Polarization Filter by Eigenimages and Adaptive Subtraction to Attenuate Surface-Wave Noise

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Summary

Multi-component recording contains full wavefield information that can be used in polarization filtering to attenuate surface-wave noise. The polarization filter used here is a station-by-station approach that combines statics, signal-to-noise ratio, and eigenimages to construct a surface-wave noise model and then applies an adaptive subtraction to remove the noise. Statics and signal-to-noise ratio are two of the key components needed to construct a reliable noise model. Applications of this filter on synthetic and real data examples illustrate the effectiveness of this method.

Introduction

The attenuation of ground roll is a major challenge in land seismic data. Ground roll is typically dispersive and much higher in amplitude than reflected signals. Its slow velocity often creates aliased noise in the data that make traditional filtering such as FK filtering less effective. In addition, the traditional filtering does not leverage the vector information of multi-component (MC) data. Recent advances of using single-point receivers in recording 3C data require processing techniques to separate signals from strong surface noise in lieu of signal enhancement through receiver-array summing. The advantages of using single-point receivers are to better preserve amplitude and bandwidth of the signals and to avoid signal distortions from receiver-array summing, especially for shear wave data when the receiver-array statics are large. Polarization filtering is one of the processing techniques that utilizes the vector information of the MC data to attenuate strong surface noise.

Polarization filtering has been demonstrated as an effective tool to estimate polarization direction and to enhance signals on MC data. Vidale (1986) recognized that the Rayleigh wave (also known as ground roll) was elliptically polarized. He applied a complex polarization filter to discriminate linearly polarized P waves from elliptically polarized Raleigh waves. Franco (2001) employed eigenimages derived from singular value decomposition (SVD) on the data matrix to enhance signals from a noisy background. Kendall et at. (2005) and Meersman (2005) modeled ground roll by a complex SVD using either multiple receiver stations or a single station and subtracted the noise model from original data.

Our polarization filter operated in a single station consists of two main steps: modeling of surface-wave noise directly from 3C data and an adaptive subtraction to remove the noise. Our method makes some improvements over Kendall's work. The improvements are to combine statics, signal-to-noise ratio, and eigenimages to construct a more reliable noise model of surface waves and to use an adaptive subtraction to account for the nonstationary nature of surface waves. This approach is a station-by-station method that does not depend on the acquisition geometry and spatial sampling of the data. It attenuates the aliased as well as non-aliased noise quite well and also does not smear the amplitudes spatially. We demonstrate the effectiveness of this filter with synthetic and real data examples.

Method

The basis of modeling surface-wave noise is to use a complex SVD to derive a noise model directly from 3C data that provide particle motions of the surface wave. In general, the polarization analysis is most accurate when there is a single wave type present in an analysis window. However, for example, ground roll is typically a wave train with a mixture of Love waves, Rayleigh waves, and shear refracted arrivals. The multiple wave types present within an analysis window significantly reduce the reliability of the polarization analysis. To avoid the drawbacks of a traditional polarization analysis, we model the strong surface wave with eigenimages. The filtering window is a time and offset variant window based on the surface-wave velocity. Within the window of a single station, surface wave noise represents the most dominant energy and the statics derived from cross correlating the 3C data aligns the dominant noise energy. This alignment helps to better extract the noise through the use of SVD. The data in the analysis window with the statics applied is first transformed into analytic signals (Vidale, 1986) and followed by a complex SVD to decompose the analytic signals into eigenimages that represent the surface-wave noise model. The signal-to-noise ratio further constrains the noise model to ensure that the noise model is only valid when the noise-to-signal ratio is greater than a user-defined threshold. This constraint is important in order to preserve the primary signals as much as possible.

There are numerous techniques to perform the adaptive subtraction. We use a time-varying least-squares Wiener match filter (Robinson and Treitel, 1980) because of its robustness in processing operations. The noise model is divided into a number of overlapping time windows. Within each time window, it uses input data and the noise model to design a least-squares Wiener match filter. The Wiener match filter adjusts the amplitude and phase of the surface-wave noise before subtracting it from the data.

Data Examples

We first demonstrate the effectiveness of this method with a synthetic data set that is a shot record of 2C (vertical and horizontal inline) data. The strong coherent ground roll is present on both components (Figures 1a and 2a) with significantly aliased energy. The polarization filter does an excellent job to attenuate most of the coherent ground roll including the aliased energy (Figures 1b and 2b). However, there is still some residual ground roll left on the data. The computed noise model, the difference between the input and filtered data (Figures 1c and 2c), indicates that the noise attenuation does not remove any visible primary signals.

We further apply this method on a 3C 3D land data set. The exploration objective is to obtain a high-resolution image of shallow targets. The typical shot interval is 24 m, the receiver interval is 18 m, and the sample rate is 1 msec. The signal bandwidth has a frequency range of 5-200 Hz.

Figures 3a and 3b show a portion of a typical shot record of vertical and radial components. The transverse component is not displayed here. The ground roll is dispersive and stronger in amplitude than reflected signals. The polarization filter virtually attenuates most of the ground roll (Figures 3c and 3d). Figures 3e and 3f show that the data removed by the polarization filter consists of dispersive, low-frequency ground roll without any noticeable primary signals.

Conclusions

A polarization filter that includes surface-wave modeling and adaptive subtraction effectively attenuates surface-wave noise on 3C data. The use of statics to align the 3C components within a station helps to better model the coherency of the surface wave. The signal-to-noise ratio constraint on the noise model minimizes the removal of primary energy and the use of adaptive subtraction improves the match between the noise model and input data. The filter is applicable to any acquisition geometry because it operates on a single station.

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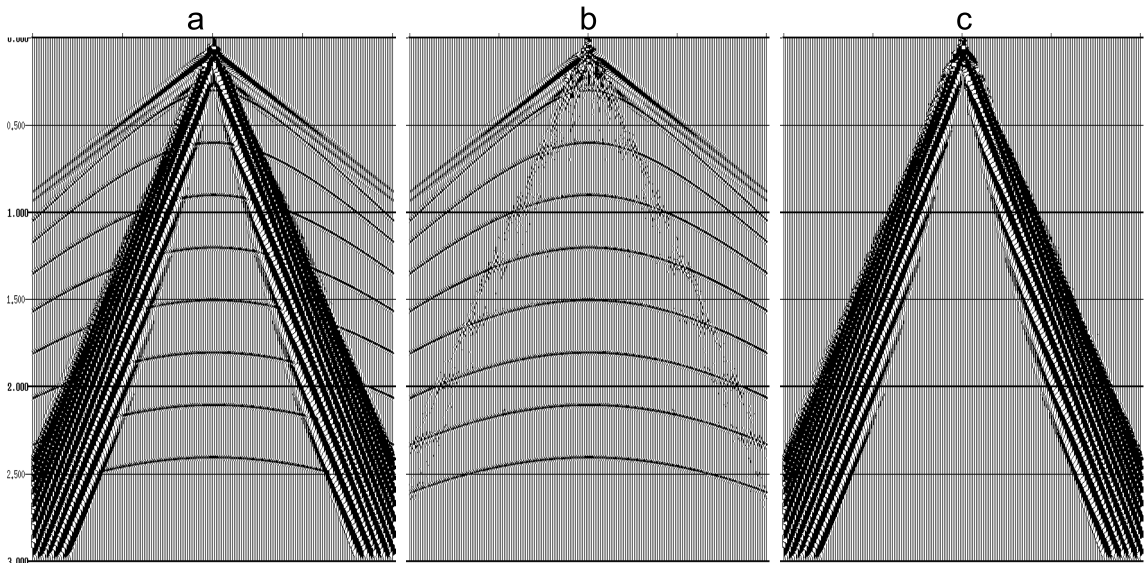

Figure 1. Ground roll attenuation on vertical components of synthetic data: (a) a shot record containing high-amplitude groundroll, (b) after polarization filter, (c) the difference.

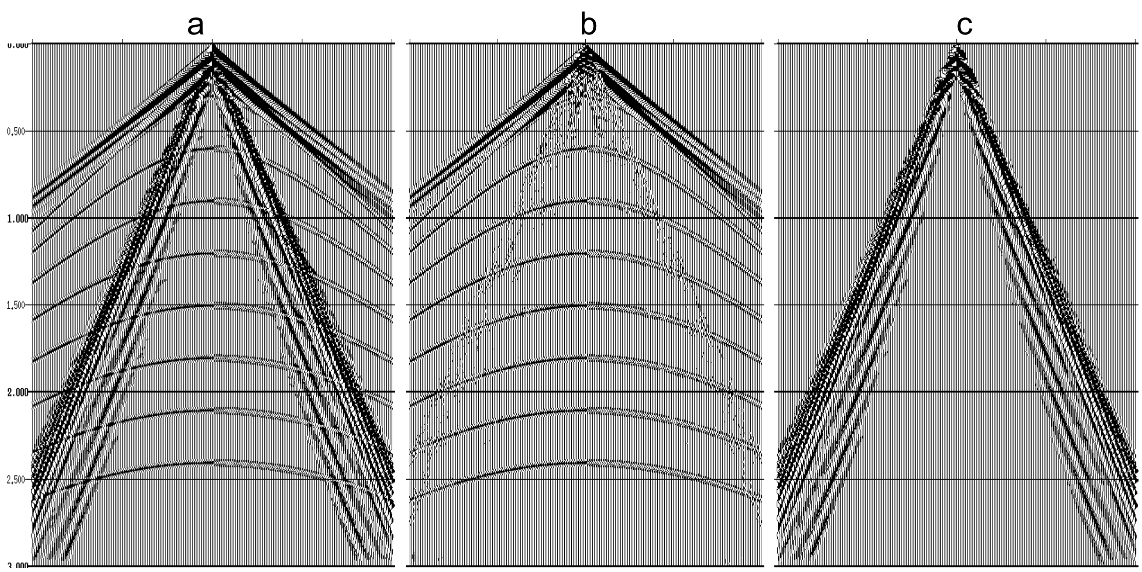

Figure 2. Ground roll attenuation on horizontal-inline components of synthetic data: (a) a shot record containing high-amplitude groundroll, (b) after polarization filter, (c) the difference.

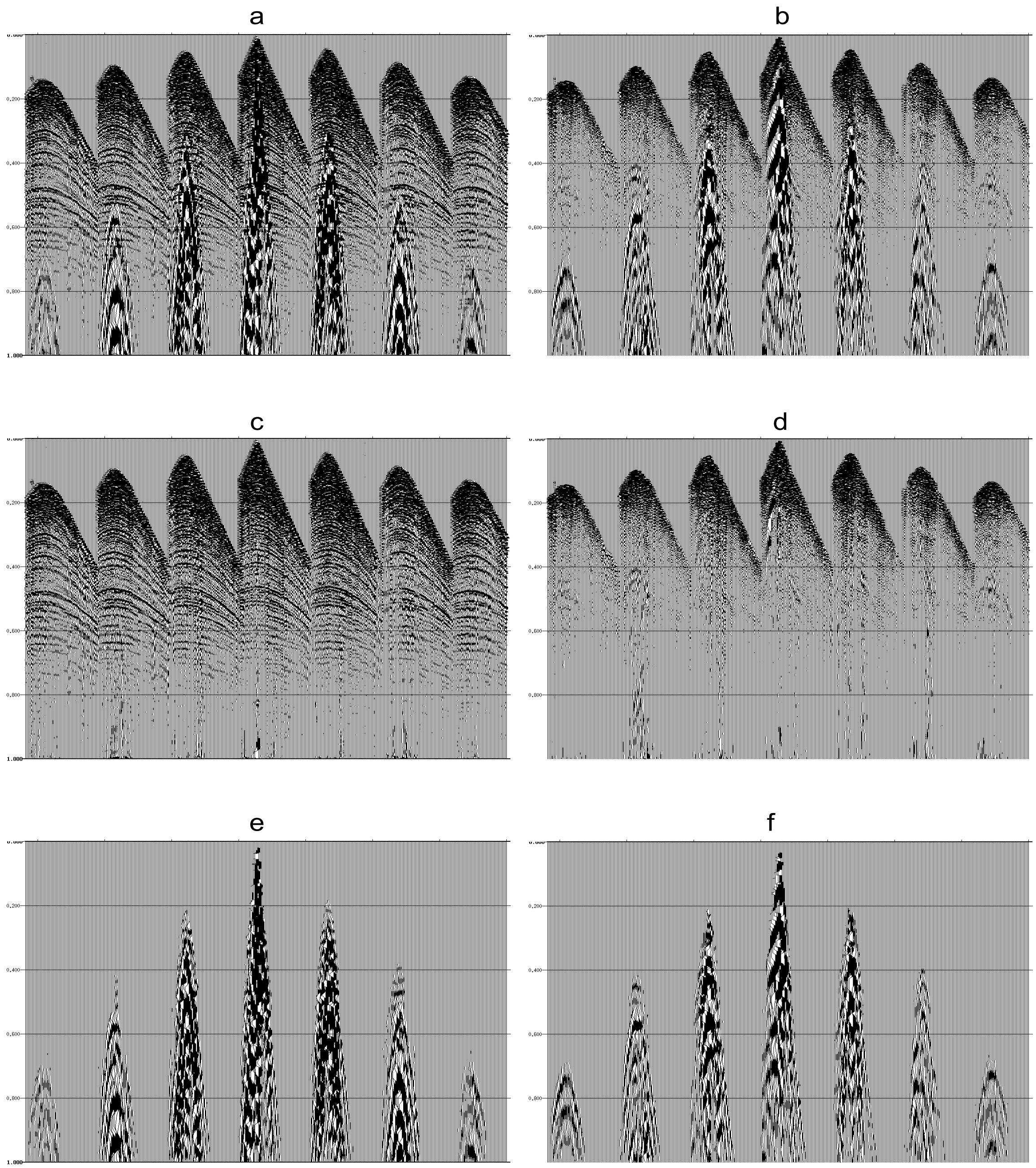

Figure 3. Results of polarization filter on a 3C 3D data: (a) raw shot records of vertical components, (b) raw shot records of radial components, (c) vertical components after polarization filter, (d) radial components after polarization filter, (e) difference of vertical components, (f) difference of radial components.