# Focused seismic $CO_2$ monitoring: from detection to characterisation.

*Victoria Brun[1], Sandy (QiaoZhi) Chen[2]*
*[1] SpotLight*
*[2] Whitecap Resources Inc.*

## Introduction

Carbon Dioxide ($CO_2$) injection has been used for Enhanced Oil Recovery (EOR) in the Weyburn field in southeast Saskatchewan in Canada for over 20 years. Since 2000, time-lapse (4D) seismic has been an essential surveillance tool to ensure safe and optimized development throughout the field (Chen et al., 2021).

After a successful blind-test over the Weyburn field (Brun et al., 2022), Whitecap piloted an innovative light 4D seismic monitoring system from SpotLight. This technique targets focused areas for dynamic $CO_2$ detection in the reservoir by using only one source/receiver pair per subsurface reservoir location (spot). To catch this dynamic, two monitor surveys have been acquired 8-month apart and the results were encouraging and positively corroborated with the injection and production data within the monitoring period.

Over the last two years, this focused seismic technology is continuing to advance its processing technique to enhance the reflected waves using a single trace. The new method provided more robust and reliable 4D traces not only to detect $CO_2$ presence in the reservoir, but the integrity of the caprock.

## Method – Acquisition Design

The optimum selection (Morgan et al., 2020, Brun et al., 2021) was done using the 2020 baseline acquisition to choose the traces with the best signal to noise ratio, which image the spots. Two seismic acquisitions were then shot in March and November 2022 to monitor 16 spots (areas of interest), using fourteen source and sixteen receiver locations. These acquisitions are very agile, cost effective and environmentally friendly comparing to conventional 3D/4D. Environmental concerns (bird nesting), acceptability (permitting), and operability (pipe and surface obstructions) were successfully taken into account to maximize the use of the solution.
Also, by drastically reducing the acquisition design, it is possible to get highly repeatable measurements by ensuring the best source and receiver repositioning and coupling : the correlation coefficients on the raw data in Weyburn data are on average around 90% for both acquisitions in the overburden area.

## Method – Processing sequence

The detection attributes, mainly time-shifts, are computed on reflected events observed on raw traces. To improve the selection of reflected events, a specific procedure has been implemented to enhance the reflected waves observed on a single trace.

On a shot point, different types of waves can be observed such as direct waves, refracted waves, reflected events, etc. The processing applied to each shot point was composed of a mute, spectral equalisation and several filtering operations to maximize the signal-to-noise ratio of the reflected waves. Figure 1 is an example of a comparison between a raw and a processed 3D seismic shot point. One trace of the shot point has been selected by the de-migration process and corresponds to an optimal trace. A global calibration operator between this optimal trace & the processed optimal traces can then be computed to extract most of the reflected waves.

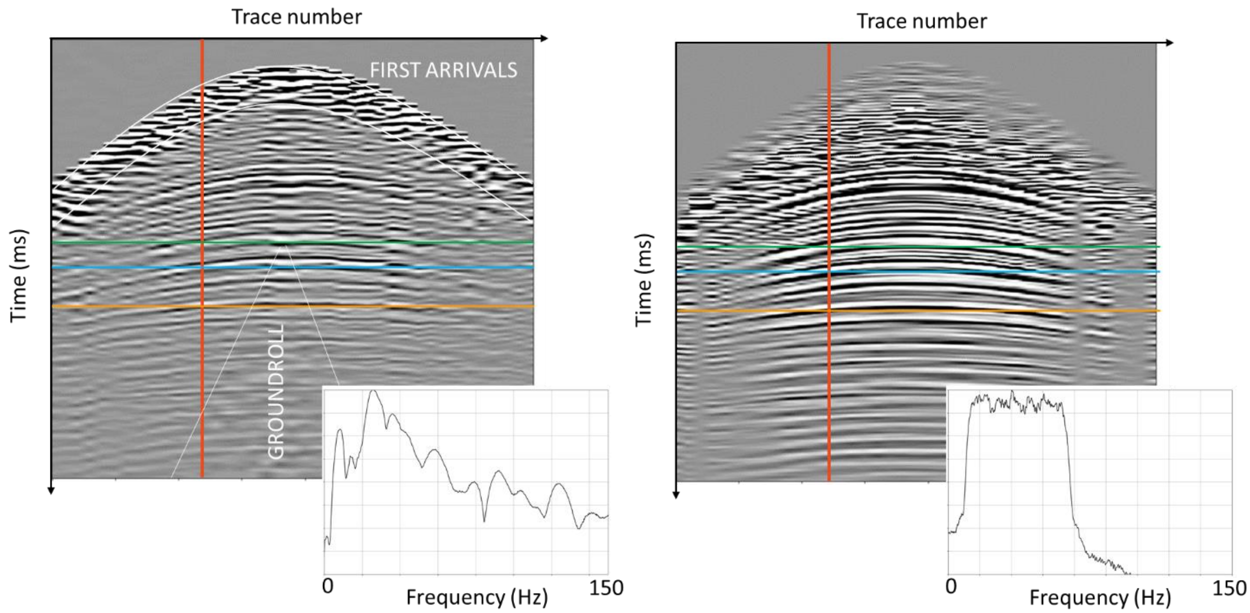


*Figure 1. Raw shot point (left) and associated processed shot point (right). The optimal trace is shown in red. Three reflected horizons are picked on the optimal trace: a reflected event in the overburden area (in green), the top reservoir (in blue) and another reflected event below the reservoir (in orange).*

## Results

The seismic dataset used for the detection is composed of three seismic traces per spot: the 2020 base and two focused monitors acquired respectively in March and November 2022. The global calibration operator computed on the base is then applied on all the seismic traces in order to preserve the amplitude and time-shift variations which could be observed on the reflected waves between the base and the two monitors. A detection is then performed on those 3 seismic traces to rule if a $CO_2$ signature effect is seen at each spot location. Caprock integrity check is also performed.

Figure 2 shows the three raw seismic traces (a) and the associated processed traces (b) on which the detection is performed. A sliding time-shift is then computed between the base and each monitor: Figure 3.

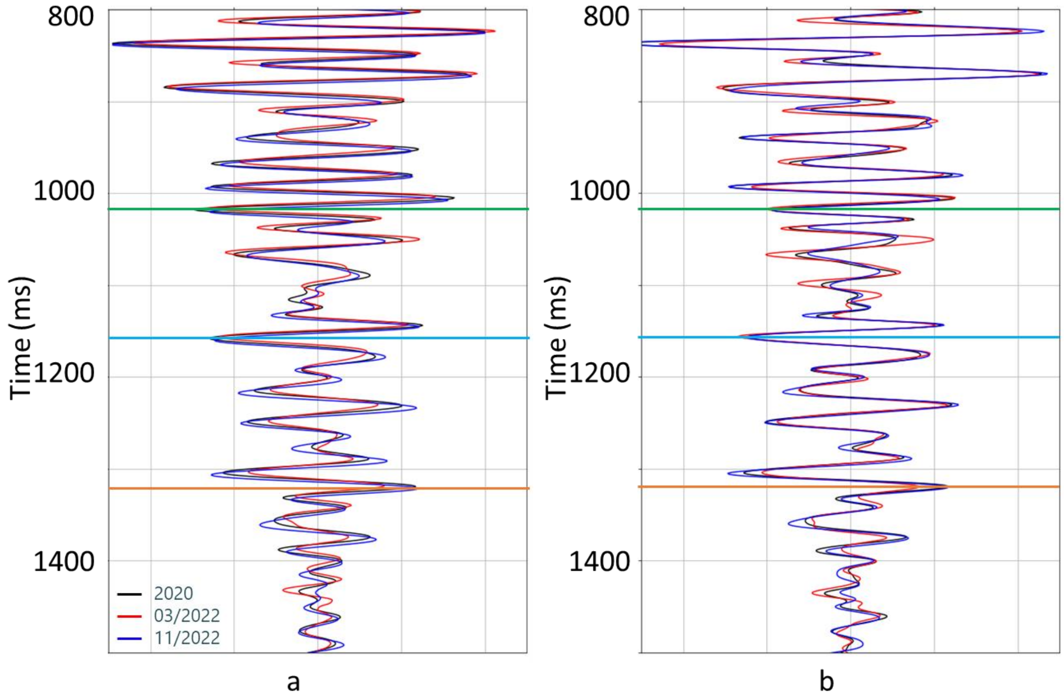


*Figure 2. Raw optimal seismic traces (a) and processed optimal seismic traces (b): 2020 (in black), March 2022 (in red) and November 2022 (in blue) acquisitions. The three horizons are similar to the ones shown on the shot point. The processing works effectively to correct the time and phase shifts observed on the raw traces.*

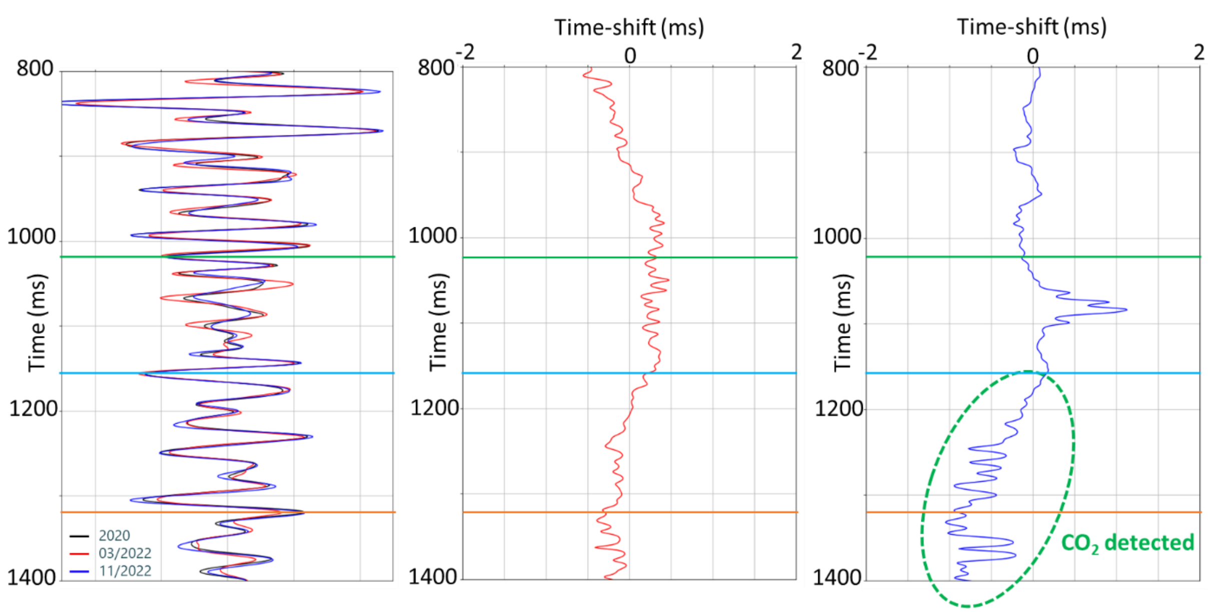

*Figure 3. Processed optimal seismic traces (left), associated sliding time-shift between 2020 and March 2022 (middle), associated sliding time-shift between 2020 and November 2022 (right).*

Figure 3 shows the results of this light and agile seismic technology. The sliding time-shift between the 2020 base and March 2022 shows a constant value that stays around 0ms from the overburden area down to the reservoir, which means that no $CO_2$ was detected during this time interval. On the contrary, the sliding time-shift between the base and November 2022 shows a constant value that stays around 0ms in the overburden area but a time-shift of around 1.5ms is observed at the beginning of the top reservoir level (blue line) that keeps building up to the reflected event below the reservoir (orange line), which is characteristic of a $CO_2$ signature. On all spots, caprock check were performed and demonstrated the integrity of the sealing.

The detections were performed at the 16 spots of the area shown in Figure 4 as the blue solid circles. Injector wells are in orange and the green circles indicate $CO_2$ caused travel-time delay observed at the spots. Red circles indicate travel-time shortening (opposite to travel-time delay) which could be related to reservoir fluid substitution, where $CO_2$ injection was replaced by water injection. The other spots indicated there were no travel-time changes detected within the reservoir. These two 4D results indicate the $CO_2$ migration passages through time and reservoir fluid changes corresponding to injection activities during monitoring period and matched well with the reservoir dynamic simulation.

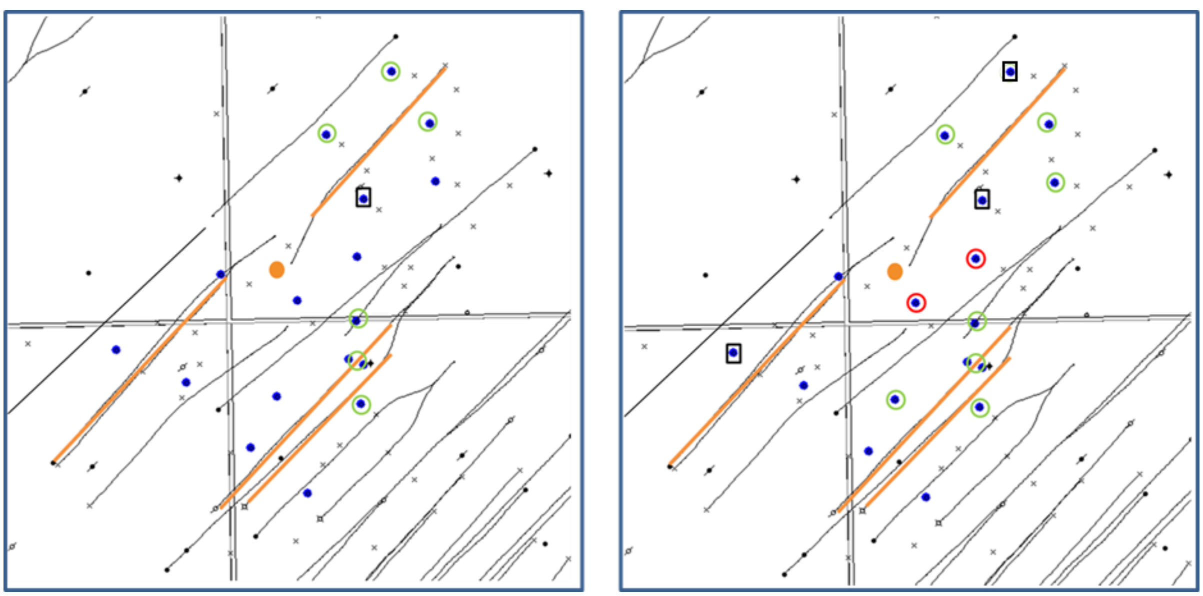

*Figure 4. Detection maps for all spots between the base (2020) and March 2022 (left) and the base and November 2022 (right).*

## Conclusion

Focused seismic monitoring methods are more often implemented for CCS/CCUS & SAGD monitoring, using one receiver and one source, leading to a single trace at each monitoring calendar time.

A new processing sequence was applied in order to enhance the reflected waves signal-to-noise ratio using standard methods thanks to a 3D baseline acquired prior to the light and agile technology. As a result, single traces measurements can be used to better characterise where the changes are happening, enabling cap rock integrity and more precise reservoir management.

Results from Weyburn Field have demonstrated that the light 4D seismic can prove to be a reliable, repeatable, and cost-effective means of monitoring $CO_2$ conformance. It also could be applied to ensure and update an *a priori* model which keeps the reservoir simulation model up to date. This predictive maintenance approach can be used to frequently confirm whether the predictions are accurate or not. If models are validated, new 4D full field images can be postponed, if not, full 4D survey can be triggered to verify $CO_2$ plume and models.

## Acknowledgements

We would like to thank Sandy Chen from Whitecap Resources for a great collaboration since the beginning of our discussions and for allowing us to present those results. Thank you to all SpotLighters who worked on the project.

#### References

Brun, V., Costa de Sousa, J., Morgan, E. [2022]. CO2 injection detection using light time-lapse seismic monitoring. 83rd EAGE Conference.

Brun, V., Morgan, E., Gerl, B., Cardozo, L., Batias, J. [2021]. Applicability of an innovative and light seismic approach to monitor SAGD operations in Surmont: a blind test. Annual Technical Conference and Exhibition (ATCE).

Chen, S., Berezowski, T. [2021]. Time-lapse seismic monitoring in CO2 enhanced oil recovery and storage at Weyburn, SE Saskatchewan. Geoconvention.

Morgan, E., Garden, M., Egreteau, A., Boubaker, Y., Gestin, K., Mari, J. [2020]. Focused and continuous ultra-light seismic monitoring: a gas storage example. 82nd EAGE Conference.