Reducing source wavelet non-repeatability for time-lapse shot gathers

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Summary

In time-lapse seismic applications, the signal produced by changes in the properties of subsurface rocks is generally obscured by noise associated with imperfect repeatability between surveys. A particularly important obstacle in the formation of time-lapse difference images is variation in the effective source wavelet between baseline and monitoring datasets. However, the partially separable influence of the wavelet within the Green's function model of seismic data permits two frequency-domain matching filters to be designed, which act to reduce source wavelet non-repeatability. One is based on the spectral ratio of the baseline and monitoring wavelets, and can be applied when prior estimates of the wavelets are available; the other is the average spectral ratio of the baseline and monitoring traces, and can be applied when prior estimates are unavailable.

Theory

We consider the 2D constant-density acoustic wave equation:

$$\frac{\partial^2 P(x,z,t)}{\partial x^2}+\frac{\partial^2 P(x,z,t)}{\partial z^2}-\frac{1}{c^2(x,z)}\frac{\partial^2 P(x,z,t)}{\partial t^2}=w(t)\delta(x-x_0)\delta(z-z_0)\,, \quad (1)$$

where $P(x,z,t)$ is the wavefield depending on coordinates (x,z) and time t, $c(x,z)$ is the P-wave velocity field, and $w(t)$ is the time-dependent source wavelet. The corresponding Green's function $G(x,z,t)$ satisfies:

$$\frac{\partial^2 G(x,z,t)}{\partial x^2}+\frac{\partial^2 G(x,z,t)}{\partial z^2}-\frac{1}{c^2(x,z)}\frac{\partial^2 G(x,z,t)}{\partial t^2}=\delta(t)\delta(x-x_0)\delta(z-z_0)\,. \quad (2)$$

Seismic data (i.e., evaluation of the wavefield P over a set of receivers) can be expressed as convolutions of the Green's function and the source wavelet:

$$d_{1k}(t)=w_1(t)*G_{1k}(t)\,, \quad (3)$$

for baseline seismic data, or

$$d_{2k}(t)=w_2(t)*G_{2k}(t)\,, \quad (4)$$

for monitoring seismic data, where the subscripts 1 and 2 represent baseline and monitoring data, respectively, and k represents the trace number.

When the source wavelets of baseline and monitoring data are different, errors caused by the source wavelet non-repeatability may destroy the final time-lapse imaging. To suppress the errors, two filters in frequency domain are designed for monitoring data. The first one is based on the spectral ratio of the baseline and monitoring wavelets, and can be applied when prior estimates of the wavelets are available, expressed as:

$$f_w(\omega) = \frac{\hat{w}_1(\omega)}{\hat{w}_2(\omega)}, \tag{5}$$

which is similar to the idea in Fu et al. (2020) the other is the average spectral ratio of the baseline and monitoring traces, and can be applied when prior estimates are unavailable, expressed as:

$$f_s(\omega) = \frac{1}{N}\sum_{k=1}^{N}\frac{\hat{d}_{1k}(\omega)}{\hat{d}_{2k}(\omega)}. \tag{6}$$

Numerical Examples and Conclusions

Synthetic shot gathers calculated based on a geological model are employed to demonstrate the feasibility of the two designed filters. Difference data, the monitoring data minus the baseline data, are plotted in Figure 1a-d for different cases. Figure 1a, showing the case of wavelets for baseline and monitoring are identical, is plotted as a reference. And in Figure 1b we observe the difference data are seriously destroyed by the wavelet non-repeatability. The difference data in Figures 1c and d illustrate the good performances of the two designed filters, although $f_s(\omega)$ is not performing as well as $f_w(\omega)$, it has shown a significant improvement when comparing its results with that in Figure 1b.

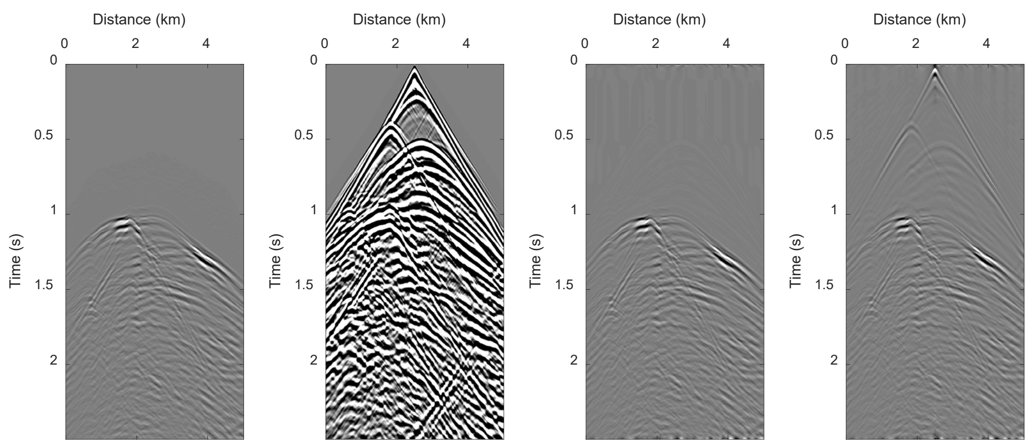

Figure 1: (a) Difference data in the case of wavelets for baseline and monitoring are identical and no filters are used, (b) difference data in the case of wavelets for baseline and monitoring are different and no filters are used, (c) difference data in the case of wavelets for baseline and monitoring are different and monitoring data are filtered by $f_w(\omega)$, (d) difference data in the case of wavelets for baseline and monitoring are different and monitoring data are filtered by $f_s(\omega)$.

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References

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