) = ||\mathbf{C}_{\mathbf{\Delta d}}^{-0.5}[\mathbf{\Delta d} - (f(\mathbf{m}) - f(\mathbf{m_0}))]||_2^2 + \lambda||\mathbf{C}_{\mathbf{\Delta m}}^{-0.5}\mathbf{\Delta m}||_2^2,$$

Improving imaging capabilities





Hermans et al., *2016* in *Geophysics*

Regular algorithm

New algorithm

Conclusions

Qualitatively, the ERT-derived breakthrough curves are correctly retrieved in time with inital part, the maximum and the tail of the curve and shows a coherent spatiotemporal behavior with respect to DTS and logger.

Quantitatively, derived ERT-temperatures are of the correct order of magnitude with difference about 10 to 20%, which is improved when integrating DTS as a constraint.

Experimentally, ERT and DTS overcome the problem of multilevel sampling and representativity of measurements in piezometers

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Petrophysics

Water conductivity increases with temperature…

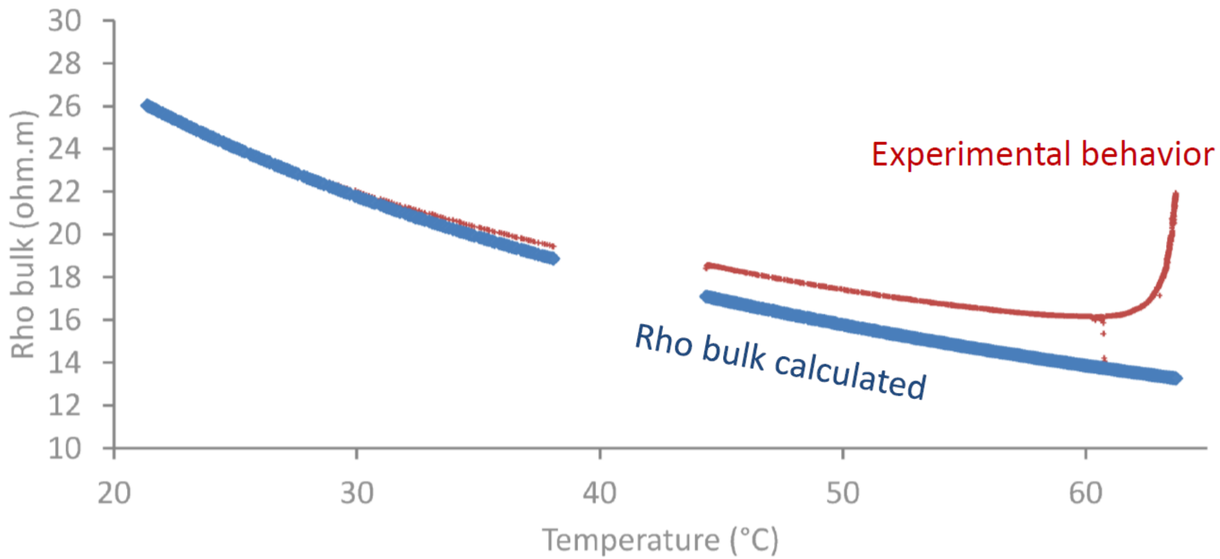
… but almost everything is changing with temperature

surface conductivity

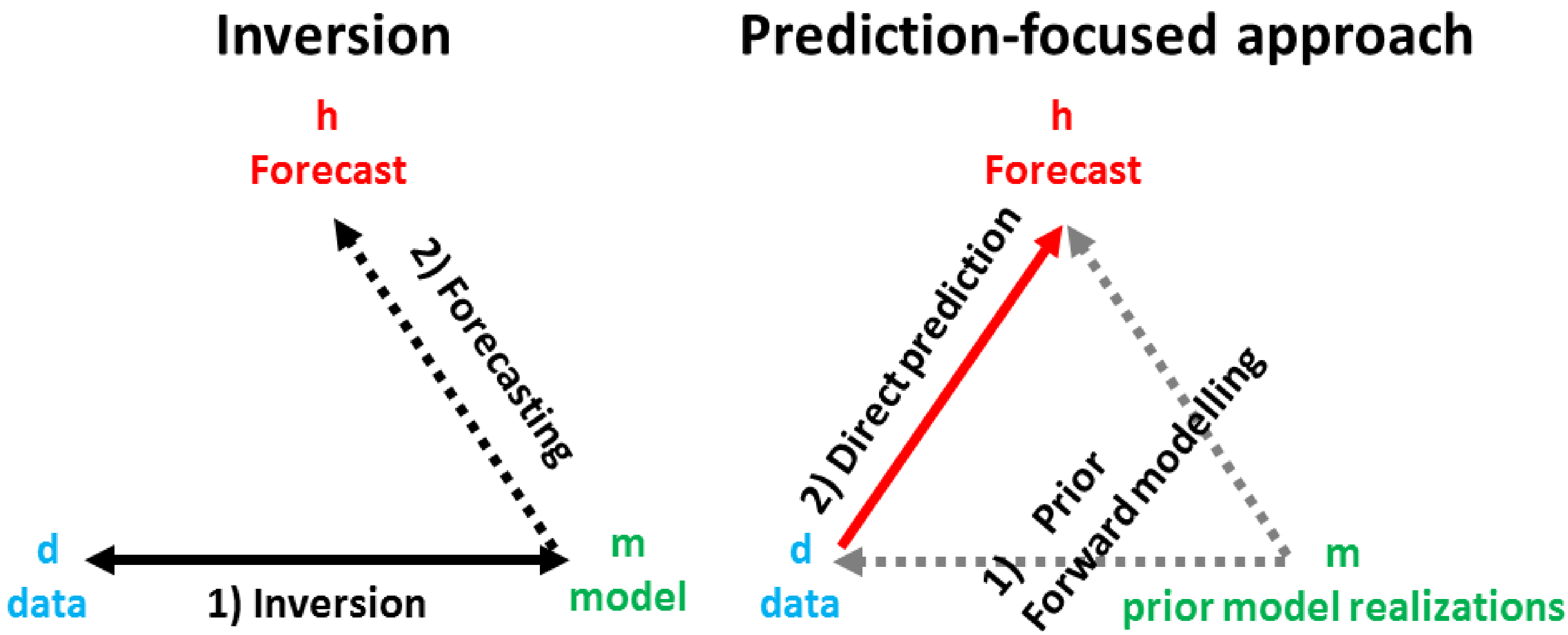
sorption/desorption processes

dissolution/precipitation processes

This effect is mainly important for long term experiments and diffusive processes



Forecasting: avoiding one (inverse) model limitations



Hermans et al., 2016, *Water Resources Research*

Thank you very much for your attention

More information at

www.appliedgeophysicsulg.wordpress.com
https://www.**researchgate**.net/profile/**Frederic_Nguyen**

Or in

Hermans T., et al., 2012,*Geophysics*.
Hermans, T., et al., 2014, *Energies*.
Wildemeersch et al., 2014, *Journal of Contaminant Hydrology*
Hermans, T., et al.,. 2015, *Geothermics*
Klepikova et al., 2016, *Journal of Hydrology*
Hermans et al*.,* 2016*, Geophysics*
Hermans et al., 2016, *Water Resources Research*