

Fast Waveform Inversion Strategies Applied to Hussar

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Rob Ferguson

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- Introduction to FWI
- Fast Waveform Inversion (FastWI)
 - Gradient
 - Well calibration
- Synthetic test 1: Simple Model
- Synthetic test 2: Marmousi
- Hussar Survey
- Processing Flow
- FastWI applied to Hussar
- Conclusions

Introduction to FWI

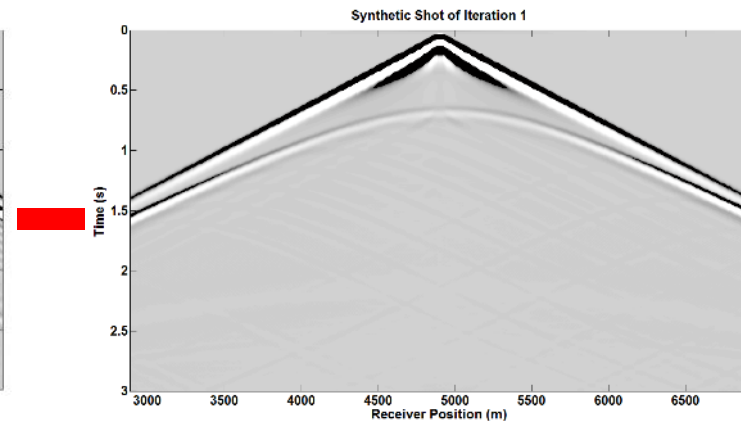
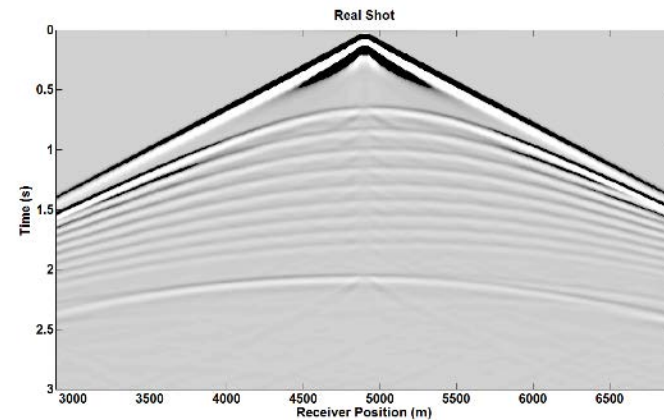
Least Squares



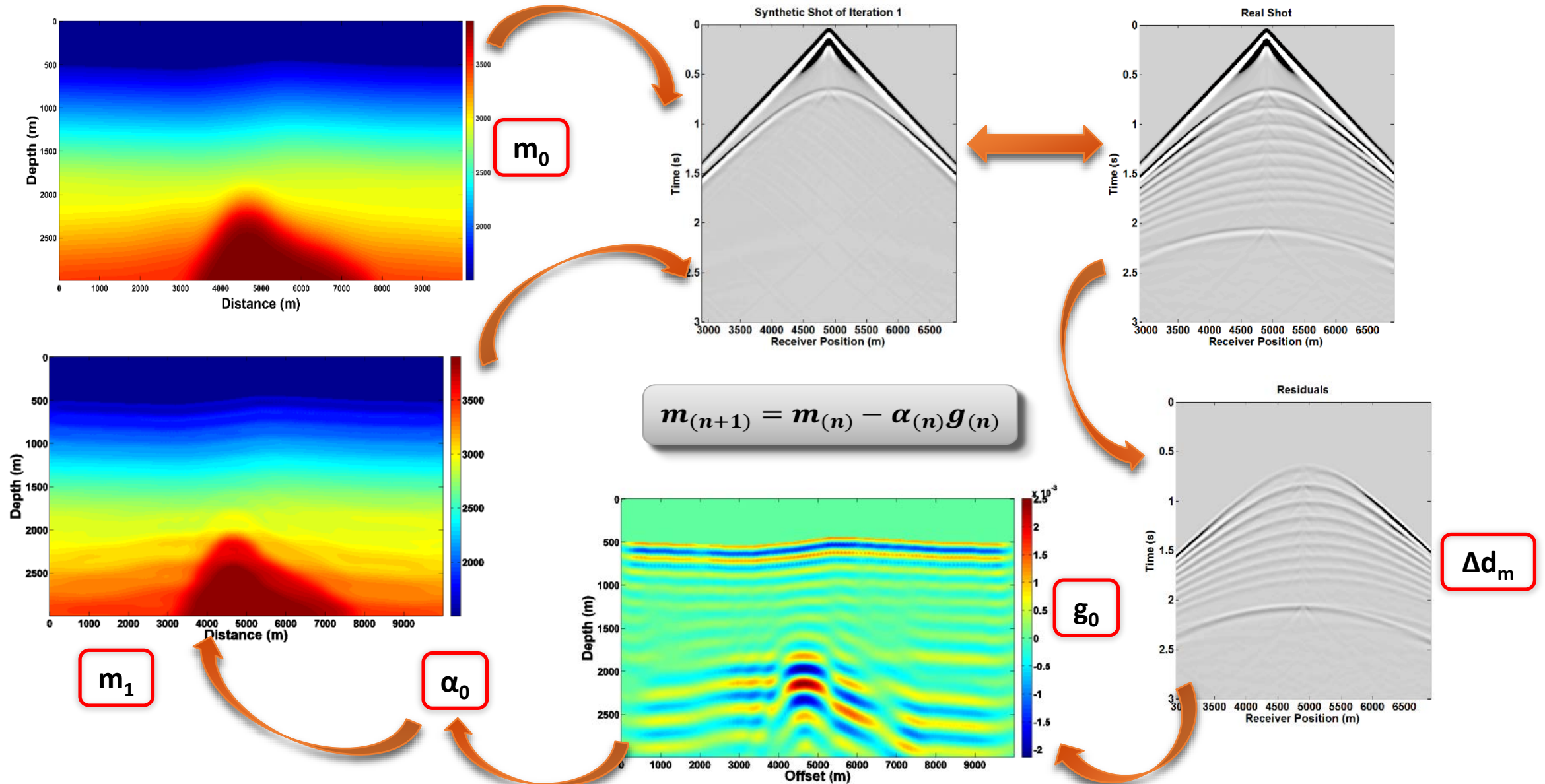
Minimize $C(m) \equiv \|\Delta d_m\|^2$



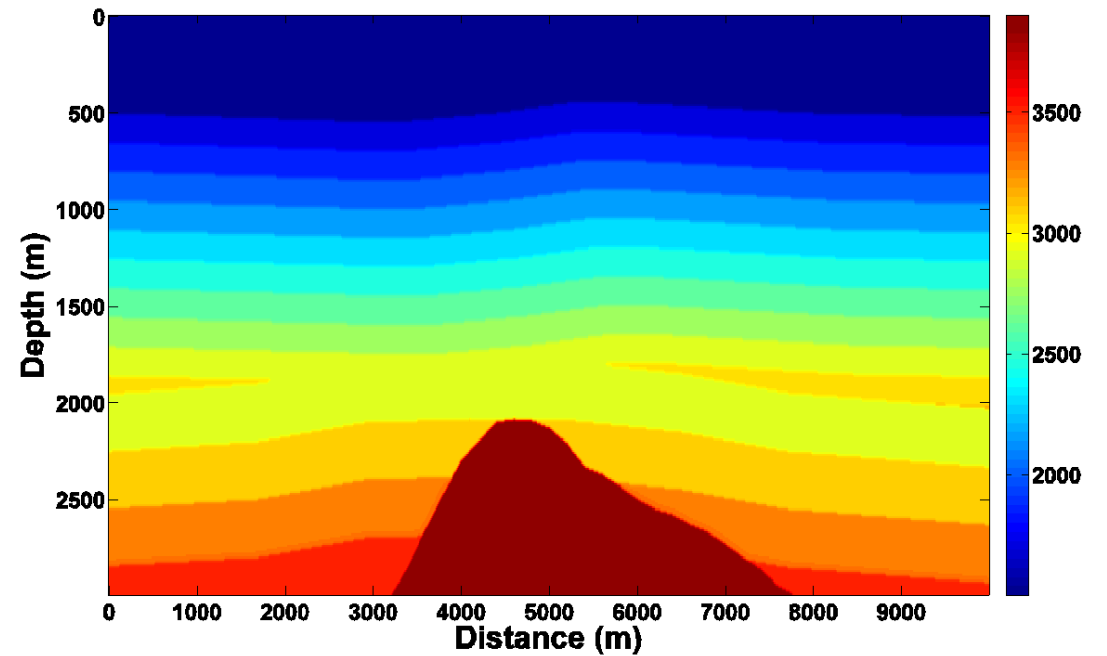
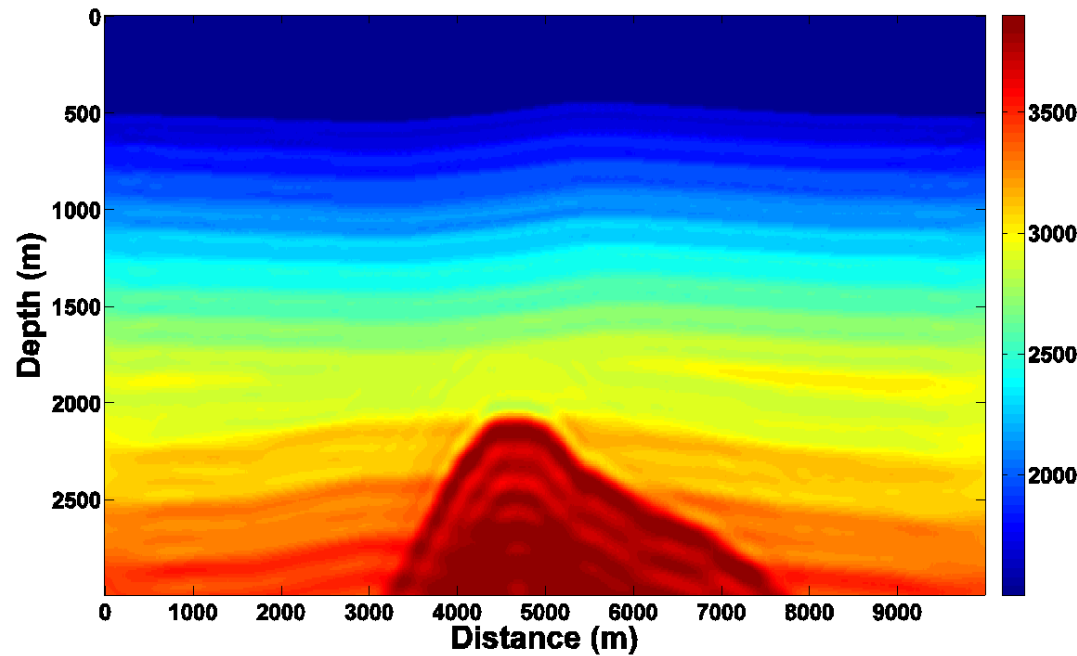
$d_{obs} - d_{syn}$



Introduction to FWI



Introduction to FWI



Fast Waveform Inversion (FastWI): Gradient

- Based on the FWI steepest-descent method
- Gradient: seismic processing tools

$$\mathbf{m}_{n+1} = \mathbf{m}_n - \alpha_n I \{S [M (\mathbf{d}_0 - \mathbf{d}_n)]\}$$

- Linear operators

$$\mathbf{m}_{n+1} = \mathbf{m}_n - \alpha_n (I \{S [M (\mathbf{d}_0)]\} - \underbrace{I \{S [M (\mathbf{d}_n)]\}}_{\text{Current Model}})$$



$$\mathbf{m}_{n+1} = \mathbf{m}_n - \alpha_n (I \{S [M (\mathbf{d}_0)]\} - \mathbf{m}_n)$$

Fast Waveform Inversion (FastWI): Gradient

- Commuting the migration and stacking operators

$$\mathbf{m}_{n+1} = \mathbf{m}_n - \alpha_n (I \{ S [M (\mathbf{d}_0)] \} - \mathbf{m}_n)$$

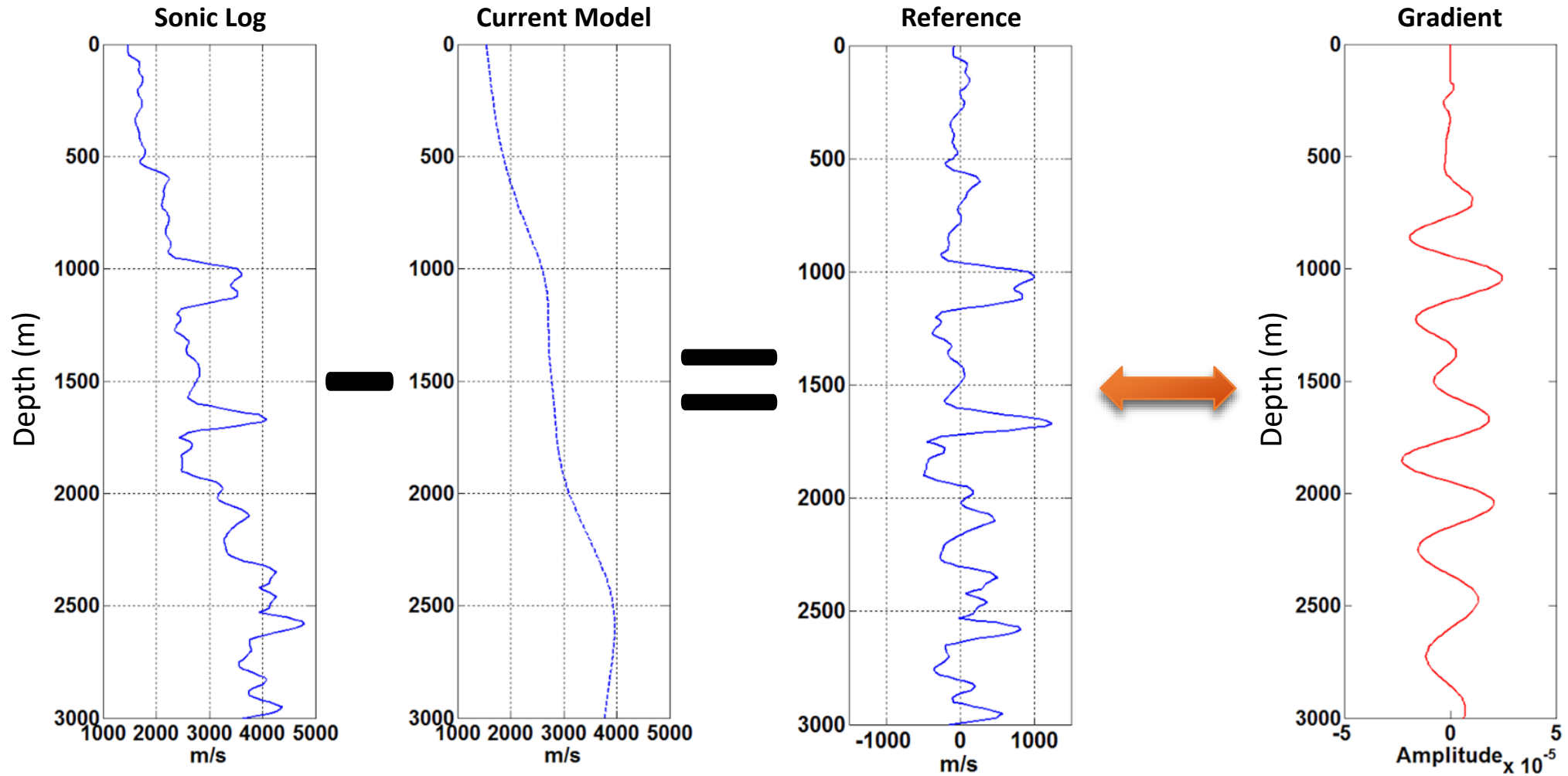


$$\mathbf{m}_{n+1} = \mathbf{m}_n - \alpha_n (I \{ M [S (\mathbf{d}_0)] \} - \mathbf{m}_n)$$

Subsurface image

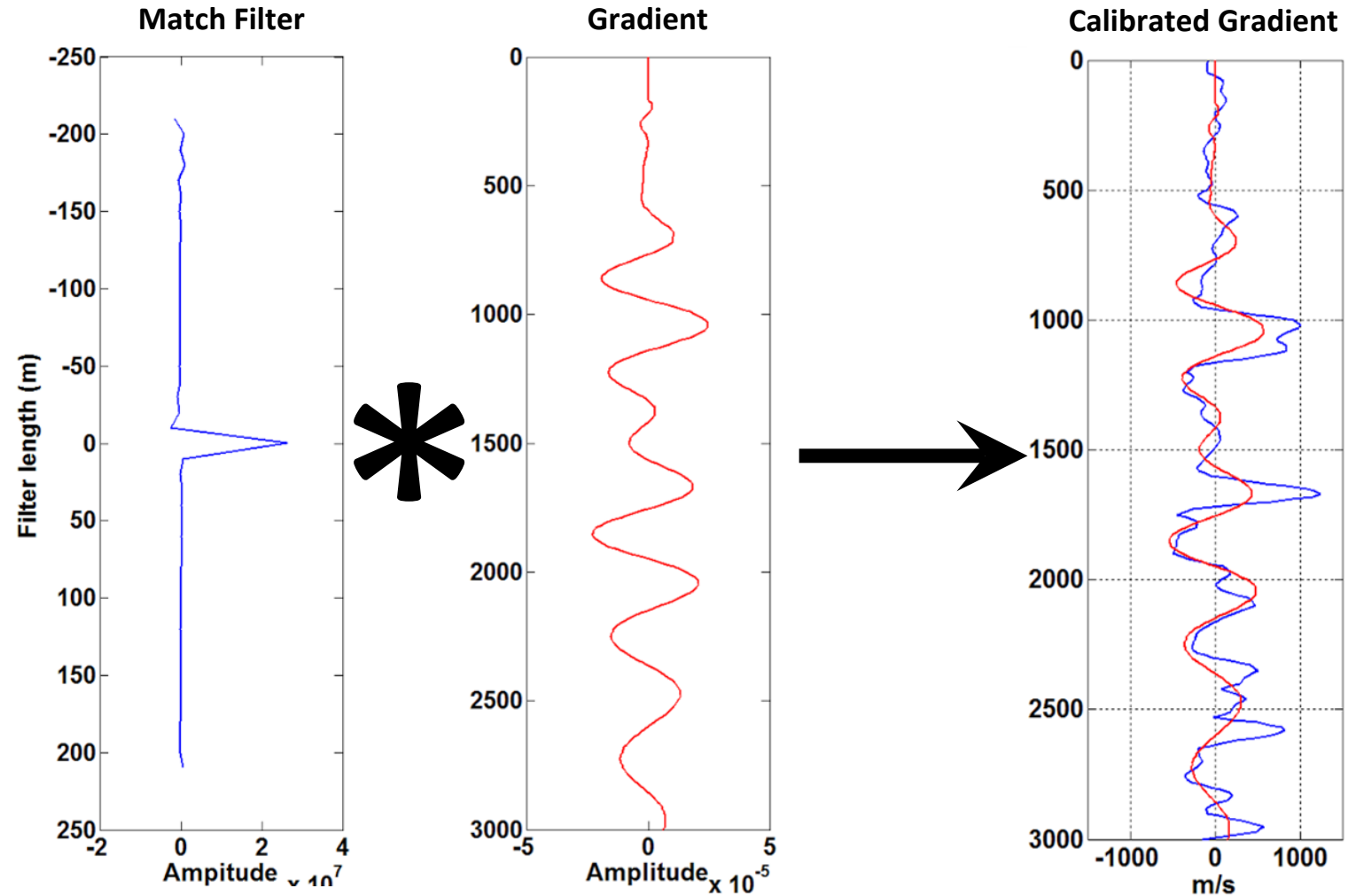
- Post-stack depth migration
- RTM or zero-offset PSPI

Fast Waveform Inversion (FastWI): Well Calibration

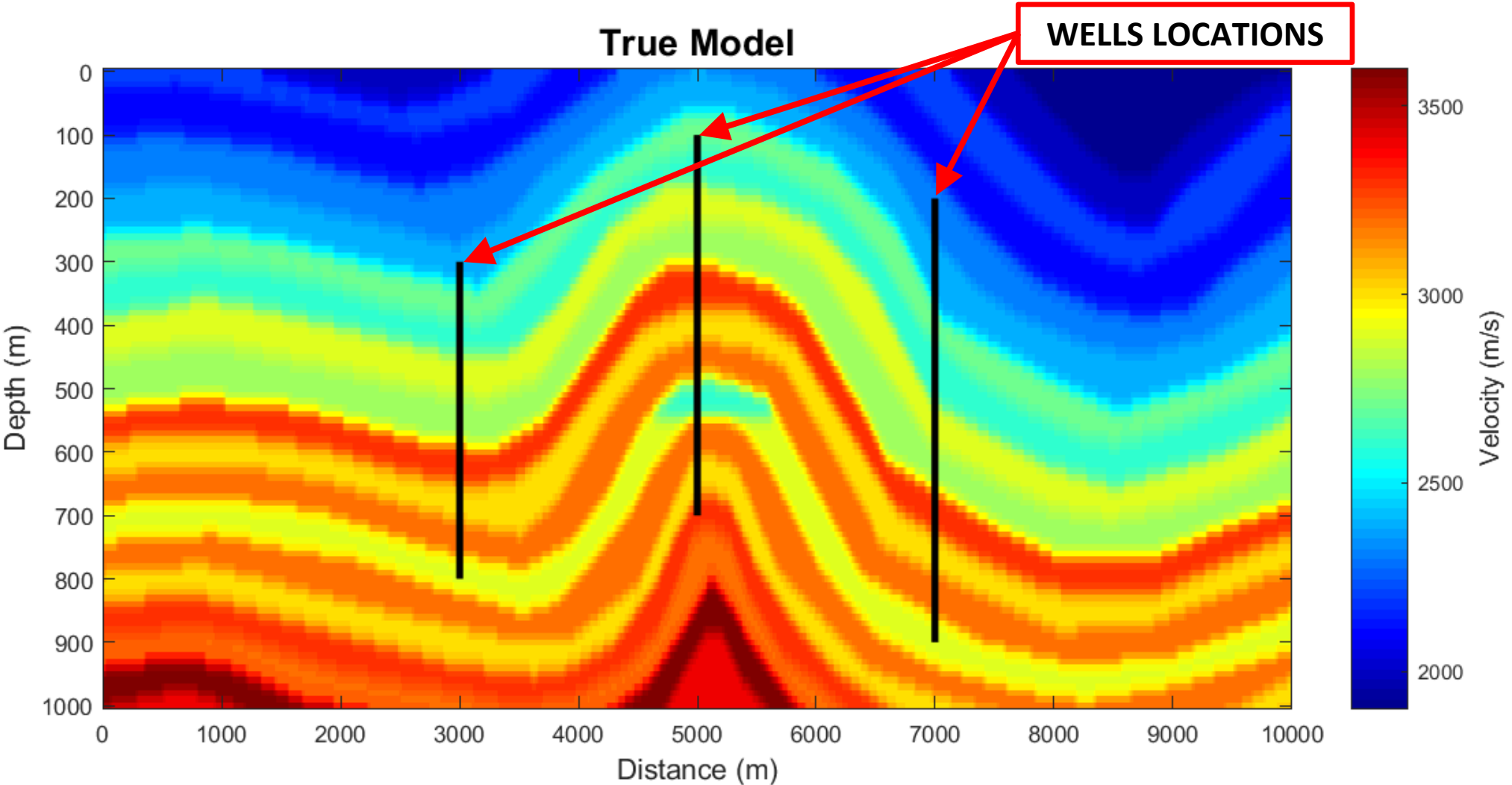


Fast Waveform Inversion (FastWI): Well Calibration

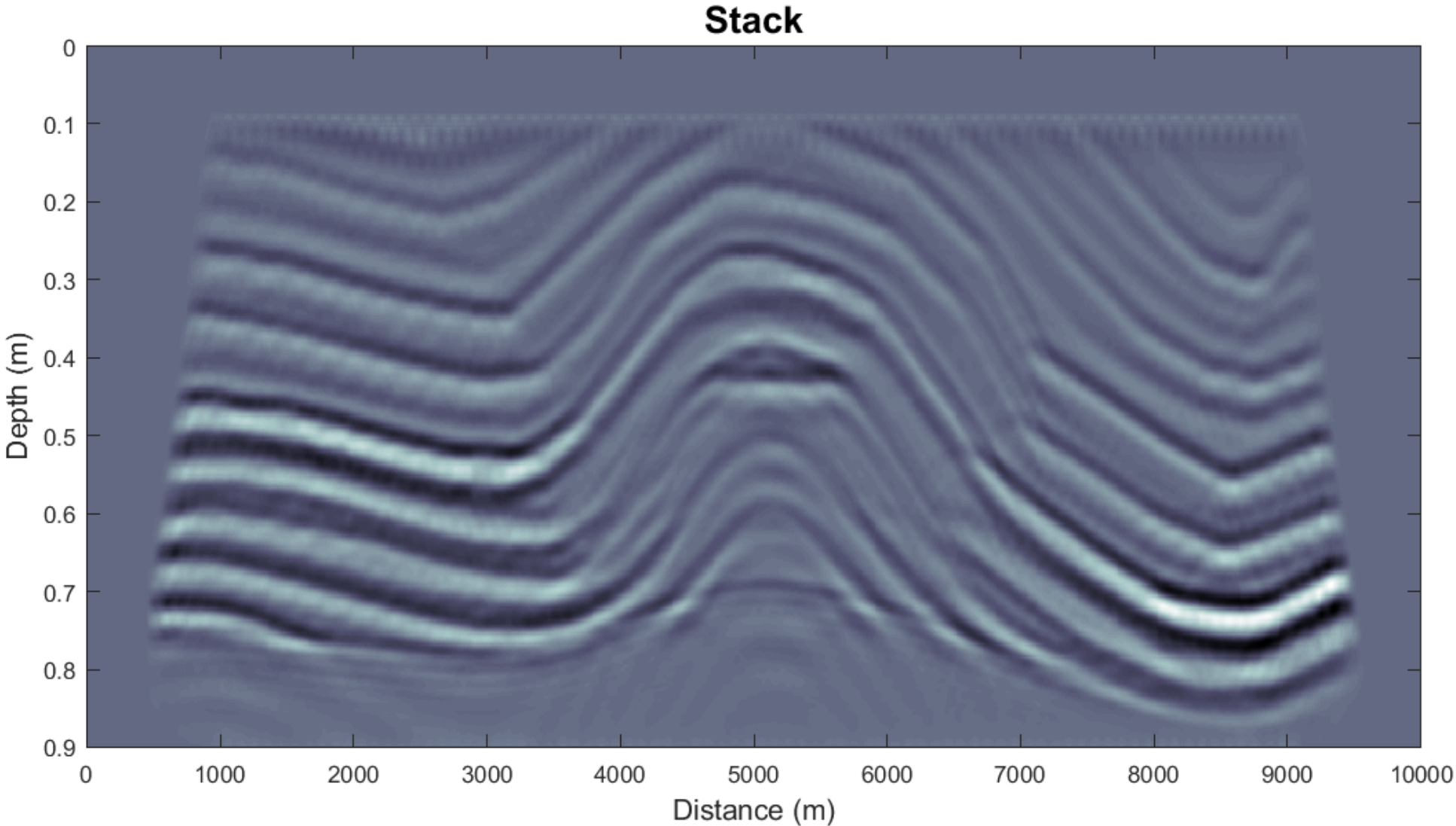
- Minimize amplitude difference
- Minimize phase difference
- Compute a match filter
- Convolve with the gradient



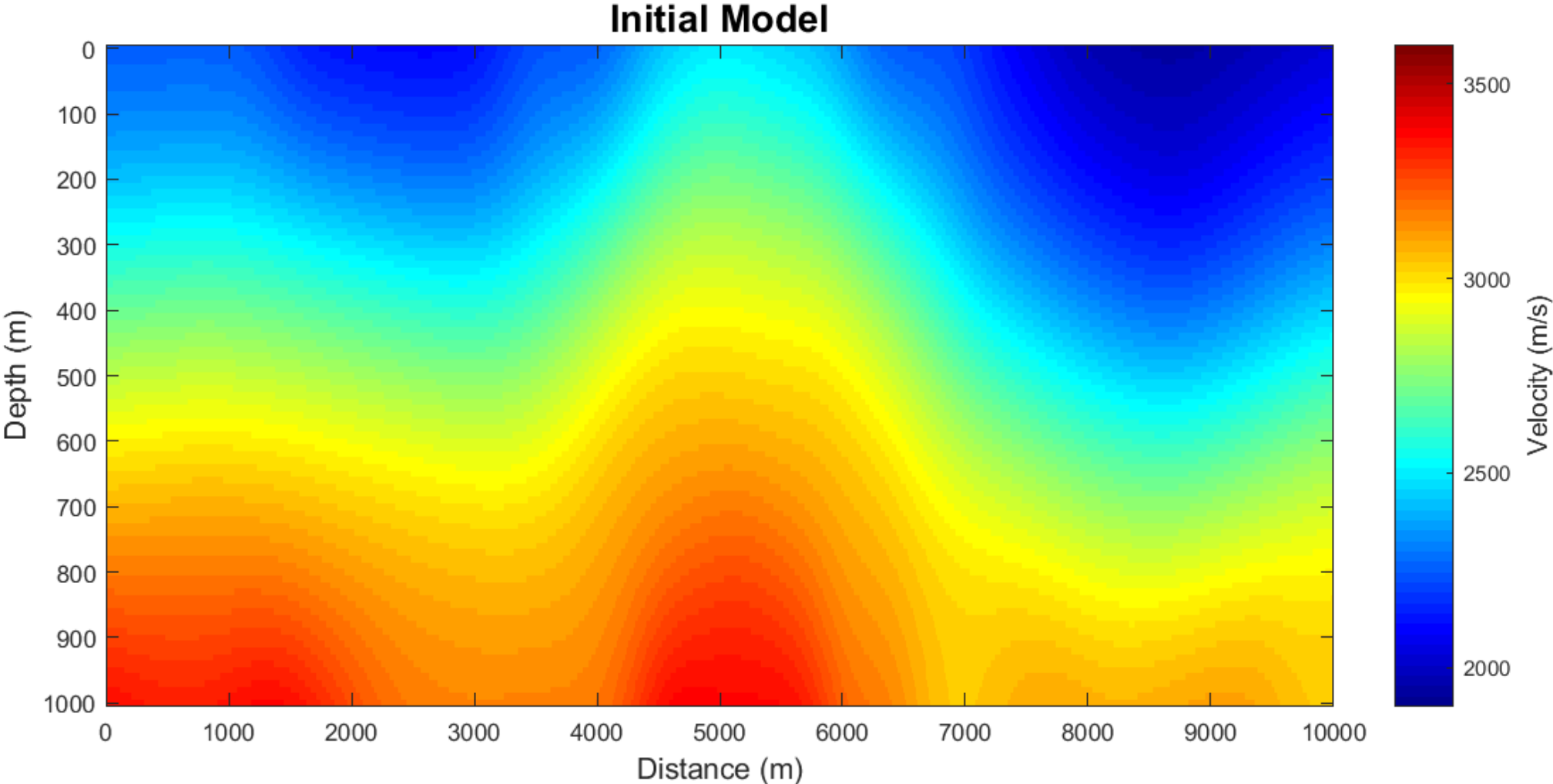
Synthetic Test 1: Simple Model



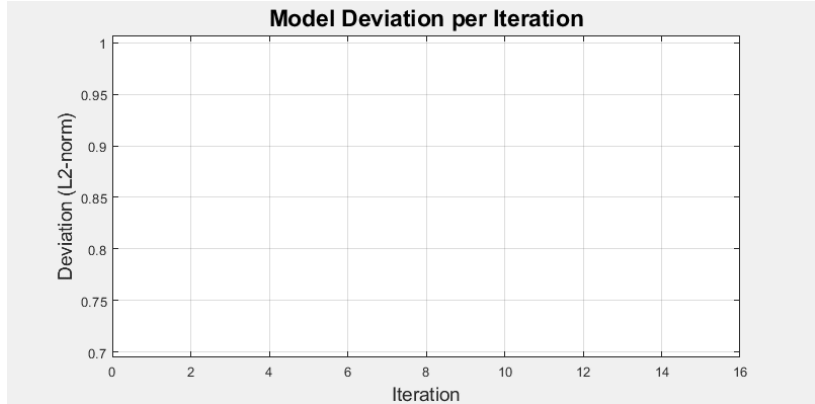
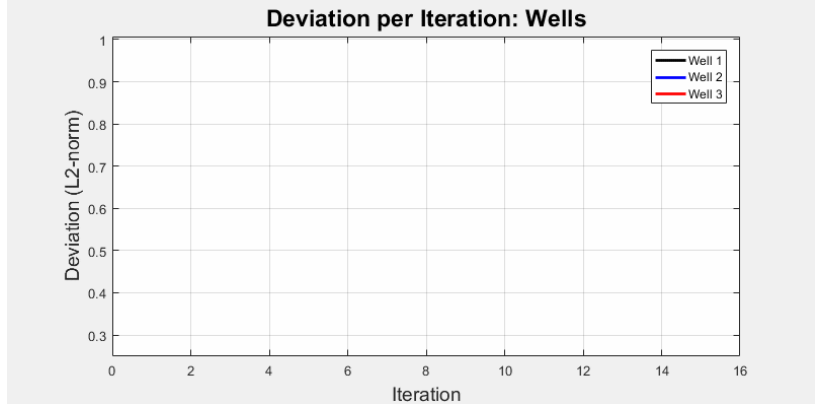
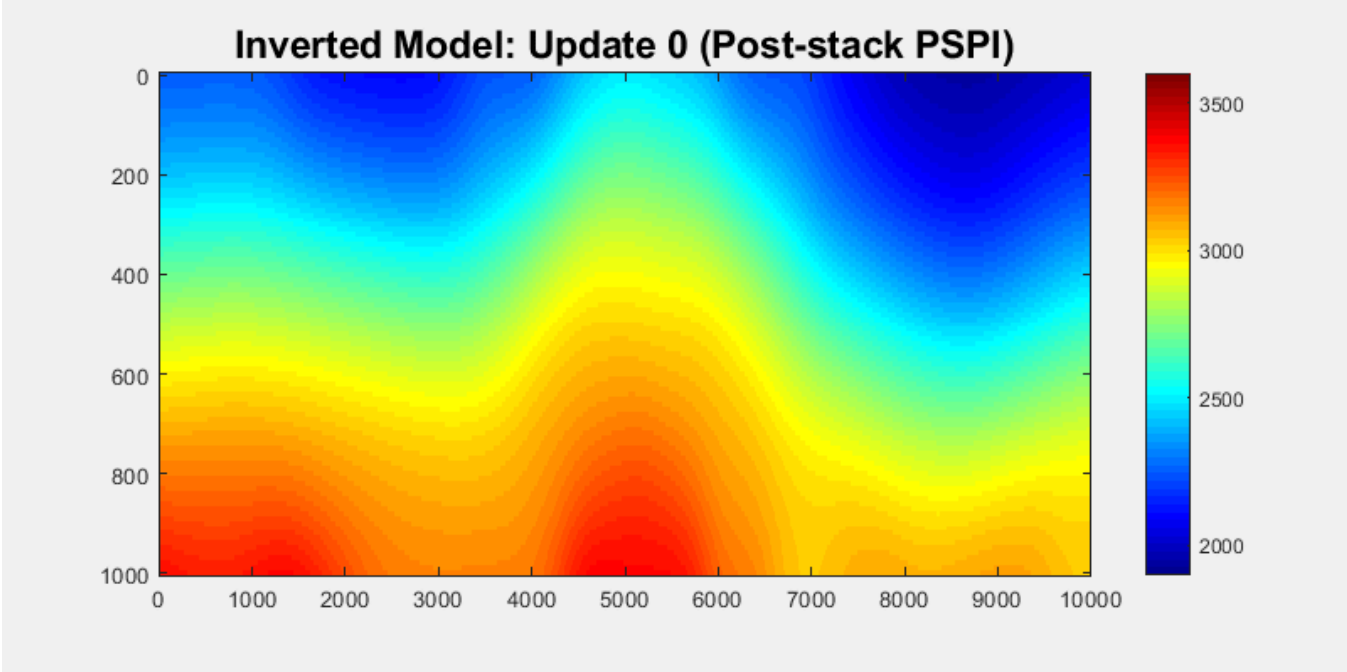
Synthetic Test 1: Simple Model



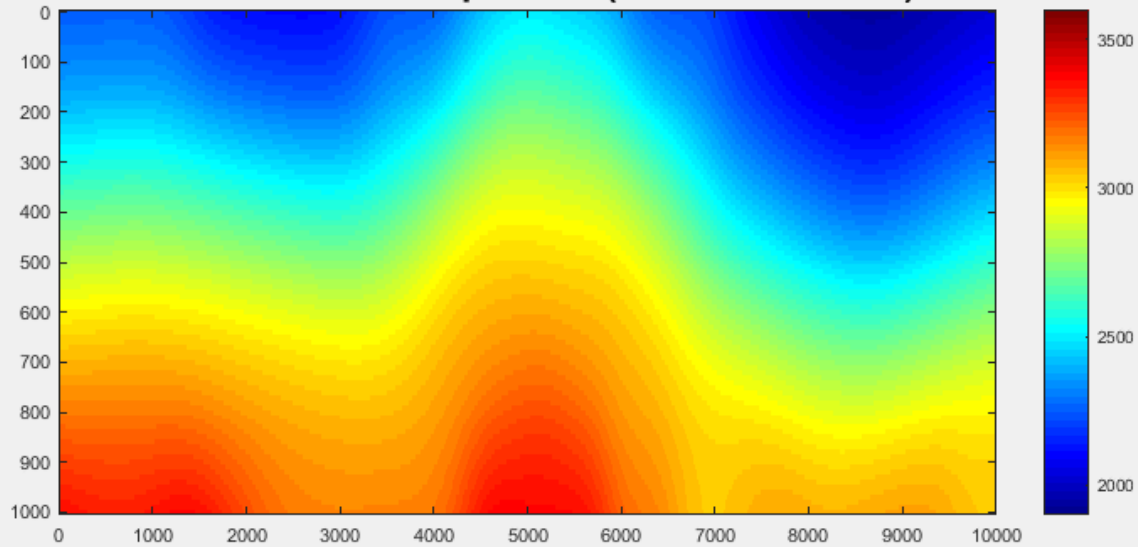
Synthetic Test 1: Simple Model



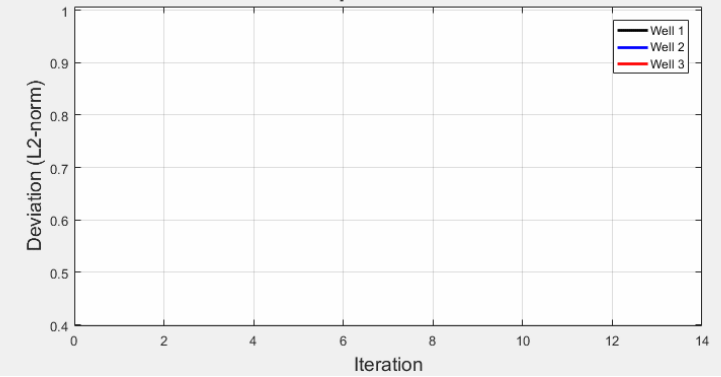
Synthetic Test 1: Simple Model



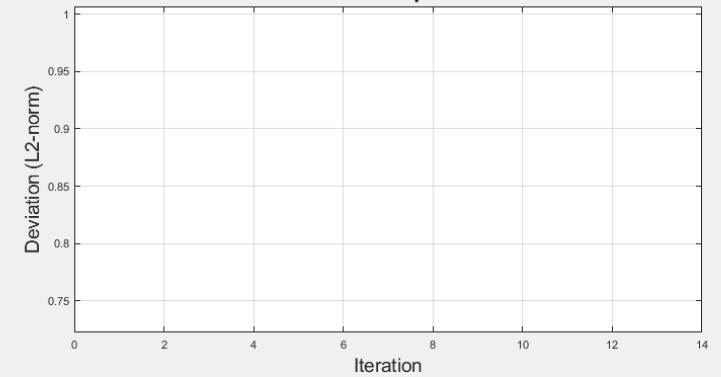
Inverted Model: Update 0 (Post-stack RTM)



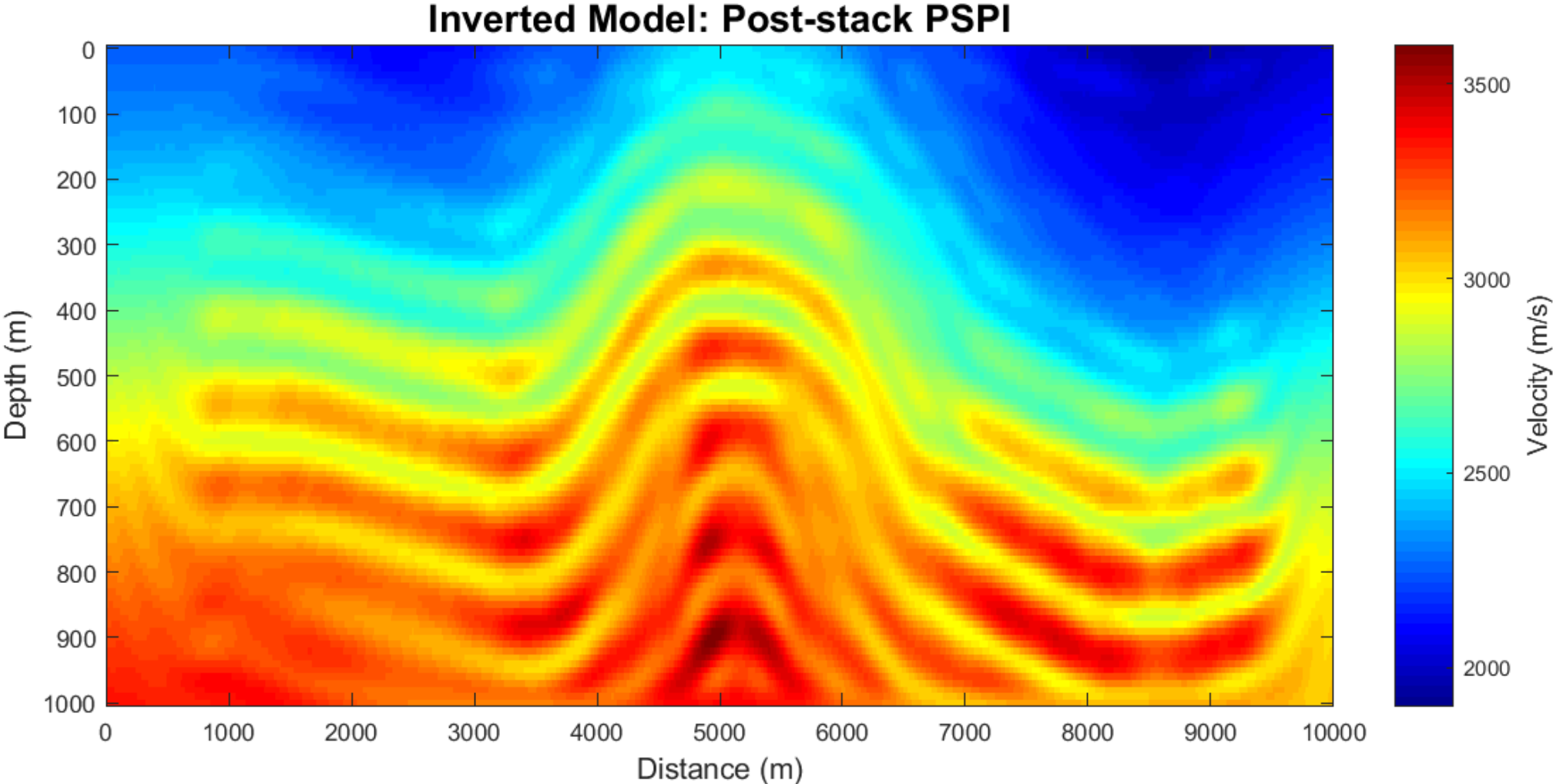
Deviation per Iteration: Wells



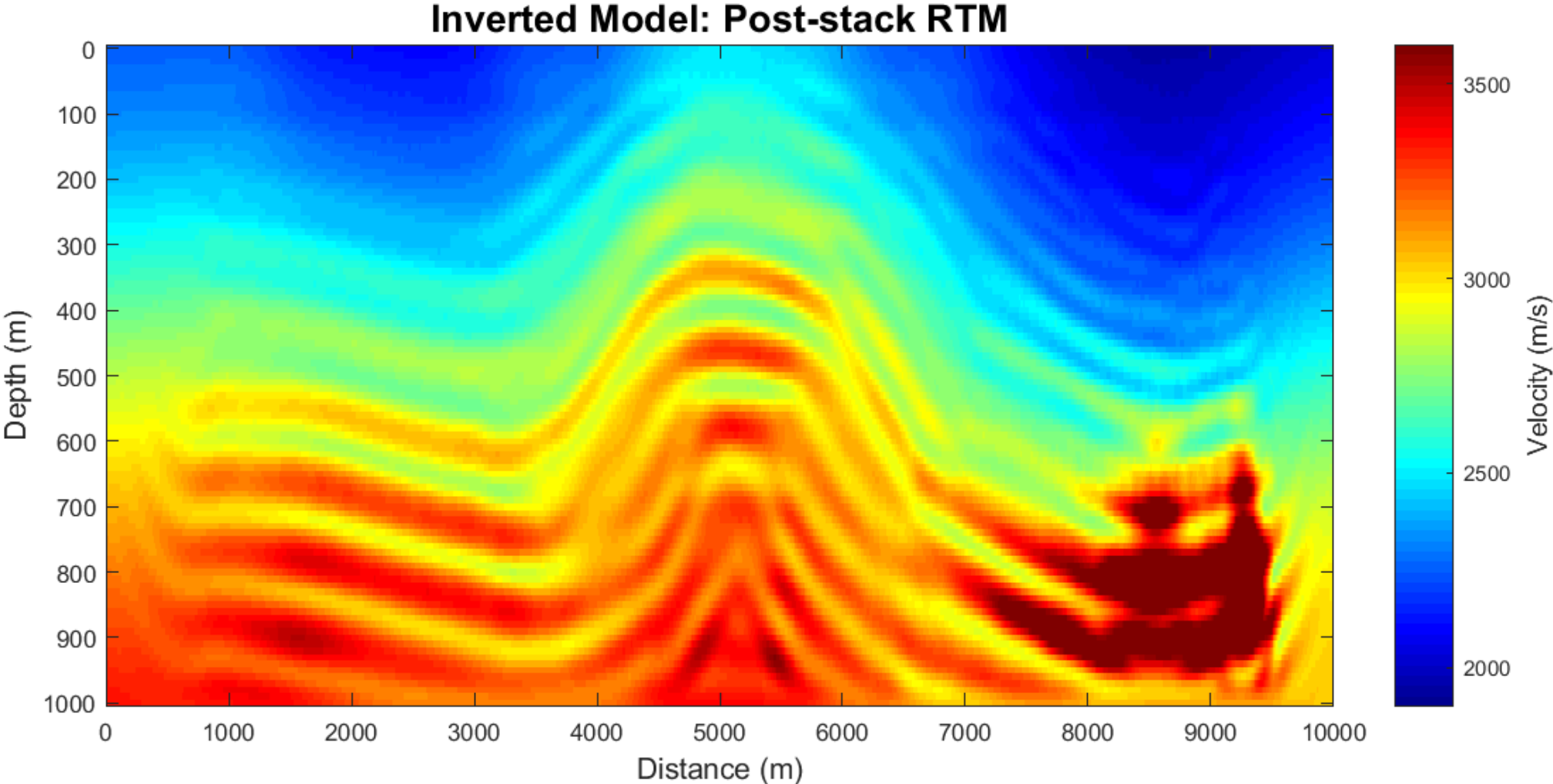
Model Deviation per Iteration



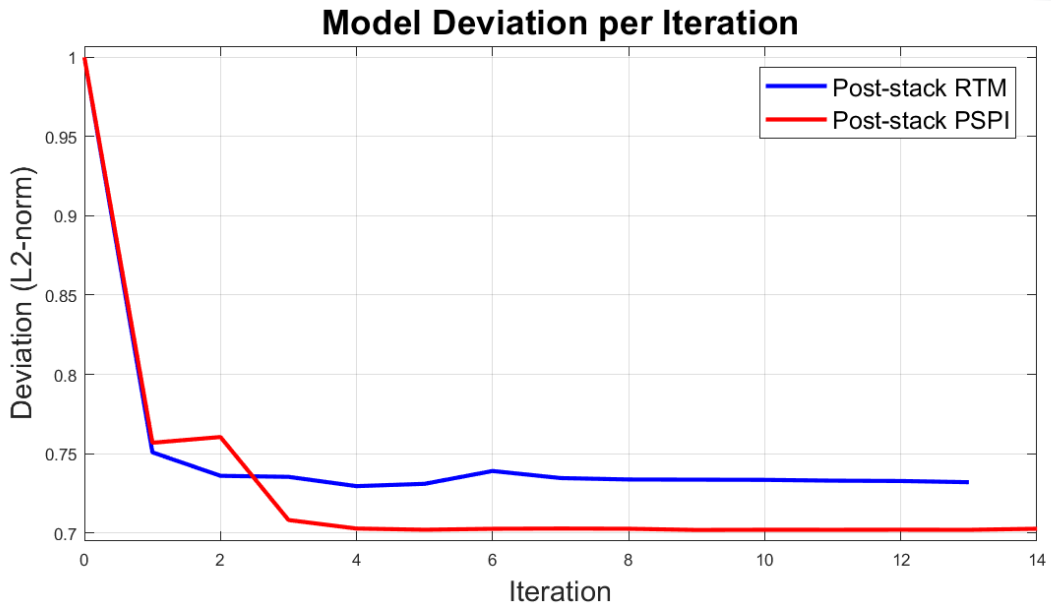
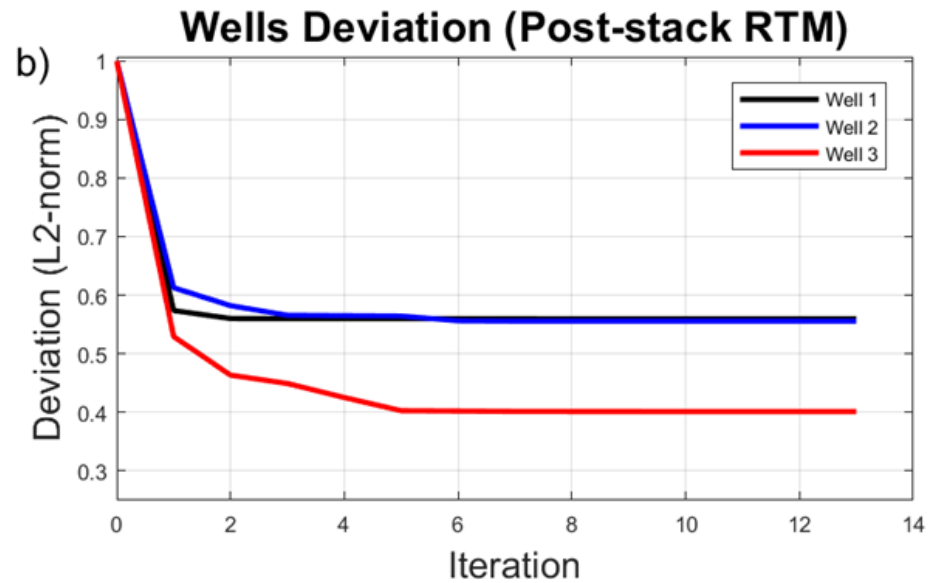
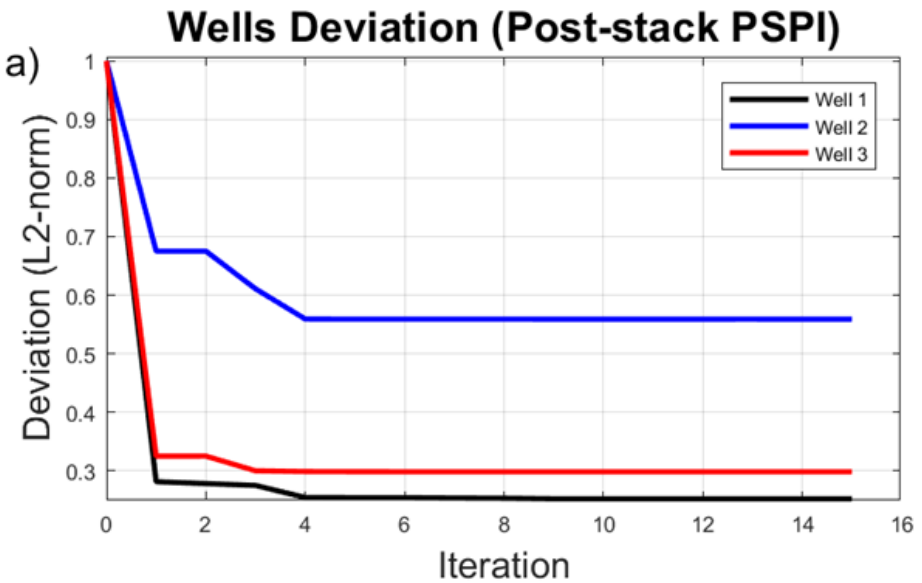
Synthetic Test 1: Simple Model



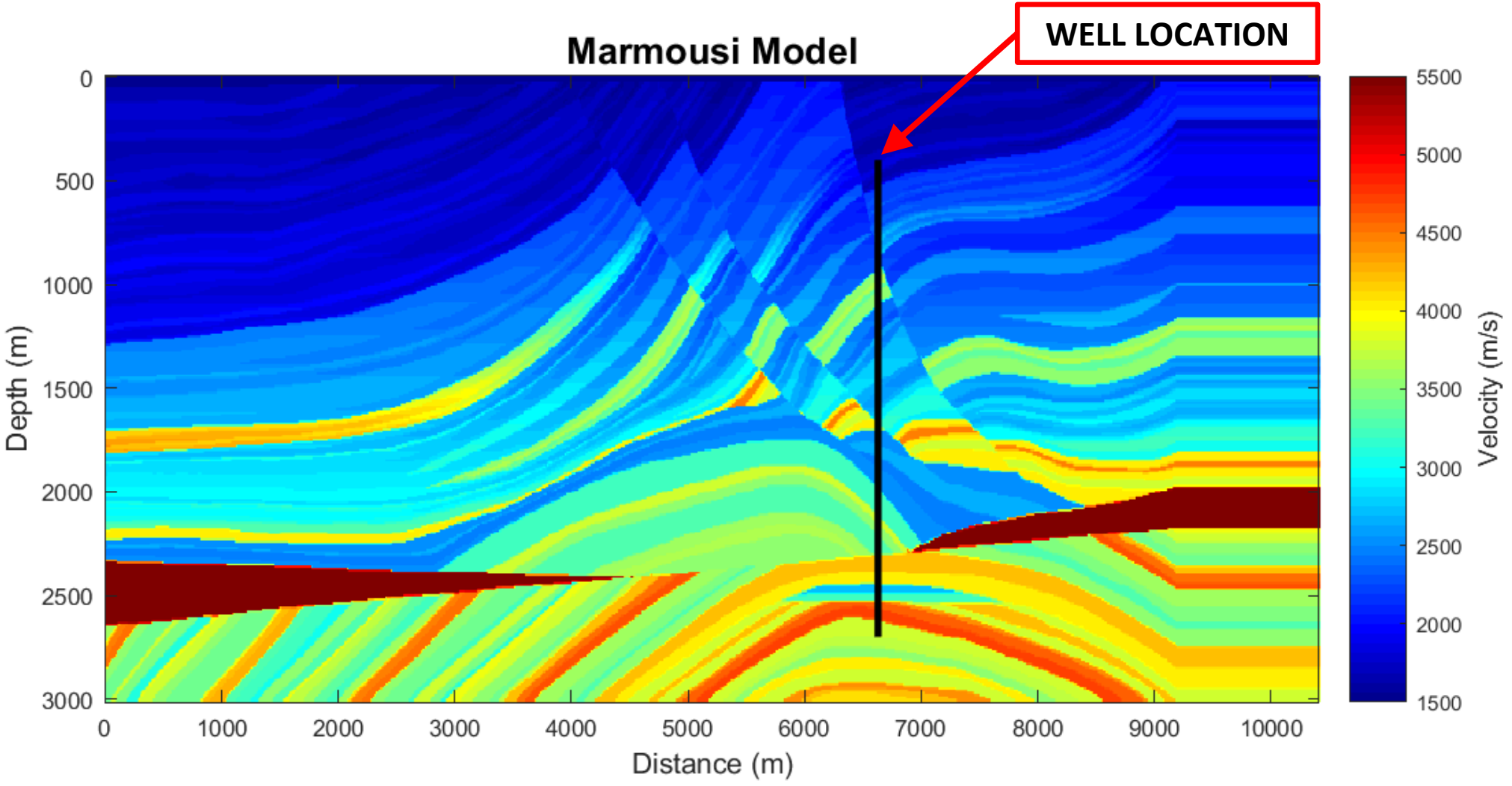
Synthetic Test 1: Simple Model



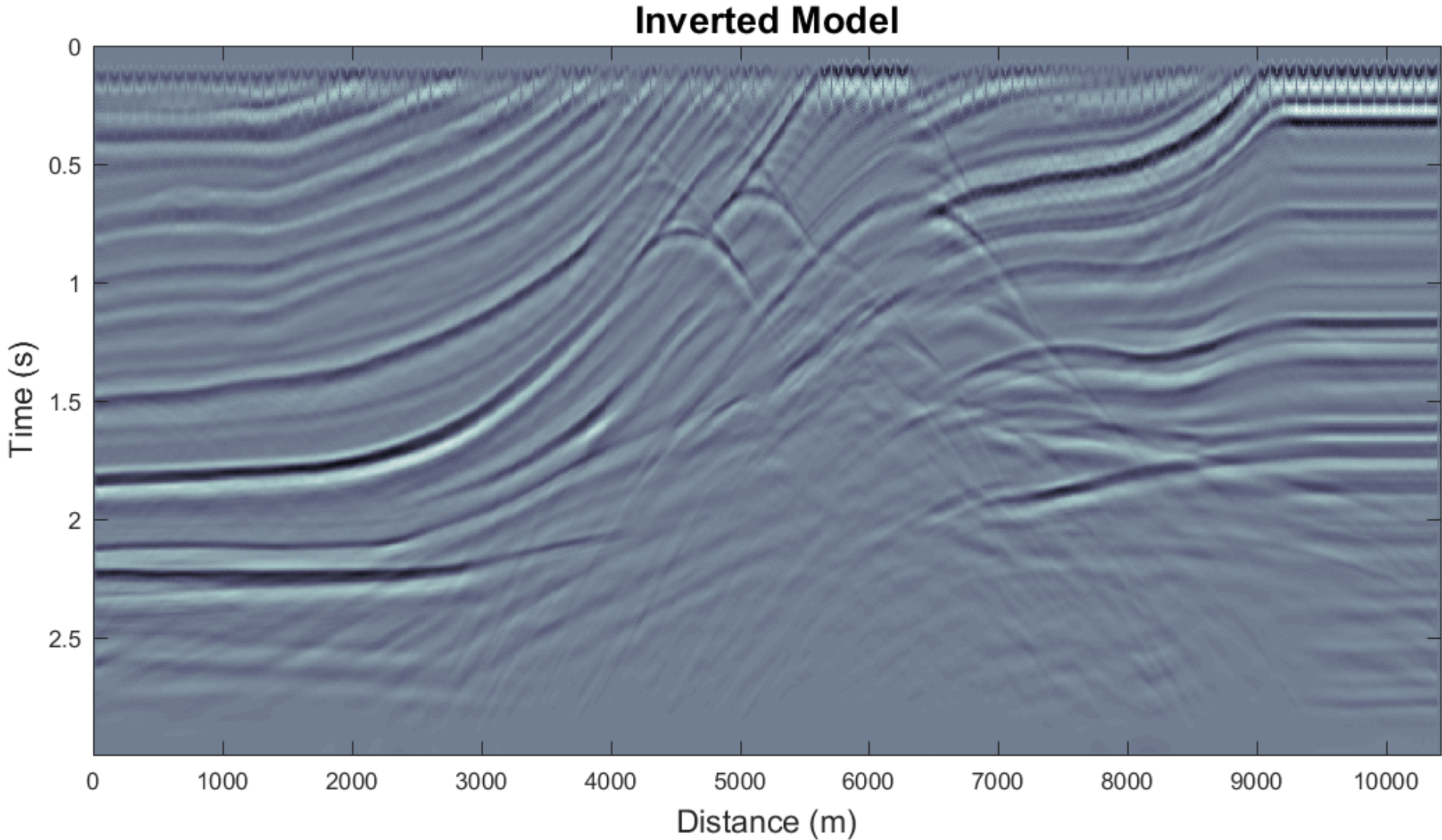
Synthetic Test 1: Simple Model



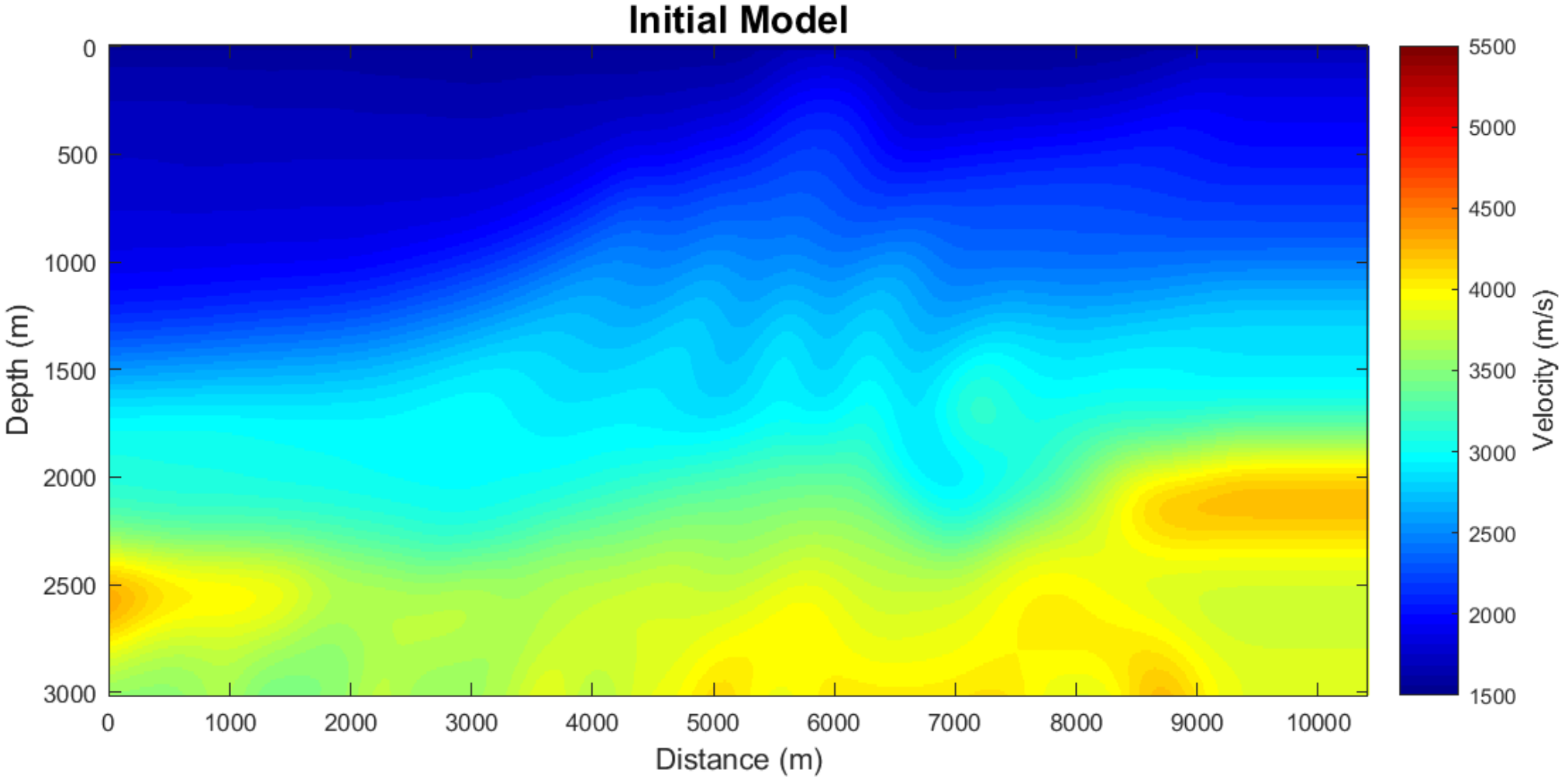
Synthetic Test 2: Marmousi



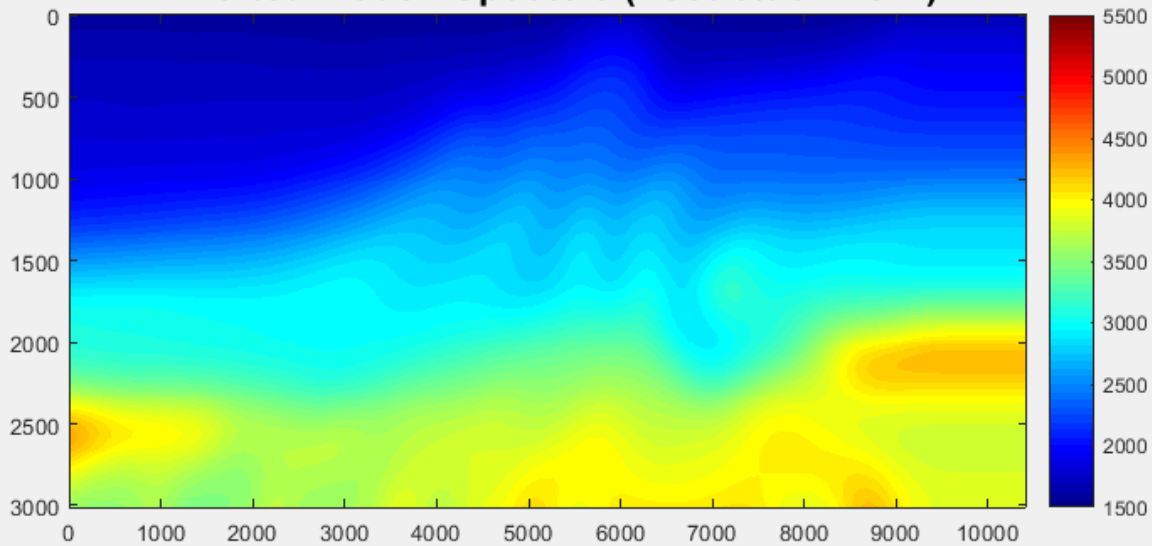
Synthetic Test 2: Marmousi



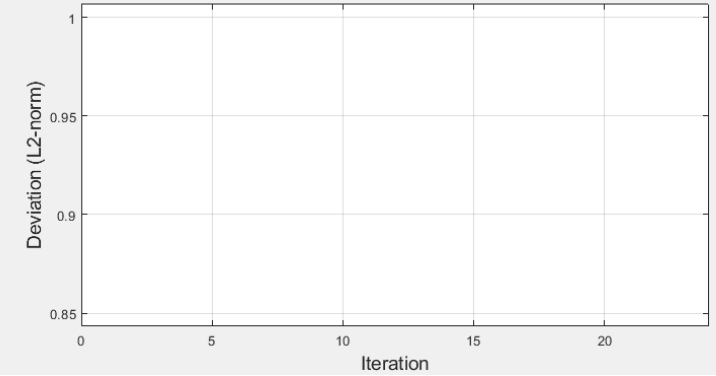
Synthetic Test 2: Marmousi



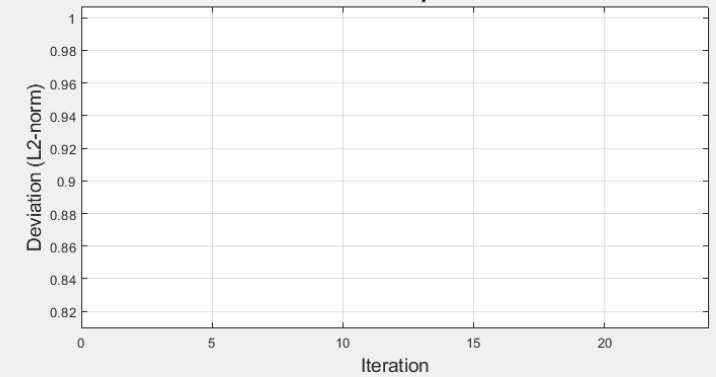
Inverted Model: Update 0 (Post-stack PSPI)



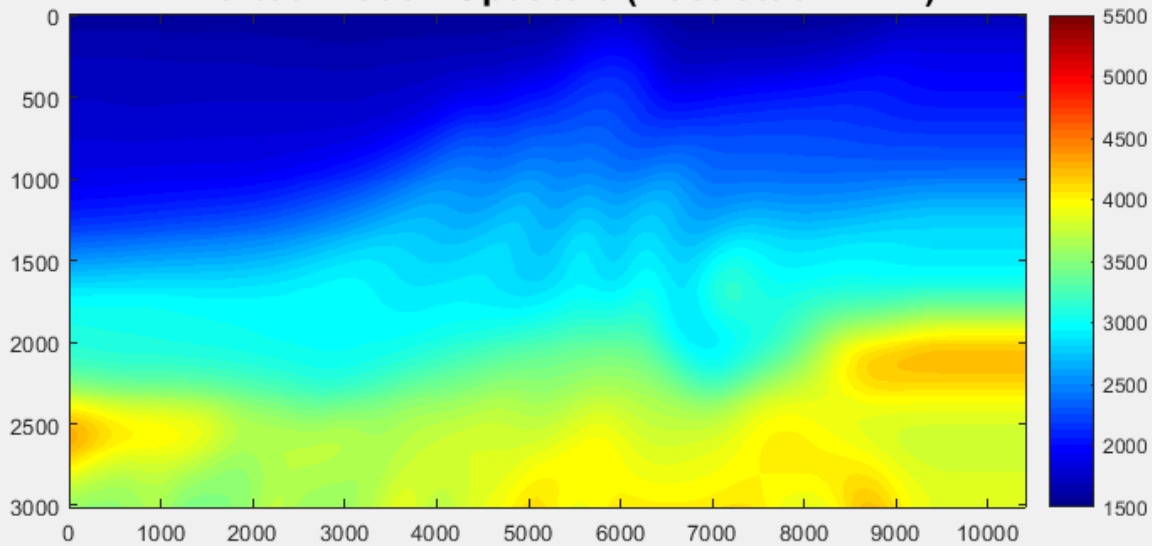
Deviation per Iteration: Well Position



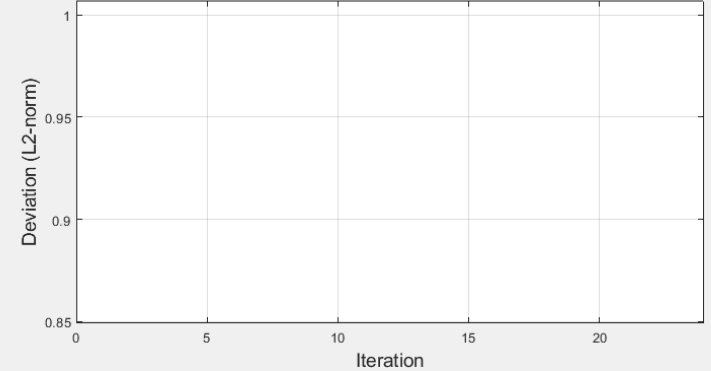
Model Deviation per Iteration



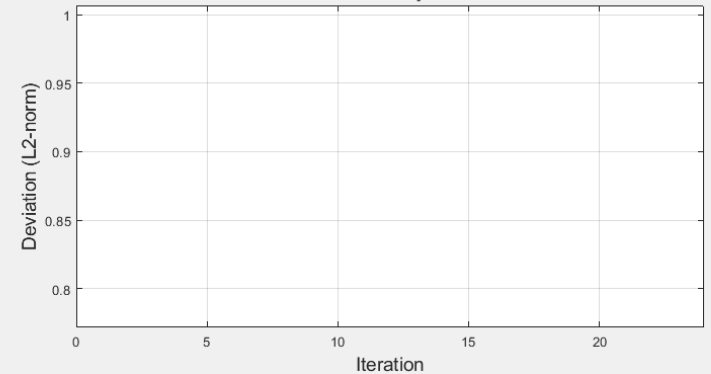
Inverted Model: Update 0 (Post-stack RTM)



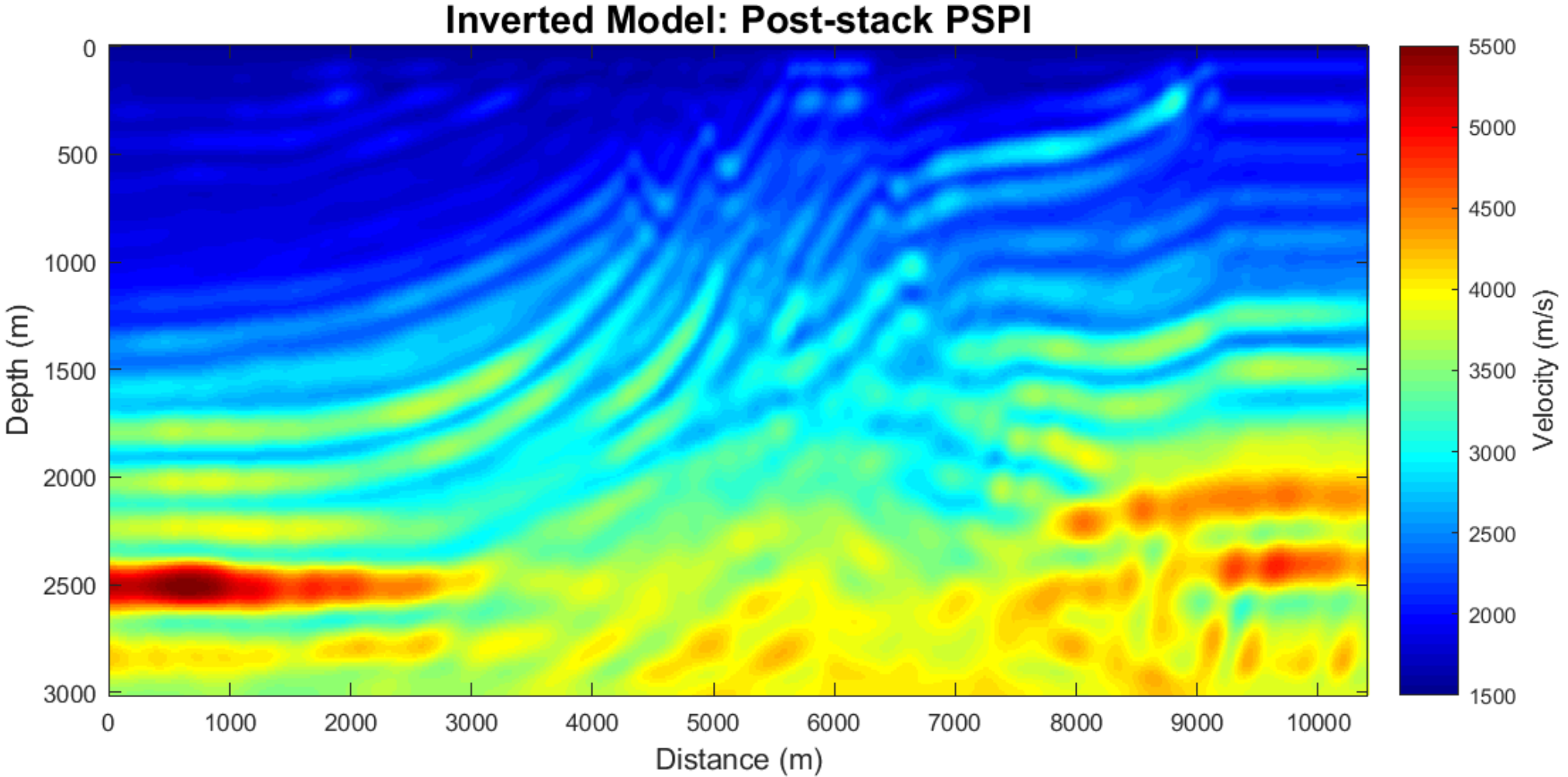
Deviation per Iteration: Well Position



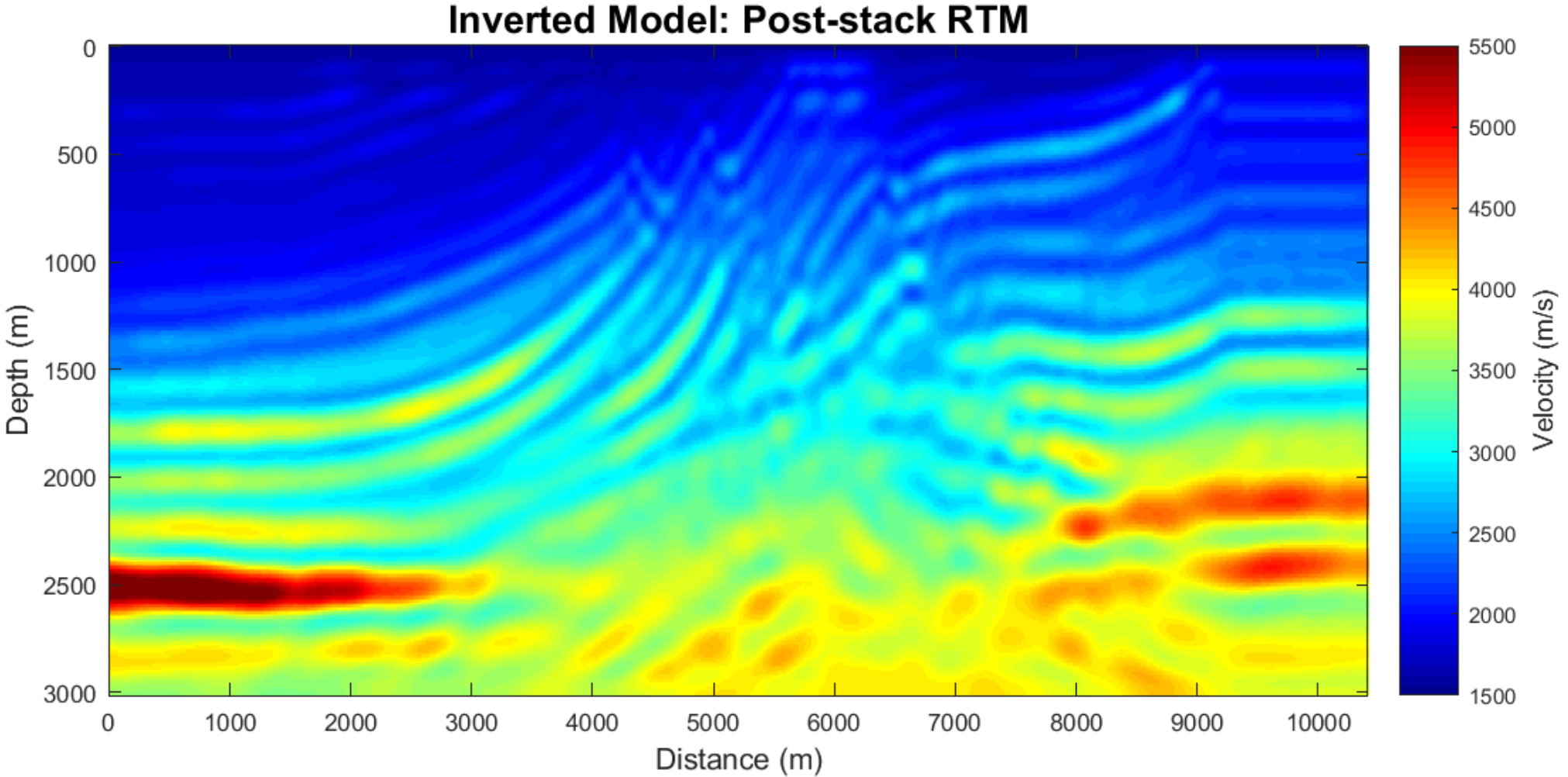
Model Deviation per Iteration



Synthetic Test 2: Marmousi

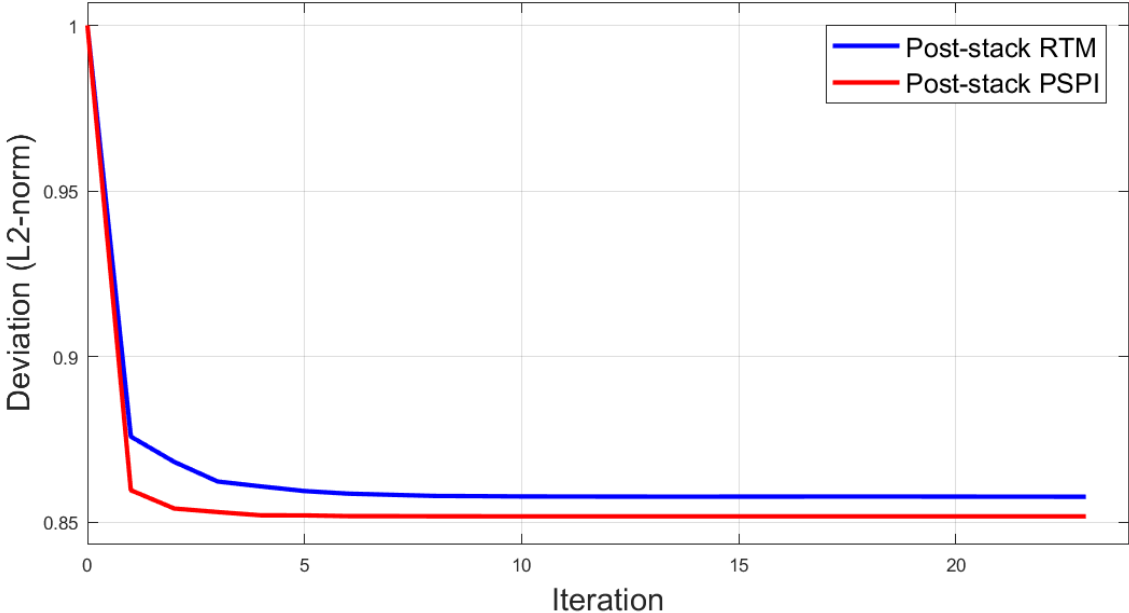


Synthetic Test 2: Marmousi

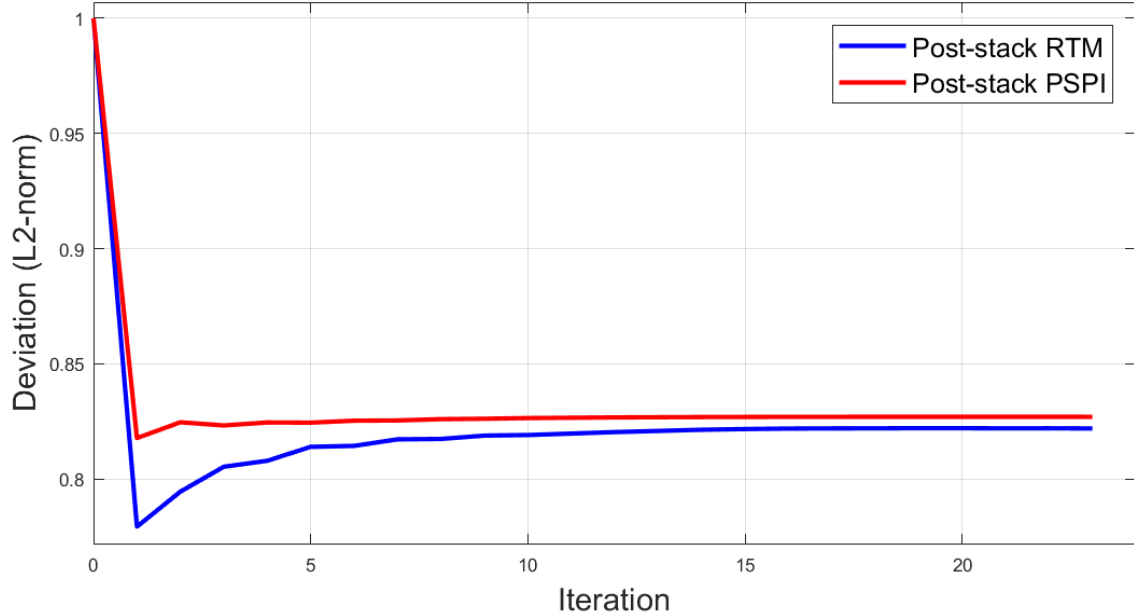


Synthetic Test 2: Marmousi

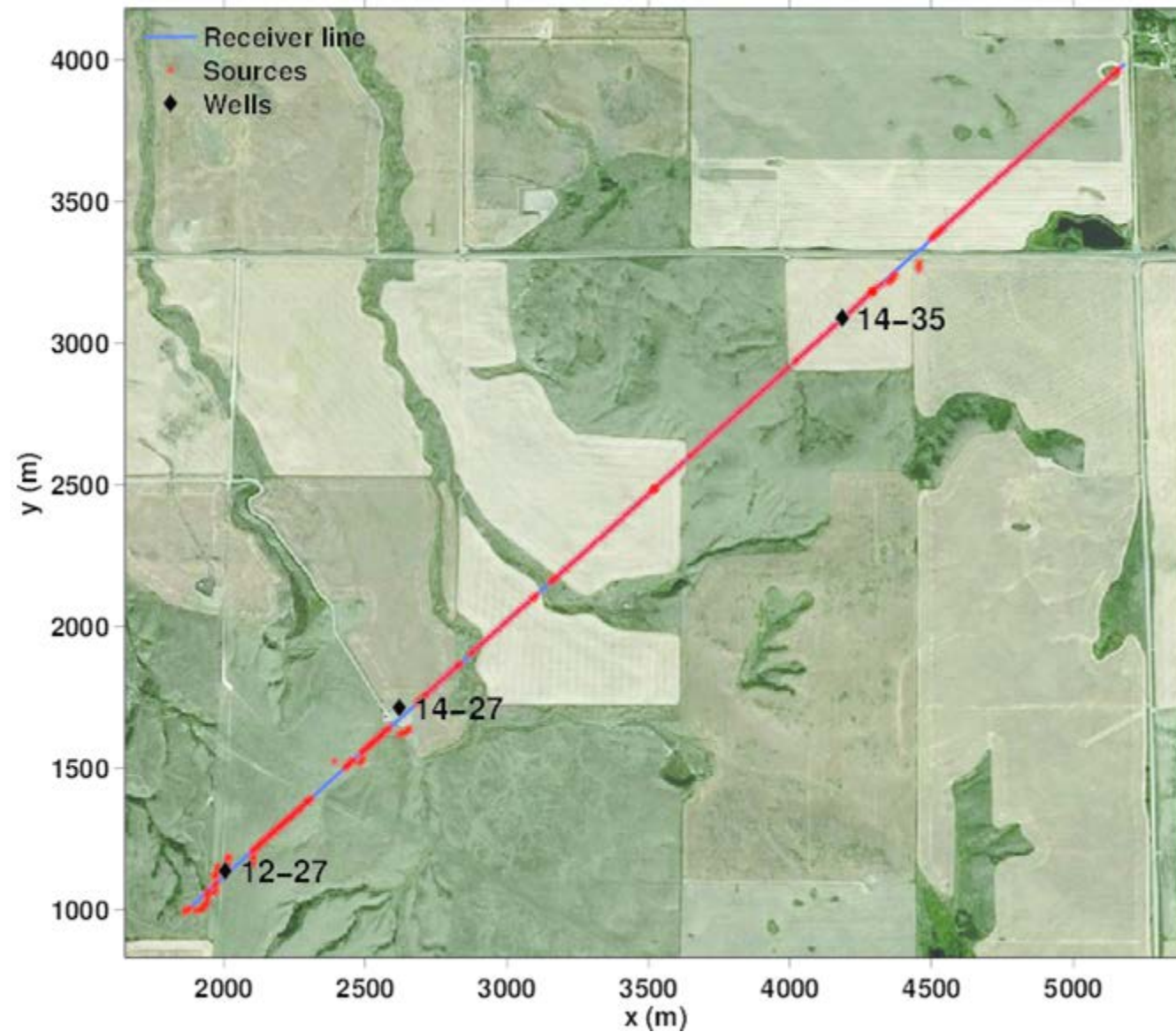
Deviation per Iteration: Well Position



Model Deviation per Iteration

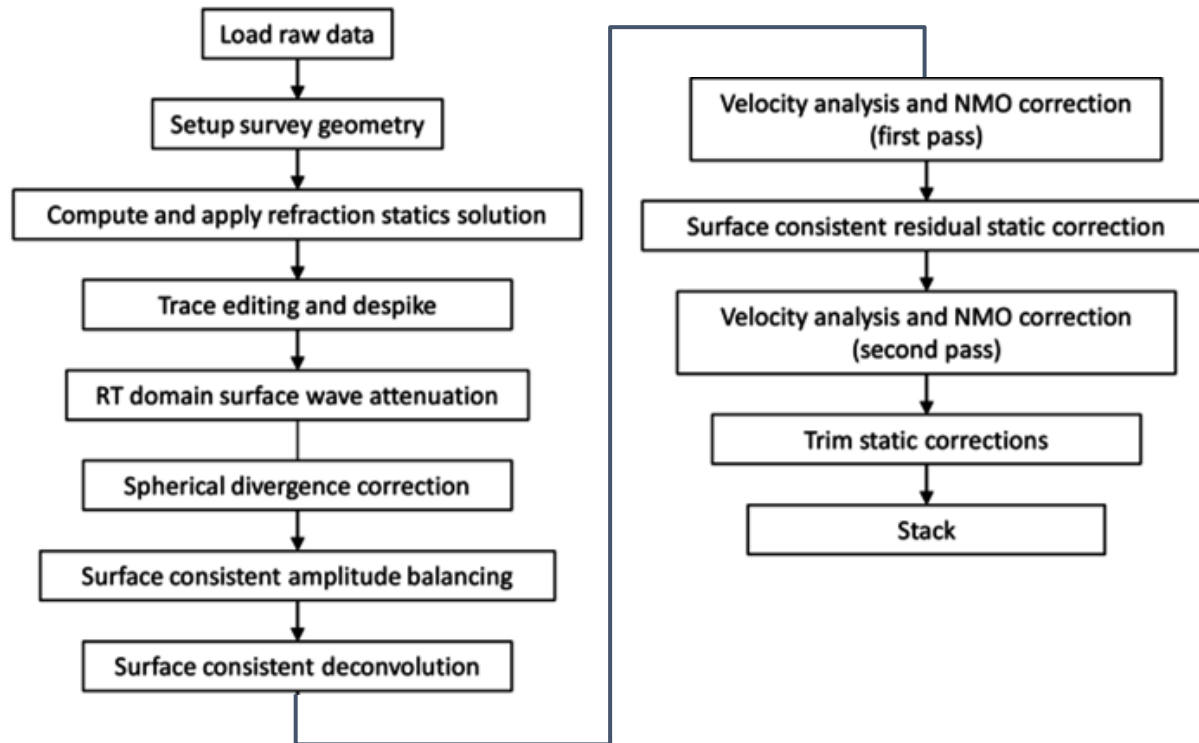


Hussar Survey

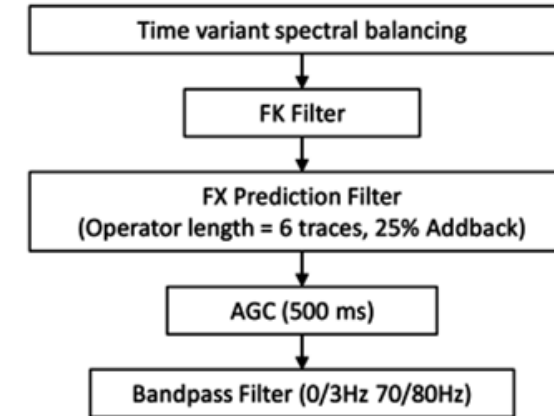


Processing Flow

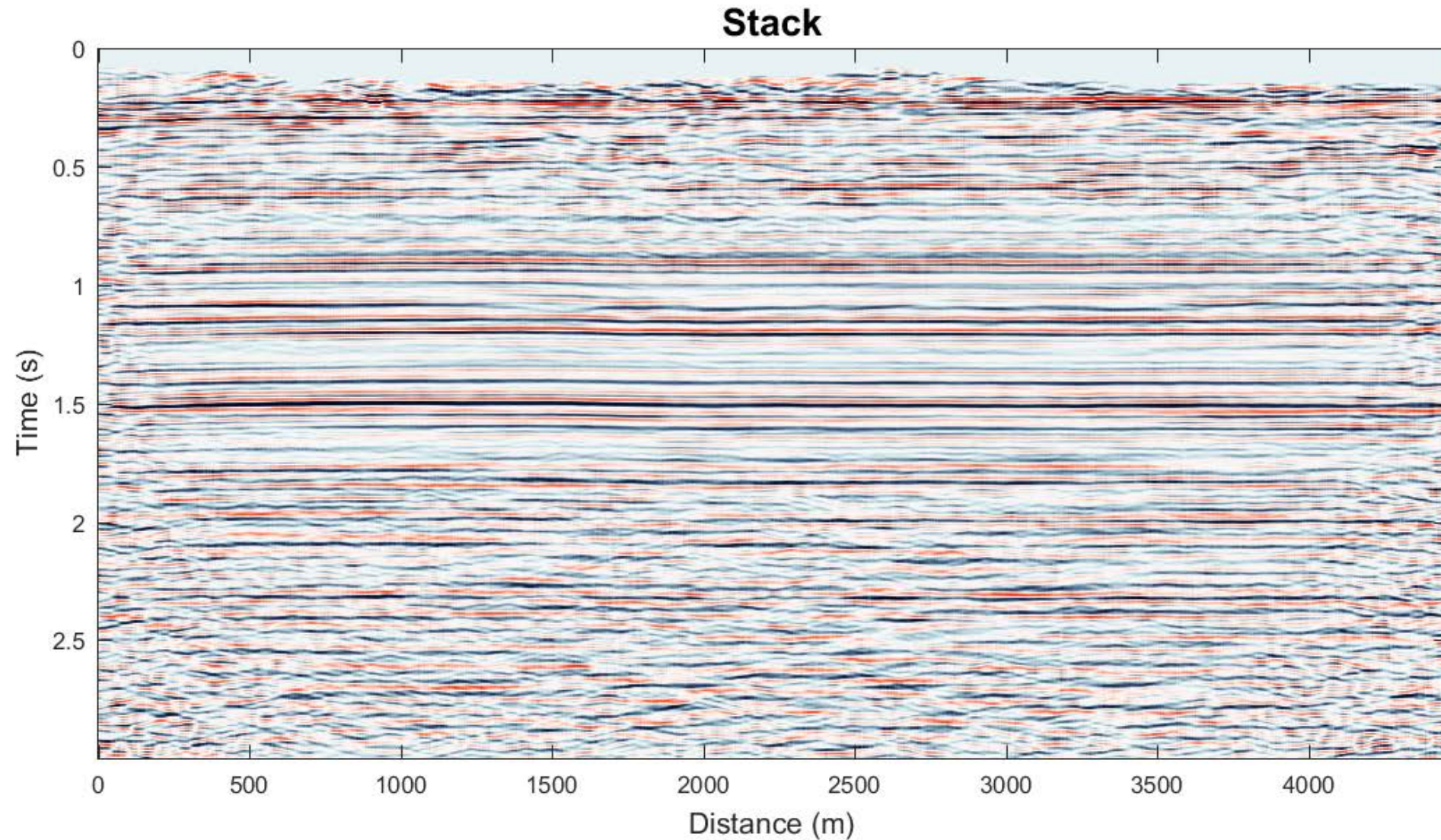
Processing Flow



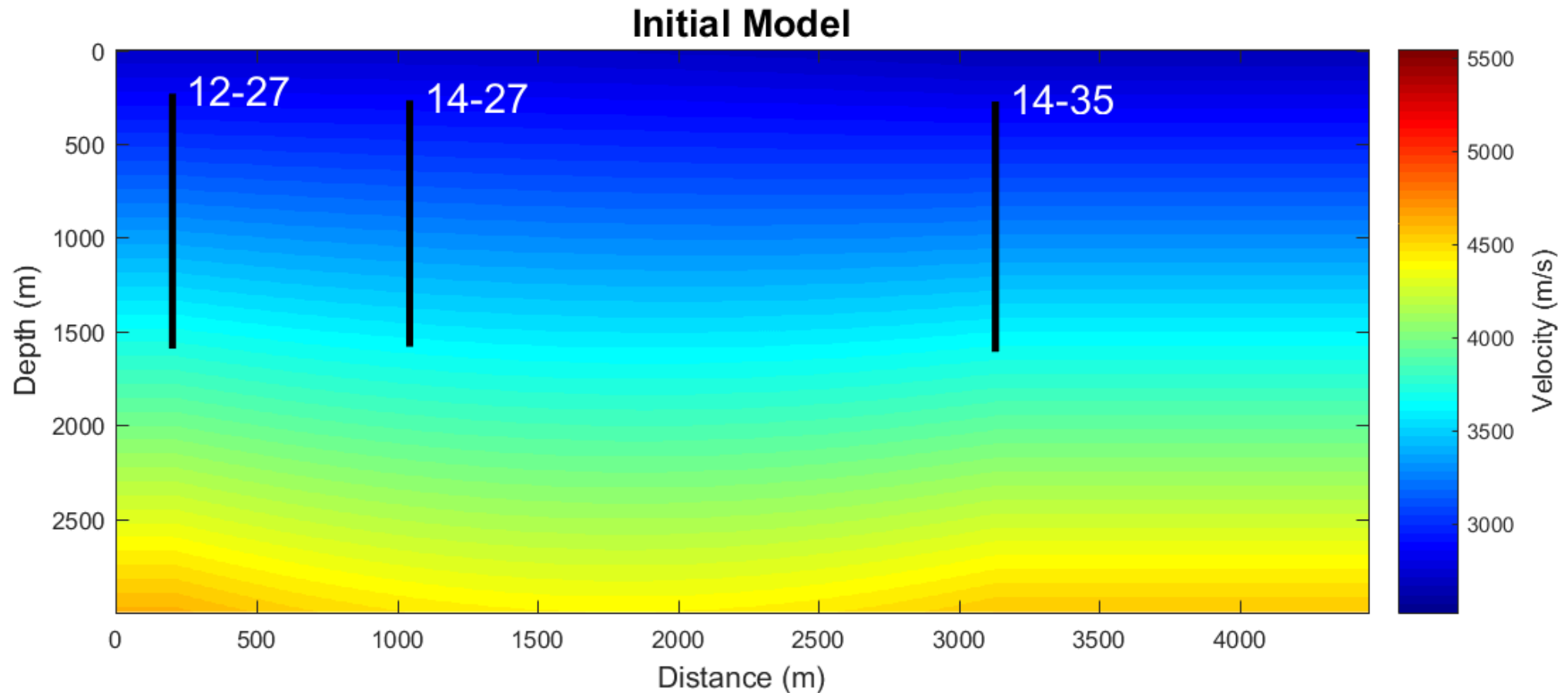
Post-processing Flow



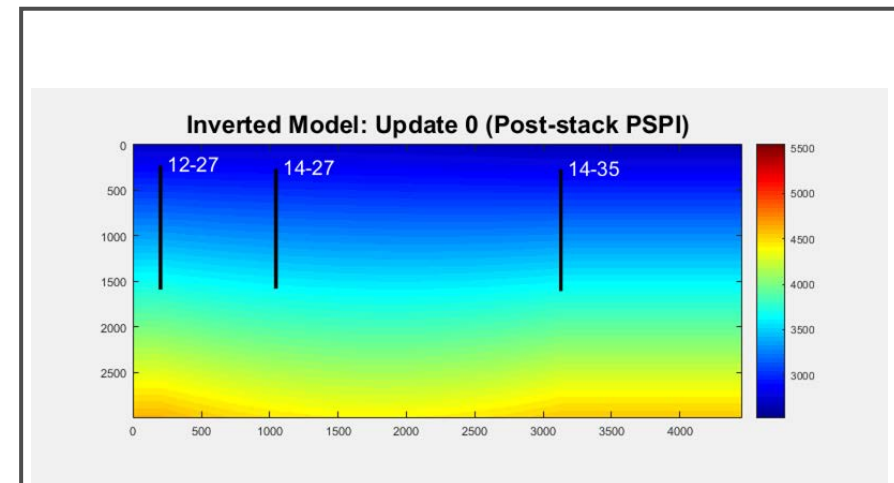
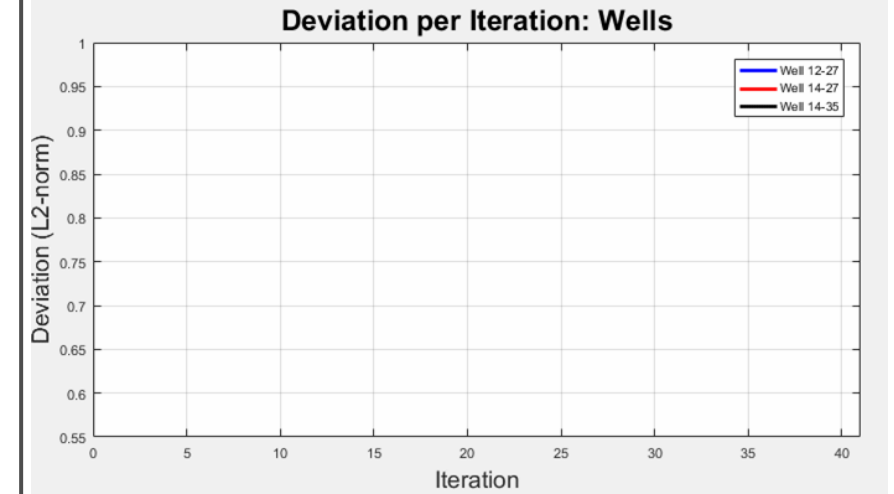
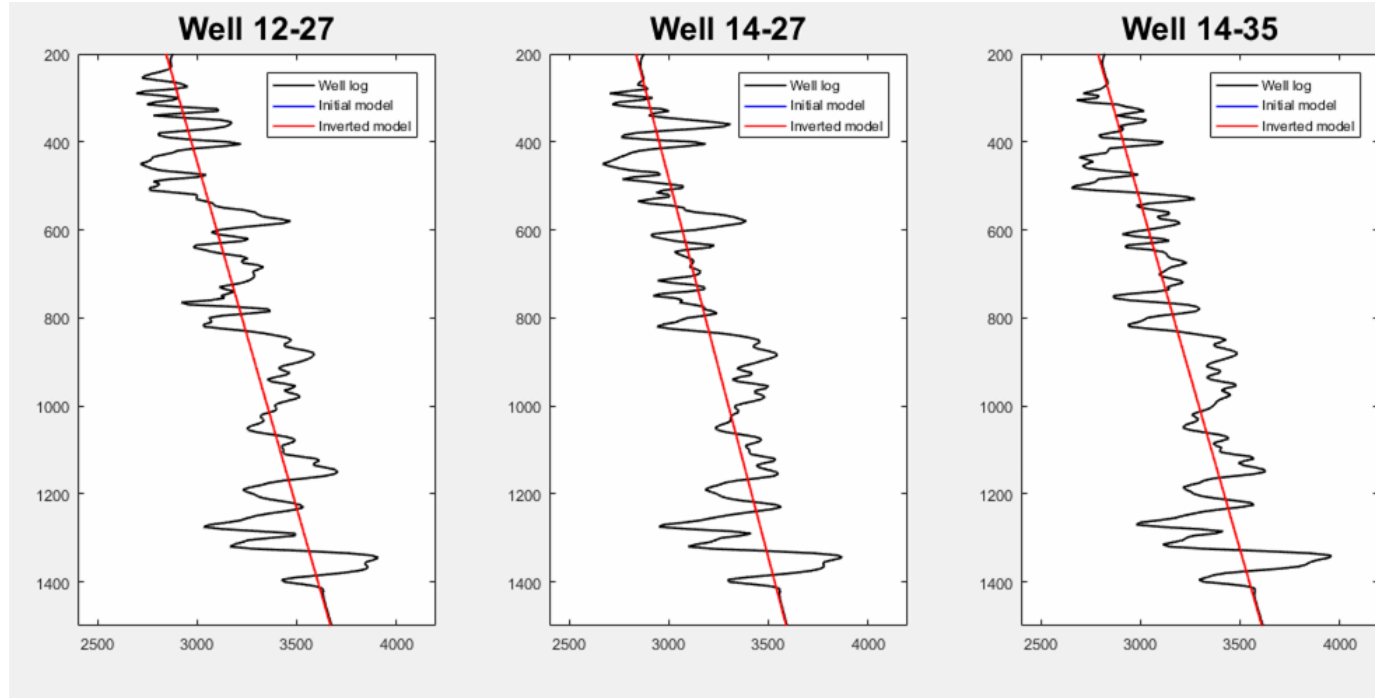
FastWI Applied to Hussar



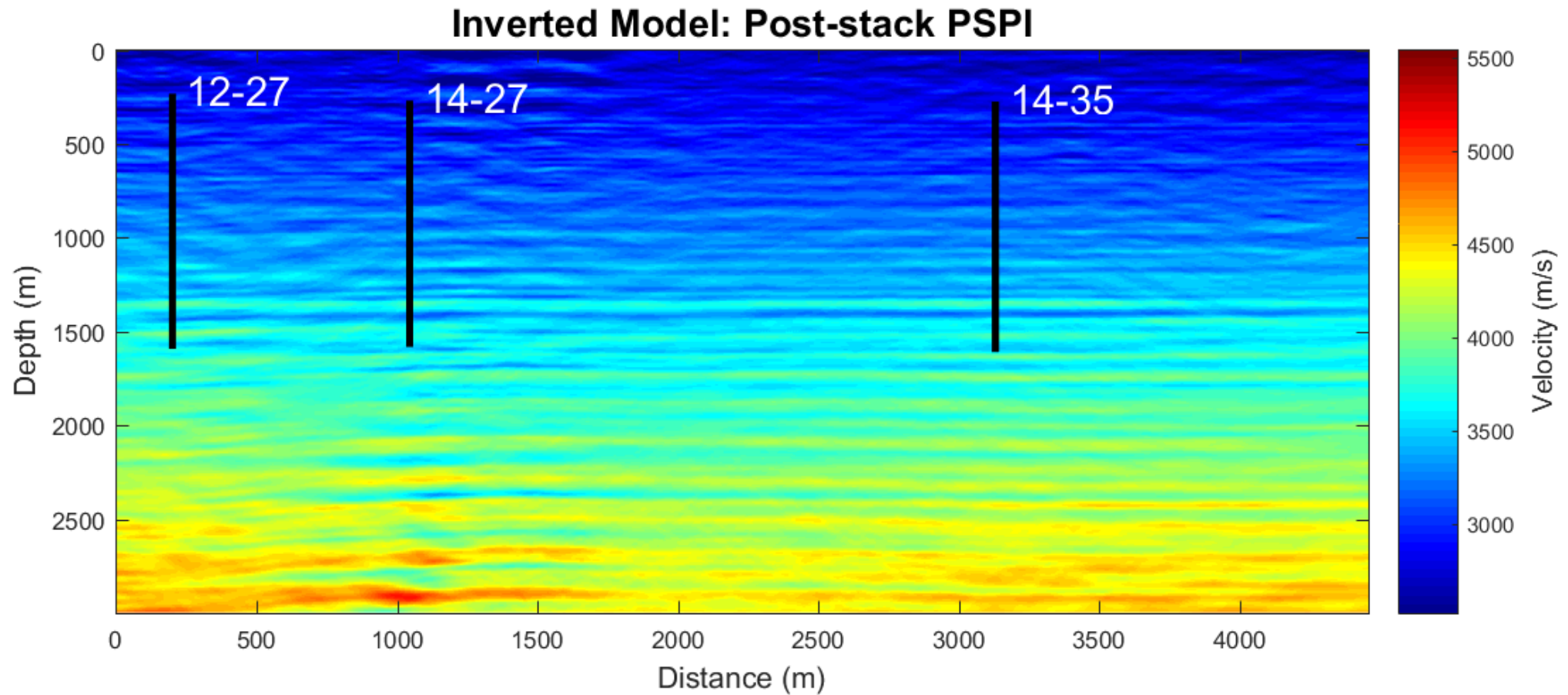
FastWI Applied to Hussar



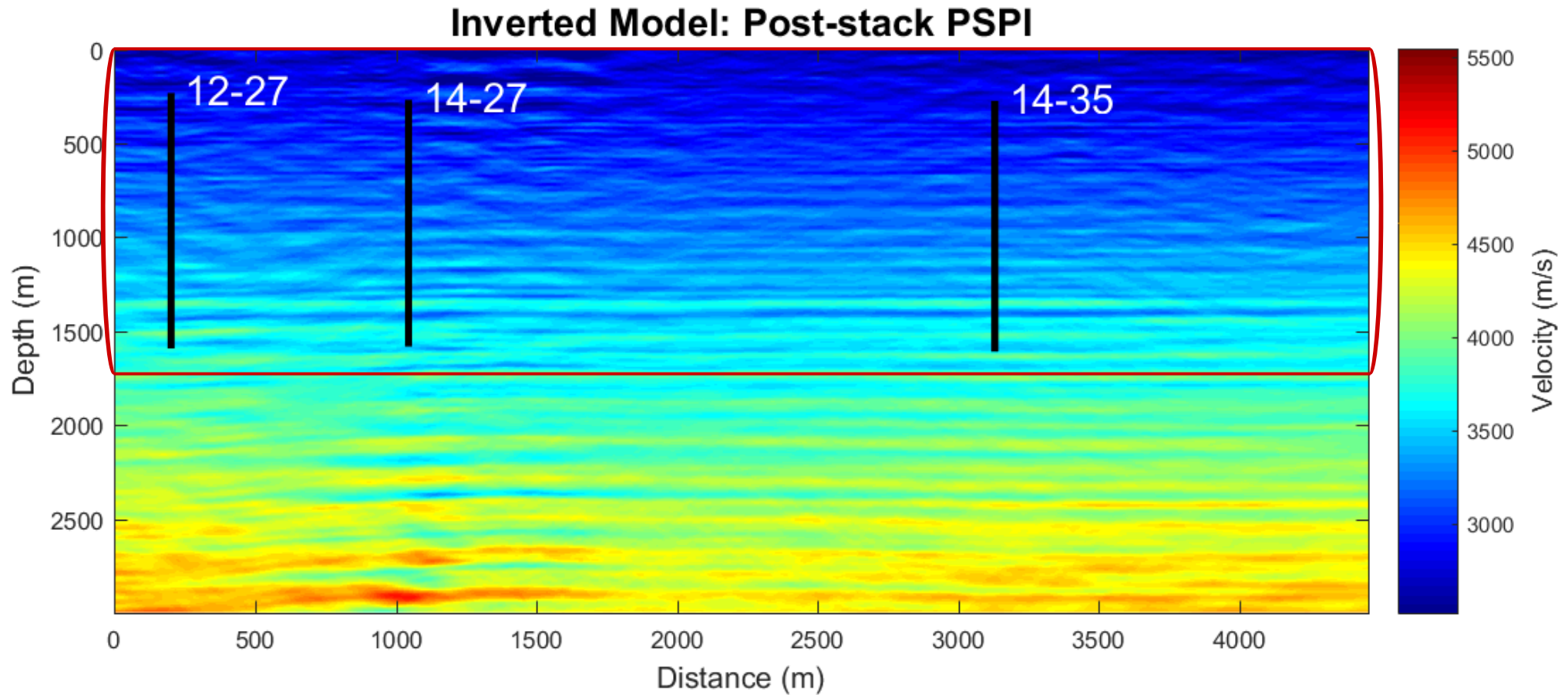
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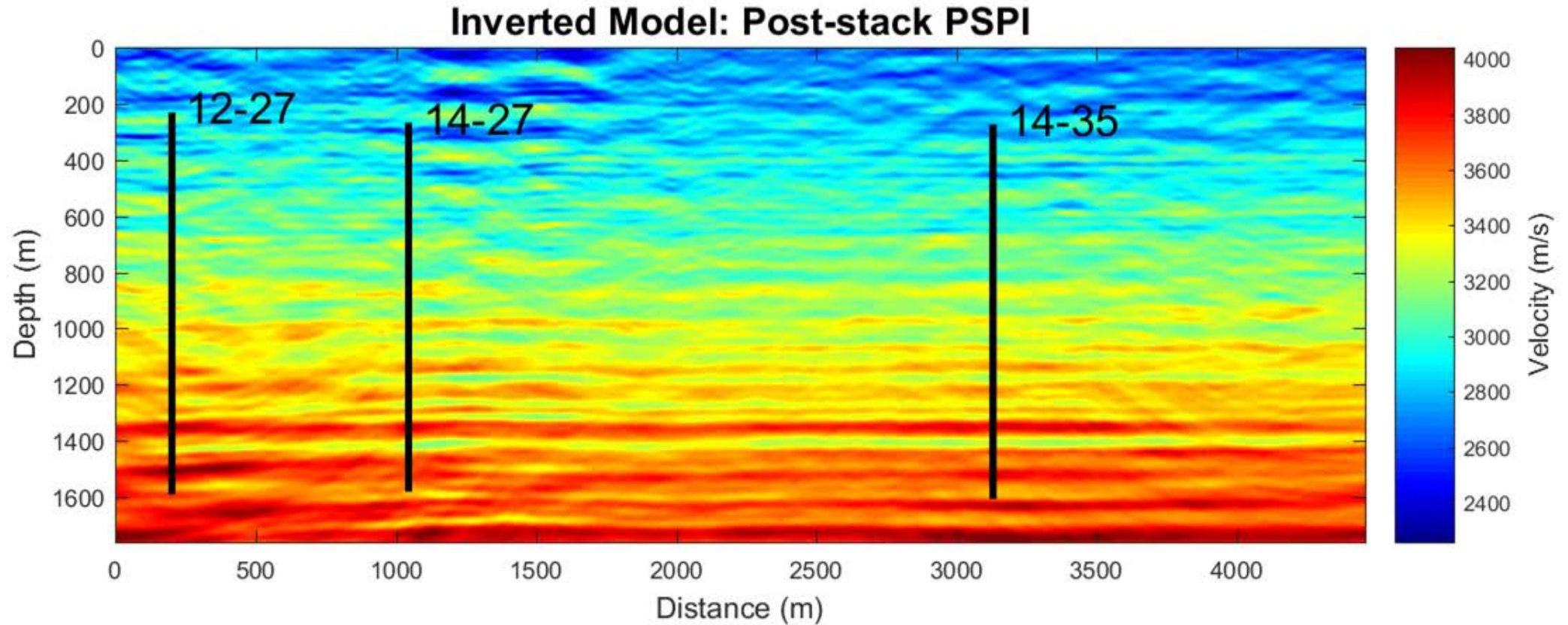
FastWI Applied to Hussar



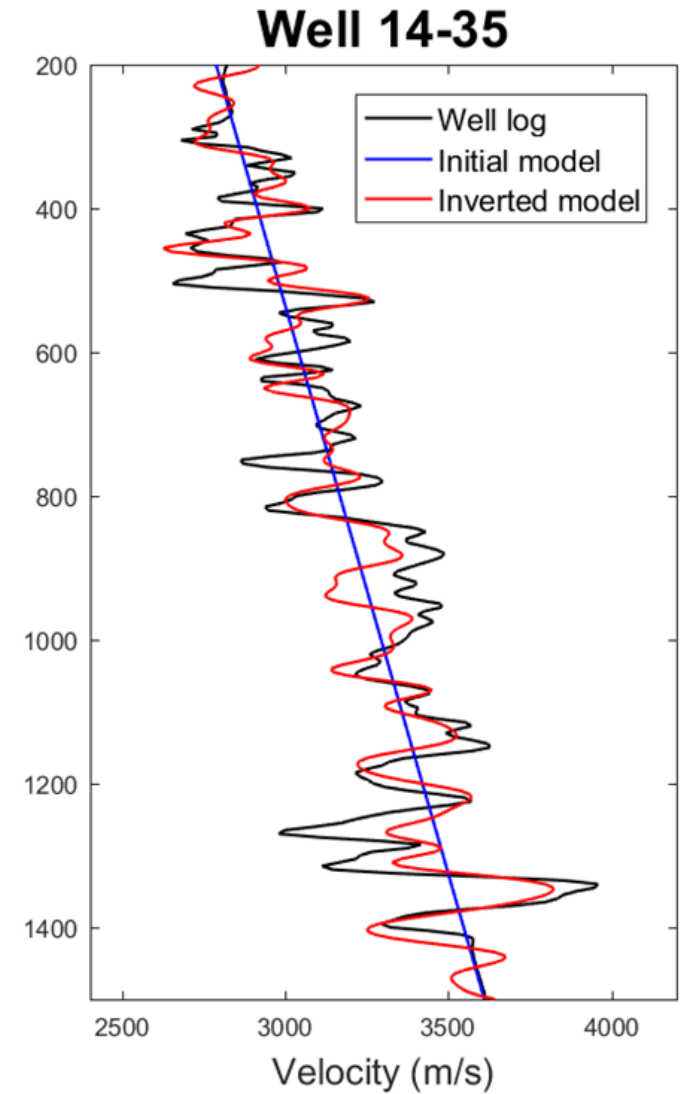
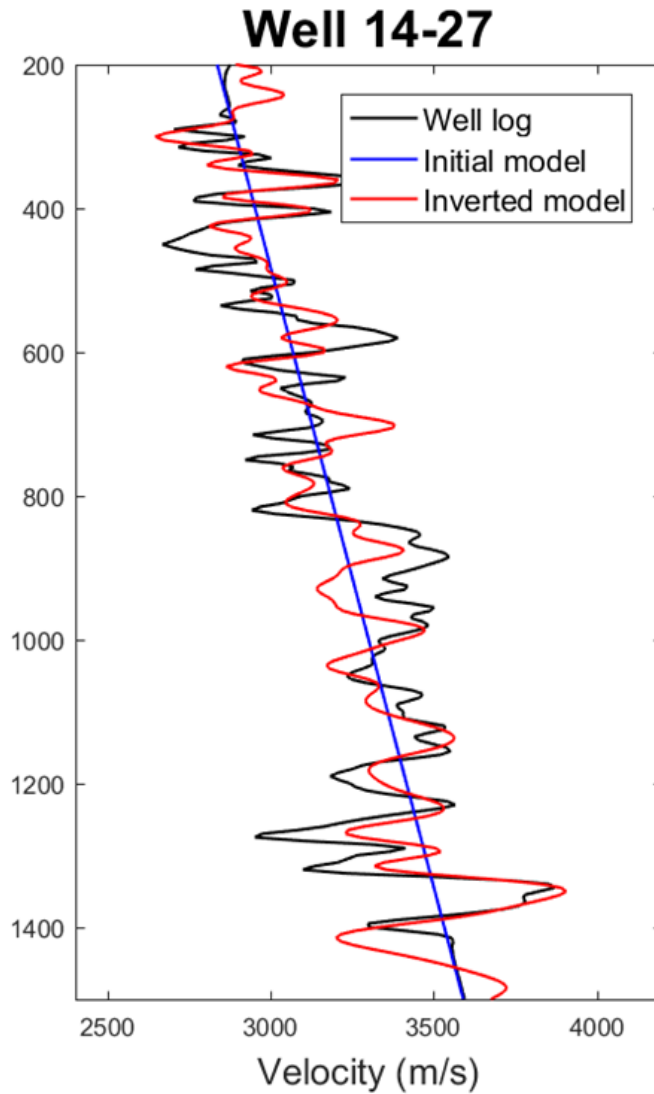
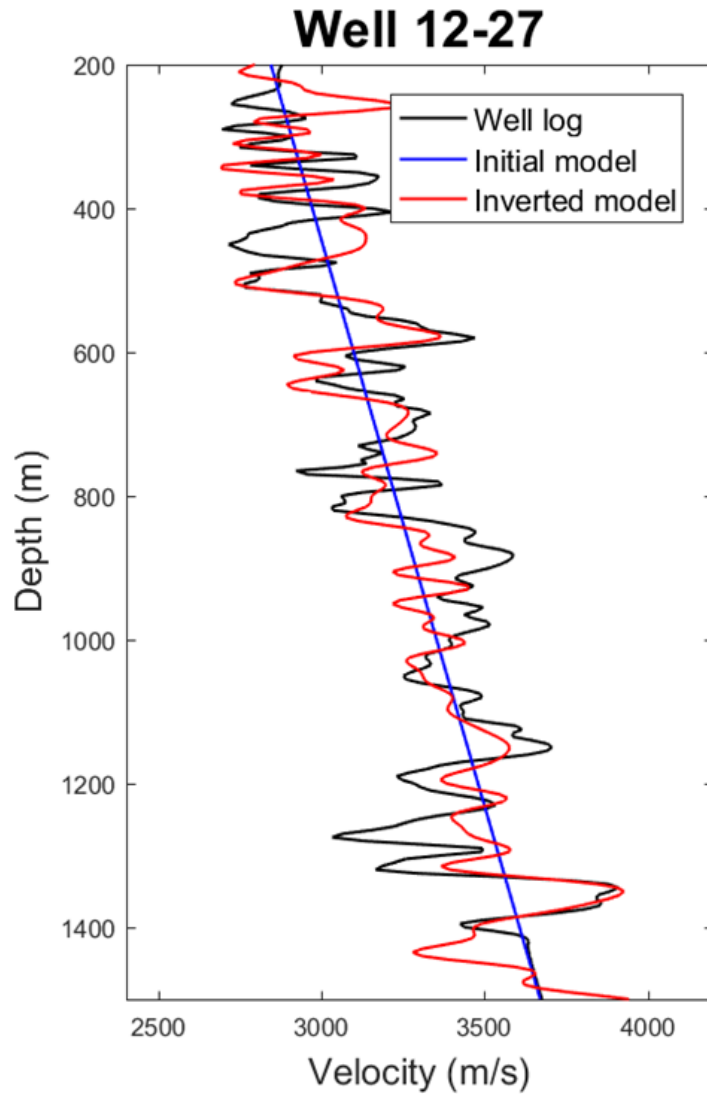
FastWI Applied to Hussar



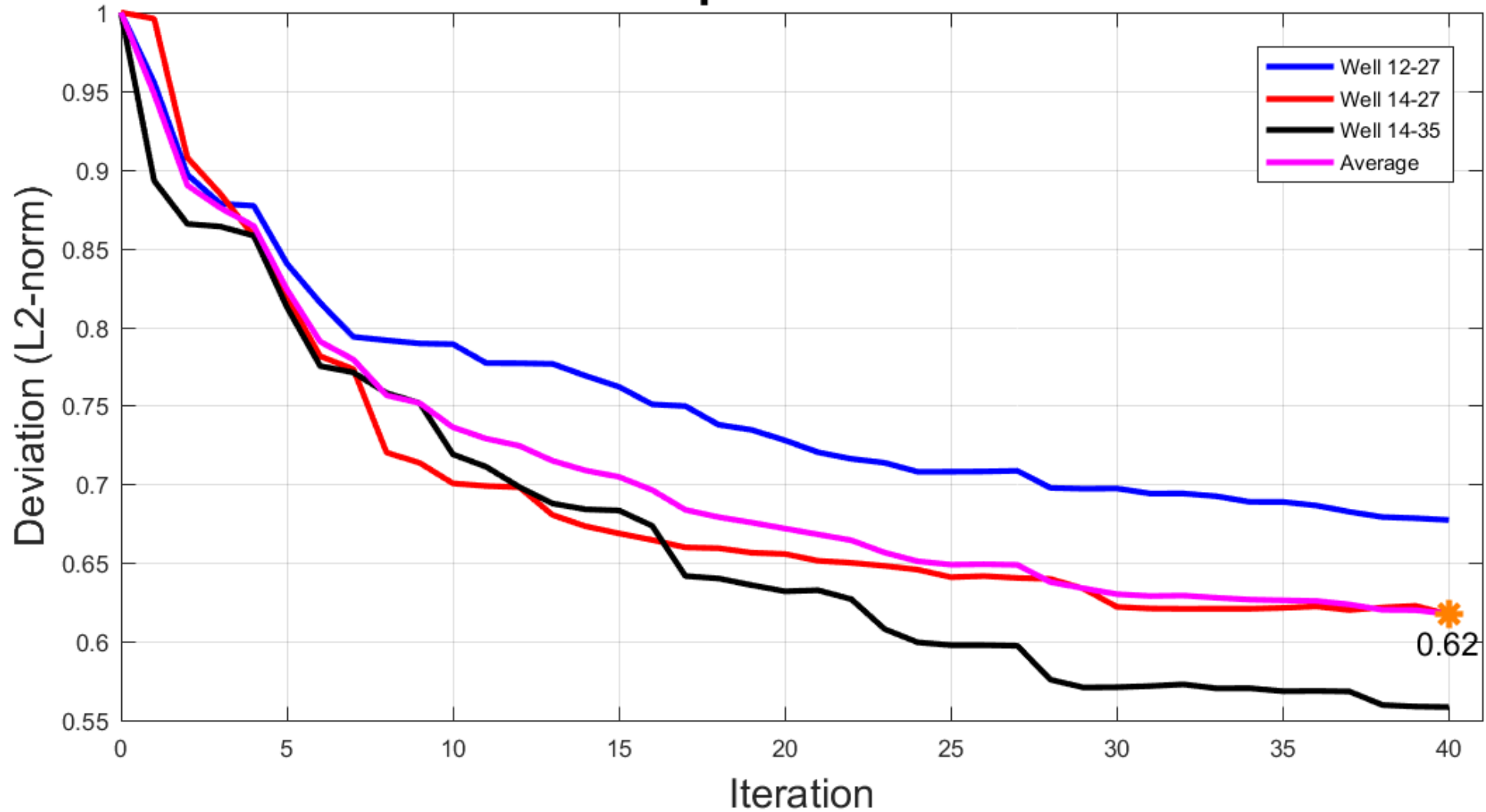
FastWI Applied to Hussar



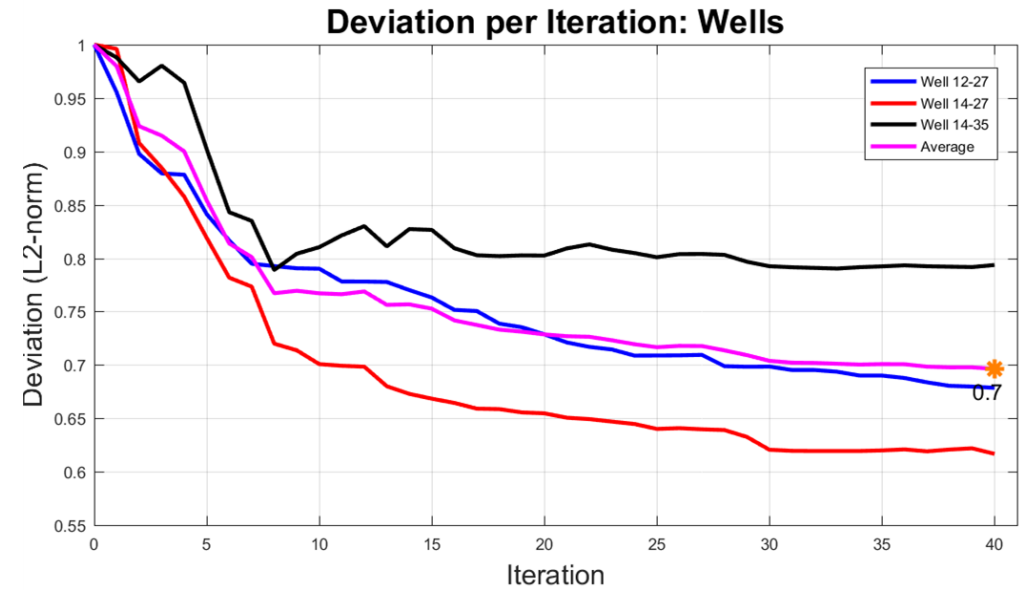
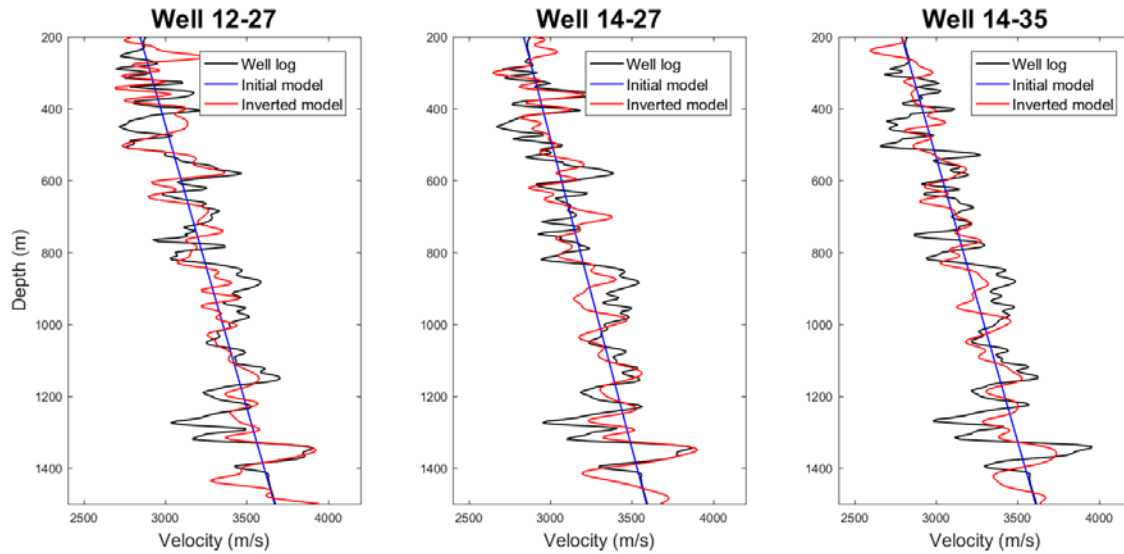
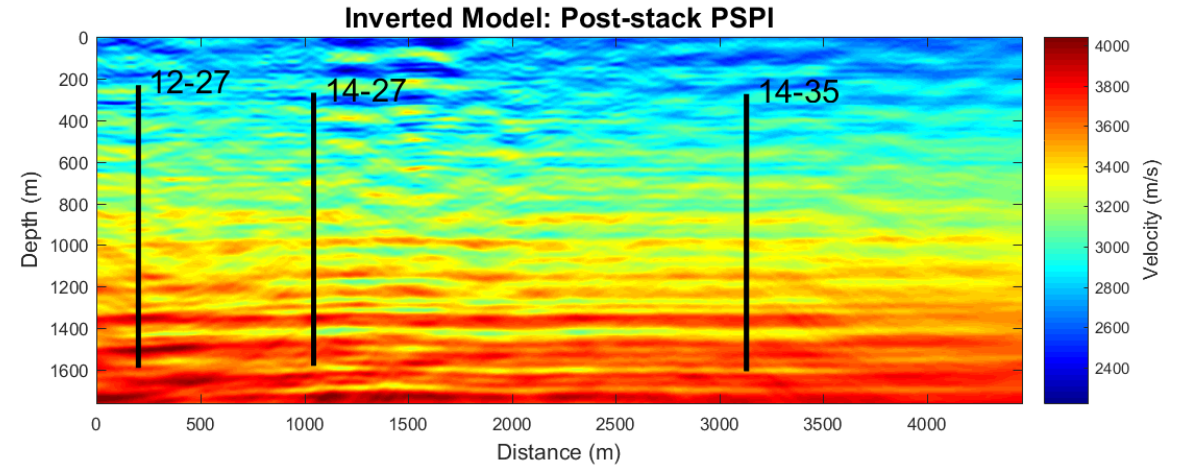
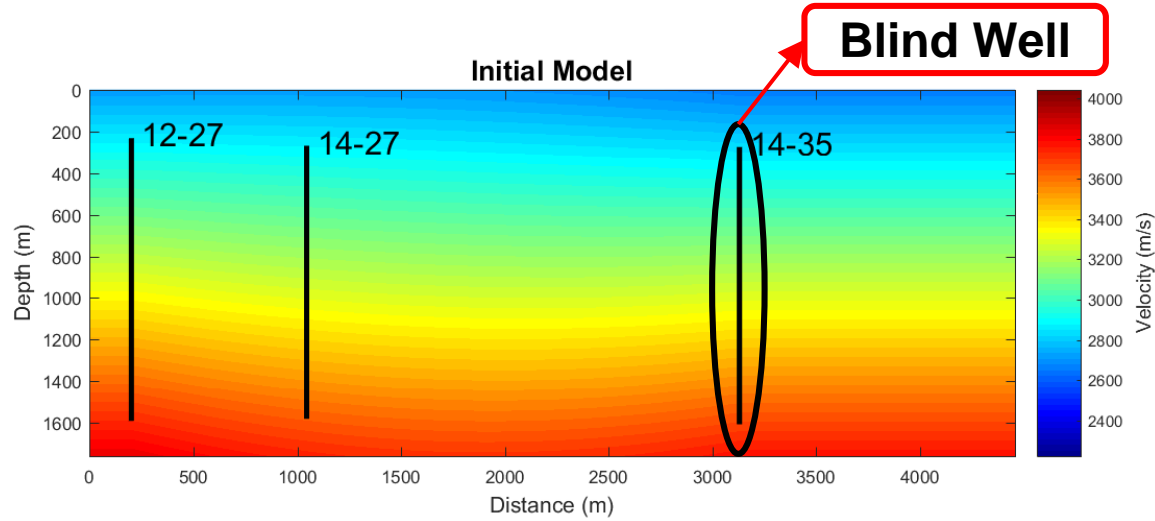
FastWI Applied to Hussar



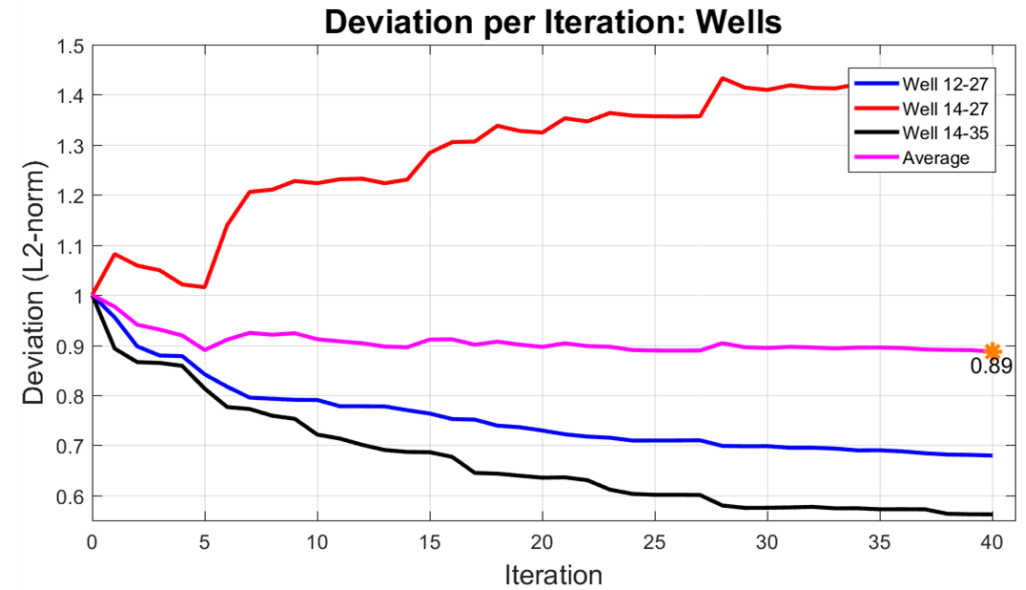
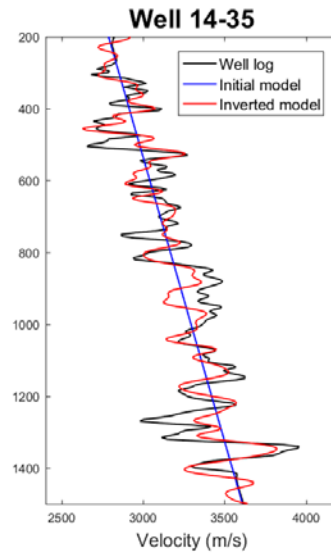
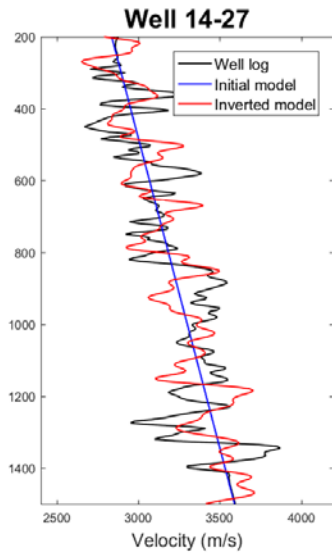
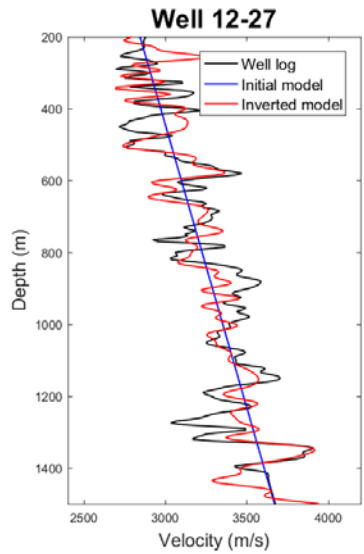
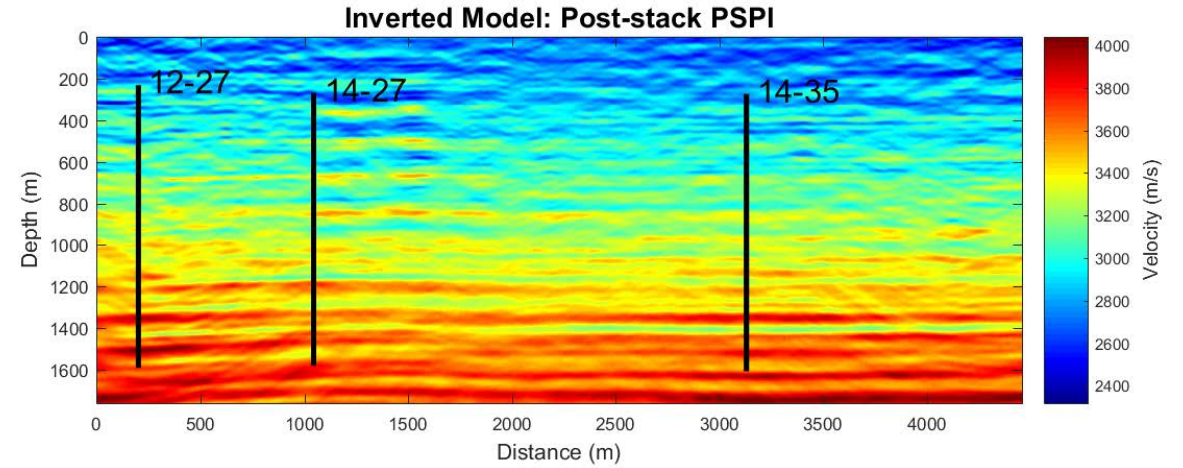
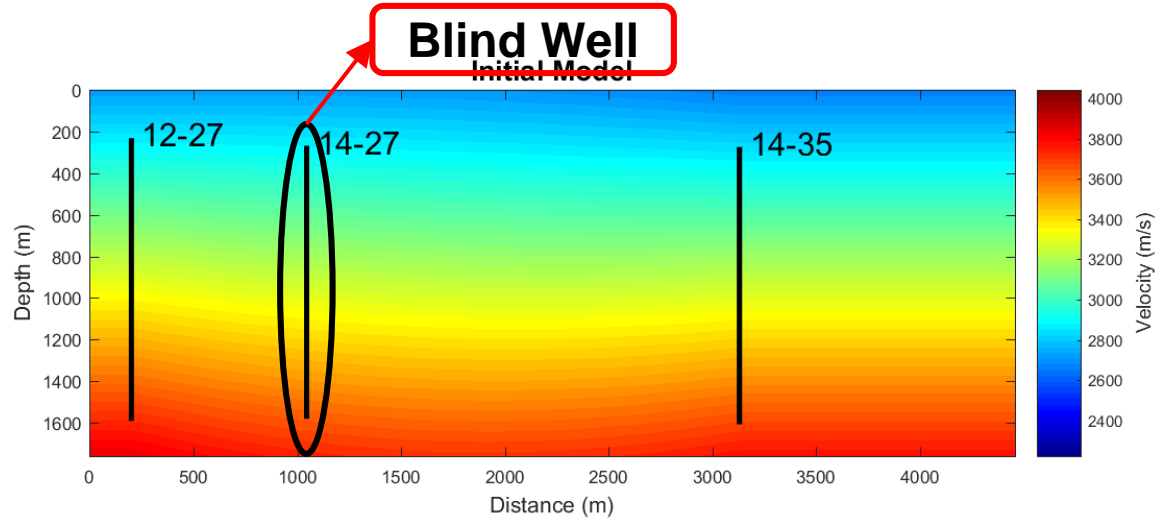
Deviation per Iteration: Wells



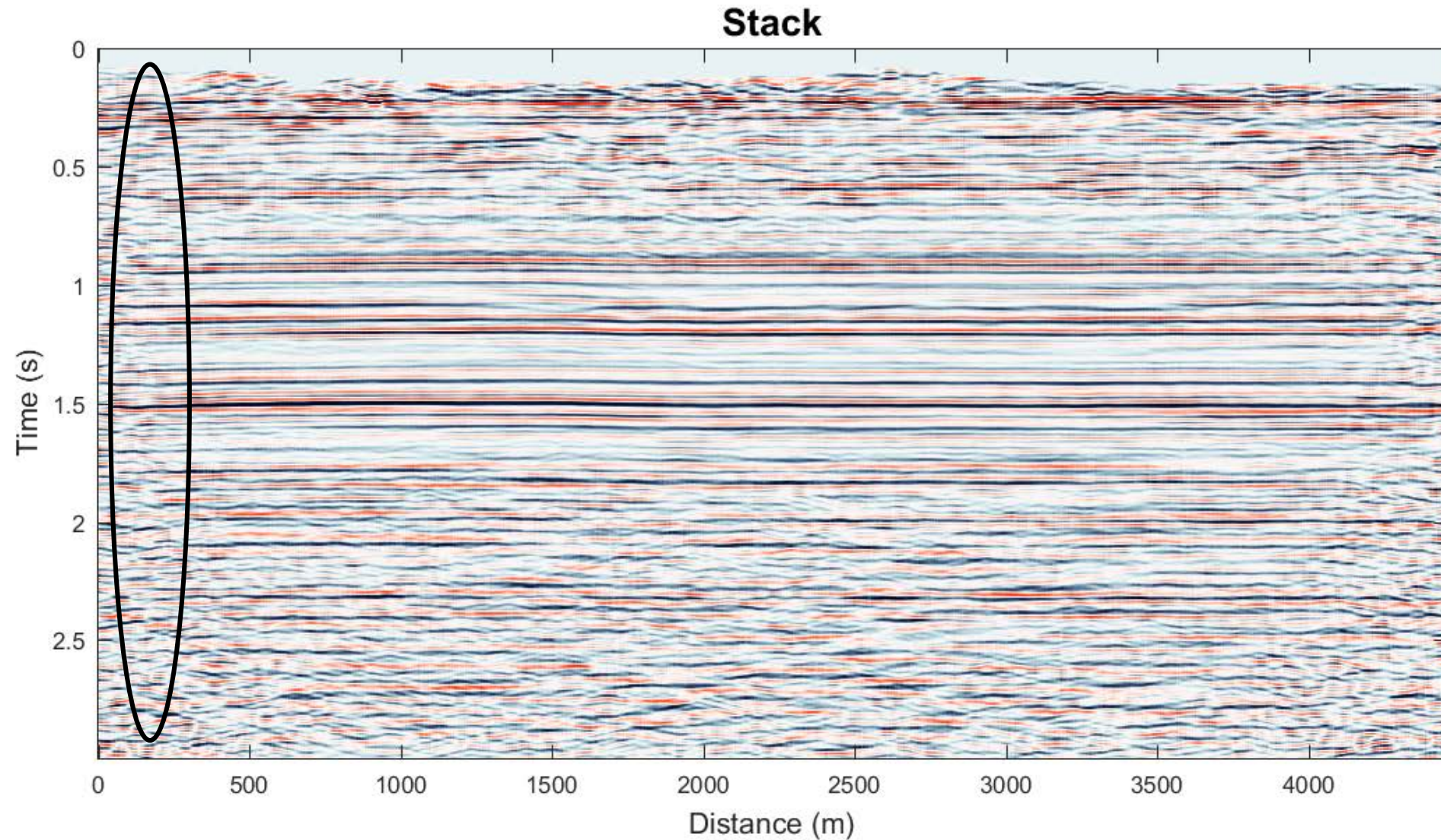
FastWI Applied to Hussar



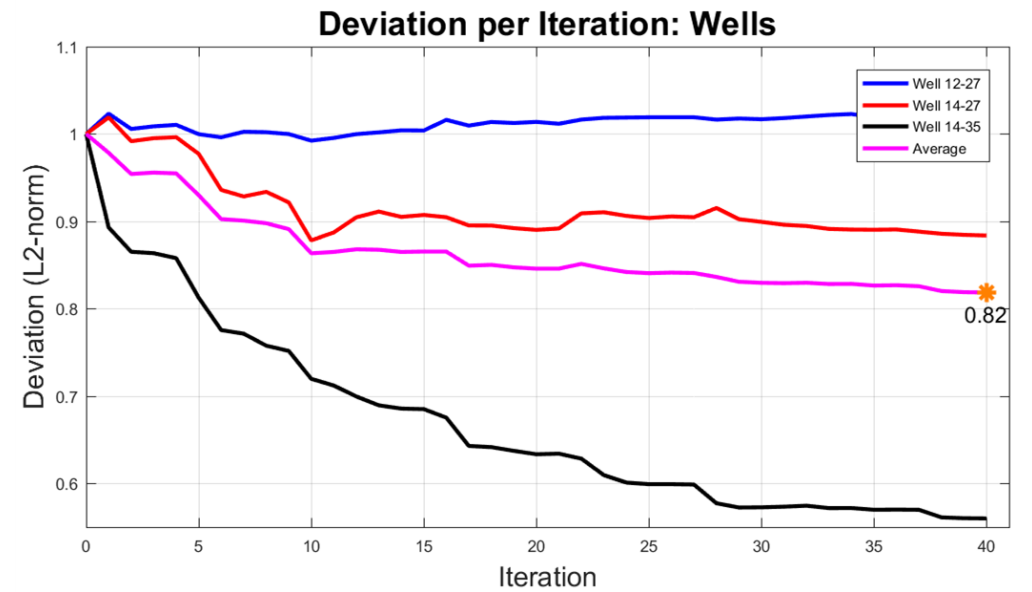
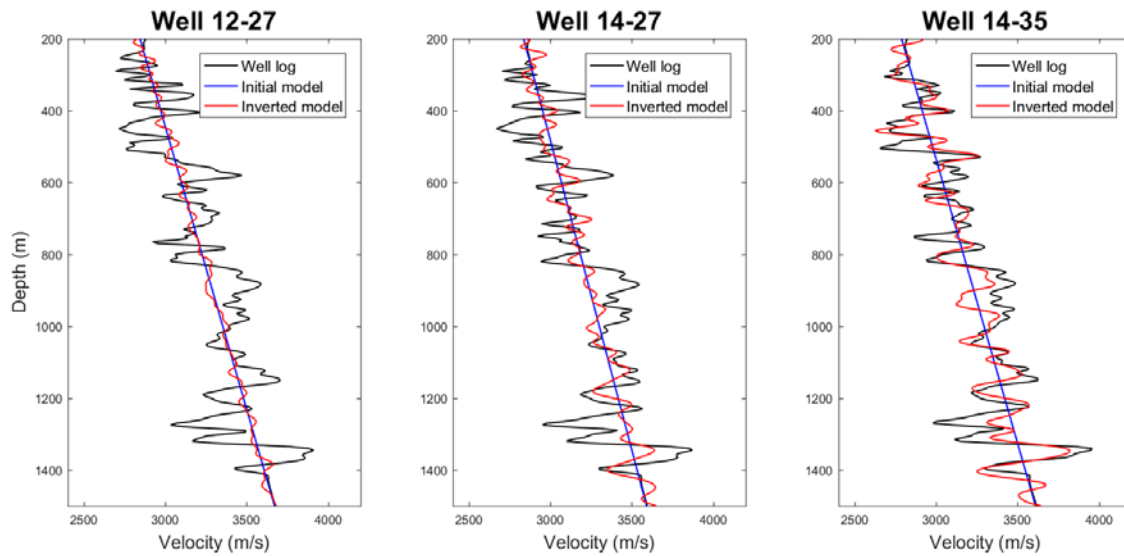
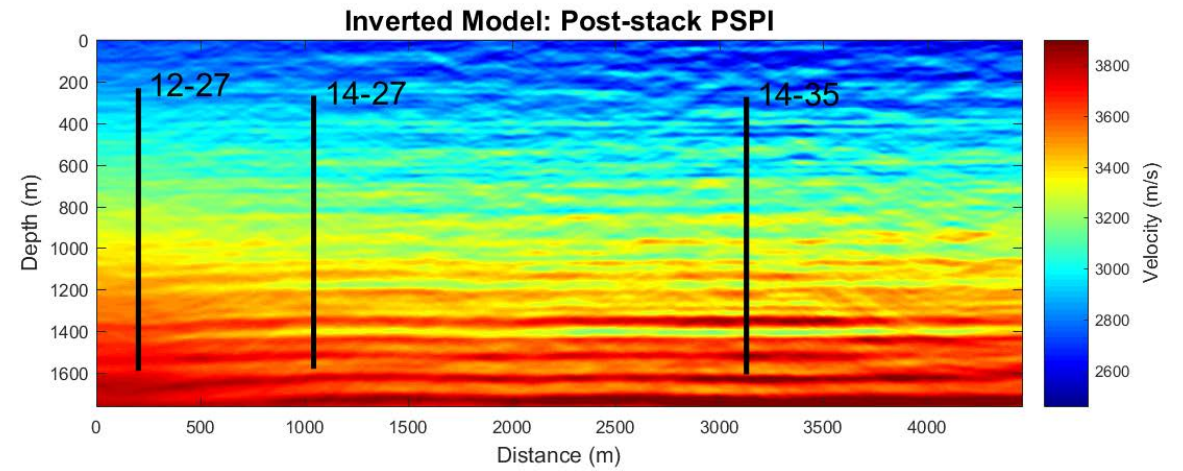
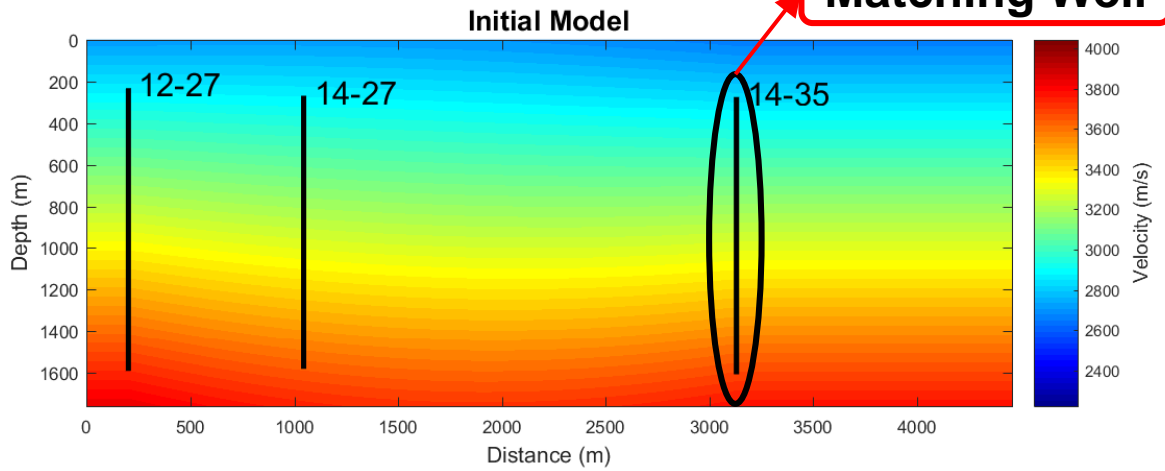
FastWI Applied to Hussar



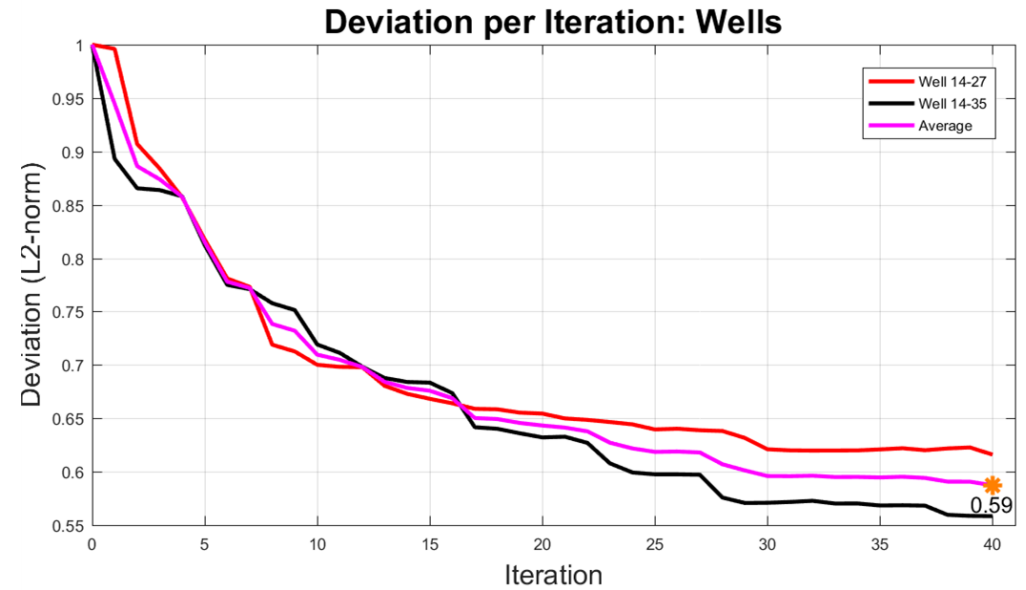
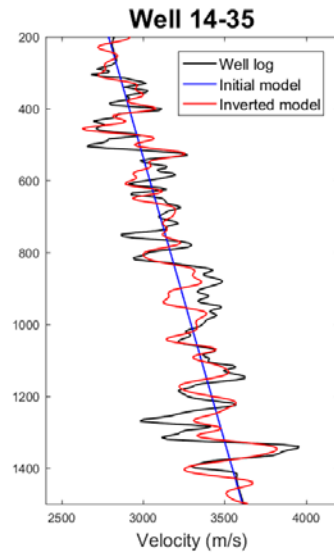
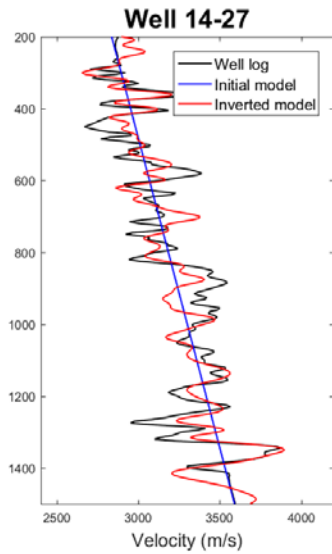
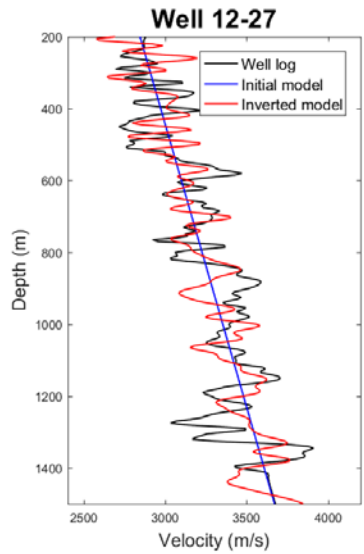
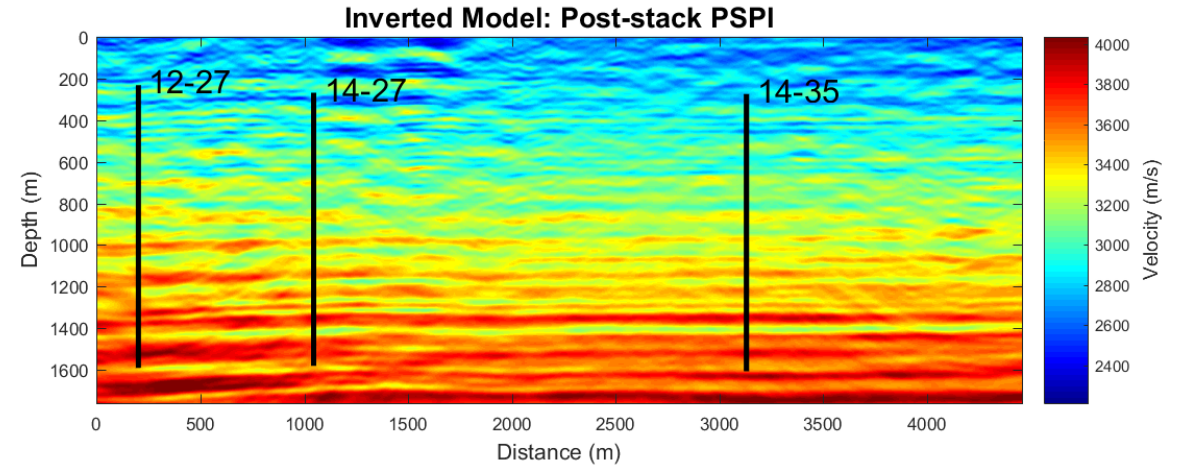
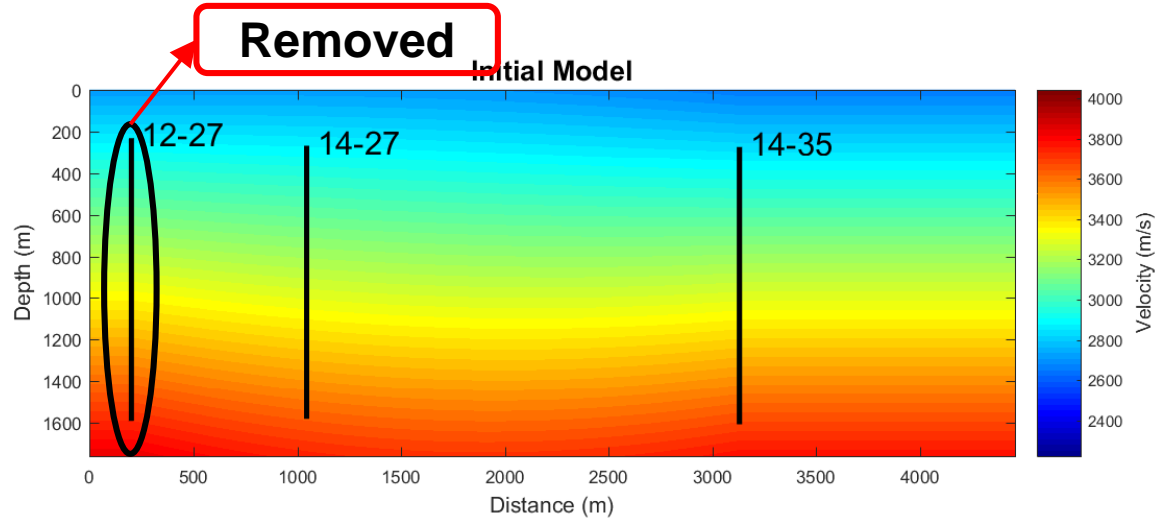
FastWI Applied to Hussar



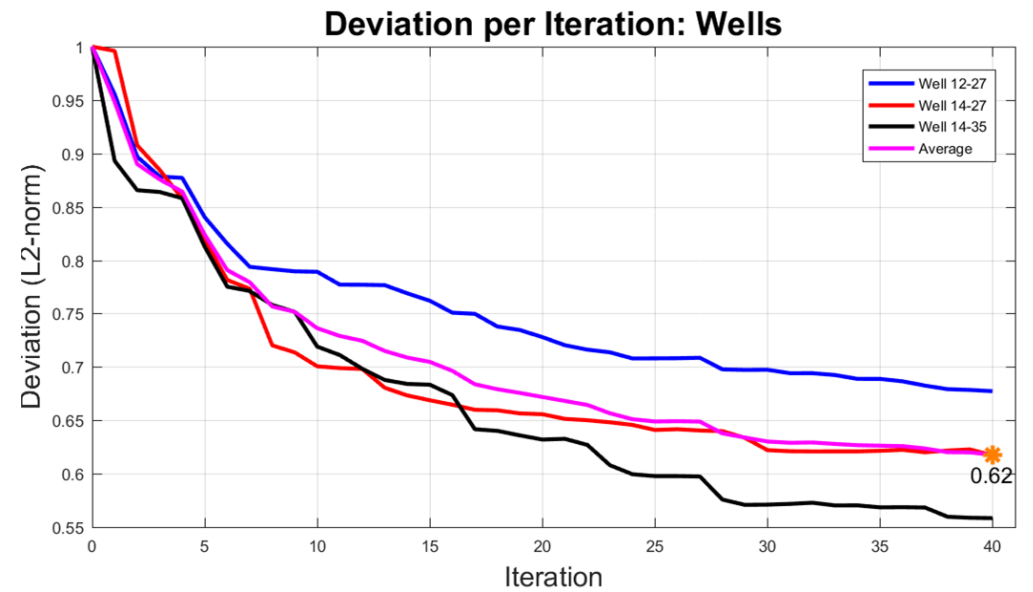
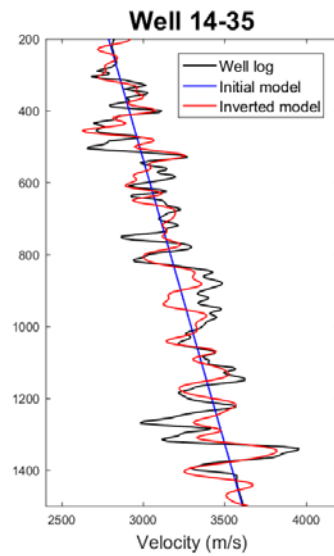
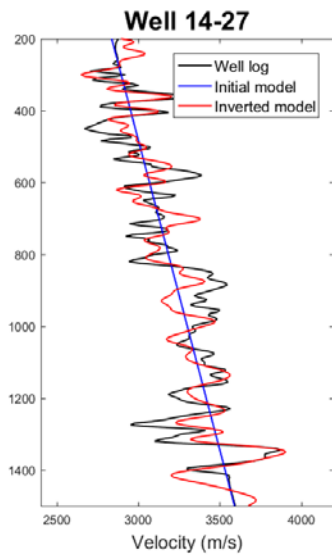
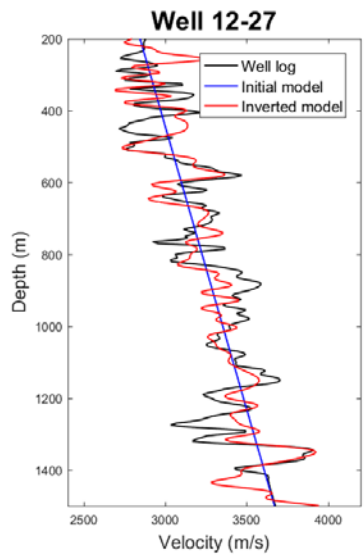
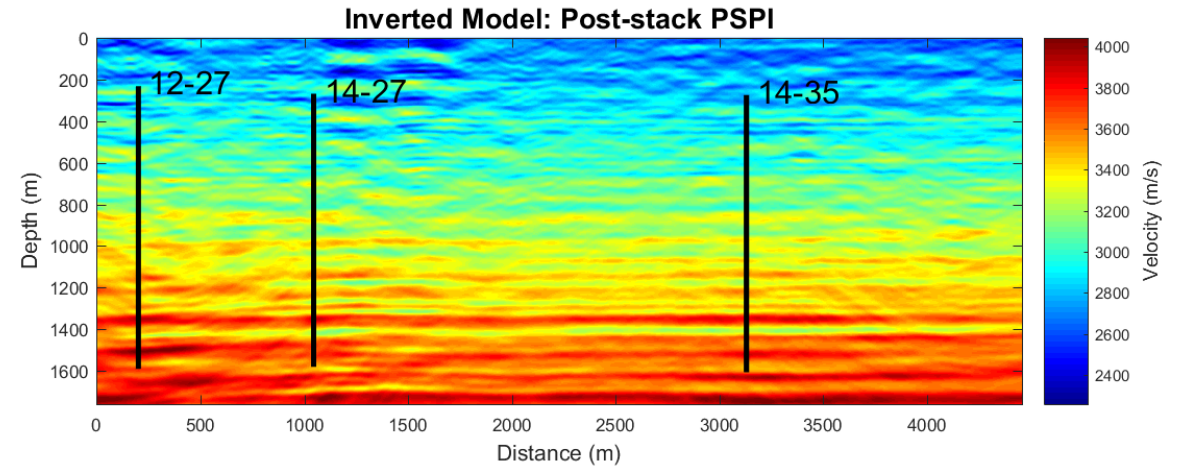
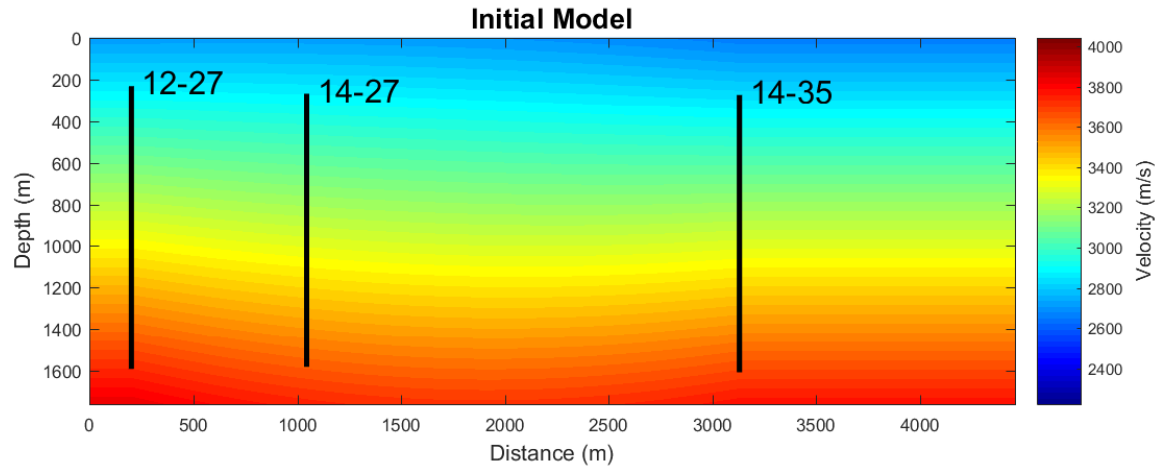
FastWI Applied to Hussar



FastWI Applied to Hussar



FastWI Applied to Hussar



Conclusions

- FastWI is based on the FWI steepest-descent method, and shows to be robust and requires low computation power
- RTM or PSPI: depends on the complexity of the model and budget
- Works with one or more sonic logs
- Converges in areas between the wells (synthetic tests)
- Hussar: convergence at wells locations
- Blind tests: convergence in between the wells
- Avoid matching wells located at low fold and S/N ratio areas of the stacked section

Future Work

- Extend to 3D
- Shear-waves?

Acknowledgements

- Co-authors
- Dr. Daniel Trad
- Dr. Yu Geng
- CREWES Sponsors
- CREWES students and staff

THANK YOU