Quantitative FWI characterization and monitoring of reservoir properties at the CMC Newell County Facility

Qi Hu, Matt Eaid, Scott Keating, and Kris Innanen

2022 Sponsors meeting

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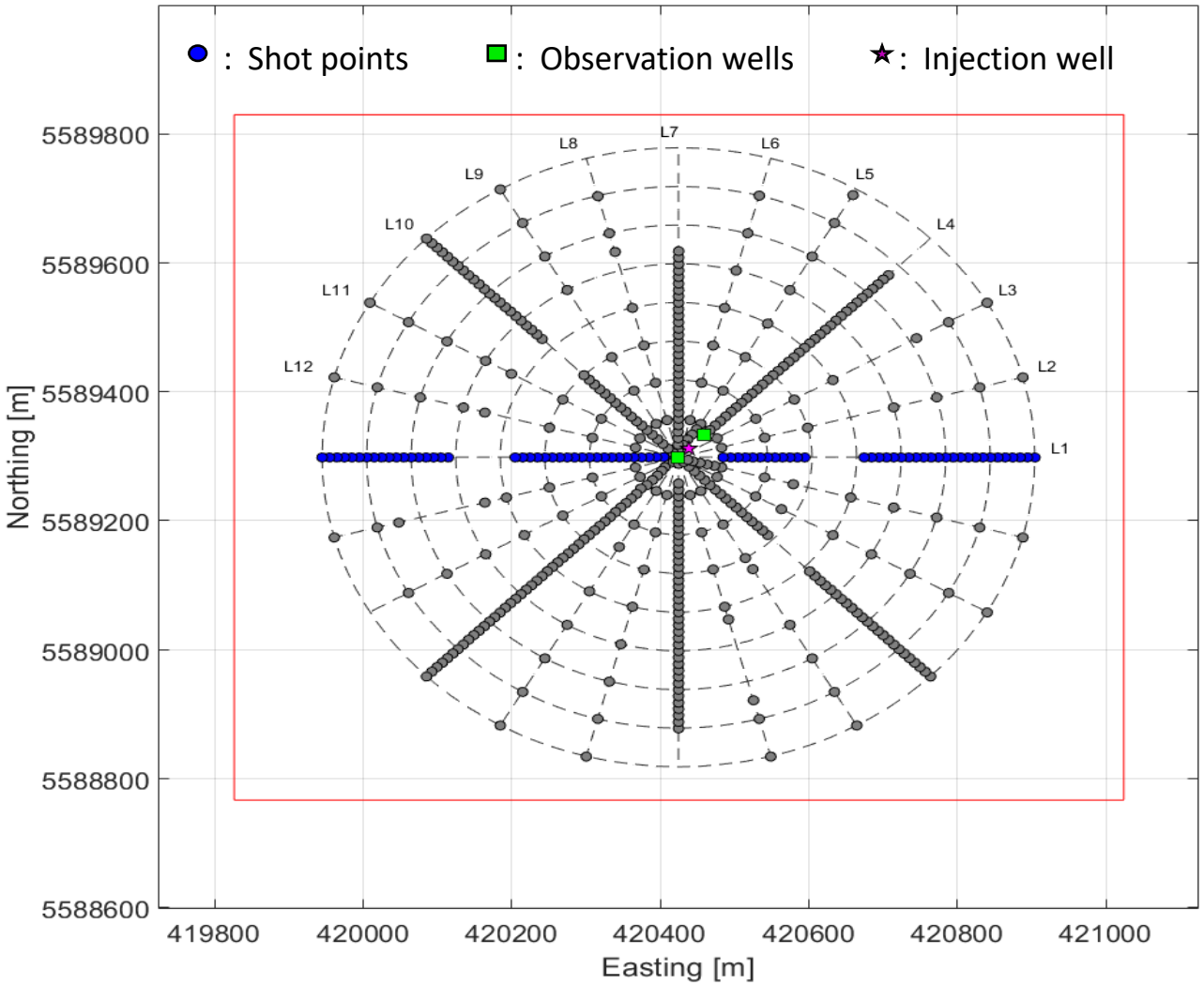
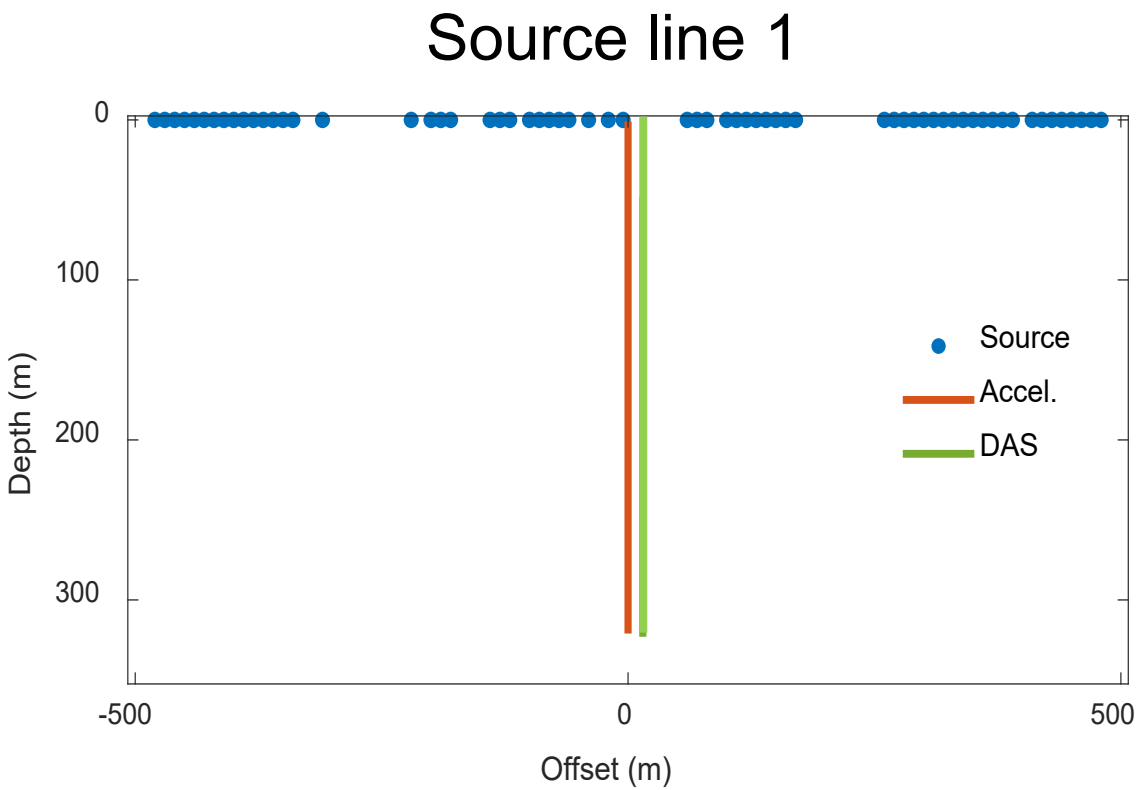
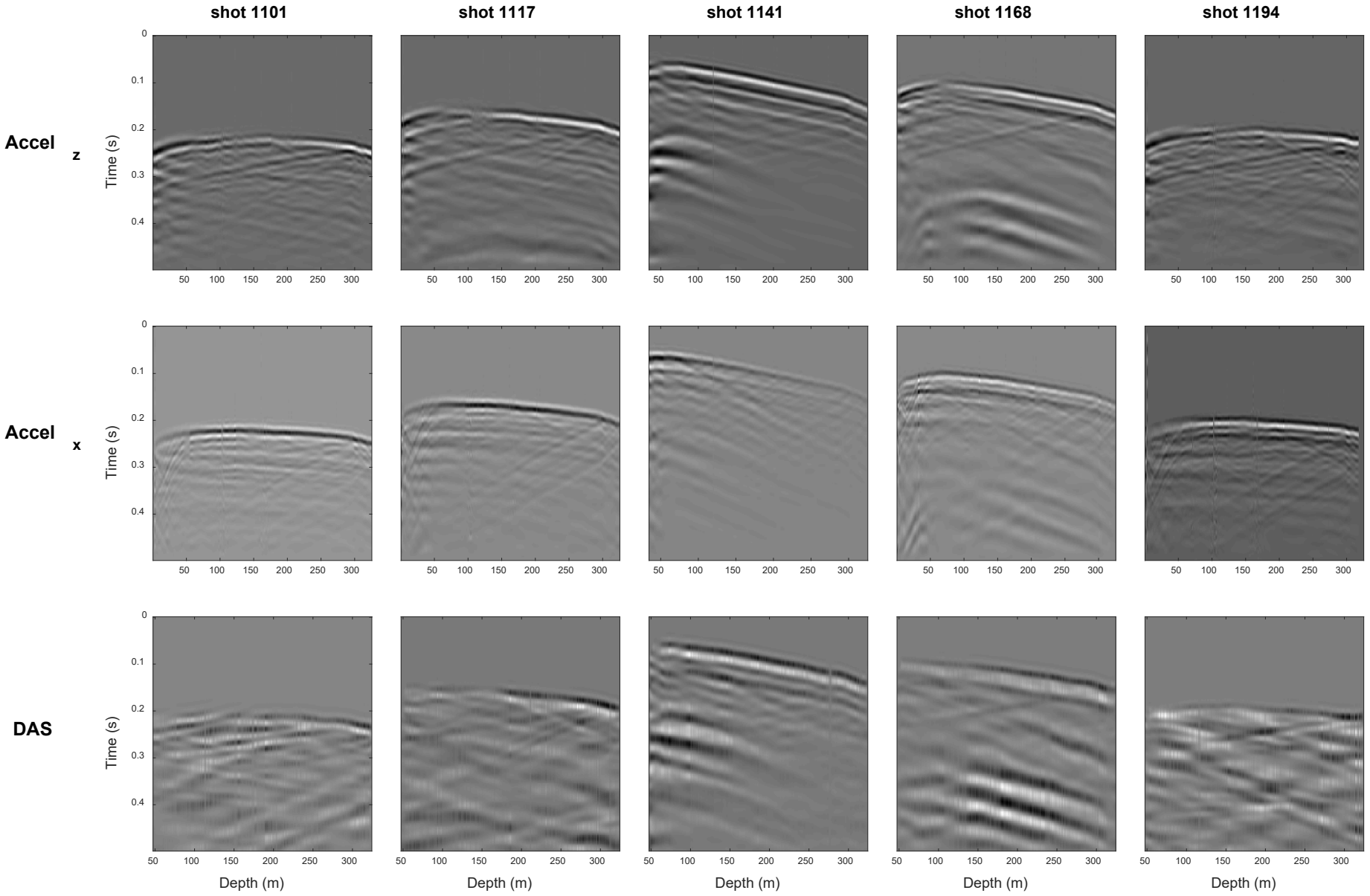
NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience
Carbon Management Canada

2018 CMC 3D VSP survey





Seismic data

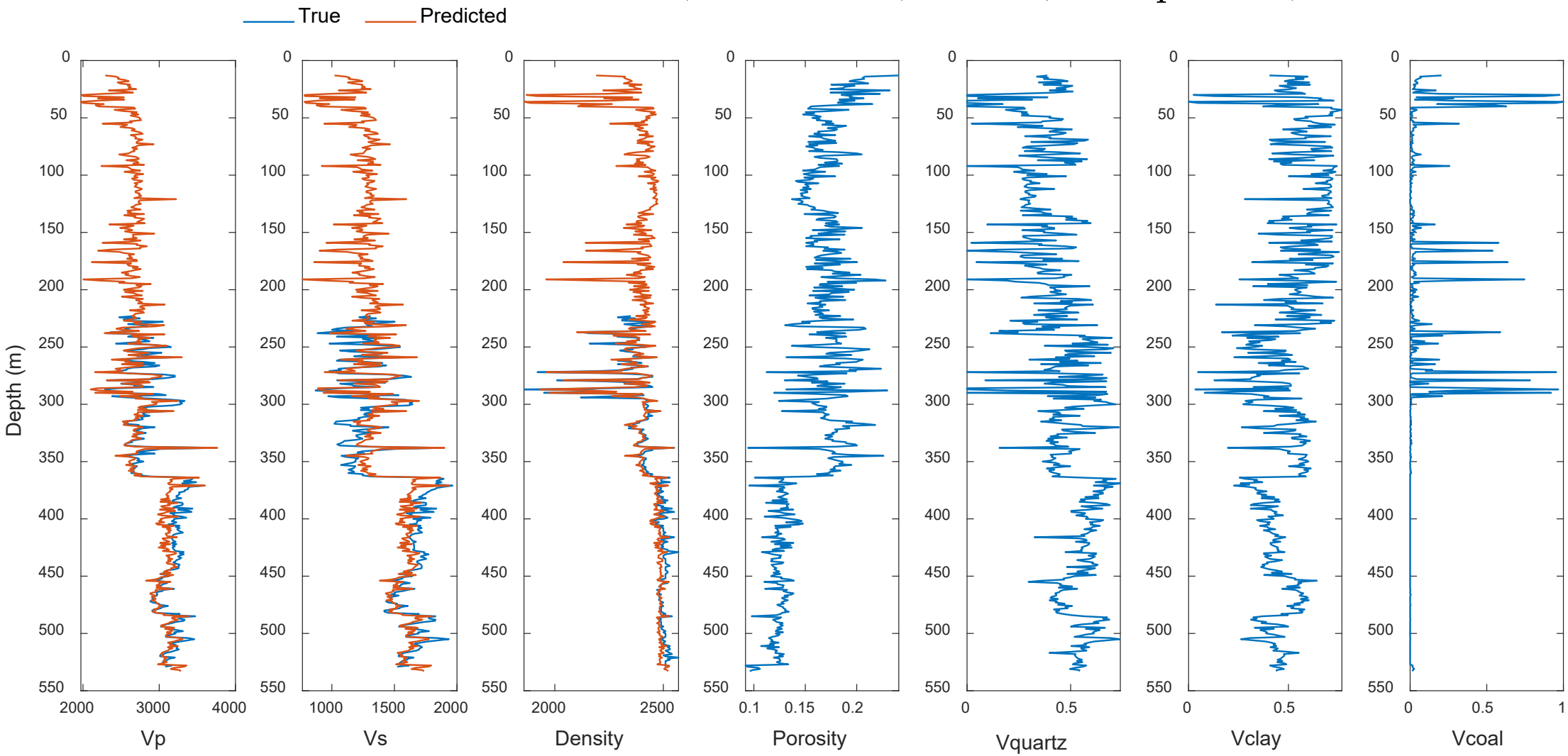


Eaid et al. (2021)

Well-log data

$$(V_{\mathrm{P}}, V_{\mathrm{S}}, \rho) = f(\phi, V_{\mathrm{qu}}, V_{\mathrm{cl}})$$

Hu et al. (2021)



Previous FWI results

- Eaid and Keating (2021)

  FWI of accelerometer, DAS, and hybrid DAS-accelerometer data sets.

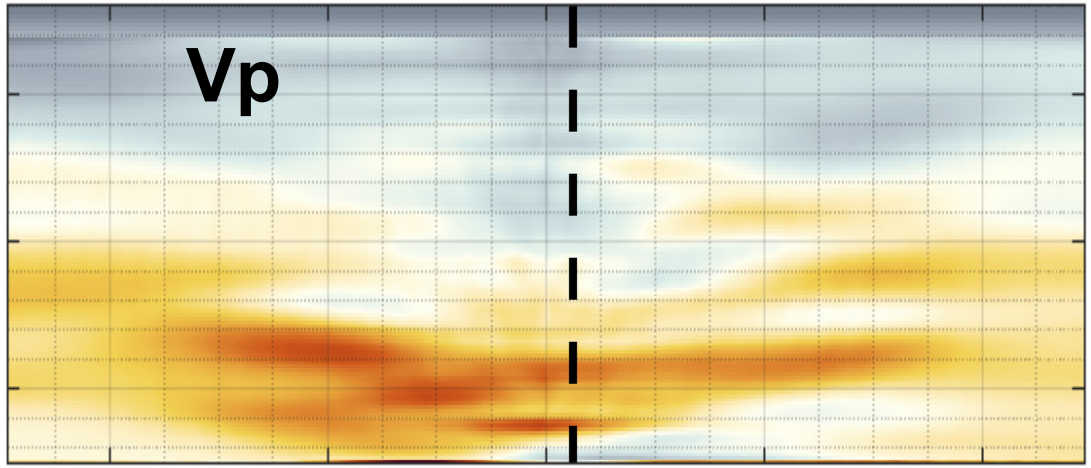
- Key strategies:

  Effective source method

  Inclusion of DAS data in inversion

  Log derived model-parameterization

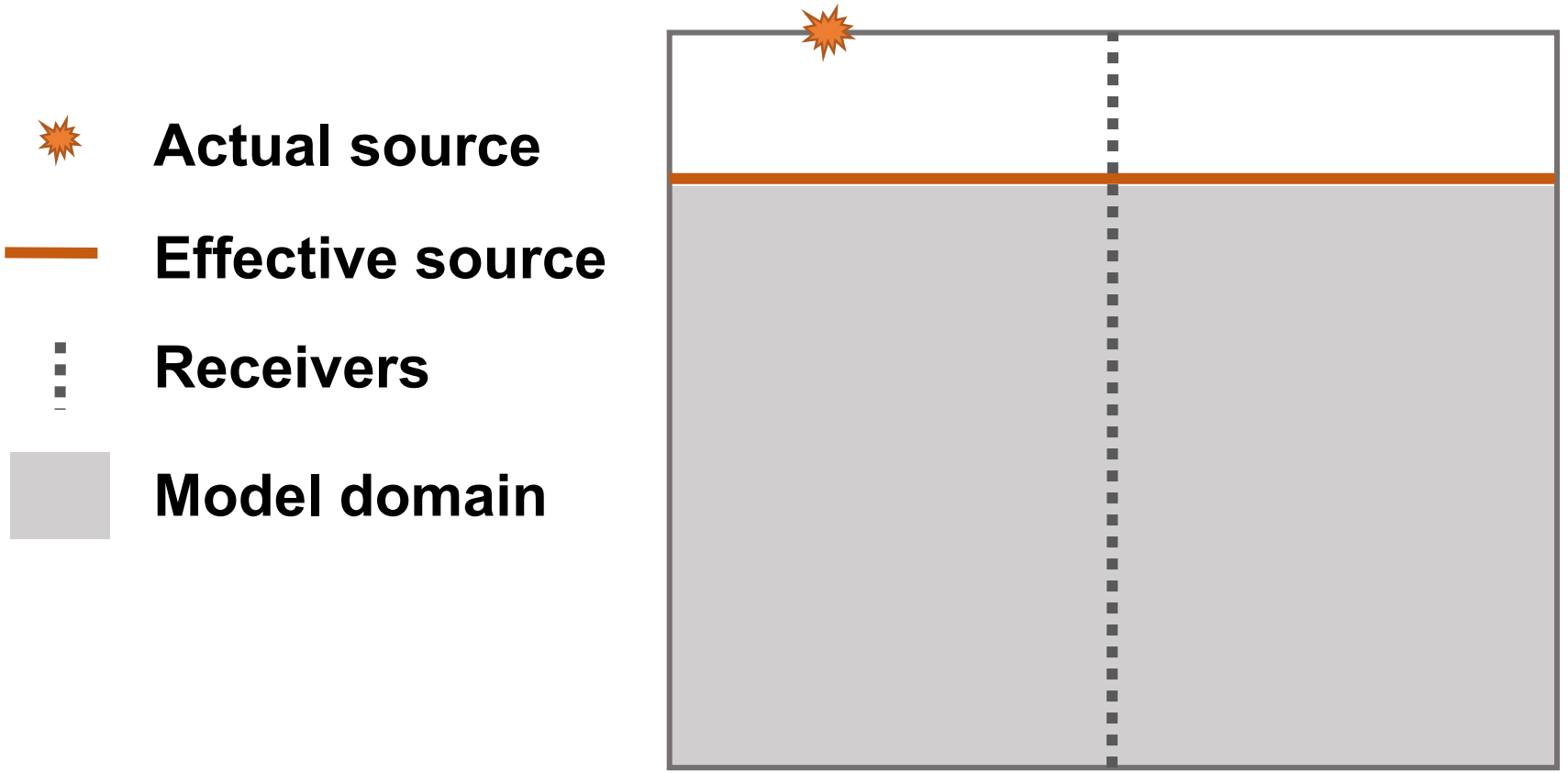
50% DAS + 50% Accelerometer



Methods

- Effective source method

$$E(\mathbf{m}, \mathbf{f}^*) = \frac{1}{2} \|\mathbf{Ru} - \mathbf{d}\|_2^2 \quad \text{subject to} \quad \mathbf{A}(\mathbf{m})\mathbf{u} = \mathbf{f}^*.$$



Methods

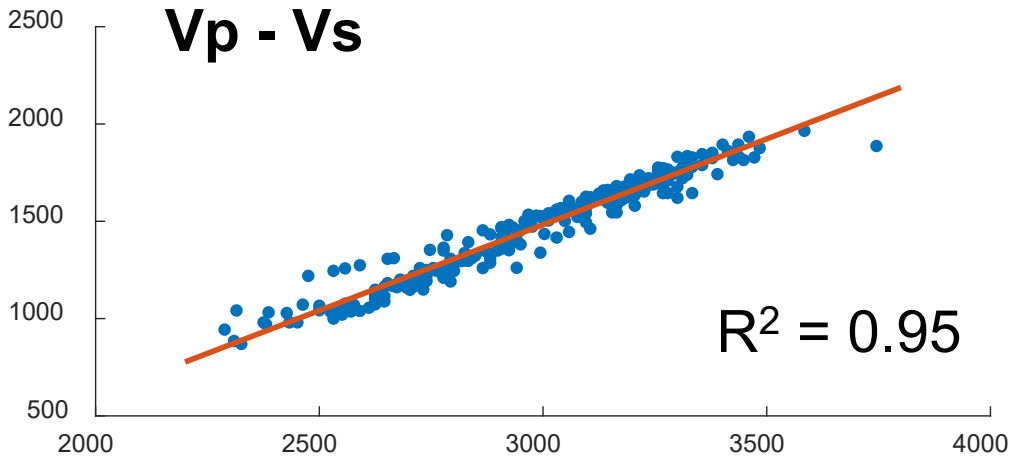
- Inclusion of DAS data in FWI

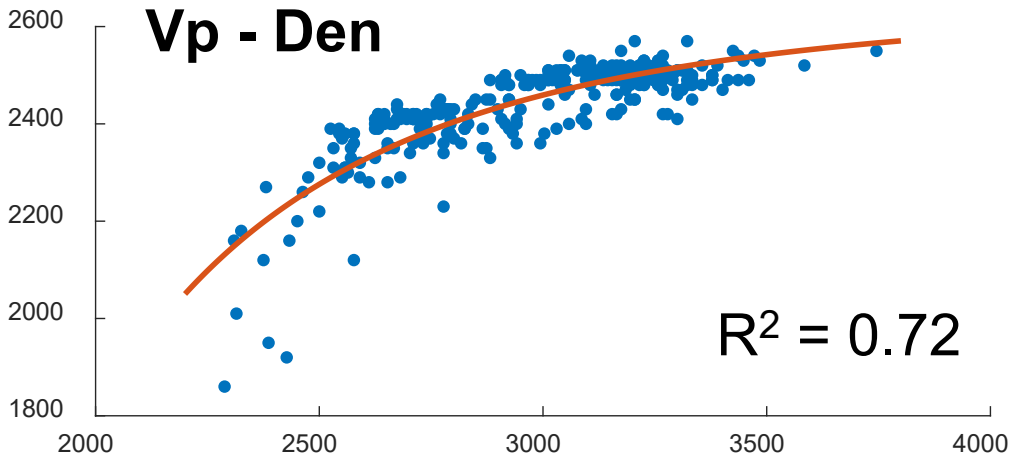
$$\mathbf{d} = \mathbf{R}\mathbf{u}$$

$$\begin{matrix} \mathbf{d}_x \\ \\ \mathbf{d}_z \\ \\ \boldsymbol{\epsilon}_t \end{matrix} \begin{bmatrix} d_x^1 \\ \vdots \\ d_x^{N_g} \\ \hdashline d_z^1 \\ \vdots \\ d_z^{N_g} \\ \hdashline \epsilon^1 \\ \vdots \\ \epsilon^{N_d} \end{bmatrix} = \begin{bmatrix} 1 & & & & & & & & & & & \\ & & & & & 1 & & & & & & \\ \vdots & & & & & & & & & & & \\ \hdashline & 1 & & & & & & & & & & \\ & & & & & & & & 1 & & & \\ & & & & & & & & & & & \\ \hdashline & & w_1 & w_2 & \dots & & & w_3 & w_4 & & & \\ \vdots & & & & & & & & & & & \\ & & & & w_1 & w_2 & \dots & & & w_3 & w_4 & \end{bmatrix} \begin{bmatrix} u_x^1 \\ u_z^1 \\ u_x^2 \\ u_z^2 \\ \vdots \\ u_x^N \\ u_z^N \end{bmatrix}$$

Methods

- Log derived model-parameterization





Pros:

- Reduce non-linearity
- Avoid unphysical result

Cons:

- Introduce errors to the inversion
- Lose elastic information

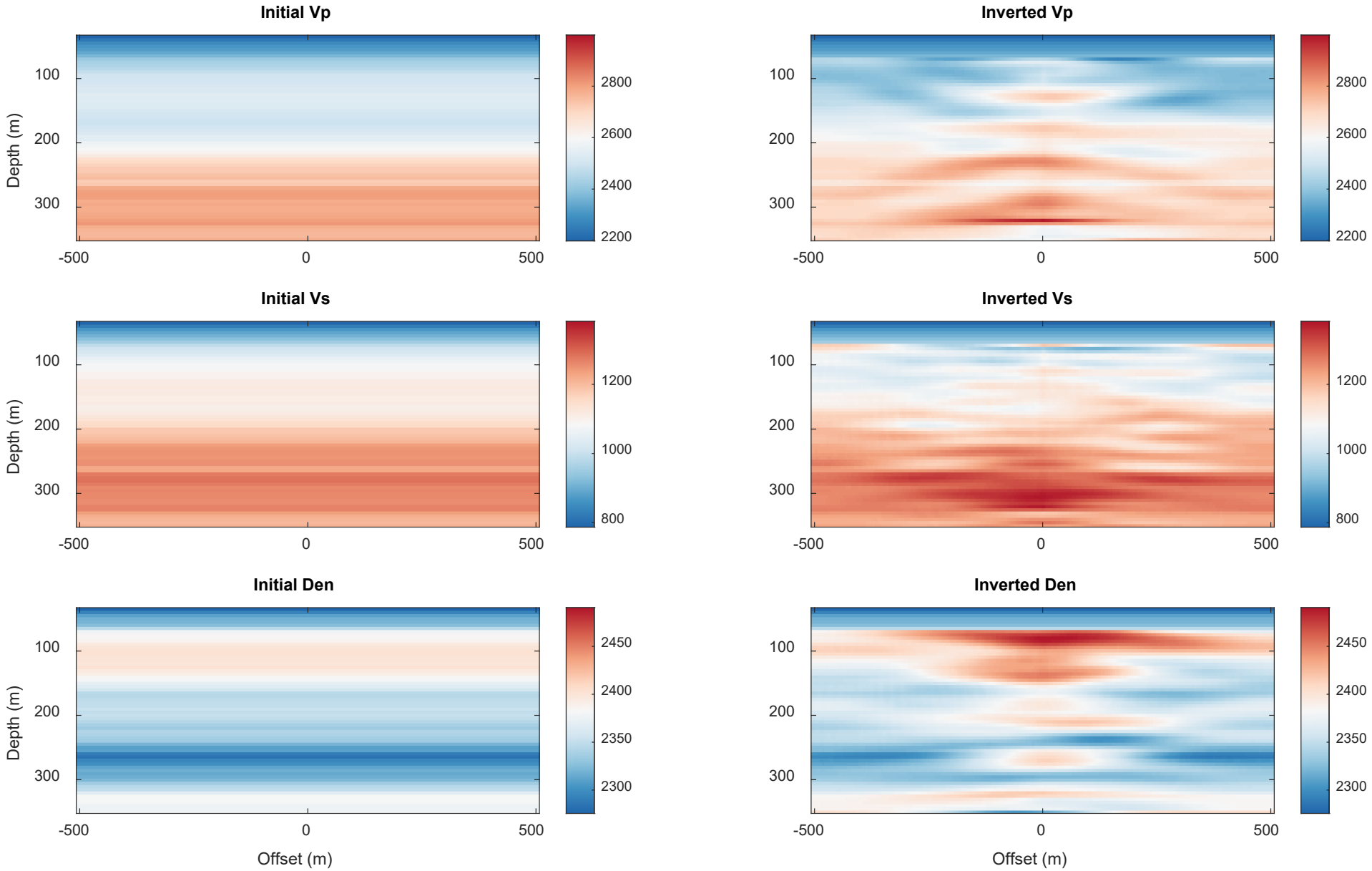
- Towards stable multi-parameter inversion
  - Model Parameterization

$$\mathbf{m}' = \log\left(\frac{\mathbf{m} - m_{\min}}{m_{\max} - \mathbf{m}}\right)$$

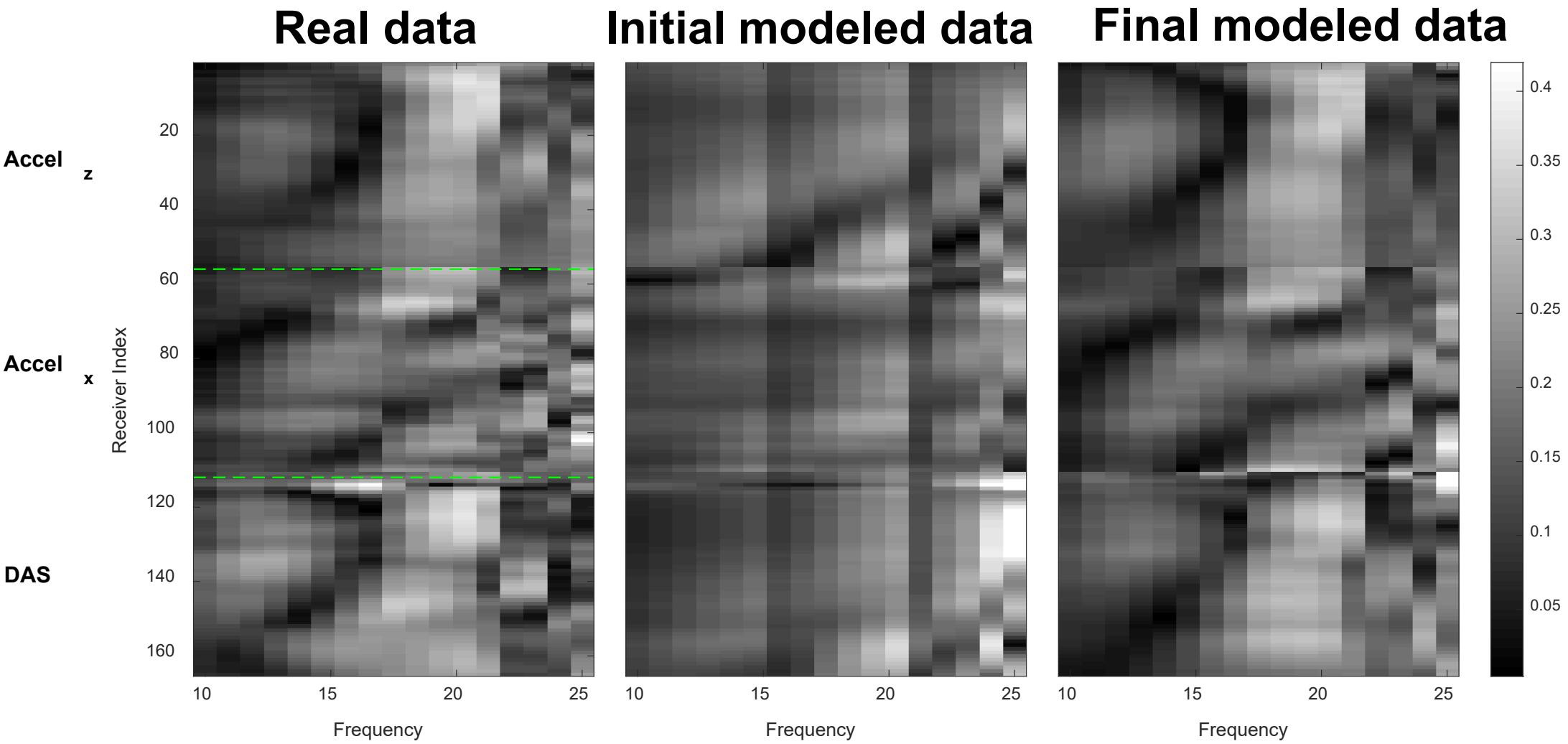
  - Model constraint

$$E = E_d + \lambda \left\| \mathbf{m}_1 - f(\mathbf{m}_2) \right\|_2^2$$

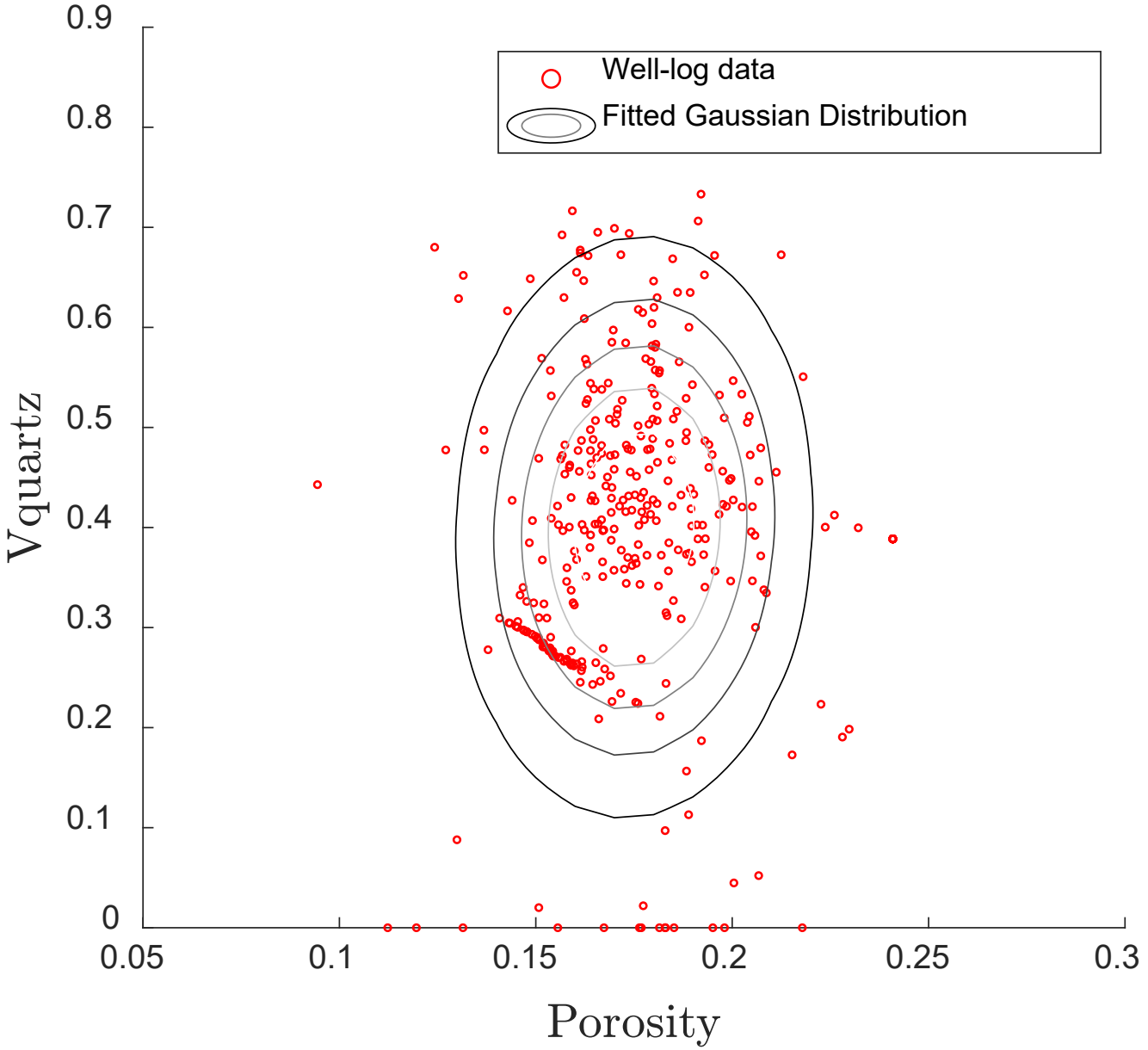
Elastic FWI result

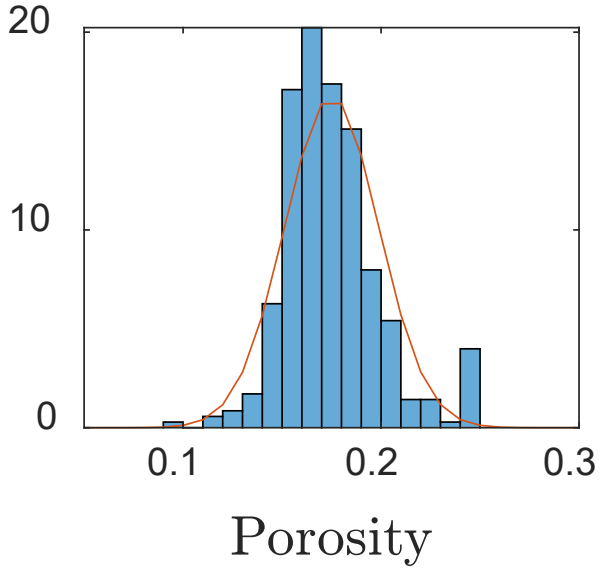


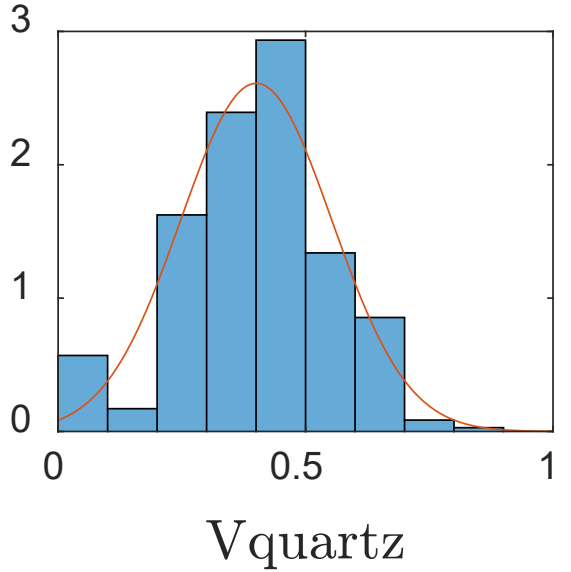
Modeled data



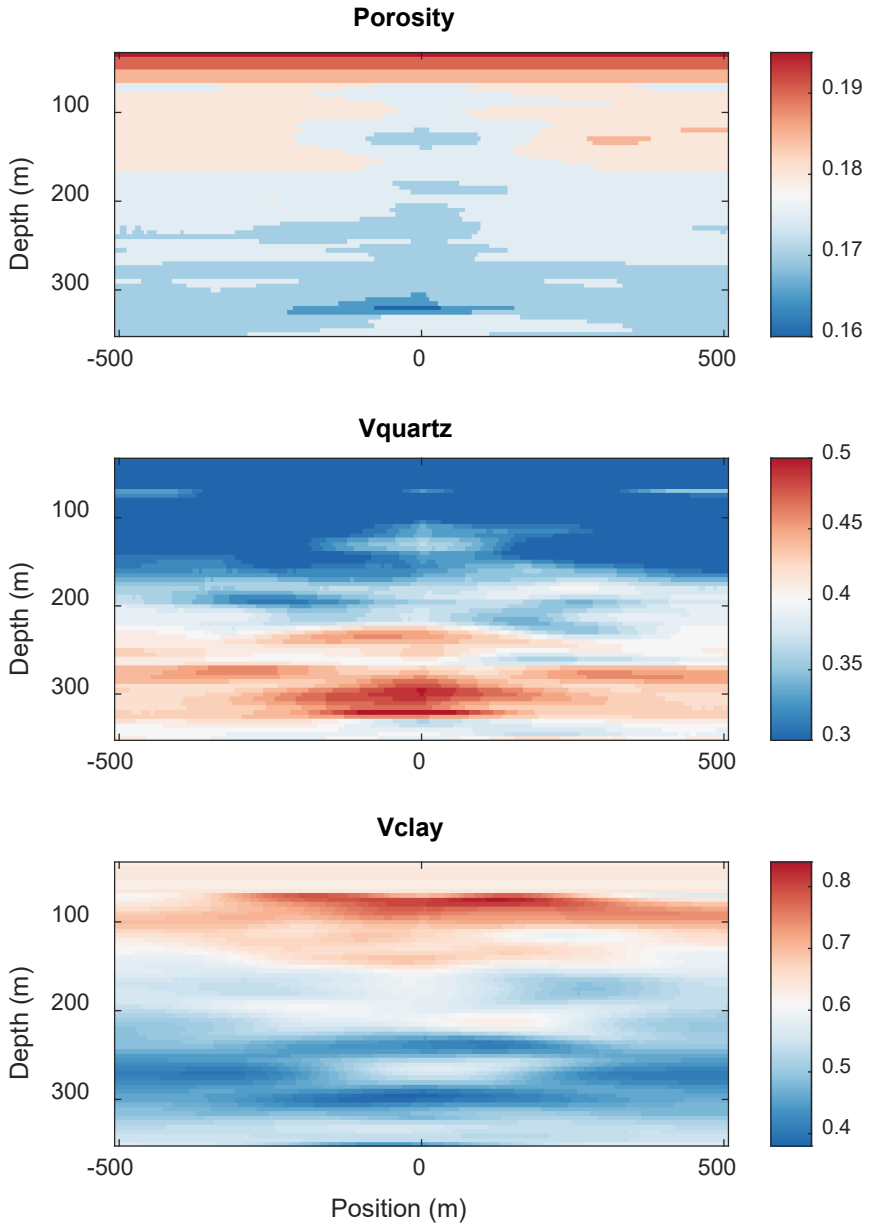
Prior distribution of rock physics variables







Bayesian rock physics inversion



Direct FWI updating of rock properties

- **General problem**

f: Wave equation

g: rock-physics model

$$\mathbf{d} = f(\mathbf{m}_e) + \mathbf{n} = f(g(\mathbf{m}_r)) + \mathbf{n}$$

$\mathbf{m}_e$: Elastic properties

$\mathbf{m}_r$: Reservoir properties

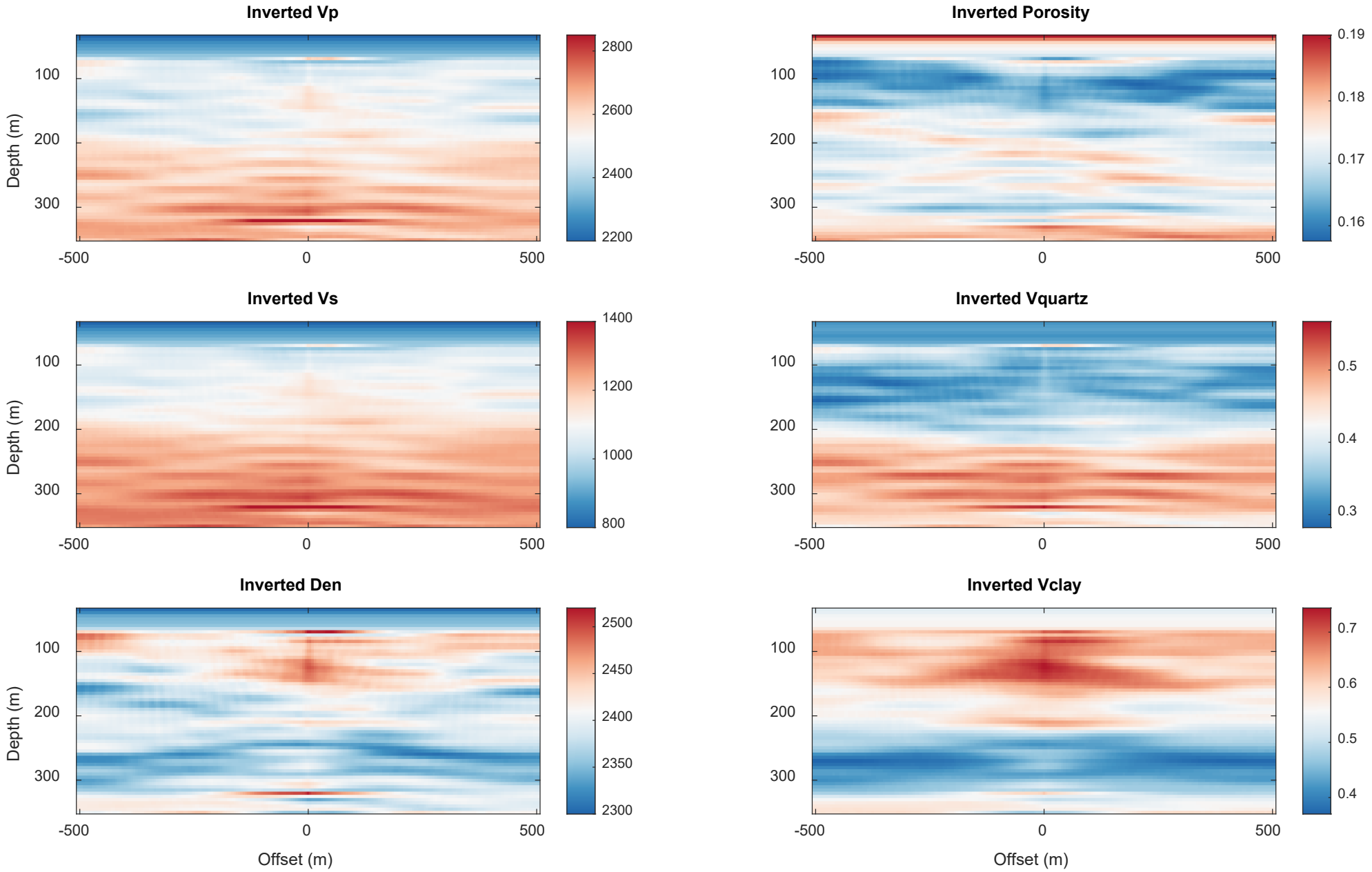
- **FWI incorporating rock physics model**

$$\frac{\partial \mathbf{A}}{\partial r_i} = \frac{\partial \mathbf{A}}{\partial e_1}\frac{\partial e_1}{\partial r_i} + \frac{\partial \mathbf{A}}{\partial e_2}\frac{\partial e_2}{\partial r_i} + \frac{\partial \mathbf{A}}{\partial e_3}\frac{\partial e_3}{\partial r_i},$$

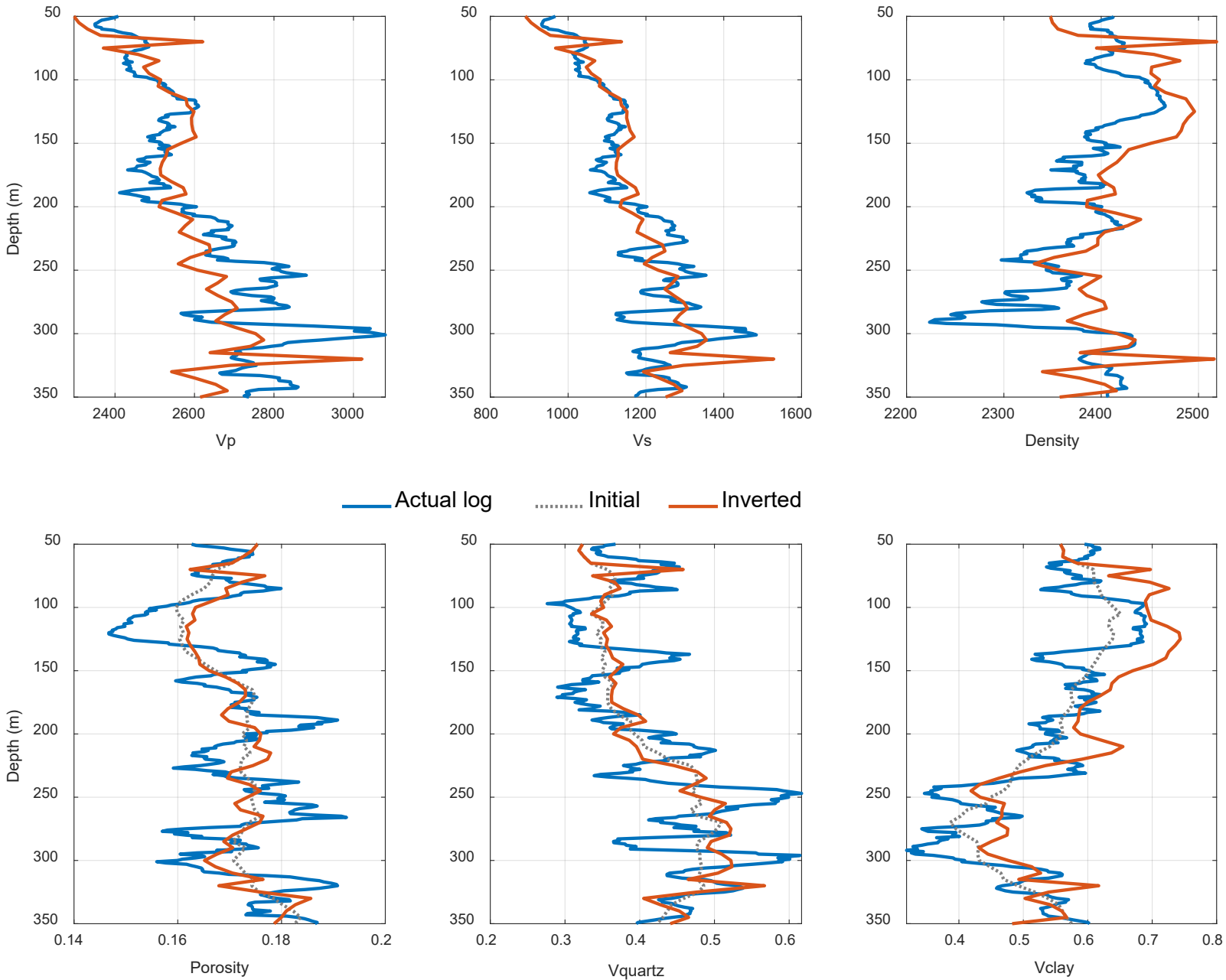
(Hu et al, 2021)

$$(e_1, e_2, e_3) = g(r_1, r_2, ..., r_N)$$

Recovered model



Model profiles



Summary

- We focus on using the technology of full-waveform inversion (FWI) to reconstruct elastic and reservoir property models from the 2018 CMC VSP survey

- The reconstructed baseline models, if verified, can be used to support further time-lapse analysis, e.g., reduce the uncertainty in predicting CO_2 distribution during injection and migration

Acknowledgements

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