Elimination of incoherent noise from seismic data

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Summary

A new method to eliminate incoherent noise from seismic data is presented. Due to the random structure of this specific class of noise the new algorithm is based on successive upward and downward continuation of data sets. Thus any incoherent noise is eliminated through an integration of the seismic traces.
By carrying out the modelling in accordance with the representation theorem for acoustic waves, we use the retarded and advanced Green's functions for a homogeneous medium as computationally efficient wave propagators acting on steep angle reflection data.

The new algorithm is applied to real zero-offset reflection data. A further numerical example demonstrates the influence of random noise on the result of a standard one-dimensional pseudo-impedance calculation.

Introduction

One major difficulty in the interpretation of seismic data has its origin in the contamination of recorded data sets in terms of coherent and incoherent noise. Both classes of these undesired effects are discussed in numerous publications where the broad spectrum of methods and recipes may additionally indicate the relevance of this problem. At present, the most prominent method in the reduction of incoherent (randomly distributed) noise is the Karhunen-Loeve Transformation (e.g. Jones et al. (1987)) which is based on an expansion of data sets in terms of a complete orthonormal system of basis functions. By following the argument that noise has small amplitudes noise-free data are generated by restricting the expansion to dominant eigenvalues. Though this argument may be valid a pratical application of this method requires a reliable criterium for the discrimination between seismics and noise. Such a criterium cannot be derived in general and is usually acquired by testing various subsets of the complete spectrum of eigenvalues. The visualization of the produced results gives (rather subjectively) a preference of restricting the series expansion to a specific spectral range of eigenvalues by which incoherent noise seems to be dominantly suppressed. However this uncertain situtation remains unchanged since during the elimination of random noise coherent components might have been removed from the data. This continues to be a weak point of this method especially when applied to huge data volumes.

The method

The proposed method for an elimination of incoherent noise is based on the simple idea that any randomly distributed seismic components will be effectively removed from the data by averaging over adjacent traces. However this simple recipe can be applied only to zero-offset data corresponding to horizontally layered subsurface structures. This undesired restriction of such a simple but potentially very effective noise elimination method has motivated us to generalize the validity of this technique for arbitrarily complex time sections. When considering this problem there are actually not many degrees of freedom upon which direction to take but the one which - qualitatively speaking - leads to an efficient operator for seismic wave propagation.
Such an operator corresponds to the Huygen's principle and finds its analytic form in various representation theorems. For our investigation it is sufficient to consider the representation theorem for acoustic waves whereby the seismic time series are regarded as steep-angle reflection data.

Let $f(\vec{x}_i,\omega)$ i= 1 ,N be the envisaged noisy data set consisting of N traces in the frequency domain. We consider the following two relations for an upward and downward continuation of the wave field through a homogeneous domain D and boundary ∂ D:

$$f'(\vec{x},\omega) = \int_{\partial D} d\vec{s}\; G^{+}(\vec{x},\vec{x}';\omega)\cdot f(\vec{x}',\omega) \qquad (1)$$

$$f(\vec{x},\omega) = \int_{\partial D} d\vec{s}\; G^{-}(\vec{x},\vec{x}';\omega)\cdot f'(\vec{x}',\omega) \qquad (2)$$

In these equations G^{+} and G^{-} denote respectively the corresponding retarded and advanced Green's functions. The integration can be restricted to the first Fresnel zone and thus improve the computational efficiency of the wave field continuation.
Incoherent noise is eliminated from the data as follows: In the first step (eq. (1)) the considered data set is upward continued whereby the integration along the first Fresnel zone represents the dominant operation for cancelling incoherent noise in the data. The second and final step deals with a backward propagation of the noise-free data to the datum of the input section and corresponds with a downward continuation of the wave field according to equation (2)

Application to real data

Figure la shows a zero-offset time section interfered by incohe-

rent noise. Following the above procedure of noise elimination a successive upward and downward continuation of the data set produces the result displayed in figure lb. A comparison of the two plots demonstrates that incoherent seismic components are eliminated from the section. In addition it is evident that a more consistent dynamic picture of the subsurface structure is produced than it can be drawn from the original data.
It is interesting to estimate at least qualitatively the influence of the noise in the presented data (Fig. la) after applying the standard one-dimensional inversion algorithm onto the data. This is shown clearly in the figures 2 a -c.
The plot of figure 2a shows the first twenty traces of the noisy and noise-free data respectively. The first processing step deals with the spectral extrapolation of the seismic traces according to the Ll-deconvolution after Oldenburg et al. (1983). The result of this-deconvolution is displayed in figure 2b. The Ll-deconvolution method applied to noisy data uses a 'contaminated' system of spectral constraints and consequently carries out a spectral extrapolation including noise. This becomes obvious in the picture in terms of randomly distributed minor additional spikes. An analogous calculation applied to the noise-eliminated data significantly improves the structural resolution. Specifically in some domains of the section various horizons are recovered from the noise. Figure 2c shows the result of the calculation of high-frequency impedances. This has been carried out by following a generalized Born inversion scheme (Kummer et al. 1988). A comparison between the two impedance sections qualitatively describes the influence of noise in terms of domains of partial laterally inconsistent amplitudes. These dynamic inconsistencies may have consequences during an interpretation of the data by inducing wrong lithological implications.

Conclusions

We have presented a new method for an elimination of incoherent noise in seismic data. The new approach is based on the representation theorem which yields an exact prescription for the upward and downward continuation of wave fields. The technique has been applied to zero-offset reflection data and shows that incoherent seismic components have been removed form the data. It is further shown that incoherent noise significantly influences the result of an impedance calculation in terms of laterally wrong amplitudes which may have consequences for a lithological interpretation.
Finally, the application of the autonomic method is ideal for processing of huge volumes of data.

References

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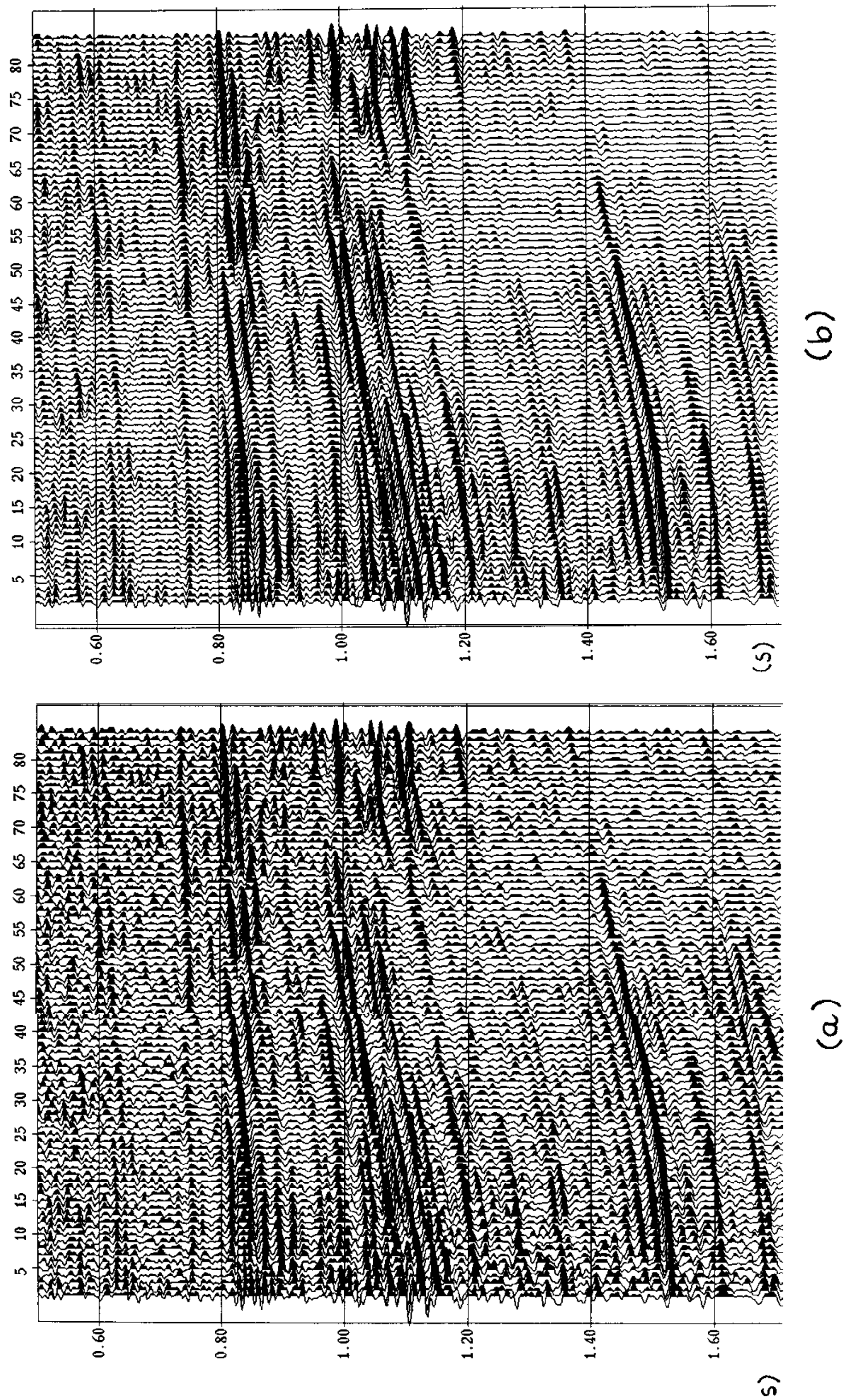

Fig. 1 Noise elimination

(a) zero–offset reflection seismograms interfered by incoherent noise
(b) noise–eliminated data by applying a successive upward and downward continuation scheme to time section (a)

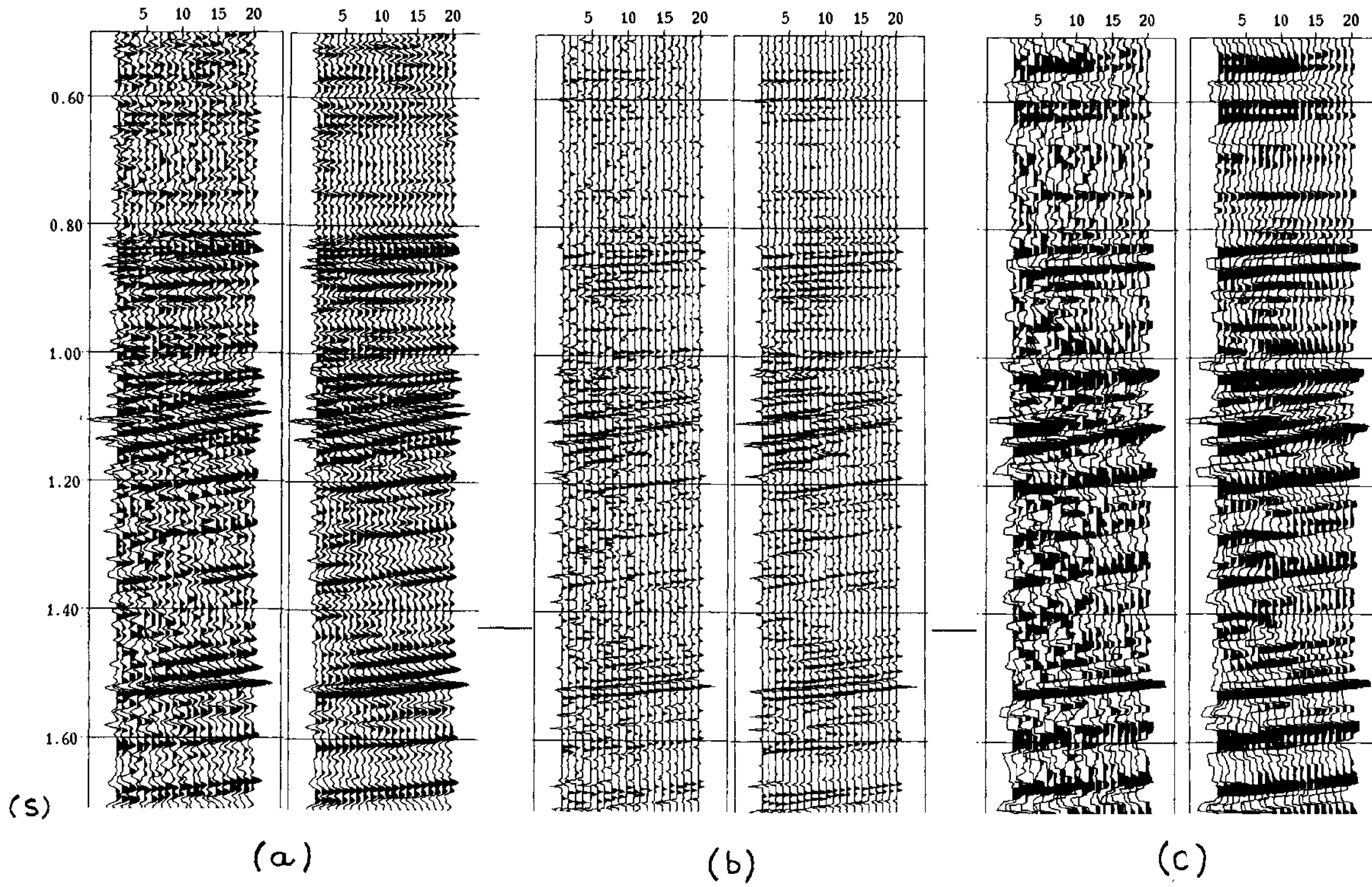

Fig. 2 **Influence of noise during a standard 1D inversion**

(a) left: 20 seismograms of the original section (Fig. 1a); right: corresponding noise–eliminated data
(b) reflectivity sections obtained by the L1–deconvolution method
(c) high–frequency impedances calculated by a generalized Born inversion method