The role of the fiber gauge length in FWI of DAS strain data

Matt Eaid*, and Kris Innanen

March 6th, 2019

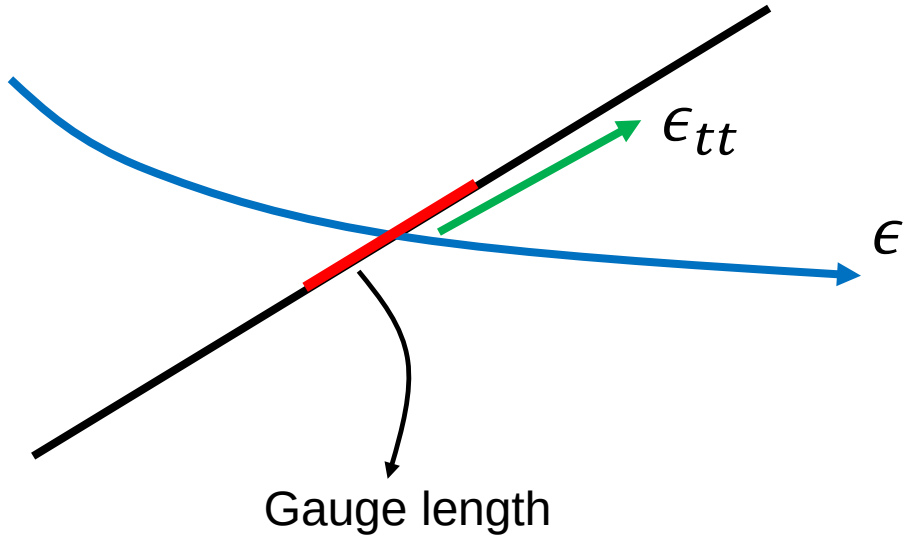
NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience

Motivation

- Advancements in DAS fiber technology have driven gauge lengths down.
- Moves DAS closer to a true elastic technology providing 6C sensing.
- Important to understand the effect reduced gauge lengths have on inversion results.

Distributed Acoustic Sensing

- DAS uses an 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

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

Forward wavefield propagation

$$\mathbf{Su} = \mathbf{f}$$

Reverse wavefield propagation

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

Full waveform inversion

Receiver matrix

Observed data

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

Modeled wavefield

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

Forward wavefield propagation

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

Reverse wavefield propagation

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

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.

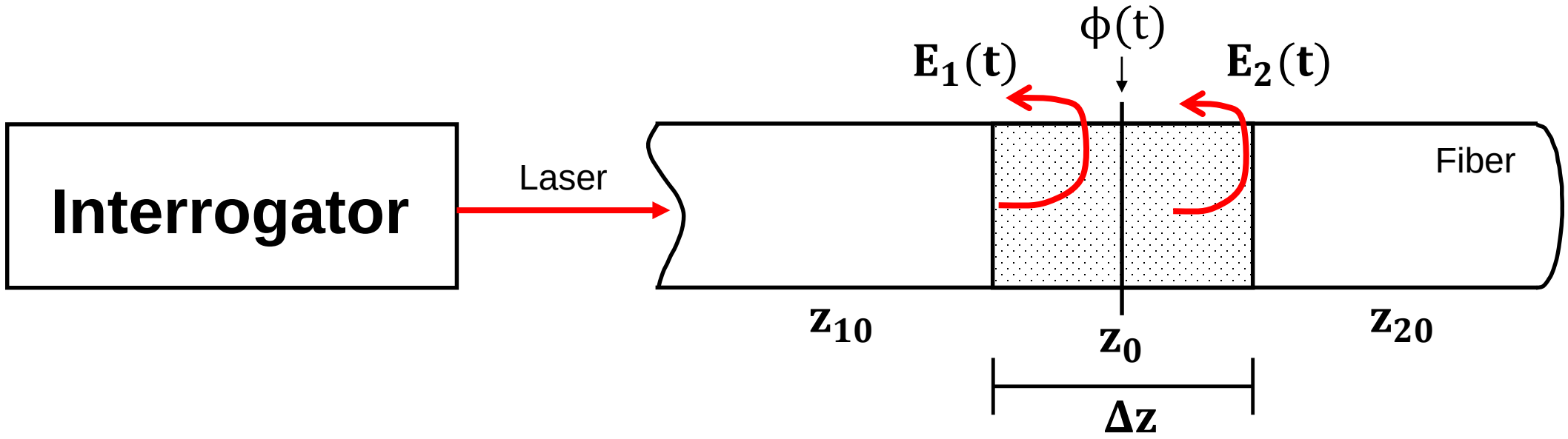
$$\begin{bmatrix} d'_1 \\ d'_2 \\ d'_3 \\ d'_4 \\ \vdots \\ d'_{N_{R-1}} \\ d'_{N_R} \end{bmatrix} = \begin{bmatrix} \\ \\ R \\ \\ \\ \end{bmatrix} \begin{bmatrix} u^1_{m_x} \\ u^1_{m_z} \\ u^2_{m_x} \\ u^2_{m_z} \\ \vdots \\ u^{N_{gx}}_{m_x} \\ u^{N_{gz}}_{m_z} \end{bmatrix}$$

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

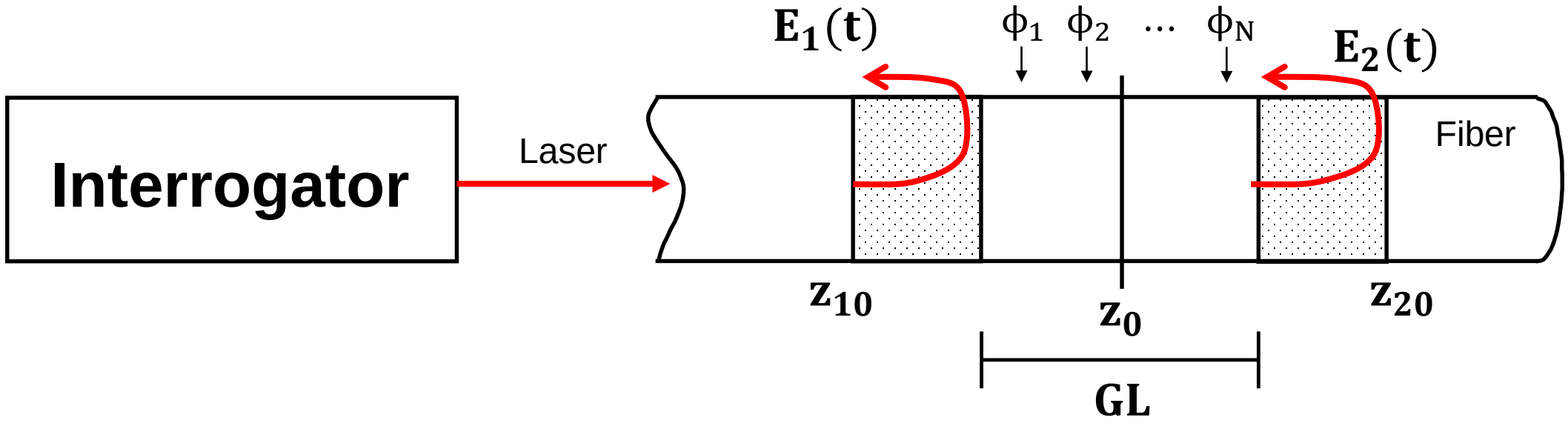
$$\begin{bmatrix} d^1_{m_x} \\ d^1_{m_z} \\ d^2_{m_x} \\ d^2_{m_z} \\ \vdots \\ d^{N_{Rx}}_{m_x} \\ d^{N_{Rz}}_{m_z} \\ \hline \\ d'_1 \\ d'_2 \\ d'_3 \\ d'_4 \\ \vdots \\ d'_{N_{R-1}} \\ d'_{N_R} \end{bmatrix} = \begin{bmatrix} R_{GEO} \\ \hline \\ R_{DAS} \\ \\ \end{bmatrix} \begin{bmatrix} u^1_{m_x}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

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

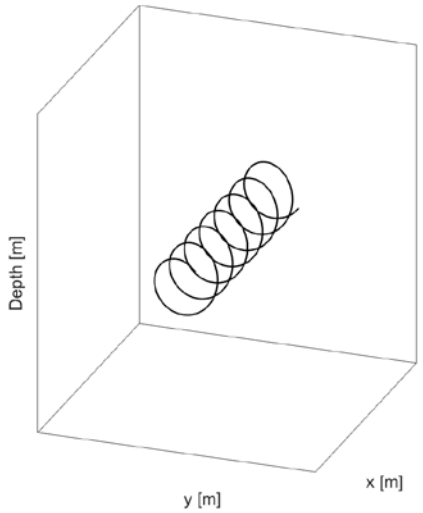
Distributed Acoustic Sensing – Basic Principles

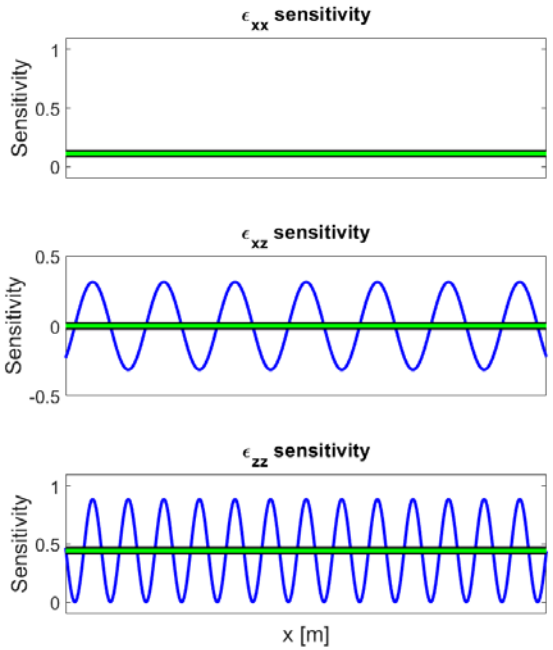


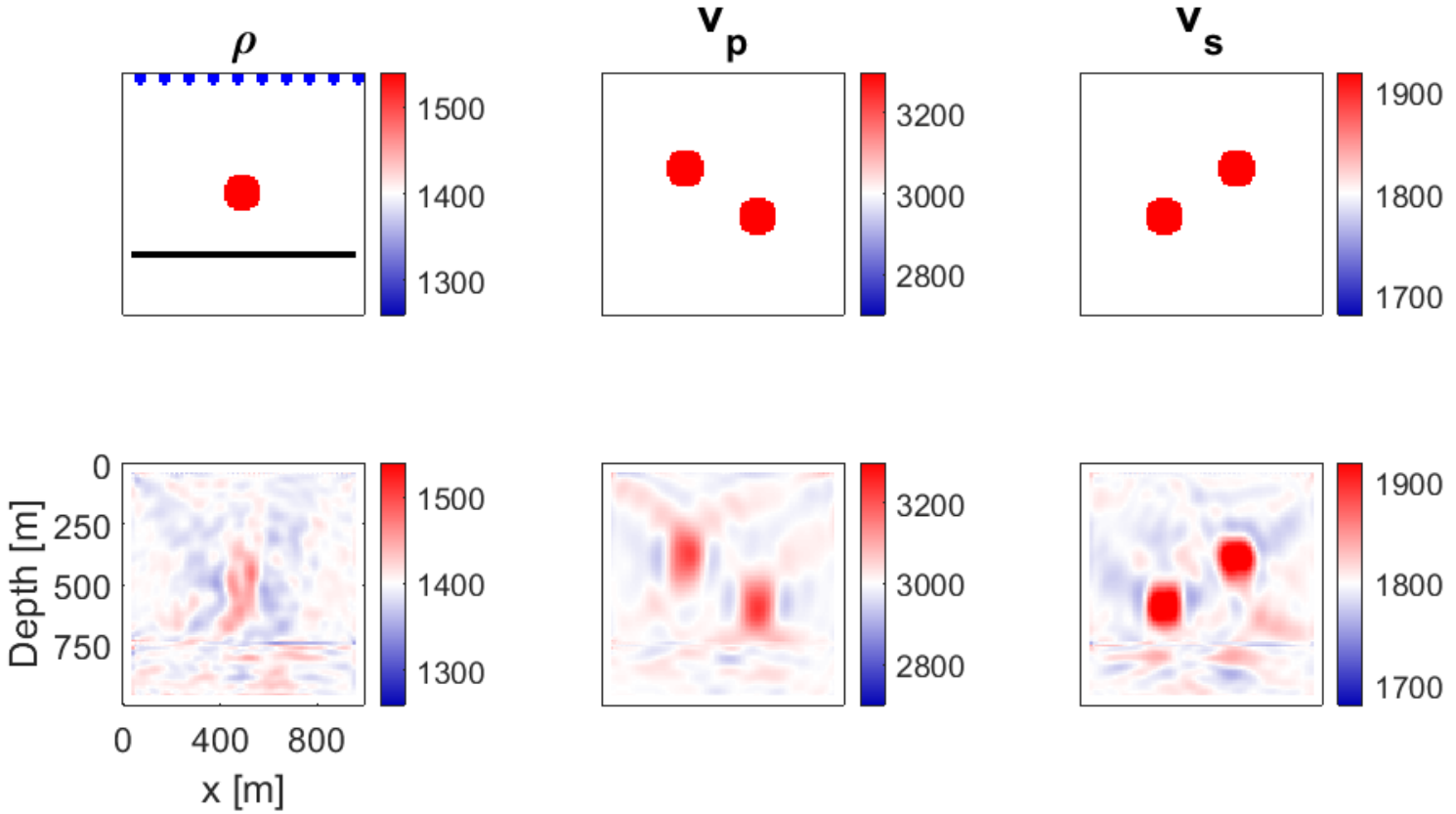
Distributed Acoustic Sensing – Gauge Length



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

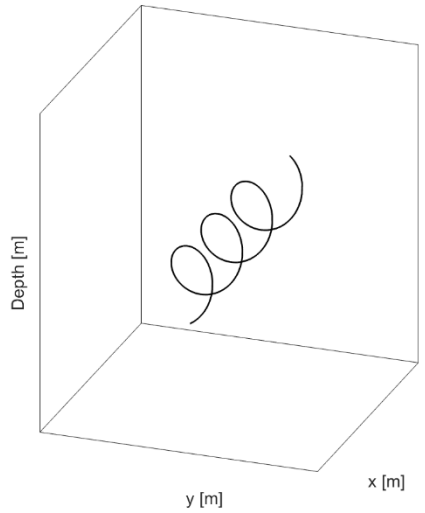


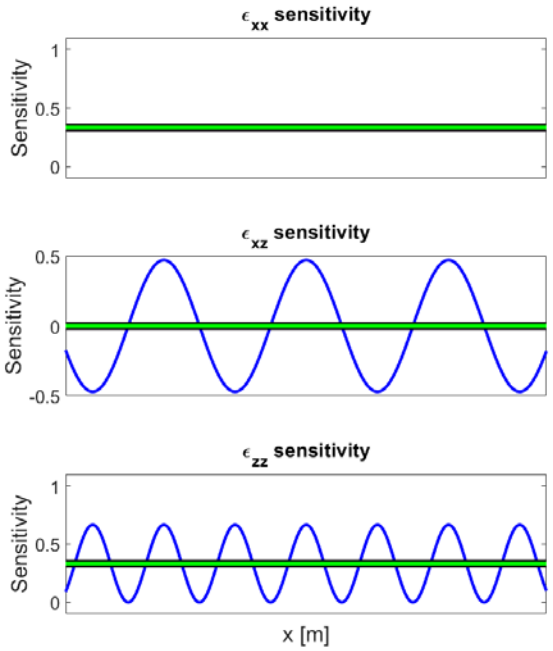


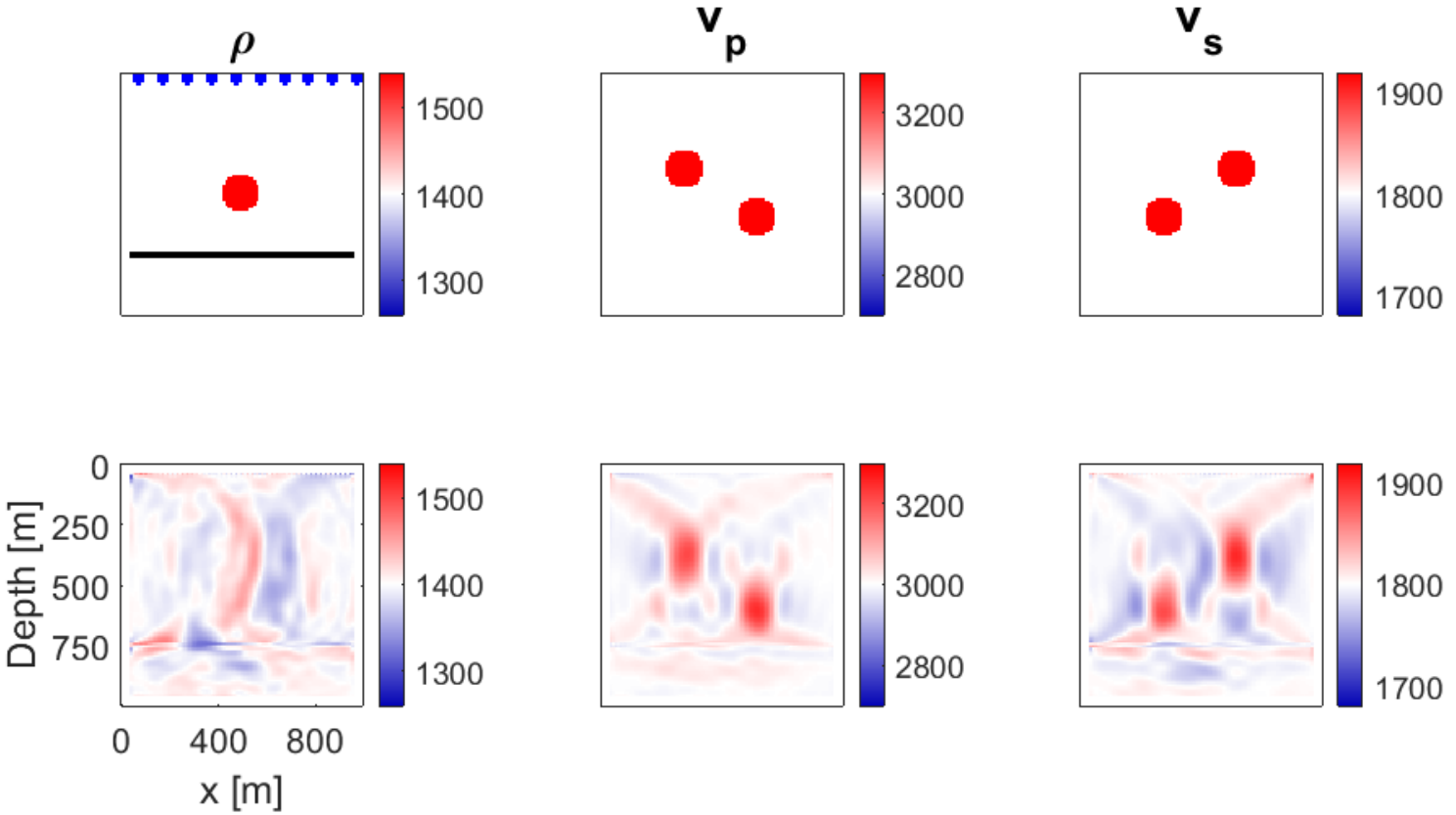


- Sensitivity is constant over the gauge length
- Fibers of this type have no sensitivity to shear strain components

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



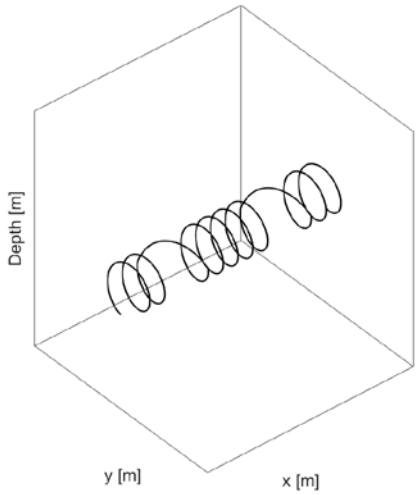


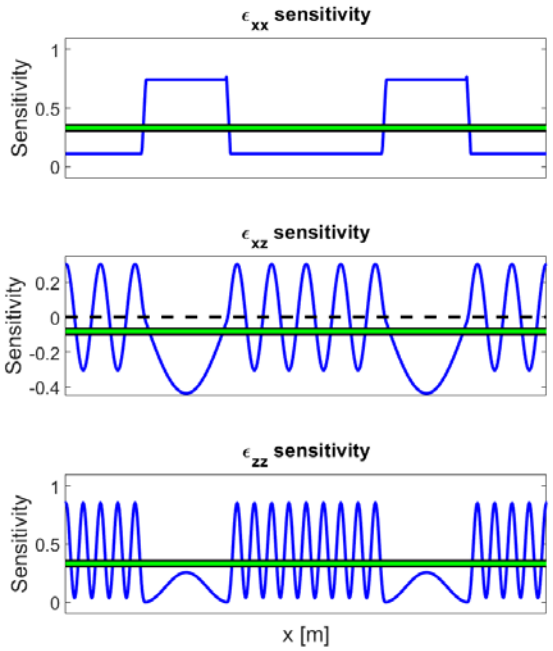


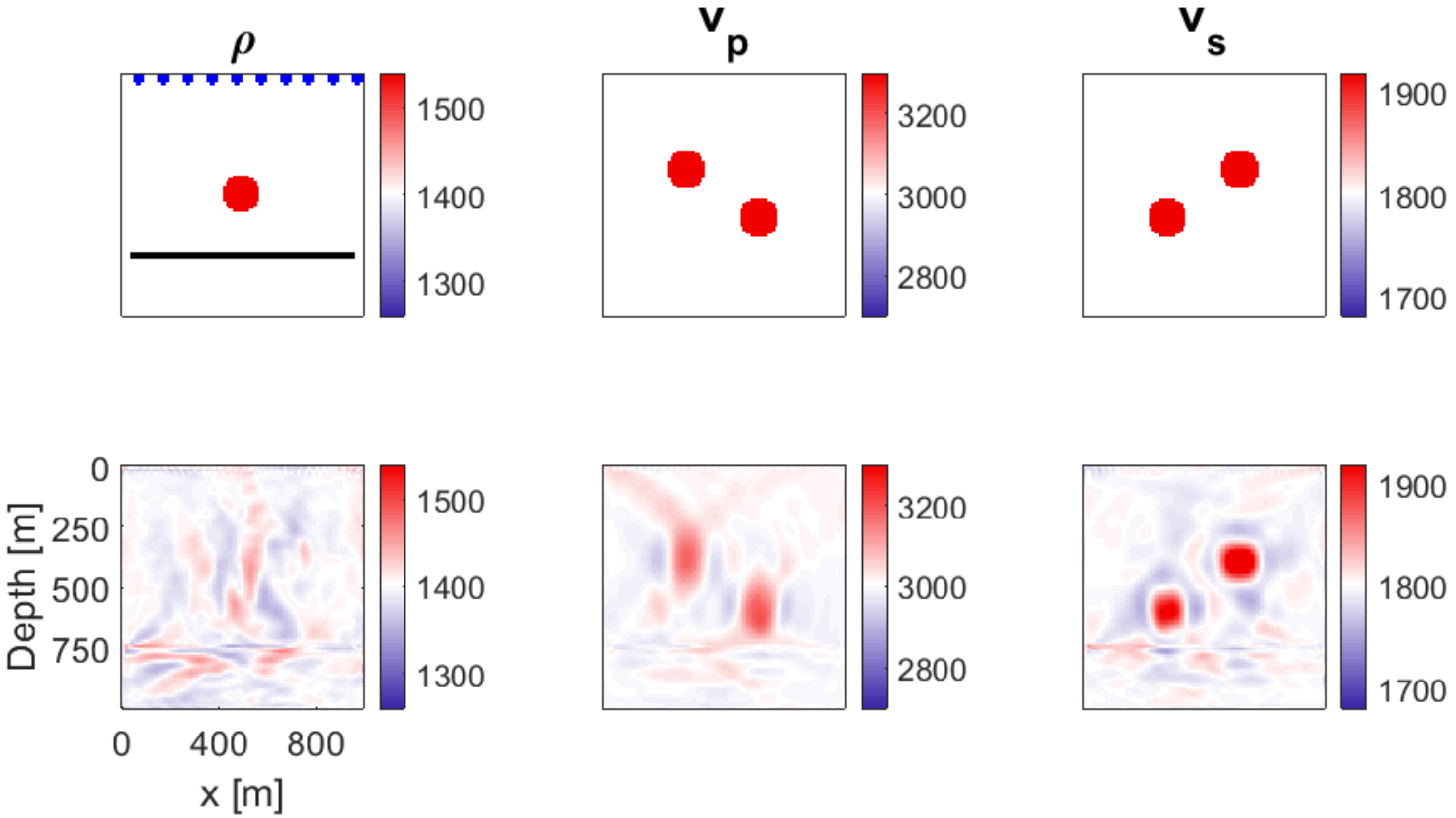
$$\epsilon_{tt} = \epsilon_{xx} + \epsilon_{zz} = \nabla \cdot u$$

- If sensitivity to ϵ_{xx} and ϵ_{zz} are equal, then fibers of this type are fully shear wave blind

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

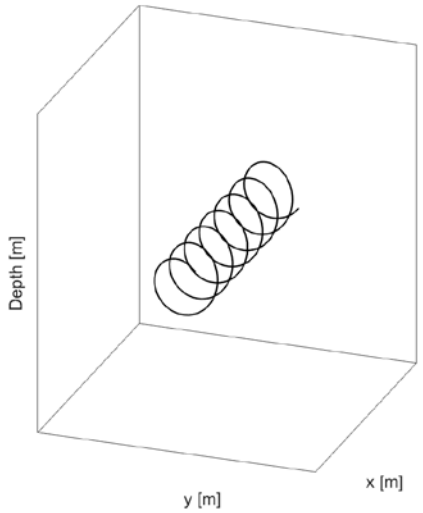


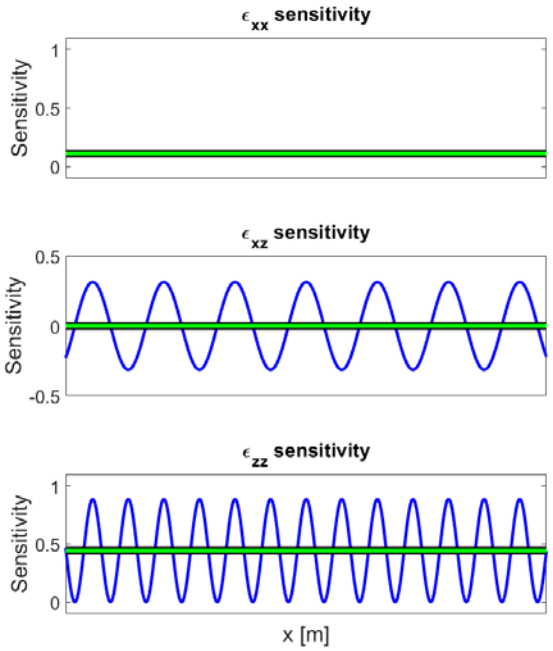


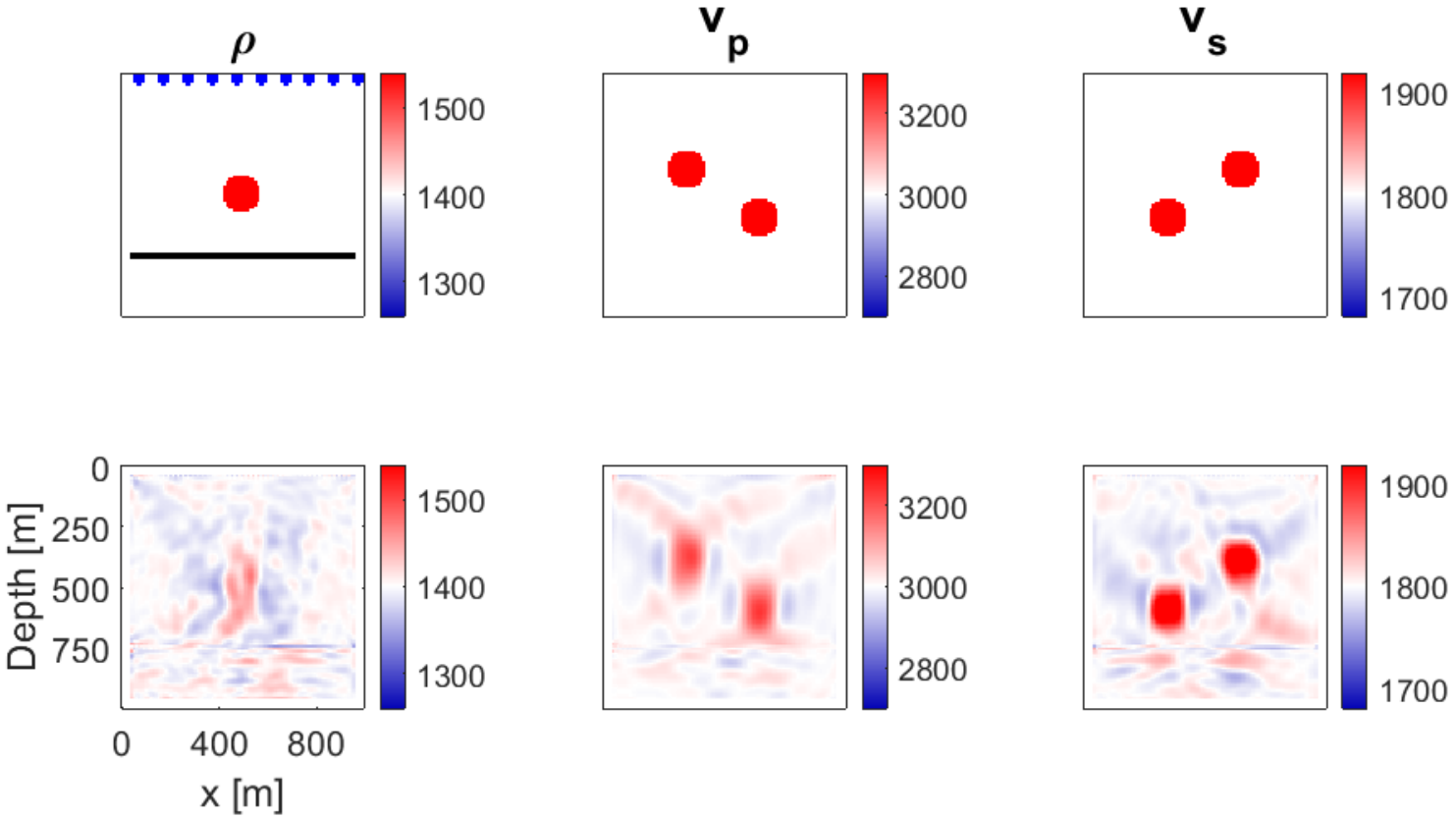


- Access to shear strain components possible through complex fiber geometry

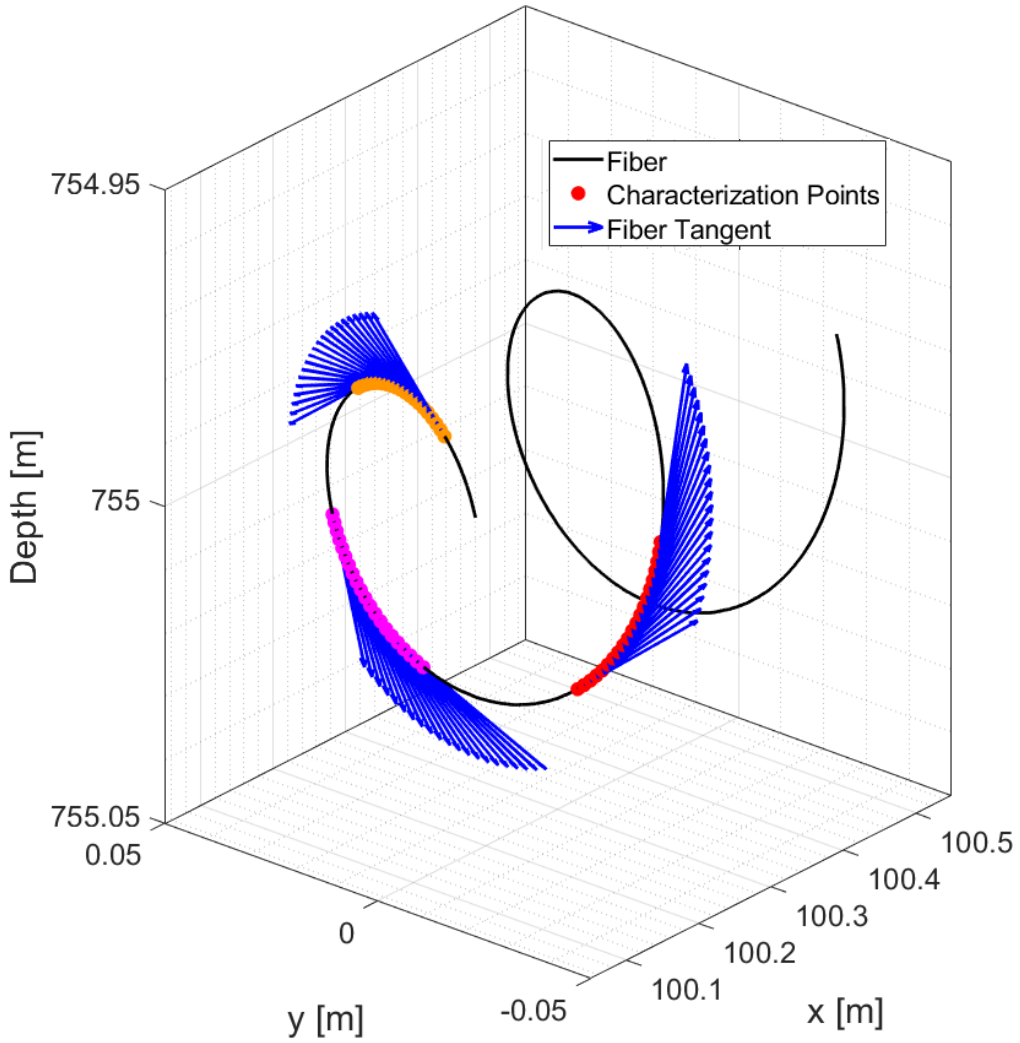
Toy Model: DAS data inversion, 19 degree lead angle (1:4)

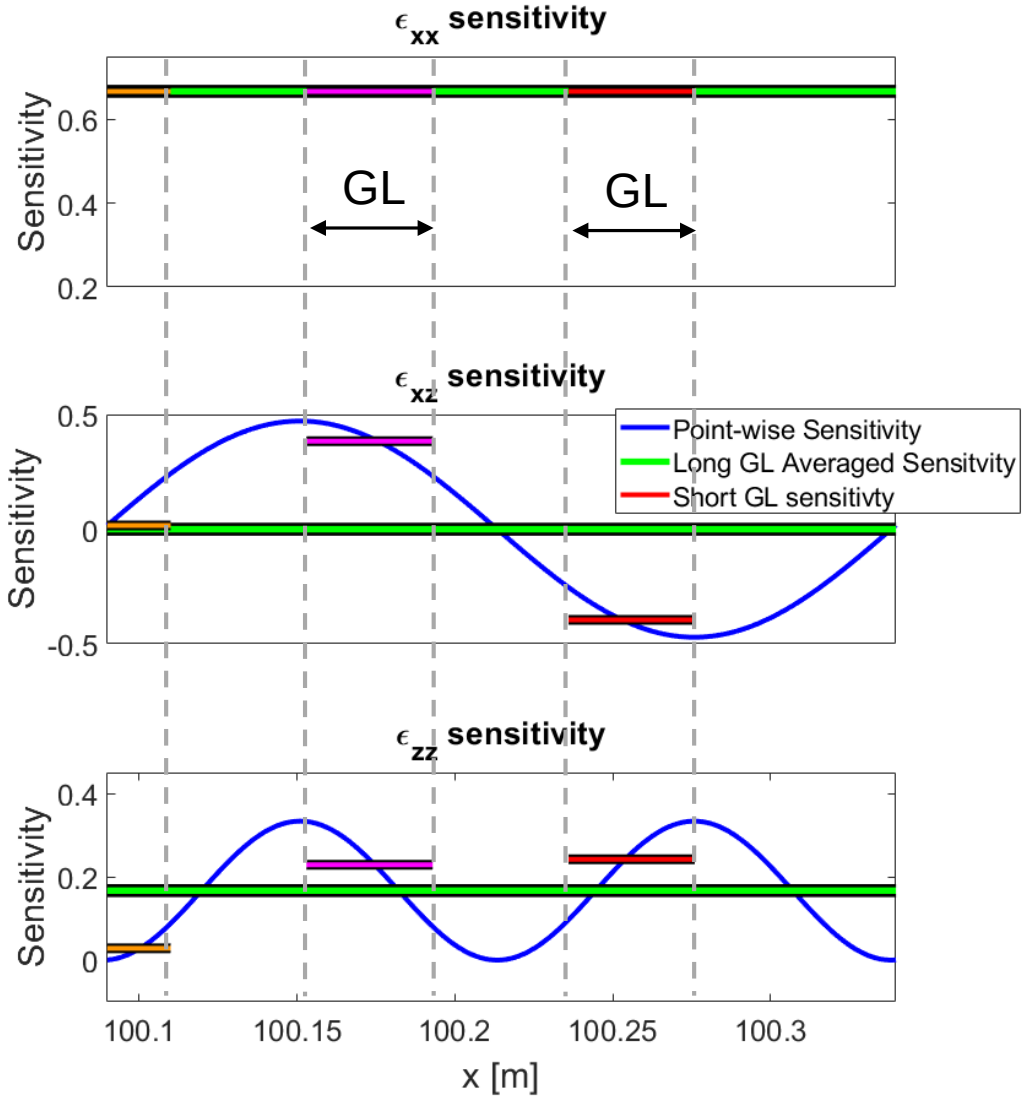




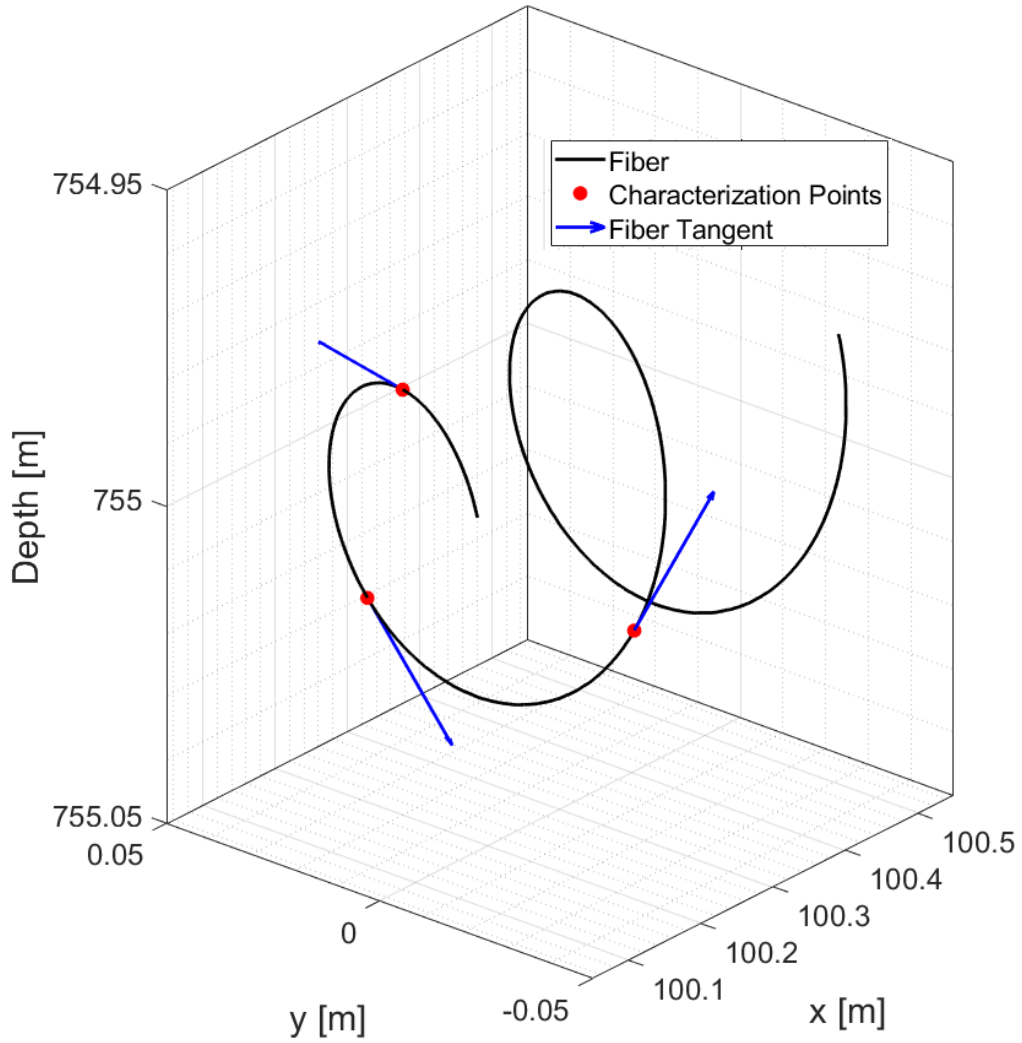


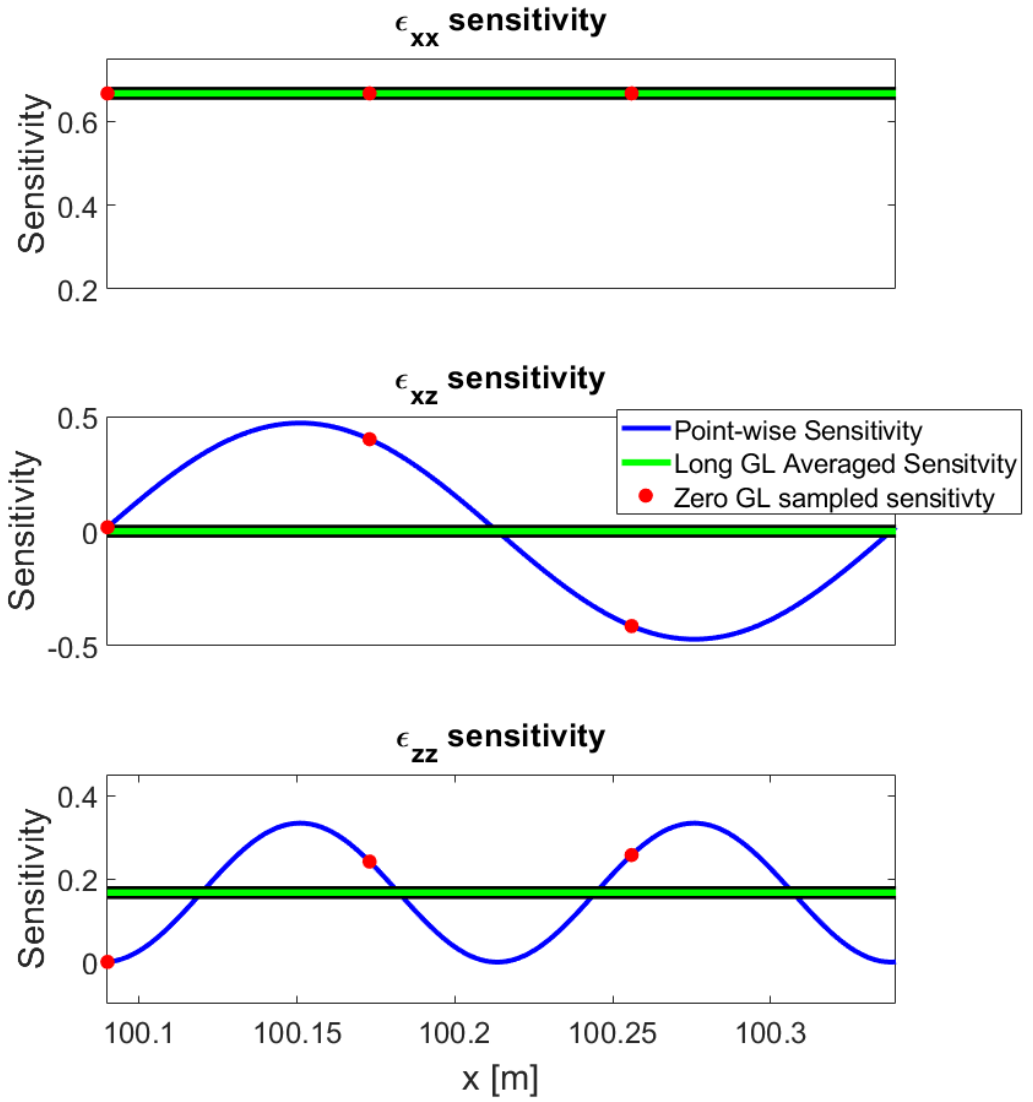
Effect of small gauge length (GL << fiber period)



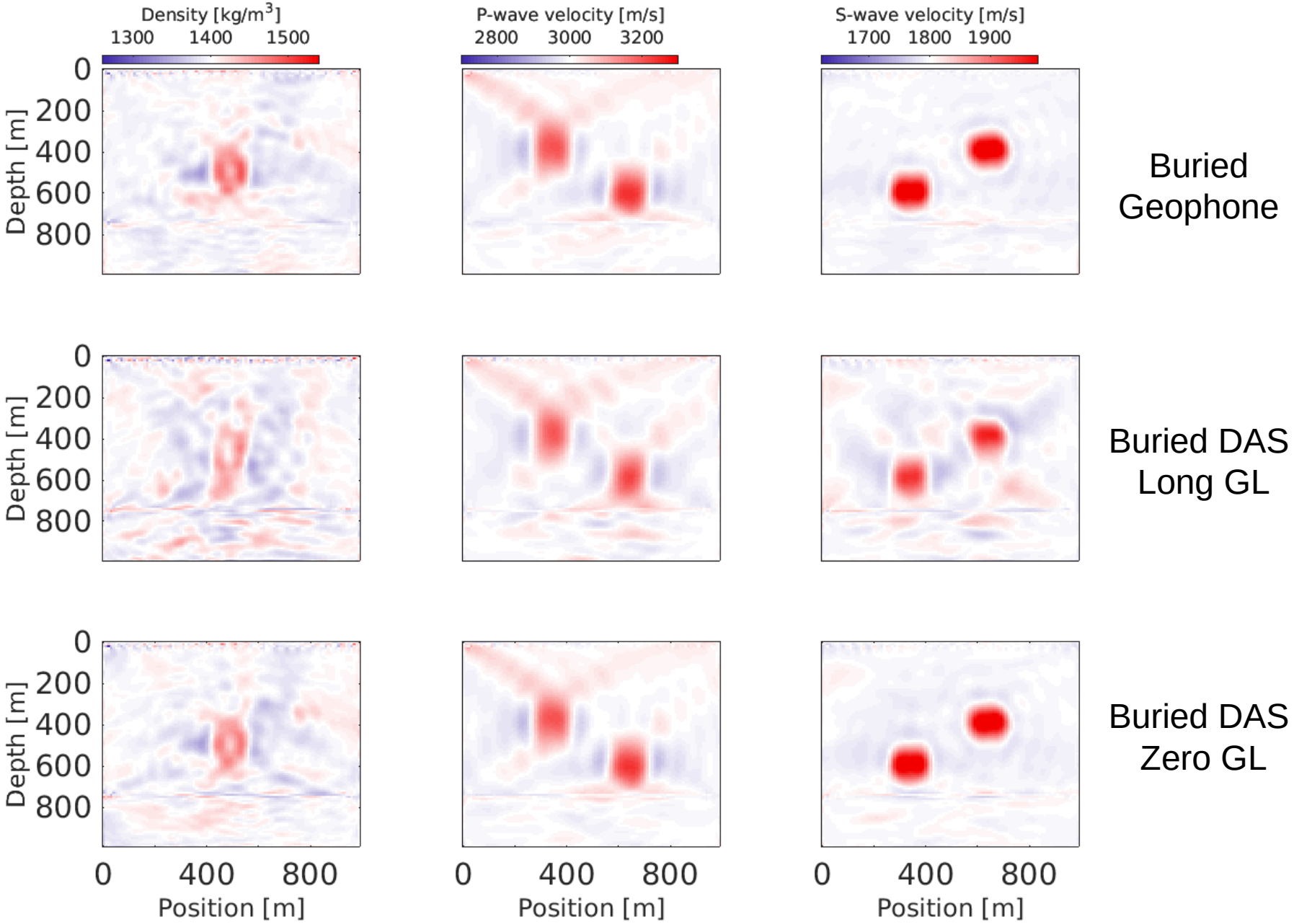


Effect of zero gauge length



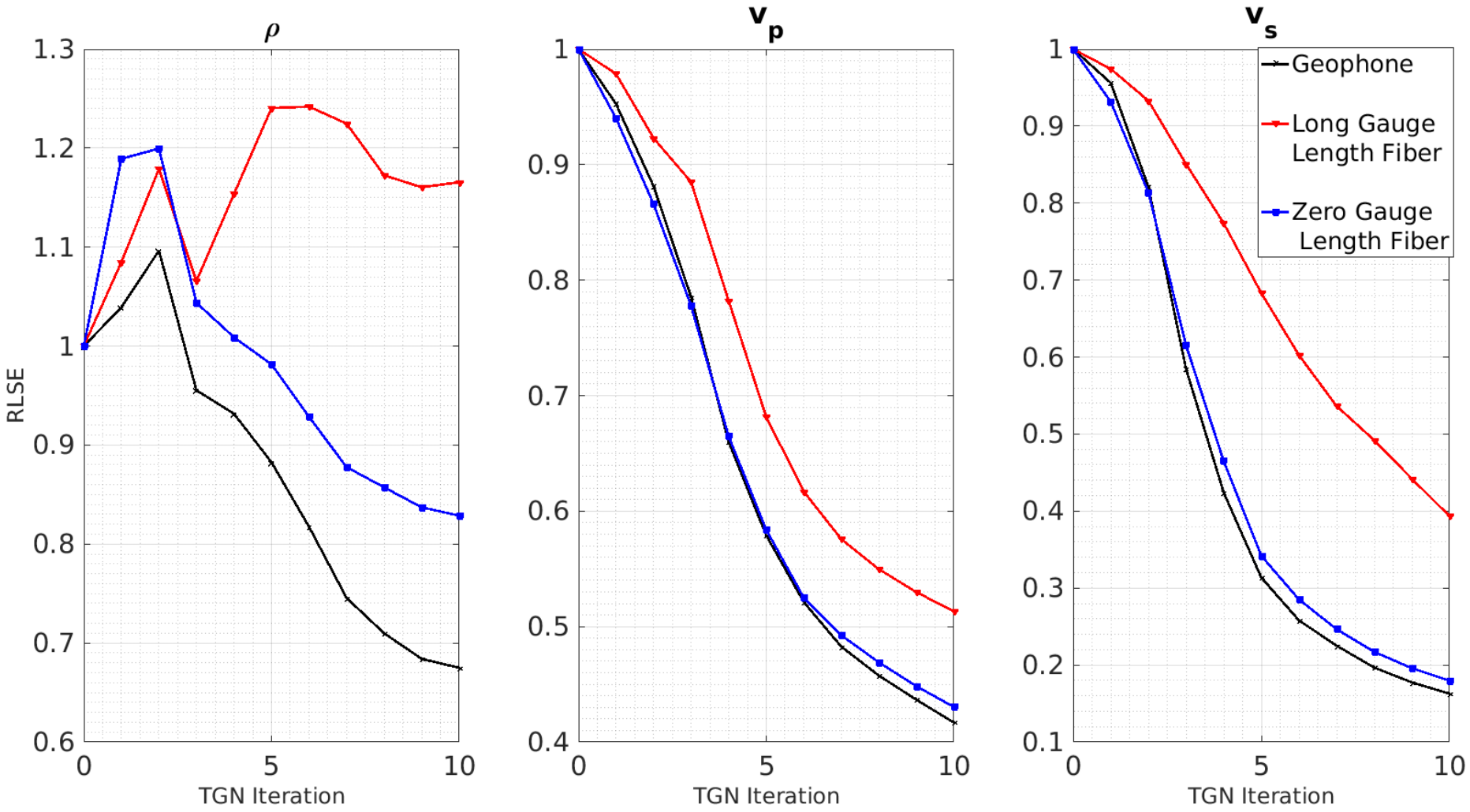


Zero GL vs long GL comparison to full elastic geophone results

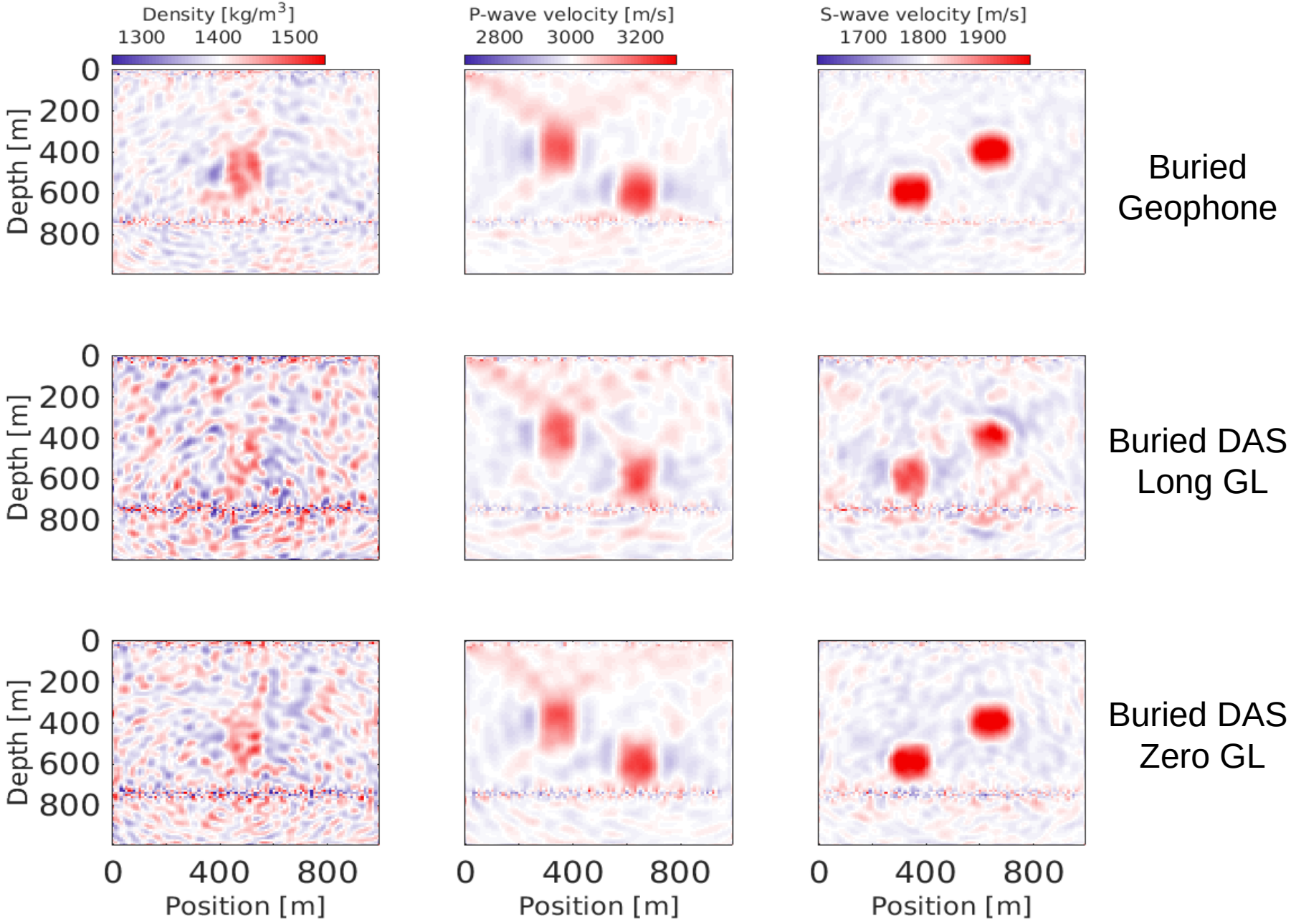


Zero GL vs long GL comparison to full elastic geophone results

$$\epsilon = \frac{\|m_k - m_t\|^2}{\|m_i - m_t\|^2}$$

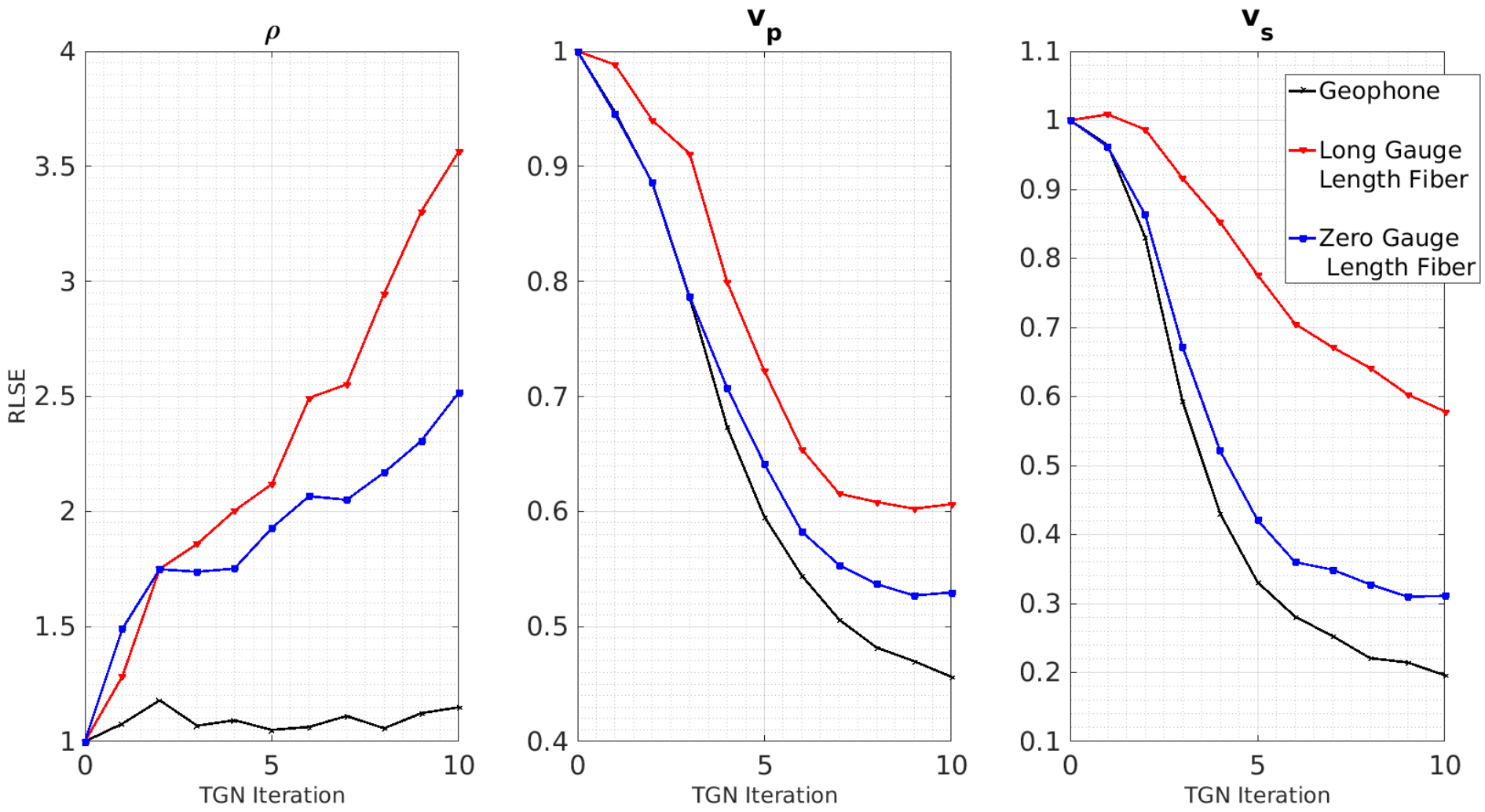


Zero GL vs long GL comparison to full elastic geophone results

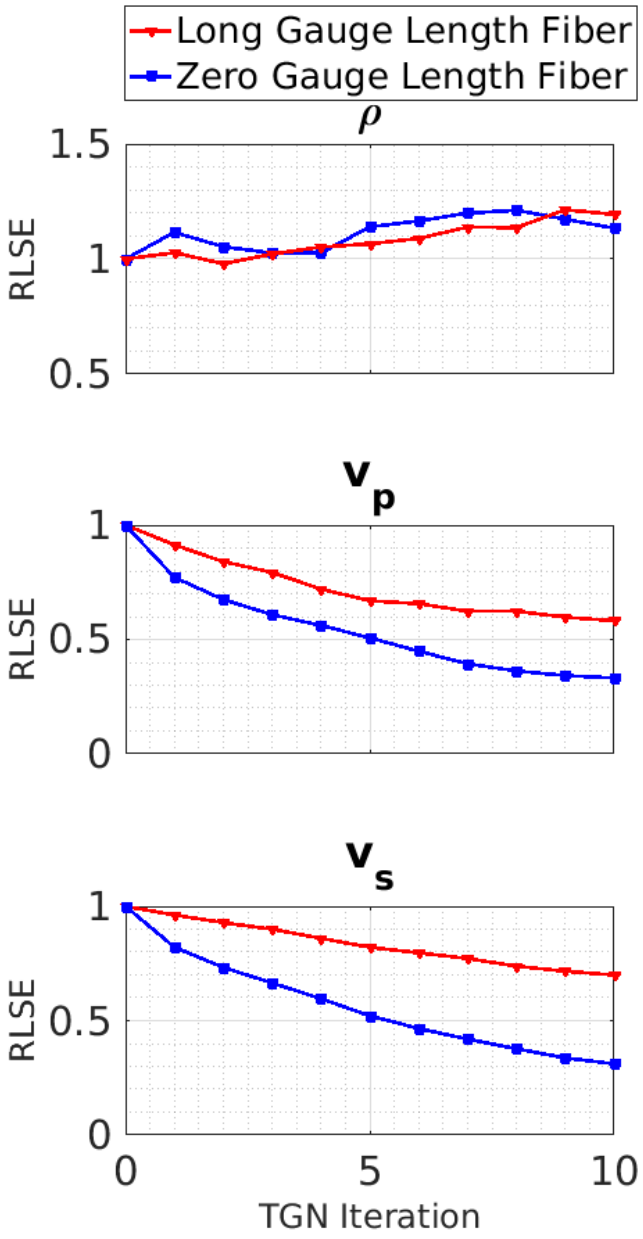


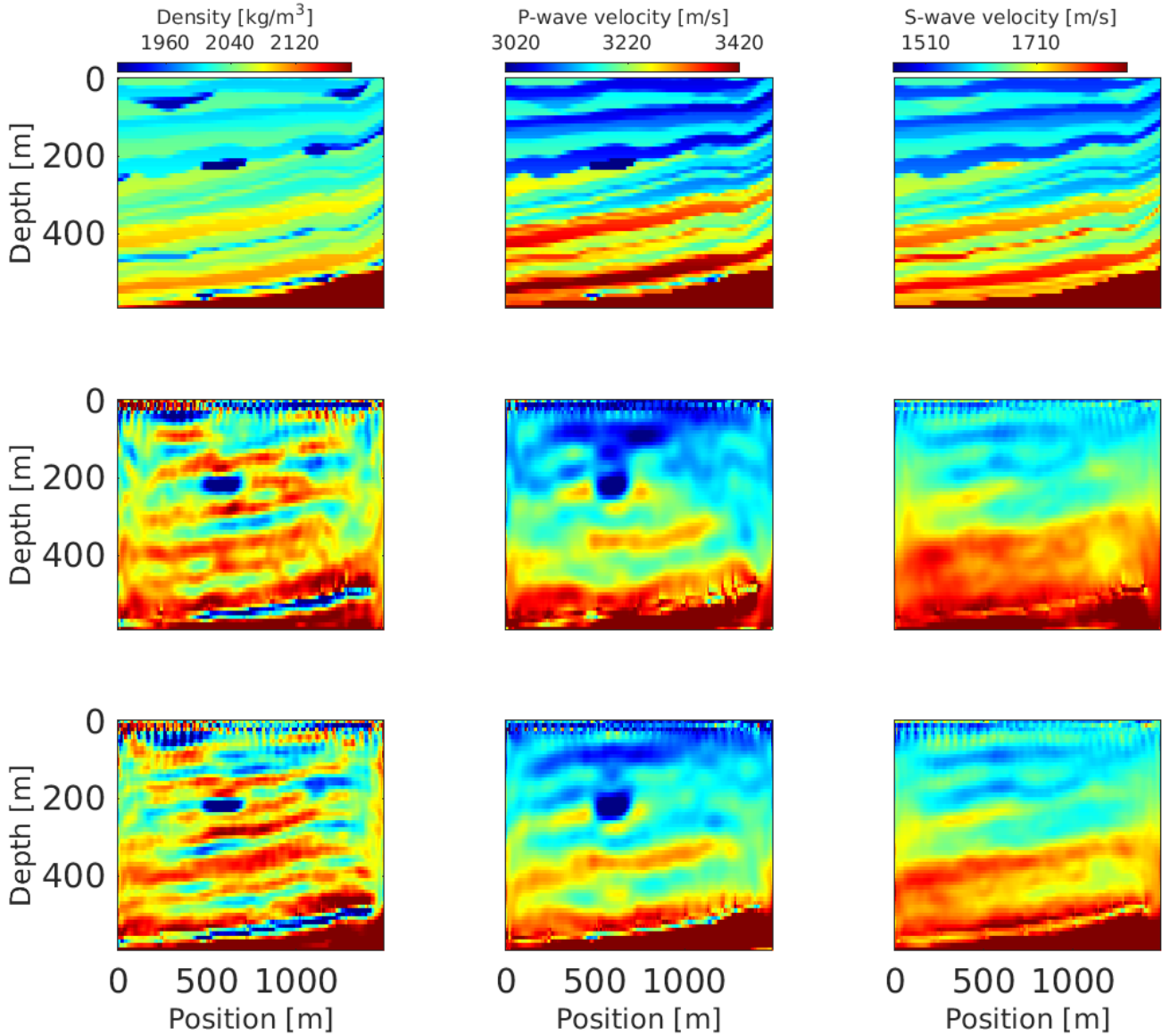
Zero GL vs long GL comparison to full elastic geophone results

$$\epsilon = \frac{\|m_k - m_t\|^2}{\|m_i - m_t\|^2}$$



Zero GL vs long GL Marmousi2





True Model

Buried DAS Long GL

Buried DAS Zero GL

Conclusions + Future Work

- Reduction in gauge lengths bring DAS closer to a true 6C sensor.
- How low do gauge lengths need to come for DAS FWI to approach geophone FWI?
- How many points per period is optimal for DAS FWI?
- Can short gauge lengths expand the applications of DAS for FWI?
- Are certain fiber geometries best for short GL?

Acknowledgements

- CREWES Industrial Sponsors
- NSERC (CRDPJ 461179-13)
- CREWES Staff and Students