Iterative multiparameter elastic waveform inversion using prestack Kirchhoff approximation

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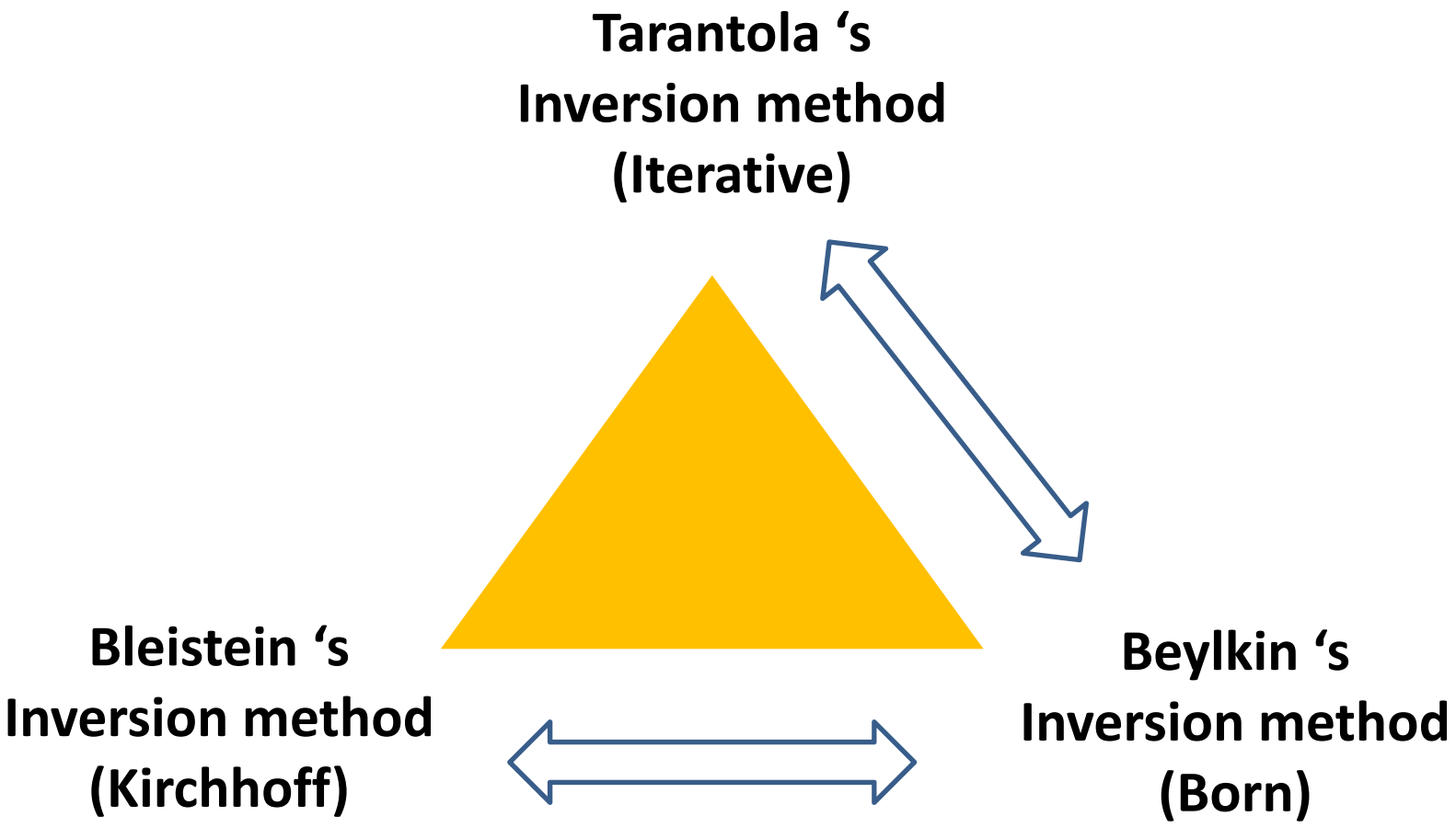
Outline

- Theory of inversion
  - Philosophy of Full Waveform Inversion (FWI)
  - Born approximation
  - Kirchhoff approximation
- Numerical implementation
  - Synthetic data
  - Real data
- Future Applications
  - 3D seismic data
- Conclusions

Background


Tarantola ‘s
Inversion method
(Iterative)
Bleistein ‘s
Inversion method
(Kirchhoff)
Beylkin ‘s
Inversion method
(Born)

Philosophy of FWI method

Moving from direct inversion to iterative inversion (Tarantola, 1984 & 1986)

model Data

$$GM = d \quad \Longrightarrow \quad M = (G^T G)^{-1} G^T d$$

Forward modeling operator

Problem: How accurate is G ?

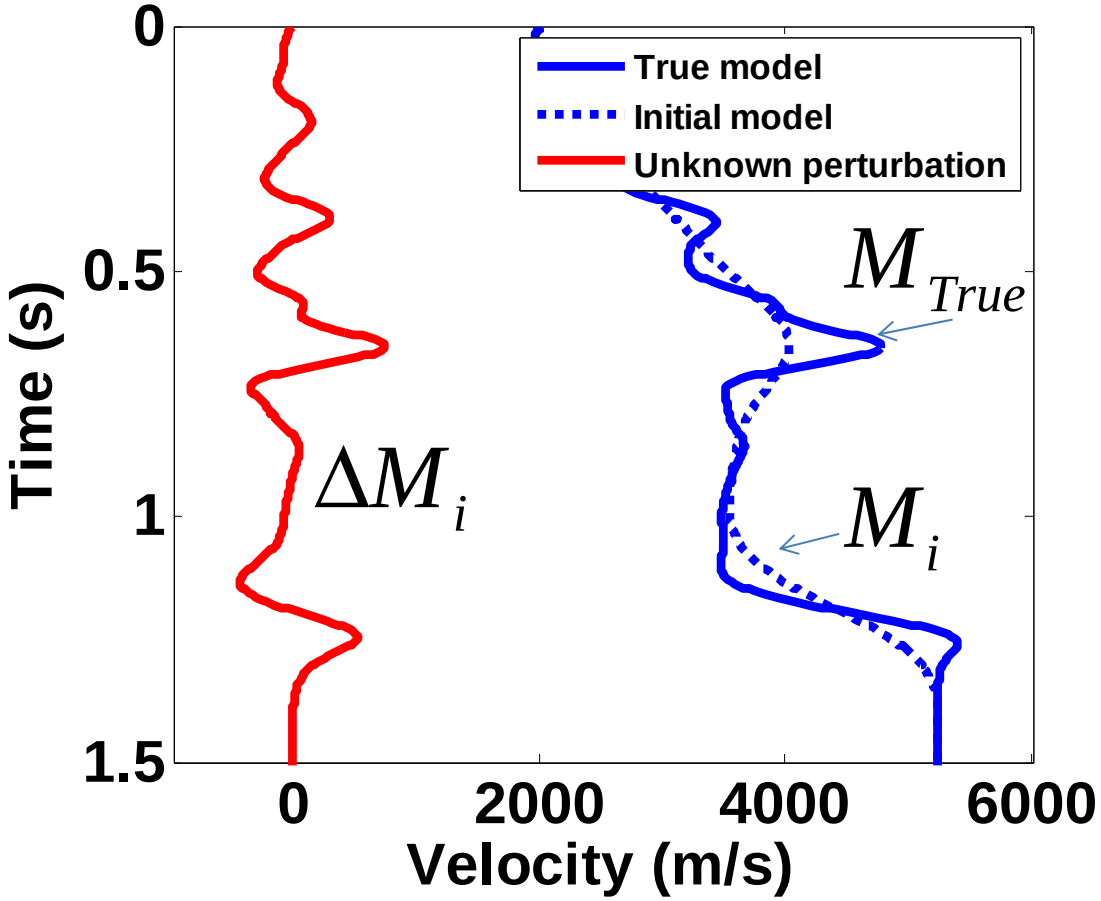
FWI: Initial guess $M_i \longrightarrow G_i \longrightarrow \Delta M_i$

$$G_i \Delta M_i = \Delta d_i \quad \Longrightarrow \quad \Delta M_i = (G_i^T G_i)^{-1} G_i^T \Delta d$$

$$M_{i+1} = M_i + \Delta M_i$$

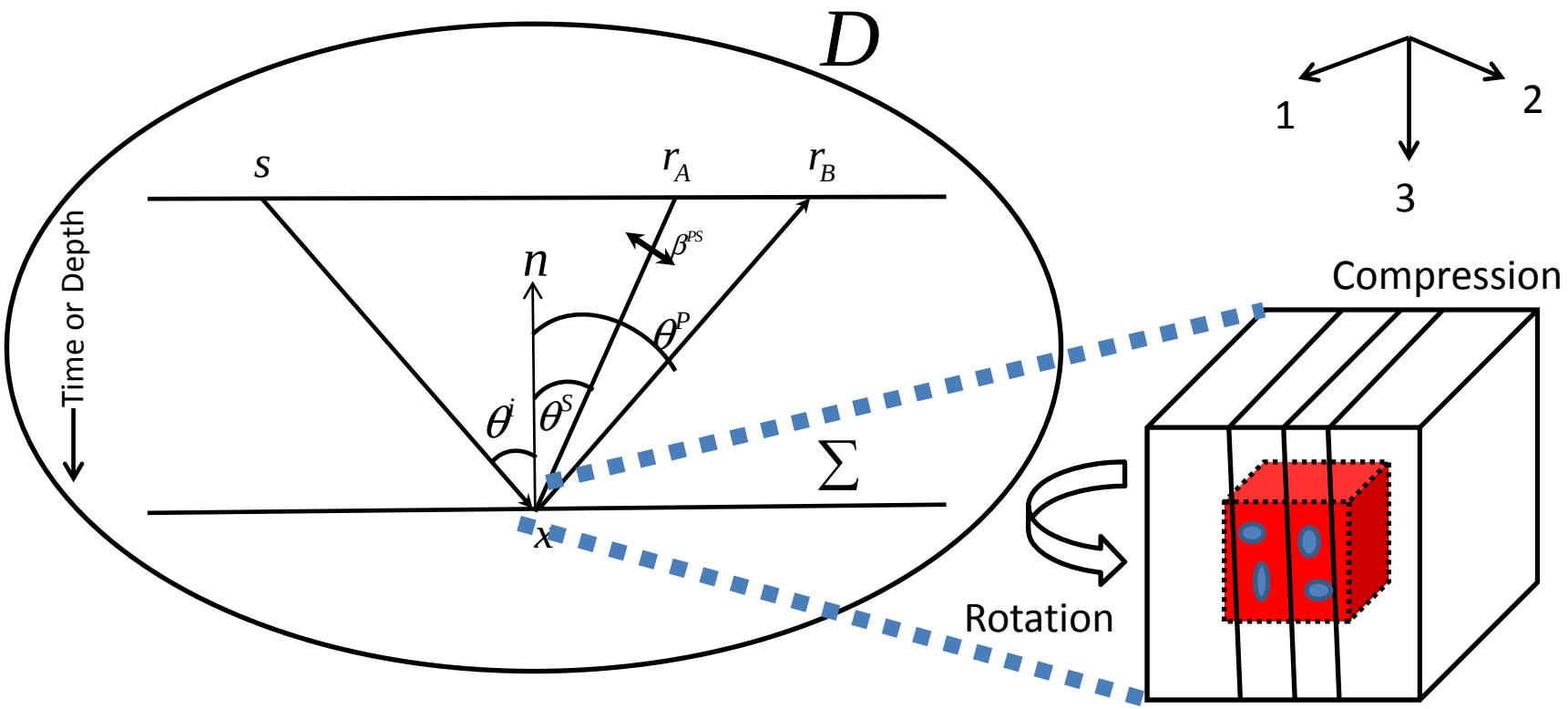
Model Perturbation in Born approximation

(e.g., Beylkin, 1984, 1990)



Theory of elasticity and scattering potentials

(e.g., Beylkin, 1985, 1990)



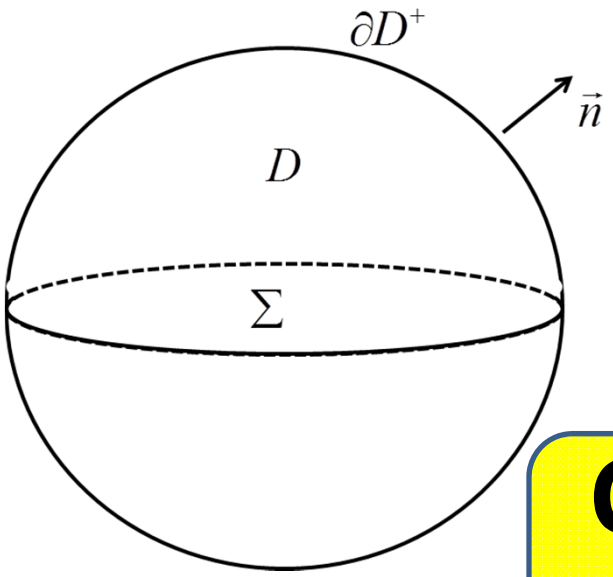
$$S(x) = [\frac{\Delta\rho(x)}{\rho_0(x)}\delta_{ik} + \frac{\Delta c_{ijkl}(x)}{c_{ijkl_0}(x)} p_j^r p_l^s] h_k^s h_i^r \qquad i, j, k \,\&\, l = 1, 2, 3$$

ρ = Density c_{ijkl} = Stiffness tensor p = Slowness h = Polarization

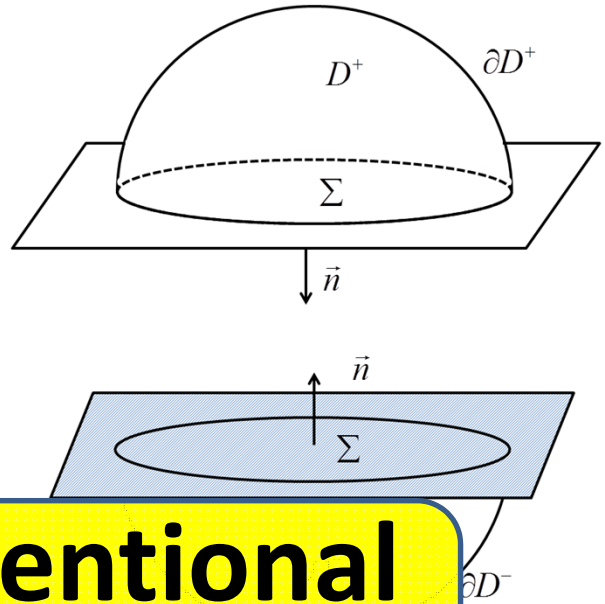
Kirchhoff approximations

(Bleistein, 1984 & 1986)

Born approximation



Kirchhoff approximation



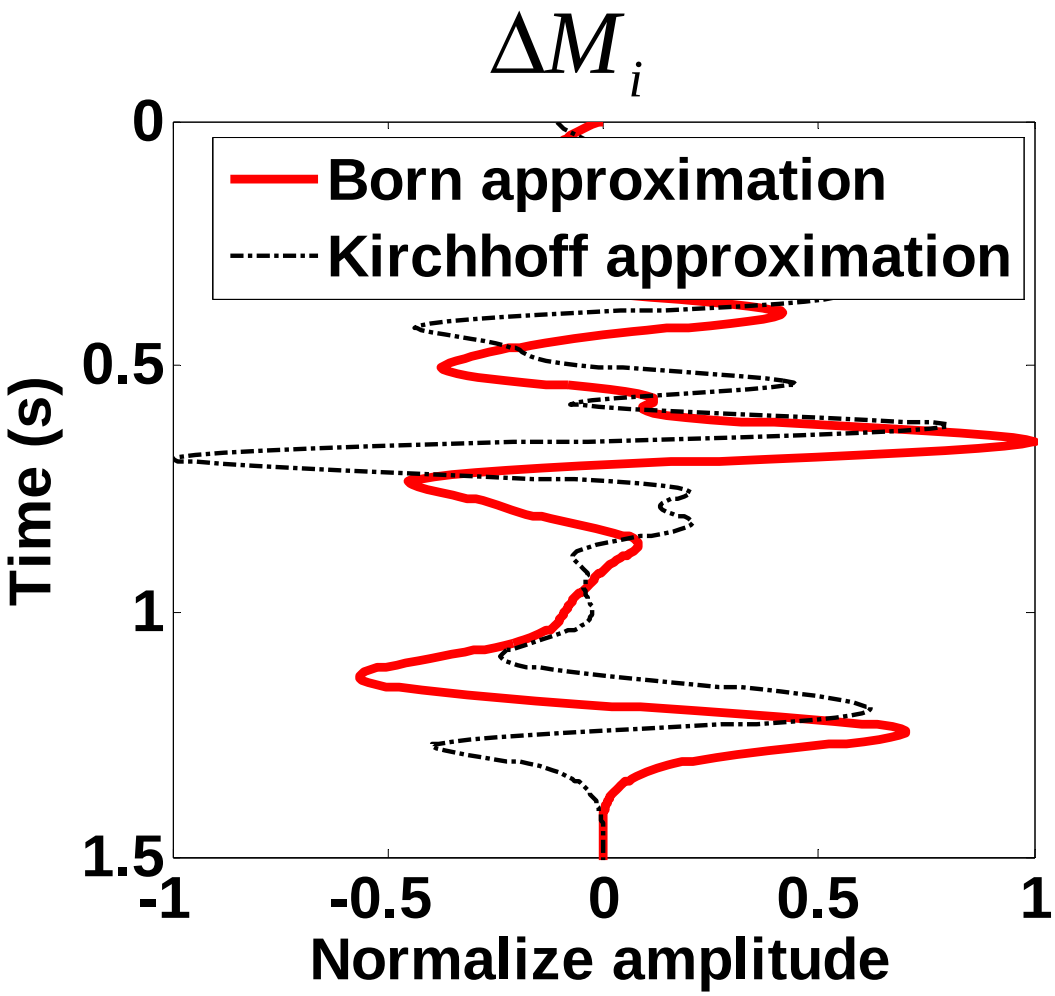
Conventional AVO inversion

$$R(x) = [\frac{\Delta\rho^+(x) - \Delta}{\rho_0(x)} + \frac{\Delta c_{ijkl}(x)}{\Delta c_{ijkl_0}(x)} p_j^r p_l^s] h_k^s h_i^r$$

$$R = \propto \frac{\partial}{\partial n} S \Rightarrow R(\frac{\Delta v_p}{v_p}, \frac{\Delta v_s}{v_s}, \frac{\Delta\rho}{\rho}, \ldots, \theta)$$

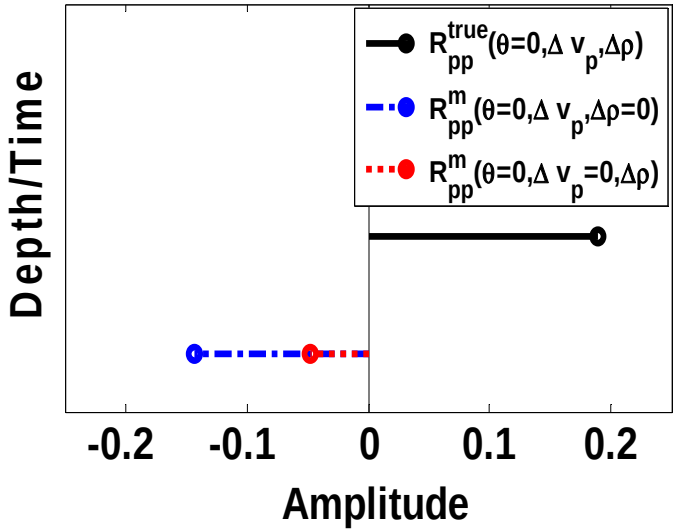
Model perturbation

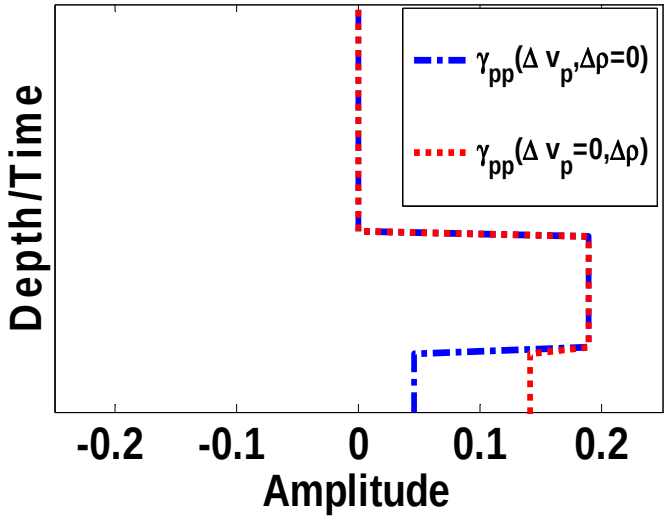
(e.g., Bleistein vs Beylkin)



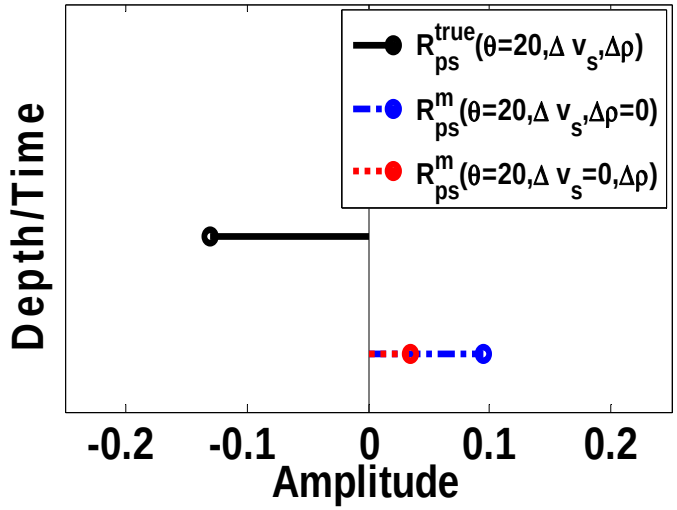
Tarantola's FWI method, elastic properties and gradient estimation

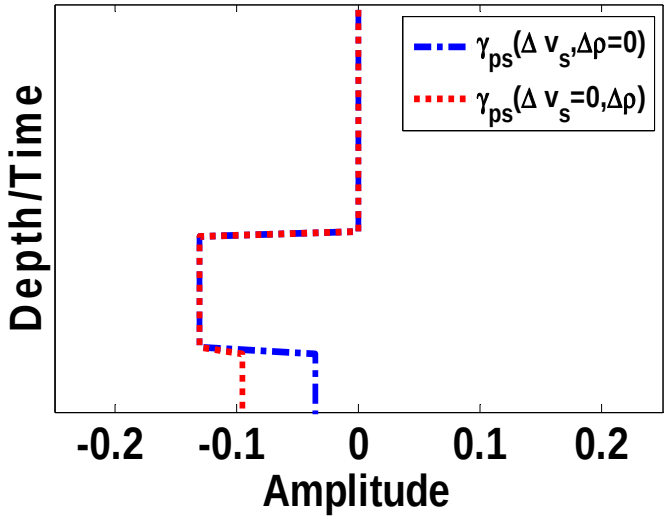
a) P-to-P data





b) P-to-S data

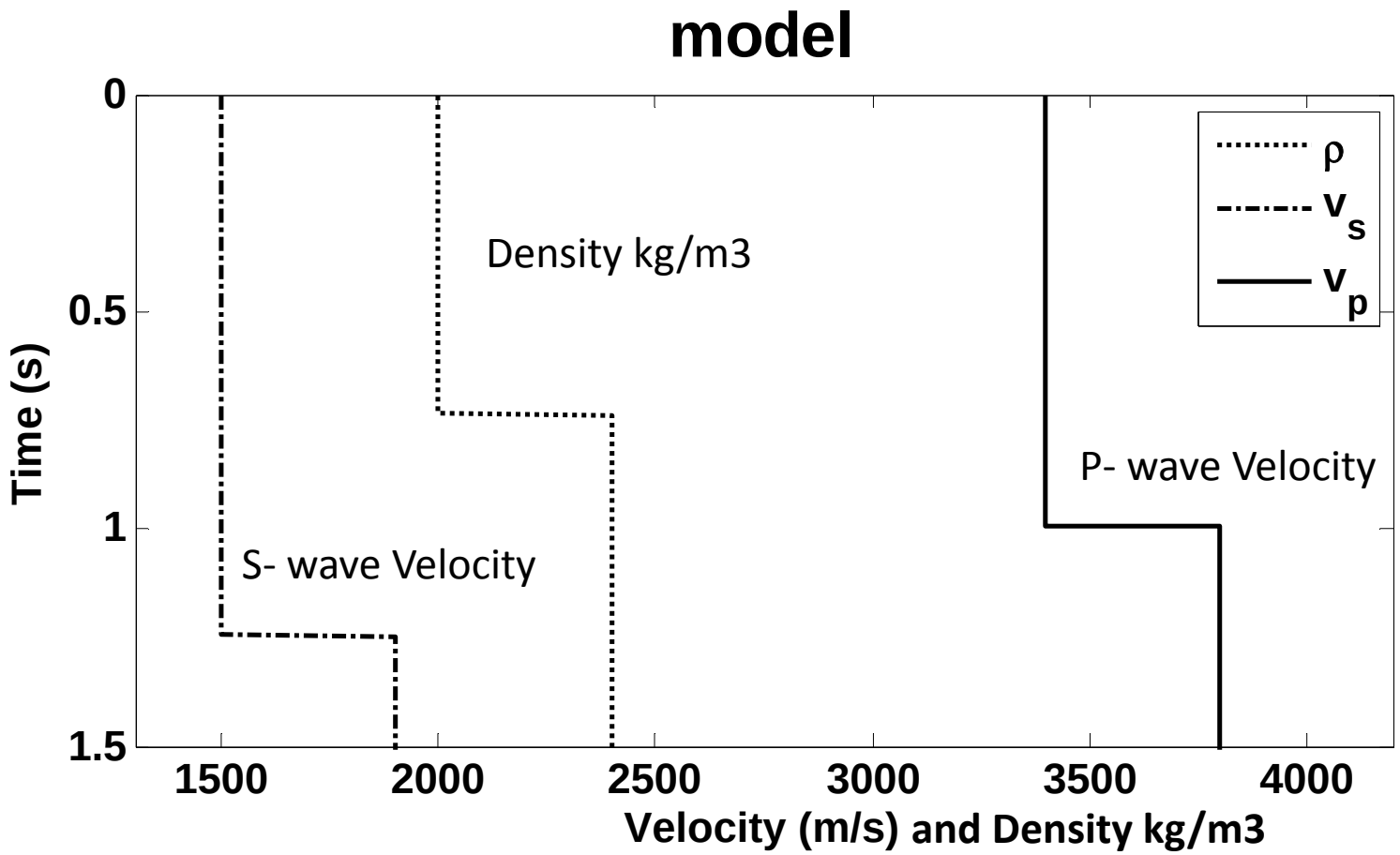




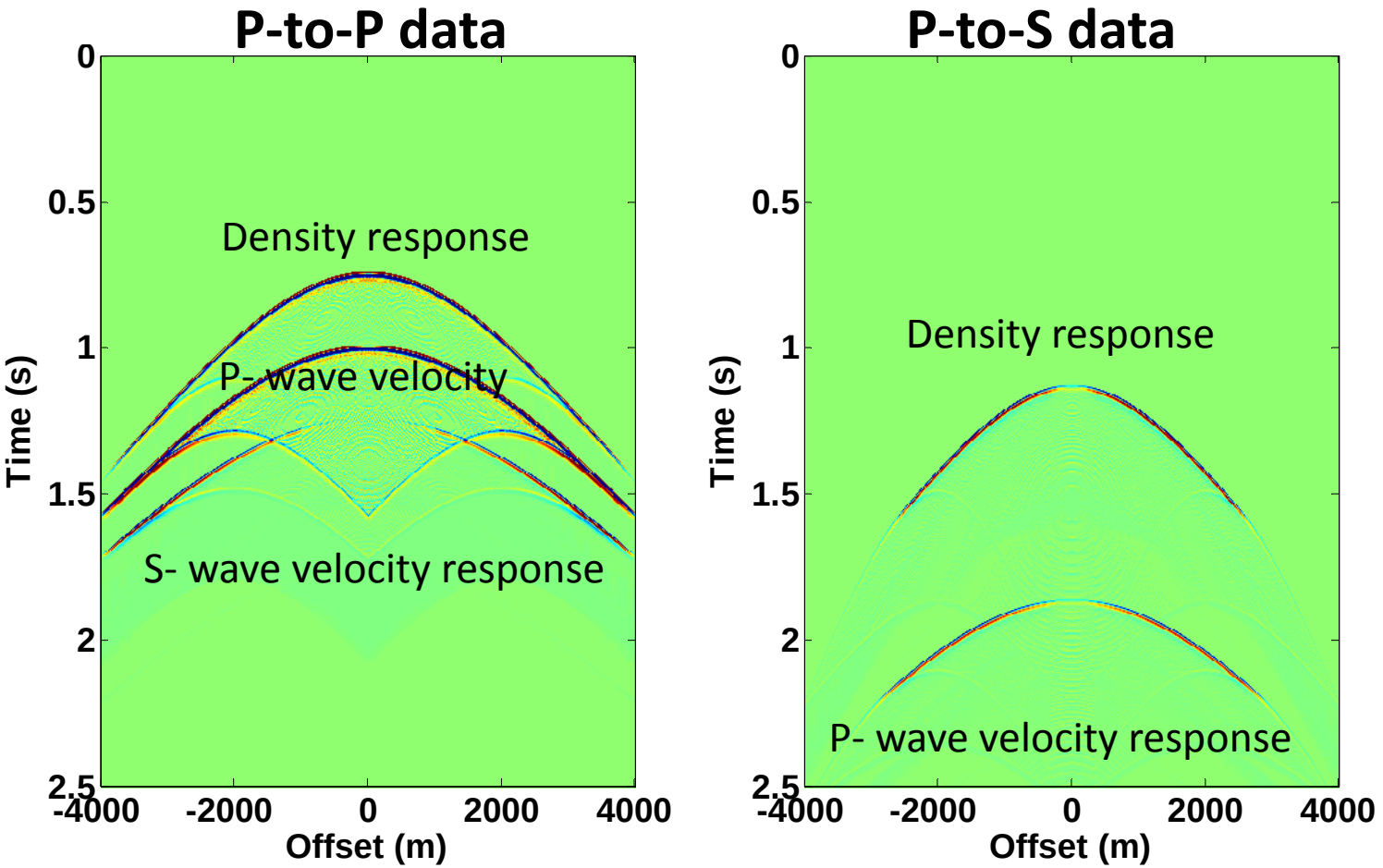
See e.g., Innanen (2011) for analytical expression of gradient functions in FWI

Numerical examples

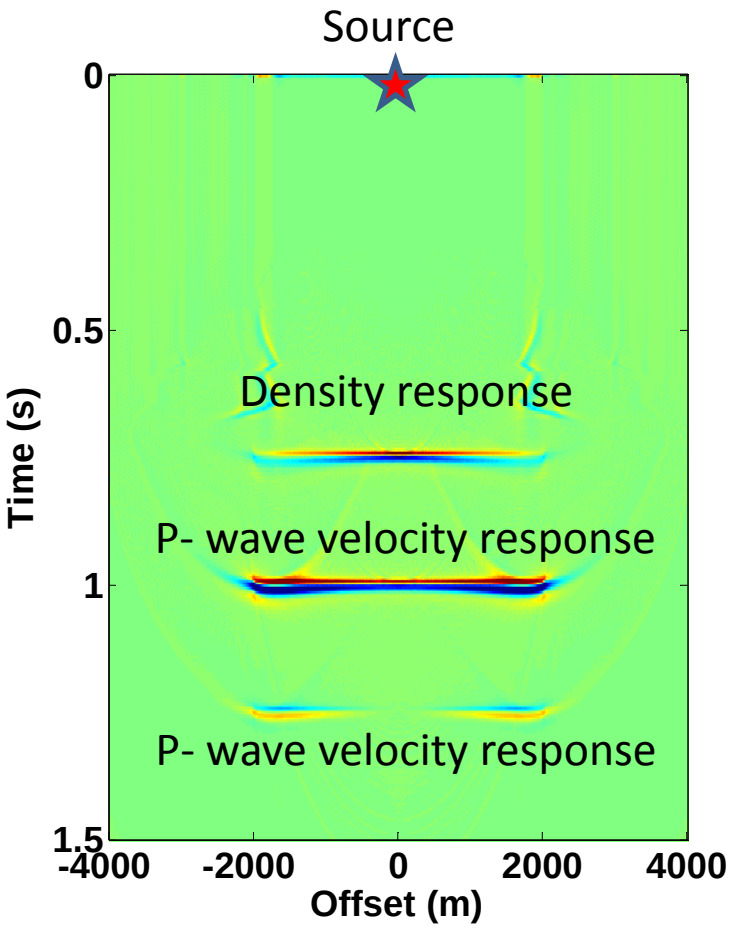
P-P and P-S radiation pattern

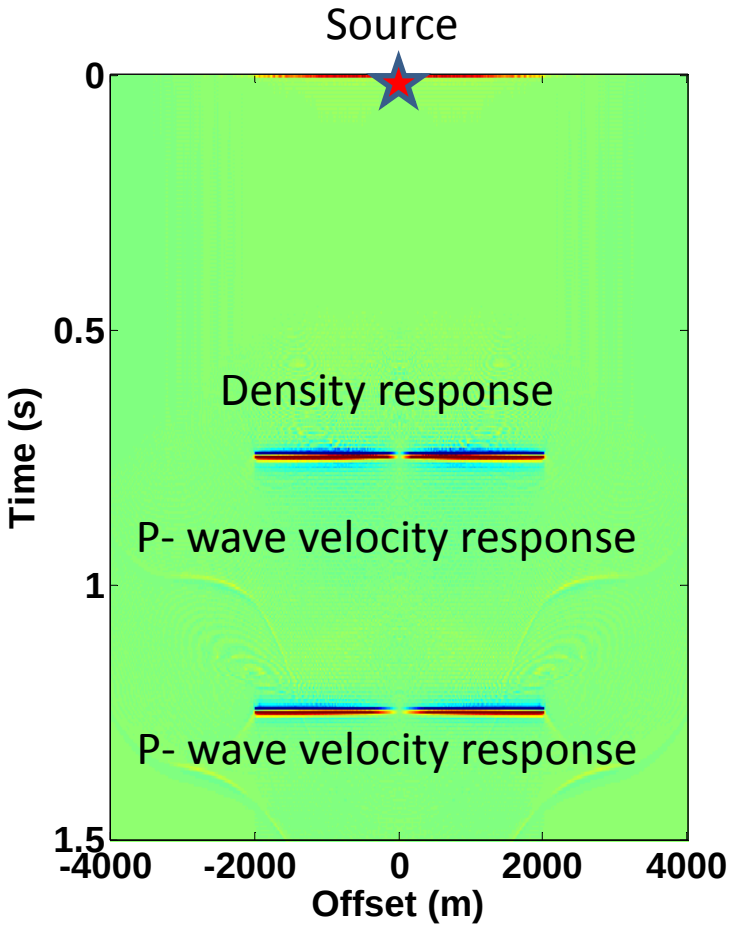


P-P and P-S radiation pattern

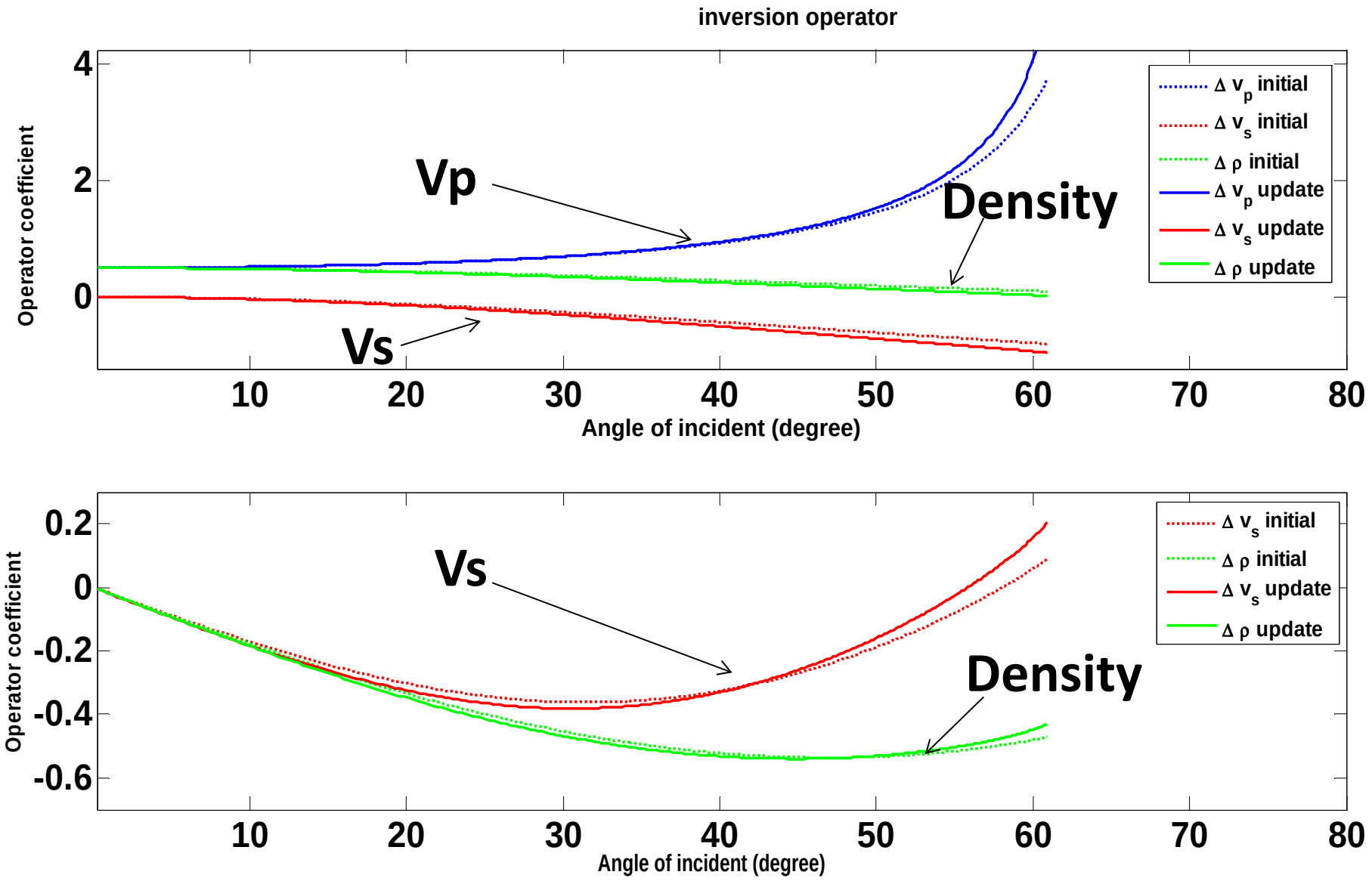


P-P and P-S radiation pattern

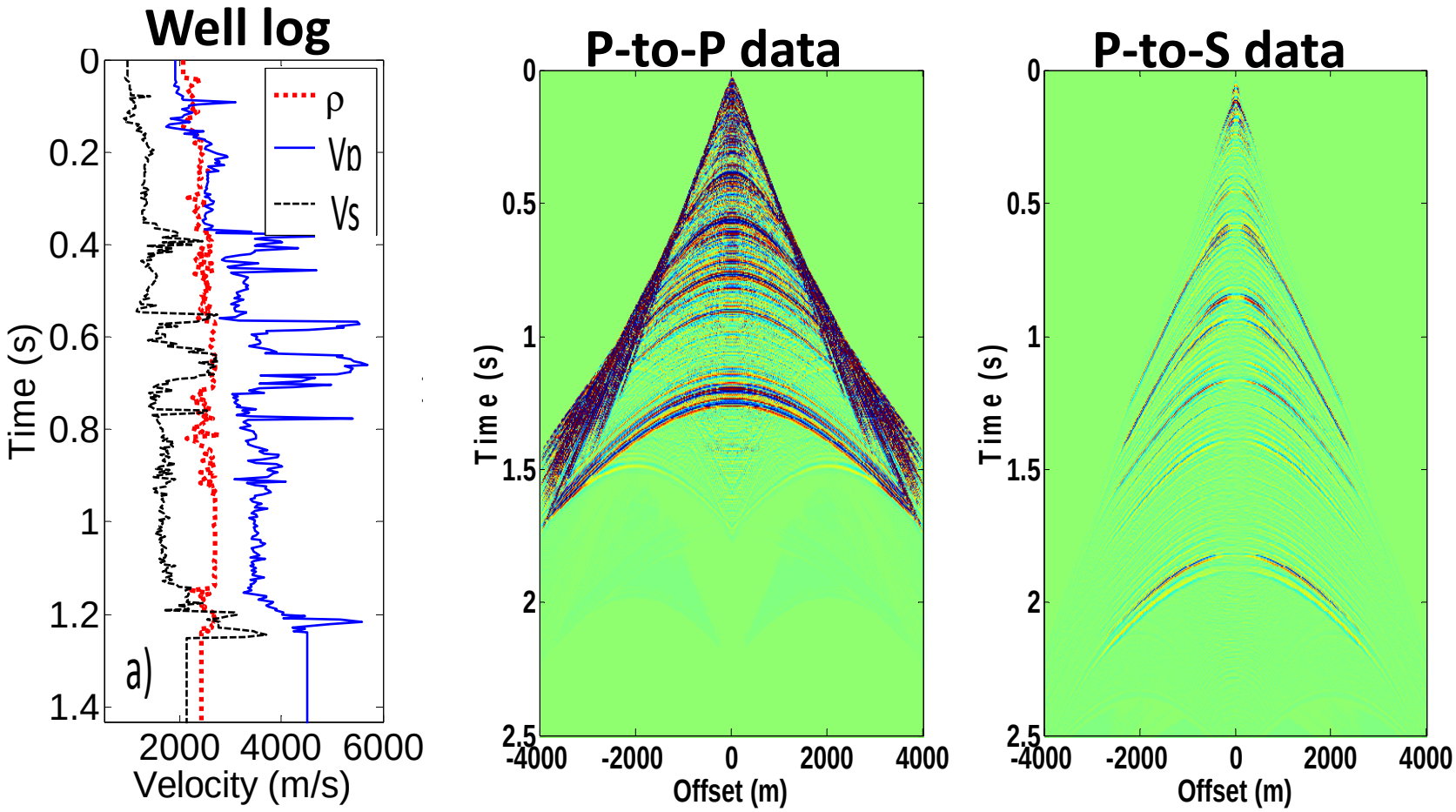




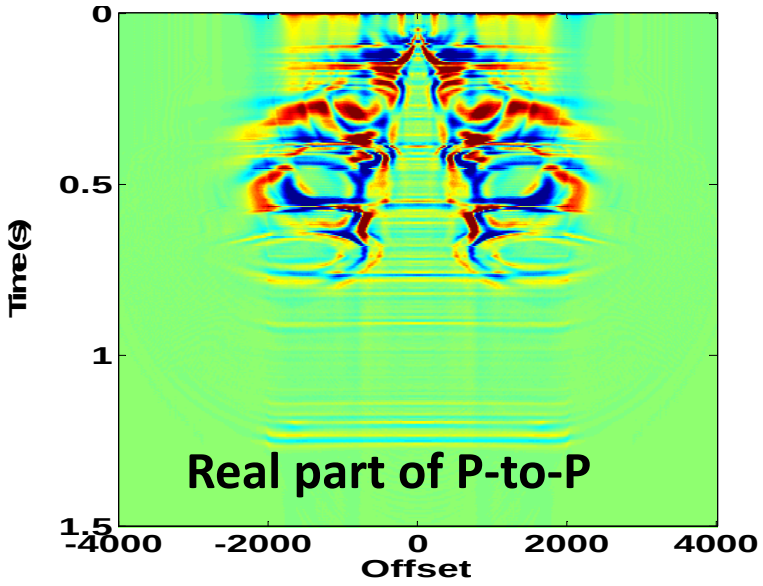
Effects of accurate model for AVO inversion

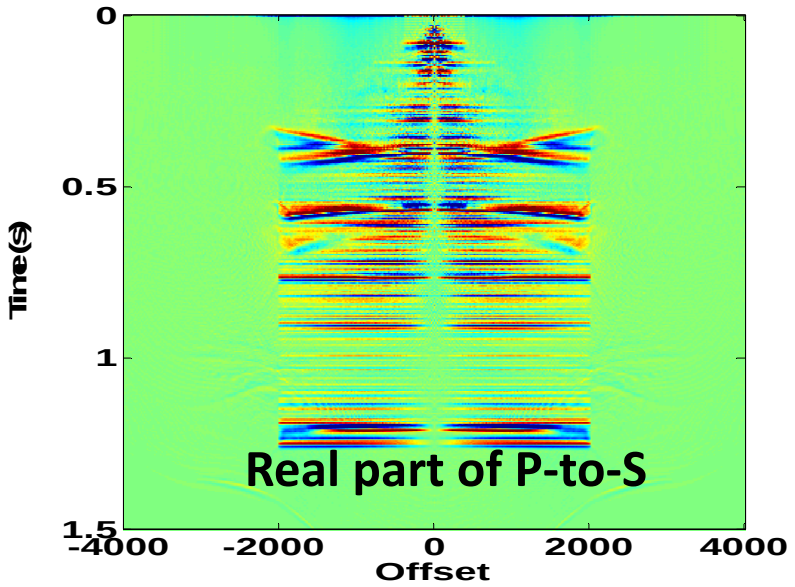


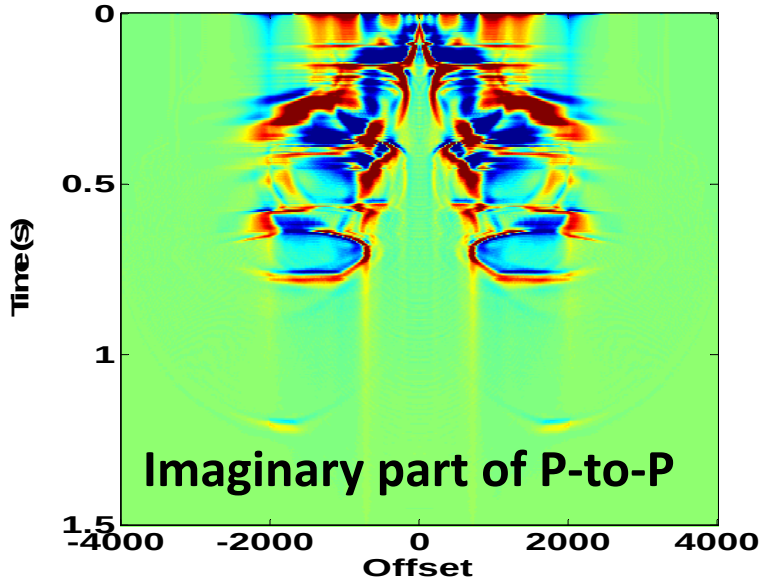
Synthetic example (well log from NEBC)
P-to-P and P-to-S wavefield

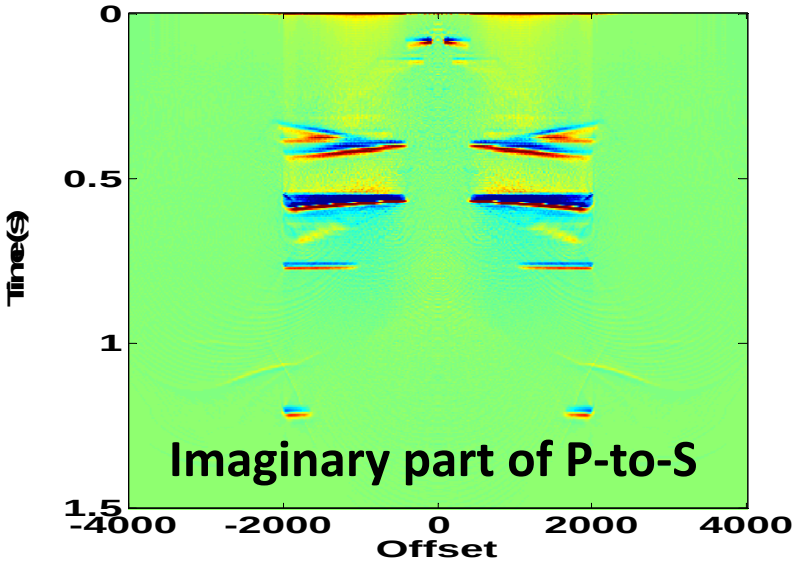


AVO and common image gather

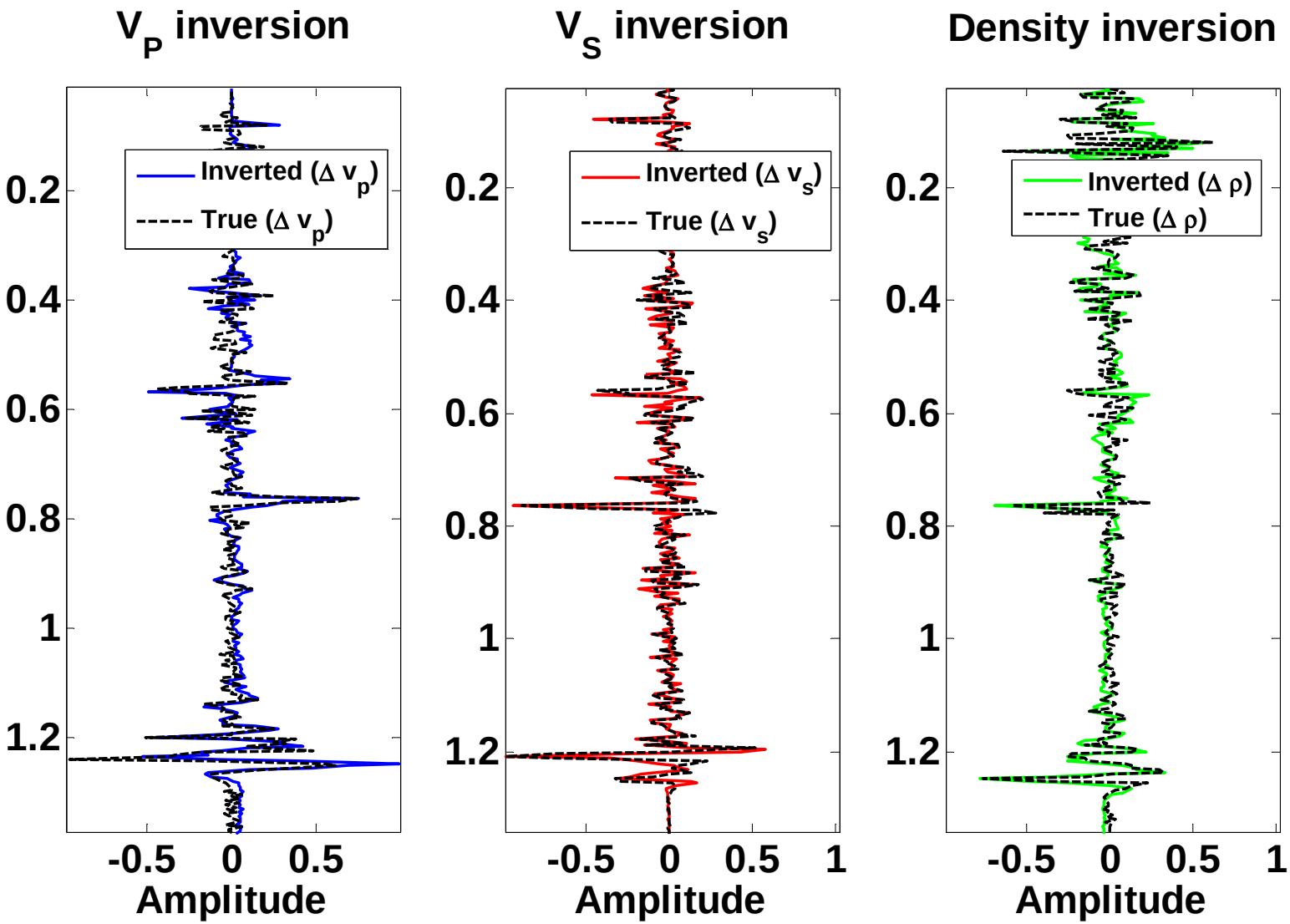




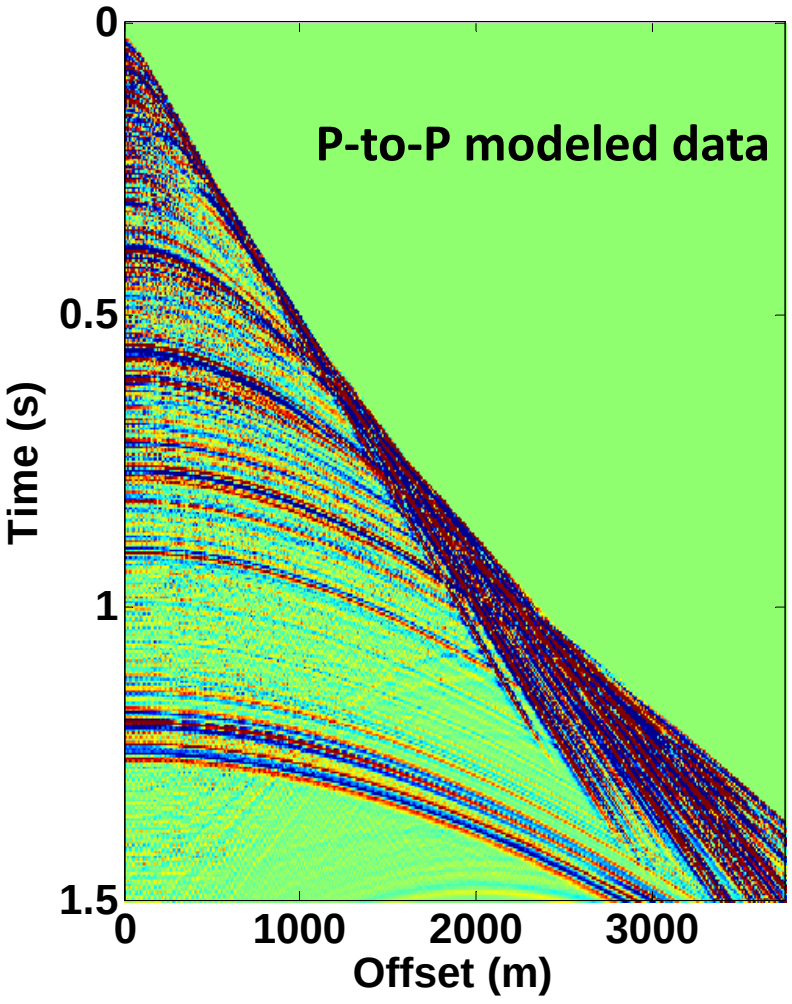


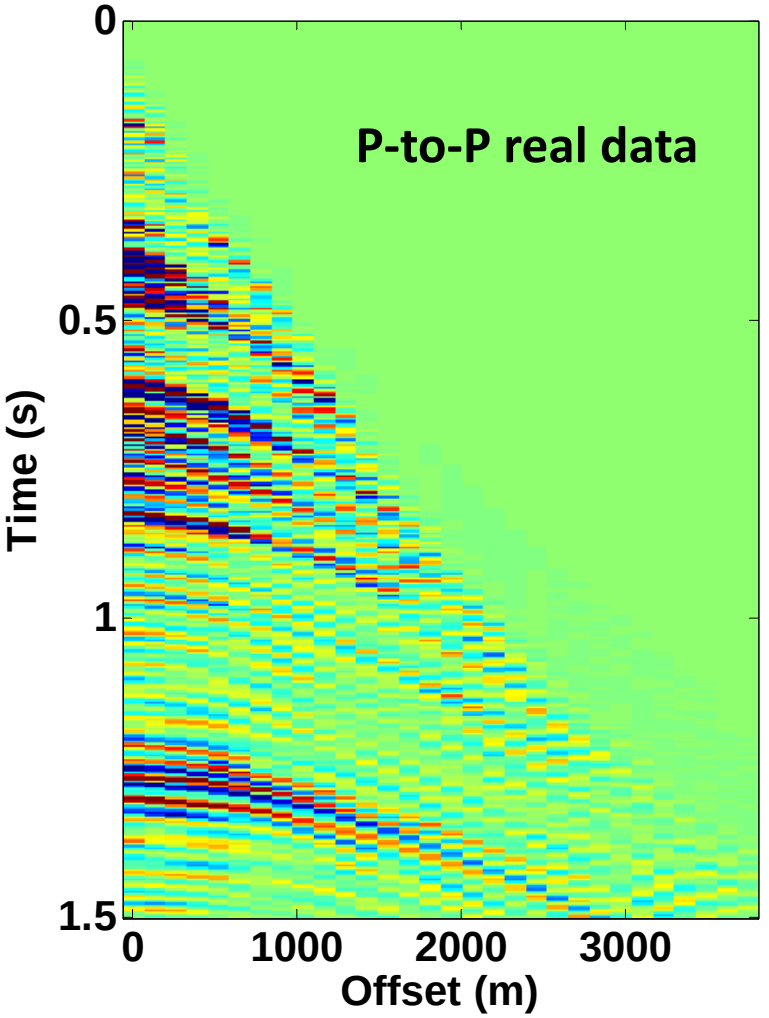


Synthetic multiparameter inversion



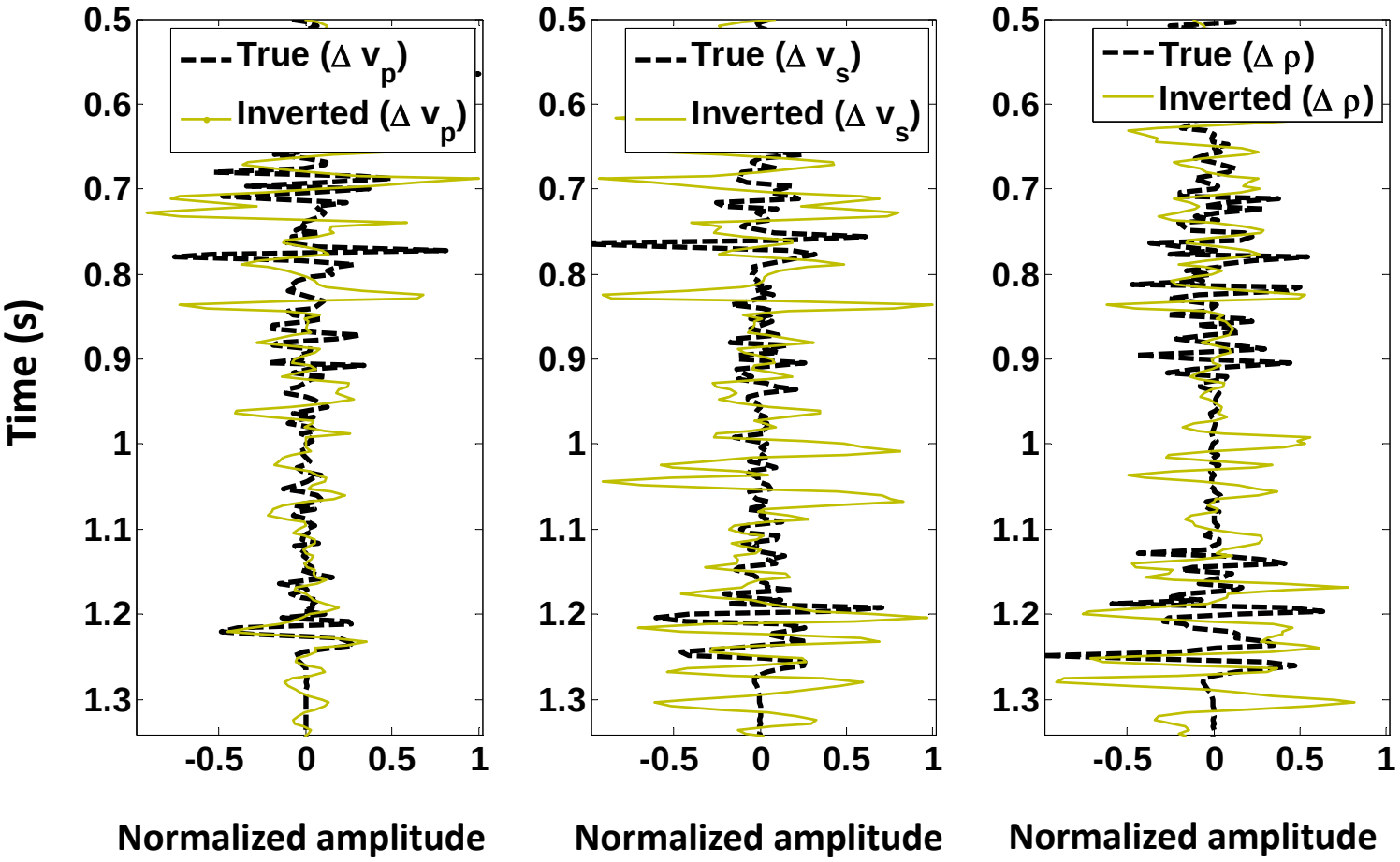
Real data: Multiparameter inversion
P-to-P wavefield only





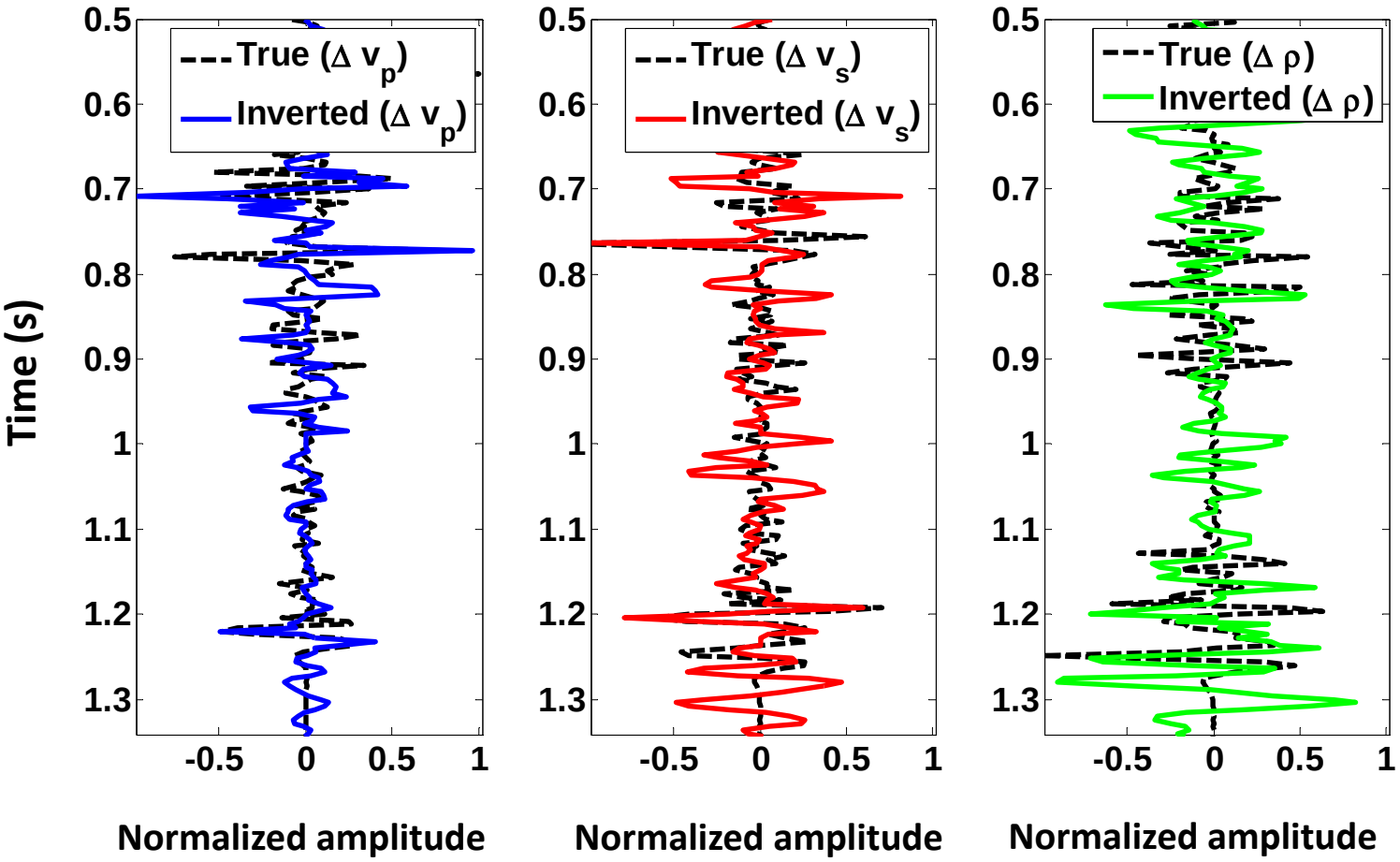
Real data: Multiparameter inversion
P-to-P wavefield only

Initial model result



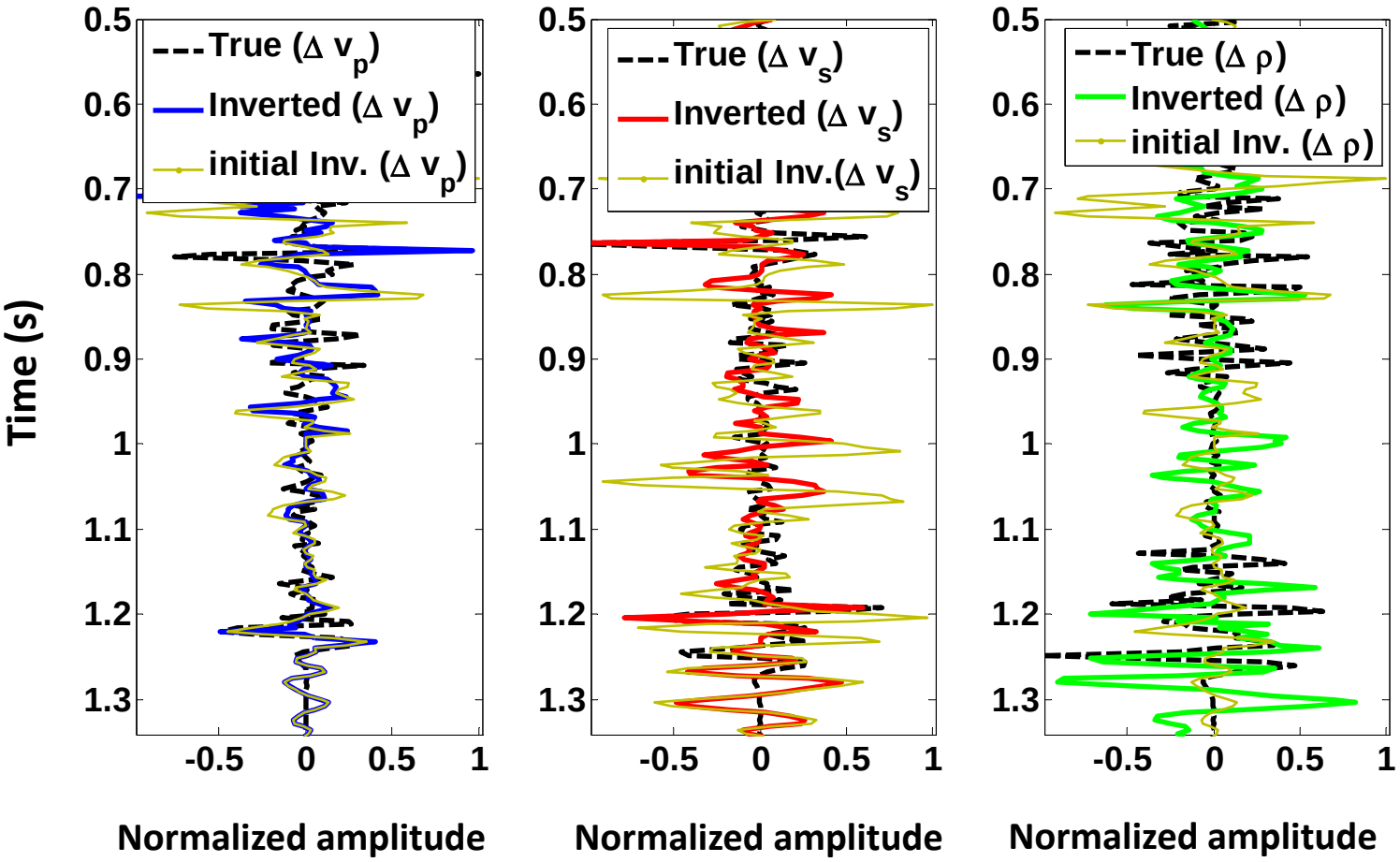
Real data: Multiparameter inversion
P-to-P wavefield only

Updated model result

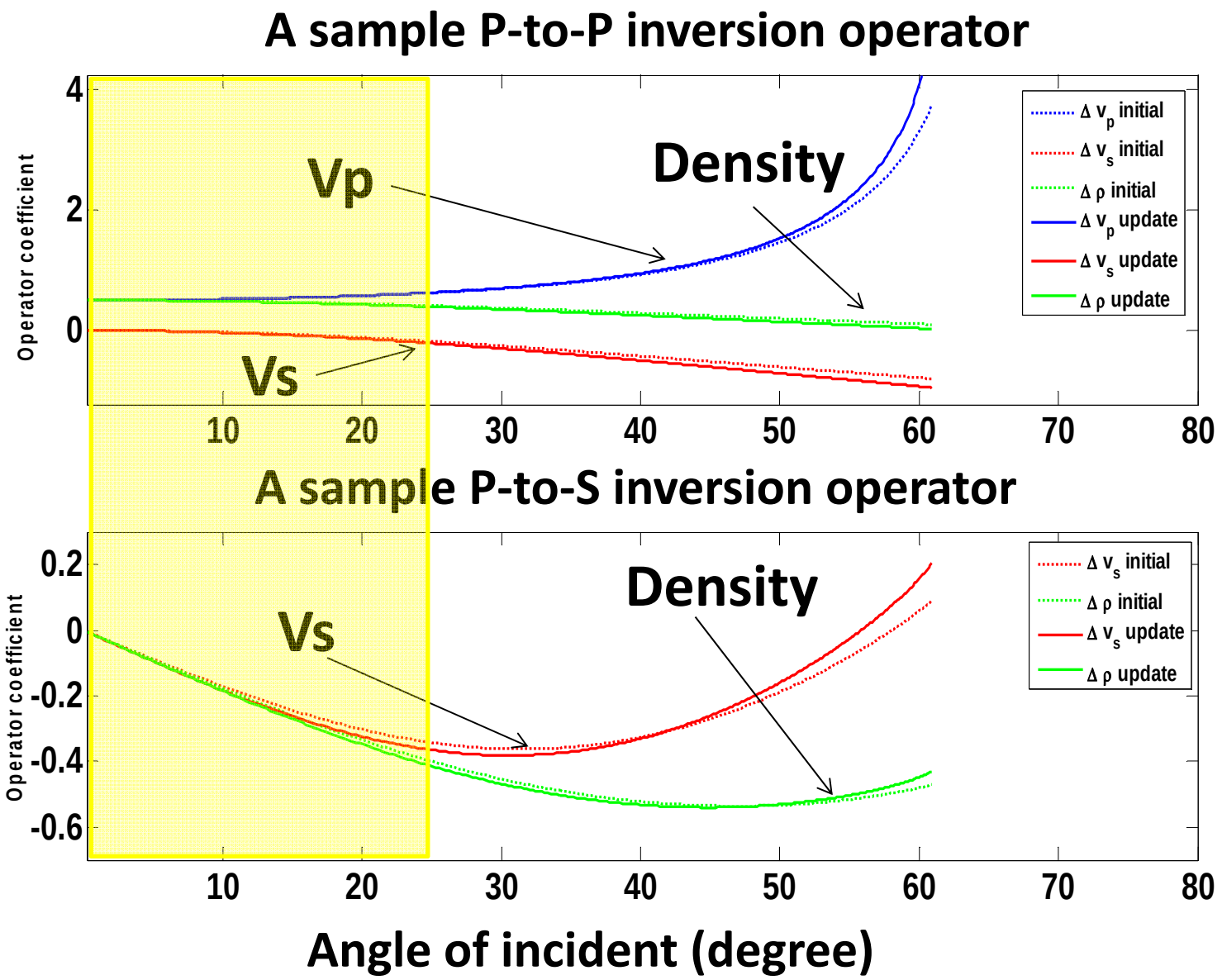


Real data: Multiparameter inversion
P-to-P wavefield only

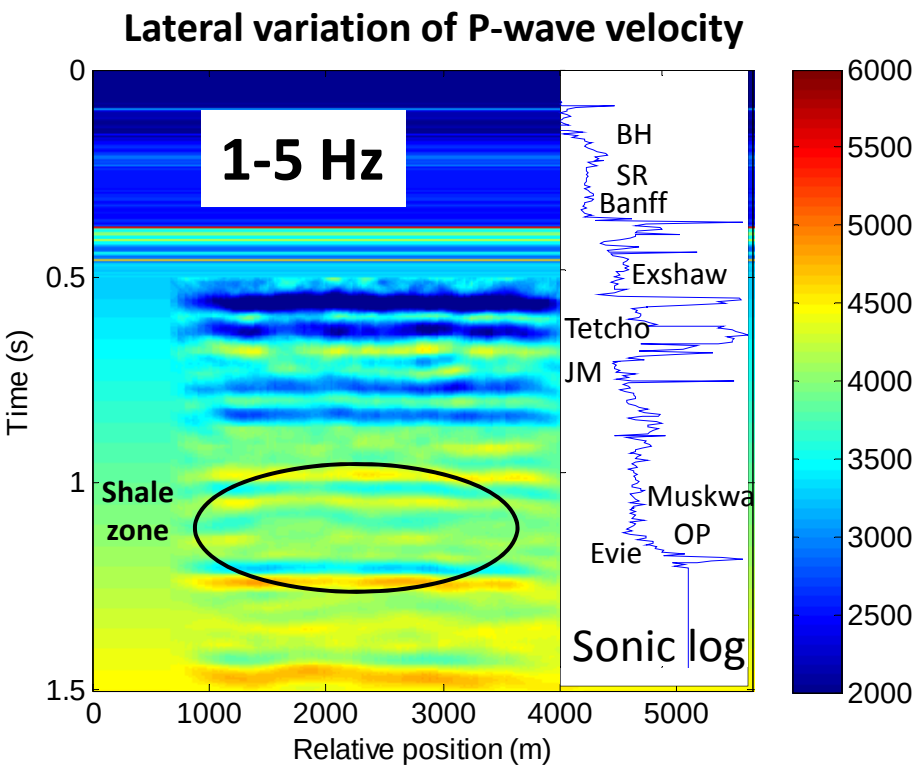
Initial vs updated model result

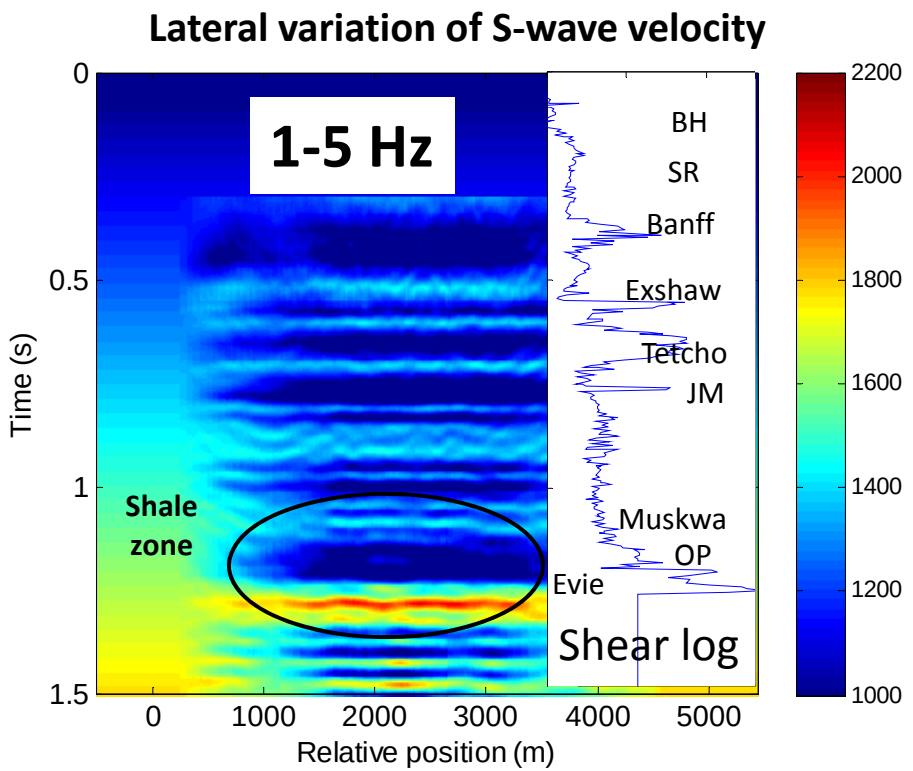


Real data: Multiparameter inversion P-to-P and P-to-S wavefield (Limited offset)



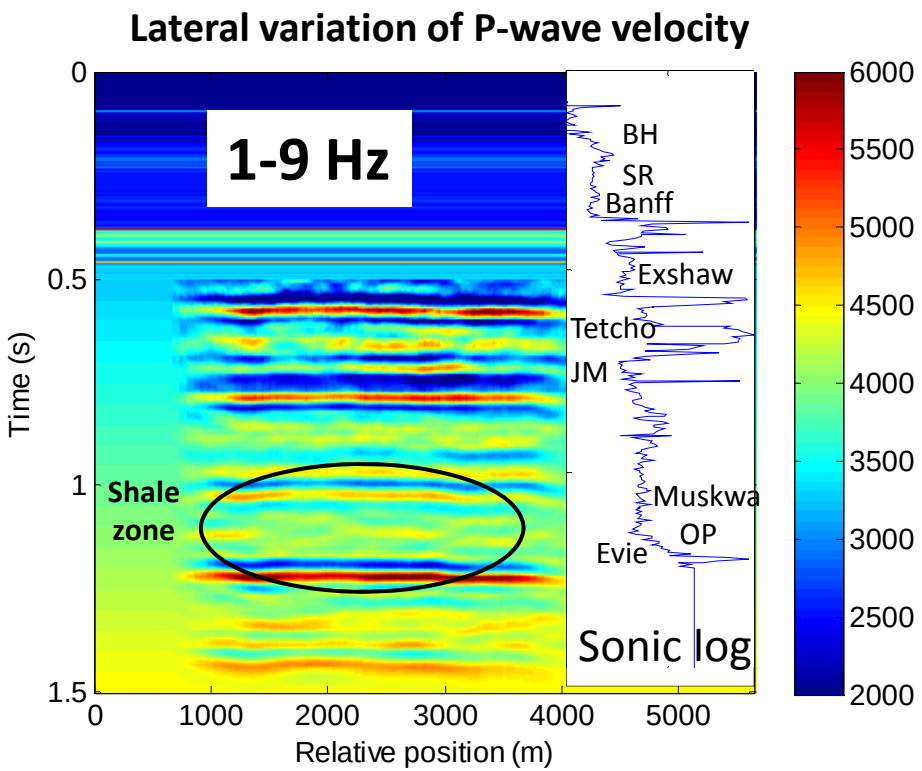
Real data example: P-P and P-Sv Waveform Inversion, NE-BC

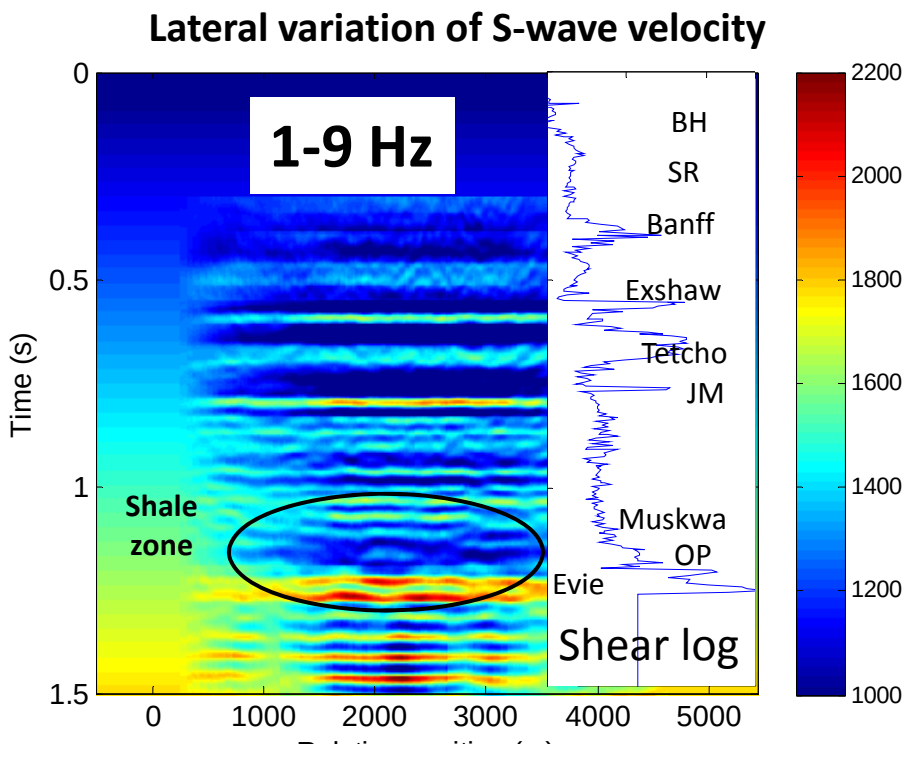




- P- wave Velocity inversion using P-P data for the frequency of **1-5 Hz** (left image)
- S- wave velocity inversion using P-Sv data for the frequency of **1-5 Hz** (right image)

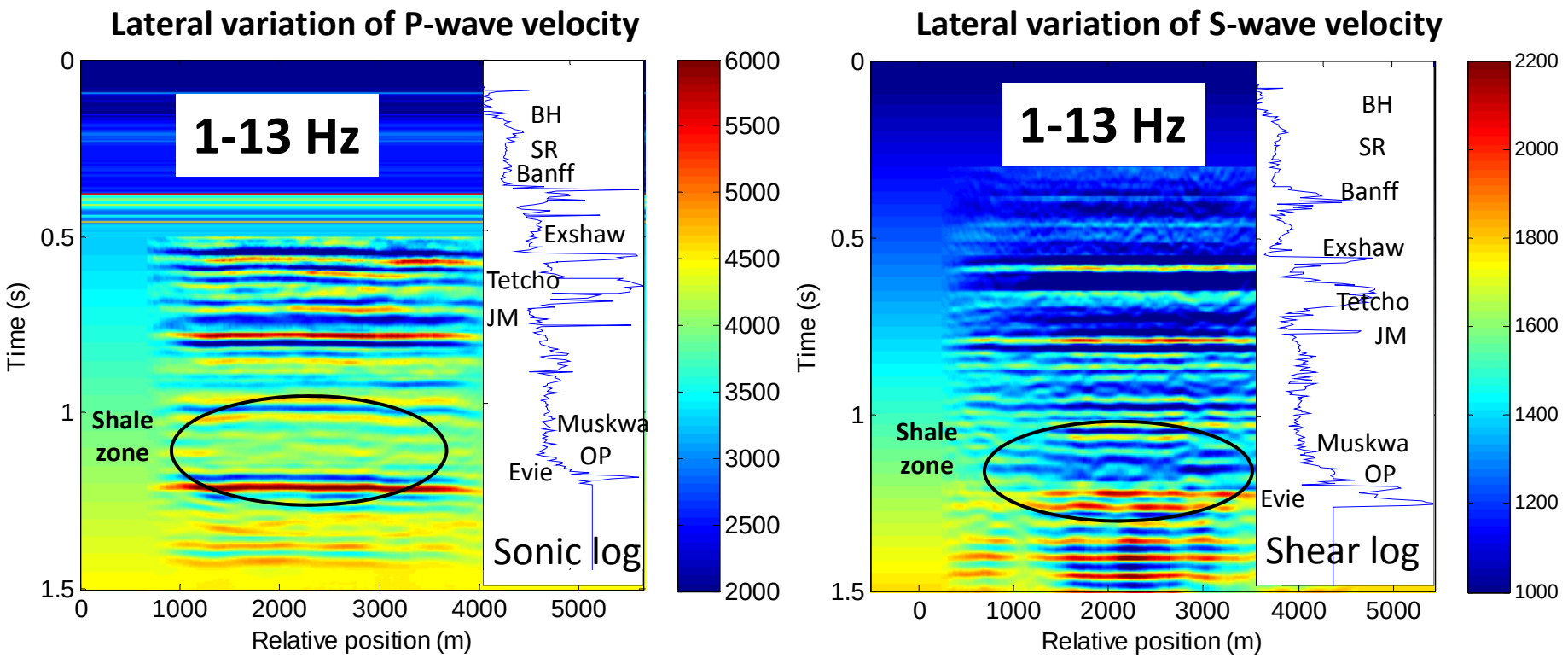
Real data example: P-P and P-Sv Waveform Inversion, NE-BC





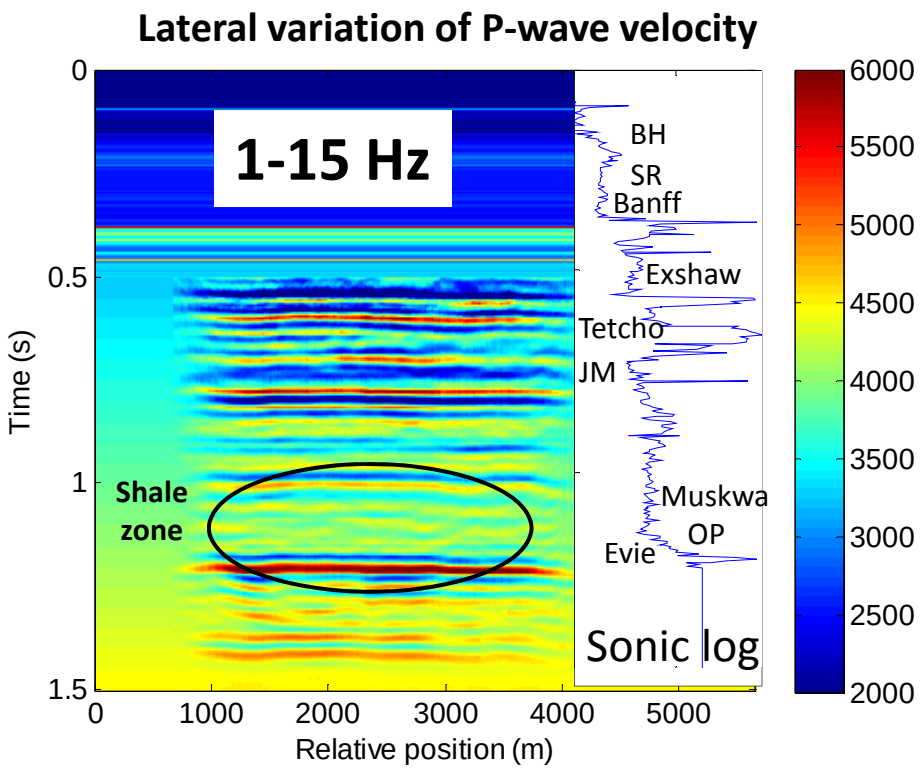
- P- wave Velocity inversion using P-P data for the frequency of **1-9 Hz** (left image)
- S- wave velocity inversion using P-Sv data for the frequency of **1-9 Hz** (right image)

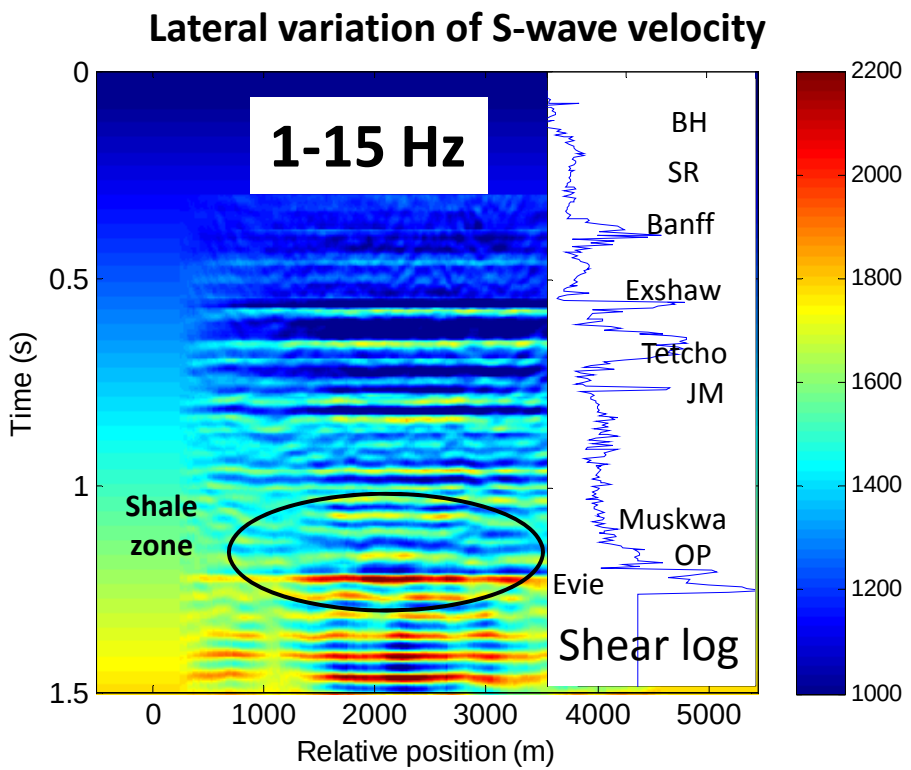
Real data example: P-P and P-Sv Waveform Inversion, NE-BC



- P- wave Velocity inversion using P-P data for the frequency of 1-13 Hz (left image)
- S- wave velocity inversion using P-Sv data for the frequency of 1-13 Hz (right image)

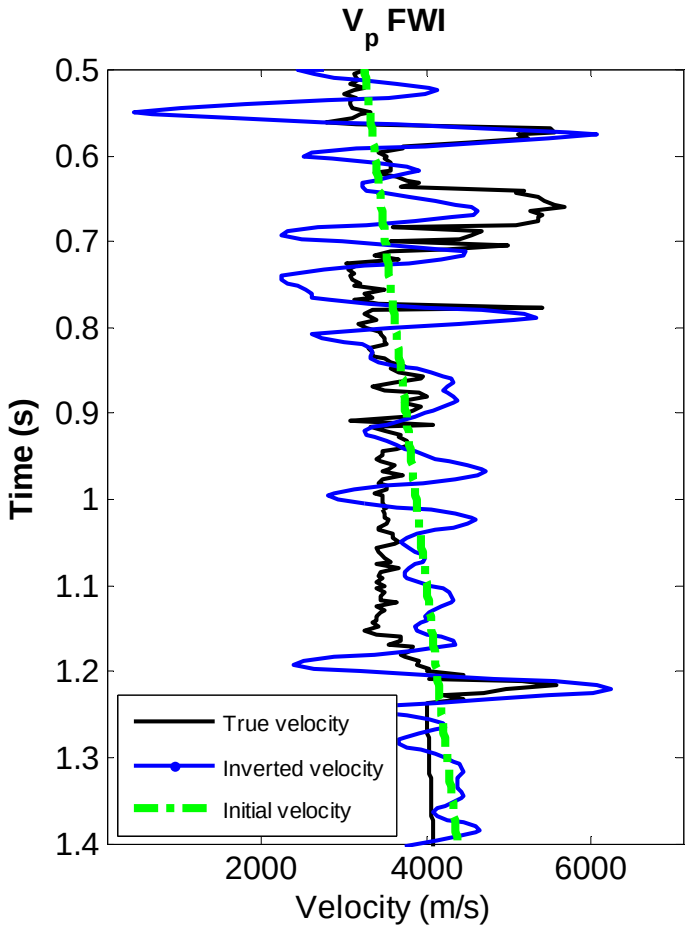
Real data example: P-P and P-Sv Waveform Inversion, NE-BC

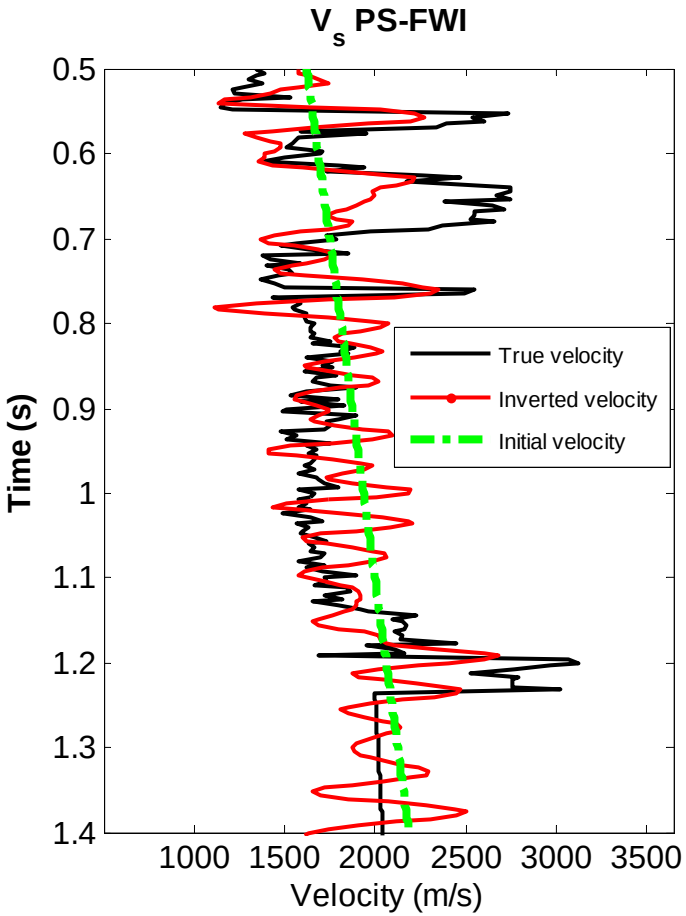




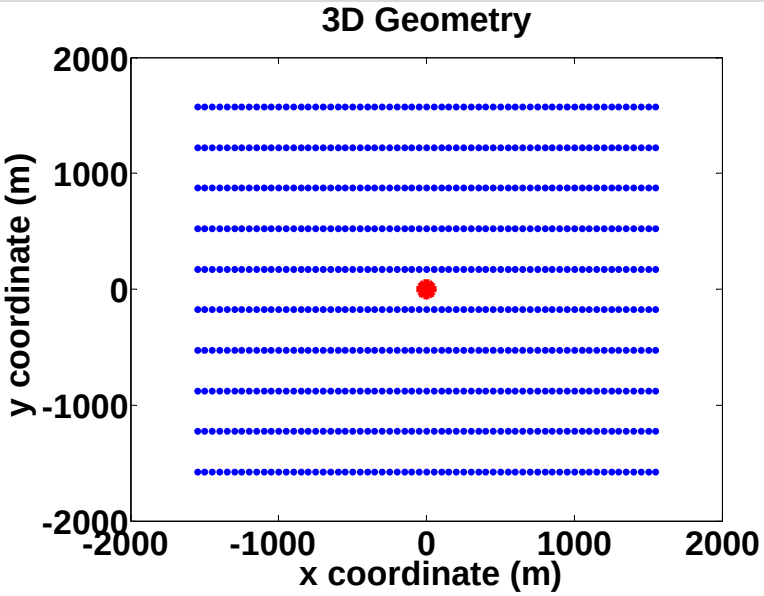
- P- wave Velocity inversion using P-P data for the frequency of **1-13 Hz** (left image)
- S- wave velocity inversion using P-Sv data for the frequency of **1-13 Hz** (right image)

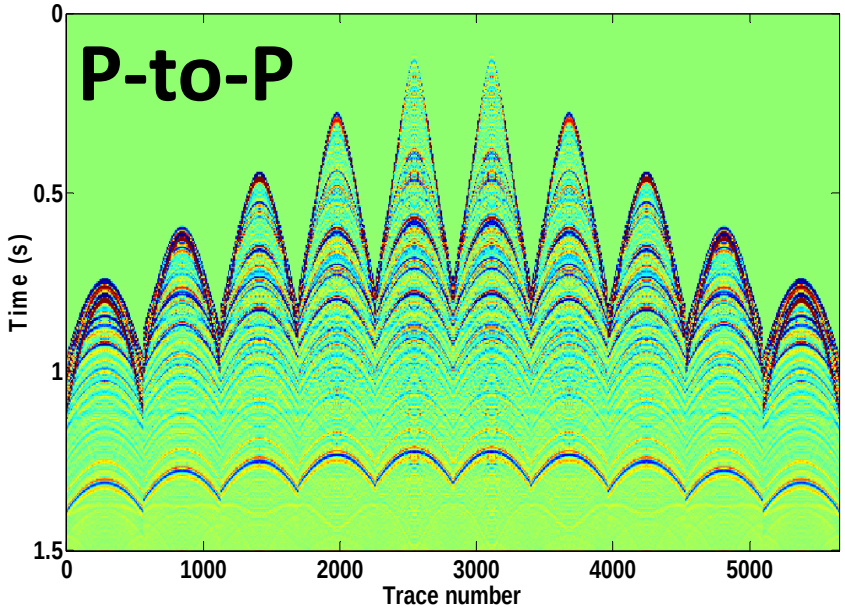
Real data example: P-P and P-Sv Waveform Inversion, NE-BC

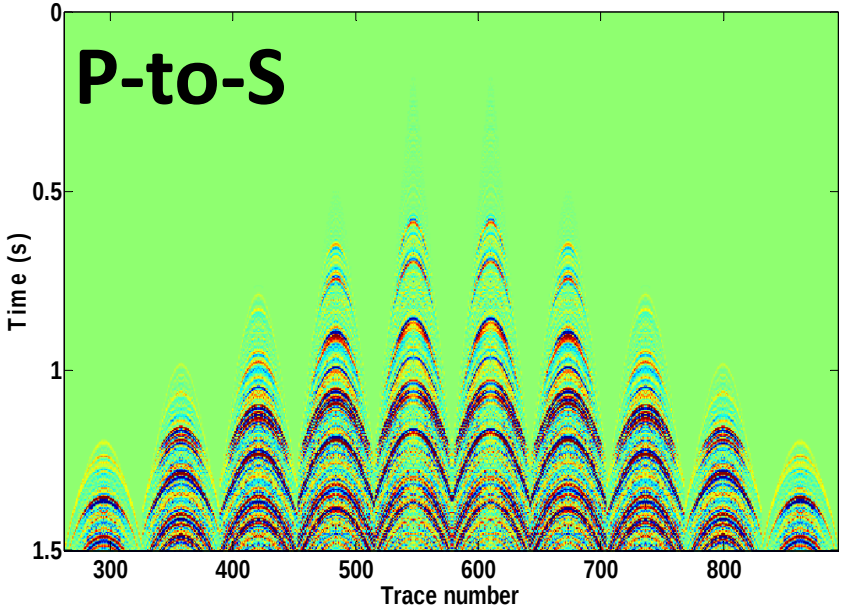




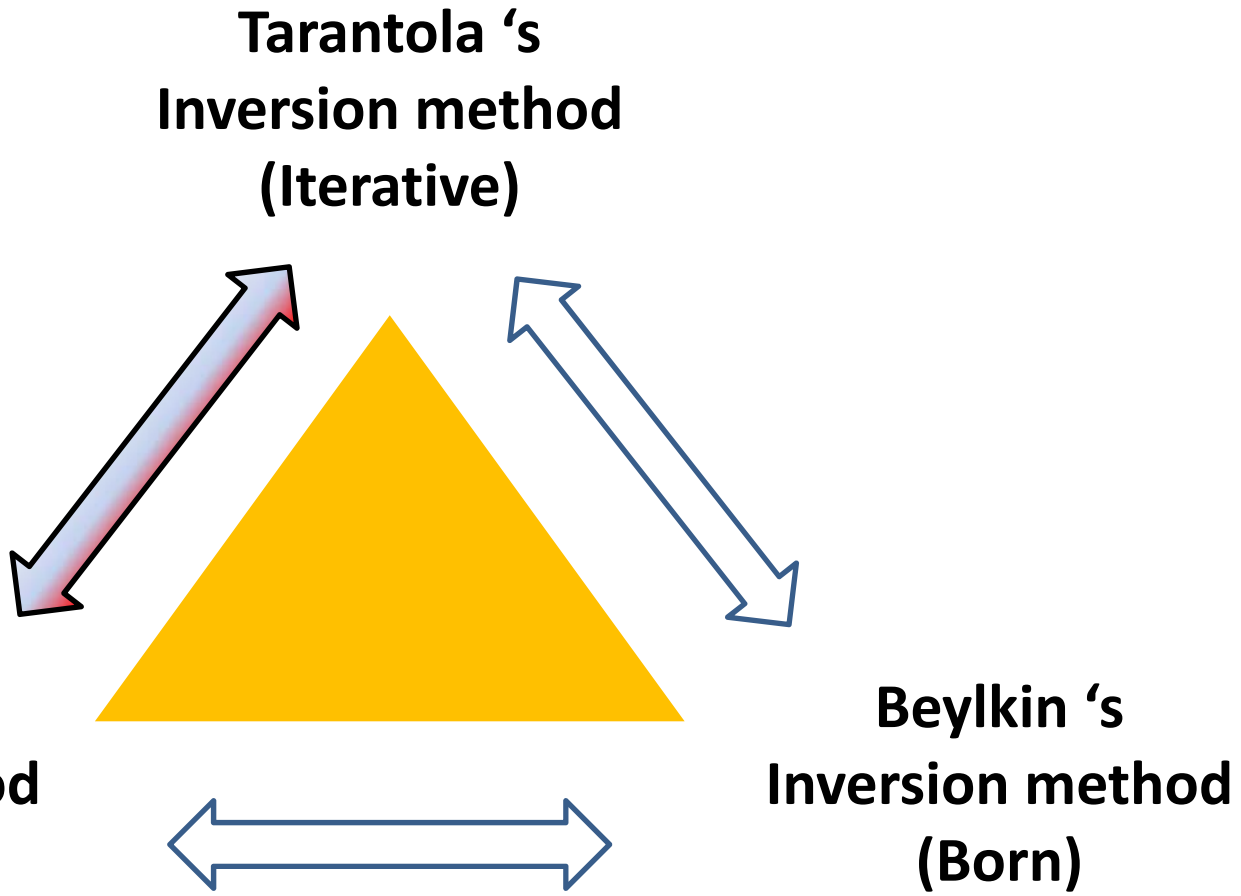
Future work: 3D data inversion







Conclusions…



Conclusions

- ✓ A standard method is developed to perform FWI method in various types of problems
- ✓ The gradient function is provided by conventional AVO inversion methods
- ✓ Fast and practical

Acknowledgments

- CREWES Faculty and Sponsors
- Nexen Energy ULC.
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THANK YOU !