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A Simple Wavelet-Estimation Approach for Well-Log to Seismic Tying

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Summary

We propose a simple method to estimate the wavelet directly from the seismic records alone. The method is based on utilizing the strongest reflectors, analogous to iterative time-domain deconvolution often used in earthquake seismology. This method is efficient for calculation, robust with respect to noise, and provides a satisfactory accuracy in synthetic and real-data tests. The method is convenient for tying well logs to stacked seismic sections, which is illustrated by the data from the Weyburn Field, Saskatchewan.

Introduction

Knowledge of seismic source waveforms is critical for several seismic data-analysis tasks such as deconvolution, tying well logs to seismic sections, or forward modeling of seismic wavefields. However, source wavelets are often difficult to measure directly and to determine from reflection seismic data. The principal difficulties of such measurements consist in non-stationary character of seismic records, noise, and in non-stationary and non-random character of reflectivity.

The existing methods for wavelet estimation can be subdivided into two broad groups: deterministic and statistical. Deterministic methods are based on known well-log reflectivity and derive the wavelet by minimizing the differences between the synthetic seismogram and the seismic trace recorded at the same location (Oldenburg et al., 1987). However, well logs are not always available, different wells can produce different results, and also because of the effects of noise on the convolutional model, the resulting wavelet may still be non-unique.

Statistical methods (Oldenburg et al., 1987;) estimate the wavelets from seismic data alone and do not require well logs. The missing well-log time series can be replaced by maximum-entropy deconvolution of seismic records (Oldenburg et al., 1987) or assumptions (approximations) about the stationarity of seismic records or pseudo-random reflectivity with white spectra. Alternatively, the resulting wavelet can be constrained by certain expected properties, such as its being zero-phase, minimum-delay, or near-constant phase (Longbottom et al, 1988; van der Baan, 2008). With respect to the noise, both deterministic and statistical methods usually assume white stationary noise within the seismic frequency band.

In this paper, we propose a simple wavelet estimation method belonging to the "statistical" group above. The underlying assumption of the method is that the strongest reflectivity within the time range of interest is statistically not correlated and "sparse", i.e. most reflections from major horizons do not overlap within the wavelet duration. This approach appears to be effective for calculating a wavelet with adequate accuracy, As an illustraton of this approach, we apply it to seismic data from the Weyburn Field, Canada.

Method

According to the seismic convolutional model (Ricker, 1953), the observed seismic trace $s(t)$ can be represented by a convolution of a seismic wavelet $w(t)$ with the earth's reflectivity $r(t)$ plus some additive noise $n(t)$:

$$s(t) = r(t) * w(t) + n(t), \quad (1)$$

where * denotes the convolution operator. In this paper, we view $s(t)$ as a single stacked seismic trace or a combination of multiple records in which the wavelet $w(t)$ is expected to be the same. The reflectivity and noise series accordingly correspond to a single or multiple locations. The key assumptions about the shape of the wavelet $w(t)$ is that it is stationary in time and space within the data subset considered. If the wavelet is non-stationary due, for example, to the effects of attenuation, then the convolutional model (1) could be applied to attenuation-compensated data (Morozov et al., in press). After correcting for attenuation and other deterministic data processing, the non-stationary should reduce, and $w(t)$ would have the meaning of time-independent, combined source and receiver effect.

Our procedure for obtaining $w(t)$ from $s(t)$ in eq. (1) consists in considering only a subset of strongest amplitudes in the (unknown) reflectivity series $r(t)$. Selection of this subset reduces to picking and stacking the strongest reflections in the seismic trace, implemented by the following procedure:

1) Extract a series of overlapping time records from the seismic trace. We achieve this by using a group of overlapping Hanning windows in time. Each window contains a flat portion and two cosine-shaped ramps of equal durations, so that the sum of all windows equals one at any time.
2) In each record $s(t)$ tapered within one window, pick several largest peaks (negative or positive) and measure the amplitudes Ai of each peak i. This amplitude is then normalized by the root-mean-square (RMS) amplitude (A_{rms}) of the tapered window record:

$$\tilde{A}_i = \frac{|A_i|}{A_{\text{rms}}}. \quad (2)$$

3) For each selected pick, extract a window centered on it. The length of this window equals the time duration of the estimated wavelet.
4) Align these wavelet windows on the times of the selected peaks and sum them with weights proportional to the relative amplitudes:

$$w_i = \tilde{A}_i \operatorname{sgn}(A_i), \quad (3)$$

where sgn is the sign function. The result of this summation is the estimated wavelet.

After the wavelet is estimated by using the above procedure, it can be transformed to zero phase (an even function of t extracted from $w(t)$) or to minimum-delay if desired. In our initial experiments (next section), it appears that this procedure generally preserves the phase but tends to recover wavelets consisting of a single peak at $t = 0$. This property results from the (empirical) sparseness of the reflectivity series $r(t)$. It appears that such property of the extracted wavelet should be suitable for practical seismic data analysis, such as evaluating the well-to-seismic ties.

Example

Figure 1 shows an application of the above procedure to one stacked, vertical-component record from the 3-D 3-C dataset acquired in 1999 for Weyburn CO_2 sequestration project. The time range for this seismic trace is 3000 ms (Figure 1a) and a taper window of 150 ms was selected. Within each of the 58 tapered records, three peaks were picked within it, aligned and stacked by using the procedure (2) – (3). Figure 1b and c show the estimated wavelet and its amplitude spectrum.

Further ongoing tests (not shown here) suggest that the wavelet estimated from stacked Weyburn records is nearly zero-phase (Figure 1a), reasonably stable within a given time-lapse dataset, but contains small differences for the three available time-lapse vintages. The wavelet is also effective and convenient for deriving well-to-seismic ties.

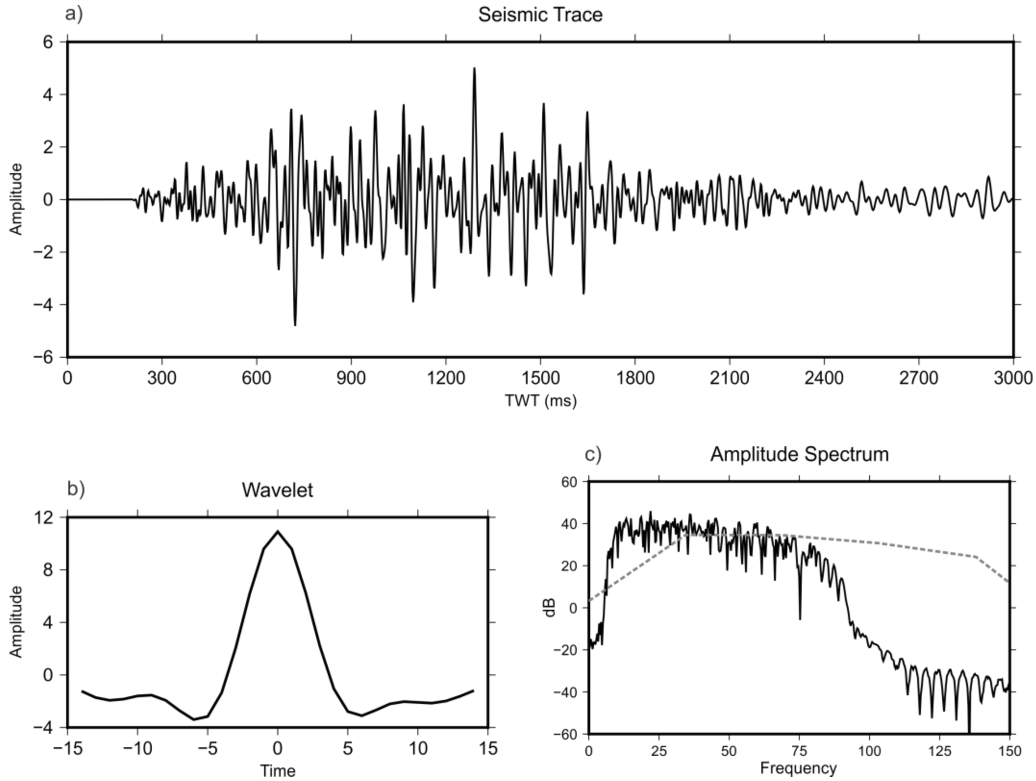

Figure 1: An example of wavelet estimation from stacked seismic data: a) seismic trace, b) estimated wavelet, and c) amplitude spectrum of the seismic trace (black curve) and of the estimated wavelet (grey dashed line).

Conclusions

We propose a simple method for estimating the seismic wavelet from reflection data alone. A real data example shows that the proposed method can provide wavelet estimates useful for seismic data analysis.

References

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