Improving AVO Fidelity by NMO Stretching and Offset Dependent Tuning Corrections*

Yong Xu[1] and Satinder Chopra[1]

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[1] Arcis Corp., Calgary, AB, Canada (yxu@arcis.com)

Abstract

Wavelet stretching due to NMO correction of seismic gathers causes problems in AVO. Coupled with the degrading action of wavelet stretching is offset dependent tuning for thin beds. Even though tuning is inherent in the data before NMO correction, its effect on AVO is more obvious on NMO corrected data. Studies have been carried out for an analytical understanding of NMO stretching and offset-dependent tuning and their correction to improve AVO fidelity. Based on these studies, we have implemented the NMO stretching and thin-bed tuning corrections in a practical fashion for production AVO analysis. Both synthetic and real data examples show that these corrections are necessary for performing reliable AVO analysis.

Wavelet Stretching and Offset Dependent Tuning Corrections

Dunkin and Levin (1973) provide an analytical expression of wavelet stretching factor or spectral compression due to NMO correction. This stretching factor in offset domain is non-stationary. Roy et al (2005) provide a stationary stretching factor for angle domain gathers. Wavelet stretching generates out-of-phase side lobes, which can generate artificial AVO anomalies. Offset-dependent tuning causes spectral expansion, a wider frequency bandwidth is required for a trace with tuning than the one without tuning to keep the same resolution of reflector series. However, the filtering effect of earth and the application of band-limited filters in the processing make the bandwidth of the far offset traces narrower than that of the near offset traces. To generate high resolution stacking and preserve AVO, both near offset and far offset traces need to keep the same bandwidth and it is required to restore AVO for every component. This requires extrapolating bandwidth of the far offset trace to match that of the near offset traces. In the presence of an AVO anomaly, the spectral shape at far offset may not necessarily match that at near offsets, and so the extrapolation of high frequency components at far offset traces needs the use of AVO knowledge or assumption, which may come from the gather itself.

Wavelet stretching and tuning correction stretching and offset-dependent tuning corrections should be done separately in the frequency domain. Wavelet stretching correction needs to be enough for mildly changed velocity field; stationarity assumption can be made (Castoro et al, 2001, Lazaratos and Finn, 2004). It is more practical to use overlapping time windows and averaging as suggested by Lazaratos and Finn (2004).

Tests have to be done to look for optimal window size for stationarity assumption and computing efficiency. Wavelet stretching correction is based on the stretching factor given by Dunkin and Levin (1973) or Roy et al (2005). Bear in mind that wavelet-stretching correction can only reliably restore the usable frequency band, which is narrower than at zero offset trace. When the wavelet does not have a boxcar spectral shape, wavelets need to be estimated first. Amplitude ratio of non-stretched wavelet to the stretched wavelet is used to scale the far offset data in frequency domain. This procedure was suggested by Castoro et al (2001). Compensation of high frequency loss due to tuning cannot be achieved by deconvolution kind of approaches used by Castoro et al (2001) and Roy et al (2005) because there is no high frequency signal left after filtering and NMO correction. The lost high frequency components at far offset can be estimated from near offset data, where the corresponding high frequency components exist. This can be done by an AVO inversion approach if stationary assumption is used for small time window or ideally for angle gathers. If wide-range offsets lose their high frequency, AVO inversion would be less reliable, and a local mud-rock line can be used to estimate a reasonable solution. In the absence of a reliable local mud-rock line, the ratio of AVO attributes, e.g. the intercept and gradient, can be estimated statistically from the reliable low frequency components in the analyzed time window after wavelet stretching correction.

Examples

Figure 1 shows stretching and tuning correction on a synthetic gather with strong AVO. The useful signal zone is about 250ms and a single window is used to calculate the stretching factor. The gathers resulting from stretching and tuning corrections closely match the ideal gathers. More importantly, AVO distortion is fixed by the stretching and tuning corrections.

A real dataset from Alberta, Canada was used to test NMO stretching and offset-dependent tuning correction. Data was processed in an AVO friendly fashion and NMO correction was applied. Figure 2 shows an NMO corrected CDP gather to demonstrate the effectiveness of corrections. Note the high frequency loss at far offset due to offset-dependent tuning and the enrichment of low frequency at far offset due to NMO stretching in Figure 2 (b). The box in dotted line indicates the frequency band weakly affected by offset-dependent tuning. Figure 2 (c) is the gather after band pass filter defined by the dot-line box in (b) and a red arrow indicates a reference event showing increasing AVO, although modeling shows a dimming AVO at this geological marker. The gather in Figure 2 (d) is generated by applying NMO stretching correction only on the gather in Figure 2 (c). The amplitude increasing AVO on reference marker event (red arrow) is reduced. Figure 2 (e) shows the gathers after compensation of high frequency components on far offset traces. An increasing AVO can be seen clearly at the reservoir target indicated by the black arrow. The reference marker indicated by the red arrow shows a dimming AVO, which matches AVO modeling.

In Figure 3, stack sections and AVO attributes from the same dataset are shown. Because tuning correction compensates the high frequency components for far offset traces, it enhances the resolution on the stack section. The intercept and gradient attributes are extracted from the gathers with and without stretching and tuning correction. The black arrows indicate the reservoir target. As a weak class III AVO (or Class II-b) is expected at reservoir targets, positive product of intercept and gradient should be seen at the reservoir zone while most of other portion of the section should have negative product value. Although the reservoir, indicated by black arrows, can be found on both (e) and (f), it is more consistent and standout on (f). The larger overall value on (e) than (f) can be explained by the fact that tuning generates larger gradient when thickness of thin layer is larger than 1/12 wavelength for dimming AVO (see the derivation by Lin and Phair, 1993). Obvious artifact anomalies can be seen on (e) at the geological marker indicated by the red arrows. This marker has a strong impedance contrast and wavelet stretching generates strong out-of-phase side lobes, which generates artifact AVO anomaly. These artificial anomalies are reasonably removed by stretching and tuning correction.

Conclusions and Discussion

There are two main reasons for the loss of AVO fidelity in the NMO correction: one is low frequency amplification due to wavelet stretching, and the other one and more important is the intrinsic loss of high frequencies due to filtering during wave propagation and processing for offset-dependent tuning events. The wavelet stretching can be restored by a relative deterministic approach, but the high frequency loss due to tuning and filtering we believe requires AVO guided frequency extrapolation in order to preserve AVO. This study suggests a stretching and tuning correction. The model and real data examples demonstrate the necessity of applying corrections for stretching and tuning for performing reliable AVO analysis. Improvement of AVO fidelity by stretching and tuning correction is more obvious for wide-angle AVO analysis and for the geological setting where the reservoir sits within a tight formation and beneath a lower impedance shale layer. The real data from WCSB shown in the above section have approximated largest angle of 39 degrees and the application of correction on it provides more reliable AVO analysis results.

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References Cited

Castoro, A., R.E. White, and R.D. Thomas, 2001, Thin-bed AVO: Compensating for effects of NMO on reflectivity sequences: Geophysics, v. 66, p. 1714-1720.

Dunkin, J.W., and F.K. Levin, 1973, Effect of normal moveout on a seismic pulse: Geophysics, v. 38, p. 635-642.

Lazaratos, S., and C. Finn, 2004, Deterministic spectral balancing for high-fidelity AVO: 74th Annual International Meeting, SEG, Expanded Abstracts, p. 219-223.

Lin, T.L., and R. Phair, 1993, AVO tuning: 63rd Annual International Meeting, SEG Expanded Abstracts, p. 727-730.

Roy, B., P., Anno, R. Baumel., and J. Durrani, 2005, Analytic correction for wavelet stretch due to imaging: 75th Annual International Meeting, SEG, Expanded Abstracts, p. 234-237.

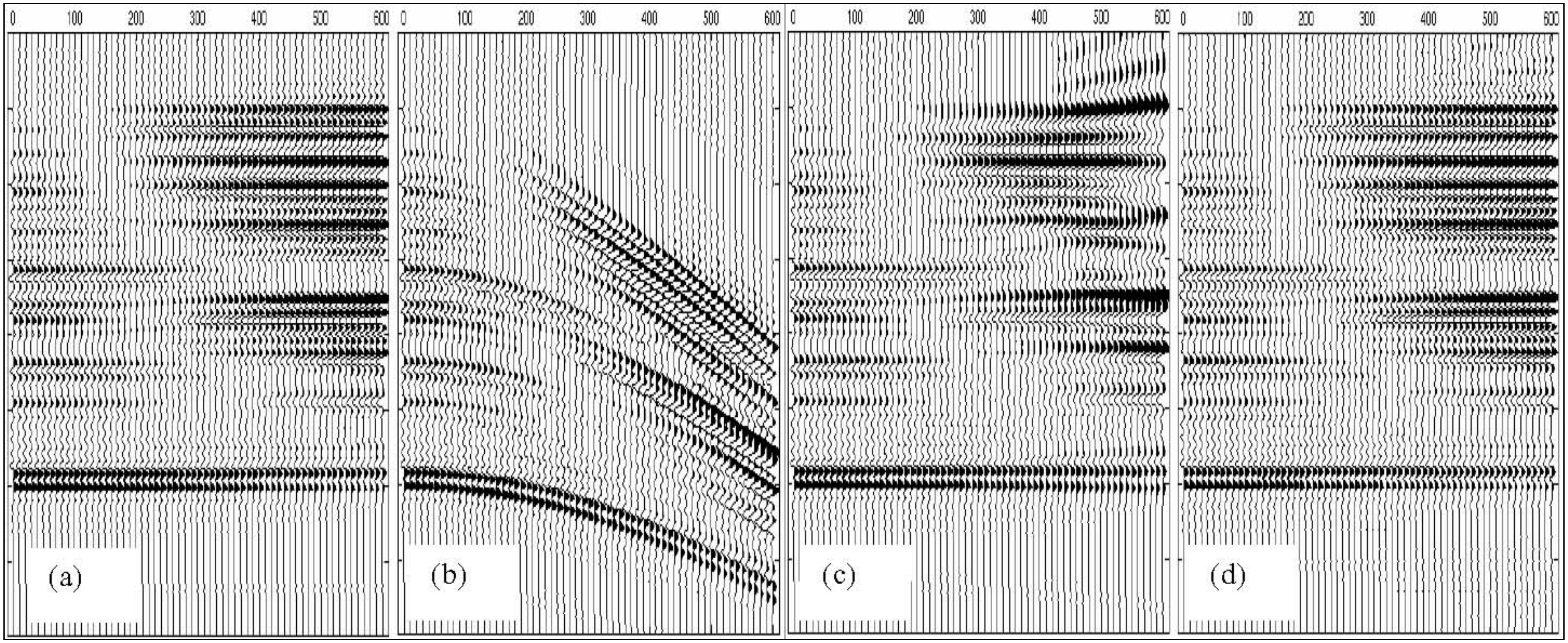

Figure 1. NMO stretching and tuning correction for an offset gather with strong AVO effect (a) Ideal gather, no stretching, no normal moveout applied; (b) before NMO correction; (c) after NMO correction. Stretching can be seen; (d) after stretching and tuning corrections applied on (c). AVO is restored at far offset traces after stretching and tuning corrections.

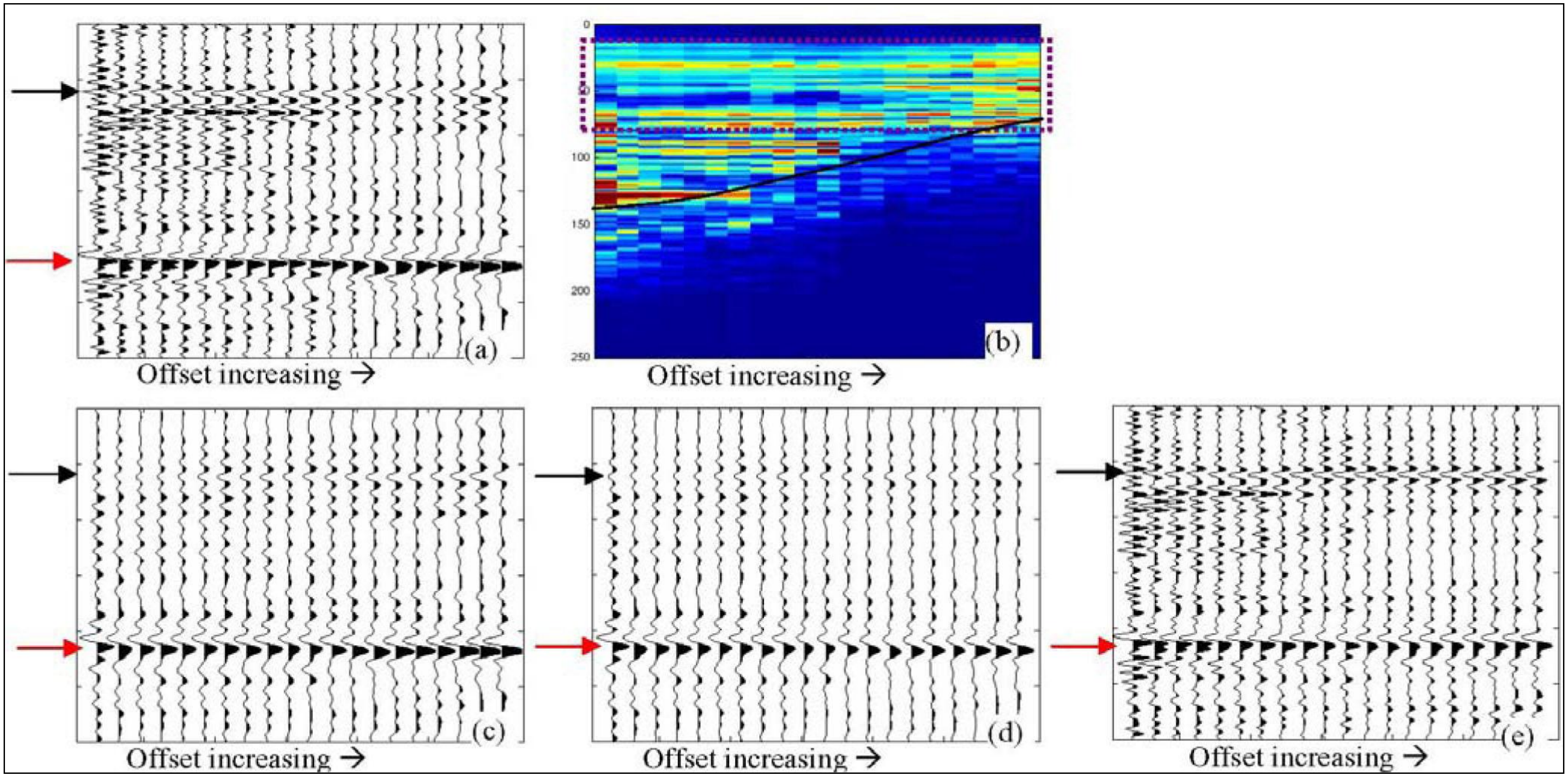

Figure 2. NMO stretching effect and correction on a CDP gather from a real seismic dataset. Figure (a) is the NMO corrected CDP gather and the reservoir target is indicated by the black arrow; (b) is the amplitude spectrum for the gather in (a). Dotted line box indicates that the frequency components within it are weakly affected by offset dependent tuning; (c) is the gather after band pass filter defined by the dotted line box in (b) and a red arrow indicates a reference event showing increasing AVO; (d) is generated by applying stretching correction on gather (c). The increasing AVO on reference marker event (red arrow) is weaker; (e) is the final gather both stretching and tuning corrected.

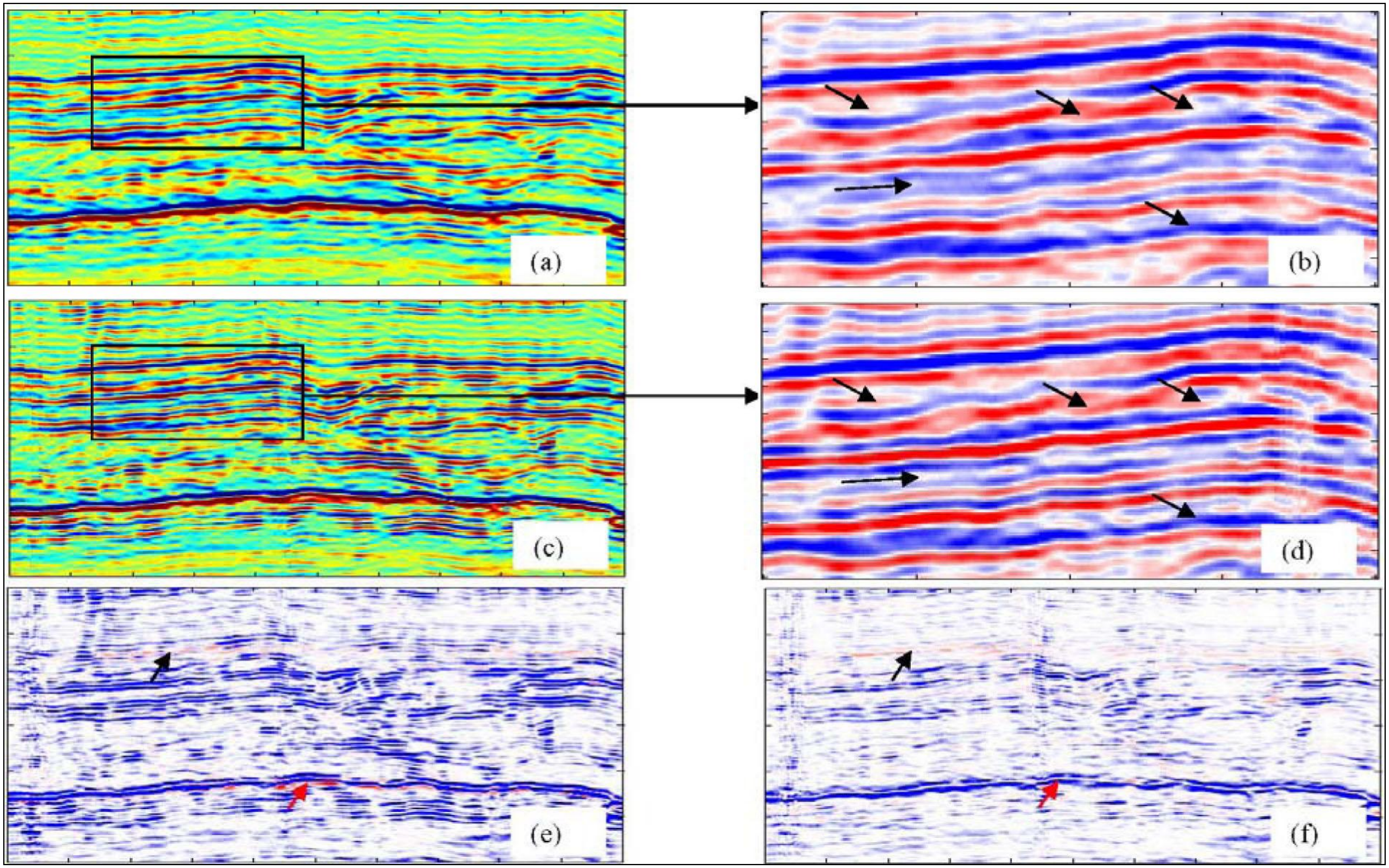

Figure 3. Comparison of real data sections with and without stretching and tuning correction. Figure (a) is a stacked section without stretching and tuning corrections, and the enlarged version for the portion inside the black box is shown in (b); (c) is the stacked section from corrections applied gathers and the enlarged portion in the black box is shown in (d); (e) is the product of intercept and gradient without stretching and tuning corrections; (f) is the product of intercept and gradient with stretching and tuning corrections.