Feasibility study of time-lapse seismic monitoring of CO_2 sequestration

Marie Macquet, Don C. Lawton, Jessica Dongas and Jacky Barraza

CREWES, University of Calgary

Summary

Geological sequestration is one way to reduce the CO_2 emissions in the atmosphere. Background studies are made prior to the beginning of the injection to ensure the security of this method. In the CaMI.FRS site near Brooks, Alberta, numerous wells give the information about the lithology, the porosity, the permeability, the velocities (and many others parameters) of the medium. In addition to well logs data, seismic surveys were conducted in order to characterize the subsurface.

After acquiring well logs information and baseline seismic surveys, we applied numerical simulations in order to characterize the feasibility of the time-lapse seismic monitoring. Indeed, once the injection begins, seismic survey will be made at regular intervals to monitor the CO_2 injection. Fluid simulations allow us to work on synthetic models, but yet are close to what it is expected in the reality.

We use Gassmann fluid substitution to obtain the elastic parameters (V_P, V_S and density) at different injection times (1 year after the beginning of the injection and 1 year after the end of the injection), for a 300m depth CO_2 reservoir. In those 3D models, synthetic data are generated then processed. This work give us a good approximation of the feasibility of a time-lapse seismic monitoring, considering the conditions of CaMI.FRS project.

Introduction

The Containment and Monitoring Institute (CaMI) is a part of CMC Research Institutes Inc. (CMC). In collaboration with the University of Calgary, they developed the Field Research Station (FRS) in Newell County, Alberta, near Brooks. The goal of the CaMI.FRS is to develop research and improvement for containment and storage of CO_2 (see for example Lawton et al. (2015b)). One of the main focus of CaMI.FRS is the MMV (Monitoring, Measurement and Verification) of the CO_2 sequestration. The plan is to inject small amount of gas (around 1000 tons/year over 5 years) at 300m and 500m depth. This controlled release of CO_2 will allow us, for example, to develop improved monitoring technologies on a small amount of CO_2 injected at shallow depth.

The principle of monitoring injection of CO_2 is to acquire surveys at different times during the injection in order to track the changes in the medium. We need a baseline, acquired before the injection, which will serve in the future as reference for the monitoring. Several surveys were acquired at the CaMI.FRS in the last past years, including a 3C-3D seismic survey in 2014 (Lawton et al., 2015a), 3C-2D surface seismic, and walkaway VSP experiment (Hall et al., 2015). Those surveys, in addition to characterizing the injection site, will serve as the baseline for future monitoring studies.

Before starting the CO_2 injection, we can work on the feasibility of seismic monitoring using synthetic data. This is the purpose of the work presented here. First, we present the Gassmann fluid substitution used to generate the different elastic properties models (V_P, V_S and density). An important part of it was to choose representative input data. Indeed, accurate input data give an accurate and validated modelling, and particular attention was to produce models the most faithful to the reality. Second, we focus on the seismic data simulation and the processing, and discuss the results.

The plan at CaMI.FRS is to inject CO_2 over a period of 5 years. In this work, we considered time-lapses for the 300m depth reservoir for the only following periods:

- 1 year after the beginning of the injection, called also t = 1 year (see black line on Figure 1).

- 1 year after the end of the injection, called also t = 6 years (see red line on Figure 1).

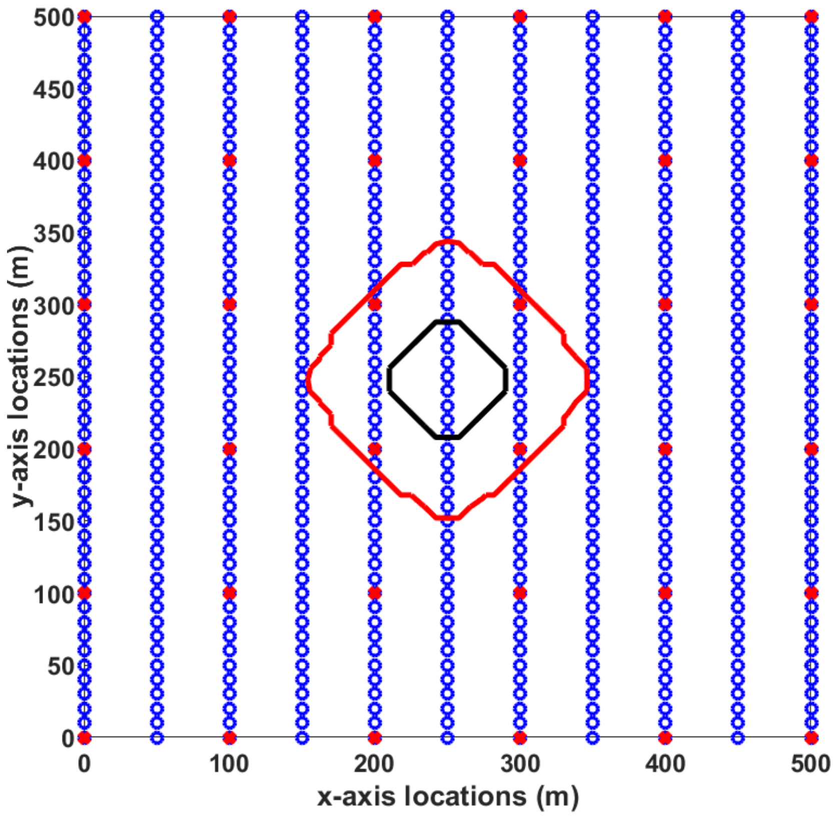

Figure 1. Maximum extension of the CO_2 injection plume (depth = 296m), 1 year after the beginning of the injection (in black) and 1 year after the end of the injection (in red). Surface survey configuration for the seismic simulation is added; blue squares are receivers, red crosses are sources.

Fluid substitution method

We use Gassmann's equation to simulate the fluid substitution for the time-lapse monitoring study. The Gassmann's equation links the bulk modulus of a rock to its pore, frame and fluid properties as in

$$K_{sat} = K^* + \frac{[1 - \left(\frac{K^*}{K_0}\right)]^2}{\frac{\phi}{K_{fl}} + \frac{(1 - \phi)}{K_0} - \frac{K^*}{K_0^2}} \quad (1)$$

where K_{sat} is the saturated bulk modulus ; K* is the frame bulk modulus (or bulk modulus of the porous rock frame, drained of any pore-filling fluid) ; K_0 is the bulk modulus of the mineral matrix ; ϕ is the porosity and K_{fl} is the bulk modulus of the fluid.

An important effort was made to use the most accurate input data to have a fluid substitution that is most faithful to reality. Here are the different data we used:

1) The initial elastic parameters (V_P, V_S, and density) have been chosen based on well logs data at the injection well. We consider a layer-cake model, which means that the models are laterally homogeneous.
2) The geostatic model and the dynamic fluid flow simulation provided by Dongas (2016) and upgraded by Barraza (2016). This provided us the porosity, the CO_2 concentration and the pressure models.
3) The mineral composition coming from the ELAN logs (Schlumberger, CMC), which allows us to calculate an accurate matrix bulk modulus (K_0 in equation 1).
4) The bulk modulus (K_{fl}) and the density of the fluids calculated using Batzle and Wang equations (1992).

Figure 2 shows the results of the Gassmann fluid substitution, as the variations of the elastic parameters, between the baseline model and the t=6 year model. As expected, the shape of the anomalies is correlated to the shape of the CO_2 reservoir. The average P-wave velocity variation for the whole 3D reservoir is -6.25%, however, the variation can reach -30% in some area. The average S-wave velocity variation for the 3D reservoir is weak, around 0.75%. The average density variation is around -1.5%.

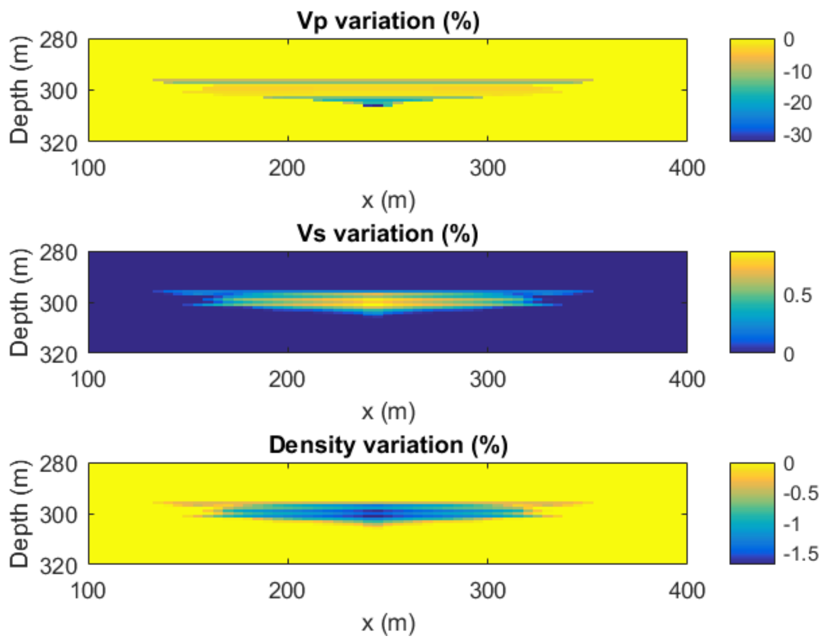

Figure 2. 2D sections in the variation of elastic parameters for t=6 year, focussed on the CO2 reservoir injection. Top: P-wave velocity variation. Middle: S-wave velocity variation. Bottom: Density variation.

Data simulation and Results

Seismic data were simulated using TIGER, a 3D finite-difference modelling software (from SINTEF Petroleum Research). We used the acquisition survey as shown in Figure 1, which is a simplified version of the survey acquired on the field in May 2014 (Isaac and Lawton, 2015). Data were then processed using Vista processing software. A standard processing is applied to the data: deconvolution, NMO correction, CMP stack, and post-stack migration. Due to the survey parameters (see Figure 1), the final bin size is 25mx25m.

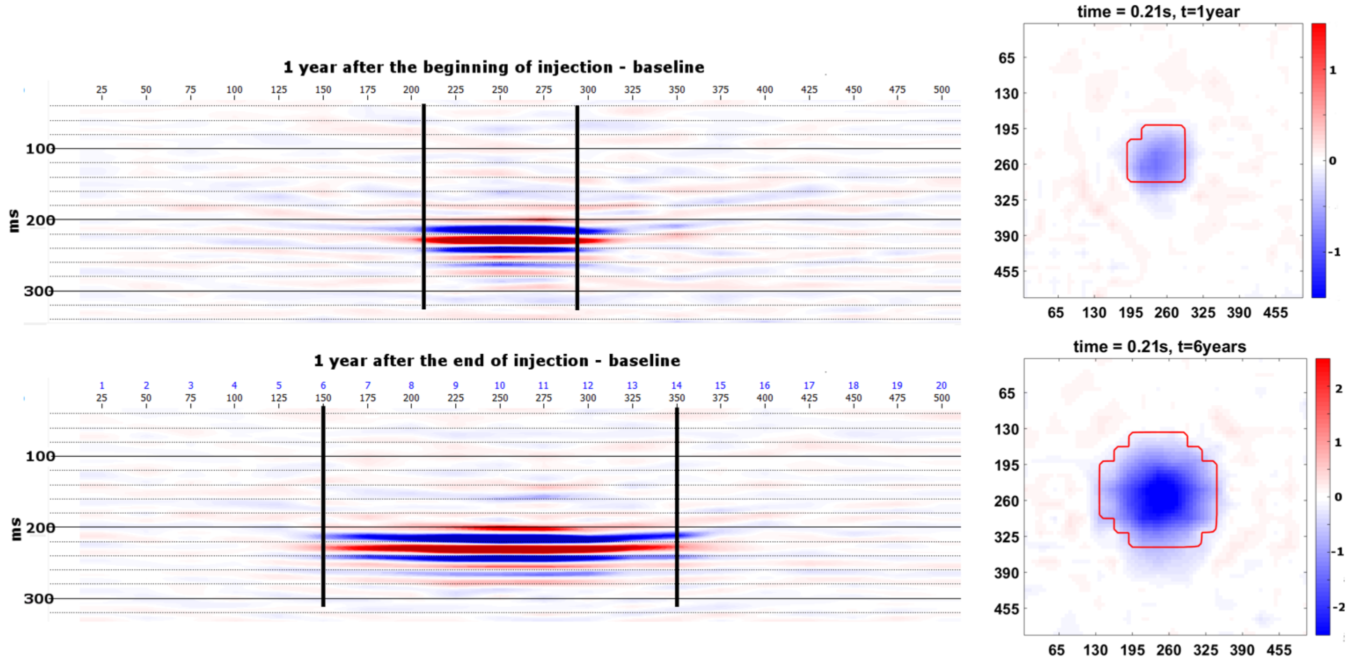

Figure 3. 2D vertical and horizontal sections in the 3D volume. ***Top left:*** Vertical section, difference between t=1 year and the baseline. ***Bottom left:*** Vertical section, difference between t=6year and the baseline. On both figures, the lateral extension of the CO_2 plume are added as black lines. ***Top right:*** Horizontal section, twt=0.21s, difference between t=1 year and the baseline. ***Bottom right:*** Horizontal section, twt=0.21s, difference between t=6 year and the baseline. Expected lateral expansion of CO_2 plume is added as red line.

Figure 3 shows 2D sections extracted from the 3D volume. The sections are smoothed due the size bin but we can see that the lateral expansion of the reflectivity anomaly corresponds well to the lateral dimension of the CO_2 plume, in the vertical sections but also in the horizontal sections.

Conclusions

The main goal of this work was to qualify the feasibility of time-lapse seismic monitoring of CO_2 sequestration considering the CaMI.FRS conditions (a small and shallow reservoir, 1000tons/year at 300m depth). Accurate input data and Gassmann fluid substitution gave us the possibility to produce accurate elastic parameters models (V_P, V_S and density) before injection and for different time-lapse surveys. Seismic data are generated in those models and processed to give us three 3D seismic volume (baseline, t=1 year and t=6 year). The difference between the time-lapse and the baseline recovers the shape of the CO_2 plume in the reservoir.

For future work, we propose to use also the horizontal component responses to study the converted PS seismic response as well. This can give us information on the S-wave velocity variation.

Acknowledgements

We thank CMC Research Institutes Inc. and the CREWES sponsors for their financial support. We also gratefully acknowledge support from NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13. We also thank SINTEF for providing access to the TIGER modelling software.

References

Barraza, J., 2016, Static model - geomodel upgraded: PPT Presentation - CMC Research Institutes, Inc.

Batzle, M., and Wang, W., 1992, Seismic properties of pore fluids: Geophysics, 57, No. 11, 1396–1408.

Dongas, J. M., 2016, Development and characterization of a geostatic model for monitoring shallow CO2 injection: Master Thesis, University of Calgary.

Gassmann, F., 1951, Uber die elastizität poröser medien: Vierteljahrsschrift der naturforschenden Gesellschaft in Zürich, 96, 1–23.

Hall, K. W., Isaac, J. H., Wong, J., Bertram, K. L., Bertram, M. B., Lawton, D. C., Bao, X., and Eaton, D., 2015, Initial 3C-2D surface seismic and walkaway VSP results from the 2015 Brooks SuperCable experiment: CREWES Research Report, 27.

Isaac, J. H., and Lawton, D. C., 2015, 3D3C seismic data at the Brooks experimental CO2 injection site:CREWES Research Report, 27.

Lawton, D. C., Bertram, M., Bertram, K., Hall, K., and Isaac, H., 2015a, A 3C-3D seismic survey at a new field research station near Brooks, Alberta: CREWES Research Report, 27.

Lawton, D. C., Bertram, M., and Bertram, K. H. K., 2015b, New approaches to seismic monitoring at the Brooks Field Research Station: CREWES Research Report, 27.