Elastic full-waveform inversion: density effects, cycle-skipping and inter-parameter mapping

Wenyong Pan*, Kris Innanen
wpan@ucalgary.ca

Summary

In this research, we will practice full-waveform inversion (FWI) methods for recovering elastic parameters. Three-parameter elastic FWI suffers from several challenges: density is difficult to reconstruct, high non-linearity results in cycle-skipping problem, and the inter-parameter cross-talk increases the uncertainties significantly.

Effects of density

Density is very important for fluid reservoir characterization. However, density is difficult to reconstruct in seismic inverse problems, which maybe caused by its insensitivity to travel time or the potential trade-off from shear-wave velocity. In this section, we will study the effects of density in elastic FWI.

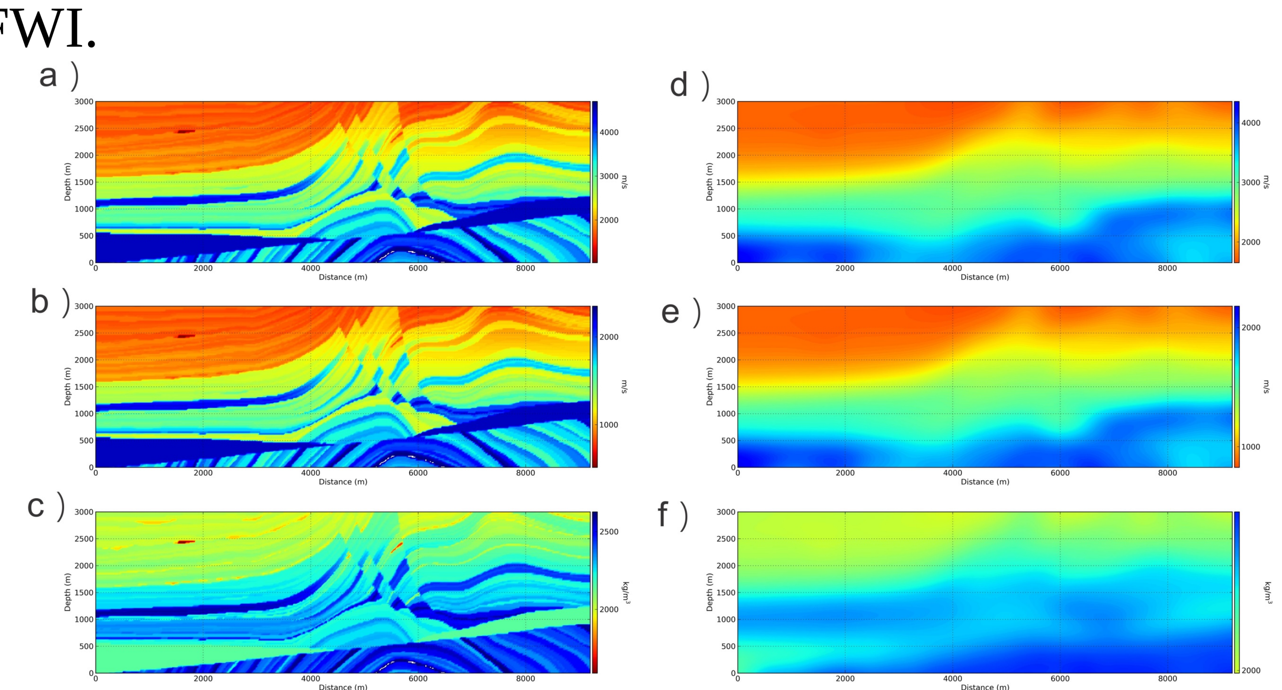

Figure 1. (a)-(c) show the true P-wave, S-wave and density models. (d)-(f) show the initial P-wave, S-wave and density models.

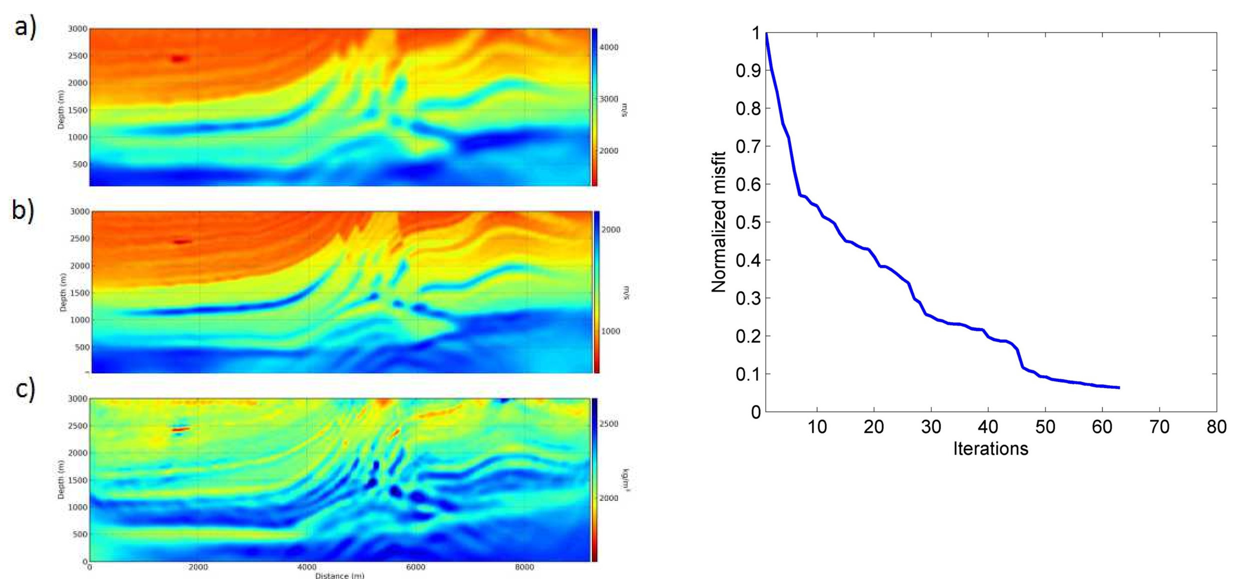

Figure 2. (a)-(c) show the inverted P-wave, S-wave and density models with a simultaneous inversion strategy.

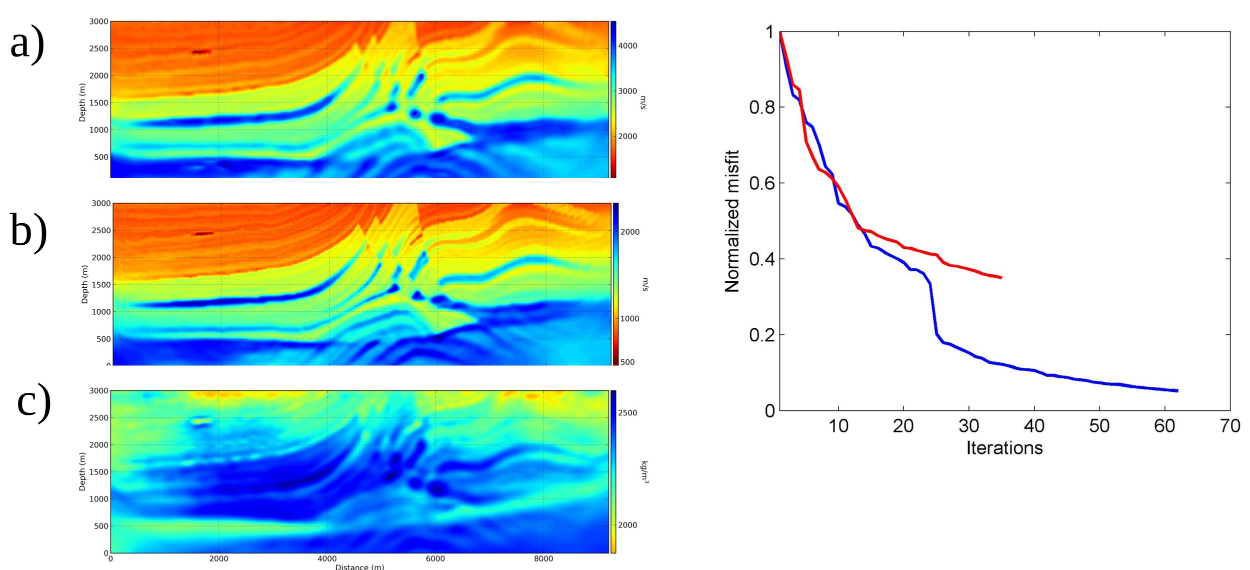

Figure 3. (a)-(c) show the inverted P-wave, S-wave and density models with a hierarchy inversion strategy.

Overcoming cycle-skipping difficulty

FWI is an ill-posed inverse problem and the model parameters are related to the seismic data non-linearly, which results in the cycle-skipping difficulty in FWI. To reduce this problem, we use wave-equation travel time inversion method. Because travel time information relates the model parameter more linearly.

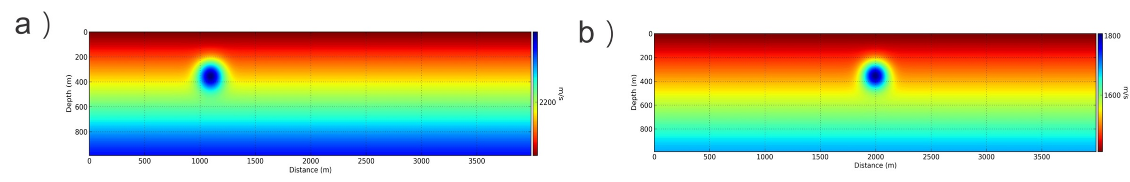

Figure 4. (a) and (b) show the true P-wave and S-wave models. The initial P-wave and S-wave models are homogeneous.

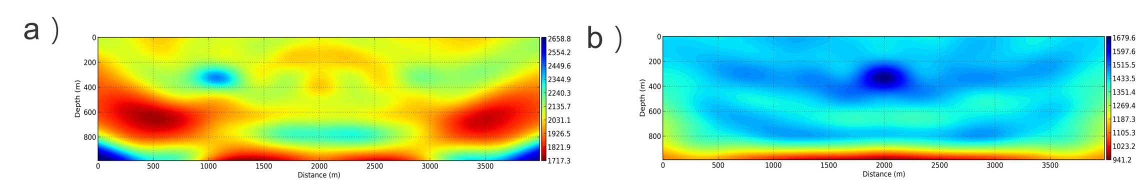

Figure 5. (a) and (b) show the inverted P-wave and S-wave models using waveform inversion method directly.

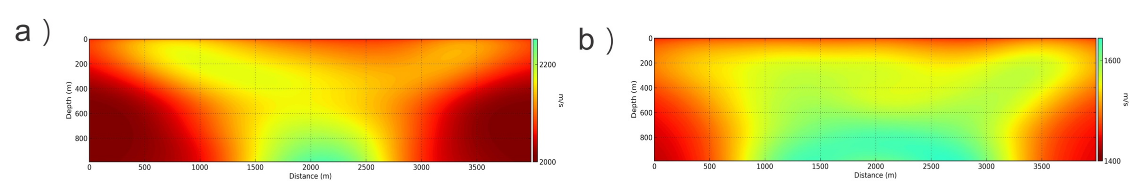

Figure 6. (a) and (b) show the inverted P-wave and S-wave models using travel time inversion method.

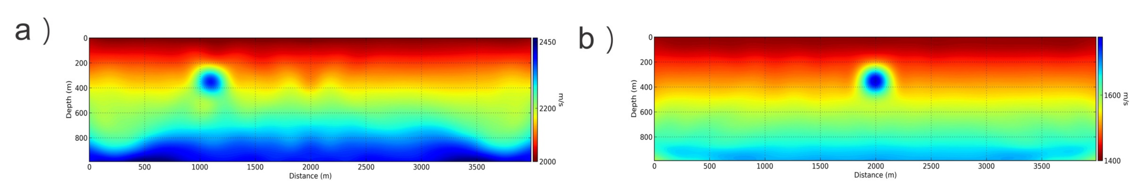

Figure 7. (a) and (b) show the inverted P-wave and S-wave models by waveform inversion using the P-wave and S-wave models shown in Figure 6 as initial models.

Figures 3a and 3b show the true P-wave and S-wave velocity models. The initial P-wave and S-wave velocity models are homogeneous. As we can see in Figure 4, the background velocity increases linearly, which represents long wavenumber component of the model. The two Gaussian anomalies represent short wavenumber components of the model. Figure 5a and 5b show the inverted models using waveform inversion method directly. We observe that the background of the models can not be inverted. Figures 6a and 6b show the inverted models using wave-equation travel time inversion method. The long wavenumber components of the models have been reconstructed. We then use the inverted models in Figure 6 as initial models to do waveform inversion. The models are inverted very well, as shown in Figures 7a and 7b.

Inter-parameter mapping problem

Multi-parameter FWI also suffer from parameter crosstalk problem. The perturbation of one physical parameter maps into the gradients of other parameters, which results in the parameter crosstalk artifacts. In this section, we give numerical examples to illustrate the parameter trade-off phenomena.

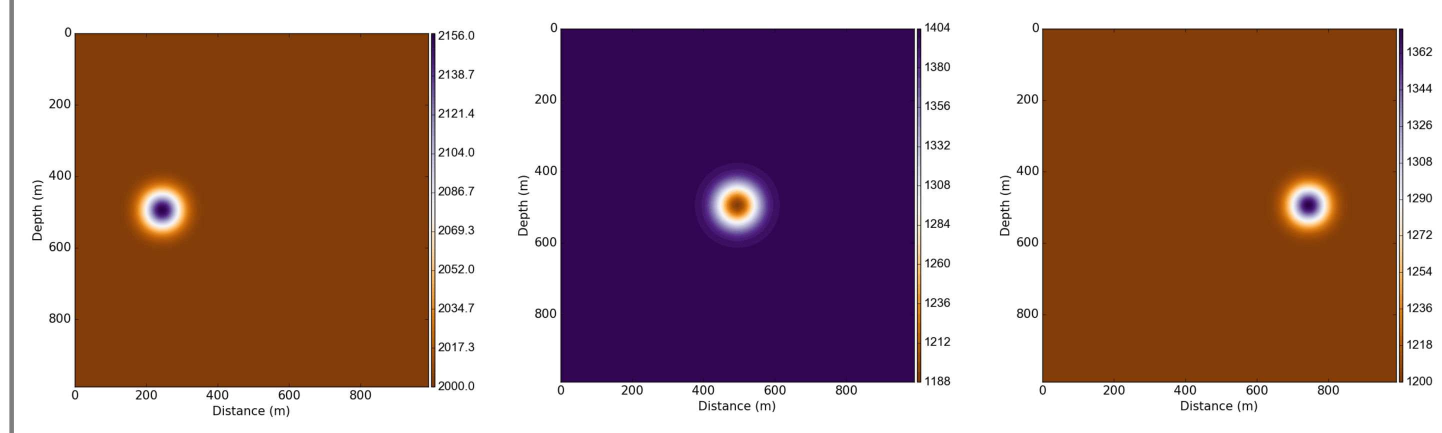

Figure 8. The left, middle and right figures show the true P-wave, S-wave and density models with Gaussian anomalies.

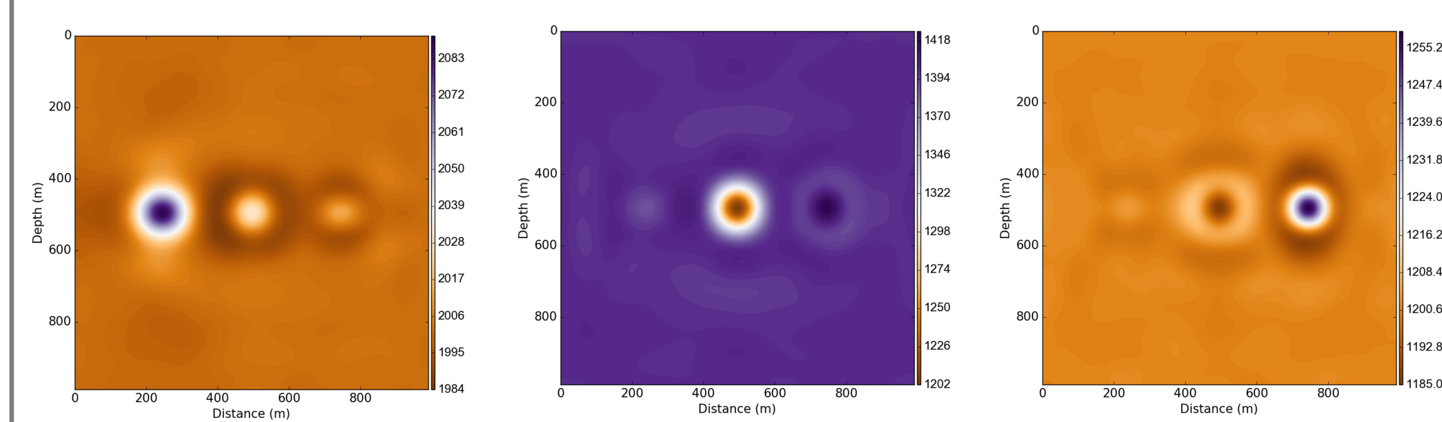

Figure 9. The left, middle and right figures show the invert P-wave, S-wave and density models with Gaussian anomalies.

Figure 8a, 8b and 8c show the true P-wave, S-wave and density models with three Gaussian anomalies, which are uncorrelated. The initial models are homogeneous. We perfect acquisition geometry. The left, middle and right figures show the inverted P-wave, S-wave and density models. It obvious that the inverted P-wave velocity model is contaminated by the mappings due to S-wave velocity and density perturbations. Similarly, inverted S-wave velocity and density also suffer from this problem.

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