Ground roll attenuation with singular value decomposition

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Abstract

Ground roll attenuation is an important step in seismic data processing. We implement a procedure to eliminate ground roll from seismic data that is based on eigen-images. We use singular-value decomposition (SVD) to distinguish between signal and noise within narrow frequency bands of the ground-roll cone at near offsets in the data. The estimate of the energy of the signal comes from an uncontaminated portion of the seismic records. The method is able to adapt to the changing character of the noise and signal about the seismic survey. The modeled noise is then subtracted from the data while preserving the reflections.

Introduction

Ground roll, which is also known as a Rayleigh waves, is a persistent form of source-generated noise on land seismic data that obscures reflection signal and degrades overall data quality. Finding an optimal method to attenuate ground roll has long been a goal in seismic data processing (Anstey, 1986). In ideal situations the partical motion of Rayleigh waves is retrograde elliptical and confined to the vertical and inline axes, but ground roll is commonly observed on all three components of multicomponent land data.

Techniques to eliminate noise are commonly developed based on the characteristics of the noise. Ground roll appears as low-velocity, low-frequency and high-amplitude 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 can have limited success because of irregular trace spacing and data aliasing. They also can generate artifacts due to spatial impulse-response smearing. It is therefore desirable to have alternative methods to attenuate ground roll.

Eigenimage filtering with the Karhunen-Loeve transform or singular value decomposition (SVD) is able to avoid many of these sampling and smearing issues (Liu, 1999; Franco and Musaccchio, 2001; Kendall and De Meersman, 2005; Chiu et al., 2007, 2008) . Our algorithm is implemented in two steps. The first step estimates ground roll using SVD from the 2-D, 3-D, 1-C or 3-C data within limited frequency bands The second step subtracts the estimated noise from the data. This two-step method tries to optimize ground roll removal while preserving the reflected energy.

Method

The objective is to develop a method to attenuate dispersive, non-stationary and aliased coherent noise in the presence of phase and amplitude perturbations.

Ground roll is dispersive, which means that each frequency travels at a different speed. In order to handle dispersion we bandpass the seismic data within the ground roll window of a shot gather into several frequency bands and process each frequency band separately. The ground roll is then linear along the offset direction and it is straightforward to align, regardless of the spatial sampling of traces. SVD can now be applied to separate the high-amplitude ground roll from the weak underlying reflections which align in a different direction.

We apply SVD to a set of neighbouring traces and apply a threshold to the number of principal components that are used to construct the noise model. The most energetic principal components determine the high-energy ground roll. The remaining principal components determine the reflection signal and random noise. This threshold can be adjusted to preserve the signal as much as possible.

A method of determining the signal-to-noise ratio is needed in order to determine the threshold between signal and noise. We use a portion of the seismic data that is uncontaminated by ground roll in order to measure the energy of the signal within each frequency band. The data within the ground roll cone contains both signal and noise. The ratio of energy between the ground roll cone and the area of signal is taken as the frequency-dependent signal-to-noise ratio that determines the threshold.

A problem with ground roll attenuation methods is that the signal-to-noise ratio can change drastically within a single seismic survey, and the frequency band of both the signal and noise can change substantially as well. The present method is able to adapt successfully to these changes.

Examples

The method is first illustrated with a 3-C example since it is able to illustrate how the algorithm adapts to different frequency content of the signal and noise. Figure 1 shows the results of ground roll attenuation using SVD on the first 1000m of offset of a single 3-C, 3-D shot gather. The top row shows the vertical, radial and transverse components before attenuation, the middle row shows the same data after attenuation, and the bottom row is the difference (the noise removed). The method has been able to remove a large amount of the noise while leaving the weaker reflections underneath the noise largely untouched.

Figure 2 shows the method applied to one-component data. Again there is excellent separation between signal and noise.

Conclusions

Separating ground roll from reflections is a difficult task. In a practical manner this goal can be partially achieved through careful extraction of the ground roll from multicomponent or single-component data using SVD and subtracting it from the original traces. The two-step procedure described here attenuates ground roll effectively from seismic data while preserving the reflections.

References

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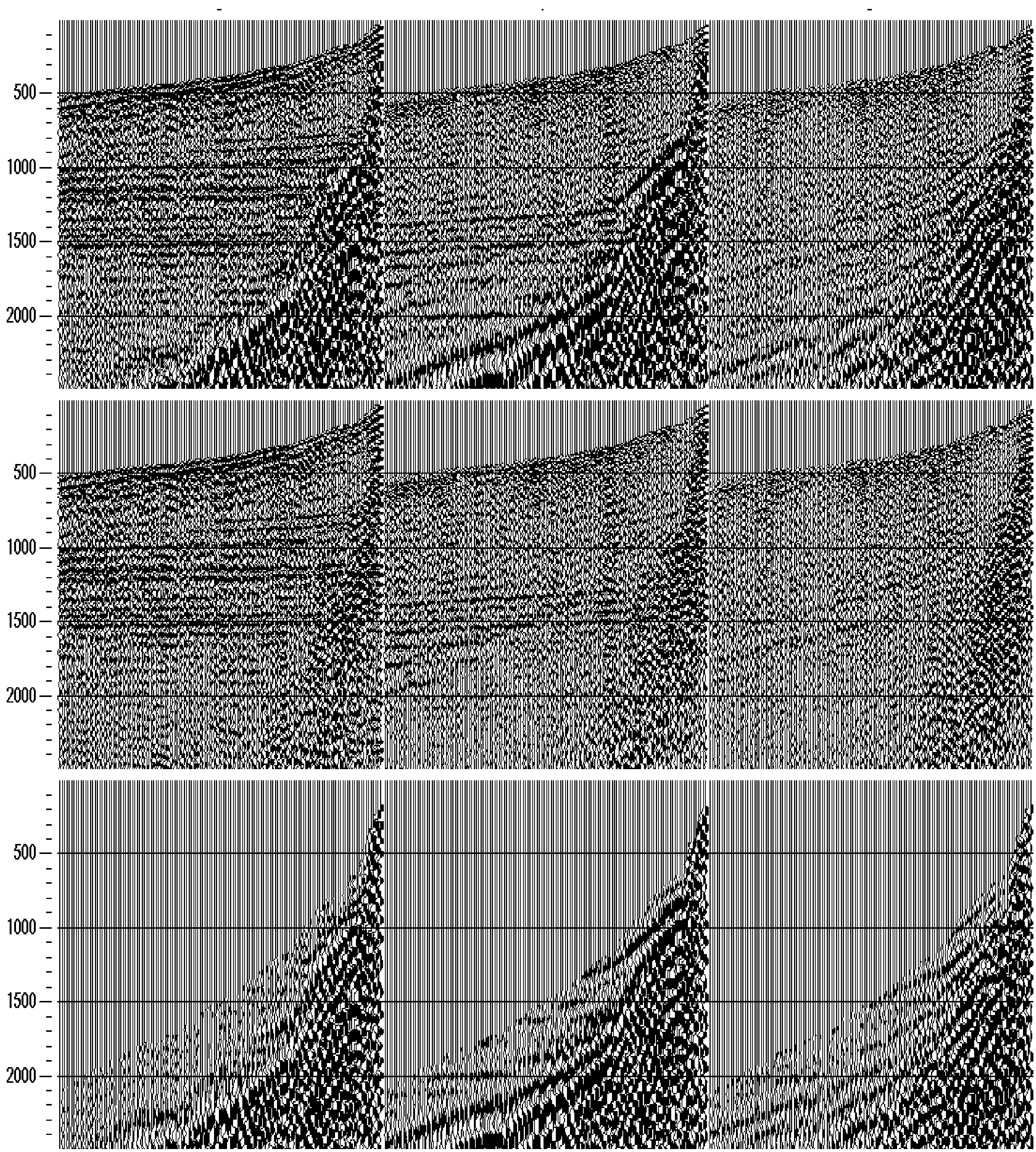

Figure 1: Top row: Vertical, radial and transverse components from a 3-D shot gather. Middle row: After ground roll attenuation using SVD and adaptive subtraction. Bottom row: Noise removed.

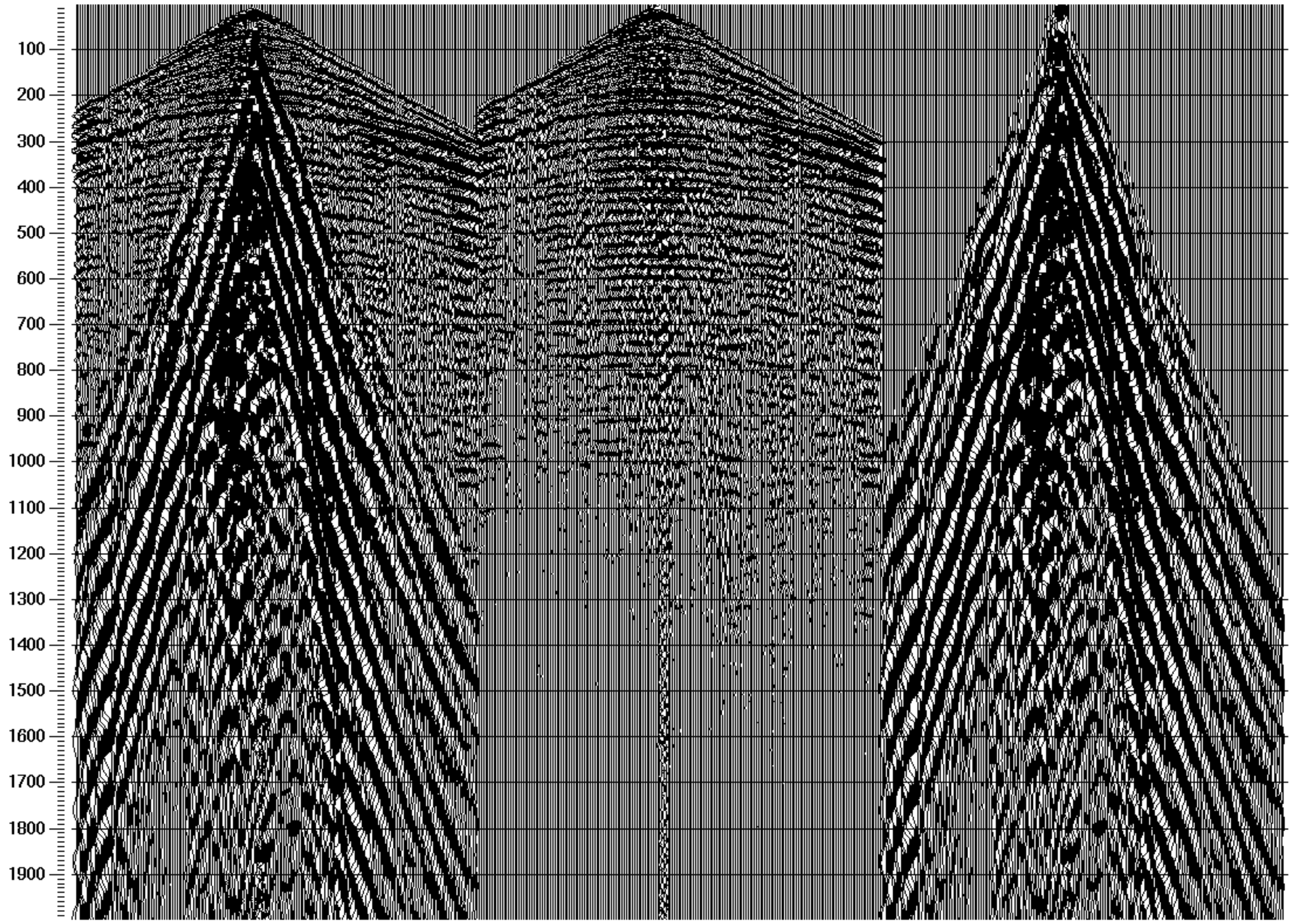

Figure 2: Left: Input 1-C, 2-D shot gather. Middle: After ground roll attenuation. Right: Noise removed.