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Inverse Attenuation-Filtering

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Summary

Inverse *Q* filtering is an important data-processing procedure broadly used for enhancing seismic data. Corrections for attenuation effects broaden the spectra and increase the resolution of seismic records, as well as correct for waveform distortions caused by velocity dispersion. At the same time, the existing approaches to inverse *Q* filtering are limited because of reliance on two assumptions: 1) the viscoelastic *Q* model for attenuation, and 2) using standard models for phase-velocity dispersion assuming that it can be inferred from the *Q*. Both of these assumptions are inaccurate, which, for example, can be seen from the fact that pore-fluid related attenuation involves secondary (slow) waves is not accurately described by a *Q*-factor. We remove both of these assumptions and propose a general approach of "inverse attenuation-filtering" (inverse *A*-filtering).

The inverse *A*-filtering consists of modeling the propagating source waveform followed by time-variant deconvolution it from the data. The modeling is done with the best possible accuracy and accounts not only for the effects of a *Q* but also for any known direct physical mechanisms: wavefront focusing and defocusing, scattering, and solid viscosity. In the future, the algorithm will also include effects of pore-fluid flows within the rock, such as Biot's poroelasticity, squirt flows, and wave-induced pore-fluid flows. For deconvolution, several algorithms are also considered.

The pre-stack inverse *A*-filtering is illustrated on synthetic examples and a real reflection dataset. Phase responses of the forward and inverse attenuation filters are sensitive to the selection of physical mechanisms, frequency-dependences of *Q*, and velocity dispersion laws. Iterative time-domain deconvolution popular in earthquake seismology appears particularly useful for enhancing the resolution of the resulting attenuation-corrected records.

Introduction

When a seismic waves or energy propagate through the Earth, they are affected by the numerous anelastic the medium. These effects might lead to changes spectra, and phases of the waveforms, which further affects the results of reflection seismic imaging. Inverse *Q* filtering (e.g., Hargreaves and Calvert, 1991) is a signal-processing procedure broadly commonly applied to compensate the effects of attenuation in reflection sections. In this paper we present an attenuation-compensation approach that is much more general that the conventional inverse *Q* filtering. This generalization is based in splitting the correction procedure into two parts: 1) modeling the propagating waveform affected by multiple factors, and 2) time-variant deconvolution of the modeled waveform from the data, also by (optionally) using multiple methods. The modeling includes multiple types and frequency dependences of the *Q*-factor as well as (potentially) non-Q type effects such as solid viscosity, scattering, and geometric spreading. Because of such generality of mechanisms, the approach can be called Attenuation-Filtering or *A*-filtering. The conventional inverse *Q*-filtering represents a special case of this procedure assuming a Q-only mechanism of attenuation and certain specific deconvolution methods. More details about the approach are given in the accompanying paper (Morozov, this Convention).

In this paper, we illustrate the “inverse A-filtering” by using2-D seismic data from Xinjiang Province in western China

Examples

The inverse *A*-filtering is applied to a part of stacked seismic section shown in Figure 1. On the same plot, we overlay a series of time tapers (black lines in Figure 1) that are used in time-variant deconvolution. As discussed by Morozov (this Convention), the attenuation and phase-velocity dispersion models cannot contain sharp contrasts, and consequently the discrete system of tapers is adequate. Interpolation of the overlapping tapers results in smooth transitions between both forward- and inverse-modeled attenuation operators. Using discrete set of overlapping windows makes the process efficient and flexible with respect to selecting the mechanisms of attenuation and deconvolution approaches.

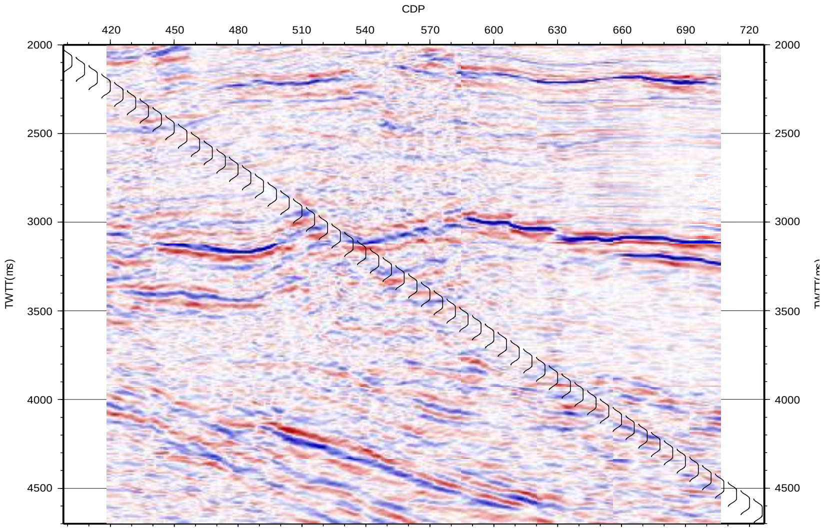

Figure 1. A portion of the lower part of the original stacked section from Xinjiang. Black lines show the overlapping Hanning-tapered time windows used for modeling the propagating waveform and deconvolution.

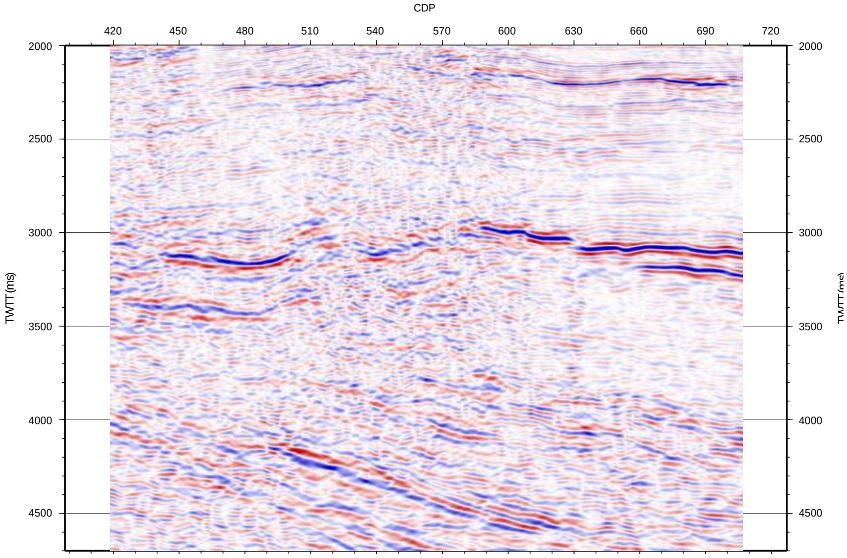

Figure 2. Stacked section in (Figure 1) corrected by using amplitude only-*Q* model, and deconvolved by using Wiener deconvolution.

By modeling the propagating waveform, we derive its phase delays and attenuation coefficient, and then build an inverse attenuation (deconvolution) filter correcting for these properties. The attenuation coefficient and particularly the phase of the waveform depend on the type of the “dispersion relation" assumed for the medium (Morozov, this Convention). Figure 2 and 3 show two Q-compensated sections using an amplitude-only Q (Figure 2) and a full constant-Q (Kjartansson's) model (Figure 3).

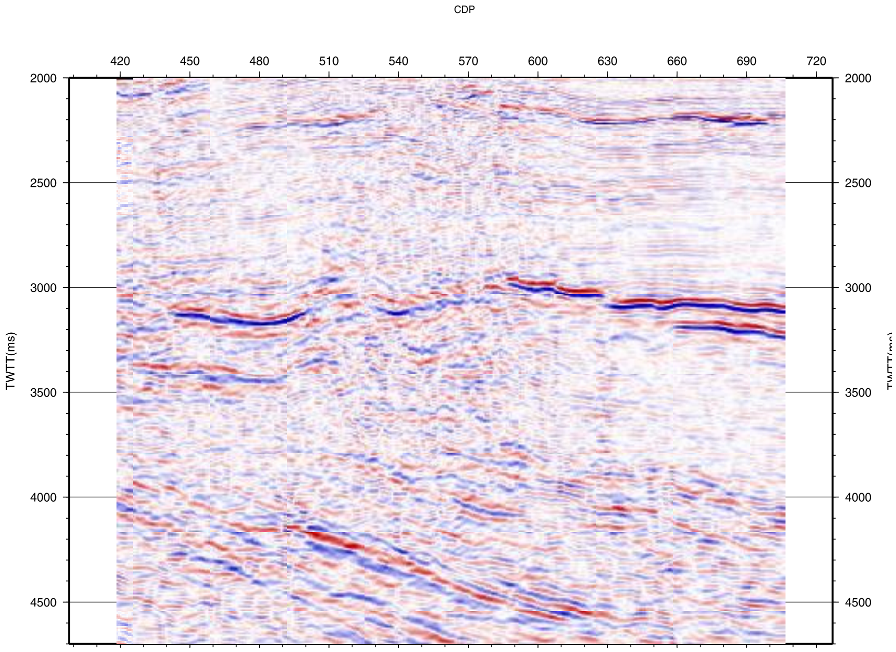

Figure 3. Stacked section (Figure 1) corrected by using a constant-*Q* model, and deconvolved by using Wiener deconvolution.

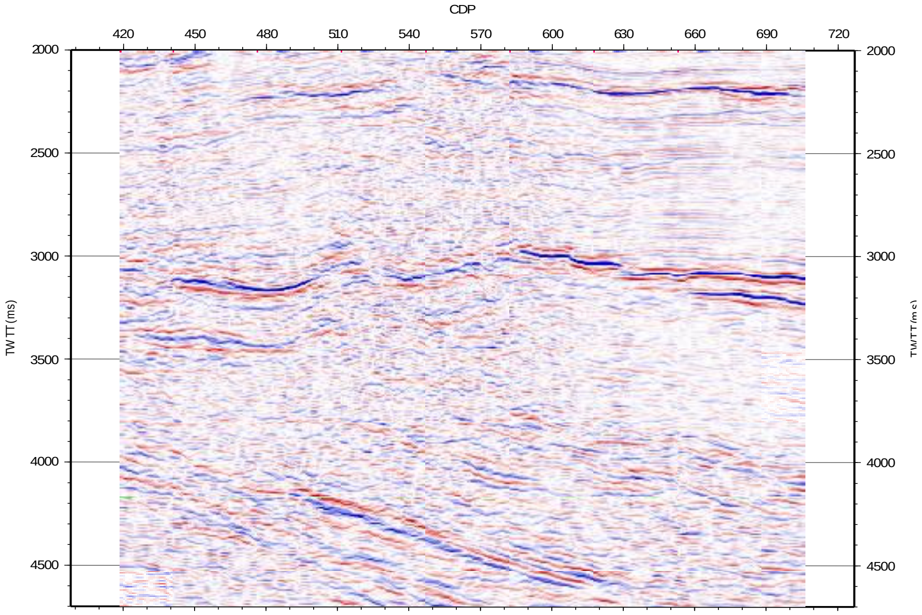

Figure 4. Stacked section (Figure 1) corrected by using an amplitude-only *Q* model and iterative time-domain deconvolution.

The results in Figures 2 and 3 were obtained by using the frequency-domain Wiener deconvolution within each of the tapered time windows (Figure 1). An attractive improvement in the recovery of the high-frequency signal is obtained by iterative time-domain deconvolution (Ligorría and Ammon, 1999). This deconvolution method is broadly used in earthquake seismology.

Time-domain deconvolution avoids ringing in the resulting records and allows imposing geologically-motivated constraints such as sparseness of target reflectors. *A*-filtering results using the iterative deconvolution are shown in Figures 4 and 5. Note the improved detail in the lower parts of the records.

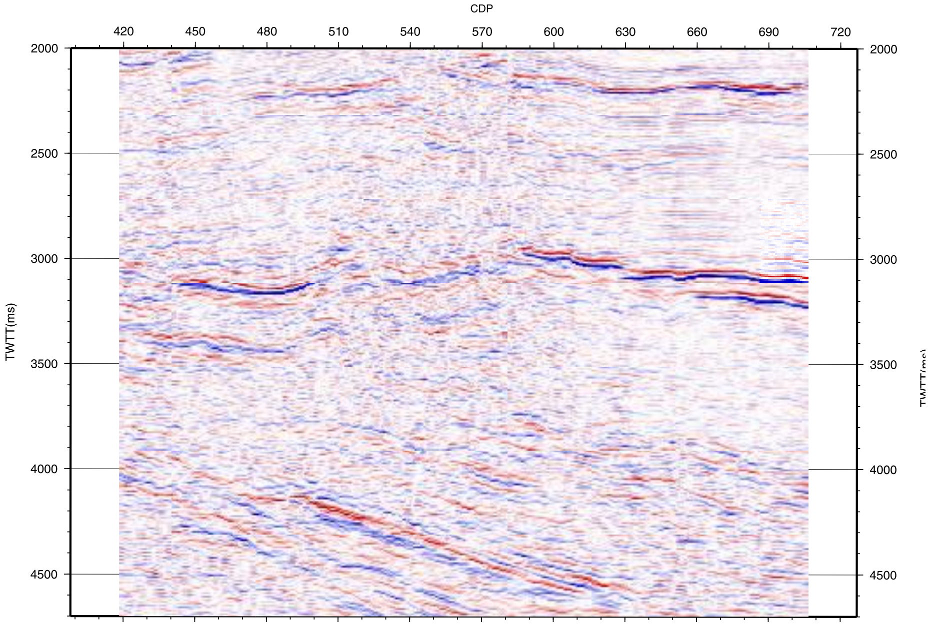

Figure 5. Stacked corrected (Figure 1) corrected by using a constant-Q model, and iterative time-domain deconvolution.

Conclusions

Inverse attenuation filtering is a general and powerful approach to correcting for the effects of decaying amplitudes and velocity dispersion in seismic records. Real-data examples show that the inverse attenuation filter is practical and achieves improvements in the resulting sections while offering variety of modeling and deconvolution choices. Using an iterative time-domain deconvolution method from earthquake seismology enhances the resolution of the attenuation-corrected records.

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