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

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1. Bayesian Evidential Learning 1D imaging

Uncertainty appraisal is a key concern to geophysicists when imaging the subsurface. This issue is classically handled by stochastic inversion (costly CPU) or by error propagation (unrealistic uncertainty). However, those methods suffer from an important CPU cost, due to the need for many runs of inversions.

Bayesian Evidential Learning 1D imaging (BEL1D) is a Bayesian method that enables the stochastic interpretation of 1D geophysical data, with a reasonable CPU cost and realistic uncertainty estimations.

The method relies on the constitution of statistical relationships between model parameters and the associated data-sets from prior realizations (Fig. 1). The method offers the advantage not to require the input of biasing information through regularization parameters as is often the case in classical inversion processes. However, the consistent definition of a prior is still required. Nonetheless, the method handles as efficiently large priors as smaller ones, thus making the use of unbiased priors easy.

Above all, the method enables the quantification of uncertainty for the model parameters.

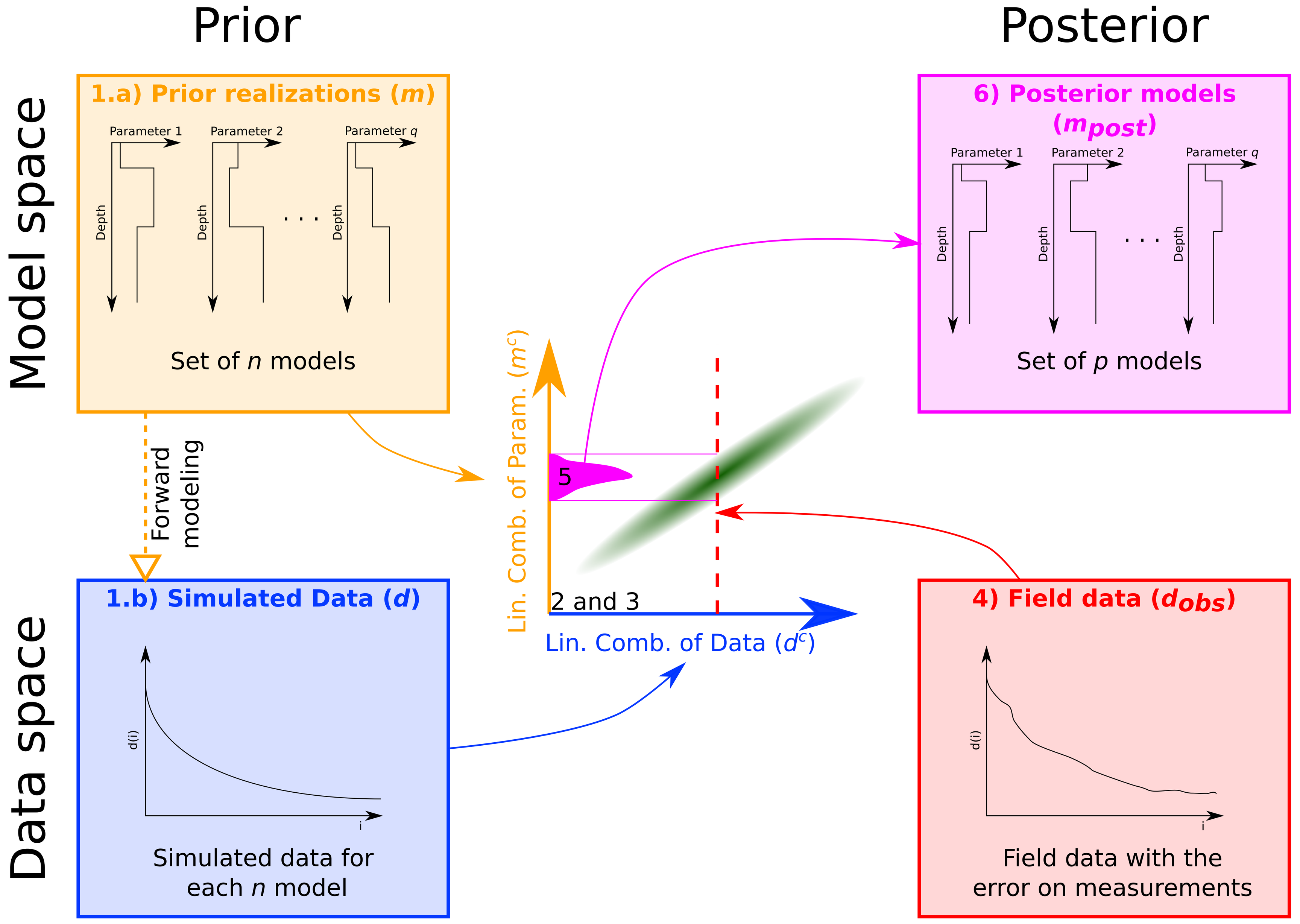

Fig. 1: Schematic illustration of BEL1D

2. Application: test model and experiments

	Thickness [m]	Water content [%]	Decay time [ms]	P-wave velocity [m/s]	S-wave velocity [m/s]	Density [kg/m³]
Layer 1	5	5	100	600	300	1600
Layer 2	/	25	200	2000	1000	2000

Table 1: Description of the synthetic model

Two geophysical experiments are tested:

- SNMR: geophysical experiment sensitive to water.
  - Water content and decay time distributions with depth
- Surface waves (SW): seismic waves that propagate parallel to the surface whose geometric dispersion is modeled thought dispersion curves.
  - P- and S- waves velocities and density distributions with depth

3. Application 1: SNMR

We applied BEL1D to a synthetic model (Table 1). The results showed the method is able to successfully reproduce the test model with uncertainties (Fig. 2) related to insensitivity rather than to a lack of accuracy of BEL1D as shown by the RMS.

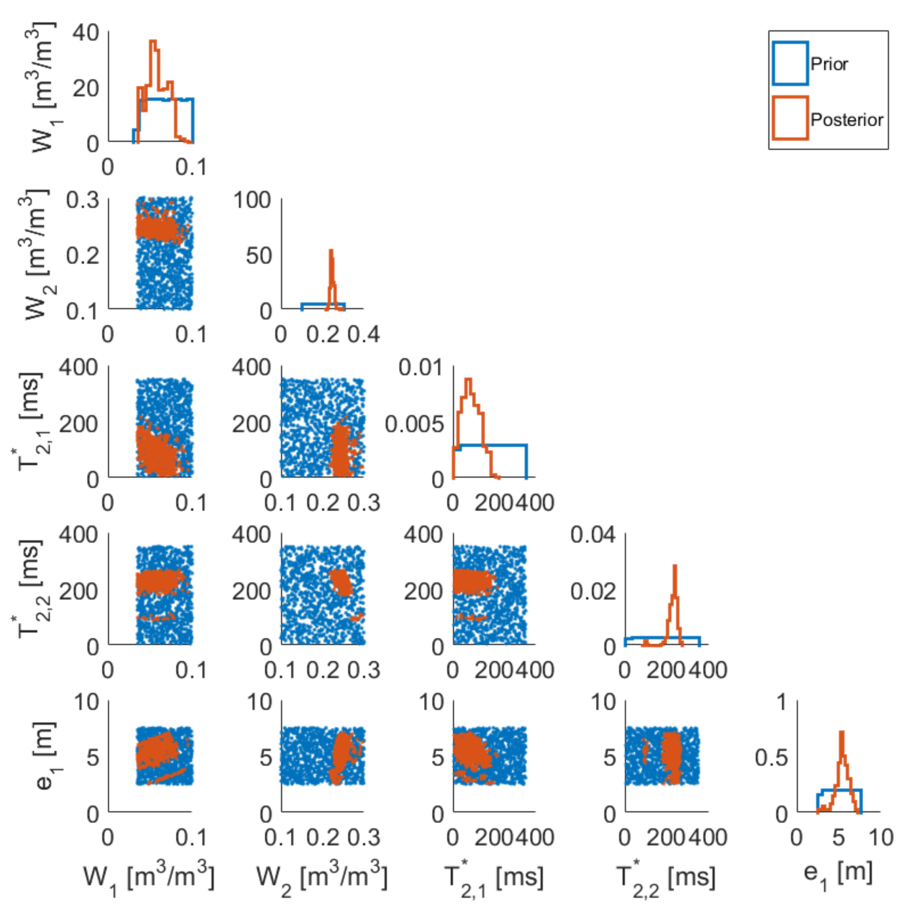

Fig. 2(a): Results of BEL1D on the synthetic SNMR data-set: model parameters space.

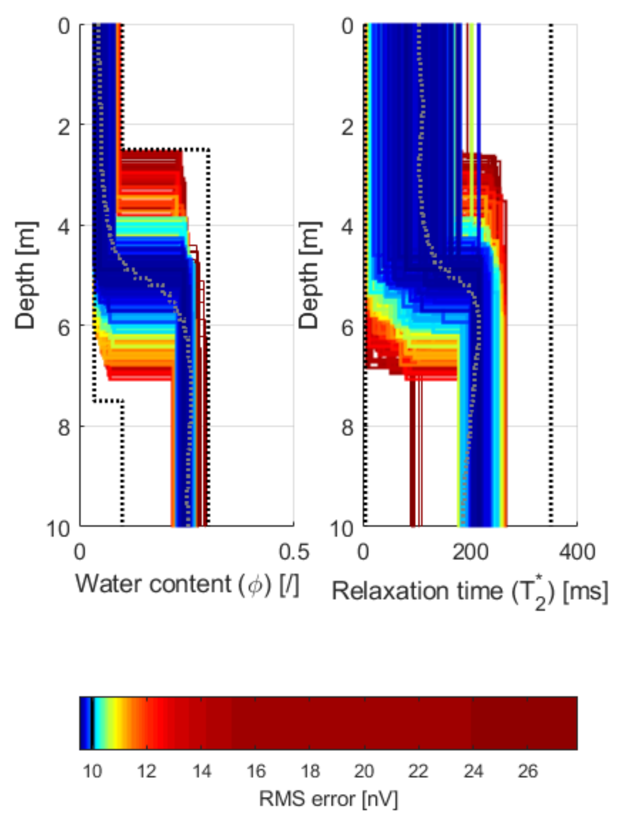

Fig. 2(b): Results of BEL1D and QT-inversion on the synthetic SNMR data-set. The prior is defined by the dashed black lines.

4. Application 2: Surface Waves

The same model (Table 1) was used to produce a synthetic dispersion curve. BEL1D was then applied and resulted in the models distributions in Fig. 3. This case shows that BEL1D performs in accordance with the theory, as the reduction of uncertainty is mainly observed in the shear-wave velocity, whereas no reduction is observed in the density profiles, a parameter not significantly impacting the dispersion curve.

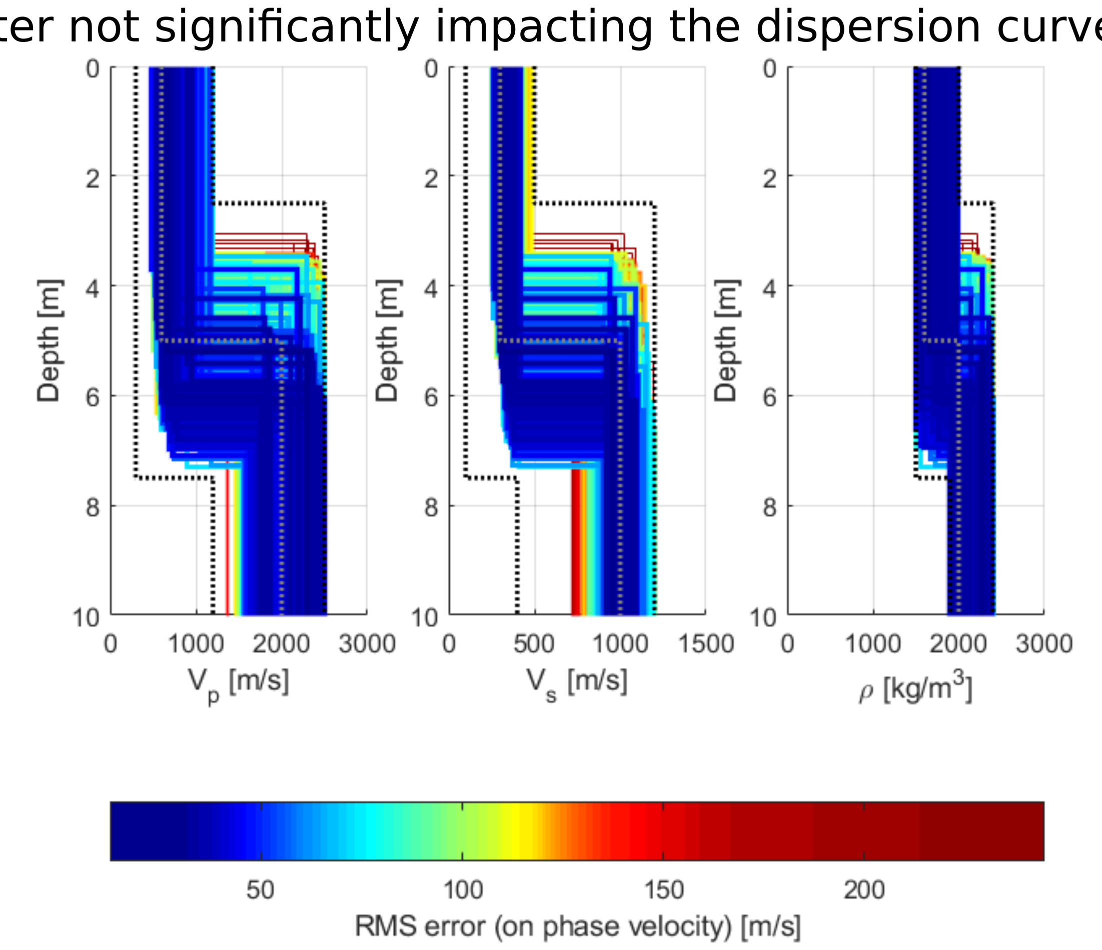

Fig. 3: Results of BEL1D on the synthetic surface wave dispersion curve. The prior is defined by the dashed black lines.

5. Conclusion

BEL1D promises a shift towards a larger use of stochastic methods for the interpretation of geophysical data in terms of physical properties. The method has been successfully applied to both SNMR and surface waves dispersion curves and permits an easy transformation to any other type of geophysical experiment, as long as an efficient forward model does exist.

In the case of SNMR, BEL1D performed similarly to the QT-inversion (Mueller-Petke et al., 2016) when considering time, but provided a much more complete set of information based on the same data-set. Moreover, the process did not require the difficult determination of regularization parameters, needed in inversion processes to stabilize the computation and ensure convergence.

In the case of surface waves, the results showed the data-set did not enable a significant reduction of uncertainty for some insensitive parameters (the density for example).

Finally, we developed a series of MATLAB codes (available on Github) that performs BEL1D for both SNMR and surface waves (as well as a generalized case) in a graphical environment, making the use of BEL1D straightforward.

Find the codes on my Github:
github.com/hadrienmichel/BEL1D