

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

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## Introduction

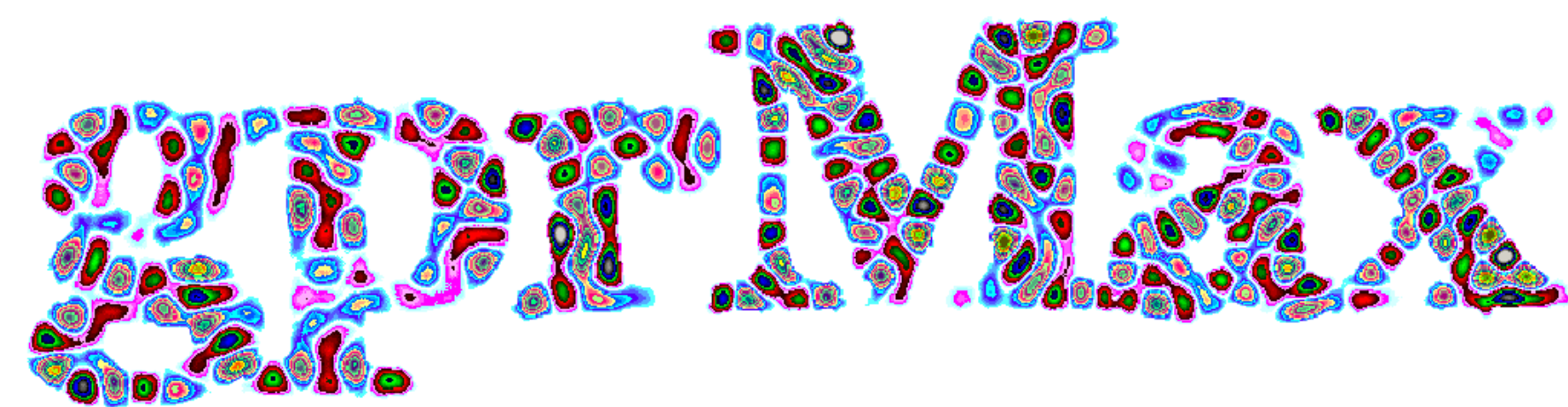
We introduce a package for full-waveform inversion (FWI) of Ground Penetrating Radar (GPR) data based on a combination of open-source programs. FWI is non-linear data-fitting procedure that aims at obtaining detailed estimates of subsurface properties from data using an iterative process. It requires a good starting model, based on direct knowledge of field conditions or on traditional ray-based inversion methods and an optimal source wavelet. With a good starting model and wavelet, the FWI can improve resolution of selected subsurface features. 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
- 4 Source Wavelet (SW) estimator
- 5 3D to 2D converter

## Forward Modeler



```
1 #medium: 6.0 0.0 0.0 0.001 1.0 0.0 sand
2 #medium: 80.0 0.0 0.0 0.001 1.0 0.0 water
3 #medium: 3.0 0.0 0.0 0.001 1.0 0.0 pvc
4
5 #domain: 1.1 1.8
6 #dx_dy: 0.001 0.001
7 #time_window: 20e-9
8
9 #box: 0 0 1.1 1.6 sand
10 #cylinder: 0.55 1.210 0.052 pvc
11 #cylinder: 0.55 1.210 0.048 water
12
13 #line_source: 1 770e6 user MyLineSource
14 #excitation_file: SW_corrected.txt
15 #analysis: 80 pipe_8cm.sca a
16 #rx: 0.13 1.62 MyLineSource 0.0 20e-9
17 #rx: 0.27 1.62
18 #tx_steps: 0.008671 0
19 #rx_steps: 0.008671 0
20 #end_analysis:
21
22 #title: 8cm-pipe-water-filled in sand
23 #messagest n
```

```
1 #gprMax2D, Ver 2.0
2 #title: 8cm-pipe-water-filled in sand
3 #iterations: 978
4 #dx: 0.001 metre
5 #dy: 0.001 metre
6 #dt: 2.04519e-011 secs
7 #number of steps: 80
8 #number of tx: 1
9 #number of rx: 1
10 #number of rx_box: 0
11 #tx: Number 1
12 #tx: Initial position 15 187 (cell coords)
13 #tx: ID MyLineSource
14 #tx: Delay 9 secs
15 #tx: Removed at 2e-008 secs
16 #rx: 31 187 (cell coords)
17 #rx_steps: 1, 0 (cell coords)
18 #rx_steps: 1, 0 (cell coords)
19
20 TIME(NS) ES(V/m) RX(A/m) RY(A/m)
21 +0.00000e+000 +0.00000e+000 +0.00000e+000 +0.00000e+000
22 +2.04519e-002 +0.00000e+000 +0.00000e+000 +0.00000e+000
23 +4.09038e-002 +0.00000e+000 +0.00000e+000 +0.00000e+000
24 +6.13557e-002 +0.00000e+000 +0.00000e+000 +0.00000e+000
25 +8.18076e-002 +0.00000e+000 +0.00000e+000 +0.00000e+000
26 +1.02259e-001 +0.00000e+000 +0.00000e+000 +0.00000e+000
27 +1.22711e-001 +0.00000e+000 +0.00000e+000 +0.00000e+000
28 +1.43163e-001 +0.00000e+000 +0.00000e+000 +0.00000e+000
29 +1.63615e-001 +0.00000e+000 +0.00000e+000 +0.00000e+000
30 +1.84067e-001 +0.00000e+000 +0.00000e+000 +0.00000e+000
```

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

## Inversion Algorithm

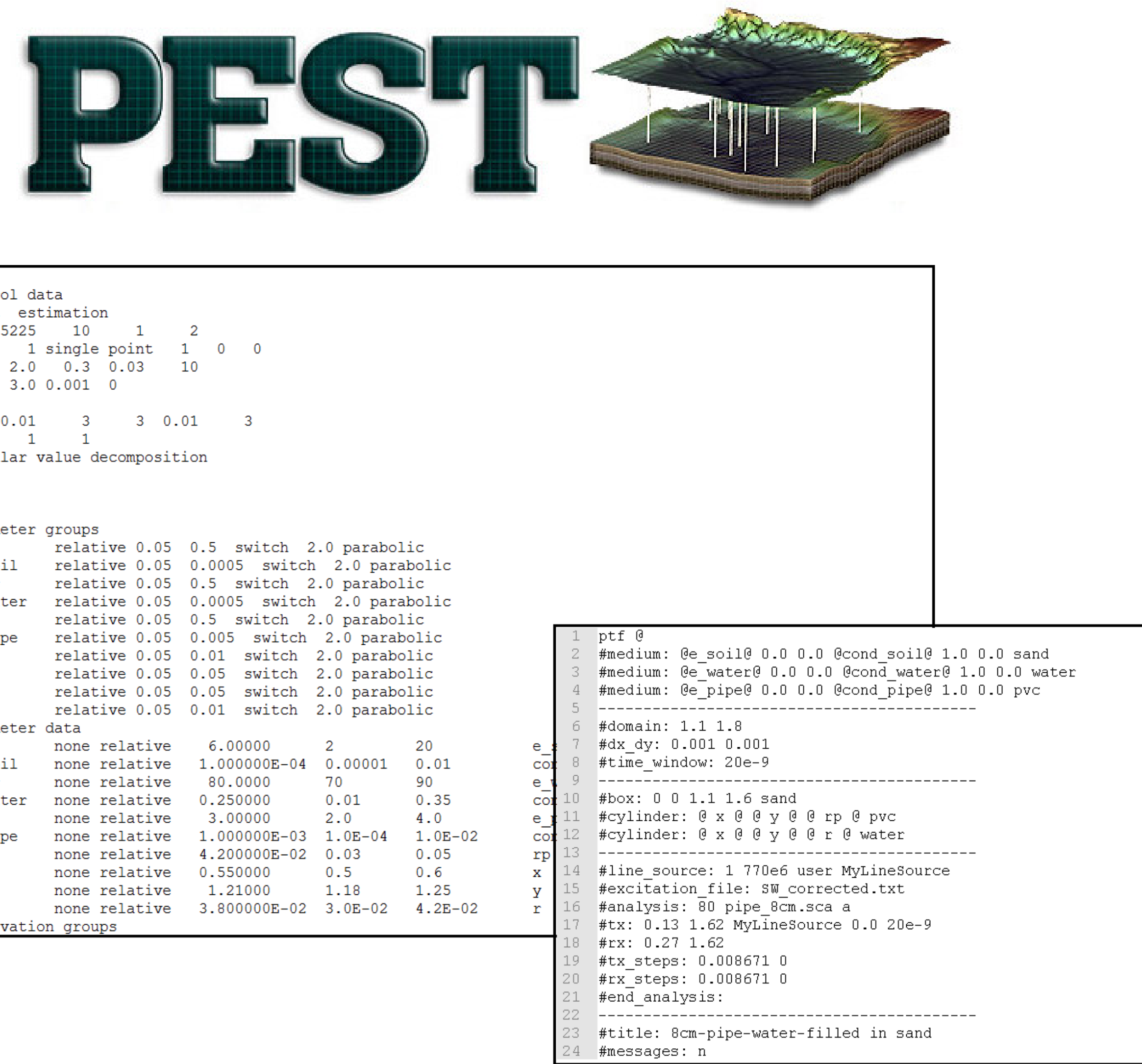


Figure 2: PEST sample control and template files [2]

## Key factors

FWI is an *iterative process*, where the **starting models** are very important to increase the success of the process. Also, no FWI process would be possibly successful without a good **source wavelet**.

## Ray-based analyzer

Use ray-based analysis to estimate the initial parameters. We use travel times of the peak amplitudes of the diffraction hyperbola within **least-squares** approaches to estimate model parameters.

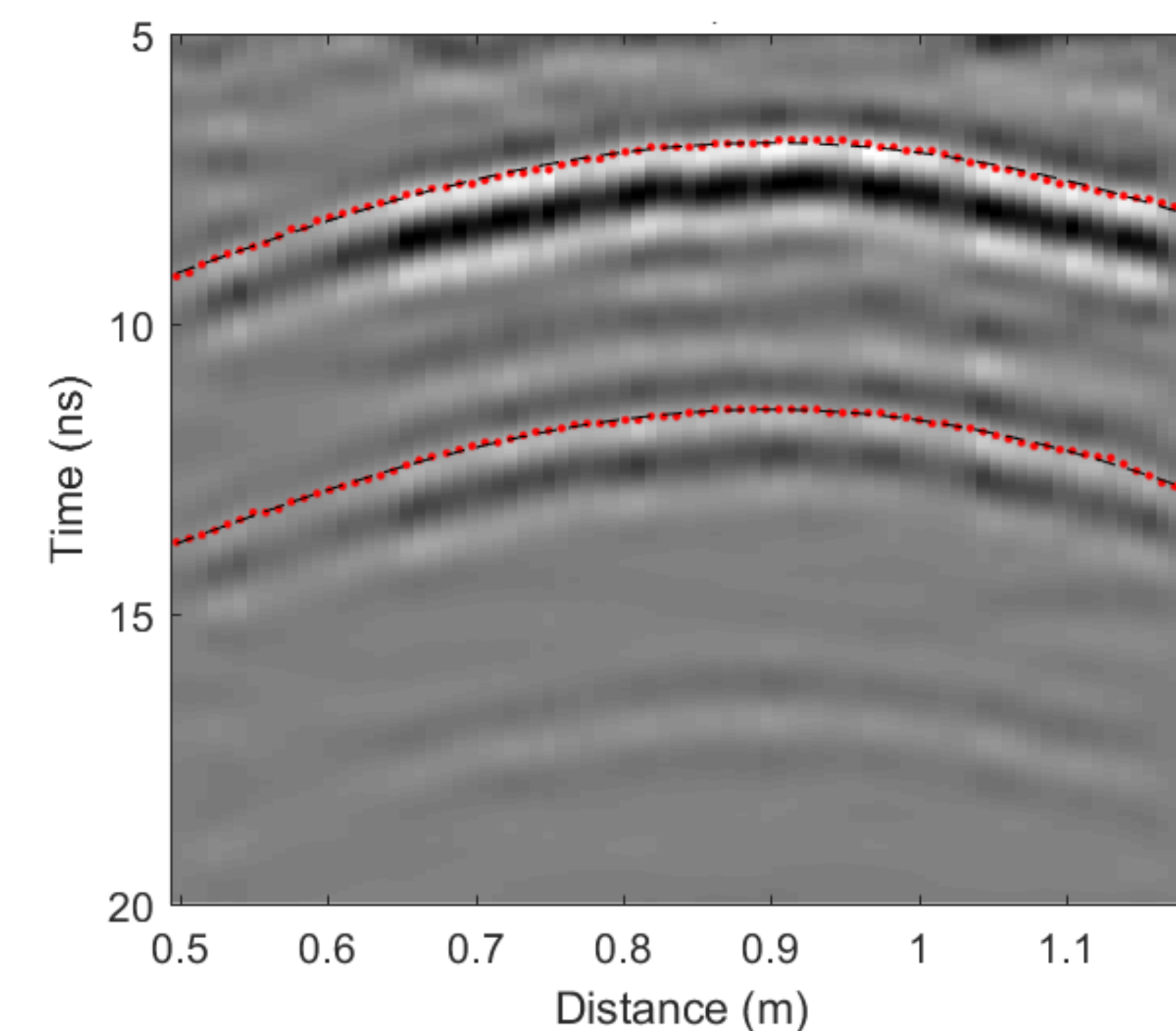


Figure 4: Ray-based hyperbola fitting on GPR data over a pipe [4]

## Source wavelet estimator

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

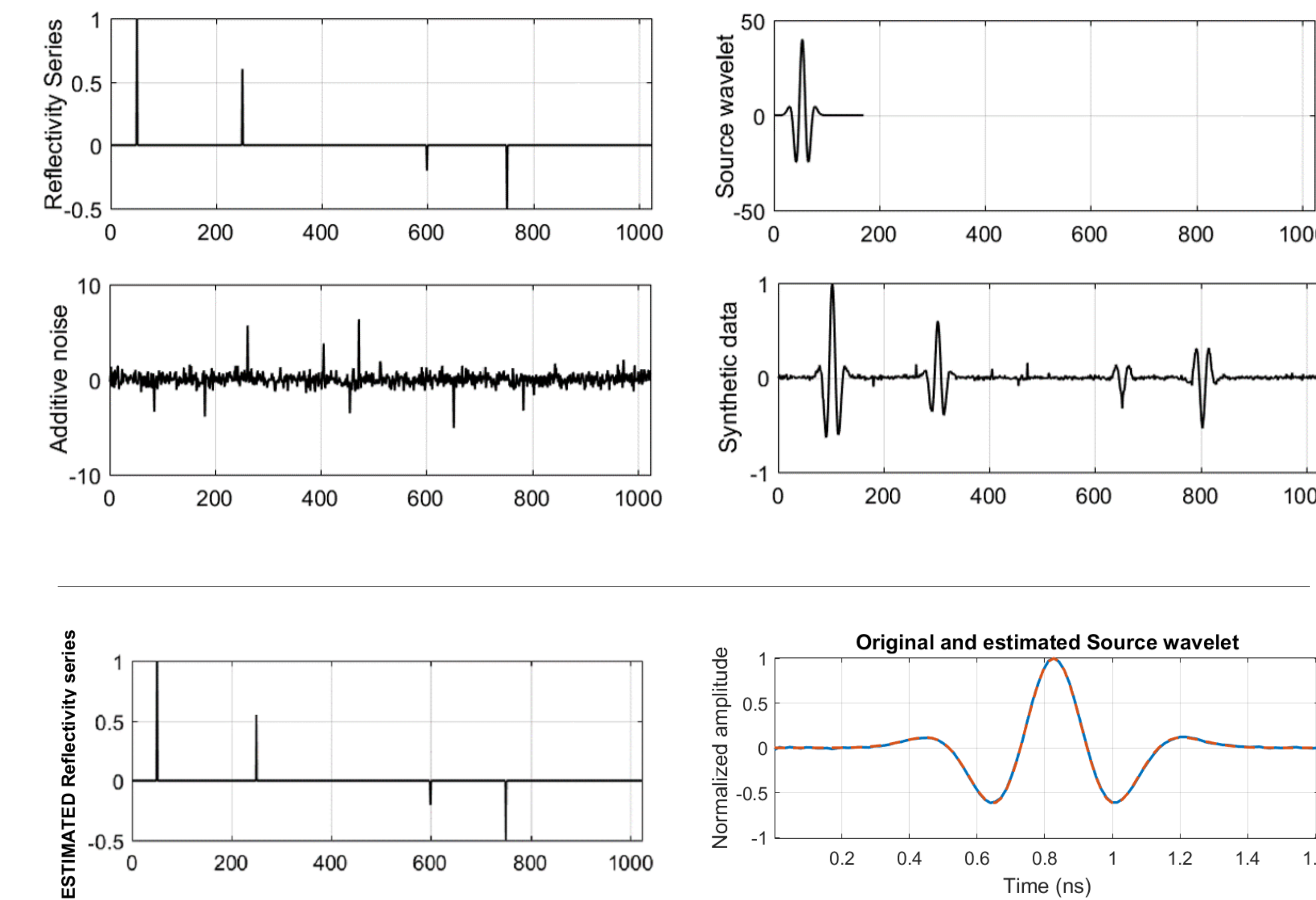


Figure 3: Sparsity Based Source wavelet estimation, synthetic case [3].  
Top: Process of generating synthetic data; Bottom: SBD results

## 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

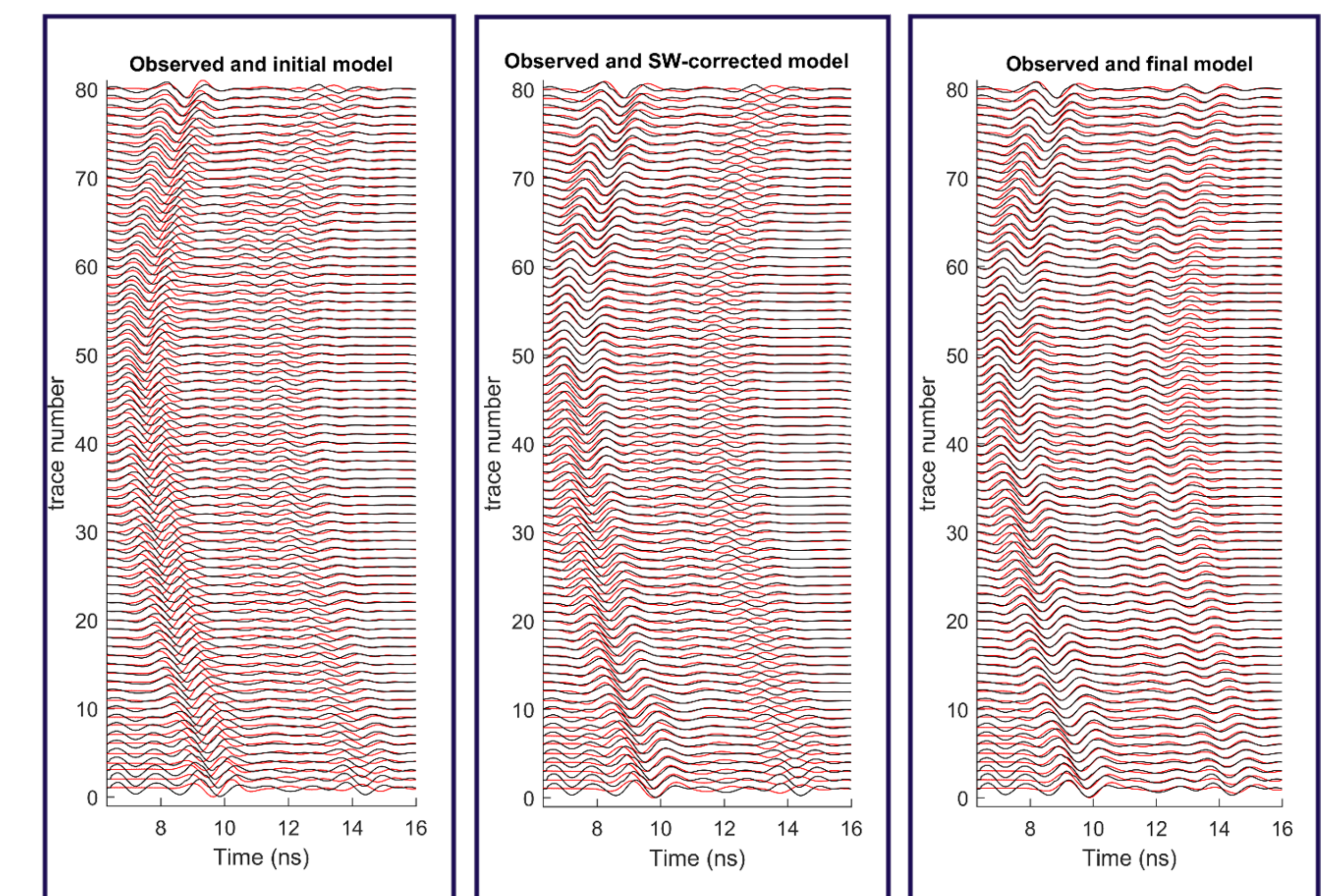


Figure 6: Collected and synthetic pipe data fit after ray-based, SW correction and FWI [4]

## 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.

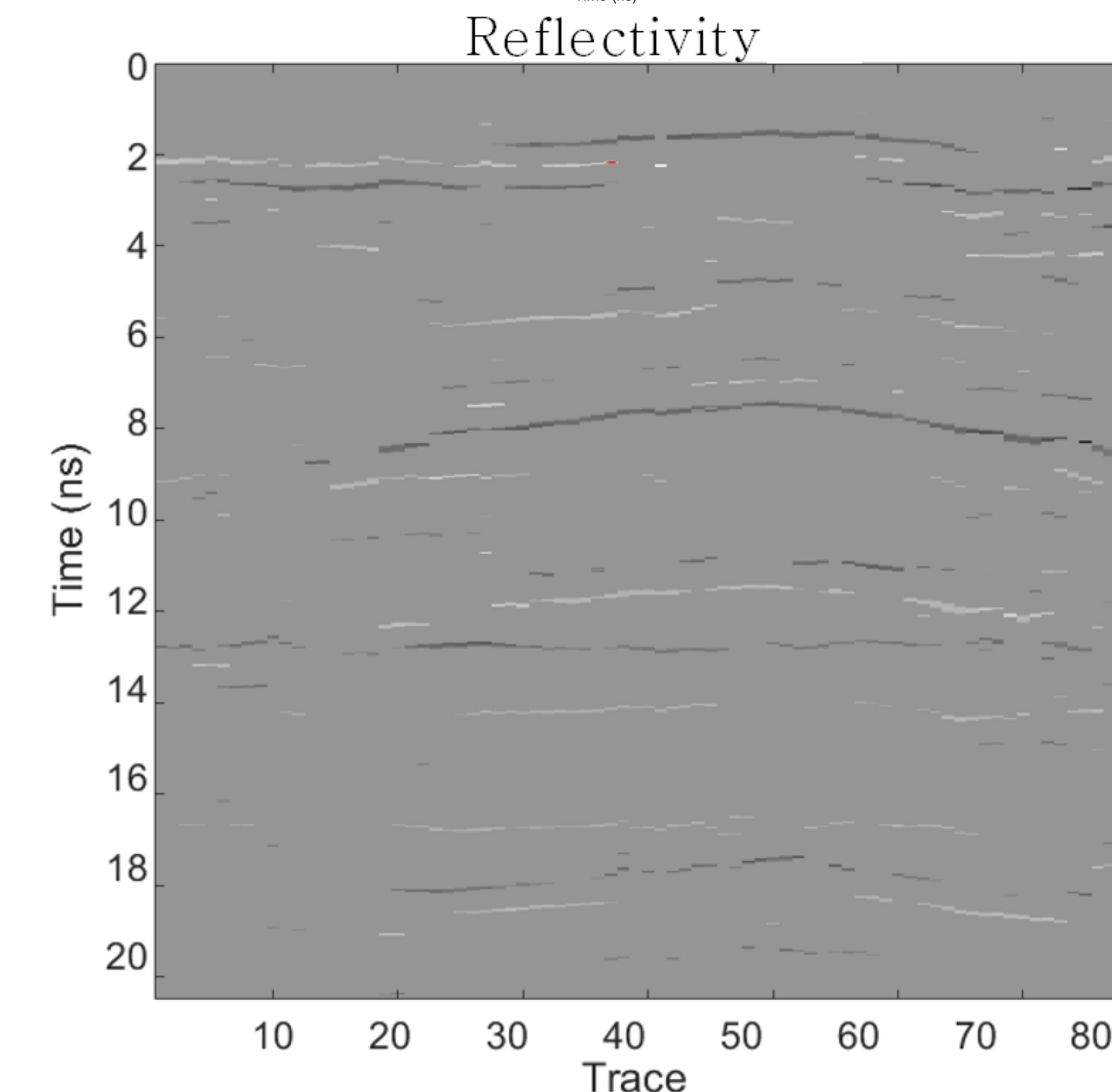
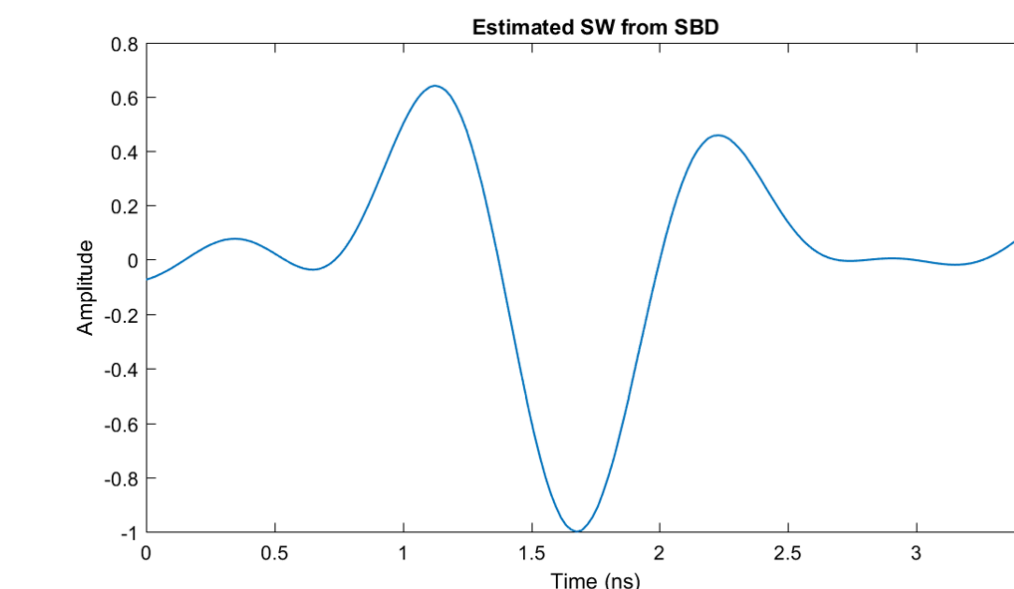


Figure 5: SBD resulted source wavelet and reflectivity series for the real pipe [3]