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Development of FWI4GPR, an open-source package for Full-Waveform Inversion of common-offset GPR data

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Introduction

We introduce a package for full-waveform inversion (FWI) of Ground Penetrating Radar (GPR) data based on a combination of open-source programs. FWI is non-linear data-fitting procedure that aims at obtaining optimal estimates of selected subsurface properties using the entire traces of GPR data in an iterative process. The FWI requires a good starting model, based on direct knowledge of field conditions or on traditional data analysis methods and a good estimate of the source wavelet. With a good starting model and wavelet, the FWI can improve resolution of selected subsurface features, such as the dimensions of buried object. The package will be made available for general use in educational and research activities.

Components

FWI is performed in an iterative process and needs initial models preparation. The package has five main components:

1. `Forward Modeler`
2. `Inversion Algorithm`
3. `Ray-based analyzer (= arrival time pick analysis)`
4. `Source Wavelet (SW) estimator`
5. `3D to 2D converter`

Forward Modeler

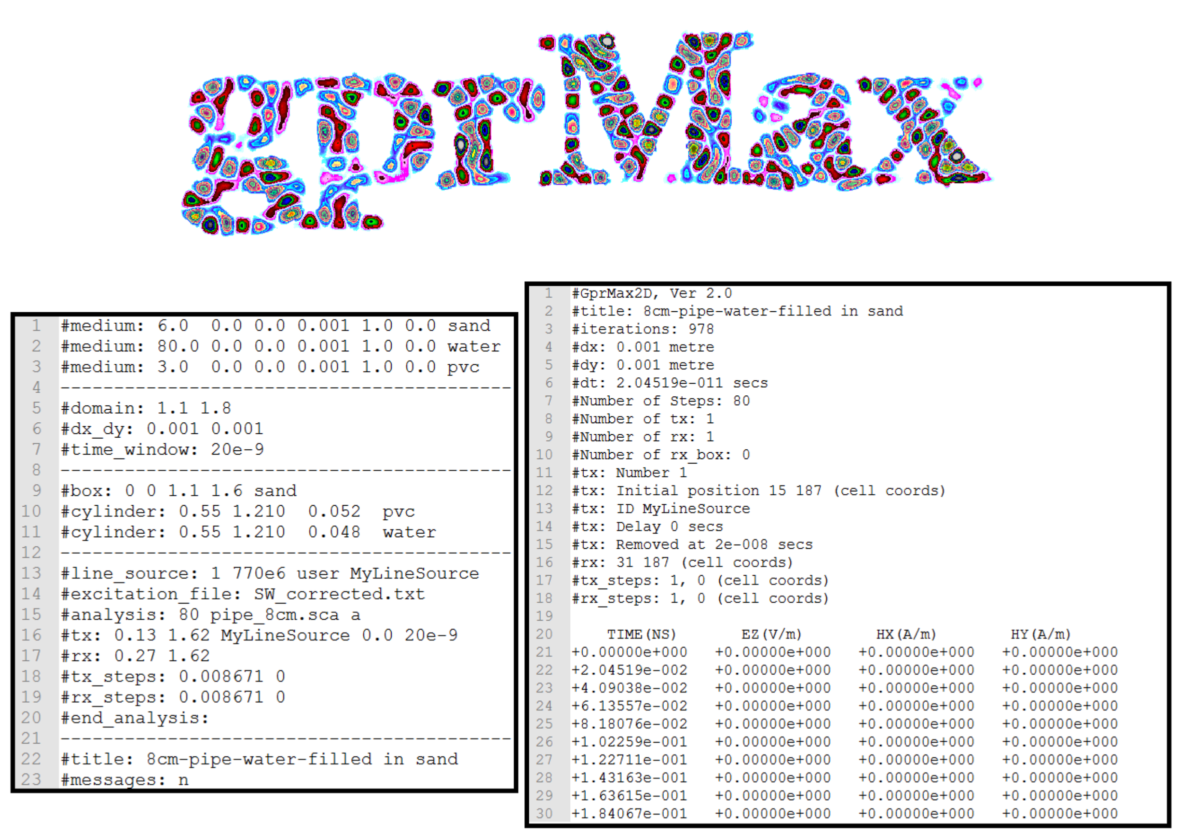

Figure 1: gprMax sample input and ASCII output [1]

Inversion Algorithm

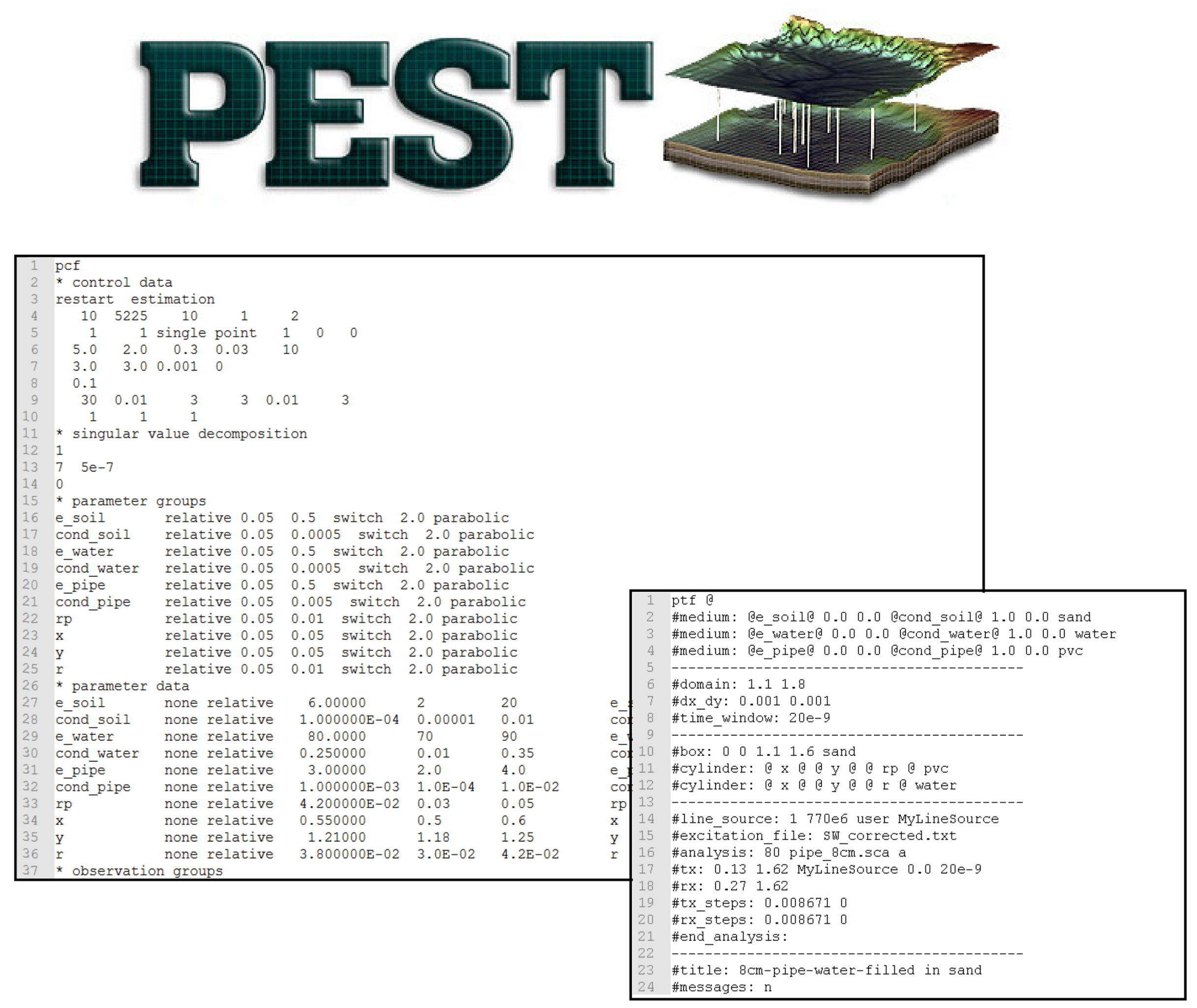

Figure 2: PEST sample control and template files [2]

Source Wavelet Estimator

Apply **Sparse Blind Deconvolution** (SBD) to estimate the transmitted waveform. Data are a convolution product of the wavelet and the reflectivity series (impulse response).

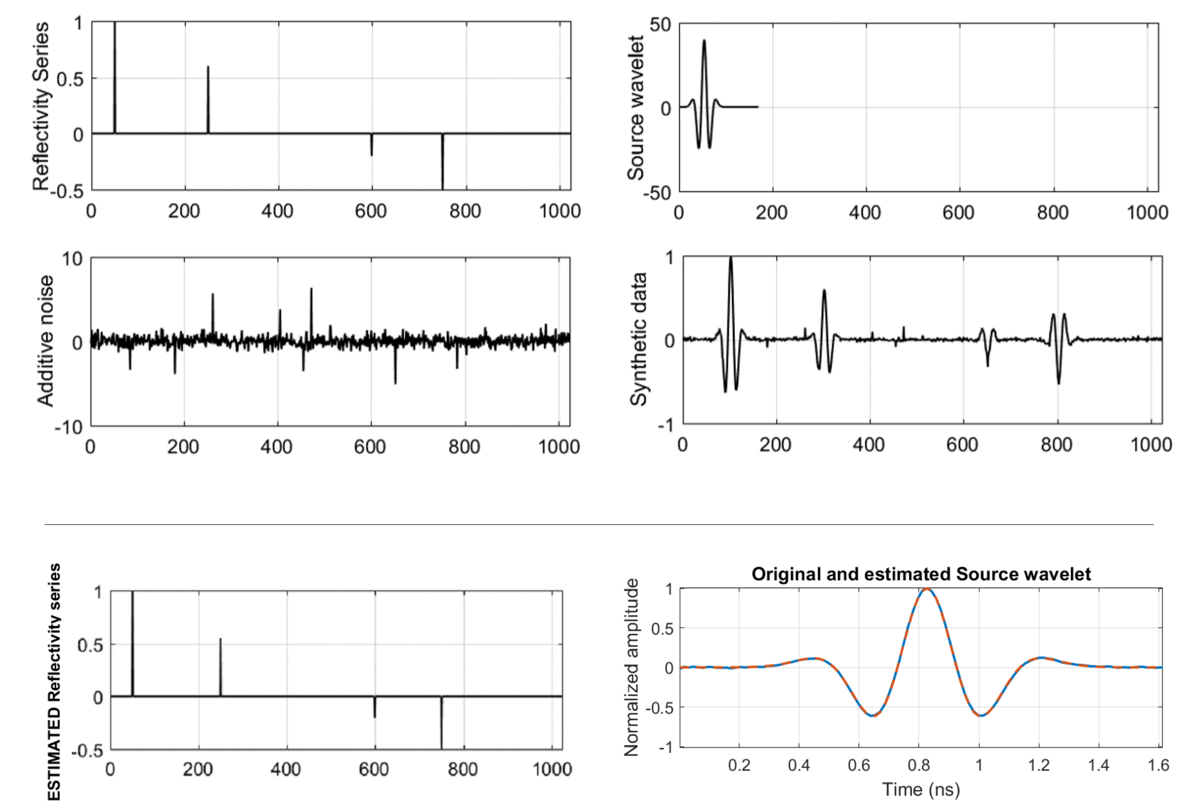

Figure 3: Sparsity based source wavelet estimation (arrivals from the near-field are not used), synthetic case [3]. Top: Process of generating synthetic data; Botton: SBD results

Key Factors

FWI is an *iterative process*, in which a good **starting model** can be improved. It requires traditional data analysis methods to generate a starting model. Similarly, a good estimate of the **source wavelet** is required.

Ray-Based Analyzer

Use ray-based analysis to estimate the initial parameters. For example, we use travel times of the peak amplitudes of the diffraction hyperbola with **least-squares** approaches to estimate model parameters.

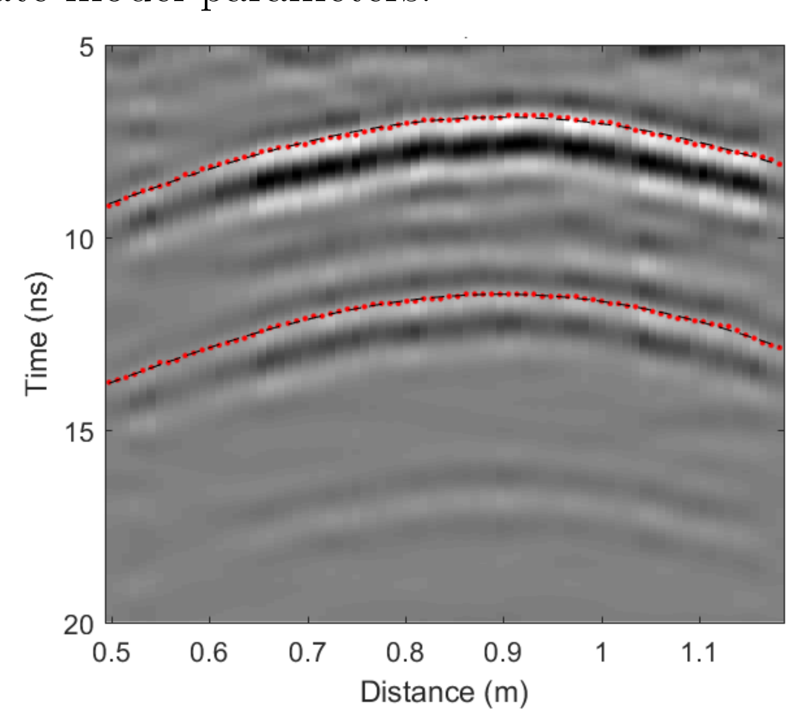

Figure 4: Ray-based hyperbola fitting on GPR data over a pipe [4]

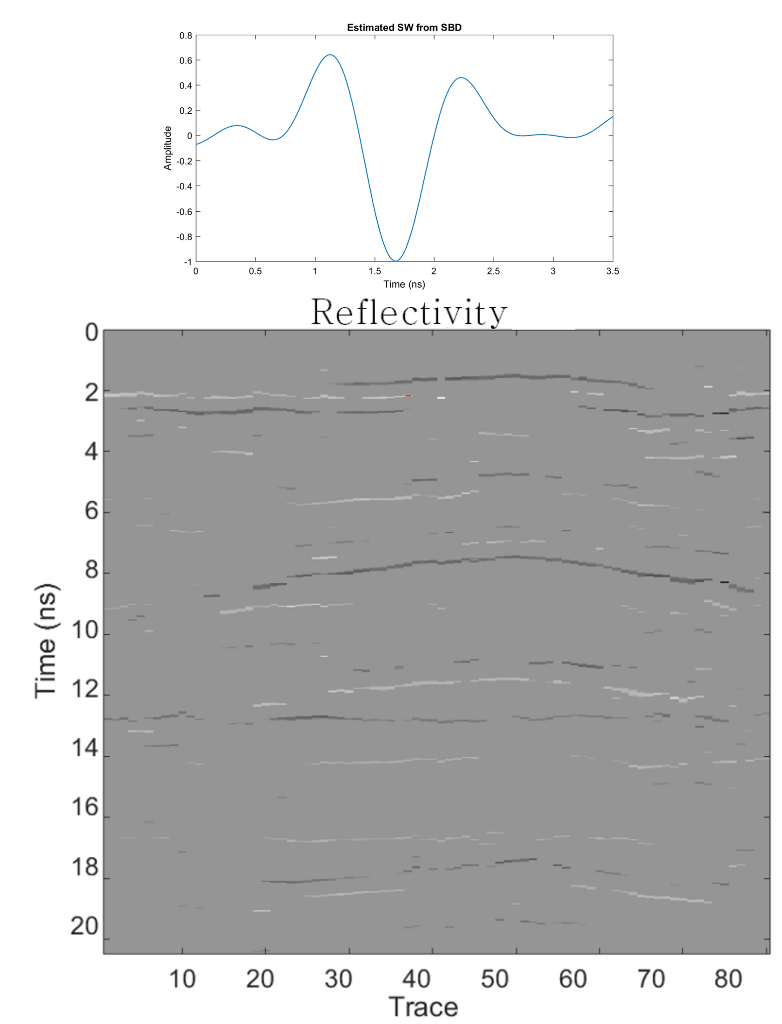

Figure 5: SBD derived source wavelet and reflectivity series for the real pipe [3]

3D to 2D Converter

Simulate 2D line-source generated waveforms that would be equivalent to those observed in the 3D data, by convolving data in the time domain with $\sqrt{t}$ where t is travel time.

Example

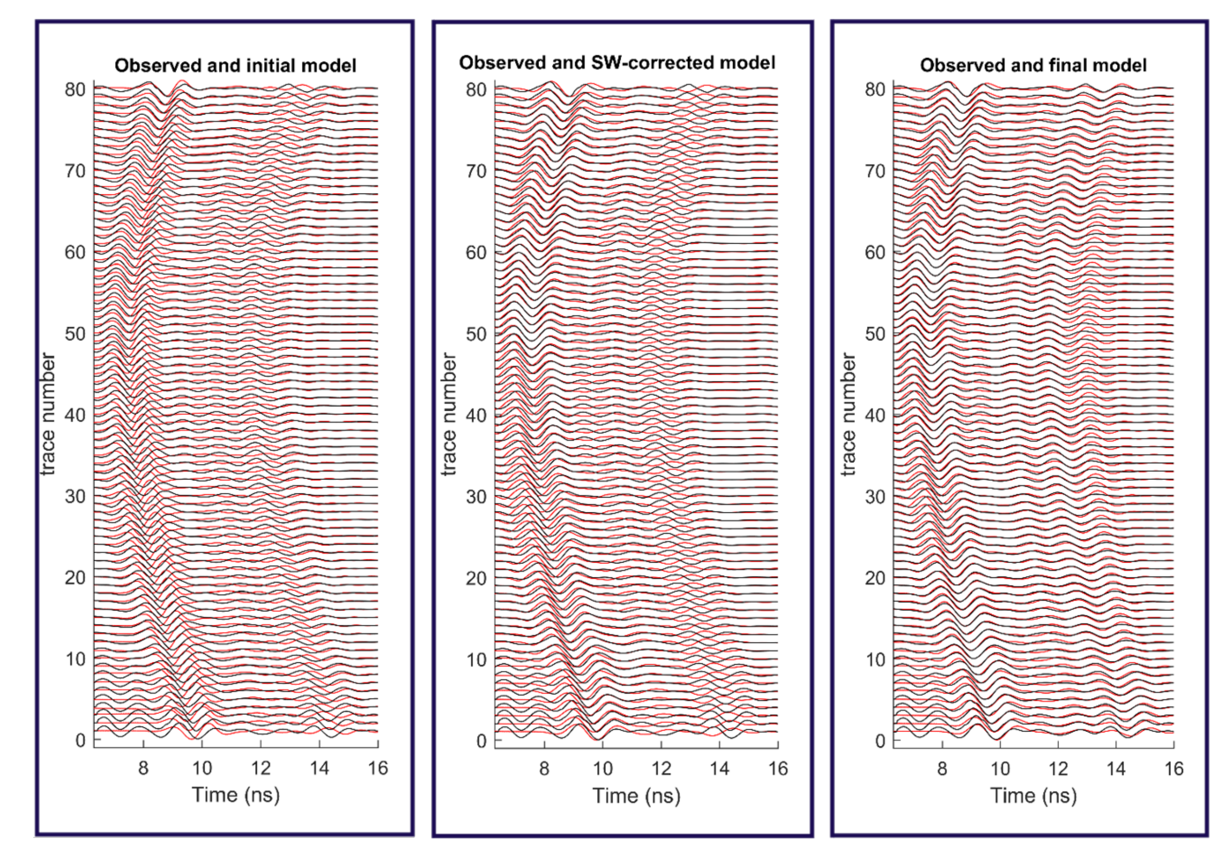

Figure 6: Collected and synthetic pipe data fit after ray-based, SW correction and FWI [4]

Acknowledgements

We would like to thank Drs. J. Doherty, A. Giannopoulos and C. Warren for making their codes open-source and Mr. A. Ebrahimi for his helpful discussions on SBD.

References

[1] `http://www.gprmax.com`.

[2] `http://www.pesthomepage.com`.

[3] Sajad Jazayeri, Alaeddin Ebrahimi, and Sarah Kruse. Sparse blind deconvolution of common-offset gpr data. In *SEG Technical Program Expanded Abstracts 2017*, pages 5140–5145. Society of Exploration Geophysicists, 2017.

[4] Sajad Jazayeri, Anja Klotzsche, and Sarah Kruse. Improving estimates of buried pipe diameter and infilling material from gpr profiles with full waveform inversion using pest. *Submitted to Geophysics*, 2017.