FWI with source illumination: A synthetic case study

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Outline

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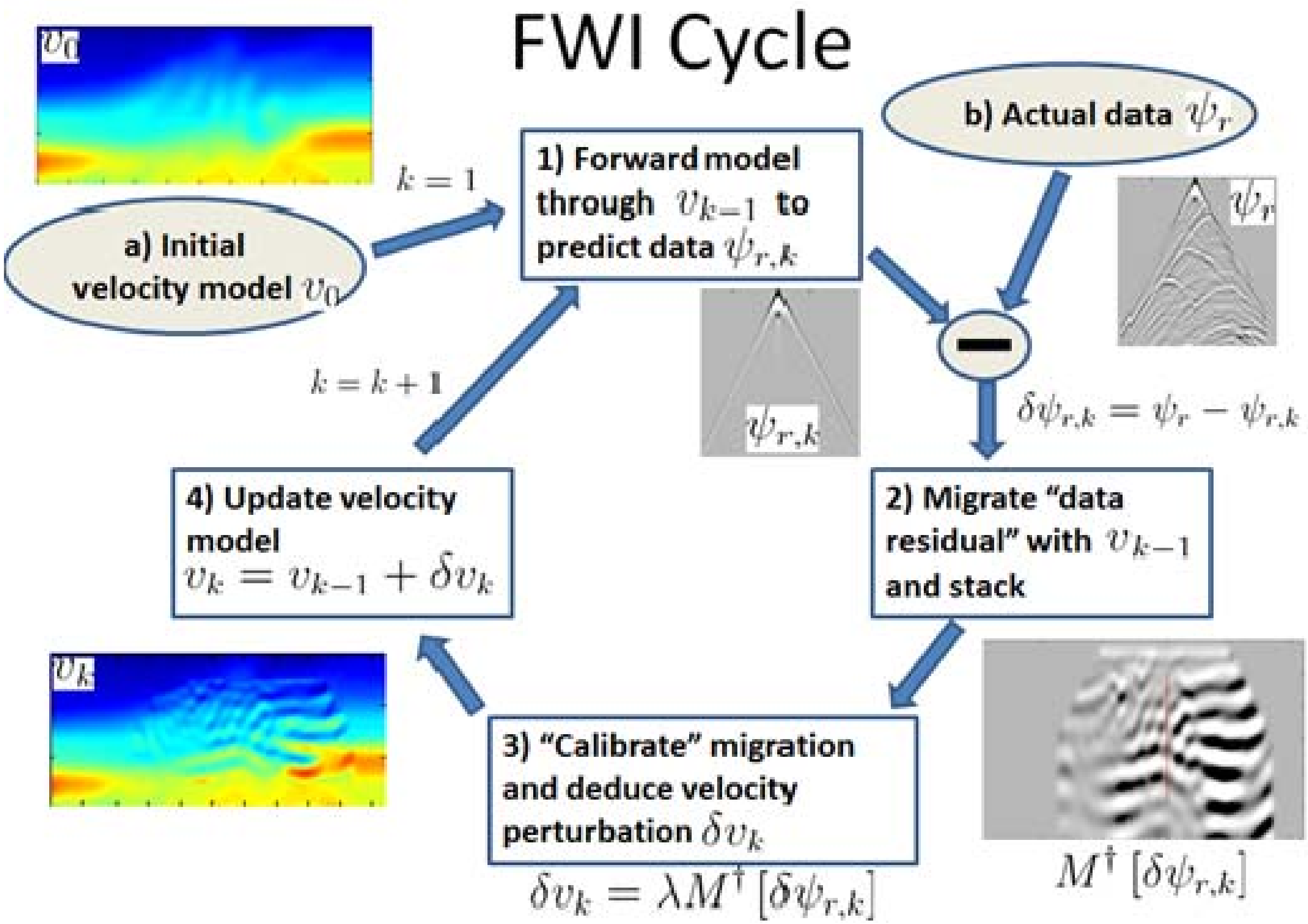
- **Synthetic Examples**
    - ***Model with flat layers***
        - **Comparing a linear velocity v(z) model with a smooth version of the real model**
        - **Comparing a line search method with well update for step length calculation**
    - ***Model with structures***
        - **Comparing a line search method with well update for step length calculation**
- **Results**
- **Conclusions and Discussions**
- **Future work**

Introduction

Full waveform inversion is an optimization technique that seeks to find a model of the subsurface that best matches the observed field data at every receiver location. The method begins from a best guess of the true model, which is iteratively improved using linearized inversions methods

Introduction



Margrave et al, 2012

Introduction

Objective functions (functionals)

1) $$\phi_k = \sum_{s,r} (\psi - \psi_k)^2$$

Conventional FWI, **validates** the predicted data ψ_k against the observed data ψ

2) $$\beta_k = \left\| \lambda G_k - (V_{well} - V_{BG})_k \right\|^2$$

Validates the migration velocity model V_{BG} against the known velocity model V_{well} at the well. Using well control (IMMI) as an alternative to line search methods

- We can search for a scalar λ using a line search method - Steepest Gradient Method
- Or we can calculate a scalar λ by minimizing 2) above w.r.t λ

$$\lambda = \frac{\sum_j \delta V_j G_j}{\sum_j G_j^2} \qquad \delta V_j = (V_{well} - V_{BG})_j$$ j indicates sample number.

Synthetic Examples: Model with flat layers

Forward modelling parameters

Shot spacing	50 meters
Receiver spacing	5 meters
Dominant frequency	50 hertz
Number of Shots	40
Number of Receivers	448
Layer thickness of model	500 meters

Synthetic Examples: Model with flat layers

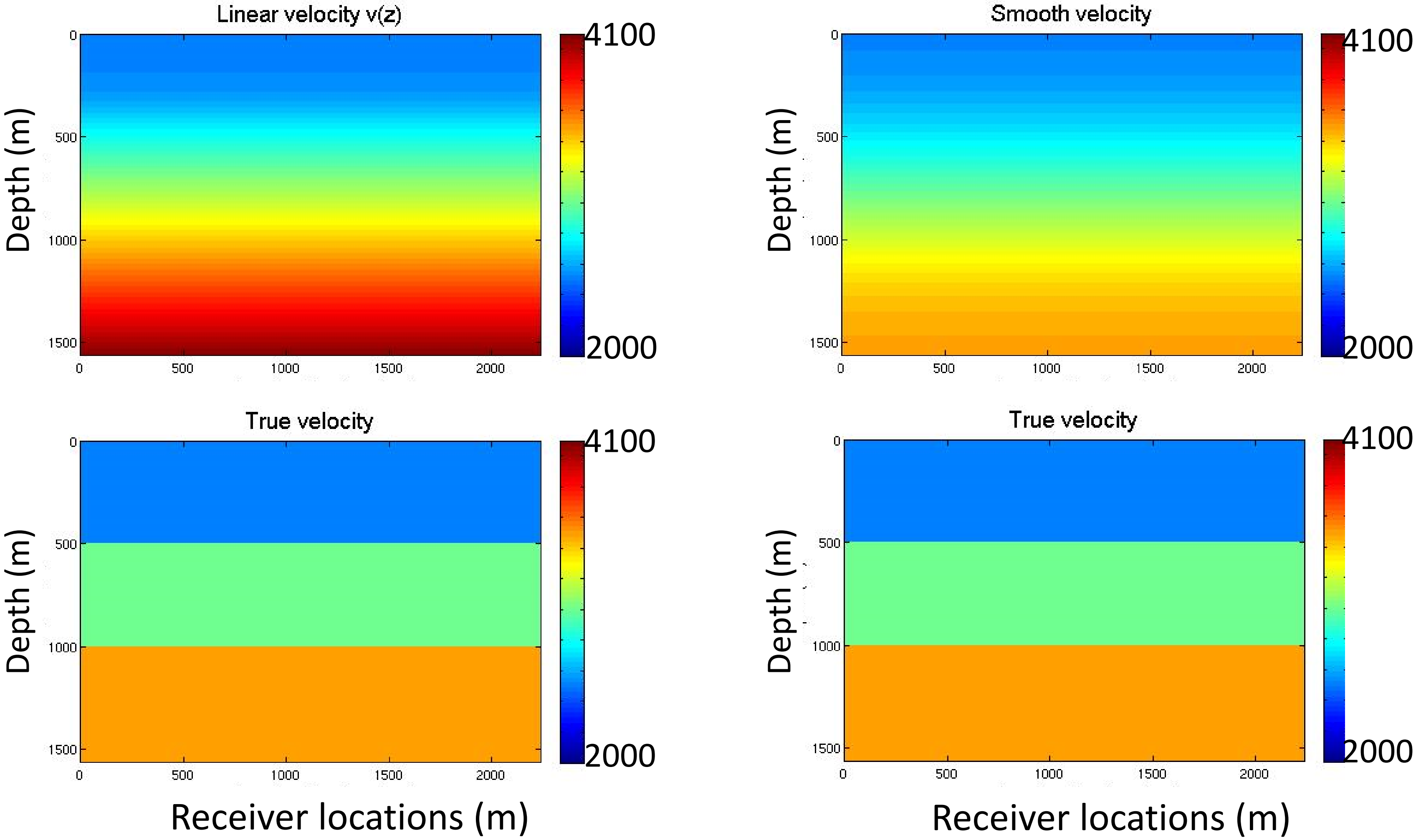
Three Layers of velocities 2.5Km/s, 3Km/s and 3.5Km/s.

Inversion

- **PSPI migration algorithm with a Deconvolution IC**
  - ❖ **Deconvolution IC has the closest link to estimating reflectivity if wavelet can be estimated correctly**
  - ❖ **The Cross Correlation IC provides an image amplitude that is the product of source and receiver wavefields and has the unit of amplitude square.**
  - ❖ **Source-normalized CC IC has the same unit and scaling as the Reflectivity**
- **Multi-scale approach (Pratt,1999)**

Synthetic Examples: Model with flat layers

Comparing Linear velocity v(z) as starting model with a smooth version of the true velocity model



Synthetic Examples: Model with flat layers

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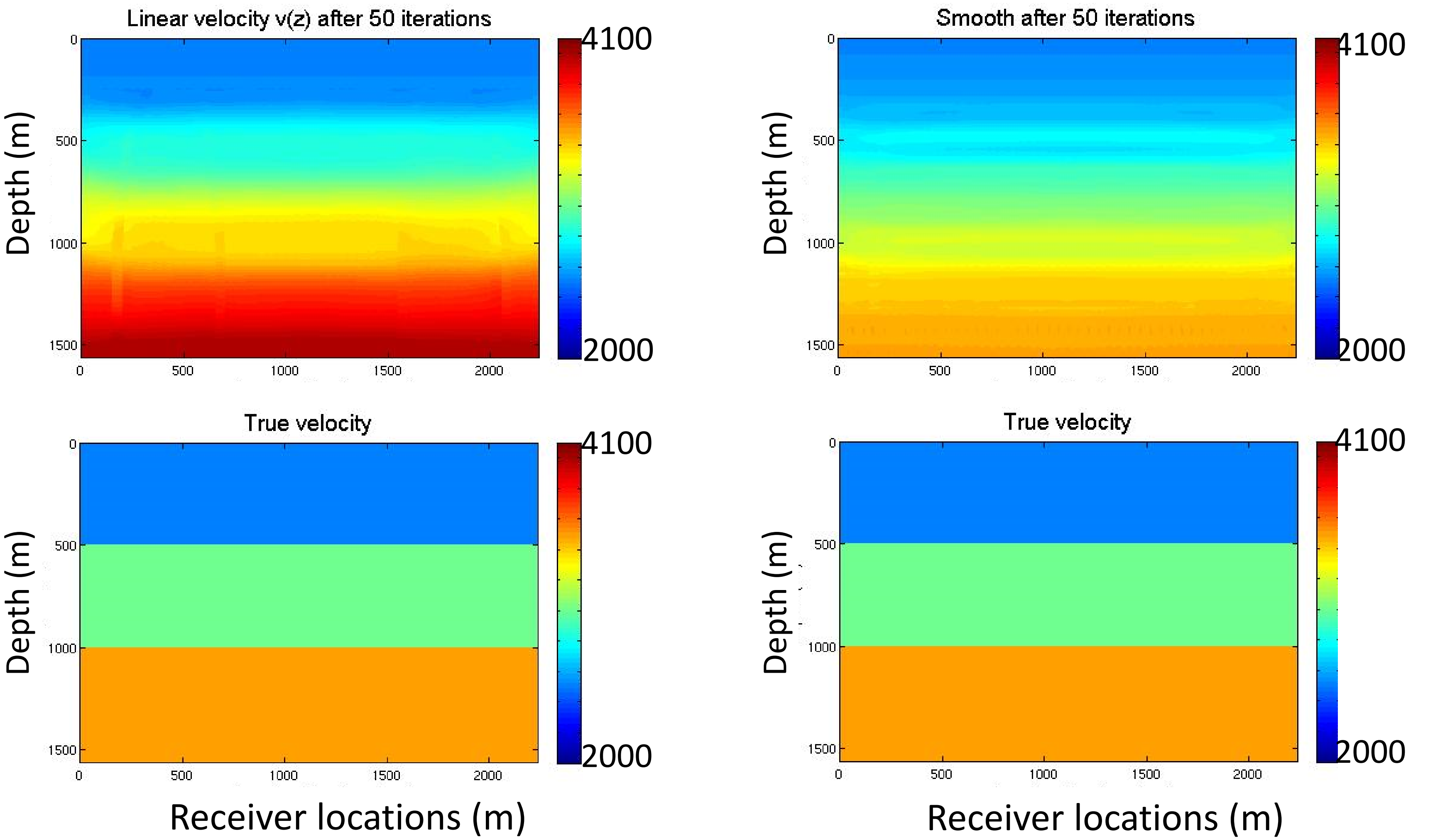
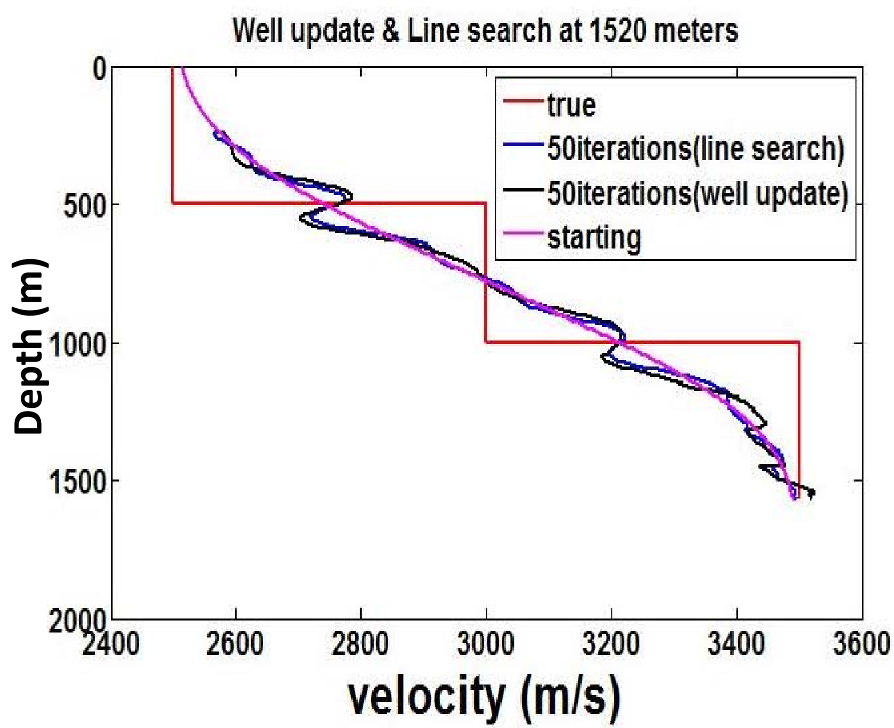
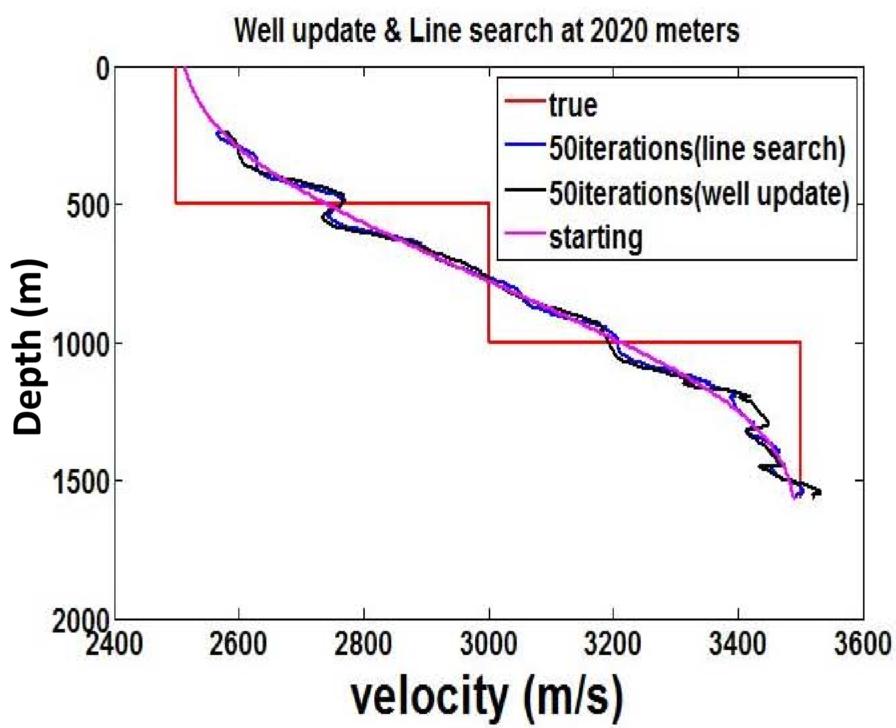


Synthetic Examples: Model with flat layers

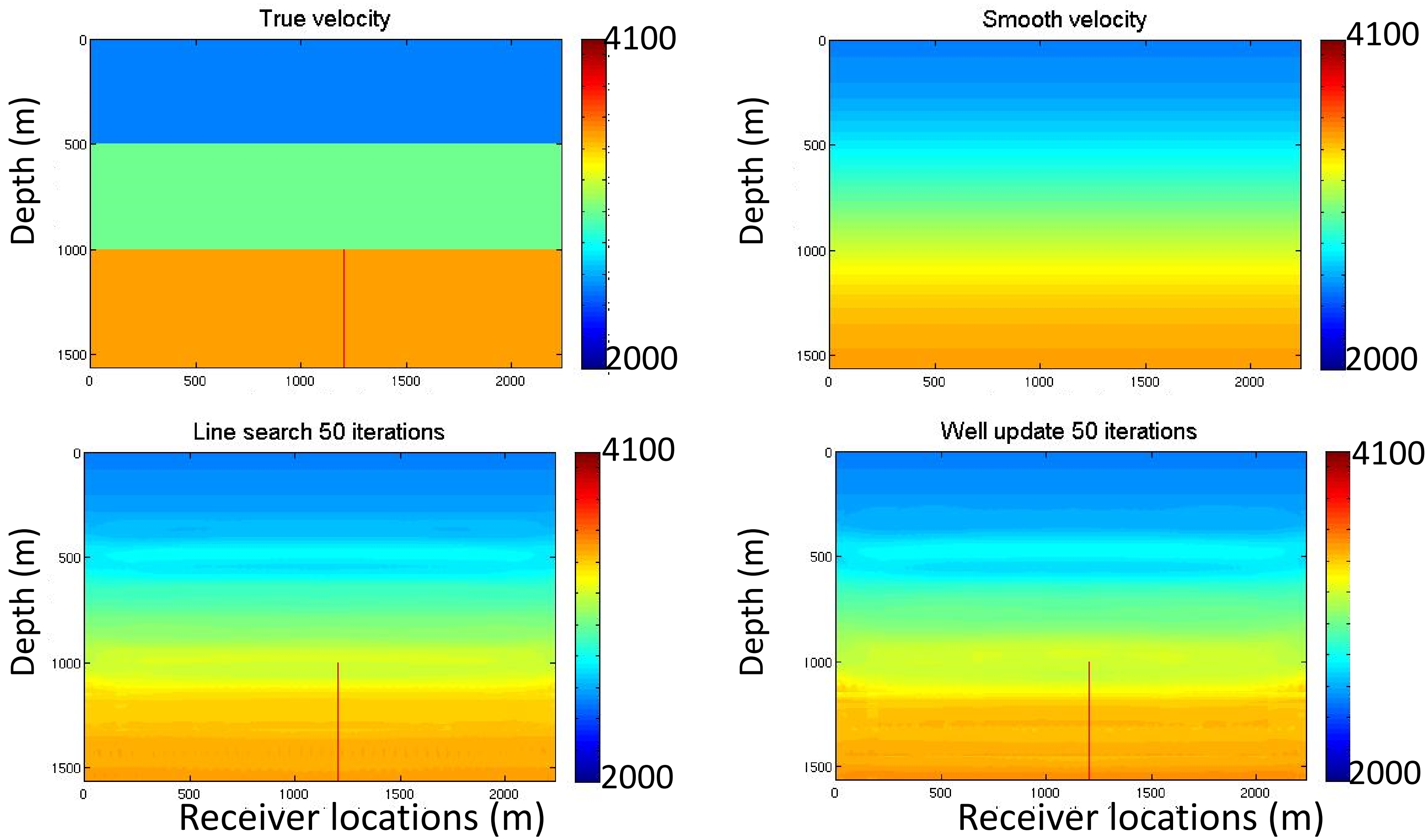
Comparing Line search optimization with a scalar deduced from well information at 1520 meters and 2020 meters.





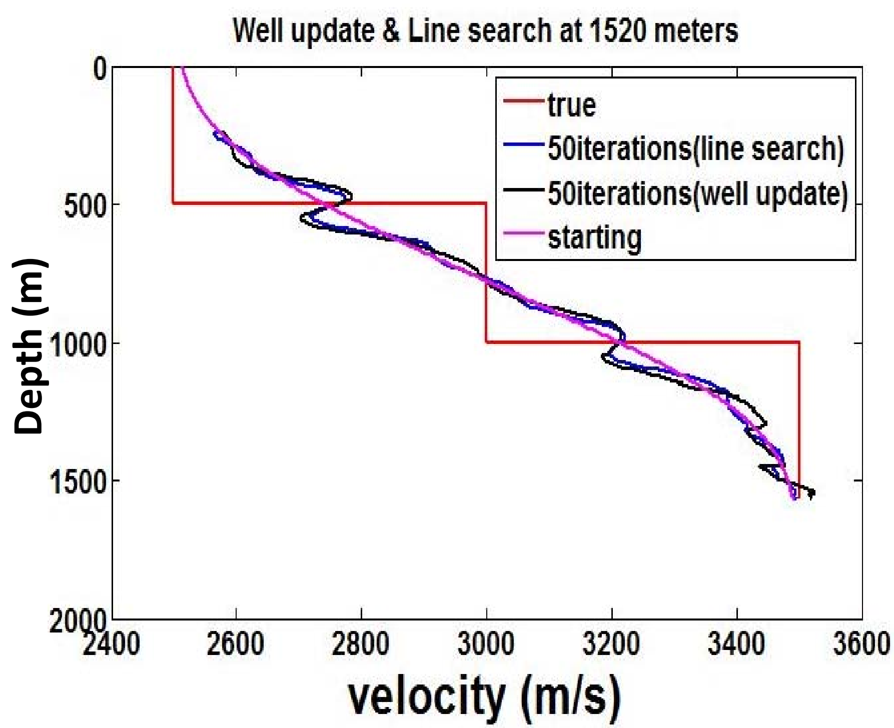
Synthetic Examples: Model with flat layers

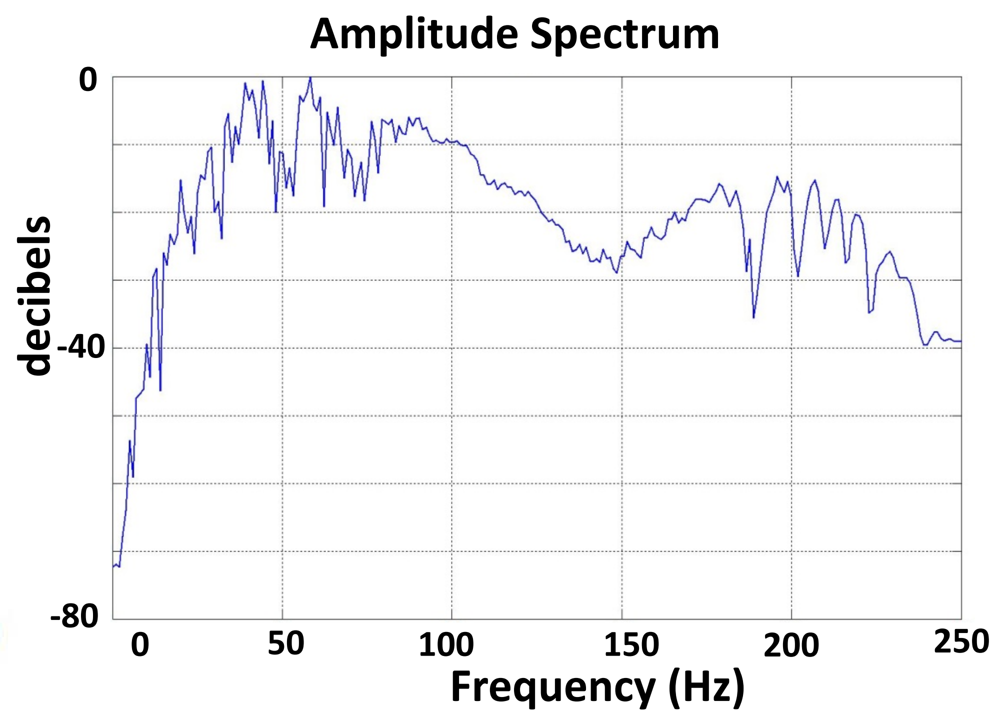
Comparing Line search optimization with a scalar deduced from well information . Starting model is a smooth version of the true velocity model



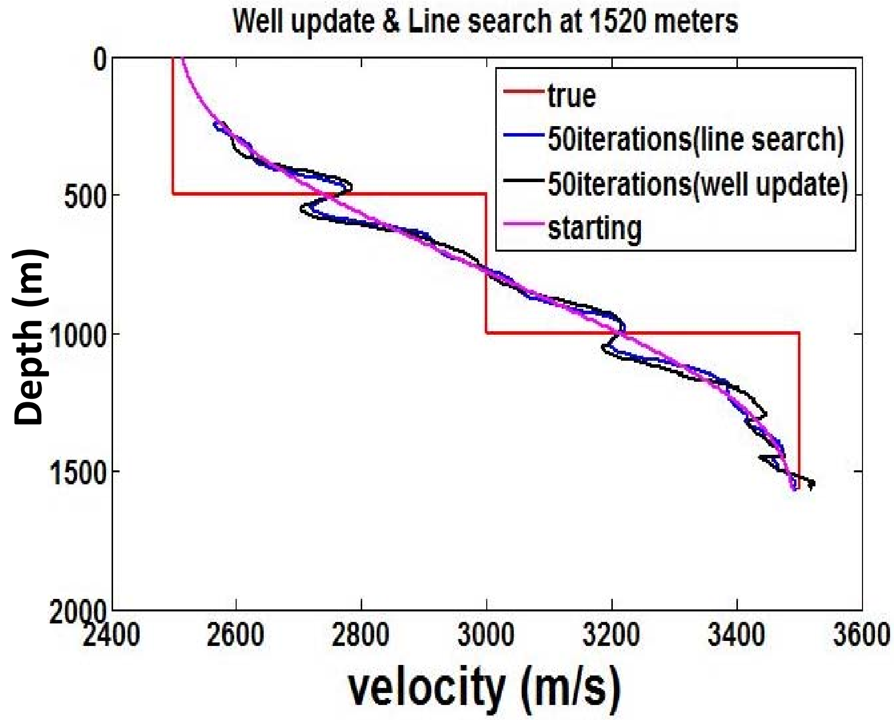
Synthetic Examples: Model with flat layers

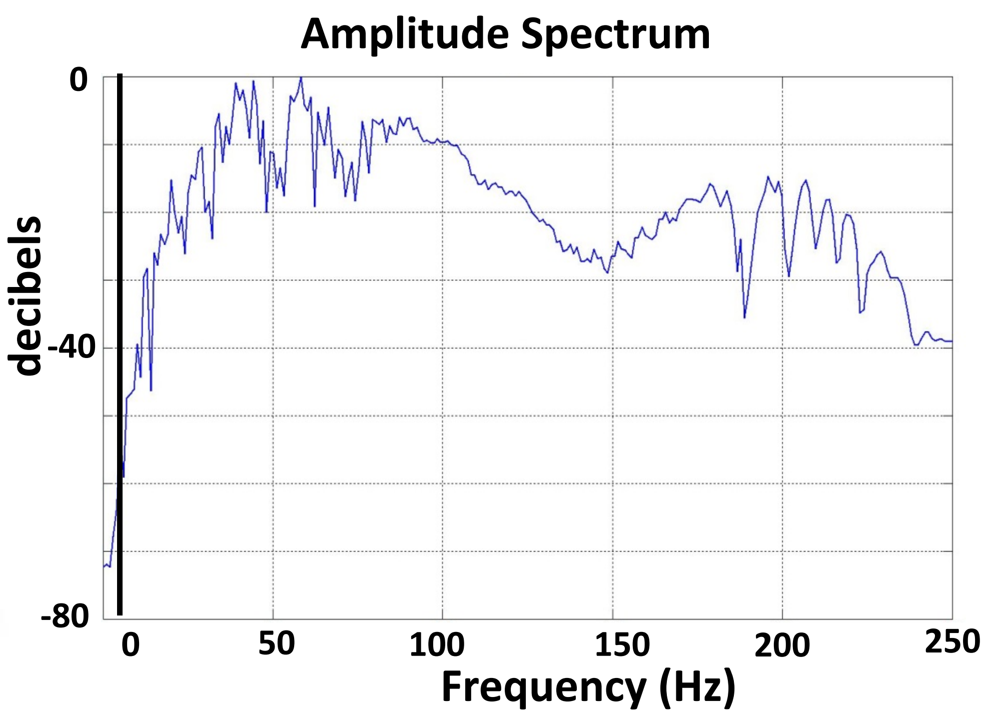
Comparing Line search optimization with a scalar deduced from well information at 1520.





Conclusions: Model with flat layers





It turns out that our simple flat layer model isn't quite simple to invert!

Conclusions: Model with flat layers

» Using a Linear V(z) velocity model as a starting model did not give 'encouraging' results with conventional FWI compared to using a smooth version of the true model.

» Comparing a line search optimization technique to a scalar derived using well log information (using a smooth version of the true model), suggests that both methods are trying to do the job but the inverted models from both methods are still quite far from convergence. Why is this so and what can we learn?

» We will repeat experiment with a lower dominant frequency, reduced layer thickness and whitening the spectrum before FWI

Synthetic Examples: Model with Structures

Structured layers with an anticlinal structure at the bottom of the model.

- Variable layer thickness.

Inversion

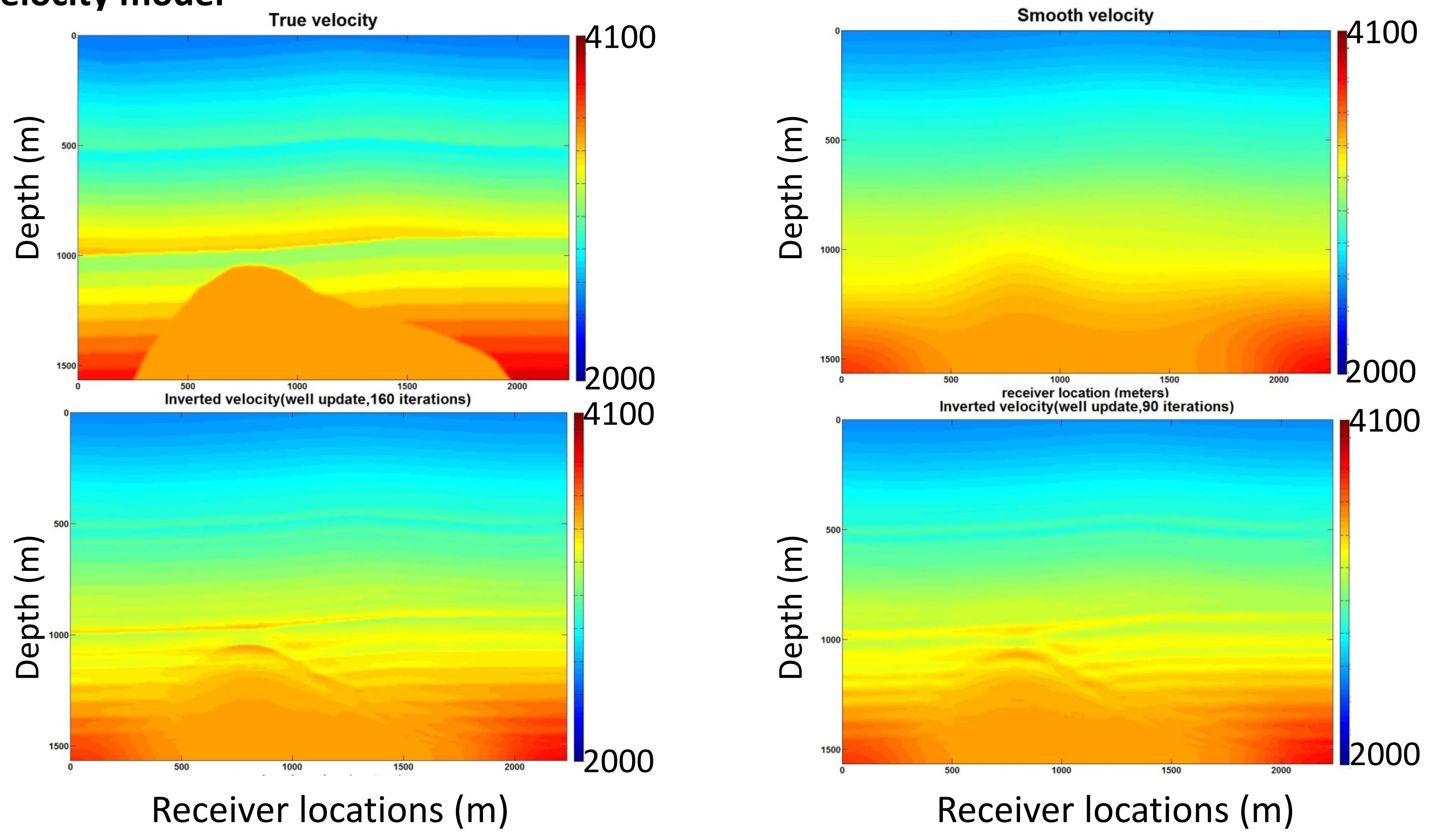
- RTM migration algorithm Cross Correlation IC
  - We used the Cross Correlation IC but we normalized the image by the square of the source illumination strength.
- Multi-scale approach (Pratt,1999)
- Used well information and a line search to determine the step-length

Synthetic Examples: Model with flat layers

Scalar deduced from well information.
Starting model is a smooth version of the true velocity model

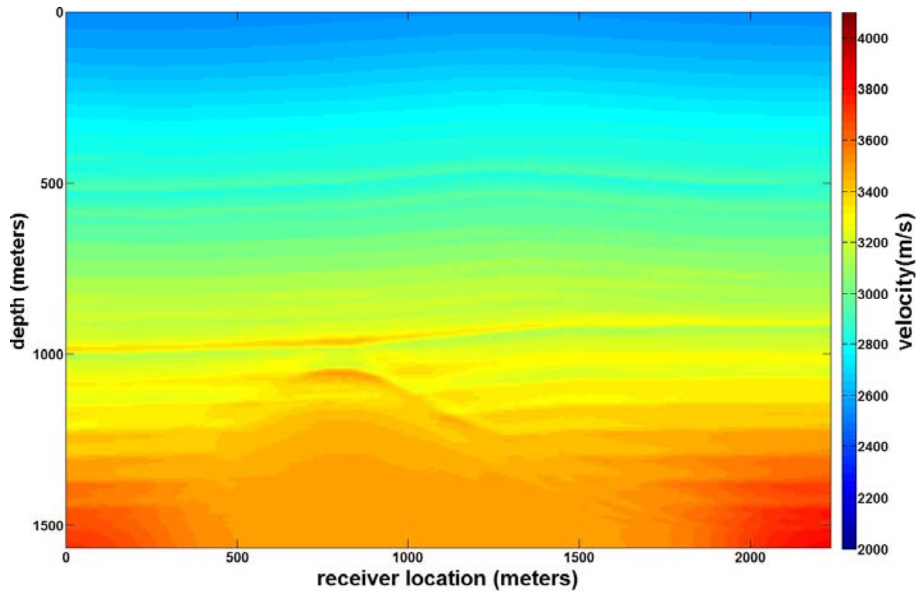
Synthetic Example: Model with Structures

Step-length deduced from well information . Starting model is a smooth version of the true velocity model

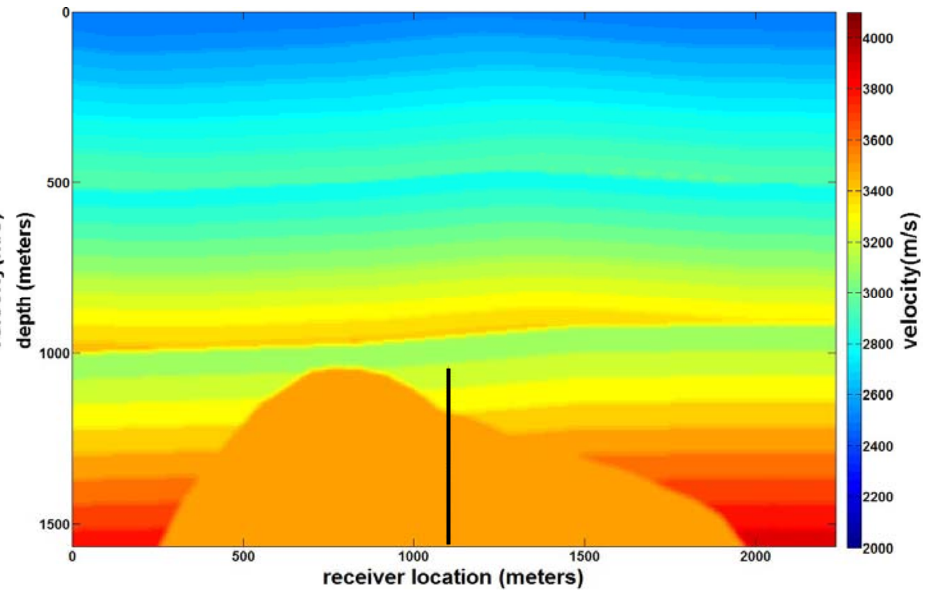


Synthetic Example: Model with Structures

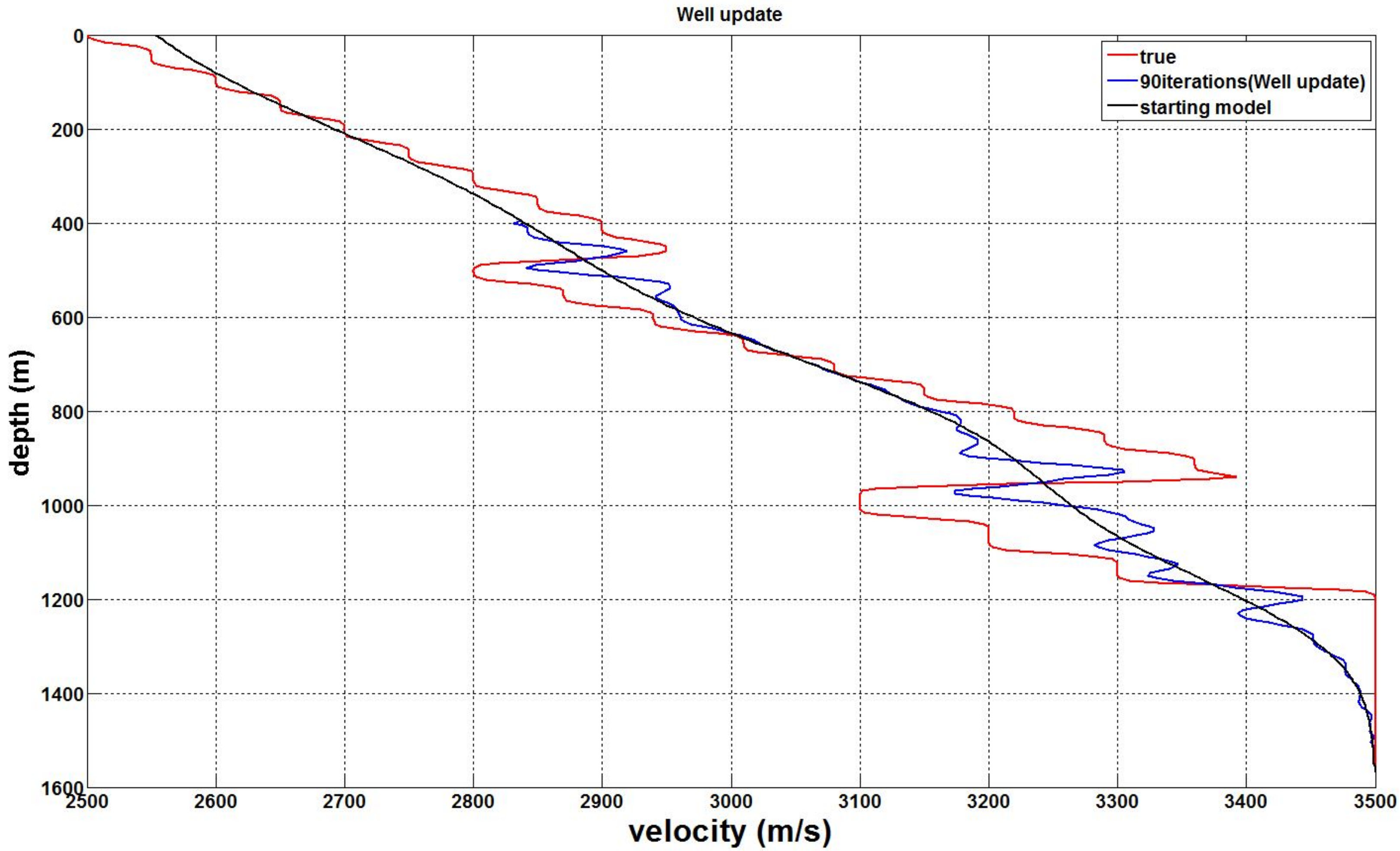
Inverted velocity model(Well update,160 iterations)



True model



Synthetic Examples: Model with Structures vertical profile at 520 meters



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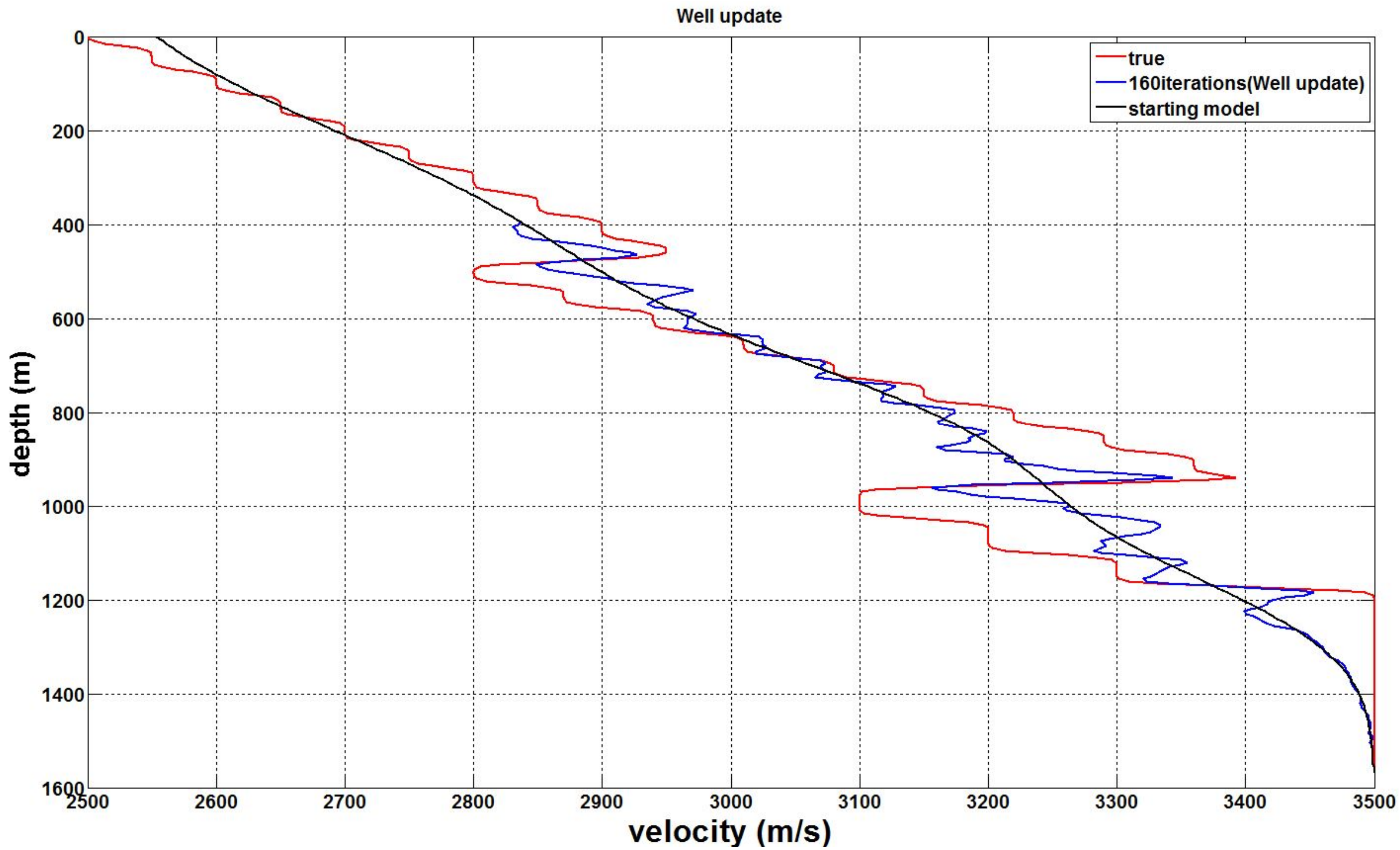

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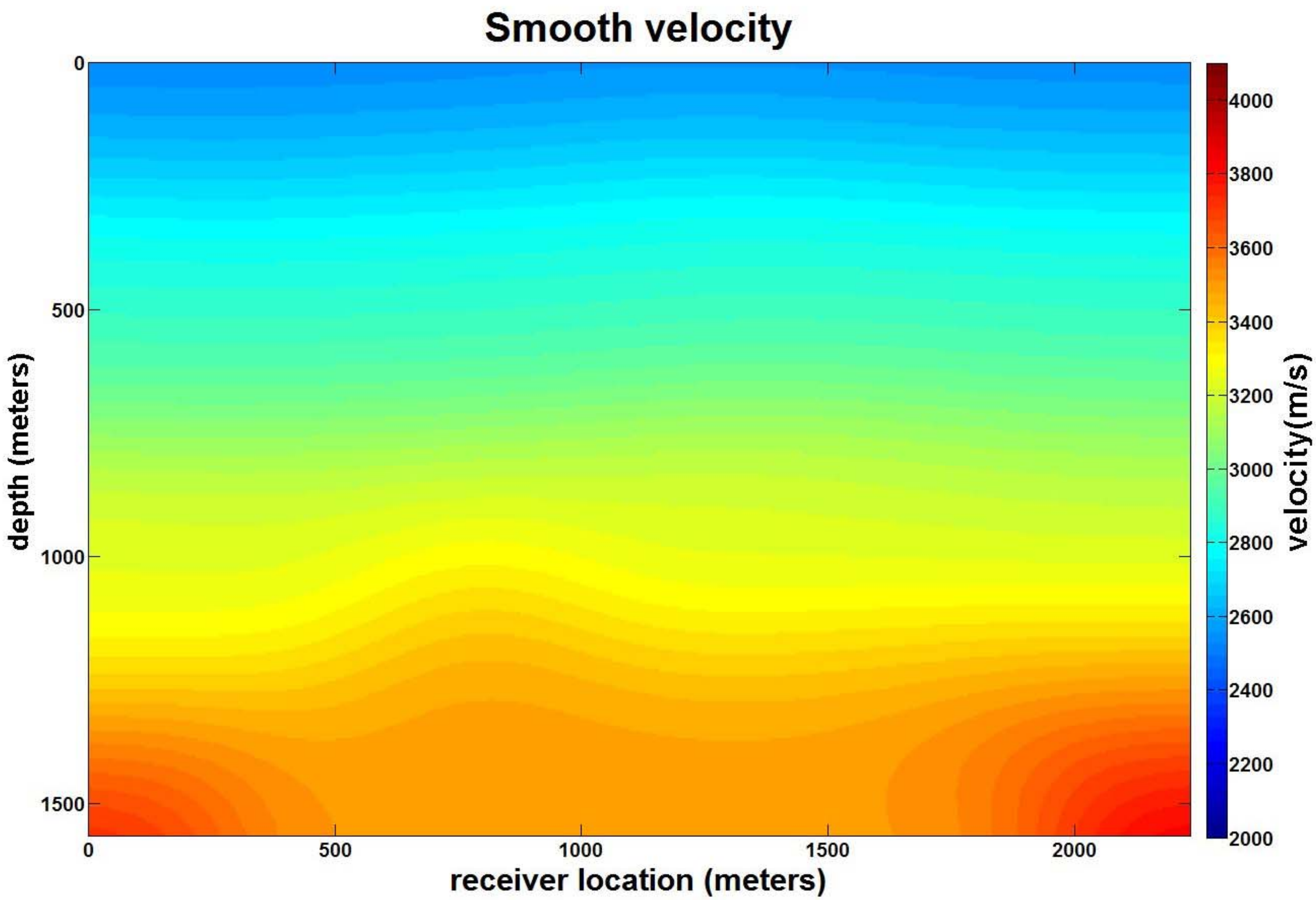

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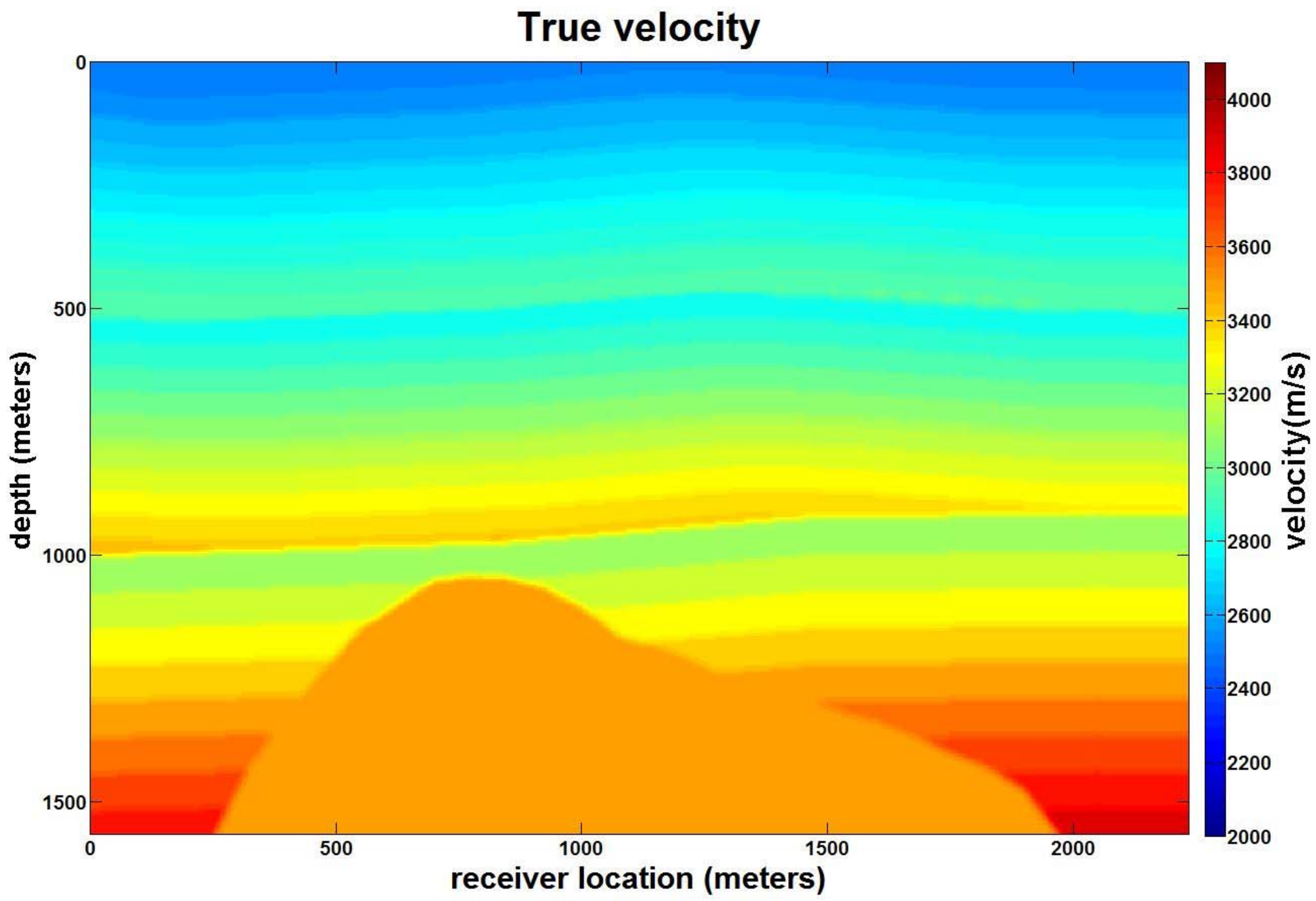

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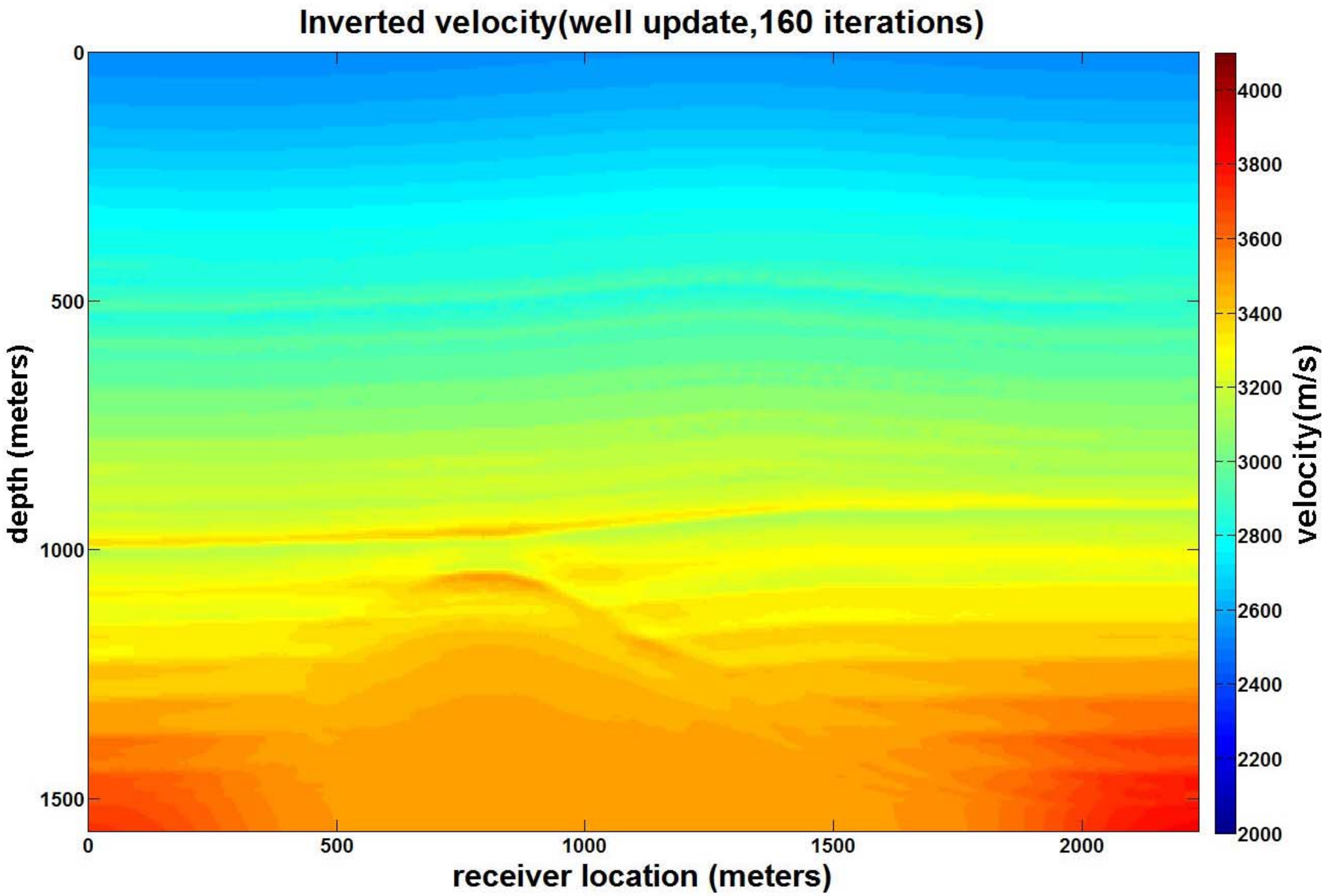
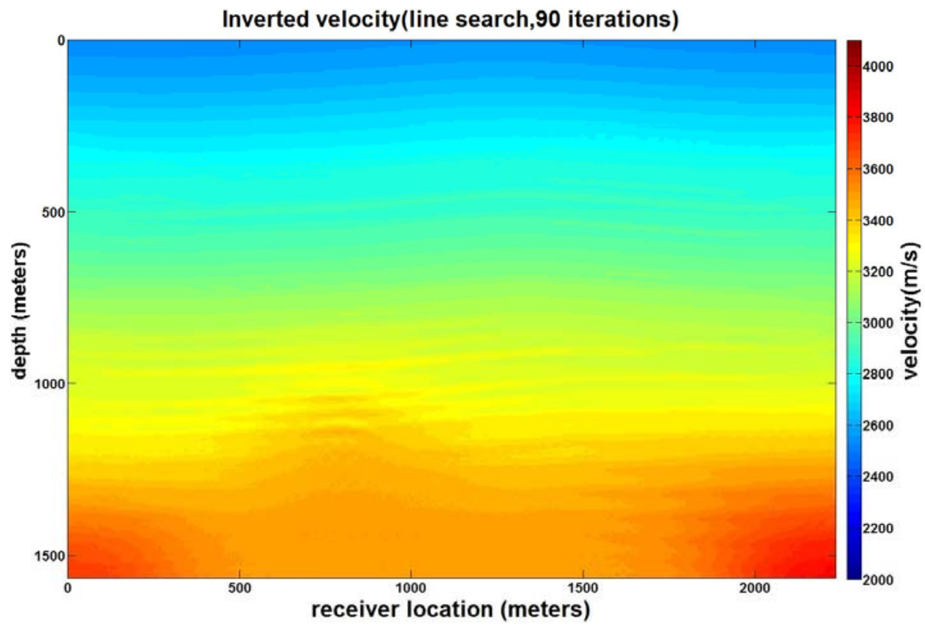
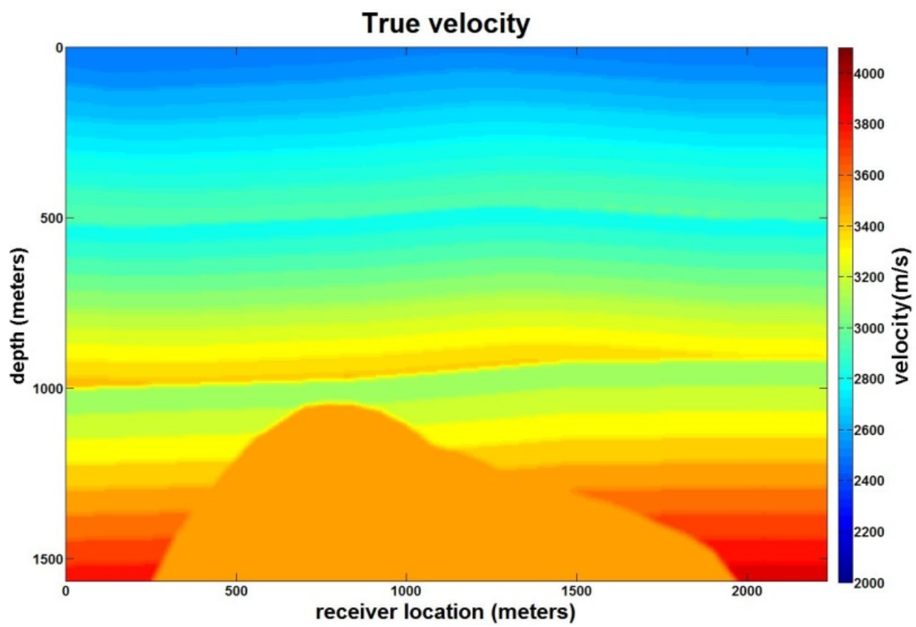


Scalar deduced using a line search.
Starting model is a smooth version of the true velocity model

Synthetic Examples: Model with Structures





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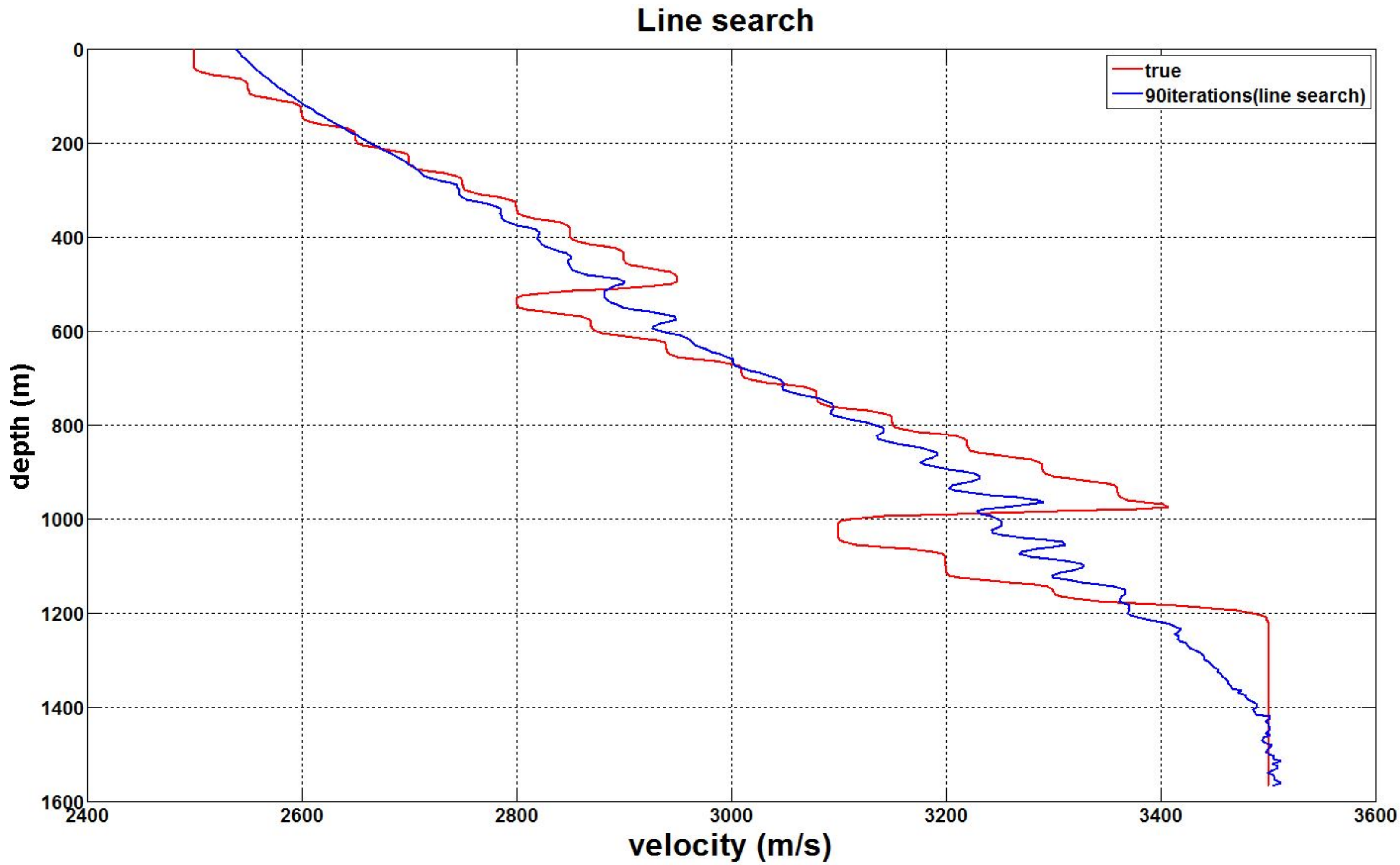

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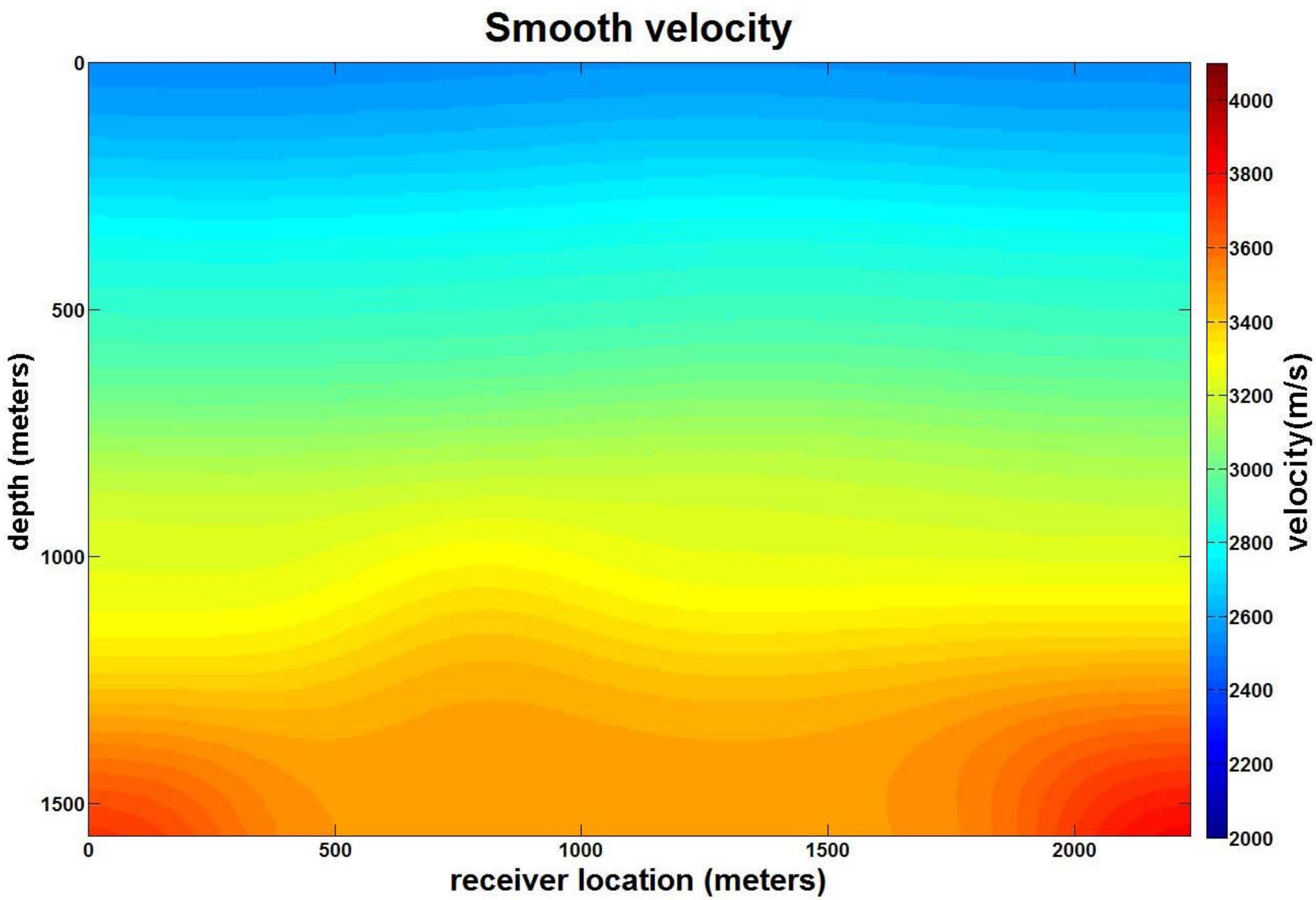

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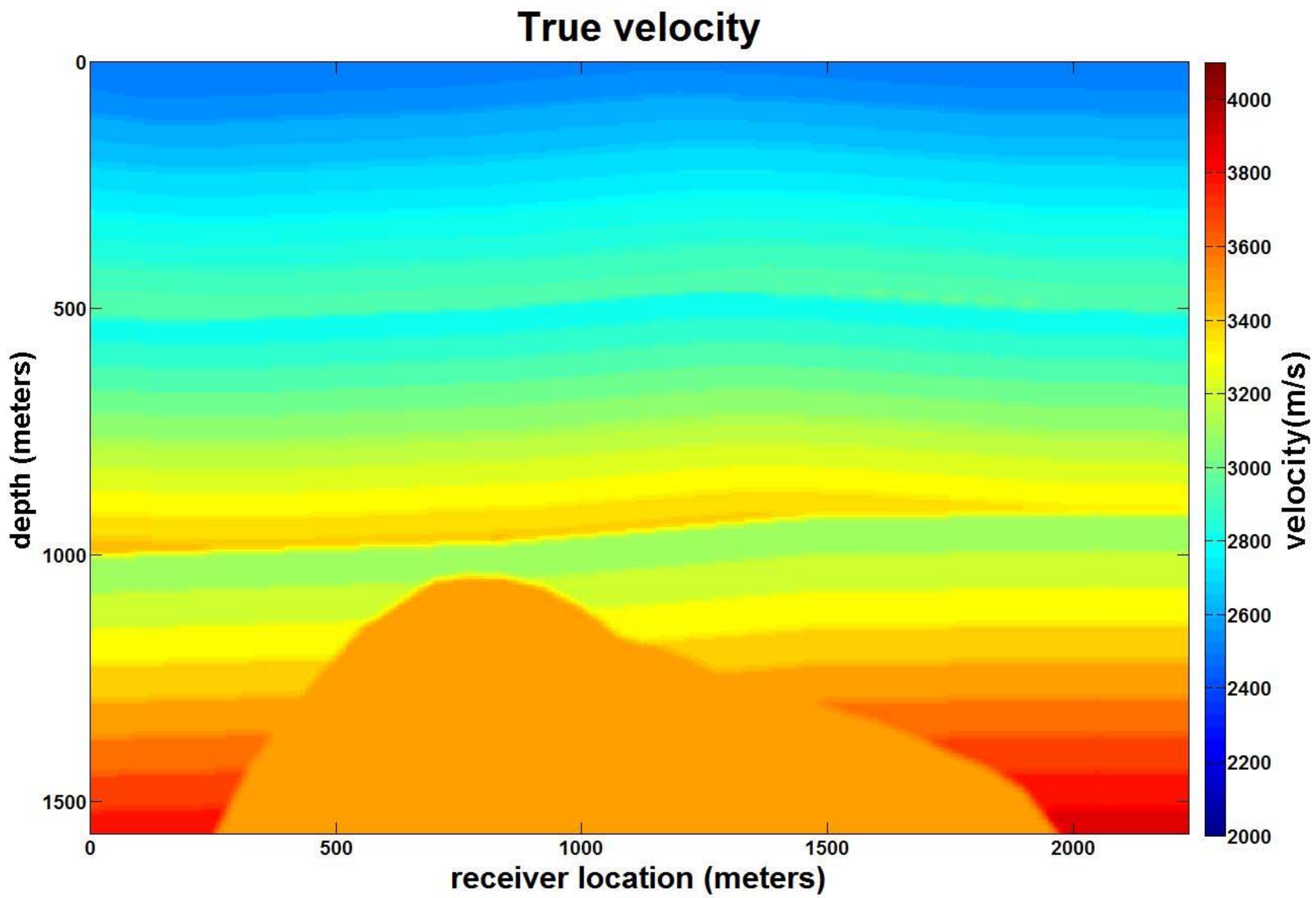

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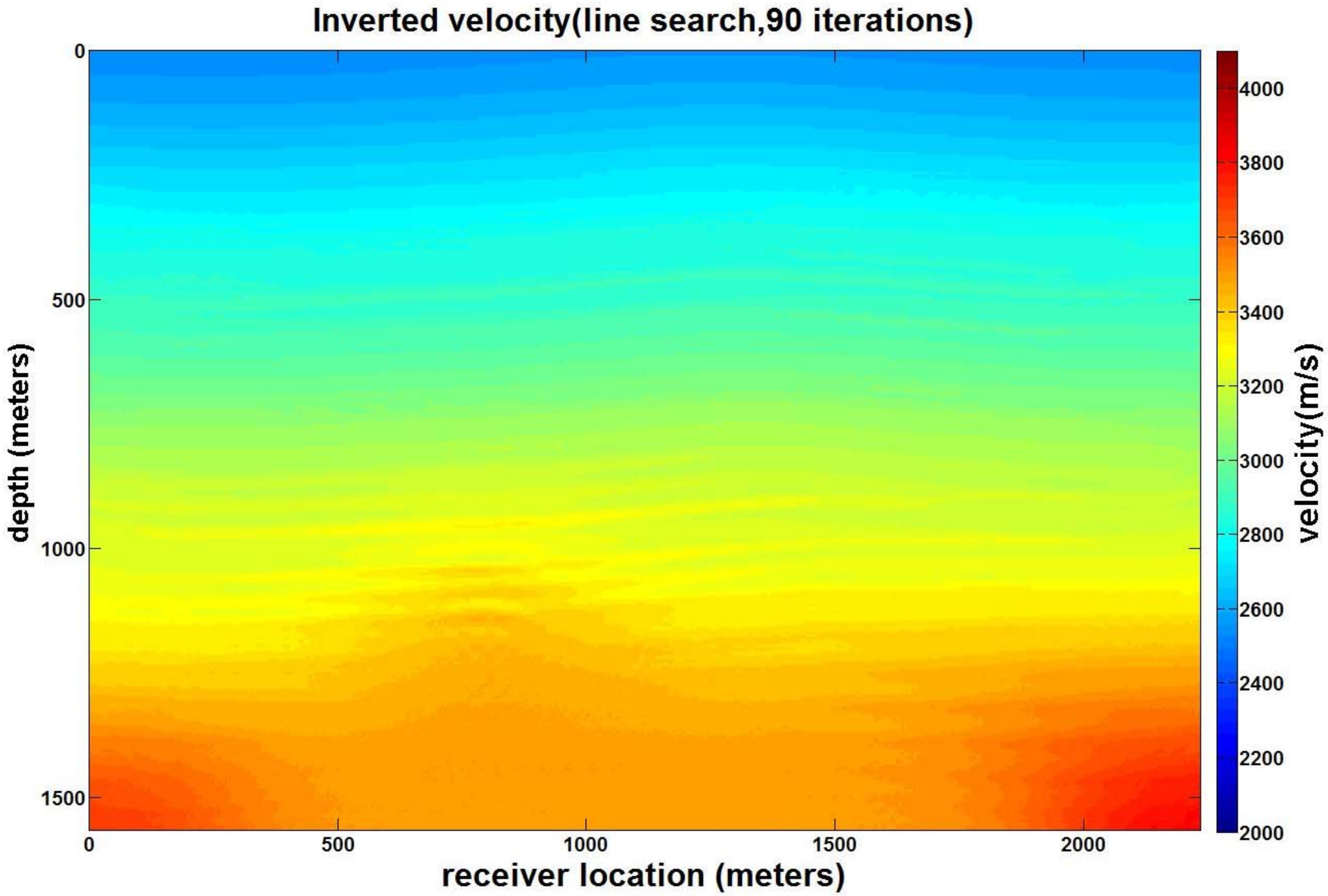
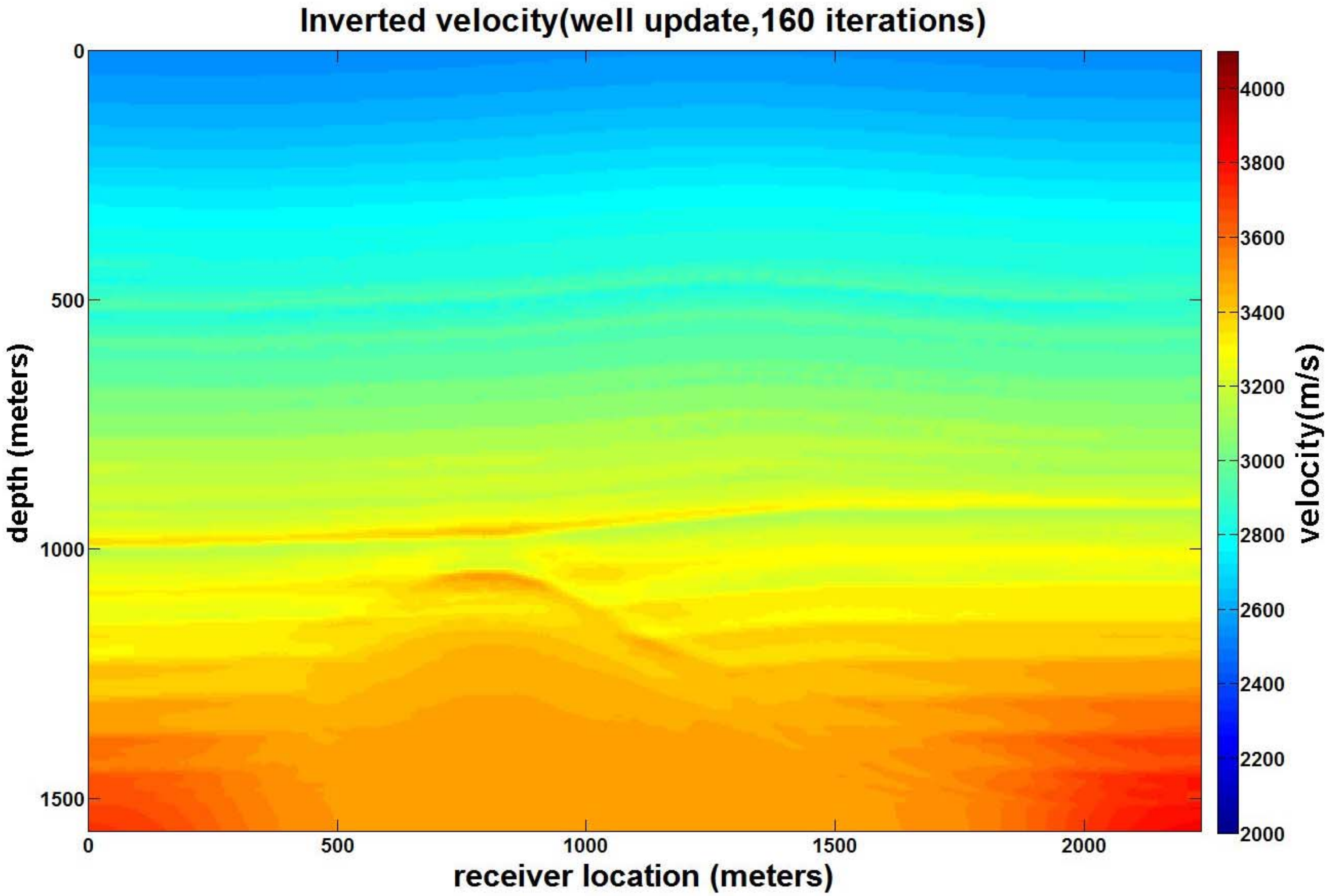


Comparing Line search optimization with a scalar deduced from well information.

Synthetic Examples: Model with Structures



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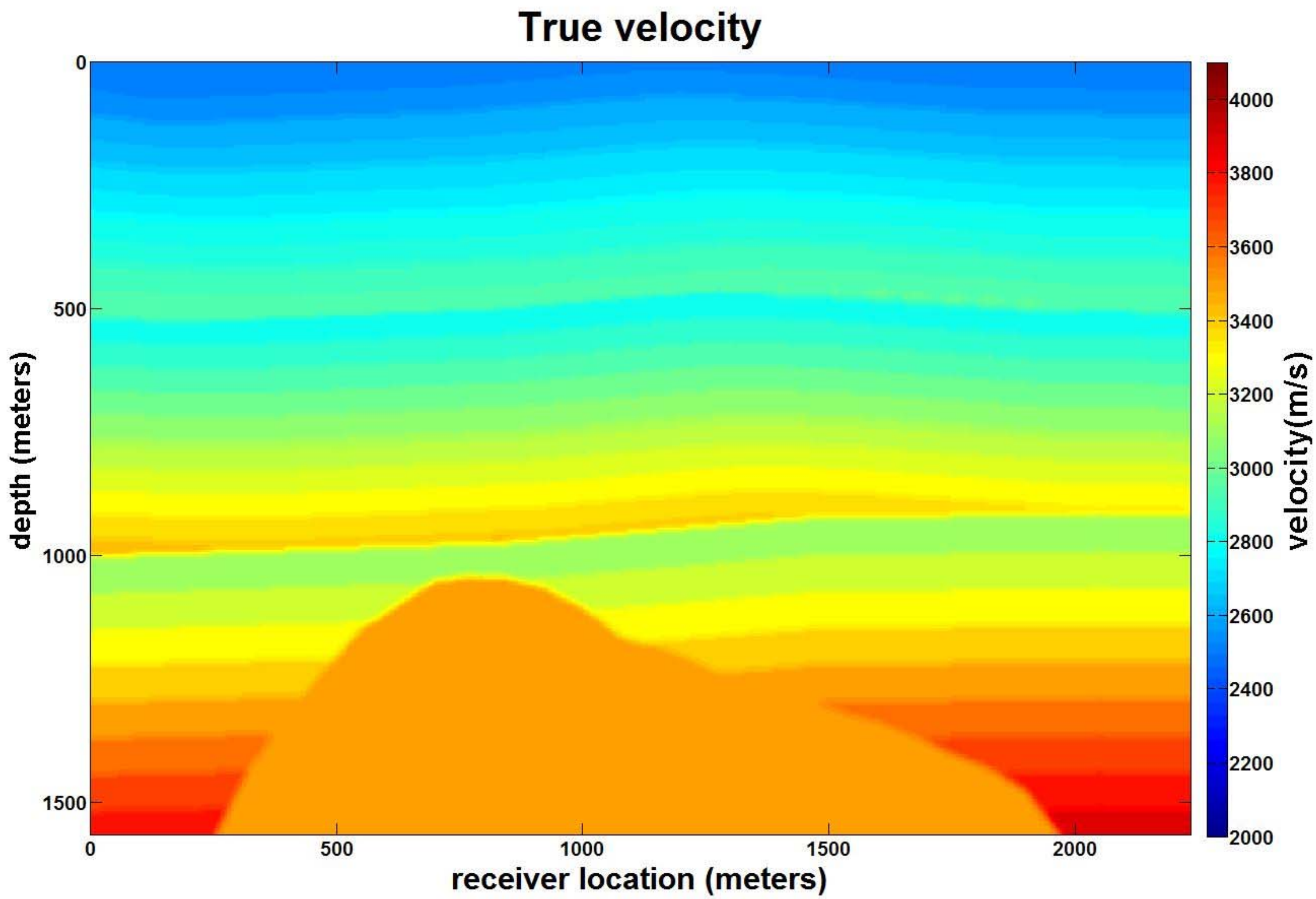

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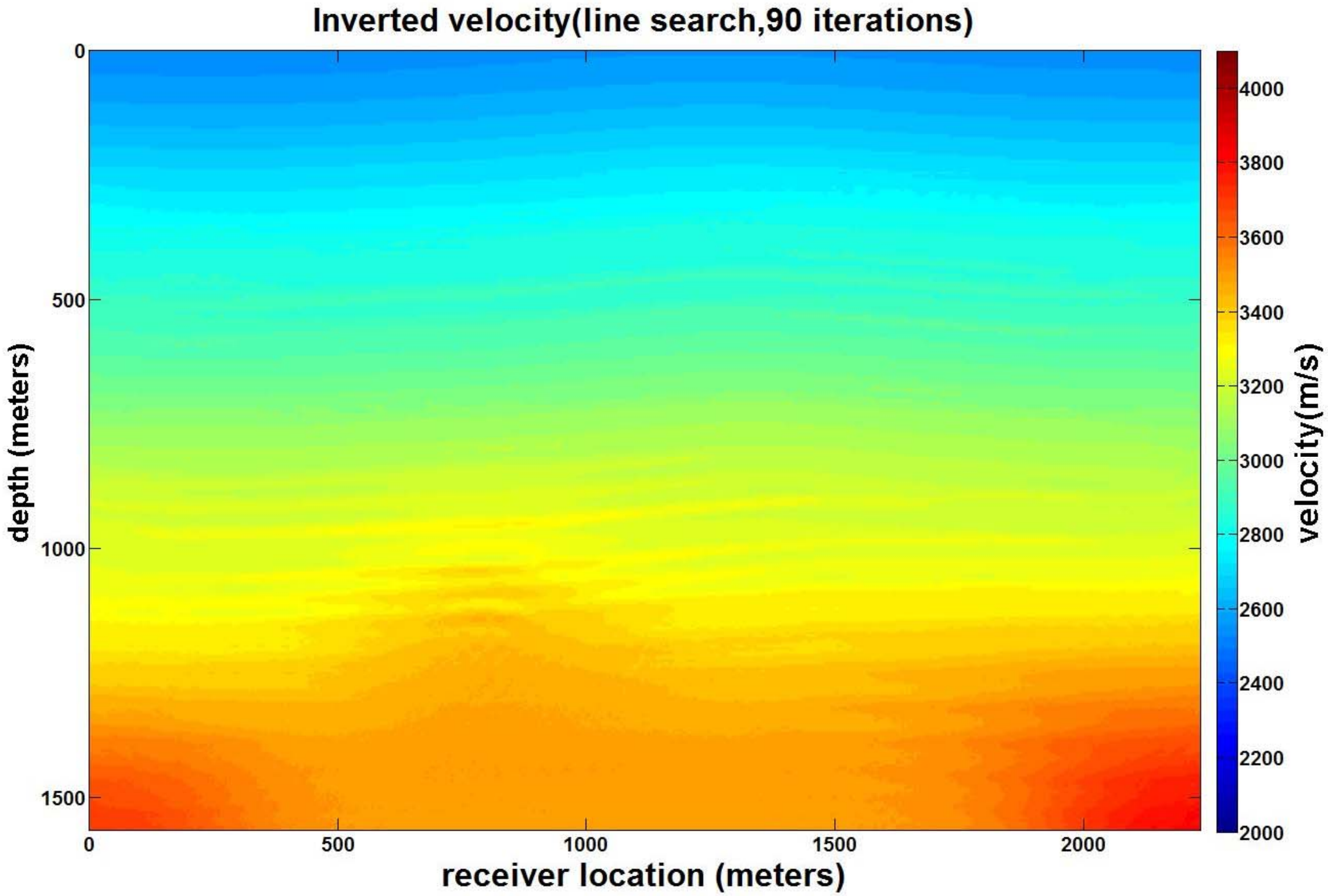

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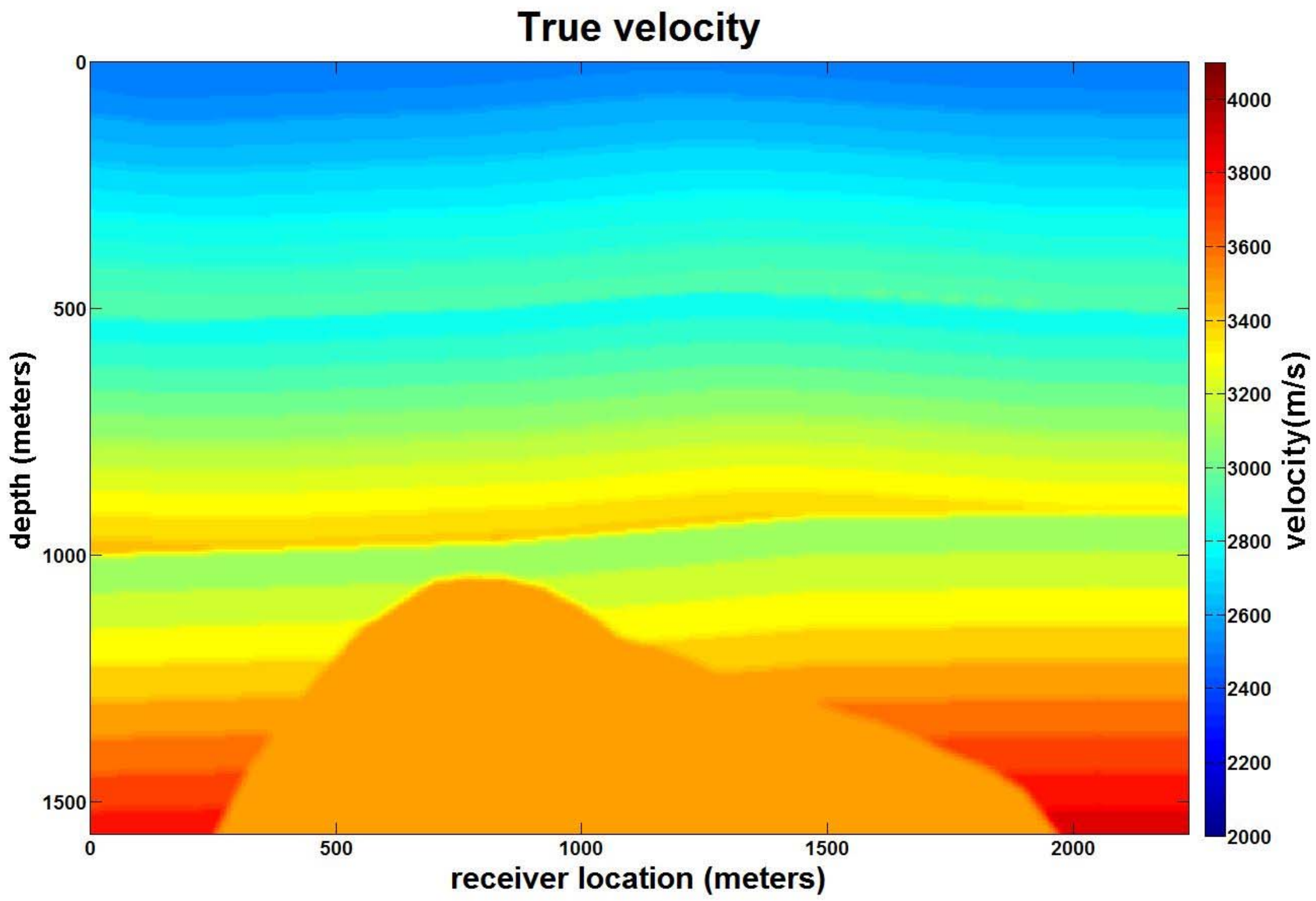

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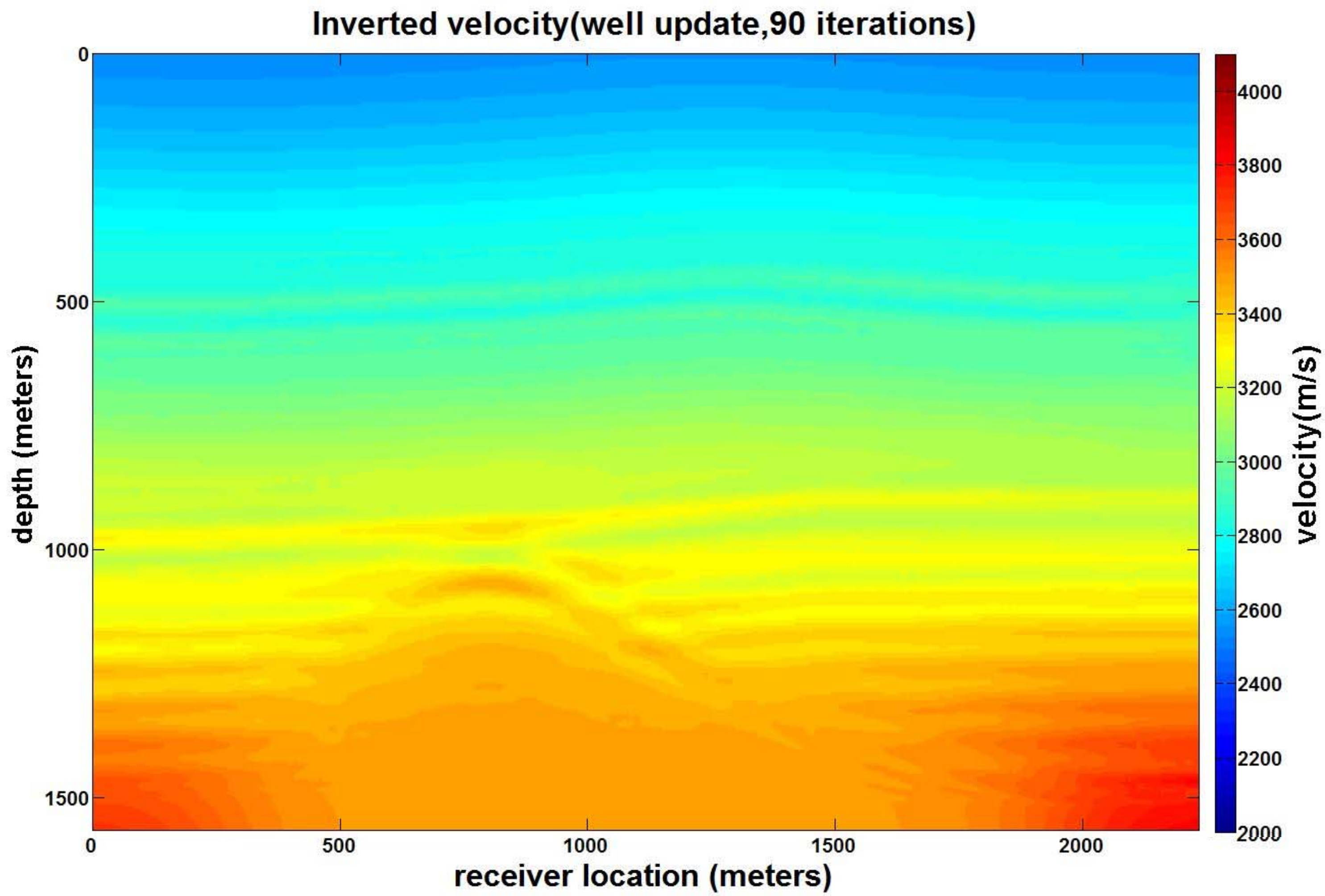

Conclusions: Model with Structures

»We have high resolution in the deeper sections than in the shallow from the inverted model using well logs.

»Using well information was able to resolve the flanks of the anticline. We can get better results if we have good well control and run more iterations.

»Information from well logs to calculate a scalar for the model update shows encouraging results and could save us some computational time compared with the line search method.

» Using a line search optimization scheme, we observe that we have better resolution in the shallow sections of the model than in the deeper sections.

Discussions

» Results from the flat layer model reiterate the importance of low frequency information in our data.

»The scalar derived from well information can be used to condition the line search code.

»We conjecture that a combination of a line search optimization scheme with well information should produce desirable results than if only one method of optimization is used.

Future Work

»Exploit the full possibilities of incorporating well Information into FWI such as having a wavelet update between iterations inside our code.

» Having a combination of a line search optimization and with well information during iterations.

»We will investigate if better results will come from a model using reflectivity from a well log, or using NMO velocities, or a tomographic model.

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THANKS!

Theory of FWI: Data validation & Well validation

DATA Validation (Margrave et al, 2012): Comparing predicted data to recorded data.

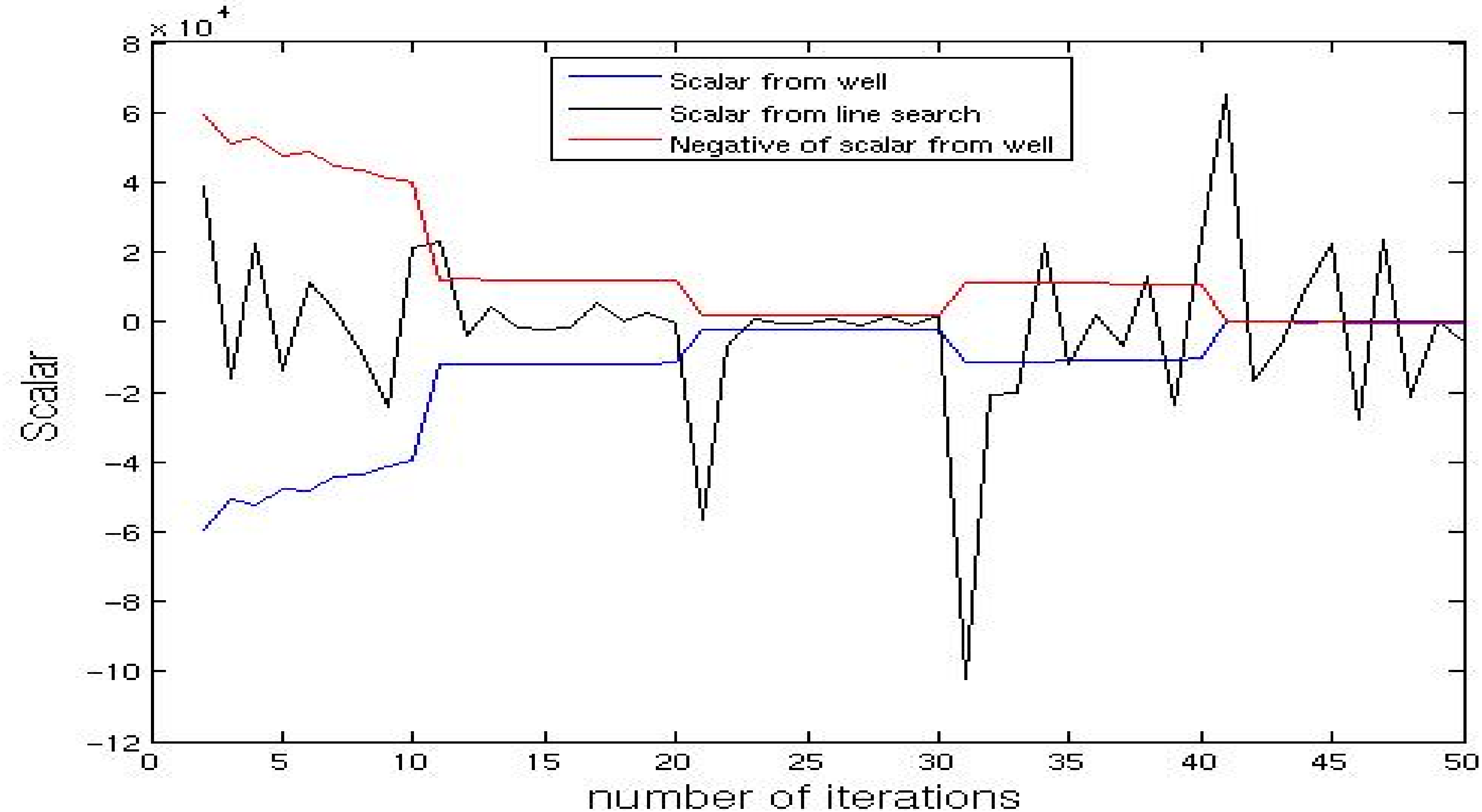
Data validation is far more sensitive to changes in the shallow part of the model than well validation.

WELL Validation (Margrave et al 2012): Comparing reflectivity image to synthetic seismograms at well locations.

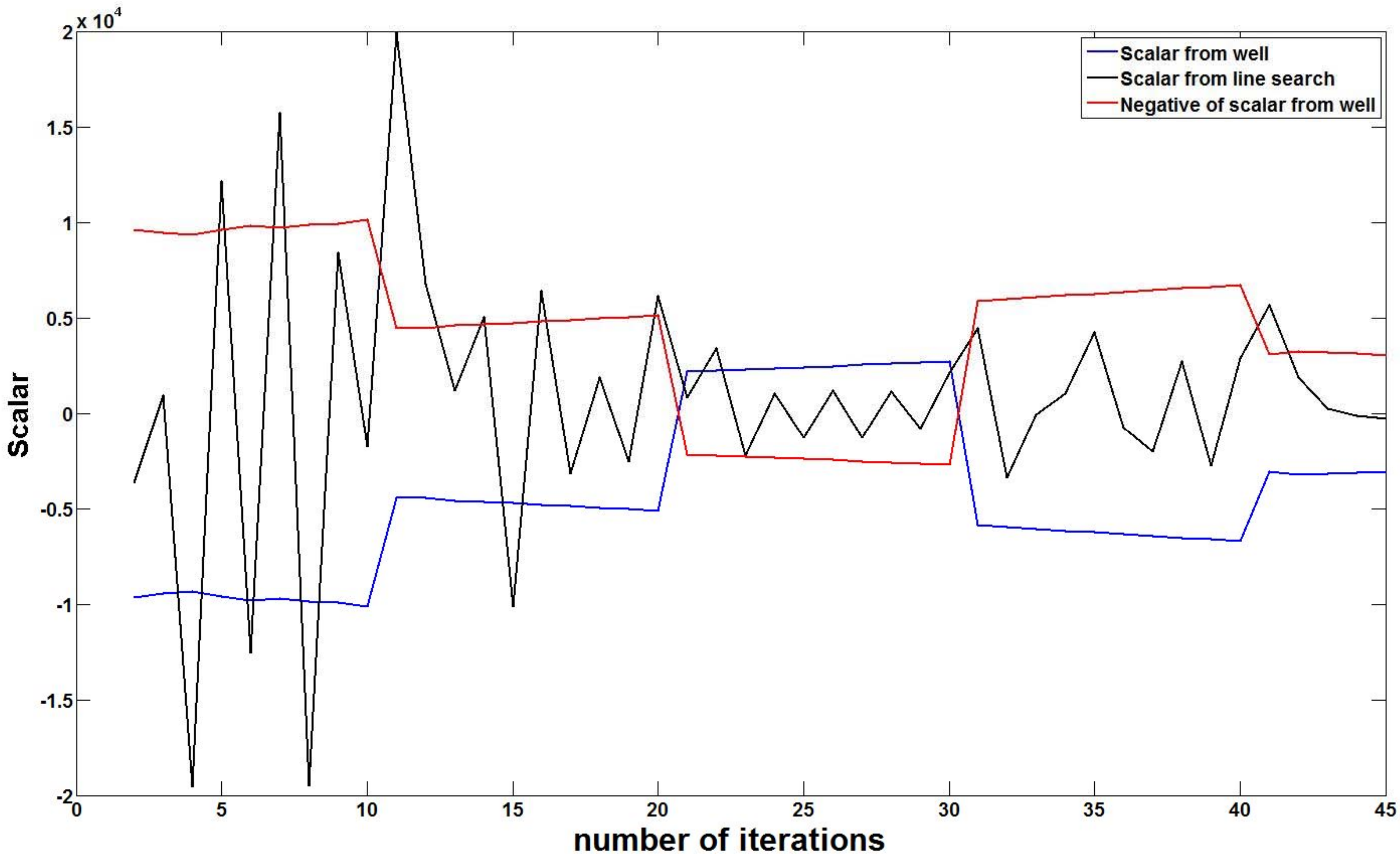
Well validation is limited by the depth range of the logs, hence it is sensitive to changes within the logged part of the model

Synthetic Examples: Model with flat layers

Comparing the paths of the Line search optimization with the paths of a scalar deduced from well information through 50 iterations

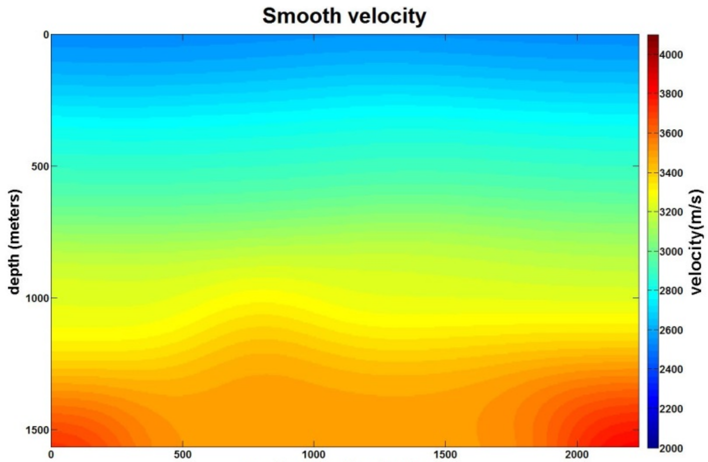


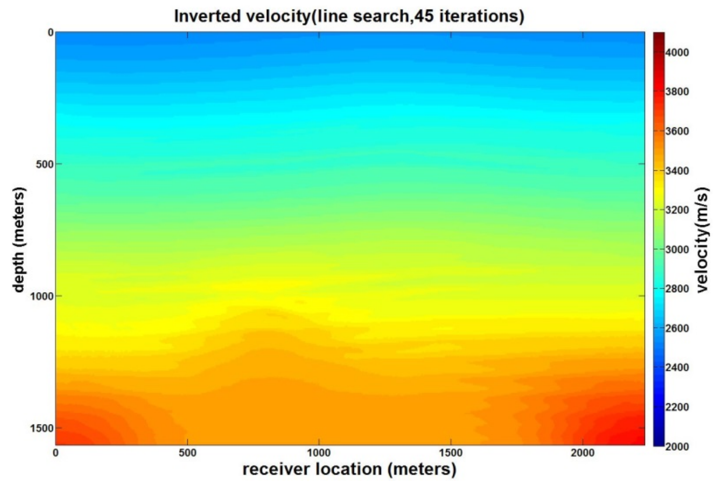
Synthetic Examples: Model with Structures

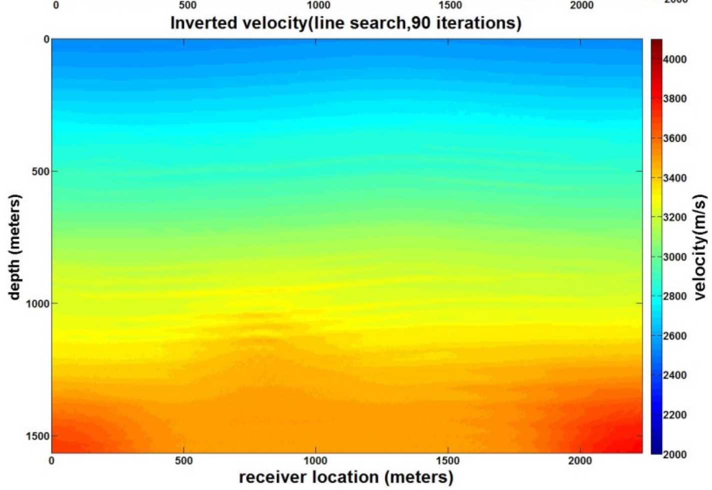


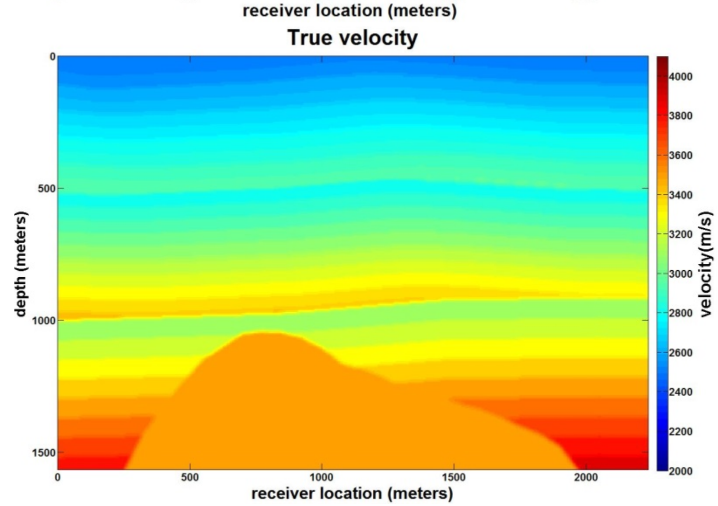
Synthetic Examples: Model with Structures

Step-length deduced from line search. Starting model is a smooth version of the true velocity model









Theory of FWI

Full waveform inversion is an optimization technique that seeks to find a model of the subsurface that best matches the recorded field data at every receiver location. The method begins from a best guess of the true model, which is iteratively improved using linearized inversions methods although the FWI problem is non-linear (Warner et al, 2013).

* $$\phi_k = \sum_{s,r} \left(\psi - \psi_k\right)^2$$

* $$g_k(x,z) = \int \sum_{s,r} \omega^2 \hat{\psi}_s(x,z,\omega) \delta \hat{\psi}^*_{r(s),k}(x,z,\omega) d\omega$$

* $$\delta v_k(x,z) = \lambda \int \sum_{s,r} \omega^2 \hat{\psi}_s(x,z,\omega) \delta \hat{\psi}^*_{r(s),k}(x,z,\omega) d\omega$$

* $$\delta v_k(x,z) = \lambda g_k(x,z)$$

* $$v_{k+1}(x,z) = v_k(x,z) + \lambda g_k(x,z)$$

  - How to obtain/search for the scalar λ in the equations above is part of the focus of this presentation

Synthetic Examples: Model with flat layers

Comparing Line search optimization with a scalar deduced from well information at 520 meters and 1020 meters.