

# FWI time-lapse monitoring of CO<sub>2</sub> injection using VSP at CaMI FRS: a feasibility study

Ninoska Amundaray, Kris Innanen, Marie Macquet and Don C. Lawton

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- Overview of methods
- Containment and Monitoring Institute Field Research Station
- Modeling the CO<sub>2</sub> injection effects
- Feasibility of time-lapse FWI at CaMI FRS
- Conclusions and future work



## Full waveform inversion (FWI)

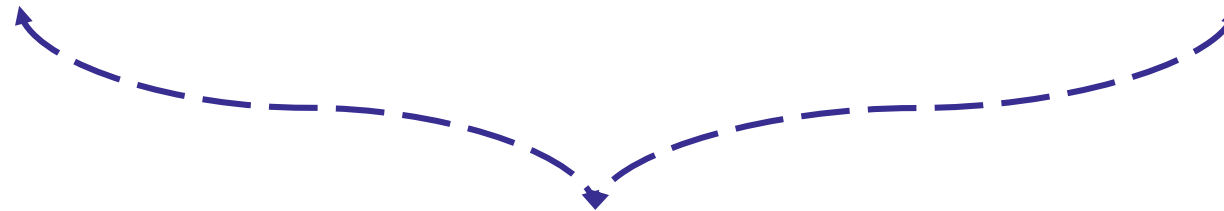
Optimization method

High-resolution subsurface models

## Seismic time-lapse

Image fluid-flow effects

Reservoir monitoring: CO<sub>2</sub> storage



## Vertical seismic profiles (VSP)

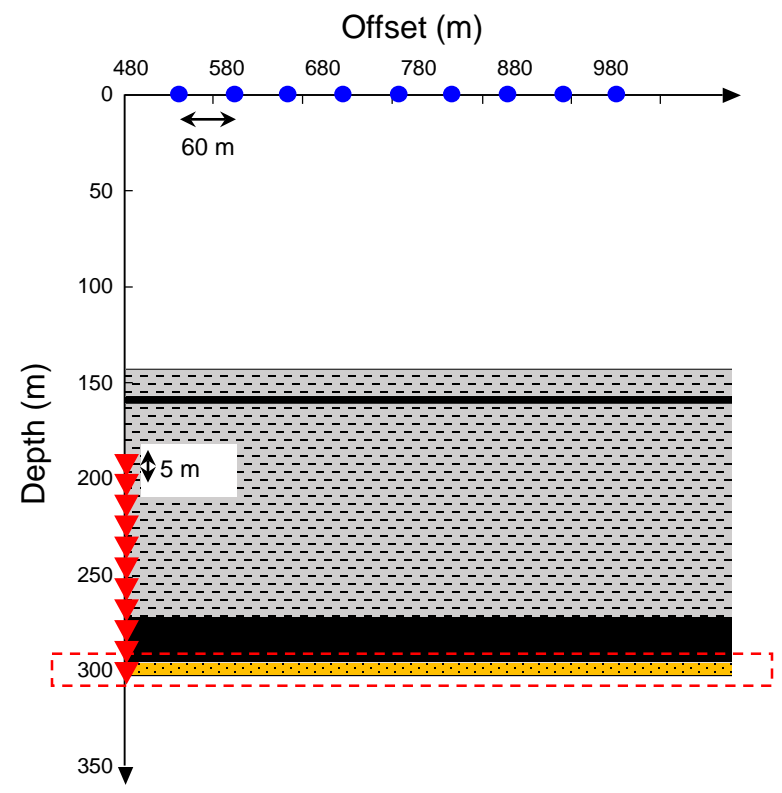
Minimizes effect of acquisition design

High signal-to-noise ratio

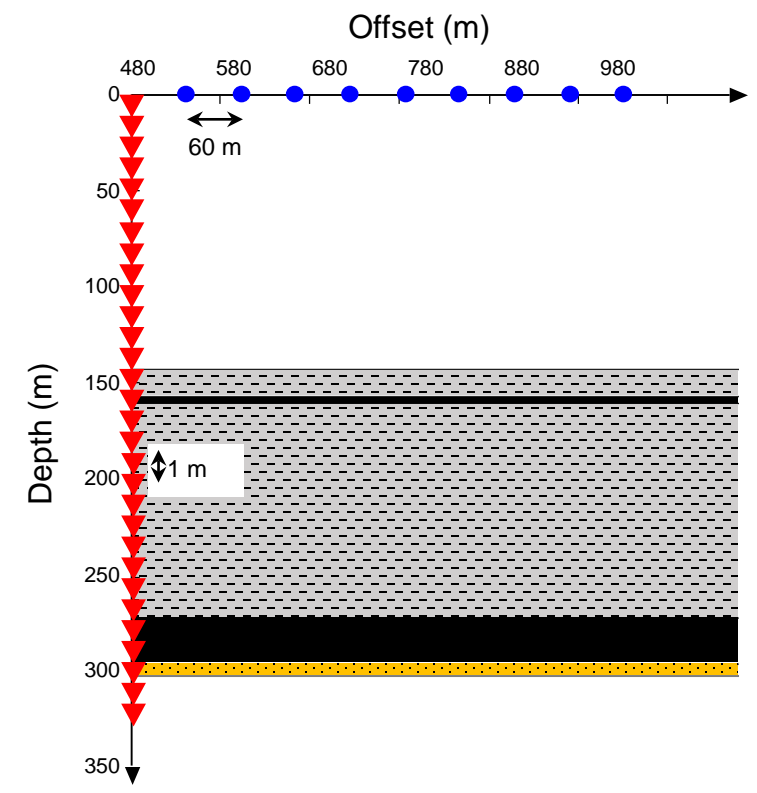




## Permanent VSP Experiment



## 2018 VSP Experiment



● Source points      ▼ Receivers

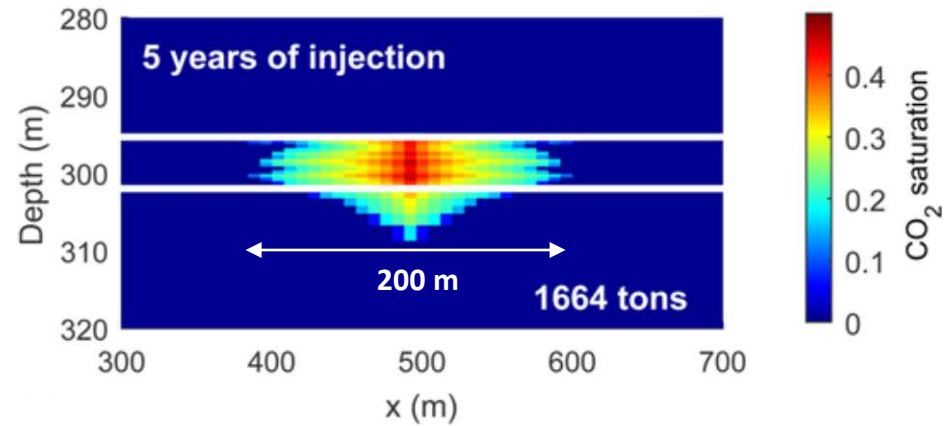
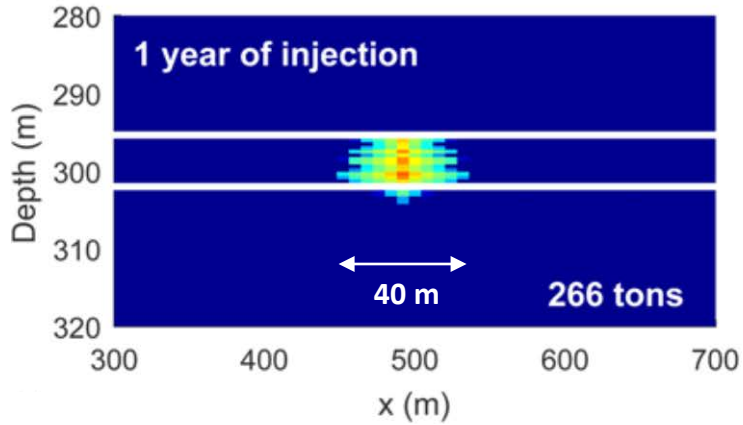
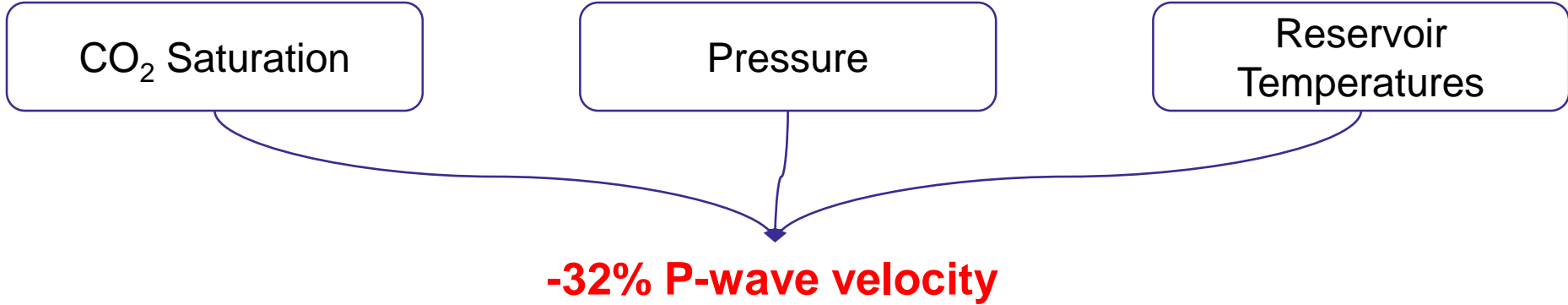
■ Sandstone      ■ Shale      ■ Coal

(Adapted from Hall *et al.*, 2018)



# Modeling the CO<sub>2</sub> injection: 266 to 1666 tons

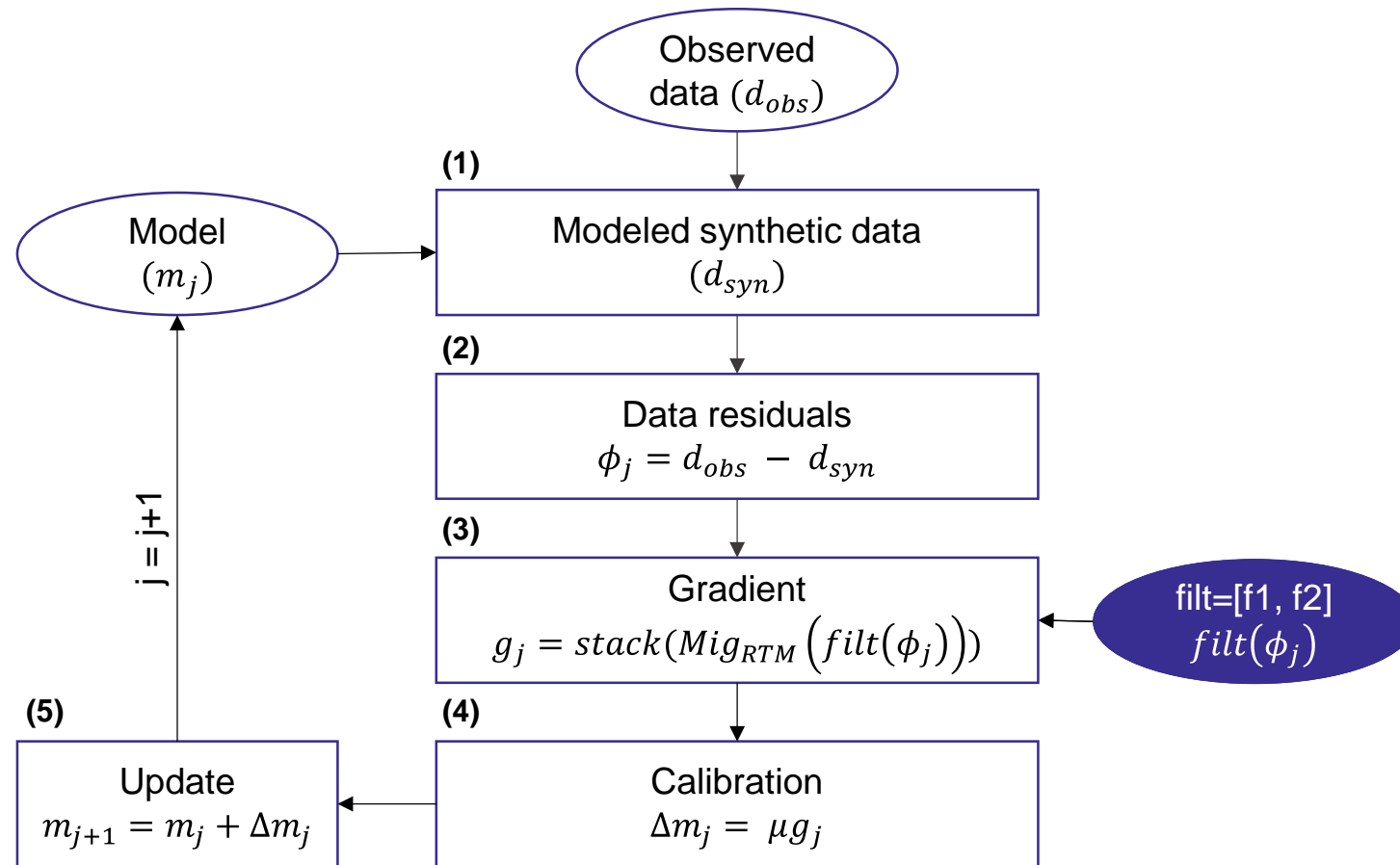
## Variations



(Taken from Macquet *et al.*, 2019)



# Modeling the CO<sub>2</sub> injection with FWI

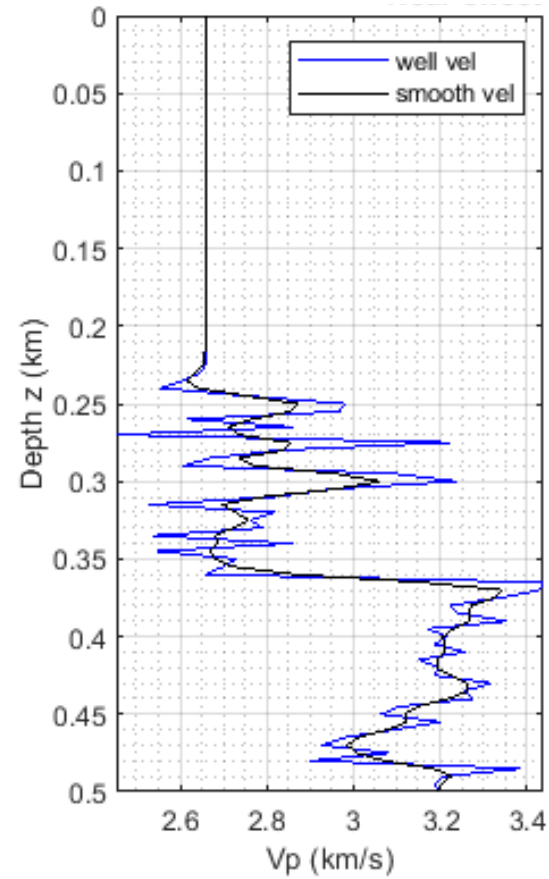


(Adapted from Romahn, 2019)

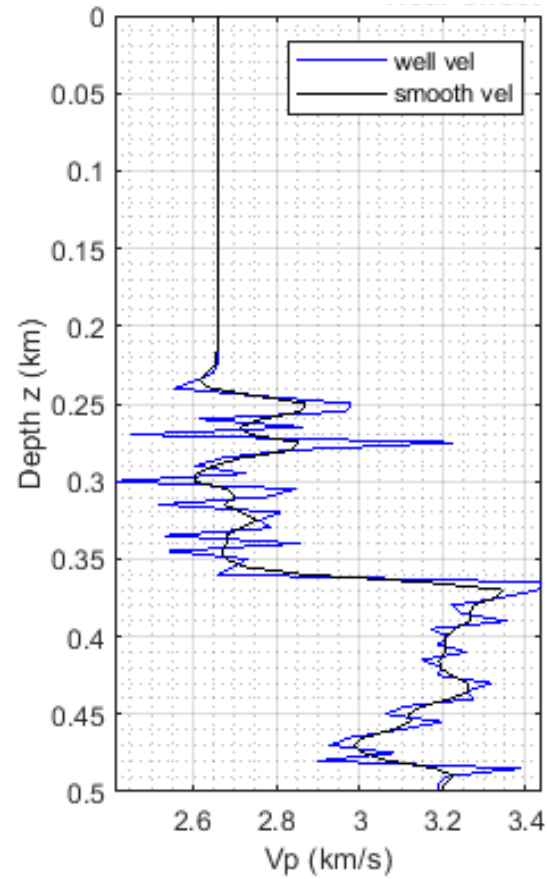


# Modeling the CO<sub>2</sub> injection with FWI

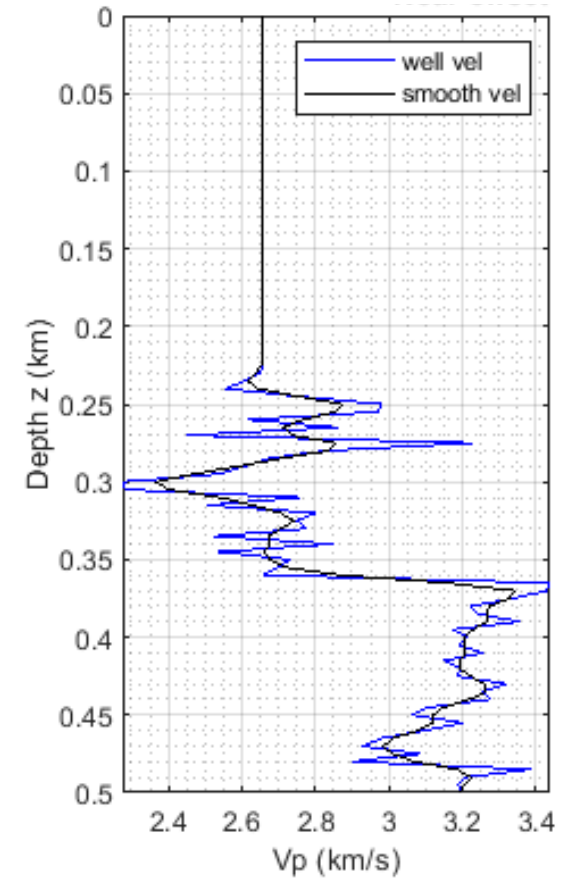
Baseline model



1 year of CO<sub>2</sub> injection



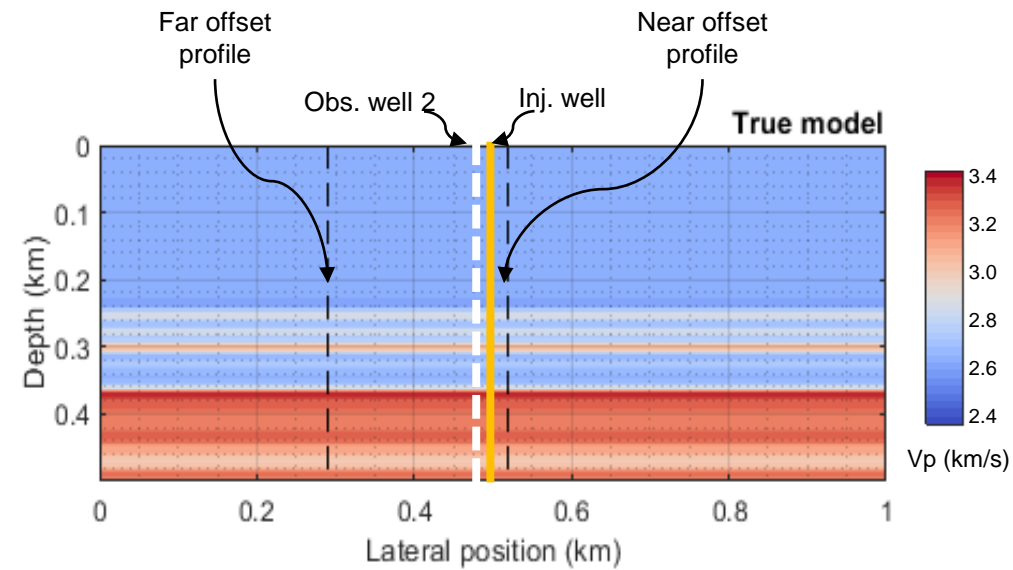
5 years of CO<sub>2</sub> injection



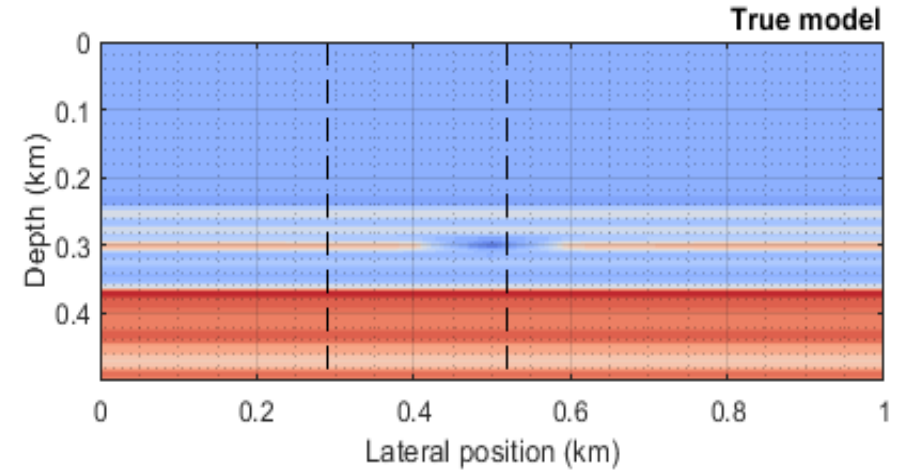


# Modeling the CO<sub>2</sub> injection with FWI

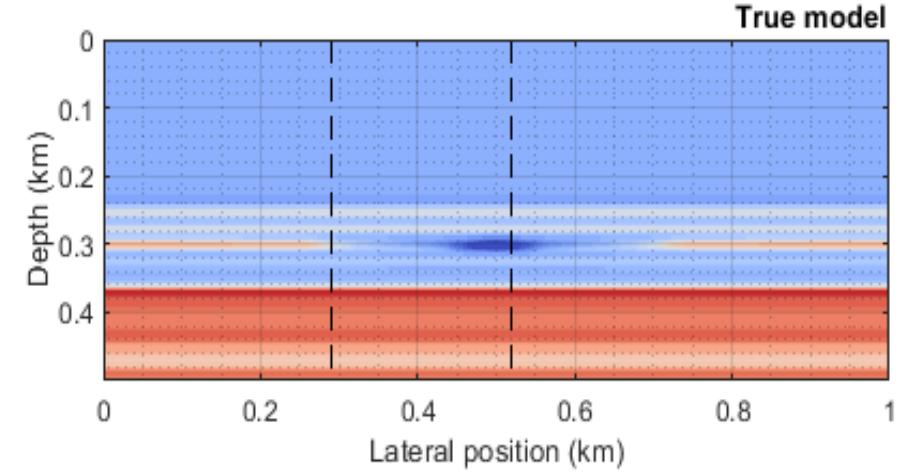
## Baseline model



## 1 year of CO<sub>2</sub> injection



## 5 years of CO<sub>2</sub> injection

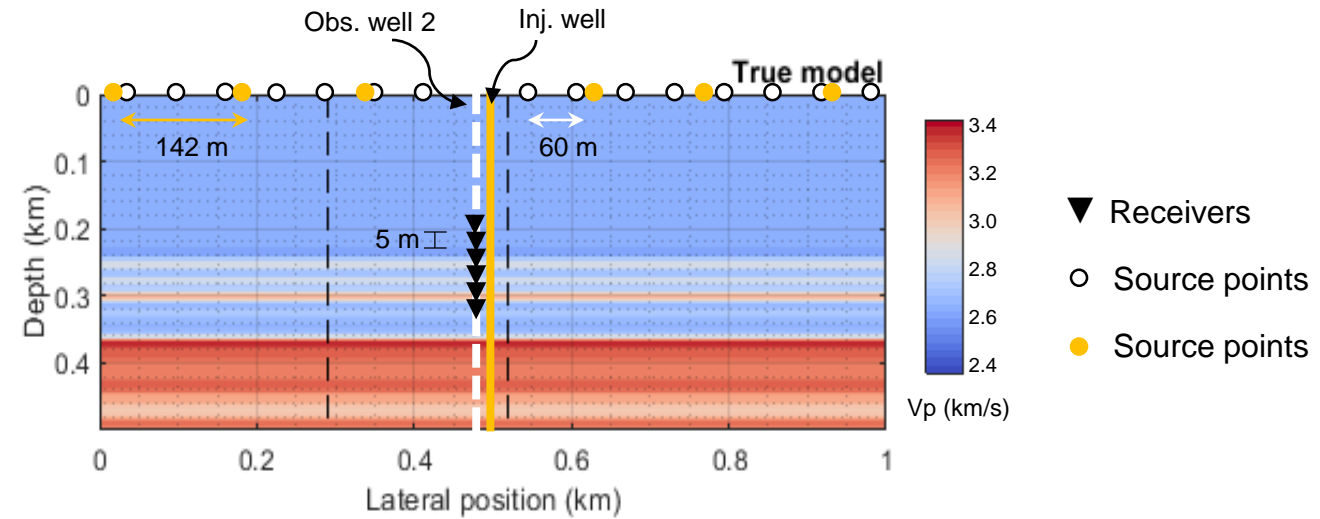




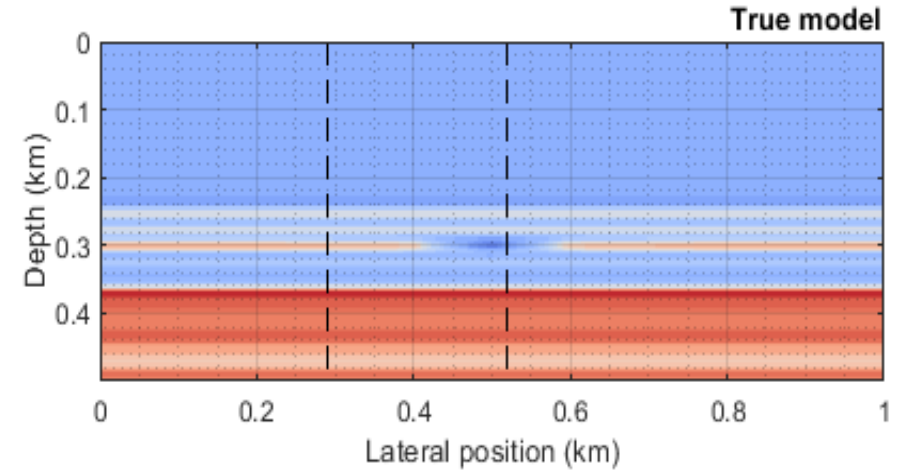


# Modeling the CO<sub>2</sub> injection with FWI

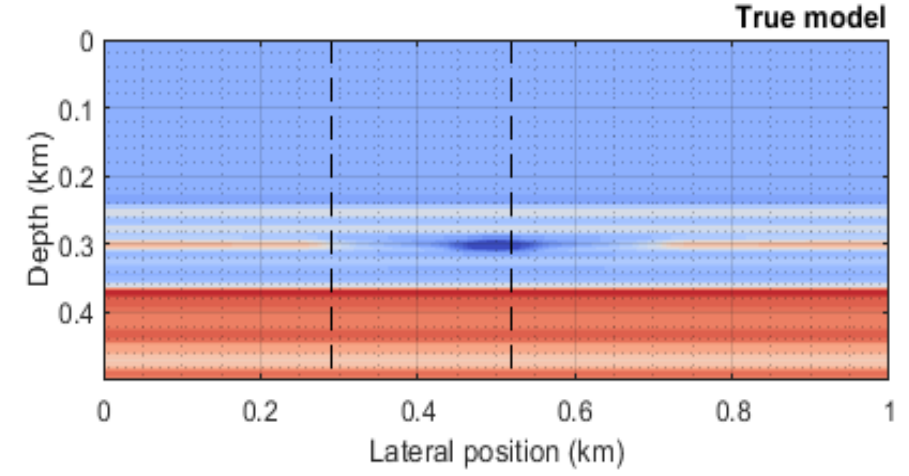
### Baseline model



### 1 year of CO<sub>2</sub> injection



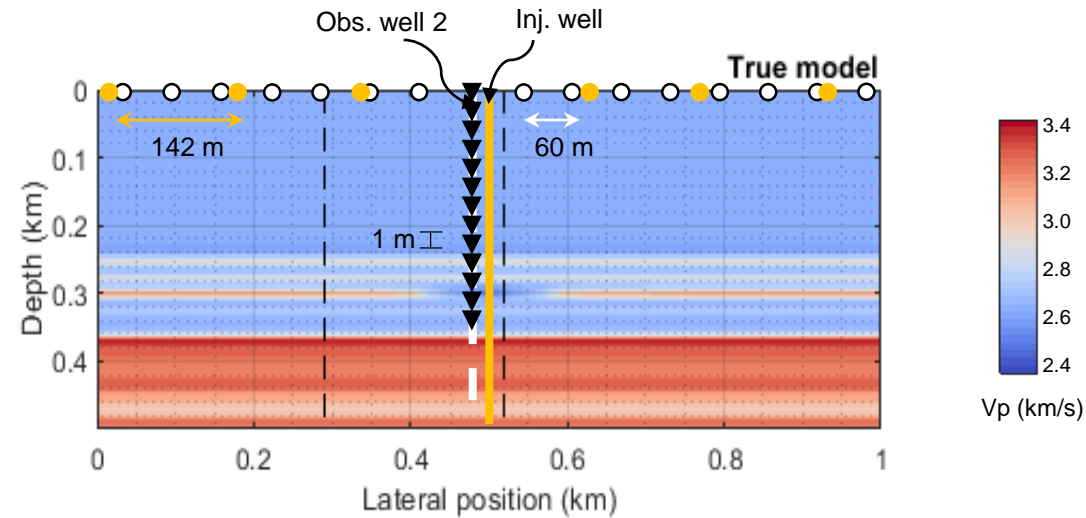
### 5 years of CO<sub>2</sub> injection



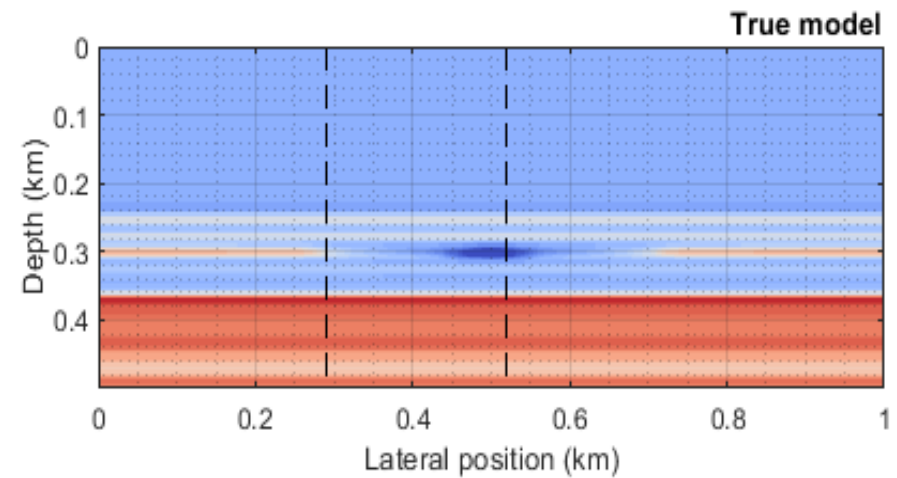


# Modeling the CO<sub>2</sub> injection with FWI

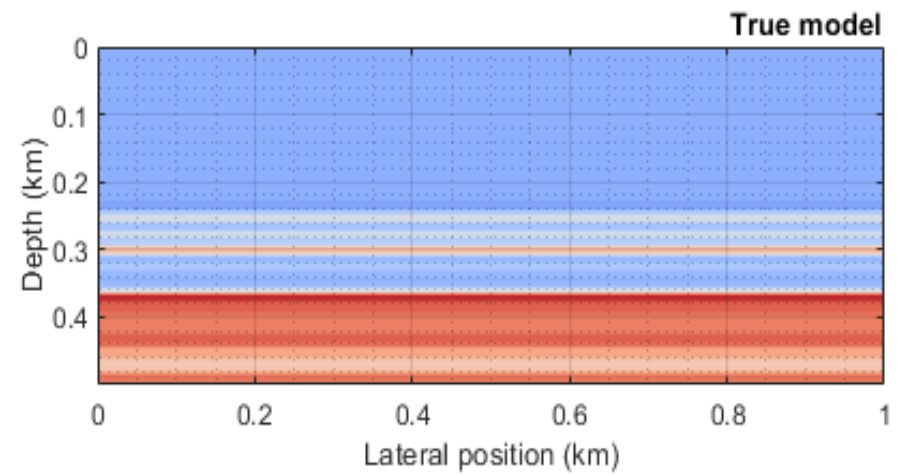
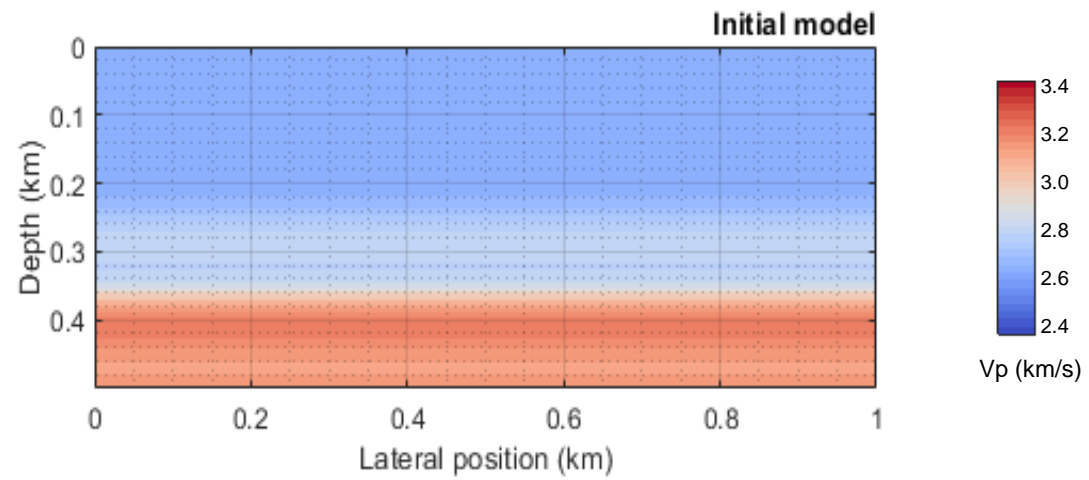
1 year of CO<sub>2</sub> injection



5 years of CO<sub>2</sub> injection



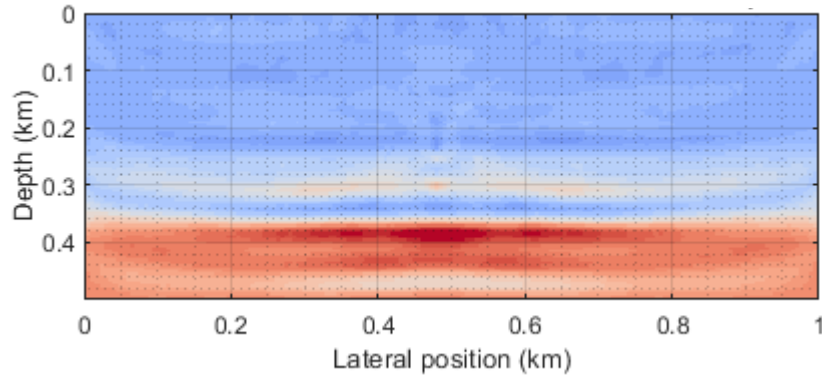
- ▼ Receivers
- Source points
- Source points



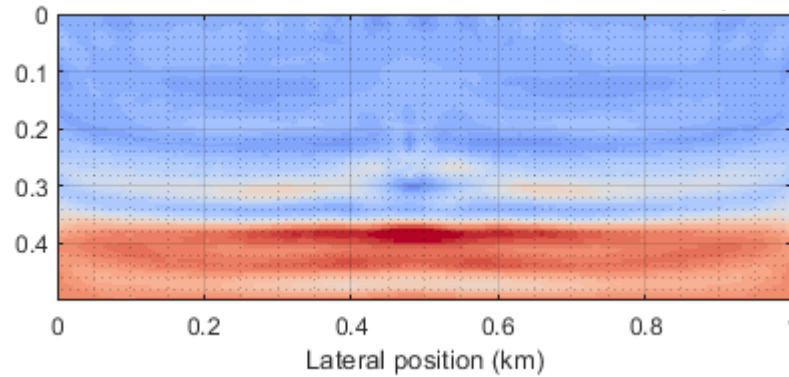


# FWI time-lapse: 60 m source spacing

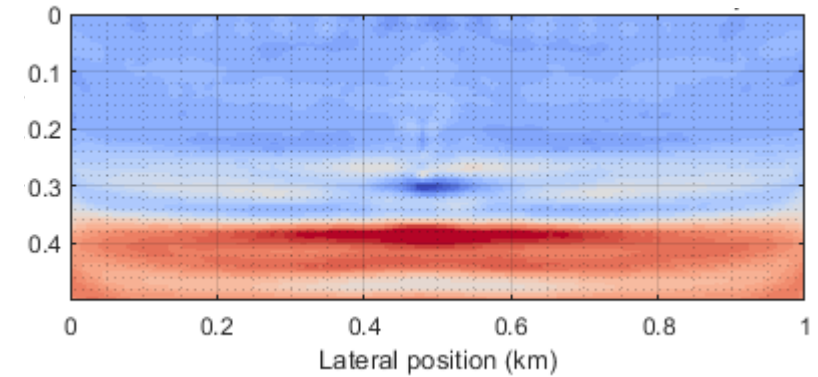
Baseline model



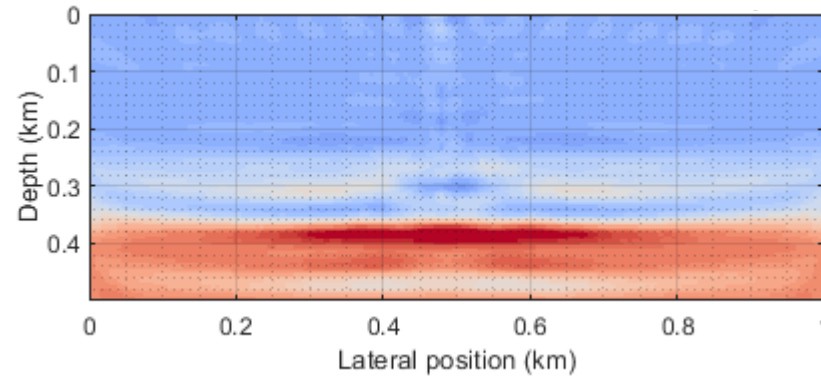
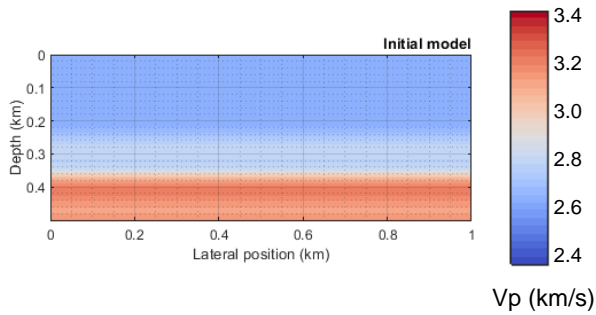
1 year of CO<sub>2</sub> injection



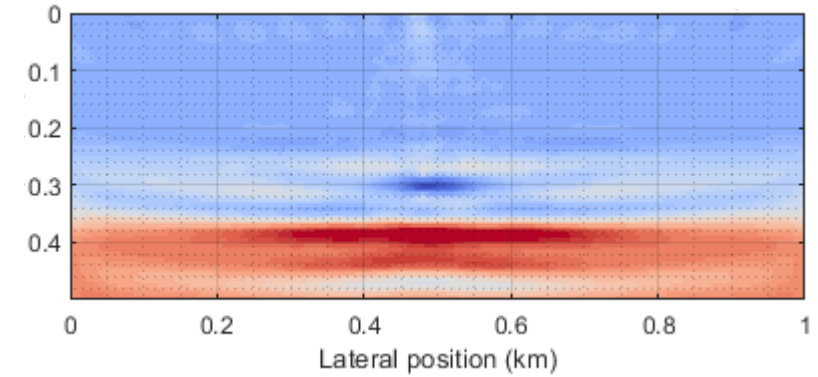
5 years of CO<sub>2</sub> injection



Frequency band [4Hz, 28 Hz]



Frequency band [4Hz, 28 Hz]

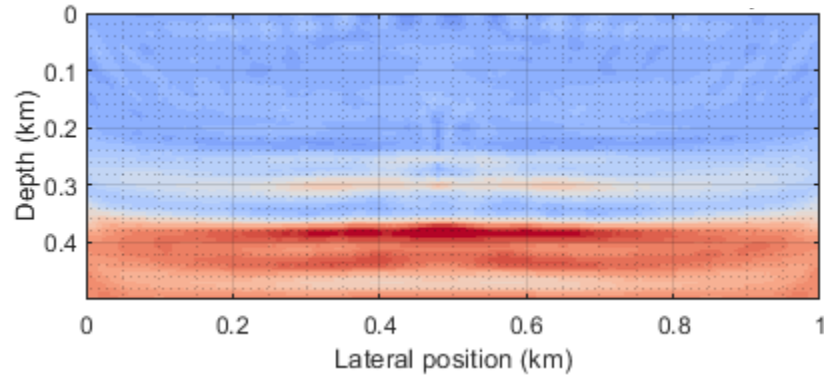


Frequency band [4Hz, 28 Hz]

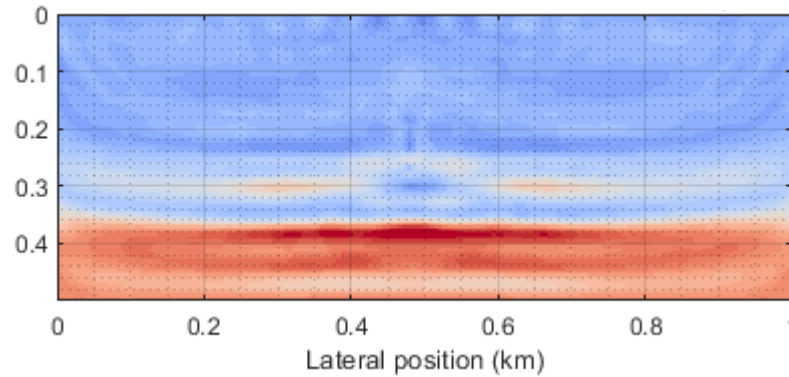


# FWI time-lapse: 60 m source spacing

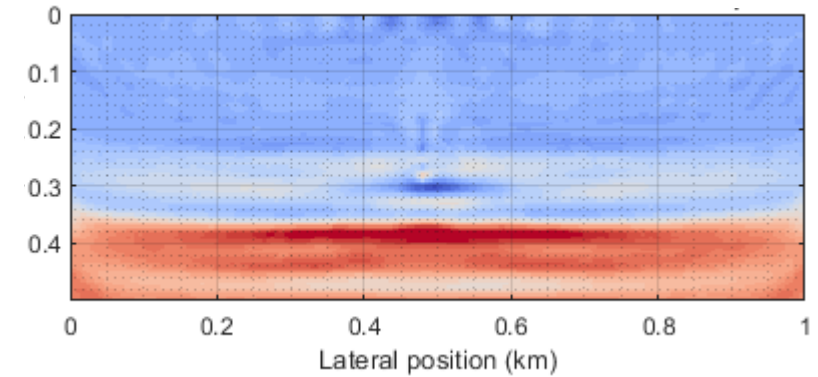
Baseline model



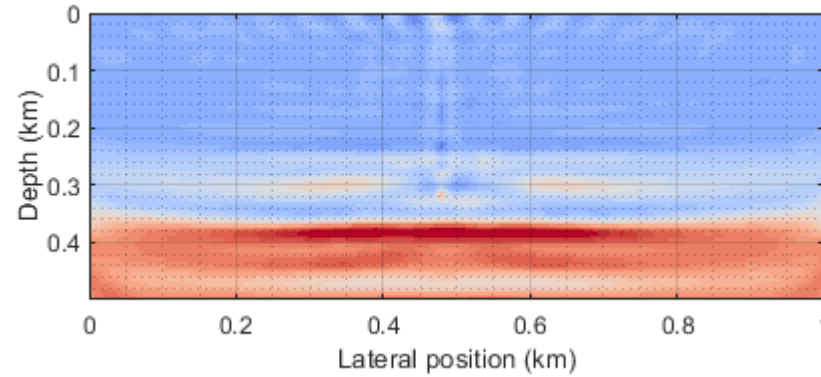
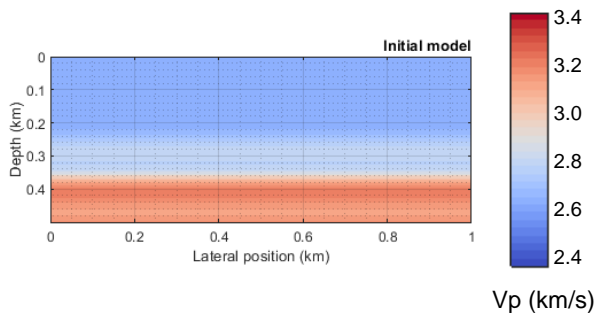
1 year of CO<sub>2</sub> injection



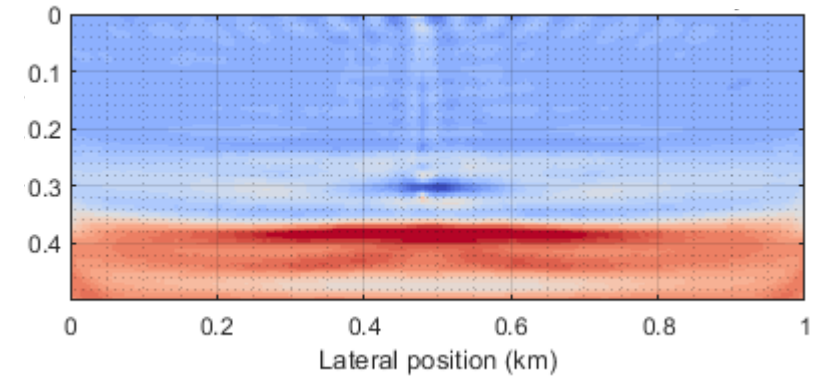
5 years of CO<sub>2</sub> injection



Frequency band [4Hz, 36 Hz]



Frequency band [4Hz, 36 Hz]

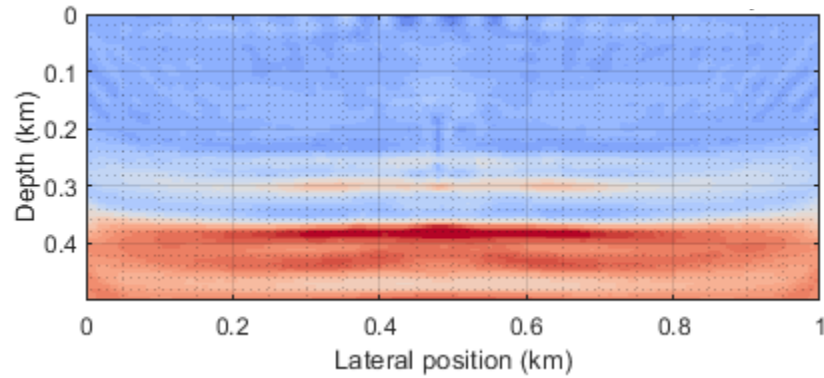


Frequency band [4Hz, 36 Hz]

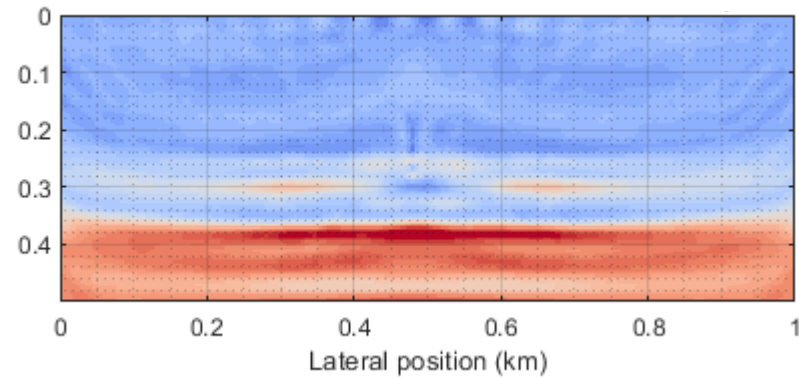


# FWI time-lapse: 60 m source spacing

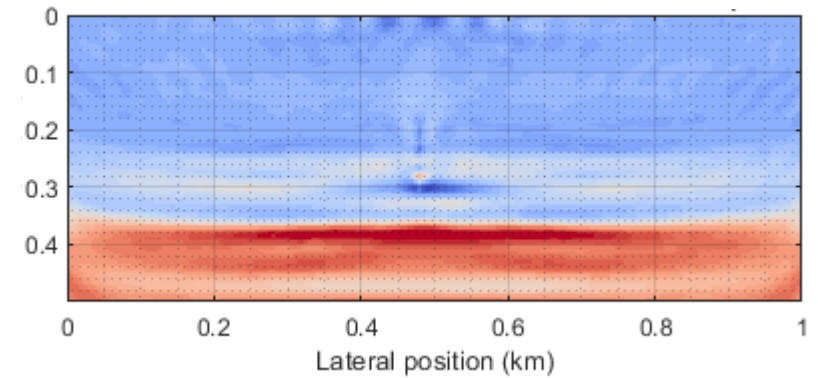
Baseline model



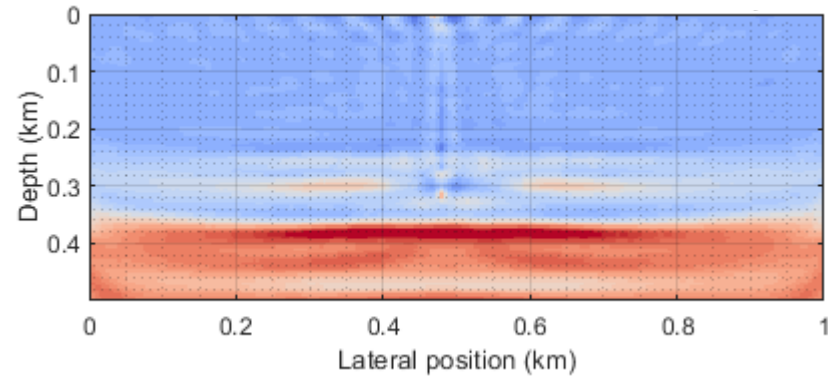
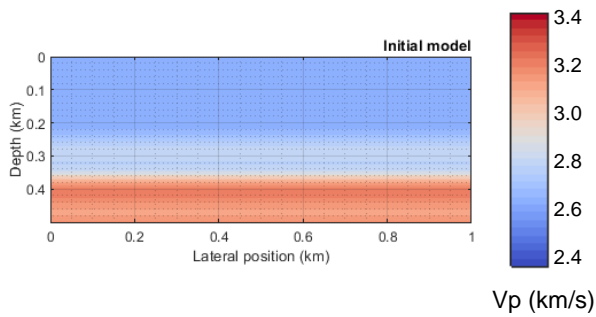
1 year of CO<sub>2</sub> injection



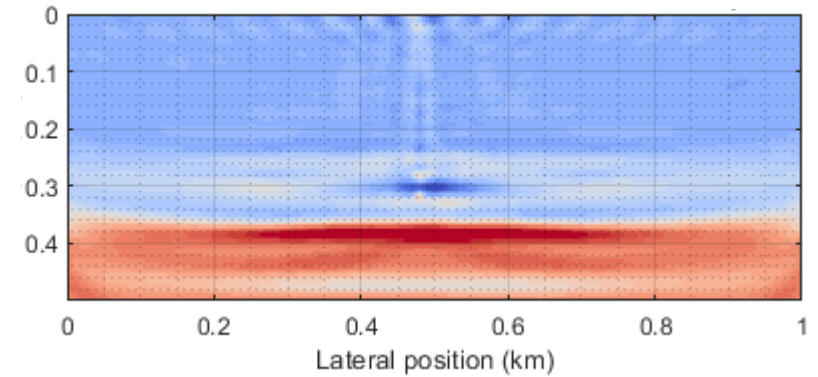
5 years of CO<sub>2</sub> injection



Frequency band [4Hz, 40 Hz]



Frequency band [4Hz, 40 Hz]

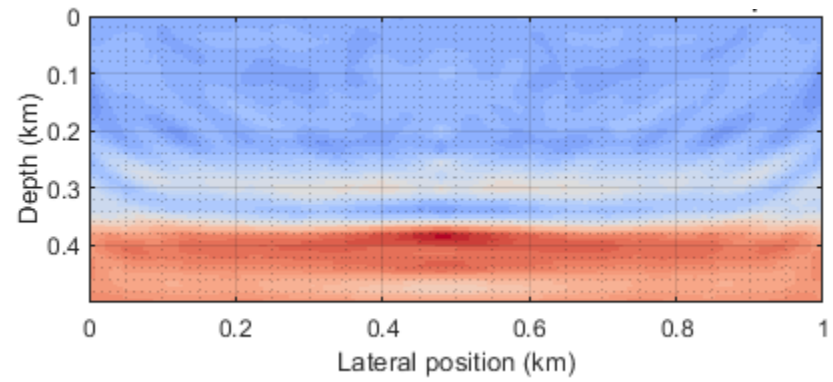


Frequency band [4Hz, 40 Hz]

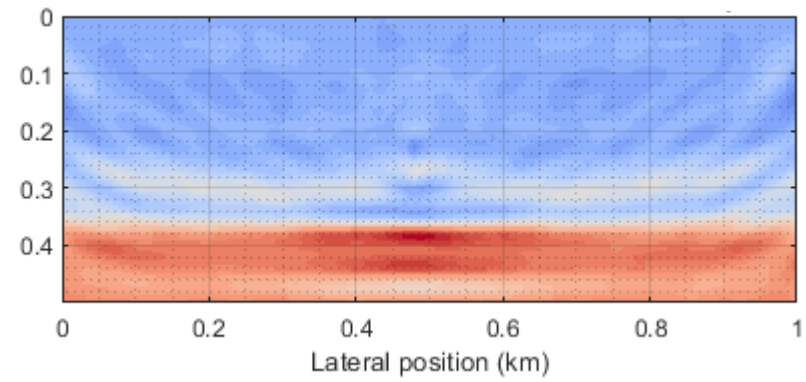


# FWI time-lapse: 142 m source spacing

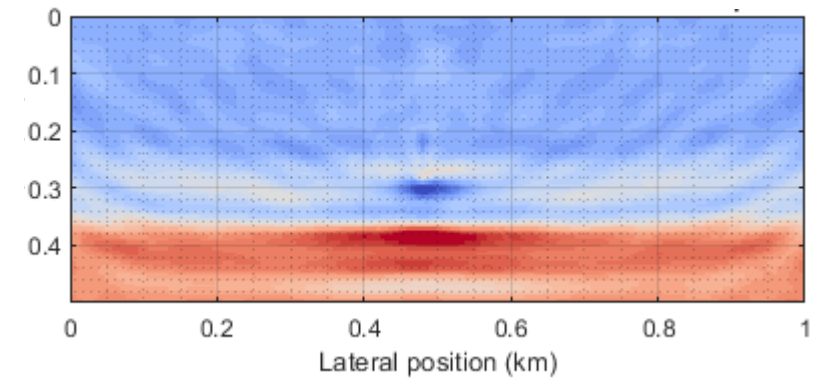
Baseline model



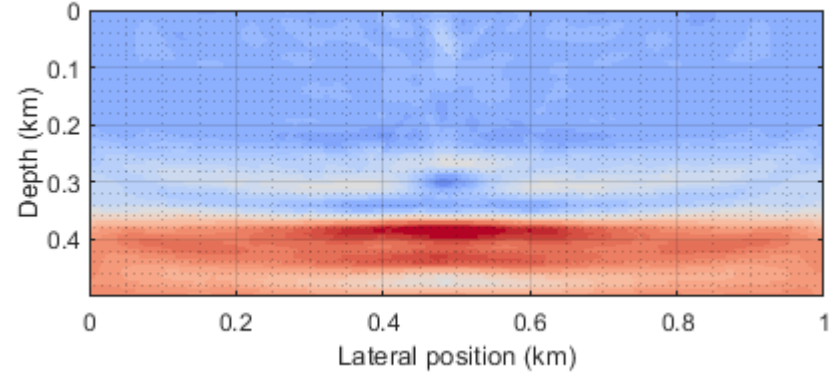
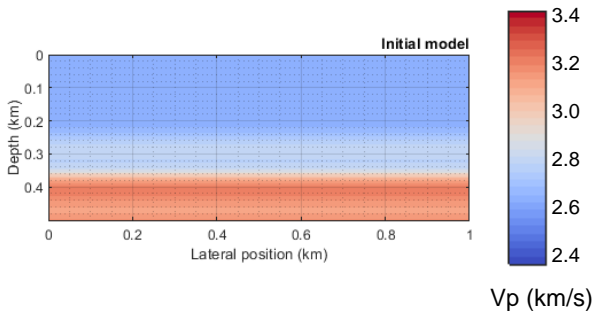
1 year of CO<sub>2</sub> injection



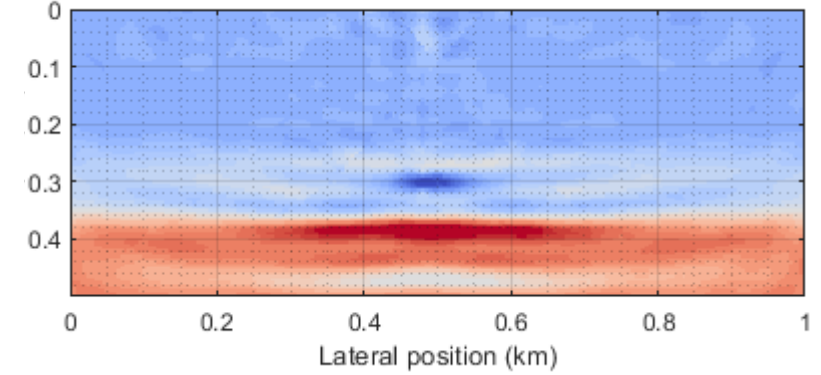
5 years of CO<sub>2</sub> injection



Frequency band [4Hz, 28 Hz]



Frequency band [4Hz, 28 Hz]

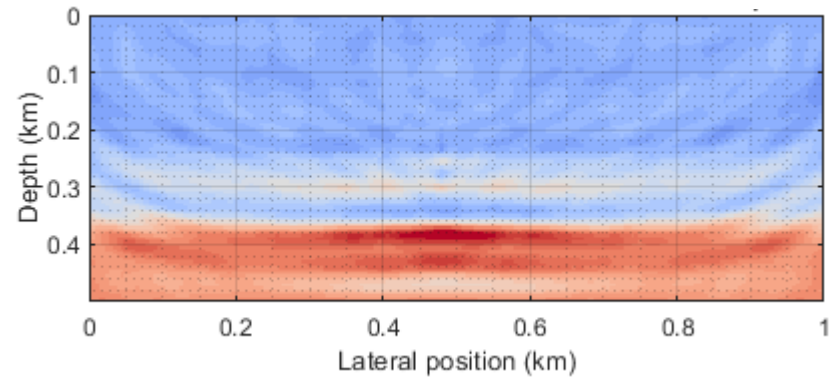


Frequency band [4Hz, 28 Hz]

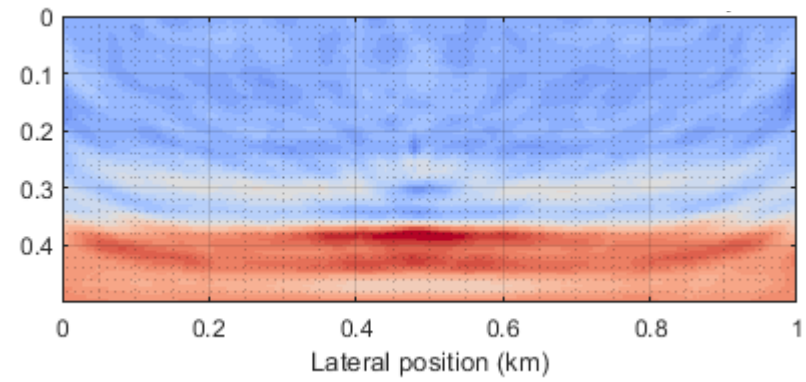


# FWI time-lapse: 142 m source spacing

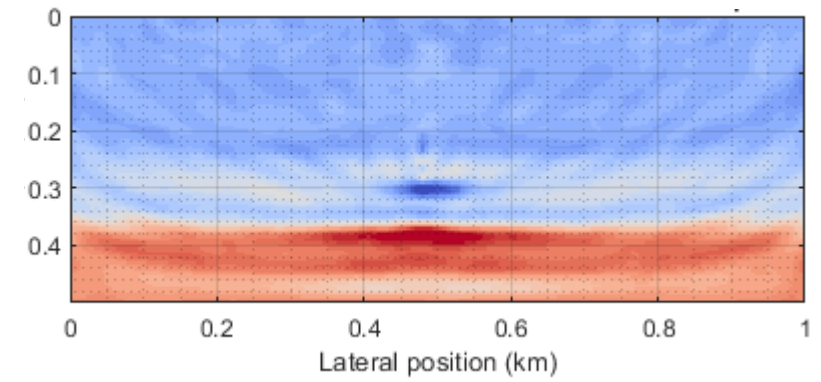
Baseline model



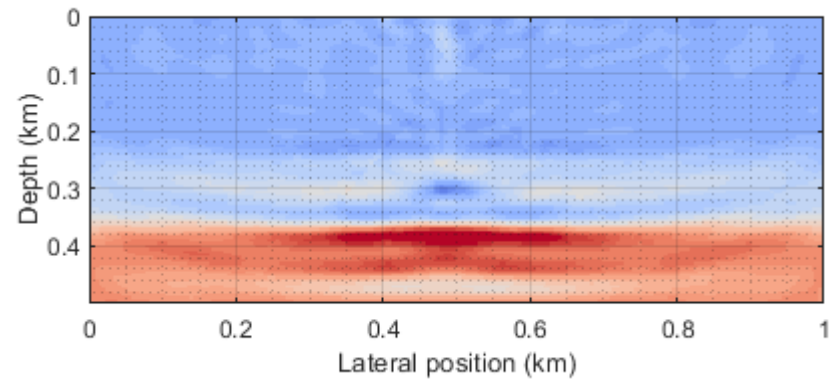
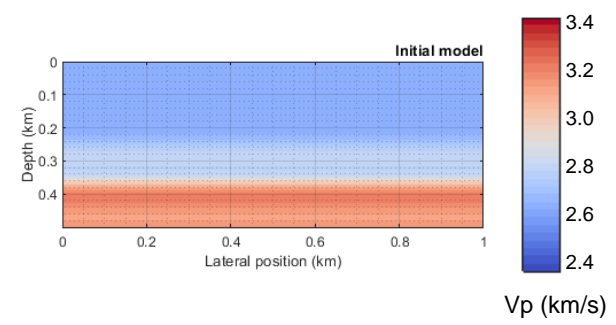
1 year of CO<sub>2</sub> injection



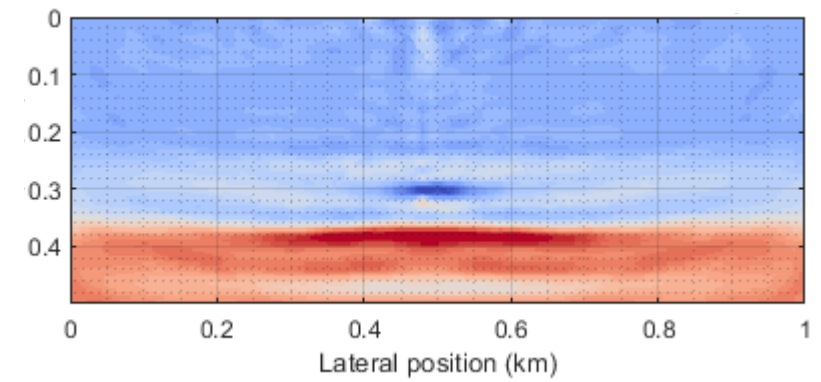
5 years of CO<sub>2</sub> injection



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Frequency band [4Hz, 36 Hz]



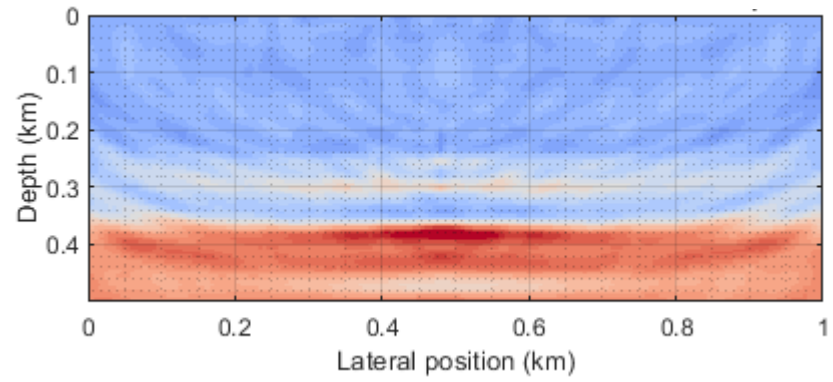
Frequency band [4Hz, 36 Hz]



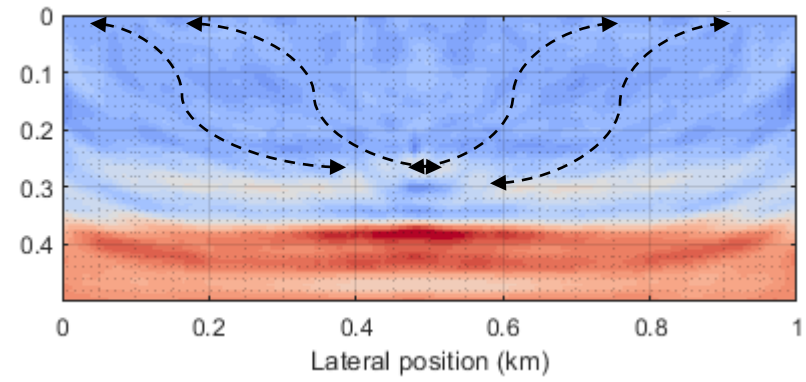


# FWI time-lapse: 142 m source spacing

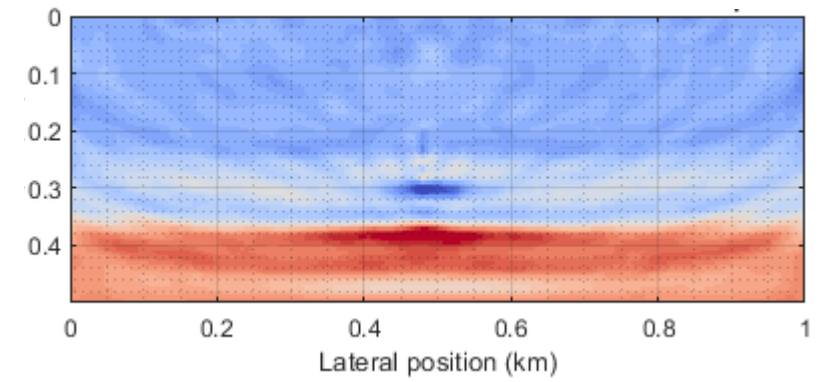
Baseline model



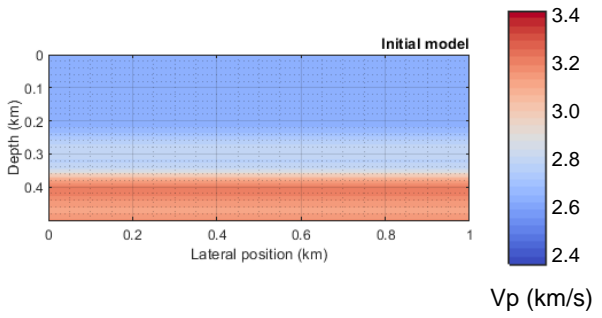
1 year of CO<sub>2</sub> injection



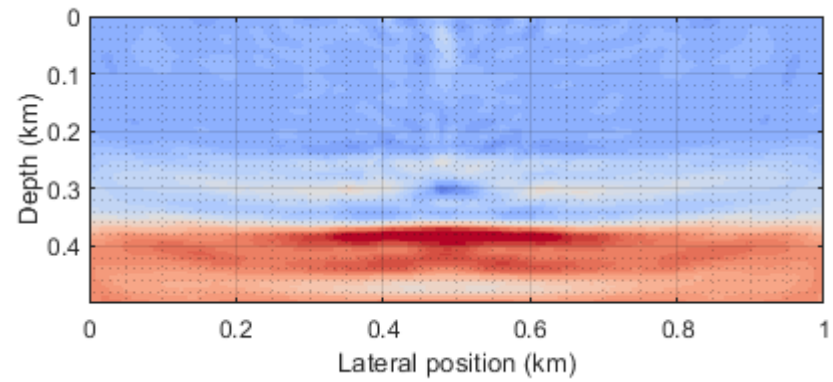
5 years of CO<sub>2</sub> injection



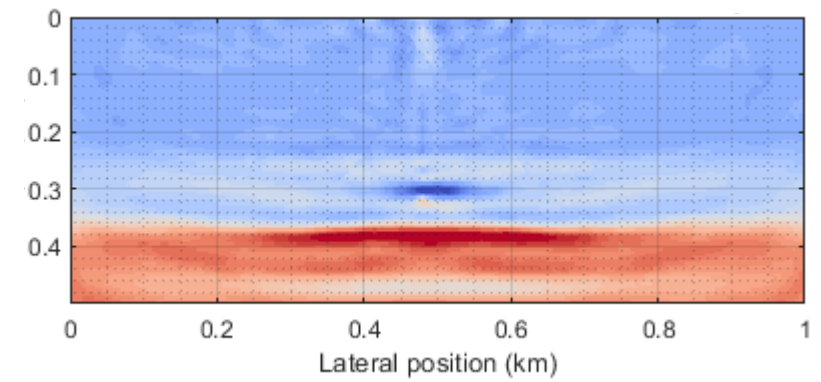
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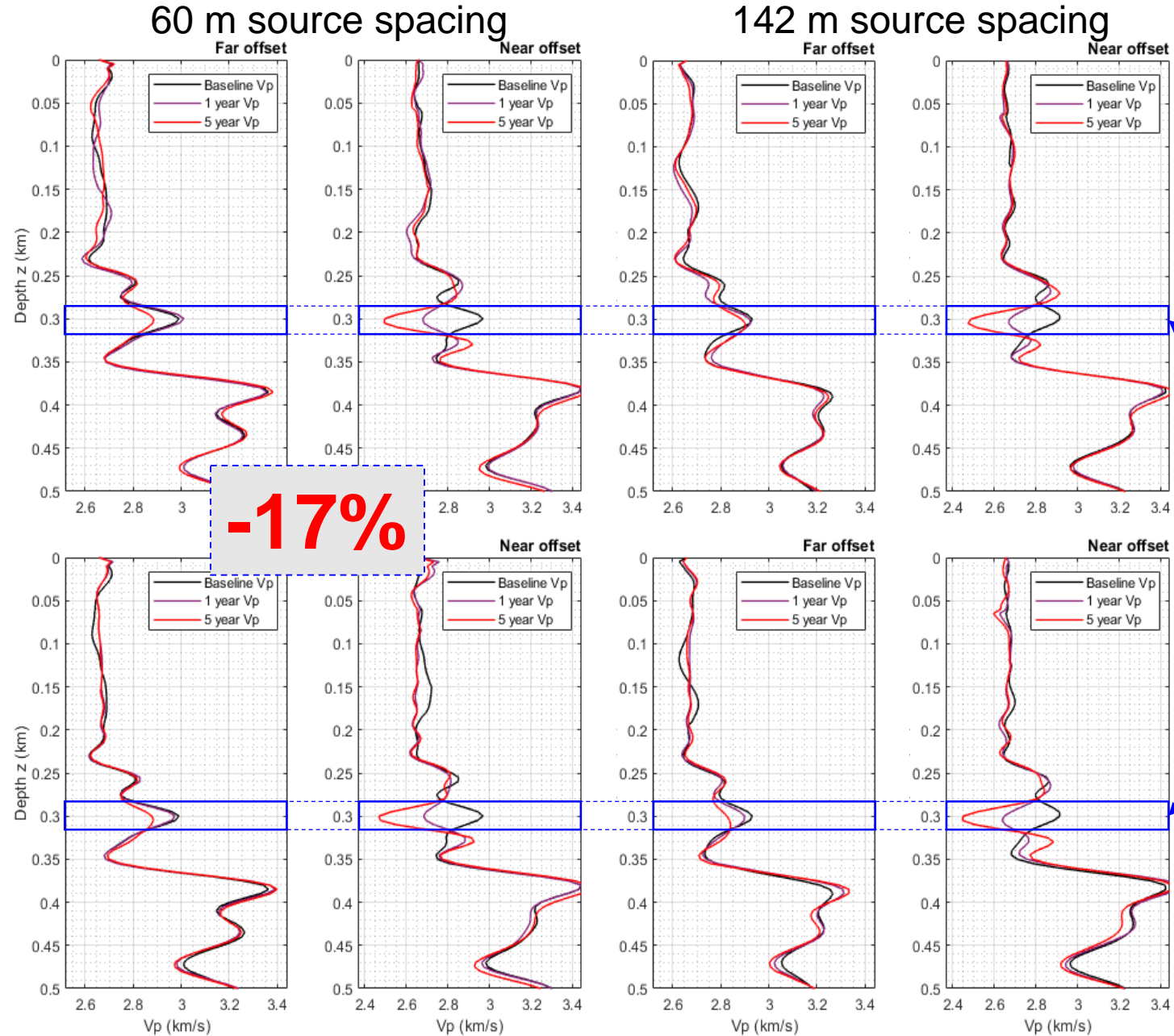




# FWI time-lapse: comparison of inverted models

Receivers (190 – 305 m)

Receivers (0 – 324 m)



Basal Belly River Sandstone

- P-wave velocity reduction modeled using an acoustic FWI.
- Comparable results obtained with different sensor disposition and similar source distribution.
- Lateral extension resolution of CO<sub>2</sub> effects highly affected by acquisition design.
- Inversion of elastic rock parameters at CaMI FRS.



- CREWES sponsors.
- CREWES faculty, staff and students.
- Natural Science and Engineering Research Council of Canada (CRDPJ 461179-13 and CRDPJ 543578-19).



Hall, K. W., Bertram, K. L., Bertram, M., Innanen, K.A.H., and Lawton, D.C., (2018), CREWES 2018 multi-azimuth walk-away VSP field experiment: CREWES Research Reports, **30**,16.

Macquet, M., Lawton, D., Saeefdar, A., and Osadetz, K., 2019, A feasibility study for detection for detections thresholds of CO<sub>2</sub> at shallow depths at the CaMI Field Research Station, Newell County, Alberta, Canada: Petroleum Geoscience, No. 25(4):509.

Romahn, S., 2019, Well-log validated waveform inversion of reflection seismic data: Masters of Science Thesis.