Ground roll attenuation with adaptive eigenimage filtering

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Summary

Eigenimage filtering has been used as a tool for separating seismic signal and coherent noise for some time. The basic idea behind the method is to estimate the high-energy coherent noise within a window of traces using the first eigenimages and then subtract out the reconstructed noise, leaving the signal. A difficulty with this approach lies with having to determine how many eigenimages should be used to optimally remove the noise and preserve the signal. The new method that is introduced here automatically determines the number of eigenimages that represent noise based on a frequency-adaptive signal-to-noise measure. The number of eigenimages that represents the noise is allowed to vary with frequency and space within a seismic survey. Within a frequency band where the signal-to-noise ratio is low, a larger number of eigenimages is used to construct the noise than in another frequency band with higher signal-to-noise. The energy of the signal that underlies the coherent noise is estimated in a separate portion of the data that is free of coherent noise, such as the deconvolution design gate. This adaptive S/N measure allows eigenimage filtering to attenuate a large amount of coherent noise such as ground roll while preserving signal.

Introduction

Techniques to eliminate noise are commonly developed based upon the characteristics of the noise. Ground roll, for example, appears as low-velocity, low-frequency and high-amplitude dispersive waves which are distributed in fan-shaped zones at near offsets about the source. Traditional filtering methods such as F-K or tau-p filtering can be very effective at attenuating ground roll but they may have limited success because of incomplete separation of signal and noise in the transform domain. They also can suffer from irregular trace spacing and data aliasing and can generate artifacts due to spatial impulse-response smearing.

Eigenimage filtering with the Karhunen-Loeve (KL) transform or singular-value decomposition (SVD) is able to avoid many of these sampling and smearing issues (Liu, 1999, Chiu and Howell, 2008). With either KL transforms or SVD the data is decomposed into a set of eigenimages with associated non-negative eigenvalues that are ordered from largest to smallest in magnitude. For portions of the data that are contaminated with coherent noise such as the ground roll cone, the eigenimages associated with the largest eigenvalues consist of large-amplitude coherent noise. Setting all but the largest eigenvalues to zero allows the coherent noise to be reconstructed and then subtracted from the original data.

A difficulty with this method of separating coherent noise and signal based on eigenimages is that the number of eigenimages that represents noise needs to be picked by the user in such a way as to optimally suppress the noise and preserve the signal. This can be difficult to do, especially in situations where the signal-to-noise ratio varies spatially within the same seismic survey. In addition, the signal-to-noise ratio is usually highly dependent on frequency. Ground roll normally dominates the low frequencies, below 10 Hz, but ground roll can extend to higher frequencies where the signal is also strong. A frequency band that is low would have a low signal-to-noise ratio, so a large number of eigenimages would represent noise. However, a higher frequency band would have a higher signal-to noise ratio and therefore a smaller number of eigenimages would represent noise.

We present a method that automatically determines the number of eigenimages that represent noise by using a signal-to-noise measure that varies with frequency and space. Within each shot gather the method attenuates noise only within the ground roll cone which is assumed to consist of the sum of coherent noise and signal. The number of eigenimages that correspond to the signal underlying the noise is determined by comparing the amount of energy in the ground roll cone to the energy in another window that is free of ground roll, such as the deconvolution gate. The signal-to-noise ratio is determined in this way for a number of separate frequency bands within each shot gather. Using this information, the coherent noise is constructed and subtracted from the original data.

It is important to note that for real data there is no exact number of eigenimages where the image switches from pure noise to pure signal. At best we can expect the first eigenimages to comprise pure noise and the next eigenimages to comprise both signal and noise. Therefore the best we can expect from eigenimage filtering is a result that preserves signal and removes most of the noise. Despite this limitation, the method works remarkably well.

Method

Our method uses SVD to decompose the data within the ground roll cone on each shot gather into a set of eigenimages for a small number of traces and within a limited set of frequency passbands. In order for SVD to concentrate the noise into the first of the eigenimages, the ground roll within the cone is first “flattened” by applying linear moveout, and then by applying a trim static that is determined by cross-correlation. Since the ground roll can change spatially even within a single shot gather, we decompose N traces within the ground roll cone at a time, where N is usually 20 to 50. We do not use any temporal windowing of the traces within the ground roll cone.

The data is bandpass filtered into a number of separate frequency bands and SVD is performed on each of them. The magnitude of the resulting eigenvalues represents the relative energy of each associated eigenimage. The first eigenimages are assumed to comprise only noise. The energy within a separate window such as the deconvolution gate is assumed to consist only of signal. Furthermore, the level of energy within the signal window is assumed to be equal to the amount of signal energy inside the ground roll gate (when appropriately normalized). The signal-to-noise ratio for each frequency passband is determined in this way and is used to determine the number of eigenimages that represent noise within each frequency band. In general, more eigenimages represent ground roll at low frequencies than at high frequencies.

The full noise model is reconstructed from the appropriate number of eigenimages from each of the frequency bands and from all sets of N traces. A simple subtraction of the modelled noise from the original data then yields the noise attenuated result. Adaptive subtraction is not used.

Data Examples

The first example illustrates the frequency dependence of the signal and the noise, and the need to use a different number of eigenimages within each frequency passband. Figure 1 (a) to (c) shows the input shot record with dispersive ground roll and scattered noise within the ground roll cone at near offsets, filtered from 0 to 15 Hz, 15 to 30 Hz and all frequencies, respectively. Obviously there is much more noise than signal from 0 to 15 Hz and more signal than noise from 15 to 30 Hz. The signal level within the noise cone was estimated by measuring the energy in the traces in the deconvolution gate which was specified as usual from a window that includes the reflections below the first break energy and outside the noise cone.

Figure 1 (d) to (f) shows the result after adaptive eigenimage filtering with the same bandpass filtering as Figure 1 (a) to (c). Notice that there is a slight amount of linear noise remaining but overall the result is very good. Figure 1 (g) to (i) illustrates the noise that has been removed, and filtered in the same way as the previous displays. Notice that there is no visible signal in the modelled noise. Also notice that the method has successfully separated out the noise and the signal in a frequency-dependent manner.

The second example illustrates the ability of the method to adapt to the spatial variations in signal-to-noise ratio. A common issue with land seismic data is that there can be large variations in the amount of signal and the amount of noise even within the same survey. A good noise attenuation method will be able to adapt to these changes.

Figure 2(a) shows a shot gather from a seismic line where there is little to no visible signal. Figure 2(d) shows another shot gather from the same seismic line that shows much better signal. Figures 2(b), (c), (e) and (f) show that our method is able to successfully remove the noise in both cases. The same parameters for the ground roll attenuation method were used for the entire line.

Conclusions

We have presented a method of applying eigenimage filtering to the problem of attenuating coherent noise on prestack seismic records. A difficulty with previous applications of this type of method is the problem of choosing the number of eigenimages that represent the noise. We have overcome this problem by designing a signal-to-noise measure that adapts to the spatial and frequency variations in the signal and the noise. The method is able to automatically remove coherent noise and preserve signal.

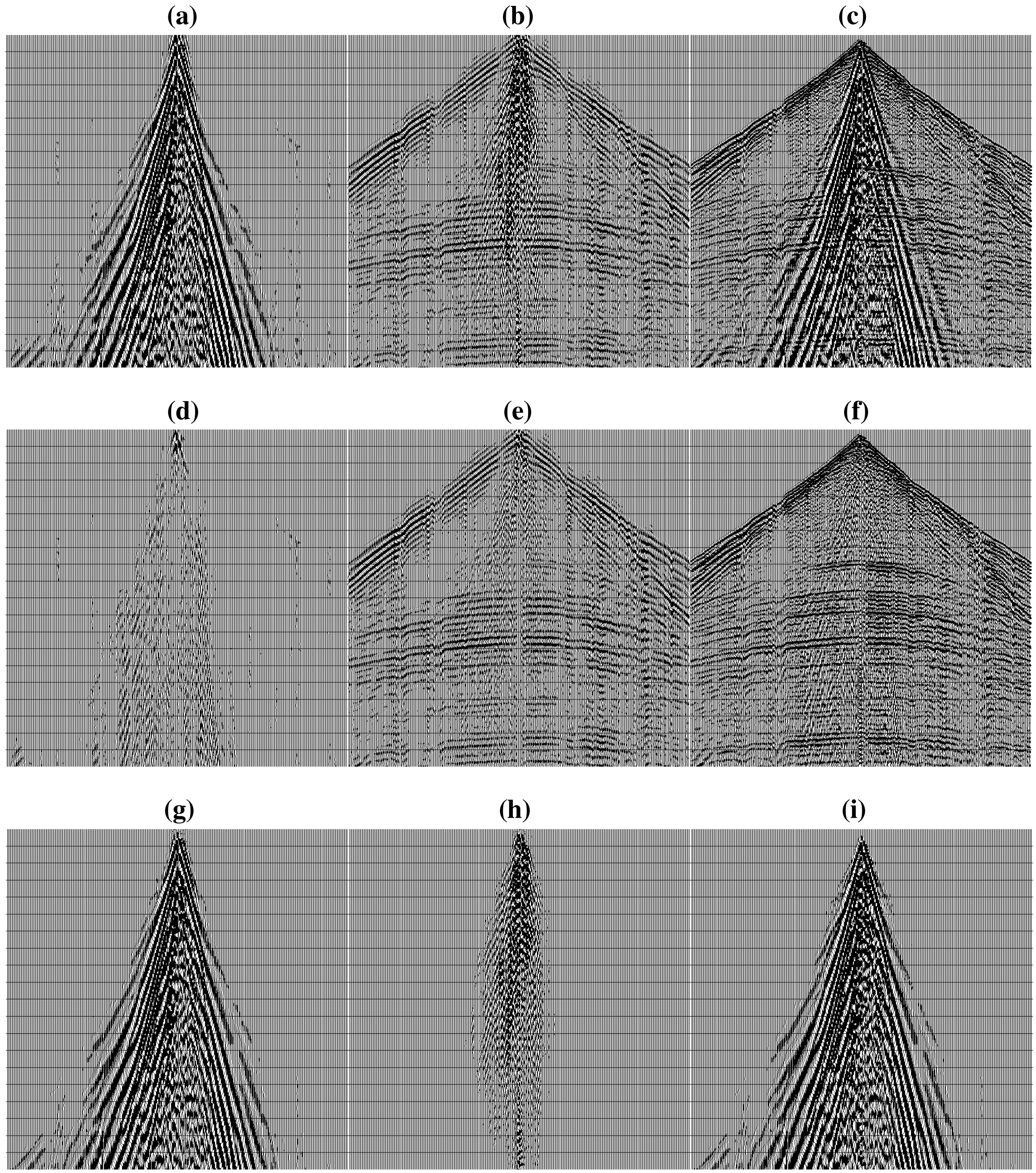

Figure 1: Attenuation of ground roll and scattered noise as a function of frequency: (a) A shot record containing ground roll and scattered noise filtered from 0 to 15 Hz, (b) from 15 to 30 Hz, and (c) unfiltered. (d) The ground roll attenuated shot gather bandpass filtered from 0 to 15 Hz, (e) from 15 to 30 Hz and (f) unfiltered. (g) The ground roll removed by eigenimage filtering bandpass filtered from 0 to 15 Hz, (h) from 15 to 30 Hz and (i) unfiltered. Notice the frequency dependence of the signal and noise, and the absence of signal in the modelled noise.

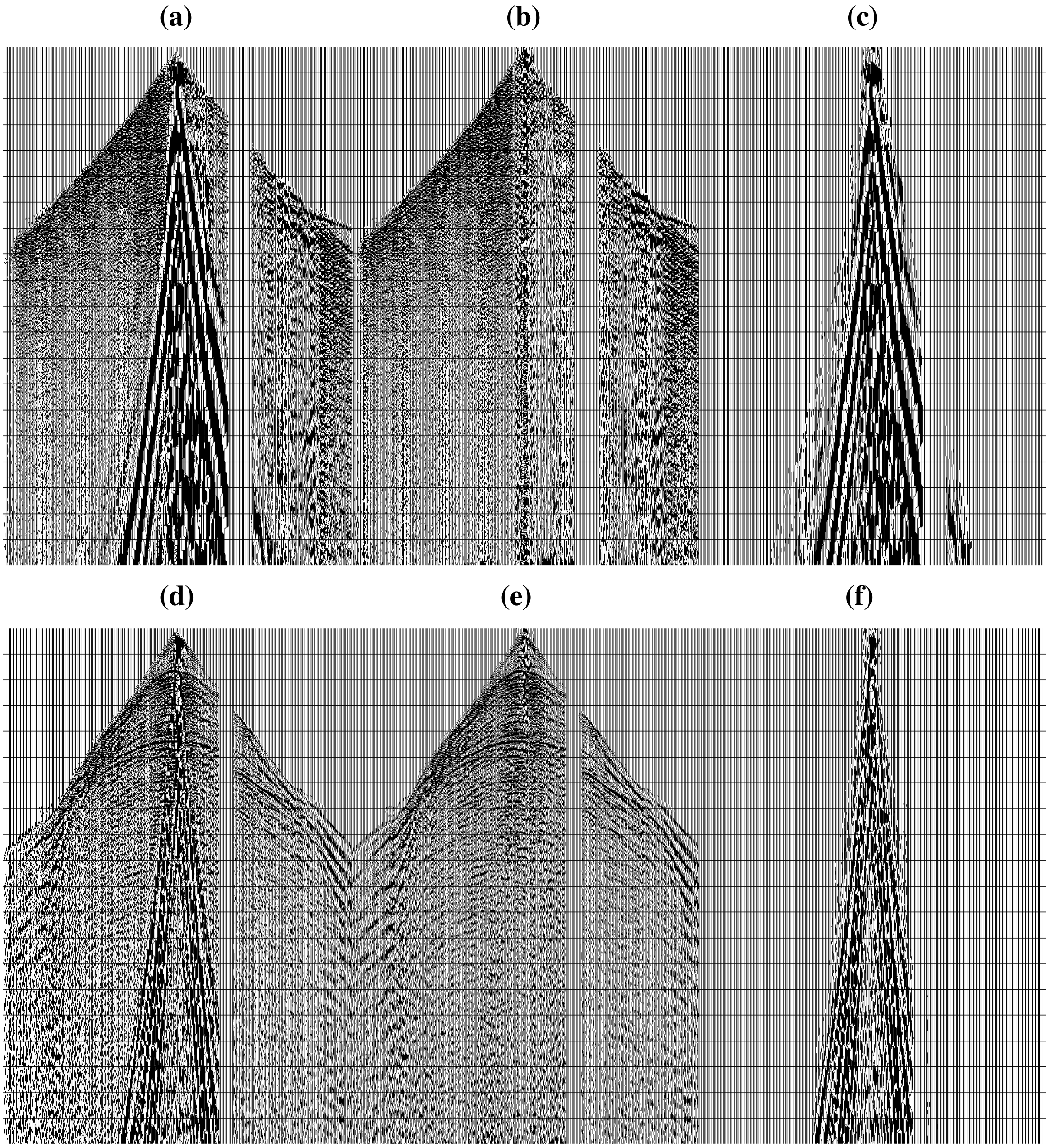

Figure 2: Attenuation of ground roll with spatially varying signal-to-noise ratio: (a) a shot gather with strong ground roll and weak signal (b) after adaptive eigenimage filtering, (c) the difference. (d) another shot gather from the same seismic line with ground roll and stronger signal, (e) after eigenimage filtering, (c) the difference.

EDITED REFERENCES

REFERENCES

Chiu, S. K., and J. E. Howell, 2008, Attenuation of coherent noise using localized-adaptive eigenimage filter: 78th Annual International Meeting, SEG, Expanded Abstracts, 2541–2545.
Liu, X., 1999, Ground roll suppression using the Karhunen-Loeve transform: Geophysics, **64**, 564–566.