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

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CREWES Annual Sponsors Meeting

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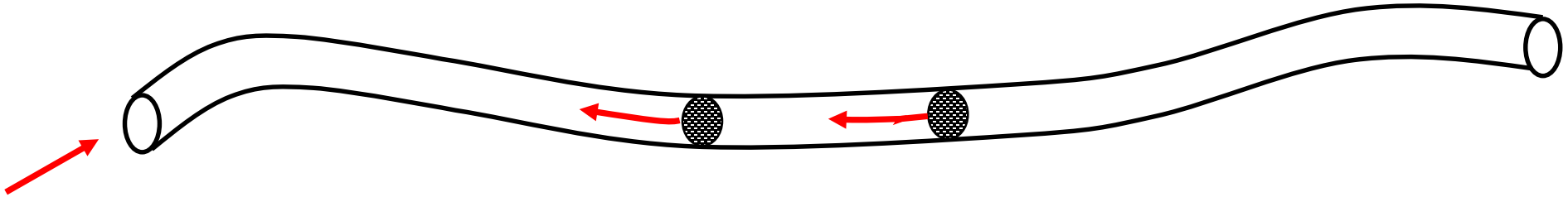
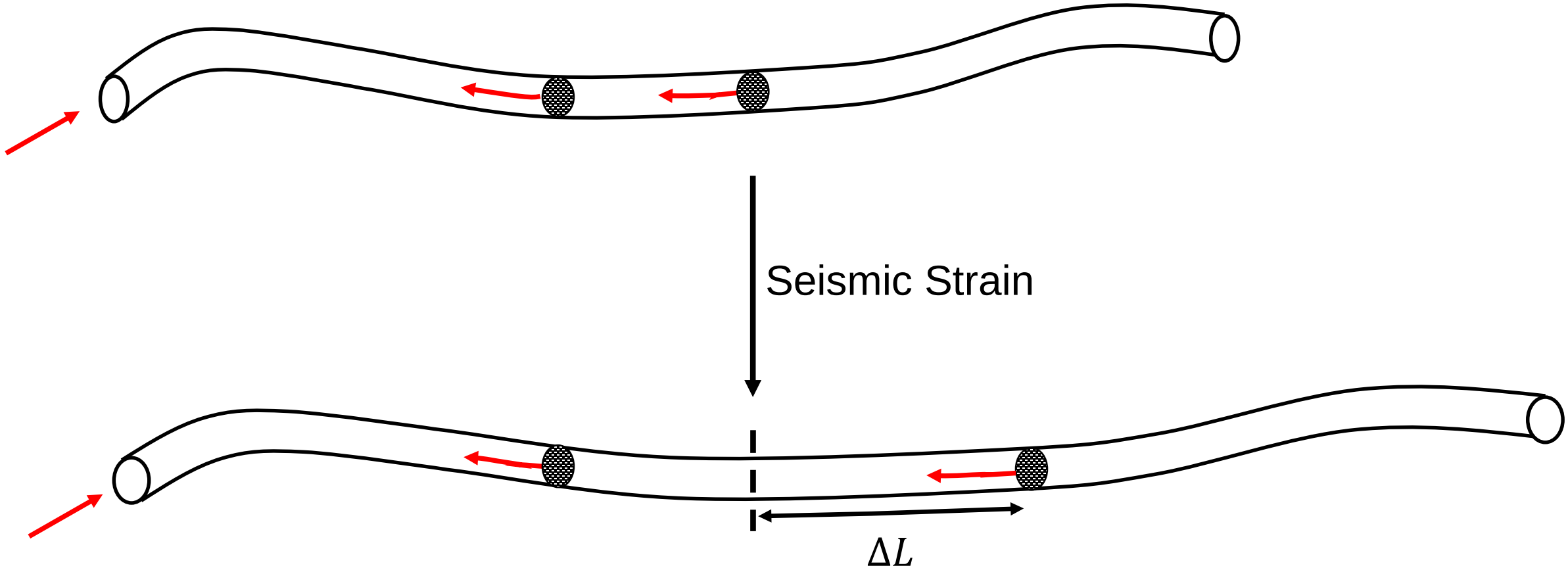
Department of Geoscience

Distributed Acoustic Sensing



- Interrogator emits laser pulse into fiber.
- Light backscatters off impurities in the fiber.
- Interrogator unit monitors the interference pattern of backscattered light.

Distributed Acoustic Sensing



Effect of gauge length on fiber sensitivity

$$d(s) \equiv \epsilon_{tt}(s) = a \cdot \epsilon_{xx} + b \cdot \epsilon_{xz} + c \cdot \epsilon_{zz}$$

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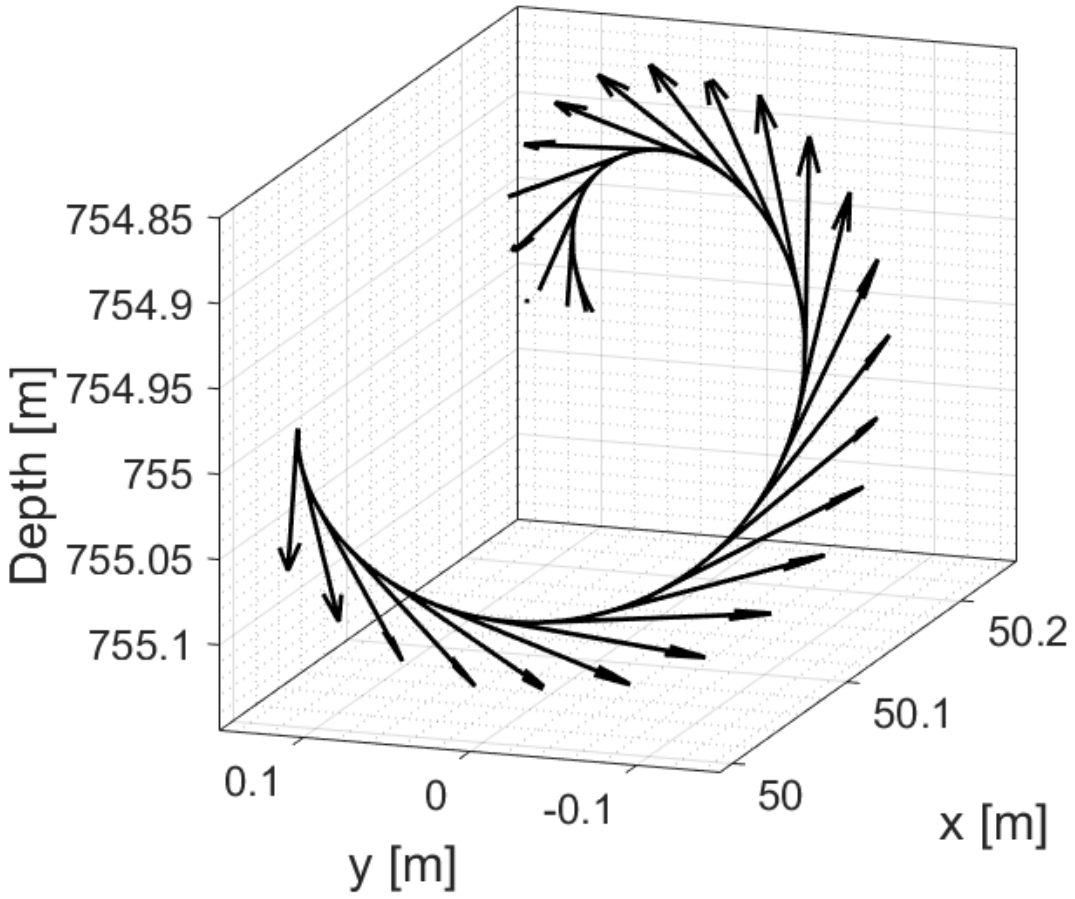

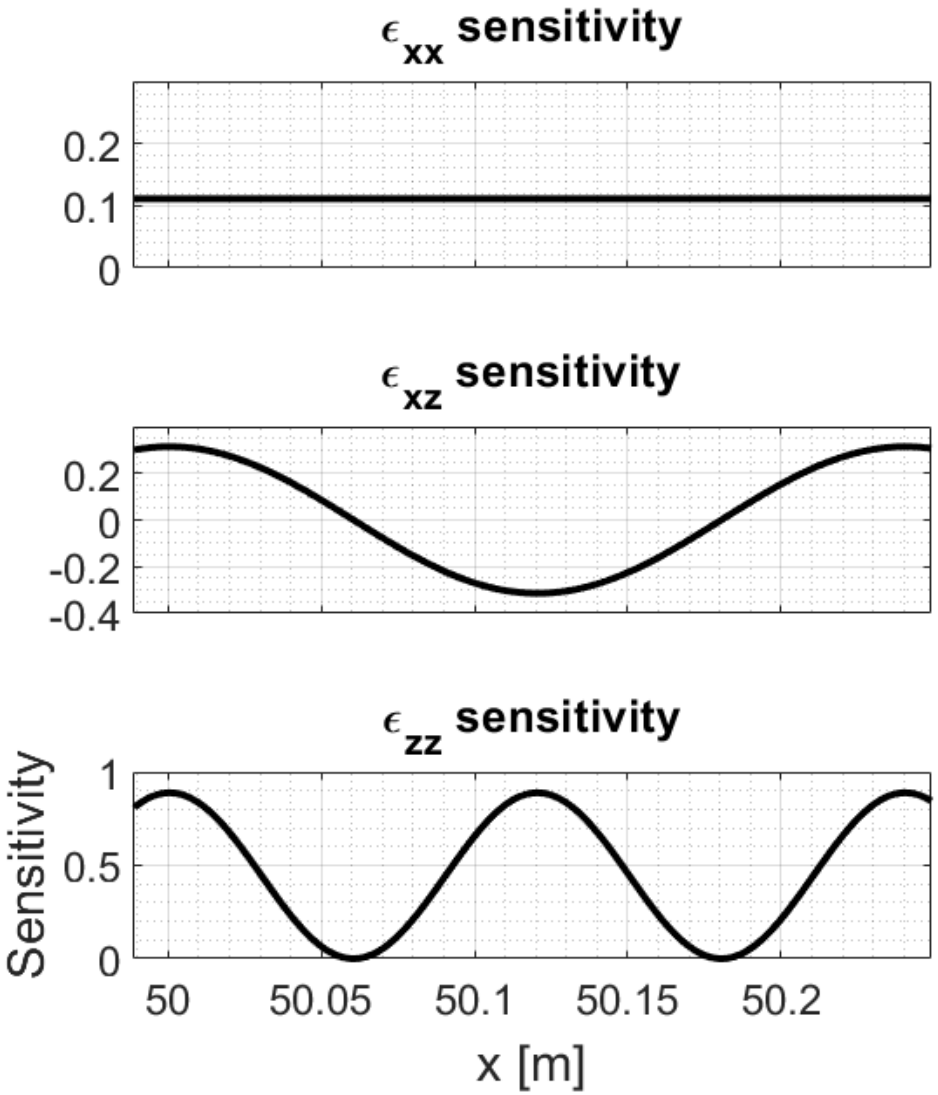

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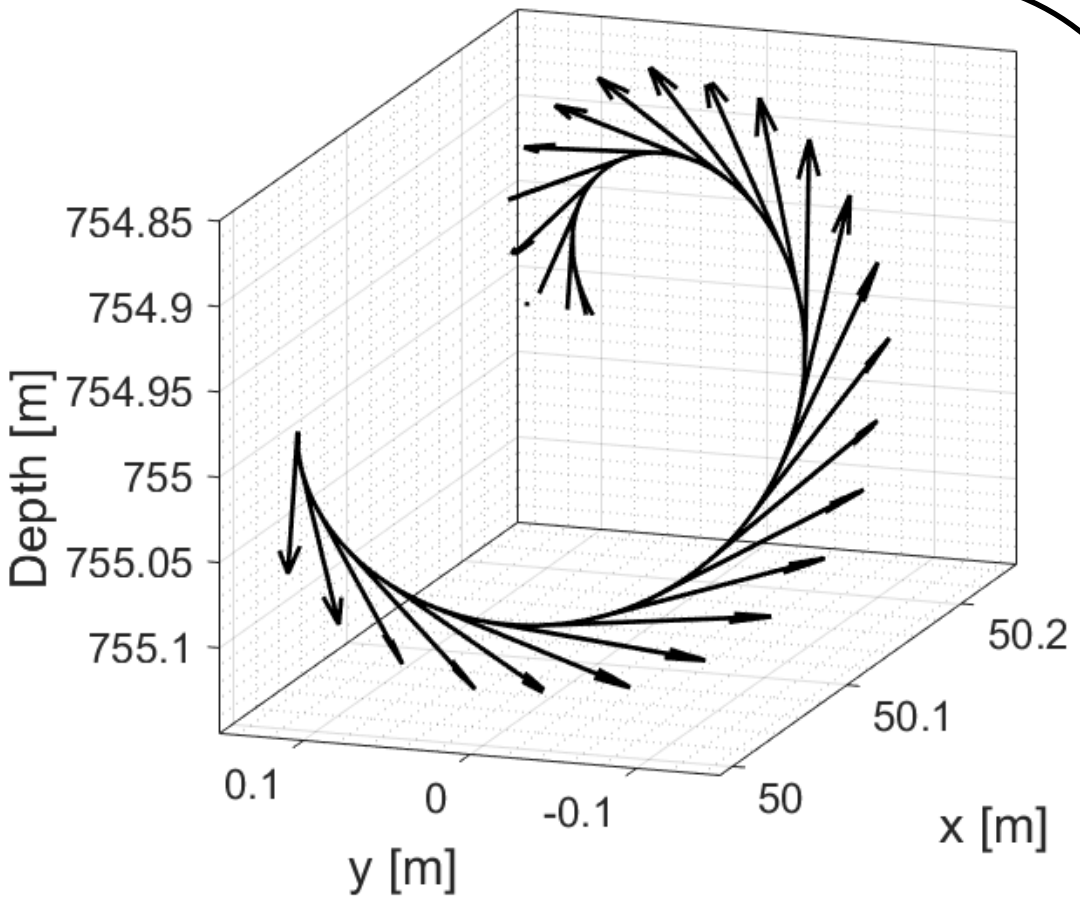
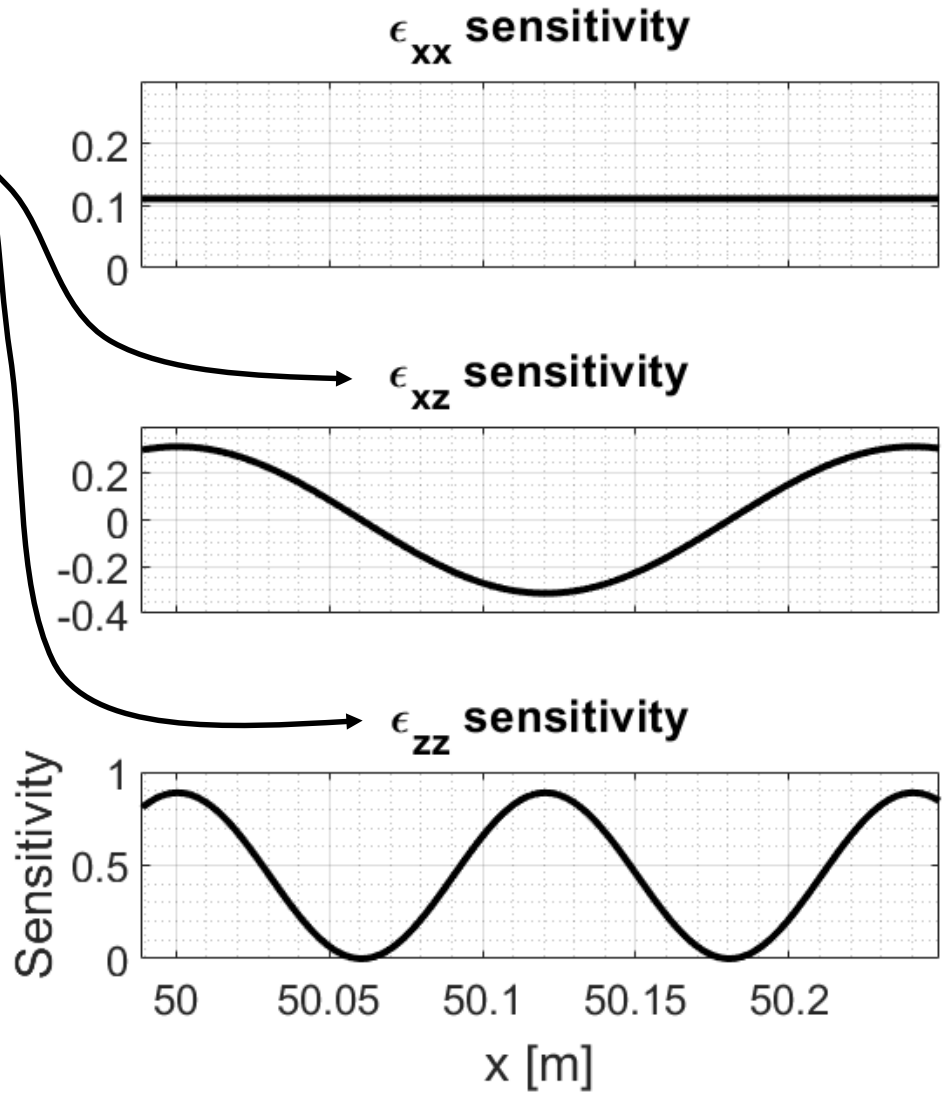
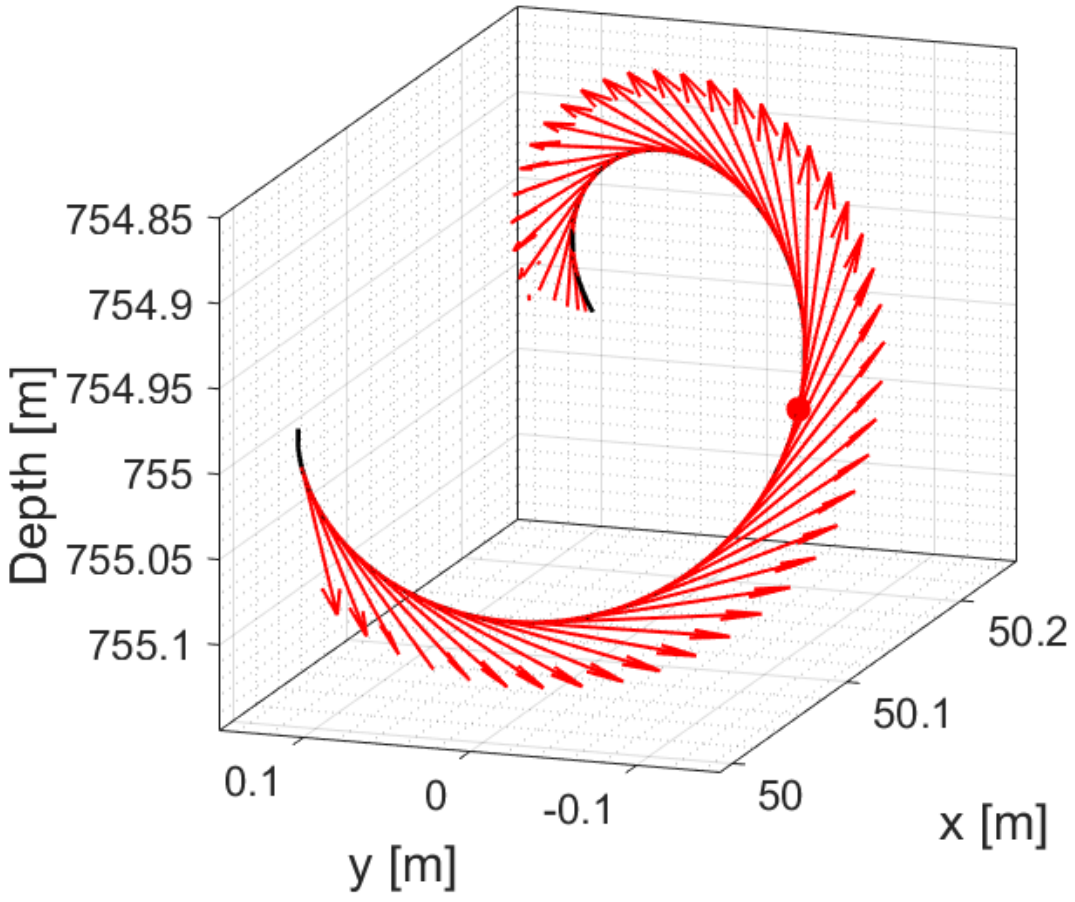
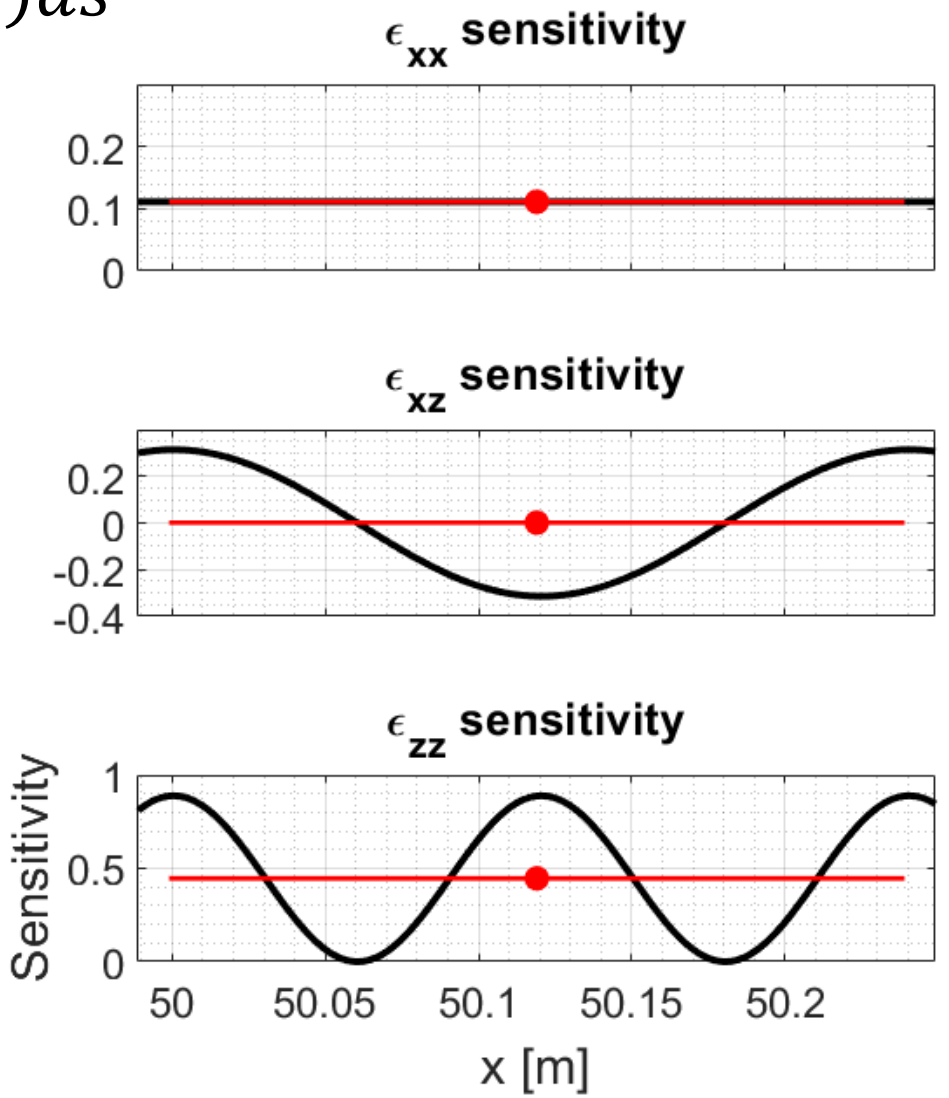




Effect of gauge length on fiber sensitivity

$$d(s) = \frac{1}{L}\int_{-L/2}^{L/2} (a \cdot \epsilon_{xx} + b \cdot \epsilon_{xz} + c \cdot \epsilon_{zz}) ds$$





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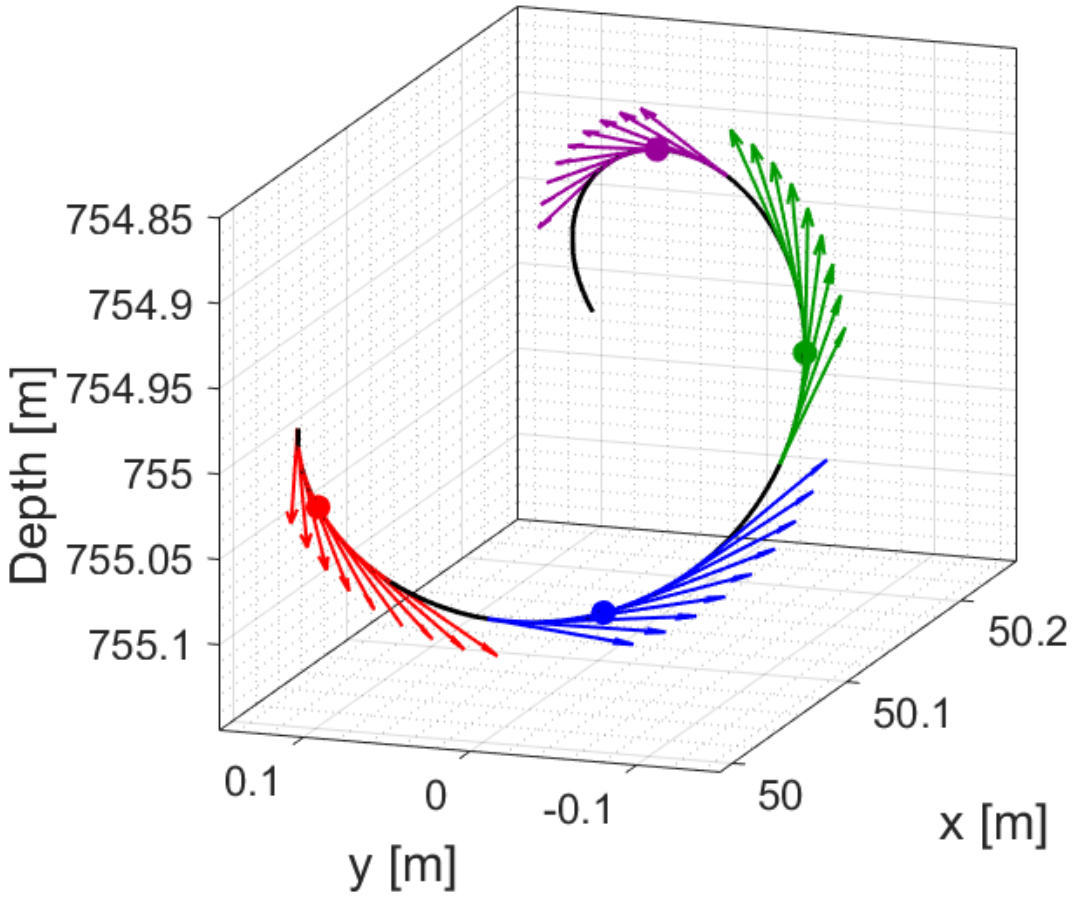

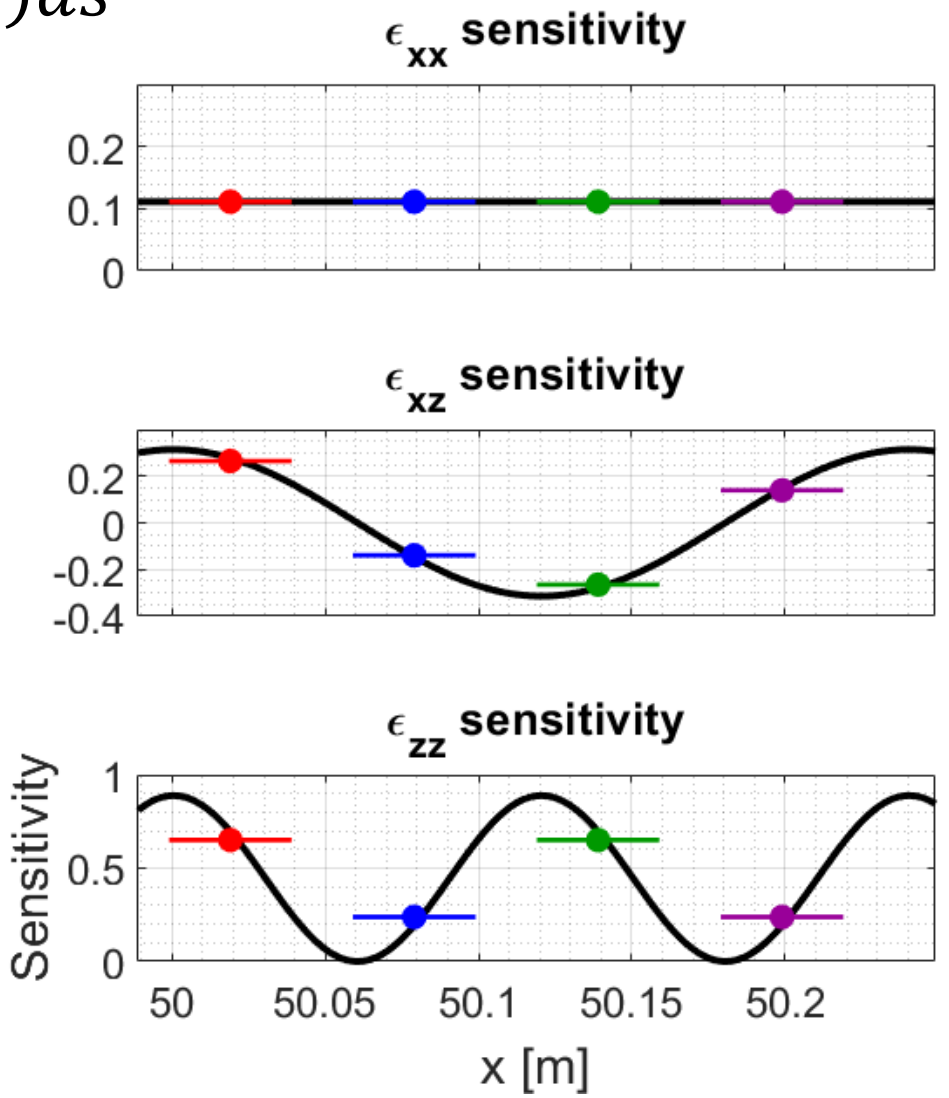

Full waveform inversion

Receiver matrix

Observed data

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

Modeled wavefield

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

Forward wavefield propagation

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

Reverse wavefield propagation

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

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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.

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

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

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

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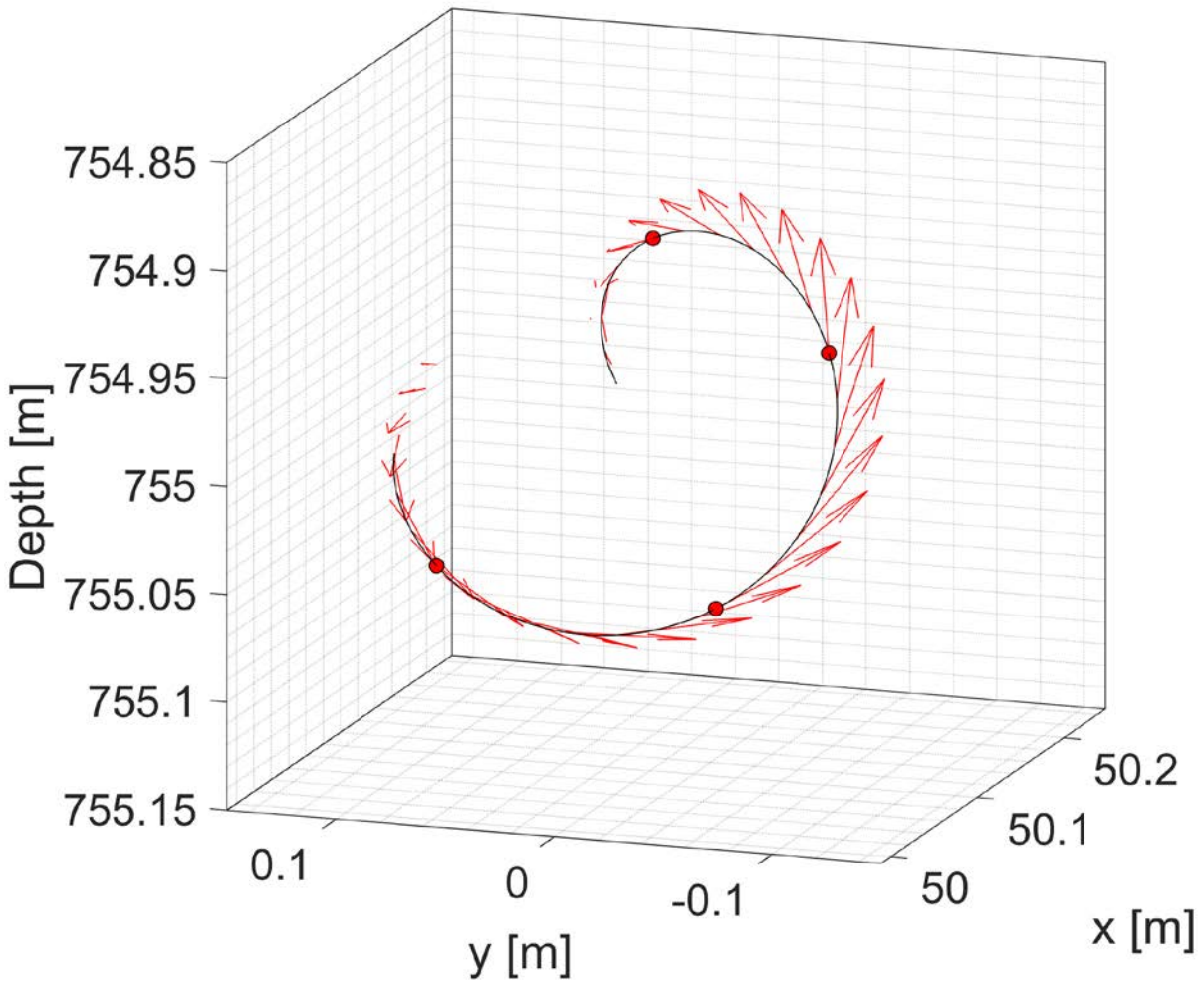
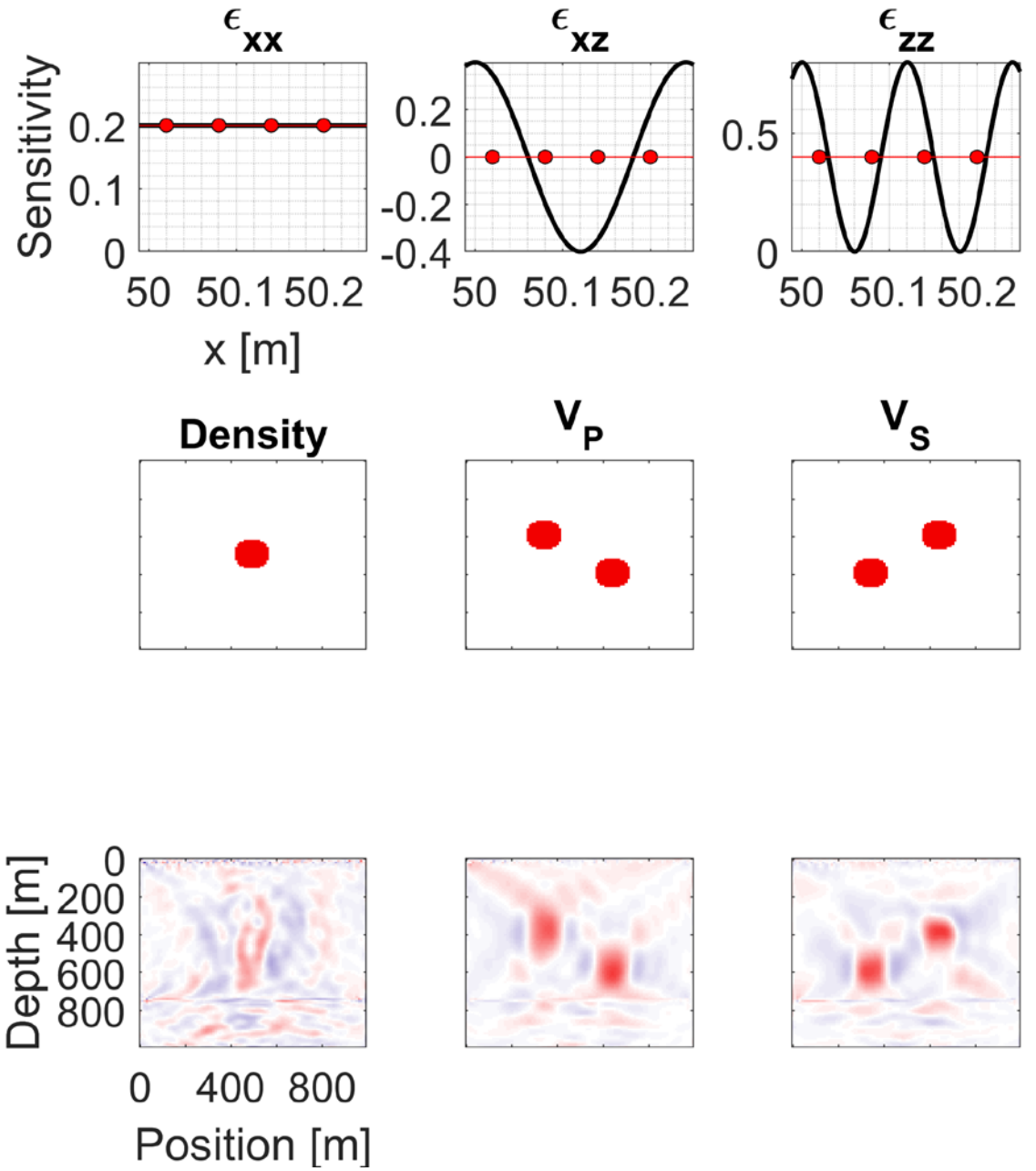
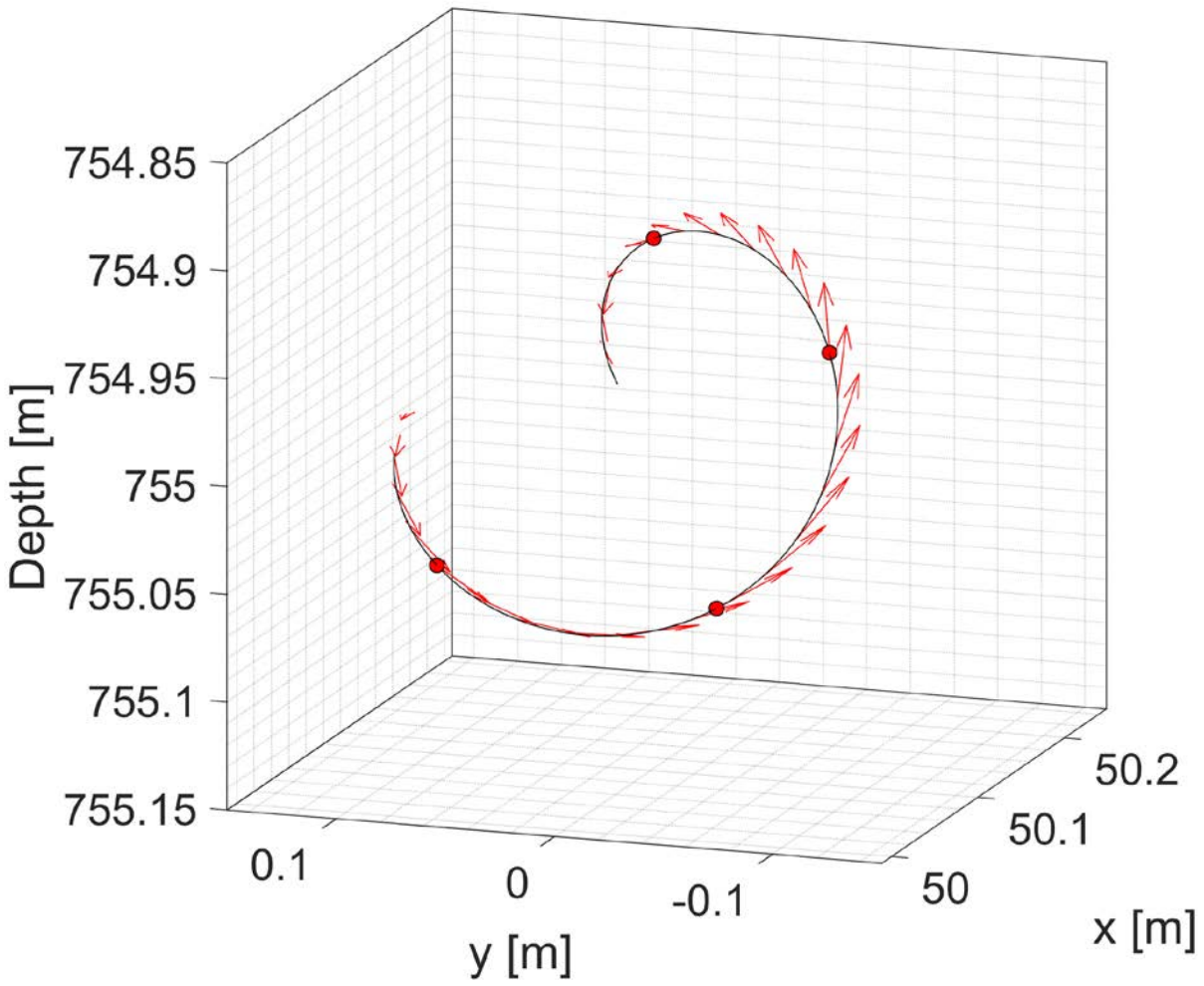
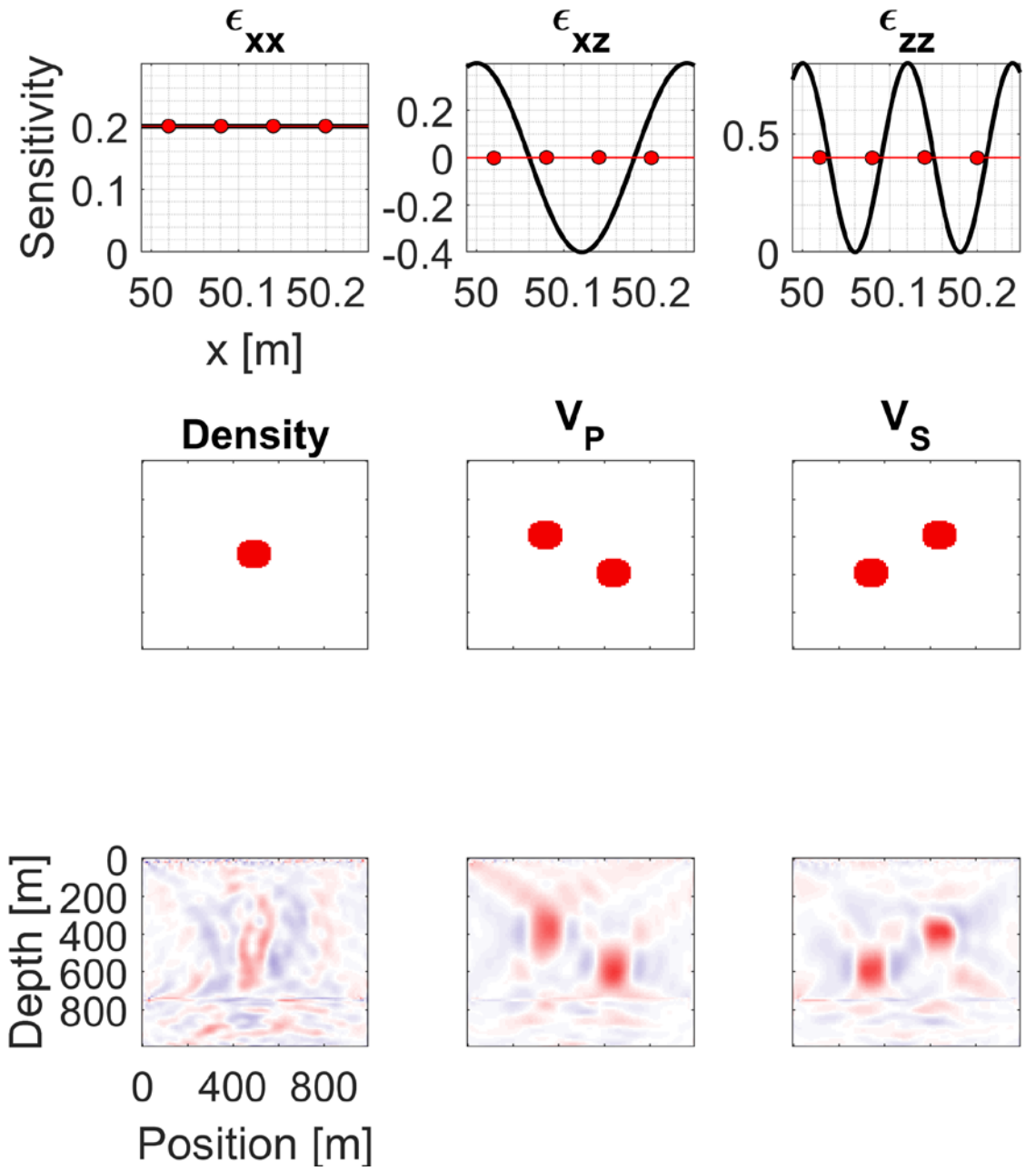
Inversion with gauge length >> fiber period



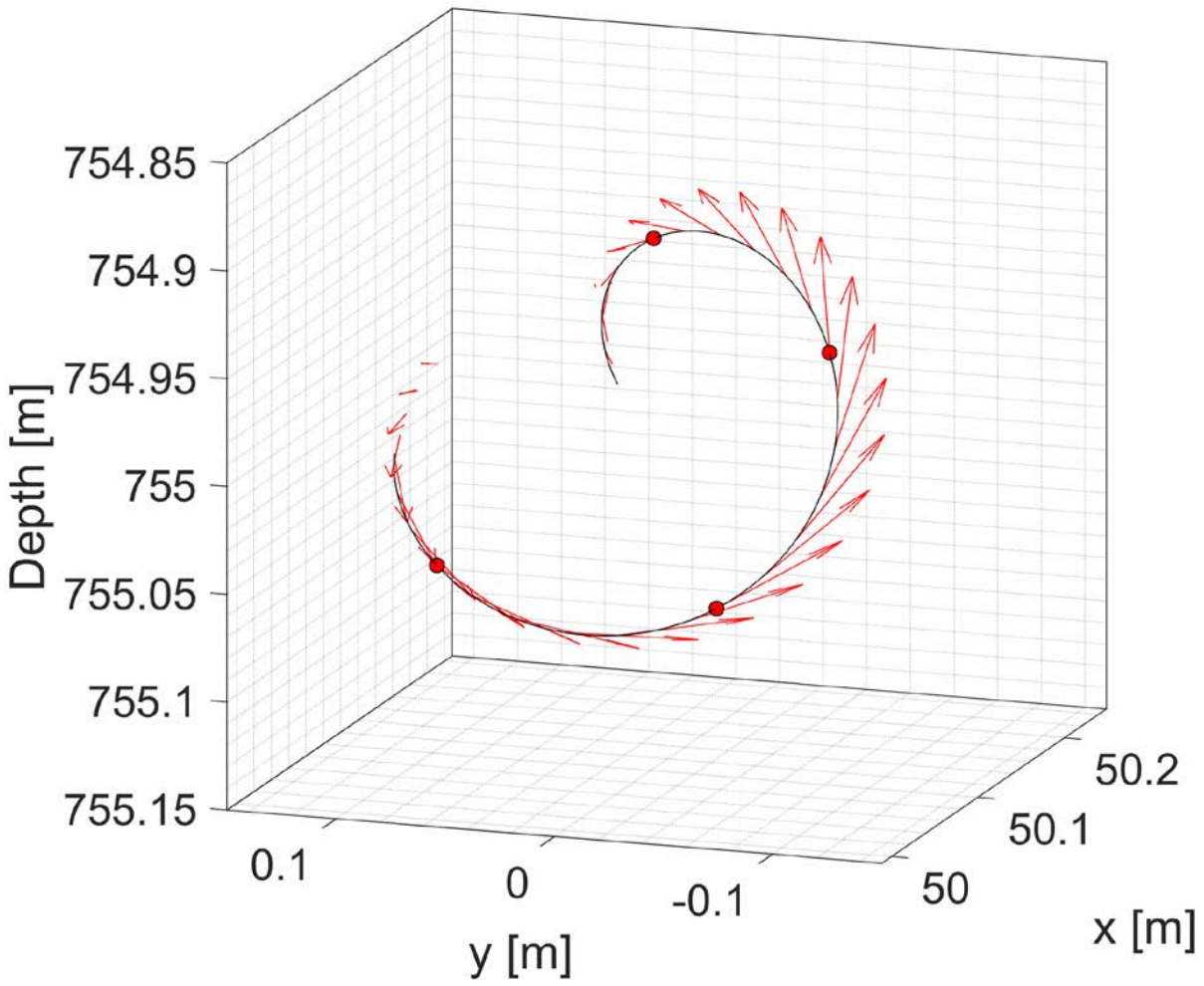


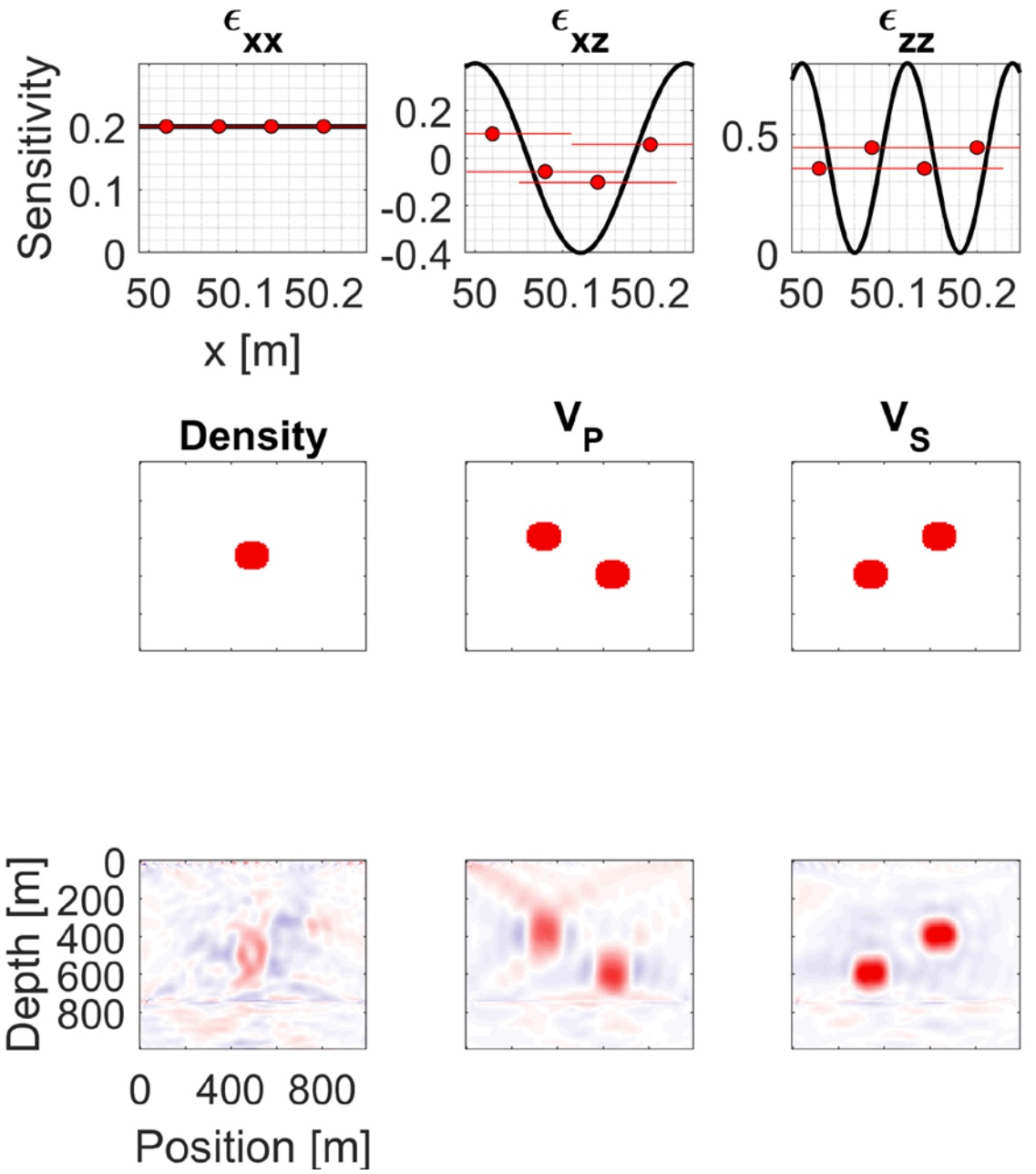
Inversion with gauge length = fiber period



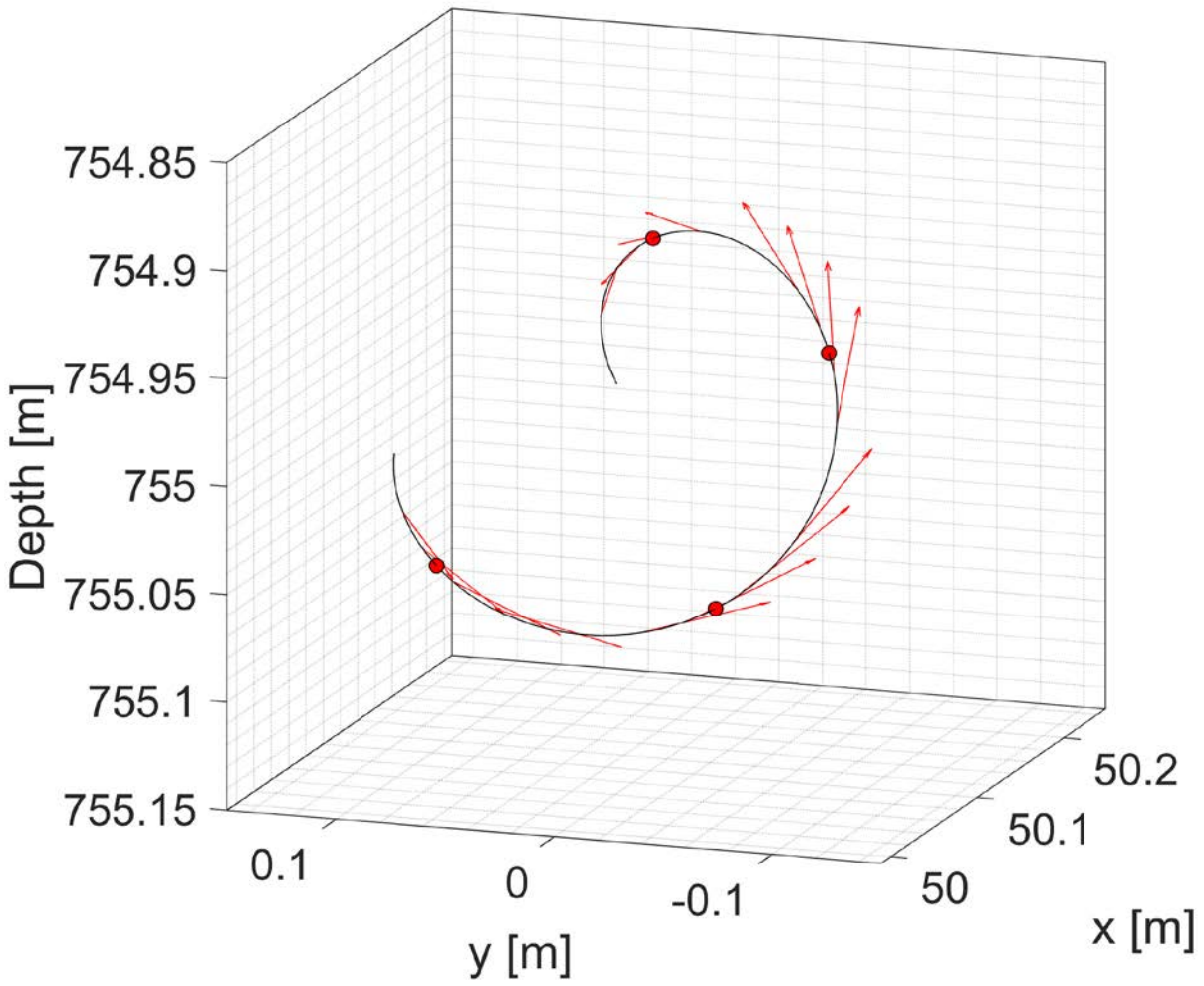


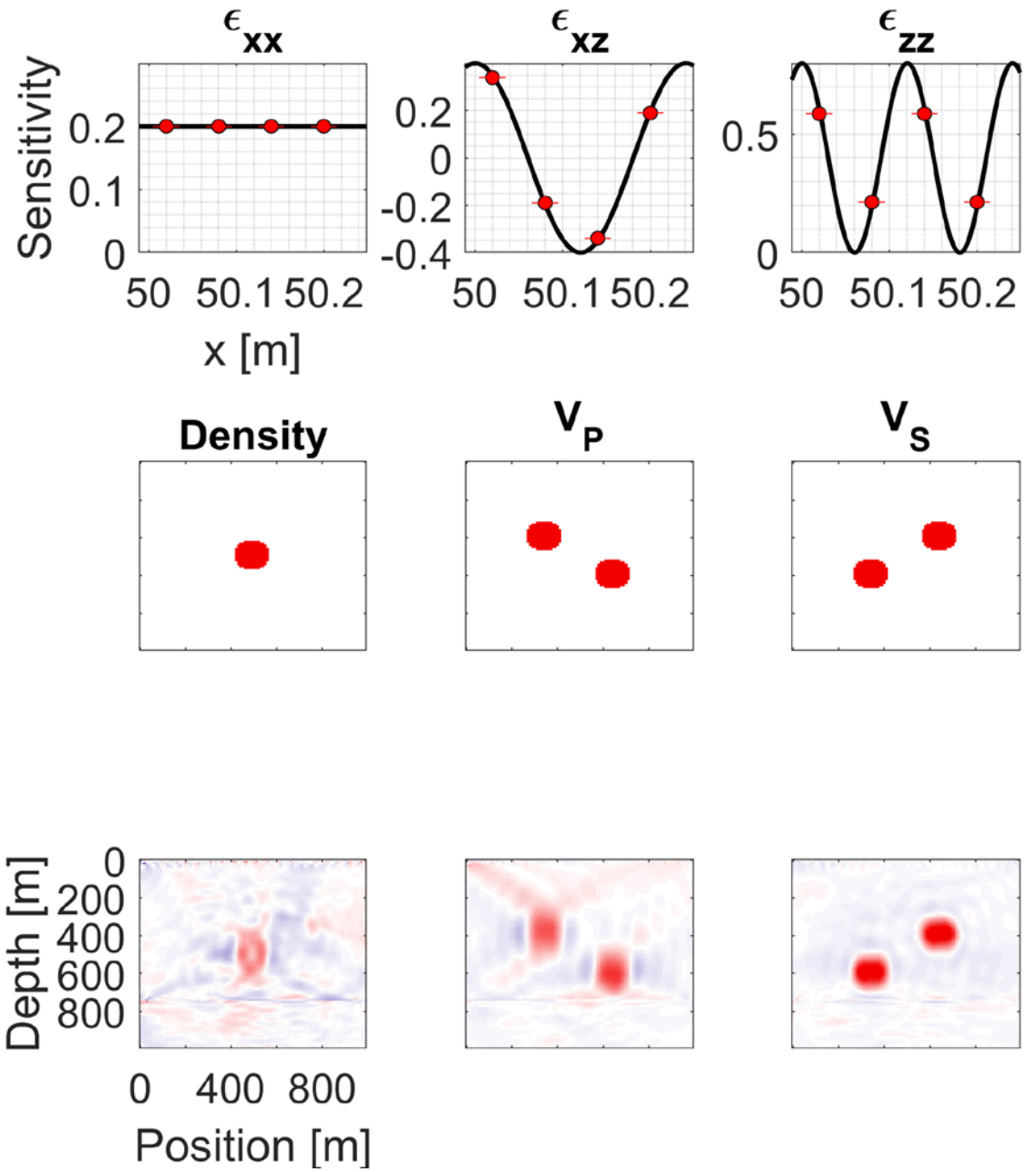
Inversion with gauge length < fiber period



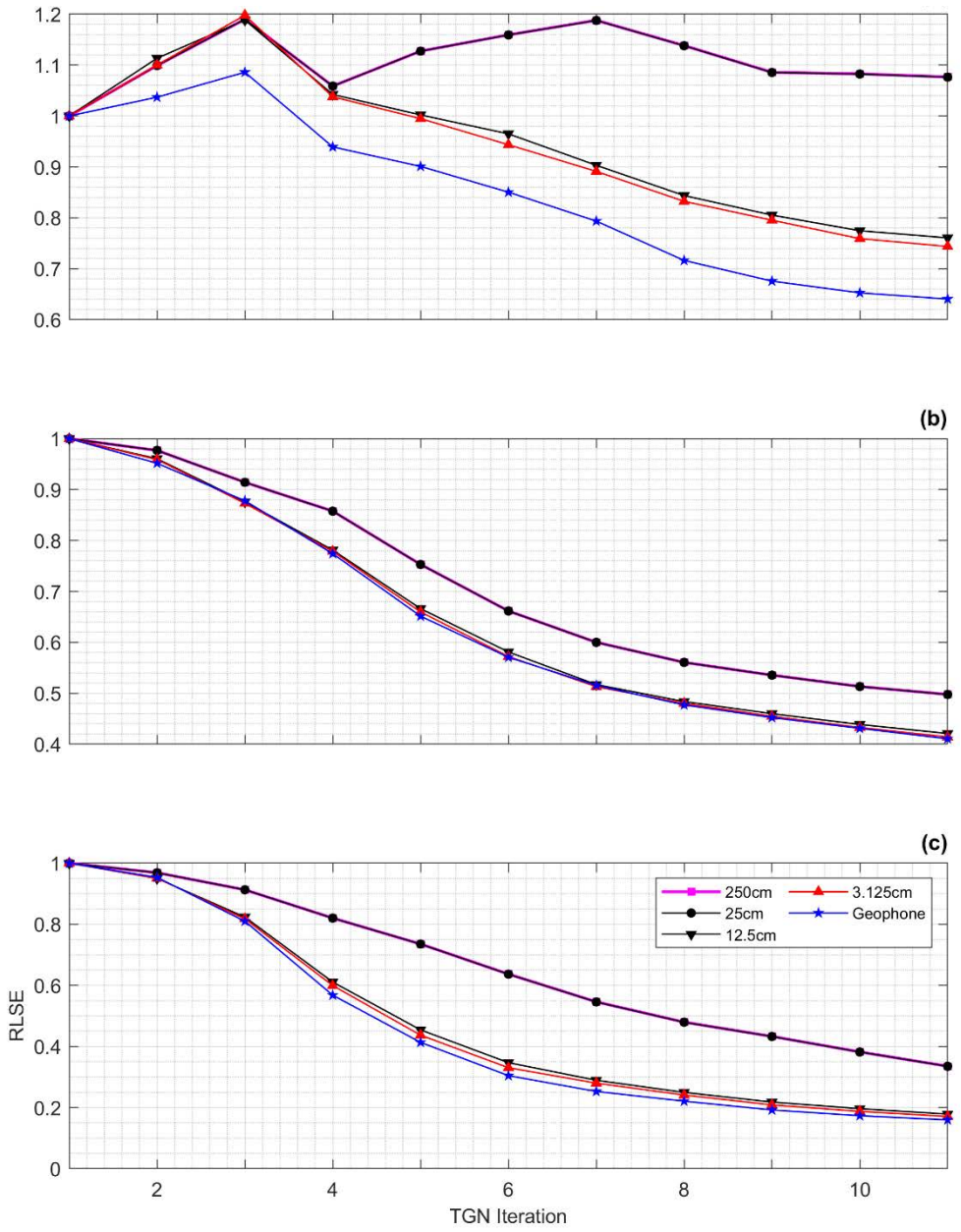


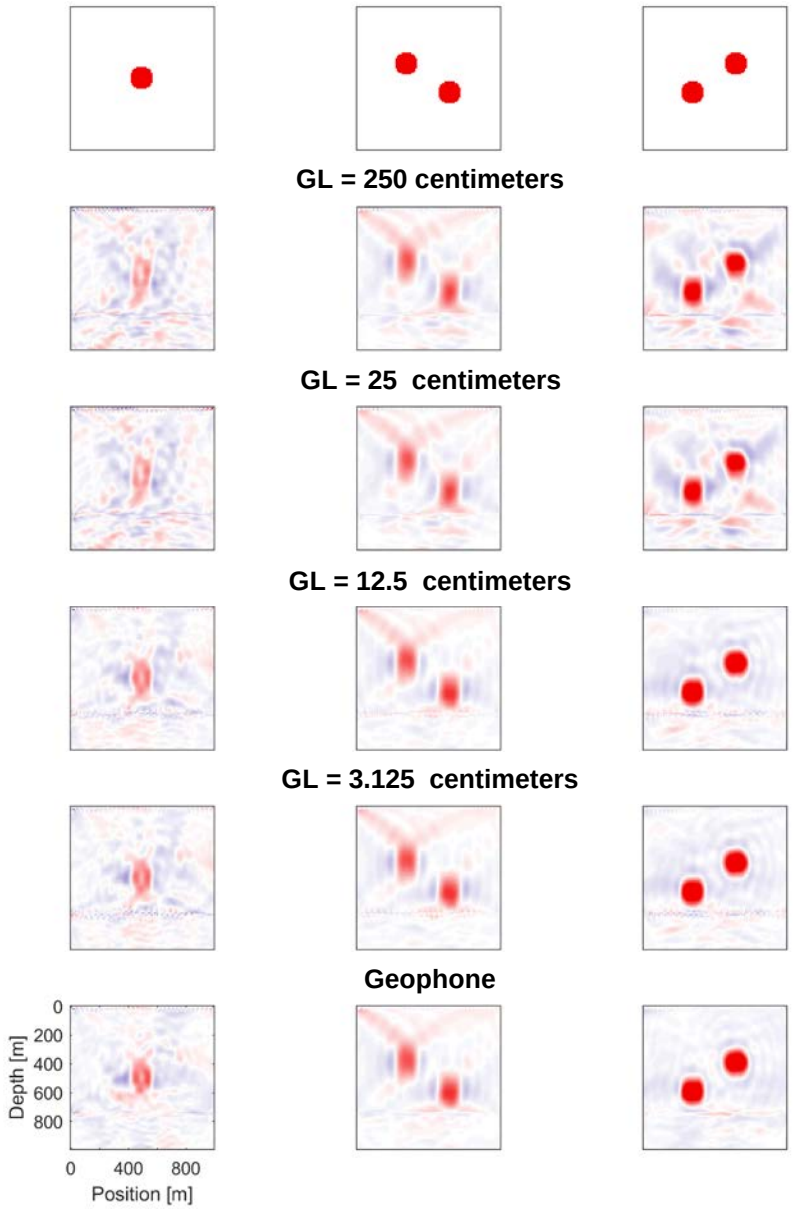
Inversion with gauge length << fiber period





Inversion with gauge length << fiber period





Conclusions

- DAS data can be readily incorporated into conventional FWI algorithms.
- Gauge lengths, especially relative to fiber geometry, play a crucial role in FWI parameter resolution.
- Technological advances have the potential to move DAS fibers towards true point sensors.

Acknowledgements

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- CREWES Staff and Students