Extrapolated Full Waveform inversion with synthesized low frequencies

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Earth
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Laboratory

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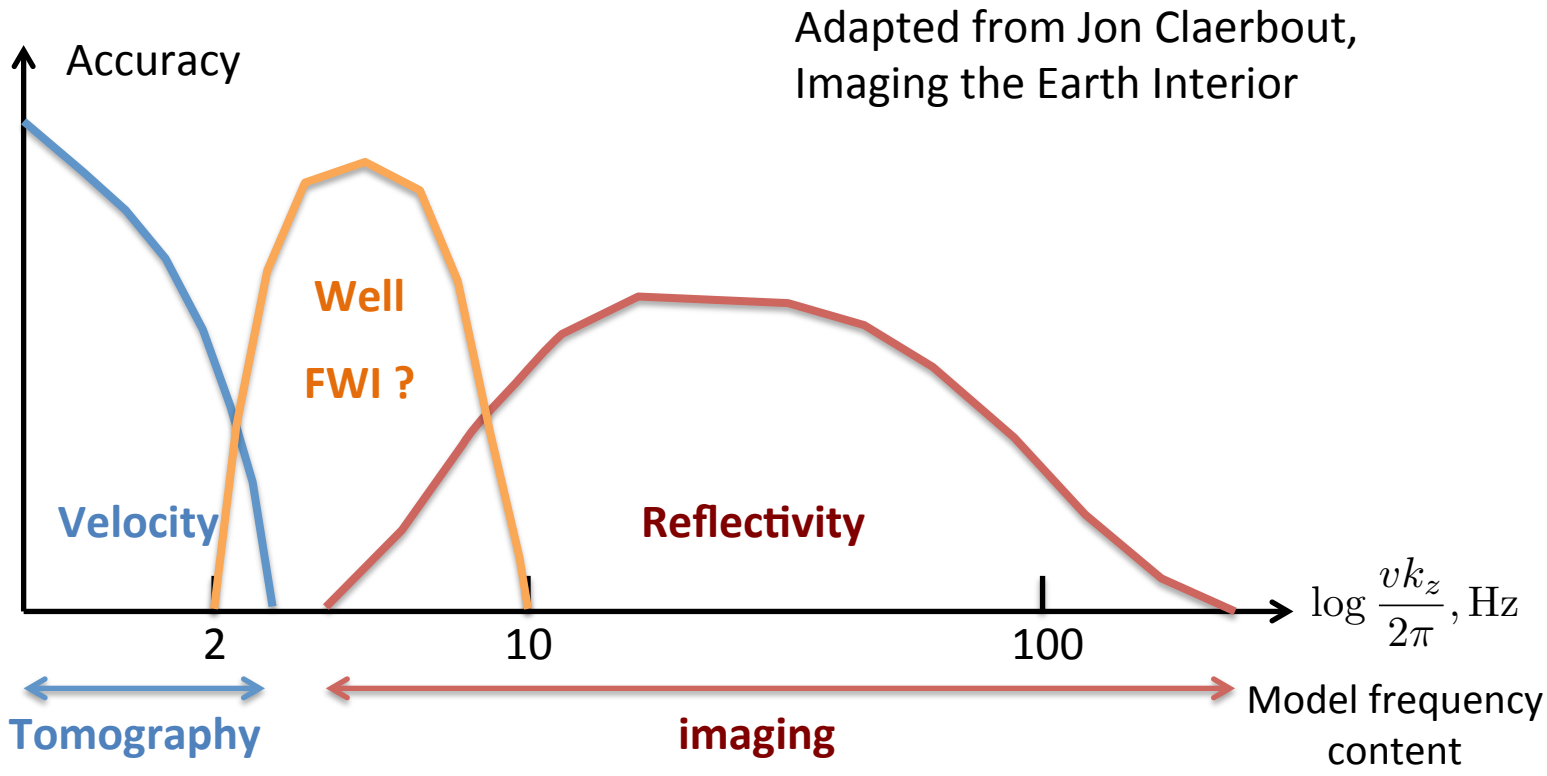
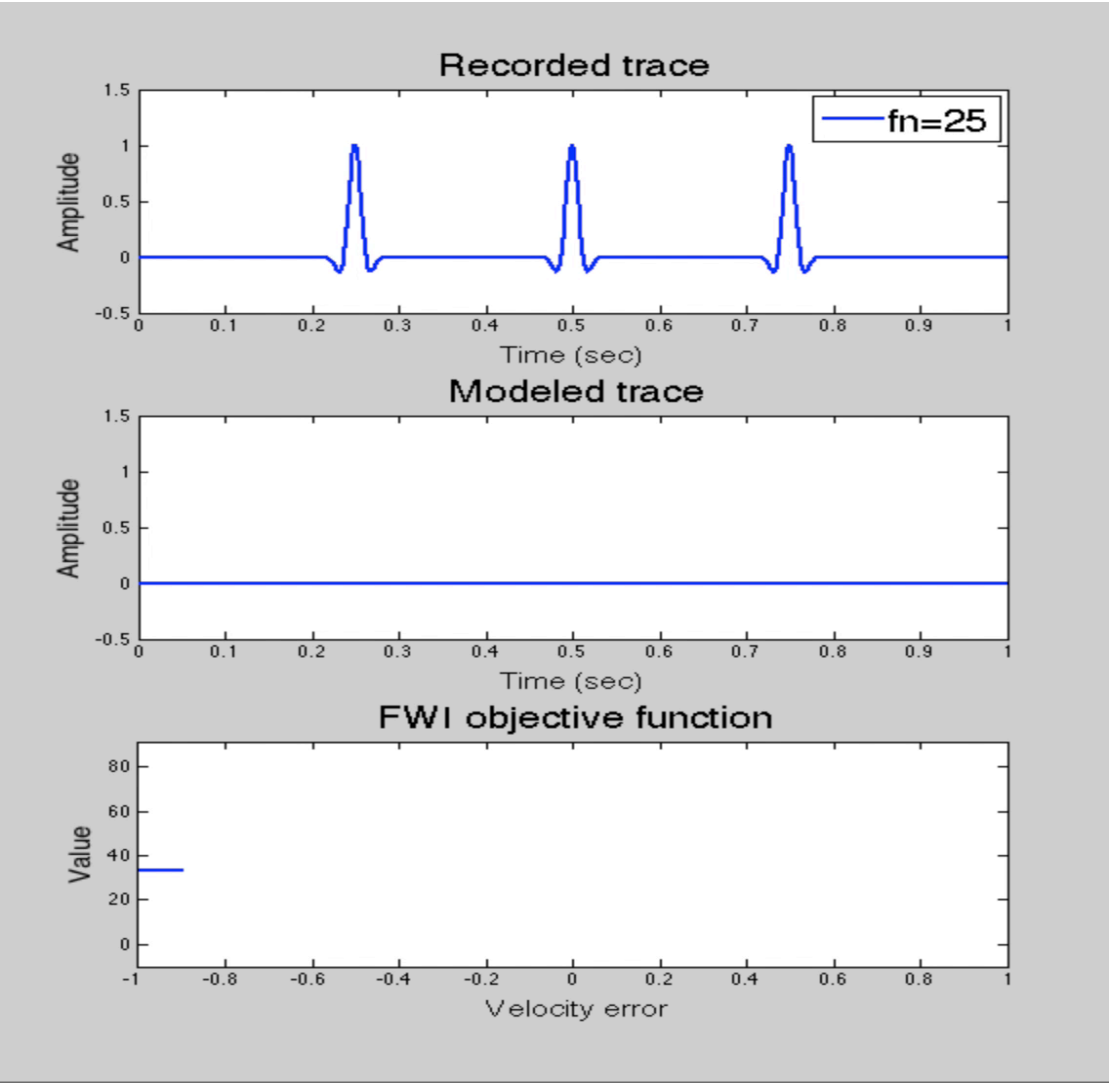
Subsurface characterization by seismic imaging

- Incomplete dataset
  - Incomplete acquisition geometry
    - Surface acquisition, VSP
  - Incomplete bandwidth
    - Band-limited seismic data
- Incomplete resolvable wavenumbers

Seismic frequency gap



Challenges of full waveform inversion



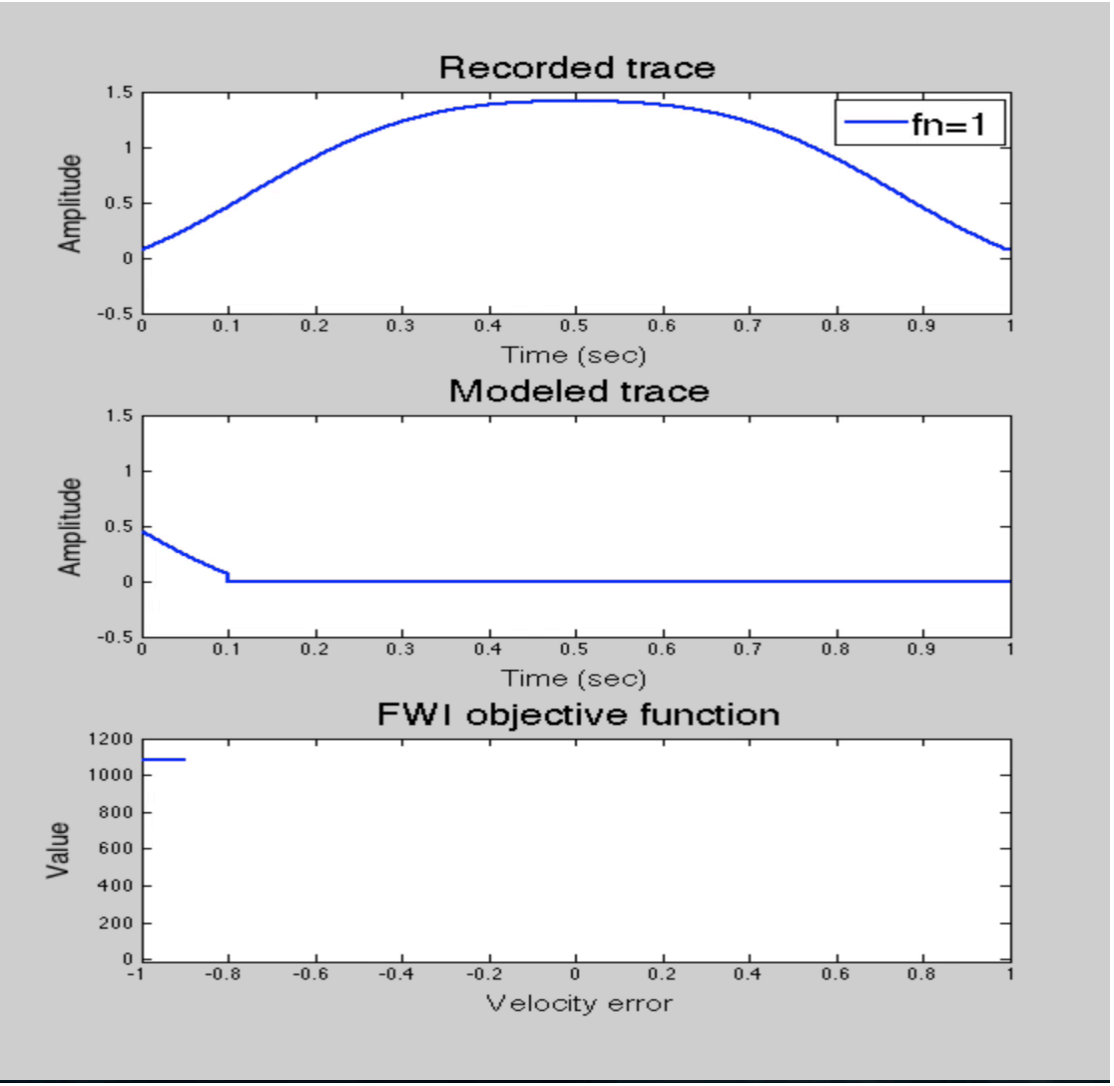
Nonconvex

Local minimum

Nonlinear inversion

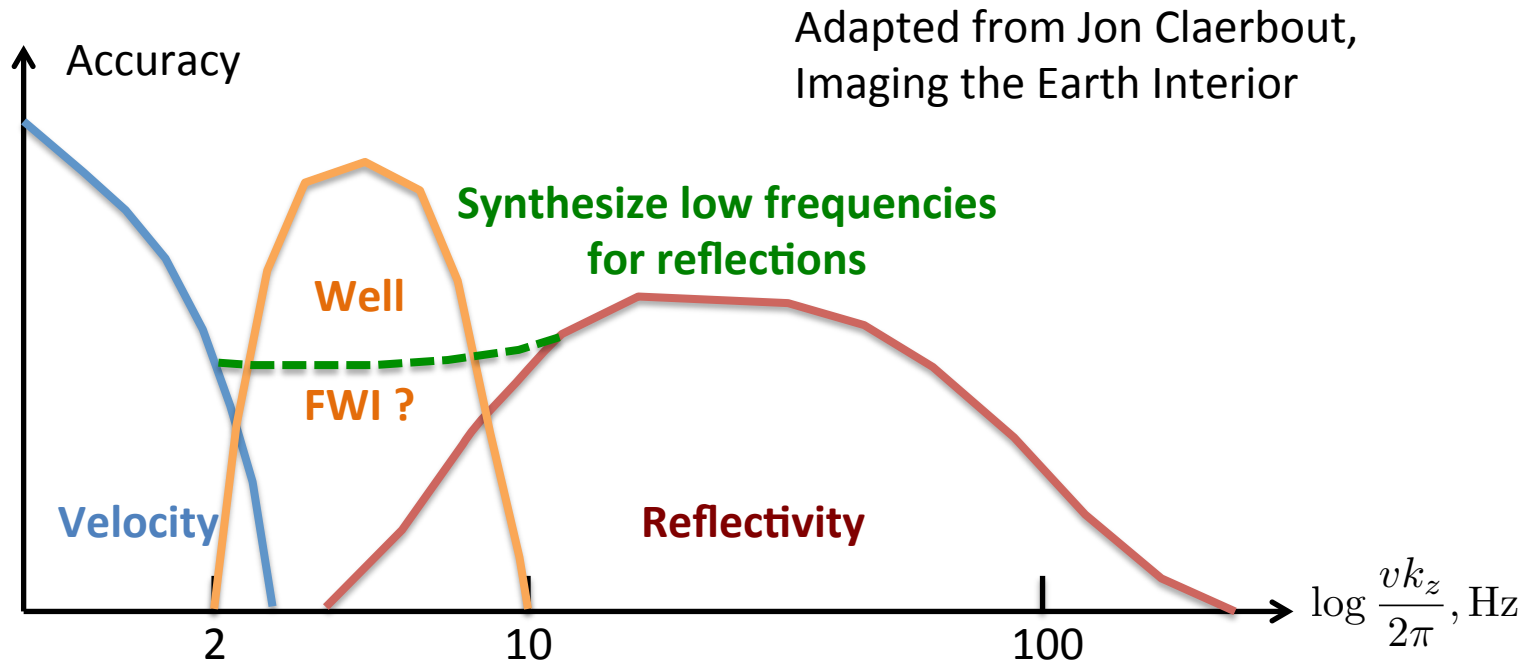
Iterative methods

Challenges of full waveform inversion



- Low frequency data
  - Missing from previous acquisitions
  - Expensive to acquire

Seismic frequency gap



Outline

- Challenges of Full Waveform Inversion
- Synthesize low frequencies
  - Data space: event separation and extrapolation
- Full waveform inversion
  - Initial solution: initialization using synthesized data
- Conclusions

Seismic event separation

Li and Demanet, Geophysics,2015

Data model:

$$\hat{d}(\omega, x) \approx \sum_{j=1}^{r} \hat{v}_j(\omega, x)$$

where atomic events

$$\hat{v}_j(\omega, x) = w(\omega) a_j(\omega, x) e^{i b_j(\omega, x)}$$

Source

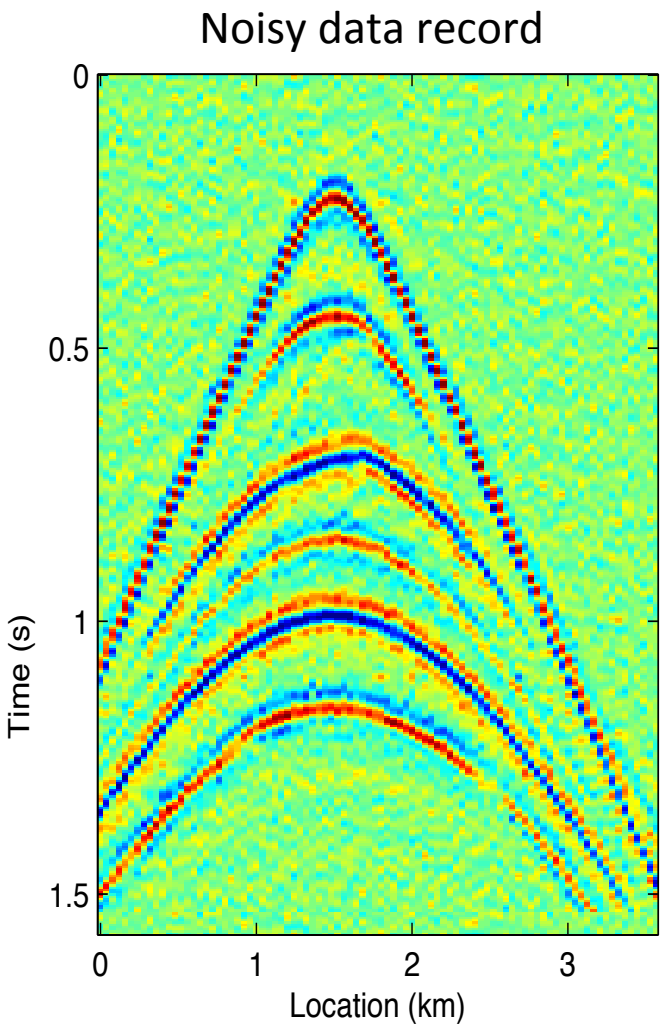
Amplitude

Phase

Separation is required for extrapolation (assuming no attenuation):

* Amplitude remains constant for all frequencies
* Phase is a linear function of frequencies

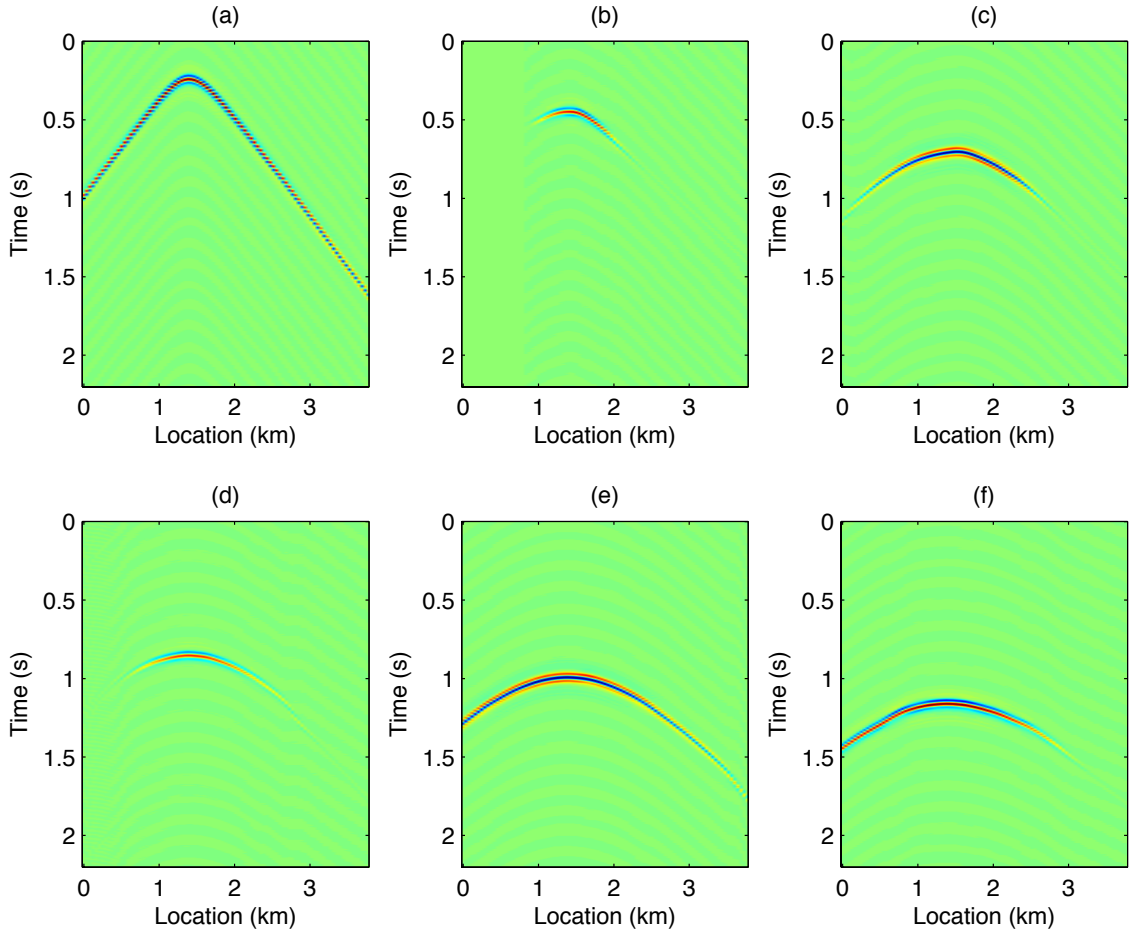
Phase and amplitude tracking



Single shot gather:

* FDTD constant density acoustic
* Additive noise of 30%
* Band-limited [7-40] Hz

Event separation

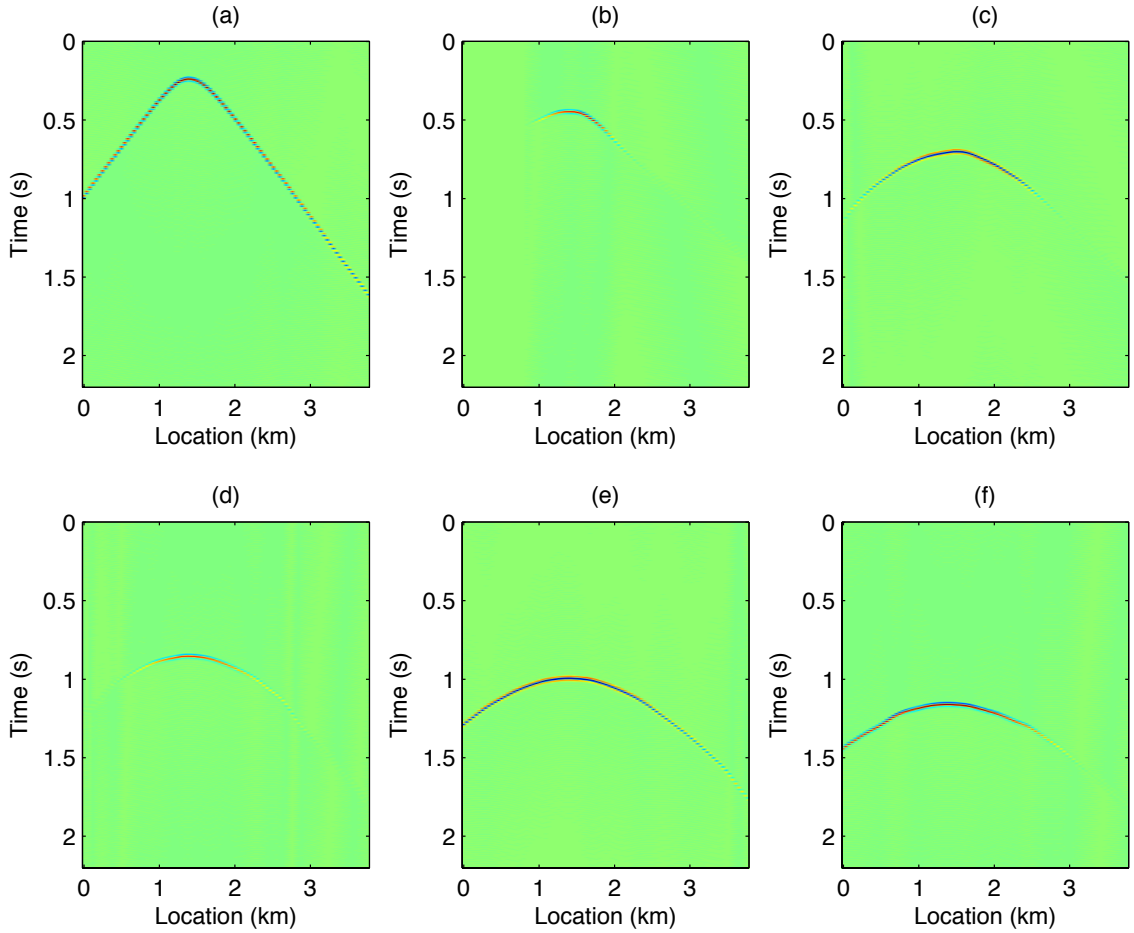


- Frequency bandwidth [7 40] Hz

$$\hat{d}(\omega) \simeq \sum_{j=1}^{r} a_j e^{i\omega\tau_j}$$

- Extrapolate to [0.5 70] Hz
  (Assuming no dispersion)

Frequency extrapolation



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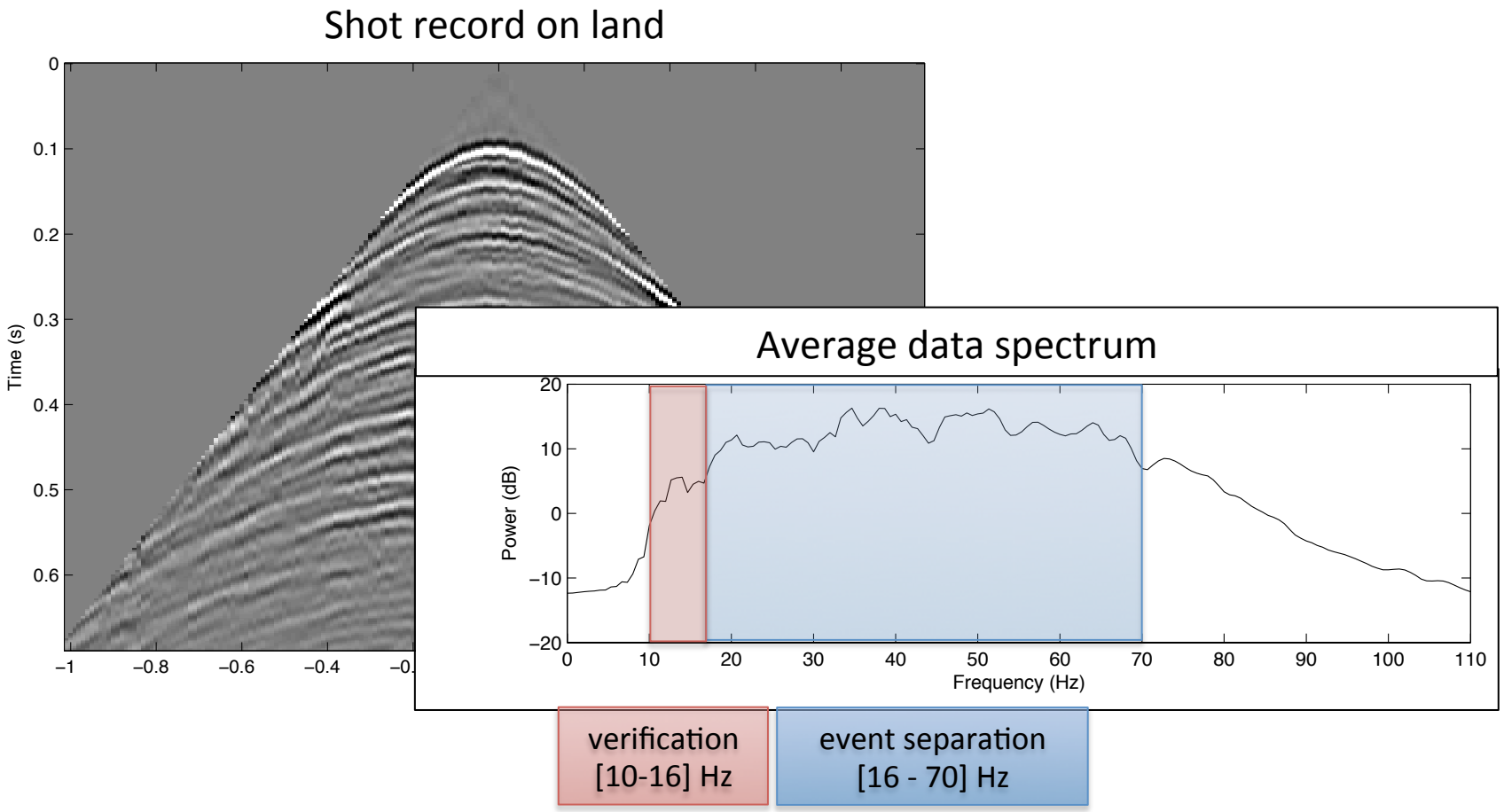
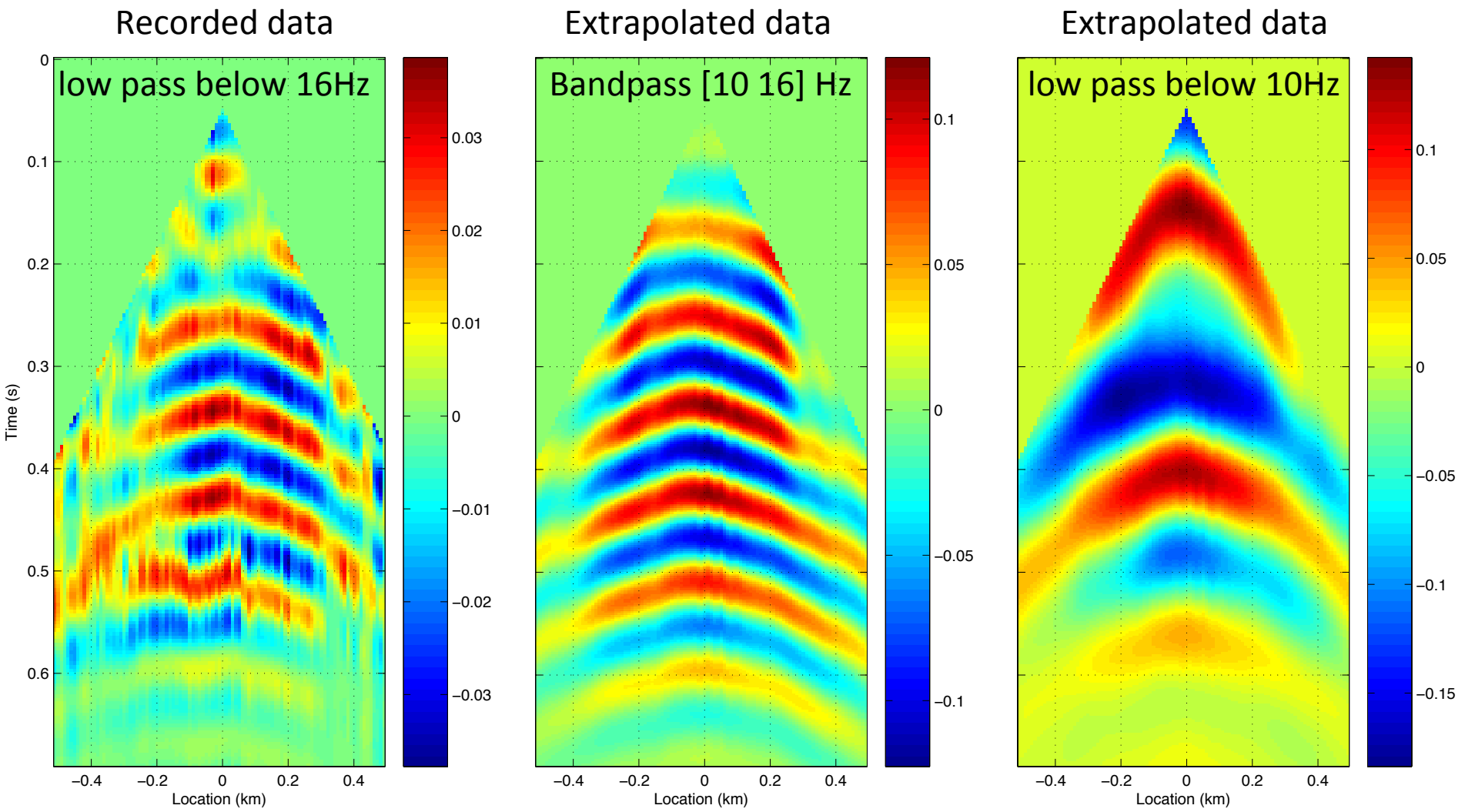
Low frequency extrapolation



Low frequency extrapolation



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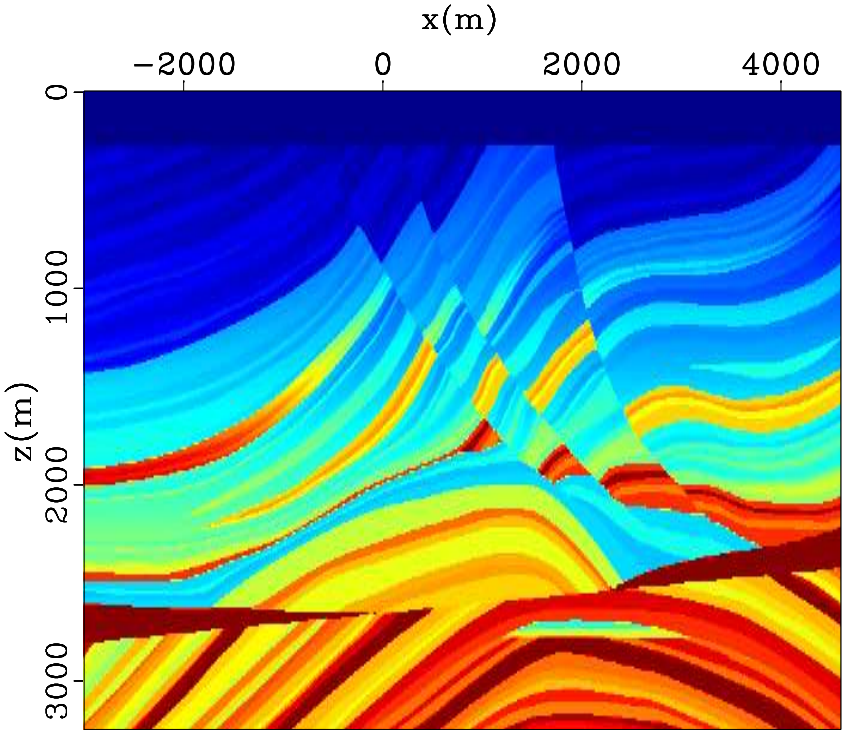
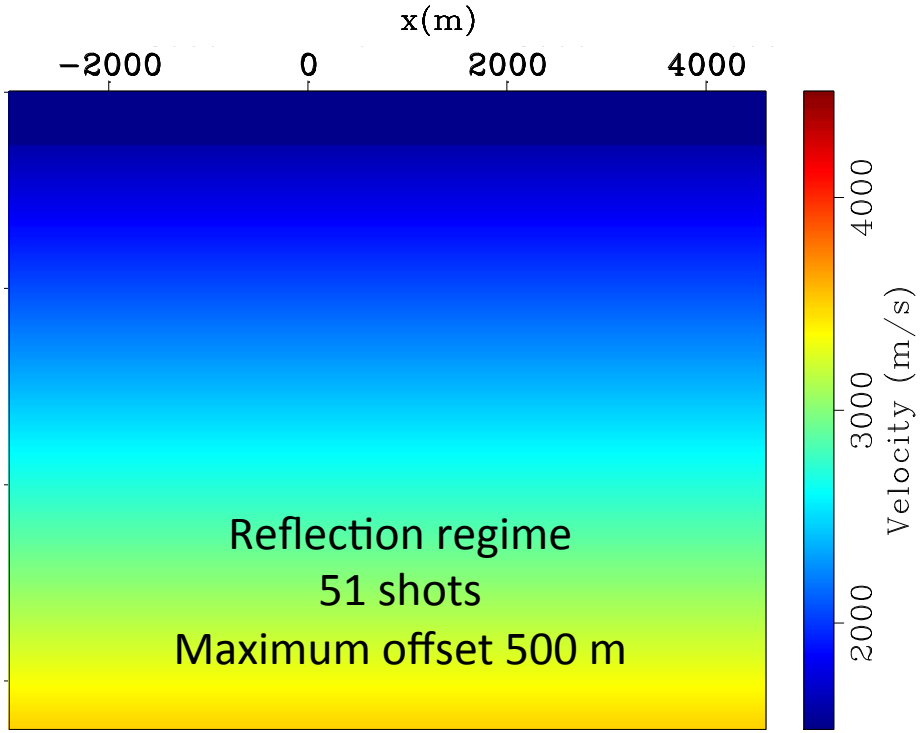
Marmousi model



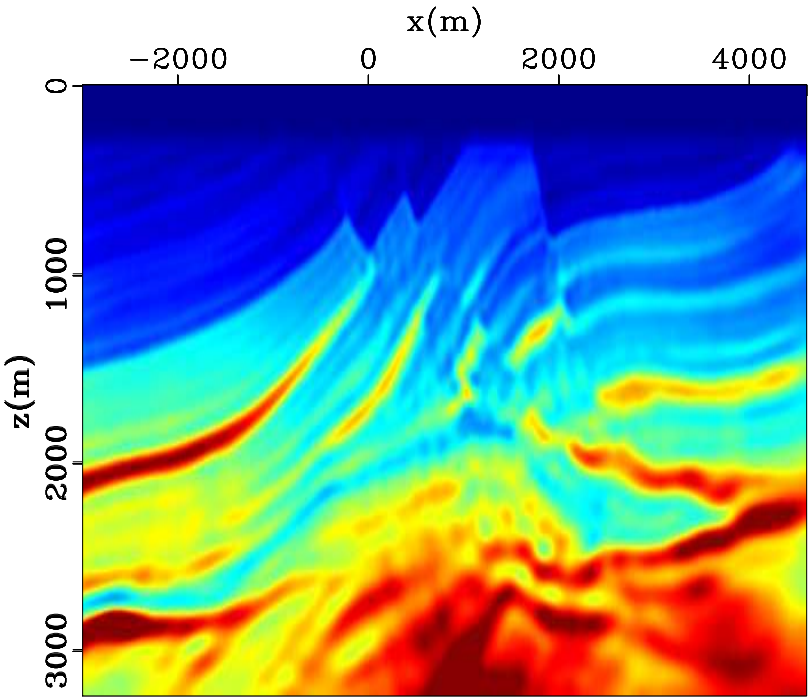
True model



Initial model

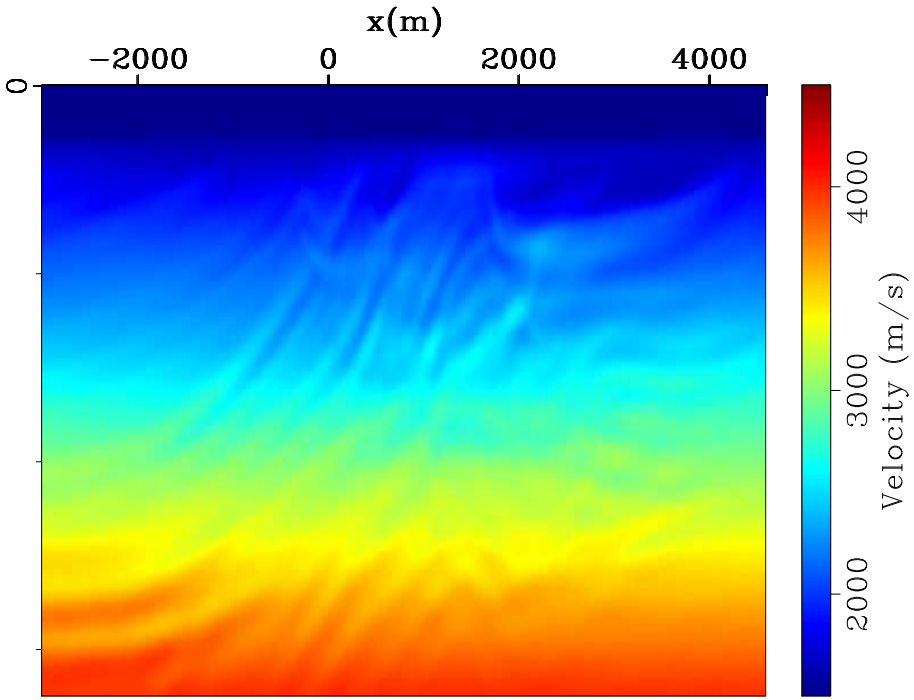
Full waveform inversion at lowest available freq.

With recorded low frequency



Data [1-15] Hz

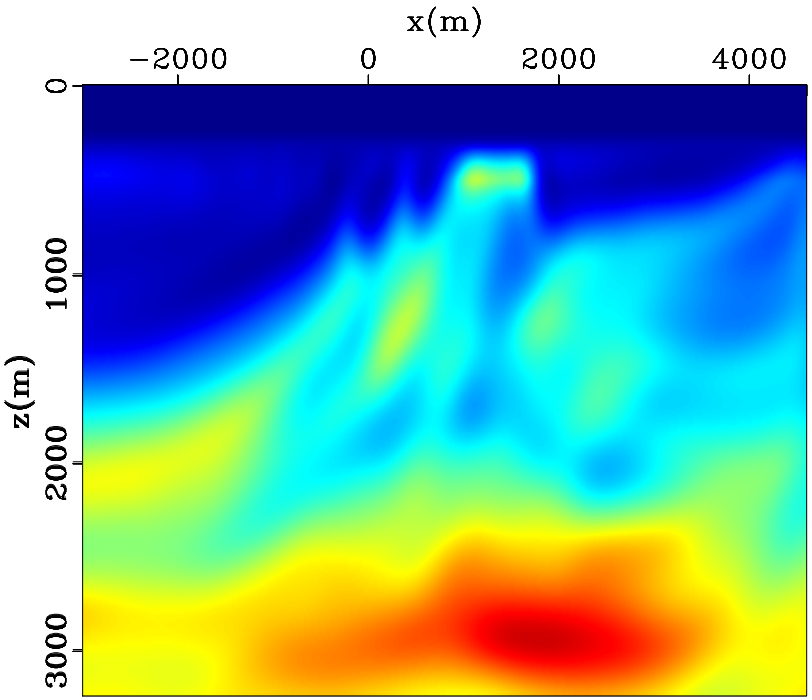
Without low frequency



Data [5-15] Hz

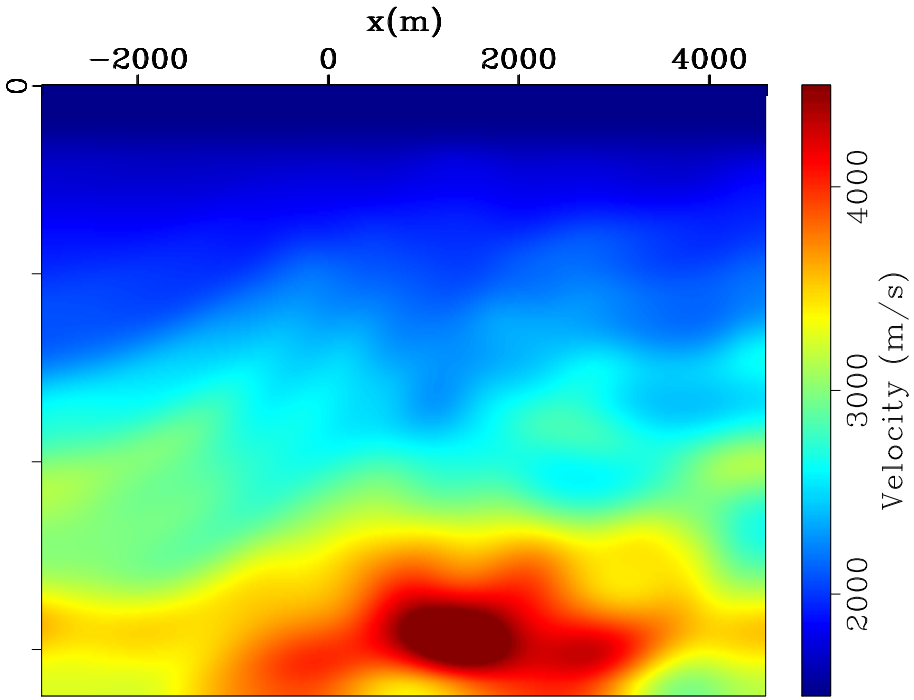
Full waveform inversion with low frequency data

With recorded [1 - 5] Hz



FWI using modeled data

With extrapolated [1 -5] Hz

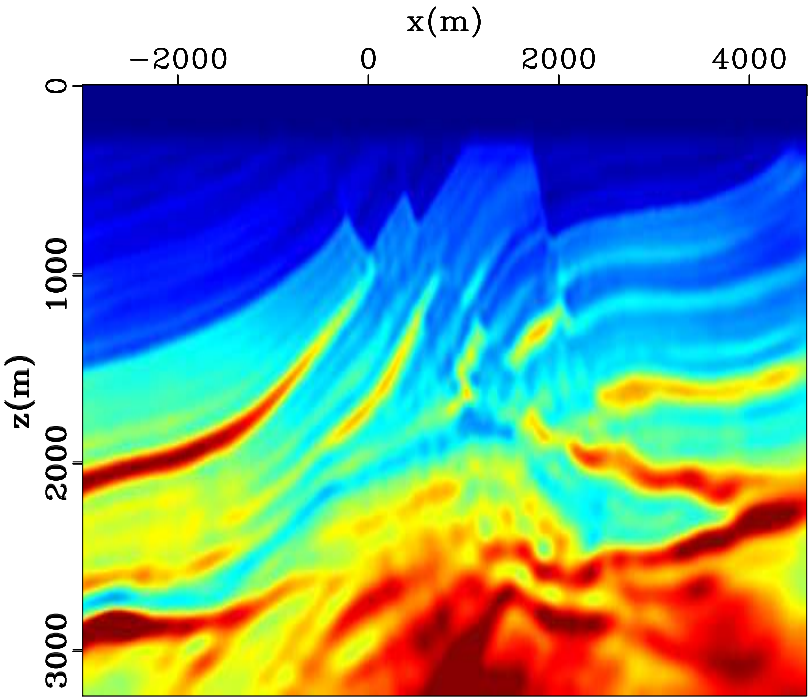


FWI using extrapolated data

Low wavenumber model to initialize FWI at higher frequencies

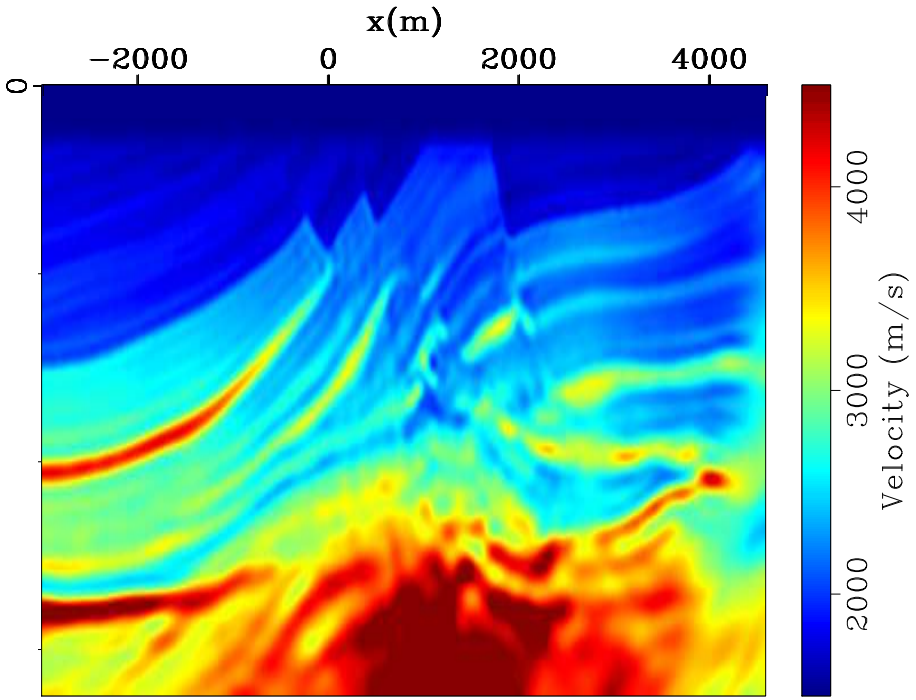
Full waveform inversion with frequency sweep

With recorded low frequency



Modeled data [1-15] Hz

With extrapolated low frequency

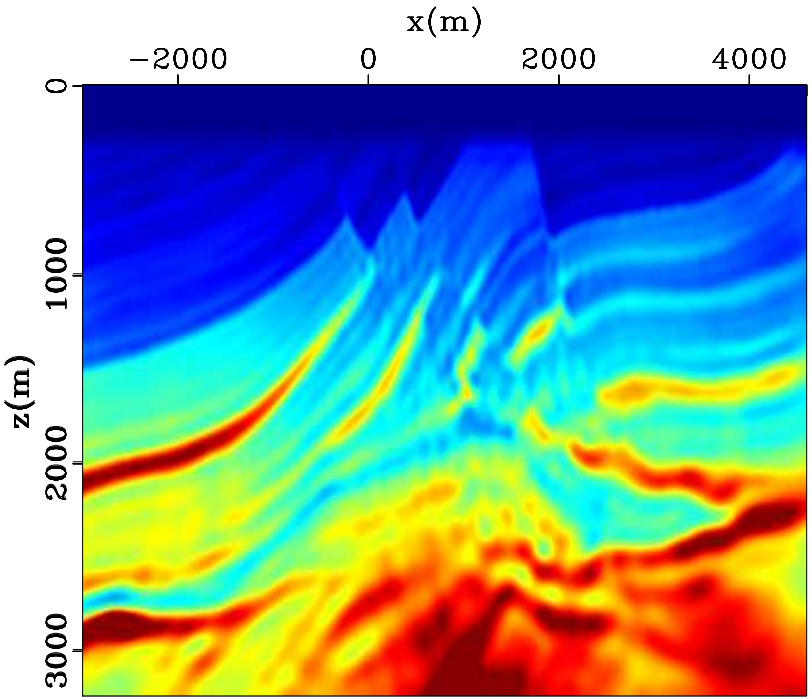


Extrapolated data [1-5] Hz
Modeled data [5-15] Hz

Li and Demanet, to appear in Geophysics, 2016

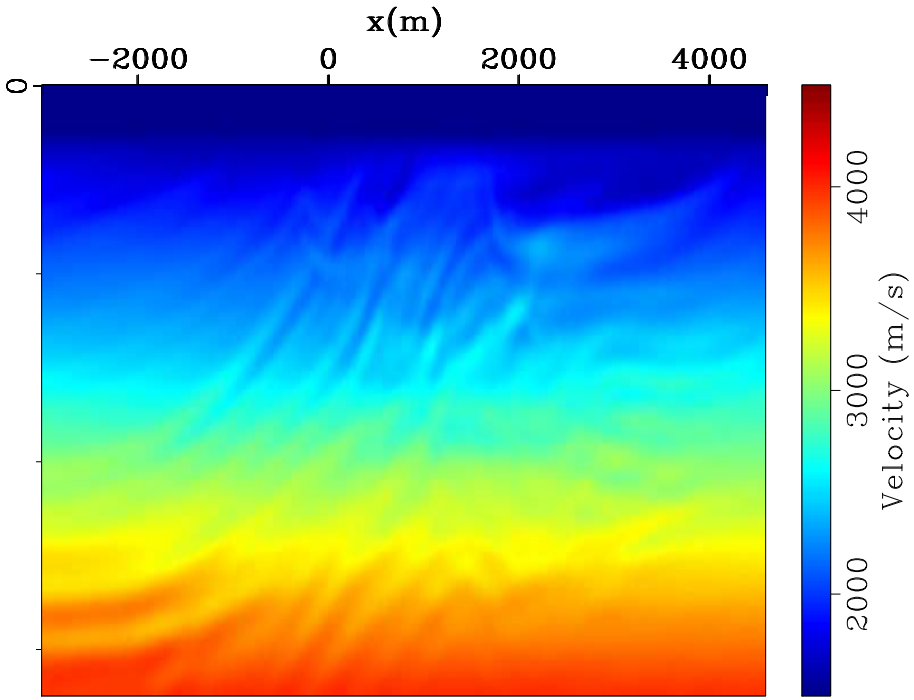
Full waveform inversion at lowest available freq.

With recorded low frequency



Modeled data [1-15] Hz

Without low frequency



Modeled data [5-15] Hz

Conclusions

I. Low frequency data can be extrapolated from the band-limited field recordings
   a. Event tracking → separation
   b. Non-attenuative medium → frequency extrapolation

II. Extrapolated low frequencies are imperfect, but reliable for initializing FWI
   a. Amplitude information → normalized
   b. Phase information → reliable for initializing FWI

Thank you!

Filling in the low frequency gap