Full waveform source and medium determination from seismic-while-drilling data

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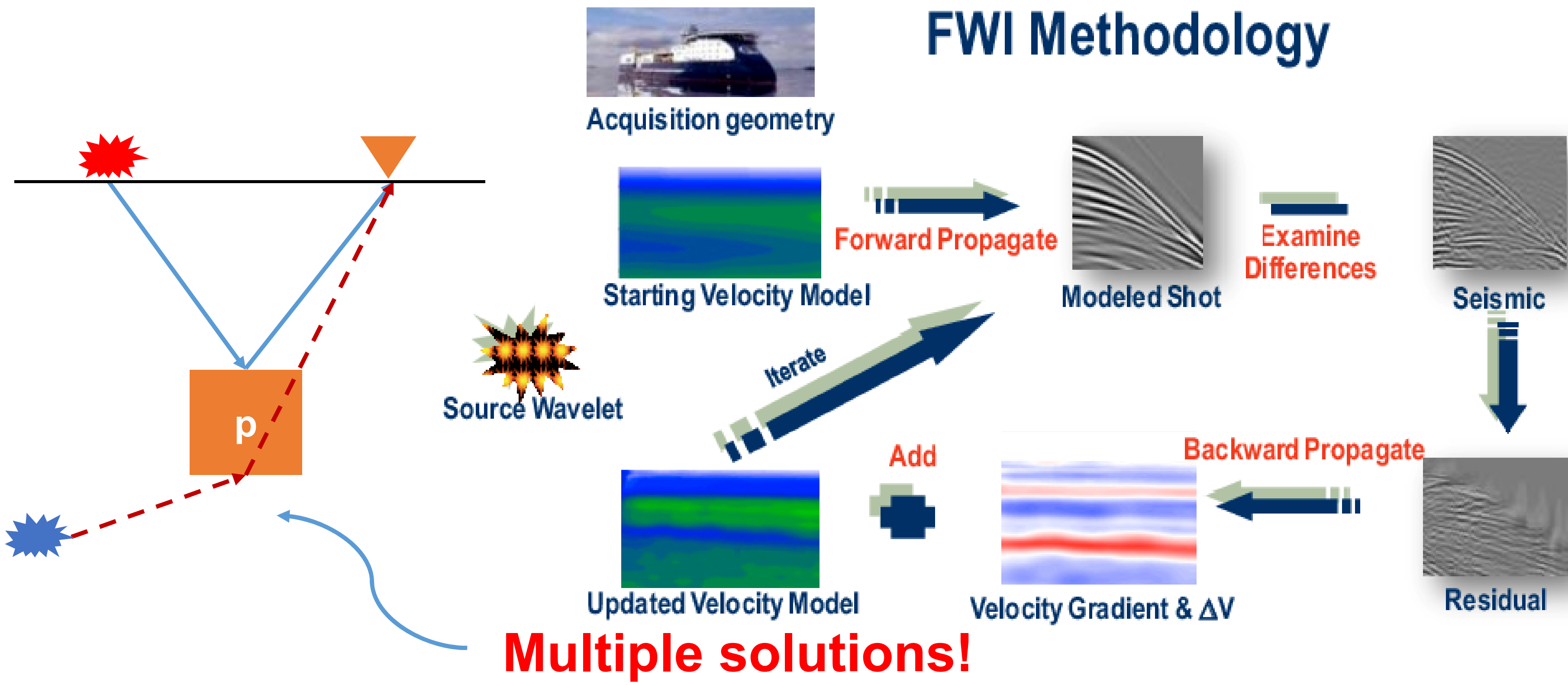
Outline

- Motivation
- Methodology
- Numerical experiments
- Conclusion

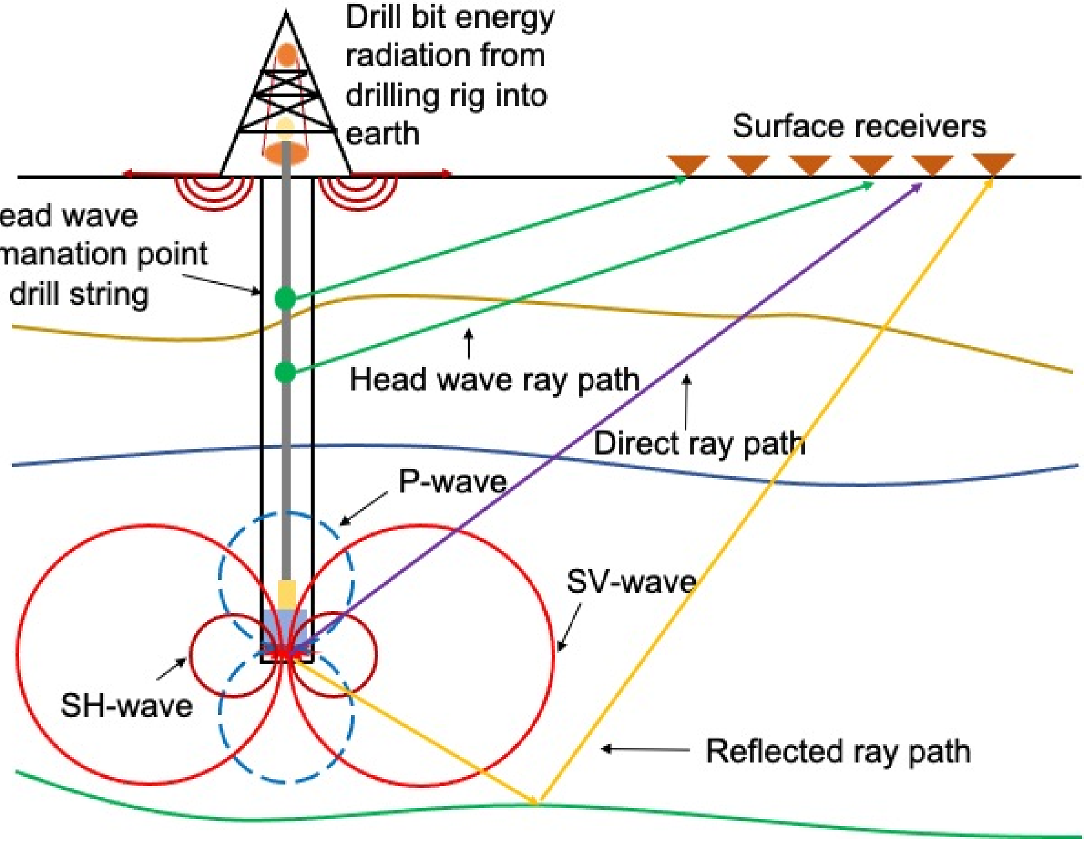
Motivation

- Full-waveform-inversion: strongly affected by acquisition



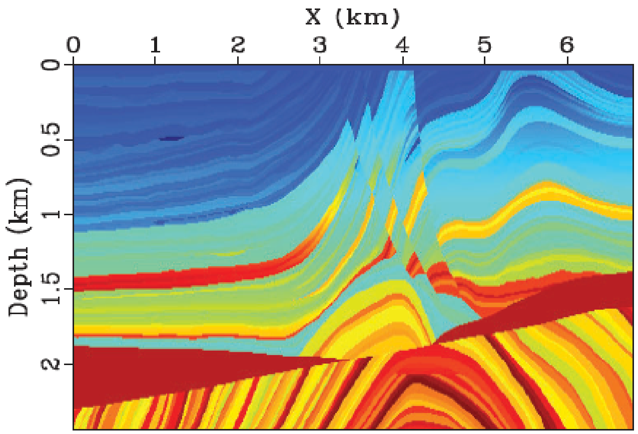
Motivation

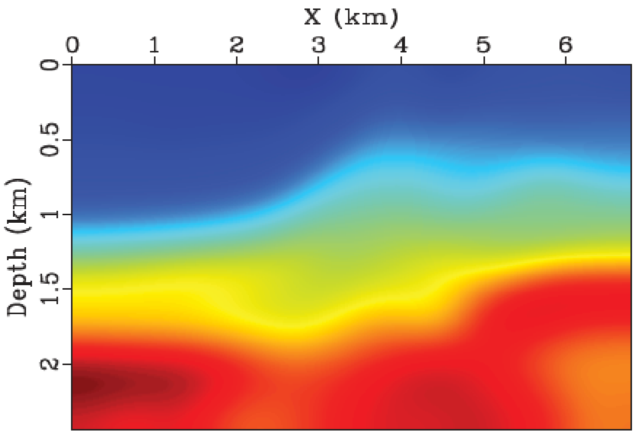
- Seismic-while-drilling (SWD) data potentially contributes to FWI by adding new ray paths



Motivation

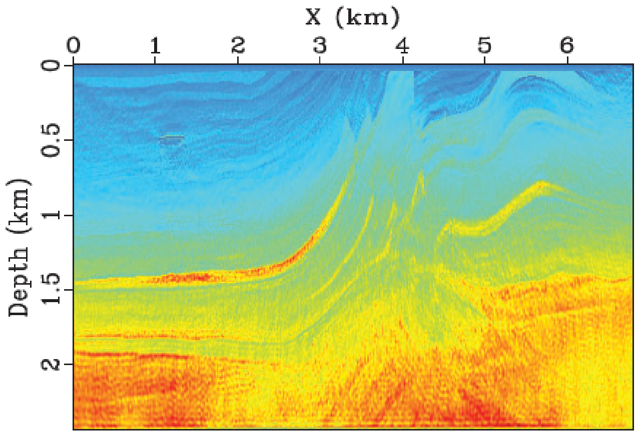
True model

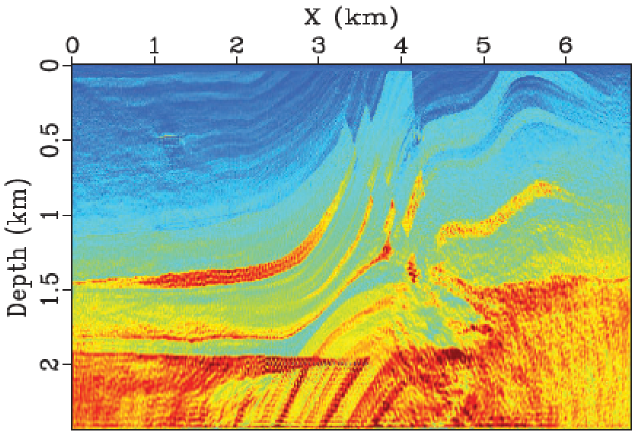




Initial model

Intermediate result





Final result

(Auriol et al., 2019; Kazemi et al., 2020)

Methodology

$$min_{\boldsymbol{p}}\phi(\boldsymbol{p}) = \frac{1}{2}\|\boldsymbol{Ru} - \boldsymbol{d}\|^2, \text{ s.t. } S\boldsymbol{u} = \boldsymbol{f}$$

Truncated Gauss-Newton method (TGN)

$$\boldsymbol{Hp}_{k+1} = -\boldsymbol{g}(\boldsymbol{p}_k)$$

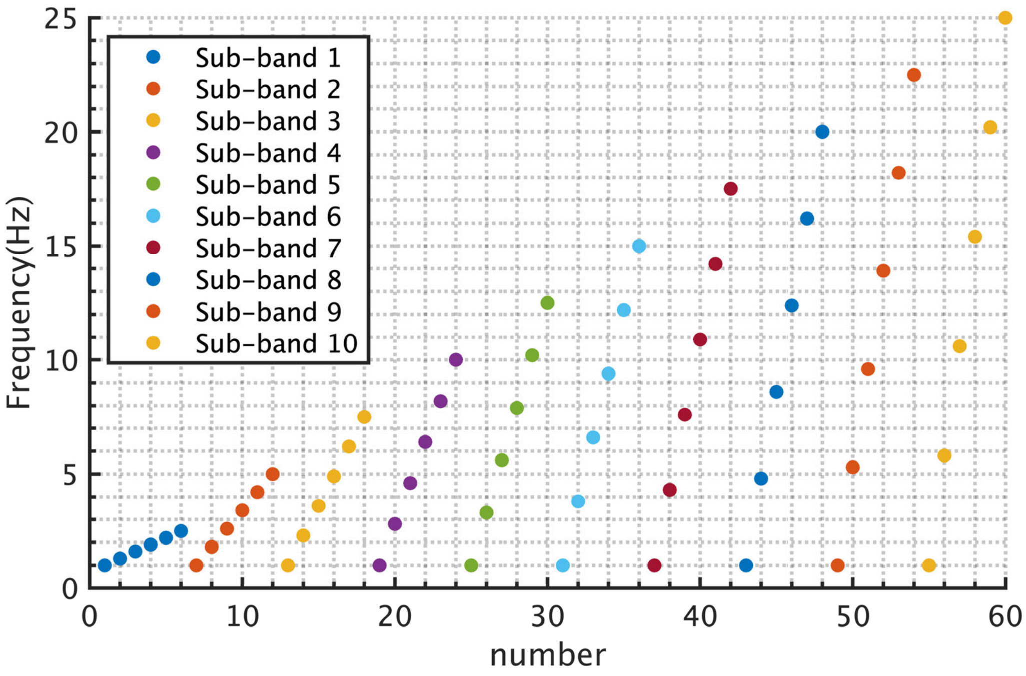
2nd derivative   1st derivative

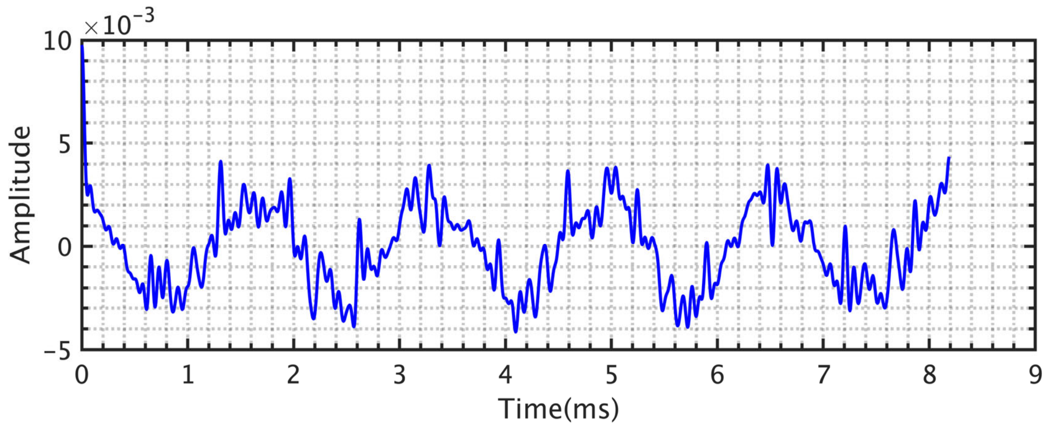
$$f_x = \begin{bmatrix} f_{M12} & f_{M11} & f_{M12} \\ f_{M11} & & f_{M11} \\ f_{M12} & f_{M11} & f_{M12} \end{bmatrix}$$

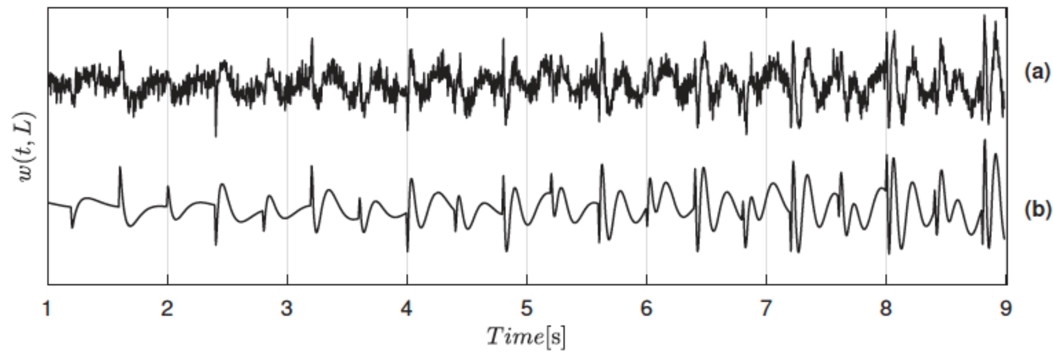
$$f_z = \begin{bmatrix} f_{M12} & f_{M22} & f_{M12} \\ f_{M22} & & f_{M22} \\ f_{M12} & f_{M22} & f_{M12} \end{bmatrix}$$

(Métivier et al., 2013; Keating 2020)

Methodology

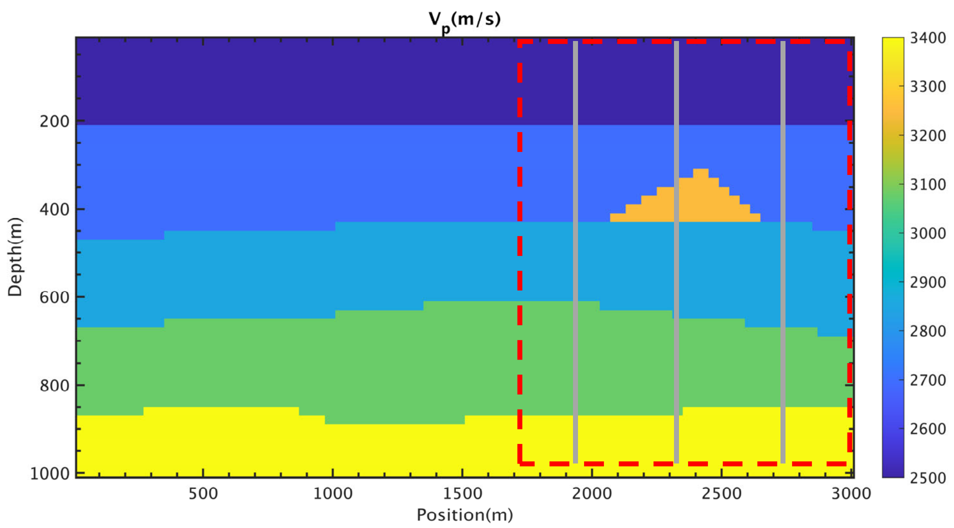


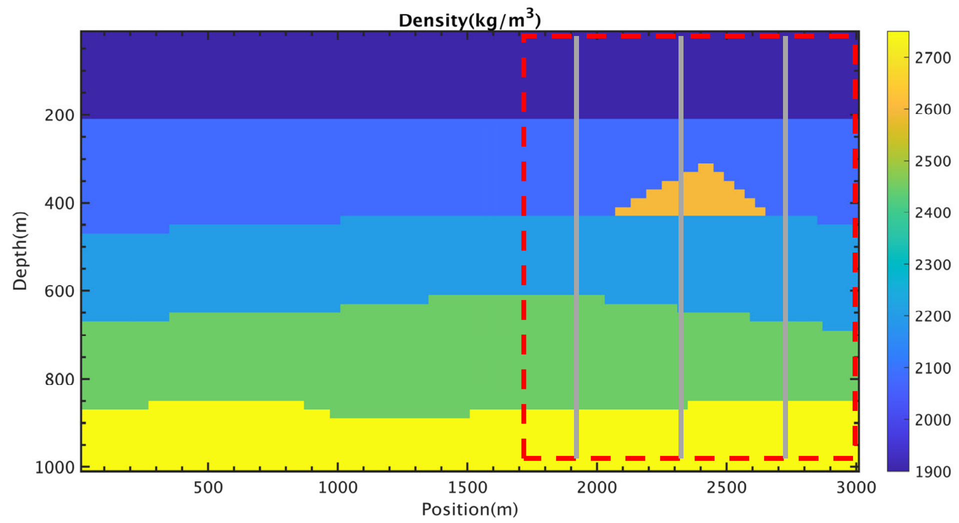




(Kazemi et al., 2020)

Numerical experiments





3 vertical profiles: x = 1960 m, 2360 m, and 2760 m

Geometry:

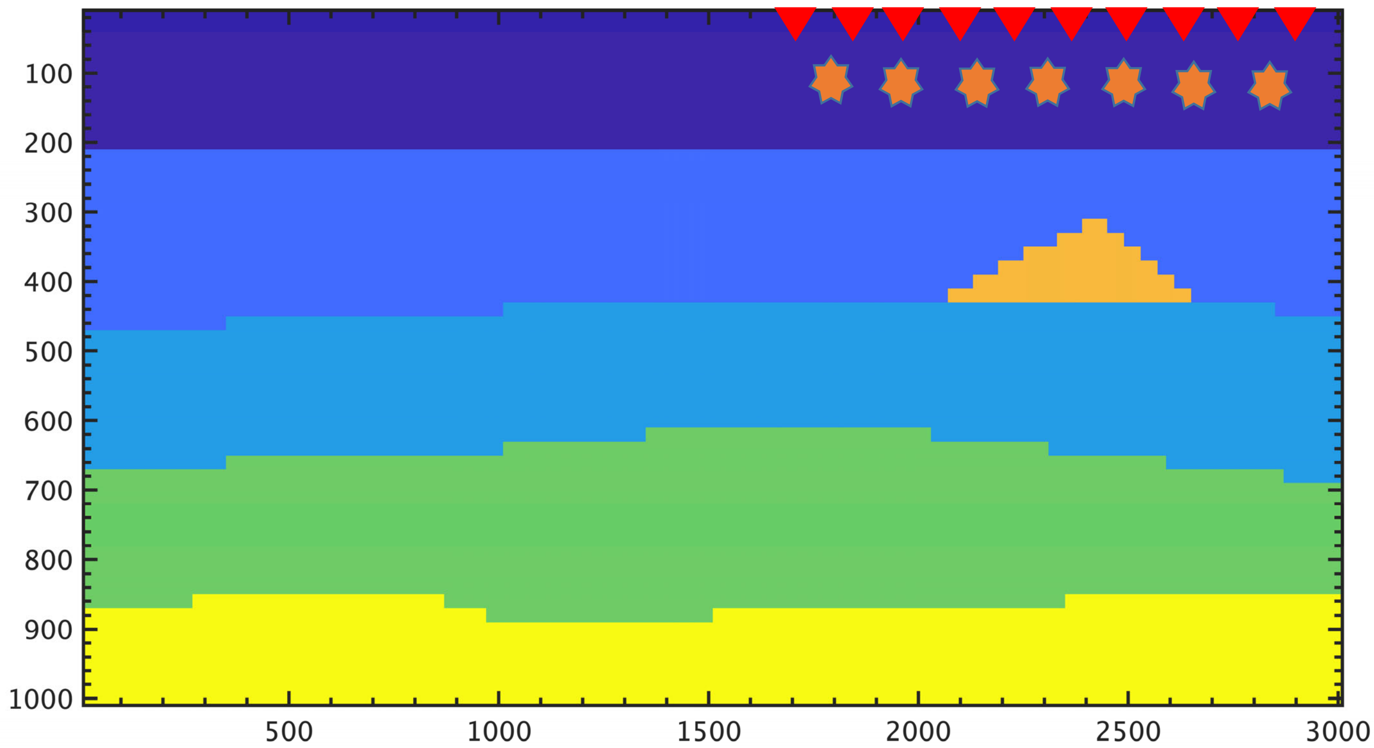
Nx = 150   Nz = 50
NPML = 12
dx = dz = 20

Initial models:

Vp: 2500 m/s
Rho: 1900 kg/m^3
Moment tensors: [-1, 1]

Numerical experiments

Case 1-a: surface seismic

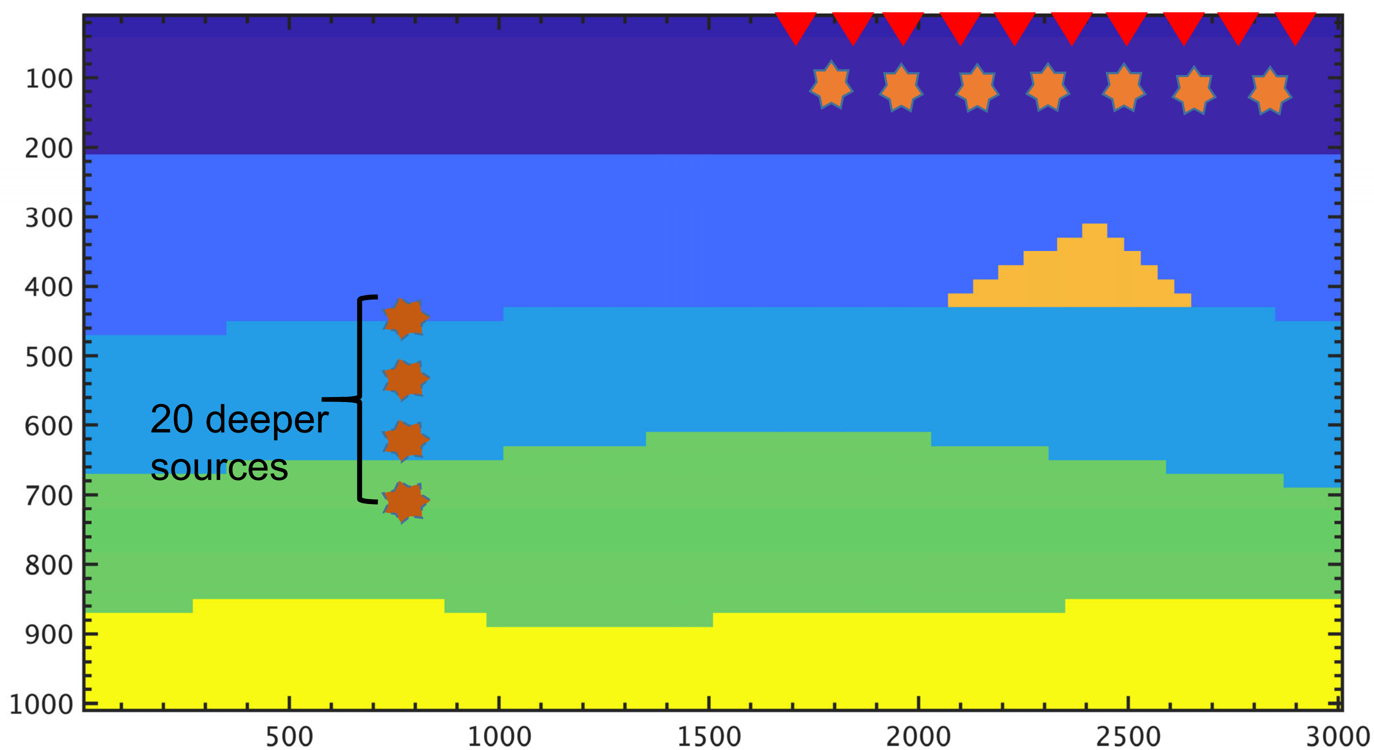


Source interval: 2
Source number: 35
Receiver interval: 1
Receiver number:70

Initial models:
Constant values, equal to the background values.

Numerical experiments

Case 1-b: surface seismic + vertical drilling path

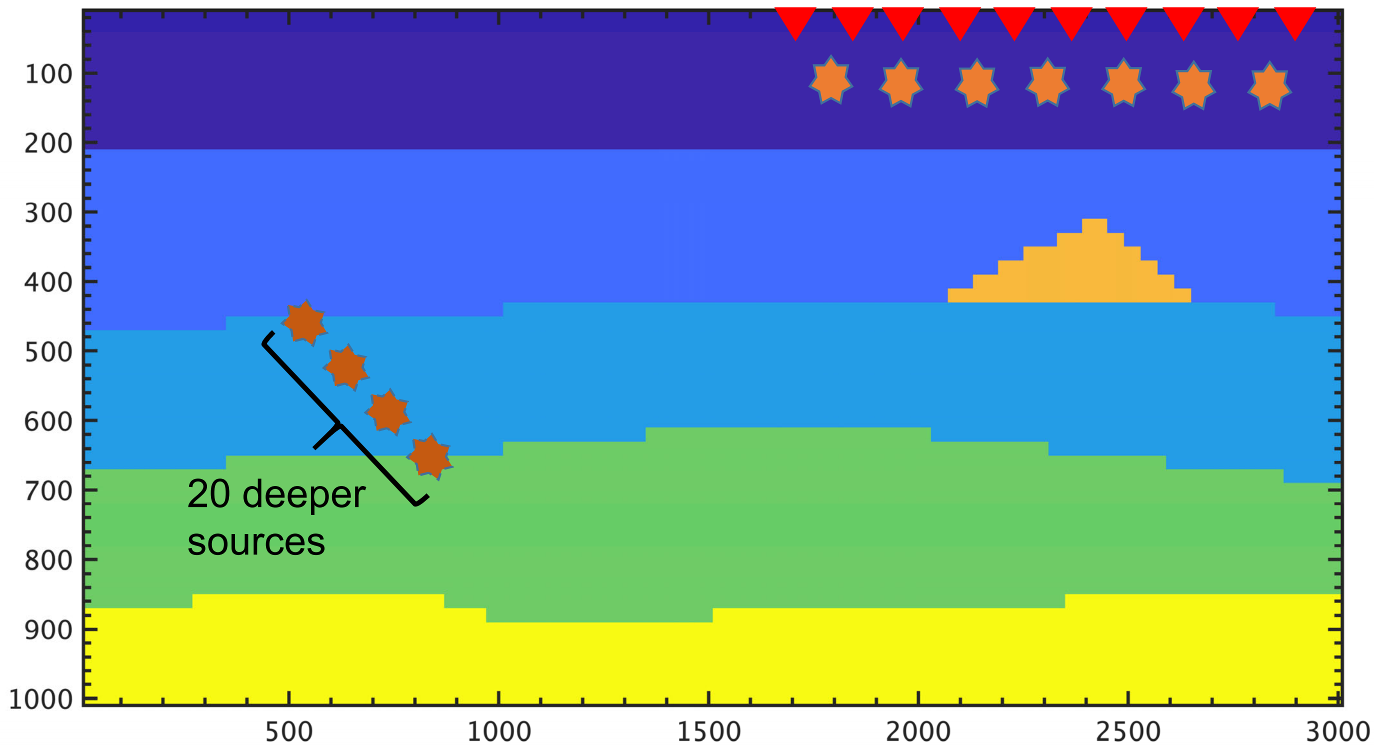


Source interval: 2
Surface source number: 35
Deeper source number: 20
Receiver interval: 1
Receiver number:70

Initial models:
Constant values, equal to the background values.

Numerical experiments

Case 1-c: surface seismic + deviate drilling path

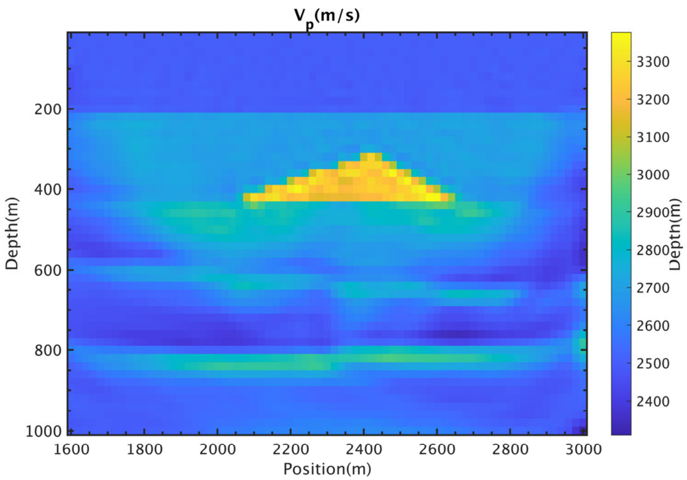


Source interval: 2
Surface source number: 35
Deeper source number: 20
Receiver interval: 1
Receiver number:70

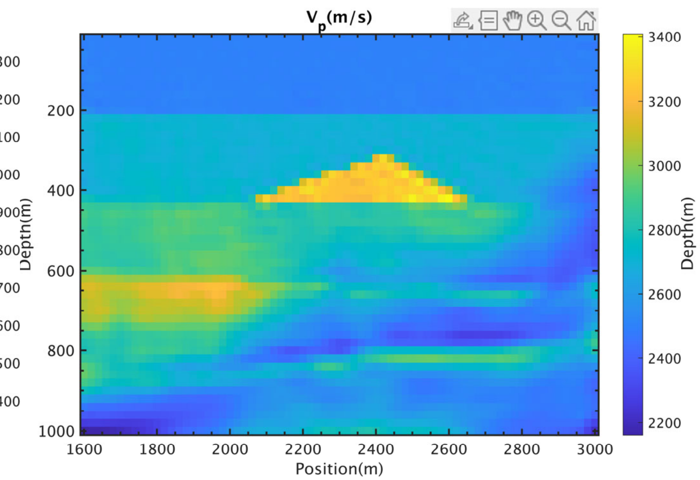
Initial models:
Constant values, equal to the background values.

Numerical experiments

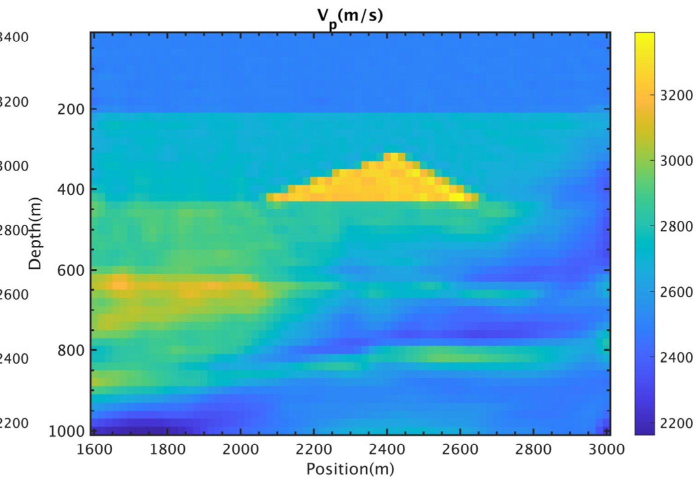
V_p



1-a (MAPE=18.9%)

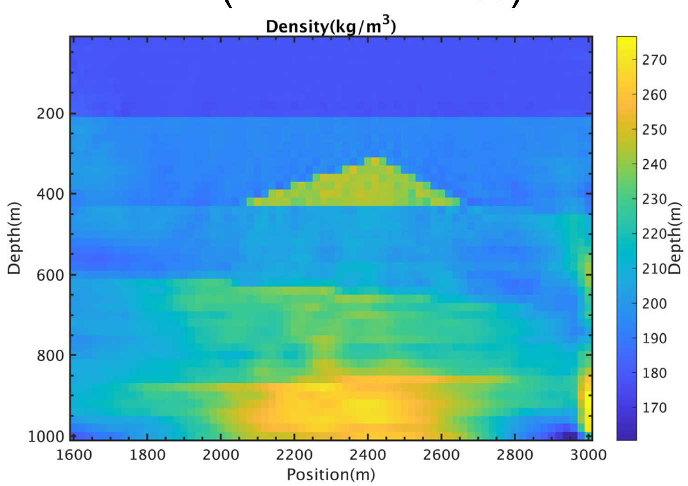


1-b (MAPE=14.9%)

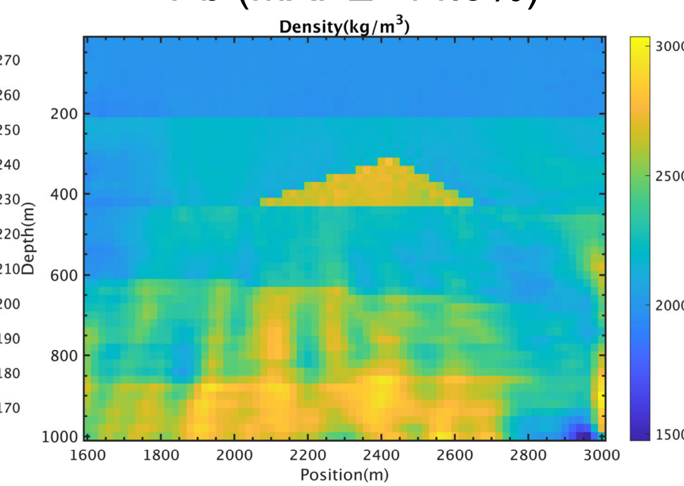


1-c (MAPE=15.2%)

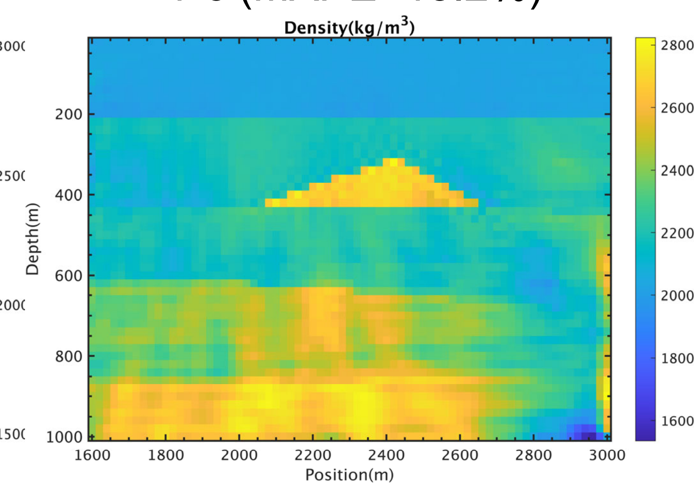
ρ



1-a (MAPE=24.7%)

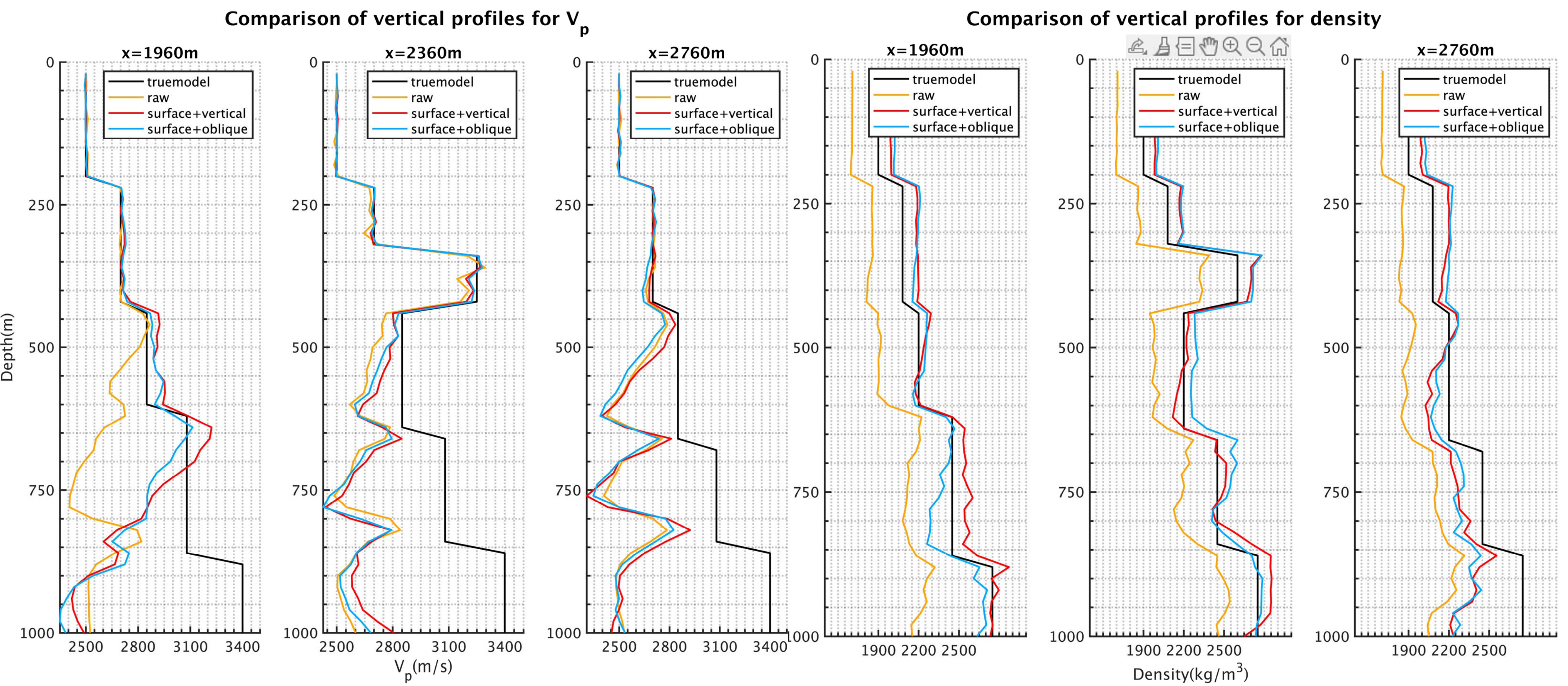


1-b (MAPE=9.2%)

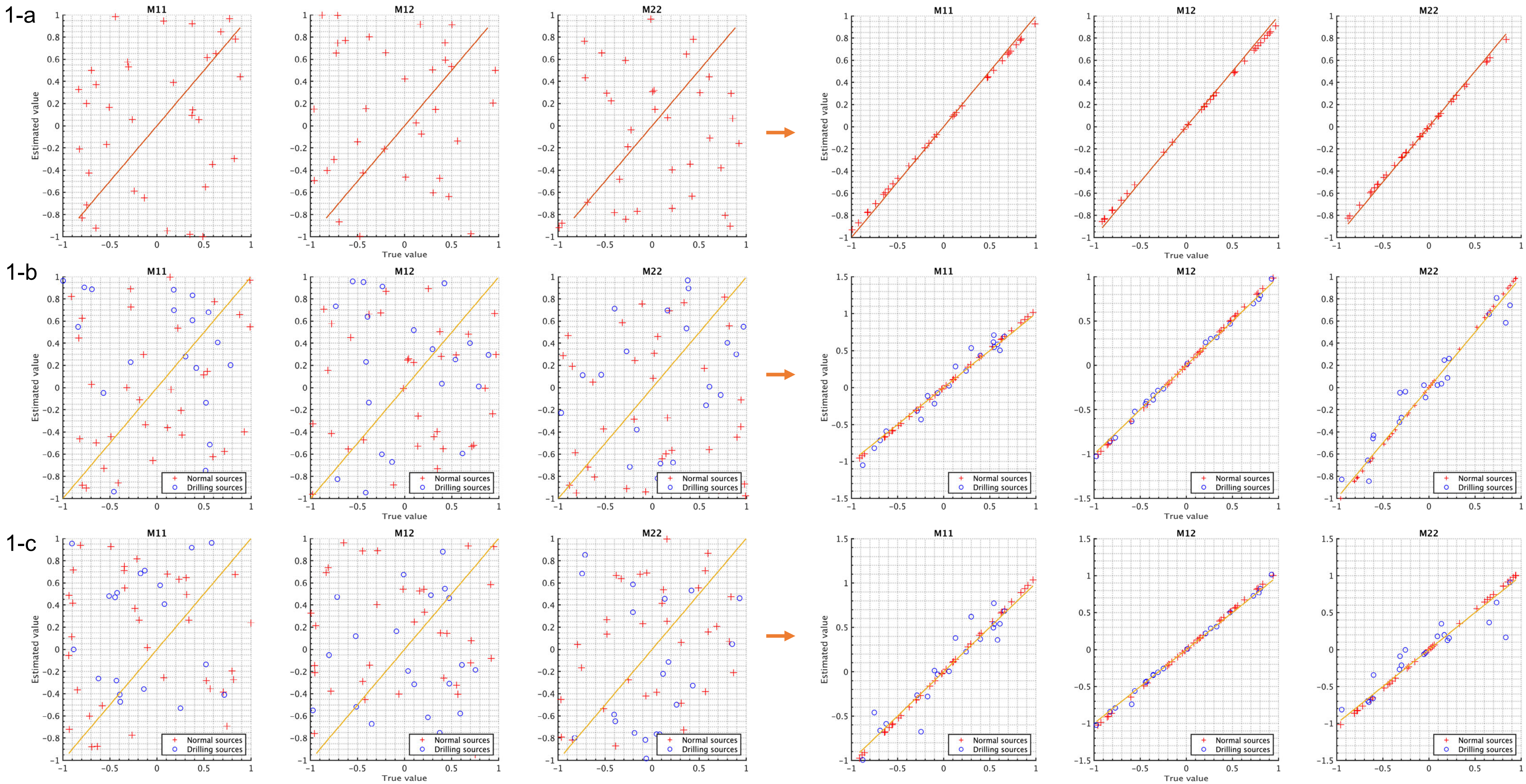


1-c (MAPE=9.8%)

Numerical experiments

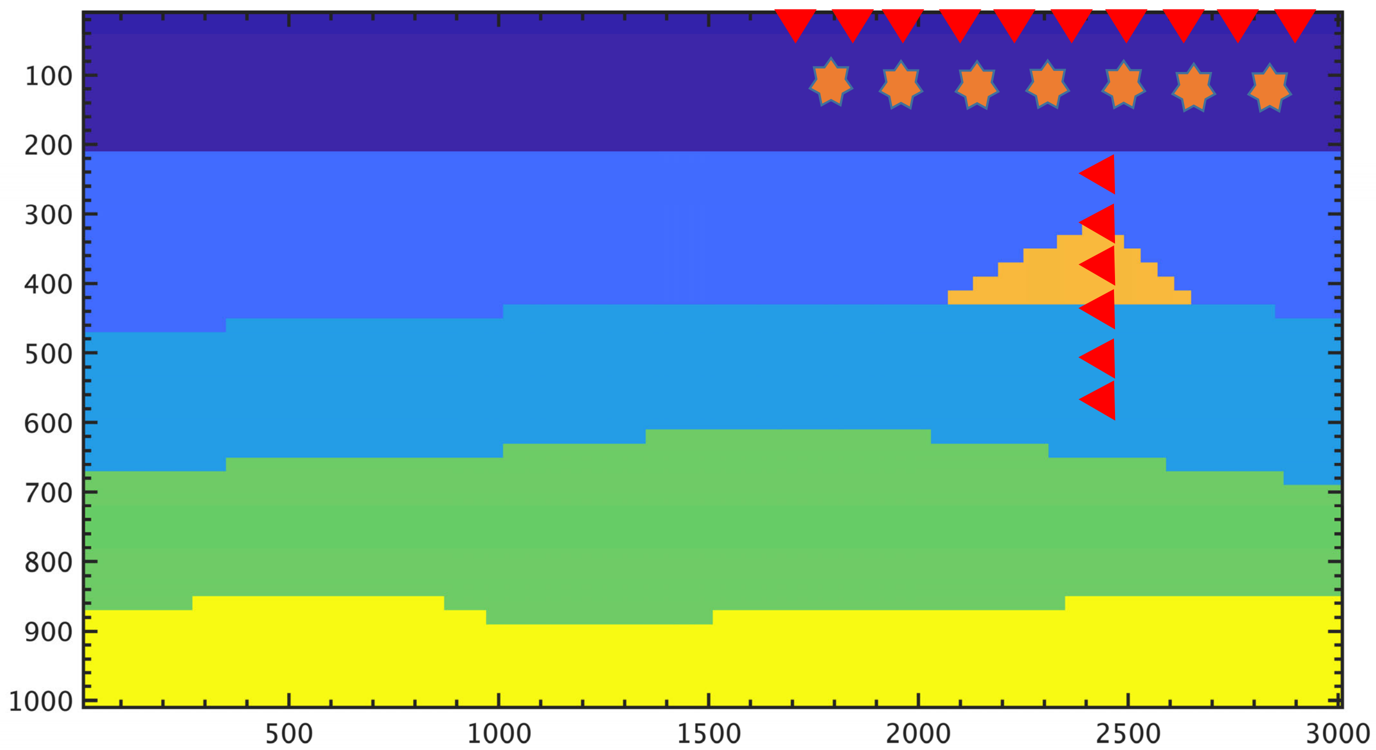


Numerical experiments



Numerical experiments

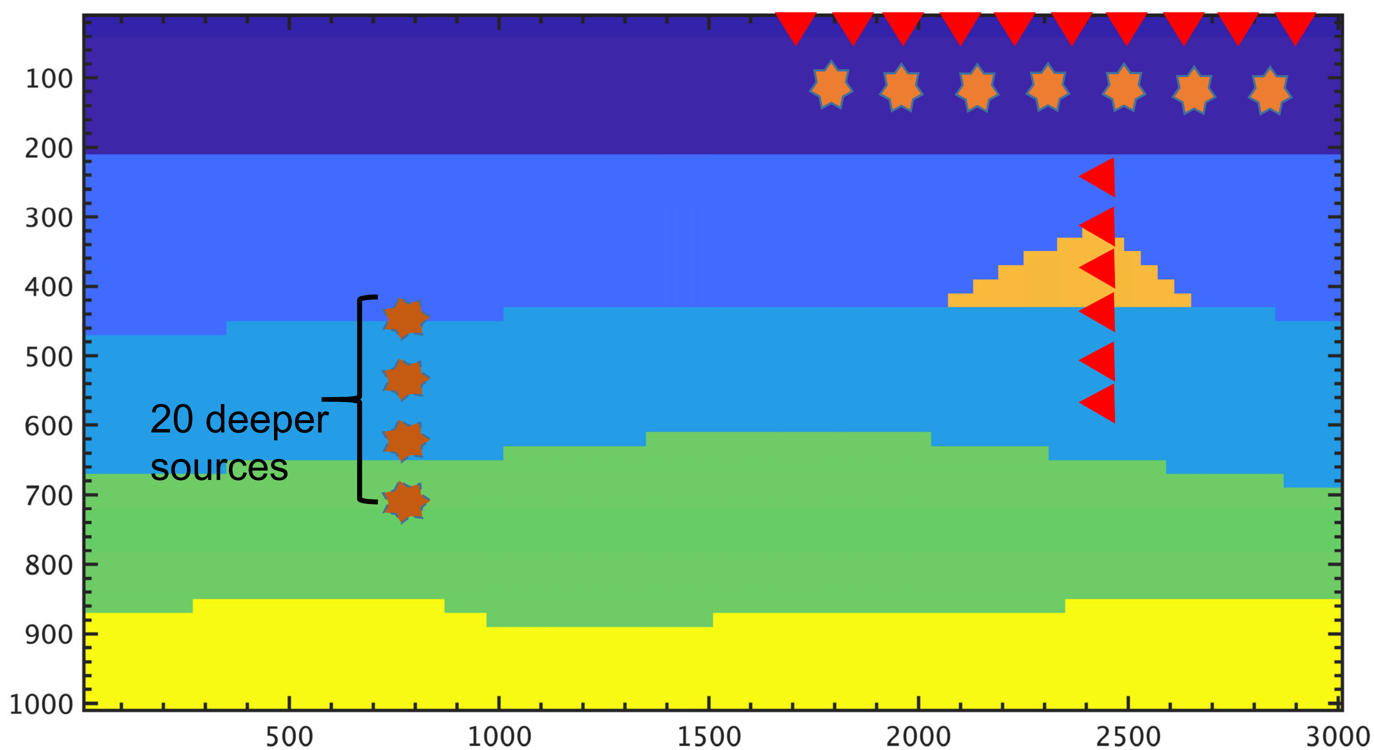
Case 2-a: surface seismic + VSP



Source interval: 2
Surface source number: 35
Receiver interval: 1
Receiver number:70 + 20

Initial models:
Constant values, equal to the background values.

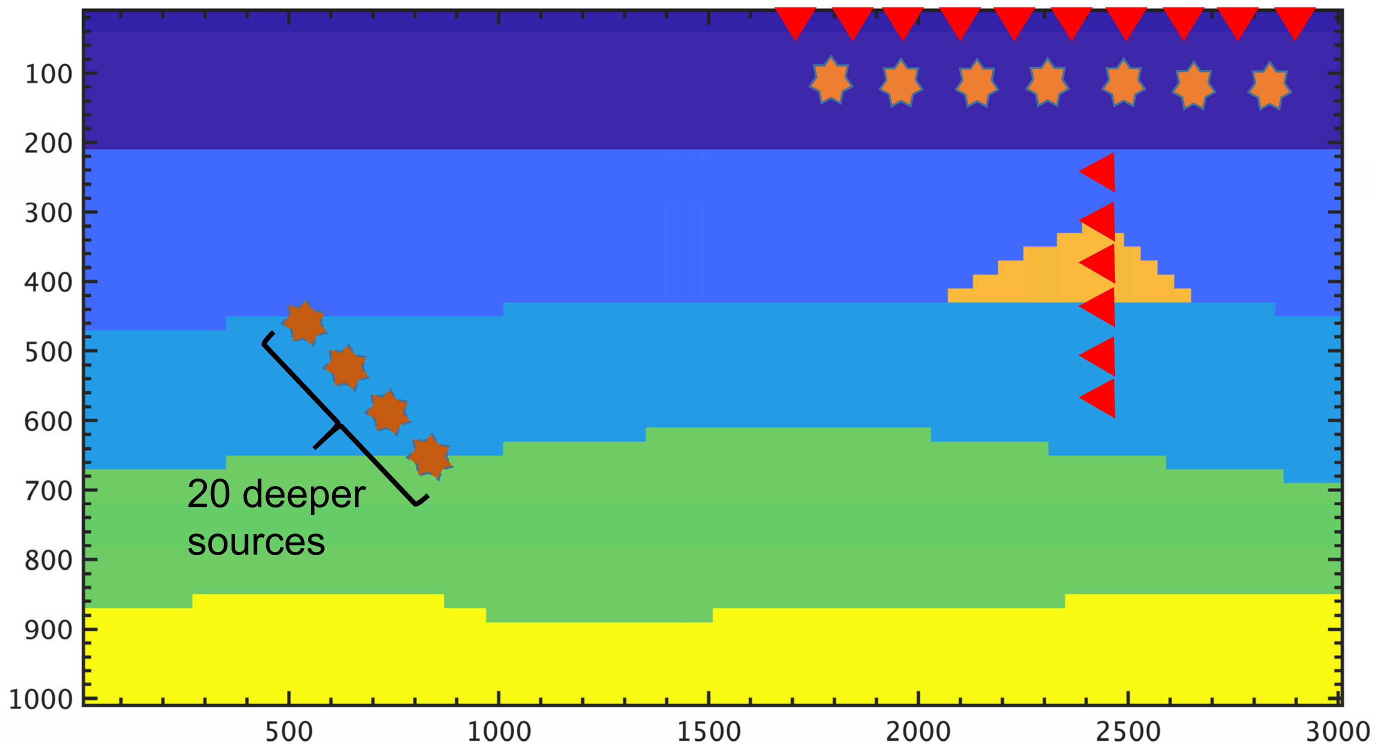
Case 2-b: surface seismic + VSP + vertical drilling path



Source interval: 2
Surface source number: 35
Deeper source number: 20
Receiver interval: 1
Receiver number:70 + 20

Initial models:
Constant values, equal to the background values.

Case 2-c: surface seismic + VSP + deviate drilling path

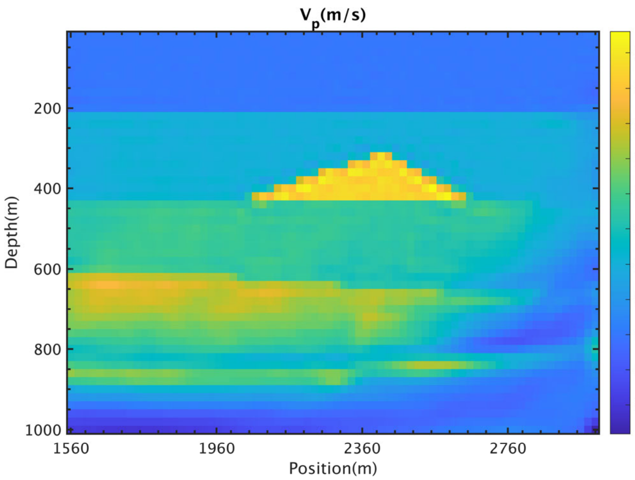


Source interval: 2
Surface source number: 35
Deeper source number: 20
Receiver interval: 1
Receiver number:70

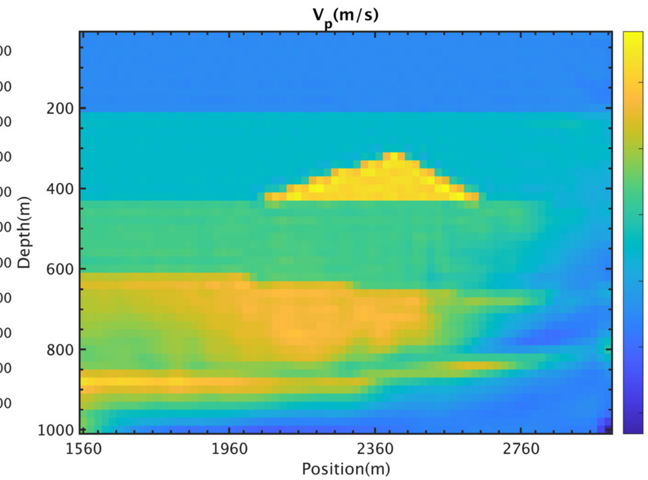
Initial models:
Constant values, equal to the background values.

Numerical experiments

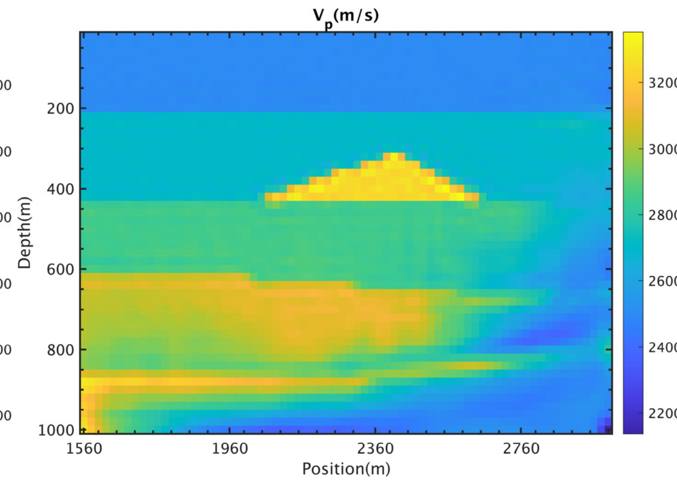
V_p



2-a (MAPE=11.9%)

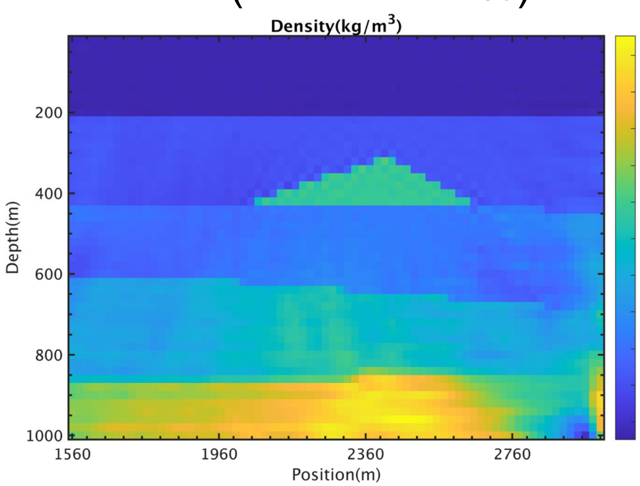


2-b (MAPE=9.2%)

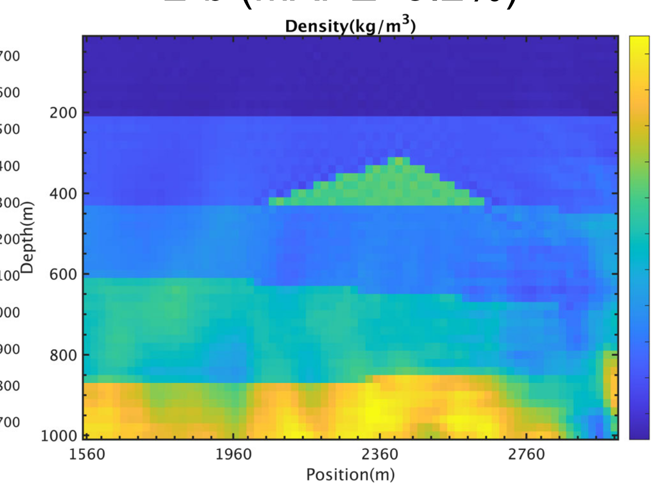


2-c (MAPE=9.4%)

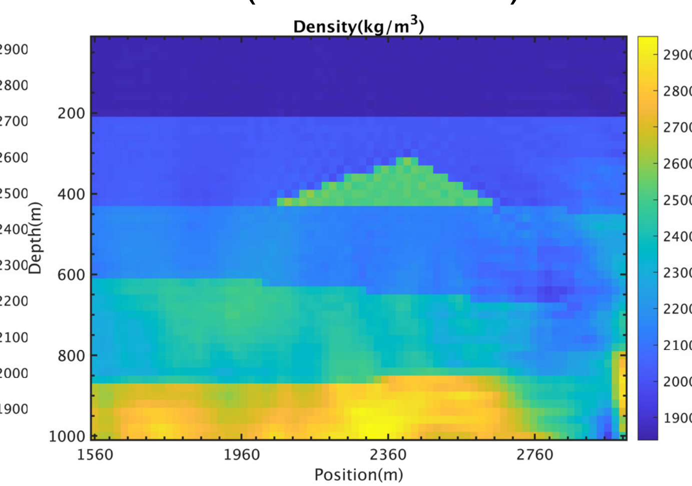
ρ



2-a (MAPE=24.5%)

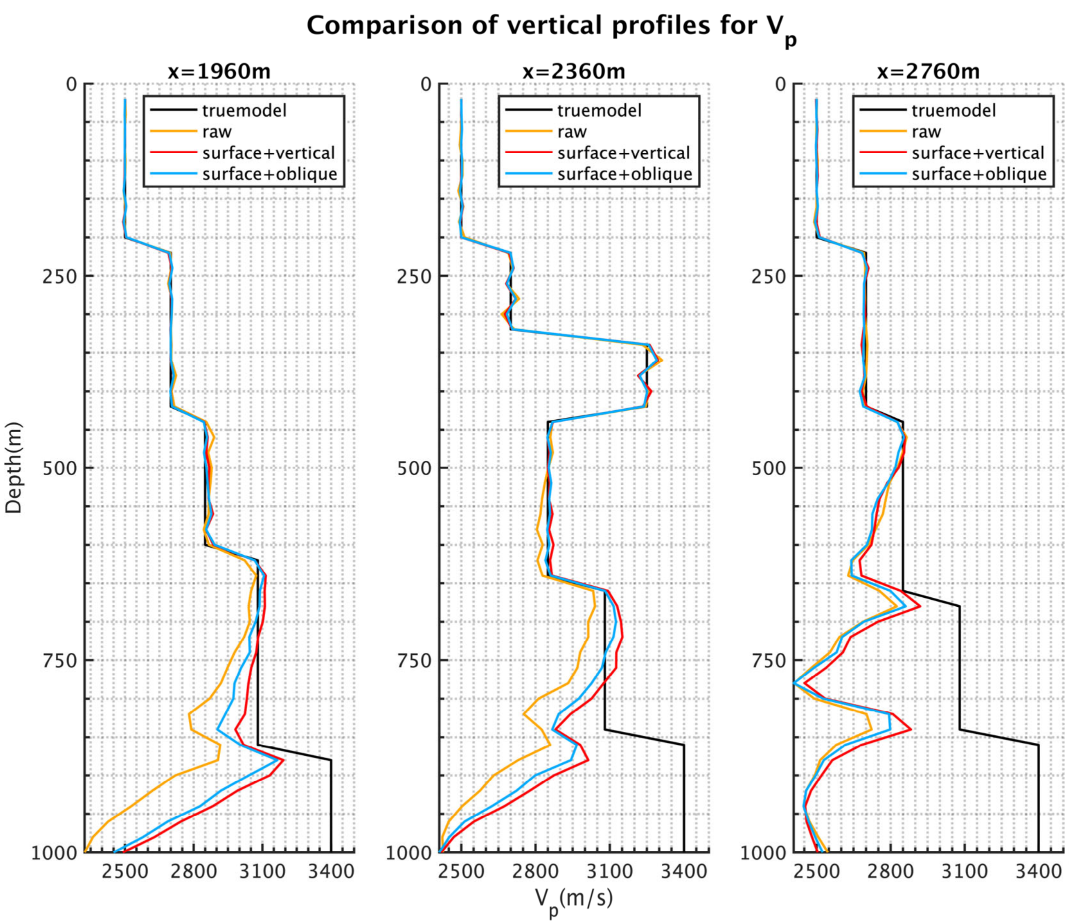


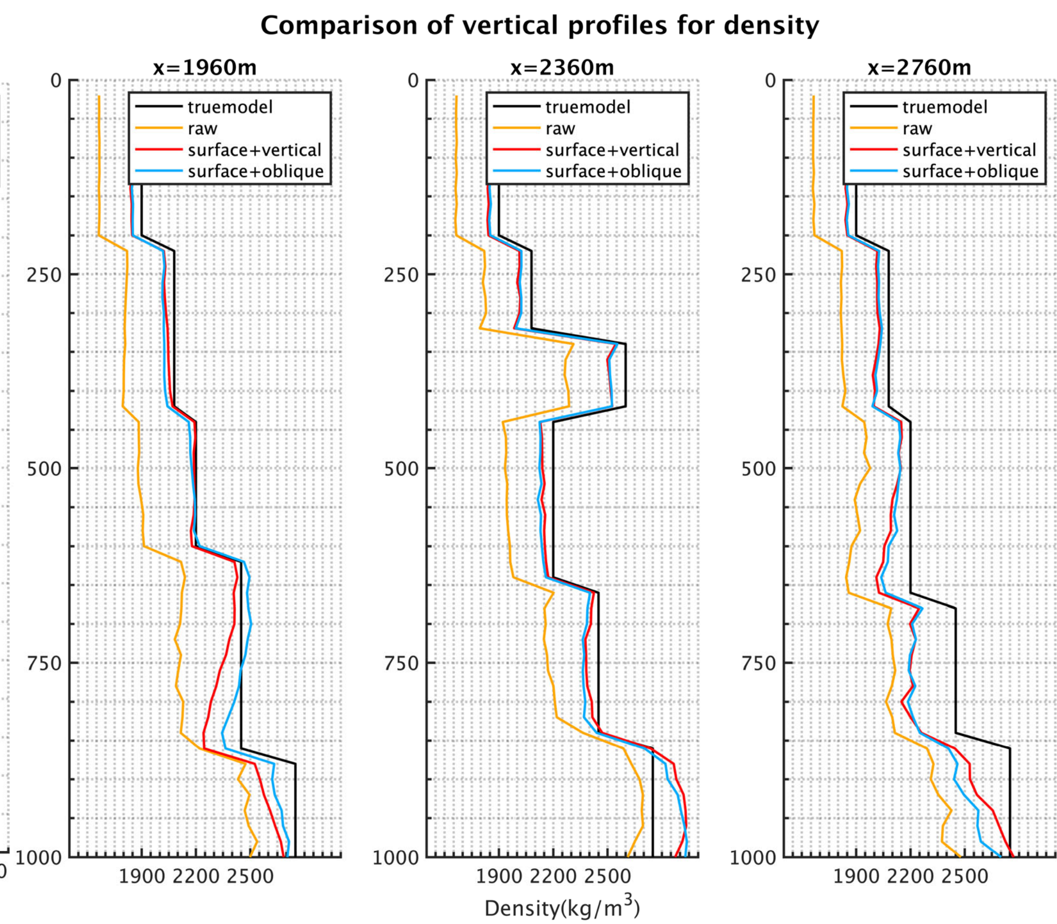
2-b (MAPE=6.7%)



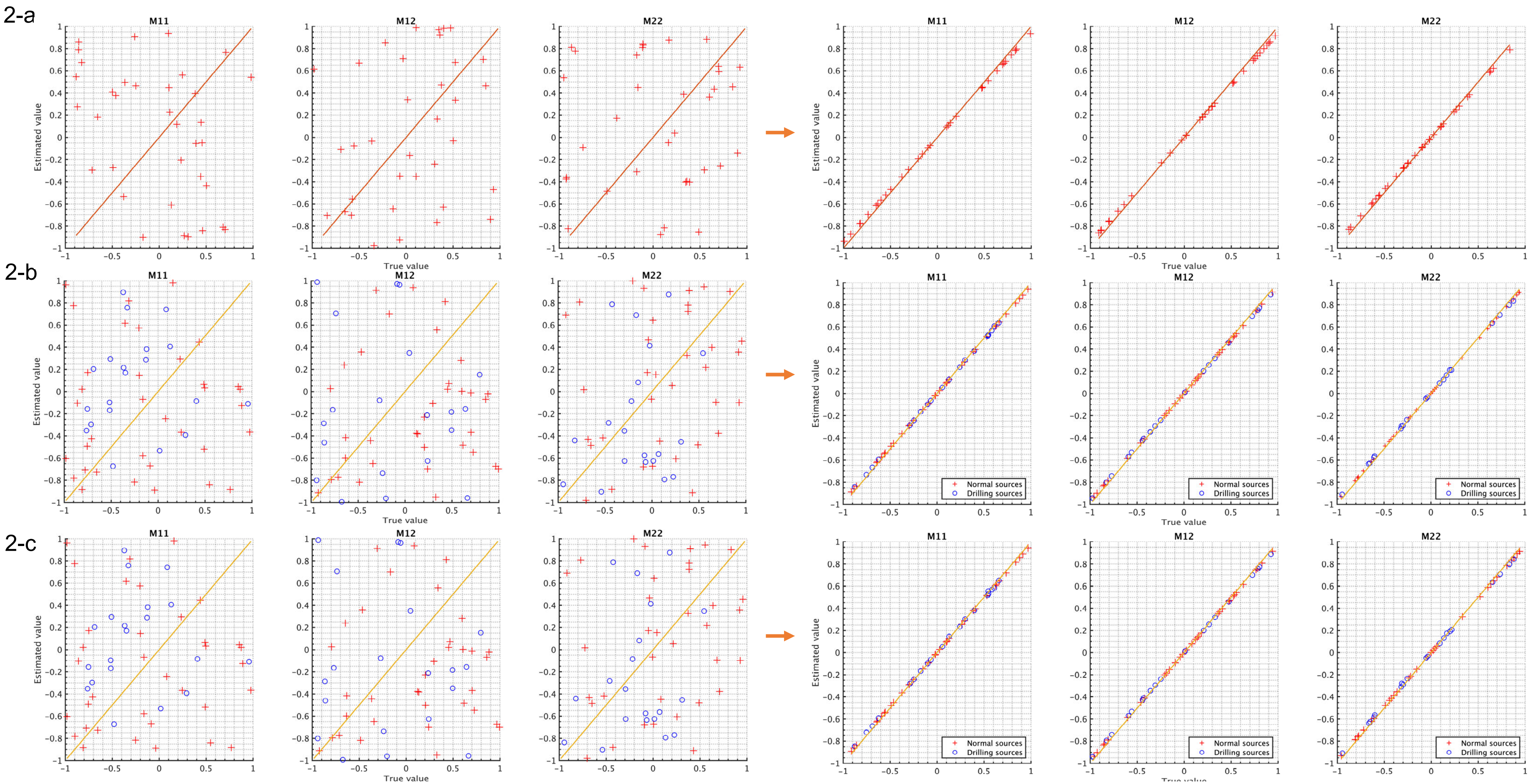
2-c (MAPE=6.2%)

Numerical experiments





Numerical experiments



Conclusion

- Added ray paths from SWD enhance FWI models
- Deeper sources play an important role
- We have added elastic models and unknown drill radiation patterns to the problem – may expand possibilities for technology
- Future work: better integration of SWD source signature using frequency components

Acknowledge

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References

1. Jean Auriol, Nasser Kazemi, Roman J. Shor, Kristopher Innanen, Ian Gates, 2019 A Sensing and Computational Framework for Estimating the Seismic Velocities of Rocks Interacting With the Drill Bit. IEEE Transactions on Geoscience and Remote Sensing, Institute of Electrical and Electronics Engineers, In press, 10.1109/TGRS.2019.2950257. hal-02462287.

2. Kazemi, Nasser & Shor, Roman & Innanen, Kristopher. 2018. Imaging with a seismic-while-drilling dataset: Presented at GeoConvention 2018.

3. Kazemi, Nasser & Auriol, J & Innanen, K & Shor, Roman & Gates, Ian, 2020. Successive Full-Waveform Inversion of Surface Seismic and Seismic-While-Drilling Datasets without Low Frequencies: Presented at 82nd EAGE Confrence & Exhibition. 10.3997/2214-4609.202011183.

4. Ludovic Metivier, Romain Brossier, Jean Virieux, Stephane Operto. Full Waveform Inversion and the truncated Newton method. SIAM Journal on Scientic Computing, Society for Industrial and Applied Mathematics, 2013, 35 (2), pp.B401-B437. 10.1137/120877854. hal-00763702.

5. Virieux, J., and Operto, S., 2009, An overview of full-waveform inversion in exploration geophysics: Geophysics, 74, No. 6, no. 6, WCC1–WCC26.

6. Keating, S., 2020, Viscoelastic full-waveform inversion: treating attenuation uncertainty, characterizing cross-talk, and quantifying confidence in inversion results: Ph.D. thesis, University of Calgary.

7. Nocedal, J., and Wright, S. J., 2006, Numerical Optimization: Springer.

Thank you!