SINBAD Consortium 2010

Sparsity-promoting migration with surface-related multiples

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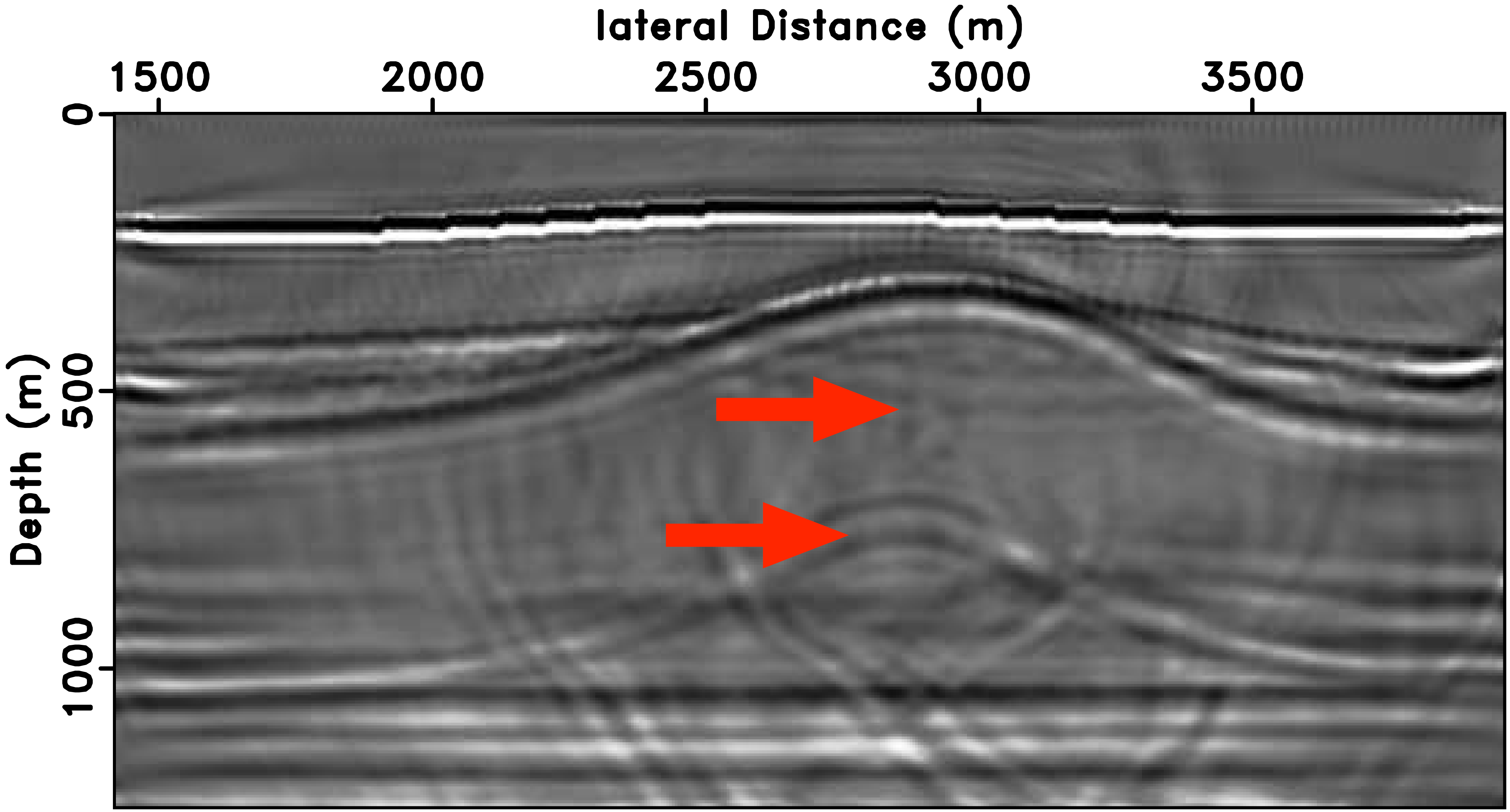
SLIM

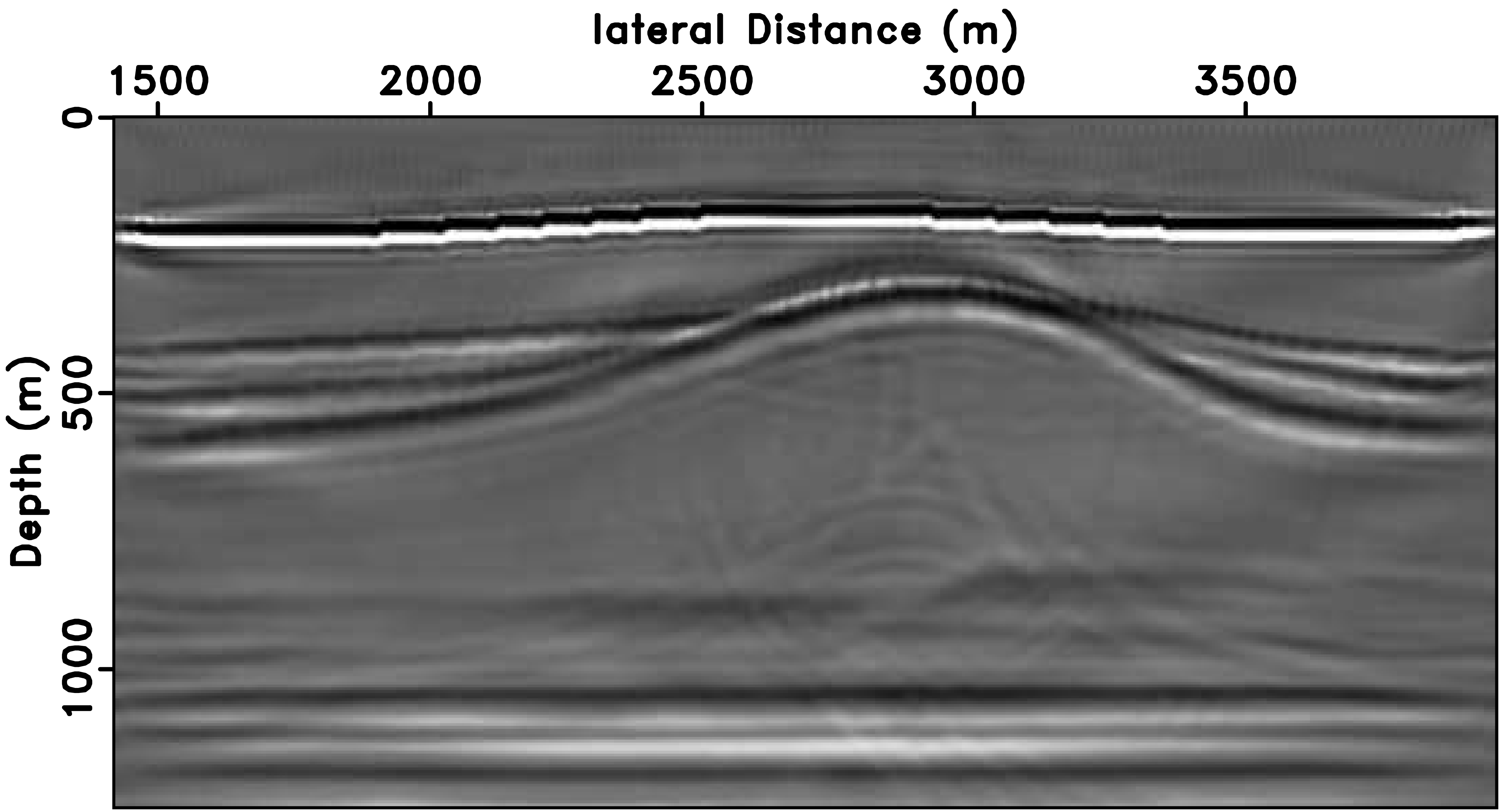
University of British Columbia

Motivation



Migration from data with surface multiples

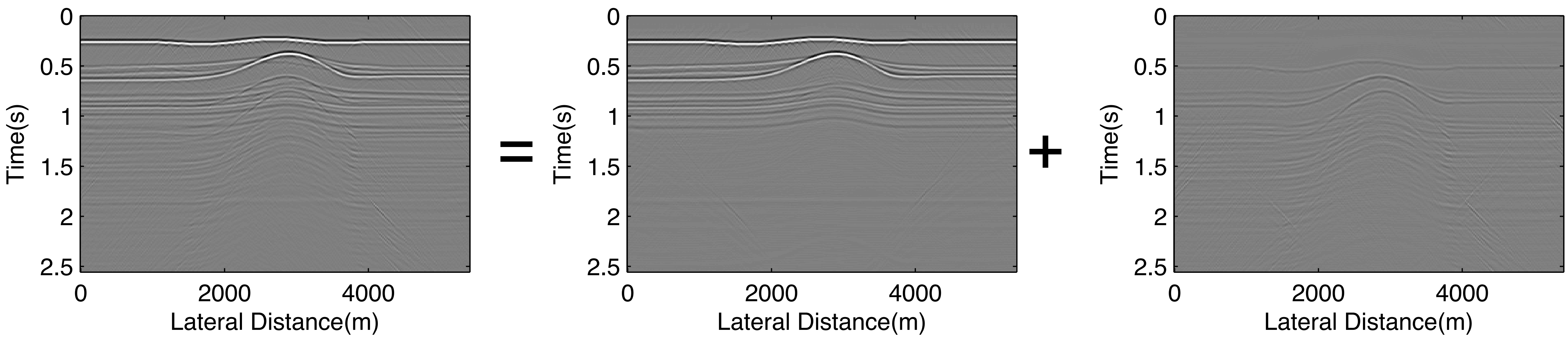
Motivation



Migration from data without surface multiples

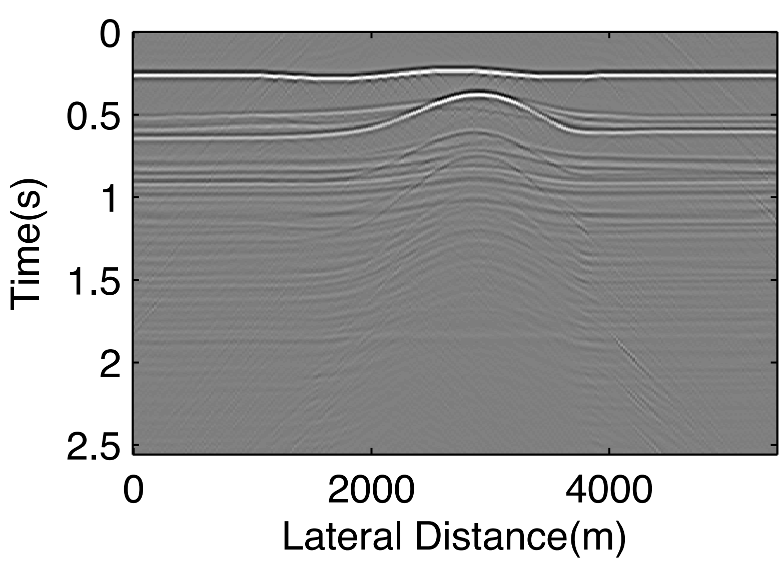
Motivation

So...



Motivation

So...



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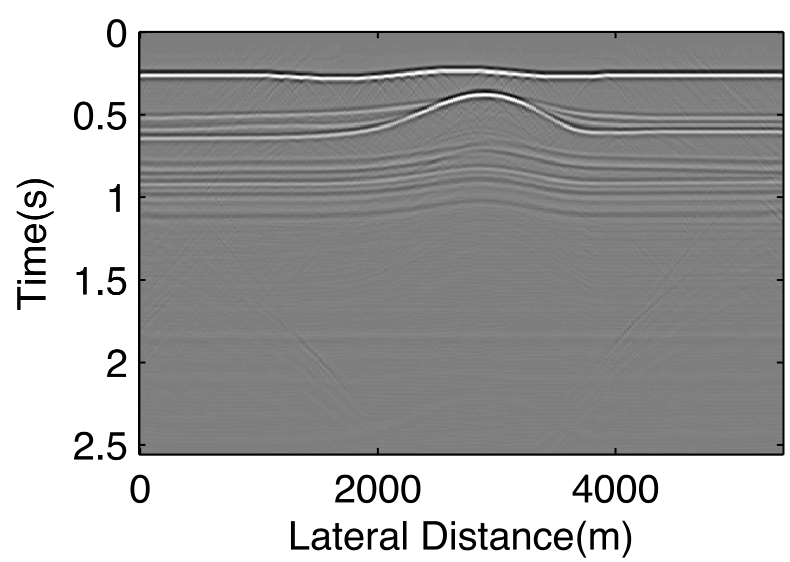

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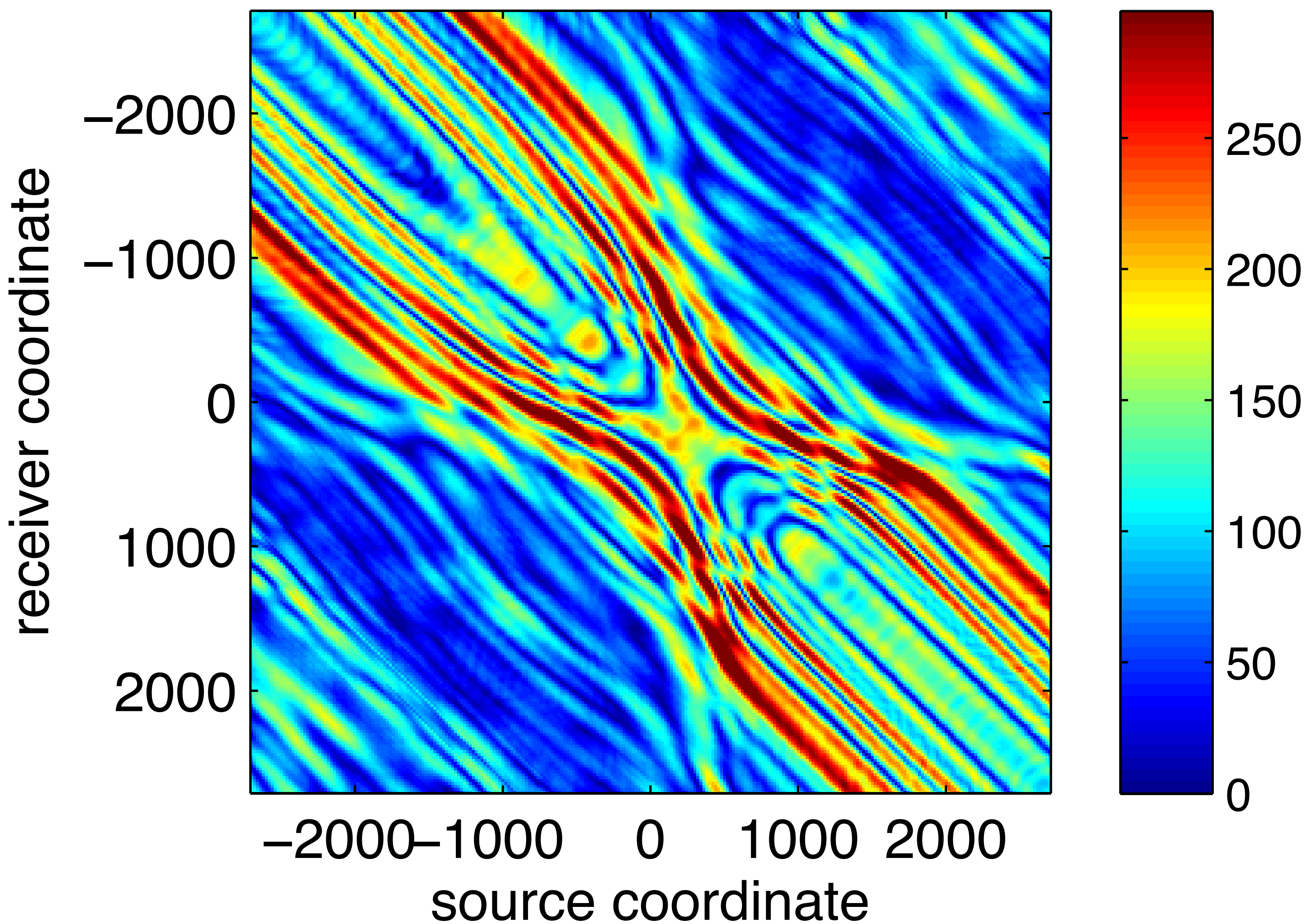
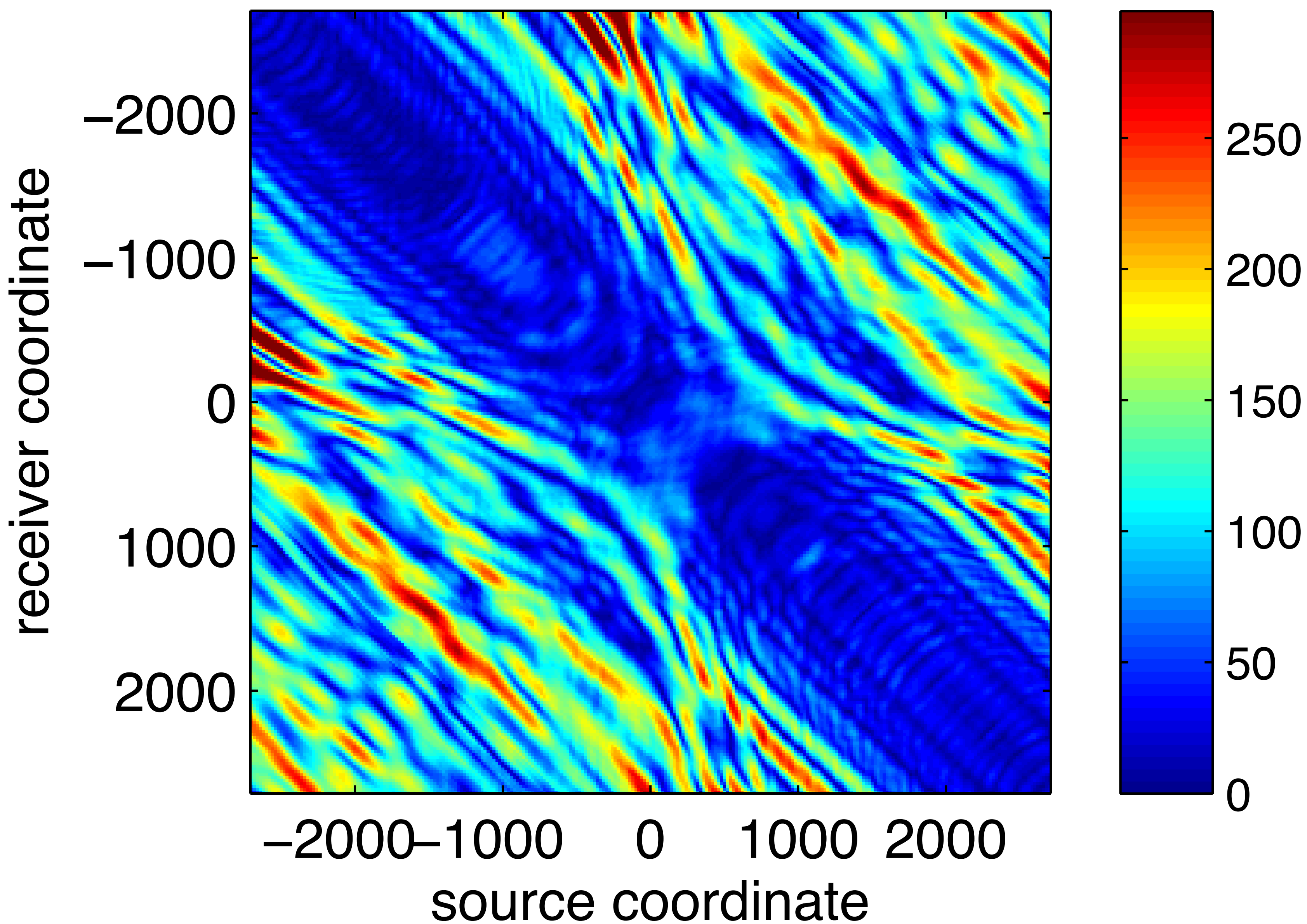
Rethink multiples



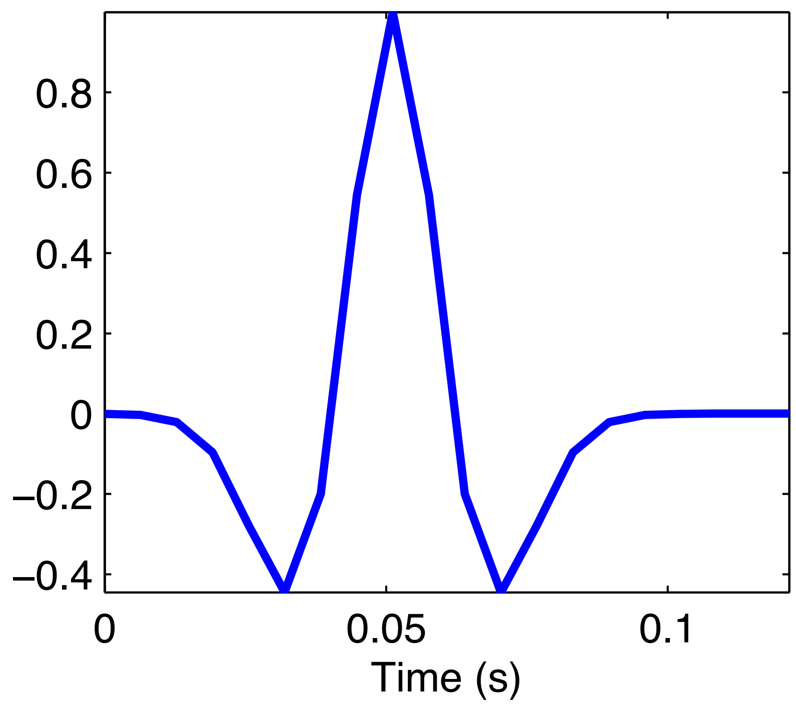
amplitude spectrum: primaries @15Hz

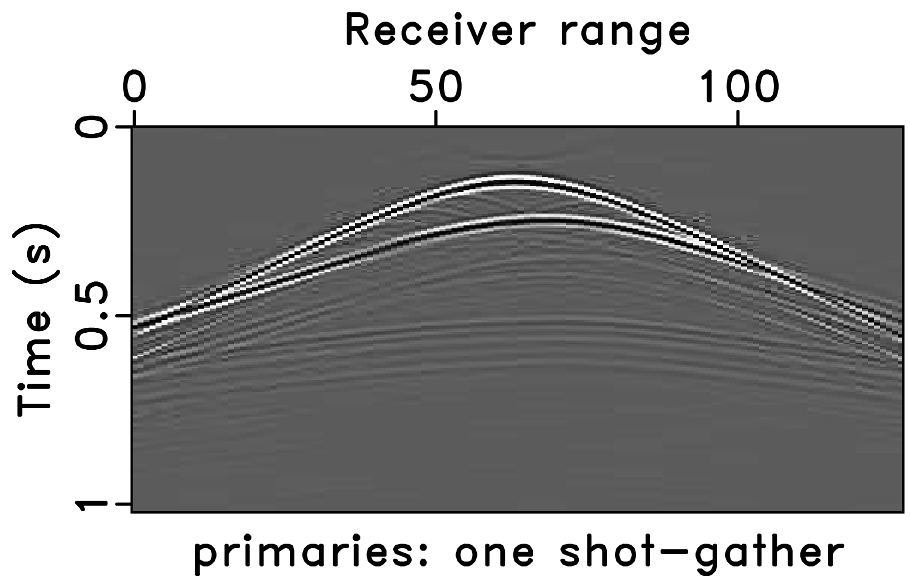
Rethink multiples



amplitude spectrum: multiples @15Hz

Rethink multiples





Rethink multiples

Lin, Tu, and Herrmann, 2010

Verschuur and Berkhout, 2011

Exploit extra illumination

point source

total data

SURFACE-FREE
GREEN'S FUNCTION

primaries

surface multiples

Verschuur, 1992

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Exploit extra illumination

From the formulation of SRME

$$\overbrace{\hat{\mathbf{G}}\hat{\mathbf{Q}}}^{\text{primaries}} + \overbrace{\hat{\mathbf{G}}(-\hat{\mathbf{P}})}^{\text{surface multiples}} = \hat{\mathbf{P}}$$

Groenestijn and Verschuur, 2009

Lin and Herrmann, 2010

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Exploit extra illumination

- Invert the Green's function directly from the total up-going wavefield.
- EPSI (Estimation of Primary via Sparse inversion) exploits the sparsity of the Green's function in data space.

Motivation

- How to exploit this extra illumination in seismic imaging?
- How to exploit the sparsity in the image space to facilitate the inversion of the Green's function?

Relate data space and model space

?

Seismic image

Total up-going wavefield

How?

Groenestijn and Verschuur, 2009

Lin and Herrmann, 2010

EPSI operator relates...

Surface-free Green's function

EPSI (modeling) operator →

← Invert the EPSI operator

Total up-going wavefield

Verschuur, 1992

Herrmann, 2008

Lin and Herrmann, 2010

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EPSI Formulation

EPSI follows the formulation of SRME:

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

Reformulating the EPSI operator:

$$\underbrace{\mathcal{F}_t^* \mathrm{BlockDiag}_{1\ldots\mathrm{nf}}[(\hat{\mathbf{Q}} - \hat{\mathbf{P}})^* \otimes \mathbf{I}]\mathcal{F}_{\mathbf{t}}}_{\mathbf{E}}\,\mathbf{g} = \mathbf{p}$$

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Robust EPSI

Robust EPSI:

$$\underbrace{\tilde{\mathbf{g}} = \min_{\mathbf{g}} ||\mathbf{g}||_{\mathbf{1}}}_{\text{sparsity promoting part}} \quad \text{subject to} \quad \underbrace{||\mathbf{p} - \mathbf{E}\mathbf{g}||_{\mathbf{2}}}_{\text{data fitting part}} \leq \sigma$$

Migration operator relates...

Model Perturbation

Linearized Born-scattering operator

Invert the Born-scattering operator

Linearized Surface-free Green's function

Herrmann and Li, 2010

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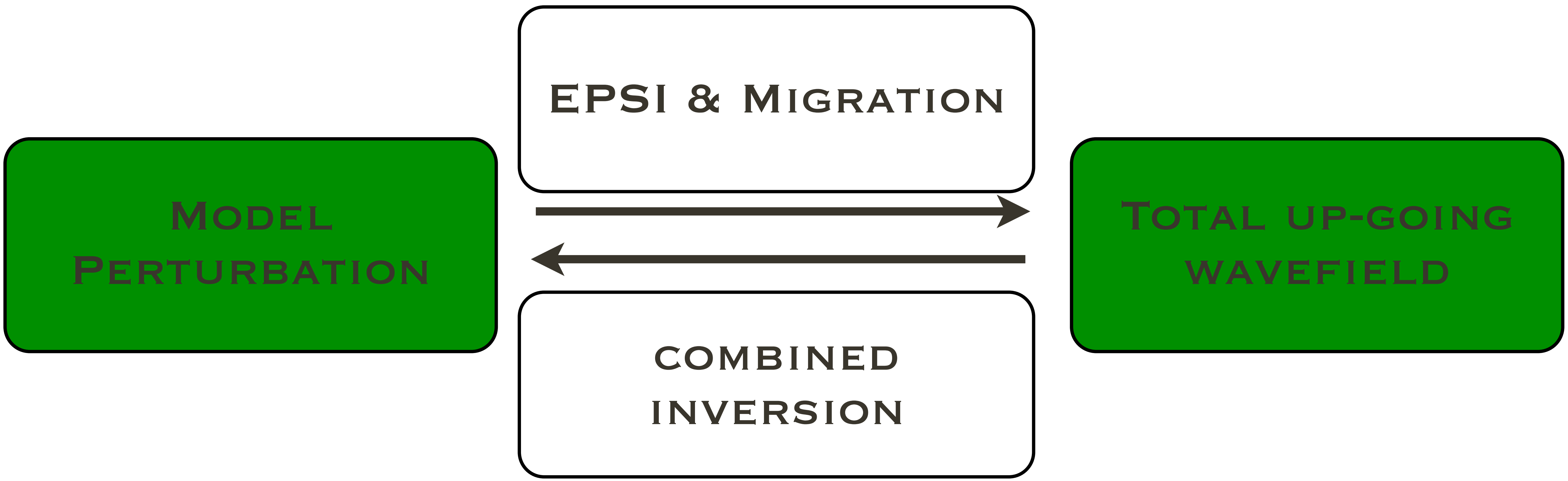
Sparsity promoting migration

By leveraging curvelet domain sparsity in the image space:

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \min_{\delta\mathbf{x}} \ ||\delta\mathbf{x}||_\mathbf{1} \text{ subject to} ||\delta\mathbf{g} - \mathbf{K}\mathbf{S}^*\delta\mathbf{x}||_\mathbf{2} \leq \sigma$$

Lin, Tu, and Herrmann, 2010

What about combine...



Approximate EPSI

EPSI follows the formulation of SRME:

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

Reformulating the EPSI operator:

$$\underbrace{\mathcal{F}_t^* \mathrm{BlockDiag}_{1\ldots\mathrm{nf}}[(\hat{\mathbf{Q}} - \hat{\mathbf{P}})^* \otimes \mathbf{I}]\mathcal{F}_\mathbf{t}}_{\mathbf{E}}\,\delta\mathbf{g} \approx \mathbf{p}$$

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Approx. Robust EPSI

Robust EPSI:

$$\underbrace{\delta\tilde{\mathbf{g}} = \min_{\delta\mathbf{g}} \|\delta\mathbf{g}\|_{\mathbf{1}}}_{\text{sparsity promoting part}} \quad \text{subject to} \quad \underbrace{\|\mathbf{p} - \mathbf{E}\delta\mathbf{g}\|_{\mathbf{2}} \leq \sigma}_{\text{data fitting part}}$$

Combine EPSI with migration

We identify the total up-going wavefield with model perturbations:

$$\delta\tilde{\mathbf{m}} = \mathbf{S}^* \min_{\delta\mathbf{x}} \ ||\delta\mathbf{x}||_\mathbf{1} \text{ subject to } ||\mathbf{p} - \mathbf{E}\underbrace{\mathbf{K}\mathbf{S}^*\delta\mathbf{x}}_{\delta\mathbf{g}}||_\mathbf{2} \leq \sigma$$

Numerical experiments

Linearized data:

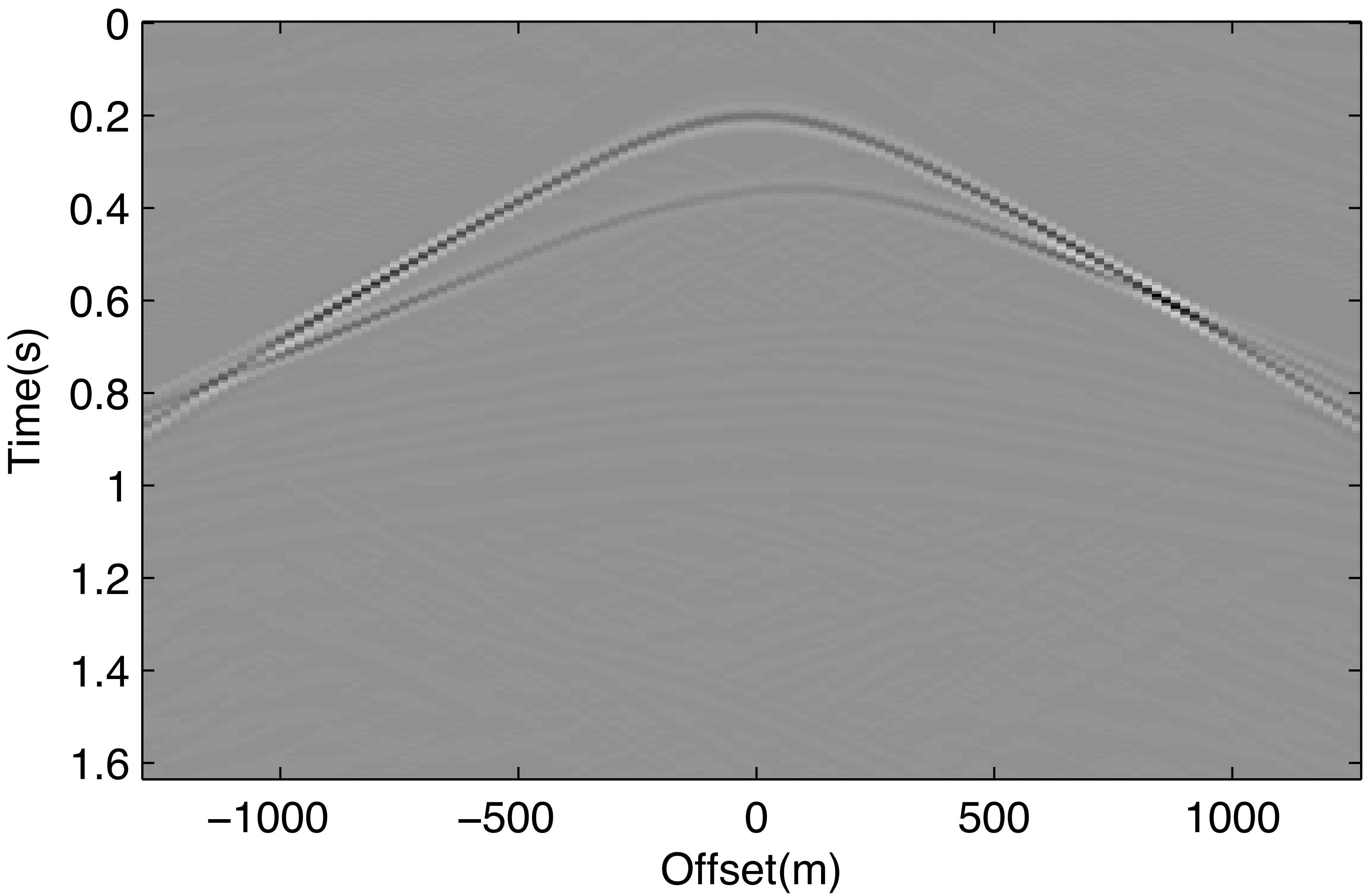
- **surface-free data**

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

- **total data**

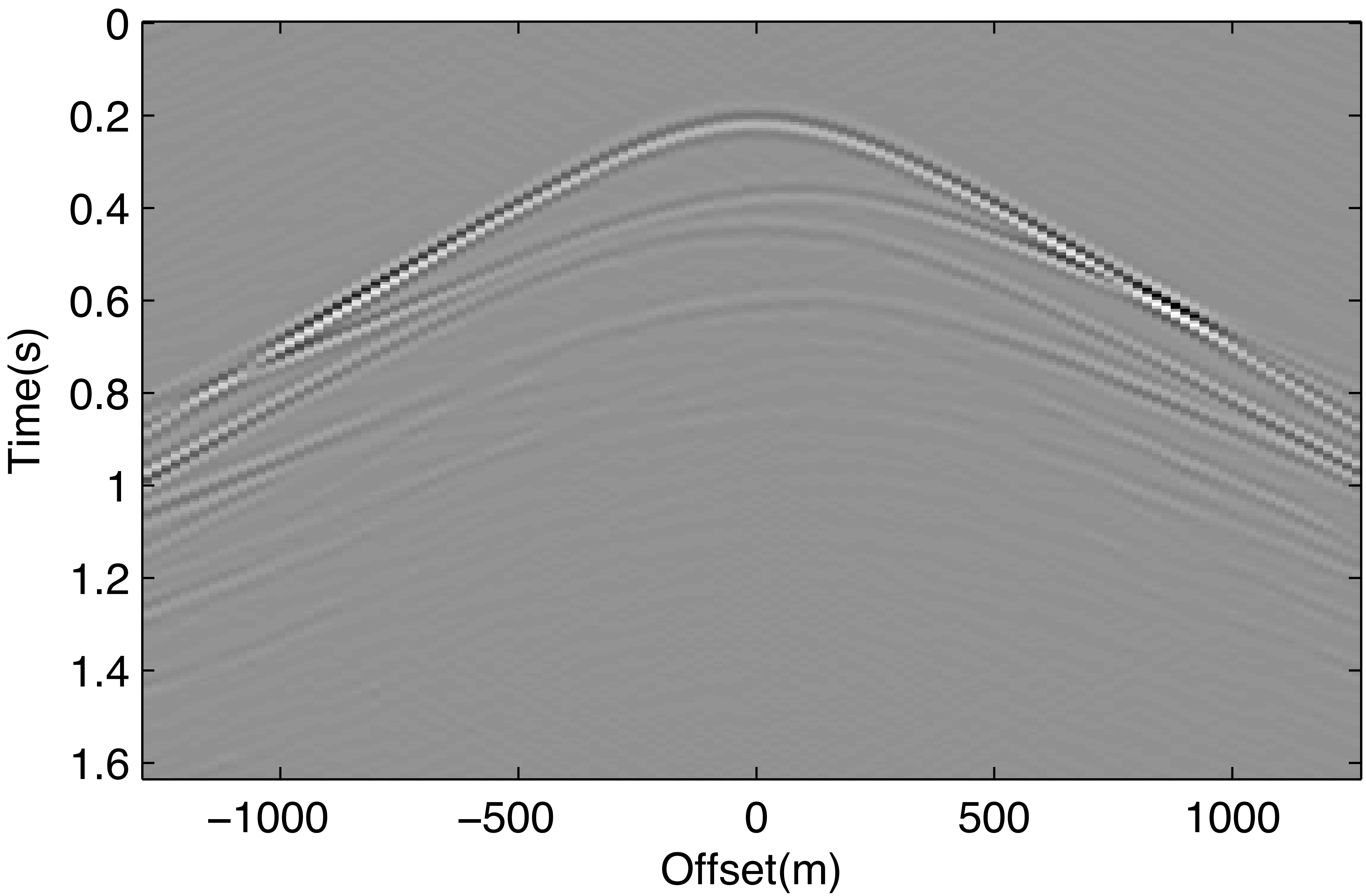
$$\mathbf{p_2} = \mathbf{E}\mathbf{K}\delta\mathbf{m}$$

Data preview: surface free data



total shots: 128, shot number: 65

Data preview: total data



total shots: 128, shot number: 65

Case study 1

- scenario 1: inversion from surface-free data
- scenario 2: inversion from total data
- scenario 3: combined inversion from total data

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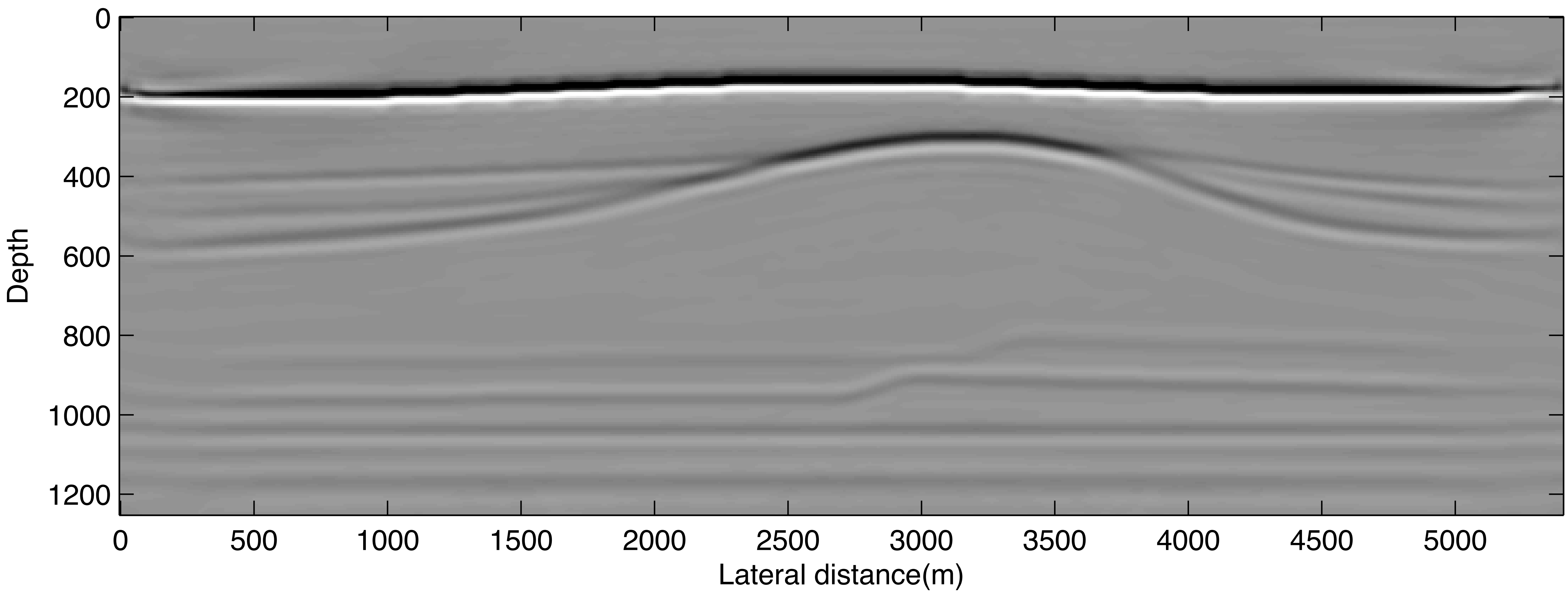
Sparse inversion of surface-free data



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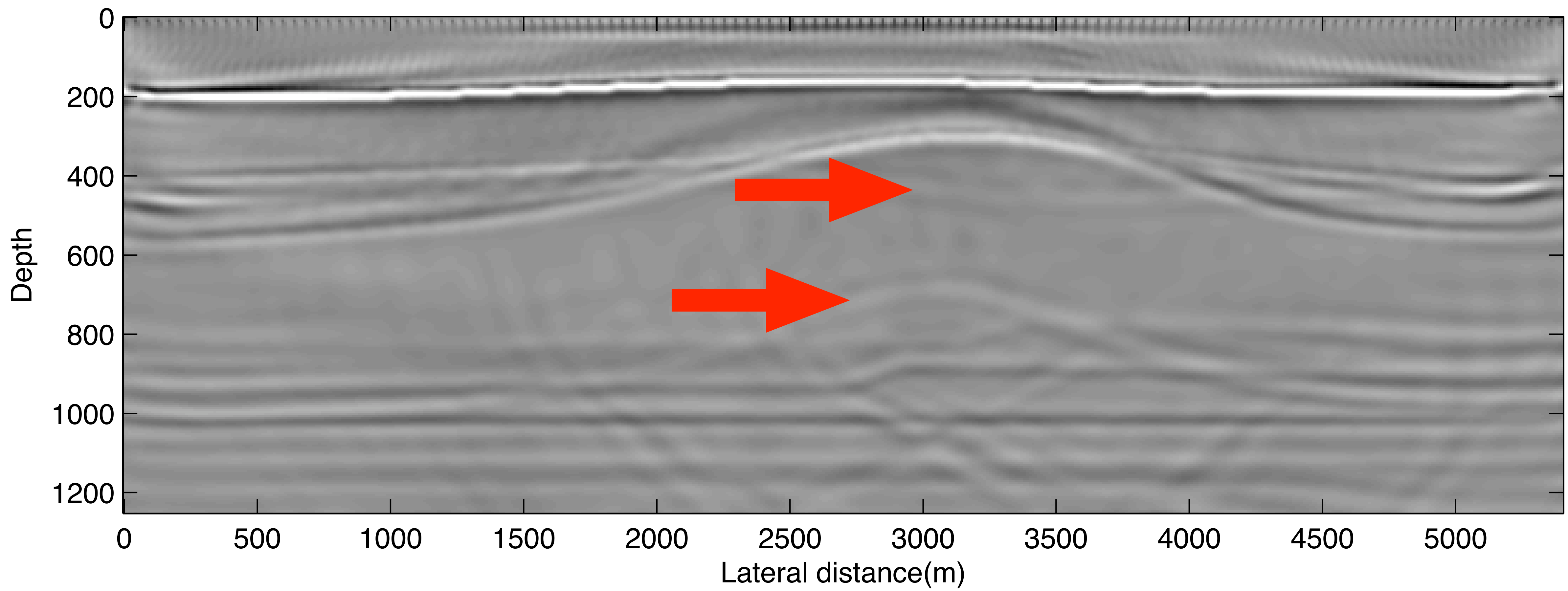
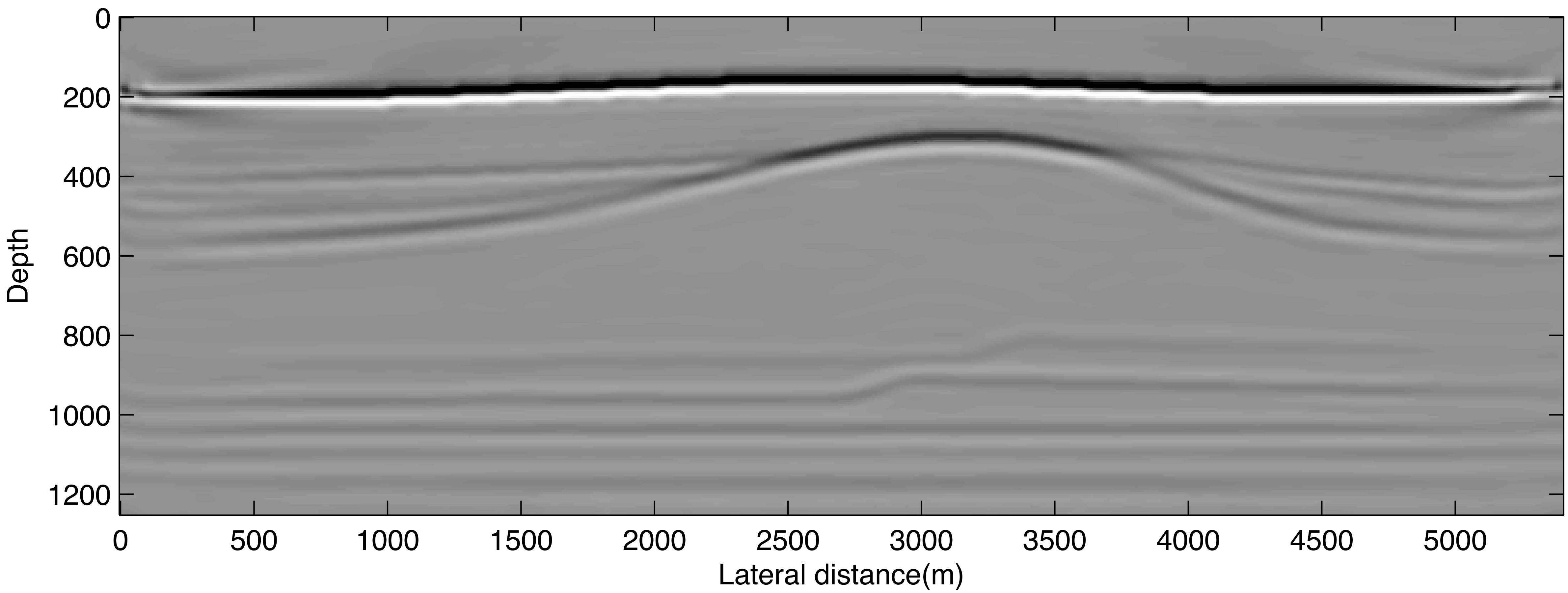
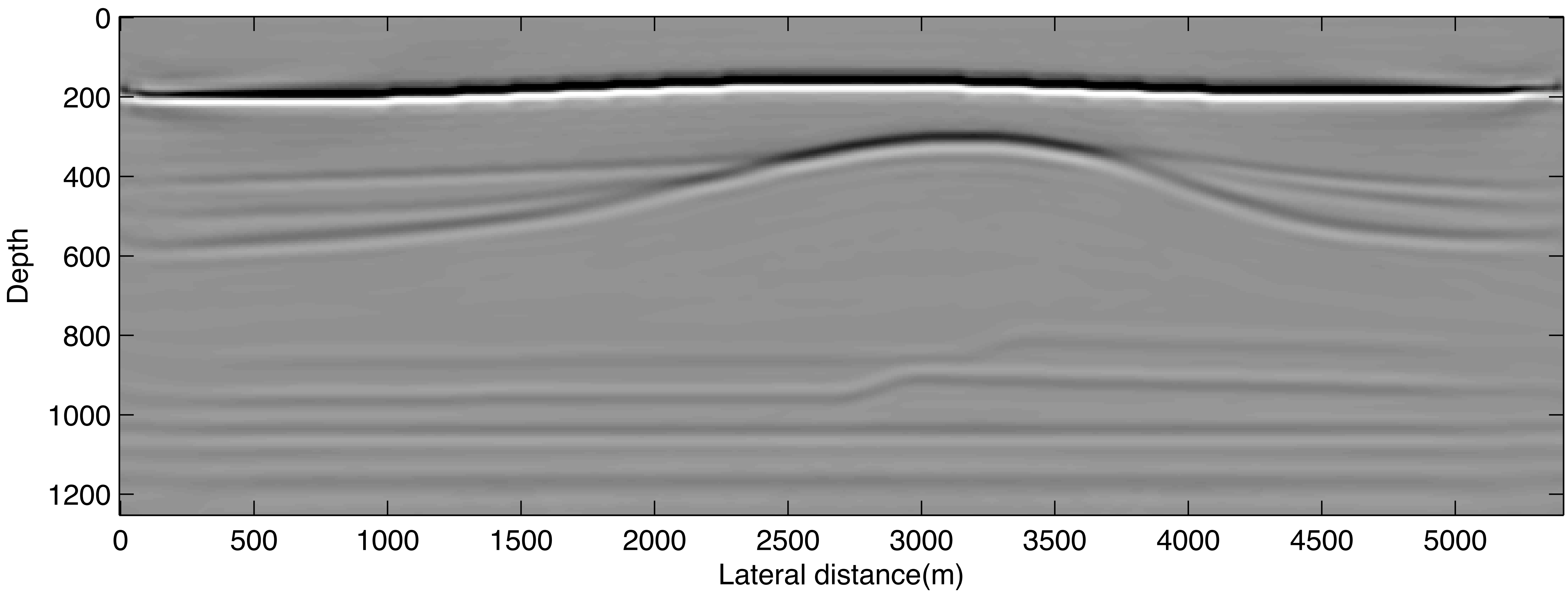
Sparse inversion of total data



Sparse inversion of data with multiples with EPSI



Sparse inversion of surface-free data



Do multiples really help ?

Both scenario 1 and scenario 3 give good results...Will this still be true when we invert from incomplete data?

Case study 2

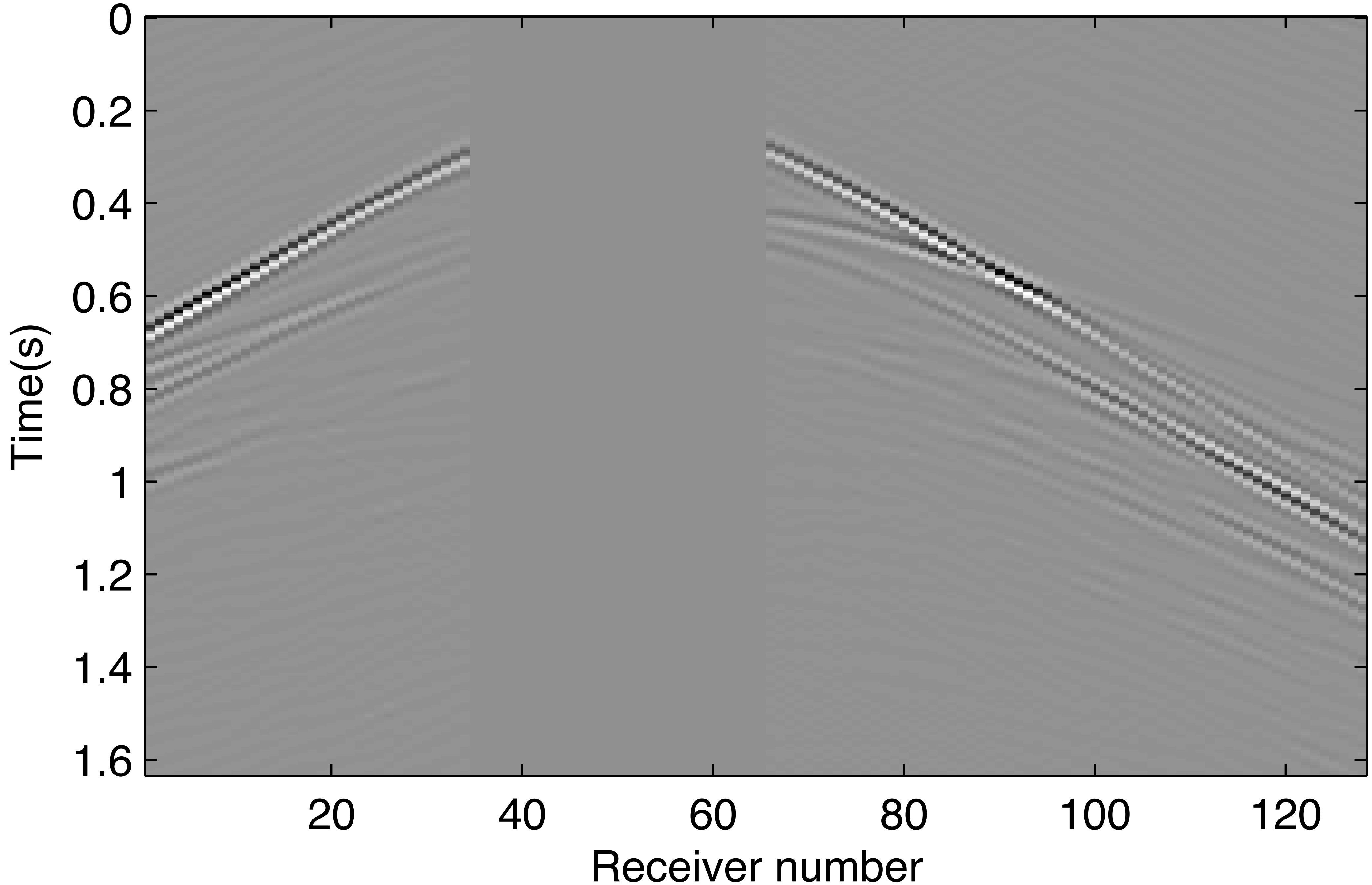
From incomplete data

- scenario 1: inversion from surface-free data
- scenario 2: combined inversion from total data

Incomplete data

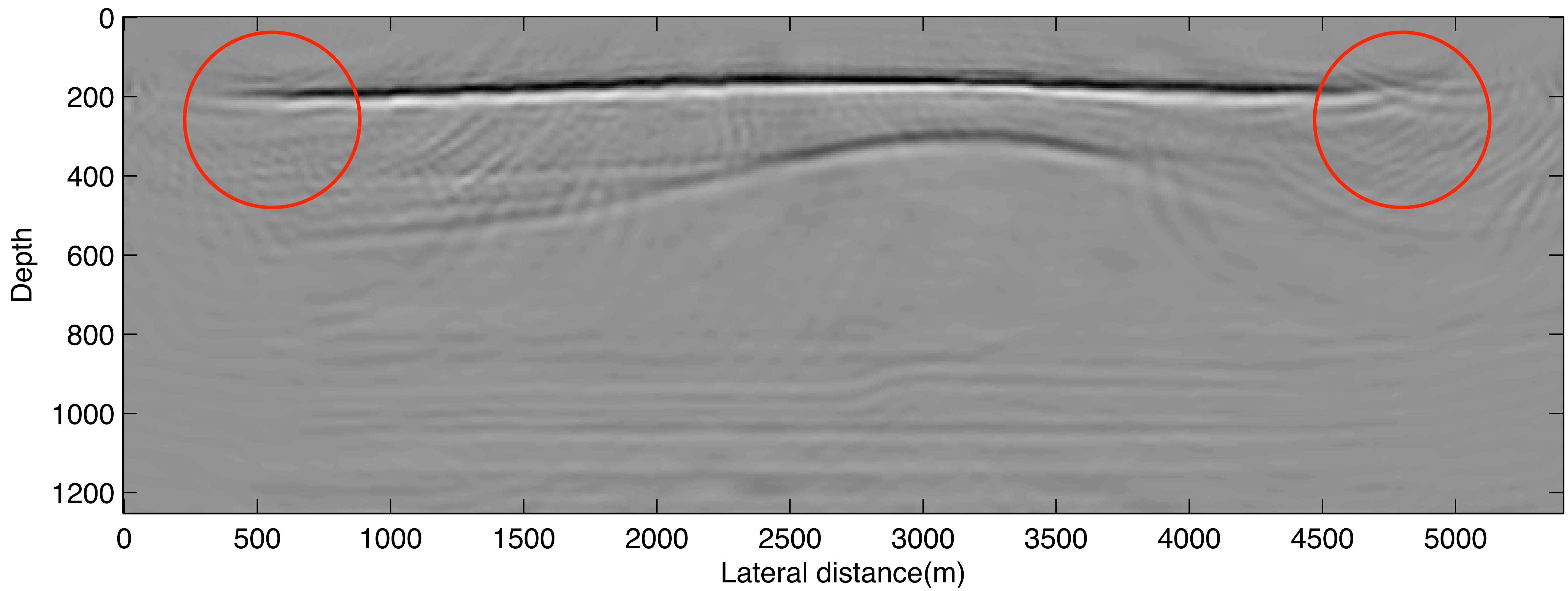
- 16 sequential shots selected randomly from a total number of 128 shots
- 300m missing near-offset

Data preview



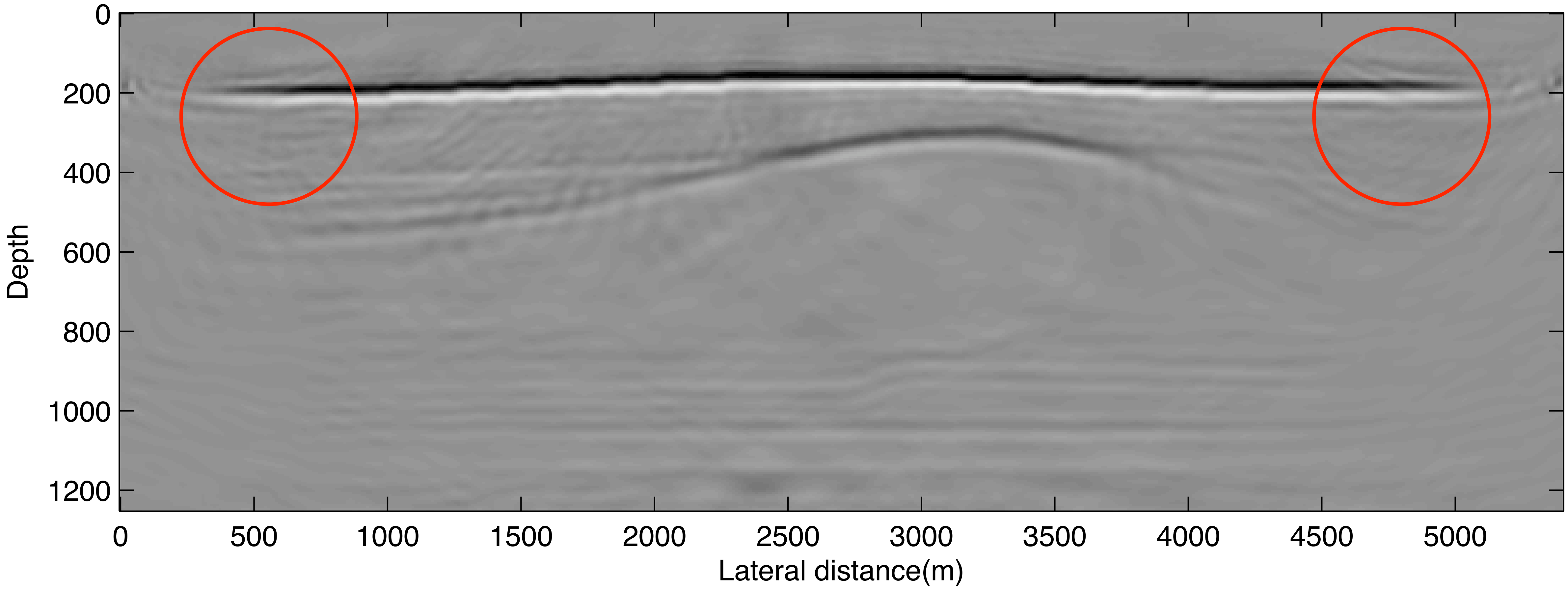
total shots: 16

Sparse inversion from surface-free data



SNR: 3.08dB (compared to true dm)

Combined inversion of total data



SNR: 3.72dB (compared to true dm)

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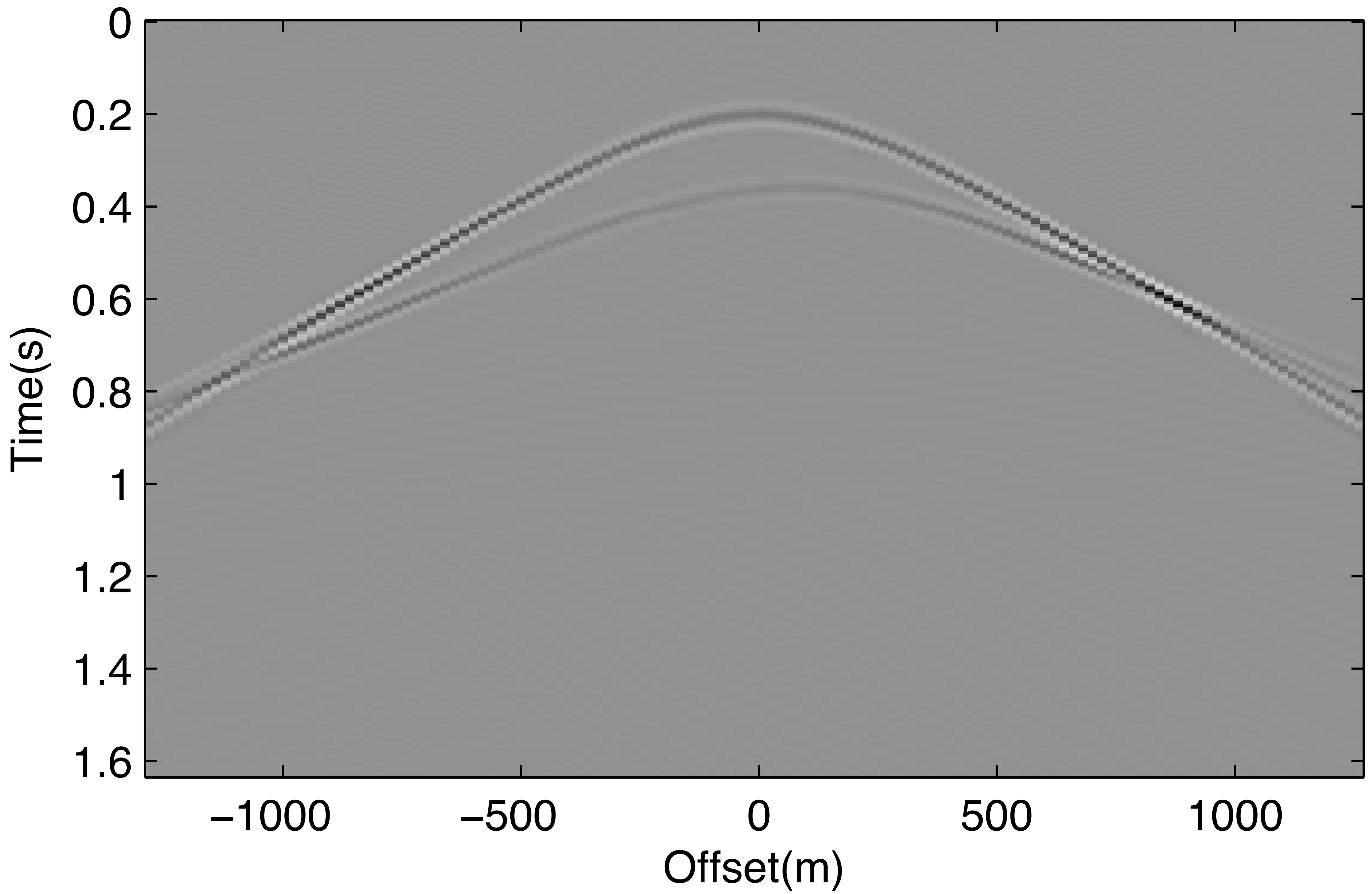
Recovered Green's function



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

In EPSI's point of view

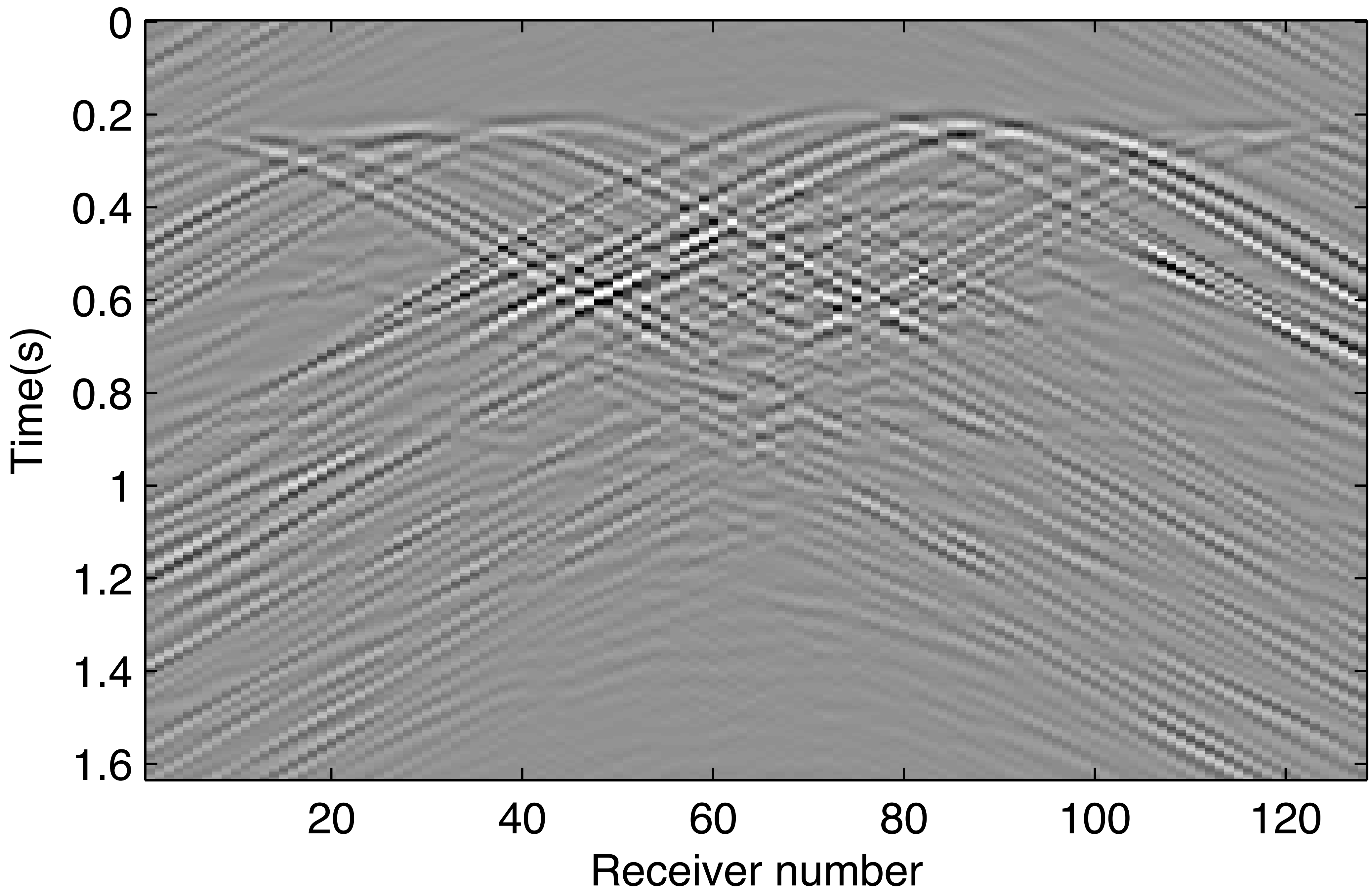
- Model perturbation is sparser than the Green's function
- Primary estimation in image space
- One joint inversion outperforms two separate inversions

Case study 3

From 12 simultaneous shots

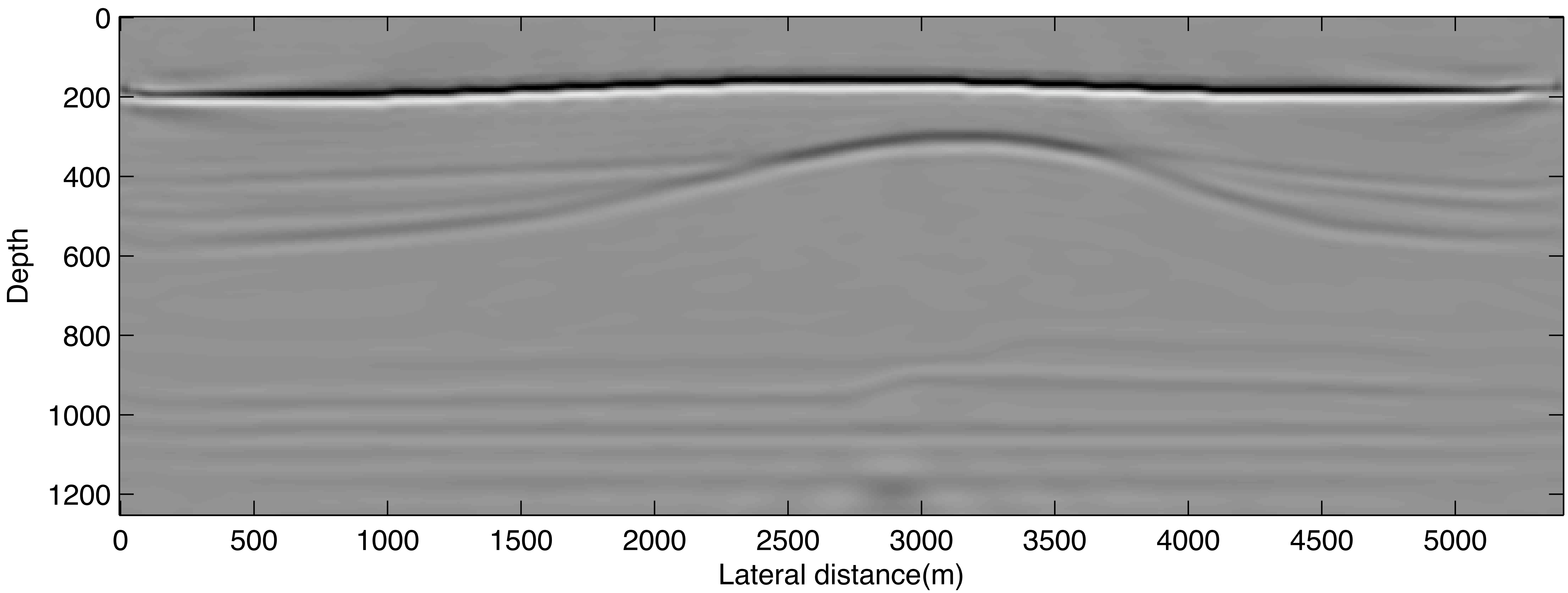
- scenario 1: EPSI & migration
- scenario 2: EPSI -> migration

Data preview



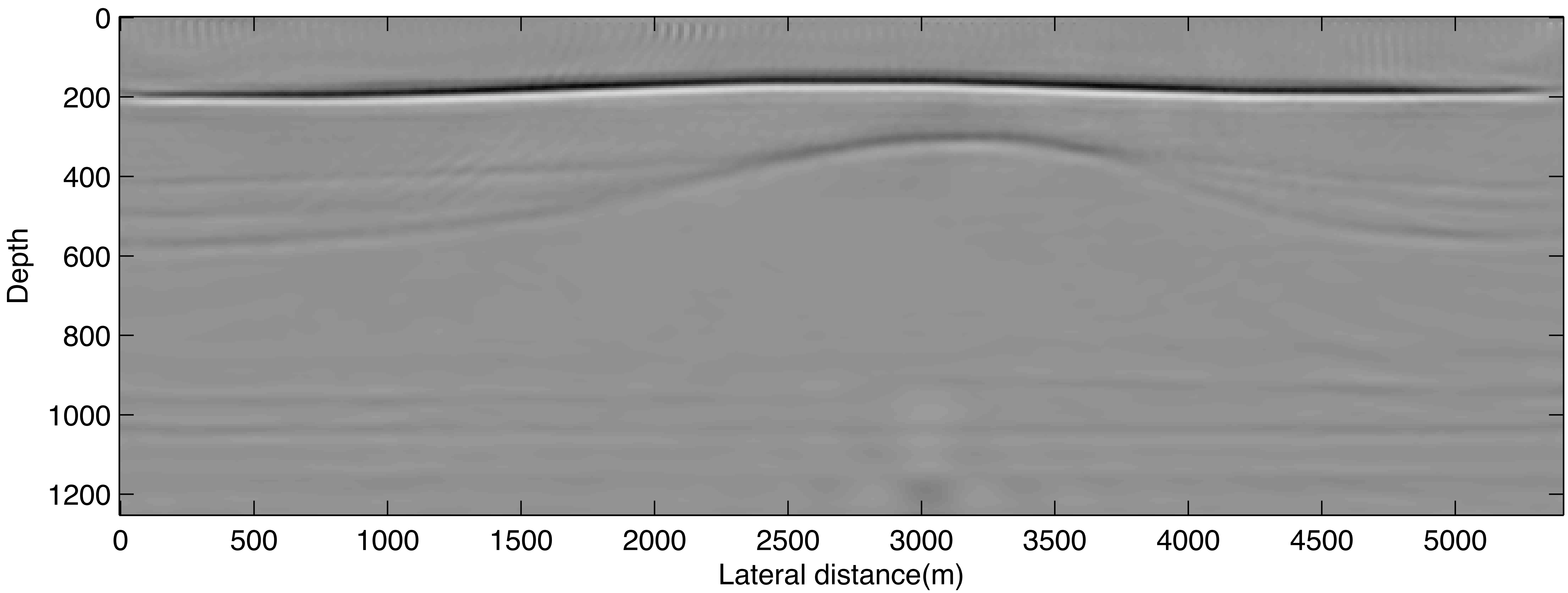
total shots: 12

Combined inversion



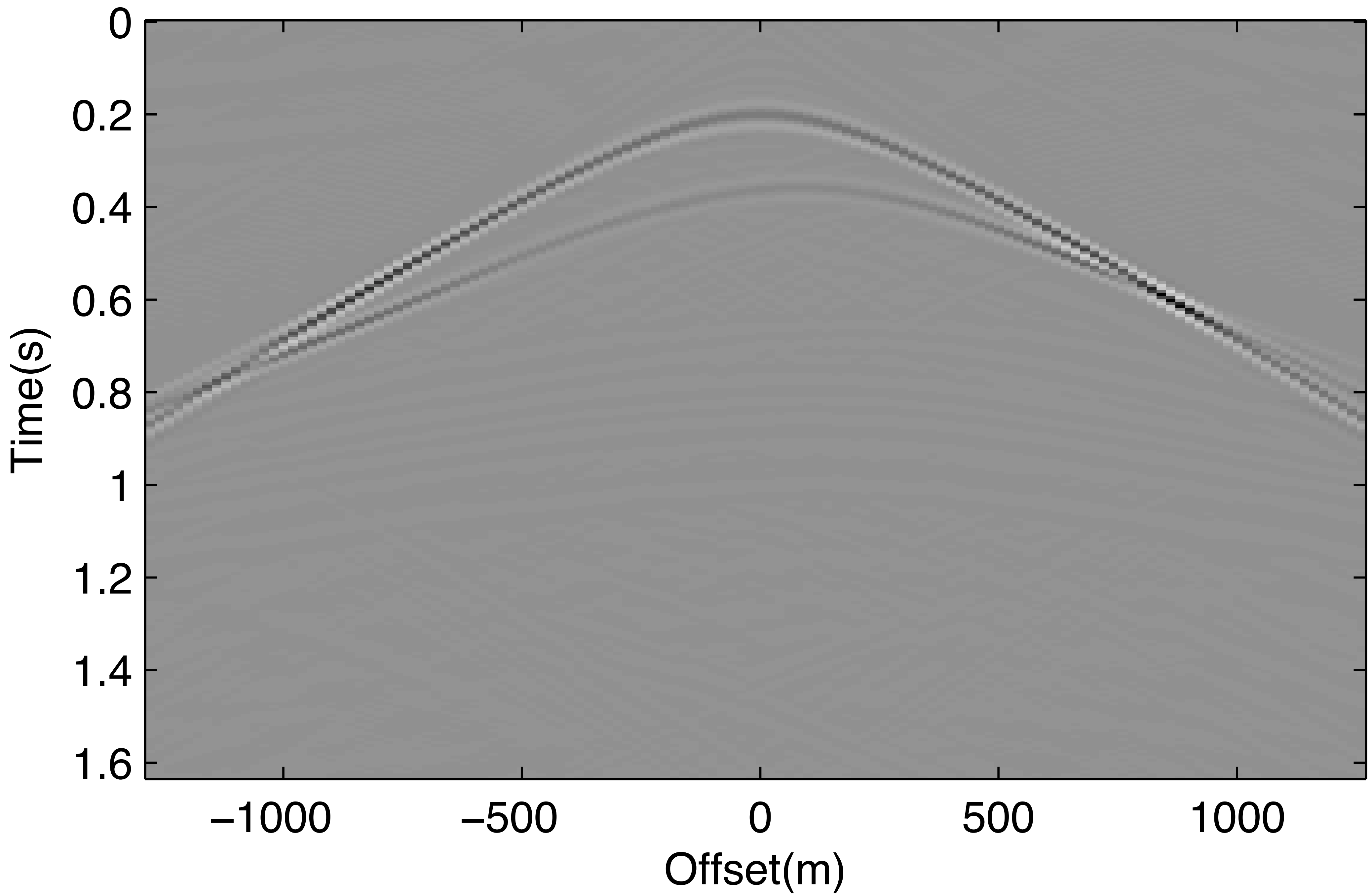
SNR: 5.30dB (compared to true dm)

Two separate inversions



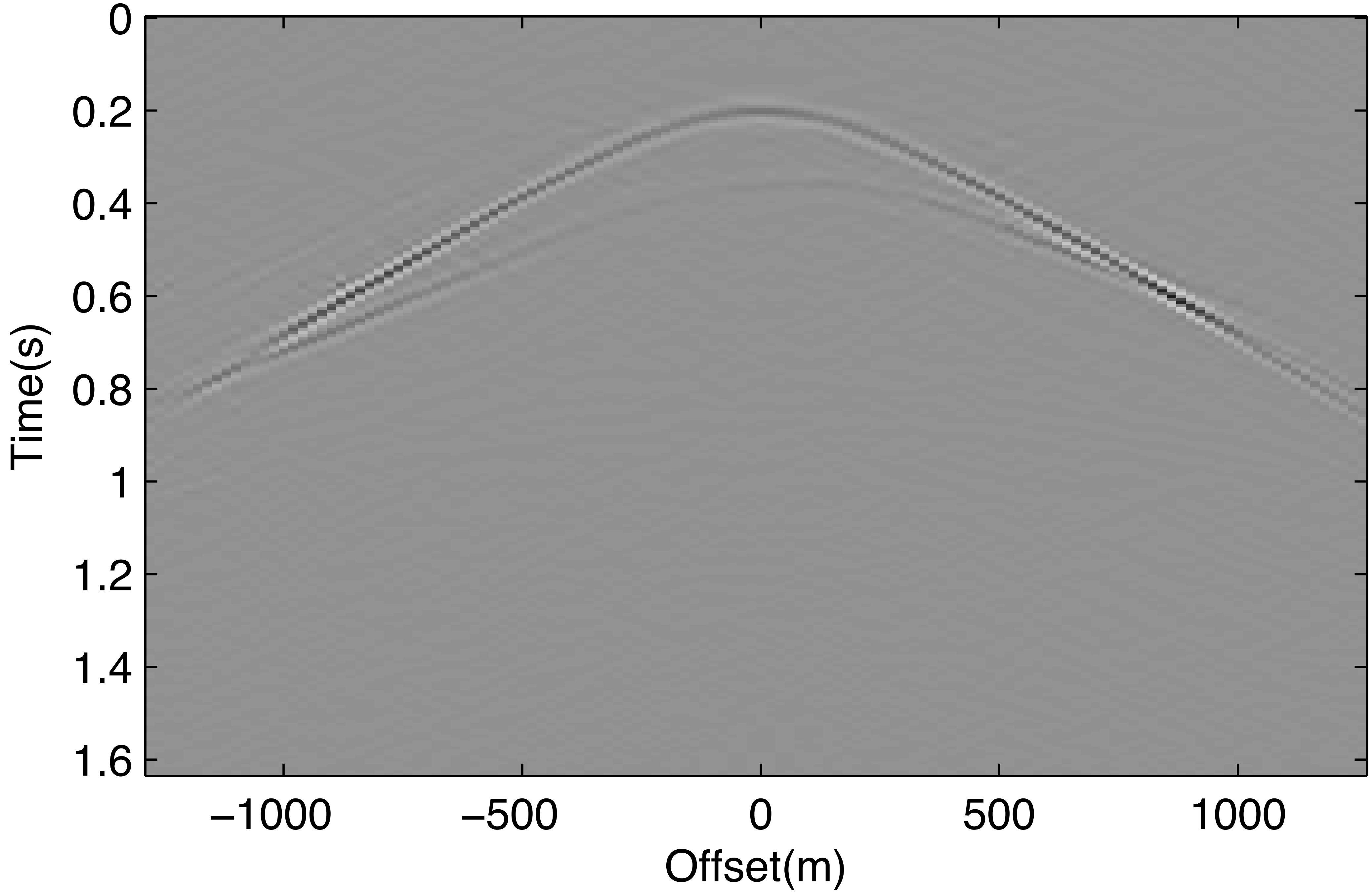
SNR: 4.52dB (compared to true dm)

Recovered Green's function in combined 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

Conclusions

By combing EPSI with migration:

- we reap benefits in seismic imaging by exploiting the extra illumination from surface multiples
- better primary estimation results by exploiting sparsity in image space

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Future plans

- How to adapt EPSI for incomplete data
- Speed-up this joint inversion by introducing simultaneous sources
- extend this work to FWI

EPSI for incomplete data

EPSI contains term G*P, matrix multiplication breaks when P is incomplete along both columns and rows.

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Compressively simulate G

EPSI needs full G too for G*P term.

- P=USV*, use U as a simultaneous shot term for G
- G*P=P*G by reciprocity, apply the simultaneous shot term on the right.

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