Practical multiparameter elastic FWI

robust sensitivities, **a land / reservoir example**, laboratory expansion plans

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Acknowledgments

CREWES industrial sponsors

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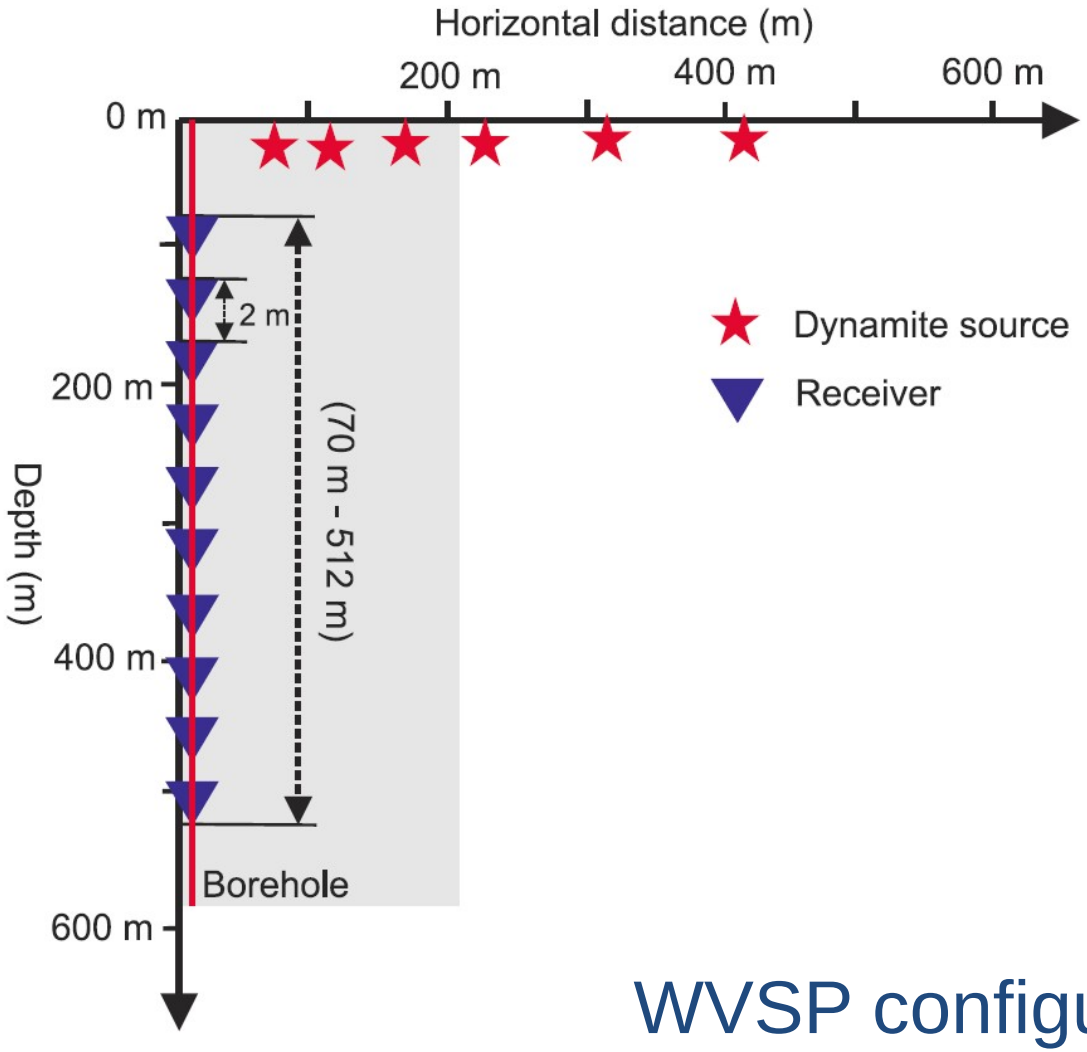
Anonymous company for W-VSP dataset

Elastic FWI on 3C-WVSP data

applied in unconventional reservoir setting

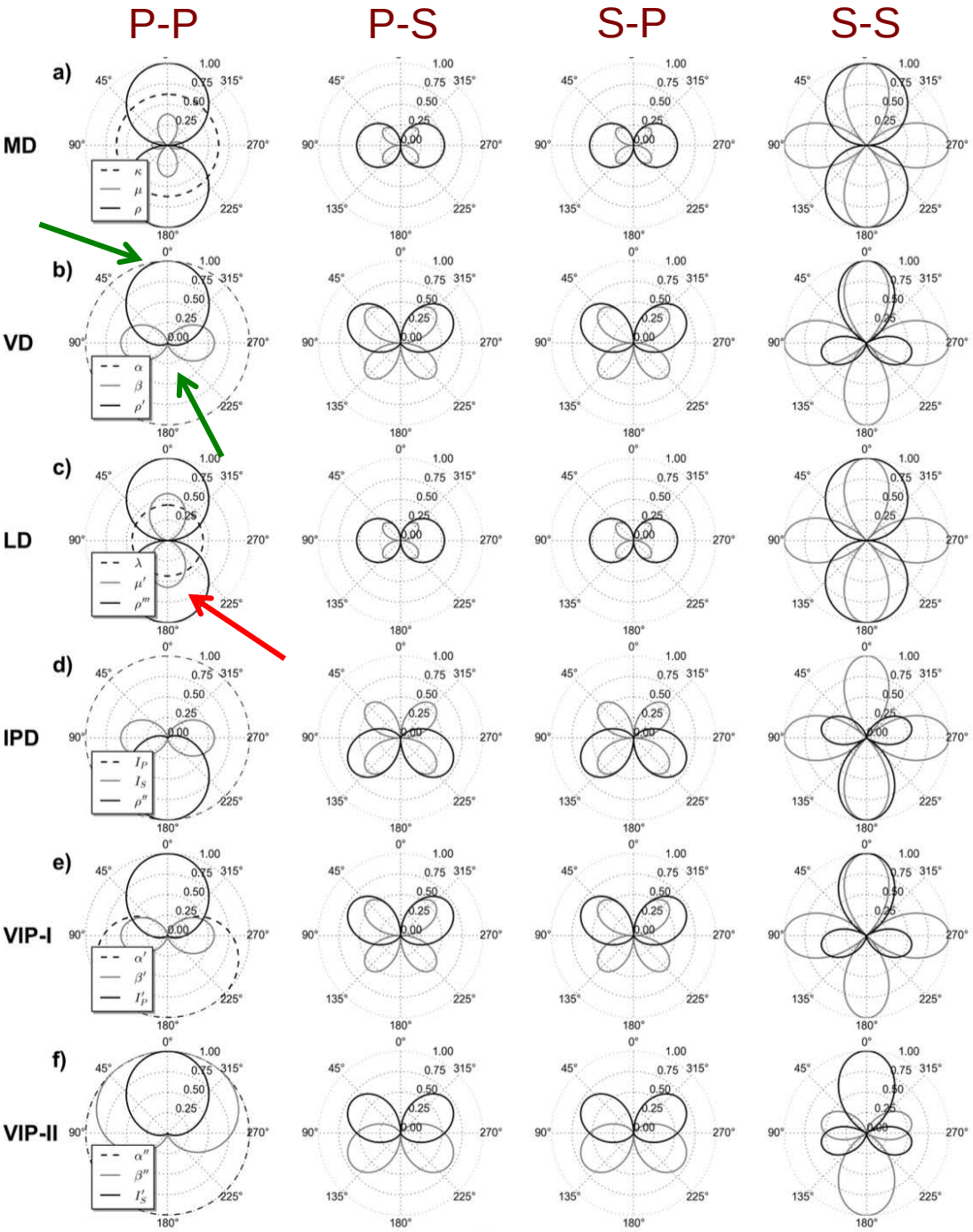
- **Parameterization analysis** critical; based on scattering radiation patterns & “contamination kernels”
- **Six isotropic-elastic parameterizations** are considered in the W-VSP configuration
- **Velocity / density** outcompetes others in most measures
- **Field data analysis** largely bears out predictions
- Setting: **unconventional (heavy oil) land reservoir**: examine geological interpretability of Poisson’s ratio, V_P/V_S ratio model constructions

Elastic FWI on 3C-WVSP data



WVSP configuration

Scattering patterns



modulus/density

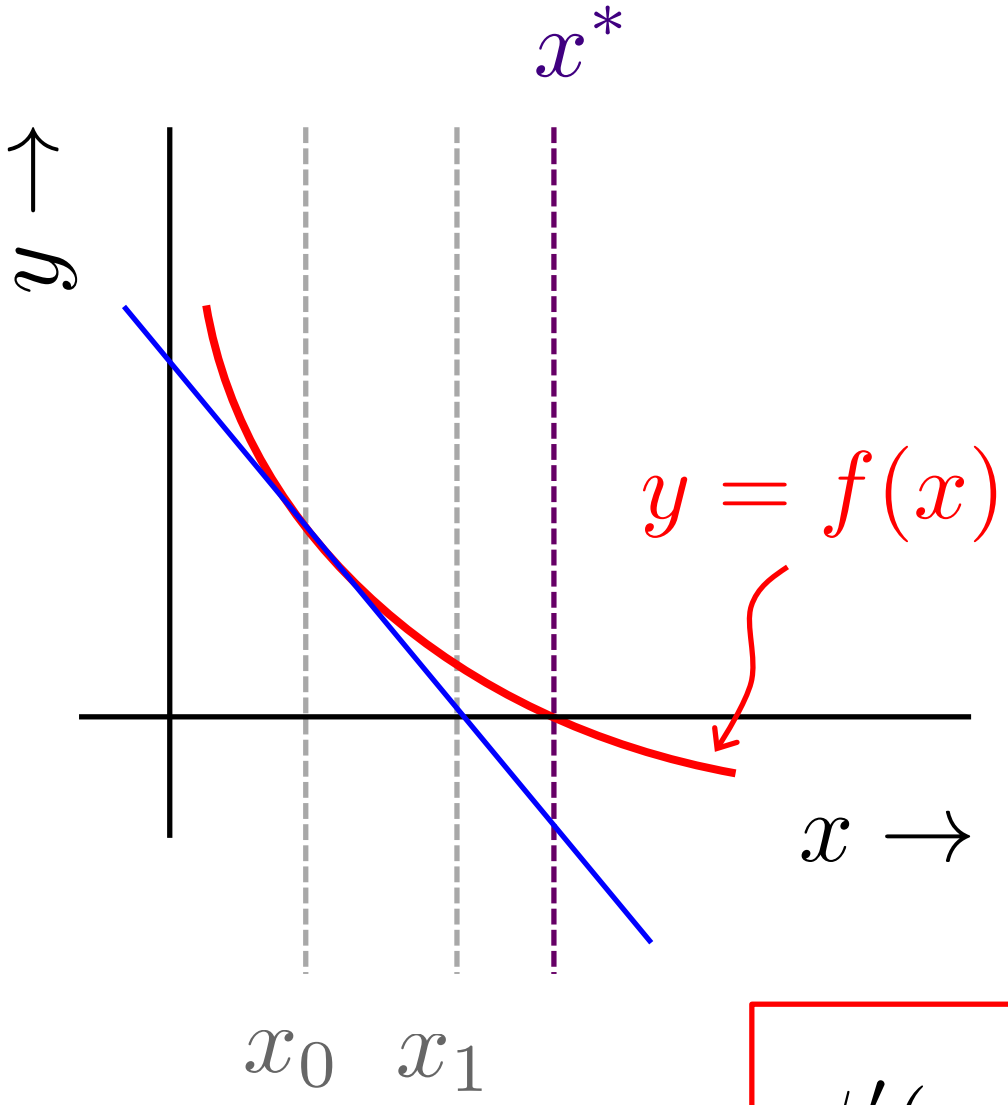
velocity/density

Lamé /density

impedance / density

velocity /impedance I

velocity / impedance II



$$\Delta x_0 = -\frac{f(x_0)}{f'(x_0)}$$

Newton system

$$\Delta x_0 = -\frac{\phi'(x_0)}{\phi''(x_0)}$$

$$\phi'(x_0) = -\phi''(x_0)\Delta x_0$$

steepest descent update

Newton system:

Hessian

Newton update

$$\mathbf{g} = -\mathbf{H}\Delta\mathbf{m}$$

...with multiple parameters:

$$\begin{bmatrix} \mathbf{g}_\alpha \\ \mathbf{g}_\beta \\ \mathbf{g}_\rho \end{bmatrix} = - \begin{bmatrix} \mathbf{H}_{\alpha\alpha} & \mathbf{H}_{\alpha\beta} & \mathbf{H}_{\alpha\rho} \\ \mathbf{H}_{\beta\alpha} & \mathbf{H}_{\beta\beta} & \mathbf{H}_{\beta\rho} \\ \mathbf{H}_{\rho\alpha} & \mathbf{H}_{\rho\beta} & \mathbf{H}_{\rho\rho} \end{bmatrix} \begin{bmatrix} \Delta\mathbf{m}_\alpha \\ \Delta\mathbf{m}_\beta \\ \Delta\mathbf{m}_\rho \end{bmatrix}$$

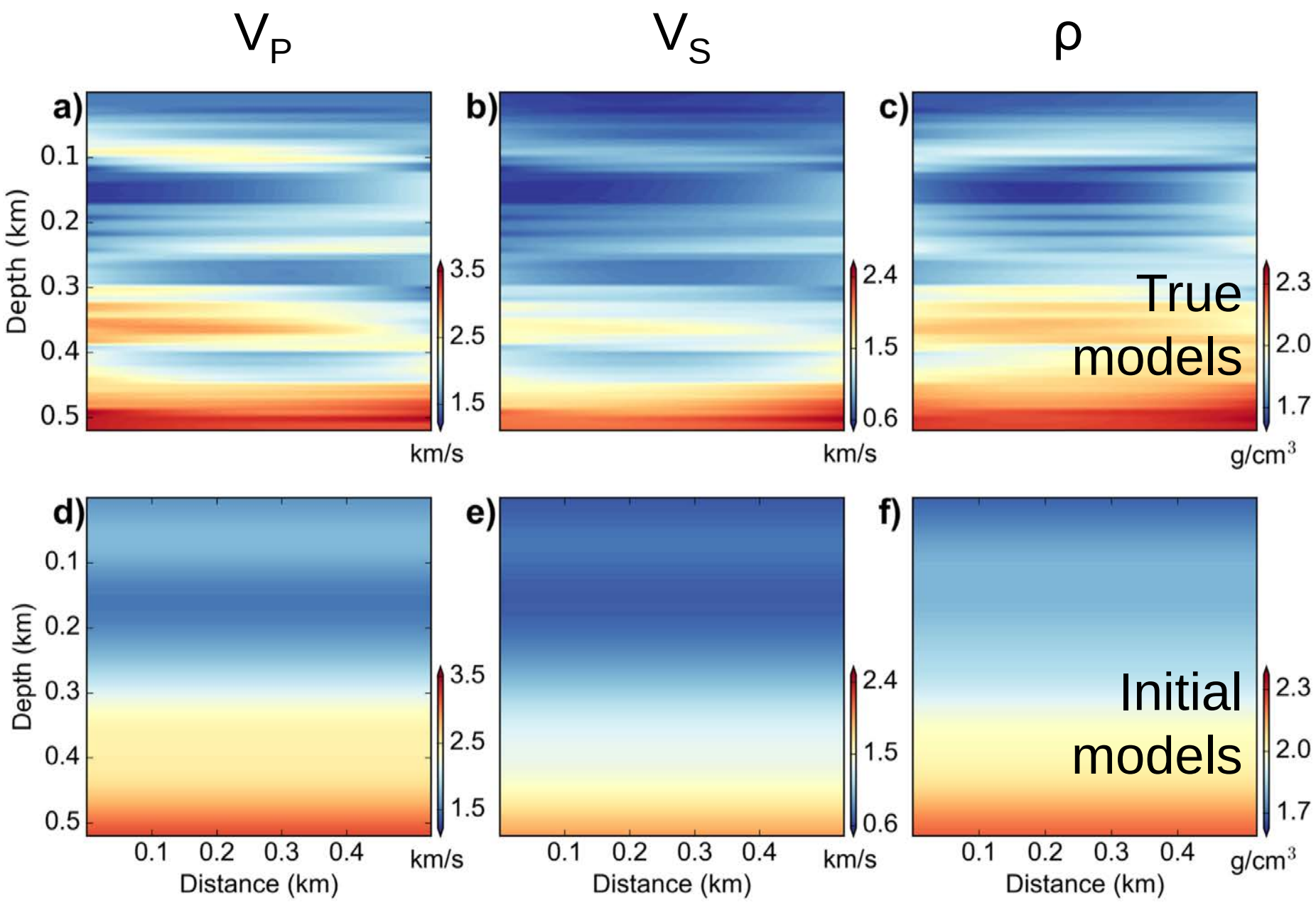
produces a steepest descent update:

$$\mathbf{g}_\alpha = -\mathbf{H}_{\alpha\alpha}\Delta\mathbf{m}_\alpha - \mathbf{H}_{\alpha\beta}\Delta\mathbf{m}_\beta - \mathbf{H}_{\alpha\rho}\Delta\mathbf{m}_\rho$$

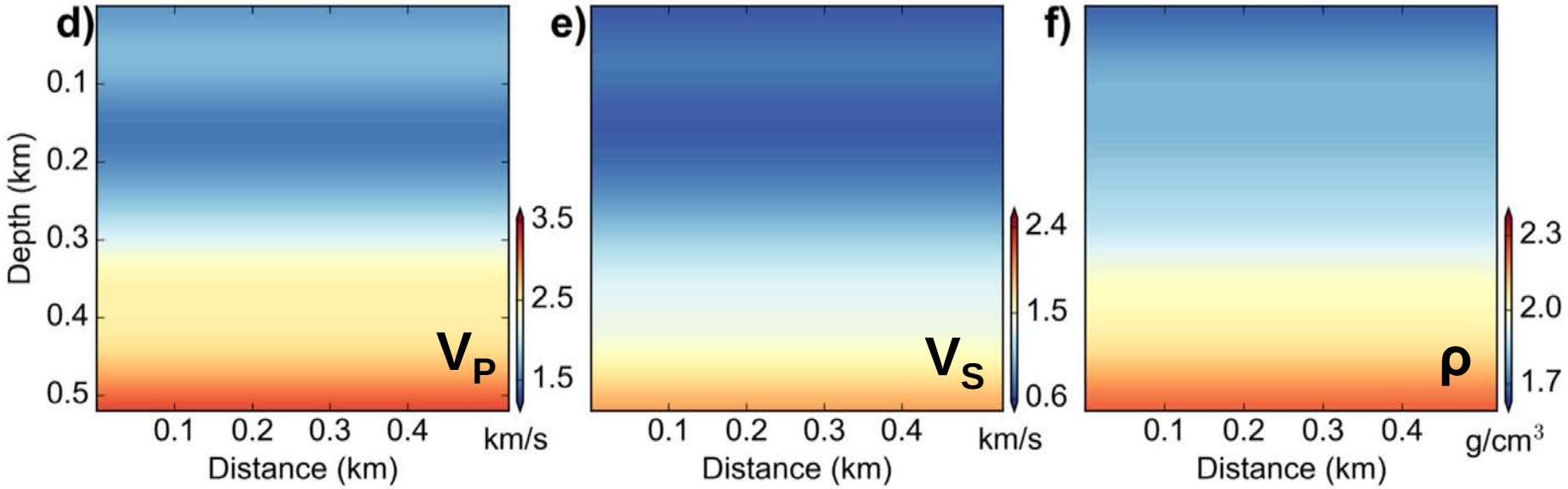
✓ ✗ ✗

‘contamination kernels’

Synthetic analysis

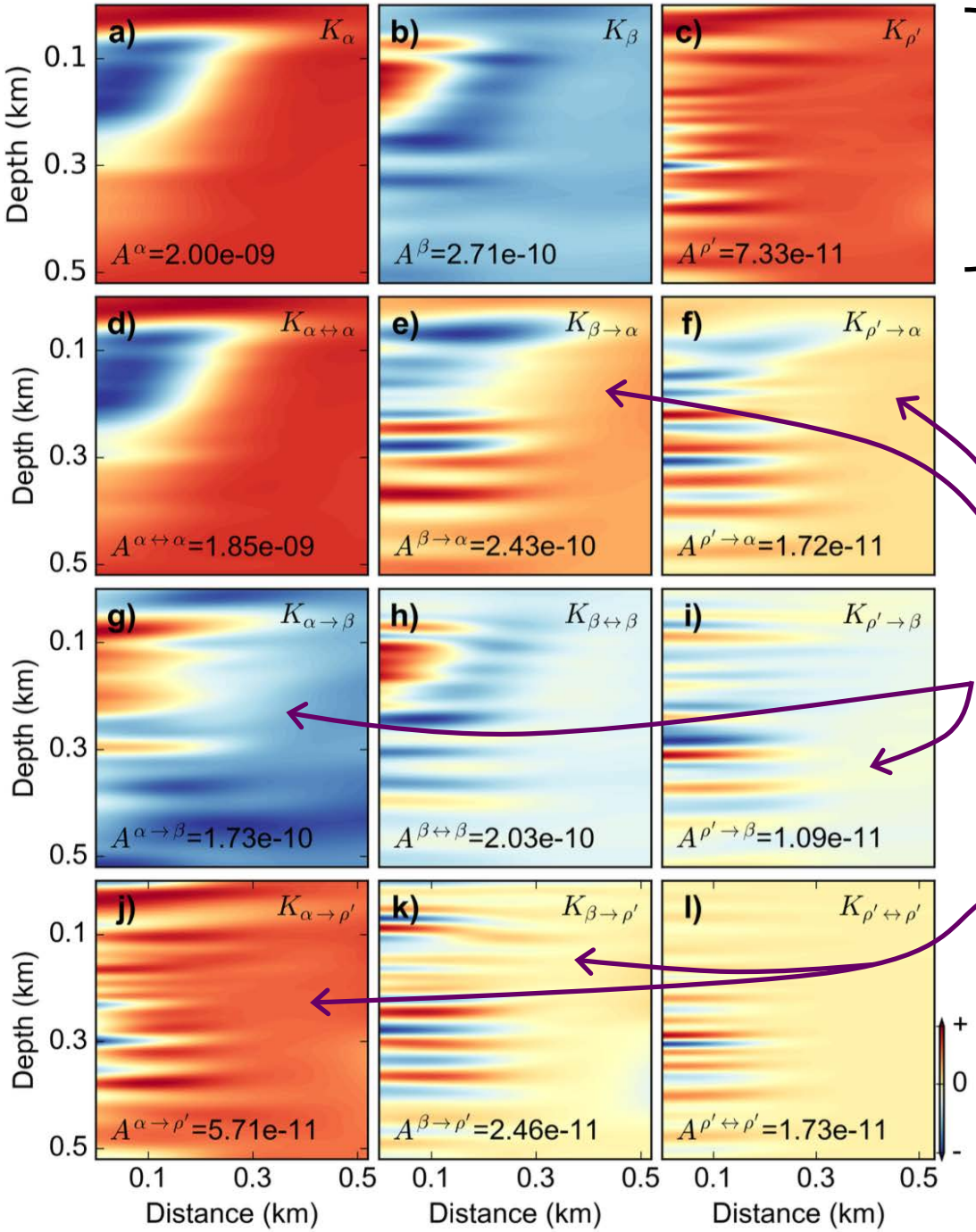


Initial models



Wavelet assumed known

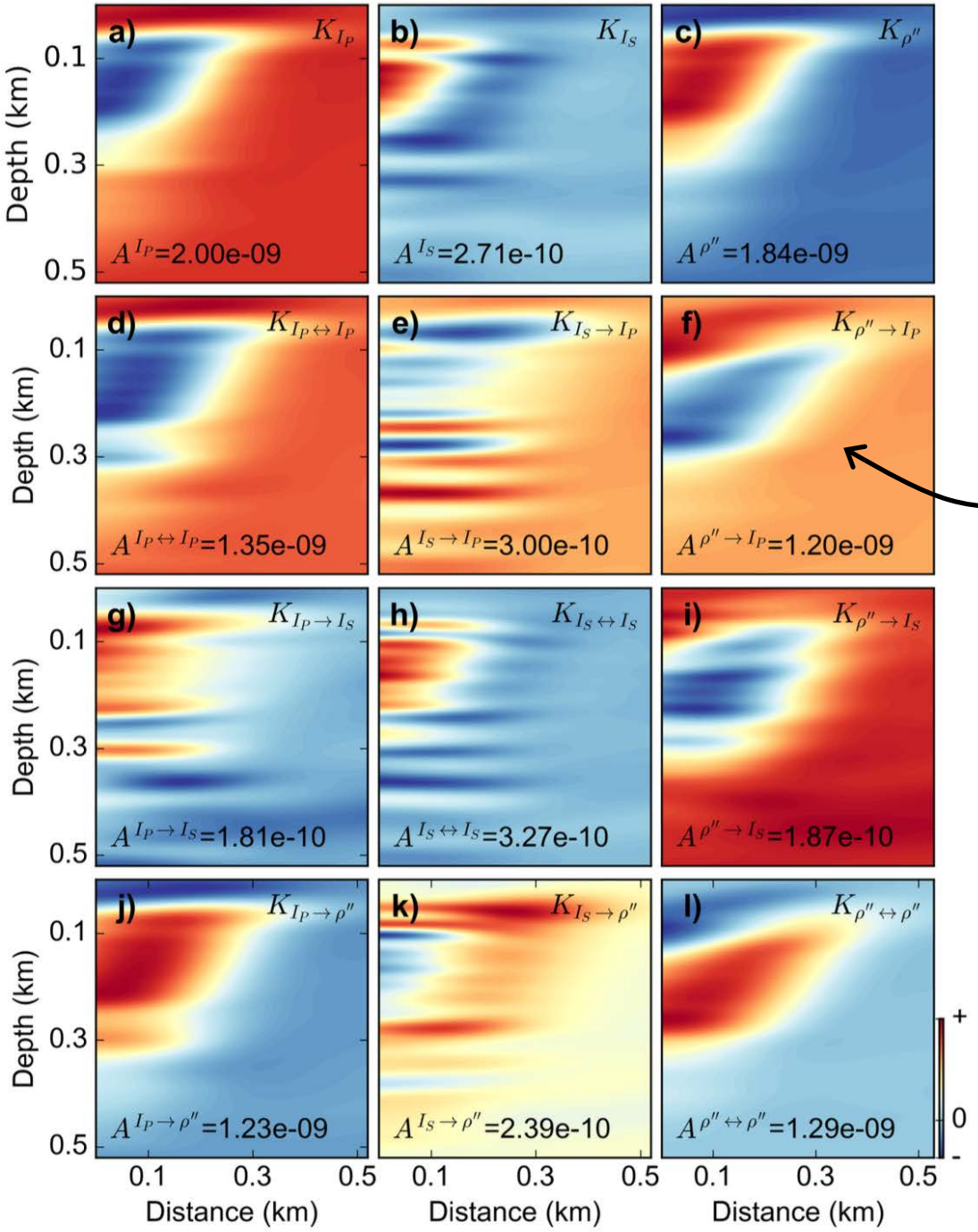
- Nonlinear conjugate gradient updates
- [10,20]Hz, [10,30]Hz, [10,40]Hz, [10,50]Hz
- <= 10 its per band



Total kernels

Contaminating kernels

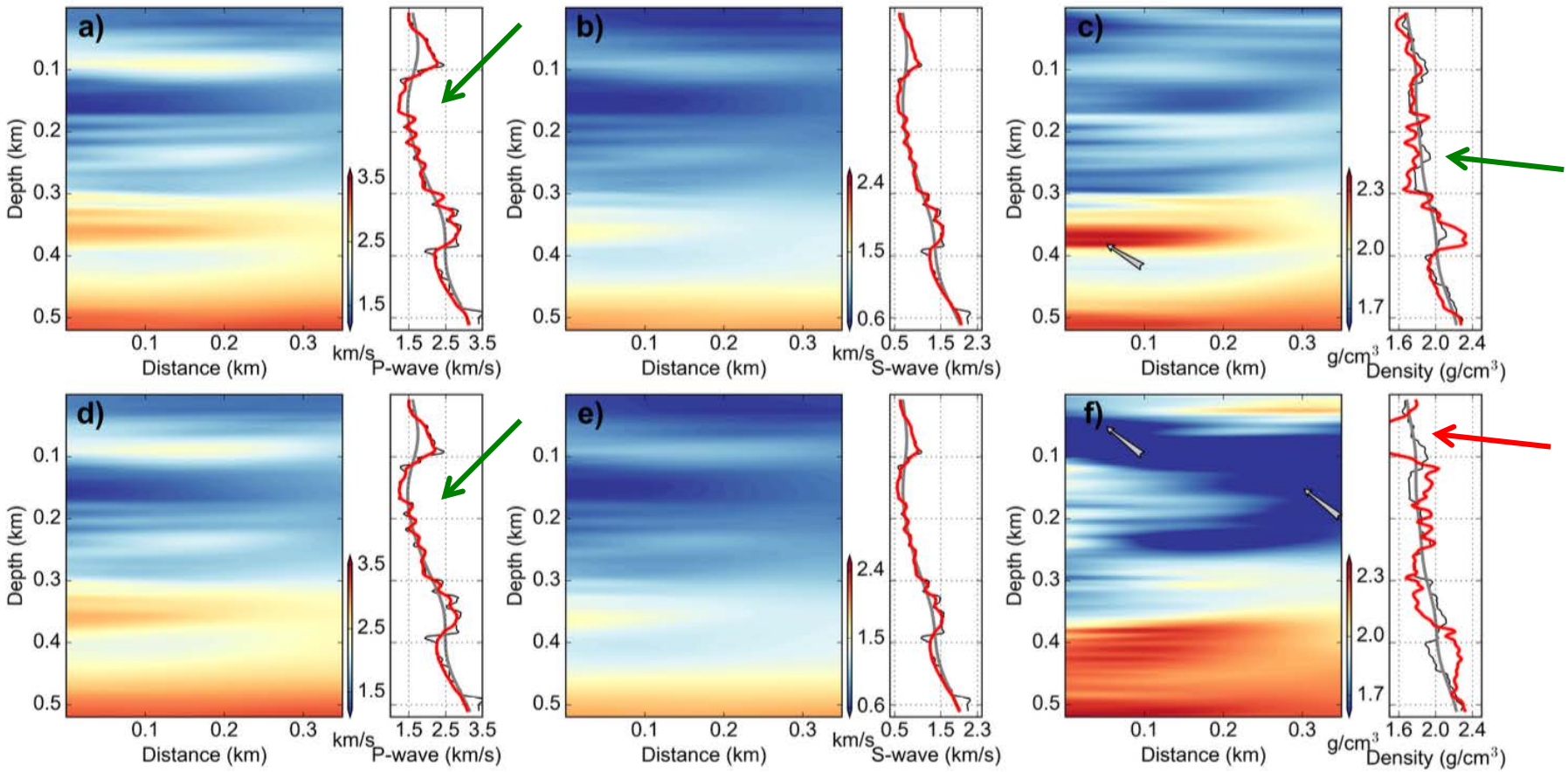
Density / velocity



e.g., strong leakage of ρ into I_P

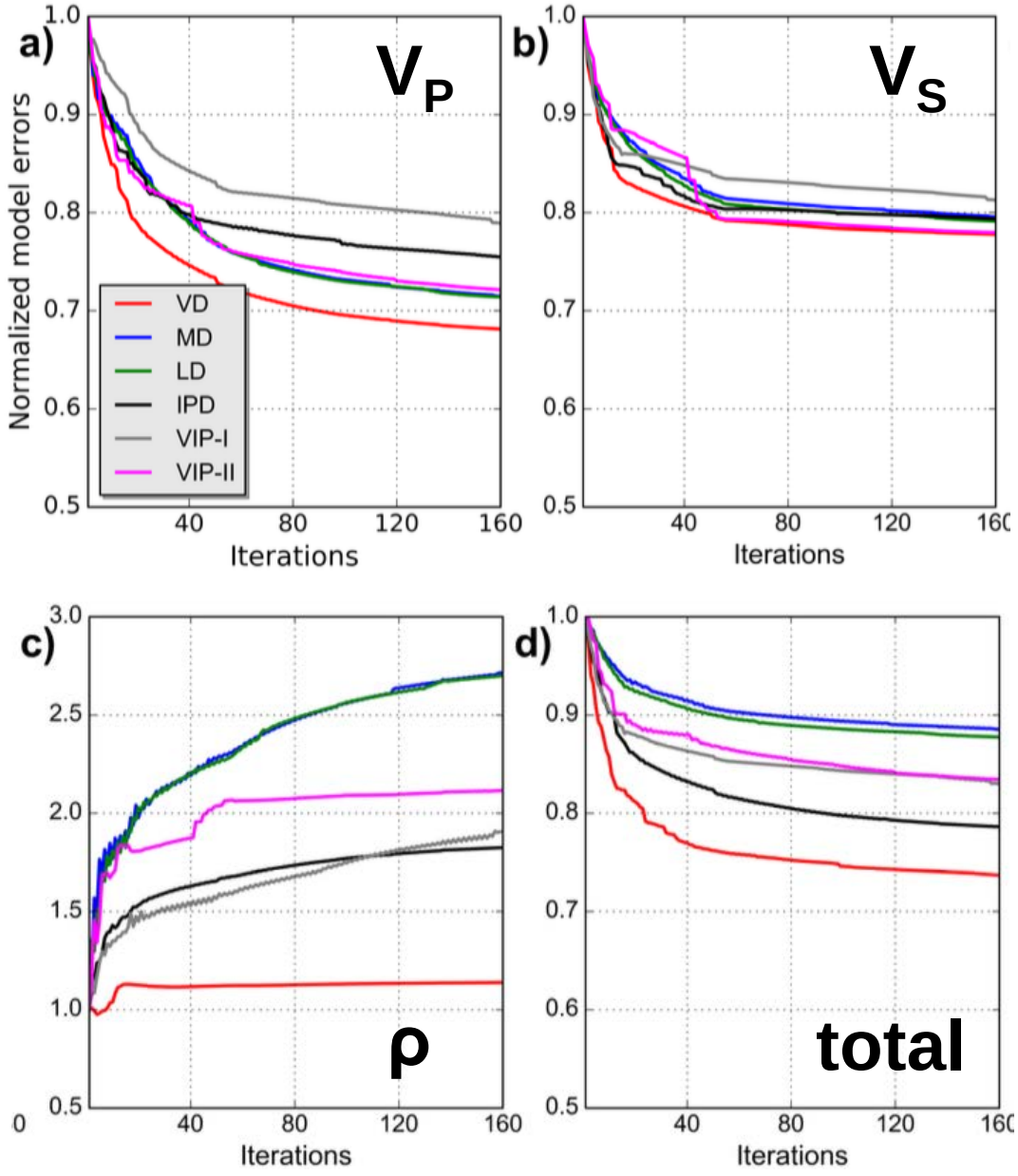
Impedance / density

Density / velocity



Density / modulus

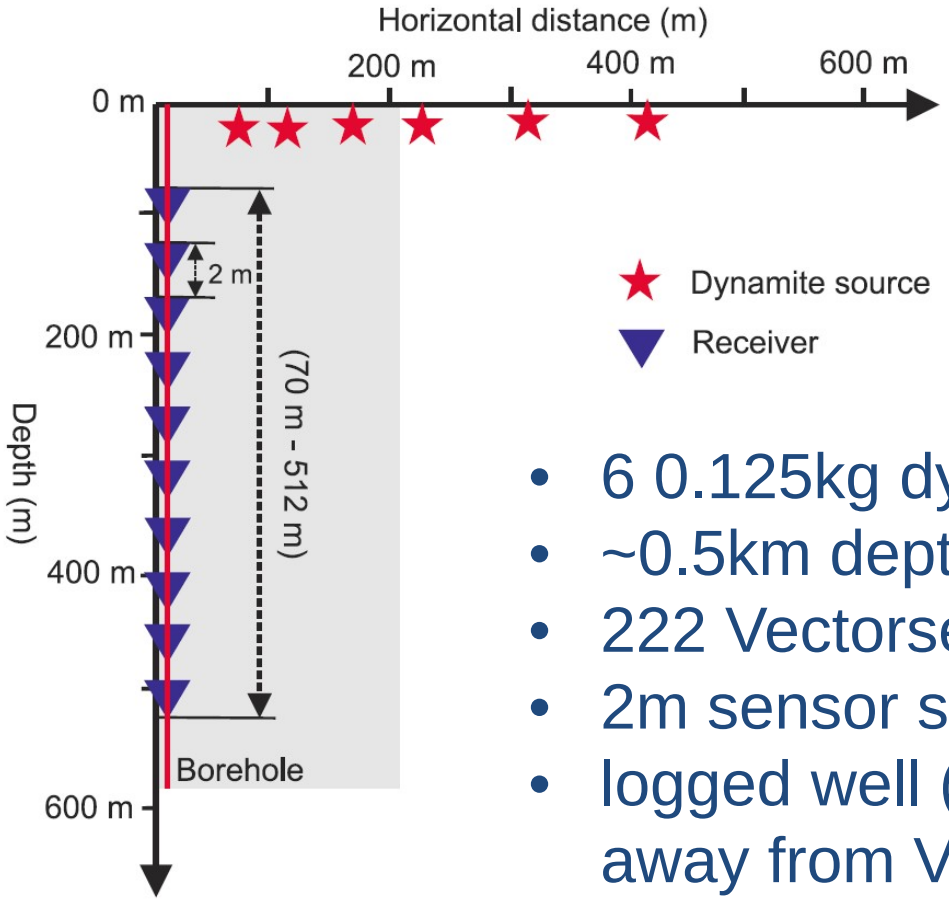
Model Error vs Iteration



← Density / velocity

Elastic FWI on 3C-WVSP data

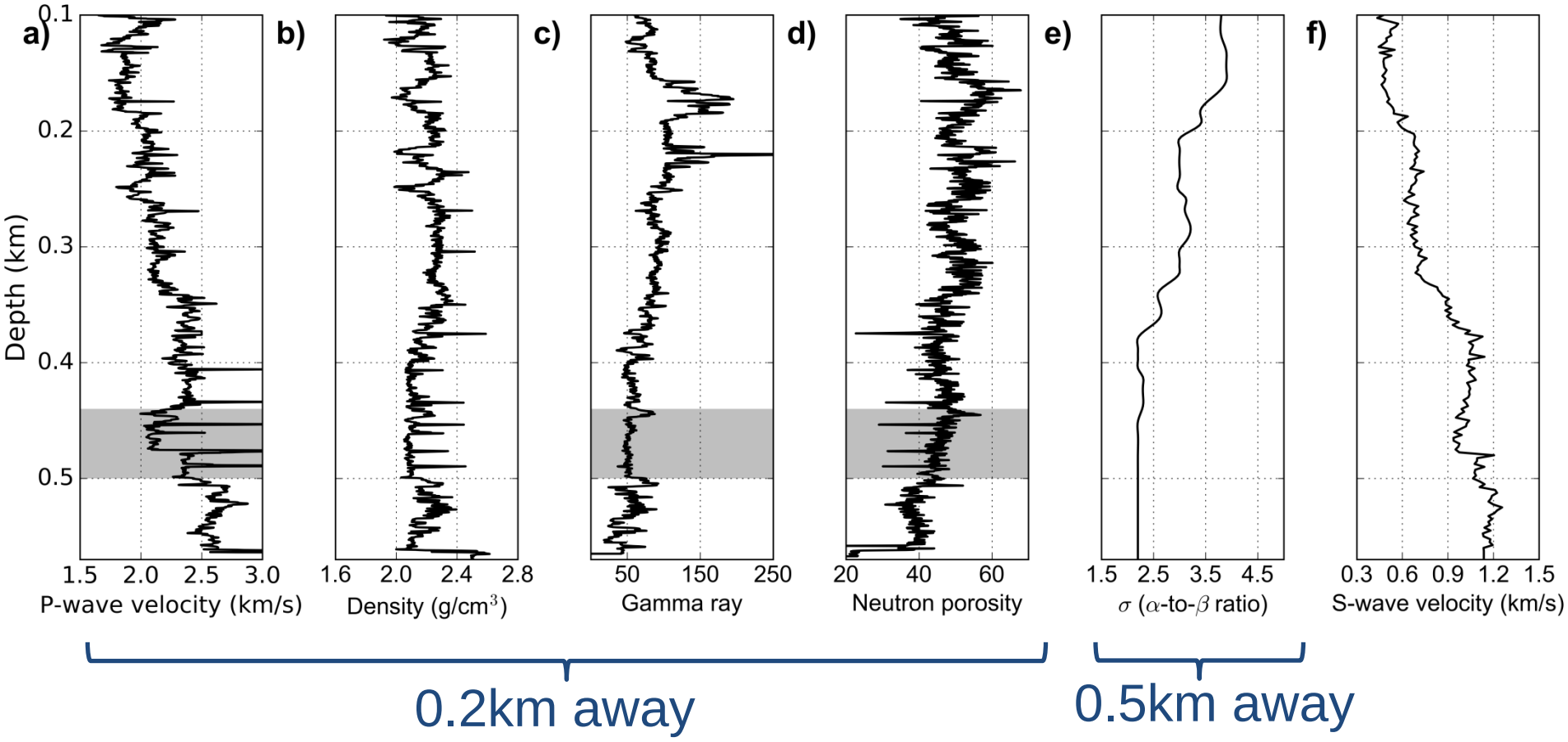
Western Canadian heavy oil reservoir (producing)

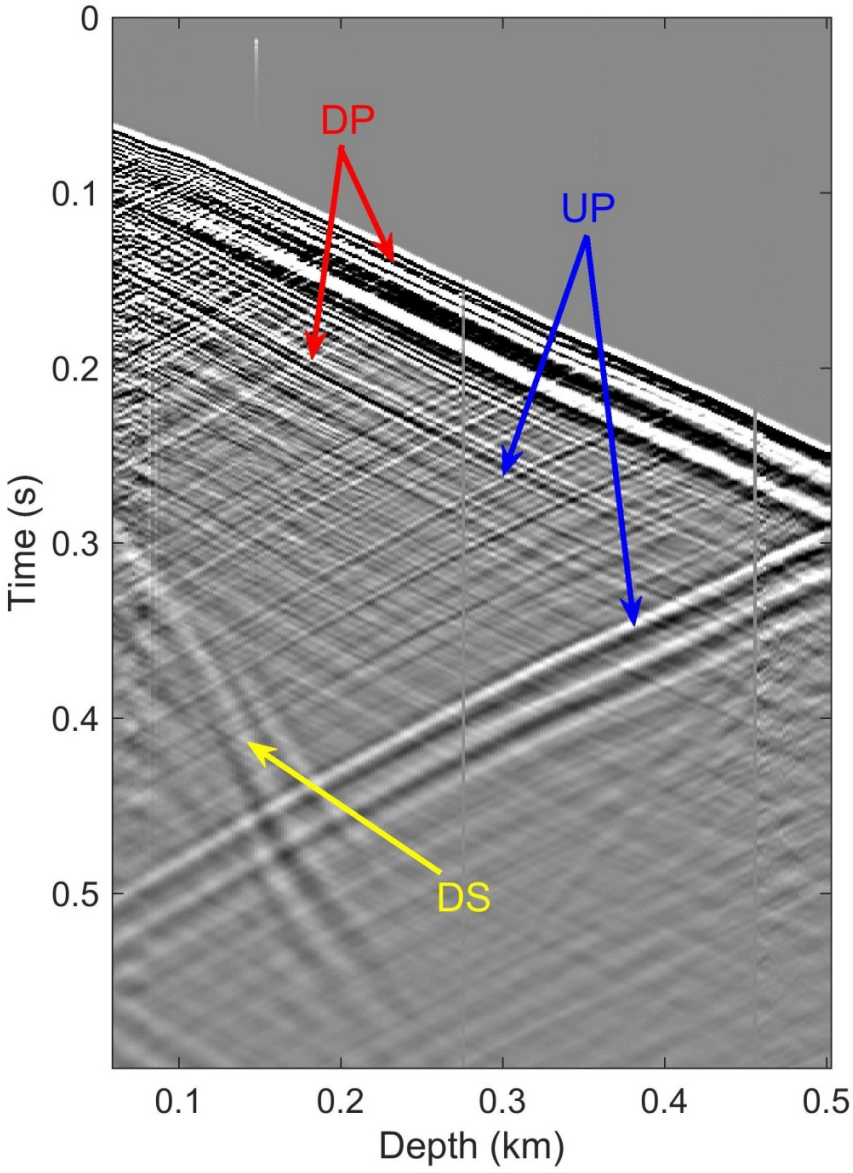


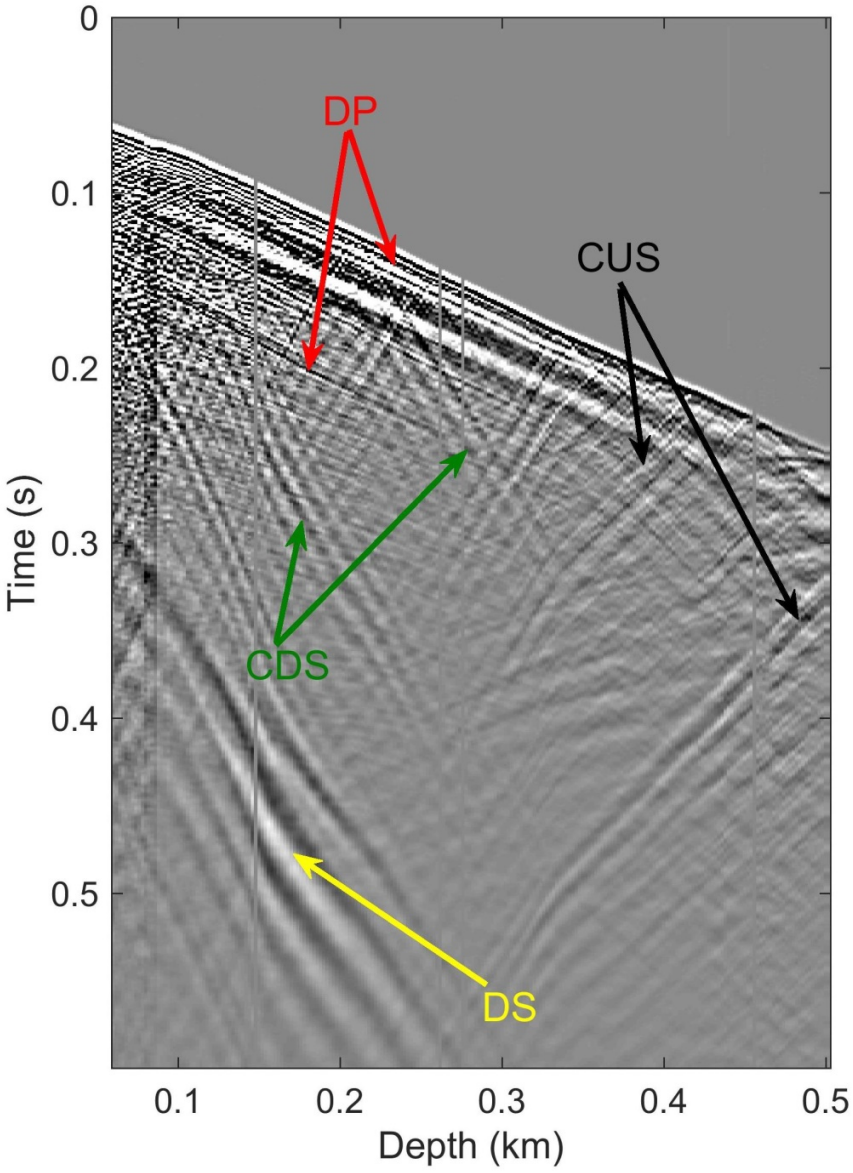
- 6 0.125kg dynamite shots
- ~0.5km depth
- 222 Vectorseis 3C phones
- 2m sensor spacing
- logged well (V_P) 0.2km away from VSP borehole

Elastic FWI on 3C-WVSP data

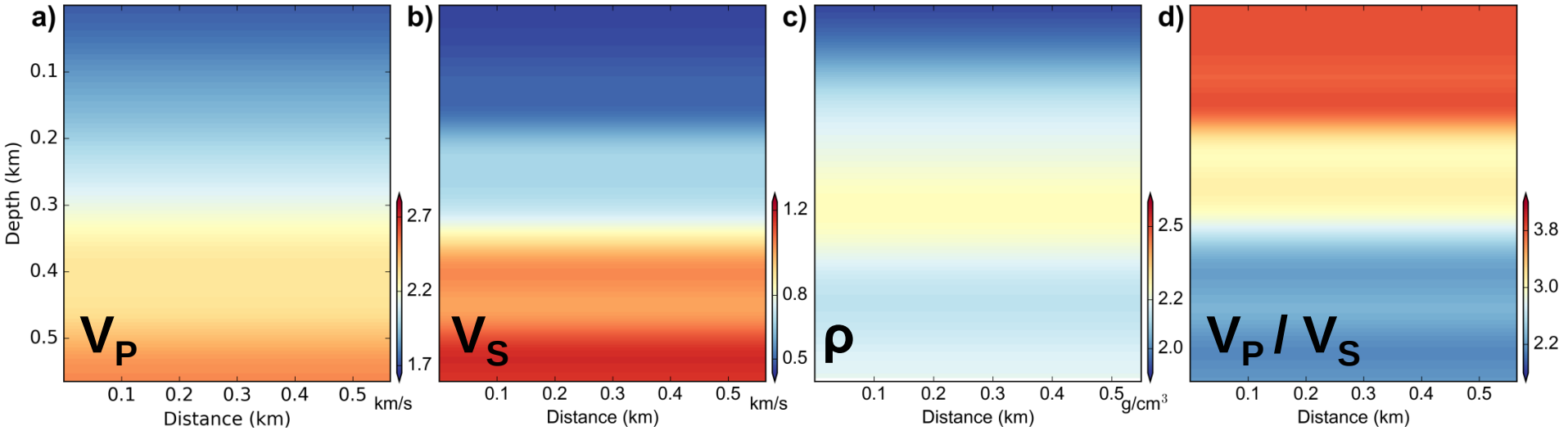
Western Canadian heavy oil reservoir (producing)

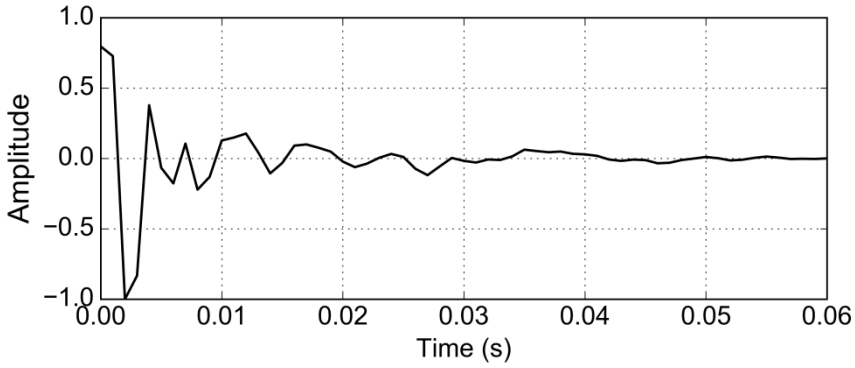



DP
UP
DS
Time (s)
Depth (km)
0
0.1
0.2
0.3
0.4
0.5


DP
CUS
CDS
DS
Time (s)
Depth (km)
0
0.1
0.2
0.3
0.4
0.5

Initial models

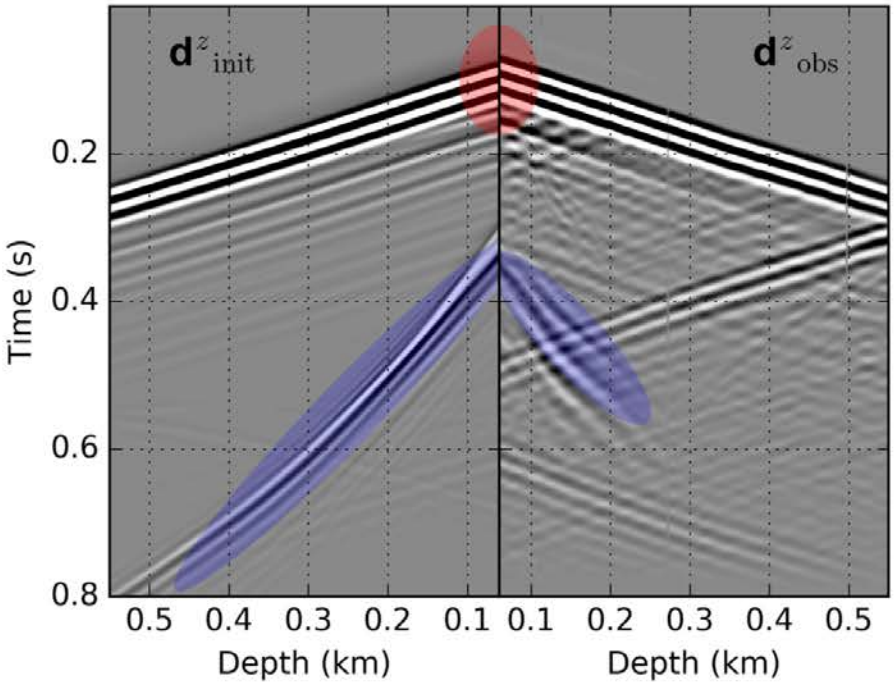




Estimated wavelet

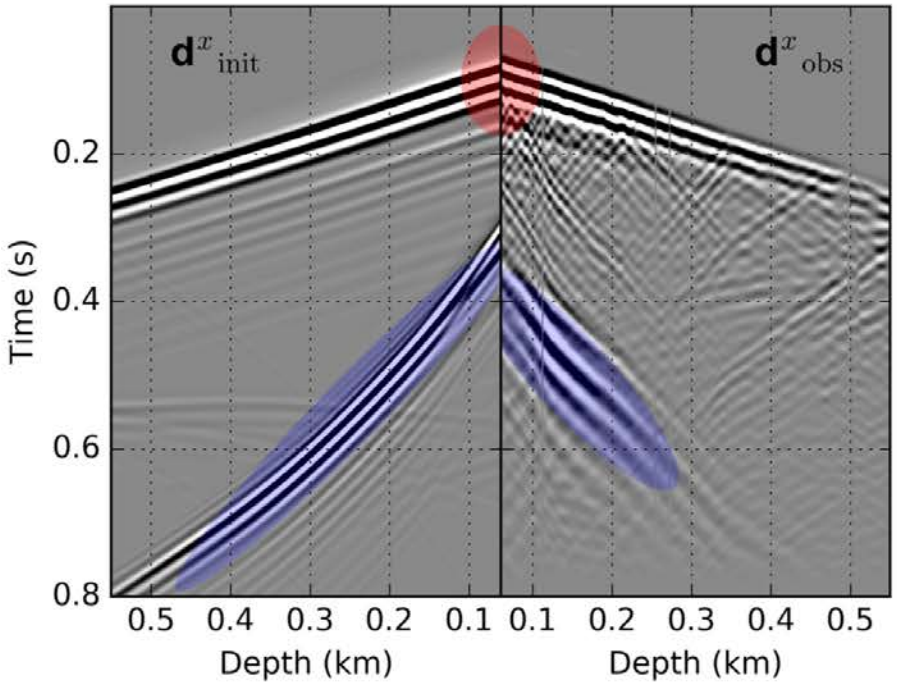
- Nonlinear conjugate gradient updates
- [10,20]Hz, [10,30]Hz, [10,40]Hz, [10,50]Hz
- <= 10 its per band

Vertical component

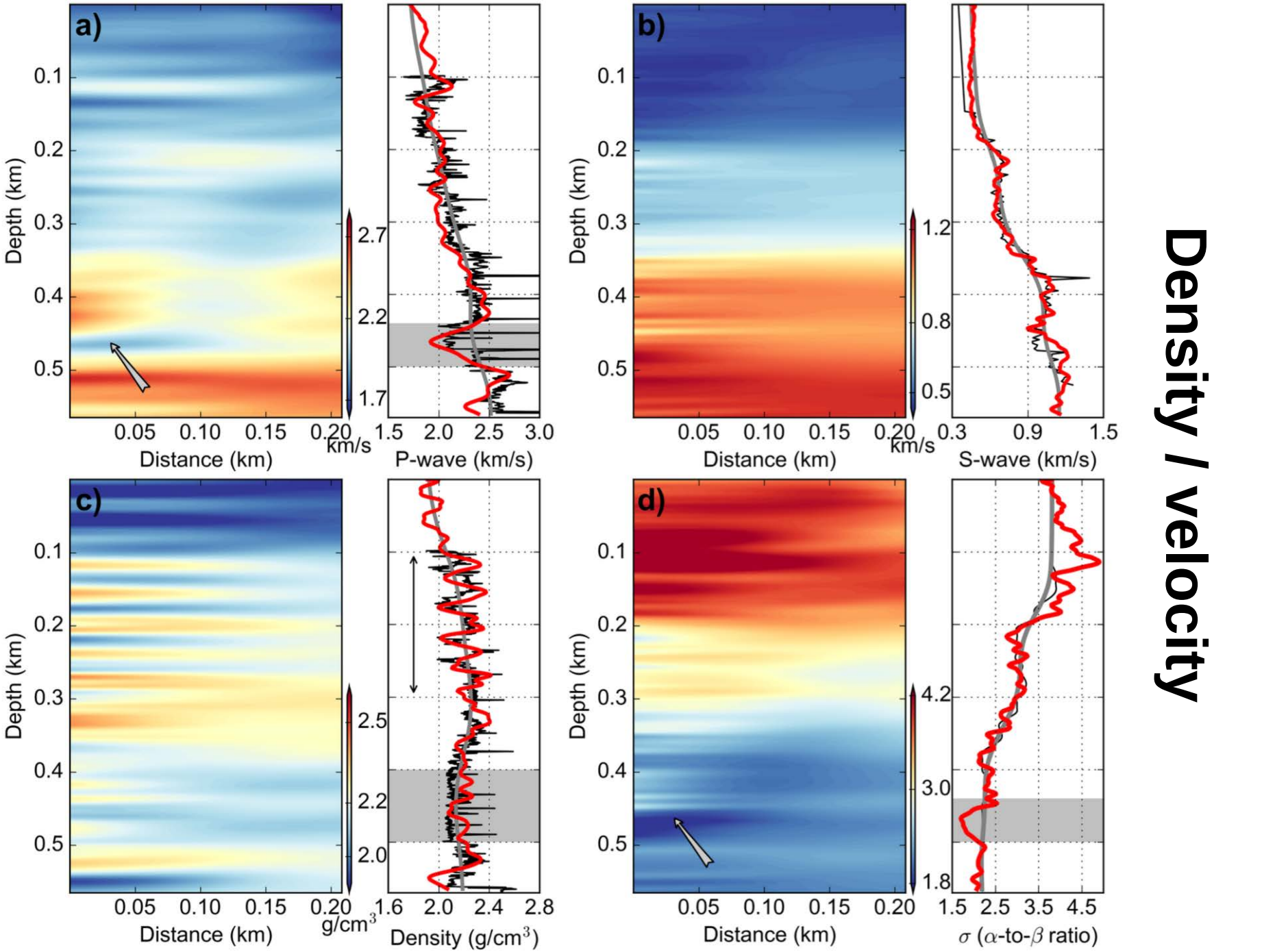


Simulated Observed

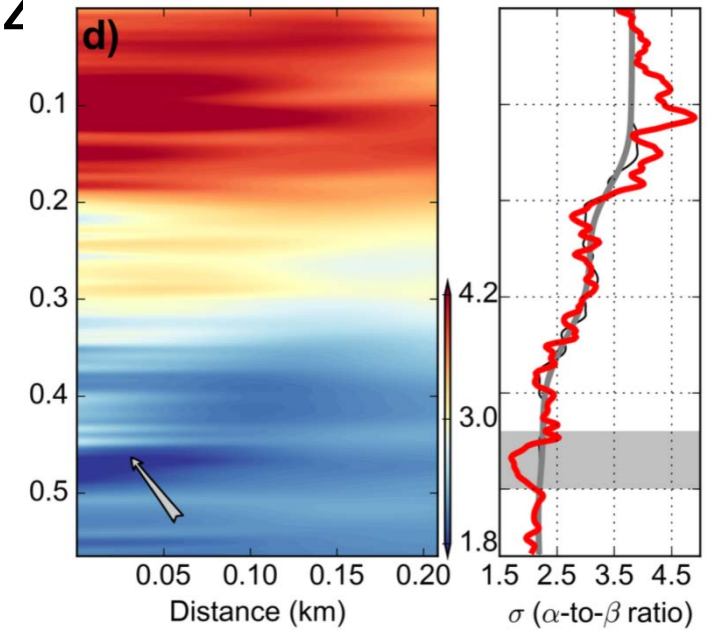
Radial component

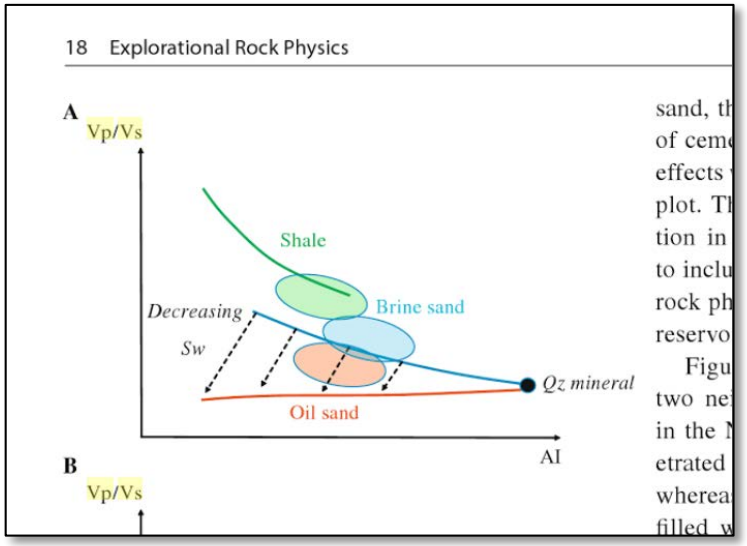


Simulated Observed

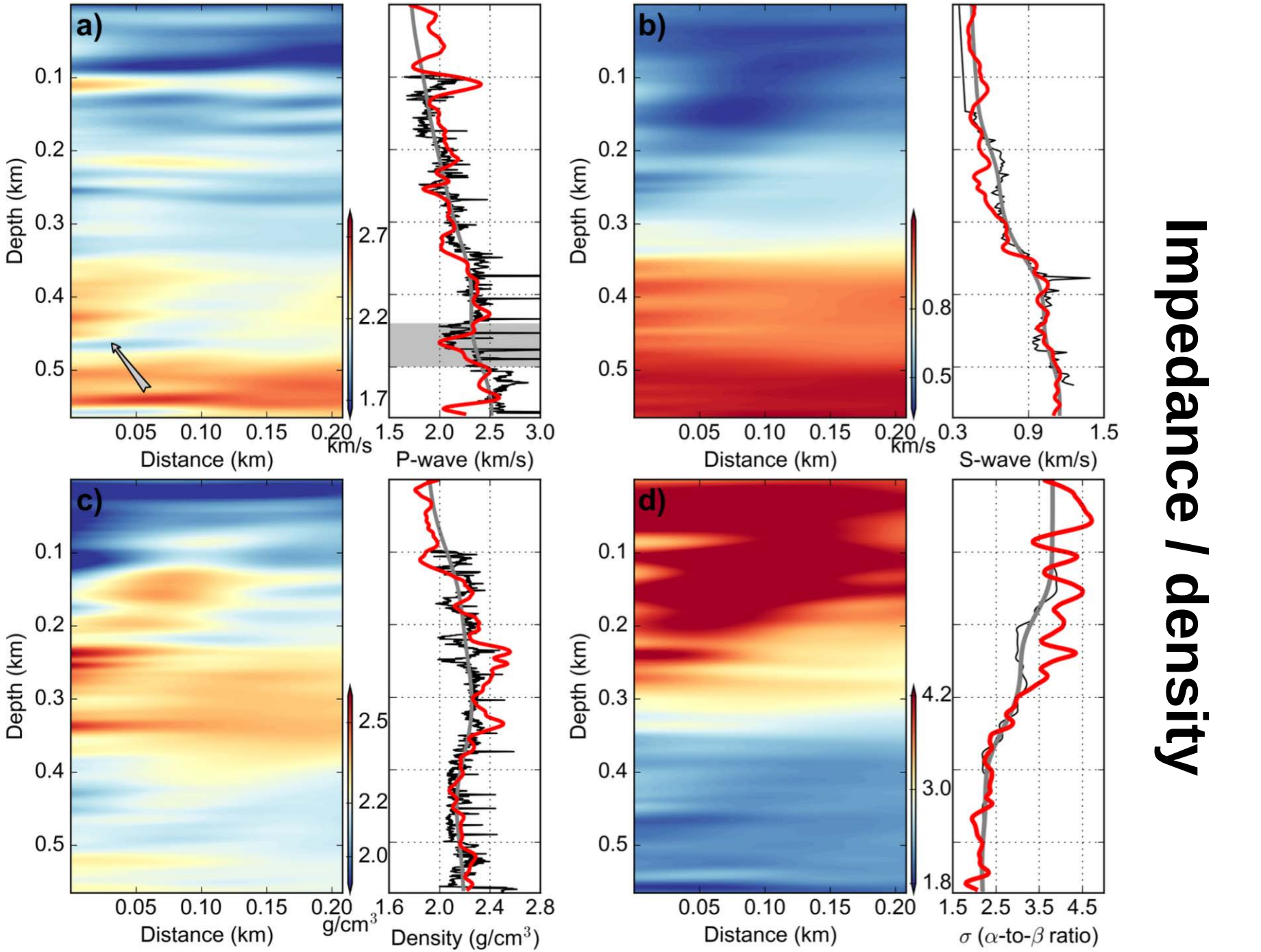

a)
b)
c)
d)
Depth (km)
Distance (km)
km/s
P-wave (km/s)
S-wave (km/s)
g/cm^3
Density (g/cm^3)
σ (α-to-β ratio)
Density / velocity

- P-wave velocity log available; smooth S-wave log synthesized V_P/V_S ratio
- Elastic FWI recovers an S-wave velocity with sharp rise 0.4-0.5km. **Not in the logs or initial model**
- Thus the **data demand** that the recovered V_P/V_S curve drops dramatically in reservoir zone





Bjorlykke, 2010 (Springer)


a)
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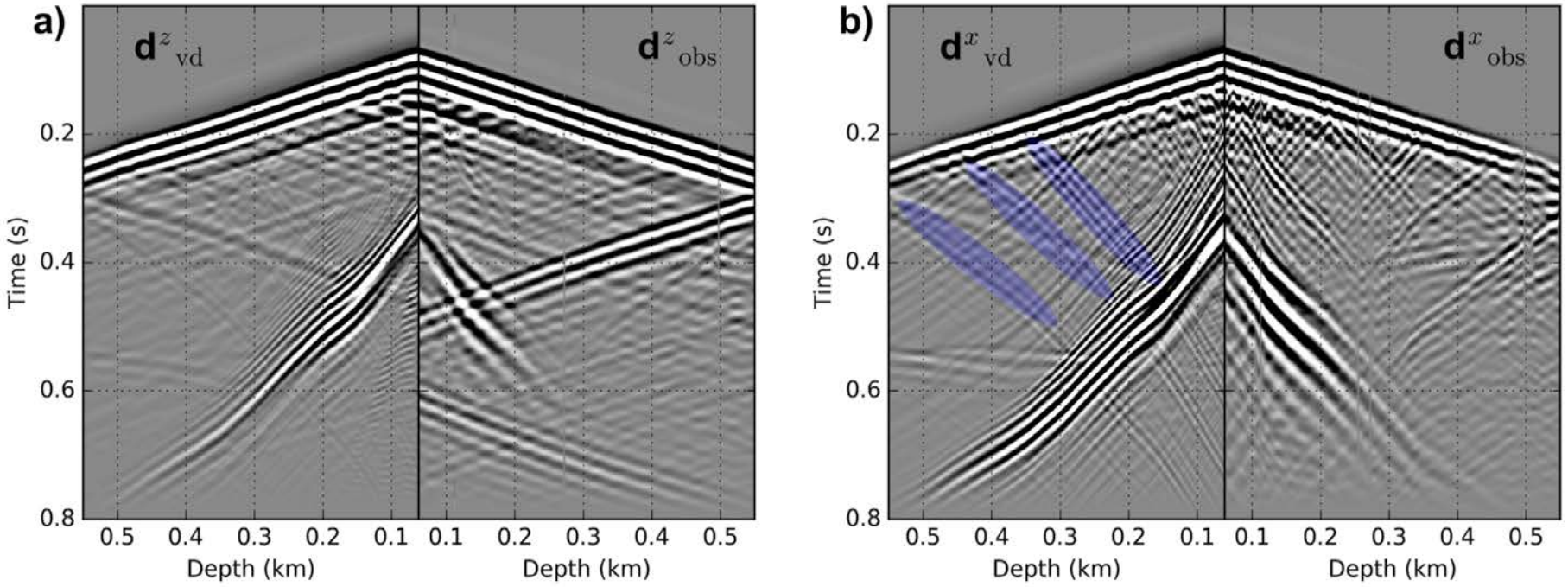
Depth (km)
Distance (km)
km/s
P-wave (km/s)
S-wave (km/s)
g/cm^3
Density (g/cm^3)
σ (α-to-β ratio)
Impedance / density

Vertical component

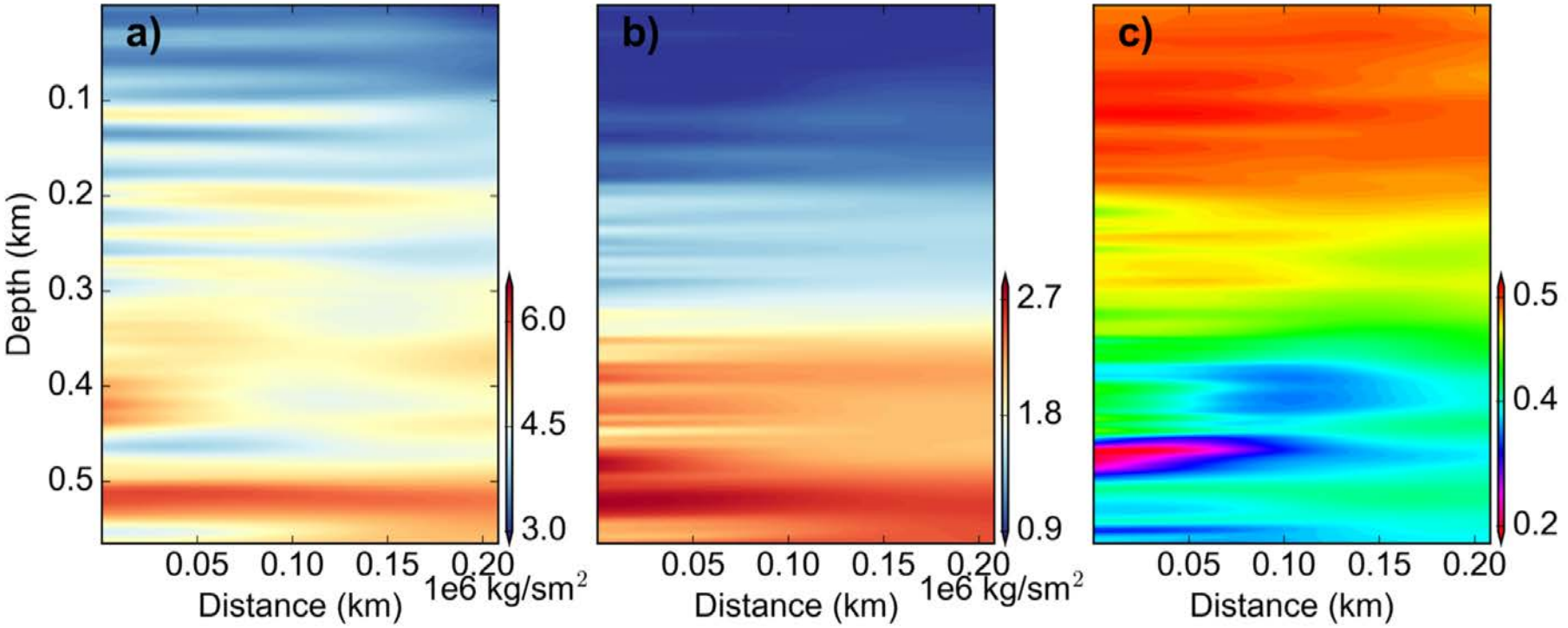
Radial component



Simulated Observed

Simulated Observed

Derived from velocity / density parameterized elastic FWI



P-wave impedance

S-wave impedance

Poisson's ratio

Conclusions

- FWI is a **production level technology** in offshore velocity model building (scalar, acoustic, sometimes anisotropic).
- Goal: bring **multi-parameter elastic FWI** to the reservoir.
- **Prediction of rock-physics / geologically interpretable** properties? Starting to look quite real.
- Validation and appraisal: hopefully we start seeing cases like this. But how to we create a framework where successes and failures are understandable, efficiently computable? **Today's talks**.
- **How do we communicate potential to interpreters, geologists, and engineers?**