The importance of non-hyperbolic and stretch effects in far-offset P and PS NMO processing

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SUMMARY

The general aim of seismic surveying is to map the subsurface in as much detail as possible, subject to economic constraints. As technology has developed so has the ability to acquire and process larger amounts of data. This often translates to acquisition of larger offsets, potentially increasing the fold and signal-to-noise ratio of the stack.

Far-offset traces are subject to non-hyperbolic NMO, which may be handled by incorporating higher-order anisotropic terms. However, even if far-offset non-hyperbolic events can be flattened, they are likely to suffer from NMO stretch. This can result in a serious reduction in dominant frequency, and hence in vertical resolution. Several techniques have been published which apply NMO to P-wave data without introducing stretch. We have focused on extending one of these techniques through analysis of modelled and production data.

We have also extended the analysis to include converted-wave (PS) data, where NMO stretch can have even greater impact. For PS surveys, reflections on the near offsets have lower amplitude and are often swamped by noise. Therefore, most of the data contributing to the stack are from the mid to far offsets, particularly at the shallower coal scale. The dominant frequency of PS data can be significantly reduced by NMO stretch. This may be one of the factors that contribute to the poorer than expected resolution observed on some PS imagery.

Both the P and PS non-stretch NMO algorithms developed in this investigation successfully incorporate anisotropic parameters to accommodate non-hyperbolic NMO effects.

Key words: NMO stretch, Constant NMO, PS wave, Anisotropy.

INTRODUCTION

While the seismic reflection technique has been well developed since its inception, the need to image smaller targets in greater detail continues to drive this development. This includes extending the productivity and usability of the P-wave technique through methods such as attribute analysis and AVO. There have also been investigations of techniques that utilise other wave types, including converted (PS) waves.

There has been a remarkable improvement in the signal-to-noise ratio, and geological knowledge derived from seismic-reflection surveys compared to the early days of exploration. However, there has arguably been some reduction in the general resolution of seismic data (Denham and Denham, 2011). One of the possible reasons for this is the increased use of far-offset data to achieve these results.

Many processing methods require that time samples are shifted or summed based on the earth's assumed velocity field. The most fundamental of these is the normal-moveout correction (NMO). The standard NMO methodology is a dynamic adjustment which shifts time samples on non-zero offset traces to the zero offset equivalent. It has been shown (Buchholtz, 1972) that this leads to stretching of the seismic wavelet with offset.

In this investigation we will be focussing on the shallow coal-scale environment since NMO stretch tends to be more prominent for shallower targets, However, these results will be equally applicable for other seismic environments (e.g far-offset marine surveys). Figure 1 illustrates the relative NMO stretch of P and PS data for a coal-scale example where the target is at 100m and the dominant frequency of the seismic data is 80Hz.

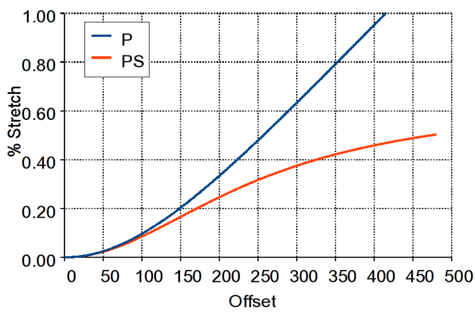

Figure 1: Stretch of a 80Hz wavelet for a target depth of 100m

As suggested by Figure 1, the problem of NMO stretch can be reduced by limiting the range of offsets, in this case to offsets less than 150m. However, this also limits the versatility and usability of the seismic-reflection technique.

There are a number of ways to deal with the far-offset stretch problem. Dunkin and Levin (1973) suggested an approach where the data are corrected after NMO by compressing and scaling the seismic wavelet at the target horizon prior to stacking. This can be difficult and only provides an approximate solution.

An alternative method is to apply NMO directly without stretching the wavelet (Shatilo and Aminzadeh, 2000). This is called constant NMO (CNMO). For this method seismic data are broken into discrete windows, centred about each target horizon. These are moved out at a constant velocity and then combined to produce an NMO-corrected record. In this investigation we will be building on this approach.

Anisotropic effects associated with horizontal laying in the earth give rises to non-hyperbolic seismic reflections, which are more significant on far-offset data. The original CNMO technique did not allow for this anisotropy.

In recent years the PS seismic reflection technique has been shown to have important applications, such as imaging in the presence of gas clouds (eg. Macleod et al., 1999) and shallow opencut coal exploration (e.g. Velseis 2003, 2007).

The aim of this investigation is to extend the CNMO technique to accommodate anisotropic earth effects for either P or PS waves.

RAYPATH MODELLING

To develop an understanding of how to use far-offset anisotropic data, we have used ray-path modelling to build P and PS seismic records (Figures 2a and 2b, last page) over a three layer model with horizontal reflectors at 10m, 50m, and 150m.

Figures 2c and 2d show the P and PS records after conventional NMO has been applied. The events have been allowed to stretch by up to 300% (beyond this the sample is muted). This is larger then would be allowed in production processing but is useful for demonstration purposes. These figures show that a lot of stretch is occurring on both the P and PS datasets. Consistent with Figure 1, the P-wave data suffer more stretch. This stretch will reduce the image quality through smearing of the seismic wavelet. The use of stretch mutes leads to a reduction in the signal-to-noise ratio. This is well demonstrated on the shallowest event where the usable fold is on the order of 3-4.

In Figures 2e and 2f the CNMO method has been applied to the data. This has produced much sharper seismic wavelets all the way out to the far offsets. The CNMO technique does generate some non-horizontal coherent noise between the seismic events. This is due to the fact that a sample on a raw record can be moved out to multiple locations by the CNMO process. If the fold of the data is high enough this noise should stack-out in the final image.

For the deeper two horizons the CNMO method has been unable to flatten the horizons. This is particularly significant on the PS data. For both the P and PS datasets this is caused but polar anisotropy (raypath bending associated with horizontal layering) and results in non-hyperbolic seismic events. If these data were stacked there would be significant smearing on the final image. To reduce this smearing the seismic records could be limited to the nearer offsets prior to stacking. However, this gives many of the same restrictions as using the standard NMO technique. An alternative approach is to modify the CNMO technique to allow for this anisotropic effect.

To account for the polar anisotropy we have replaced the hyperbolic NMO equation used in CNMO with an anisotropic one based on Thompsen (2002). Figures 2g and 2h show that the anisotropic CNMO method can flatten all of the seismic events for both the P and PS datasets. Table 1 compares the calculated P and S velocities for each method with the true zero-offset RMS velocities for the model. These results suggests that the anisotropic CNMO technique provides the best estimate of the true earth velocities.

Layer	Zero-Offset RMS (m/s)		NMO (m/s)		CNMO (m/s)		Anisotropic CNMO (m/s)	
	P	S	P	S	P	S	P	S
1	1000	500	980	613	1000	500	1000	500
2	1800	900	1700	1259	1920	1200	1790	994
3	3067	1533	3100	2296	3400	2125	3000	1667

Table 1: Calculated velocities for each moveout method.

REAL PS-DATA ANALYSIS

While the raypath modelling has demonstrated that this investigation is equally applicable to P and PS data, one of the main goals has been to improve PS seismic imagery.

One of the potential advantages of using PS waves for seismic imaging is an improvement in resolution (Velseis 2003). The S-wave travels with velocities which are lower than P-waves. This means that provided the frequency content is similar, the PS-waves should exhibit shorter wavelengths, and hence better resolution, than P-waves. Unfortunately, PS-wave stacks generally have lower frequency content than P-wave stacks and no resolution improvement is observed. It has been suggested that this could be due to S-waves being more susceptible to frictional attenuation(Strong and Hearn, 2008).

Another possibility is that the PS data are being significantly affected by NMO stretch. Figure 3a shows the amplitude for the P and PS top-of-coal reflectors. The PS energy is biased towards far offsets while more of the P energy is at near offsets. This suggests that PS images may be affected more by NMO stretch (Figure 3b).

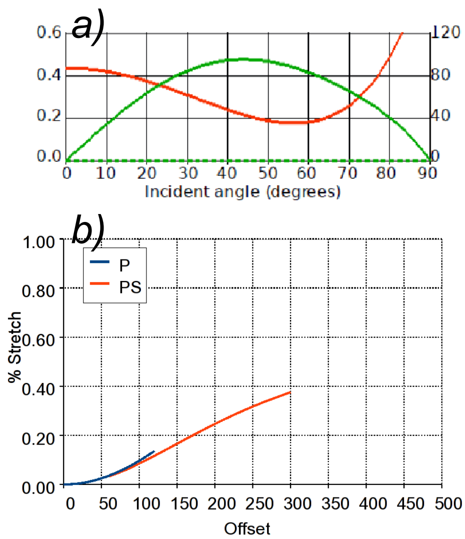

Figure 3: a) P (red) and PS (green) reflection energy. b) NMO stretch expected at dominant offsets.

Figure 4 compares the anisotropic NMO and CNMO algorithms for a real PS data set. The seismic records and corresponding magnitude spectra indicate that the standard NMO method creates significant stretch on most offsets which results in an apparent attenuation of the high frequencies. For the CNMO technique this does not occur and as a result the CNMO method producers sharper stacked sections (Figures 4e and 4f).

CONCLUSIONS

This investigation has demonstrated that NMO stretch can have a significant impact on both P and PS datasets. In applications where far offsets are required it is essential the methods such as CNMO be applied and where possible these should account for polar anisotropy.

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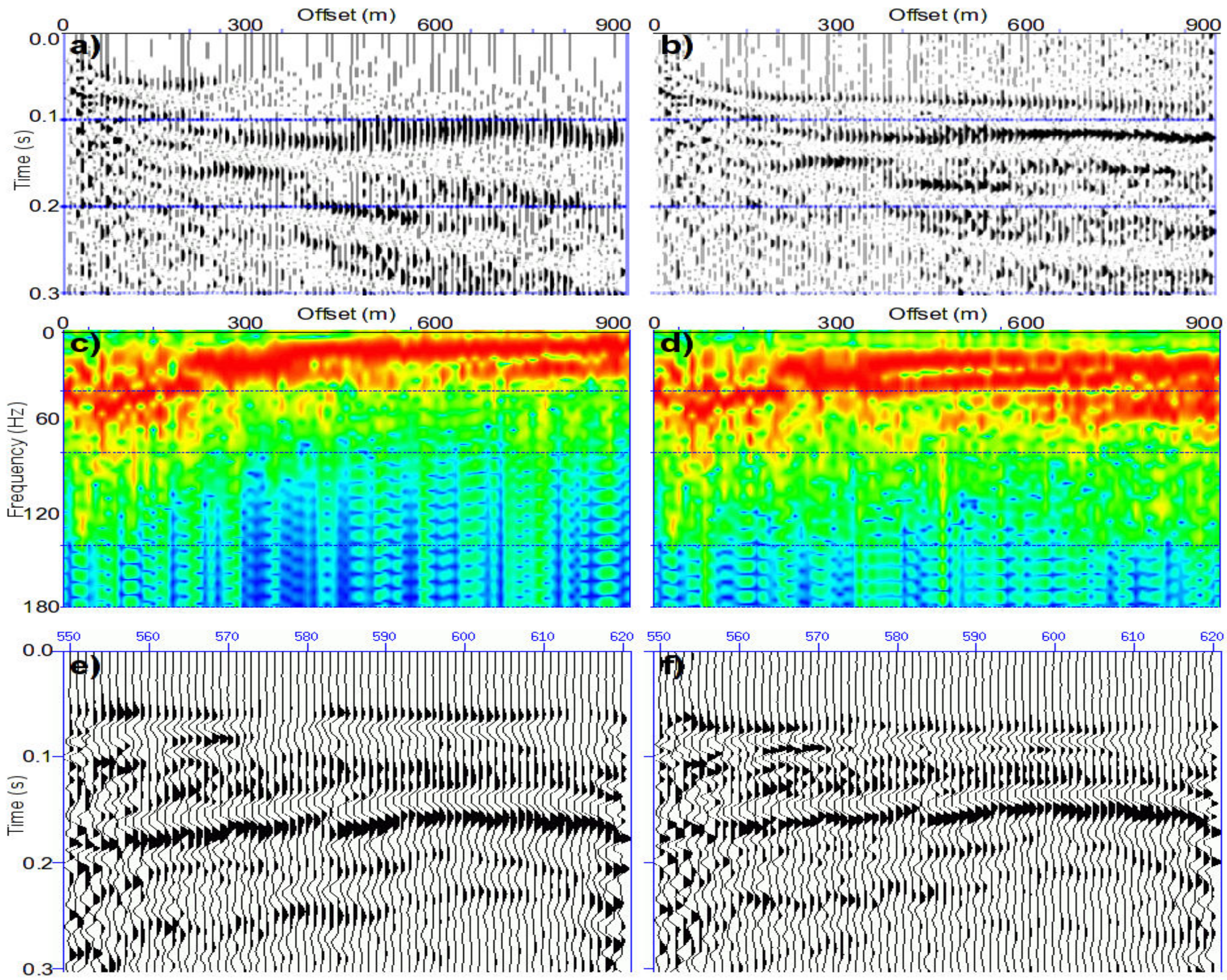

Figure 4: Real data comparison of anisotropic NMO (left) and anisotropic CNMO (right) for a PS dataset. a) and b) shot records with moveout correction applied. c) and d) magnitude spectra of a) and b) where red represents high spectral magnitudes. e) and f) corresponding 2D CCP stacks.

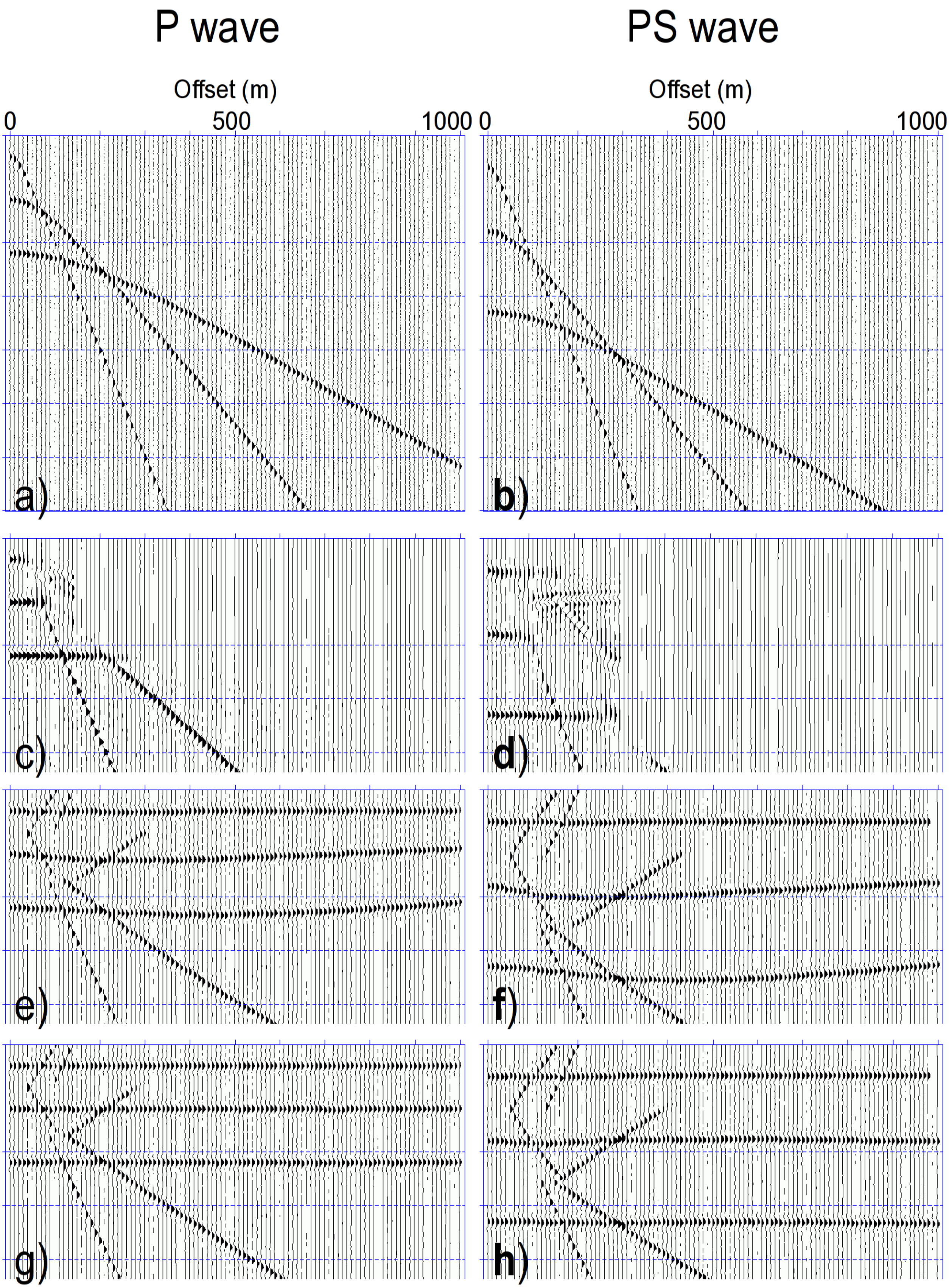

Figure 2: Comparison of NMO methods for P and PS data. a) and b) show the raw P and PS records generated from ray-trace modelling. c) and d) after standard NMO. e) and f) after CNMO has been applied. g) and h) after anisotropic CNMO has been applied.