

Time-Lapse Repeatability in 3C-3D Dataset from Weyburn CO₂ Sequestration Project

Jinfeng Ma^{1,2} *, Le Gao¹, and Igor Morozov¹

¹ Department of Geological Sciences, University of Saskatchewan, Canada,
jinfeng.ma@mail.usask.ca

² Department of Geology, Northwest Univ., China

Summary

The success of time-lapse seismic monitoring relies on repeatability of dataset parameters. In this study, the consistency of source and receiver coordinates was measured and compared with baseline in 3C-3D seismic dataset used in IEA Weyburn CO₂ Sequestration and Monitoring Project. We examine the repeatability of source, receiver and stacked data and suggest how these measurements can be used to support calibrated data processing. The results suggest that the 2002 vintage of the dataset is can be considered repeatable with the 1999 baseline, whereas the 2001 monitor is difficult to calibrate because of the differences in shot patterns. New, pre-stack calibration approaches are required in order to achieve consistent repeatability that could be sufficient for deriving calibrated AVO attributes.

Introduction

Time-lapse 3D seismic surveying is a new technology to image the fluid change, pressure front and locate the oil bypassed in the reservoir (Lumley, 2004). It is also the key monitoring techniques used to control the distribution of CO₂ in the IEA Weyburn CO₂ sequestration and monitoring project, conducted in Encana Weyburn field in Saskatchewan. Time-lapse 3D observations have already increased the understanding of CO₂ sequestration in Weyburn reservoir (Li, 2003). However, the initial processing of these datasets (Sensor Geophysical, 2005) focused on post-stack imaging and migration, and pre-stack information of 3D3C datasets was not utilized until now. The objective of the present reprocessing is to fully utilize the three-component character of these datasets and to use AVO inversion to characterize the changes in shear-wave properties of the reservoir under CO₂ injection (Brown, et al., 2007). However, without repeatability measurements, interpretation of the differences between the baseline and monitor datasets could be problematic (Altan, 1997), and particularly in AVO attributes.

Starting from a baseline in 1999, several 3C-3D datasets were acquired for this project, of which the 1999, 2001 and 2002 vintages are available to the present study. In this paper, we perform repeatability measurements of these three vintages of the vertical-component data by using the traditional techniques. We measure the accuracy of source and receiver coordinates, amplitudes and phases in shot and CMP gathers. These measurements help in evaluating the repeatability limitations resulting from seismic acquisition and developing the calibrated processing sequence and its parameters. We further suggest that a more complete, pre-stack calibration technique is needed in order to achieve accurate calibration suitable for AVO-based monitoring of the changes in the reservoir.

Repeatability of the vertical-component Weyburn 3C-3D dataset

Similarly to the original processing of this dataset (Sensor Geophysical, 2005), we used identical geometry, statics, and RMS velocity model in processing all of its three vintages. However, the CMP bin size was selected as 80×80 m (compared to 40×40 m used before), corresponding to the nominal source and receiver intervals of 160 m. The basic dataset parameters are given in Table 1.

Table 1. Weyburn 3C-3D acquisition parameters.

Parameters\Year	Baseline (1999)	Monitor (2001)	Monitor (2002)
Shot number	630	882	630
Receiver station	986	986	986
Sample rate	2 ms	2 ms	1 ms
Maximum offset	2152.87	3445.84	2105.627
Maximum fold	77	132	78
Source type	Dynamite,1kg,12 m	Dynamite,1kg,12 m	Dynamite,1kg,12 m
Receiver type	Mitcham, 3C Frequency 10Hz Damping 70%	OYO, 3C Frequency 10Hz Damping 1%	OYO, 3C Frequency 10Hz Damping 0.7%
Source interval	160 m	160 m	160 m
Receiver interval	160 m	160 m	160 m
Patch	19 lines x 39stations	19 lines x 39stations	19 lines x 39stations

Our key reprocessing steps included refraction static correction, true-amplitude recovery, surface-consistent deconvolution (SCD), time-variant spectral whitening, and velocity analysis by using ProMax. Operations most strongly distorting the amplitudes, such as F-XY, AGC, and migration were not used in our flow. Spiking deconvolution (included in SCD) was found to lead to uncontrollable time shifts in the datasets, and it was replaced with predictive deconvolution. Also although the use of residual statics in conventional time-lapse processing (Sensor Geophysical, 2005) aligned reflections in the CMP gathers, it is also prone of distorting the wavelet and reducing the AVO responses. Therefore, we try minimizing the use of such operations in our re-processing.

In each of the monitor datasets, we measured the deviations of the source and receiver coordinates and elevations, first-break time shifts and amplitude variations in shot gathers. We also checked the differences in offset and azimuth distributions between the baseline and monitor datasets.

The source and receiver coordinates show significant differences in the three vintages (Figs. 1 and 2). For most source and receiver locations, monitor data deviate by several meters, with occasional 20-m deviations from the baseline. Elevation deviation of source and receiver are mostly within 0.5 m. Considering that the data were acquired by re-deploying the geophones for each monitor survey, the repeatability of spread locations is good. However, the observed deviations in the source and receiver coordinates still remain among the main reasons causing time shifts and amplitude variances in the monitor datasets.

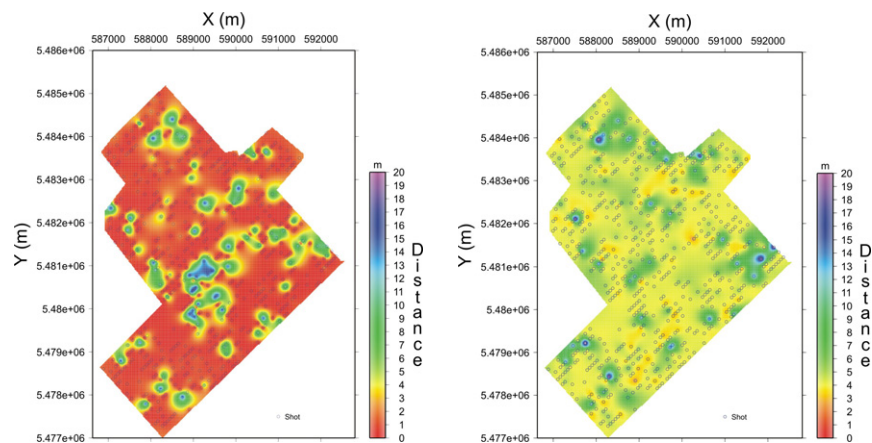


Figure 1. Shots coordinate deviation. Left: 2001 minus 1999 coordinates; Right: 2002 minus 1999 coordinates.

The first-arrival time differences were measured in several shot gathers of the baseline and monitor datasets. For shot 2116171 (Fig. 3), the time shifts between the 2001 monitor and baseline are around -10 ms. Between the 2002

monitor and the baseline, the time differences are around 6 ms. However, time shifts are also dependent on the receiver locations, which make it difficult to align all first breaks accurately. These shifts could be related to the variations in the subsurface conditions.

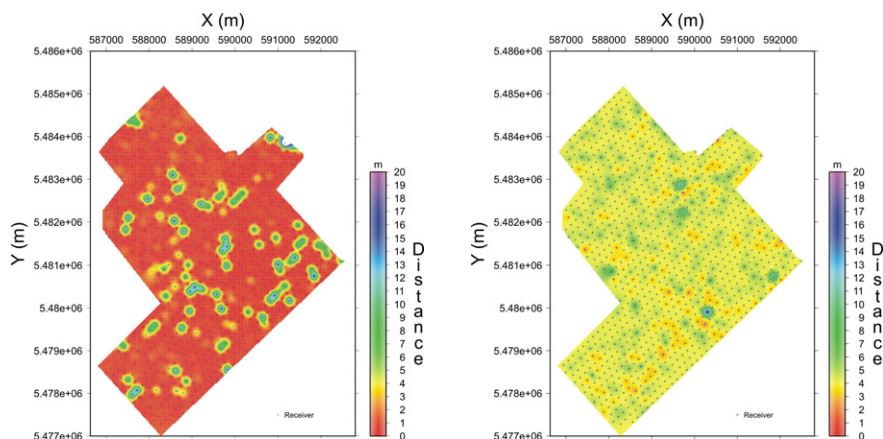


Figure 2. Receiver coordinate deviation. Left: 2001 minus 1999 coordinates; Right: 2002 minus 1999 coordinates.

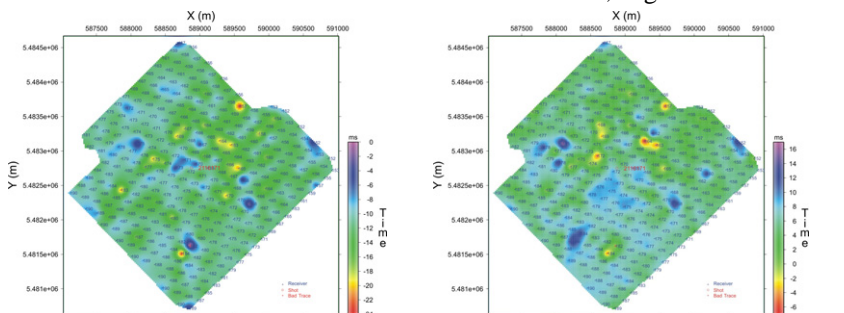


Figure 3. First-break time deviation at shot 2116171. Left: 2001 minus 1999; Right: 2002 minus 1999.

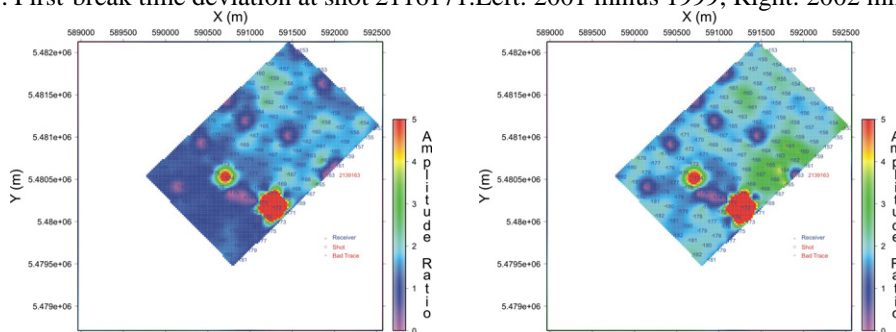


Figure 4. First-break average amplitude ratio in shot 2139163. Left: 2001/1999 ratio; Right: 2002/1999 ratio.

In order to study the consistency of amplitudes, the first-arrival amplitude ratios were measured (Fig. 4). As an example typical for the 2001 survey, shot 2139163 shows a characteristic amplitude decrease in the south of the swath (Fig. 4). This difference should be due to the fact that this shot was actually conducted as two separate shots during the data acquisition. Further inconsistency of first-arrival amplitudes should be caused by geophone coupling, spectral differences between the shots, and potentially variations in the near-surface velocity and attenuation.

The (non-) repeatability of amplitudes in shot gathers datasets still does not automatically mean the same in the CMP domain. The consistency of NMO velocities, folds, offset ranges, and azimuths may cause additional uncertainties in stacked amplitudes and also lead to incorrect AVO inversion. We therefore performed similar repeatability measurements in CMP gathers. The general result confirmed the above observations of the 2001 dataset being less repeatable compared to 1999 and 2002.

Finally, we also checked the resulting amplitude changes above and below the reservoir (Fig. 5). The measurements were repeated before and after the residual static correction. The 2001 dataset still revealed non-consistency in the

middle of the observation area, and the 2002 monitor showed a better repeatability (Fig. 5). In addition, acquisition footprints (edges of shot swaths) are visible in the 2001/1999 comparison (Fig. 5, left). As above, the non-consistency of the amplitude ratios should relate to different shot swaths used in the 2001 survey.

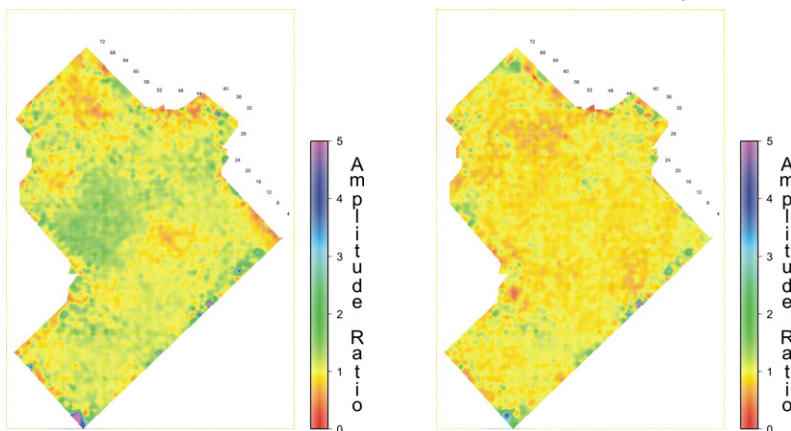


Figure 5. Average amplitude ratio in stacked data above the target zone (near 750 ms). Left: 2001/1999 ratios; Right: 2002/1999 ratios. Not the stronger deviation and acquisition footprint in the 2001/1999 amplitude ratios.

Conclusions

The 2002 monitor dataset from the Weyburn CO₂ Sequestration and Monitoring project shows higher consistency with the baseline, whereas the 2001 monitor is less consistent. Most of this inconsistency appears to be related to the use of different receiver swaths in 2001 data acquisition. The deviations of the source and receiver locations are moderate but still lead to first-arrival time and amplitude variations. Velocity variations in the subsurface, source parameters and geophone coupling may also lead to further variations.

From this analysis, it appears that calibration approaches based on the traditional time-lapse data processing are limited in the degree of repeatability that they can achieve. Improved, fully pre-stack calibration methods are required. It appears that by using calibration in multi-component, multi-vintage, common-record gathers (Morozov and Gao, this Convention), accurate time, amplitude, spectral, and phase-shift alignment still can be achieved. .

Acknowledgements

This work is as a part of Weyburn Phase II CO₂ Sequestration and Monitoring Project. J. Ma's research was also supported by NSFC Grant 40674041, China 863 Program Grant 2006AA09Z313, 973 Program Grant 2006CB202208.

References

- Altan,S.,1997, Time-lapse seismic monitoring: repeatability processing tests: 67th Annual International Meeting, SEG, Expanded Abstract,866-867.
- Aritman, B.C.,2001, Repeatability study of seismic source signatures: Geophysics, 66,1811-1817.
- Brown, S.J., Bussod,G. Junction, W.R.,Hagin,P., 2007, AVO monitoring of CO2 sequestration: A benchtop-modeling study: The Leading Edge,26,1576-1583.
- Li,Guoping,2003,4D seismic monitoring of CO2 flood in a thin fractured carbonate reservoir: The Leading Edge 22, 690-695.
- Lumley, D.E. 2004. Business and technology challenges for 4D seismic. reservoir monitoring: The Leading Edge 23, 1166-1168.
- Morozov, I. B., and G. Le, 2009. Pre-stack Calibration of 3-C 3-D Time-Lapse Seismic Data, 2009 CSPG/CSEG/CWLS Convention
- Sensor Geophysical Ltd., 2005. Re-processing sequence of Weyburn Phase I seismic data, Internal project report.