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Source-independent acoustic full-waveform inversion

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Summary

Full waveform inversion (FWI) can reconstruct high-resolution subsurface velocity and lithological structure even in complex geological settings, and has been widely developed. But reliable inversion of real data usually requires accurate source wavelet information, which remains one of the main challenges of FWI. In this paper, based on the traditional iterative estimation of source signature (IES) method, a new source wavelet estimation equation is used to propose a new source-independent FWI method. The new method is demonstrated by testing it on synthetic data with different starting models, different real models, different levels of random noise, and different types of source wavelets. It does not require any prior source wavelet information. It does not require an exact starting model; even a 1D starting model is feasible to output accurate wavelet estimates. It is stable against random noise. Based on the newly proposed wavelet estimation equation, good estimates of source wavelets can be obtained from poorly converged models. In summary, the performance of the new source-independent FWI on synthetic data tests is close to that of the known-source wavelet FWI, while maintaining the ease of operation of the IES method.

Theory

In a conventional source-independent FWI method, i.e. the IES method, the source wavelet is updated iteratively via (Song et al., 1995; Pratt, 1999) :

$$\widehat{w}^k(\omega) = \frac{\sum_{i=1}^{n} \hat{d}_{obs}(\omega,i)conj\left(\hat{G}_{syn}^k(\omega,i)\right)}{\sum_{i=1}^{n} \hat{G}_{syn}^k(\omega,i)conj\left(\hat{G}_{syn}^k(\omega,i)\right)}, \quad (1)$$

where $\widehat{w}$ is the frequency-domain source wavelet, $\hat{d}_{obs}$ is frequency-domain observed data (shot gathers), $\hat{G}_{syn}$ is the frequency-domain Green's function, ω is the angular frequency, $conj(\cdot)$ is the conjugate operator, i is the index of traces in a certain shot gather, n is the total receiver number, and the superscript k is the iteration number. Nevertheless, a good source wavelet estimation using equation (1) requires accurate input model parameters, which are rarely satisfied. Hence, we develop a new formula for source wavelet estimation, given by:

$$\widehat{w}^k(\omega) = \frac{1}{n}\sum_{i=1}^{n} \frac{\hat{d}_{obs}(\omega,i)conj\left(\hat{G}_{syn}^k(\omega,i)\right)}{\hat{G}_{syn}^k(\omega,i)conj\left(\hat{G}_{syn}^k(\omega,i)\right)}. \quad (2)$$

Results, Observations, Conclusions

An acoustic model, considering P-wave velocity only, is applied to have comparisons between the conventional IES method, i.e., the IES method based on equation 1, and the new IES method, i.e., the IES method based on equation 2. In Figure 1, the true P-wave velocity model and four starting models are plotted. In Figure 2, the final estimated wavelets using different starting models for both conventional and new IES methods are plotted. In Figure 3, the final inverted models using different starting models for both conventional and new IES methods are plotted. Moreover, in Figure 3, we also plotted the inverted results of the know-source-wavelet (KSW) method as references, in which the true wavelet is employed as the input during the inversion. The results demonstrate that the new formula (equation 1) is better than the conventional one, can estimate source wavelet more accurately, and the performance of the new IES FWI on synthetic data tests is close to that of the KSW FWI.

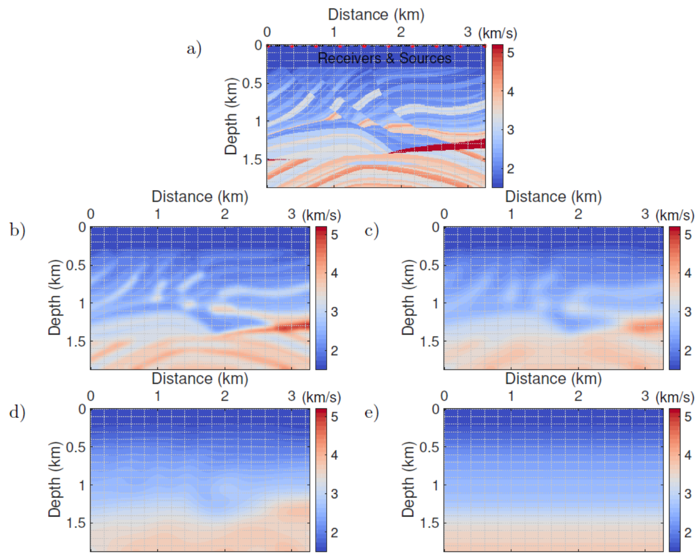

Figure 1: (a) True model (P-wave velocity) and acquisition geometries, (b) starting model 1, (c) starting model 2, (d) starting model 3, (e) starting model 4. Models 1 to 4 become smoother and smoother, and starting model 4 is 1D. The dash lines and asterisks in (a) are the locations of receivers and sources, respectively.

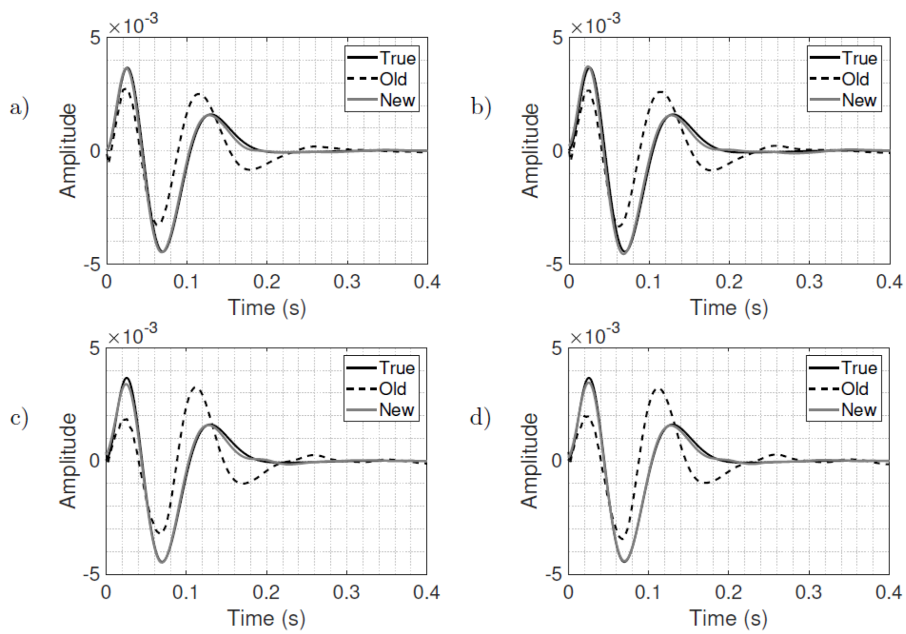

Figure 2: The final estimated source wavelets of the conventional method and the new method using starting models 1 (a), 2 (b), 3 (c), and 4 (d), respectively. In each panel, the black line is the true source wavelet, the dashed line is estimated from the old method, and the gray line is estimated from the new method.

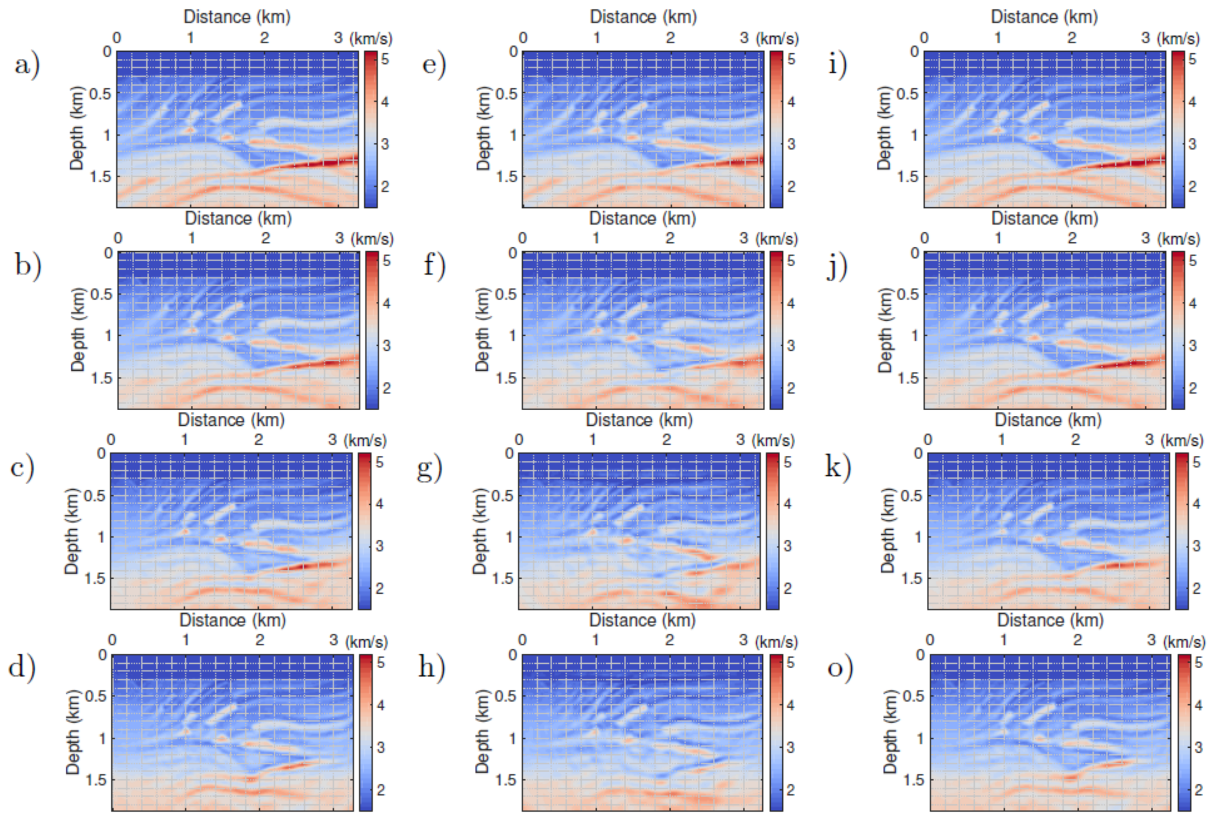

Figure 3: The first column is the final inverted results of the KSW method (using the true wavelet) using starting models 1 (a), 2 (b), 3 (c), and 4 (d), respectively. The second column is the final inverted results of the conventional IES method using starting models 1 (e), 2 (f), 3 (g), and 4 (h), respectively. The third column is the final inverted results of the new IES method using starting models 1 (i), 2 (j), 3 (k), and 4 (o), respectively.

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References

Reference Style (use Arial 9pt normal)
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