Elastic microseismic full waveform inversion: synthetic and real data

Nadine Igonin* and Kris Innanen
naigonin@ucalgary.ca

Summary

We propose a modified FWI scheme that iteratively solves for both source distribution and velocity model. We show numeric examples in a 2D elastic framework. Examples of the source-location gradient are shown in a variety of scenarios in order to begin to understand its behaviour. We see that low frequencies are best for the source-term gradient to produce a correct update. This update has the form of a dipole, with a negative lobe at the incorrect source location and a positive lobe in the direction of the correct source location. In the future, application to real data is proposed.

Background and Theory

Microseismic events are small-magnitude earthquakes that can be induced by a variety of processes, such as hydraulic fracturing. One of the goals of microseismic processing is to obtain accurate locations for the events.

→ This requires an accurate velocity model

We propose a multiparameter FWI scheme that combines the conventional FWI framework to invert for velocity with the microseismic source location problem. We call this ***microseismic FWI***, or MFWI. We start with an objective function:

$$\phi = \sum_{r_g, r_s} \frac{1}{2} \int dt \left(d(\mathbf{r}_g, \mathbf{r}_s, t) - p(\mathbf{r}_g, \mathbf{r}_s, t | s_c, s_s) \right)^2$$

Modelled data; Source distribution; Observed data; Squared-slowness model; Source and receiver position

Then we define a Newton system:

$$\begin{bmatrix} \delta \mathbf{s}_c \\ \delta \mathbf{s}_s \end{bmatrix} = - \begin{bmatrix} \mathbf{H}_{cc} & \mathbf{H}_{cs} \\ \mathbf{H}_{sc} & \mathbf{H}_{ss} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{g}_c \\ \mathbf{g}_s \end{bmatrix}$$

Update to model space; Hessian; Gradients; Velocity model gradient; Source position gradient

where the source-term gradient is given by:

$$g_s(\mathbf{r}) = - \sum_{r_g, r_s} \int dt \, \delta p(\mathbf{r}_g, \mathbf{r}_s, t | \mathbf{s}_c, \mathbf{s}_s) g(\mathbf{r}_g, \mathbf{r}, t - t^* | \mathbf{s}_c, \mathbf{s}_s),$$

Source position gradient; Residual: difference between observed and modelled data; Event origin time; Wavefield

Results: Elastic Source-term Gradient

We focus on the source-term gradient and its behaviour. Legend:

- ✱ True source position
- ✱ Maximum of gradient (= next update starting position)
- ● Starting position

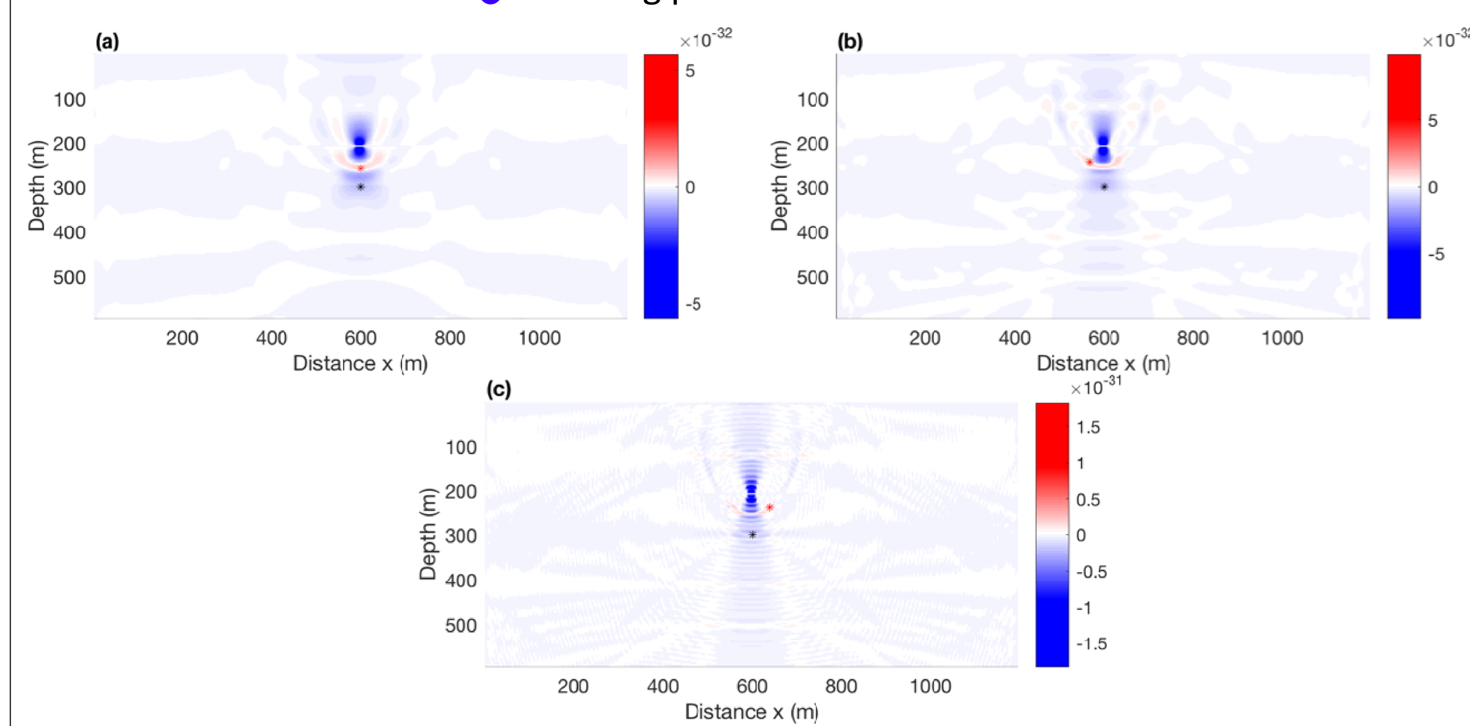

Figure 1: Source-term gradient as a function of frequency: (a) 30 Hz, (b) 60 Hz, (c) 120 Hz.

→ *Conclusion*: **lower** frequencies produce more stable results

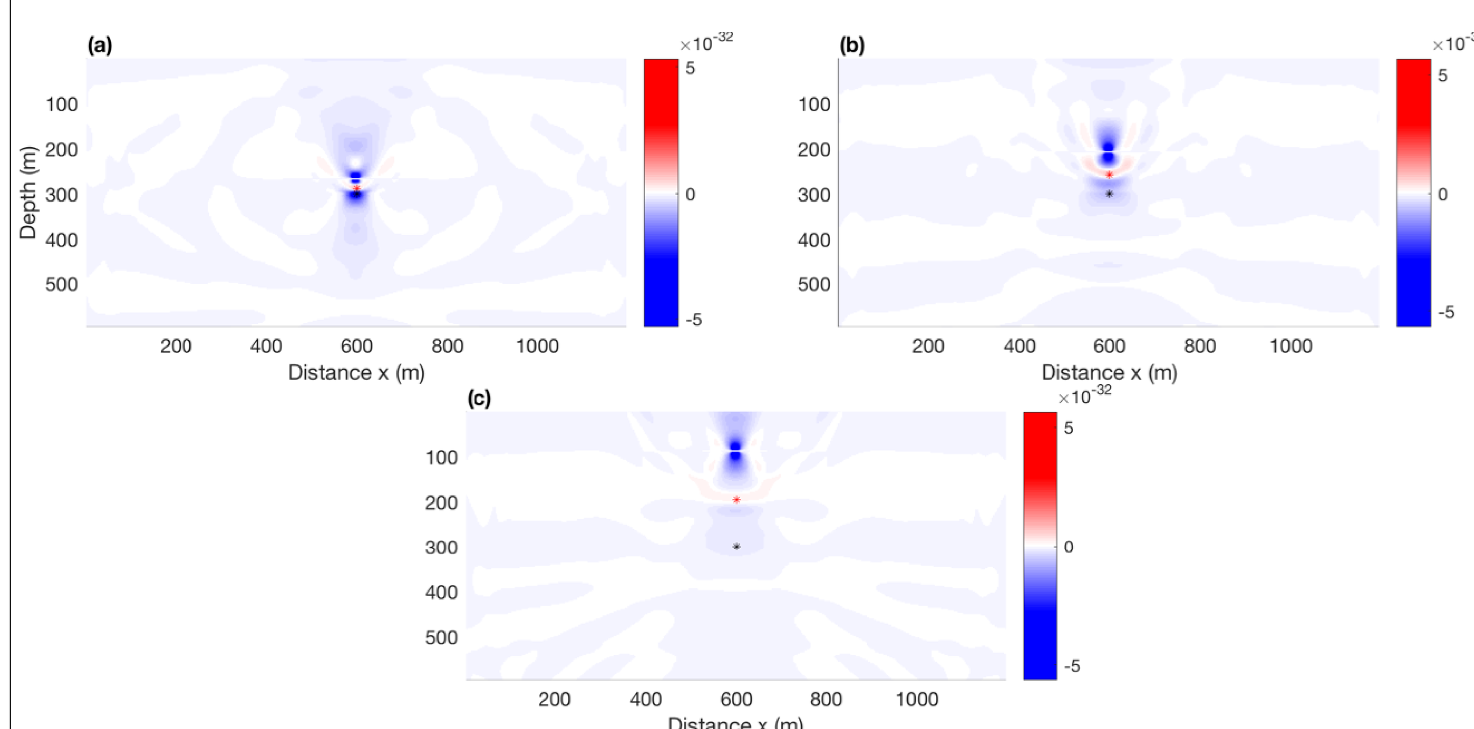

Figure 2: Source-term gradient as a function of separation distance: (a) 30 m, (b) 90 m, and (c) 210 m.

→ *Conclusion*: The gradient retains its shape at large separation distances.

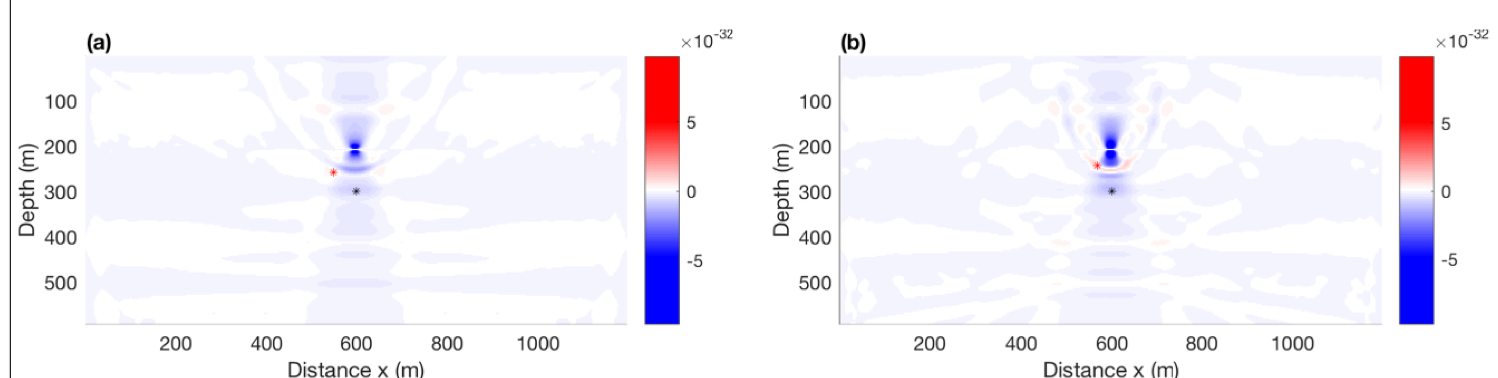

Figure 3: Source-term gradient as a function of moment tensor (MT): (a) explosive source; (b) double-couple source.

→ *Conclusion*: Although the MT changes the shape of the gradient slightly, this parameterization is mostly unaffected by the moment tensor.

Pros: Do not need to solve for the MT to locate events/update velocity.

Cons: May be missing valuable detail, and there is the risk of cross-talk due to not accounting for the MT.

Real Data

In the future, we would like to apply this method to a hydraulic fracturing dataset from the Horn River basin. The geometry, velocity model, and example event are shown in Figure 4. This dataset is ideal because the microseismic events occurred a few hundred meters away from the monitoring well.

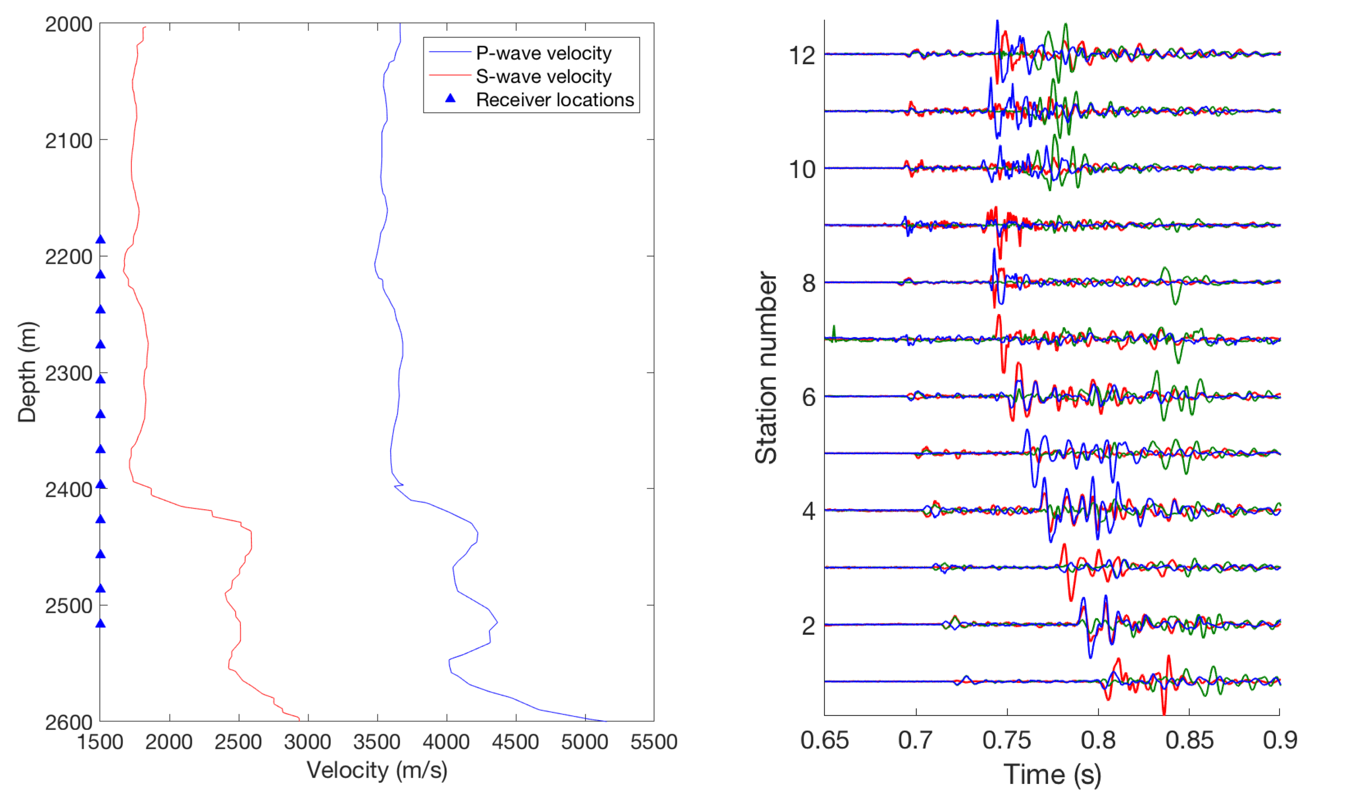

Figure 4: (a) Velocity model and receiver depths, (b) a M_W -1.3 event 346 m away from the receiver well.

The observed events are rich in high frequencies, so the events will either have to be filtered, or a modelling engine capable of accurately modelling high frequency waveforms will have to be used.

Discussion

Elastic multiparameter MFWI aims to solve for the source-term gradient and velocity gradient simultaneously.

In conclusion:

- The source-term gradient moves in the correct direction of the true source location.
- Source-term updates have the character of a **dipole**.
- Regularization and data preconditioning will be important for real data.

Acknowledgements

The authors thank the sponsors of CREWES for continued support. This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13. We also thank the sponsors of the Microseismic Industry Consortium for providing the data. Nadine Igonin is also funded through the NSERC PGS-D and SEG Earl D. and Reba C Griffin Memorial Scholarship.