Impedance Inversion of Phase Corrected Data- A Case Study

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Summary

Deconvolution with minimum phase wavelet assumption leaves the data with spurious phase. The phase correction required to remove the spurious phase can be done by a simple parameterization of the underlying mixed phase wavelet. The simple parameterization involves estimation of all-pass operator coefficients via cumulant matching technique. The 4^{th} order cumulant of the whitened data (data after removal of the minimum phase wavelet) and the 4^{th} order moment of the all-pass operator are matched by updating the all-pass operator coefficients. Since this is a blind deconvolution problem, the shape of the cost function is unknown. Hence the optimization is performed by simulated annealing algorithm (an optimization procedure that has the ability to "jump out" of local minima and proceed towards the global minimum). The optimized coefficients of the all-pass operator is convolved with the minimum phase wavelet to estimate the mixed phase wavelet.

The case study involves estimation and subsequent deconvolution of the mixed phase wavelet from the data belonging to the central Alberta plains. An average mixed phase wavelet is computed from the 3 mixed phase wavelets estimated at 3 different locations. The data volume is deconvolved with the average wavelet. The phase corrected data is further used to invert for the P-impedance. Comparison of impedance inversion with and without the phase correction shows that the impedance inversion of the phase corrected data not only shows better correlation with the well logs but also provides more subtle information that are absent in the inversion of original data.

Introduction

An accurate estimation of wavelet is crucial to an effective and accurate deconvolution. Autocorrelation of the seismic trace is an estimator of the autocorrelation of the wavelet. Since, autocorrelation does not have phase information, the usual practice is to assume that the underlying wavelet is minimum phase. This assumption may not always be true. Hence data that contain non-minimum phase wavelet will show spurious phase when deconvolved with a minimum phase wavelet. Under the assumption that the reflectivity consists of a non-Gaussian white series, the 4^{th} order cumulants preserve the phase characteristics of the wavelet (Lazear, 1993). Non-minimum phase wavelet can be parameterized in terms of minimum phase wavelet and all-pass operator (Porsani and Ursin, 2000). Such a parameterization greatly simplifies the problem because coefficients of a suitable all-pass operator is all that need to be optimized. Deconvolution of the seismic trace with a minimum phase wavelet broadens the bandwidth of the data which subsequently helps in the estimation of all-pass operator coefficients (Velis and Ulrych, 1996). Mixed phase wavelet at different data locations are estimated from a 3D data set using simulated annealing method where the wavelet is parameterized in terms of minimum phase wavelet and all-pass operator (Misra and Sacchi, 2007). Subsequently an average mixed phase wavelet is computed from the individual estimated wavelet and the spurious phase is removed from the data by deconvolving the data with the average mixed phase wavelet. The phase corrected data is further used for the impedance inversion.

Theory

A mixed phase wavelet is parameterized as a convolution of a minimum phase wavelet and an all-pass operator.

The Z-transform of an all-pass operator is written as

$$F(Z) = Z^{p} \frac{B(Z^{-1})}{B(Z)} \; , \tag{1}$$

where $b_t = b_0, b_1, b_2, \ldots, b_p$ is a minimum phase sequence of length p. The cost function for the optimization is given by

$$\sum_{\tau_1}\sum_{\tau_2}\sum_{\tau_3}\left[C_4^s(\tau_1,\tau_2,\tau_3) - M_4^w(\tau_1,\tau_2,\tau_3)\right]^2 , \tag{2}$$

where $C_4^s(\tau_1,\tau_2,\tau_3)$ is the fourth-order trace cumulant, $M_4^w(\tau_1,\tau_2,\tau_3)$ is the fourth-order wavelet moment and the cumulant lags are given by τ_1,τ_2,τ_3 . A minimum phase wavelet is estimated from the input data by Wiener-Levinson algorithm. The input data are deconvolved with the minimum phase wavelet to obtain the whitened data. Fourth-order trace cumulant of the whitened data is calculated and a misfit is computed between the fourth-order moment of the all-pass operator. The coefficients of the all-pass operator are computed by means of Kolmogoroff technique. The all-pass operator coefficients are updated according to the simulated annealing procedure till the cost function is minimized as per the user criteria. The all-pass operator thus obtained is convolved with the earlier estimated minimum phase wavelet to compute the mixed phase wavelet. The spurious phase in the data is removed by deconvolving the mixed phase wavelet from the data.

The impedance inversion is performed on the phase corrected data by estimating a wavelet and updating a suitably chosen initial impedance model till the error between the forward modeled data and the phase corrected data reaches a user defined minimum. The final impedance model is accepted as the solution to the impedance inversion.

Examples

The proposed method is applied on a 3D seismic volume acquired over the central Alberta plains. The post-stack sub-volume encompassing the locations of 3 well logs is chosen from the larger volume. Three locations within this sub-volume are chosen for estimation of mixed phase wavelet. Figure 1 (a) shows the input data at the location 1. Figure 1(b) shows the equivalent phase corrected data and figure 1 (c) shows the estimated mixed-phase wavelet. Likewise Figure 2 (a), (b), (c) and Figure 3 (a), (b), (c) show the input data, the phase corrected data and the estimated mixed phase wavelet for the locations 2 and 3 respectively. Notice that the wavelets extracted from the data are not the same. This indicates lateral variation of the wavelet within the 3D seismic volume. Figure 4 (a) shows a part of the input data that encompasses the locations of two well logs. Figure 4 (b) shows the phase corrected data. Figure 5 (a) shows that impedance inversion of the original data and figure 5 (b) shows the impedance inversion of the phase corrected data. Figure 6 (a) shows that impedance inversion of the original data and figure 6 (b) shows the impedance inversion of the phase corrected data at another well location. It is clearly noticed that the resolution is much improved in the inversion of phase corrected data. In addition, a low impedance thin shale zone sandwiched between two high impedance layers is visible in the impedance inversion of the phase corrected data. This zone is marked by an arrow.

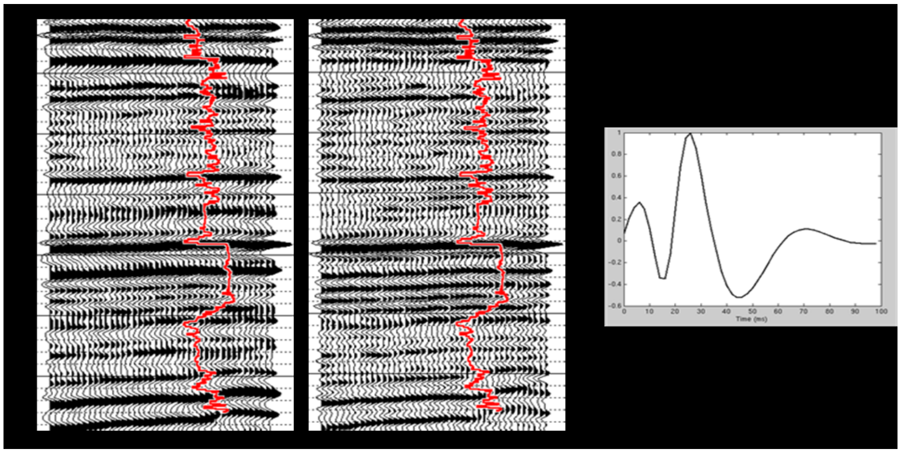

Figure 1:(a) The input seismic data at location 1. (b) The phase corrected data and (c) the estimated mixed phase wavelet. The red curve is the P-impedance log.

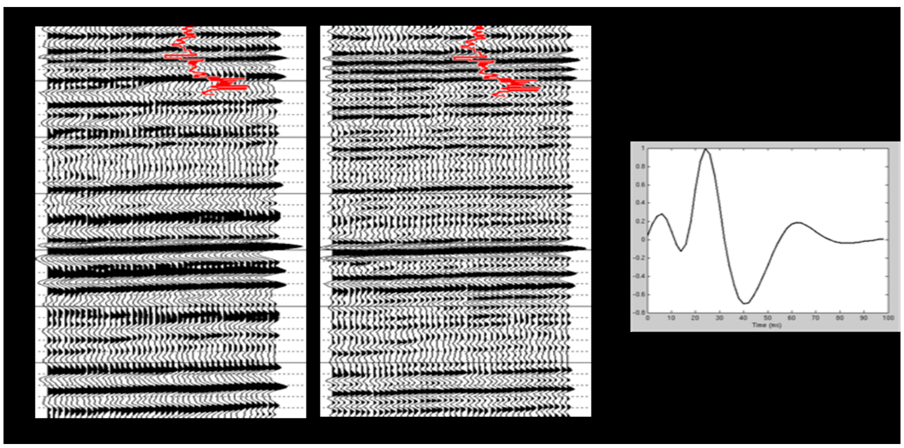

Figure 2:(a) The input seismic data at location 2. (b) The phase corrected data and (c) the estimated mixed phase wavelet. The red curve is the P-impedance log.

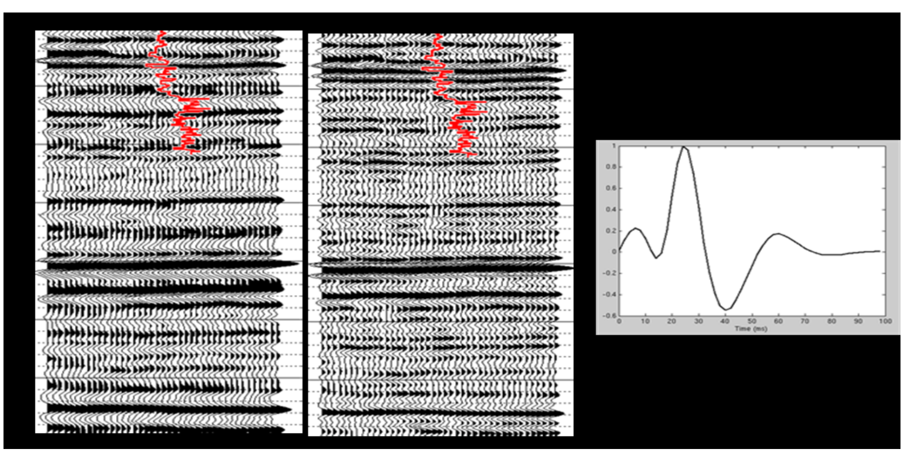

Figure 3:(a) The input seismic data at location 3. (b) The phase corrected data and (c) the estimated mixed phase wavelet. The red curve is the P-impedance log.

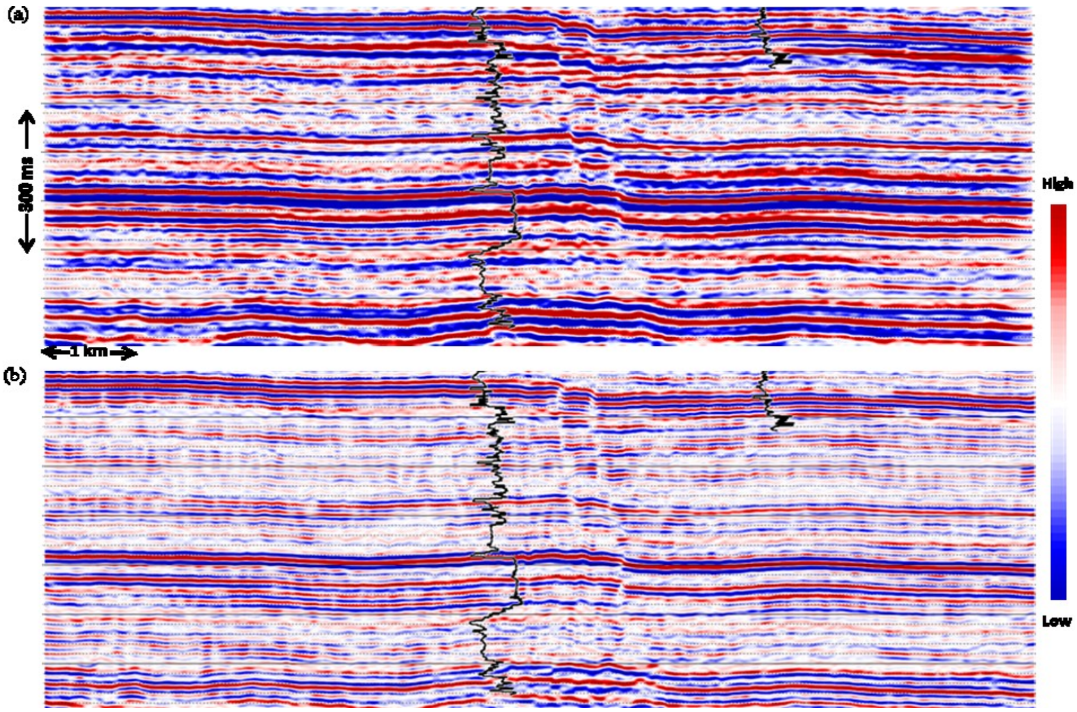

Figure 4: (a) The input seismic data and (b) the phase corrected seismic data. The inserted black curves are the P-impedance logs. Notice the cleaner and enhanced resolution look of the section after phase correction. The correlation seems to be much better with the impedance log. Also the fault definitions appear to be crispier.

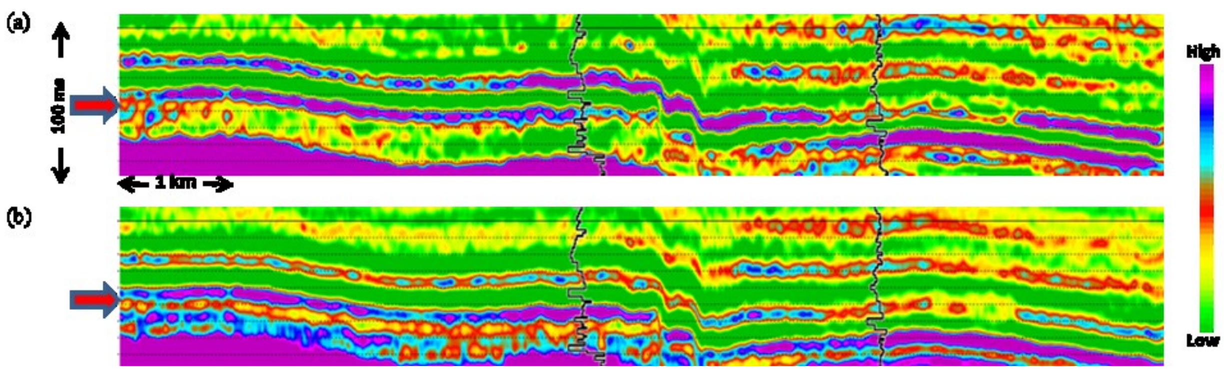

Figure 5: (a) Impedance inversion with the original data. (b) Impedance inversion with the phase corrected data. The inserted black curves are the P-impedance logs. The thick red arrow points to the thin low impedance layer sandwiched between the high impedance layers in (b) which is not seen in the inversion of the original data in (a).

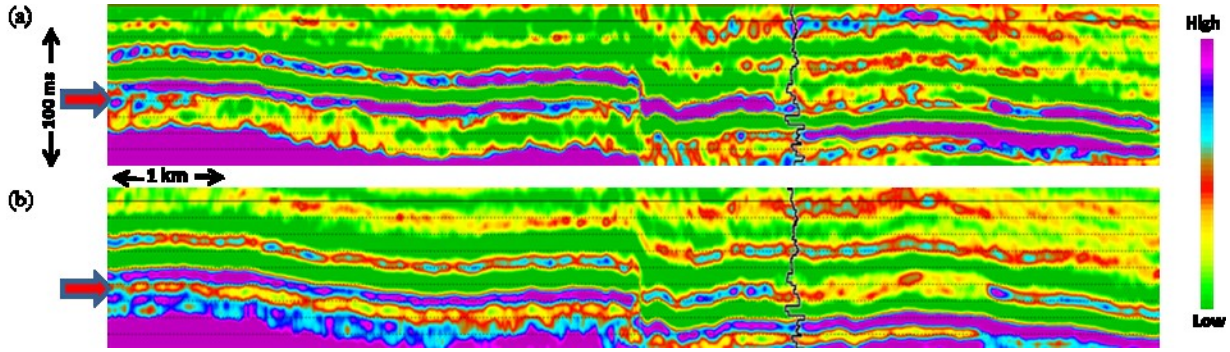

Figure 6: (a) Impedance inversion with the original data. (b) Impedance inversion with the phase corrected data. The inserted black curve is the P-impedance log. The thick red arrow points to the thin low impedance layer sandwiched between the high impedance layers in (b) which is not seen in the inversion of the original data in (a).

Conclusions

Lateral variation in the phase of the seismic data could cause serious problems for the seismic interpreters. So it is always desirable to interpret data that have a consistent zero phase wavelet. While this goal could be somewhat ambitious, correction of phase in the data so as to get a wavelet that is close to zero phase is what could be achieved in practice. Our attempts in this direction have revealed that removal of spurious phase has helped the seismic data to have a better resolution and better well correlation. Also the impedance inversion of the phase corrected data shows more subtle features which are otherwise absent in the impedance inversion of the data with spurious phase. Such phase corrections would definitely lead to more accurate interpretations.

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