Feasibility study of time-lapse seismic monitoring of CO_2 sequestration

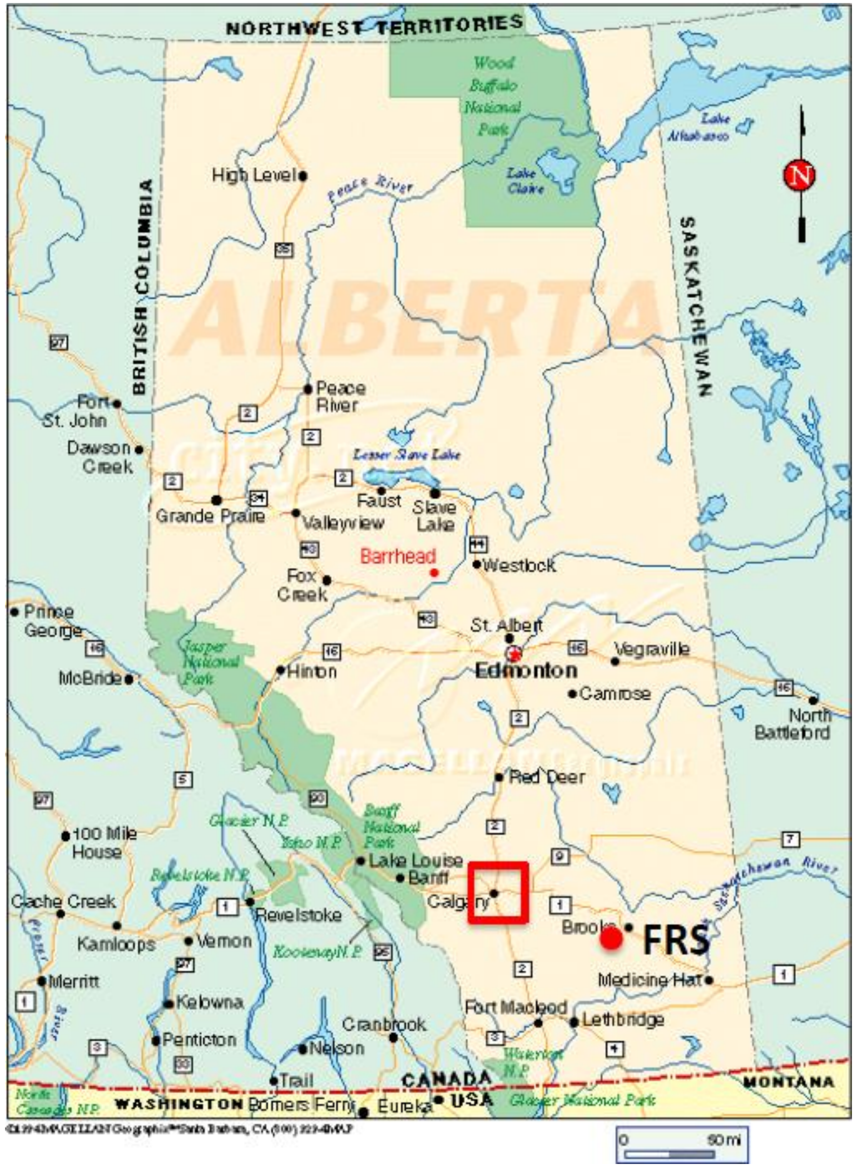
Marie Macquet, Donald C. Lawton, Jessica Dongas and Jacky Barraza

CREWES Annual Meeting, December 1st 2016, Banff, AB

Outline

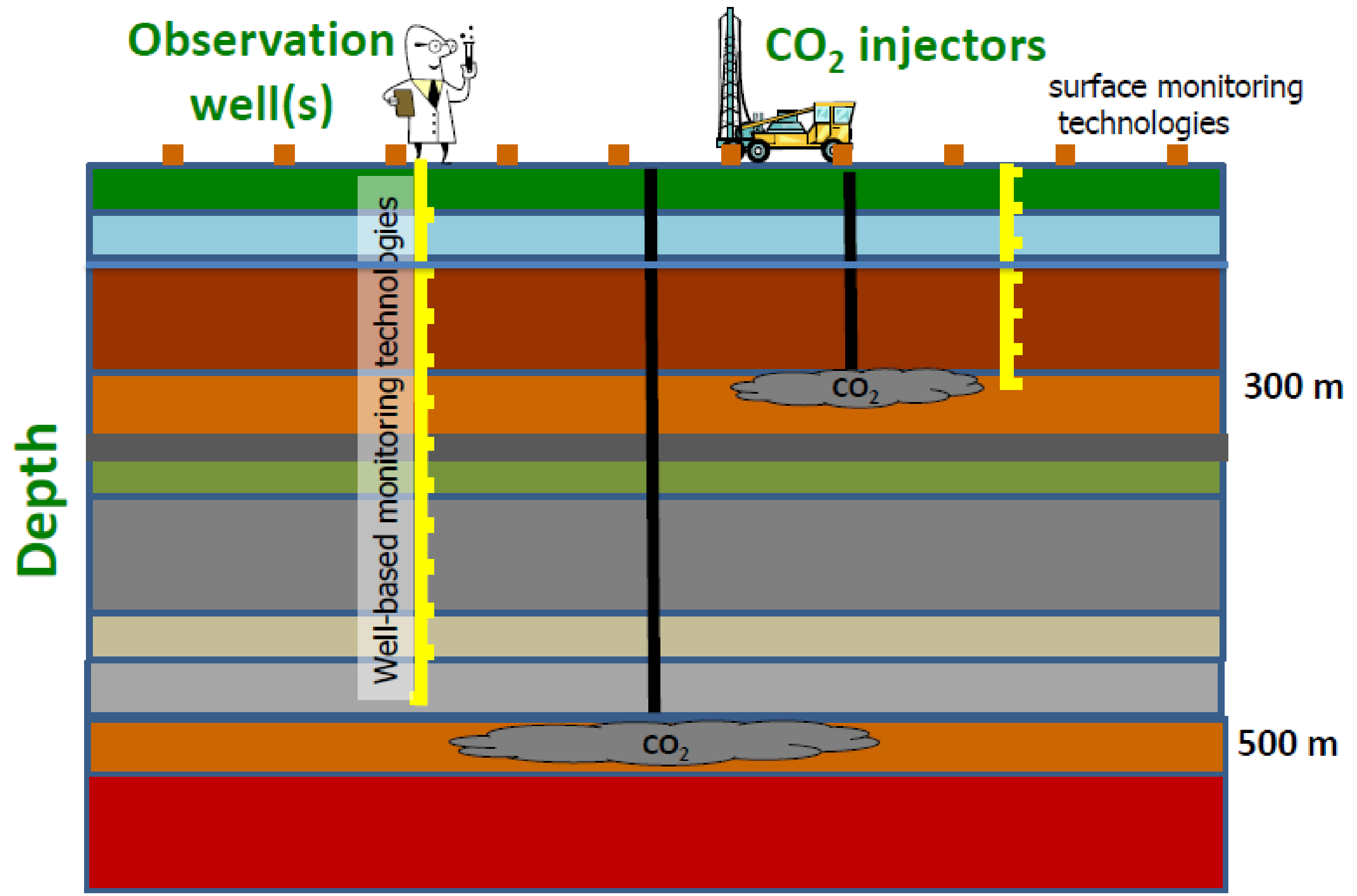
- Introduction
- Gassmann fluid substitution
- Data simulation, processing and results
- Work in progress
- Conclusions and Future Work
- Acknowledgements

Introduction – CaMI.FRS



- Facilitate academic and industry training and research ;
- Develop improved monitoring technologies ;
- Determine CO_2 detection thresholds ;
- …

Introduction – CaMI.FRS - pre-injection period



- 2 target zones : **300m** and 500m depth
- 1000 ton/year during 5 years
- **Baseline surveys** :
  - 3C 3D seismic survey (Isaac and Lawton, CRR 2015)
  - 3C 2D seismic survey and VSP experiment (Hall et al., CRR 2015)
- Feasibility study of time-lapse seismic monitoring

Introduction - Feasibility study of time-lapse seismic monitoring

Aims of the work :

(1) Modelling the seismic changes expected to result from predicted CO_2 injection

(2) Determining whether and how the changes can be observed

Focus on three periods, for the 300m depth target:

(1) baseline; before the injection

(2) t = 1 year; 1 year after the beginning of the injection

(3) t = 6 years; 1 year after the end of the injection

Modelling the seismic changes

Considering initial elastic parameters ($V_{S(init)}$, $V_{P(init)}$ and $\rho_{(init)}$), we want to calculate the new elastic parameters after the CO_2 injection

$$\rho_{(\boldsymbol{new})} = \rho_{matrix} * (1 - \phi\,) + \rho_{fl(new)} * \phi\,; \qquad \boldsymbol{V}_{\boldsymbol{S}(\boldsymbol{new})} = \sqrt{\frac{\mu_{sat}}{\rho_{(new)}}}\,; \quad \boldsymbol{V}_{\boldsymbol{P}(\boldsymbol{new})} = \sqrt{\frac{K_{sat(new)} + {}^{4}/_{3}\,\mu_{sat}}{\rho_{(new)}}}$$

Modelling the seismic changes

Considering initial elastic parameters ($V_{S(init)}$, $V_{P(init)}$ and $\rho_{(init)}$), we want to calculate the new elastic parameters after the CO_2 injection

$$\rho_{(\boldsymbol{new})} = \rho_{matrix} * (1 - \phi) + \rho_{fl(new)} * \phi \,;$$

$$\boldsymbol{V}_{\boldsymbol{S}(\boldsymbol{new})} = \sqrt{\frac{\mu_{sat}}{\rho_{(new)}}} \,;$$

$$\boldsymbol{V}_{\boldsymbol{P}(\boldsymbol{new})} = \sqrt{\frac{K_{sat(new)} + {}^{4}/_{3}\, \mu_{sat}}{\rho_{(new)}}}$$

$$\rho_{fl(new)} = (S_{brine} * \rho_{brine}) + (S_{CO2} * \rho_{CO2})$$

$$\mu_{sat} = \rho_{(init)} * V_{S(init)}^{2}$$

Gassmann Fluid Substitution - Method

Considering initial elastic parameters ($V_{S(init)}$, $V_{P(init)}$ and $\rho_{(init)}$), we want to calculate the new elastic parameters after the CO_2 injection

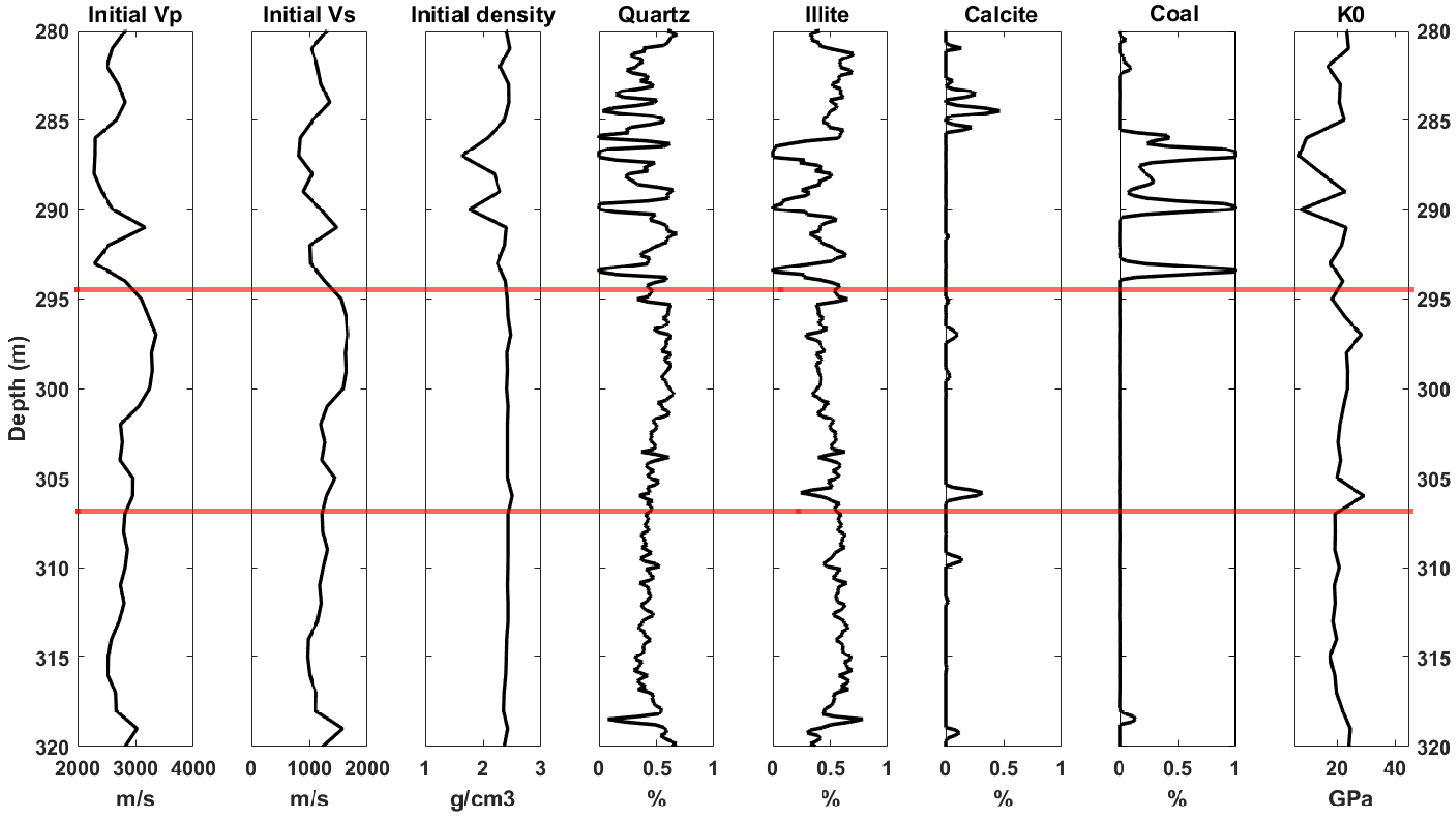
$$\rho_{(\boldsymbol{new})} = \rho_{matrix} * (1 - \phi) + \rho_{fl(new)} * \phi \; ; \qquad \boldsymbol{V_{S(new)}} = \sqrt{\frac{\mu_{sat}}{\rho_{(new)}}} \; ; \qquad \boldsymbol{V_{P(new)}} = \sqrt{\frac{K_{sat(new)} + {}^{4}/_{3}\, \mu_{sat}}{\rho_{(new)}}}$$

Gassmann's equation links the bulk modulus of a rock to its pore, frame and fluid properties (Gassmann, 1951)

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

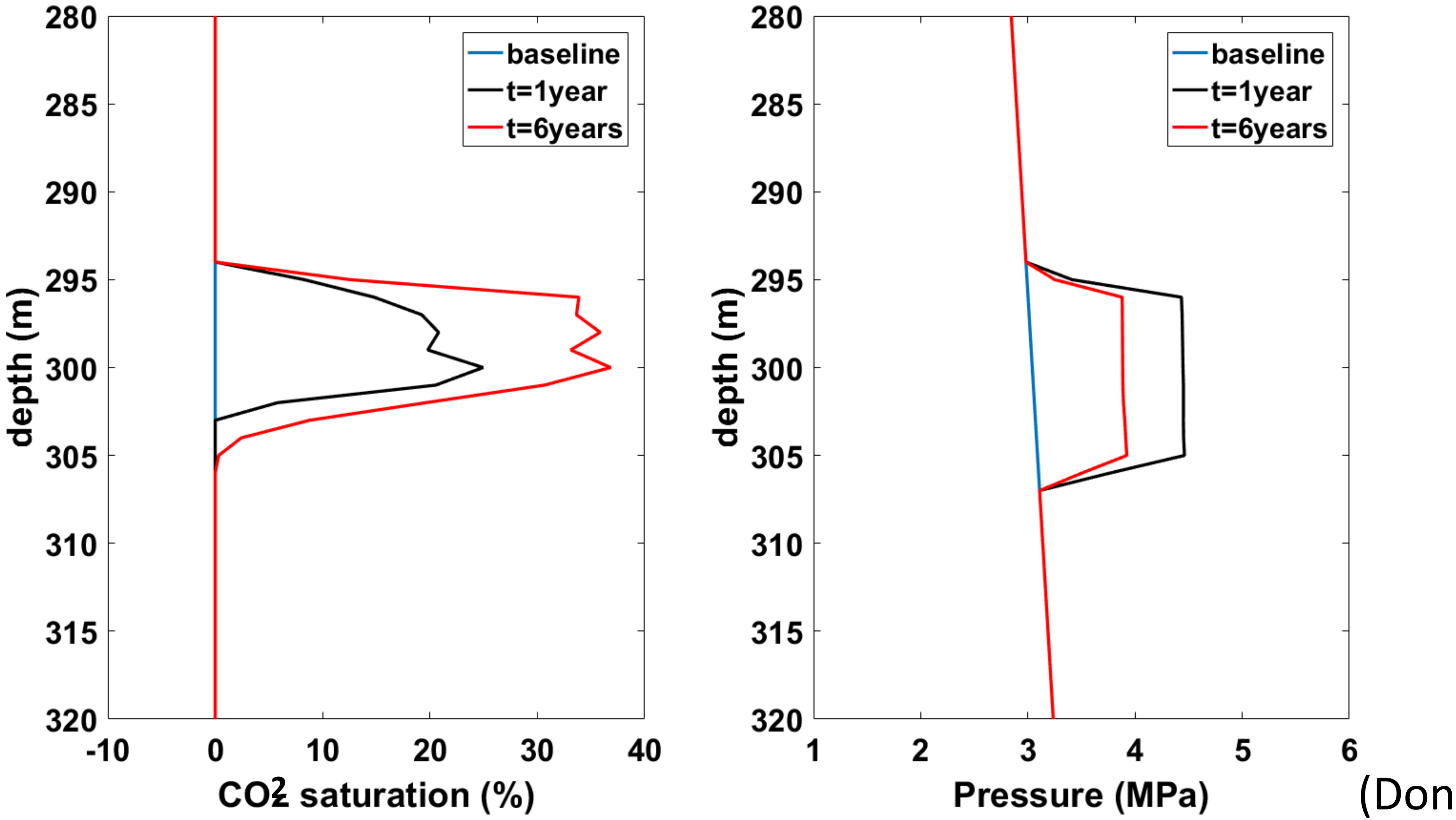
Gassmann Fluid Substitution – Input data

1) Well logs



Gassmann Fluid Substitution – Input data

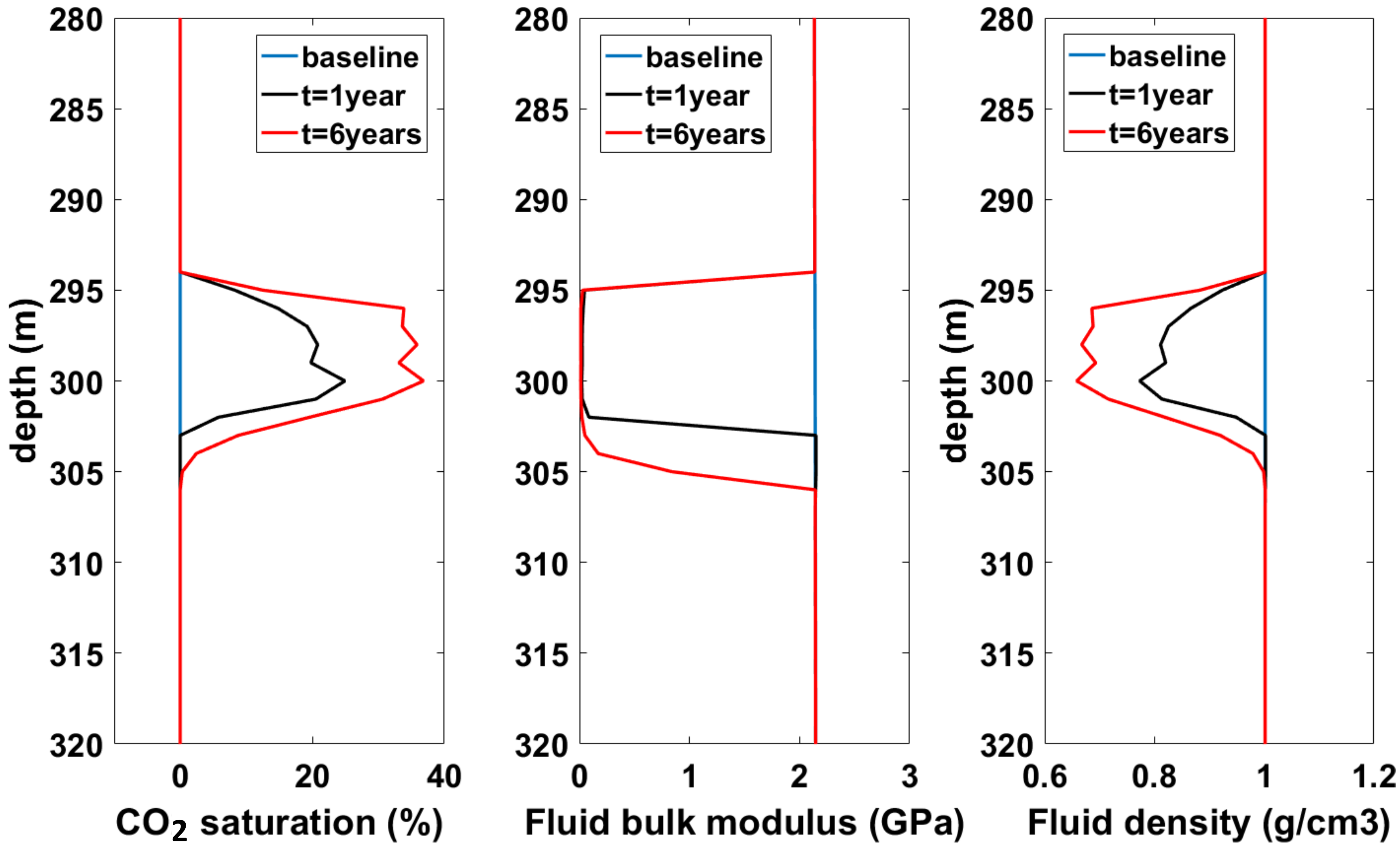
2) Dynamic fluid-flow simulation from Dongas (2016) and Barraza (2016)



(Dongas, 2016)

Gassmann Fluid Substitution – Input data

3) Bulk modulus and density of fluids (Batzle and Wang, 1992)

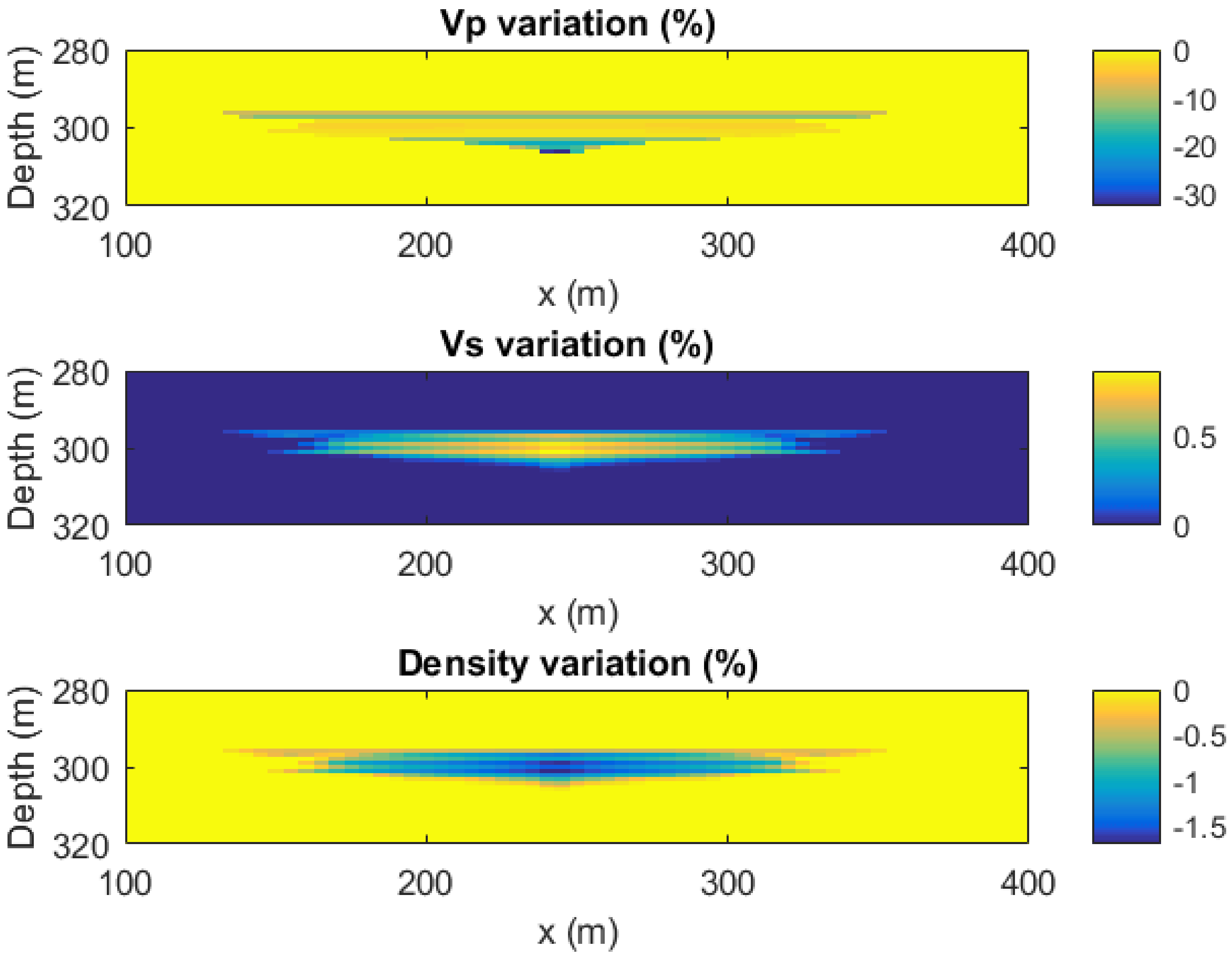


Gassmann Fluid Substitution – Results for t = 6 year

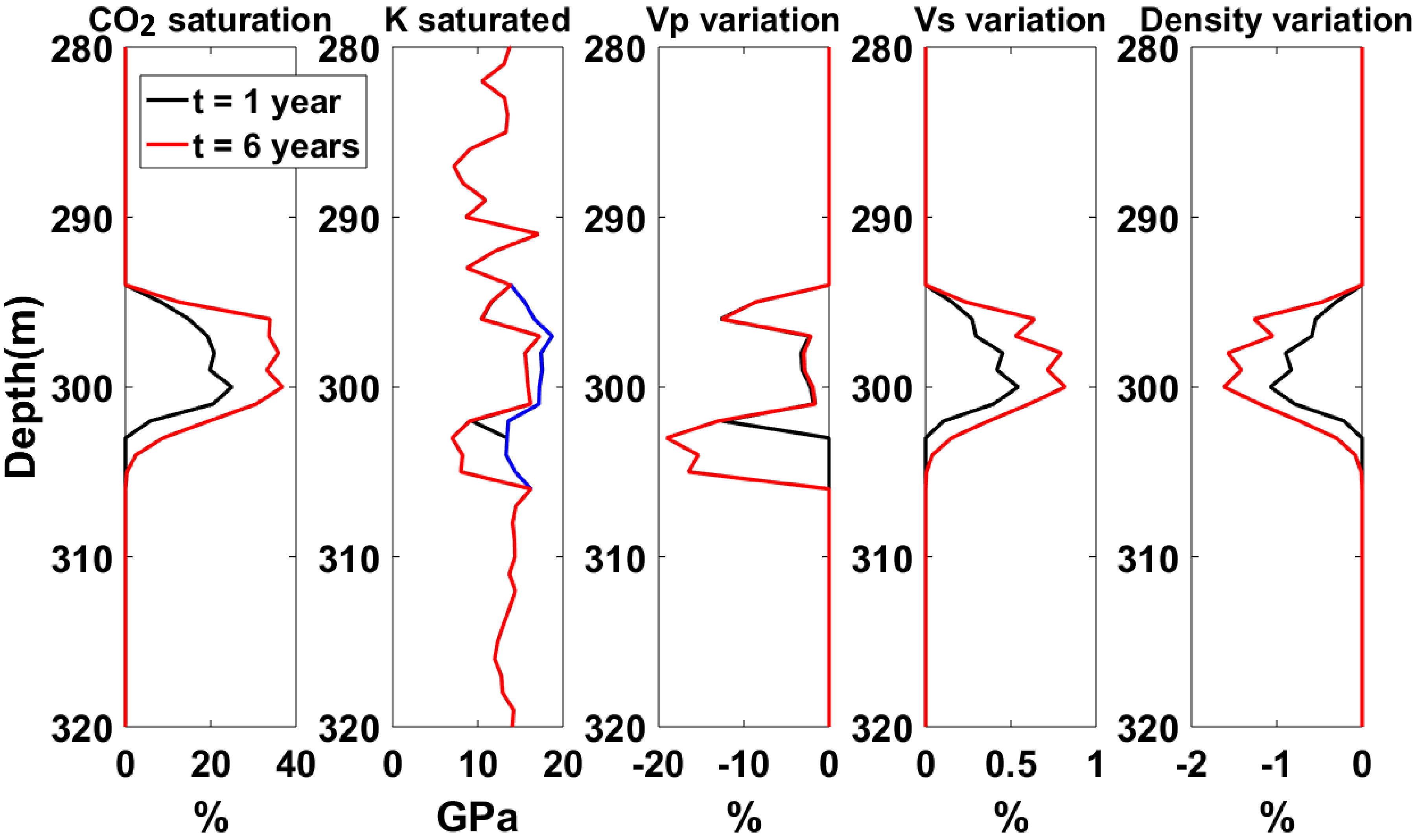
$$V_{P(new)} = \sqrt{\frac{K_{sat(new)} + {}^{4}/_{3}\ \mu_{sat}}{\rho_{(new)}}}$$

$$V_{S(new)} = \sqrt{\frac{\mu_{sat}}{\rho_{(new)}}}$$

$$\rho_{(new)} = \rho_{matrix} * (1 - \phi) + \rho_{fl(new)} * \phi$$



Gassmann Fluid Substitution - Results



$$\rho_{(new)} = \rho_{matrix} * (1 - \quad) + \rho_{flnew} * \phi$$

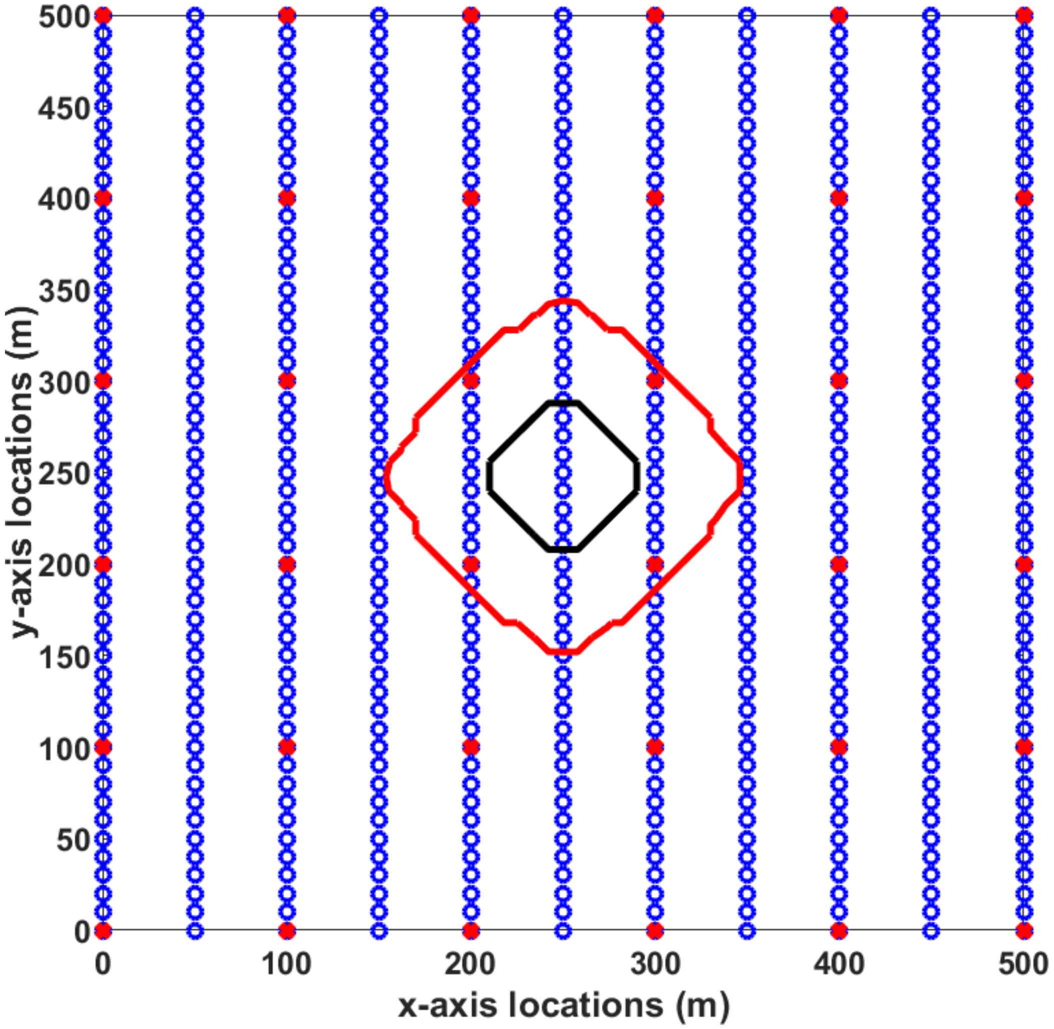
$$\rho_{fl(new)} = (S_{brine} * \rho_{brine}) + (S_{CO2} * \rho_{CO2})$$

$$V_{S(new)} = \sqrt{\frac{\mu_{sat}}{\rho_{new}}}$$

$$V_{P(new)} = \sqrt{\frac{K_{sat(new)} + {}^{4}/_{3}\,\mu_{sat}}{\rho_{(new)}}}$$

Data simulation and processing

Data simulation with Tiger, a 3D anisotropic finite-difference modelling software (SINTEF)



- 561 receivers **(blue)**
- 36 sources **(red)**

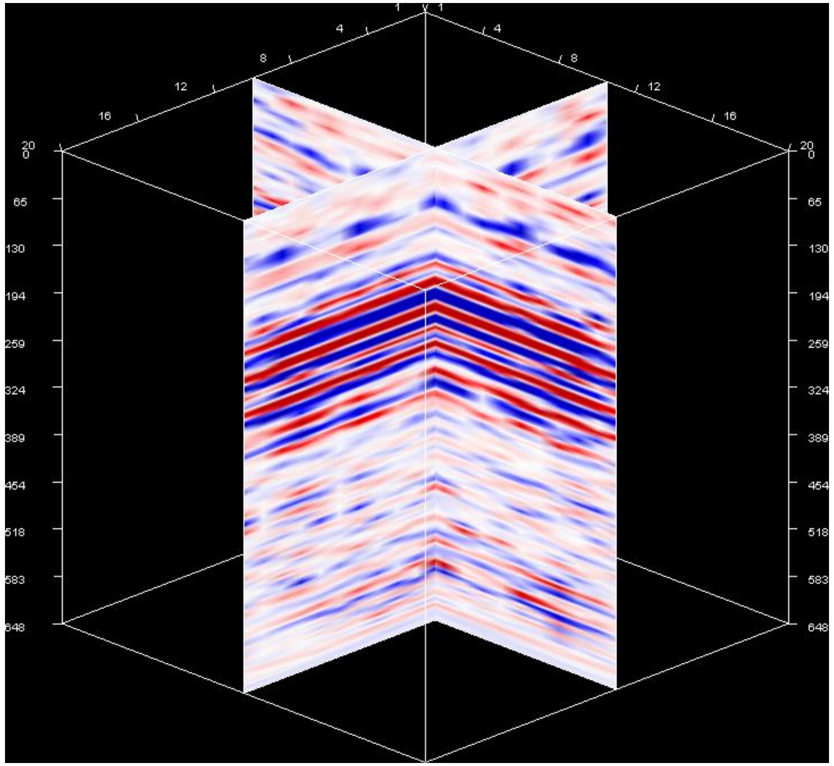
Standard processing with Vista

- Deconvolution
- NMO
- CMP stack
- Post-stack time migration

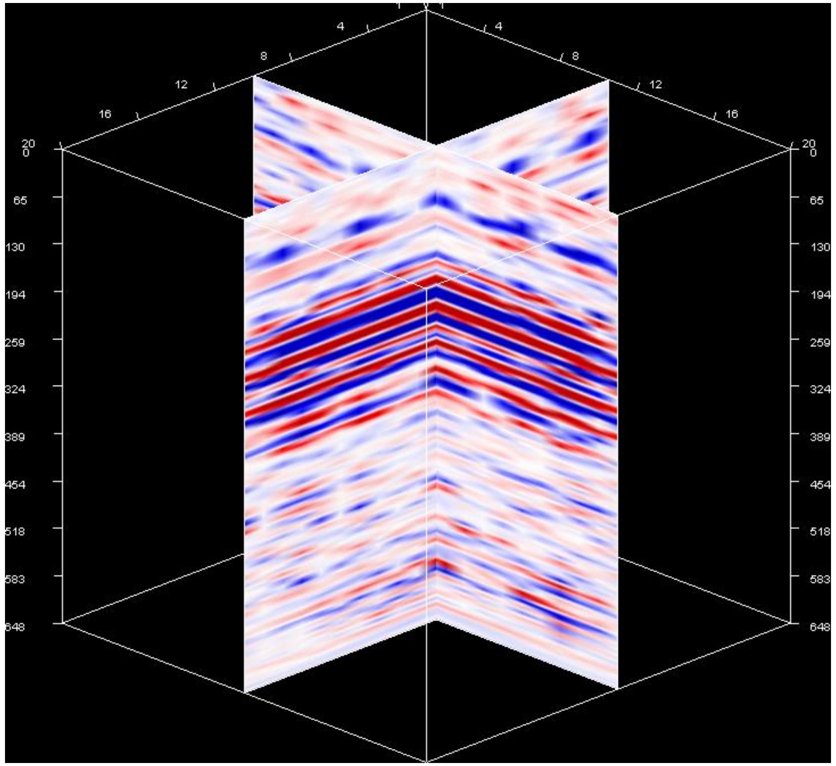
Bin size : 25m x 25m

Data simulation and processing - Results

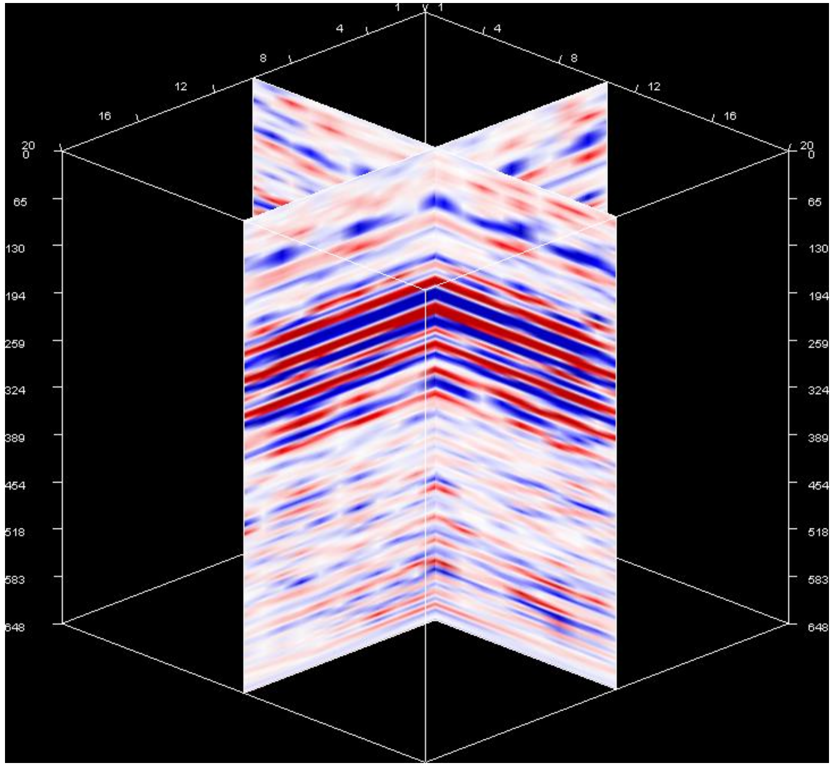
Baseline



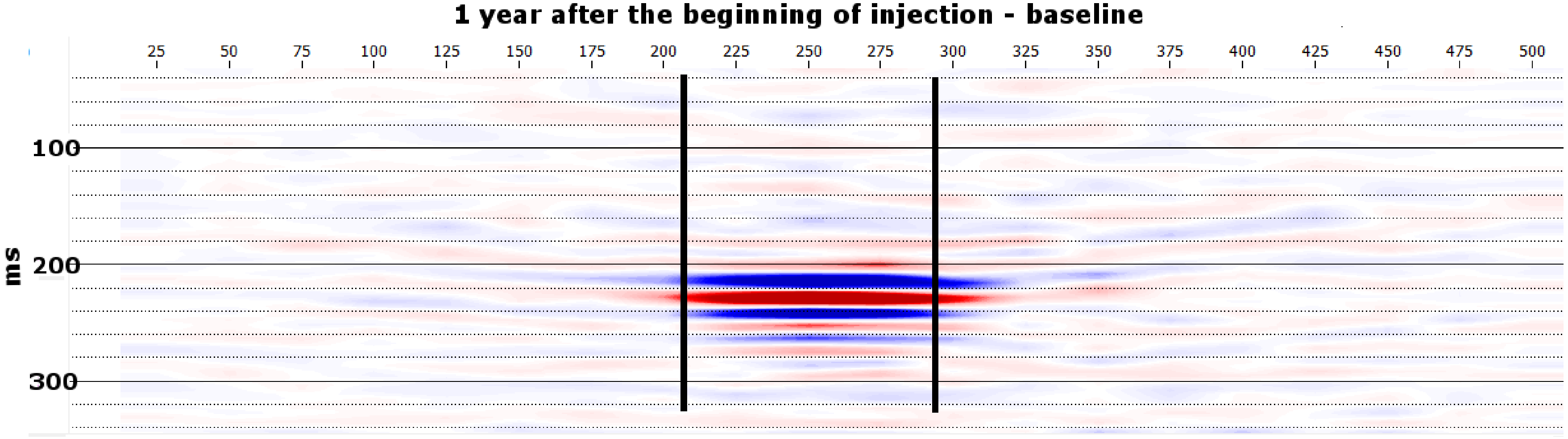
1 year after the beginning of the injection

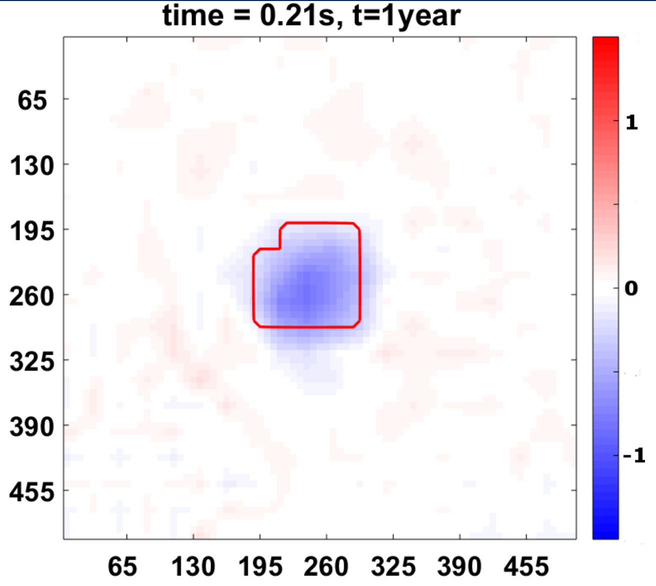


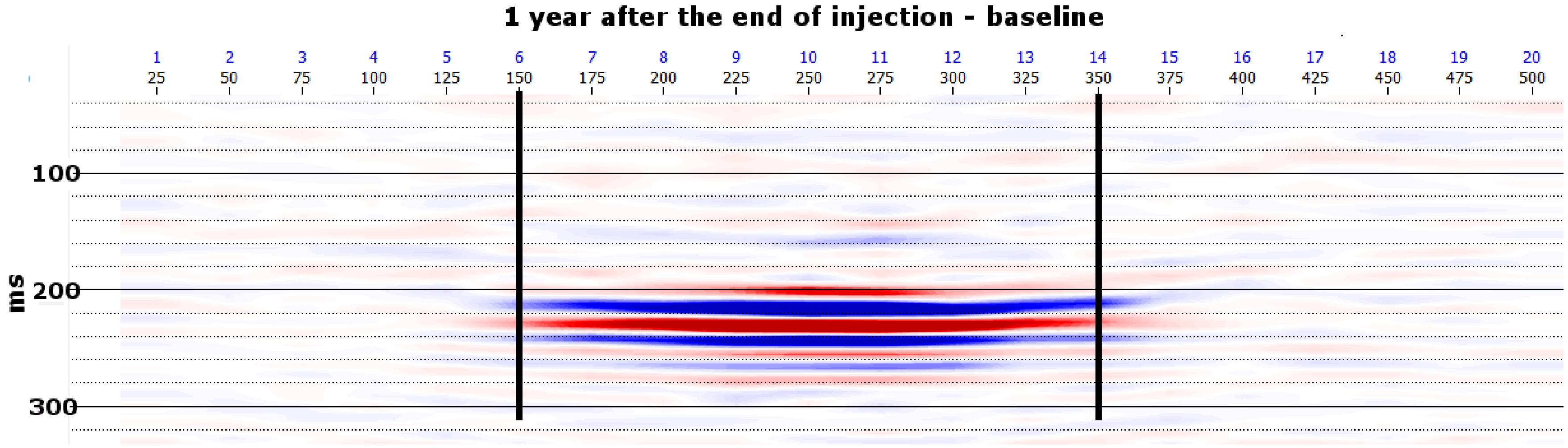
1 year after the end of the infection

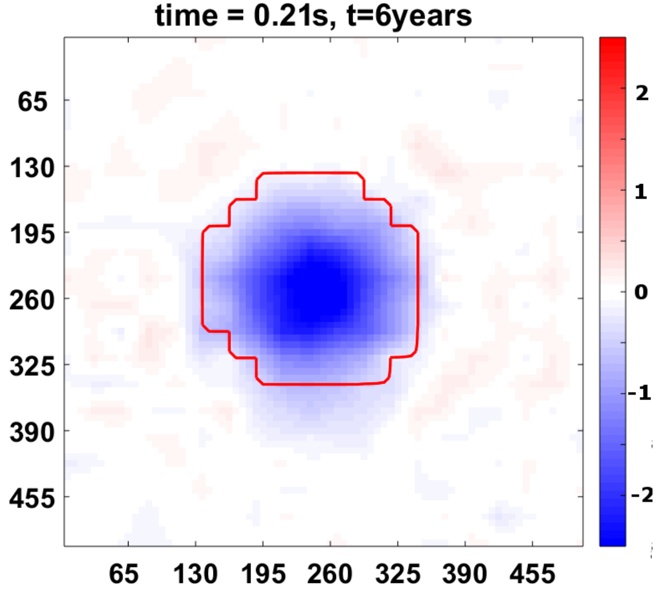


Data simulation and processing - Results









Work in progress

- With the synthetic seismic data, we can recover the size of the CO_2 plume and migration into the reservoir (one of the **M**onitoring and **M**easurement **V**erification goals)

- Detecting issues in CO_2 injection

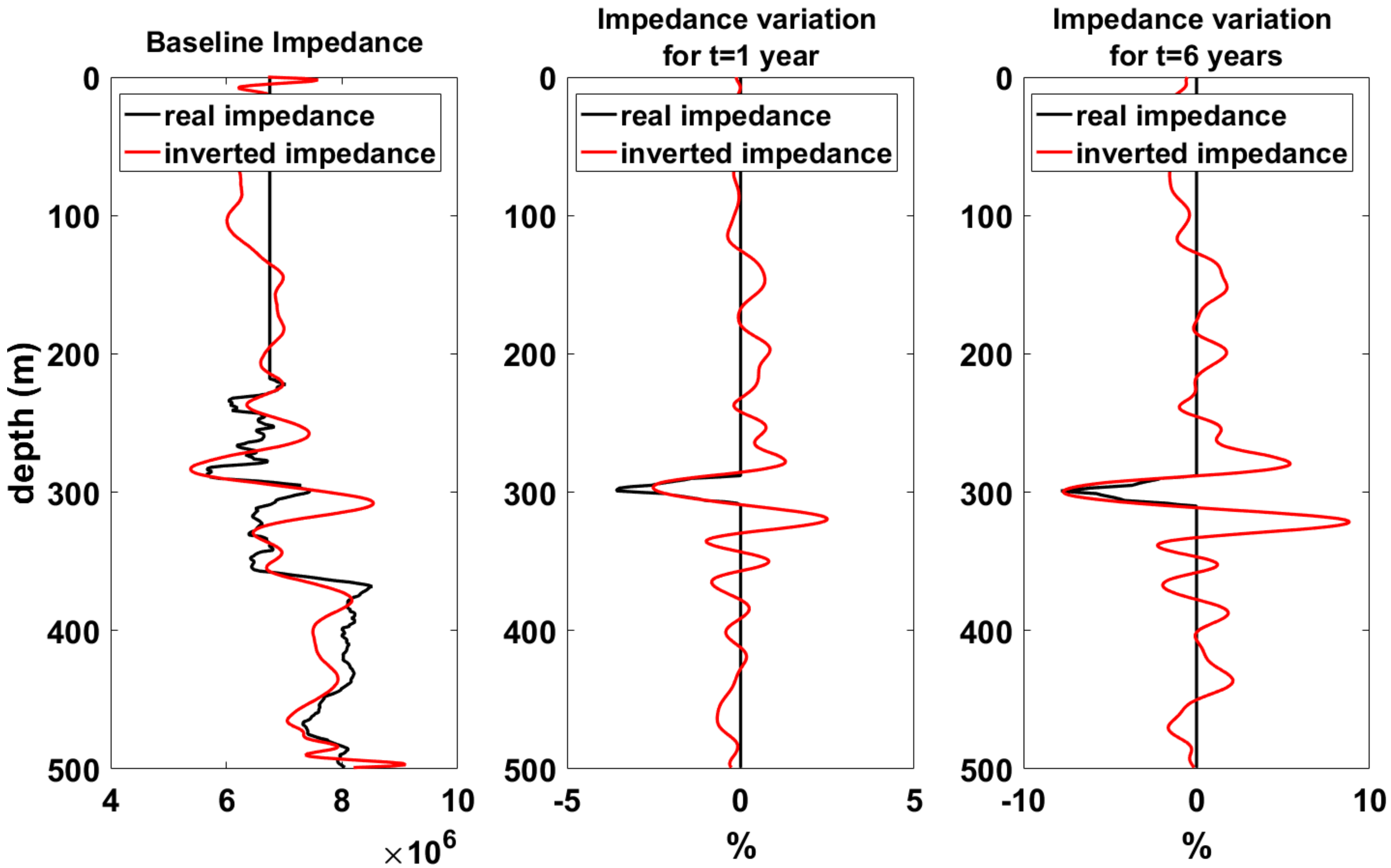
- Examining the possibility of recovering the CO_2 saturation and Pressure from seismic data, using

  => amplitude studies

  => time-shift studies

  => $\mathbf{V_P}$, $\mathbf{V_S}$ and ρ from impedance inversion

Work in progress – P-Impedance Inversion (ρV_P)



Conclusions and Future Work

Conclusions :

- Simulated seismic data, considering the CaMI.FRS conditions, can recover the shape of the CO_2 plume
- Impedance inversion is able to recover the P-impedance variation

Future work :

- Work on PS data using horizontal component data

  => Obtain S-Impedance

- VSP studies
- Different survey configurations
- Real data

Acknowledgements

- CREWES sponsors
- CMC - CaMI
- NSERC - grant CRDPJ 461179-13
- CREWES staff and students,

  special thanks to L. Baird, F. Mahmoudian and K. Hall
- SINTEF and Schlumberger for Tiger modelling software and Vista processing software

Thank you