Constructing meaningful FWI gradients from DAS data

Matt Eaid*, Scott Keating, and Kris Innanen

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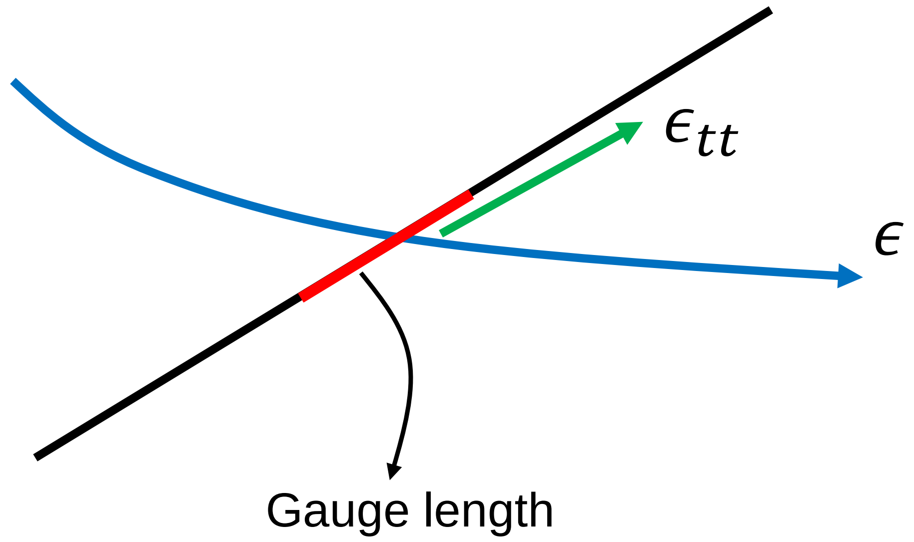
NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience

Motivation

- Growing interest in the use of DAS fibres for seismic acquisition.
- Need to develop strategies for including the data they provide in FWI.
- Geophones and DAS provide complementary datasets.

Distributed Acoustic Sensing

- DAS uses and optical fibre to make measurements of seismic strain
- Fibres are only sensitive to strain along the tangent of the fibre
- Measurements are spatially averaged over the gauge length to improve SNR



Full waveform inversion

Receiver matrix

Observed data

$$\phi = \frac{1}{2}\|\mathbf{Ru} - \mathbf{d}\|_2^2$$

Modeled wavefield

$$\frac{\partial \phi}{\partial \mathbf{m}} = \left\langle \frac{\partial S}{\partial \mathbf{m}} \mathbf{u}, \lambda \right\rangle$$

Forward propagated wavefield

Back-propagated adjoint wavefield

Forward wavefield propagation

$$S\mathbf{u} = \mathbf{f}$$

Reverse wavefield propagation

$$S^{\dagger}\lambda = \mathbf{R}^{\mathrm{T}}(\mathbf{Ru} - \mathbf{d})$$

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Receiver Matrix (R)

Geophones	DAS
▪ Samples displacement wavefield at location of geophones	▪ Computes strain from displacement wavefields. ▪ Computes fibre strain, using fibre geometry. ▪ Invokes gauge length averaging of fibre sensitivity.

$$\begin{bmatrix} d'_1 \\ d'_2 \\ d'_3 \\ d'_4 \\ \vdots \\ d'_{N_{R-1}} \\ d'_{N_R} \end{bmatrix} = \begin{bmatrix} \\ & R & \\ \\ \end{bmatrix} \begin{bmatrix} u^1_{m_x} \\ u^1_{m_z} \\ u^2_{m_x} \\ u^2_{m_z} \\ \vdots \\ u^{N_{gx}}_{m_x} \\ u^{N_{gz}}_{m_z} \end{bmatrix}$$

$$(N_R \times 1) \quad (N_R \times 2N_g) \quad (2N_g \times 1)$$

$$\begin{bmatrix} d^1_{m_x} \\ d^1_{m_z} \\ d^2_{m_x} \\ d^2_{m_z} \\ \vdots \\ d^{N_{Rx}}_{m_x} \\ d^{N_{Rz}}_{m_z} \\ \hline d'_1 \\ d'_2 \\ d'_3 \\ d'_4 \\ \vdots \\ d'_{N_{R-1}} \\ d'_{N_R} \end{bmatrix} = \begin{bmatrix} R_{GEO} \\ \hline R_{DAS} \end{bmatrix} \begin{bmatrix} u^1_{m_x} \\ u^1_{m_z} \\ u^2_{m_x} \\ u^2_{m_z} \\ \vdots \\ u^{N_{gx}}_{m_x} \\ u^{N_{gz}}_{m_z} \end{bmatrix}$$

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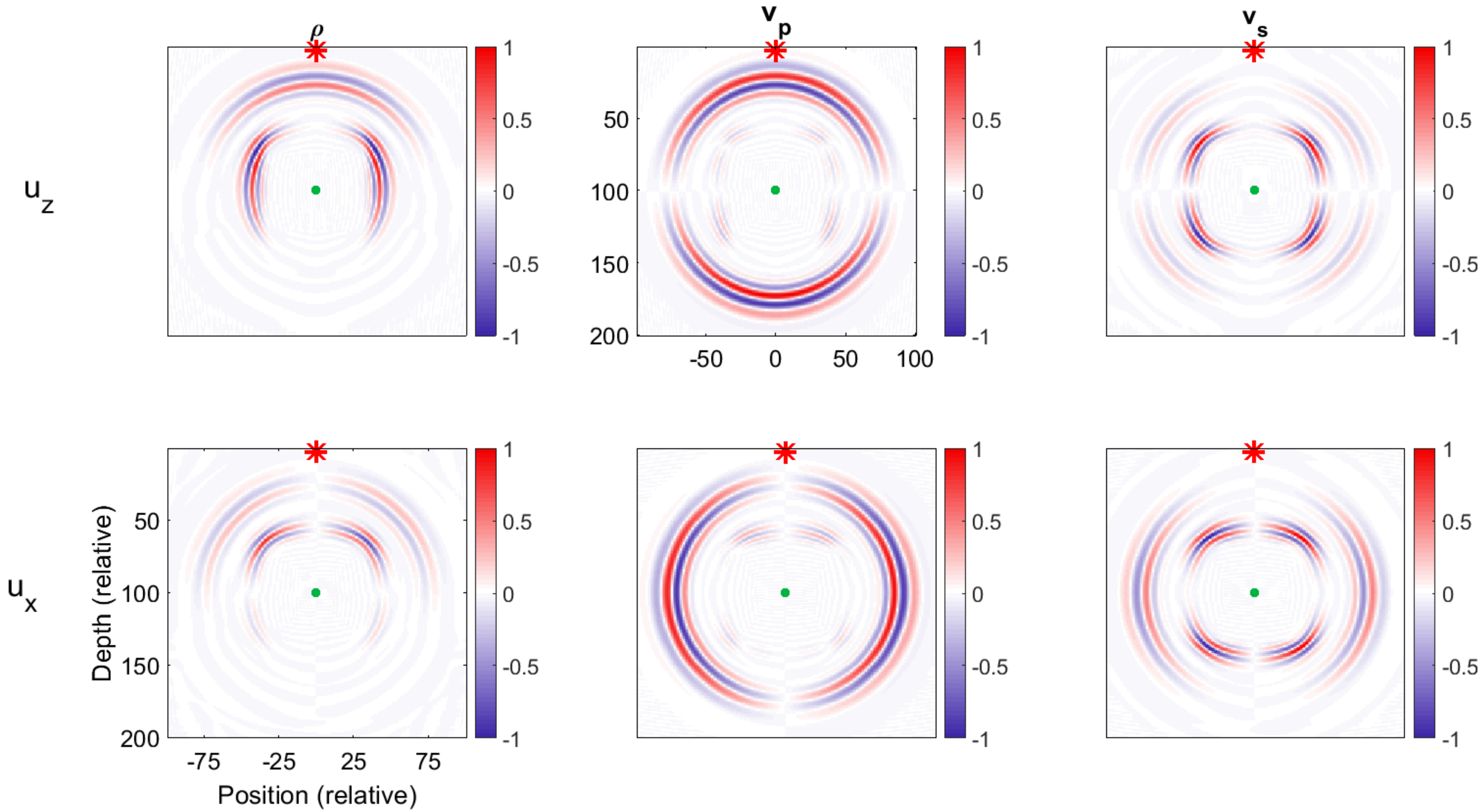
Scattering Radiation Patterns: Displacement



Scattering radiation patterns provide insight into the sensitivity of the wavefield to perturbations in certain model parameters.

$$\frac{\partial \mathbf{u}}{\partial \mathbf{m}} \approx \mathbf{u_p} - \mathbf{u_r}$$

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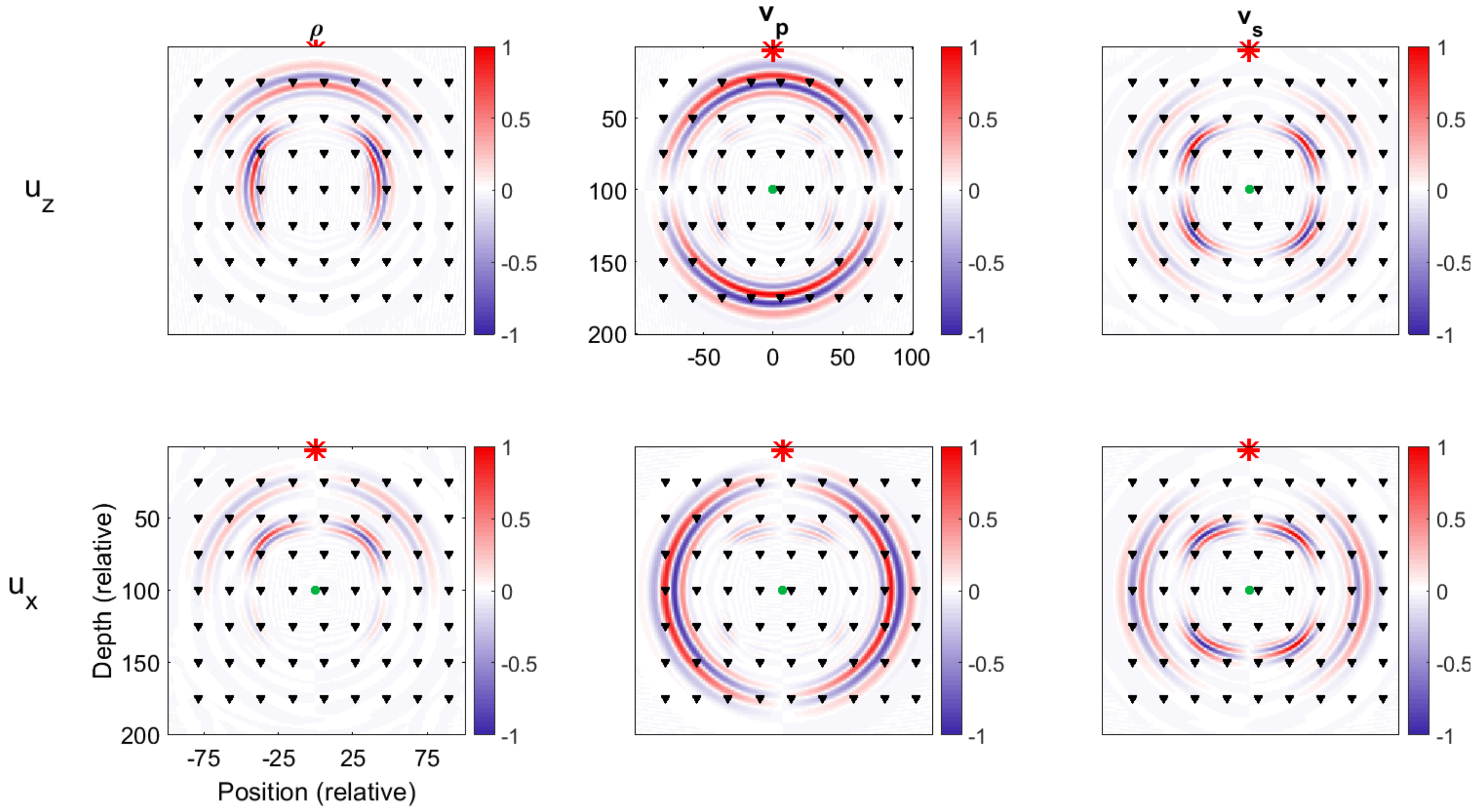

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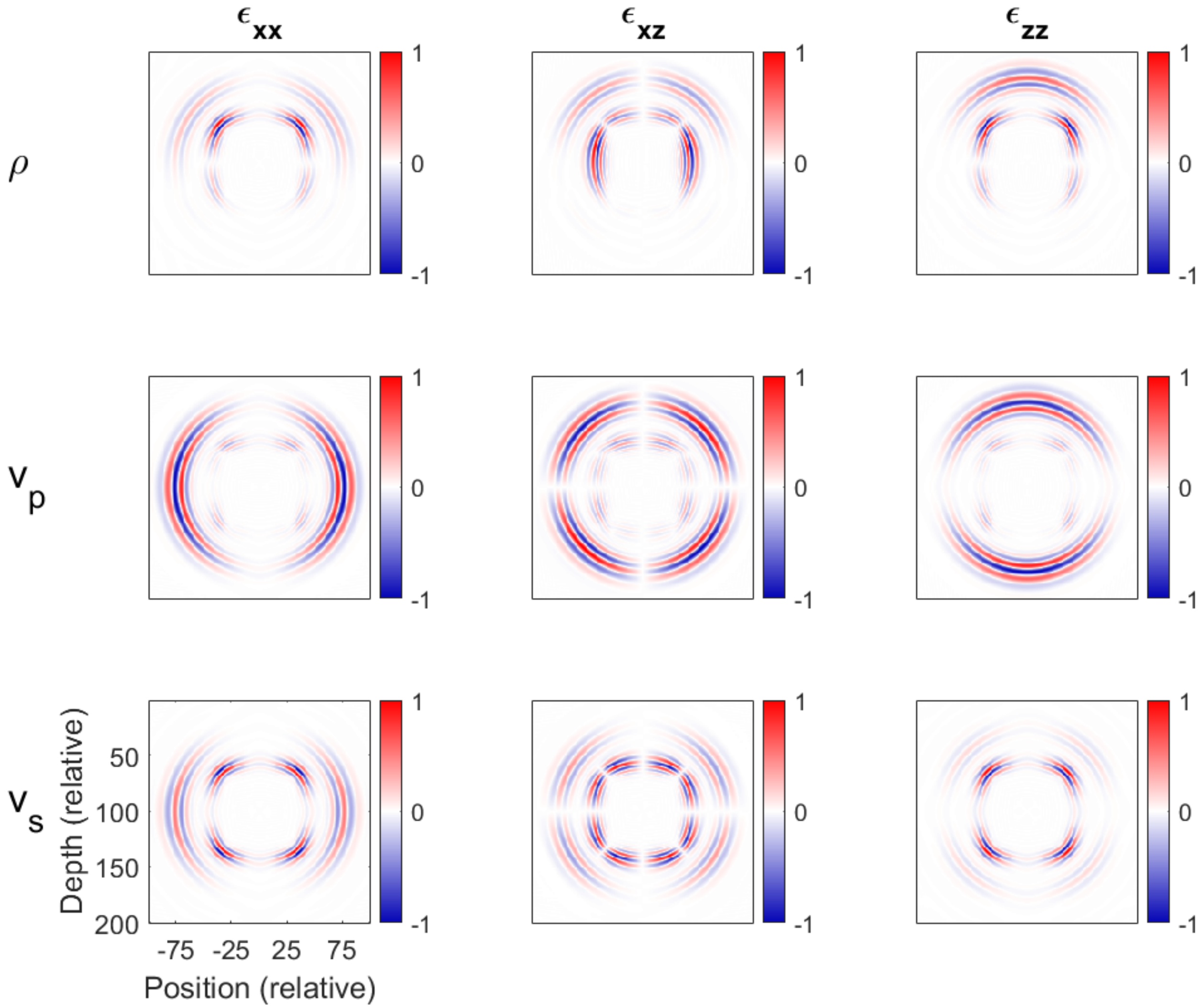
Scattering Radiation Patterns: Strain



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$$\epsilon_{ij} = \frac{1}{2}\left(\frac{u_i}{x_j} + \frac{u_j}{x_i}\right)$$

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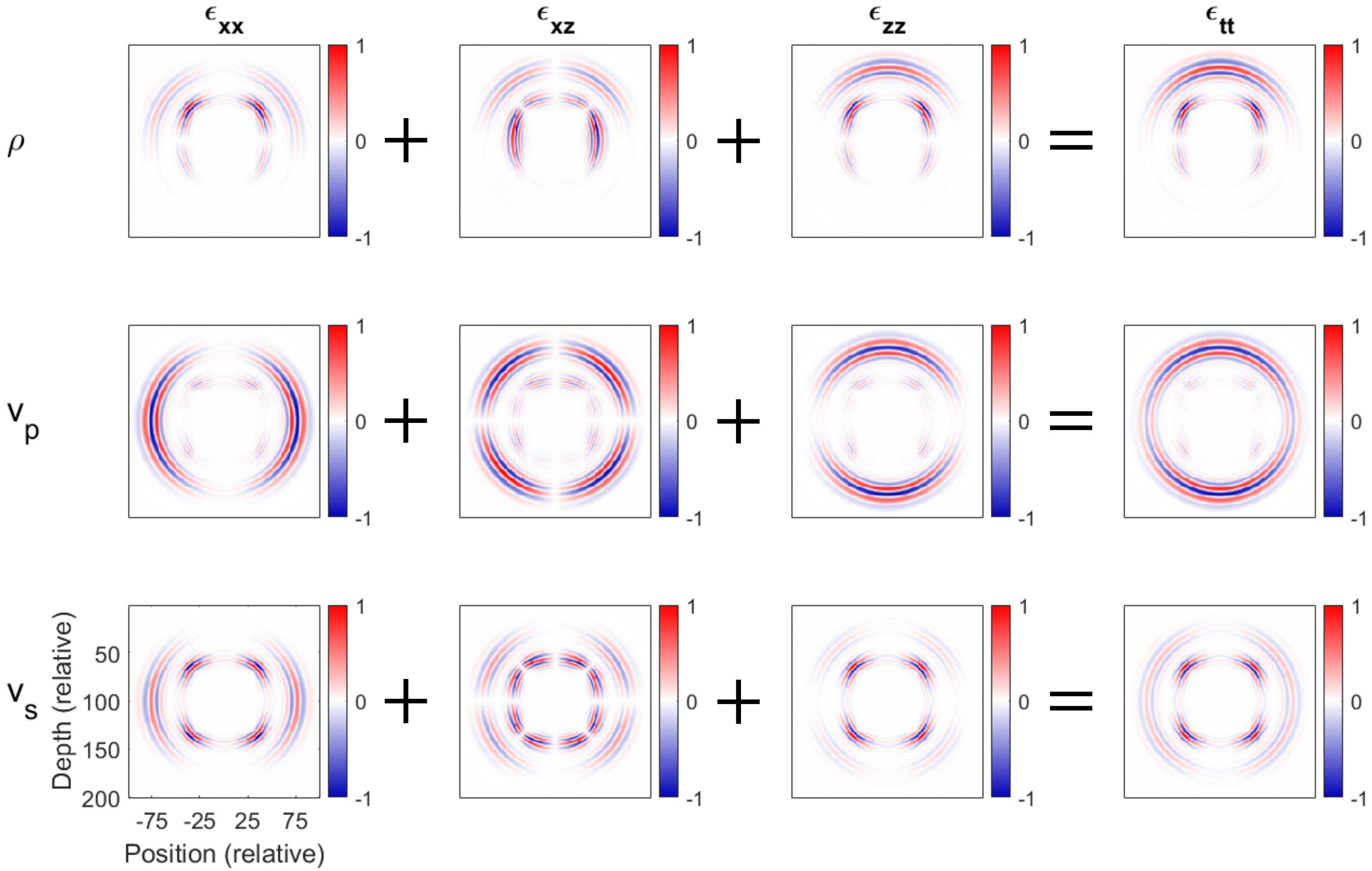

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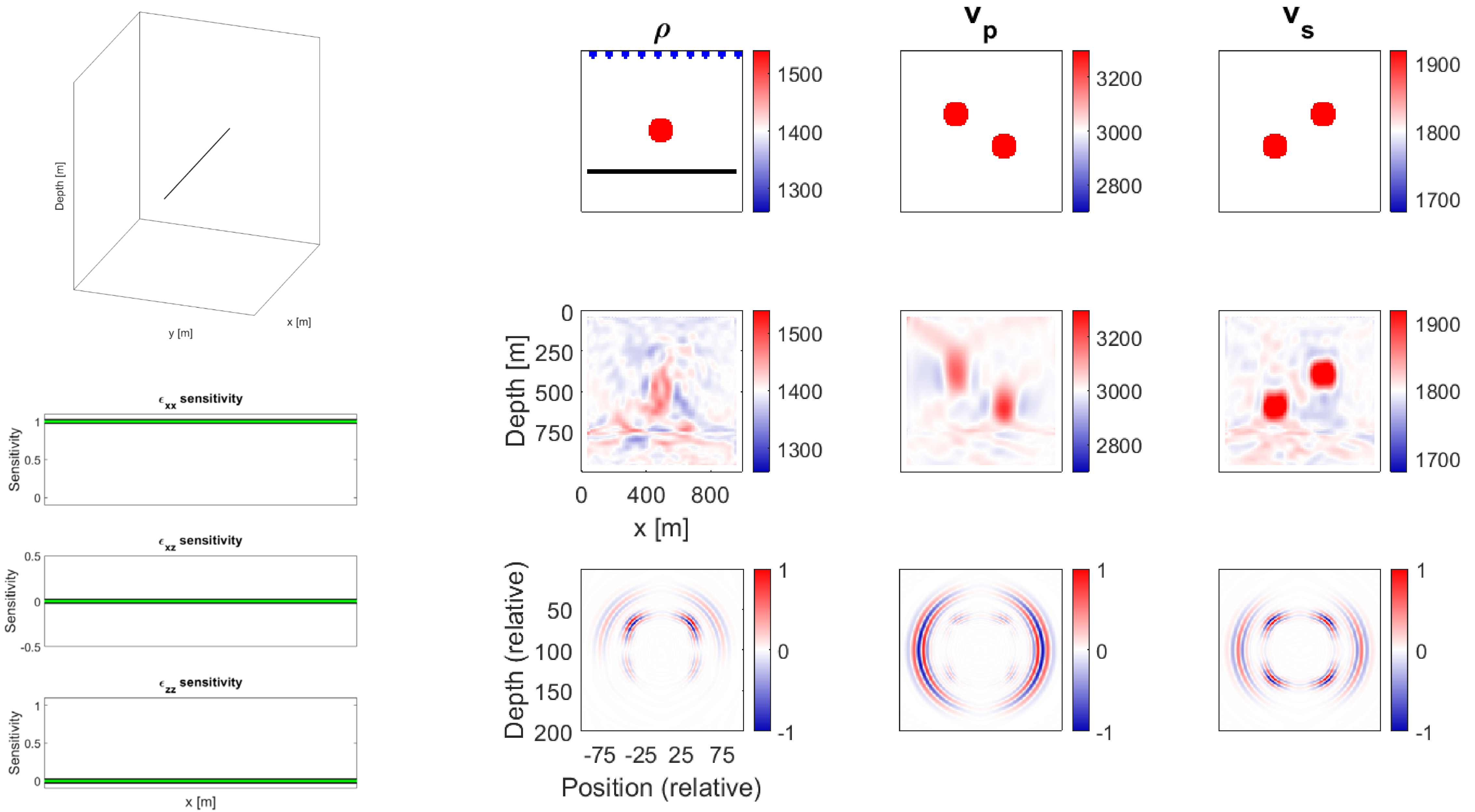
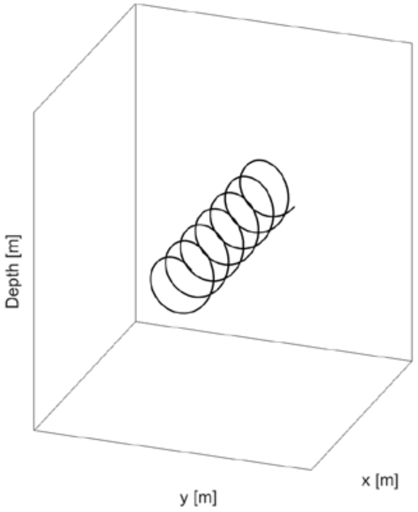
The fibre sensitive radiation patterns are formed through a weighted sum of the strain radiation patterns.

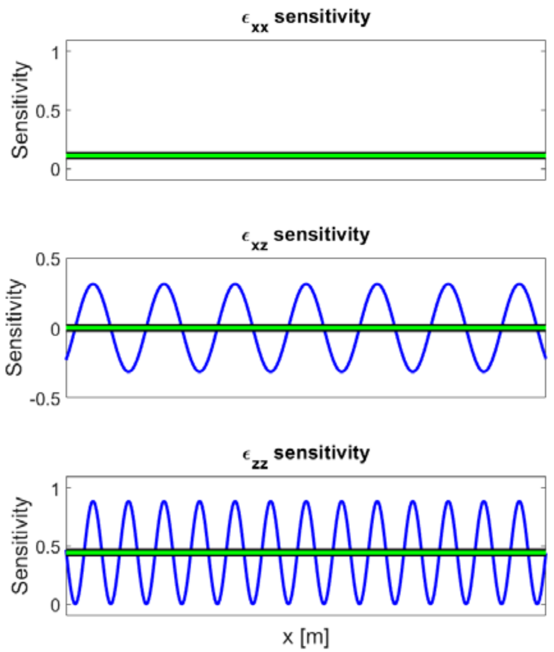
$$\epsilon_{tt} = \mathrm{a}^2\epsilon_{xx} + 2\mathrm{b}\epsilon_{xz} + \mathrm{c}^2\epsilon_{zz}$$

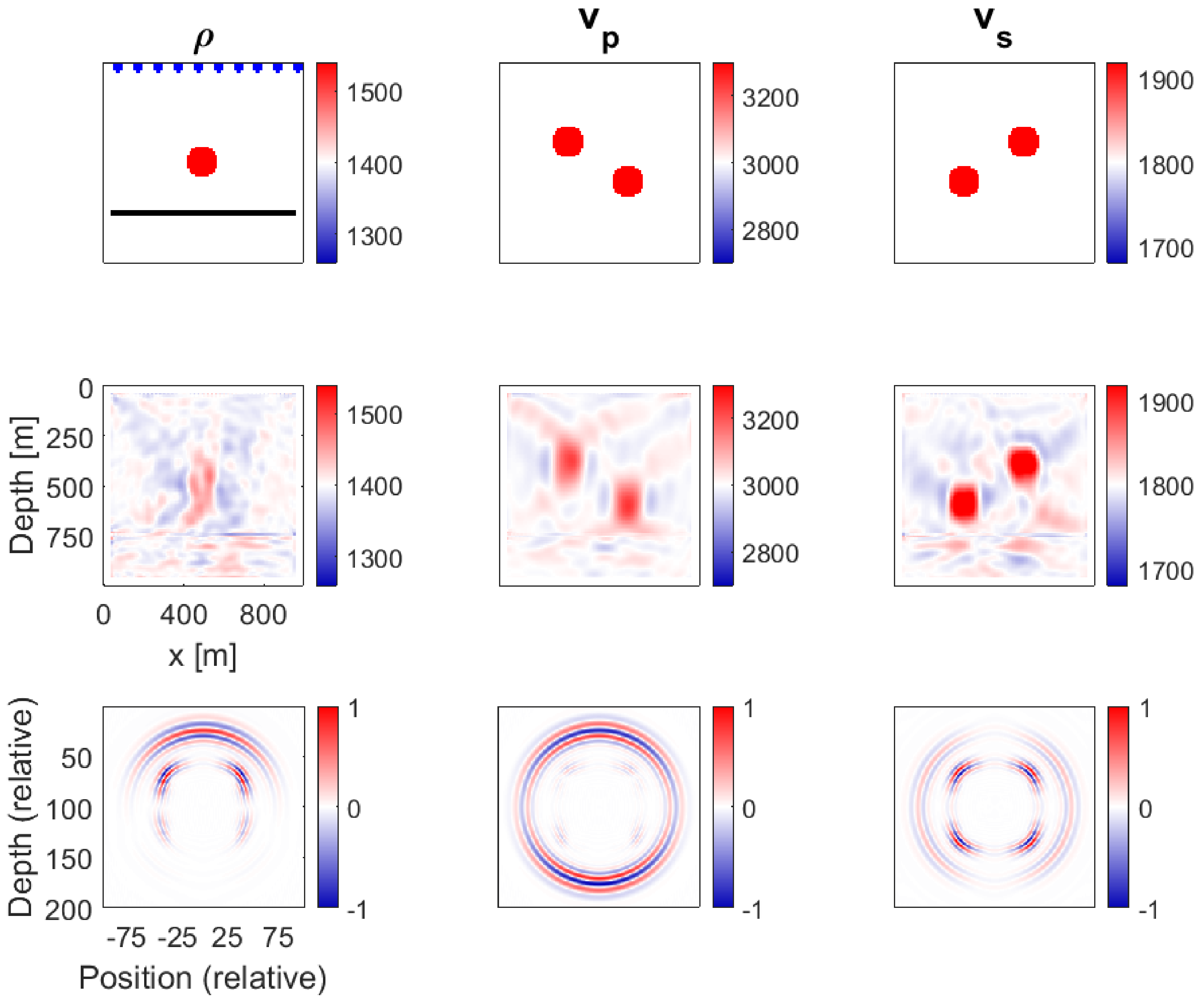
Toy Model: DAS data inversion, straight fibre



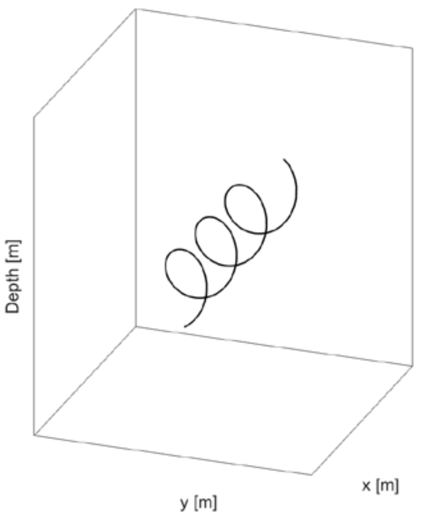
Toy Model: DAS data inversion, 19 degree lead angle (1:4)

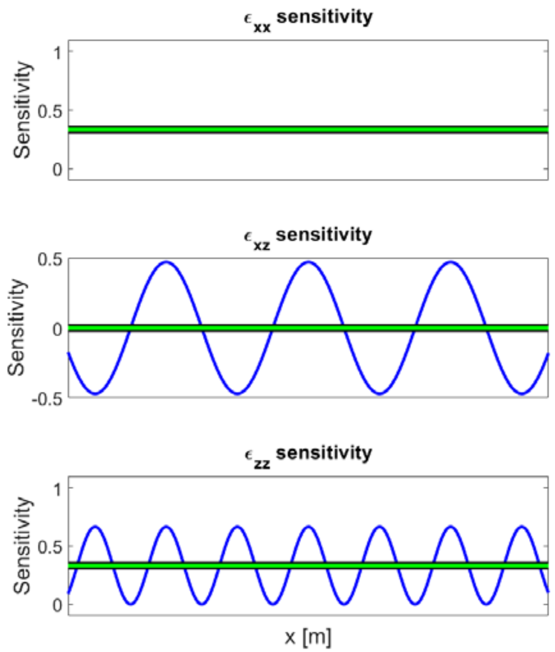


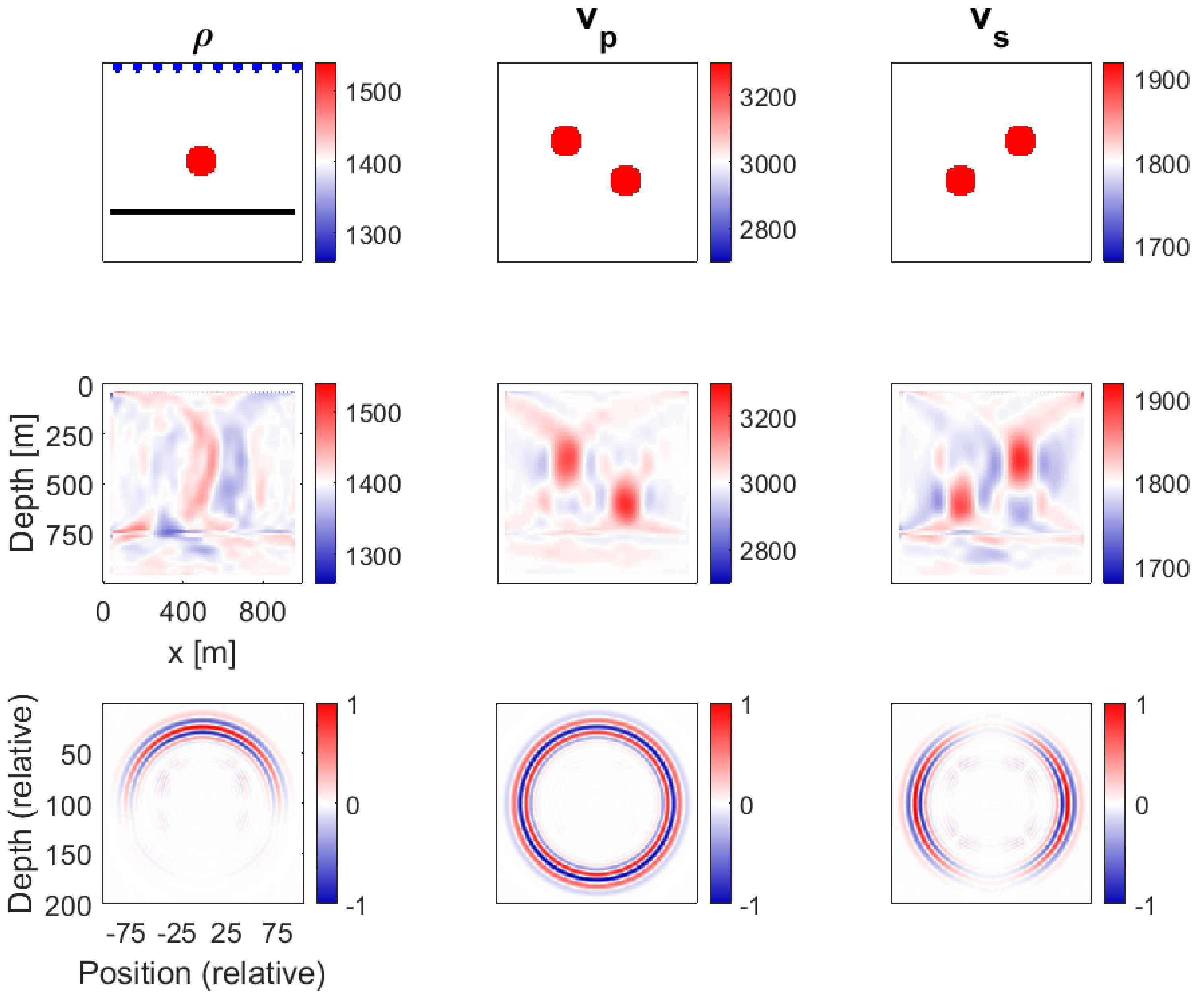




Toy Model: DAS data inversion, 35 degree lead angle (1:1)







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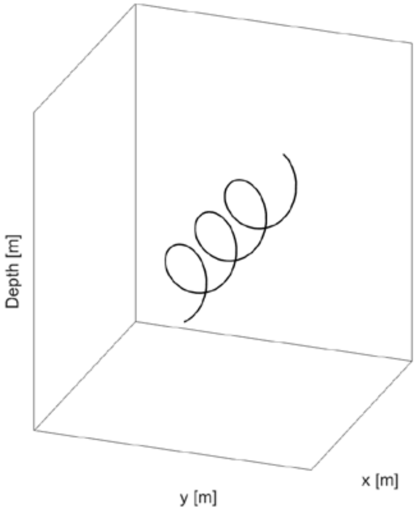
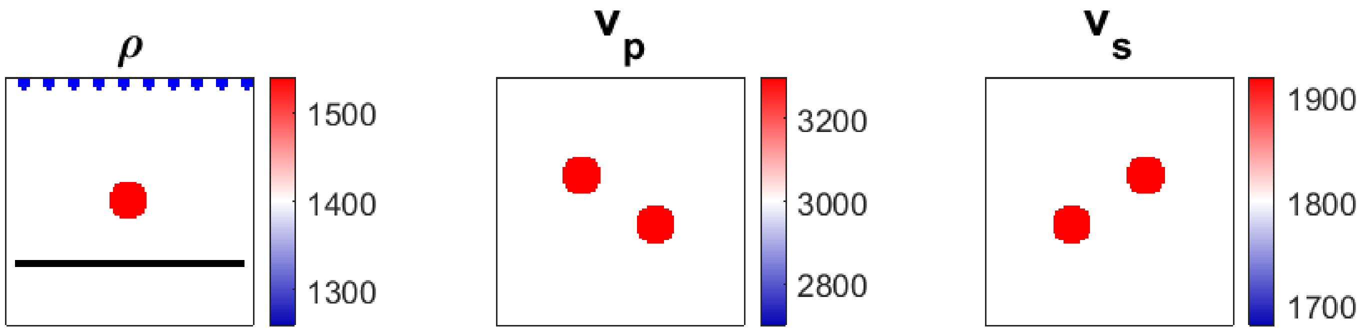
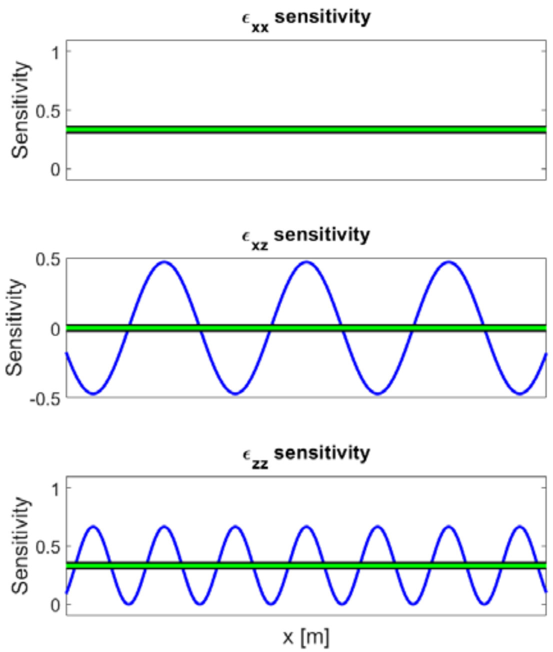
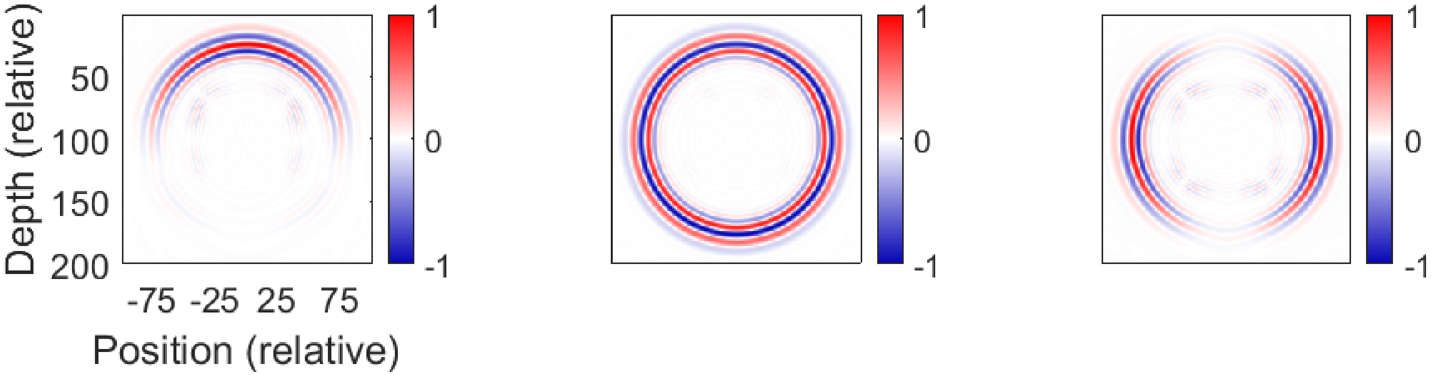


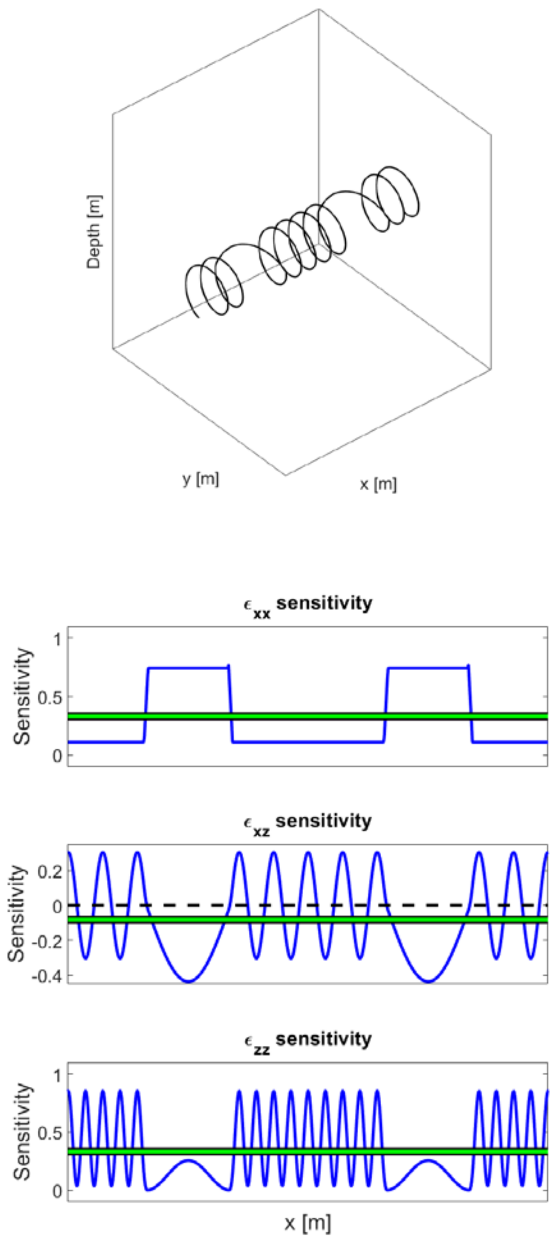


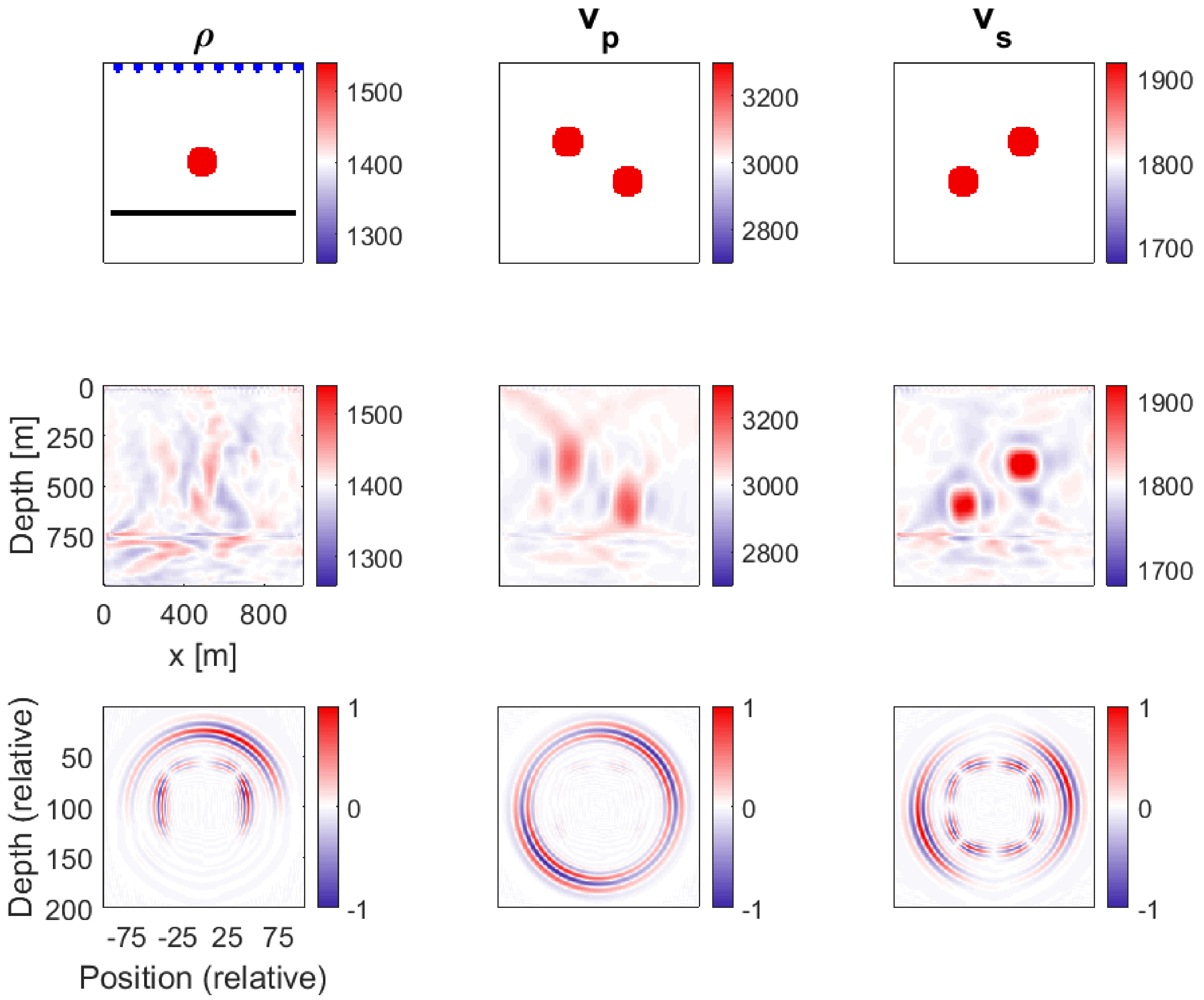
$$\epsilon_{tt} = 1\epsilon_{xx} + 1\epsilon_{zz} = \frac{\partial u_x}{\partial x} + \frac{\partial u_z}{\partial z} = \nabla \cdot u$$



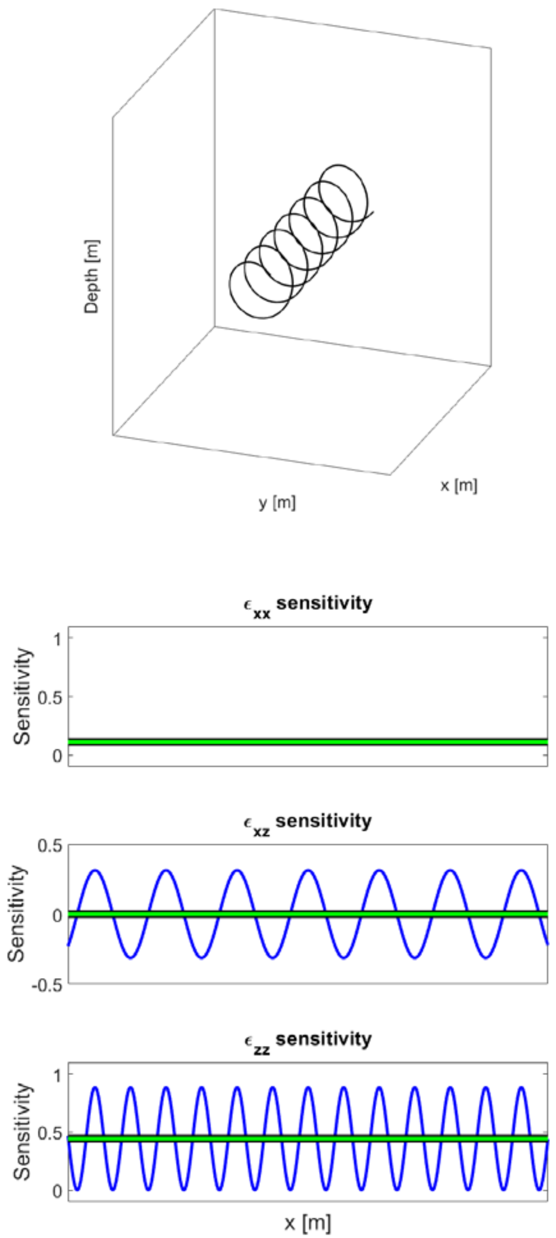


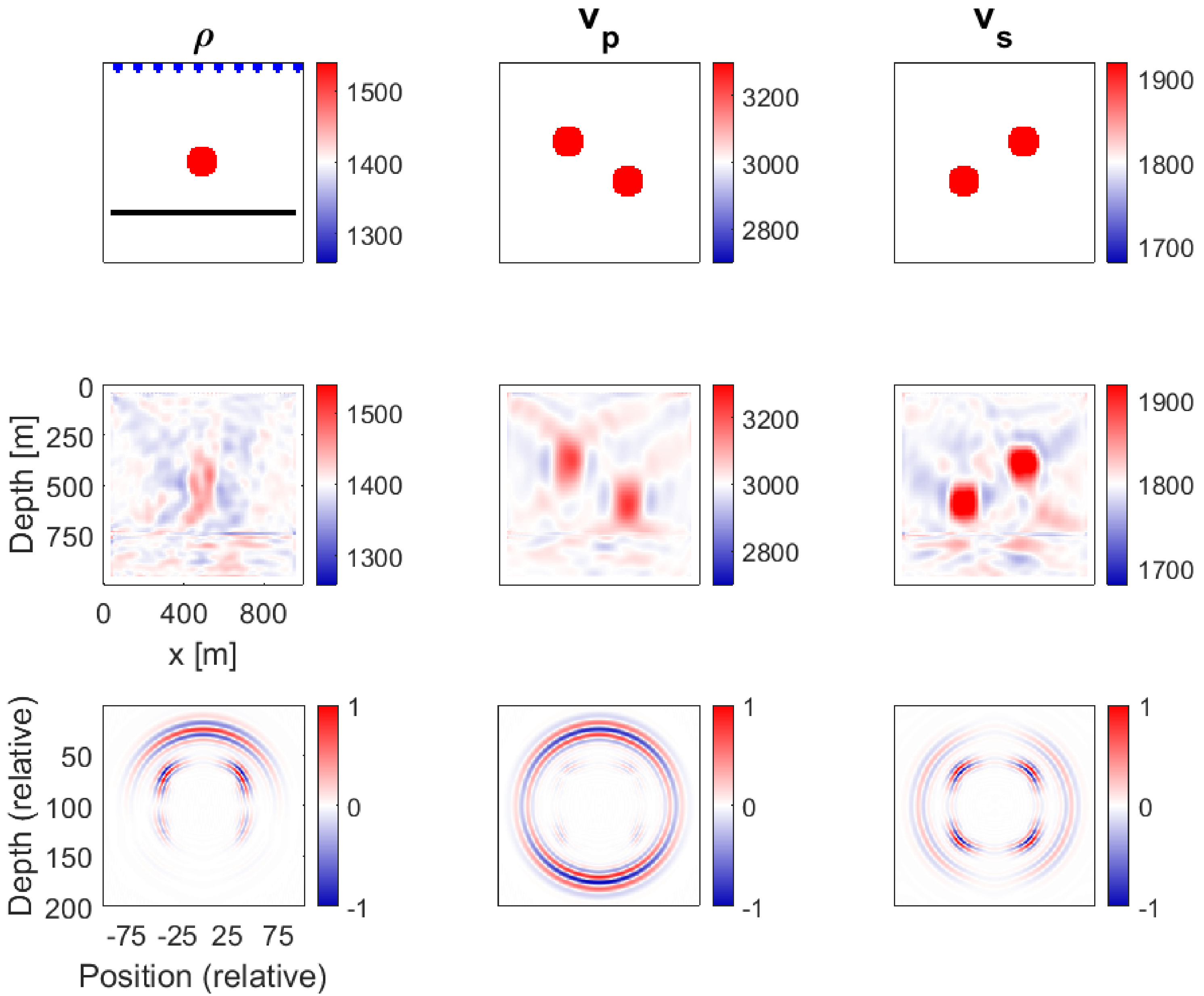
Toy Model: DAS data inversion, asymmetric fibre (2:1:2)



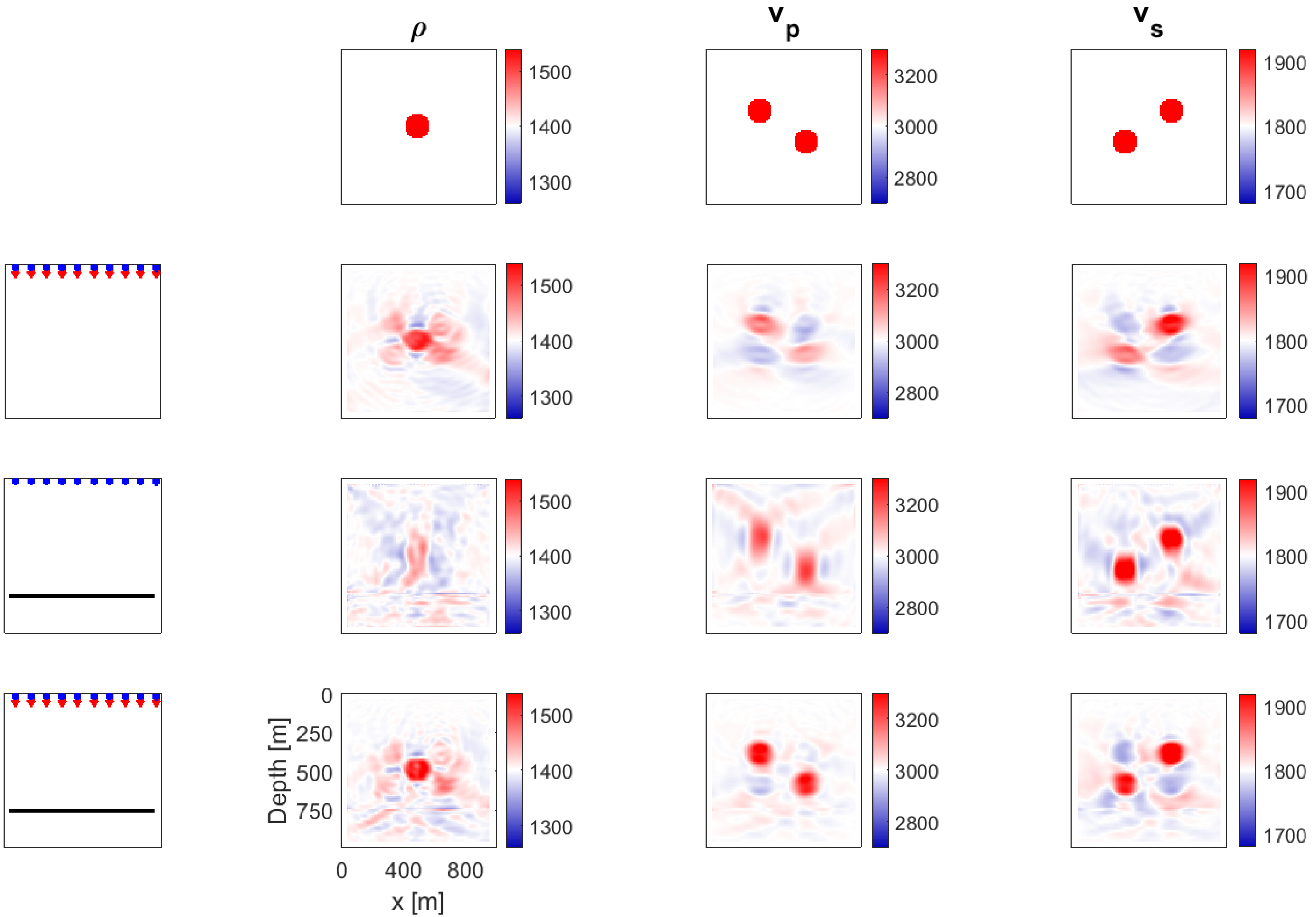


Toy Model: DAS data inversion, 19 degree lead angle (1:4)

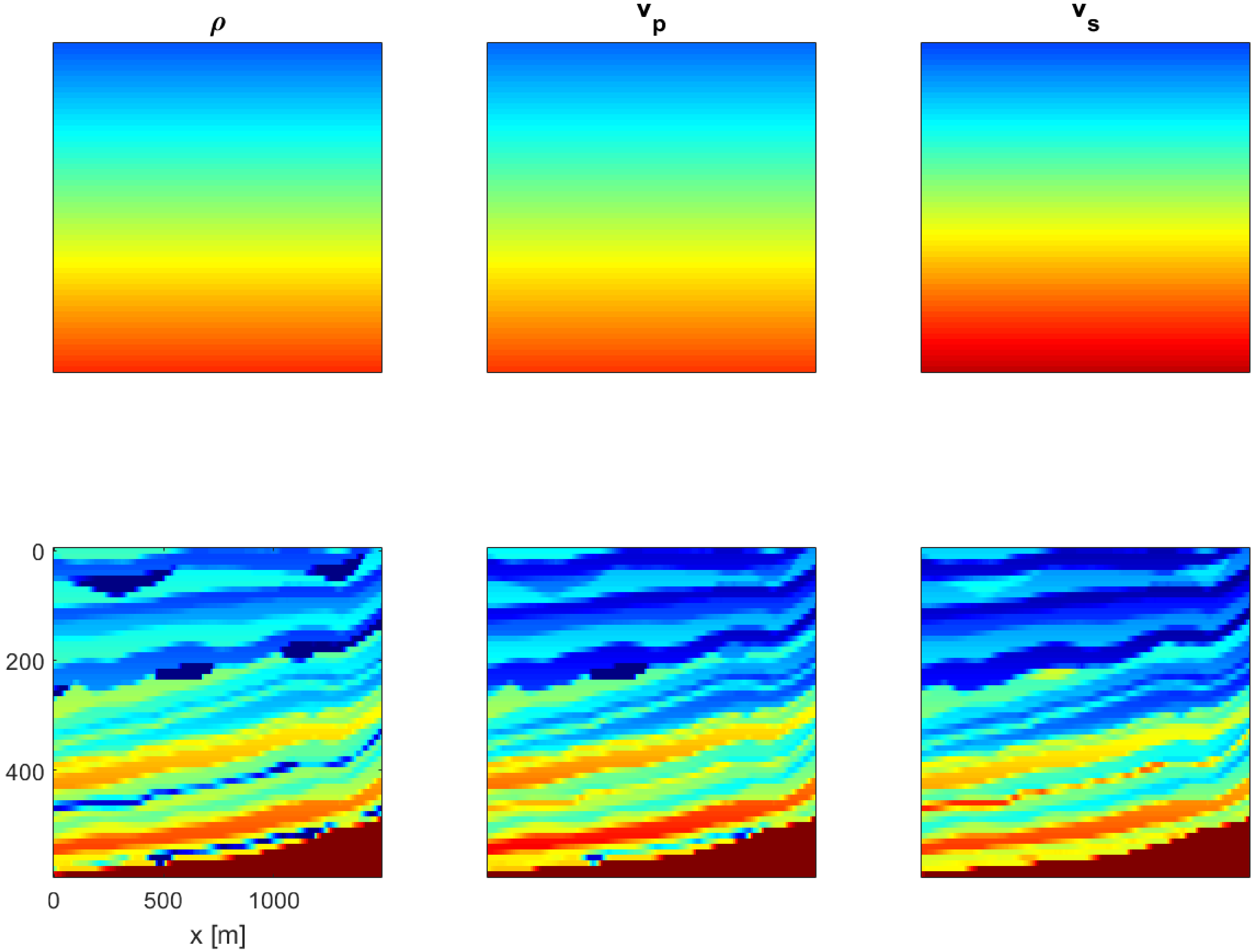




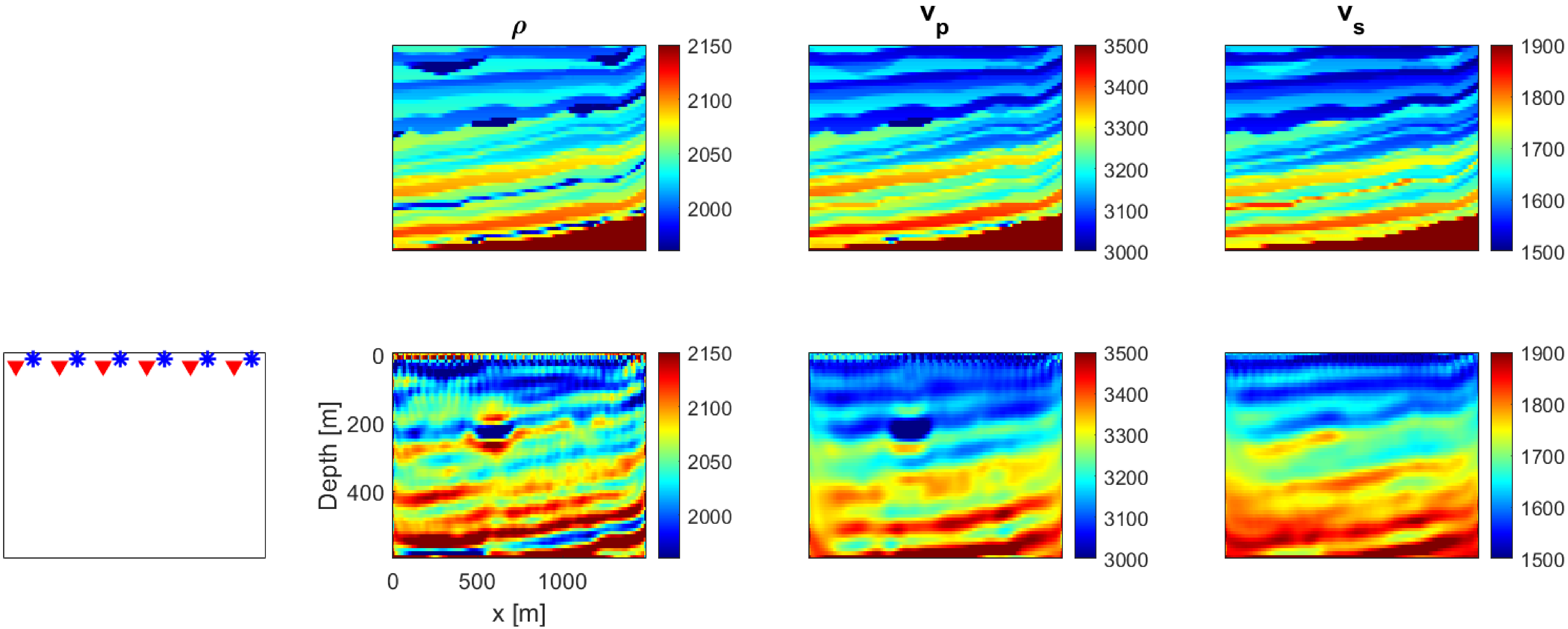
Toy Model: Geophone and DAS Simultaneous Inversion



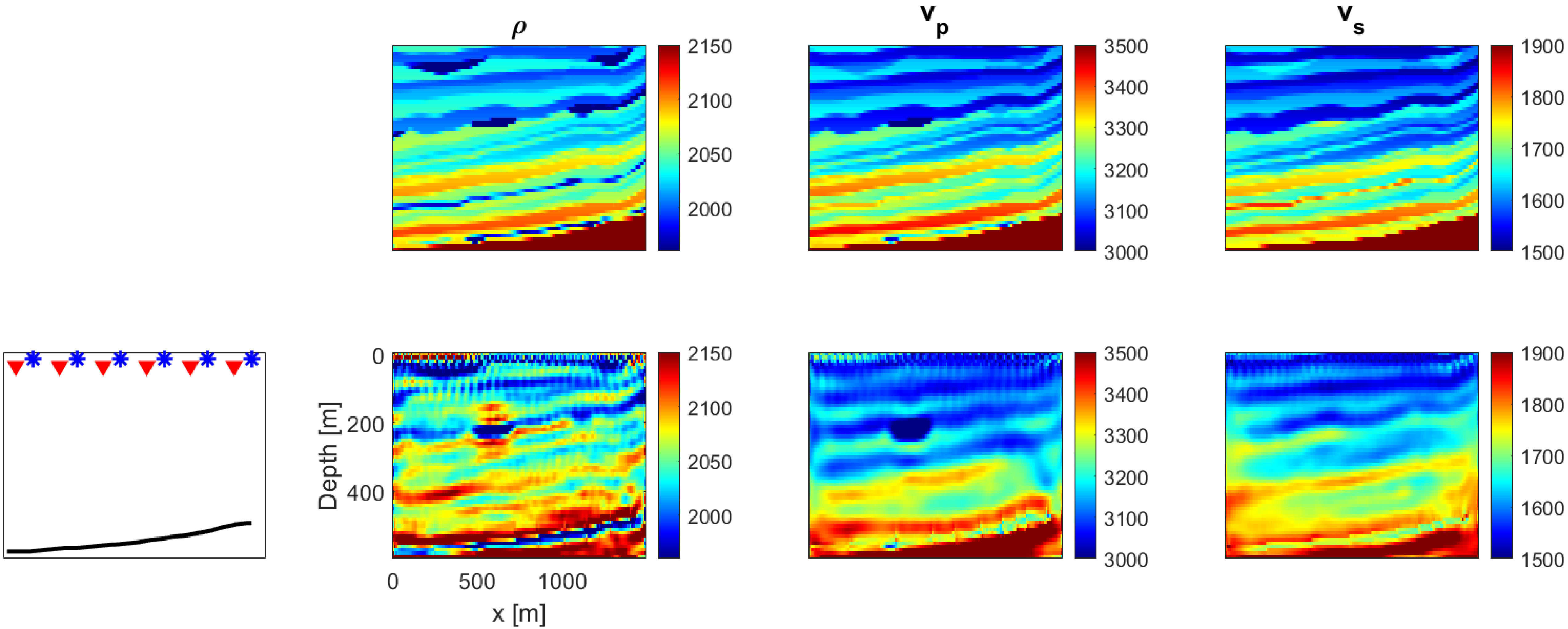
Marmousi 2 Models



Marmousi 2: geophone data inversion



Marmousi 2: simultaneous geophone and DAS data inversion



Conclusions

- DAS data can be readily accommodated in standard FWI algorithms by redefining R.
- Varying the fibre geometry greatly alters their sensitivity and ability to estimate parameters.
- DAS and geophones can provide complementary information that results in improved parameter estimations.

Acknowledgements

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