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Time-lapse FWI prediction of CO_2 saturation and pore pressure

Qi Hu* and Kris Innanen
qi.hu1@ucalgary.ca

Abstract

We propose a complete rock physics workflow combing Macbeth's model and Gassmann's equations to predict elastic properties as a function of porosity, mineralogy, saturation and pressure. We validate this workflow using a published dataset. In particular, we demonstrate the advantages of Macbeth's model in predicting the effect of pressure changes. Furthermore, we propose a full waveform inversion (FWI) algorithm incorporating the proposed model for the prediction of the time-evolution of CO_2 saturation and pore pressure. We derive static rock properties, such as porosity and clay content, from baseline data and use them as input to predict dynamic reservoir properties (saturation and pressure) from monitor data. We illustrate the potential of the approach using a synthetic time-lapse dataset.

Considerations for rock physics model

Definition of pressure

$$P_e = P_c - \eta P_p, \quad P_c = g\int_0^z \rho(z')dz', \quad P_p = \rho_w g z, \qquad (1)$$

MacBeth's model

$$K_{\text{dry}}(P_e) = \frac{K^\infty}{1 + A_K e^{-\frac{P_e}{P_K}}}, \qquad (2)$$

Modified MacBeth's model

$$K_{\text{dry}}(P_e) = \frac{K^\infty}{1 + \frac{K^\infty - K_0}{K_0} e^{-\frac{P_{\text{eff}} - P_0}{P_K}}}; \qquad (3)$$

$$K^\infty = \lambda_1(\phi + aV_{\text{clay}}) + \lambda_2,$$

Gassmann's equation

$$K_{\text{sat}}(S_{co_2}, P_p) = K_{\text{dry}}(P_p) + \frac{[1 - K_{\text{dry}}(P_p)/K_m]^2}{\phi/K_f(S_{co_2}, P_p) + (1-\phi)/K_m - K_{\text{dry}}(P_p)/K_m^2},$$

$$\mu_{\text{sat}}(P_p) = \mu_{\text{dry}}(P_p),$$

$$\rho_{\text{sat}}(S_{co_2}, P_p) = (1-\phi)\rho_m + \phi\rho_f(S_{co_2}, P_p), \qquad (4)$$

Steps of rock physics modeling

Solid phase:	$K_m = f(K_q, K_c, V_{\text{clay}})$	Voigt-Reuss-Hill
Fluid phase:	$K_{\text{co2,w}} = f(T, P_p)$	Baztle-Wang
	$K_f = f(K_{\text{co2}}, K_w, S_{\text{co2}})$	Brie
Dry rock:	$K_{\text{dry}}(P_0) = f(K_m, \phi, P_0)$	Hertz-Mindlin
	$K_{\text{dry}}(P_{\text{eff}}) = K_{\text{dry}}(P_0) + f(P_{\text{eff}} - P_0)$	MacBeth
Saturated rock:	$K_{\text{sat}} = f(K_m, K_f, K_{\text{dry}}, \phi)$	Gassmann
➡	$(V_P, V_S, \rho) = f(\phi, V_{\text{clay}}, S_{\text{co2}}, P_p)$	

Fig. 1: Complete rock physics workflow.

Model Calibration

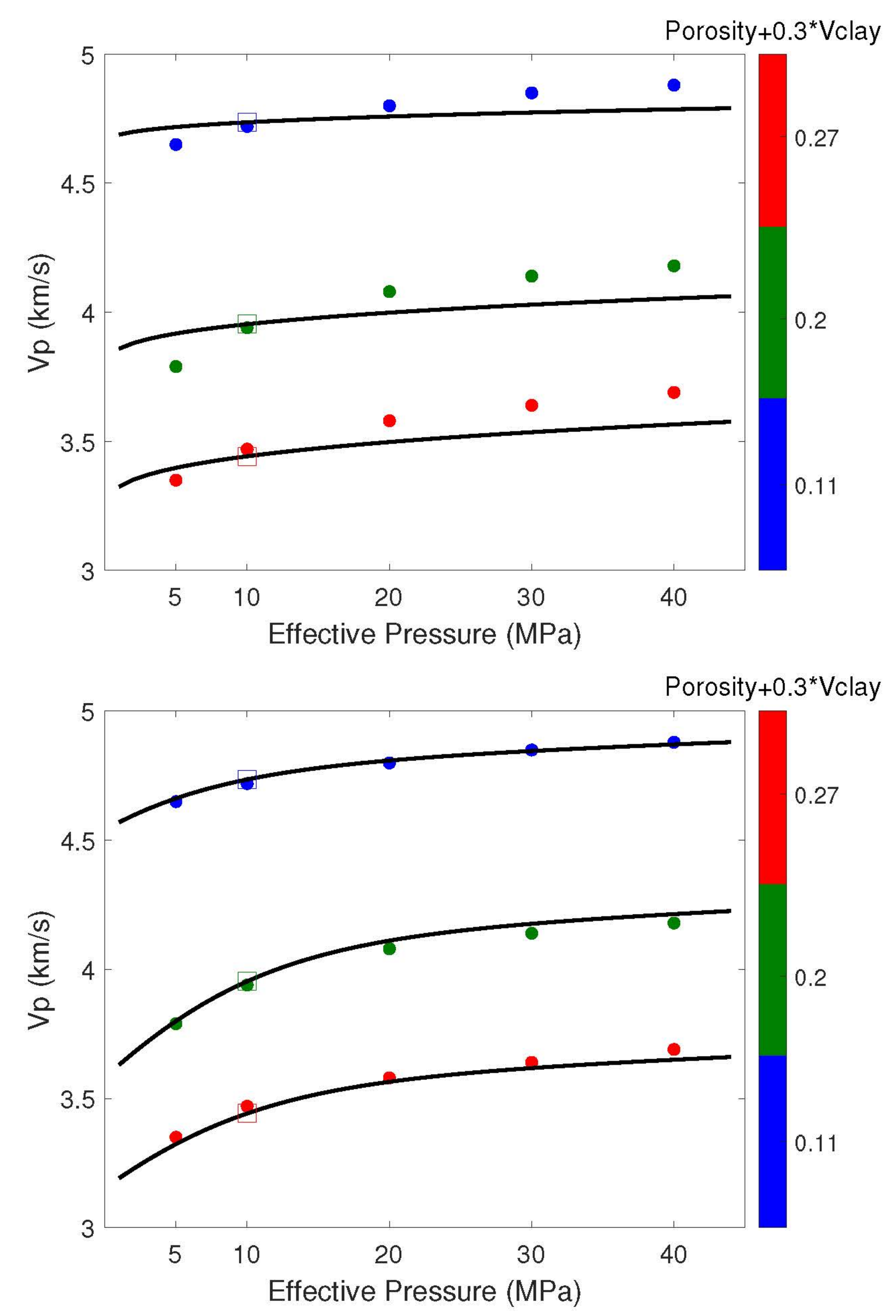
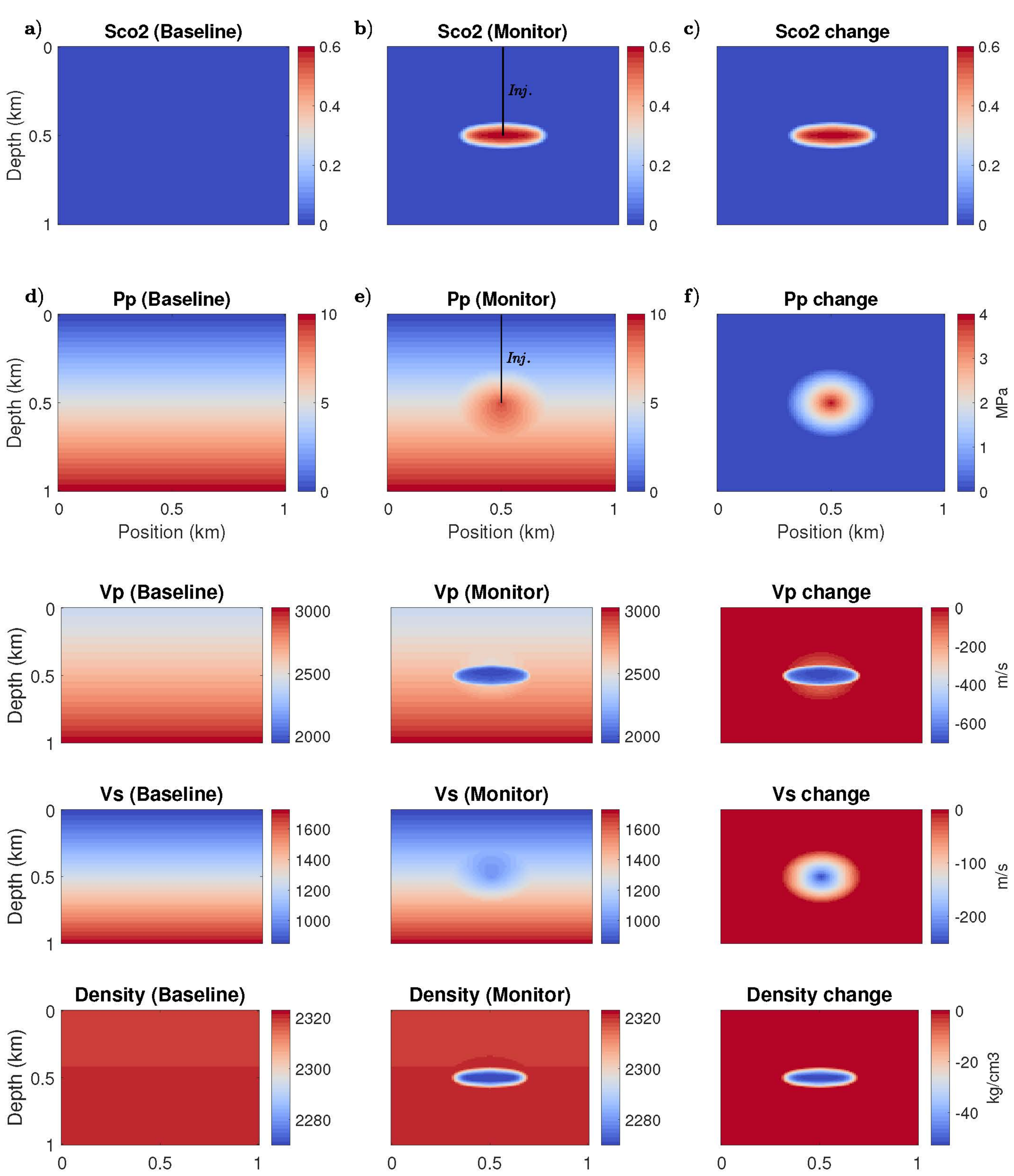


Fig. 2: Hertz- Mindlin model VS Macbeth's model.

Numerical example



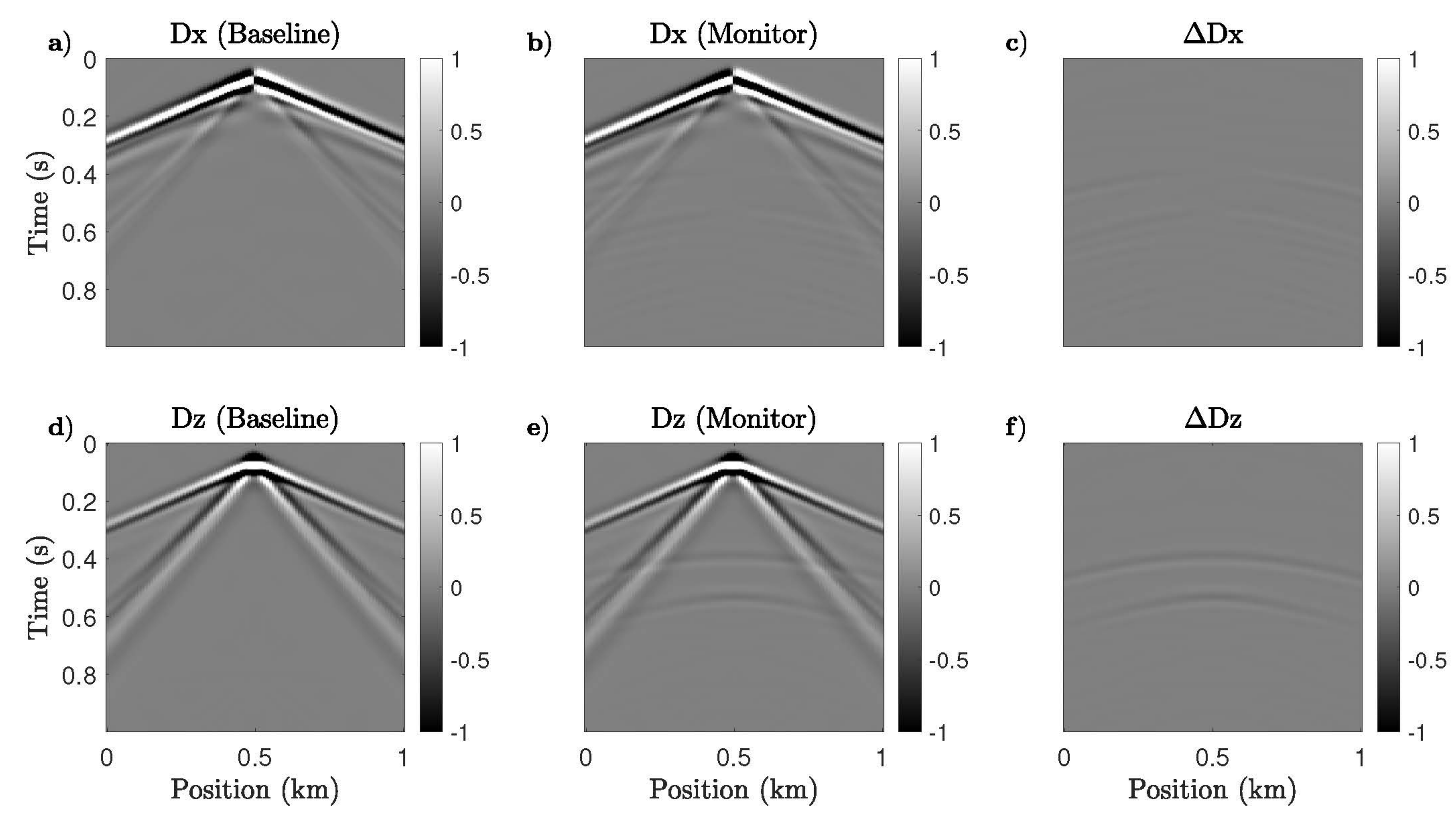


Fig. 4: Baseline, monitor, and differential seismograms.

Results

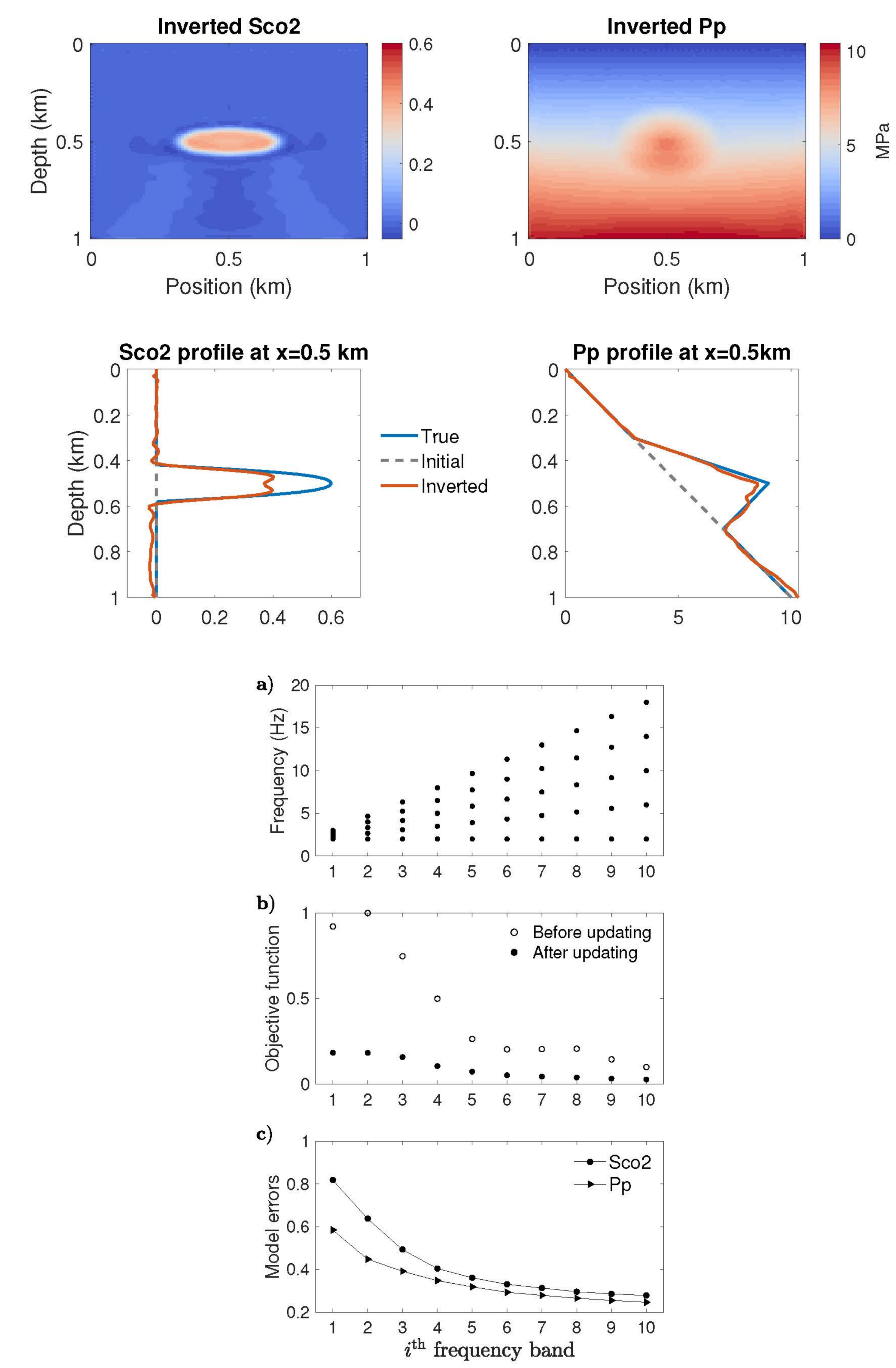


Fig. 5: Recovered model + Convergence properties

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UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience