Improving BEL1D accuracy for geophysical imaging of the subsurface

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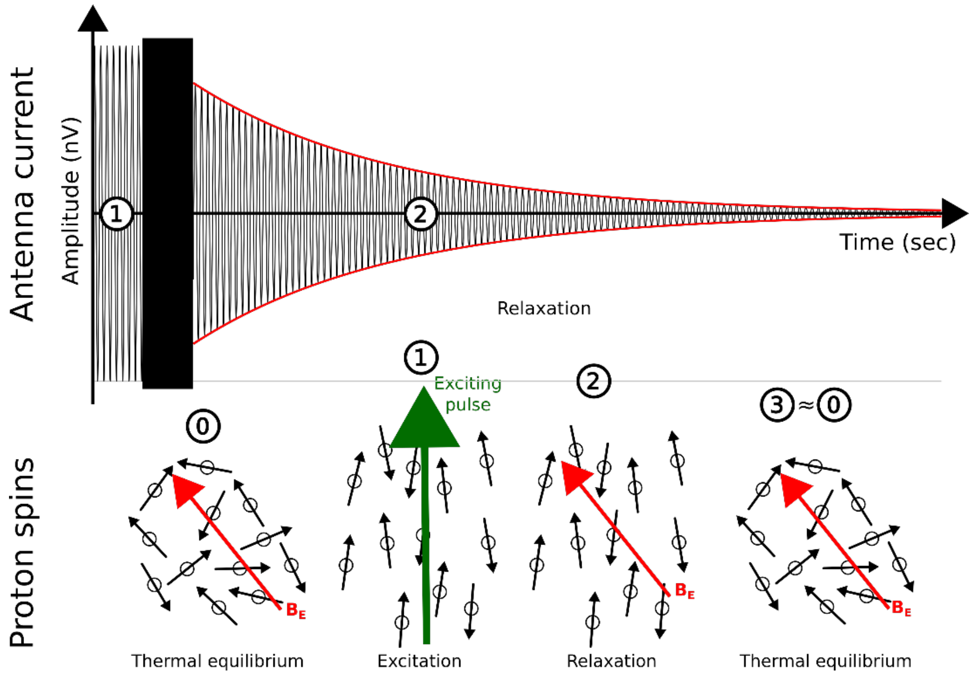
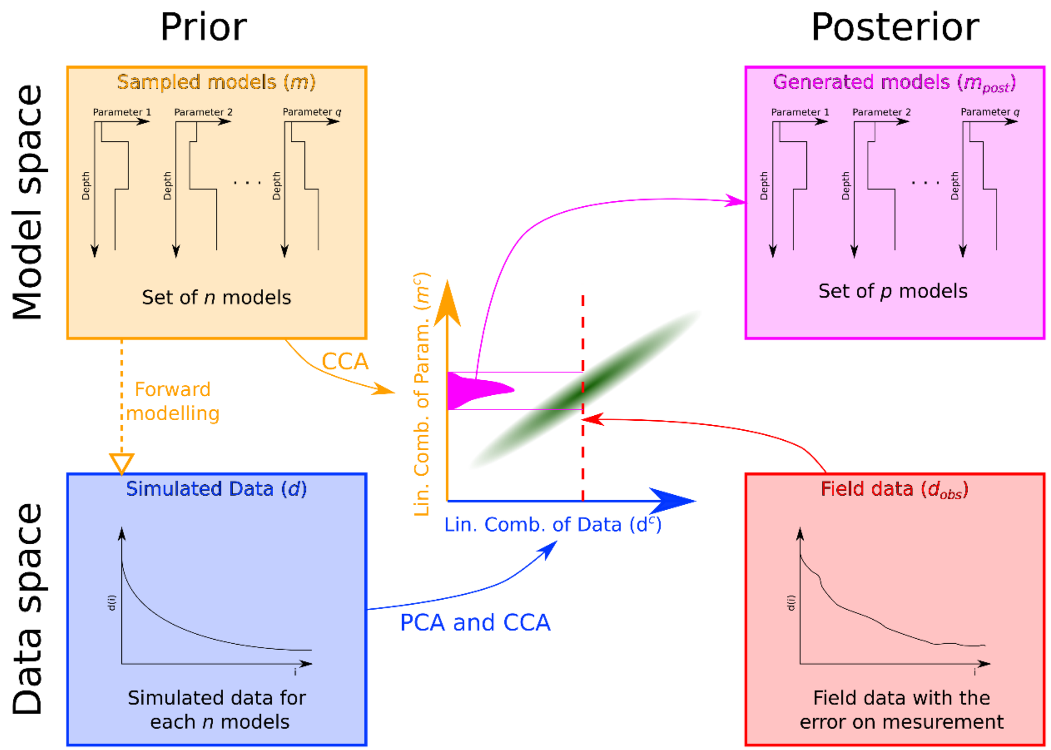
sNMR



- sNMR = surface Nuclear Magnetic Resonance
- Detecting groundwater from the surface
- After inversion:
  - Water content distribution
  - Relaxation time distribution

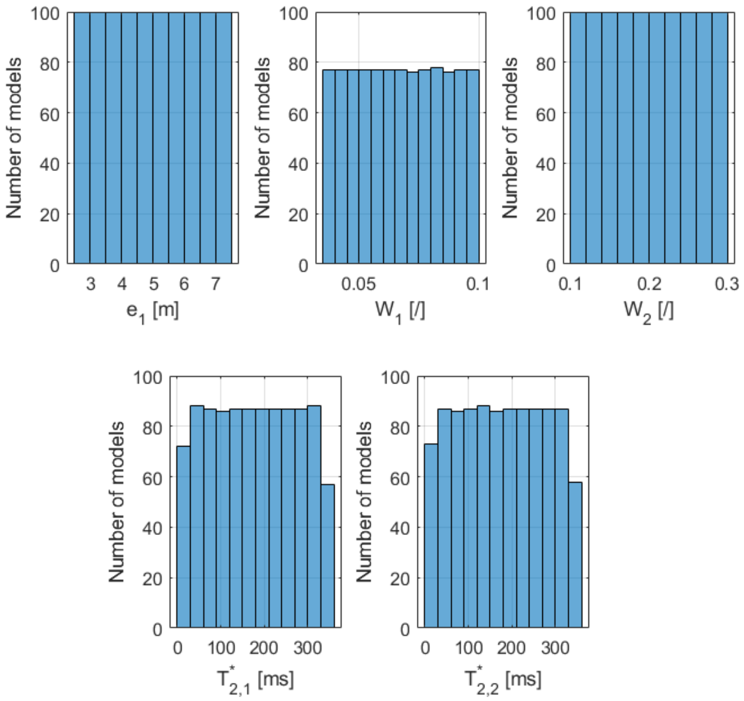
BEL1D

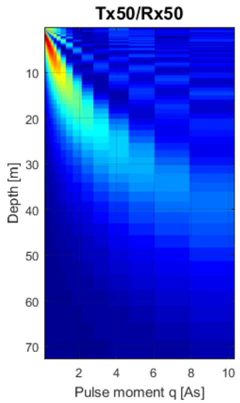


- Adaptation from BEL (Schiedt et al., Quantifying Uncertainty in Subsurface Systems, 2018)
- Building a relationship between:
  - Synthetic models
  - The associated datasets
- Extracting the posterior from this relationship

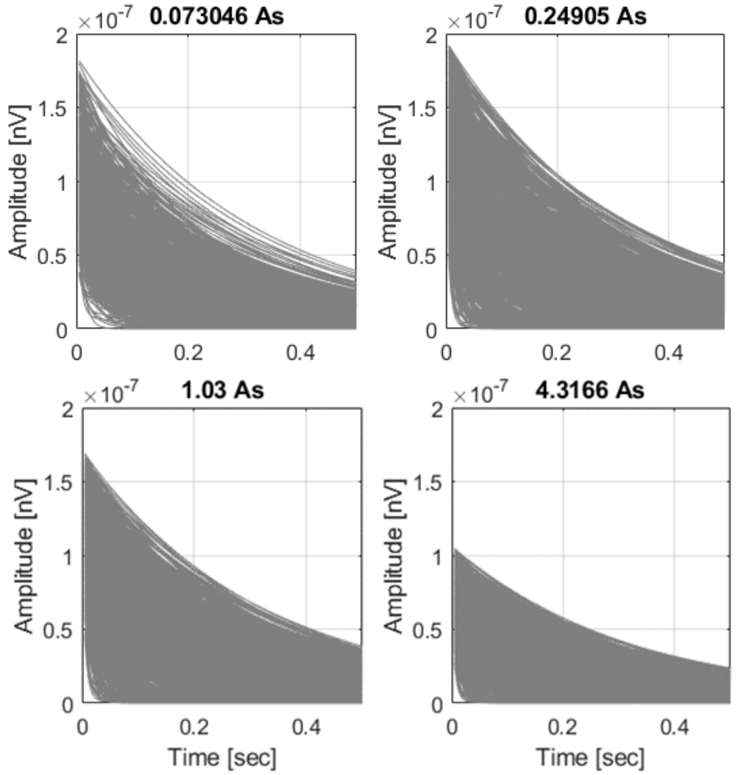
BEL1D

Sampling models and forward modelling





d = G(**m**)

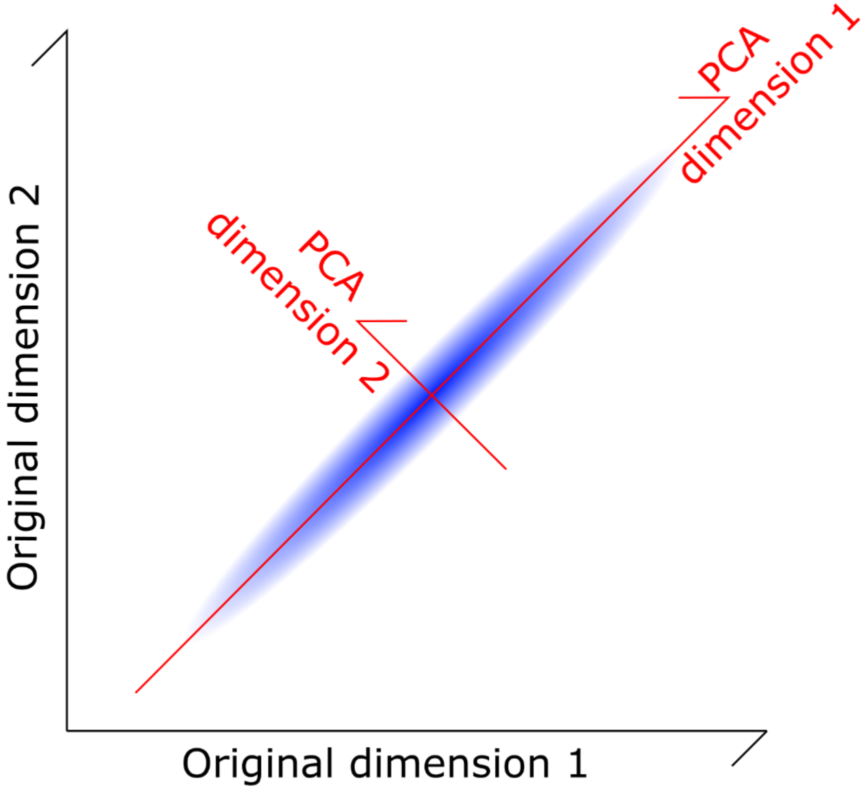


SEG20

BEL1D

Reducing dimensionality (PCA)

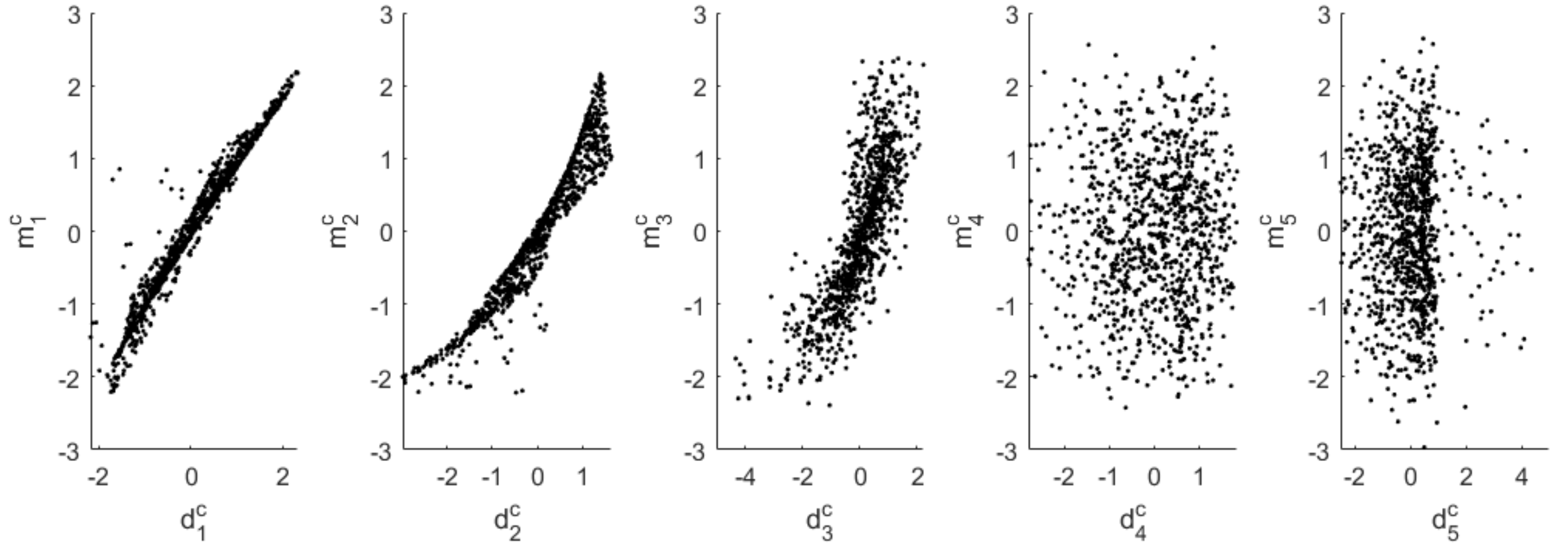
- From 10,000 dimensions in the dataset to around 10
  - Keeping 90% variability
- Not applied to the models
  - Uncorrelated prior
  - Poor performances



BEL1D

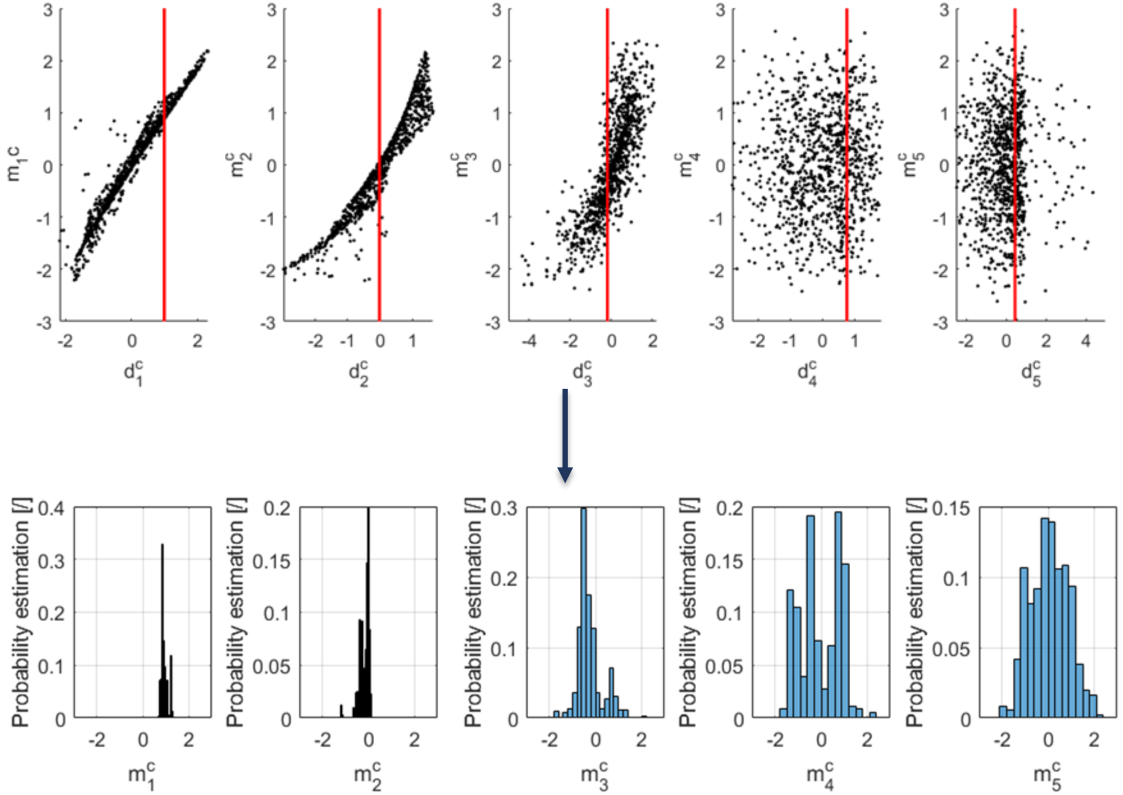
Canonical correlation analysis

- Linking the models parameters to the reduced datasets → CCA



BEL1D

Extracting the posterior in reduced space



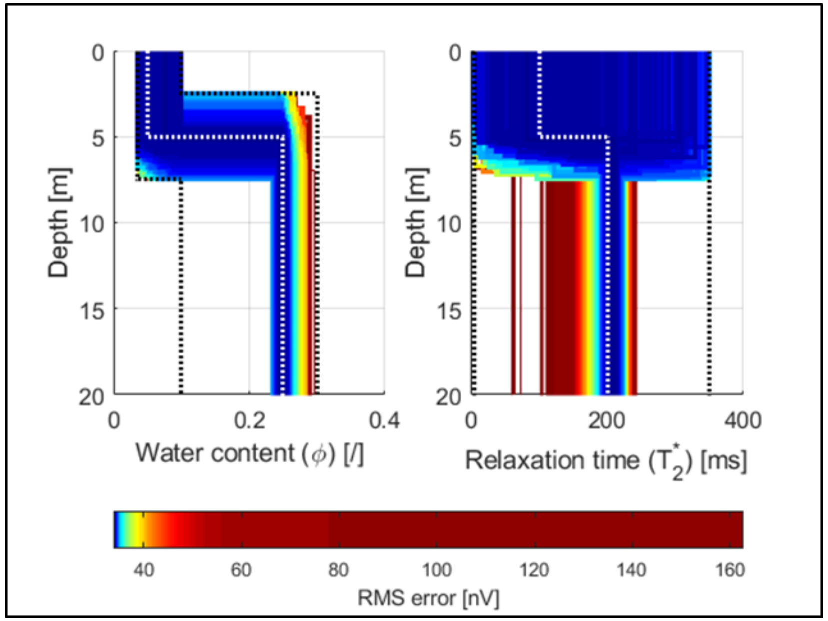
- Transform the field dataset (PCA and CCA)
- Report in the CCA space
- Extract the obtained distribution (Kernel Density Estimation)

SEG20

BEL1D

Back-transform into original space

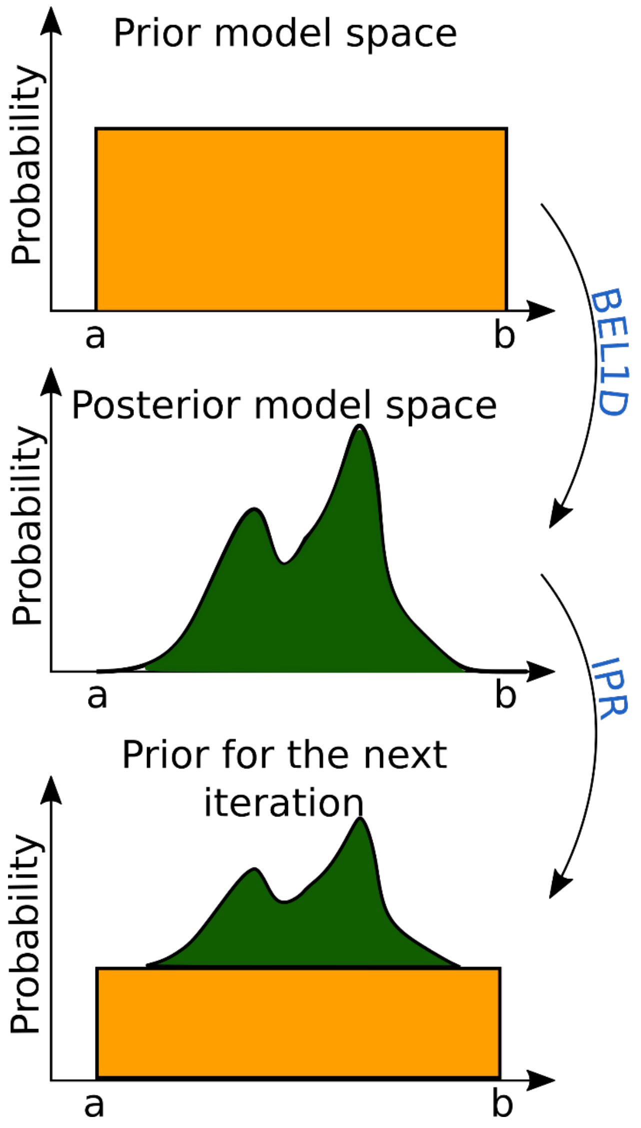
- Apply the inverse transform (CCA) to sampled models in reduced space



BEL1D

Improving with IPR, the concept

- IPR = Iterative Prior Resampling
- Inspired by Iterative Spatial Resampling (Mariethoz et al., 2010, Water Resour. Res.) and Sampling Importance Resampling (Dosne et al., 2016, J PHARMACOKINET PHAR)
- Process:
  - Adding the sampled models to the prior
  - Re-running the BEL1D operations
  - Repeat until convergence:
    - Threshold on the difference between the obtained distributions (Wasserstein distance in normalized space)



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Numerical benchmark

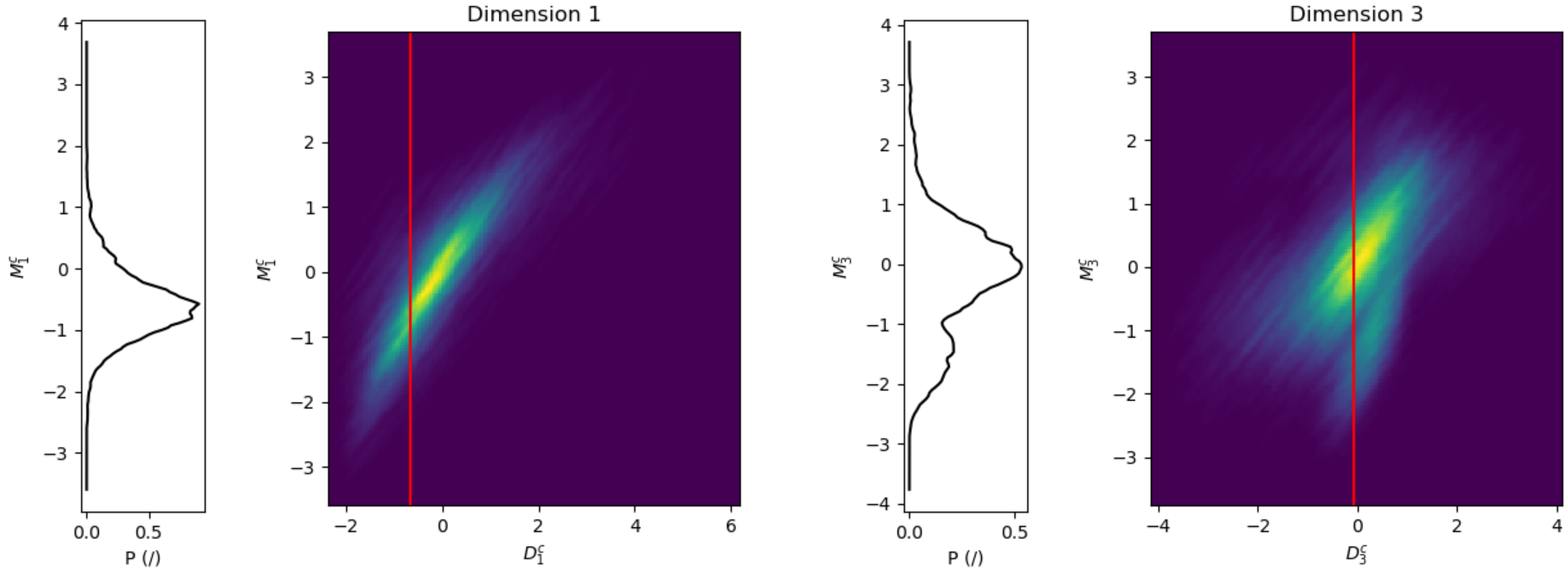
- Simple 3-layer model
- Experimental design:
  - Same transmitter/receiver loop
  - 50 m diameter → penetration depth about 50 meters
  - Noise = 10nV (Gaussian)
- Prior defined accordingly but still large

Layer #	Thickness e [m]			Water content W [%]			Decay time T_2^* [ms]		
	Min	True	Max	Min	True	Max	Min	True	Max
1	0	25	50	0	5	15	0	100	500
2	0	25	50	15	25	50	0	200	500
Half-space	/	Inf	/	0	10	15	0	50	500

Numerical benchmark

Applying BEL1D

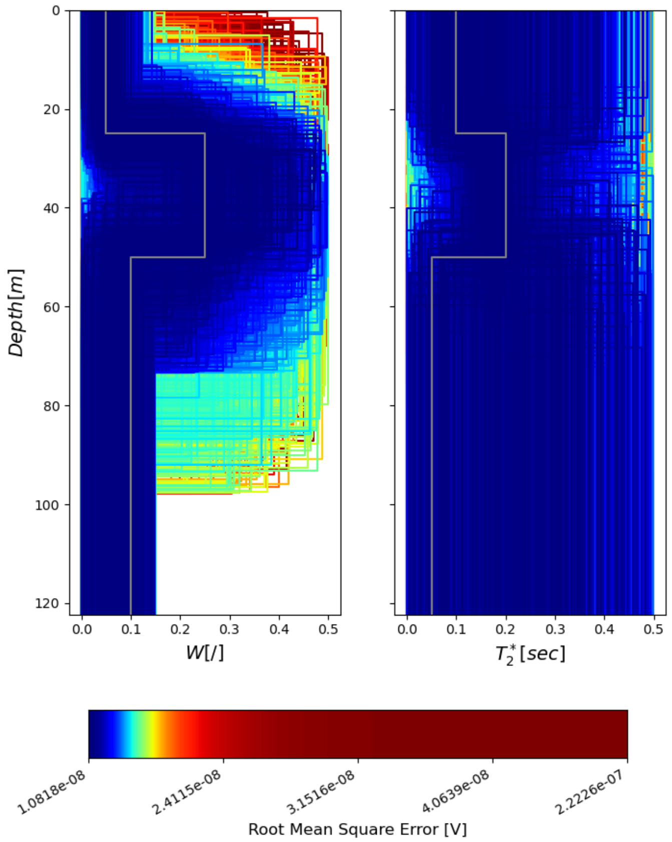
Building the CCA space relationship

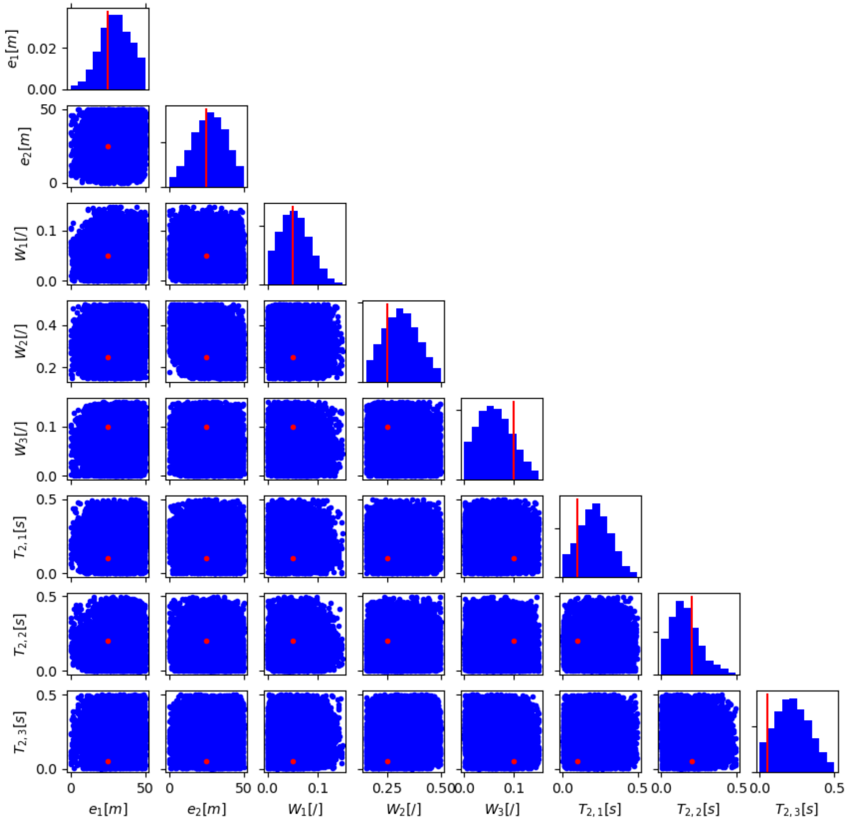


Numerical benchmark
Applying BEL1D

- Reduced uncertainty
- Still very large!
- RMSE above noise level

→Room for improvement

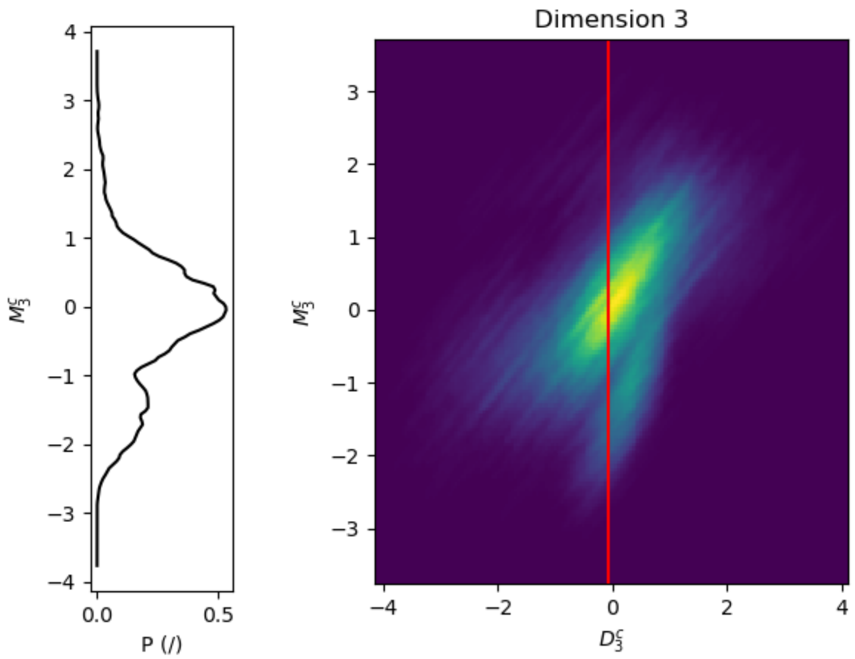




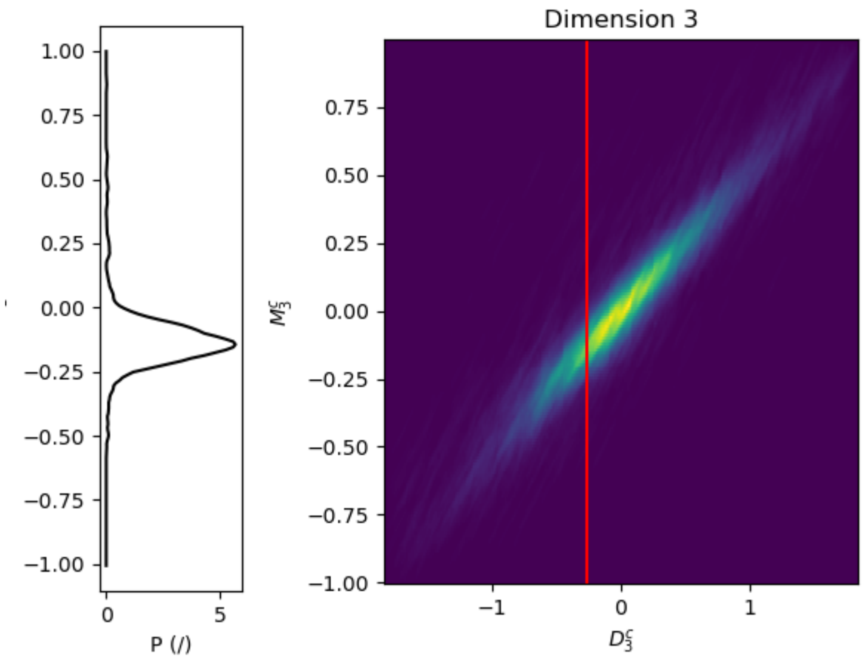
Numerical benchmark

Improving with IPR

1st iteration

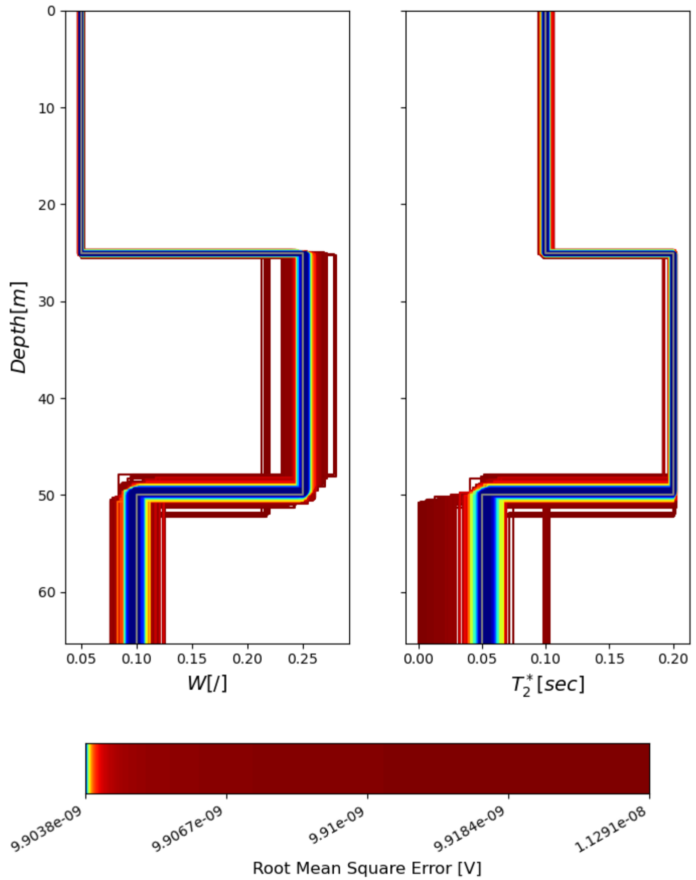


Last iteration

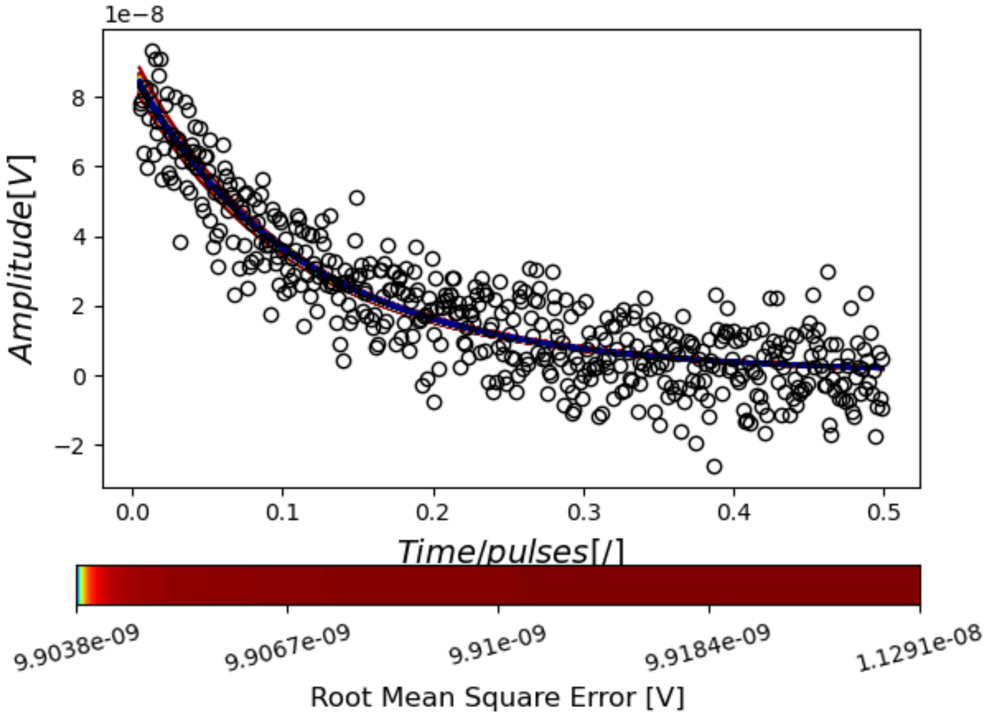


Numerical benchmark

Improving with IPR



- Narrow uncertainty
- Sensitivity lower in depth
  - From experimental design



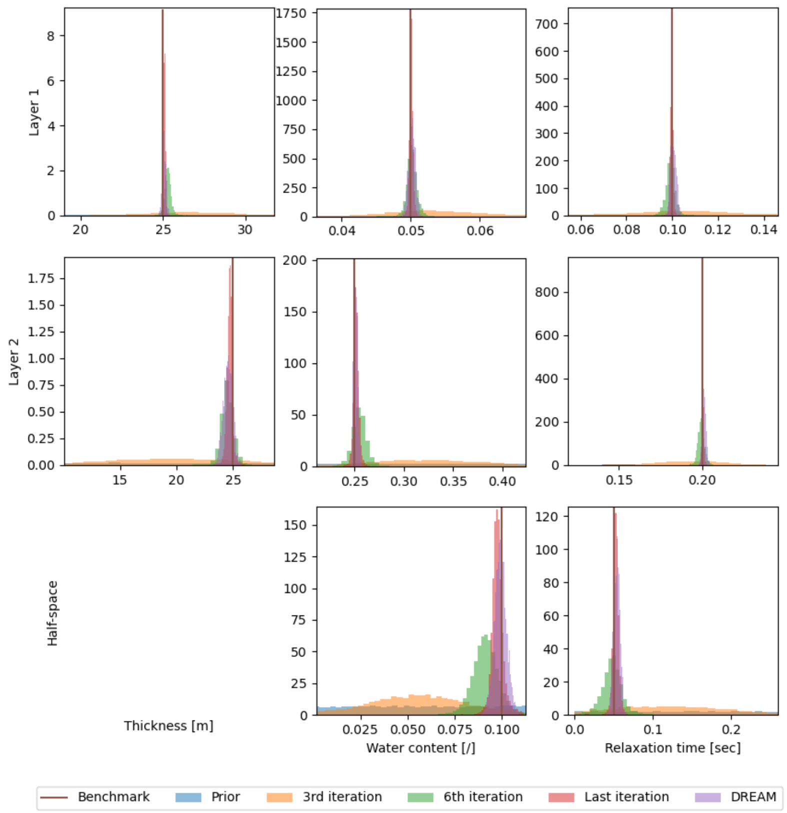
Numerical benchmark

Comparing with McMC

- Using DREAM$_{(zs)}$ (e.g., Vrugt, 2016, ENVIRON MODELL SOFTW and Laloy et al., 2018, Water Resour. Res.)
- Tuned to convergence:
  - Number sequences: 20
  - Samples per chain: 10,000
  - Jump rate: 0.1

Numerical benchmark

Comparing with McMC



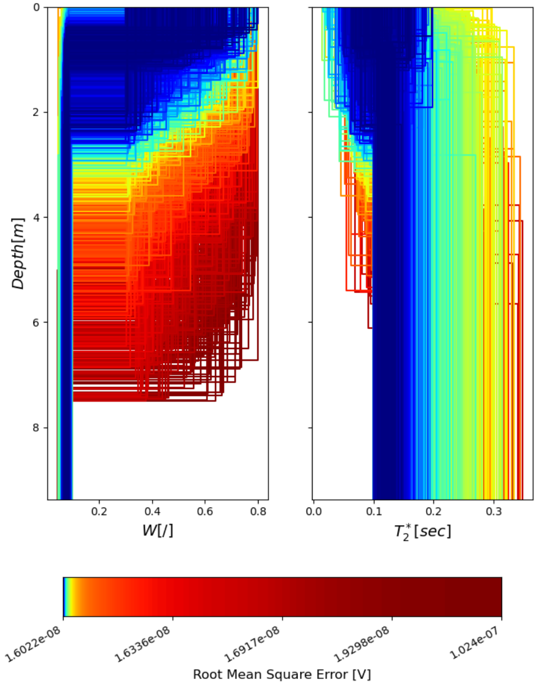
- The last iteration coincide with results from DREAM
- However:
  - CPU time is lower (250 seconds for BEL1D vs 500 for $\text{DREAM}_{(zs)}$)
  - Difficulty to tune to convergence in DREAM

Case study: Mont Rigi

- Natural reserve in the Eastern part of Belgium
- Metric peat above Cambrian bedrock
- Experiment:
  - Single transmitter/receiver
  - 20 meters in diameter
  - Noise ~ 18 nV

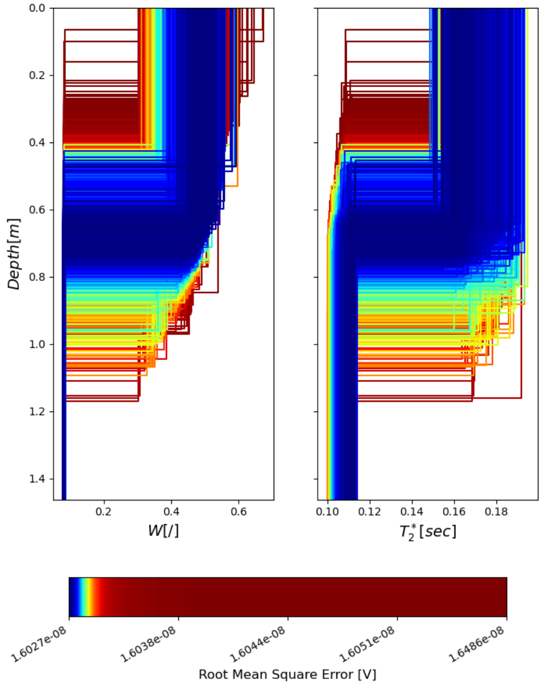
Case study: Mont Rigi

First iteration



- Significant reduction of uncertainty
- Still an observable (W_1, e_1) link
- Trend for the relaxation time
- CPU time = 30 sec

Last (6th) iteration



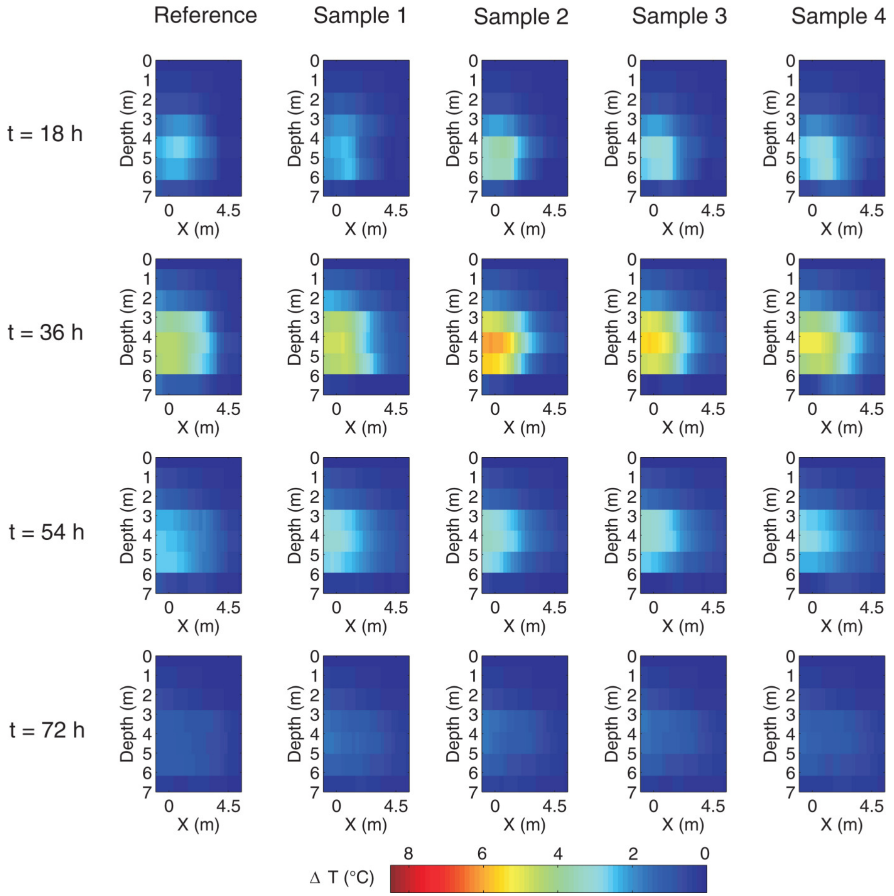
Conclusion and perspectives

- BEL1D combined with IPR is:
  - Accurate (comparison with McMC)
  - Efficient (CPU time)
  - Easy to tune to convergence
- Significant improvement over BEL1D without iterations

- Currently developing other use case (MASW, EM)
- Near future: Smooth models, 2D, etc.

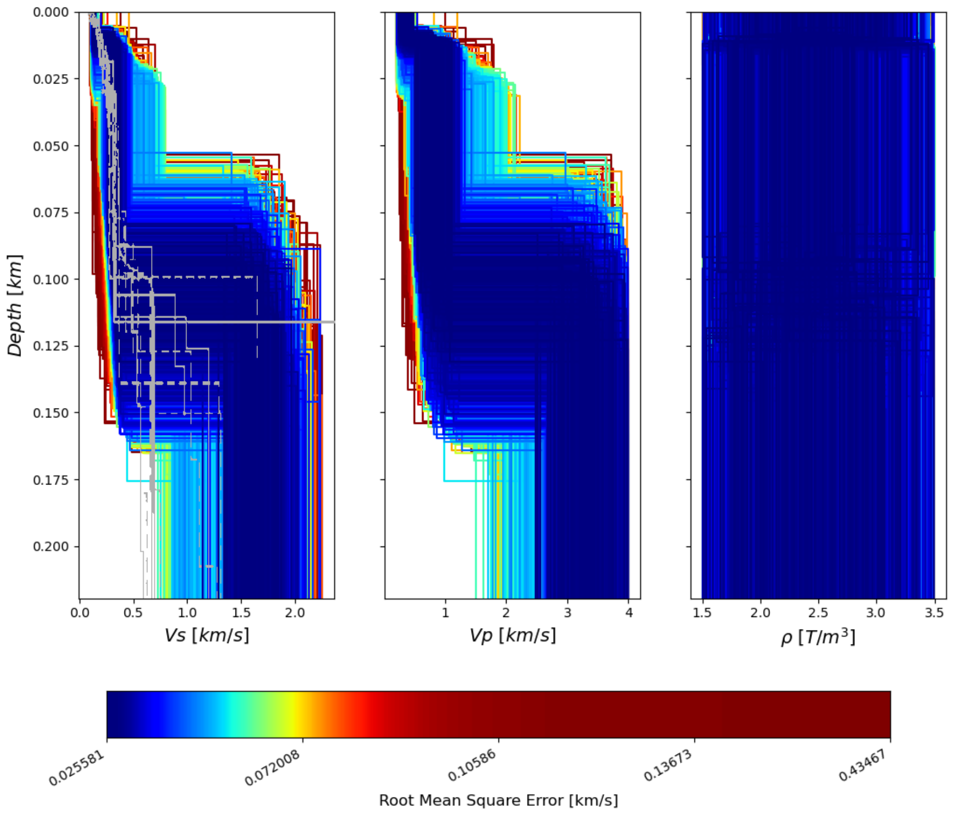
Conclusion and perspectives
2D case – Time-Lapse ERT

- Time-lapse ERT (Hermans et al., 2016, Water Resour. Res.)
- Heat tracer experiment
- Captures the behavior of the heat tracer.



Conclusion and perspectives
Work in progress – Surface waves preview

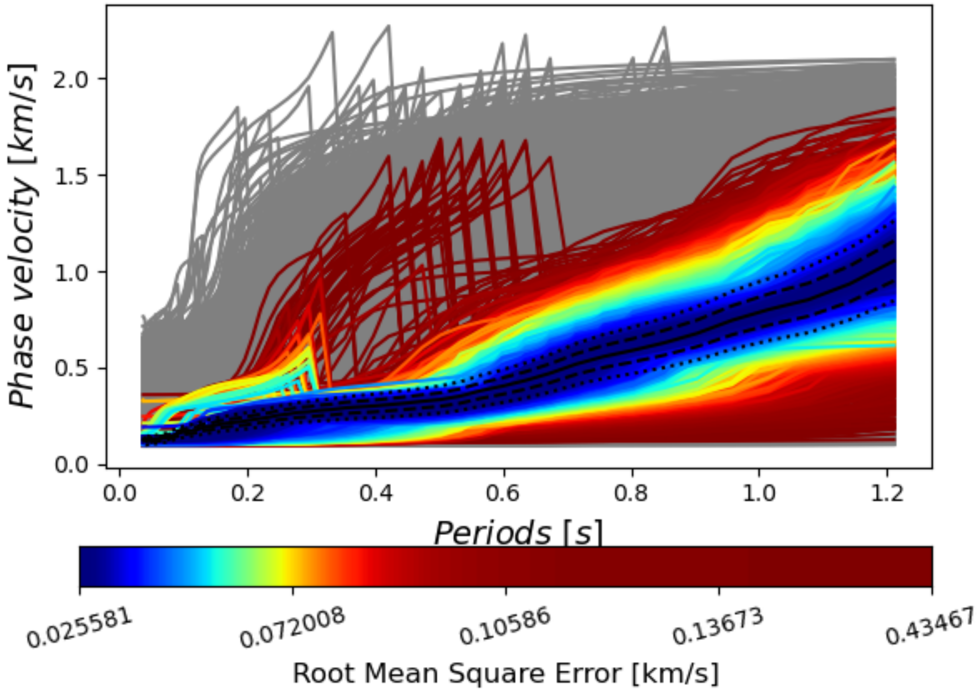
- Mirandola (Italy) case study from INTERPacific (Garofalo et al., 2016, SOIL DYN EARTHQ ENG)
- Comparison of the results with IPR with the different experts curves



Conclusion and perspectives

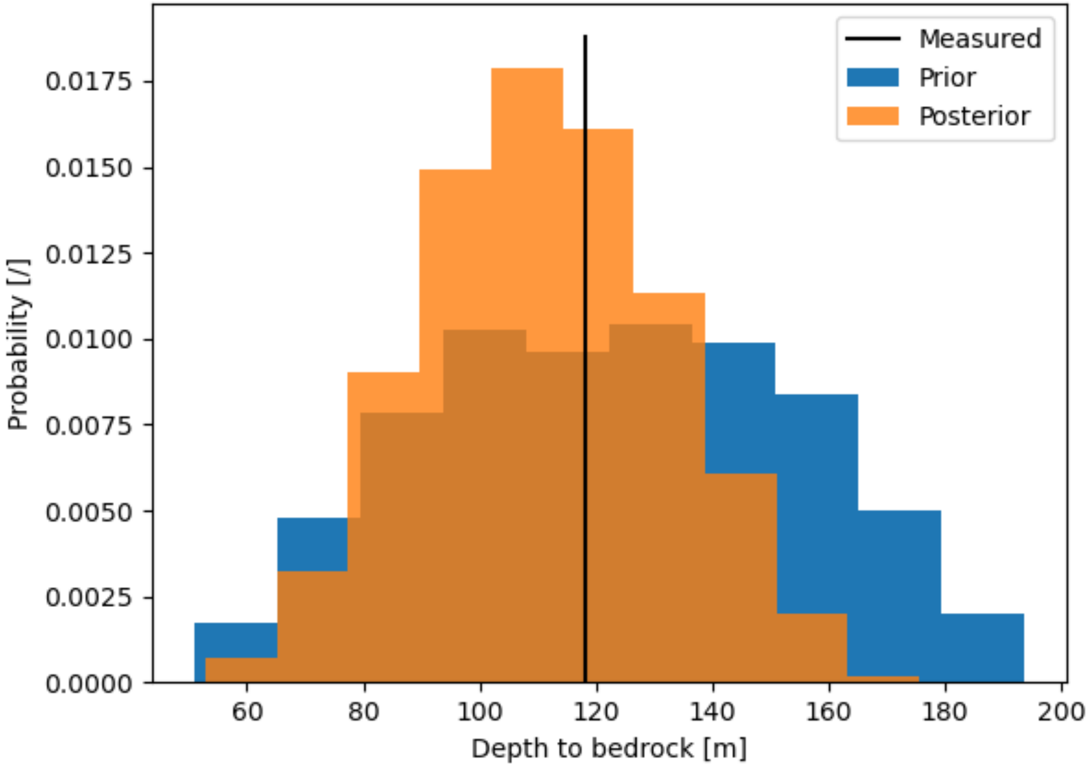
Work in progress – Surface waves preview

- Efficient reduction of the dataspace from the prior (gray) to the posterior at the last (15th) iteration
- The error model fits nicely the posterior dataspace
  - The noise is not of the same kind as the one in sNMR



Conclusion and perspectives
Work in progress – Surface waves preview

- Field benchmark available: Depth to the bedrock = 118m (Garofalo et al., 2016, SOIL DYN EARTHQ ENG)
- Accurately reproduced by BEL1D



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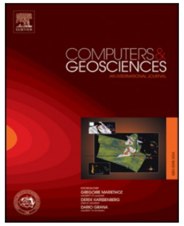

1D geological imaging of the subsurface from geophysical data with Bayesian Evidential Learning

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Thanks for your attention!

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