Microseismic FWI: trade-offs between source and medium properties

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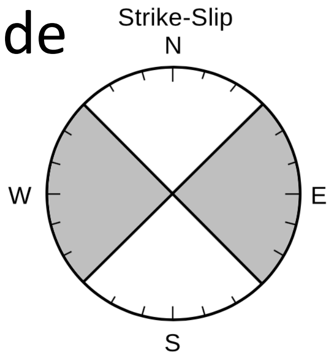
Outline

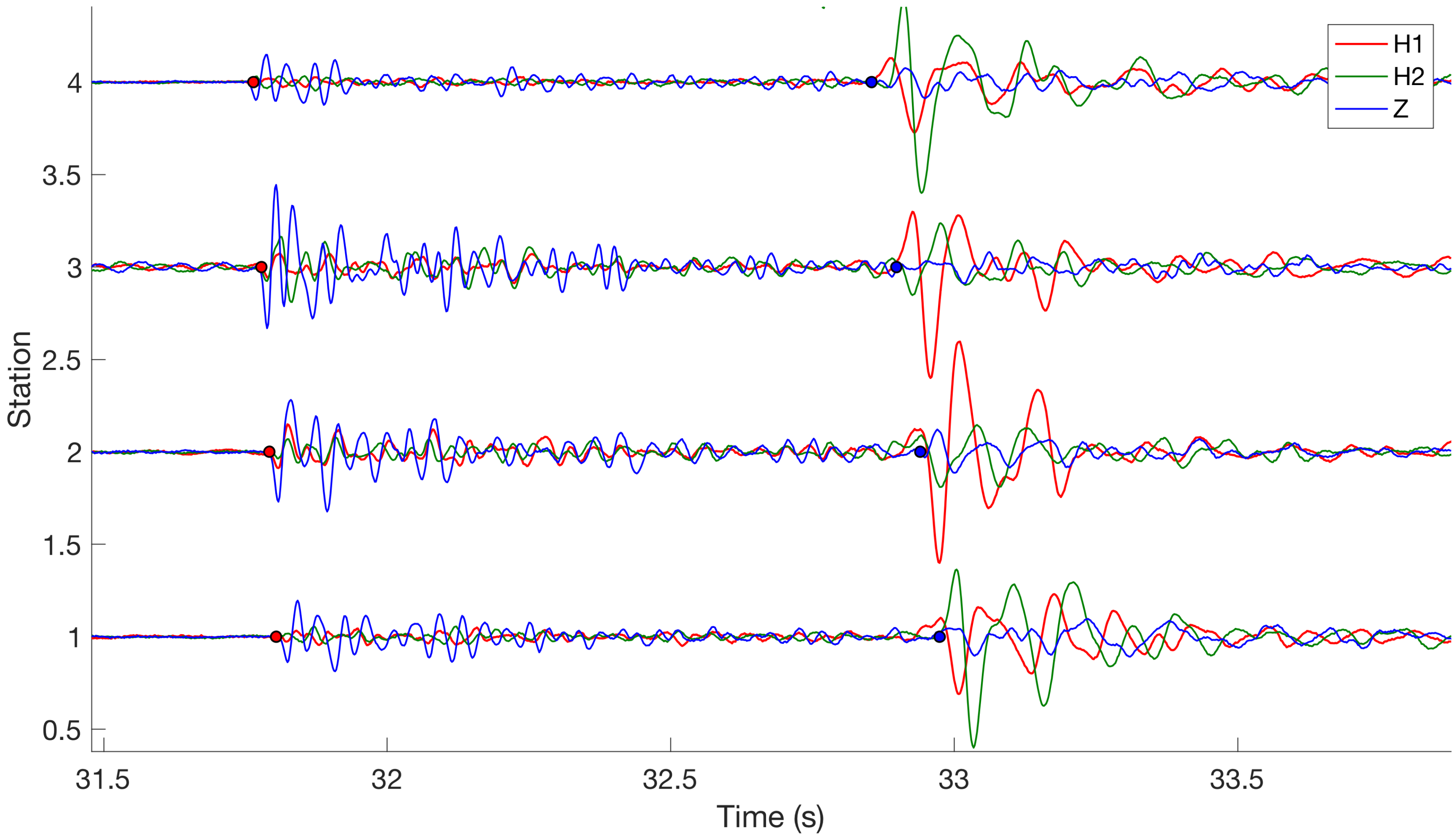
- Introduction and theory:
  - Microseismic
  - MFWI
- Results:
  - Source position error
  - Cross talk
- Conclusion and future work

Microseismic: waveform nature

Characteristics:

- P- and S-waves
- Amplitude and polarity determined by moment tensor
- Frequency inversely proportional to magnitude

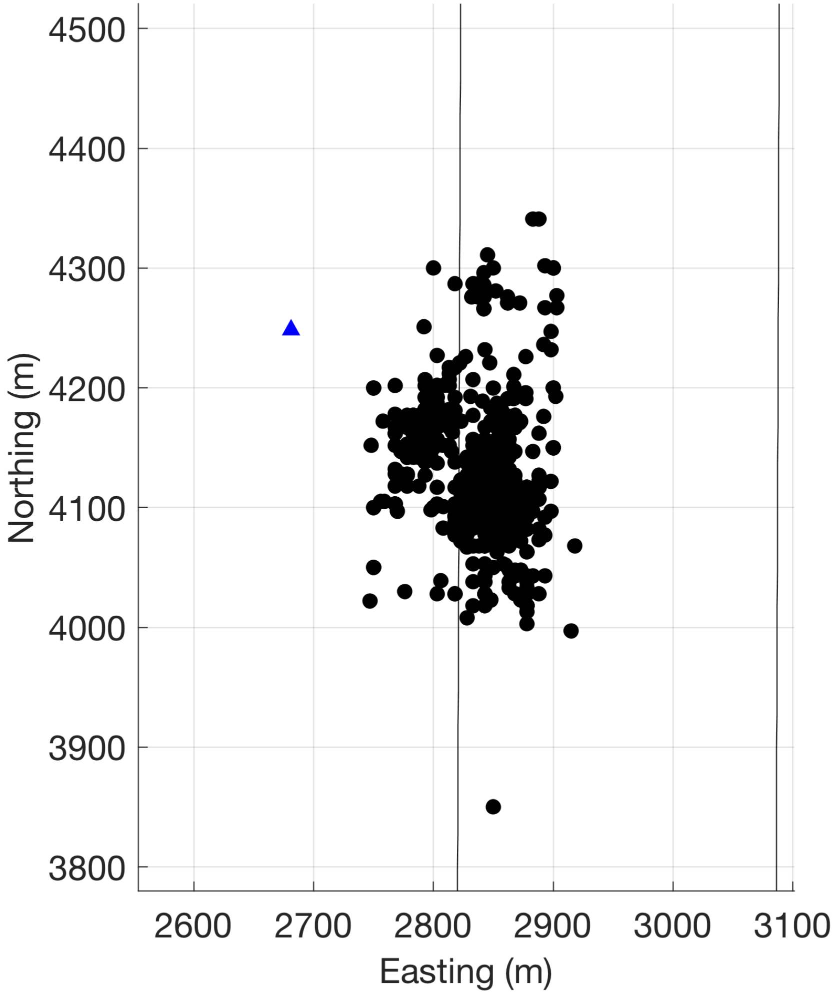




Example microseismc event

Microseismic: spatial characteristics

Type 1: Hydraulic fracturing



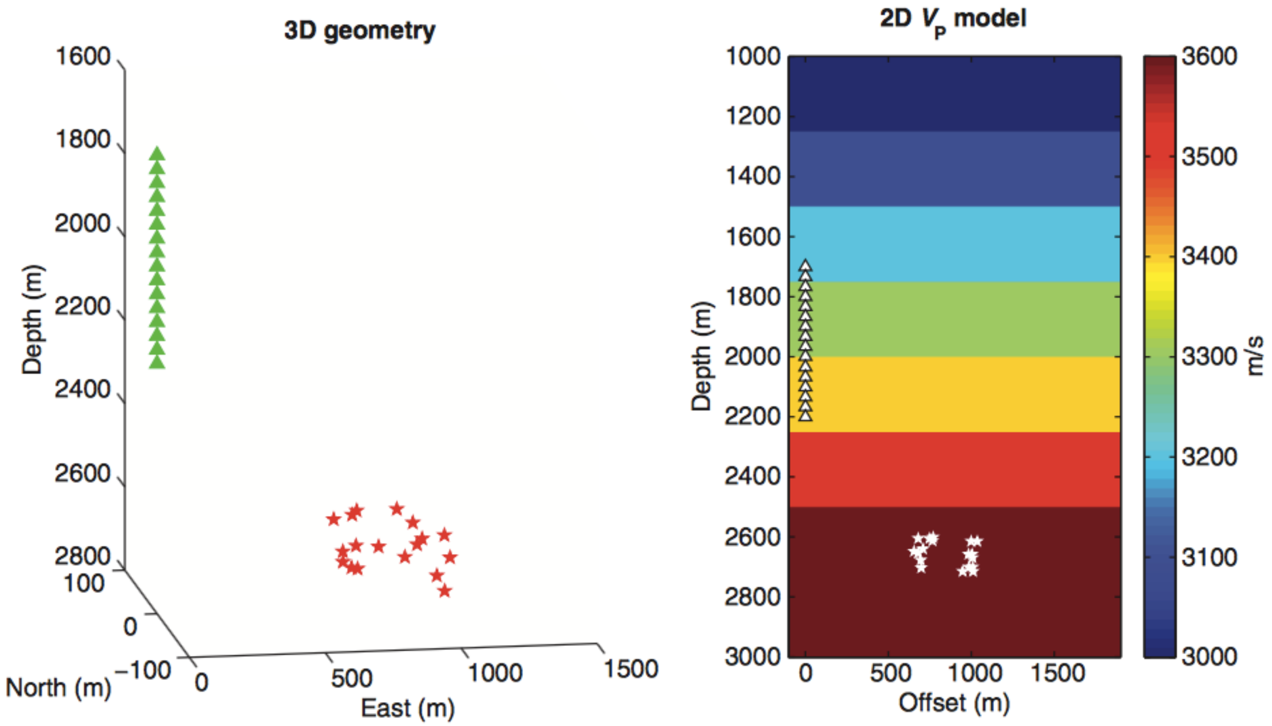
Microseismic FWI (MFWI)

In the microseismic world, we need

- An accurate velocity model
- Precise source locations

We propose a FWI scheme to iteratively solve for both of these parameters

→ Microseismic FWI (MFWI)



Poliannikov, 2014

Microseismic FWI (MFWI)

$$\underbrace{\begin{bmatrix} \delta \mathbf{s}_c \\ \delta \mathbf{s}_s \end{bmatrix}}_{\text{Update to model space}} = - \underbrace{\begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 \\ \mathbf{H}_3 & \mathbf{H}_4 \end{bmatrix}^{-1}}_{\text{Hessian}} \underbrace{\begin{bmatrix} \mathbf{g}_c \\ \mathbf{g}_s \end{bmatrix}}_{\text{Gradients}}$$

Velocity model term

Source location term

Microseismic FWI (MFWI)

$$\begin{bmatrix} \delta \mathbf{s}_c \\ \delta \mathbf{s}_s \end{bmatrix} = - \begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 \\ \mathbf{H}_3 & \mathbf{H}_4 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{g}_c \\ \mathbf{g}_s \end{bmatrix}$$

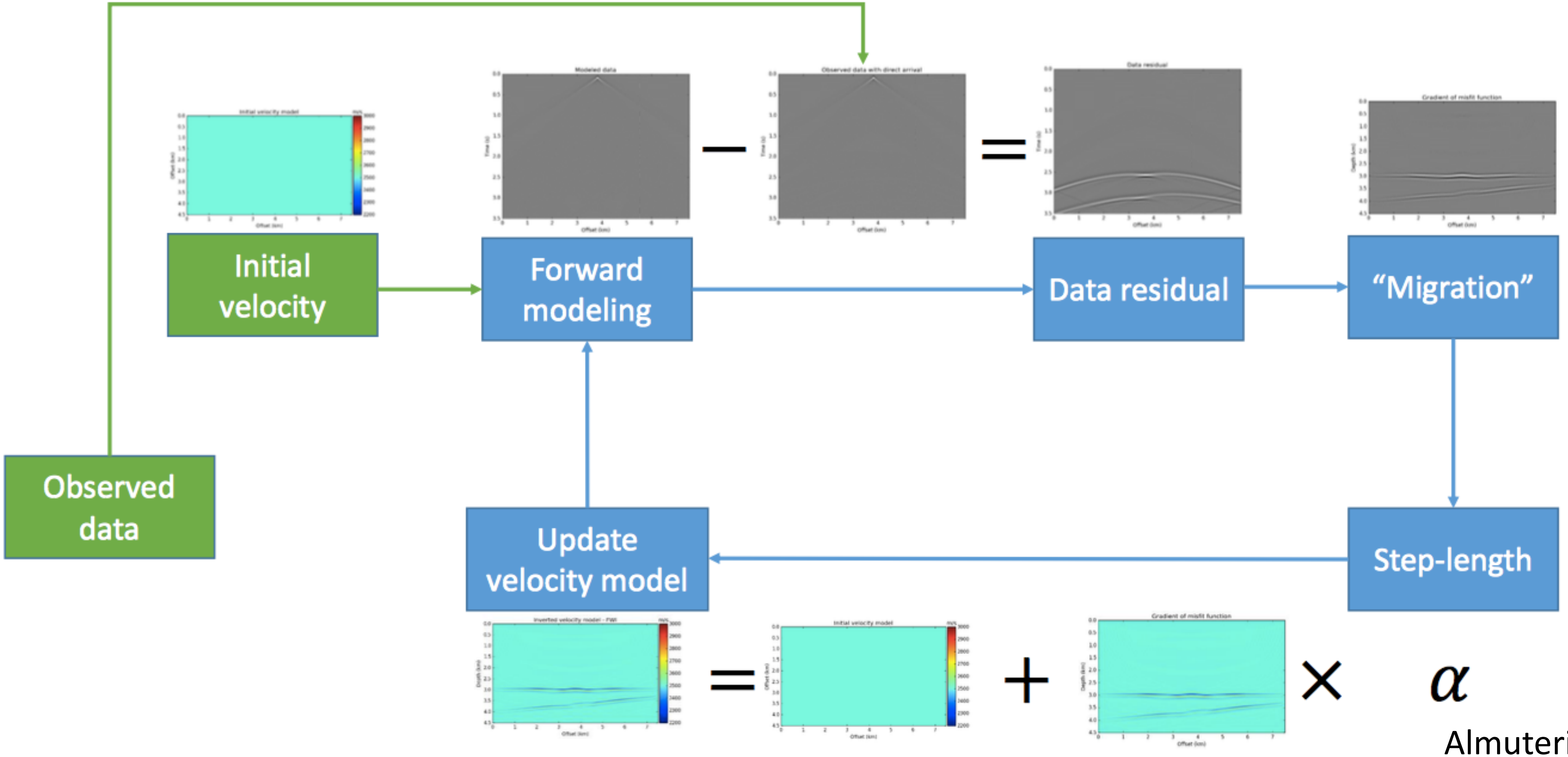
Velocity model term

Source location term

$$\mathbf{g}_s = - \sum_{r_g, r_s} \int dt \underbrace{\delta P(\mathbf{r}_g, \mathbf{r}_s, t | s_c, s_s)}_{\text{Residuals}} \underbrace{g(\mathbf{r}_g, \mathbf{r}, t - t^* | s_c, s_s)}_{\text{One-way Green's function}}$$

Implementation

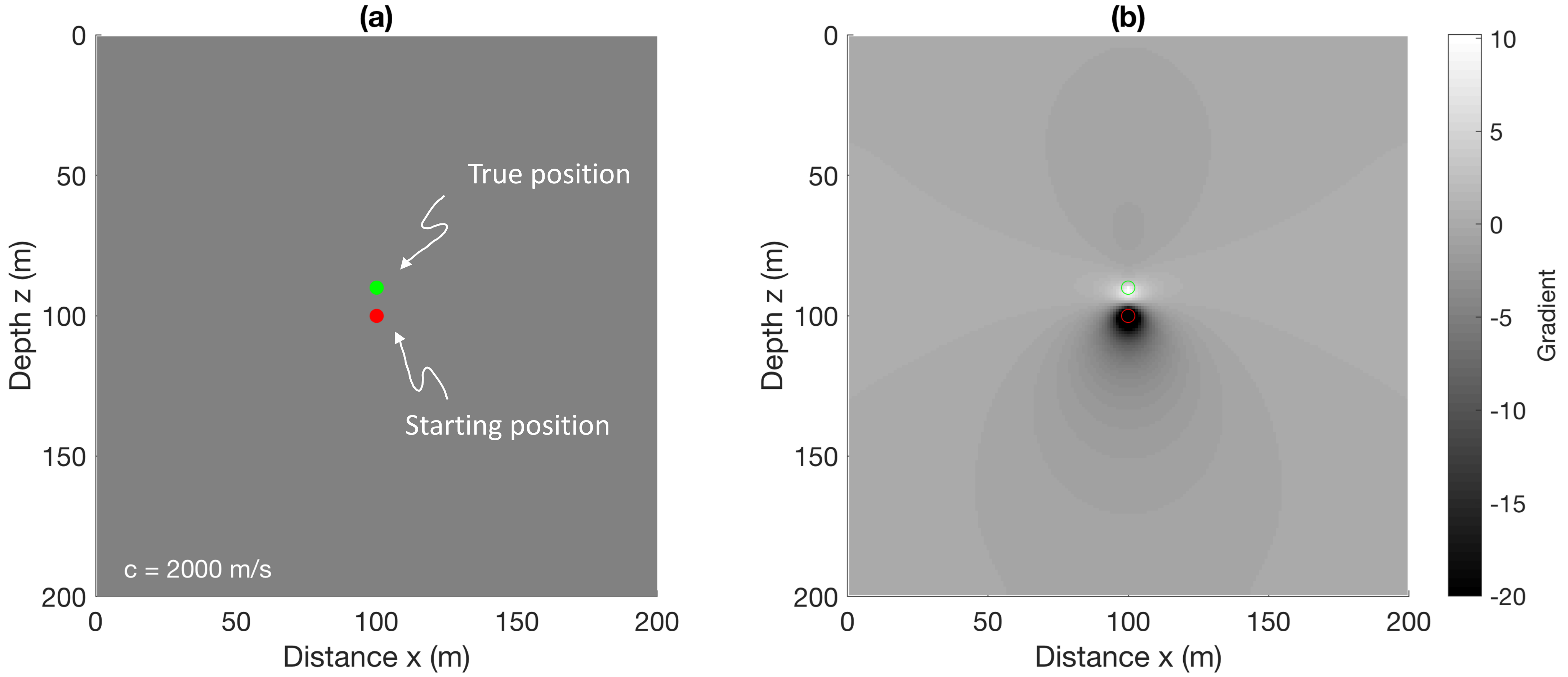
- We use 2D acoustic time-domain FWI codes developed by Almuteri and Innanen (2016) in Python to build the new source-term gradient.



Almuteri et al., 2016

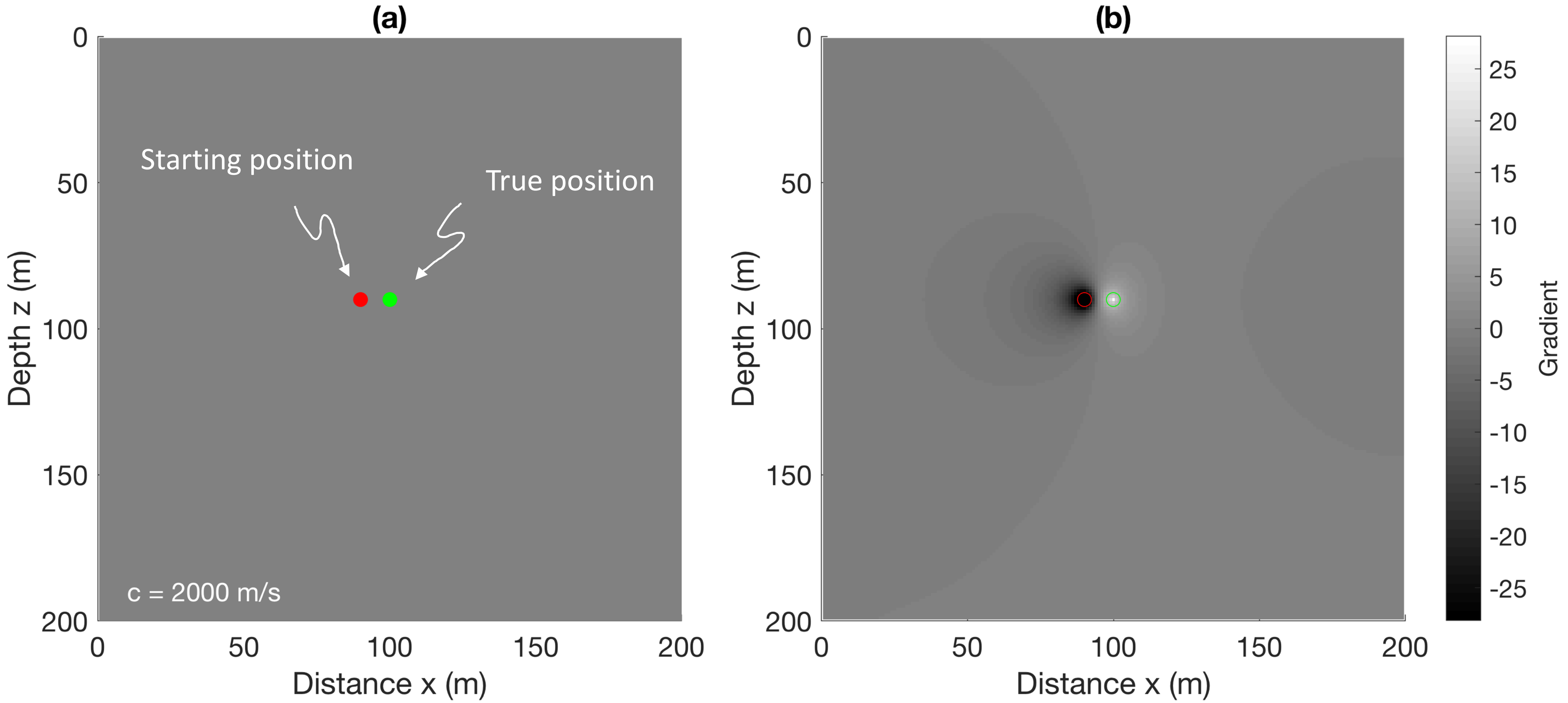
MFWI: Source error

- 10 m separation distance, 5 Hz dominant frequency



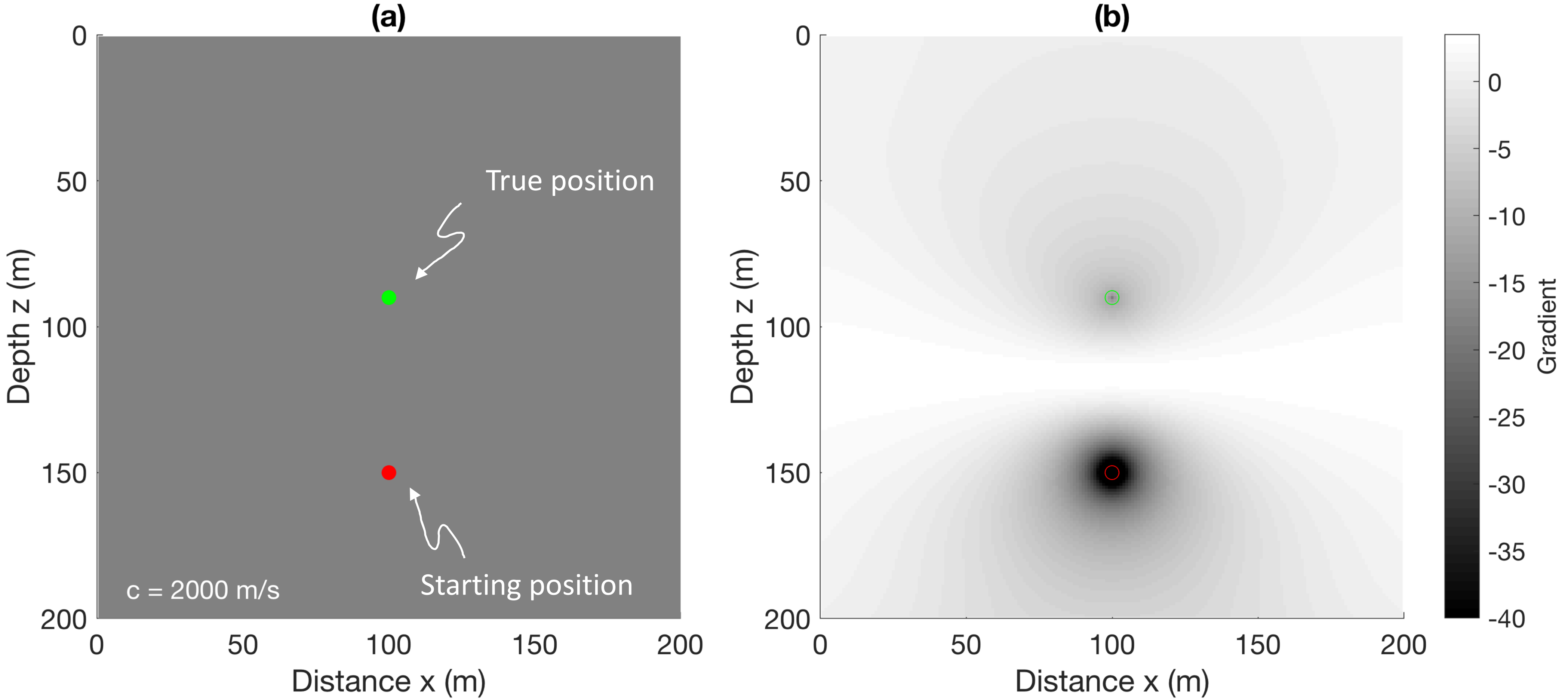
MFWI: Source error

- Consistent directionality and symmetry



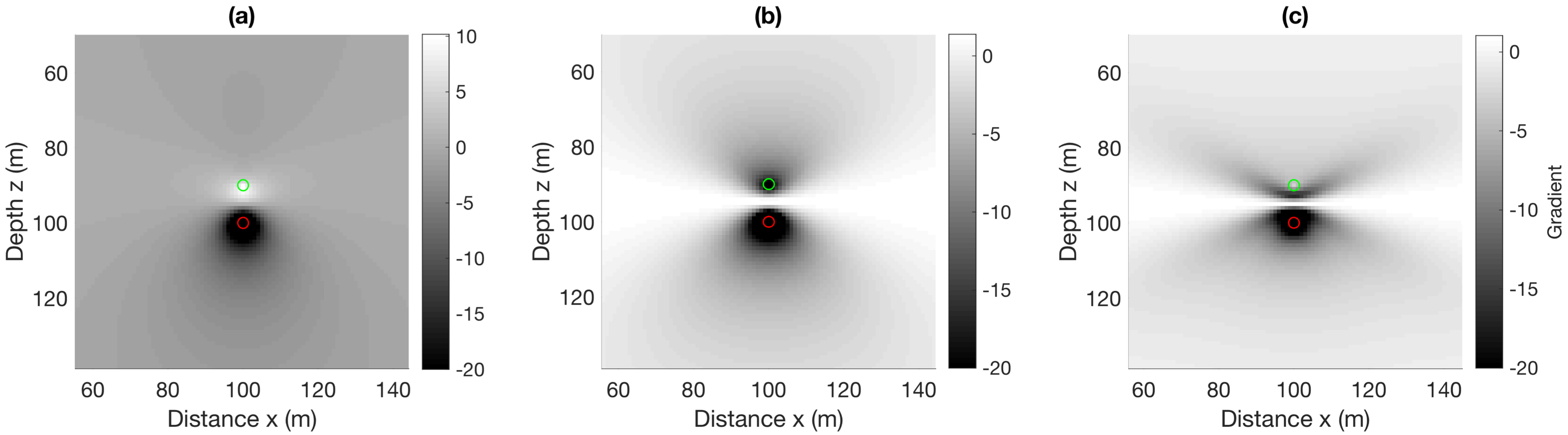
MFWI: Source error

- Large separation distance: 60 m. Indications of cycle skipping?



MFWI: Source error

- Gradient as a function of frequency



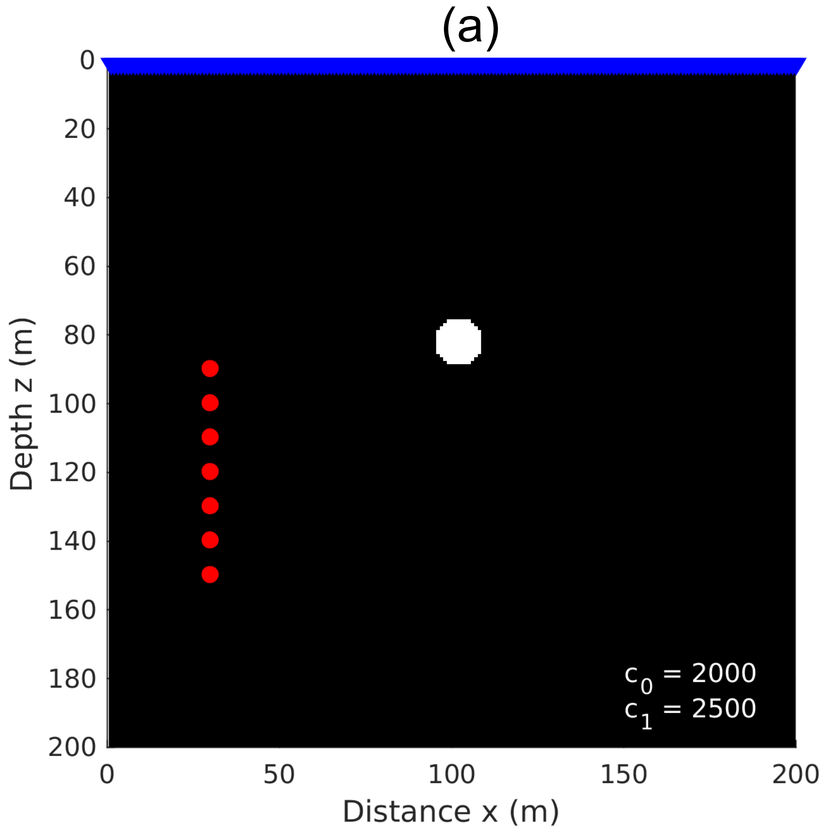
5 Hz

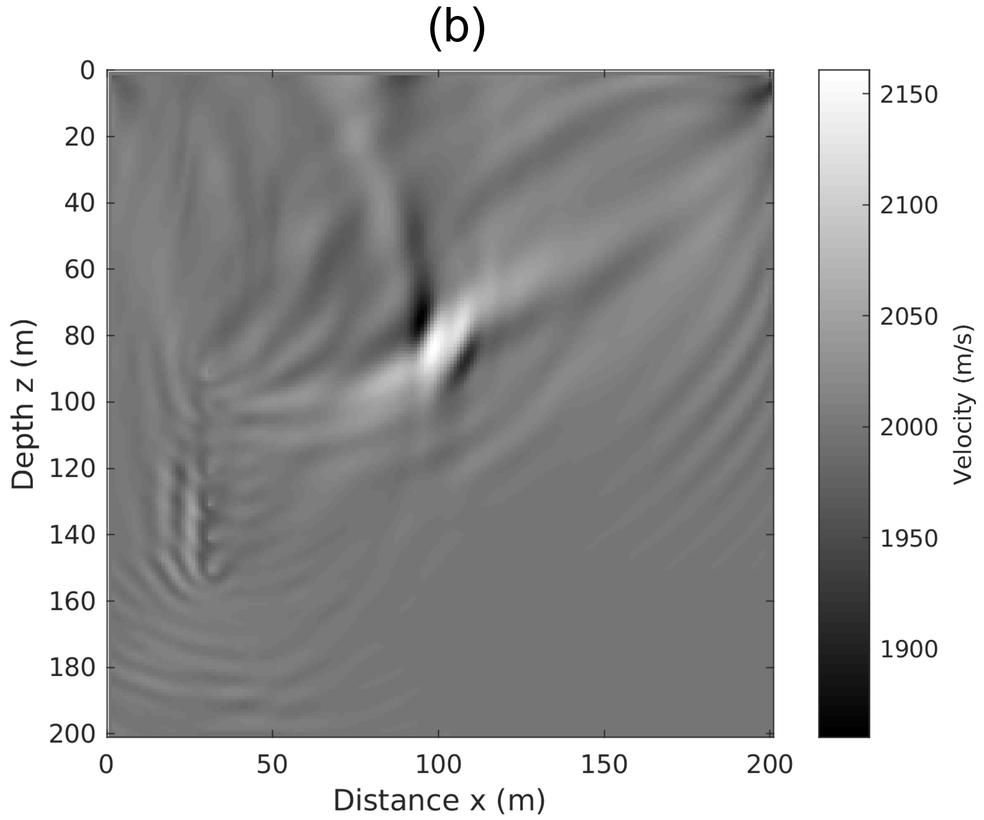
20 Hz

40 Hz

MFWI: Velocity inversion

- Sources arranged as activation of a vertical fault, receivers at surface



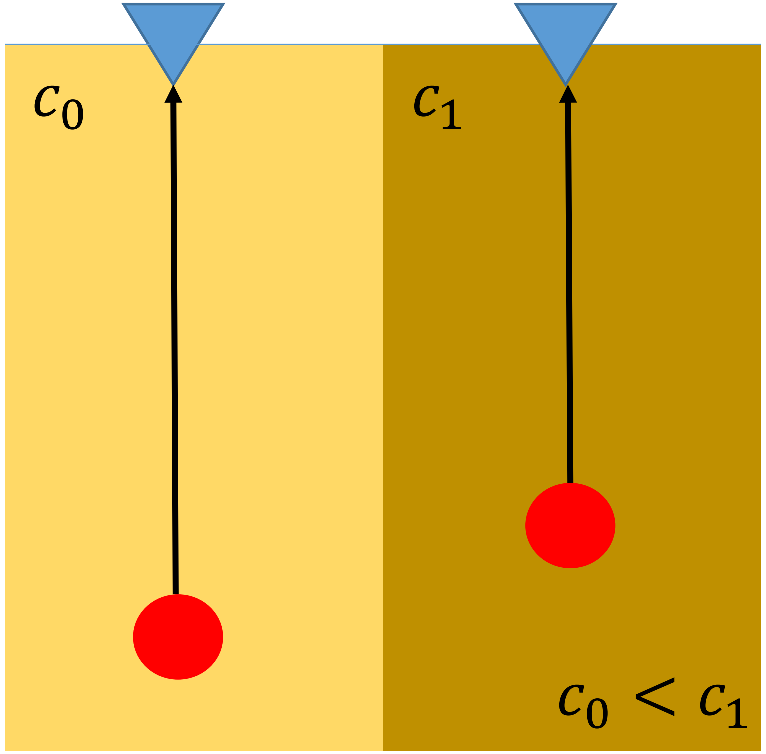


- We need enough unique ray-paths to accurately resolve the anomaly

Cross-talk

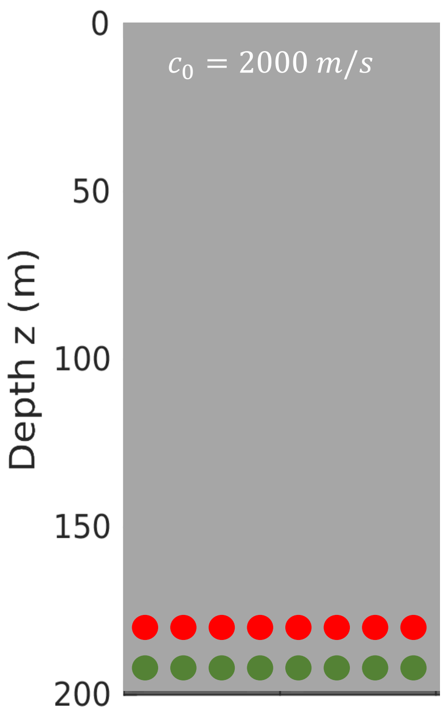
- ***Cross-talk***: One parameter is updated in response to data variations caused in part by a different parameter.

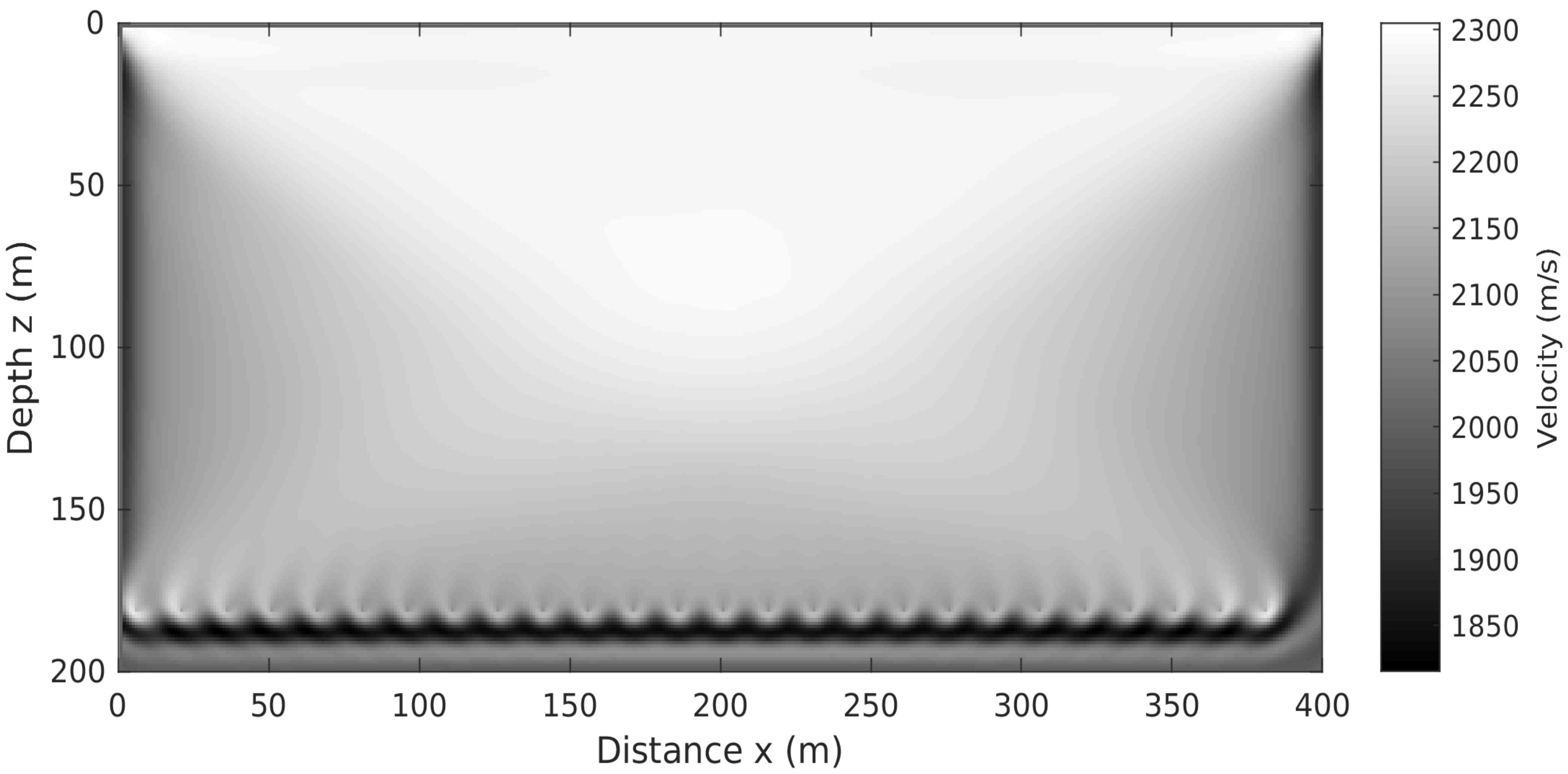
- Ex. In 1D, moving the source closer to the receiver produces the same arrival time data as raising the background velocity



Cross-talk: velocity term

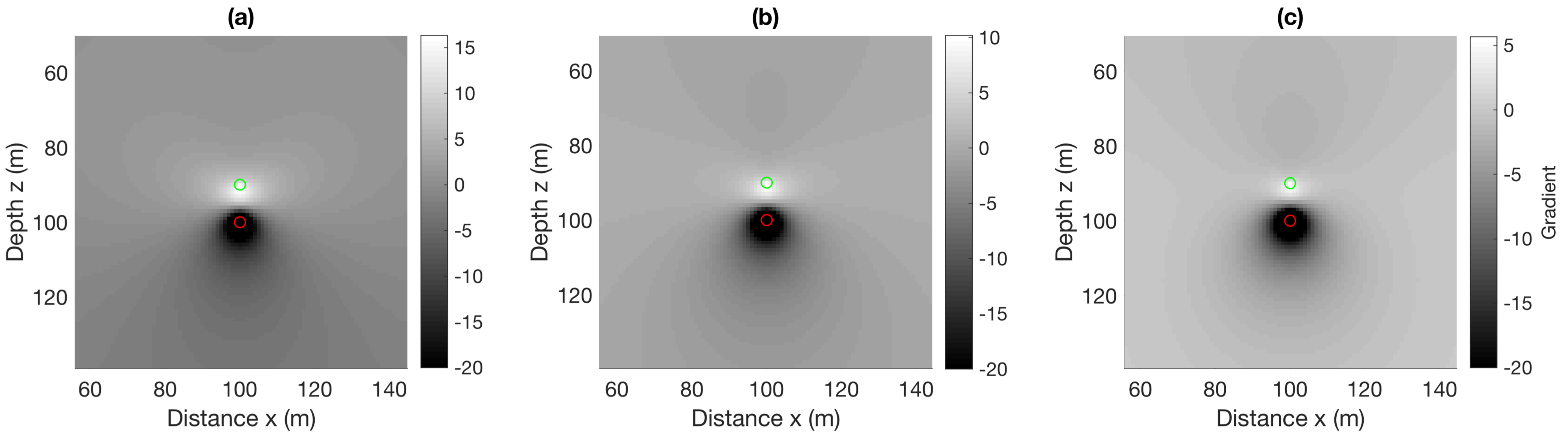
- Consider moving all the sources up by 10 m → the velocity gradient interprets this as a bulk increase to the model





Cross-talk: source term

- An erroneous background velocity changes the shape of the update



$v_t < v_0$ $\quad$ $v_t = v_0$ $\quad$ $v_t > v_0$

Future work (1)

- To complete the formulation, we require the Hessian

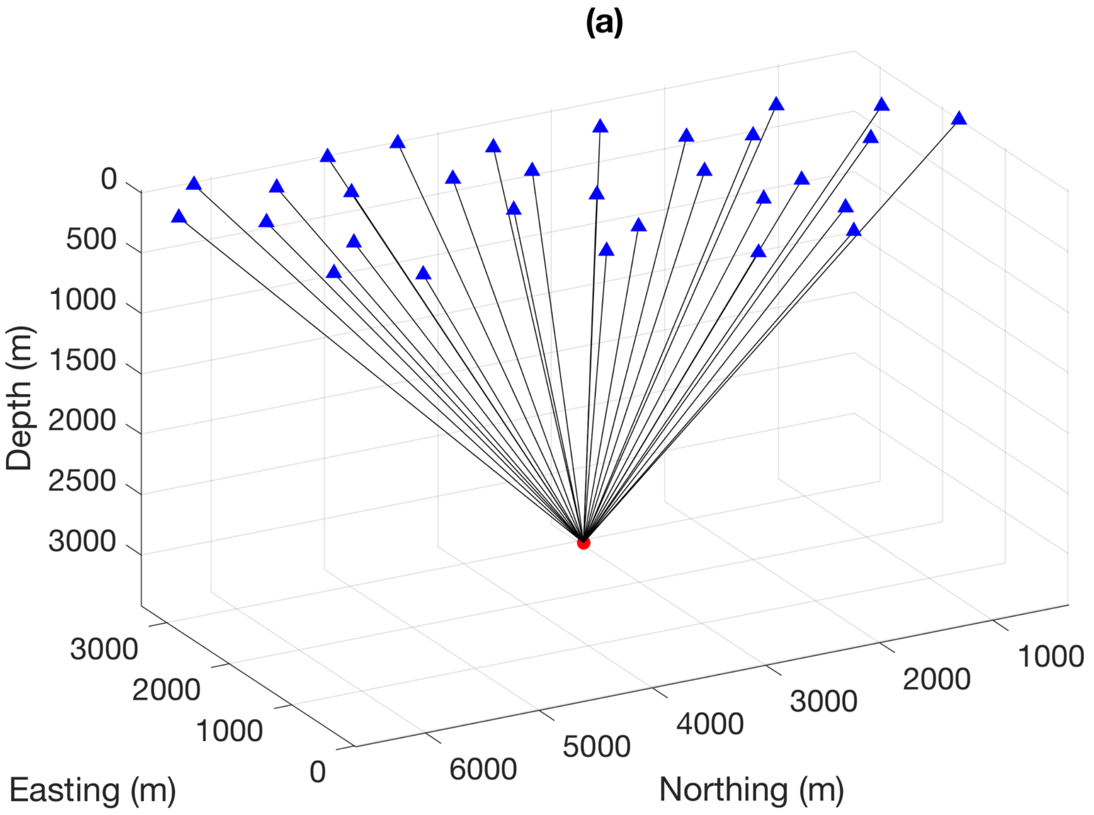
$$\begin{bmatrix} \delta \mathbf{s}_c \\ \delta \mathbf{s}_s \end{bmatrix} = - \begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 \\ \mathbf{H}_3 & \mathbf{H}_4 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{g}_c \\ \mathbf{g}_s \end{bmatrix}$$

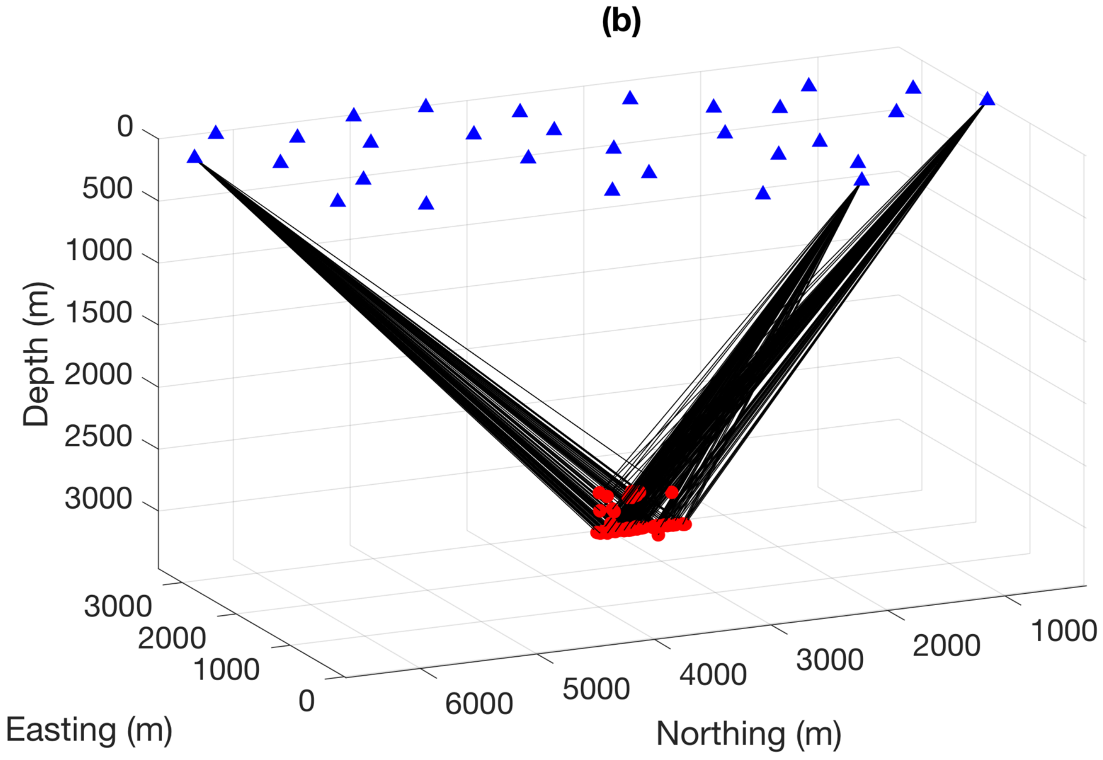
- To incorporate a moment tensor, we need to move to an elastic environment, and re-parametrize to invert for a moment tensor also

- To test the method more fully, physical modeling data can be made in the CREWES physical modeling lab

Future work (2)

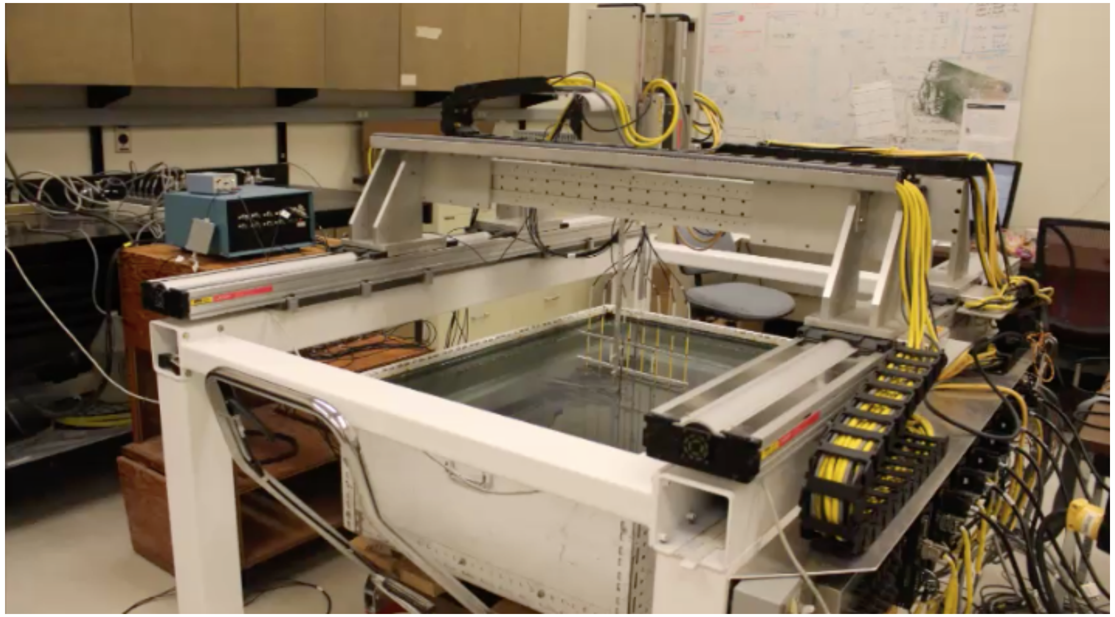
- The superposition of ray paths will have more effect at the source location → potential to ***image faults***





Conclusion

- MFWI is a FWI implementation that attempts to converge upon both source location and velocity model.
- The parameter cross-talk is a big challenge.
- Future work will involve integrating the Hessian, moving to an elastic environment and using physical modelling data.



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Questions/comments?