SINBAD Consortium 2010

Sparsity-promoting migration with surface-related multiples

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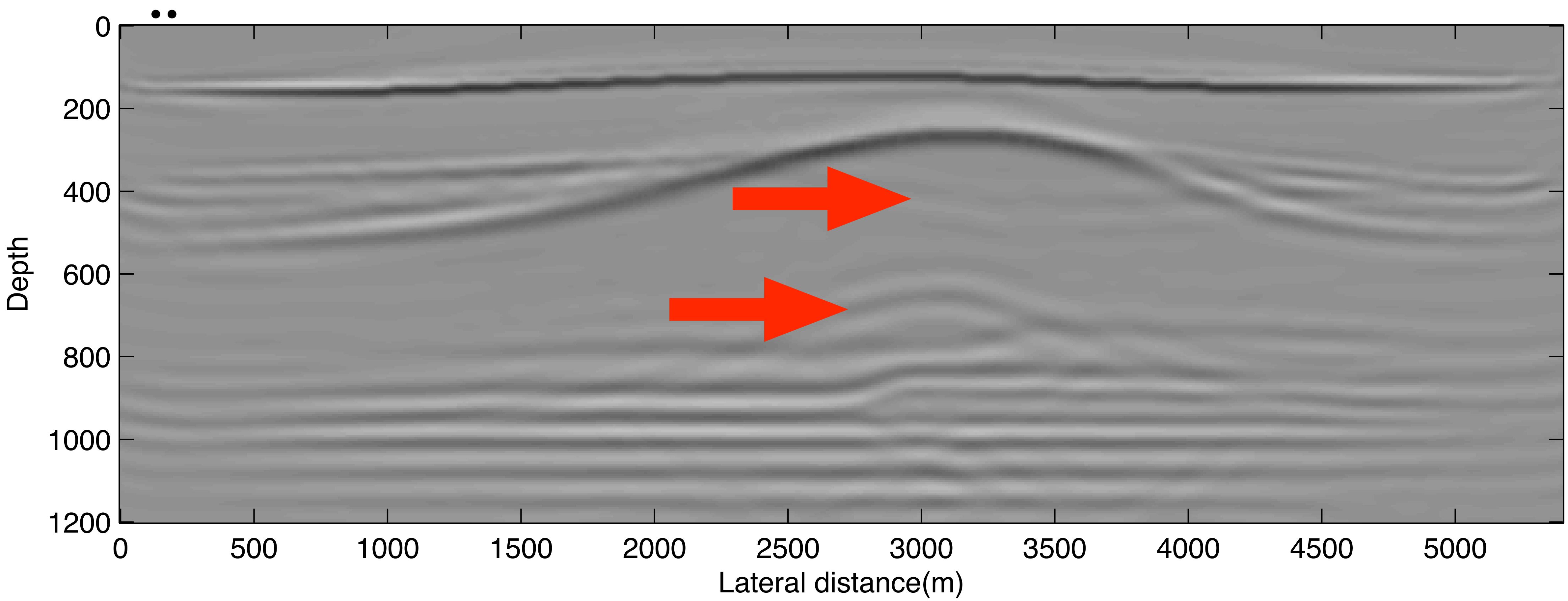
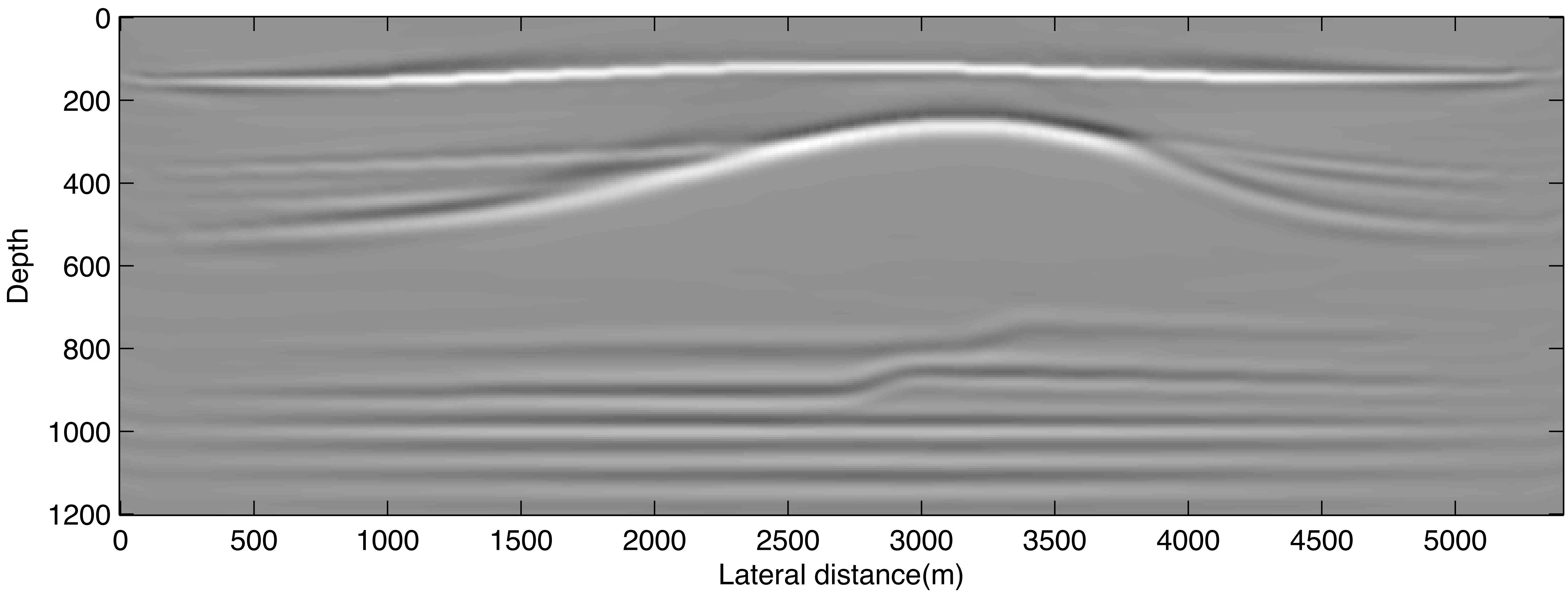
Courtesy of Verschuur, 2009

Motivation



a migrated section from data with multiples

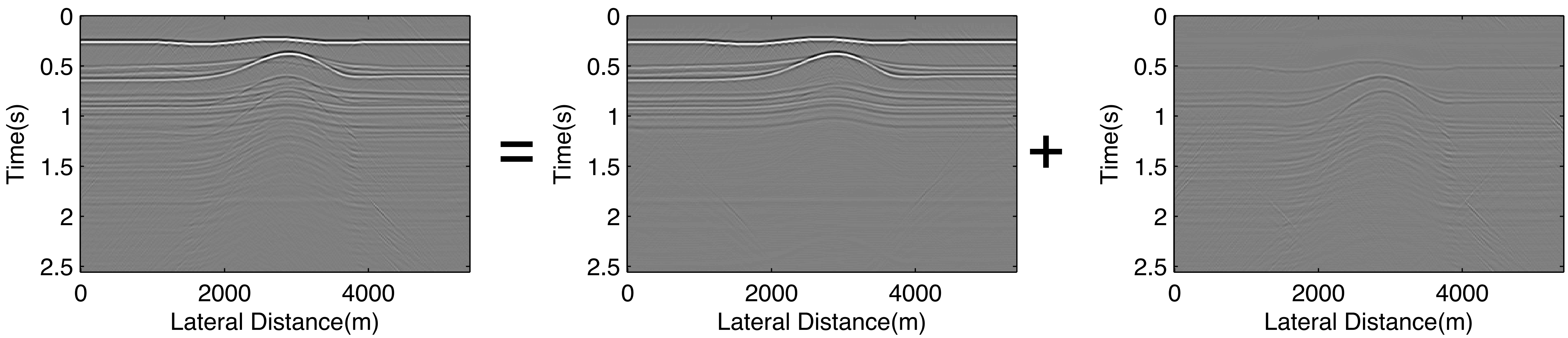
Motivation



a migrated section from multiple free data

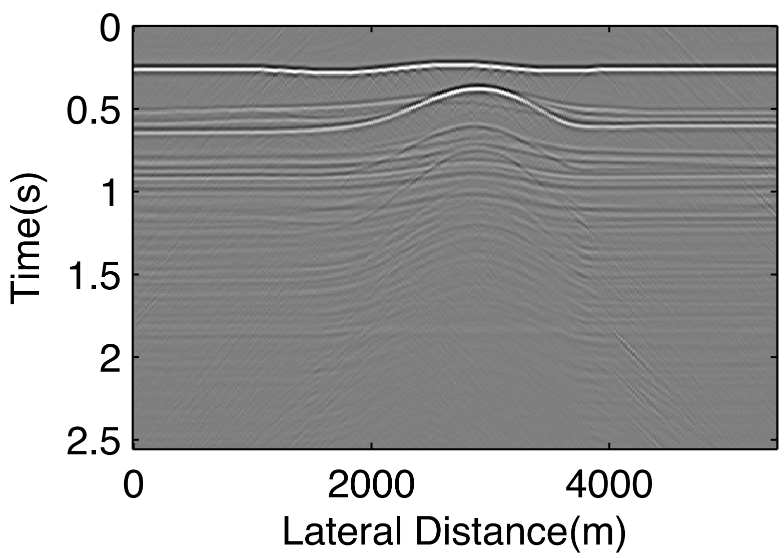
Motivation

So...



Motivation

So...



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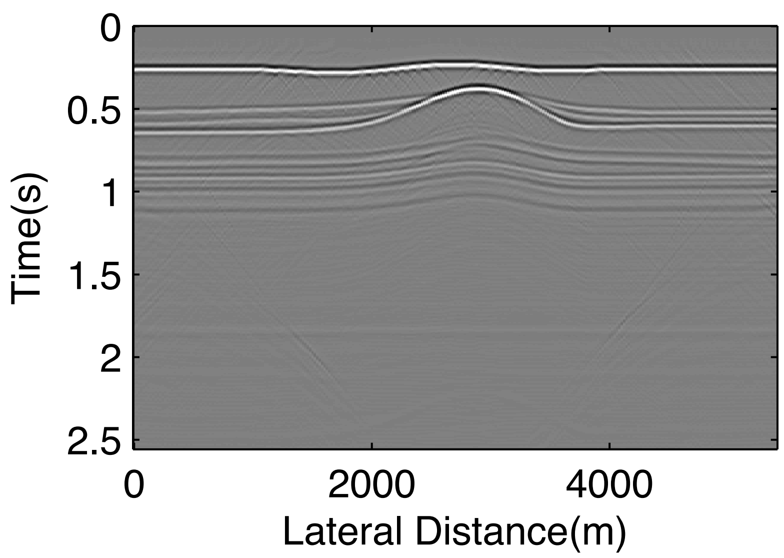

+

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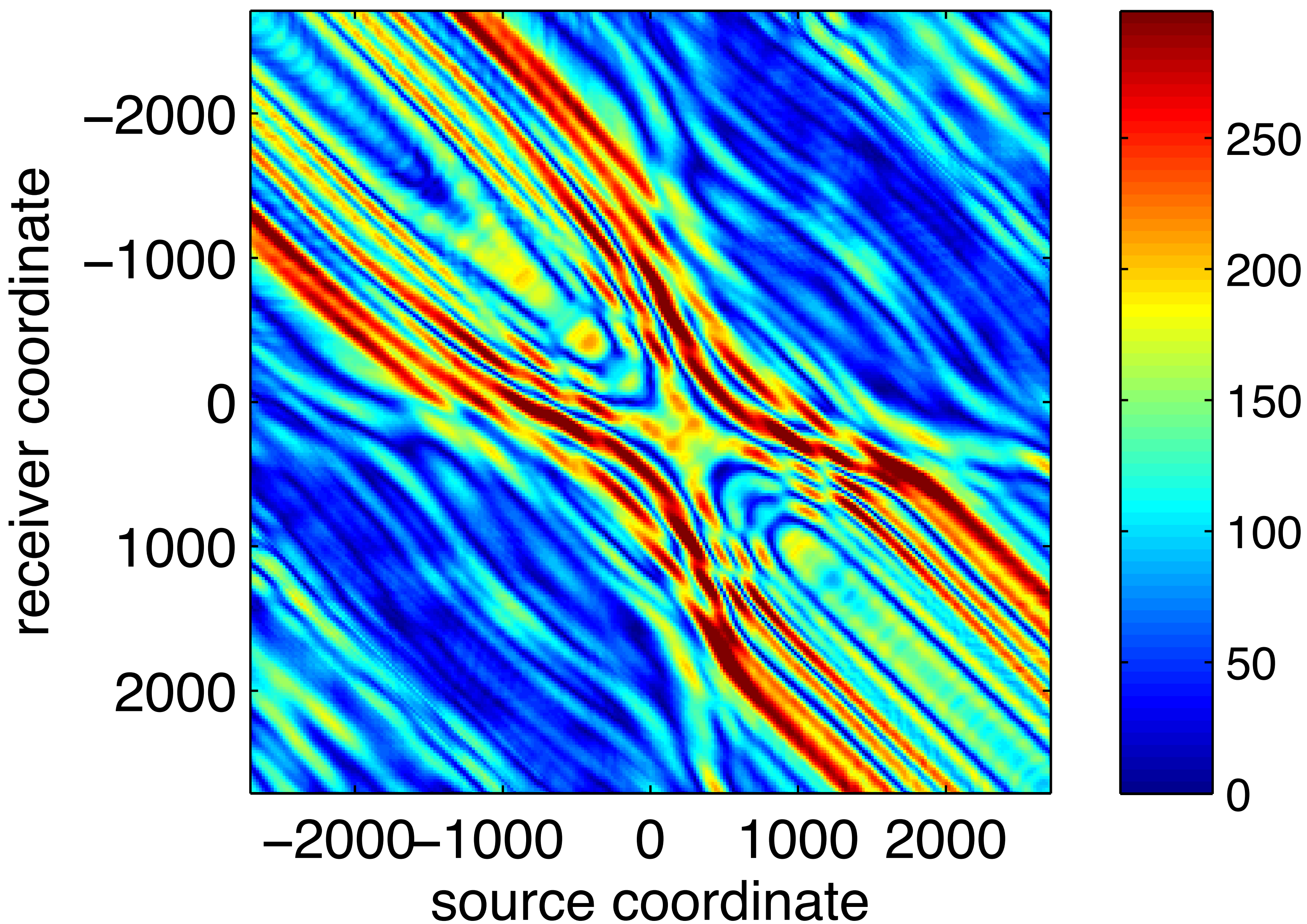
Rethink multiples



amplitude spectrum: primaries @15Hz

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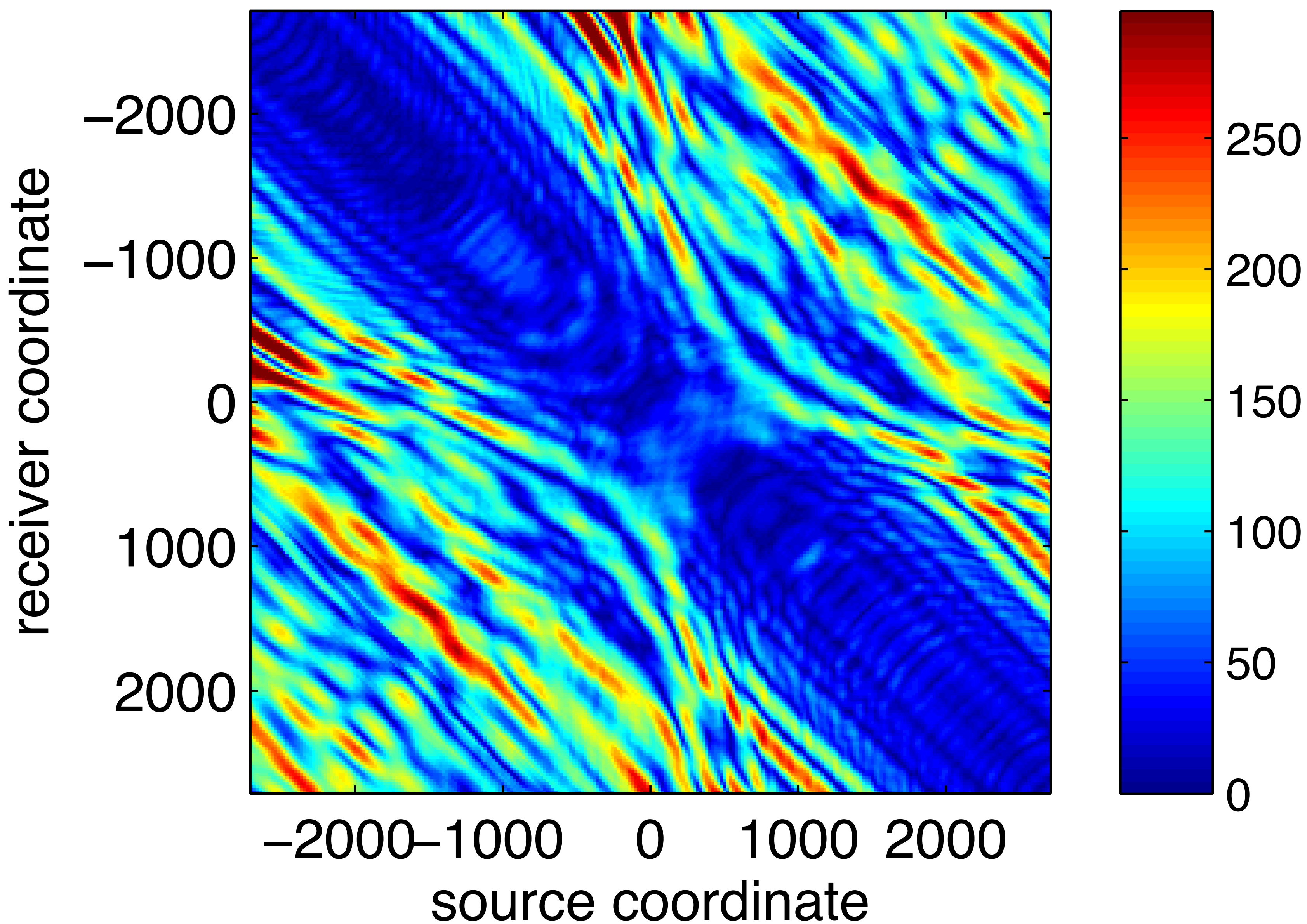
Rethink multiples



amplitude spectrum: multiples @15Hz

Rethink multiples

Surface-related multiples:

- provide wider illumination angles
- contain more higher spatial wavenumber contents
- more sensitive to velocity changes

Rethink multiples

They may help to deduce subsurface structure...but how?

van Groenestijn and Verschuur, 2009

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Motivation

- EPSI (Estimation of Primaries via Sparse Inversion) exploits the sparsity of the up-going Green’s function
- EPSI tries to derive the Green’s function
- velocity perturbation is a lot sparser than Green’s function

Motivation

There seems to be some interaction between EPSI and imaging...what about let them get married, and how?

Tarantola, 1984

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Multiples in imaging

Introduce free surface to the ‘smooth’ background velocity model

- violates the Born approximation assumptions
- more requirements on the exactness of the velocity model

Reiter, 1991

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Multiples in imaging

Full-waveform inversion

- "de-multiple" before inversion
- consists of several migration based updates

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Berkhout and Verschuur, 2003

Multiples in imaging

Focal transform

- first multiples mapped to primaries
- needs the estimate of the primaries as the operator
- de-multiple followed by migration

Our approach

We combine EPSI with migration

- EPSI models primaries as well as multiples
- combine EPSI with sparsity promoting migration

Verschuur, 1992

Lin and Herrmann, 2010

Herrmann, 2008

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EPSI Formulation

EPSI reveals the relationship:

$$\hat{\mathbf{P}} = \hat{\mathbf{G}}(\hat{\mathbf{Q}} - \hat{\mathbf{P}})$$

Formulating the EPSI operator:

$$\underbrace{\mathcal{F}_t^* \mathrm{BlockDiag}_{\mathrm{f}}[(\hat{\mathbf{Q}} - \hat{\mathbf{P}})^* \otimes \mathbf{I}]\mathcal{F}_{\mathbf{t}}}_{\mathbf{E}}\, \mathbf{g} = \mathbf{p}$$

van Groenestijn and Verschuur, 2009

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EPSI Formulation

$$\tilde{\mathbf{g}} = \underset{\mathbf{g}}{\mathrm{argmin}} \, ||\mathbf{p} - \mathbf{E}\mathbf{g}||_\mathbf{2} \ \mathbf{s.t.} ||\mathbf{g}||_\mathbf{0} \leq \mathbf{k}\tau$$

$\tilde{\mathbf{g}}$: estimate of the Green's function

$\mathbf{p}$: the up-going wavefield

Robust EPSI

Replace the computationally prohibitive L_0 norm with L_1 norm.

Robust EPSI:

$$\tilde{\mathbf{g}} = \underset{\mathbf{g}}{\operatorname{argmin}} ||\mathbf{g}||_{\mathbf{1}} \text{ s.t.} ||\mathbf{p} - \mathbf{E}\mathbf{g}||_{\mathbf{2}} \leq \sigma$$

Nemeth, 1999

Wang and Sacchi, 2007

Regularized least-squares migration

Regularized least-squares migration:

$$\delta\tilde{\mathbf{m}} = \underset{\delta\mathbf{m}}{\operatorname{argmin}} \frac{1}{2}||\mathbf{g} - \mathbf{K}\delta\mathbf{m}||_{\mathbf{2}}^{\mathbf{2}} + \lambda||\delta\mathbf{m}||_{\mathbf{2}}^{\mathbf{2}}$$

Herrmann and Li, 2010

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Sparsity promoting migration

Sparsity-promoting migration:

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \operatorname*{argmin}_{\delta\mathbf{x}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\mathbf{g} - \mathbf{K}\mathbf{S}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

Combine EPSI with migration

We formulate this linearized inversion process as

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \underset{\delta\mathbf{x}}{\operatorname{argmin}} ||\delta\mathbf{x}||_1 \text{ s.t.} ||\mathbf{p} - \mathbf{EKS}^*\delta\mathbf{x}||_2 \leq \sigma$$

Numerical experiments

Make linearized data:

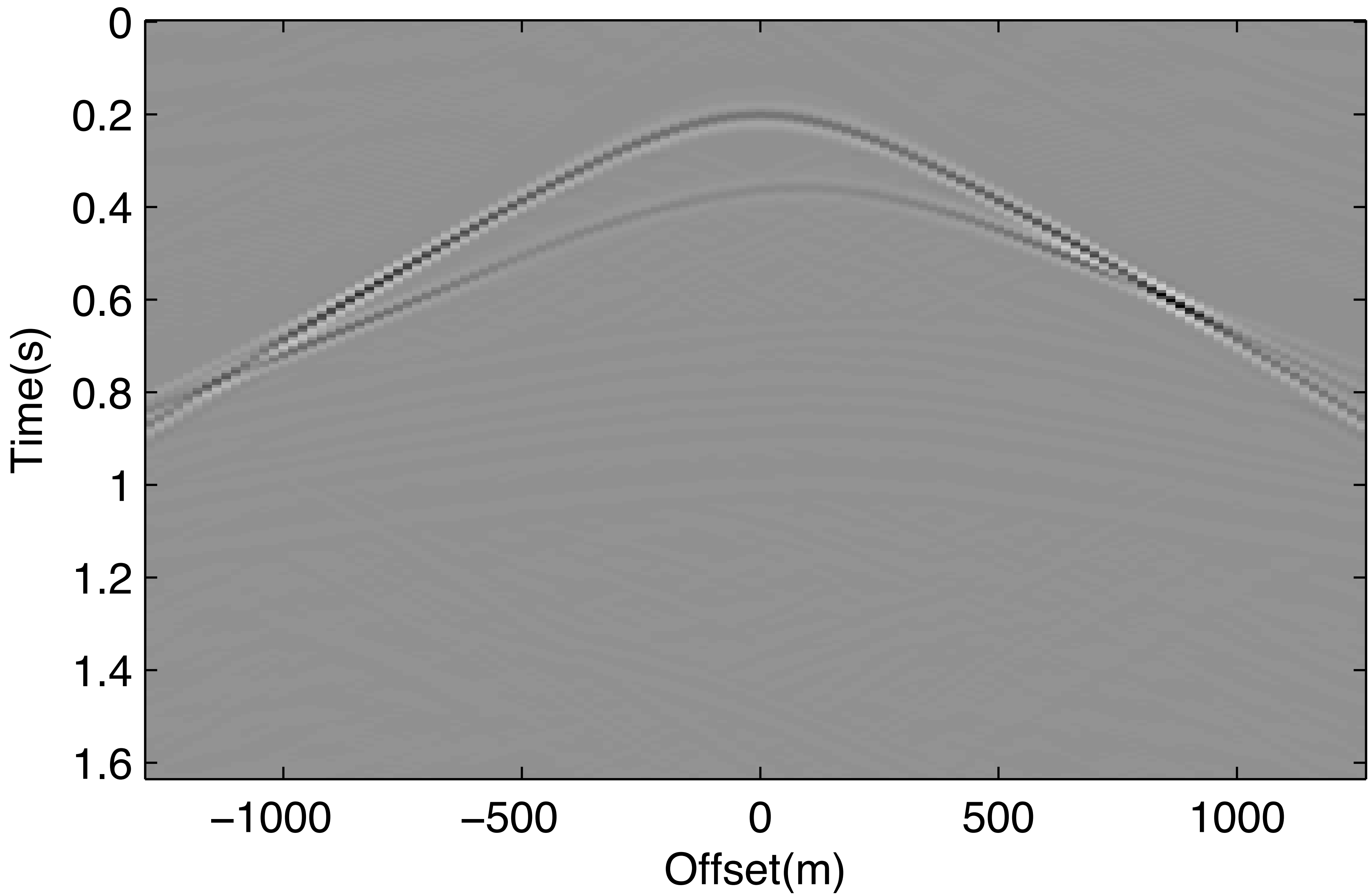
- multiple-free data

$$\mathbf{p_1} = \mathbf{K}\delta\mathbf{m}$$

- data with multiples

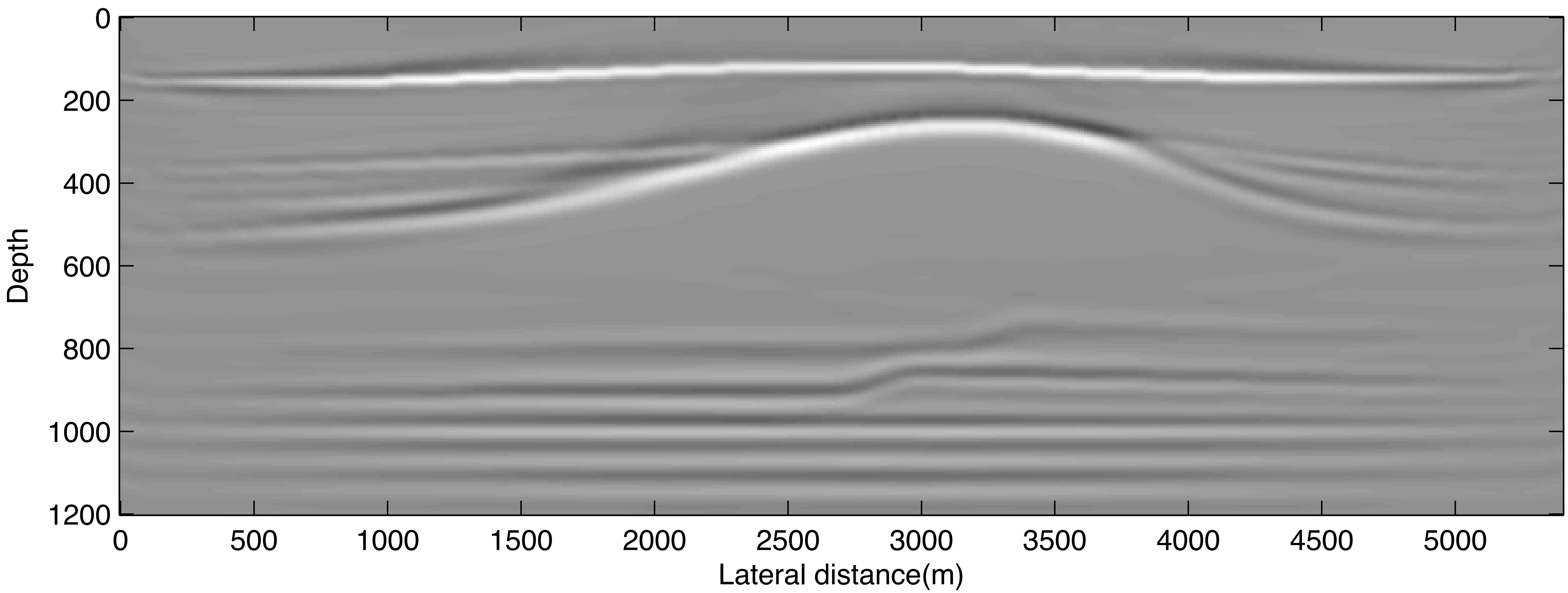
$$\mathbf{p_2} = \mathbf{E}\mathbf{K}\delta\mathbf{m}$$

Data preview: multiple free



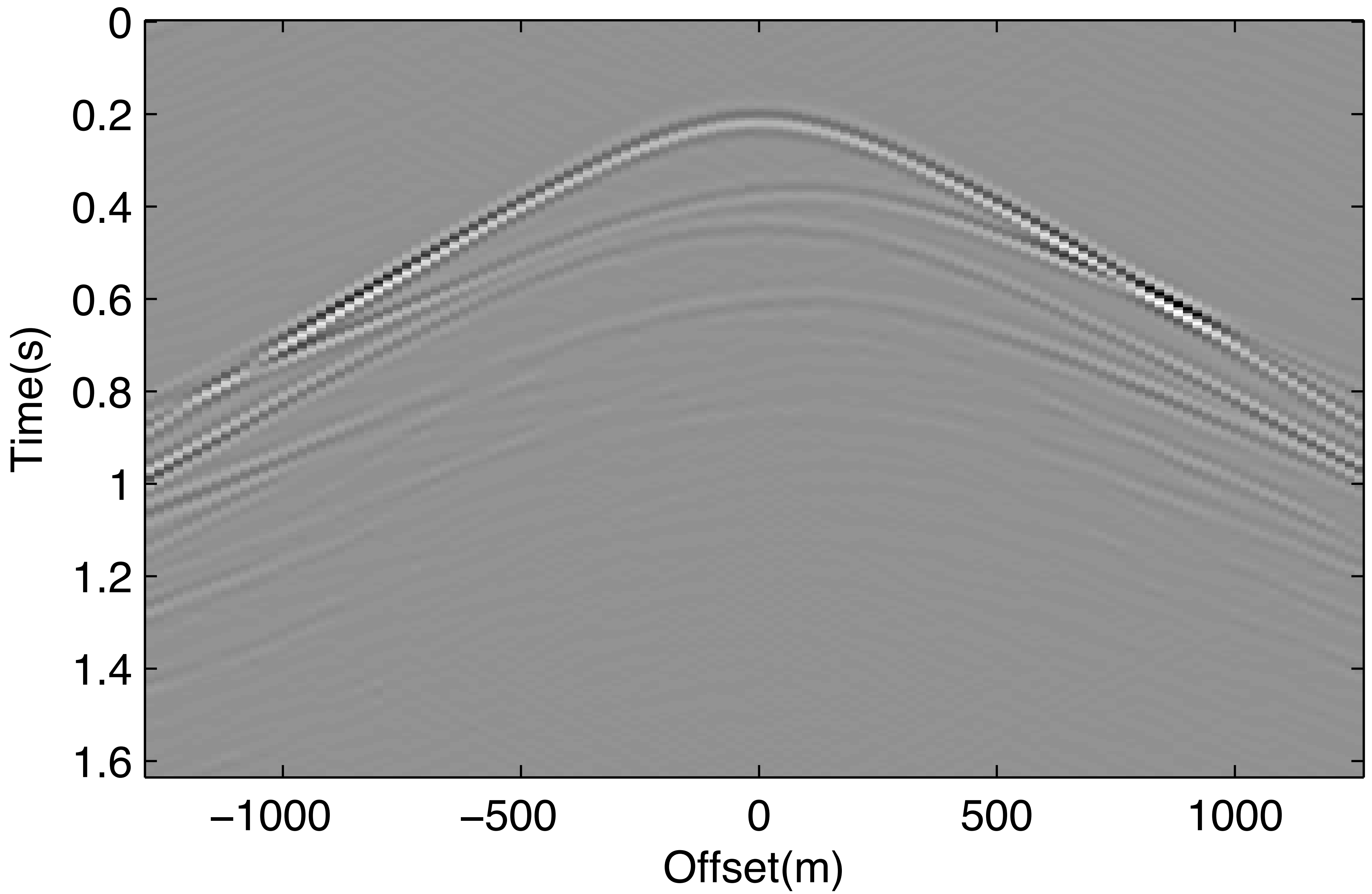
total shots: 128, shot number: 65

Image preview: multiple free



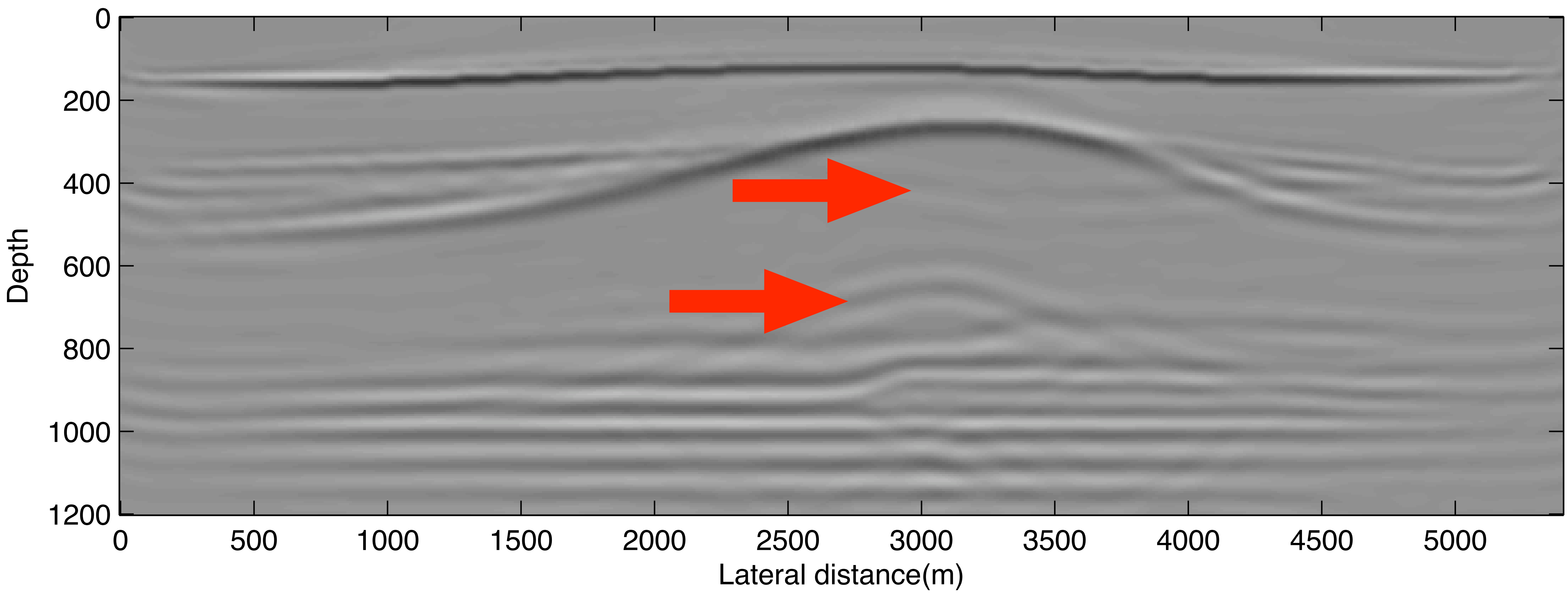
migrated section: time-weighted

Data preview: with multiples



total shots: 128, shot number: 65

Image preview: with multiples



Scenario 1

Sparse inversion from multiple free data:

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \operatorname*{argmin}_{\delta\mathbf{x}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\mathbf{p_1} - \mathbf{K}\mathbf{S}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

Scenario 2

Sparse inversion from data with multiples:

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \underset{\delta\mathbf{x}}{\operatorname{argmin}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\mathbf{p_2} - \mathbf{KS}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

van der Berg and Friedlander, 2008

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Scenario 3

Sparse inversion with EPSI from data with multiples:

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \underset{\delta\mathbf{x}}{\operatorname{argmin}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\mathbf{p_2} - \mathbf{EKS}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

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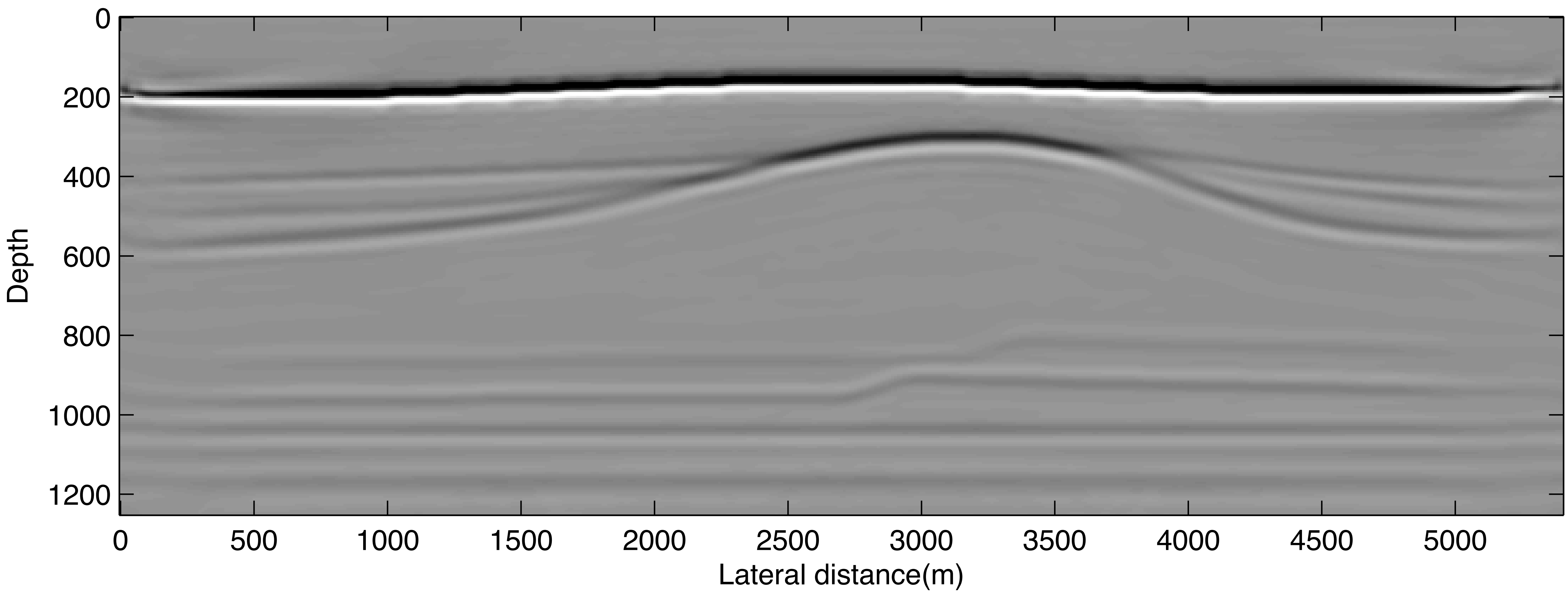
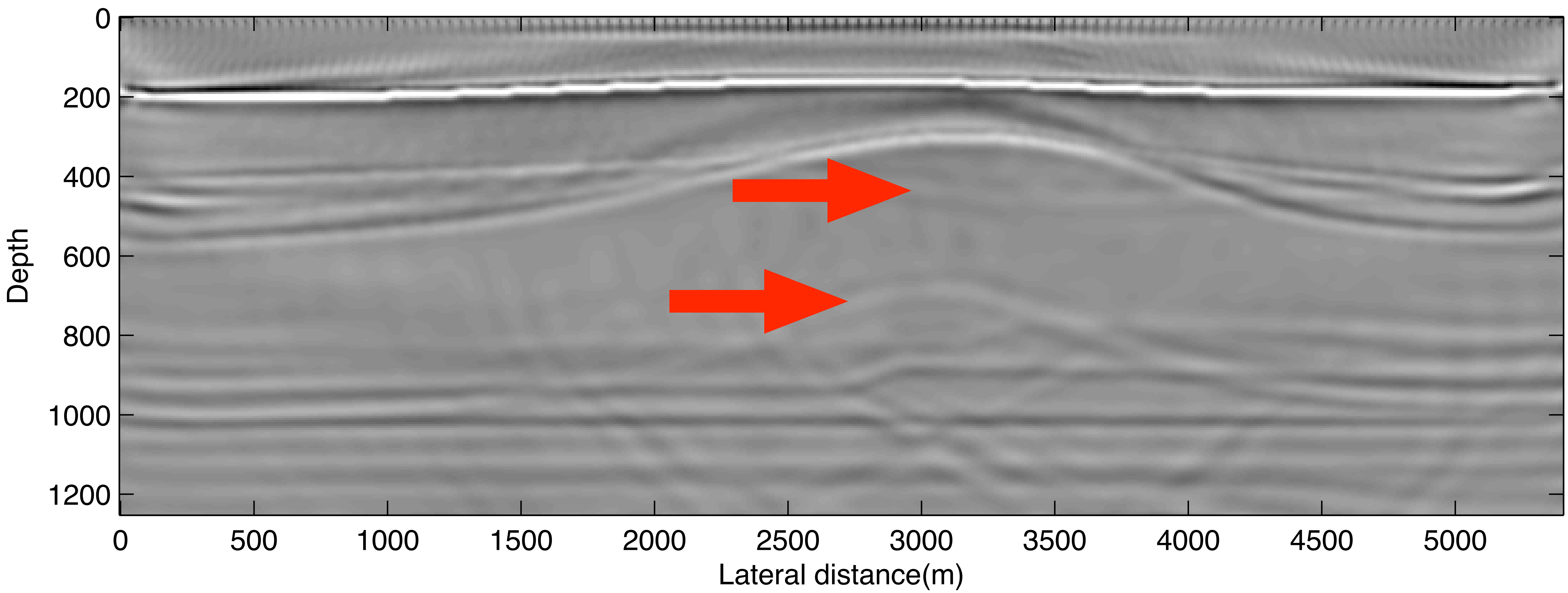
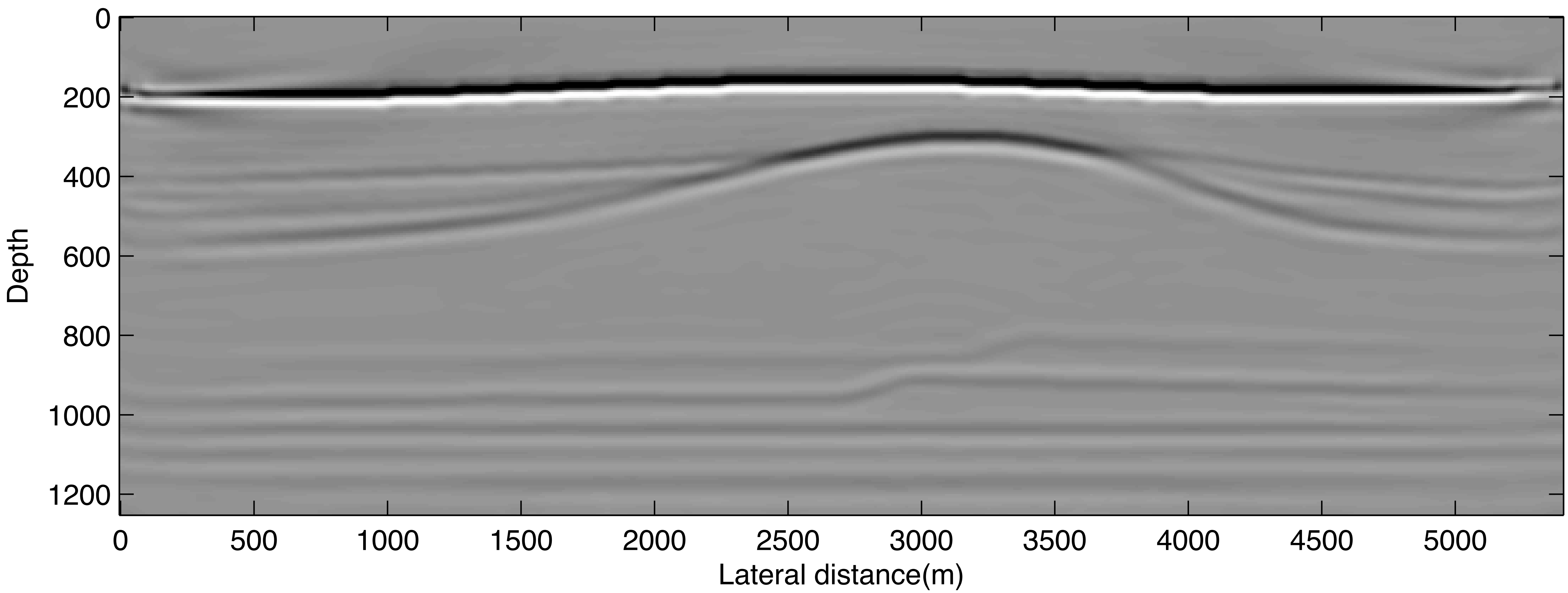
Sparse inversion of multiple-free data



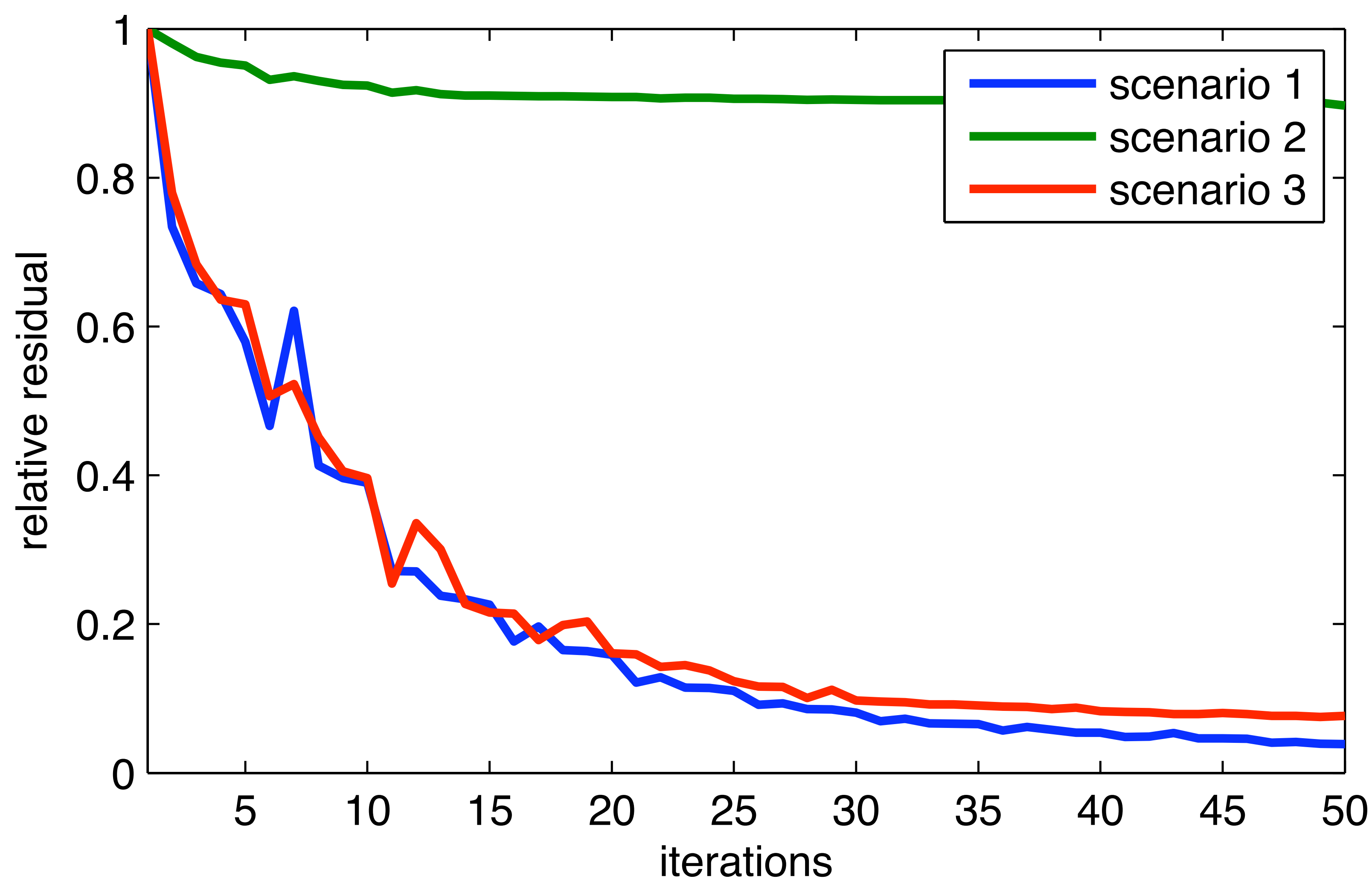
Sparse inversion of data with multiples



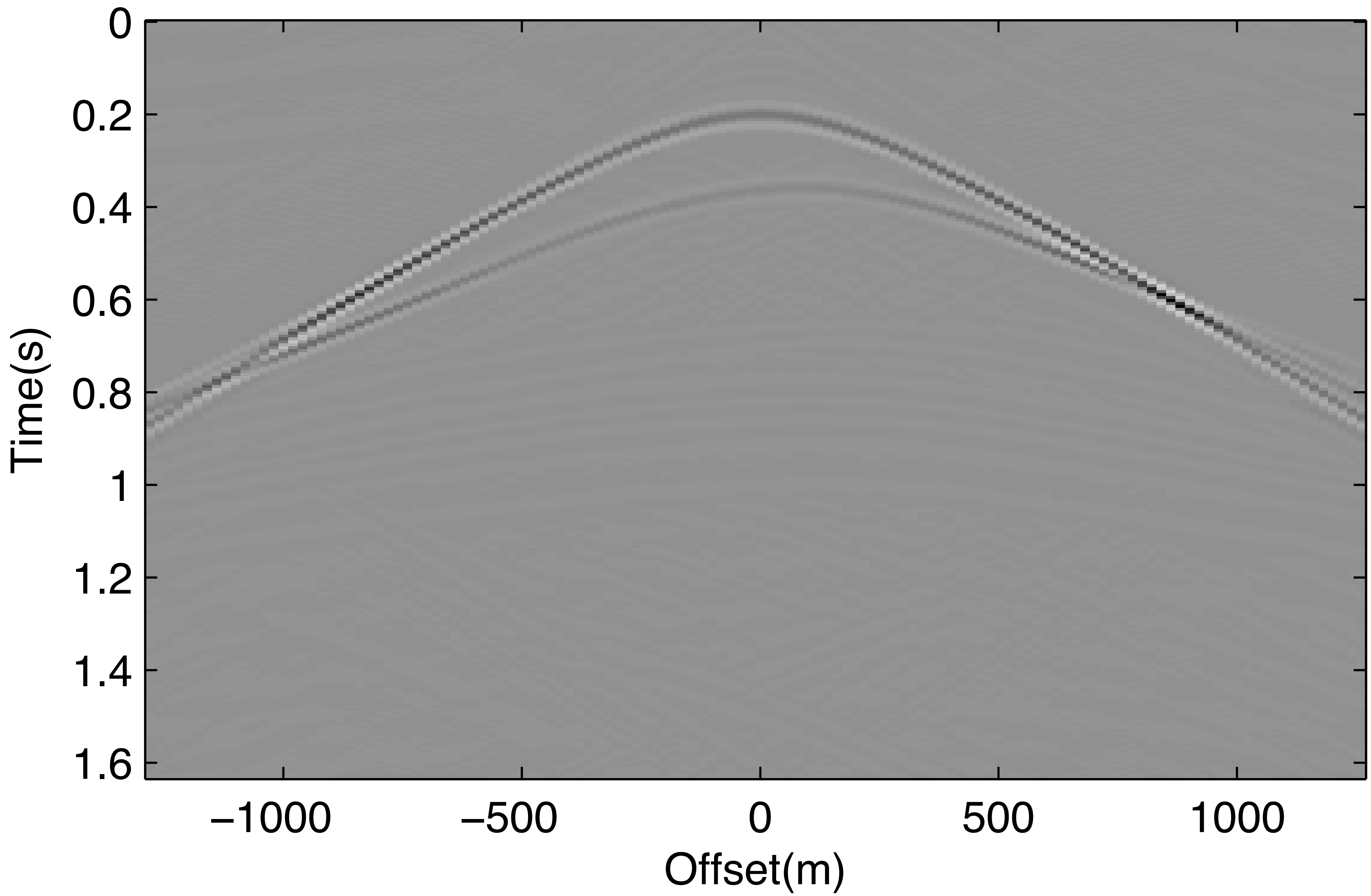
Sparse inversion of data with multiples with EPSI



Convergence rate with/ without EPSI



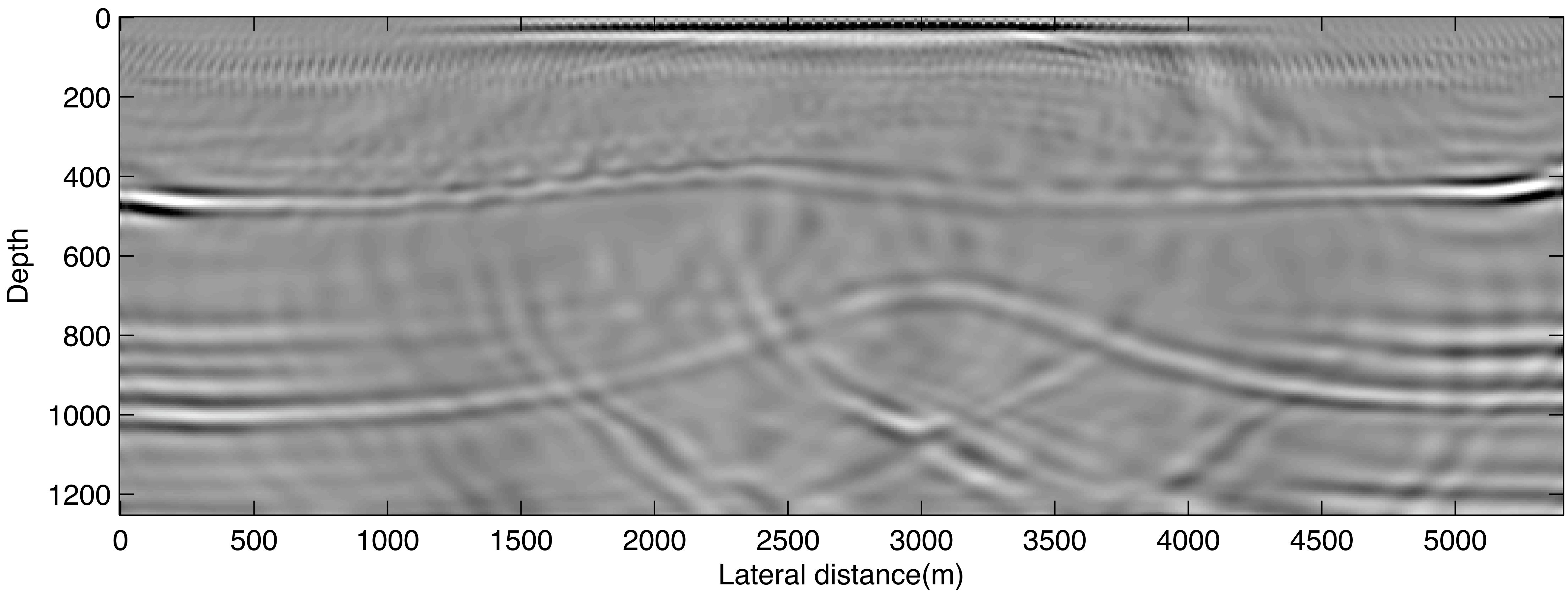
De-migrated section



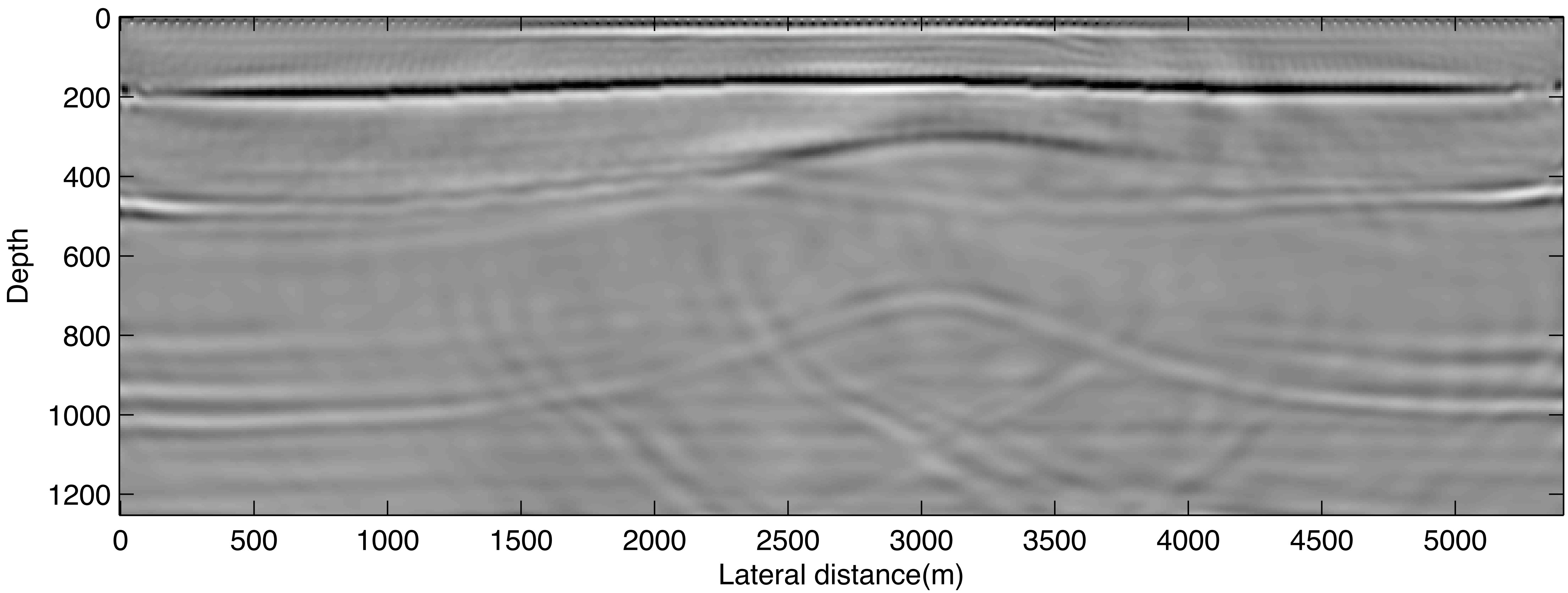
total shots: 128, shot number: 65, SNR: 23dB

Guitton, 2002

Sparse inversion of multiples



Sparse inversion of multiples with EPSI



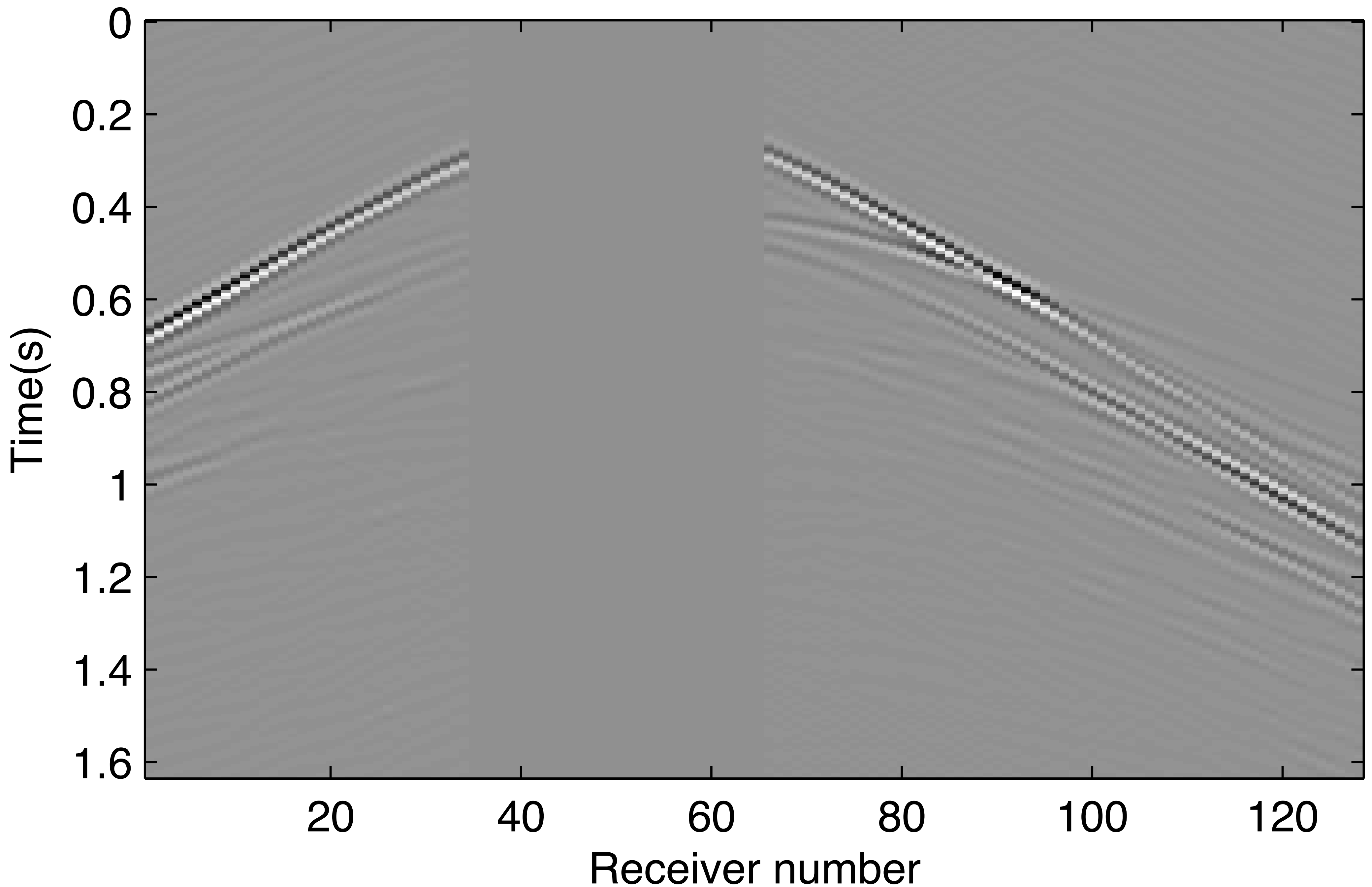
Do multiples really help ?

Both scenario 1 and scenario 3 give good results…How about when only incomplete data is available?

Incomplete dataset

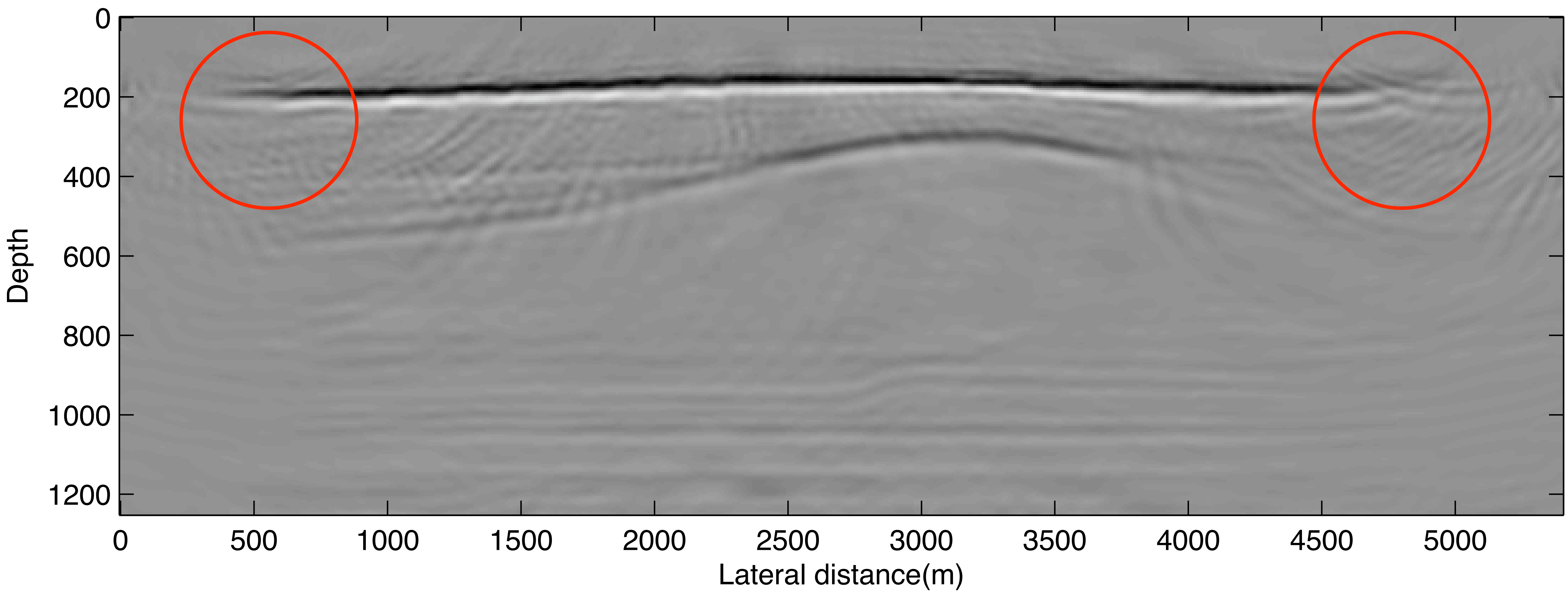
- 16 sequential shots
- 300m missing near-offset
- 7 frequencies

Data preview



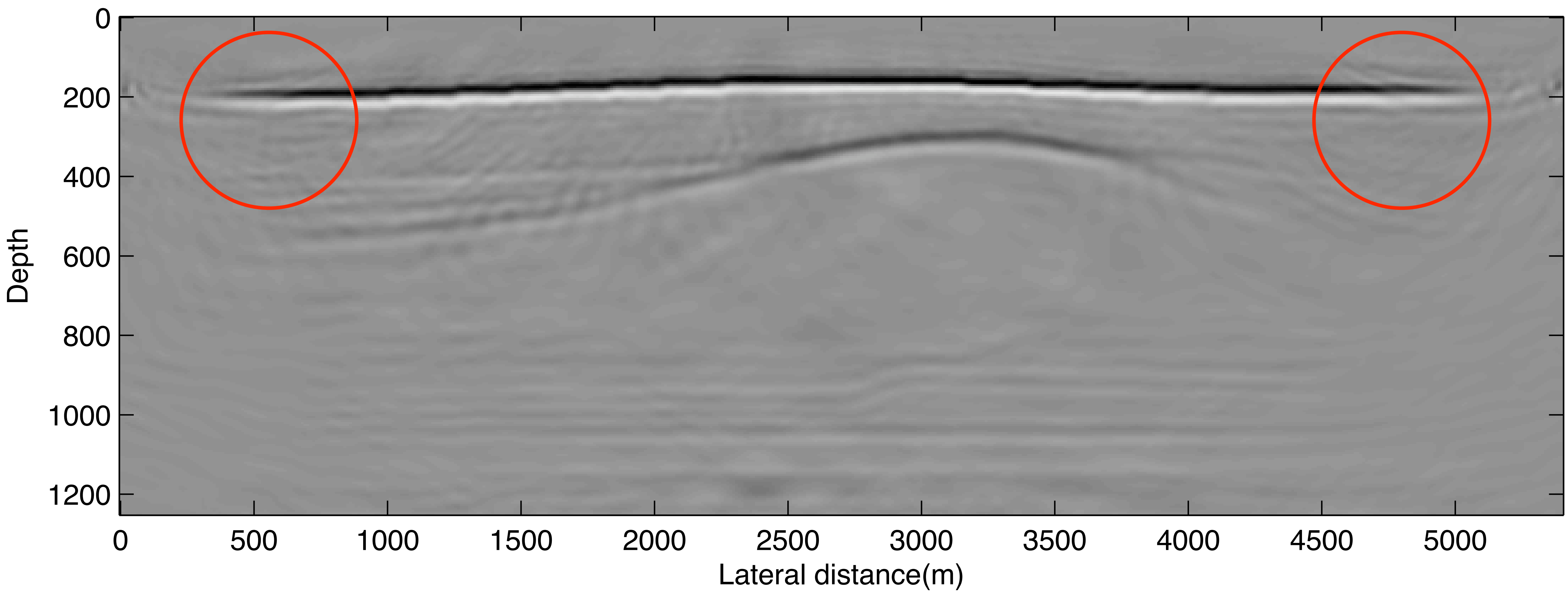
total shots: 16

Sparse inversion from multiple-free data



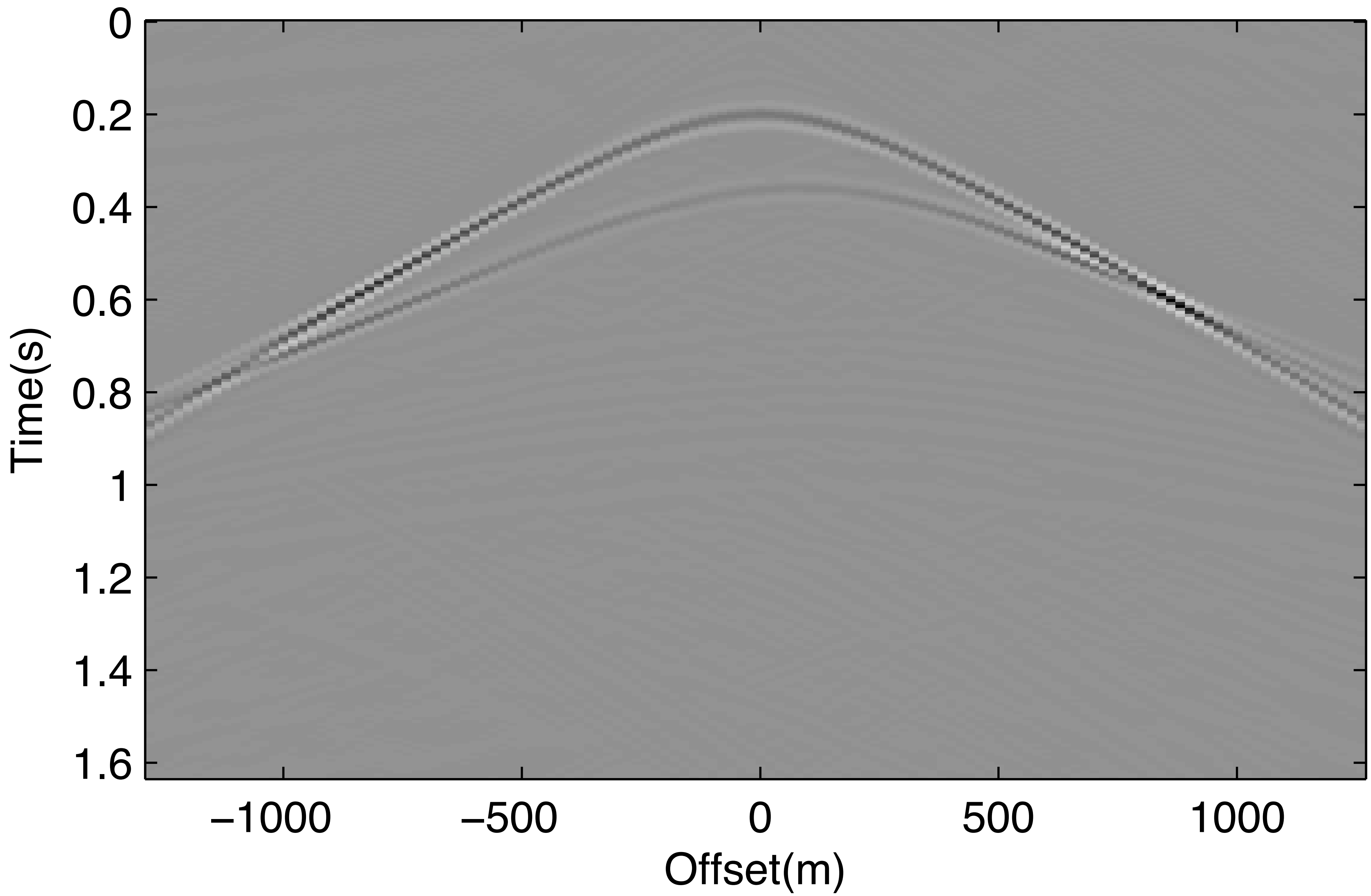
SNR: 3.08dB (compared to true dm)

Sparse inversion of data with multiples with EPSI



SNR: 3.72dB (compared to true dm)

Recovered Green's function



total shots: 128, shot number: 65, SNR: 15.4dB

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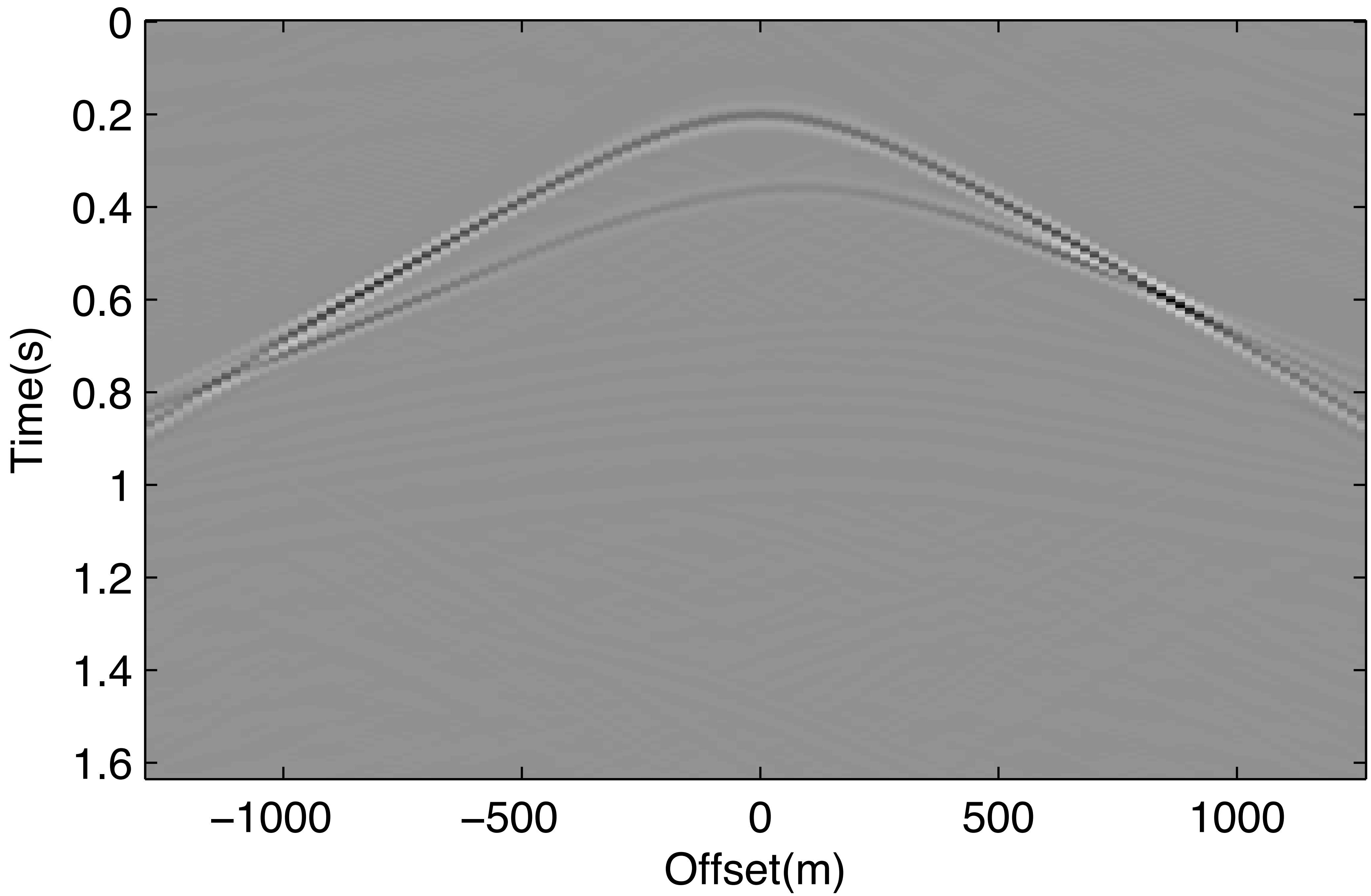
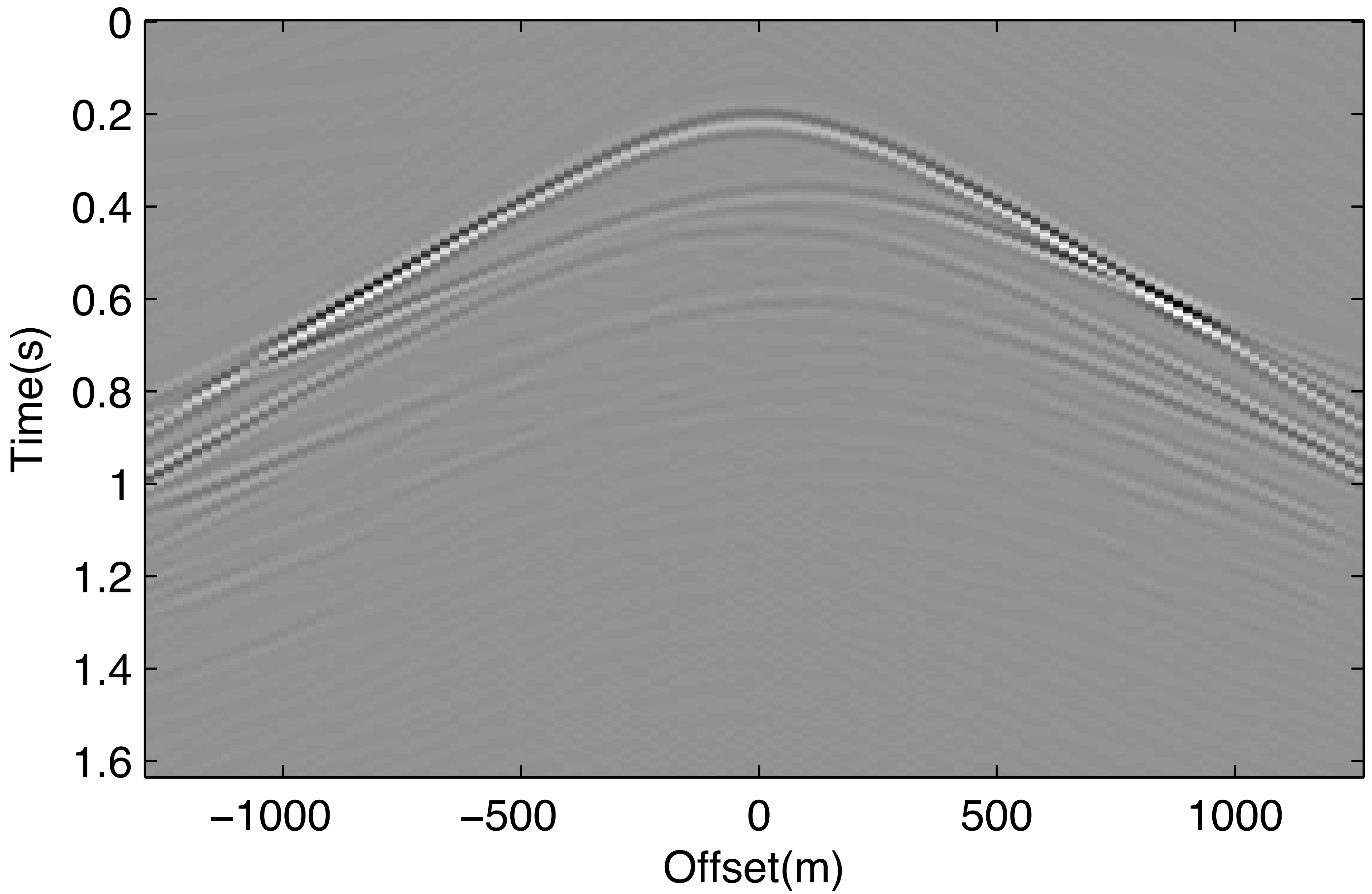
Multiple free data



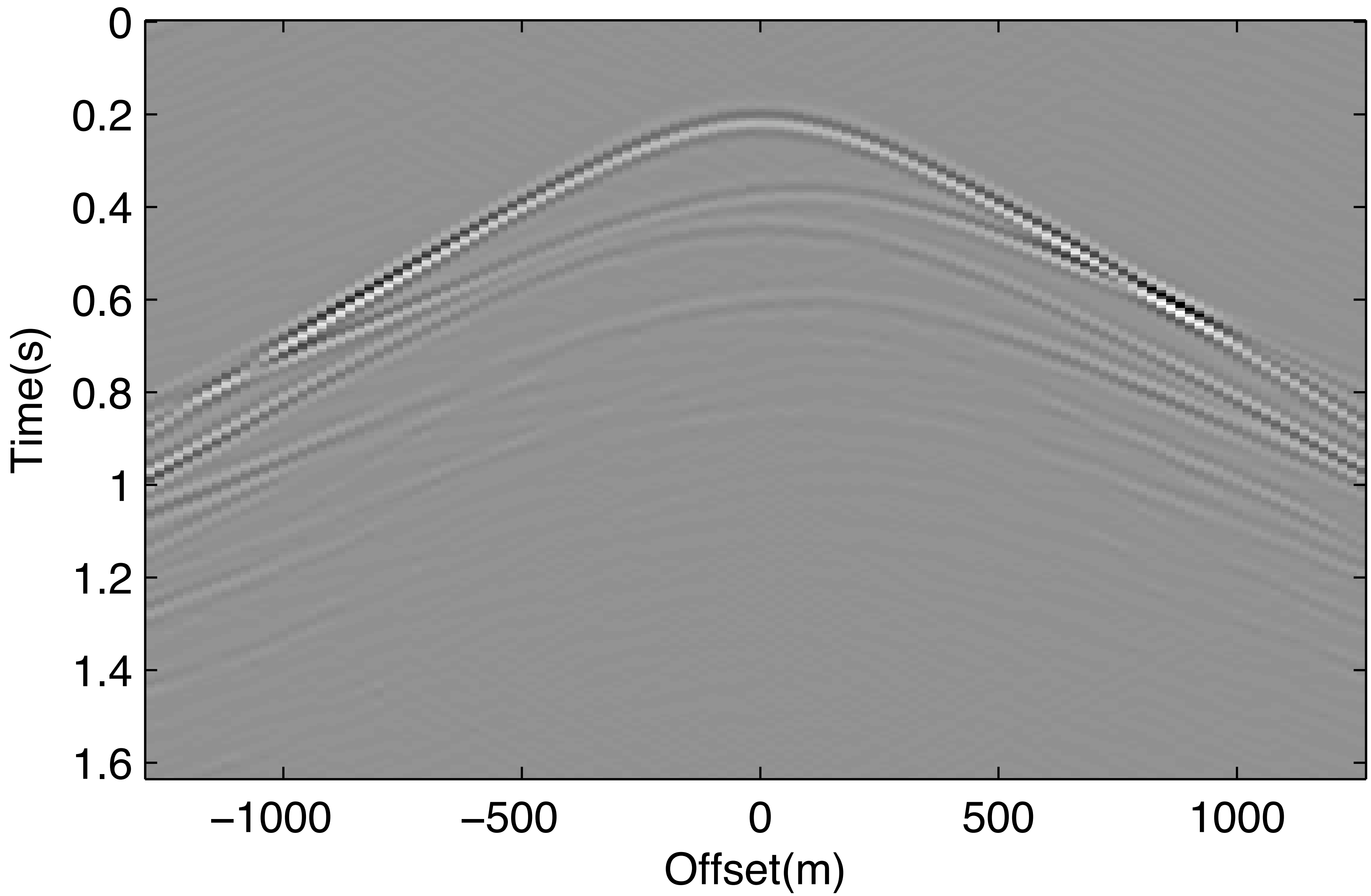
total shots: 128, shot number: 65

Recovered full wavefield



total shots: 128, shot number: 65, SNR: 13.9dB

Data with multiples



total shots: 128, shot number: 65

In EPSI's point of view

- Velocity perturbation is sparser than Green's function
- So one joint inversion could perform better than two separate inversions

Two schemes

- scheme 1: joint inversion

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \operatorname*{argmin}_{\delta\mathbf{x}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\tilde{\mathbf{p}} - \mathbf{RMEKS}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

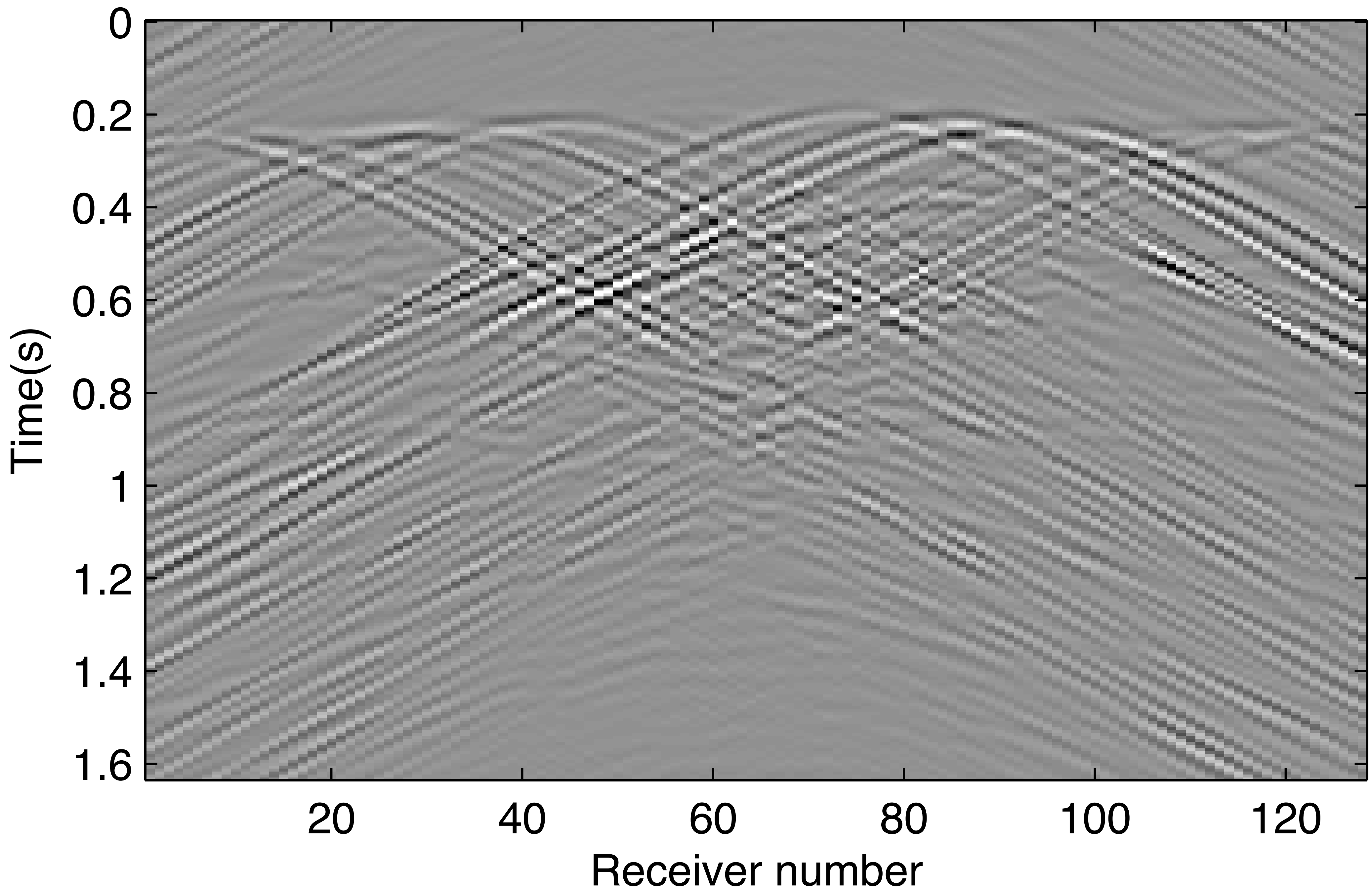
- scheme 2: two separate inversions

$$\tilde{\mathbf{g}} = \mathbf{S}^* \operatorname*{argmin}_{\delta\mathbf{x}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\tilde{\mathbf{p}} - \mathbf{RMES}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \operatorname*{argmin}_{\delta\mathbf{x}} ||\delta\mathbf{x}||_\mathbf{1} \text{ s.t.} ||\tilde{\mathbf{g}} - \mathbf{KS}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

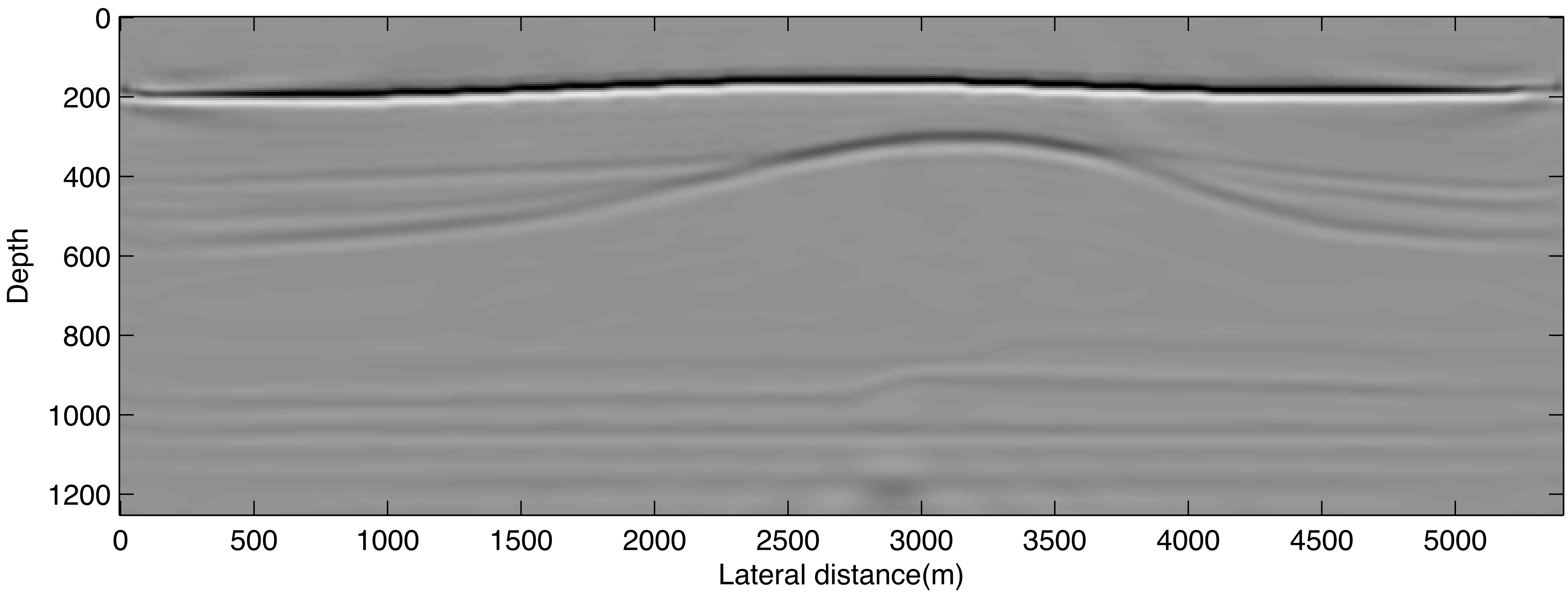
- 12 simultaneous shots in both schemes

Data preview



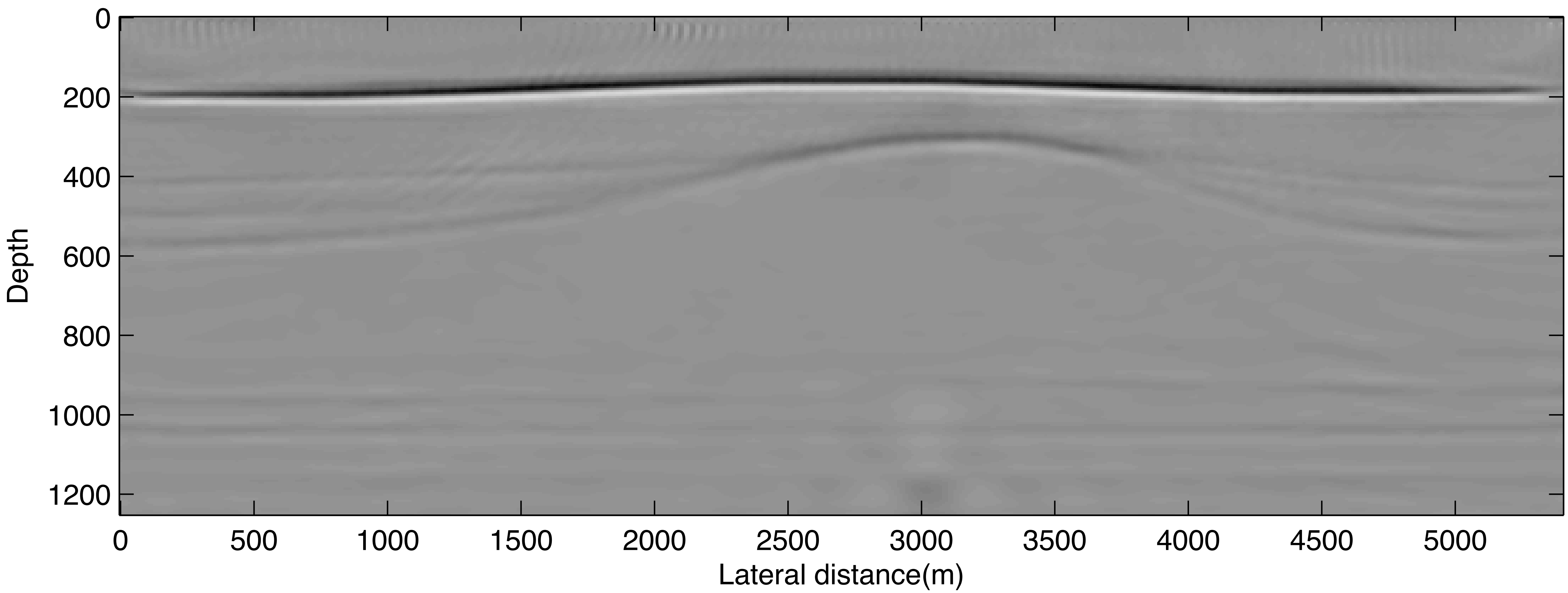
total shots: 12

Joint inversion



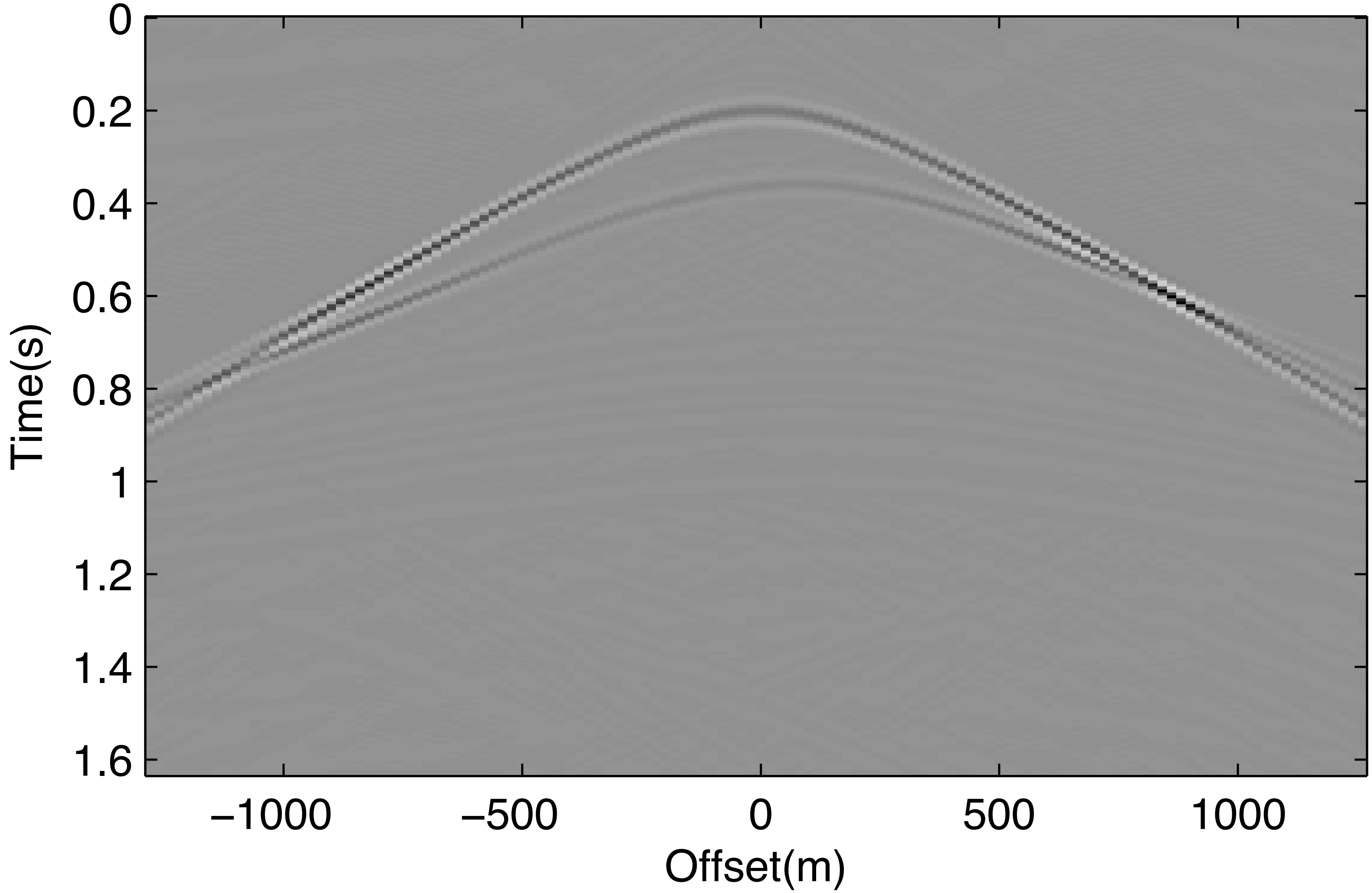
SNR: 5.30dB (compared to true dm)

Two separate inversions



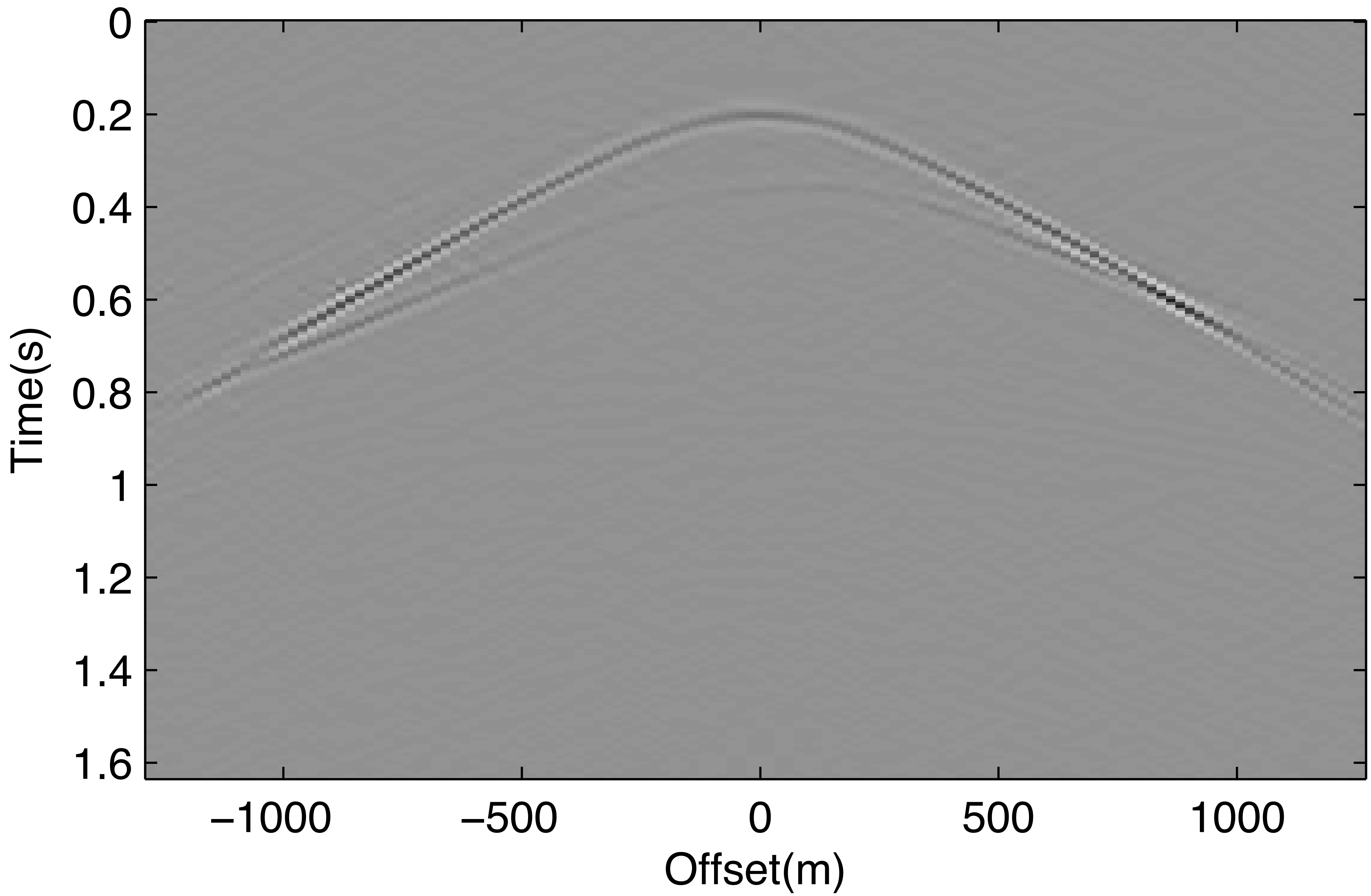
SNR: 4.52dB (compared to true dm)

Recovered Green's function in joint inversion



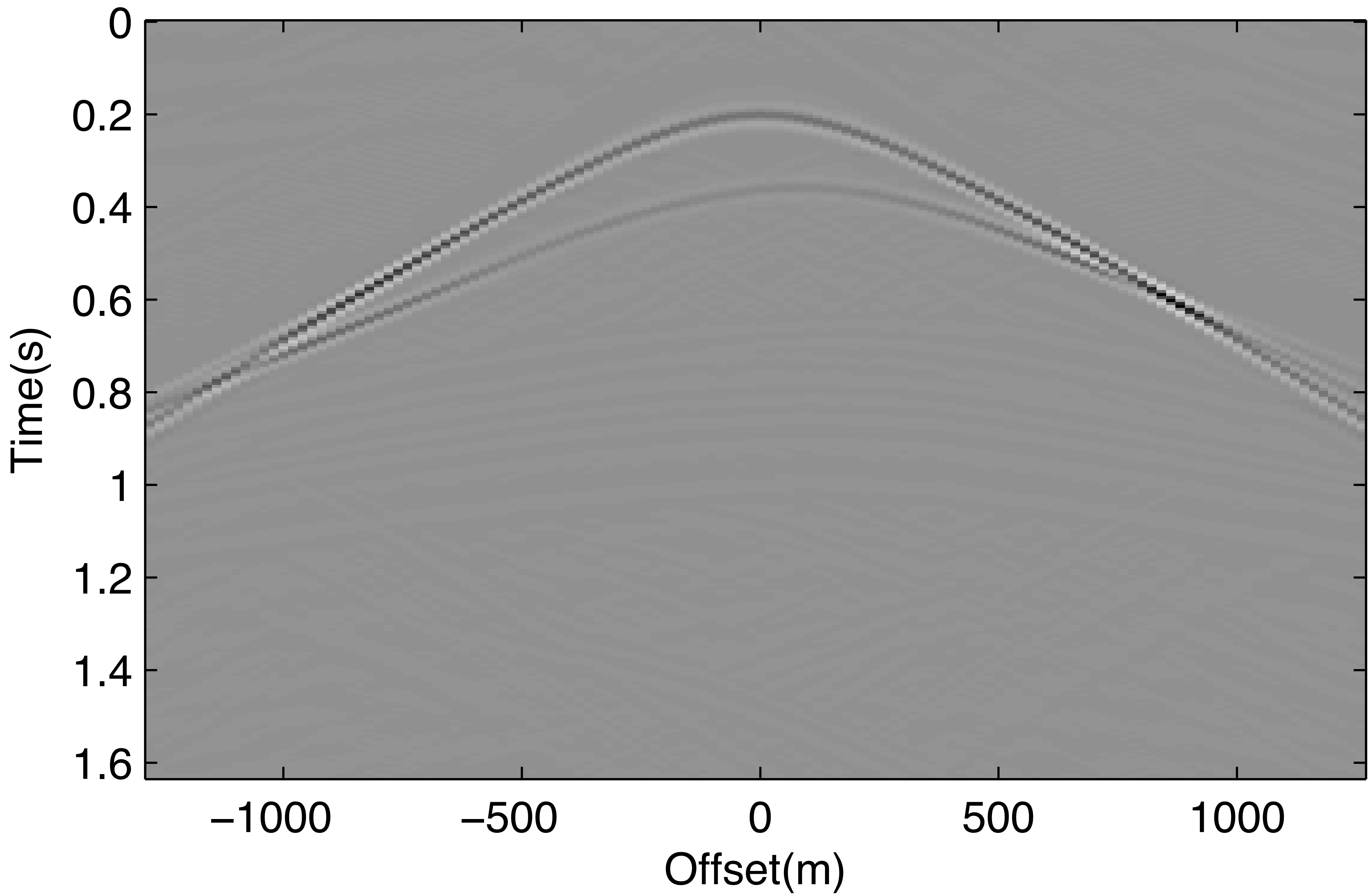
total shots: 128, shot number: 65, SNR: 22.4dB

Recovered Green's function in separate inversions



total shots: 128, shot number: 65, SNR: 5.4dB

Data preview: multiple free



total shots: 128, shot number: 65

Conclusions

By combing EPSI with migration:

- multiples are well handled
- multiples help imaging
- better primary estimation results

Future plans

Alternating optimization

- now EPSI operator is built using a pre-calculated wavelet
- wavelet will be estimated during the imaging process

Work on real-data

Incorporate into full-waveform inversion

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