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Removing NMO/Migration Stretch Effects for Improved AVO Analysis

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Summary

An un-stretching algorithm in reflection angle domain is presented and demonstrated with examples. It shows excellent results and improved AVO analysis.

Introduction

The effect of NMO/migration stretch has recently become an important topic of discussion in the context of AVO analysis (Swan, 1997, Castoro, White, and Thomas, 2001,

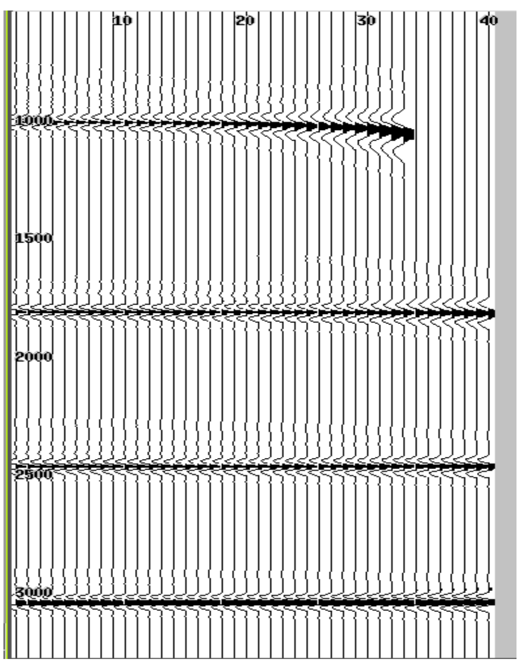
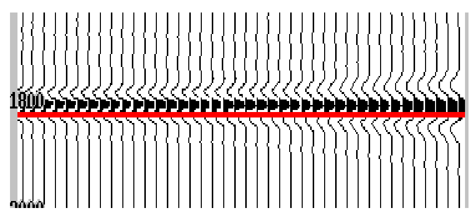


Figure 1: Offset gather – created by common offset migration of synthetic data.

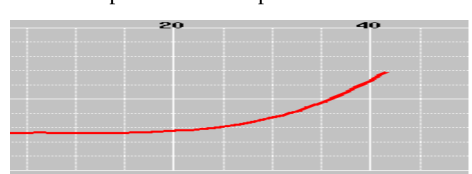
and Hicks, 2002, Perez and Marfurt 2006). NMO/migration stretch causes wavelet distortions as a function of offset, which then creates a significant error in measuring AVO gradients, and significantly distorts amplitude inversion and seismic reservoir characterization procedures.

Figure 1 displays an offset gather created by common offset Kirchhoff prestack migration. Input to migration was a synthetic dataset that was composed of four horizontal interfaces with constant reflectivity at all offsets. Note that stretch at far offsets is mostly evident at shallow layers where angle of incidences are large. Note also that the stretch varies with time at a given offset.

Figure 2 focuses on the top reflection which is highly stretched and illustrates the effect of the stretch in creating false AVO anomalies.



a)Offset gather, red line marks the location of the AVO response which is presented in b.



b) AVO signature for the trough marked red in a. Note that input for migration was data with constant amplitude with offset. Still, the measured AVO has a sharp decay with offset which is false and is caused by the stretch.

Figure 2:False AVO response due to stretch.

Theory

Migration stretch is similar to NMO stretch; it is created when mapping an input time interval ΔT to its vertical time equivalent, Δt_o (Figure 3). Since $\Delta T<\Delta t_0$ there is wavelet stretch. Let us consider a simple case of constant velocity $v=2000$ m/sec. Let c be the normalized offset; $c=2h/v$ where h is half offset; t_0 the vertical time; and T the travel time at offset c. Figure 4 displays the ray path associated with the common offset case. Note that the angle of incidence θ varies with t_0. The travel time for fixed c is given by:

$$T=\sqrt{t_0^2+c^2}\ , \qquad (1)$$

where the NMO stretch is:

$$\frac{dT}{dt_0}=\frac{t_0}{\sqrt{t_0^2+c^2}}=\cos\theta<1 \qquad (2)$$

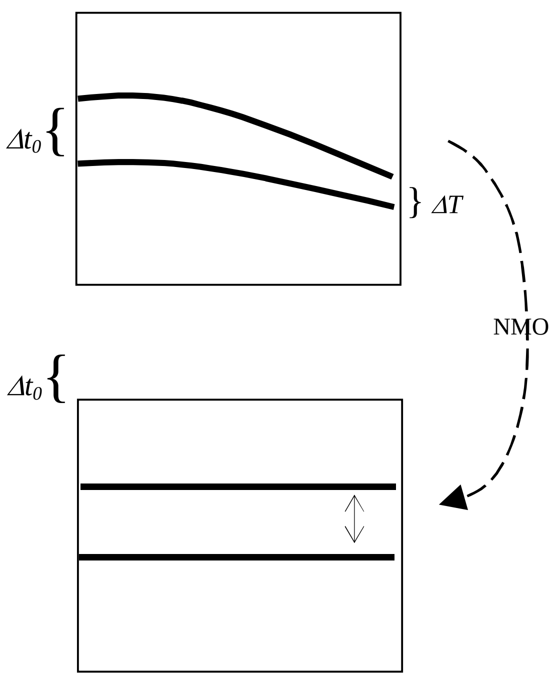


Figure 3: NMO stretch for offset gathers

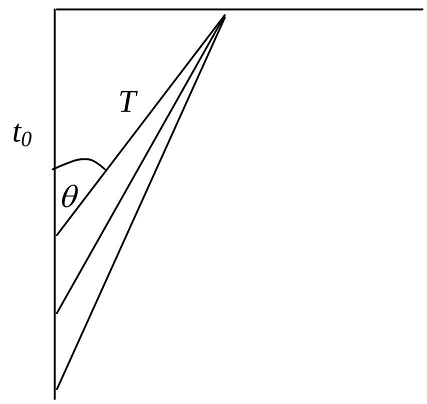


Figure 4: Common offset ray path variation with t_0

In other words, NMO stretch is invariant with θ, which suggests that working in common angle domain is advantageous. In the common angle domain the ray path is described in Figure 5, while $t_0=T\cdot\cos\theta$.

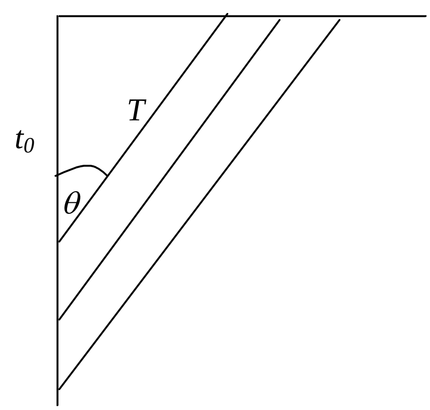


Figure 5: Common angle ray path variation with $t_{0.}$

This analysis leads to the development of an un-stretching algorithm which operates in the angle domain, where the stretch is stationary. In this domain a single operator can be used for each trace. The convolutional model will be our starting point. Using this model the seismic trace at zero offset $f_0(t)$, is a convolution of the zero-offset reflectivity trace $r_0(t)$ with the wavelet $w(t)$:

$$f_0(t)=r_0(t)*w(t)\xrightarrow{FT}\tilde{r}_0(\omega)\cdot\tilde{w}(\omega)\ . \qquad (3)$$

We assume that after NMO (and stretch), the seismic trace at angle of incidence θ is given by:

$$f_\theta(t) = r_\theta(t) * w_\theta(t) \xrightarrow{FT} \tilde{r}_\theta(\omega) \cdot \tilde{w}_\theta(\omega) \;, \qquad (4)$$

where w_θ is the stretched wavelet and $r_\theta(t)$ is the reflectivity at θ. The objective of the un-stretching algorithm is to replace w_θ with the zero offset wavelet w. Since in angle domain the stretching is constant and is given by:

$$dt_0 = \frac{dt}{\cos\theta} \;, \qquad (5)$$

the stretched wavelet w_θ is a resample version of the zero-offset wavelet w:

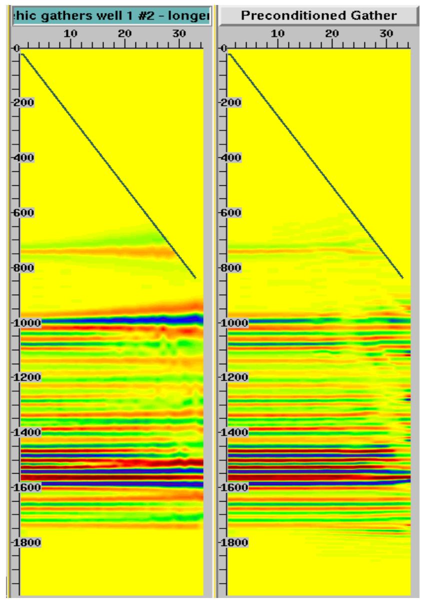
$$w_\theta(t) = w\left(\frac{t}{\cos\theta}\right) \xrightarrow{FT} \tilde{w}(\omega \cdot \cos\theta) \;. \qquad (6)$$

- → Assuming that the zero offset wavelet $w(t)$ is known, the un-stretching algorithm works a follows: FFT^{-1}
- → Convert from angle back to offset.
- → Convert data from offset to reflection angle
- → FFT
- → Apply the operator $\dfrac{\tilde{w}(\omega)}{\tilde{w}(\omega \cdot \cos\theta)}$

To obtain a wavelet an automatic wavelet estimation procedure is applied to the zero offset data. Spectral balancing and regularization is applied to the operator to avoid singularities and noise enhancements.

Examples

Figure 6 is the first example. Panel a) is the input offset gather and b) is the un-stretched gather demonstrating the ability of this method to remove the stretch. Figure 7 displays a spectral analysis of the result. The red curve is the amplitude spectrum of the near offset data. The green curve is the amplitude spectrum of the original far offset data. Notice how the stretching distorts the amplitude spectrum of the data. The black curve is the amplitude spectrum of the far offset data after the un-stretching process was applied. Notice how it successfully balances the spectrum over all offsets as required.



a) b)

Figure 6: a) Input gather, b) Gather after unstreaching

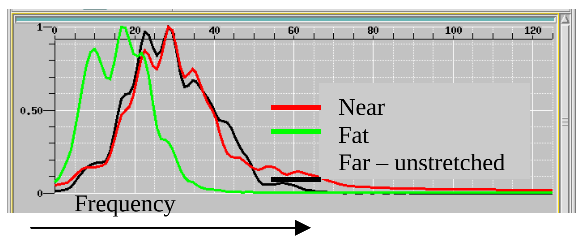


Figure 7: Spectral analysis before and after un-stretching

Figure 8 demonstrates the effects of un-stretching on the AVO response showing how distortive the NMO stretch can be f or prestack amplitude inversions.

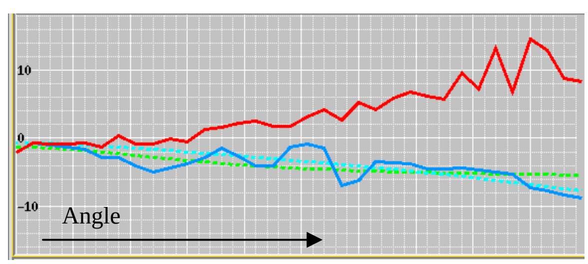
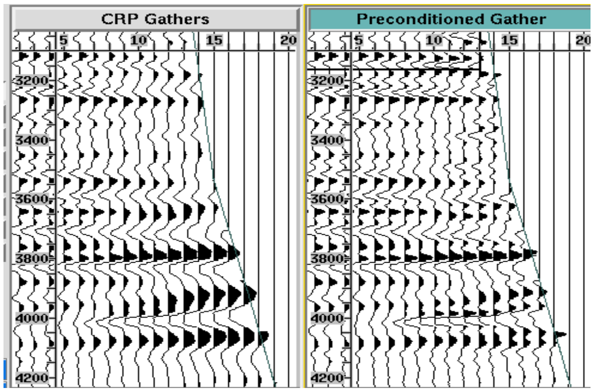


Figure 8: AVO response before (red) and after (blue) un-streaching.



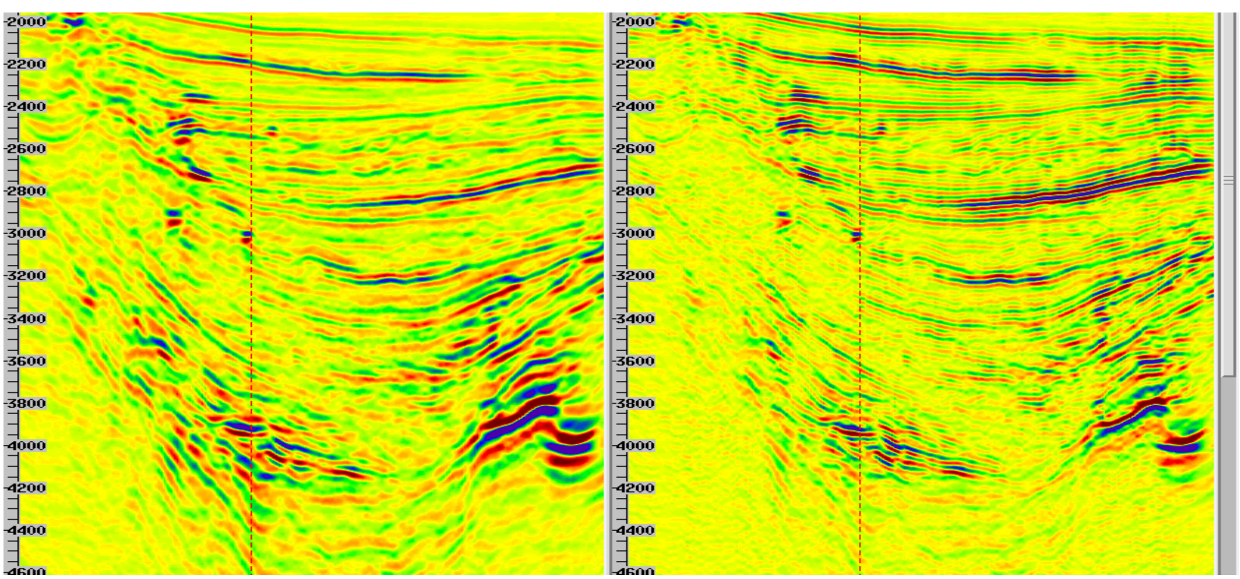
a) b)

Figure 9: Effect of un-stretching on a real gather
a) original gather, b) un-stretched gather

In the next example effect of un-stretching is demonstrated on AVO attributes – angle stacks. Figure 10 shows far angle stacks before and after un-stretching. Here a very visible effect is seen. Resolution of the data is significantly improved especially at the shallow parts, but also at depth, lending itself to an improved AVO inversion. Figure 11 shows an AVO gradient section with and without un-stretching, on part of the data, demonstrating the significant effect the un-stretching has on amplitude inversions.

Conclusions

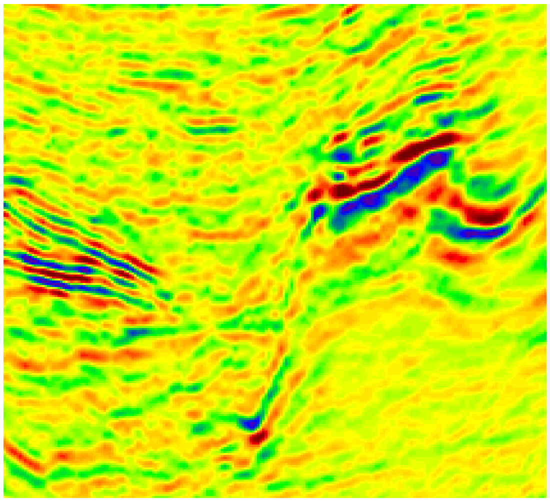
Effects of wavelet stretching in the offset domain and in reflection angle domain were described. An algorithm for removing them was constructed showing excellent results and improved AVO analysis.



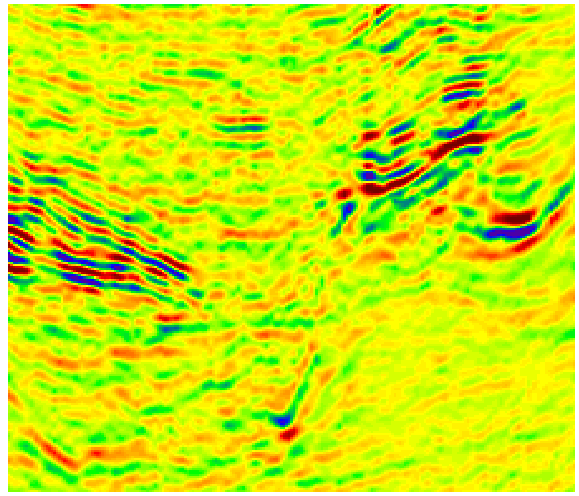
a) Far angle stack.

b) Far angle stack after un-stretching.

Figure 10. :



a) Gradient



b) Gradient after un-stretching

Figure 11.

Reference:

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