Uncertainty quantification of the subsurface water content through BEL1D interpretation of SNMR data

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1. Introduction

Quantification of groundwater resources from surface based geophysical measurements is an efficient alternative to direct measurements (boreholes), both in terms of cost and of spatial coverage. In the large panel of geophysical techniques, SNMR offers the unique advantage to only be sensitive to water.

However, the interpretation of SNMR data is complex and often relies on deterministic approaches. Those methods offer rapid and unique models of the subsurface, but cannot take into account the uncertainty contained in the data producing unreliable models.

Stochastic inversions allow to fill the gap but are rarely applied due to their very high computational costs. BEL1D proposes to overcome the issue by using new Bayesian techniques to asses uncertainty on models at a minimal computational cost.

2. SNMR

SNMR (surface nuclear magnetic resonance):

- surface-based geophysical method
- only responsive to water
- sounding up to 100 meters

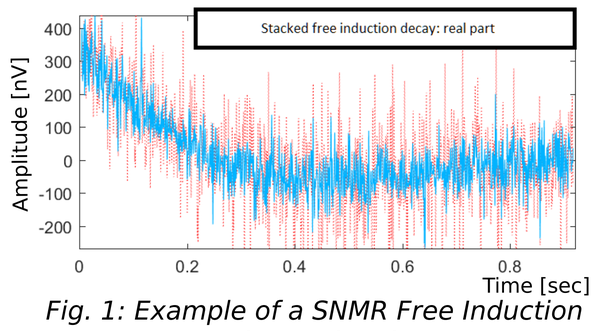


Fig. 1: Example of a SNMR Free Induction decay signal

Pros	Cons
Detects only water	Strong impact of electromagnetic noise
-	-
Cost-effective	Complex data processing and interpretation
-	-
Rapid acquisition	Deterministic inversion lacks the ability to provide uncertainty
-	
Distinction between trapped and free water	
-	
Hydrogeological parameters accessible	

3. BEL1D

BEL1D (Bayesian Evidential Learning 1D imaging) is a new Bayesian technique to interpret geophysical data into 1D models of the subsurface. BEL1D relies on the constitution of statistical relationships between synthetic models and associated synthetic data through a combination of PCA and CCA (machine learning).

In SNMR, the models parameters are:

- ➢ Thicknesses of each layer (except the half-space)
- ➢ Water content of each layer
- ➢ Decay time of each layer

and the data is the free induction decay (a decreasing exponential)

The method has proven effective for both SNMR and seismic surface waves data but can easily be modified to accommodate other methods.

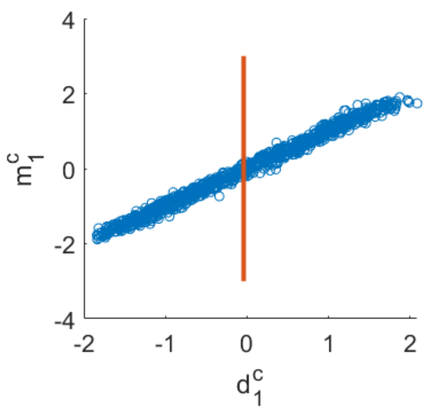


Fig. 2: Extract of the statistical relationship obtained through BEL1D

4. Test case

Mont Rigi (Belgium)

- 2-layers
- Saturated peat (~3m)
  - ➢ High water content
- Cambrian bedrock
  - ➢ Low water content
- Low EM noise levels

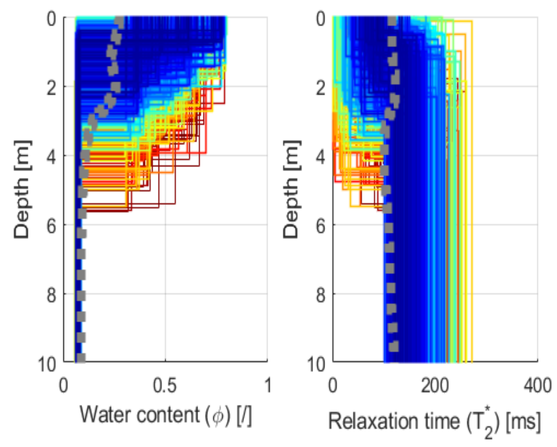


Fig. 3: Results of BEL1D on the Mont Rigi test-site. The dashed gray line is the determinisitic inversion result.

Results of BEL1D (Fig. 3):

- Produced models are coherent
- The solution is non-unique
- Uncertainty is intrinsic to the data
  - ➢ Low water contents → high uncertainty in decay time
  - ➢ Peat thickness is linked to its water content (uncertain)

5. Conclusion and perspectives

BEL1D proposes an efficient alternative to stochastic inversions in order to asses uncertainty on models based on geophysical data.

- ➢ CPU timing similar to deterministic inversion (SNMR)
- ➢ Produced models contain the deterministic results
- ➢ Recovers relationships between different parameters
- ➢ Provides distributions for the parameters values according to field data
- ➢ Handles the non-uniqueness of the solution

The method can still be improved by:

- ➢ The use of smooth discretizations (instead of the current blocky models)
- ➢ Implementation of reusable prefield calculations to speed-up interpretation
- ➢ And many more . . .

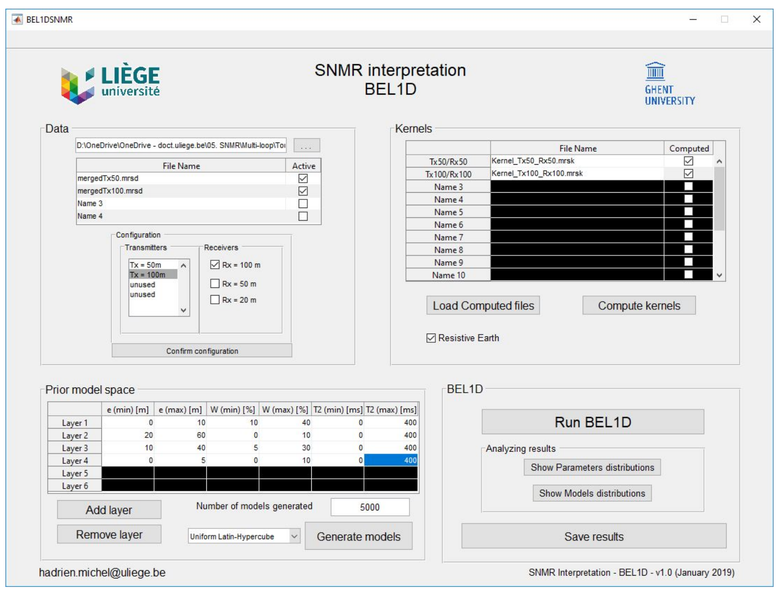
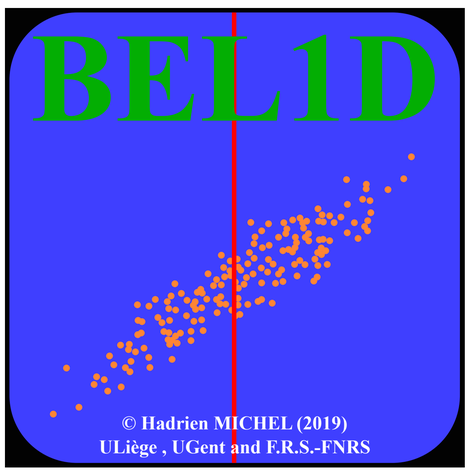


Fig. 4: Graphical user interface for the interpretation of SNMR data thought BEL1D (available on GitHub)



Find the codes on GitHub