CREWES

www.crewes.org

# Elastic full waveform inversion of DAS strain data


Matt Eaid*, Scott Keating, and Kris Innanen

mveaid@ucalgary.ca



## Abstract

Distributed acoustic sensing (DAS) uses optical fibres to provide measurements of seismic strain. A lingering question is how to best utilize the data provided by DAS to estimate subsurface properties. Elastic FWI is a powerful tool for parameter estimation but is conventionally formatted for geophone data. Here we present a reformulation of the conventional FWI objective function and gradient that allows for the inclusion of DAS strain data.


## Theory

The response of DAS fibre to a 2D strain field can be expressed as,

$$\epsilon_{tt} = (\hat{\mathbf{t}} \cdot \hat{\mathbf{1}})^2 \epsilon_{xx} + 2(\hat{\mathbf{t}} \cdot \hat{\mathbf{1}})(\hat{\mathbf{t}} \cdot \hat{\mathbf{3}})\epsilon_{xz} + (\hat{\mathbf{t}} \cdot \hat{\mathbf{3}})^2 \epsilon_{zz}. \quad (1)$$

where $\hat{\mathbf{t}}$ is the fibre tangent. Our goal is to include data of this type in FWI.

The FWI objective function seeks to find a minimum of the $L_2$ norm of the difference between modeled data $\mathbf{u}$ and observed data $\mathbf{d}$,

$$\min_{\mathbf{m}} \frac{1}{2} ||\mathbf{Ru} - \mathbf{d}||_2^2 \qquad \text{subject to} \qquad \mathbf{S}\mathbf{u} = \mathbf{f}. \quad (2)$$

The gradient of equation (2) is given by,

$$\frac{\partial \phi}{\partial \mathbf{m}} = \left\langle \frac{\partial \mathrm{S}}{\partial \mathbf{m}} \mathbf{u}, \lambda \right\rangle \quad \text{with} \quad \mathrm{S}^{\dagger}\lambda = \mathbf{R}^{\mathrm{T}}(\mathbf{Ru} - \mathbf{d}). \quad (3)$$

where $\mathbf{R}$ is a matrix that handles receiver sampling. In our method this matrix is reformulated to handle properties of DAS receivers, computing the data in equation (1), allowing for the simultaneous inversion of geophone and DAS data.

## Results

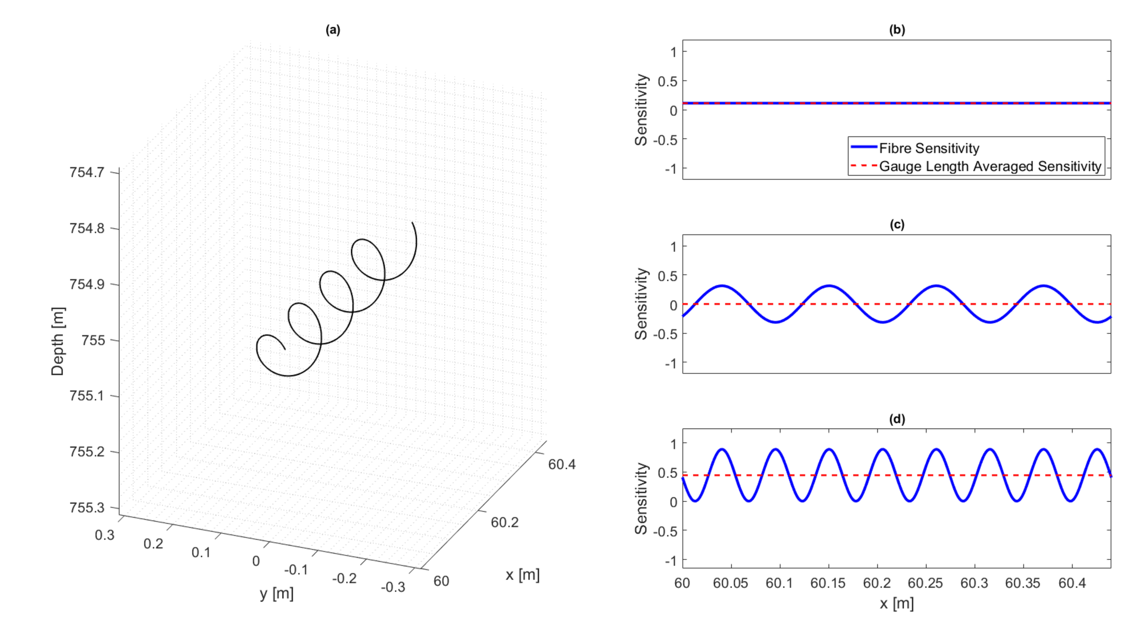


Figure: Helical fibre (a), and its sensitivty to $\epsilon_{xx}$ (b), $\epsilon_{xz}$ (c), and $\epsilon_{zz}$ (d).

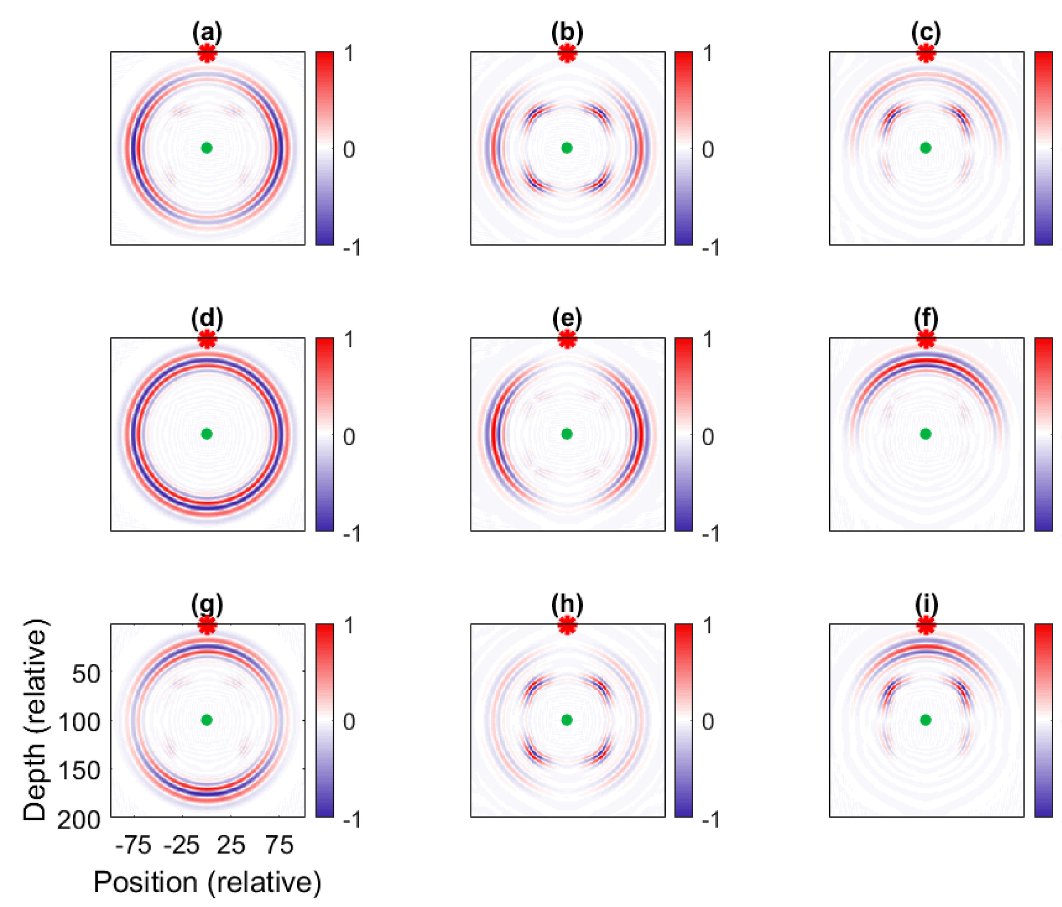


Figure: Fibre scattering radiation patterns for $v_p$ (column 1), $v_s$ (column 2), and $\rho$ (column 3) for 70.5 degree (a)-(c), 35.2 degree (d)-(f), and 10 degree (g)-(i) helical fibres.

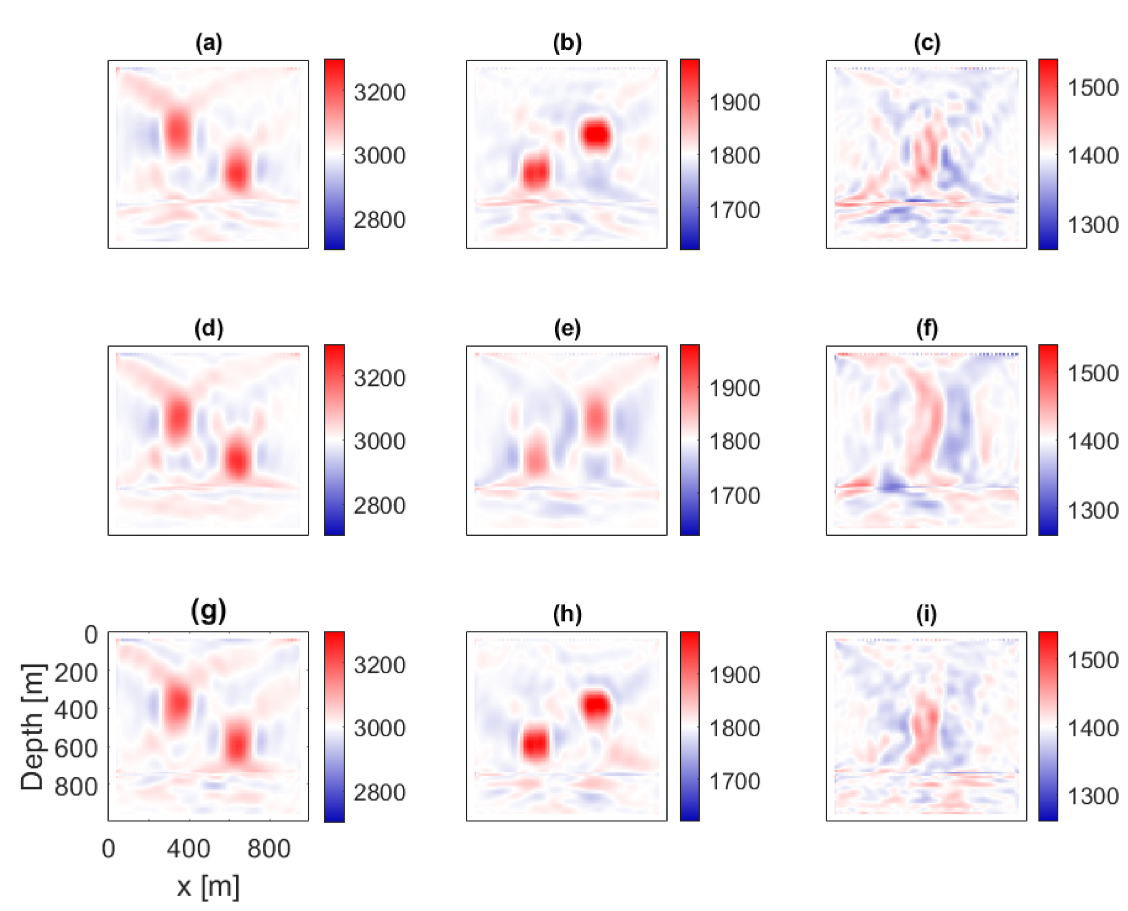


Figure: Inversion results from a toy model for $v_p$ (column 1), $v_s$ (column 2), and $\rho$ (column 3) for 70.5 degree (a)-(c), 35.2 degree (d)-(f), and 10 degree (g)-(i) helical fibres.

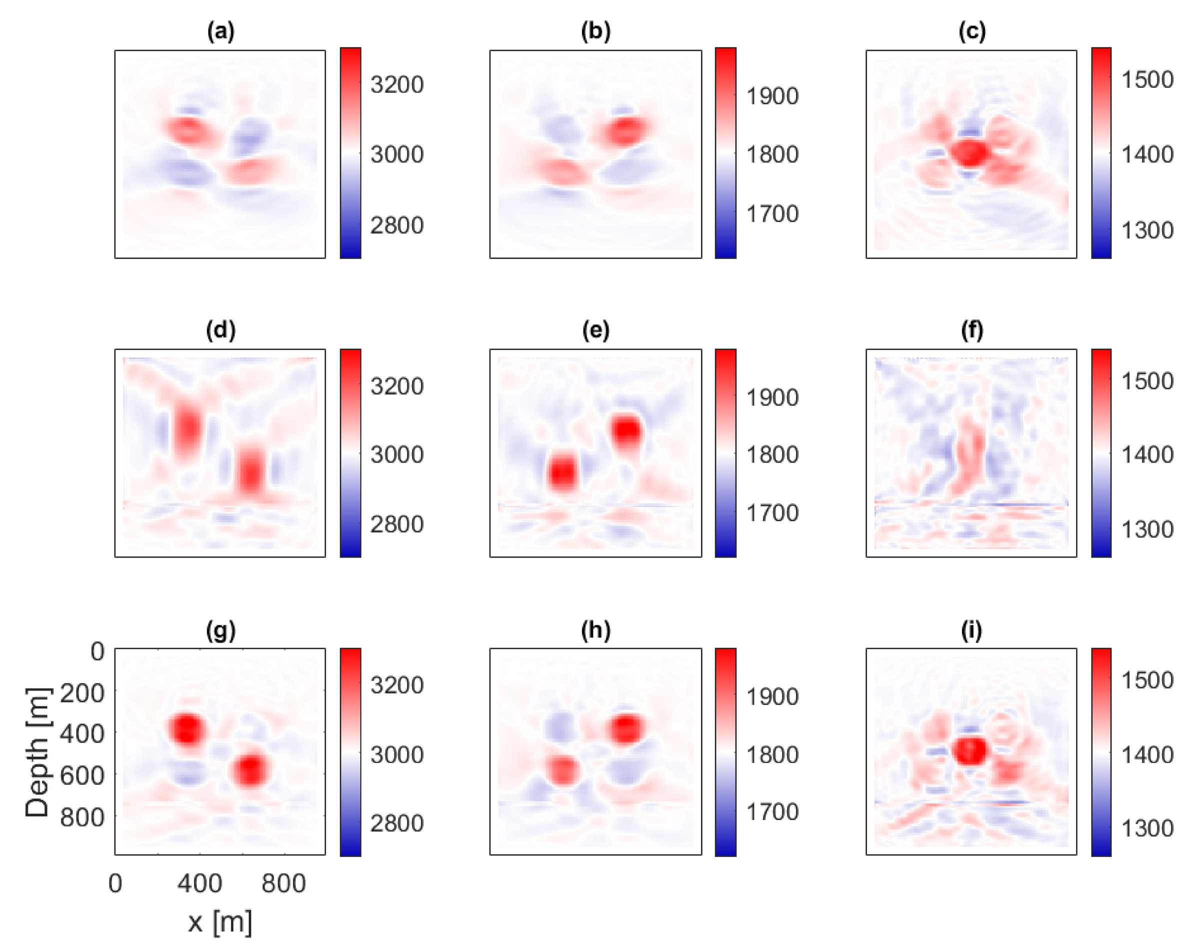


Figure: Inversion results from a toy model for $v_p$ (column 1), $v_s$ (column 2), and $\rho$ (column 3) for reflection geophone data (a)-(c), strain data from a 10 degree helical fibre in a horizontal well (d)-(f), simultaneous inversion of reflection geophone data and strain data from a 10 degree helical fibre in a horizontal well (g)-(i).

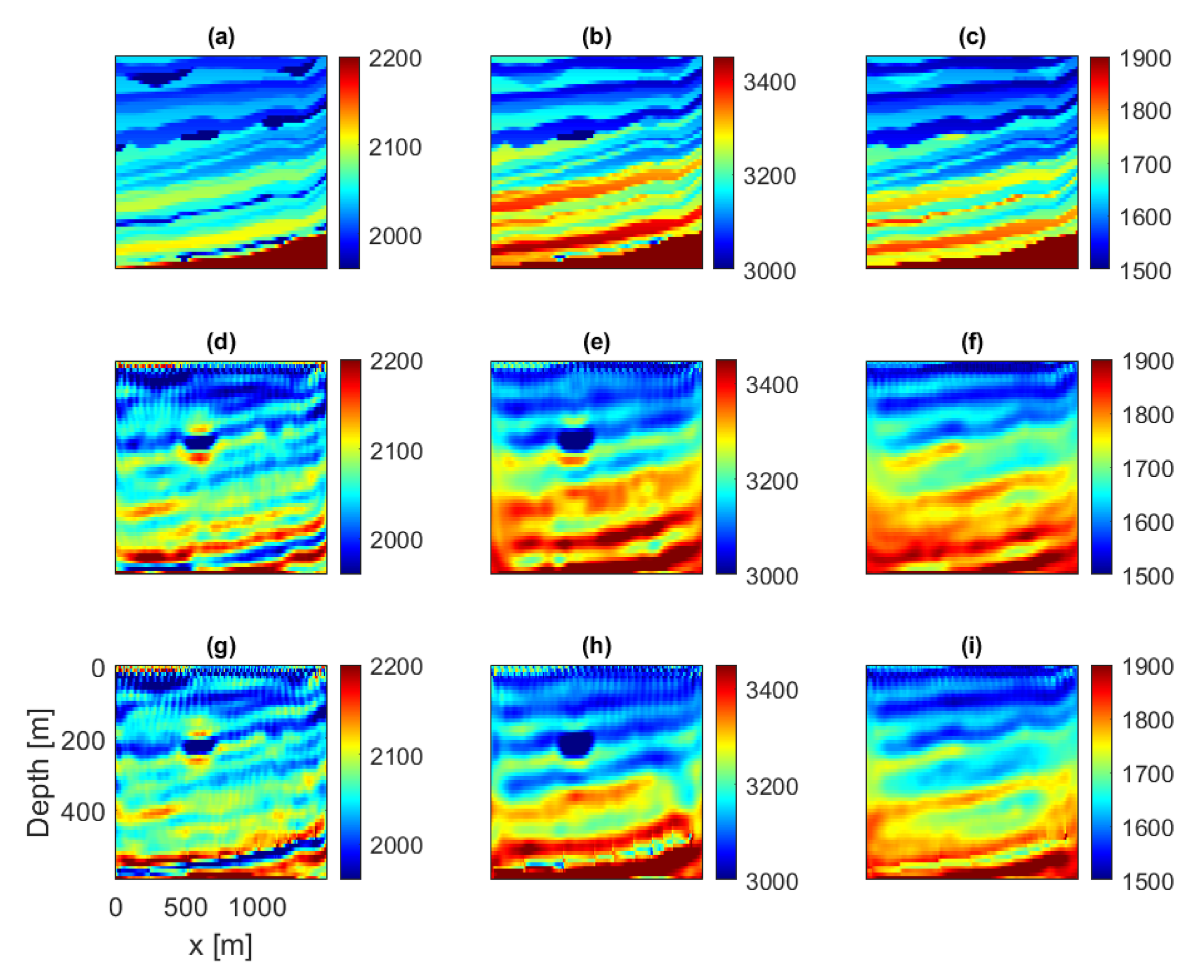


Figure: True models from a portion of the Marmousi2 model for $\rho$, $v_p$ and $v_s$ in (a)-(c), inversion results using only geophones $\rho$, $v_p$ and $v_s$ in (d)-(f), and inversion results using a fibre in a horizontal well and surface geophones for $\rho$, $v_p$ and $v_s$ in (g)-(i).

## Summary

- We develop a method for the inversion of DAS data, that can also incorpate geophone data for a simultaneous inversion of both datasets.
- Investigated the role of the wrapping angle of helical fibres on inversion results.
- Simultaneous inversion of geophone and DAS data supplies improved parameter estimates over using either dataset alone.


NSERC CRSNG

UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience