Experimental comparison of seismic repeatability metrics

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Abstract

Time-lapse experiments were performed on the nrms repeatability (NRMS), predictability (PRED) and signal to distortion ratio (SDR) repeatability metrics. First, controlled time-shift, amplitude and additive noise perturbations were made to a baseline seismic trace. Time-shift had approximately linear effects on NRMS of about 15%/ms, subtle hyperbolic effects on PRED and a negligible effect on SDR. Amplitude tests showed that multiplication of the baseline trace by 0.9 resulted in an NRMS value of 10.5% and SDR value of $10^{2.04}$, while PRED remained unaffected by any amplitude change. Additive noise experiments revealed that NRMS and PRED are very sensitive to the strength and character of the noise, while SDR seems to be affected little by the noise character.
Second, all three metrics were calculated using a 2D walkaway vertical seismic profile (VSP) dataset from Violet Grove, Alberta, which consisted of three lines. For Lines 1, 2 and 3, NRMS values were 60.6%, 61.4% and 45.2% for horizontal components, and 46.3%, 42.6% and 41.4% for the vertical component. PRED was 0.73, 0.72 and 0.83 for the horizontal components, and 0.82, 0.83 and 0.87 for the vertical component. Finally, SDR was $10^{0.38}$, $10^{0.29}$ and $10^{0.70}$ for the horizontal components and $10^{0.74}$, $10^{0.85}$ and $10^{0.79}$ for the vertical component.

Controlled experiment

In order to test the separate effects of time-shift, amplitude difference and noise, a trace was chosen from the baseline survey. Copies of this trace were then perturbed in several ways:

1) The traces were time-shifted by values ranging from -5 ms to +5 ms, incrementing by 0.1 ms with and without resampling of the initial trace.

2) The traces were multiplied by constants ranging from 0.5 to 1.5, incrementing by 0.01.

3) Noise, extracted from the first 500 ms of both the baseline and monitor traces, was multiplied by ratios of the maximum noise to maximum signal of the baseline trace, ranging from 0 to 0.5 in increments of 0.02.

Seismic repeatability metrics

NRMS repeatability is defined as (Kragh and Christie, 2002)

$$NRMS = \frac{2\sqrt{\sum_{t_1}^{t_2}(b_t - m_t)^2/N}}{\sqrt{\sum_{t_1}^{t_2}(b_t)^2/N} + \sqrt{\sum_{t_1}^{t_2}(m_t)^2/N}} \quad (1)$$

where b and m are the baseline and monitor traces, t_1 and t_2 are the start and end times of the desired window, and N represents the total number of samples within the window.

Predictability is defined as (Kragh and Christie, 2002)

$$PRED = \frac{(\sum_{-n}^{+n} b \otimes m)^2}{(\sum_{-n}^{+n} b \otimes b)(\sum_{-n}^{+n} m \otimes m)} \quad (2)$$

where $\otimes$ is the crosscorrelation operator, and the sum is performed over lags $-n$ to $+n$. Signal to distortion ratio is defined as (Cantillo, 2011)

$$SDR = \frac{\sum_{t_1}^{t_2} b_t^2}{\sum_{t_1}^{t_2} d_t^2} = \frac{\max(b \otimes m)^2}{1 - \max(b \otimes m)^2} \quad (3)$$

Discussion

Figure 2 shows the results of the time-shift tests. Time-shift does not have a largely detrimental effect on SDR; NRMS appears to have a linear dependence on time-shift and PRED seems to have a hyperbolic trend. The results of the amplitude tests are shown in Figure 3. Interestingly, PRED remains unchanged regardless of the amplitude ratio. Repeatability for the additive noise test is shown in Figure 4; the two curves represent two different noise sources. The noise taken from the monitor was dominated by a 60 Hz cable signal, and can be considered as non-random. Finally, Figure 5 shows plots of $\log_{10}$ SDR alongside NRMS as well as PRED, for the z-component of receiver 3.

Conclusions

• Residual time-shift between a noise-free baseline and monitor trace will cause NRMS to change almost linearly by 15%/ms; the effect is much more subtle on PRED, only changing it by about 0.03 for 1 ms difference. Time-shift has essentially no effect on SDR, which is intended from its definition.

• Amplitude perturbations between a noise-free baseline and monitor trace showed that NRMS changed by 10.5% and SDR is $10^{2.04}$ when the amplitude ratio of the two traces was 0.9; PRED remained unaffected by amplitude changes.

• When additive noise was introduced to the monitor trace, SDR showed results that were very similar for both the baseline (random) and monitor (non-random) noise; while there was a large drop in its value when a slight amount of noise was added, further addition of noise resulted in a nearly linear response with a gentle slope. NRMS and PRED produced curves that were easily distinguishable between the types of noise added. NRMS appeared to have a linear response while the noise strength was low; PRED changed little with low noise strength, and was more sensitive to the type of noise added.

• Repeatability analysis of the Violet Grove horizontal component data yielded NRMS values of 60.6%, 61.4% and 45.2%, PRED values of 0.73, 0.72 and 0.83, and SDR values of $10^{0.38}$, $10^{0.29}$ and $10^{0.70}$ for Lines 1, 2 and 3 respectively.

• Repeatability analysis of the Violet Grove vertical component data yielded NRMS values of 46.3%, 42.6% and 41.4%, PRED values of 0.82, 0.83 and 0.87, and SDR values of $10^{0.74}$, $10^{0.85}$ and $10^{0.79}$ for Lines 1, 2 and 3 respectively.

Field experiment

The VSP field data used in this study was taken from the Pembina CO_2 enhanced oil recovery project; this oilfield is about 100 km southwest of Edmonton, Alberta, and the Cardium in this area is the largest conventional oil pool discovered in Western Canada (Hitchon, 2009). The VSP consisted of eight 3-component geophones placed every 20 m, starting at 1498 m depth, in the observation well 07-11-048-09W5 near Violet Grove, Alberta (Hitchon, 2009). The baseline dataset was acquired in March 2005, and the monitor dataset was acquired in March 2007. Three surface seismic lines were common between them: Line 1, which runs North-South, and Lines 2 and 3, which run East-West (Figure 1).

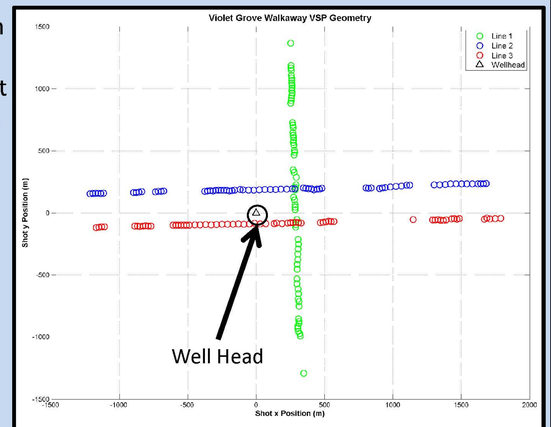

FIG. 1. Surface geometry for Violet Grove walkaway VSP.

Results

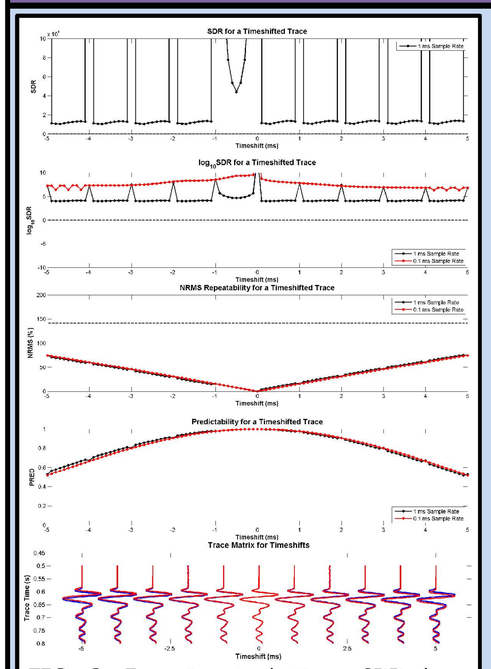

FIG. 2. From top to bottom: SDR, $\log_{10}$ SDR, NRMS and PRED for time-shift experiment. Bottommost panel is a wiggle display of the time-shifted traces (red) overlapping the original trace (blue).

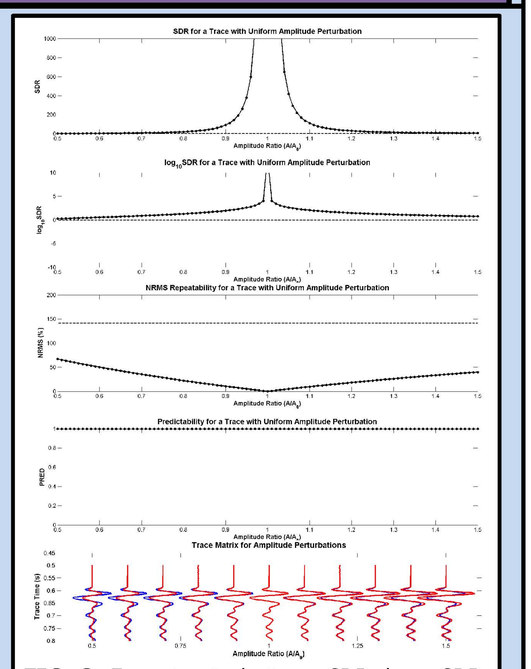

FIG. 3. From top to bottom: SDR, $\log_{10}$ SDR, NRMS and PRED for amplitude experiment. Bottommost panel is a wiggle display of the amplitude modified traces (red) overlapping the original trace (blue).

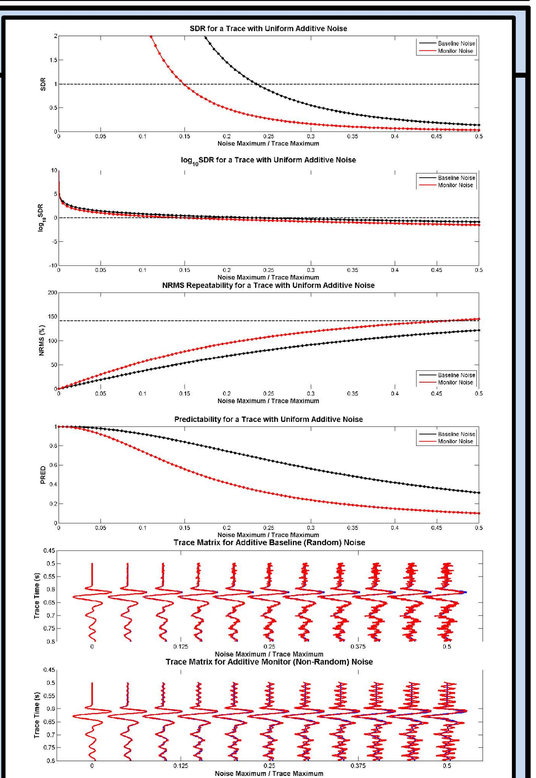

FIG. 4. From top to bottom: SDR, $\log_{10}$ SDR, NRMS and PRED for noise experiment. Bottommost panel is a wiggle display of the noisy traces (red) overlapping the original trace (blue).

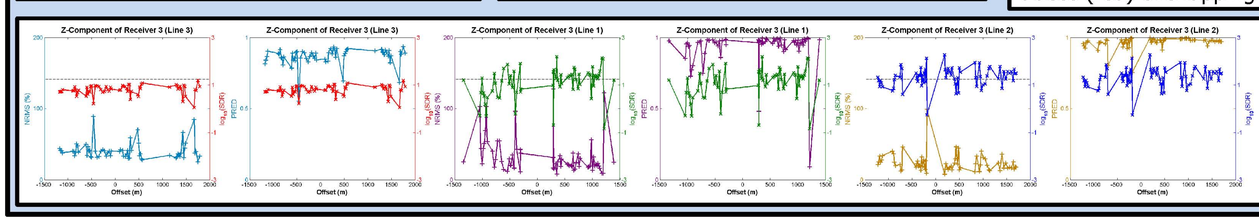

FIG. 5. Comparison of NRMS, PRED and $\log_{10}$ SDR of z-component of receiver 3 for field experiment.

References

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