Residual converted wave statics

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ABSTRACT

In a departure from the commonly found pilot trace technique of residual static estimation we adapt a method based on near-neighbour trace cross-correlation and outlier rejection. This method *without pilot trace* is applied to converted-wave static computations for selected common receiver gathers of the Spring Coulee three component survey. Pre-processing of the input common receiver gathers includes NMO-correction, deconvolution, P-wave shot statics application, AGC and a band-pass filter. From the cross-correlation lags of every receiver gather we remove structure terms and residual NMO. Then residual shot statics are estimated and corrected. The next step is outlier rejection and stacking of common receiver gather traces followed by cross-correlation of the stacked traces. The resulting cross-correlation lags yield a first estimate of S-wave receiver static shifts.

INTRODUCTION

Converted wave surveys are conducted with increased frequency nowadays because of the additional shear-wave information available without the expense of shear-wave sources. The processing of C-wave seismic data is well established by now, and techniques like common conversion point (CCP) binning and non-hyperbolic moveout are well understood. Cary and Eaton (1993) state that, from the processor's perspective, the most problematic step is often the determination of residual S-wave statics which are commonly two to ten times greater than same-location P-wave statics according to Tatham and McCormack (1991). The topic of C-wave statics is addressed in the first ever volume of CREWES research reports by Schafer (1989). Two years later the same author (Schafer, 1991) compares C-wave statics methods and concludes that C-wave statics are best solved using hand-picked common receiver point (CRP) stacks. The same year Eaton et al. (1991) report on a stack power optimization method for C-wave residual statics estimation. This approach is developed further by Cary and Eaton (1993) into an automatic method no longer requiring hand picking of CRP-stacks. They state that obtaining initial receiver statics from CRP-stacks allows CCP-binning to be delayed until after the large receiver statics are resolved and applied; thereby V_p/V_s-ratio determination is postponed to a processing state with better signal-to-noise ratio. Cox(1999) and Garotta (2000) also suggest the CRP-stack method for large C-wave receiver statics and we shall follow their recommendation. A number of methods for statics estimation have been investigated in the intervening years, for example F-X statics (Chan and Stewart, 1996; ibid, 1997) and CSP gathers (Li and Bancroft, 1996; ibid, 1997), but they all appear to be based on stack power optimization and/or pilot traces.

There is another method, based solely on cross-correlation of neighbouring traces and outlier rejection, which seems largely ignored but is said to outperform the Wiggins et al. (1976) approach (R. Rubenok, personal communication). We shall try to adapt the Rubenok method to residual C-wave statics estimation.

THEORY

The basic travel time equation given by Schneider (1971) gives a sum of normal incidence time plus move out time plus shot static plus receiver static plus estimation error or, in the notation of Cox (1999),

$$T_{ijk} = G_k + S_i + R_j + M_k X_{ij}^2 + N \qquad (1)$$

where T is the total reflection time following NMO-correction,

i is the source location index,

j is the receiver location index,

$k = (i+j)/2$ is the mid point location index,

G is the structure component,

S is a surface consistent source static correction,

R is a surface consistent receiver static correction,

M is the residual move out coefficient,

$X = (j-i)$ is the source-receiver offset and

N is a noise component.

With modern high-fold data it is possible to set up an over-determined system of equations starting from Equation 1, but first we reject outliers and condition raw time shifts. These time shifts are cross-correlation lags of neighbouring traces representing relative time differences. Non-zero structure components and non-zero residual NMO-terms will distort residual static estimates if not removed or at least minimized (Cox, 1999). Residual static shifts change from trace to trace and thus constitute a high frequency "*signal*". Structure terms are low frequency *"signals"* that can be estimated by an average (DC-bias) of the time shifts (Cox, 1999) and then removed. Residual NMO is a function of squared offset and can be eliminated by, firstly, curve fitting any trend in the time shifts depending on squared offset and, secondly, removing it. Because C-waves show non-hyperbolic moveout behaviour, we are planning to test an additional fourth order offset term in the future. When combining DC-bias and squared offset dependence we obtain for our model function M

$$M = a + bX^2 \qquad (2)$$

which we fit to the data points D (cross-correlation time differences) in the least-square-error sense, that is

$$\frac{d}{dm}\left[\sum_n (D_n - M)^2\right] = 0 \tag{3}$$

where m are the model parameters a and b of Equation 2 and

n represents the number of data points.

Introducing Equation 2 into 3 and taking the derivatives leads to

$$\frac{d}{da}\left[\sum_n (D_n - a - bX_n^2)^2\right] = 2na + 2b\sum_n X_n^2 - 2\sum_n D_n = 0 \quad \text{and} \tag{4a}$$

$$\frac{d}{db}\left[\sum_n (D_n - a - bX_n^2)^2\right] = 2a\sum_n X_n^2 + 2b\sum_n X_n^4 - 2\sum_n D_n X_n^2 = 0\ . \tag{4b}$$

With Equations 4a and 4b we have two equations for the two unknowns a and b in terms of data points D_n and their offsets X_n which allows us to calculate

$$b = \left[\frac{\sum_n D_n X_n^2}{\sum_n X_n^2} - \frac{1}{n}\sum_n D_n\right] \Bigg/ \left[\frac{\sum_n X_n^4}{\sum_n X_n^2} - \frac{1}{n}\sum_n X_n^2\right] \quad \text{and} \tag{5}$$

$$a = \frac{1}{n}\sum_n D_n - \frac{b}{n}\sum_n X_n^2\ . \tag{6}$$

Equations 5 and 6 are the desired coefficients for Equation 2 that enable us to remove DC-bias and residual NMO from the cross-correlation time shifts in the least-square-error sense.

COMMON RECEIVER GATHERS AND COMMON RECEIVER STACKS

Figure 1 shows the first of 20 common receiver point gathers (CRG) selected for this investigation. It is part of the Spring Coulee three component survey shot in January of 2008 and processed by Han-xing Lu as well as one of the authors (D. Henley). The pre-processing for Figure1 includes NMO correction, deconvolution, shot statics application, AGC and a 4/8-55\70Hz band-pass filter. Cross-correlation time shifts of the CRG in Figure 1 before and after DC-bias/residual-NMO correction are displayed in Figure 2; also plotted is the model-curve fitted to the time shifts before correction. Note that outlier- rejection is accomplished by a ± 20ms time window: any time shifts outside this window are ignored by the DC-bias/residual-NMO computation/correction. We observe in Figure 2 that, firstly, there is a non-zero residual NMO-estimate and, secondly, correction size depends on the squared offset.

Receiver static shifts are the same for every trace in Figure 1 because we are looking at a common receiver gather. Cross-correlations ignore this common receiver shift but they are sensitive to the difference in shot static shifts between traces that are input to the correlation. As there are two shots involved in every cross-correlation we set up an over-determined system of equations to solve for the individual shot static contributions in the least-square-error sense. Shot static corrections thus computed can be seen in Figure 3. For comparison purposes we added the result of the same computations but without RNMO-correction and note that shot static shifts with prior RNMO-correction are somewhat smaller than comparisons without as could be expected. Another way of looking at static corrections is the histogram. We define a row of 100 bins, each 2ms wide, with bin number 50 assigned -1ms to +1ms, bin 49 from -3 to -1, bin 51 from 1 to 3 and so on. Next we sort all shot corrections according to size into these bins. Figure 4 demonstrates the size distribution of residual shot static corrections plotted in Figure 3. Firstly they are concentrated around the zero mark and, secondly, there is a rapid decay in the number of contributors away from the origin. This fact allows us to reject outliers.

Applying the shot static corrections of Figure 3 to all CRP-traces, rejecting outliers and stacking the remaining traces within each CRP-gather gives the CRP-stack traces in Figure 5. The relative shift between the traces of Figure 5 is a first estimate of receiver static corrections (Cary and Eaton, 1993). Figure 6 shows nearest-neighbour cross-correlations computed from CRP-stack traces plotted in Figure 5. The cross-correlations in Figure 6 are enhanced (raised to the fourth power) and normalized for display purposes. The most notable non-zero cross-correlation lag can be seen in traces 5 and 6 (from the top) of Figure 6. When applying receiver static corrections derived from these lags to CRG-stack traces the cross-correlations given in Figure 7 are the result. At least at first glance relative receiver static shifts are greatly reduced in Figure 7. The next logical step is to apply these corrections to common shot gathers and then compute "*residual*" receiver statics following the estimation/removal of DC-bias/residual-NMO.

CONCLUSIONS

The Rubenok method of residual static estimation by cross-correlation and outlier rejection is successfully adapted to converted-wave static computations for selected common receiver gathers of the Spring Coulee three component survey. From the cross-correlation lags of traces within each receiver gather we remove any DC-bias (structure term) and residual normal moveout first. Then residual shot statics are estimated and corrected. Common receiver gather traces are stacked next following outlier rejection. Cross-correlation of these common receiver stack traces yields a first estimate of S-wave receiver static shifts. Following S-wave receiver static correction with this first estimate we are finally ready to sort traces into shot gathers and estimate *residual* receiver statics when DC-bias and RNMO are removed.

ACKNOWLEDGEMENTS

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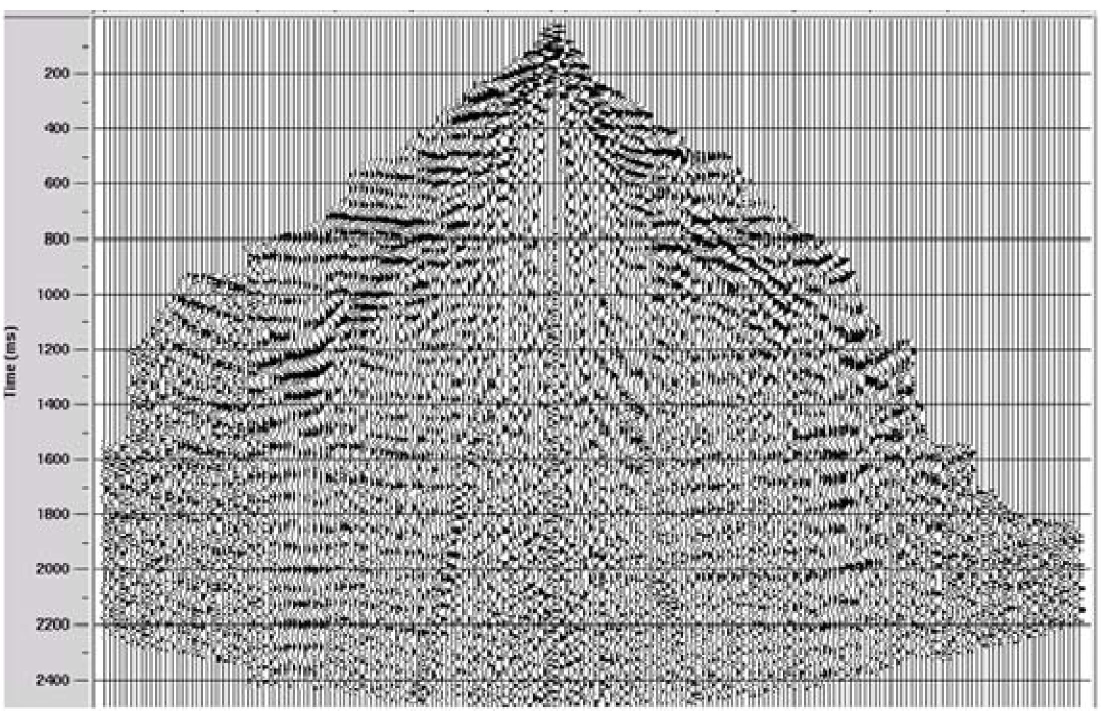

FIG. 1. Spring Coulee Common Receiver Gather.

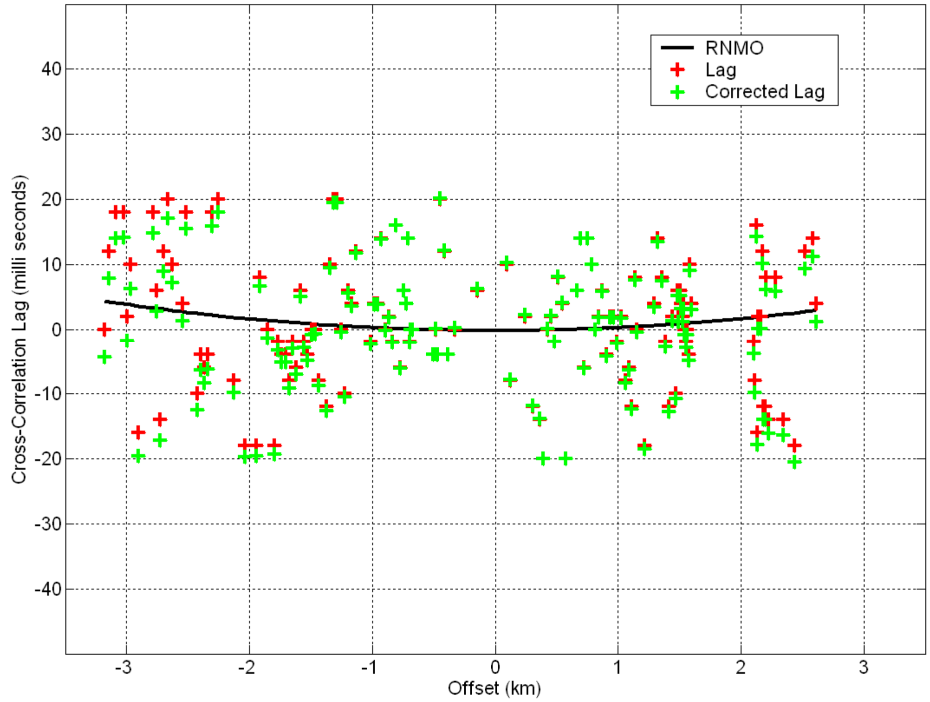

FIG. 2. Spring Coulee DC-bias and residual-NMO estimate.

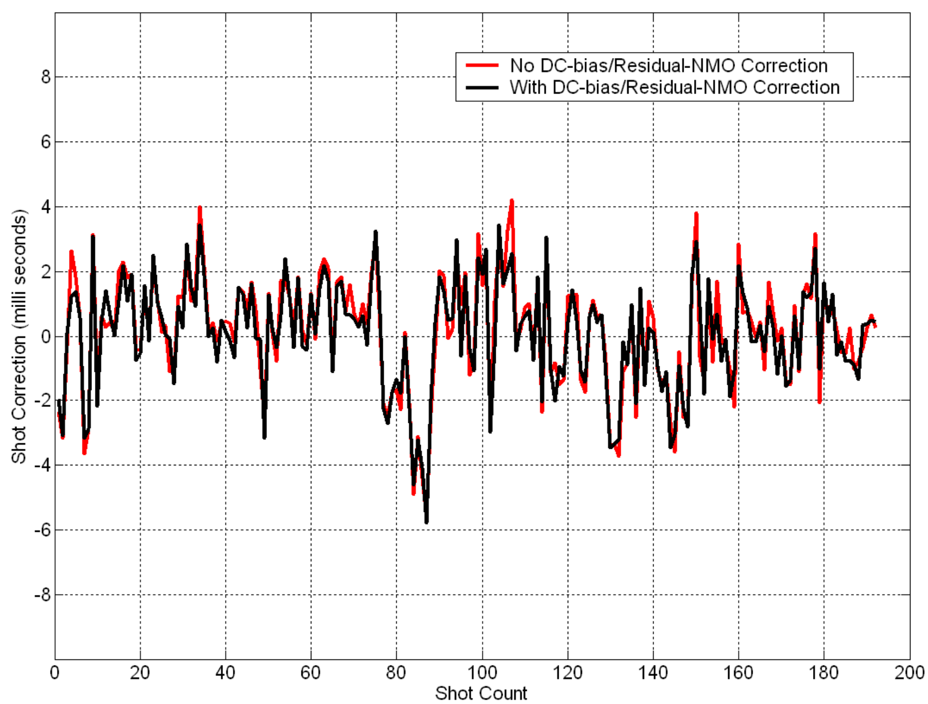

FIG. 3. Spring Coulee Residual Shot Static Correction.

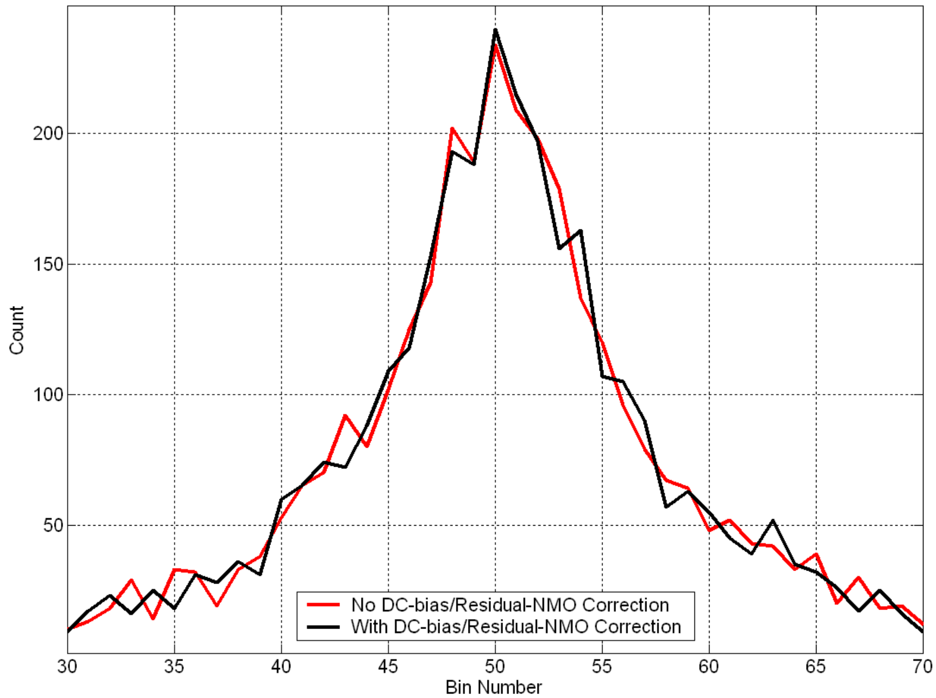

FIG. 4. Spring Coulee Residual Shot Static Histogram.

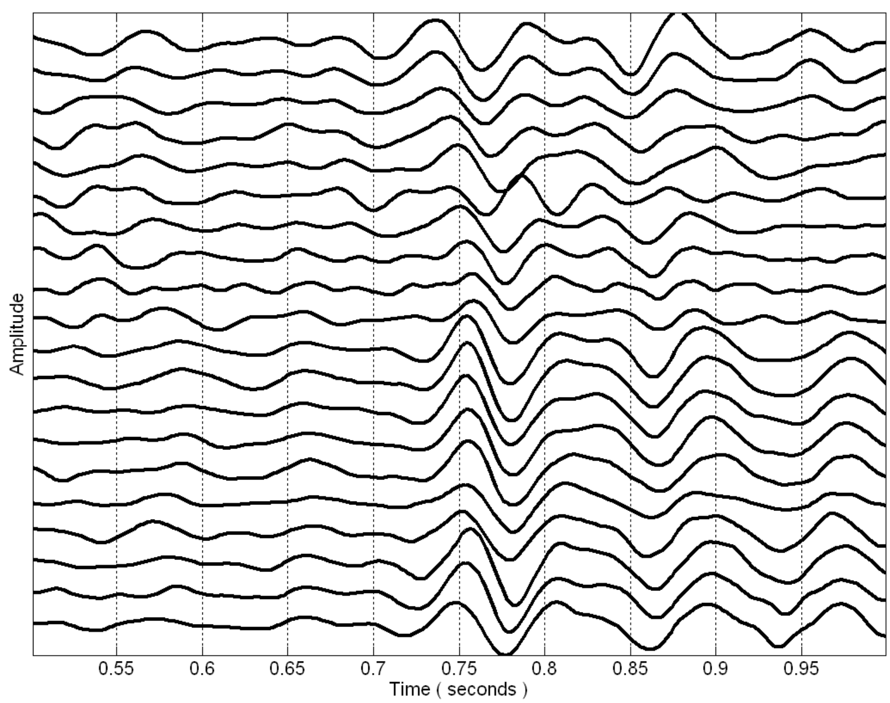

FIG. 5. Spring Coulee CRG-Stack with Residual Shot Static Correction (±10ms window).

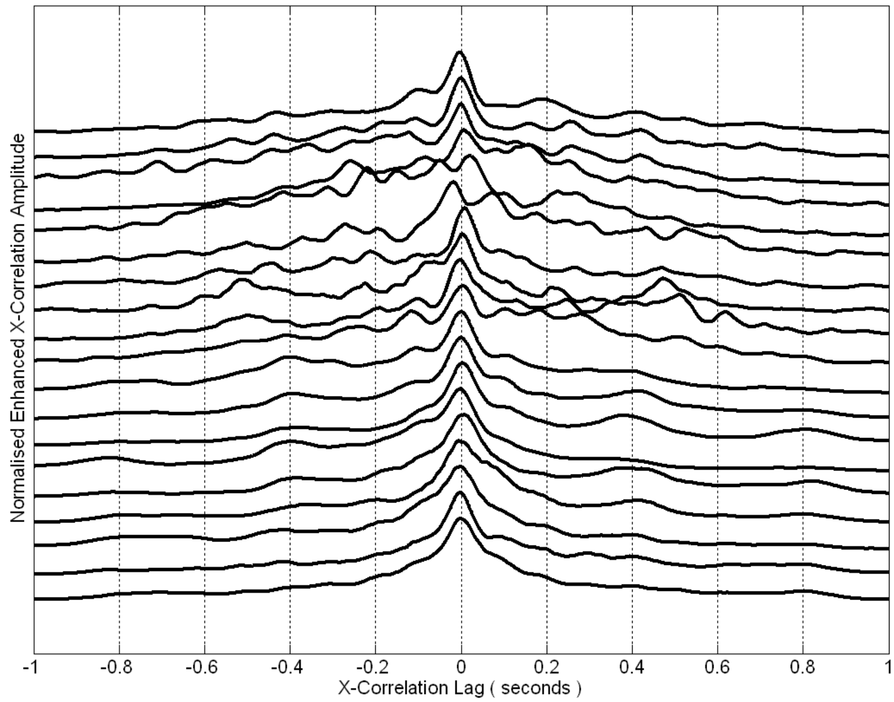

FIG. 6. Enhanced Nearest-Neighbour Cross-Correlations of the Traces in Figure 5.

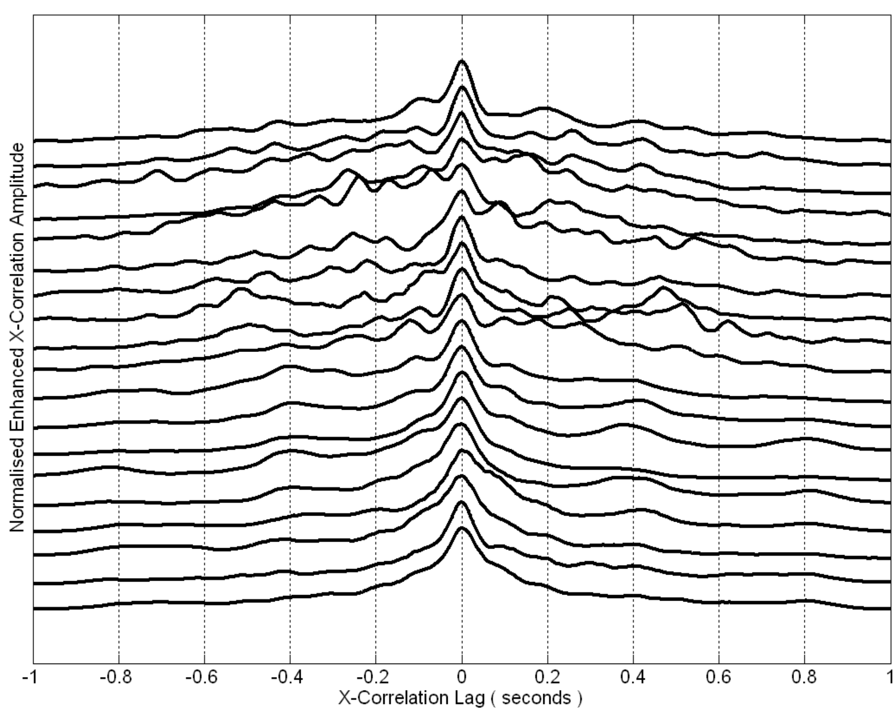

FIG. 7. Enhanced Nearest Neighbour Cross-Correlations of CRG-Stack Traces Following the Application of First-Estimate Receiver Static Corrections.