InnovationS in near-surface geophysics: going beyond state-of-the-art imaging

Frédéric Nguyen, University of Liège

January 20th 2020

METIS scientific day

Acknowledgements

- Thomas Hermans
- Sarah Garré
- Jorge Alvis Lopez
- Sien Benoit
- Kevin Gommers
- Tamara Pilawski
- Frank Delvigne
- Tanguy Robert
- David Caterina
- …

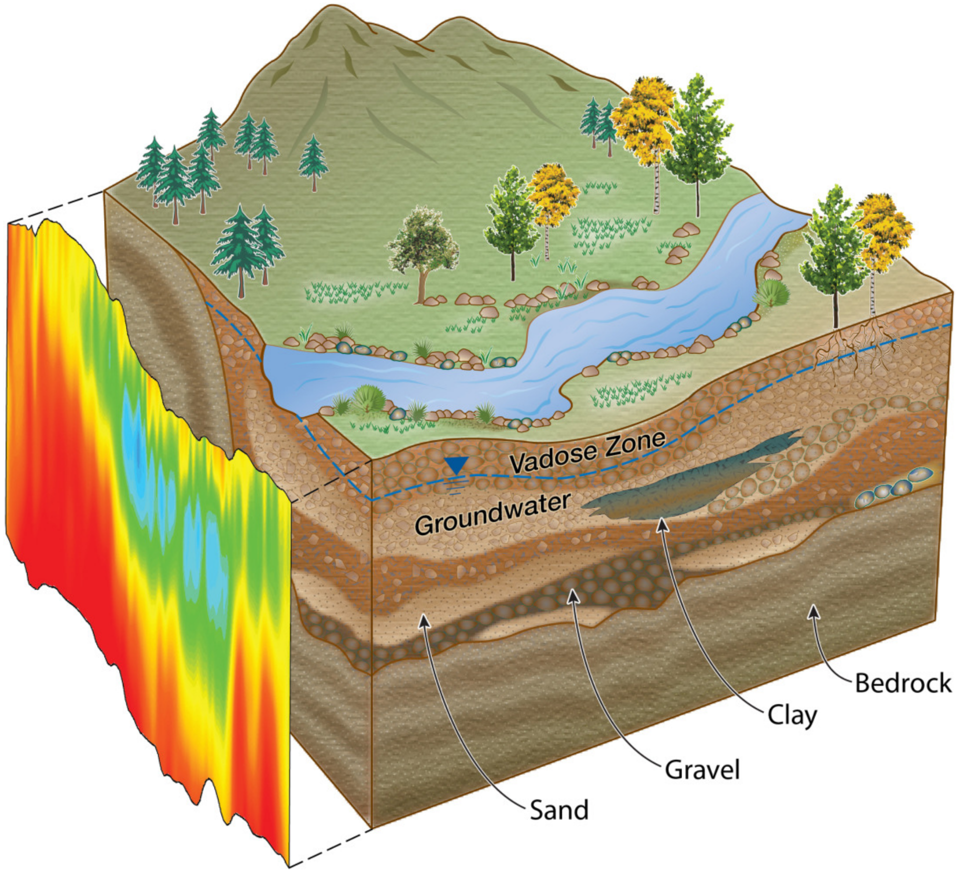
fnrs
LA LIBERTÉ DE CHERCHER

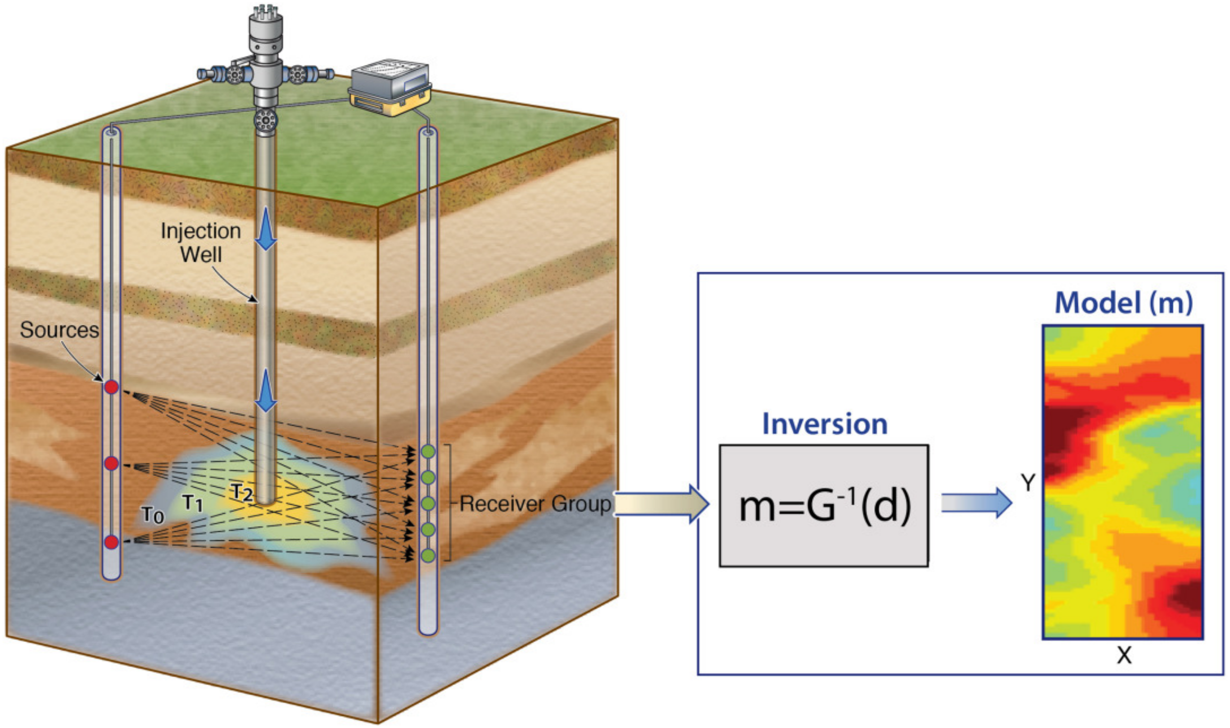
Horizon 2020
European Union Funding
for Research & Innovation

Wallonie

LIÈGE
université

Near-surface geophysics: twisting reality?





Binley et al., 2015, WRR

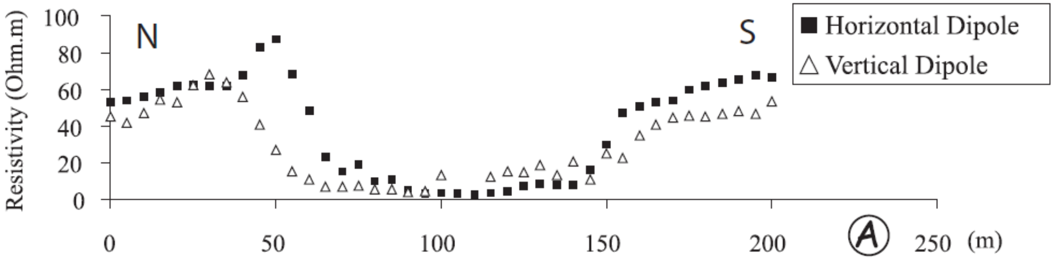
A revolution in space

A historical perspective in images

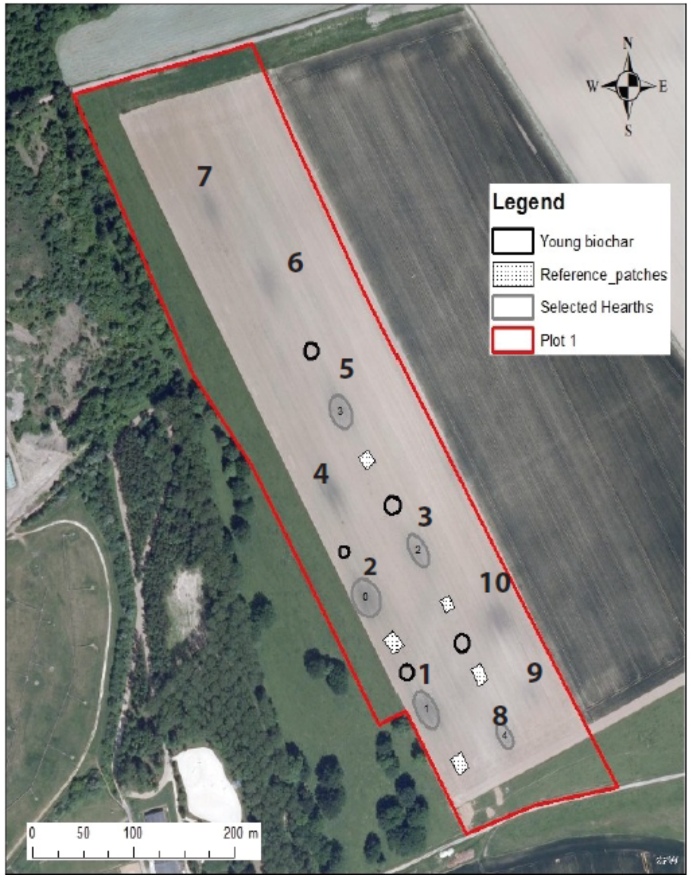
Geonics ®

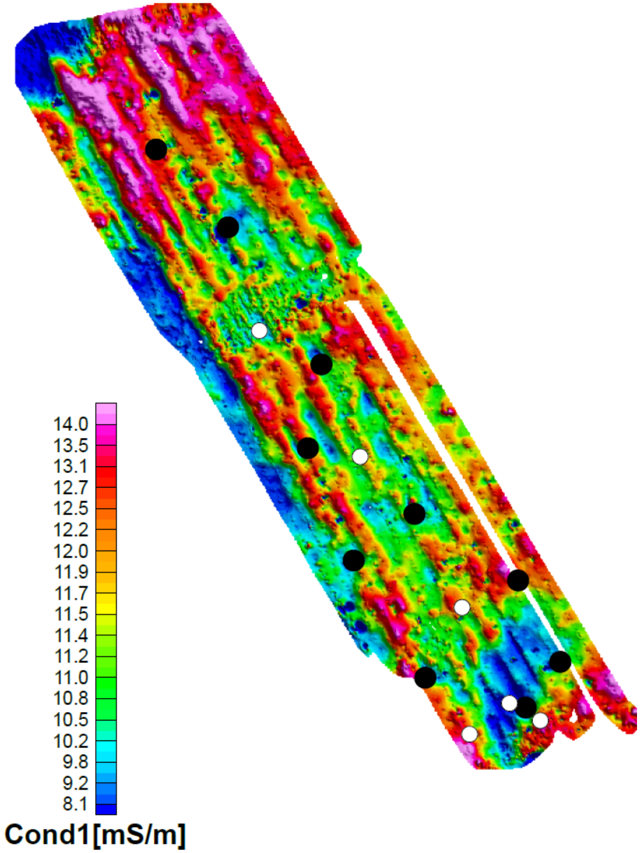
CHAR project, ULiege

A historical perspective in images



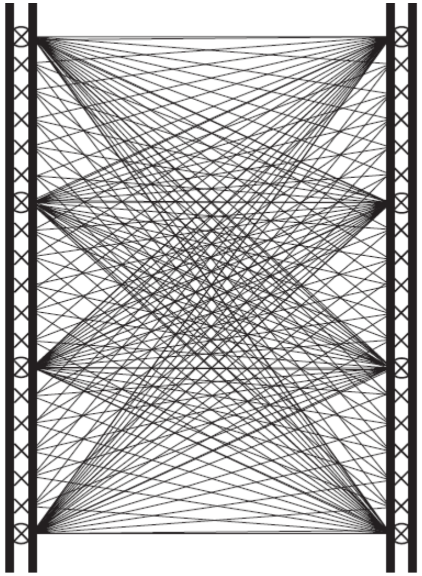
Nguyen, 2005

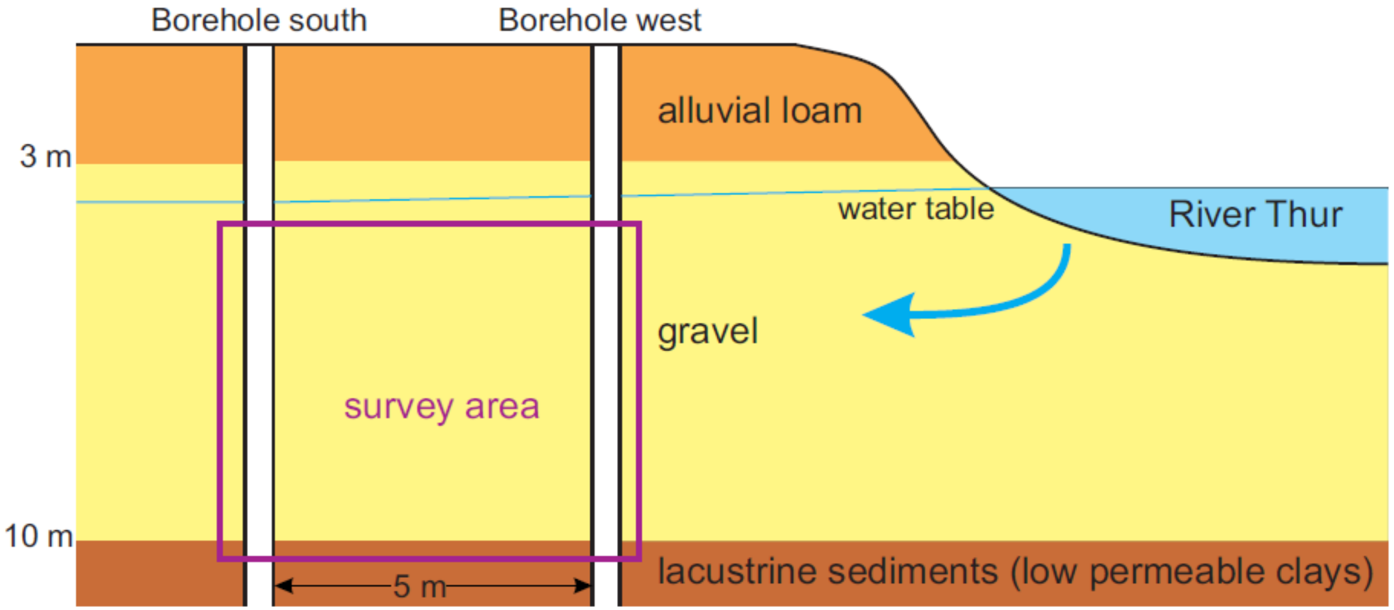


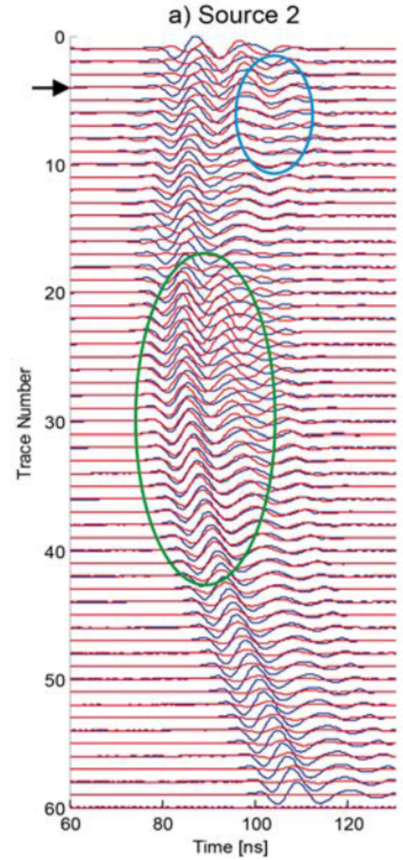


CHAR project, ULiege

Advances in modeling physical phenomena to improve imaging

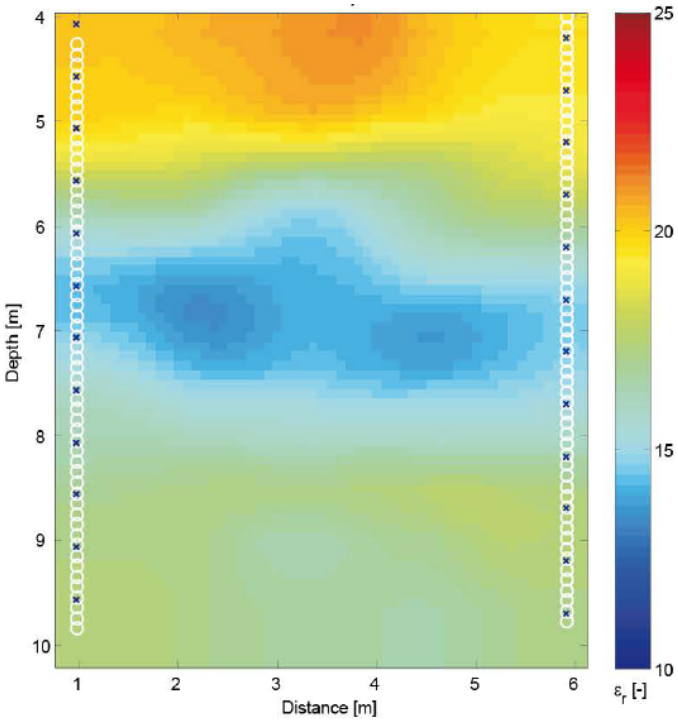


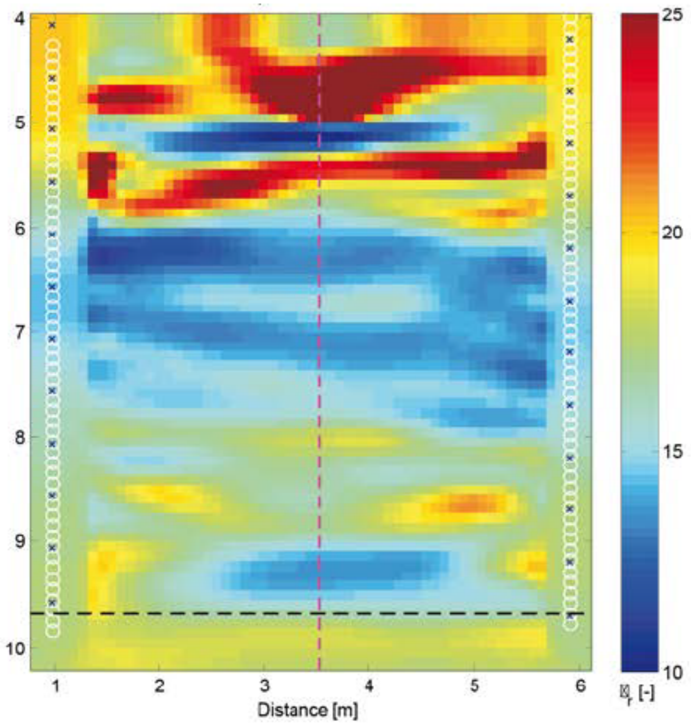


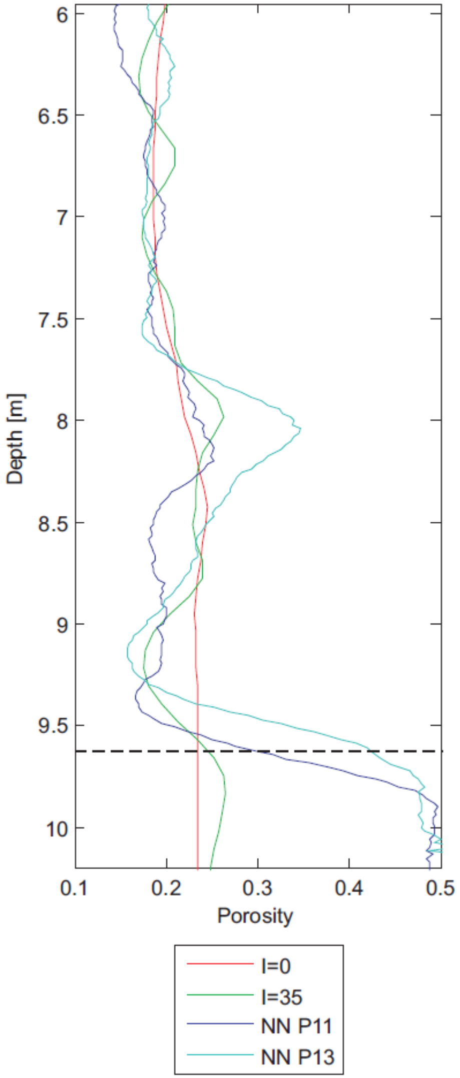


Klotzsche, et al., 2010

Full waveform inversion brings high resolution

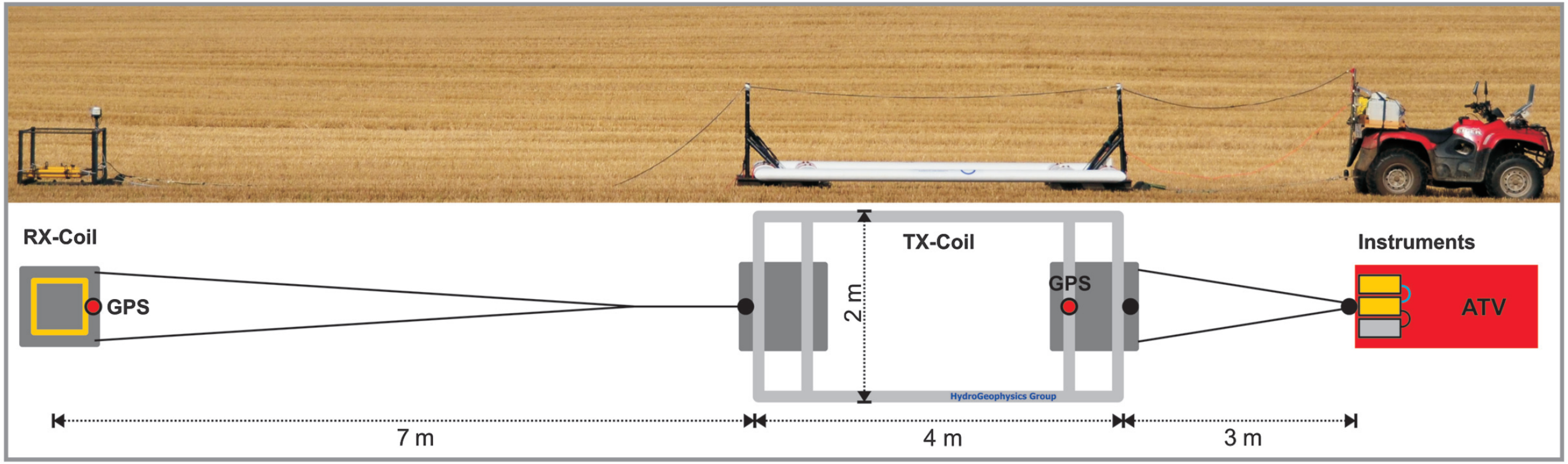




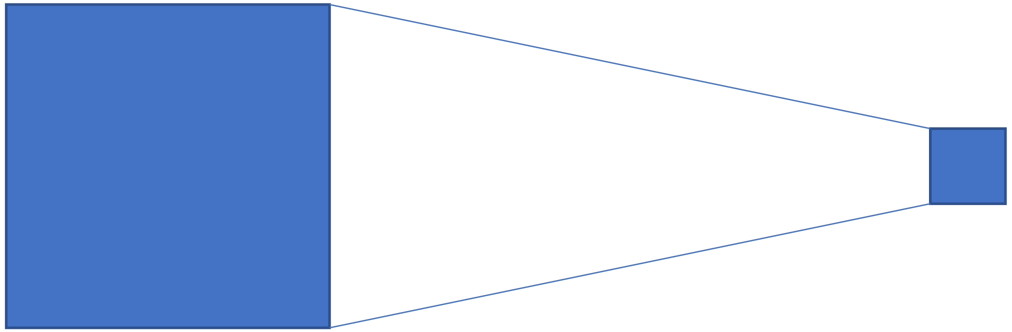


Klotzsche, et al., 2010

Mapping surveys

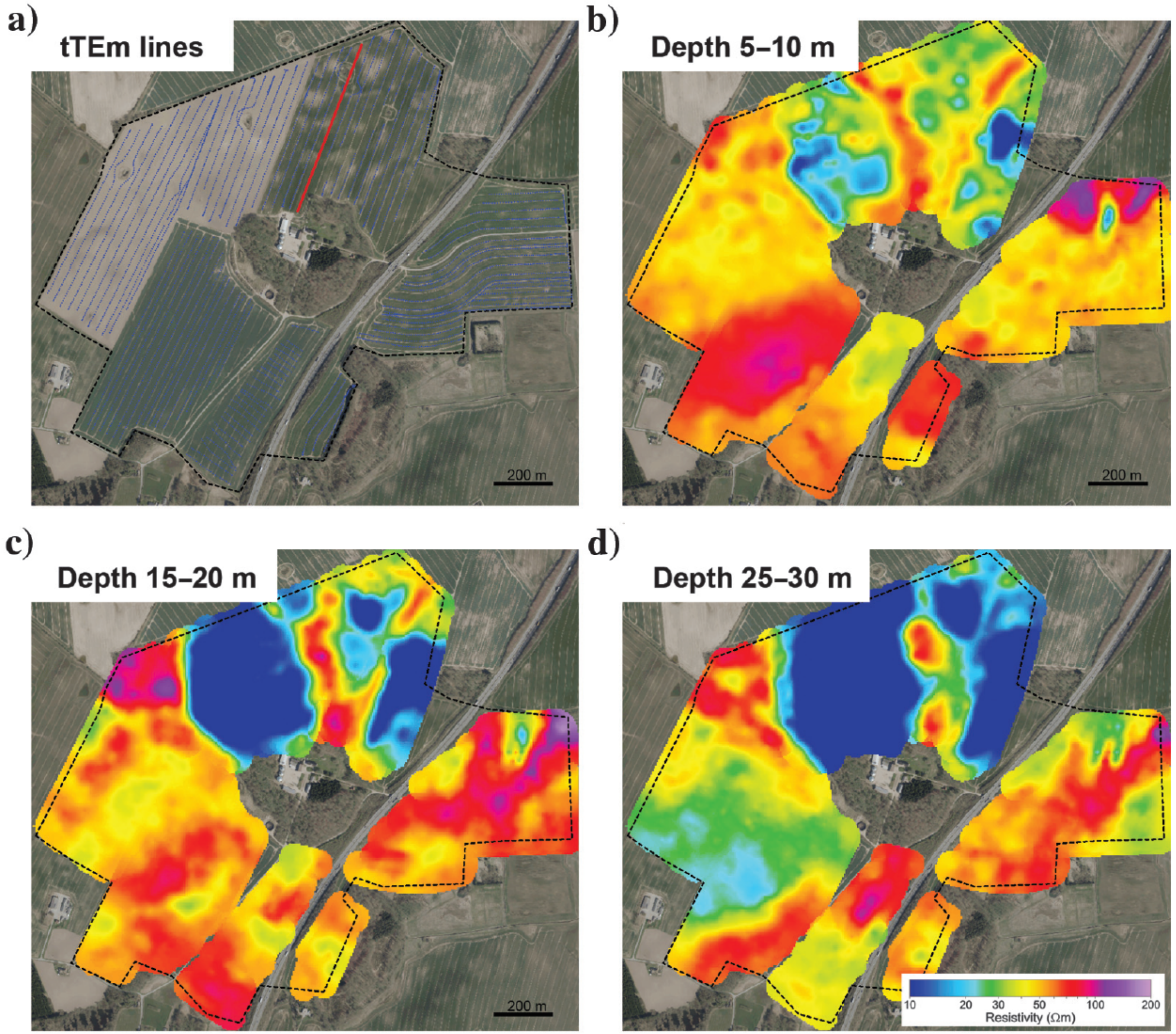


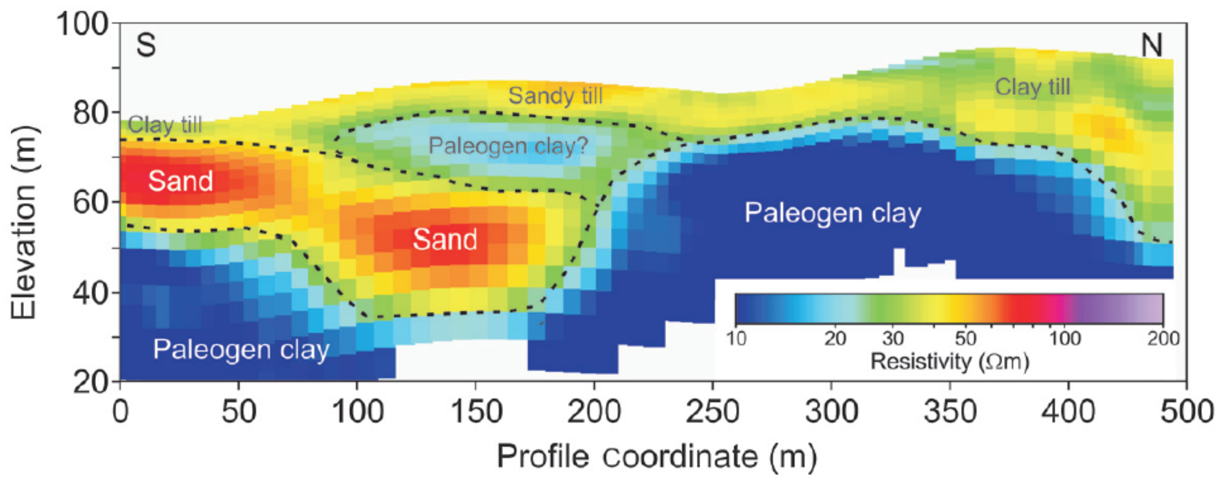
Auken et al., 2019



Challenges: maintaining the depth of investigation while reducing the loop

Mapping surveys: 2 days to image 1.6 km^2 down to 70 m with a 25 m resolution

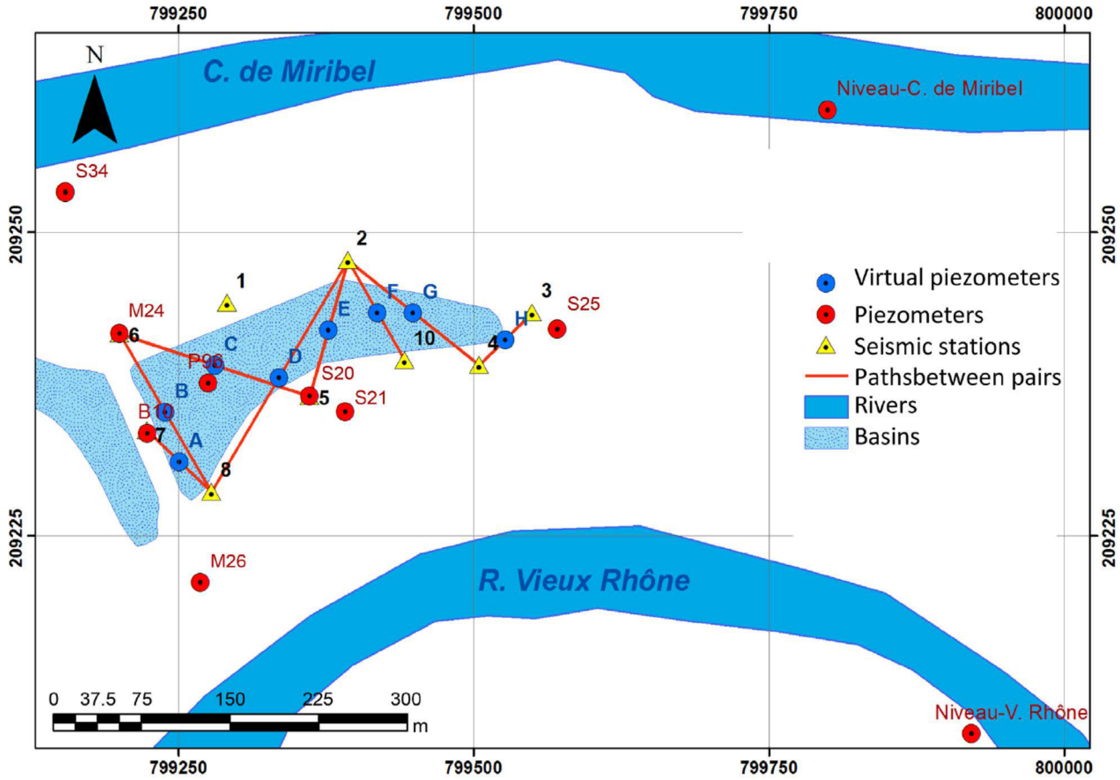




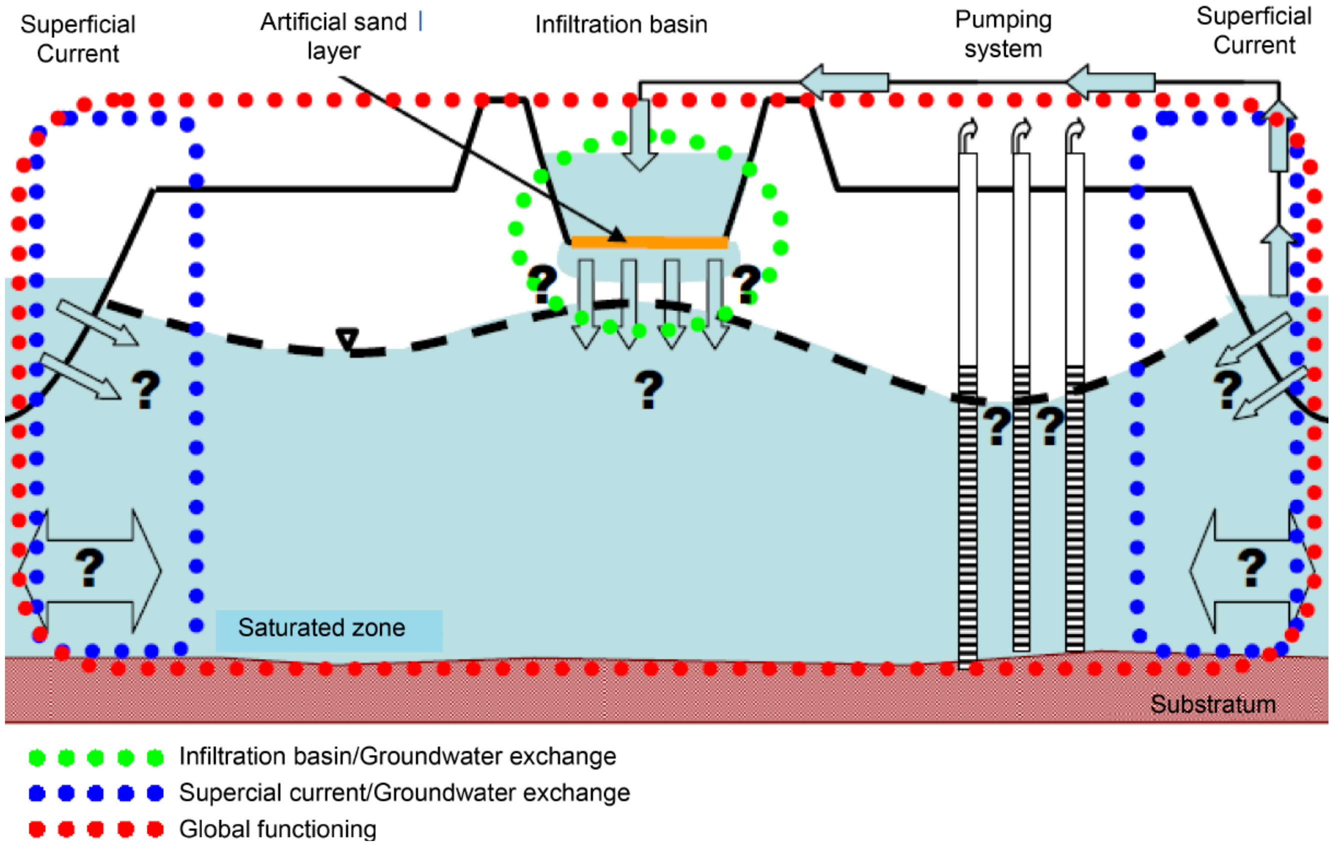
Auken et al., 2019, Geophysics

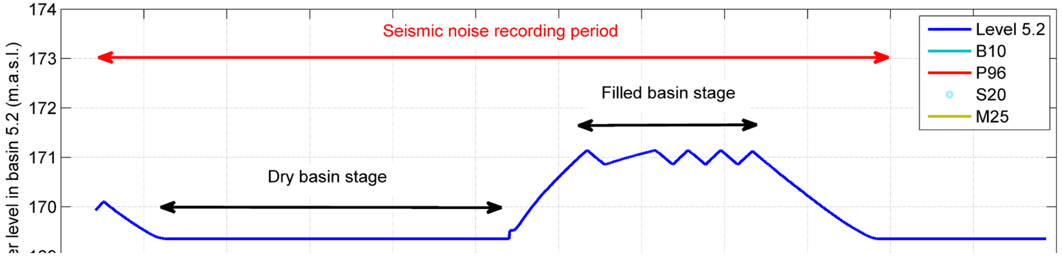
Then in time…

Data processing: making sense out of noise

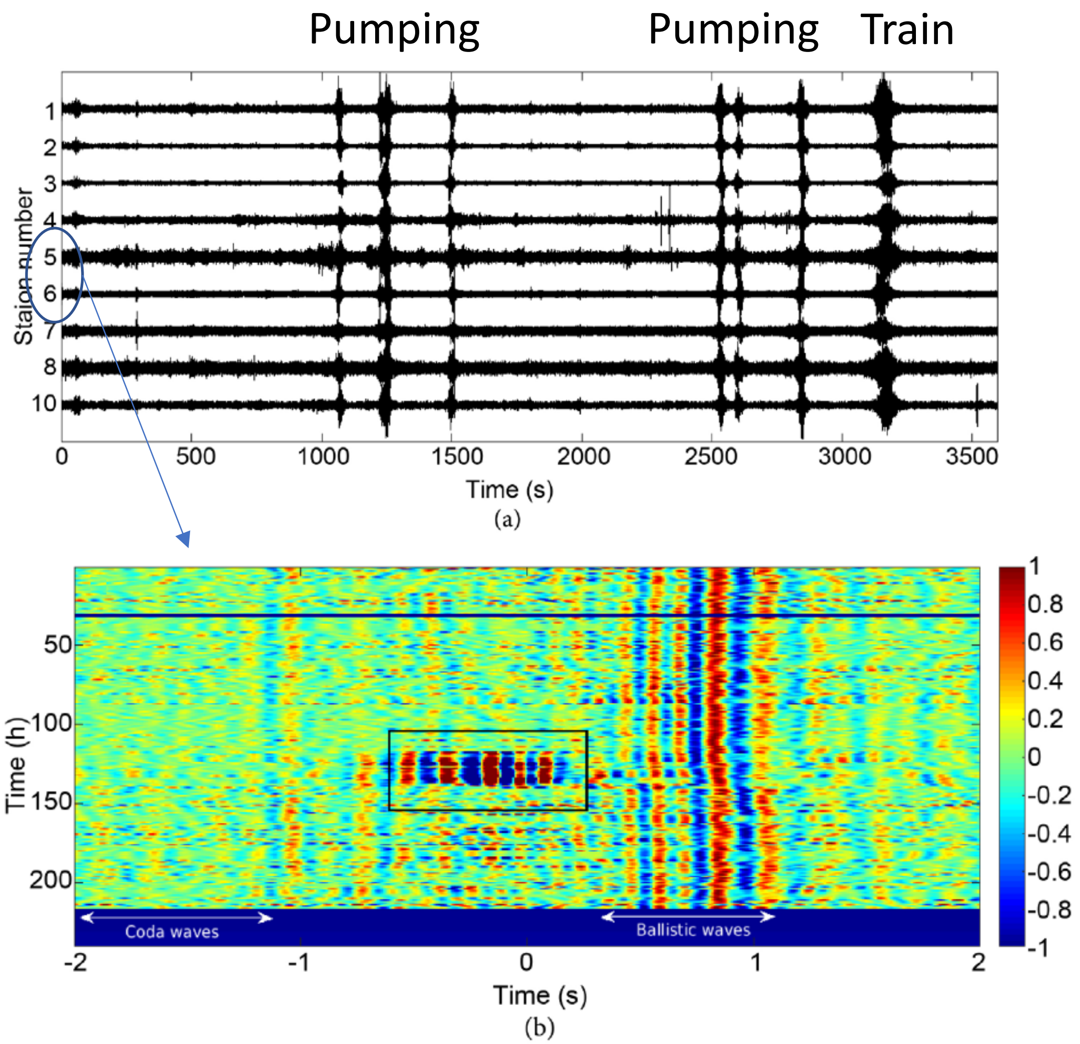


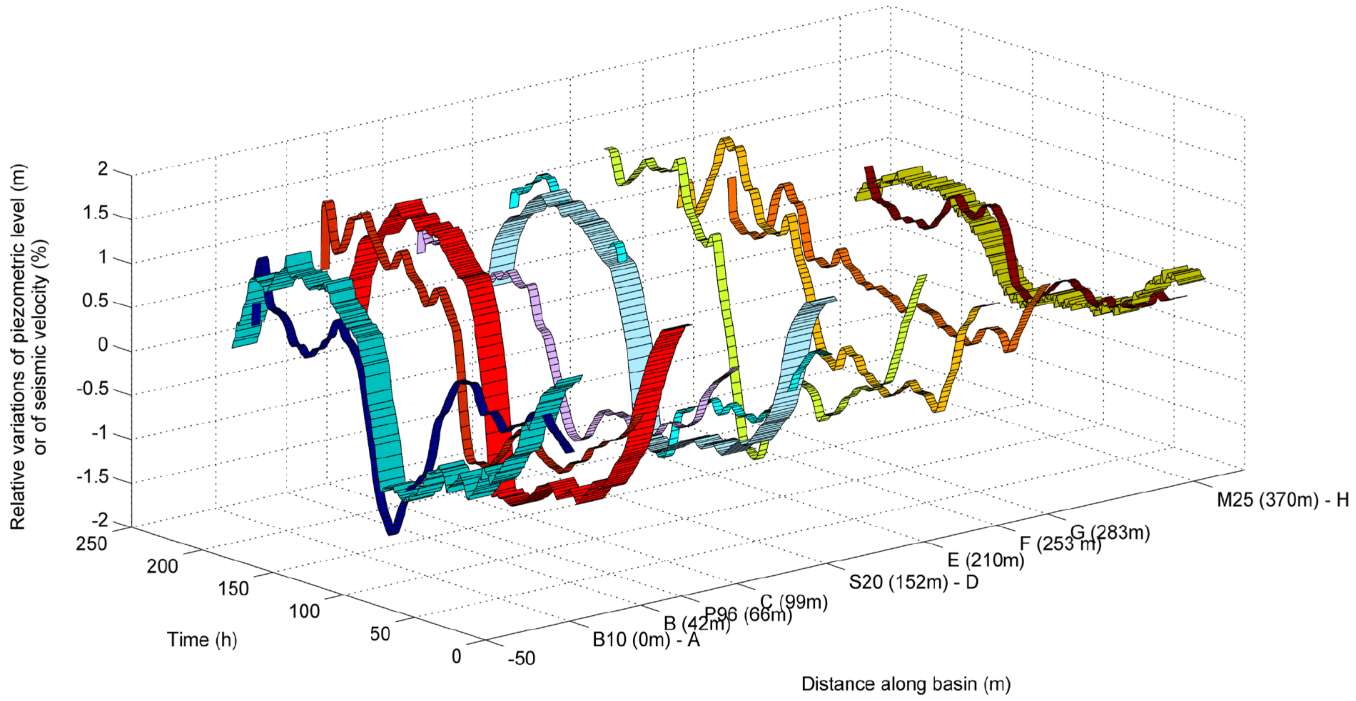
Voisin et al., 2017, JWARP





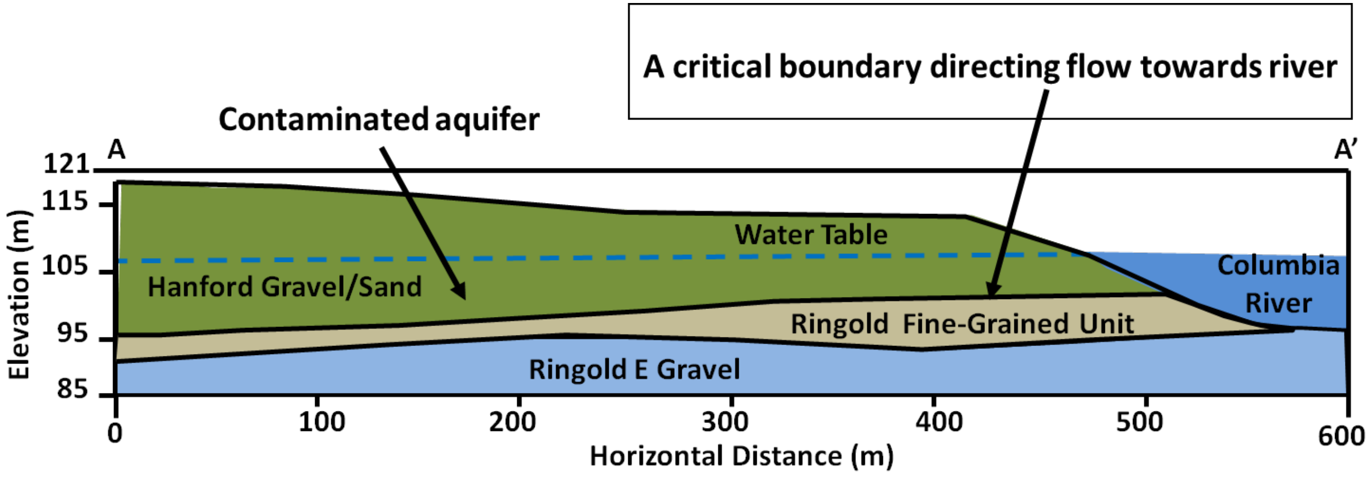
Data processing: making sense out of noise



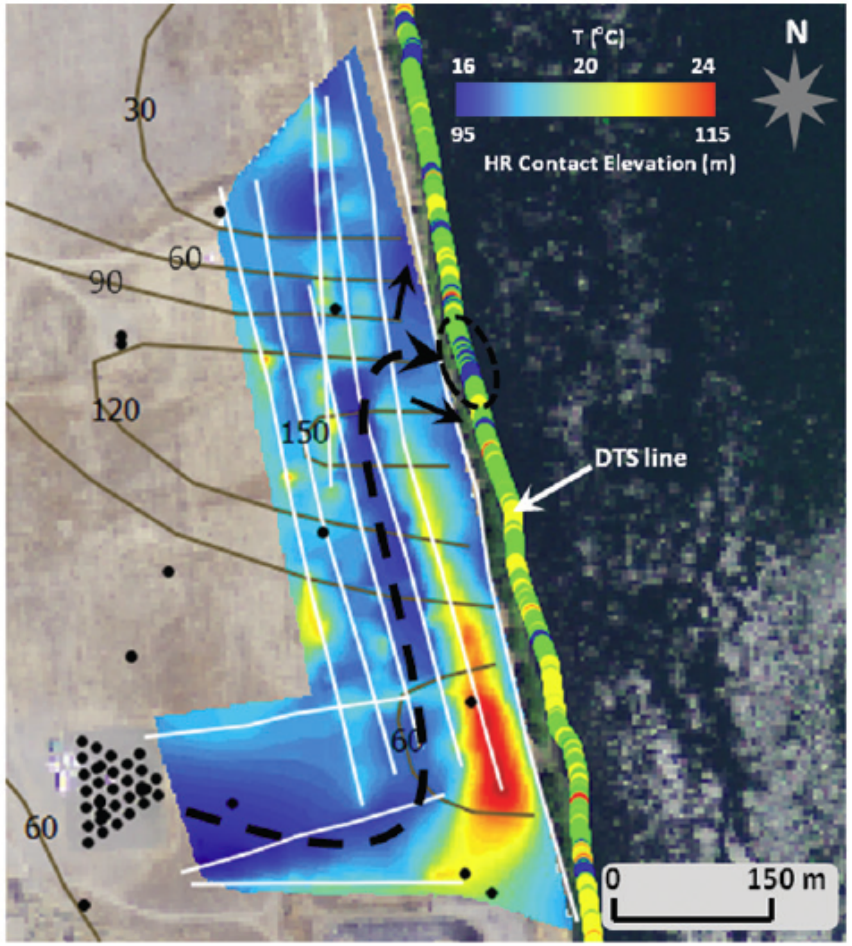


Voisin et al., 2017, JWARP

4D imaging at Hanford, WA

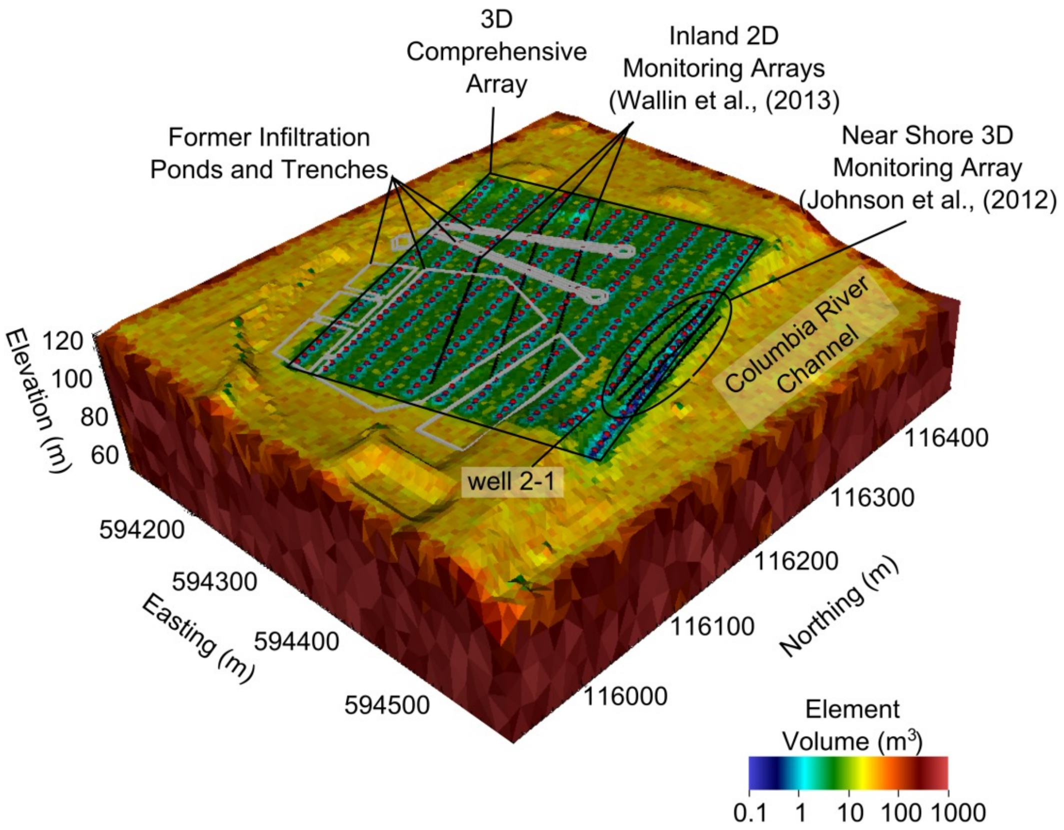


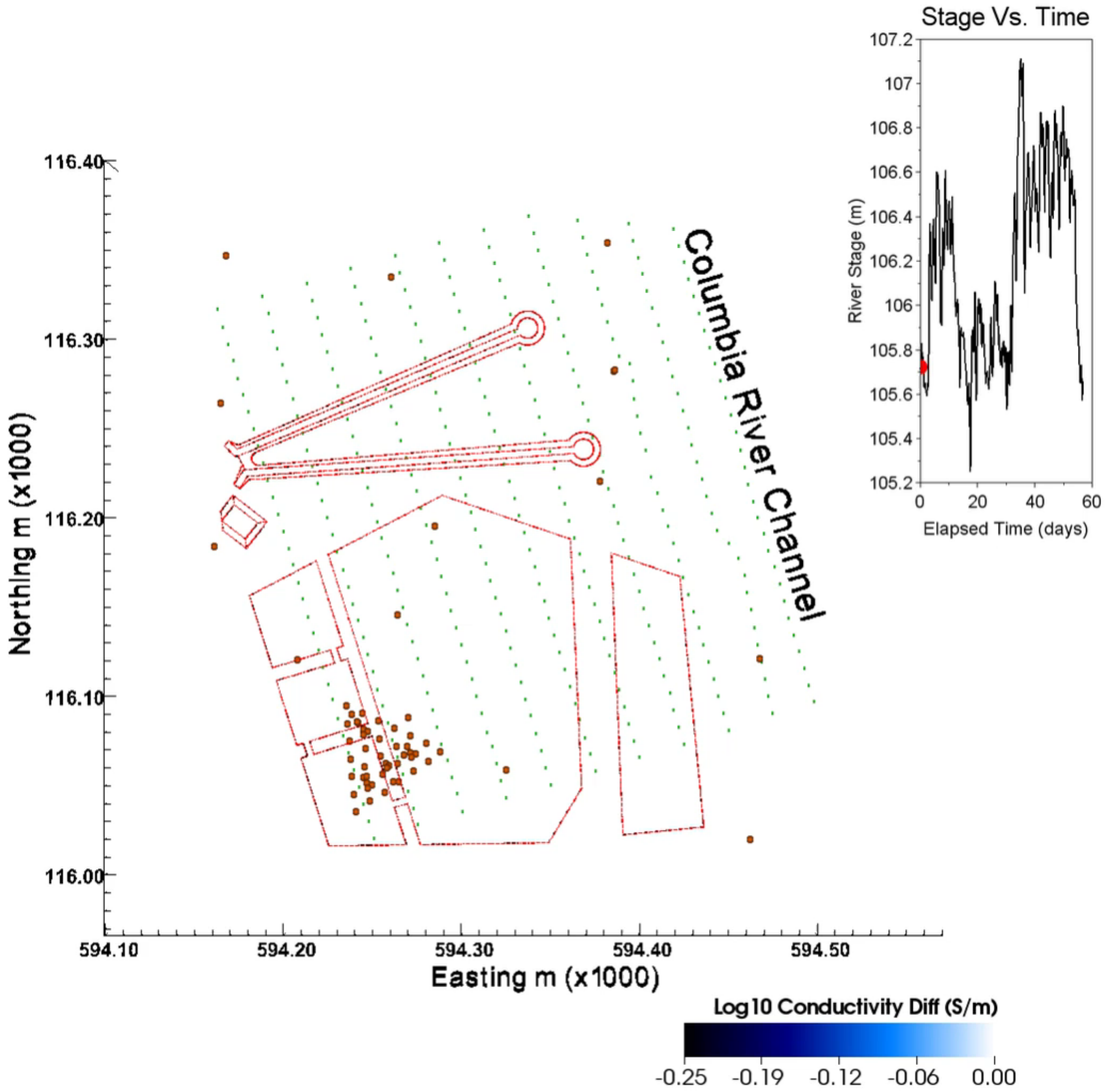
Paleochannels incised into the Ringold unit suspected to channel flow towards the river



Courtesy of Prof. Lee Slater

ERT 3D + time

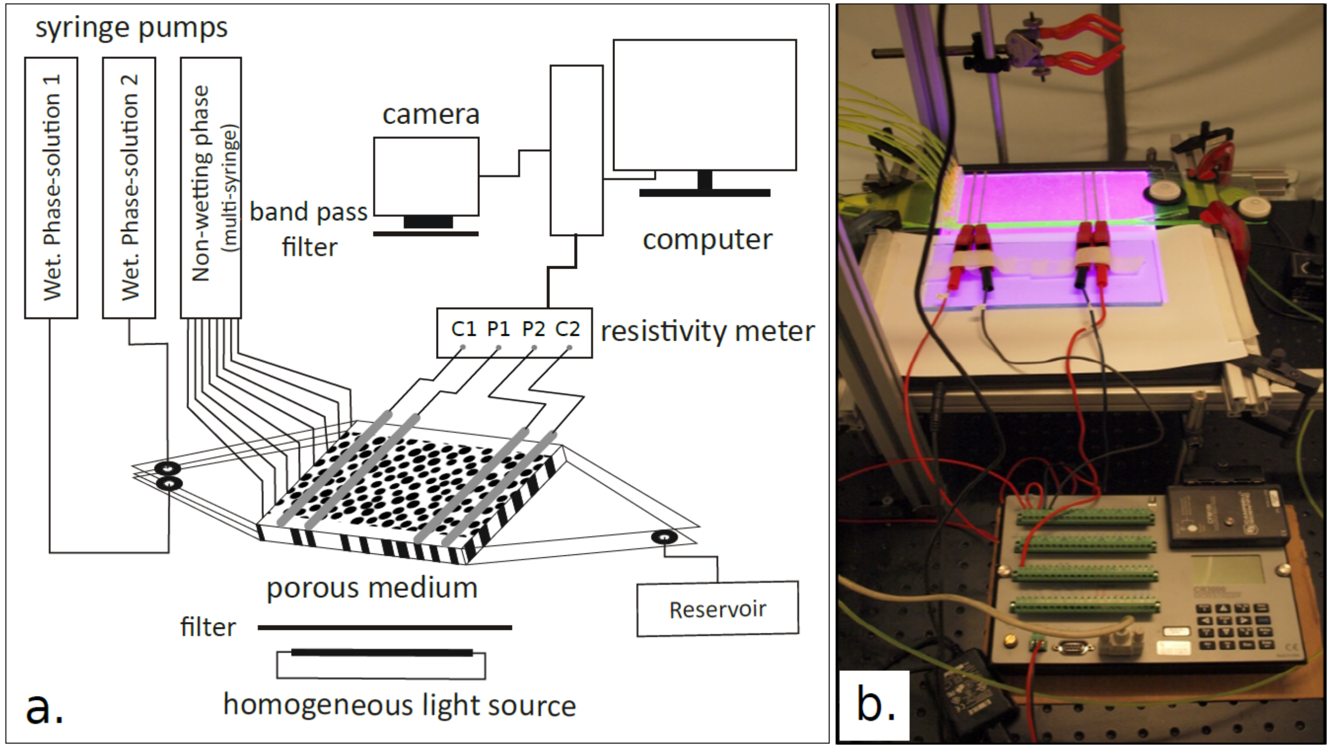




Johnson et al., 2015, WRR

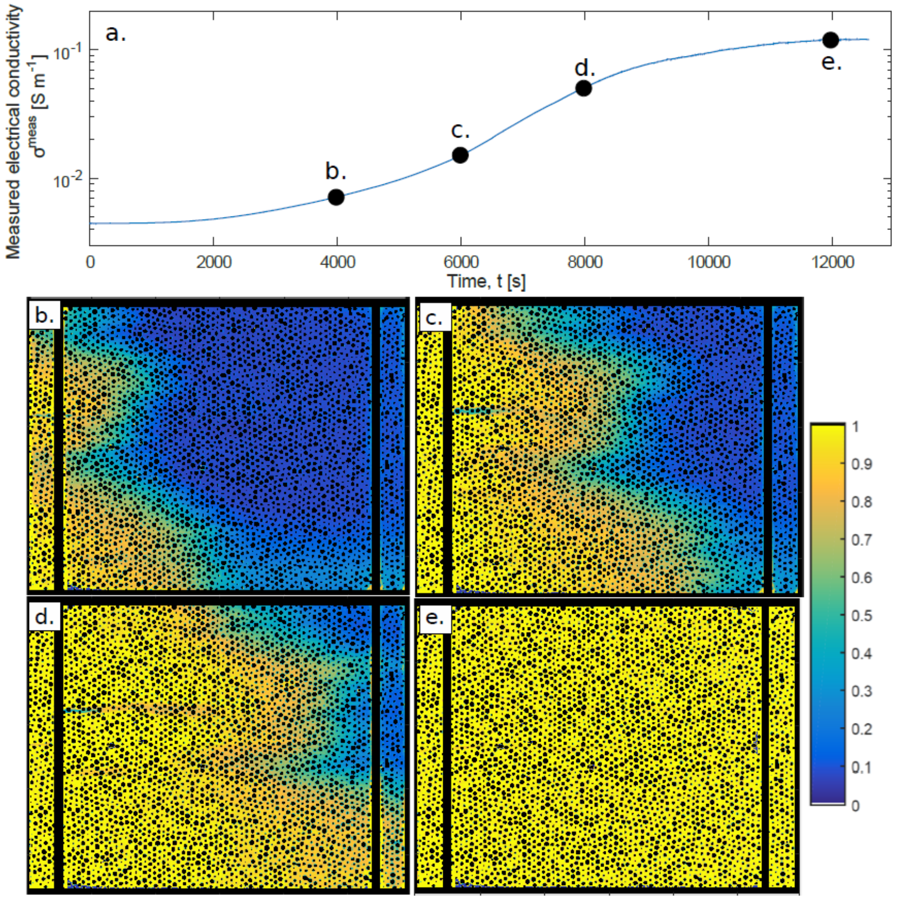
Relation to state variables…

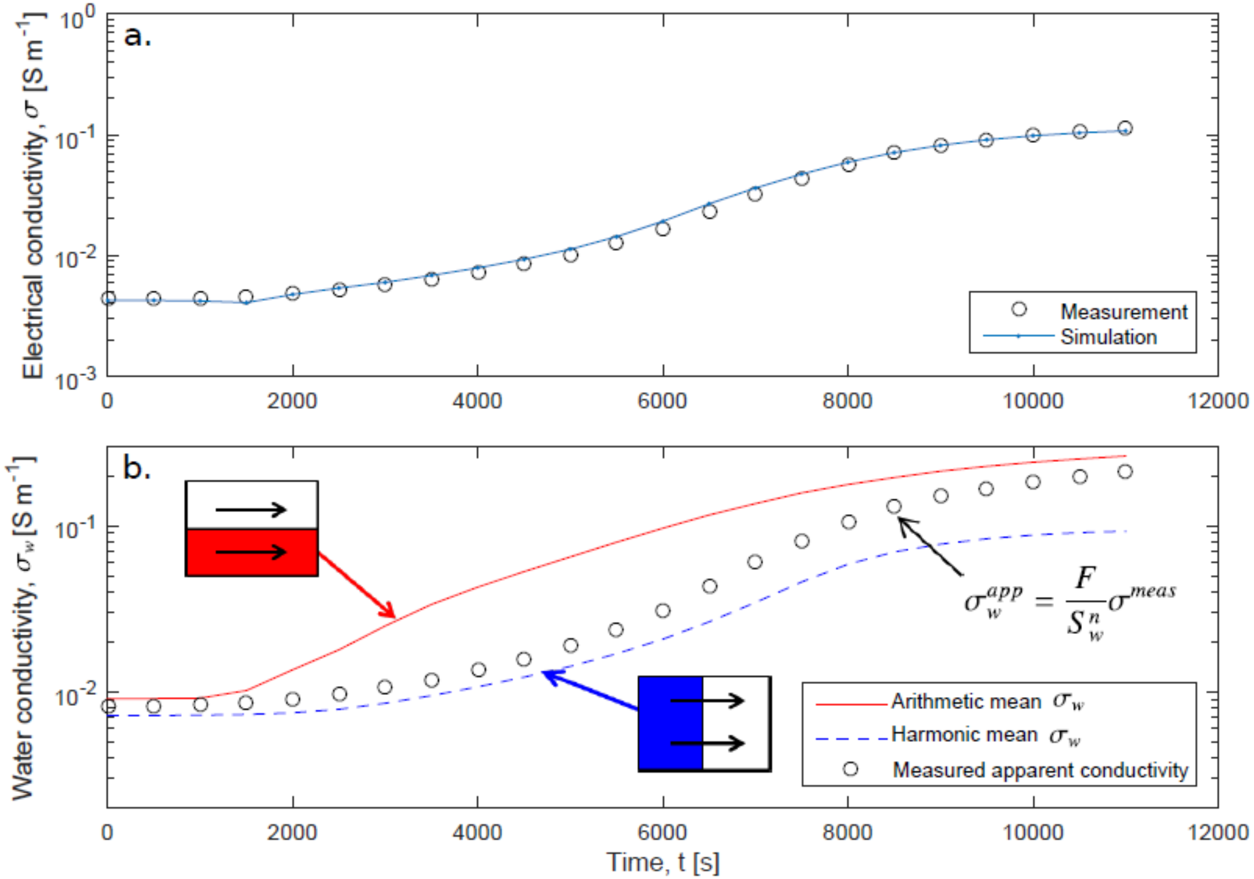
Petrophysics: the power to quantify…or not



Jougnot et al., 2018

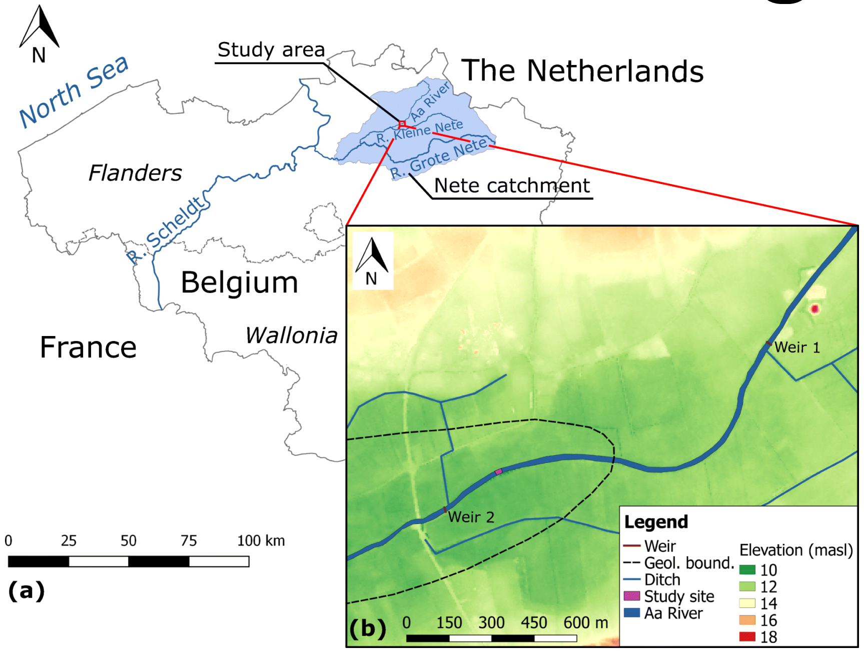
Petrophysics: testing hypothesis

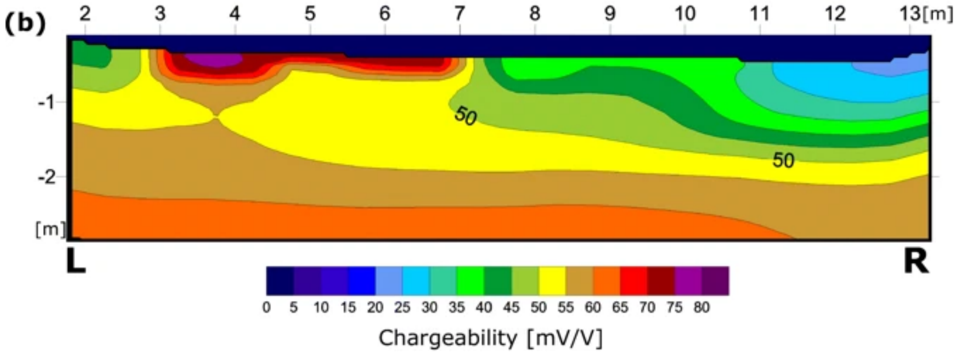


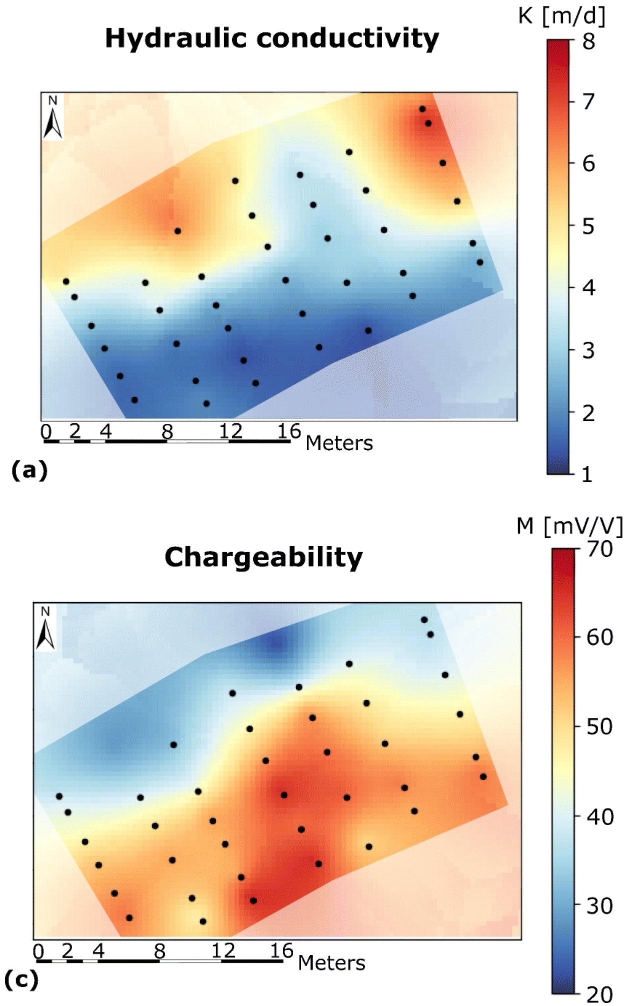


Jougnot et al., 2018

And understanding field limitations

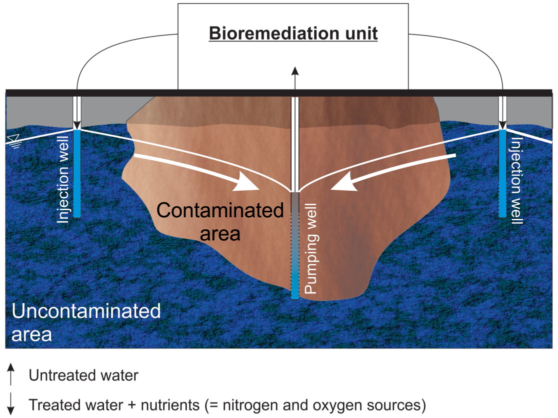






Benoit et al., 2019

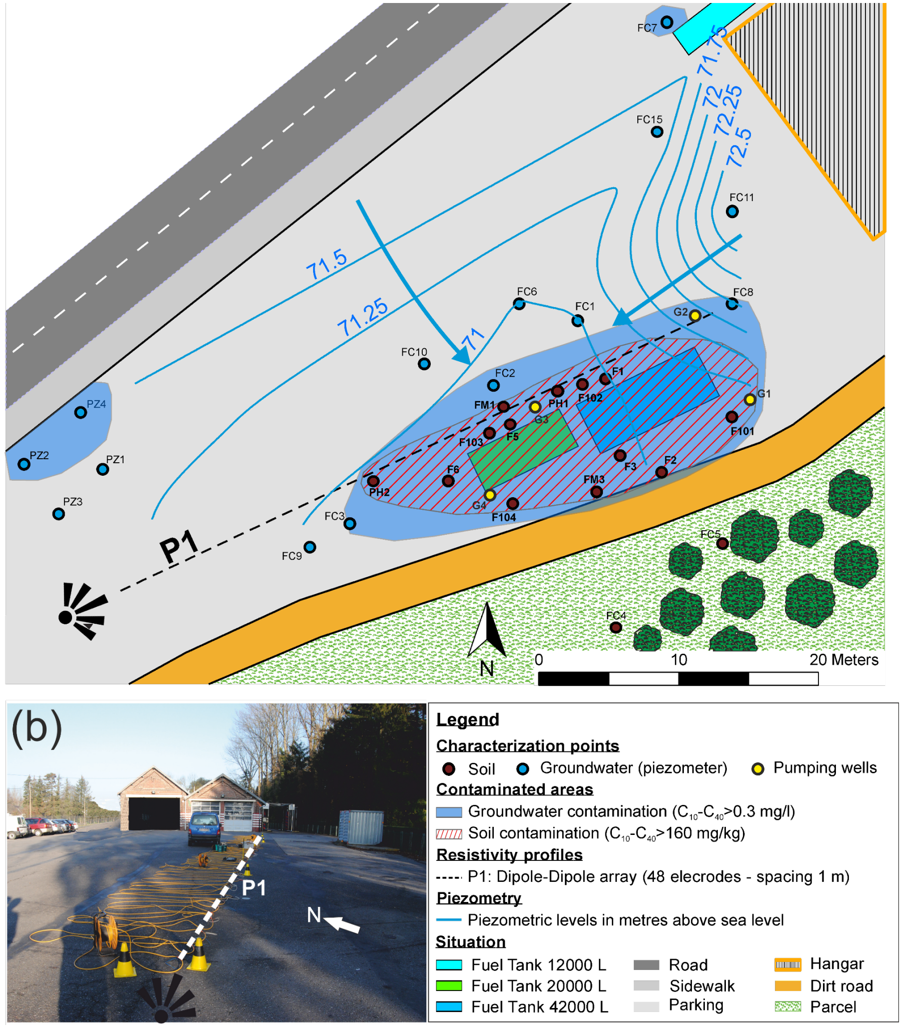
Biogeosystems: the next frontier…

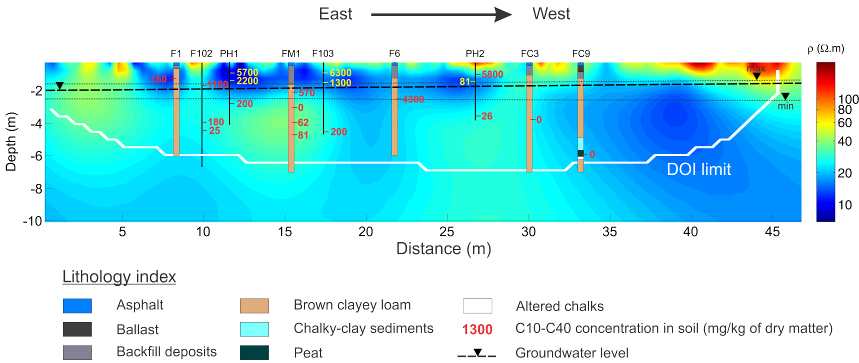


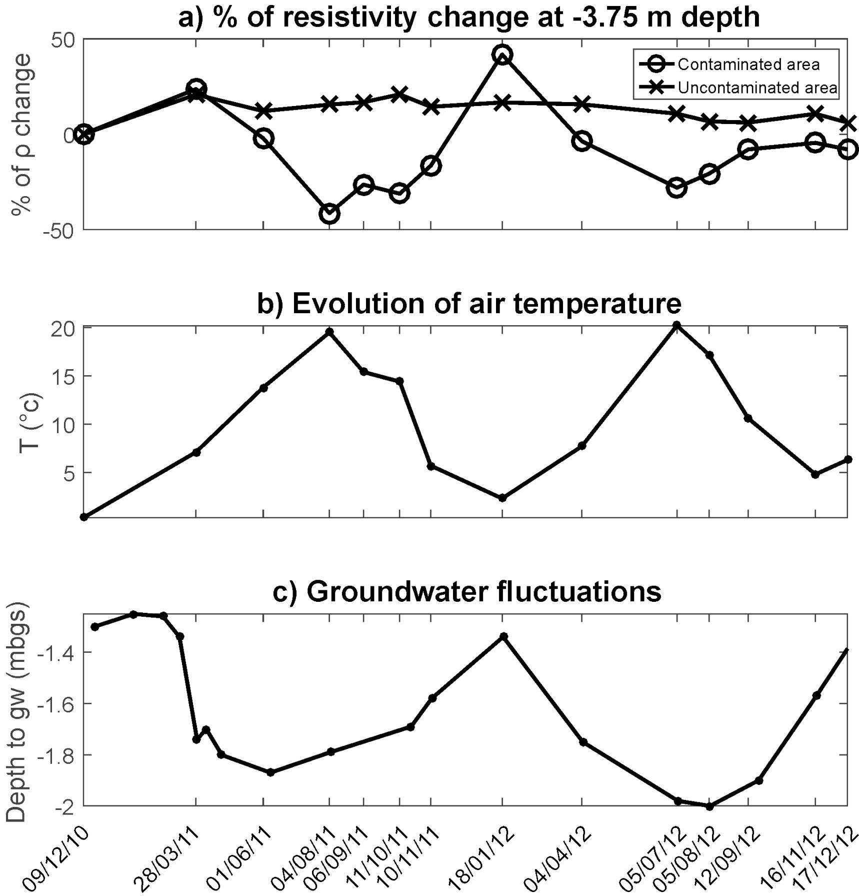
Pumping of contaminated water

Biological treatment in the bioremediation unit

Reinjection of the treated water amended with nutrients (nitrogen source) and electron acceptors (O_2) in the periphery



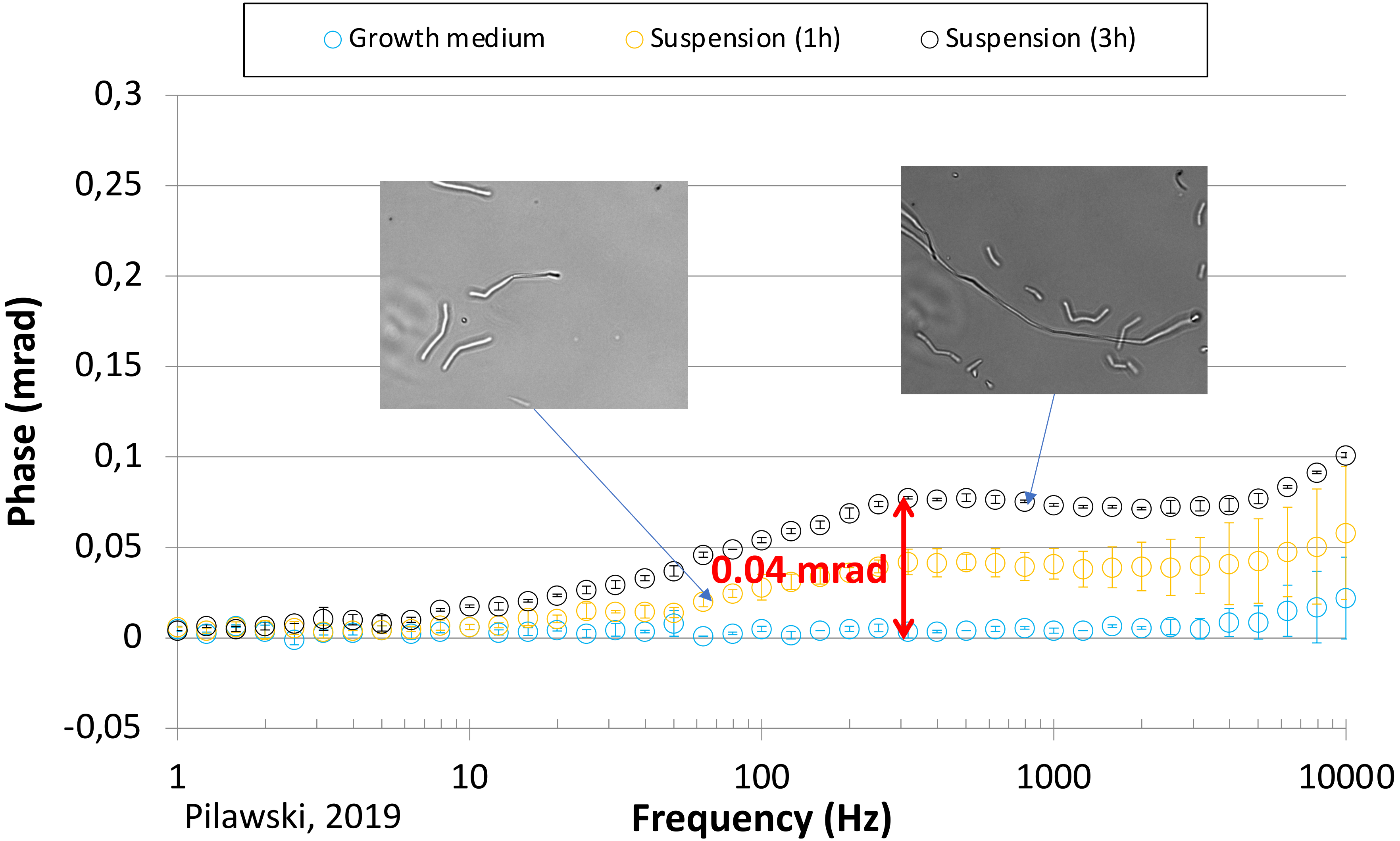




Caterina et al., 2017

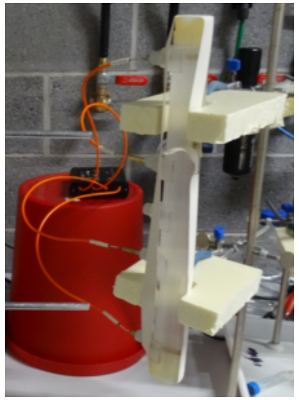
Started in mid-2008, ended in mid 2011

…but requires fundamental studies

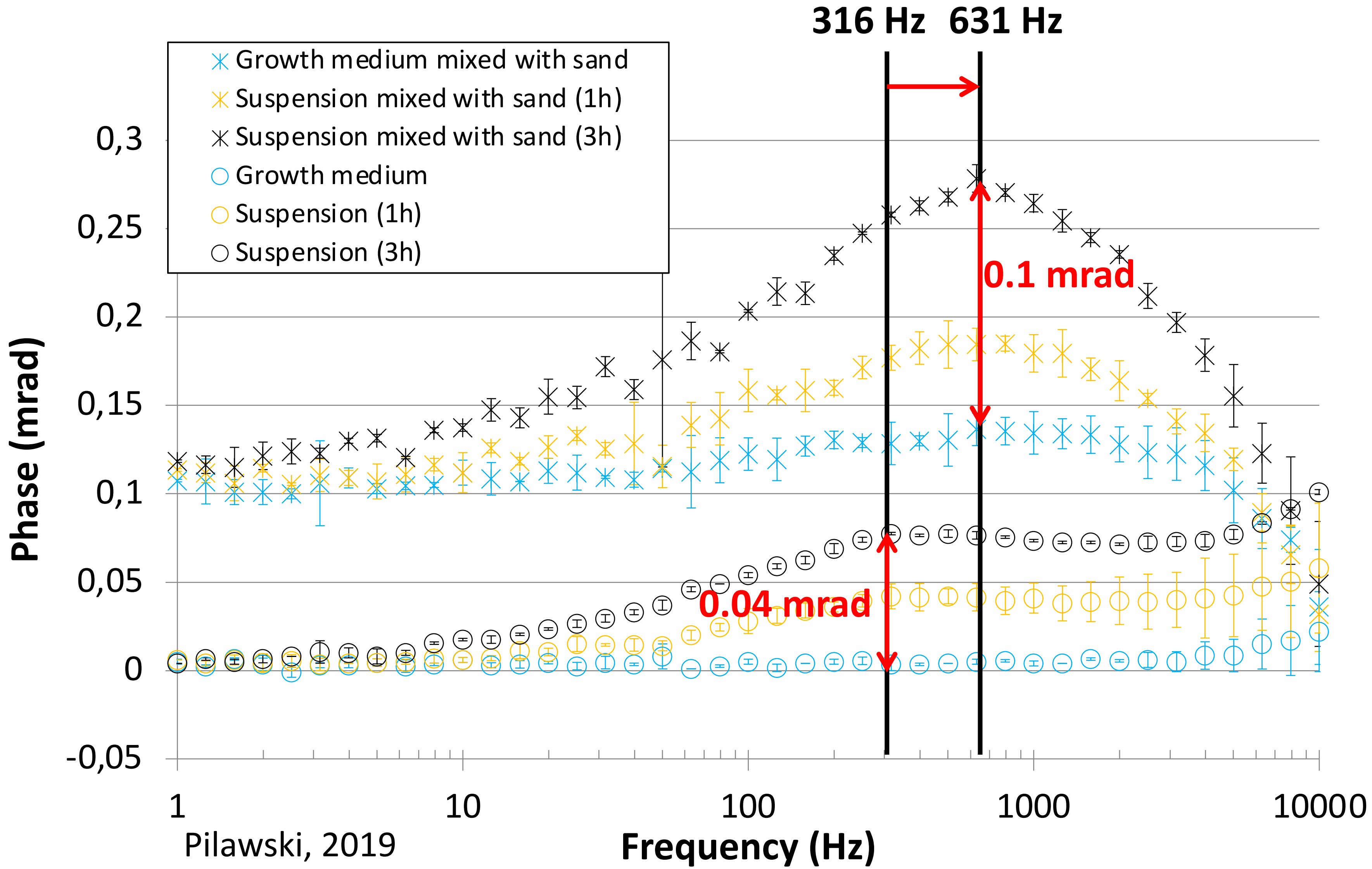


Pilawski, 2019

Bacillus subtilis RL5260



Tackling biogeosystems...

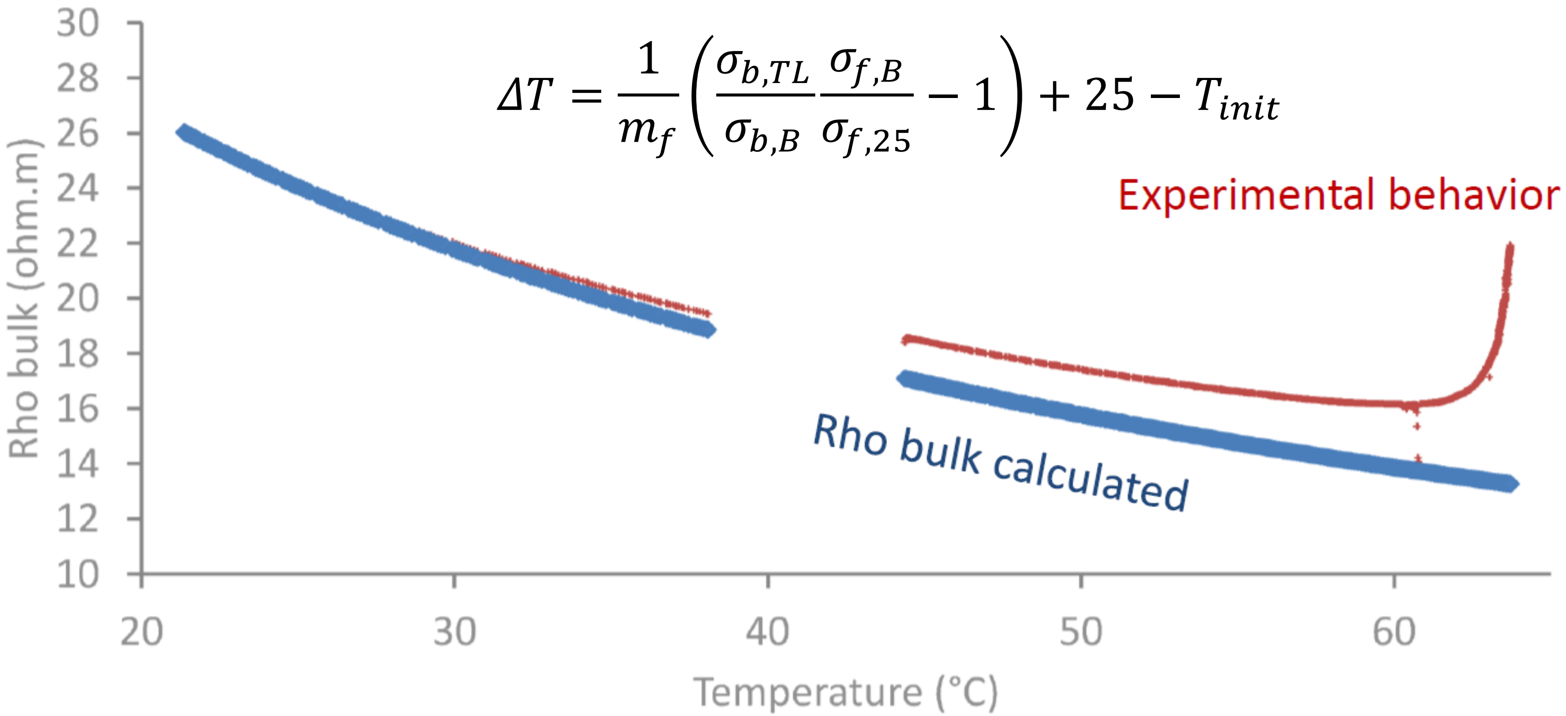


Pilawski, 2019

Process oriented imaging

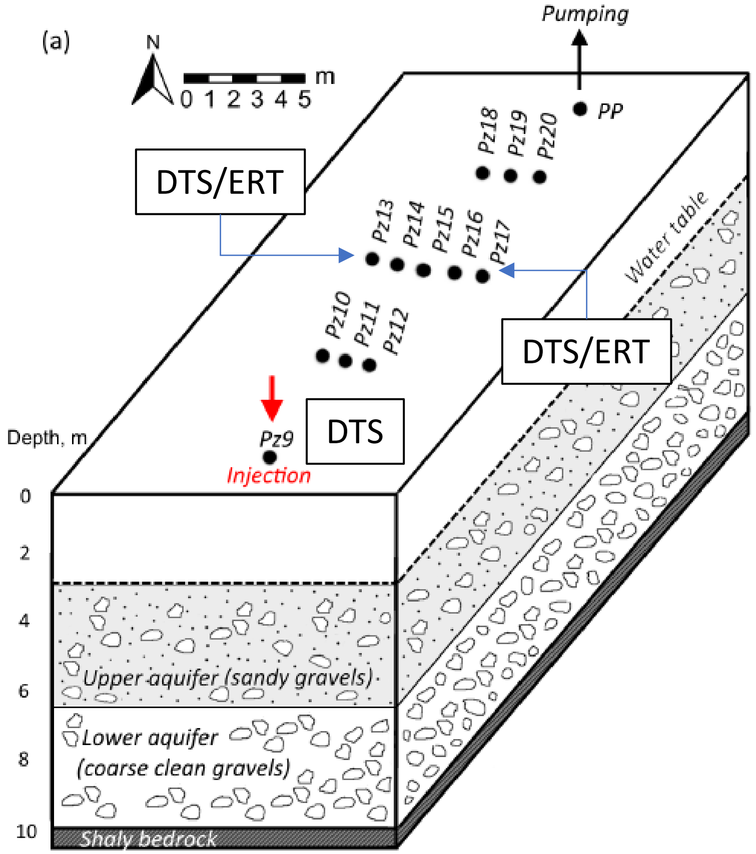
Water conductivity increases with temperature…**2% changes per °C**

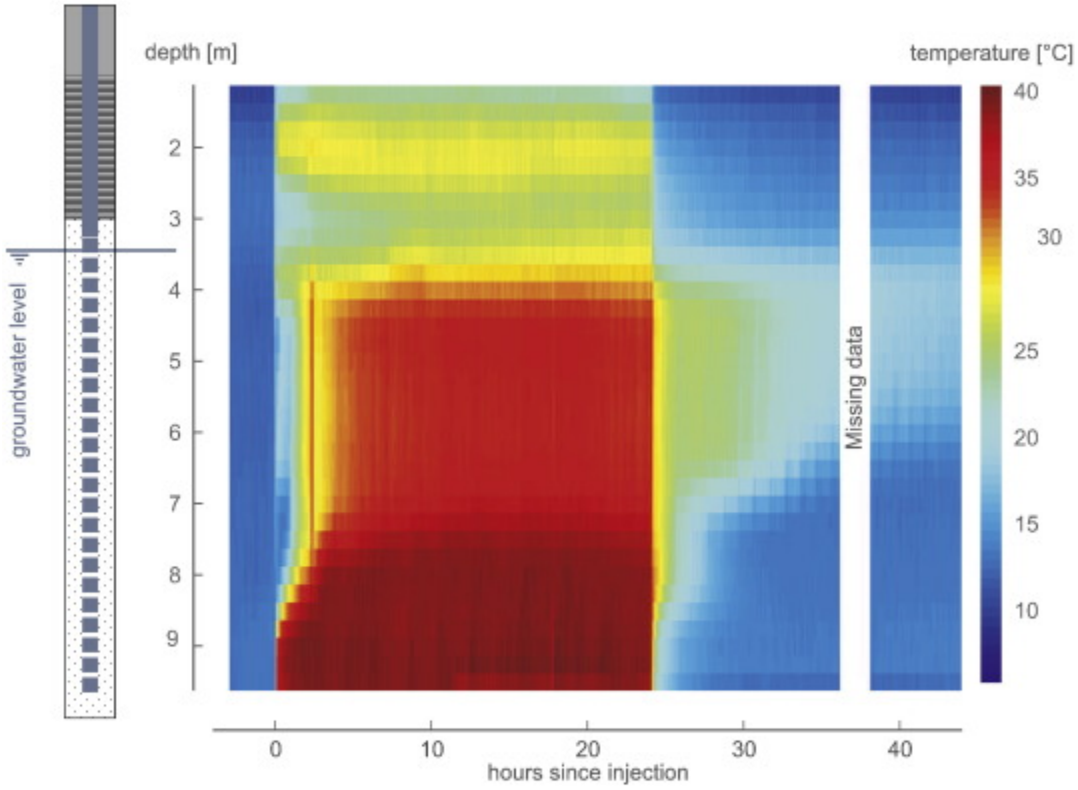
$$\Delta T = \frac{1}{m_f}\left(\frac{\sigma_{b,TL}}{\sigma_{b,B}}\frac{\sigma_{f,B}}{\sigma_{f,25}} - 1\right) + 25 - T_{init}$$



Robert et al., GELMON

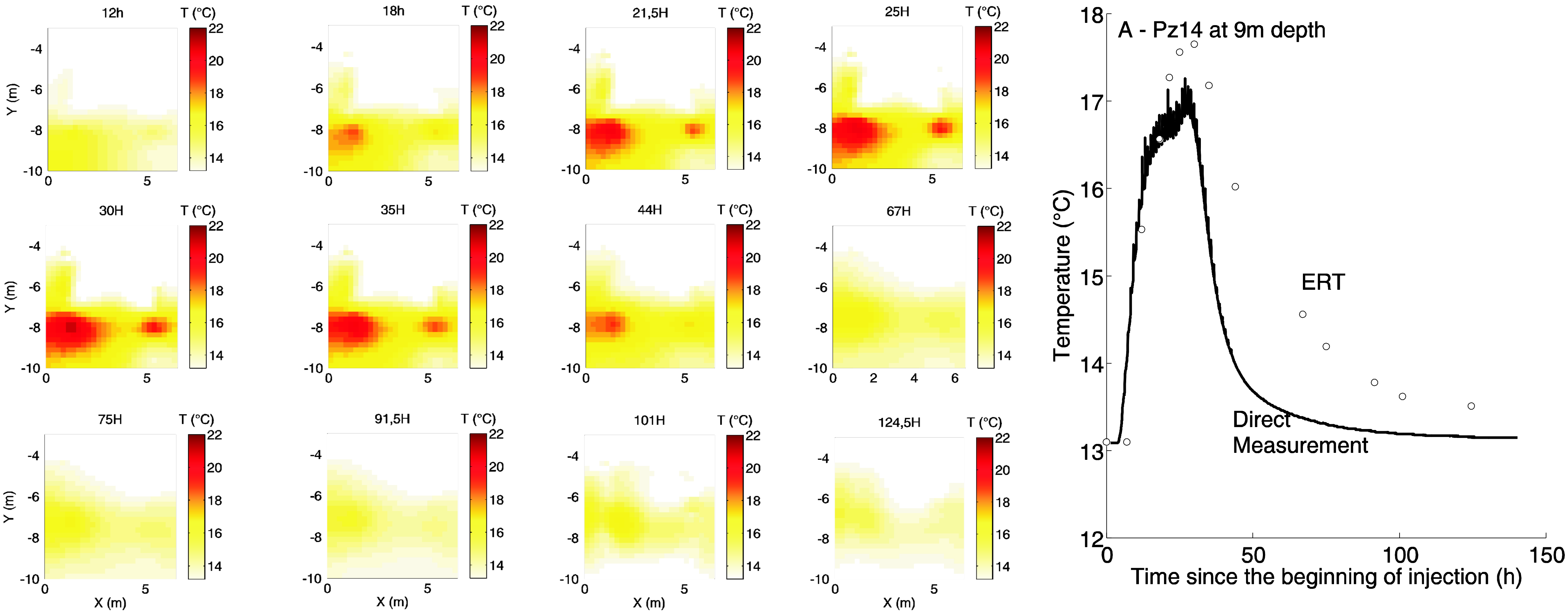
Process oriented





Wildermeersch et al., 2014

Process oriented imaging

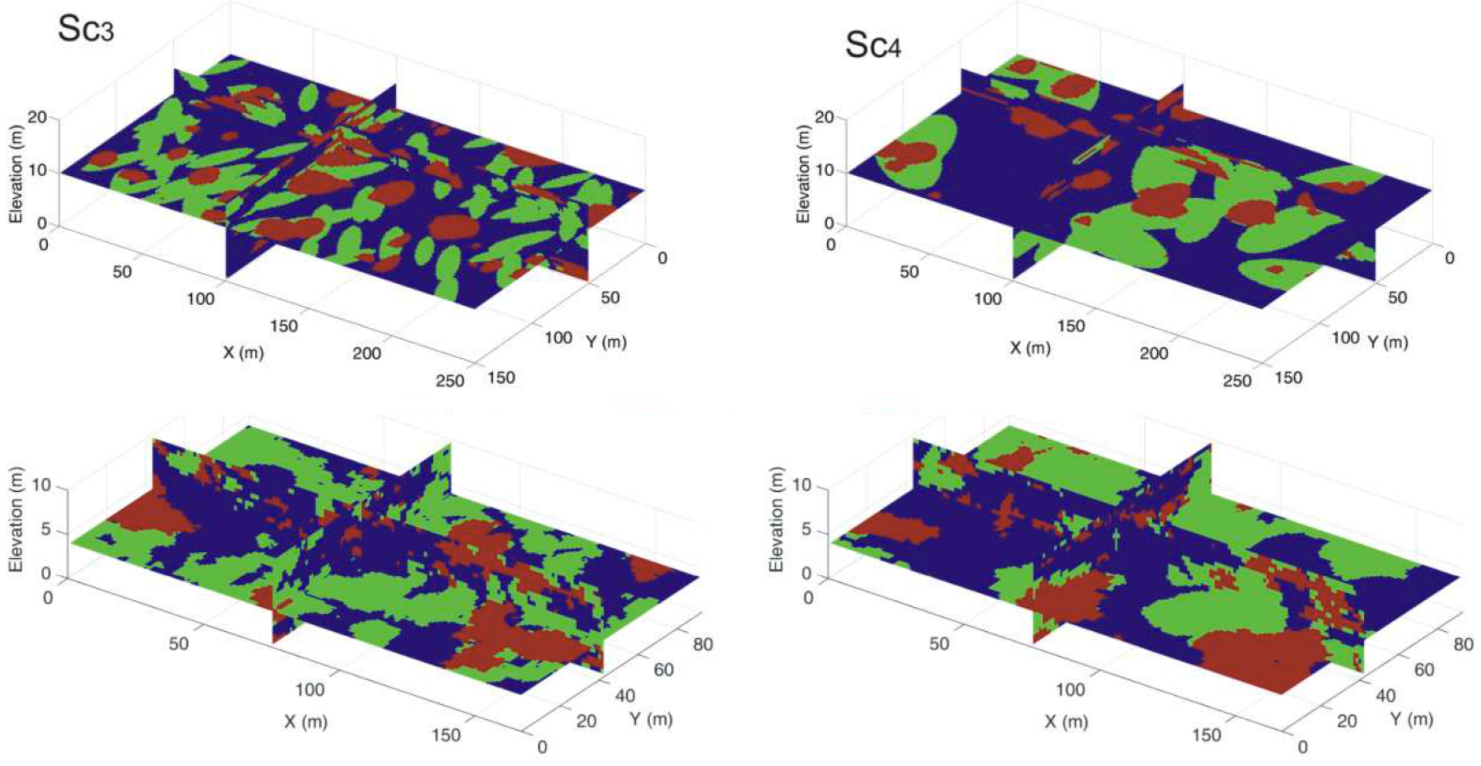


Hermans et al., 2015

Data integration

Earth Sciences modeling = dealing with uncertainty

We can rely on stochastic modeling based on a prior distribution of geological model parameters to generate realistic subsurface models.



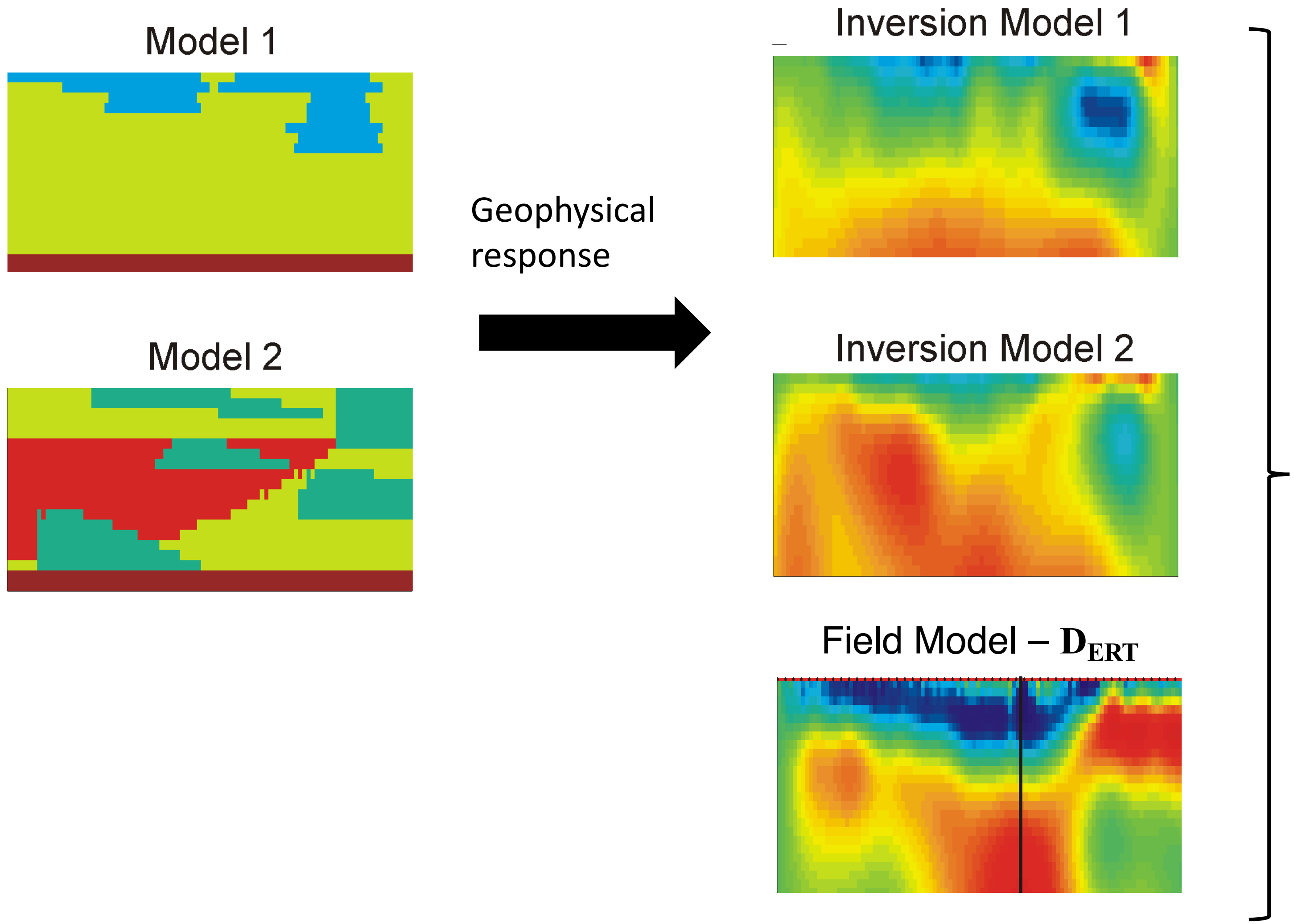
Prior

Models

Hermans et al., 2015, WRR

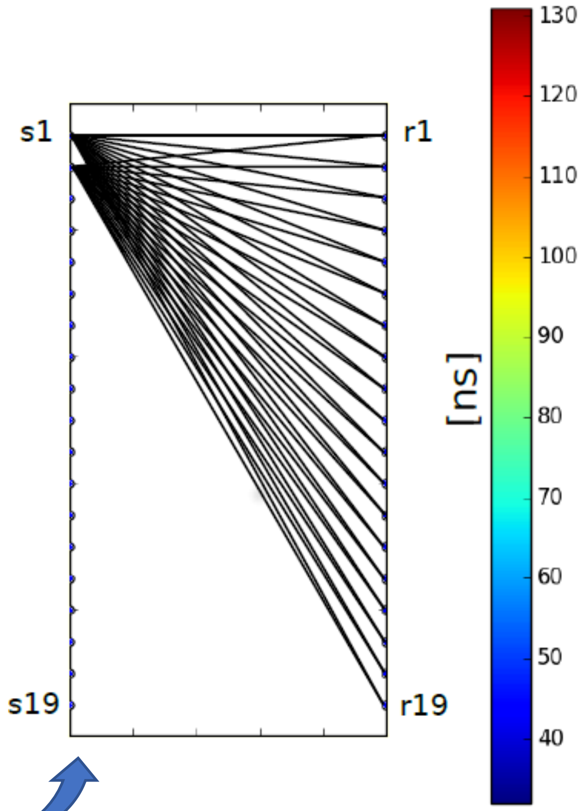
Sand Gravel Clay

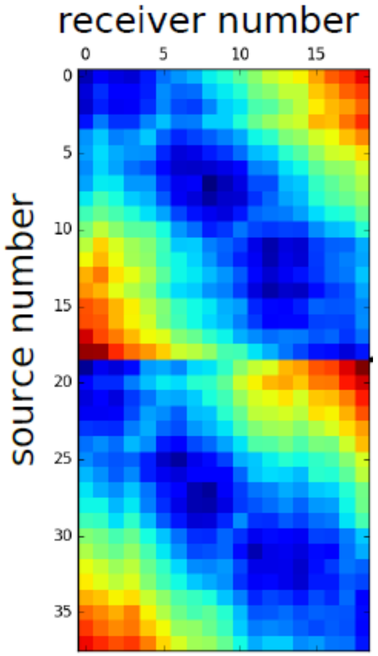
Geophysics provide dense information but indirect and uncertain information

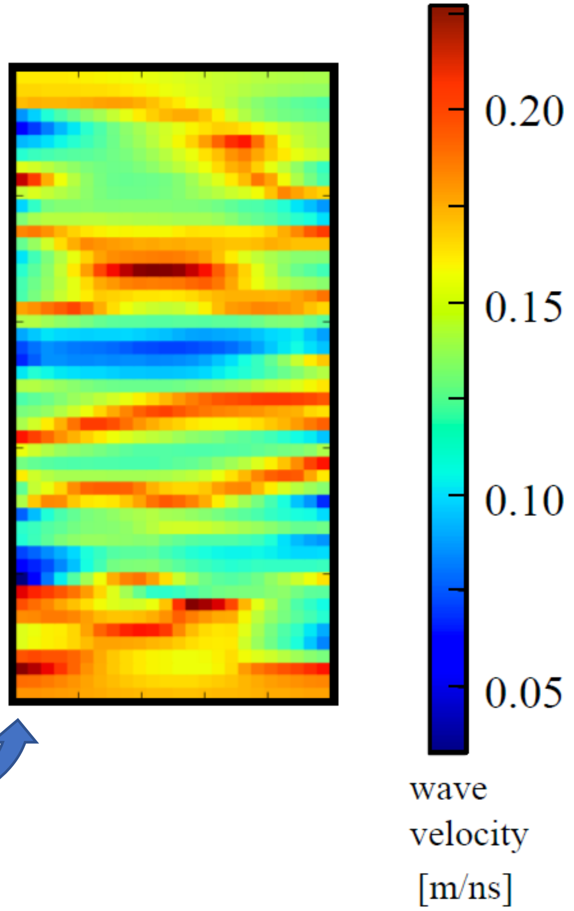


Global comparison of all the models
Not necessary to match any data

Inversion introduce a strong bias (smoothing), so what could we do ?







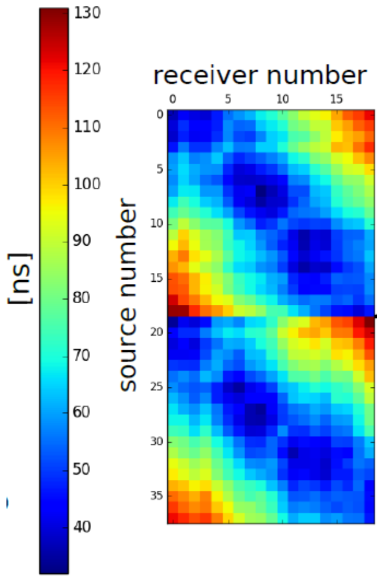
Lopez et al., 2019

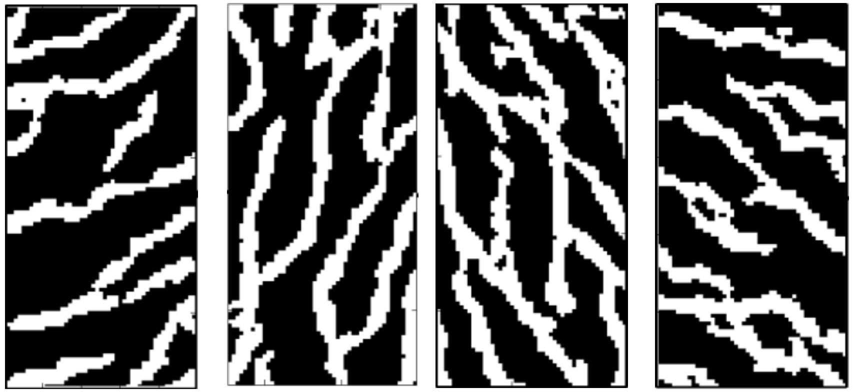
Collected data

PyGIMLi's Refraction module (Rucker et al., 2017).

Inversion

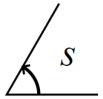
Instead, we could define features of geophysical data f(d) that inform on the prior



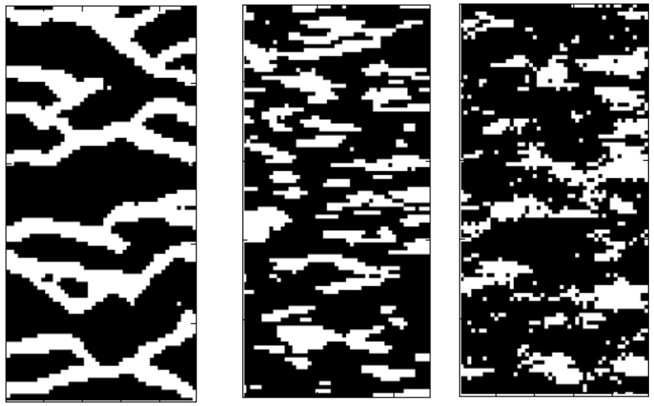


200 samples from s ∈ (0; π)

Channel orientation



$$p(s|\mathbf{d}) \approx p(s|f(\mathbf{d}))$$



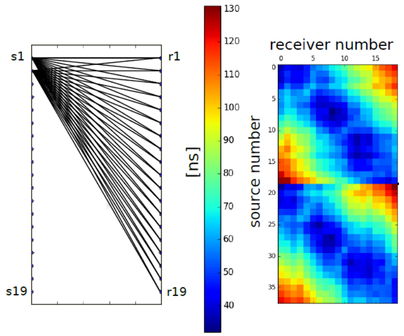
50 samples 50 samples 50 samples

3 scenarios

Approach to test the features

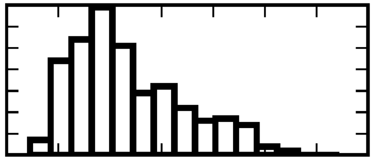
- Uniform sampling of a structural prior, e.g. orientation s = 0.5 π

- Realization of a facies distribution, e.g.

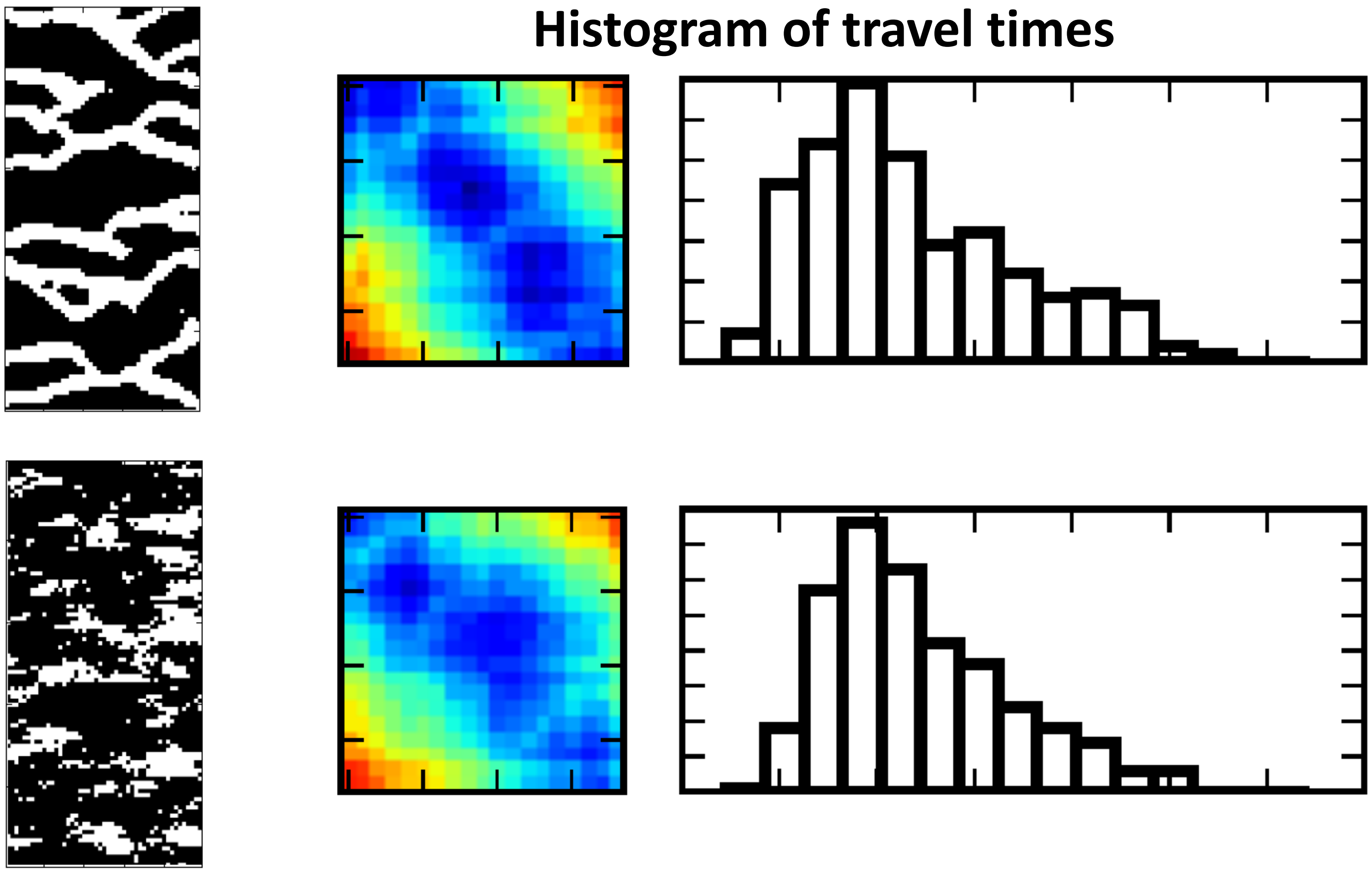


- From facies to geophysical data

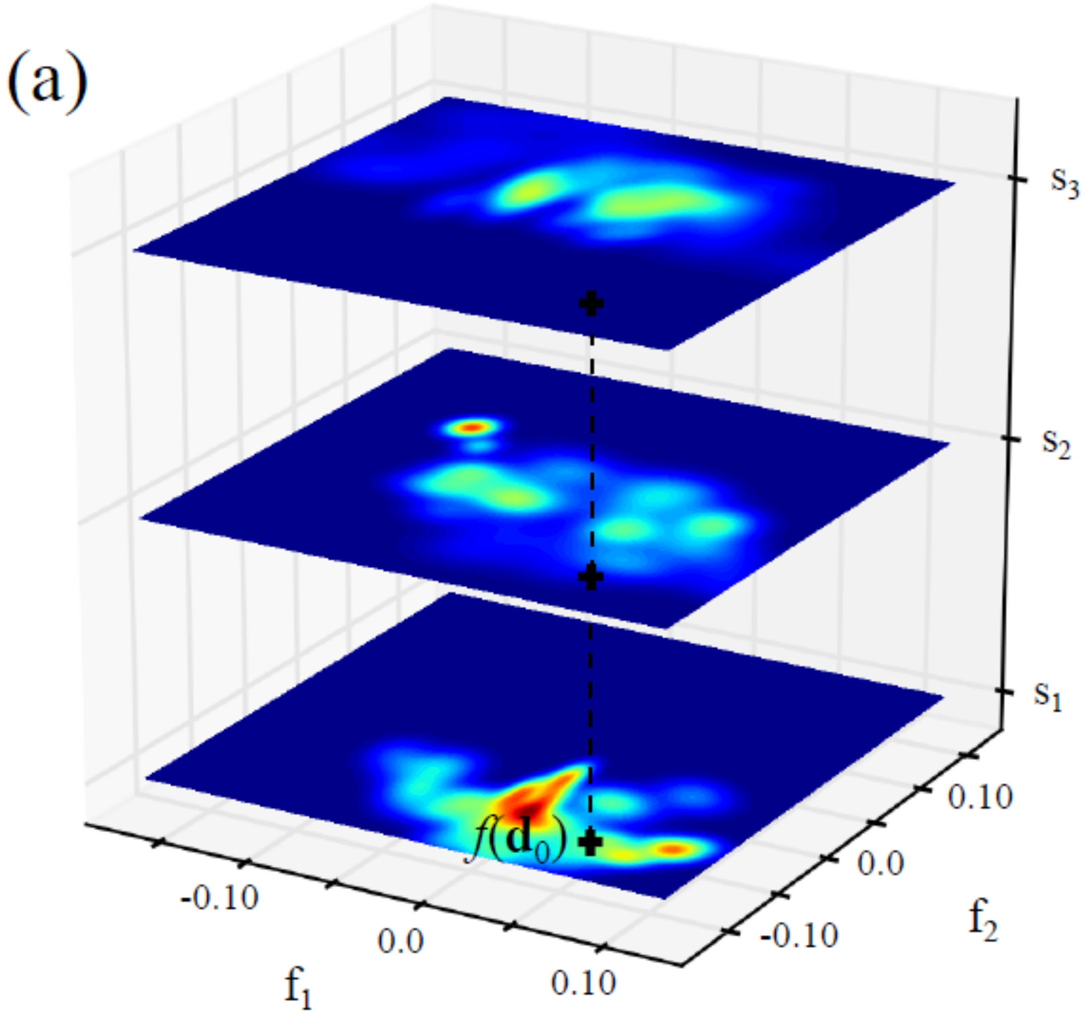
- Design features of geophysical data

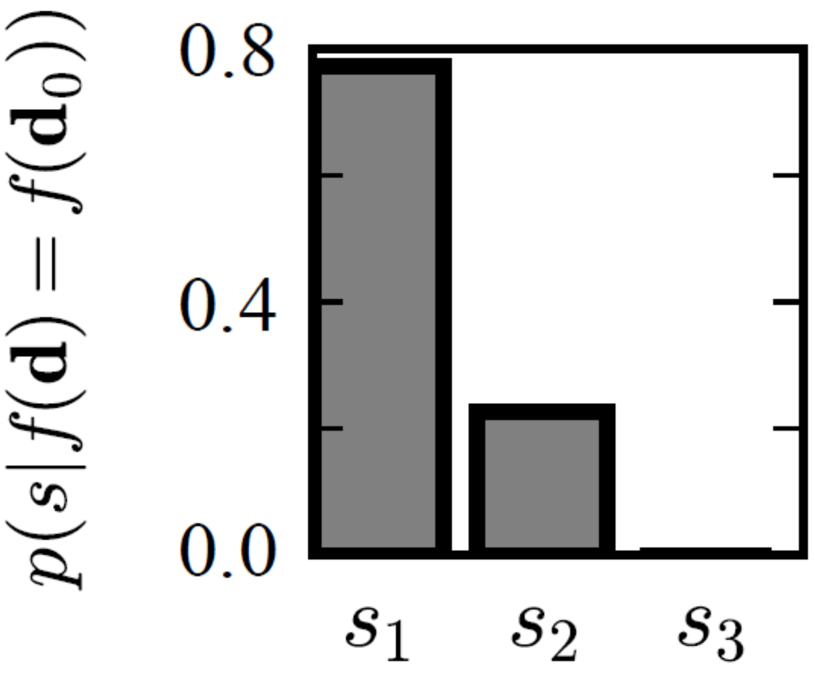


Exploring the prior falsification potential of:



Joint probability distribution for discrete s with + = s1 along with posterior





Testing the features of MDS on the histogram of travel times

Data integration: geophysics as a fully integrated dataset

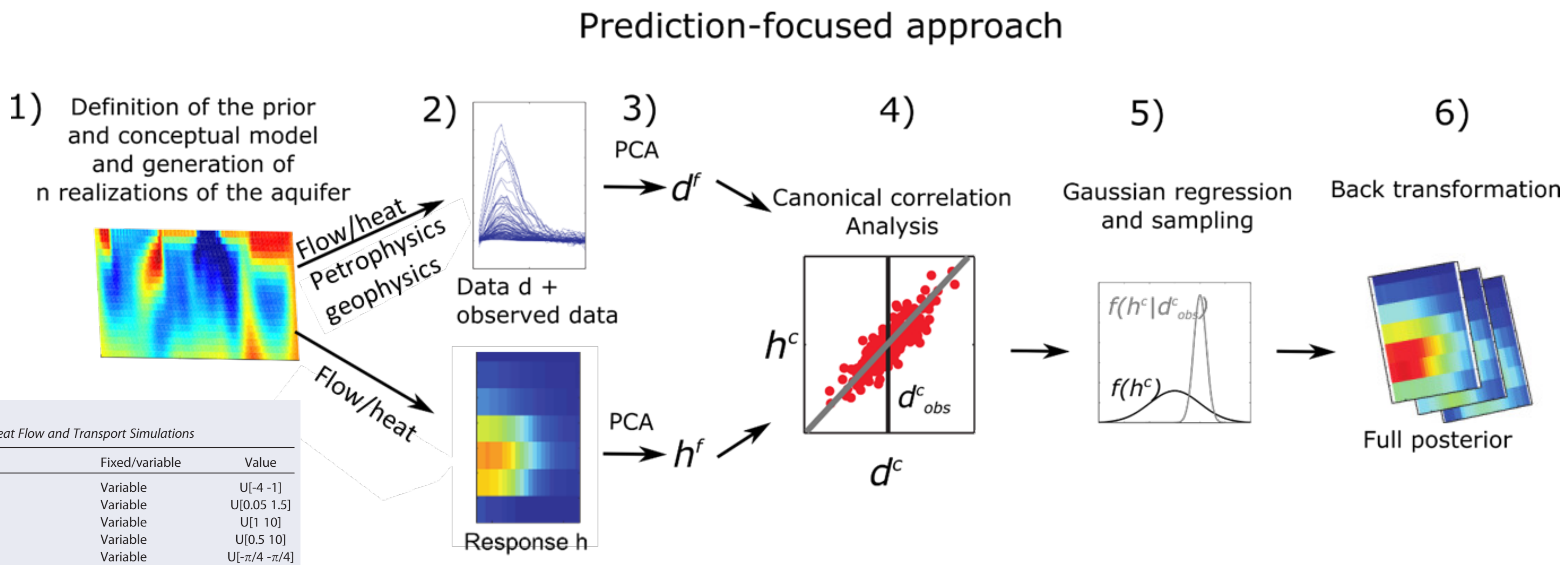
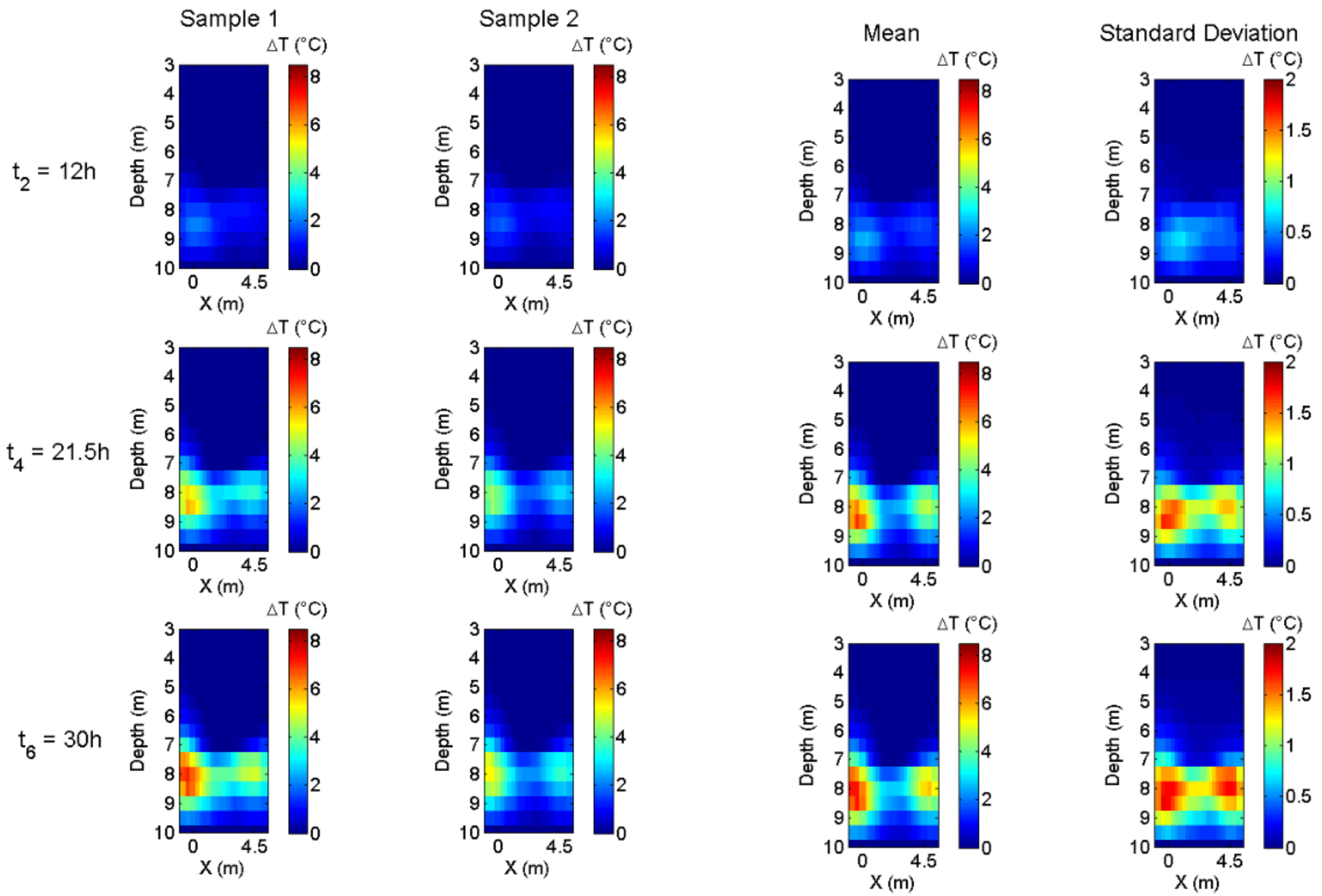


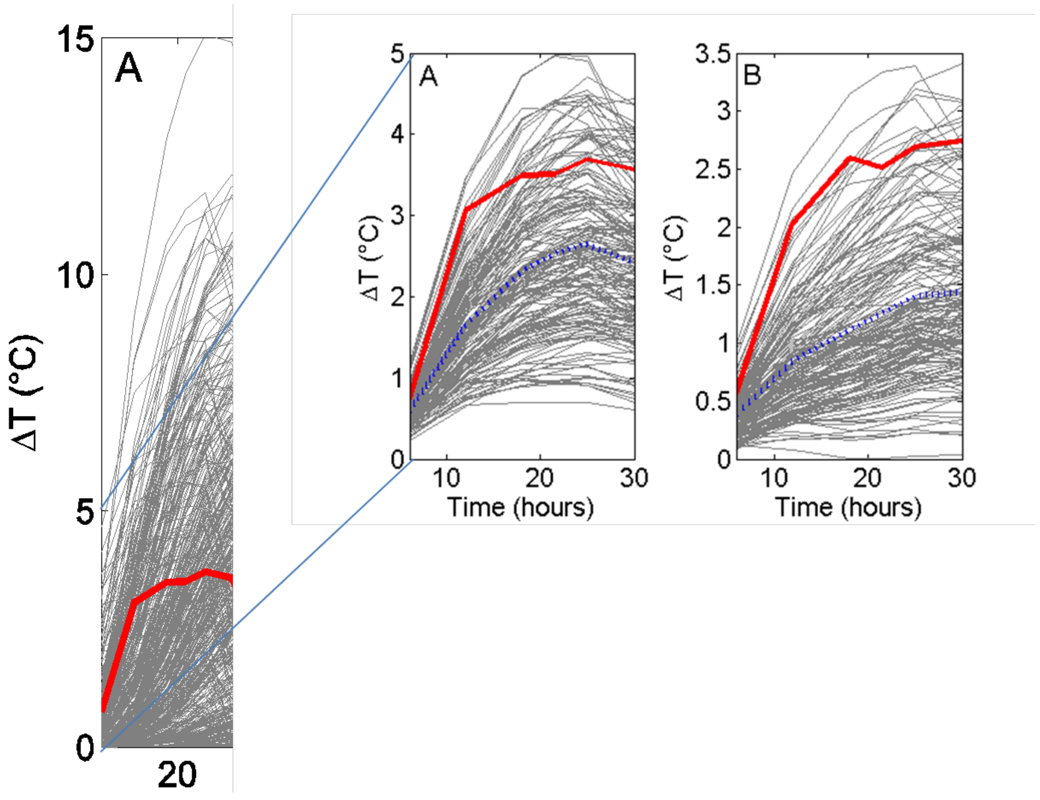
Table 1
Parameters Used for the Heat Flow and Transport Simulations

Parameters	Fixed/variable	Value
Mean of $\log_{10}$ K (m/s)	Variable	U[-4 -1]
Variance $\log_{10}$ K (m/s)	Variable	U[0.05 1.5]
Range (m)	Variable	U[1 10]
Anisotropy ratio	Variable	U[0.5 10]
Orientation	Variable	U[$-\pi/4$ $-\pi/4$]
Porosity	Variable	U[0.05 0.40]
Gradient (%)	Variable	U[0 0.167]
$\log_{10}$ *K* (m/s) – upper layer	Fixed	10^{-5}
Longitudinal dispersivity (m)	Fixed	1
Transverse dispersivity (m)	Fixed	0.1
Solid thermal conductivity (W/mK)	Fixed	3
Water thermal conductivity (W/mK)	Fixed	0.59
Solid specific heat capacity (J/kgK)	Fixed	1,000
Water specific heat capacity (J/kgK)	Fixed	4,189

Hermans et al., 2018

Data integration





Hermans et al., 2018

Conclusions and outlook

- Quantitative geophysics in the sense that we will be able to quantify for example a water content is a sweet dream far far away…

- However, qualitative information which is spatiotemporally distributed is probably more important for the studied processes to reduce the inherent subsurface uncertainty…

- In that sense, data density/quality improv’t, understanding fundamental “petro”physics, improved physical modeling, imaging and data integration methods lead the way forward.