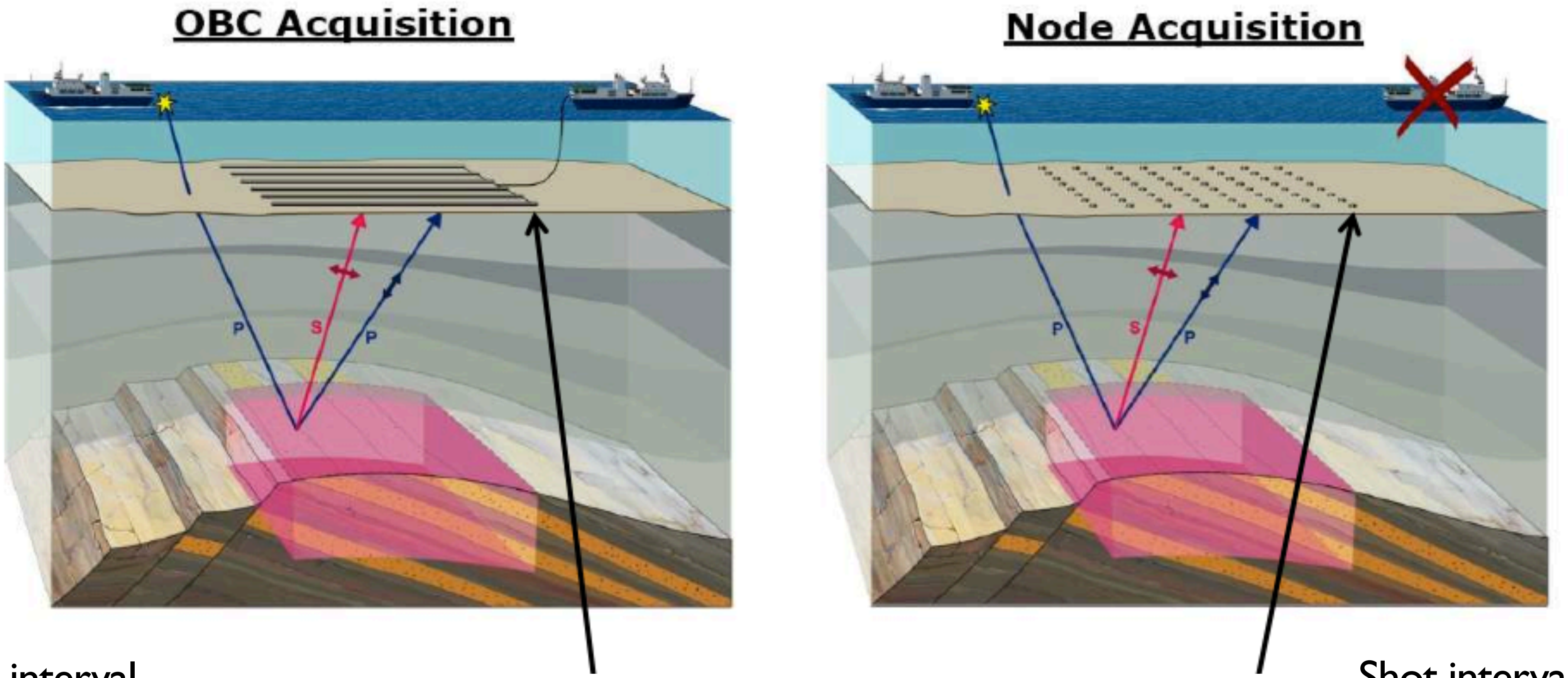
Ocean bottom seismic acquisition via jittered sampling

Haneet Wason, and Felix J. Herrmann

SLIM
University of British Columbia

Motivation



Shot interval
50 m

Receiver/group interval
25 m

4 component seismic sensor:
3 geophones (XYZ), 1 hydrophone

Shot interval
50 m

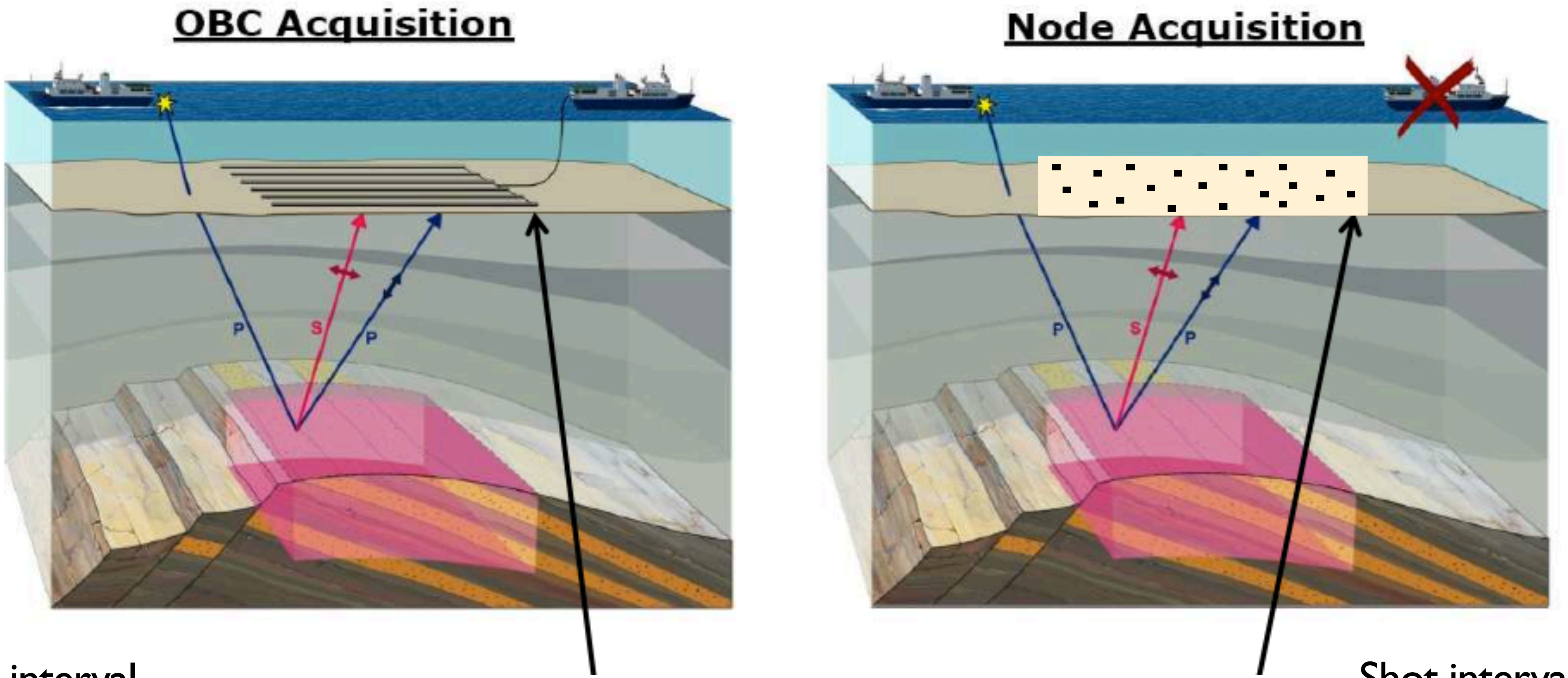
Receiver/group interval
300 - 400 m

[http://sgs-neworleans.org/luncheons/120308%20Olofsson%20-%20OBN%20Acquisition.pdf]

Motivation

- Is there a way to circumvent the Nyquist-related acquisition/processing costs?
- Design seismic acquisition within the compressed sensing framework
- Rethink marine acquisition (OBC, OBN)

Motivation



Shot interval
random

Receiver/group interval
random

4 component seismic sensor:
3 geophones (XYZ), 1 hydrophone

Shot interval
random

Receiver/group interval
random

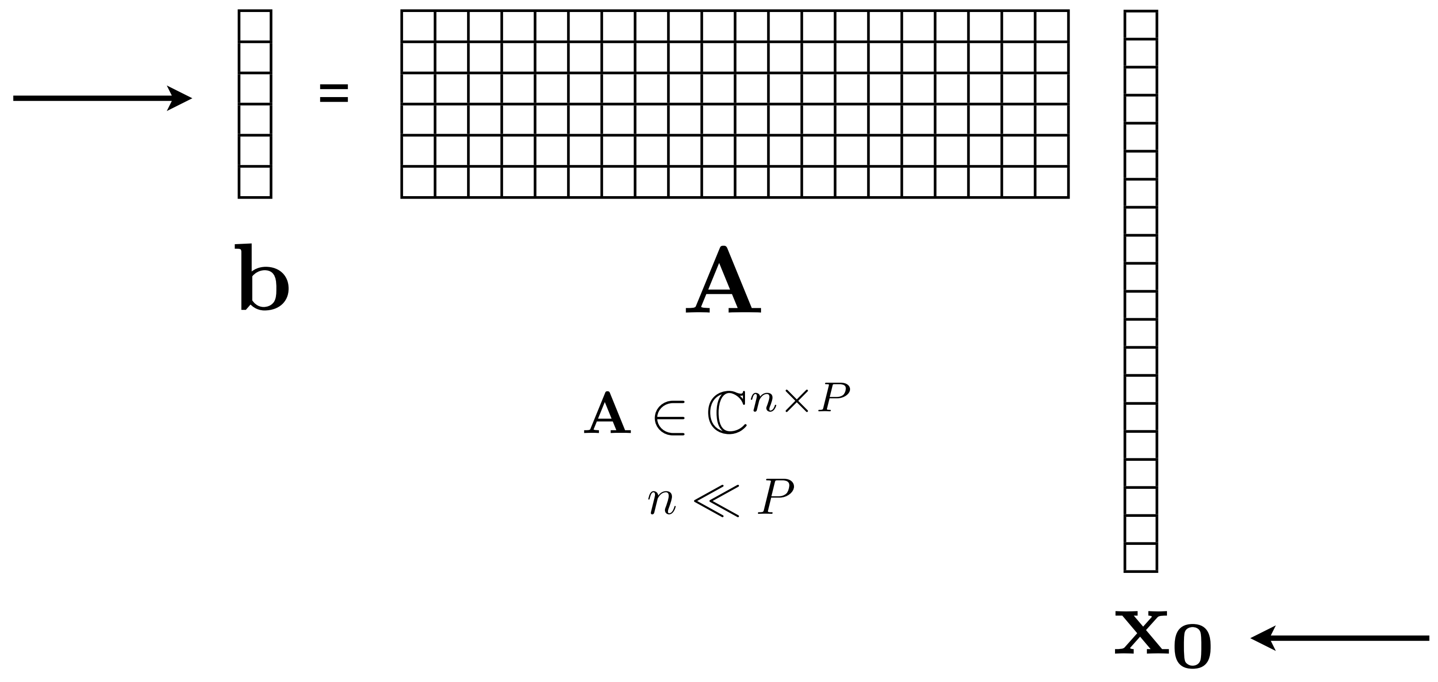
[http://sgs-neworleans.org/luncheons/120308%20Olofsson%20-%20OBN%20Acquisition.pdf]

Outline

- Problem statement & recovery strategy
- Design of *jittered*, ocean bottom cable acquisition
    - jitter in *time* (⇒ jittered shot locations)
- Experimental results of *sparsity*-promoting processing
    - demultiplexing, and interpolation from coarser to finer sampling grid

Problem statement

Solve an *underdetermined* system of *linear* equations:



data (measurements /observations)

$\mathbf{b} \in \mathbb{C}^n$

$\mathbf{A} \in \mathbb{C}^{n \times P}$

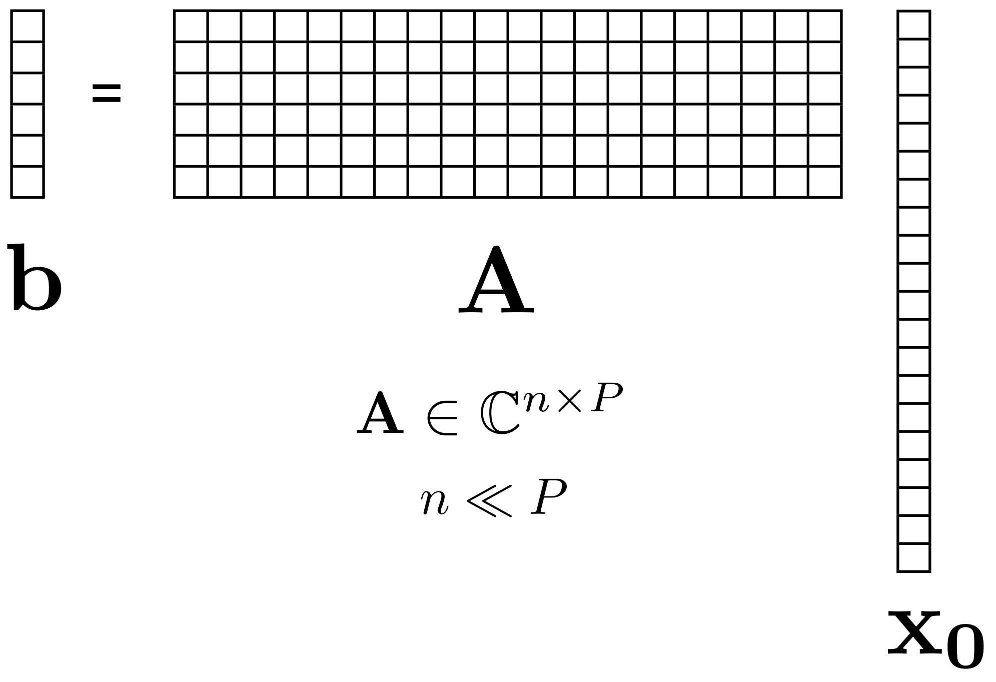
$n \ll P$

unknown

$\mathbf{x_0} \in \mathbb{C}^P$

Problem statement

Solve an *underdetermined* system of *linear* equations:



data
(measurements
/observations)

$\mathbf{b} \in \mathbb{C}^n$

$\mathbf{A} \in \mathbb{C}^{n \times P}$

$n \ll P$

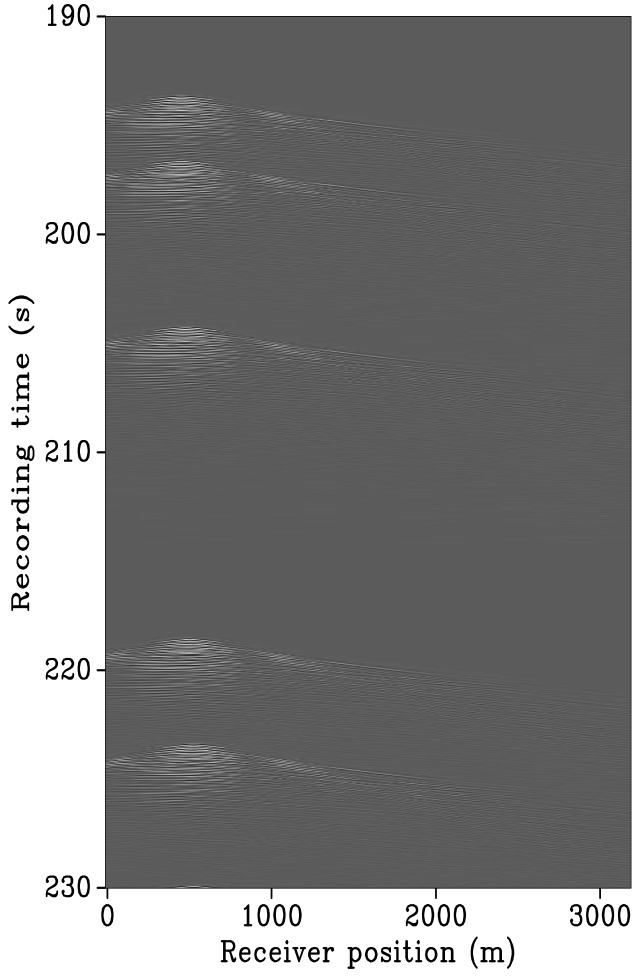
unknown

$\mathbf{x_0} \in \mathbb{C}^P$

$$\boxed{\mathbf{A} = \underbrace{\mathbf{RM}}_{\text{sampling matrix}}\mathbf{S^H}}$$

transform matrix

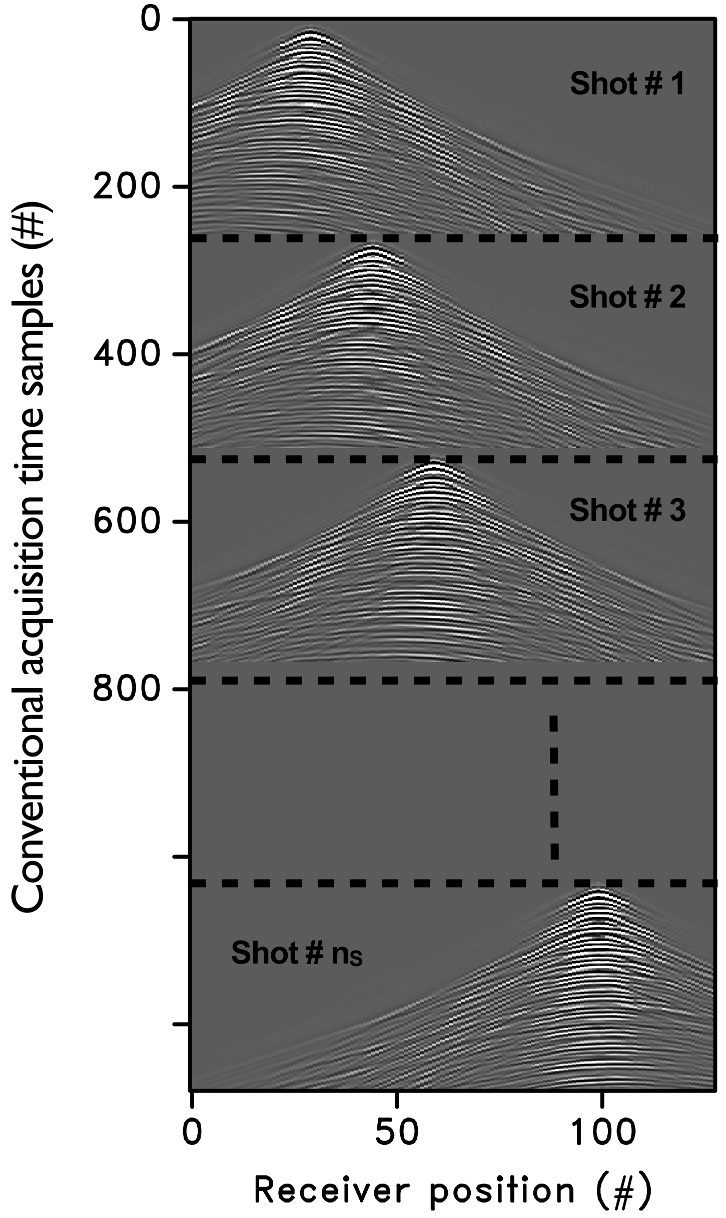
b


190
200
210
220
230
Recording time (s)
0
1000
2000
3000
Receiver position (m)

=

RM

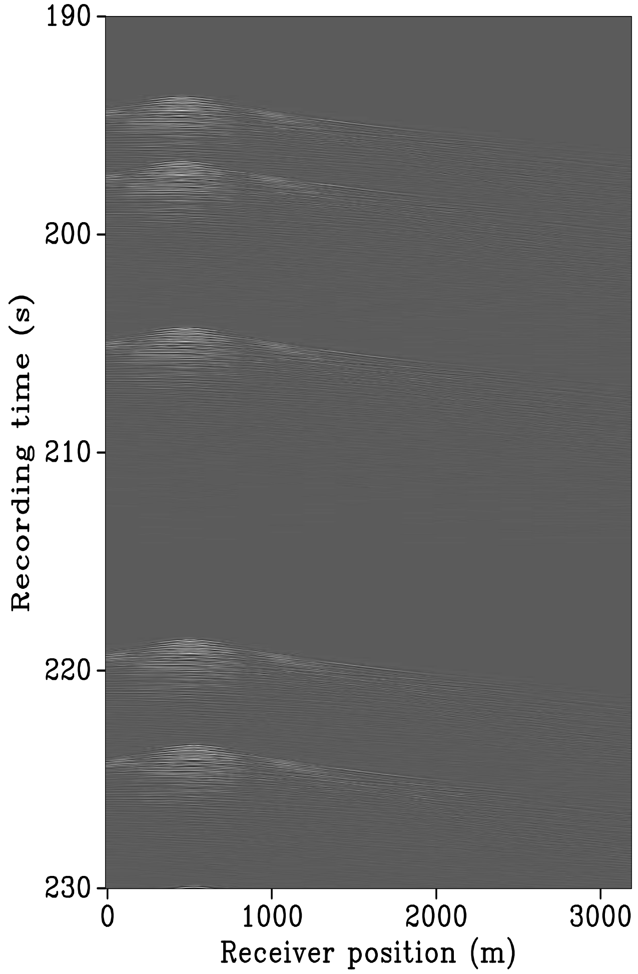
d

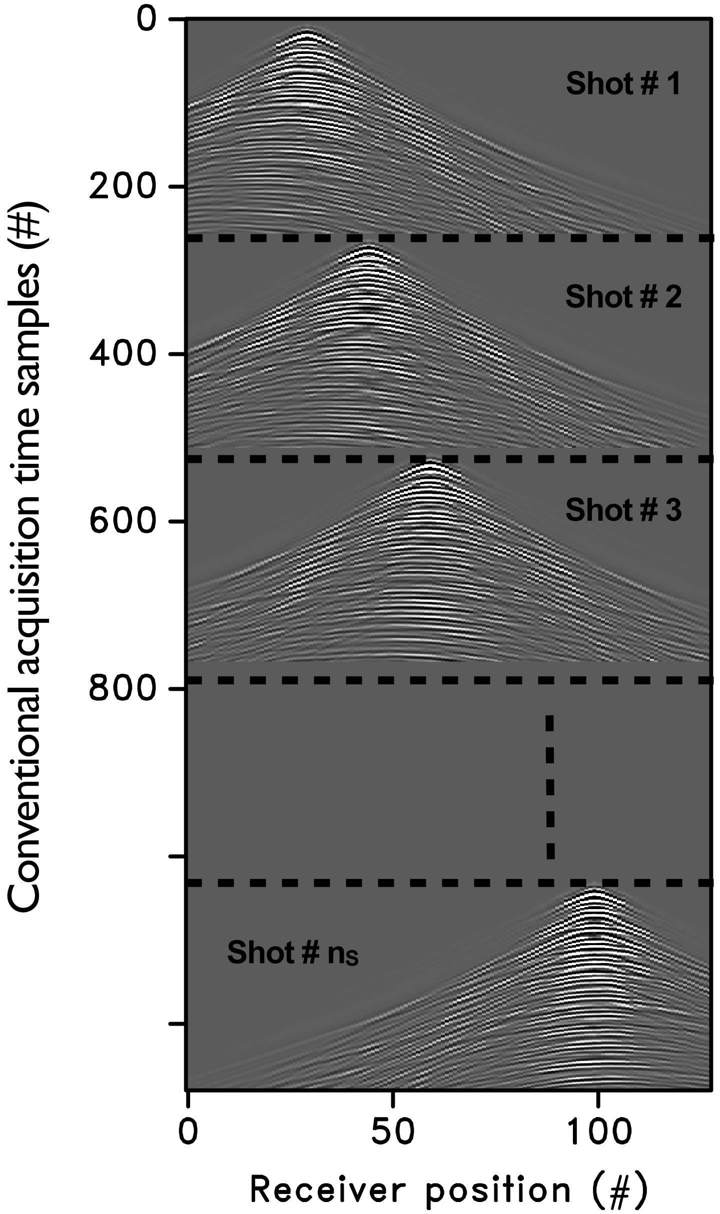

0
200
400
600
800
Conventional acquisition time samples (#)
Shot # 1
Shot # 2
Shot # 3
Shot # n_S
0
50
100
Receiver position (#)

ACQUIRE IN THE FIELD

WOULD LIKE TO HAVE

$$\mathbf{b} = \boxed{\mathbf{RM}} \quad \mathbf{d}$$





Sparse recovery

Exploit *curvelet*-domain sparsity of seismic data

Sparsity-promoting program:

$$\tilde{\mathbf{x}} = \underbrace{\arg\min_{\mathbf{x}} \|\mathbf{x}\|_1}_{\text{support detection}} \quad \text{subject to} \quad \underbrace{\mathbf{A}\mathbf{x} = \mathbf{b}}_{\text{data-consistent amplitude recovery}}$$

Sparsity-promoting solver: $\mathbf{SPG}\ell_1$ [van den Berg and Friedlander, 2008]

Recover single-source prestack data volume: $\tilde{\mathbf{d}} = \mathbf{S}^{\mathbf{H}}\tilde{\mathbf{x}}$

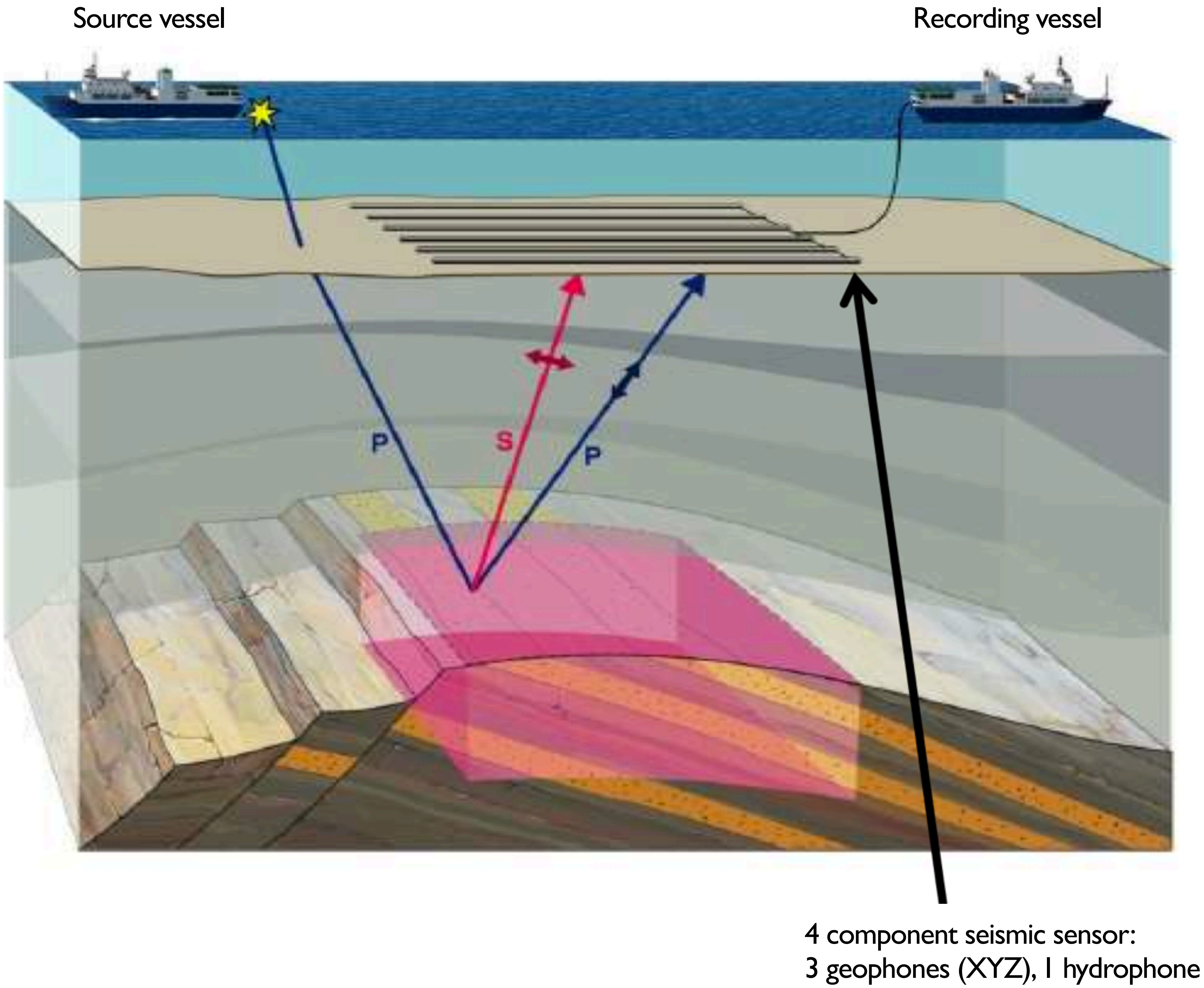
Outline

- Problem statement & recovery strategy

- Design of *jittered*, ocean bottom cable acquisition
  - jitter in *time* (⇒ jittered shot locations)

- Experimental results of *sparsity*-promoting processing
  - demultiplexing, and interpolation from coarser to finer sampling grid

Conventional OBC acquisition

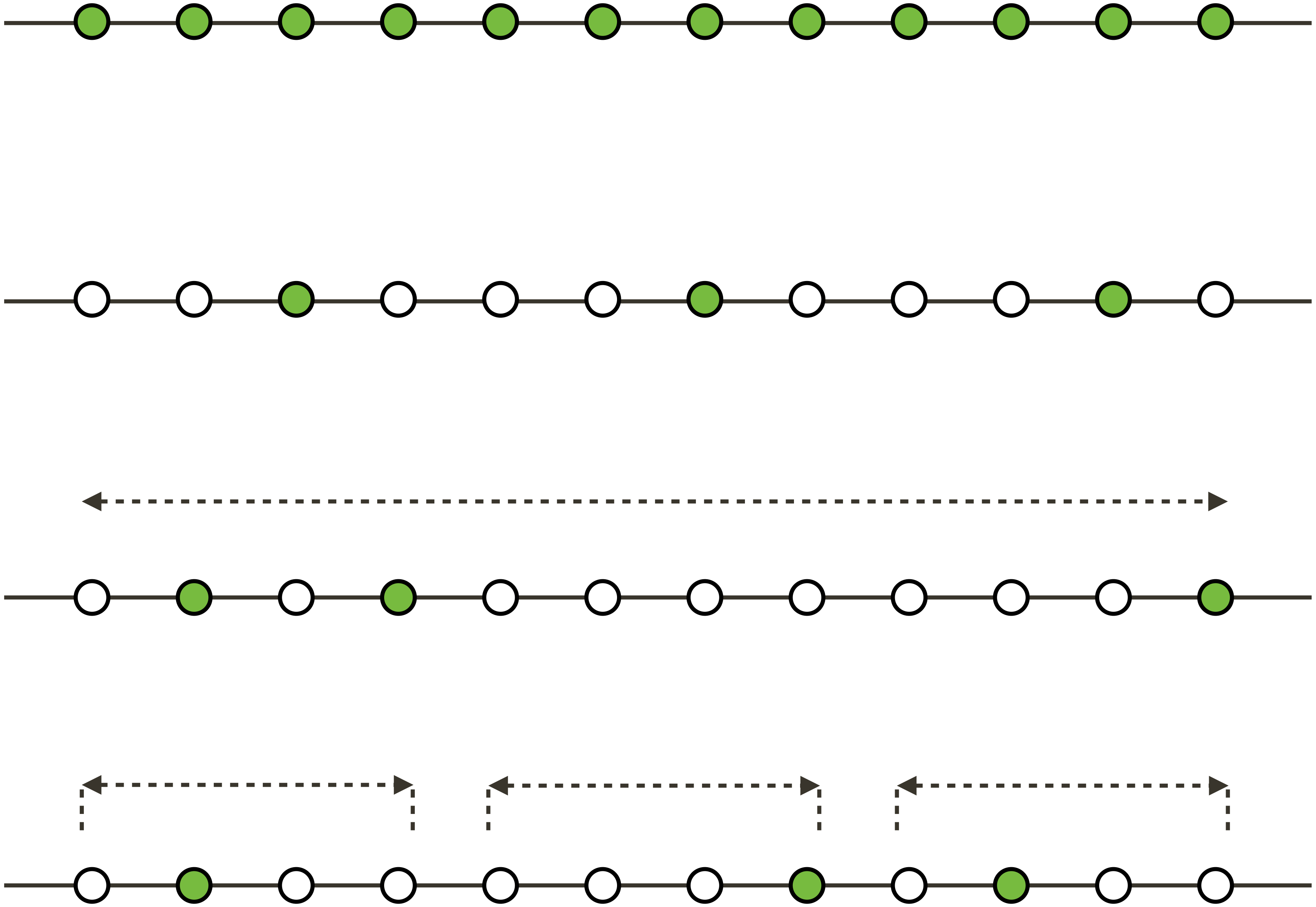


Shot interval
50 m

Receiver/group interval
25 m

[http://sgs-neworleans.org/luncheons/120308%20Olofsson%20-%20OBN%20Acquisition.pdf]

Sampling schemes



FULL SAMPLING

REGULAR UNDERSAMPLING

($\eta = 4$)

UNIFORM RANDOM UNDERSAMPLING

($\eta = 4$)

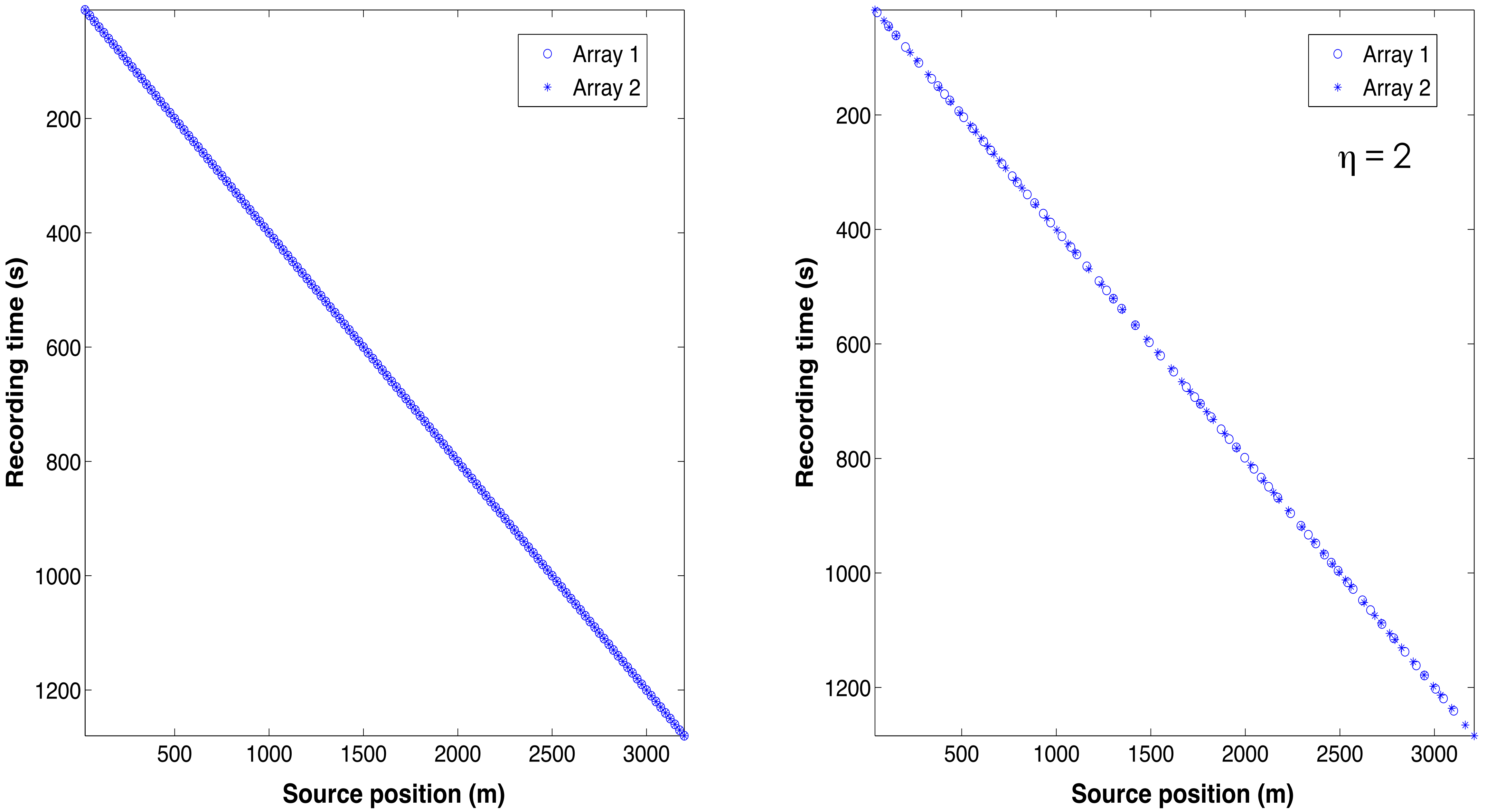
JITTERED UNDERSAMPLING

($\eta = 4$)

Conventional vs. *jittered* sources

[Speed of source vessel = 9 km/hr = 2.5 m/s]

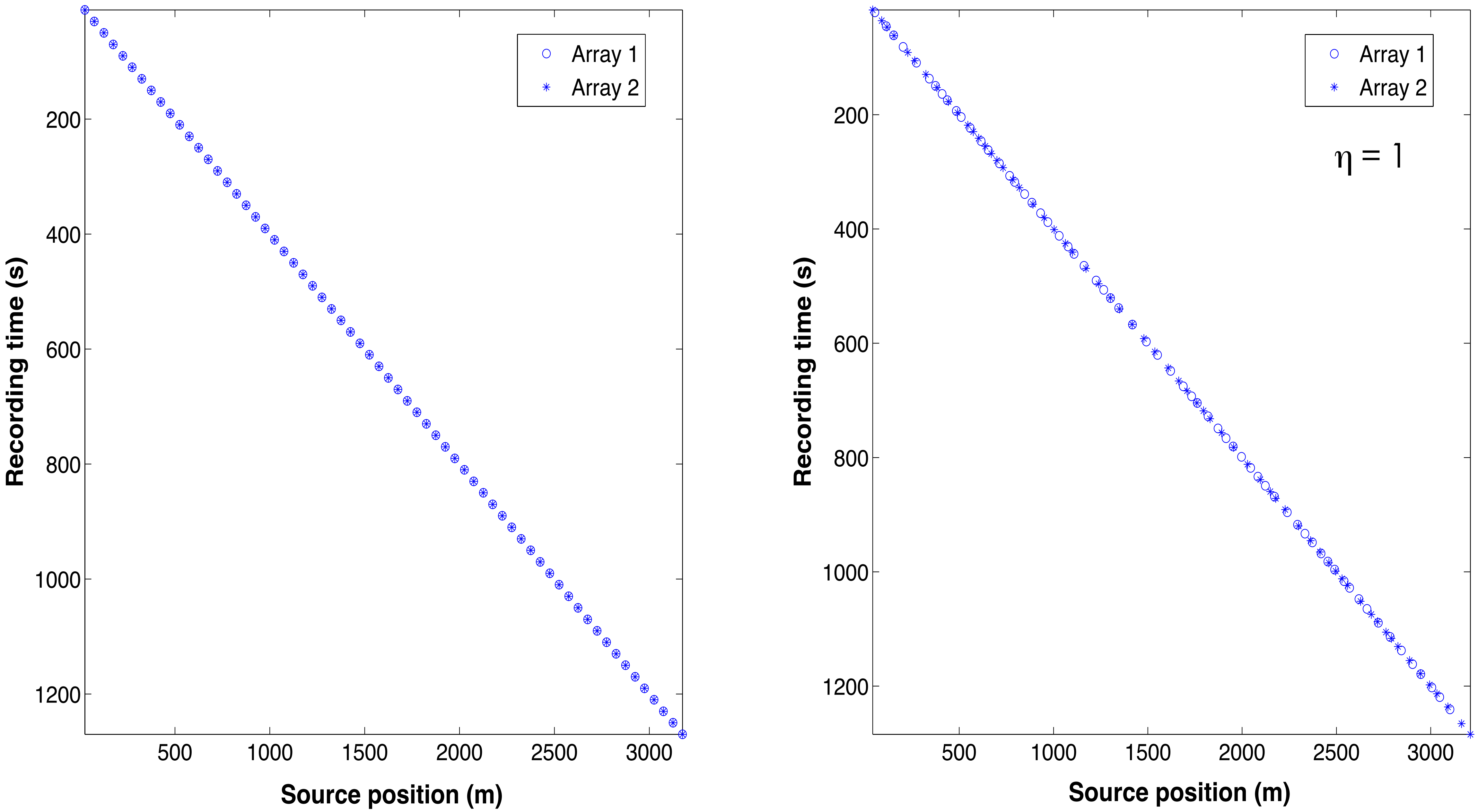
shot interval: **25** m



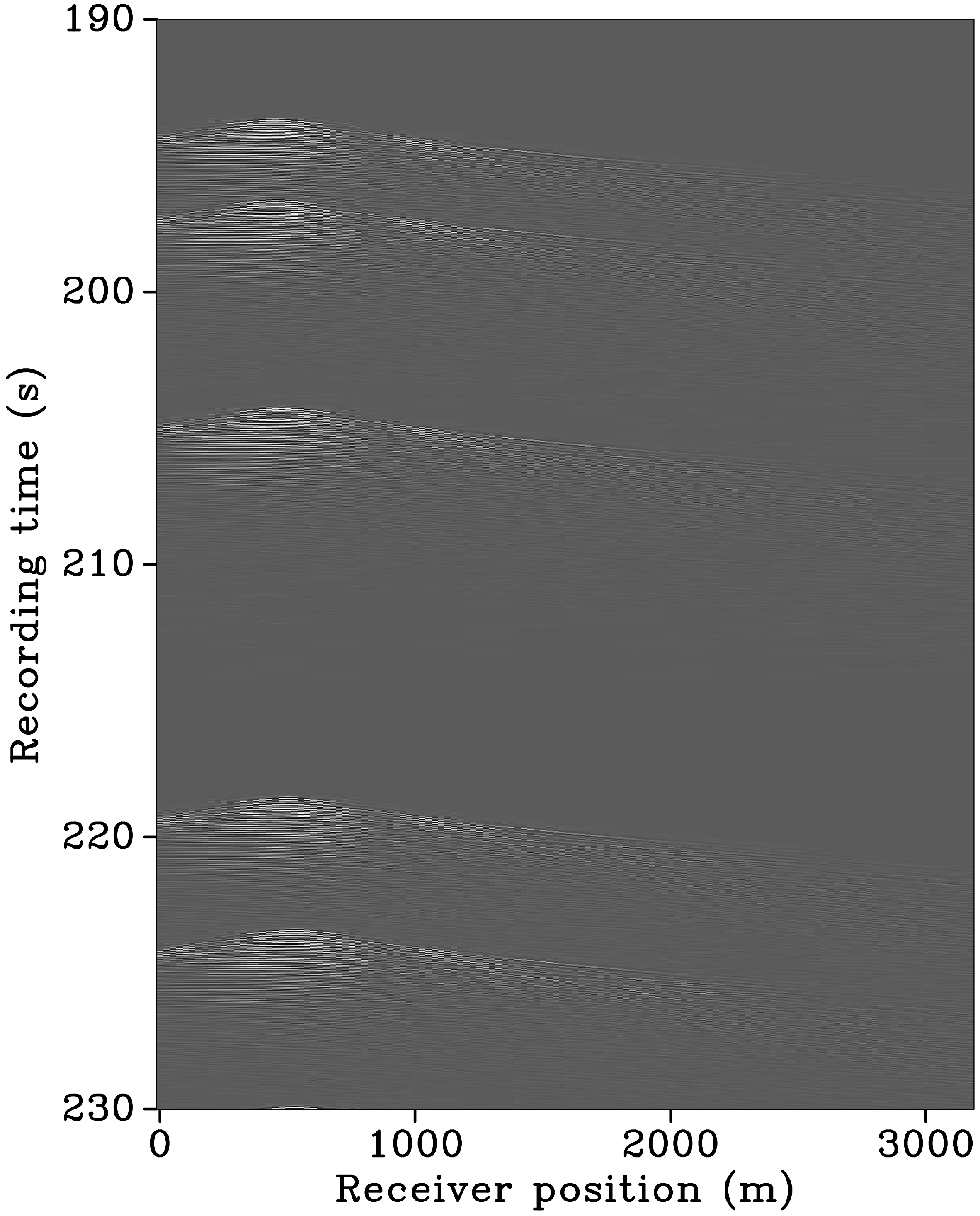
Conventional vs. *jittered* sources

[Speed of source vessel = 9 km/hr = 2.5 m/s]

shot interval: **50** m

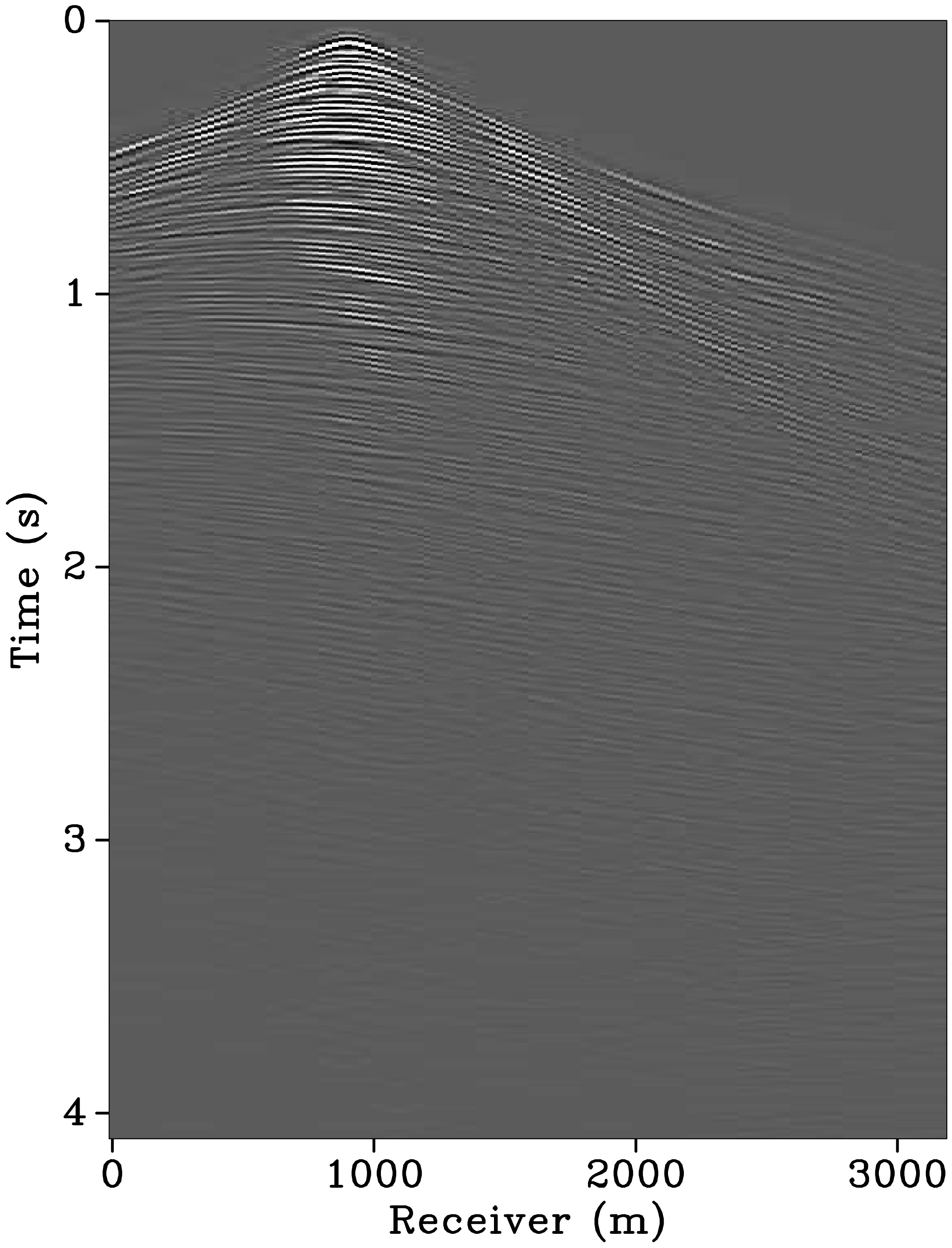


Measurements [b]



Outline

- Problem statement & recovery strategy
- Design of *jittered*, ocean bottom cable acquisition
  - jitter in *time* (⇒ jittered shot locations)
- Experimental results of *sparsity*-promoting processing
  - demultiplexing, and interpolation from coarser to finer sampling grid



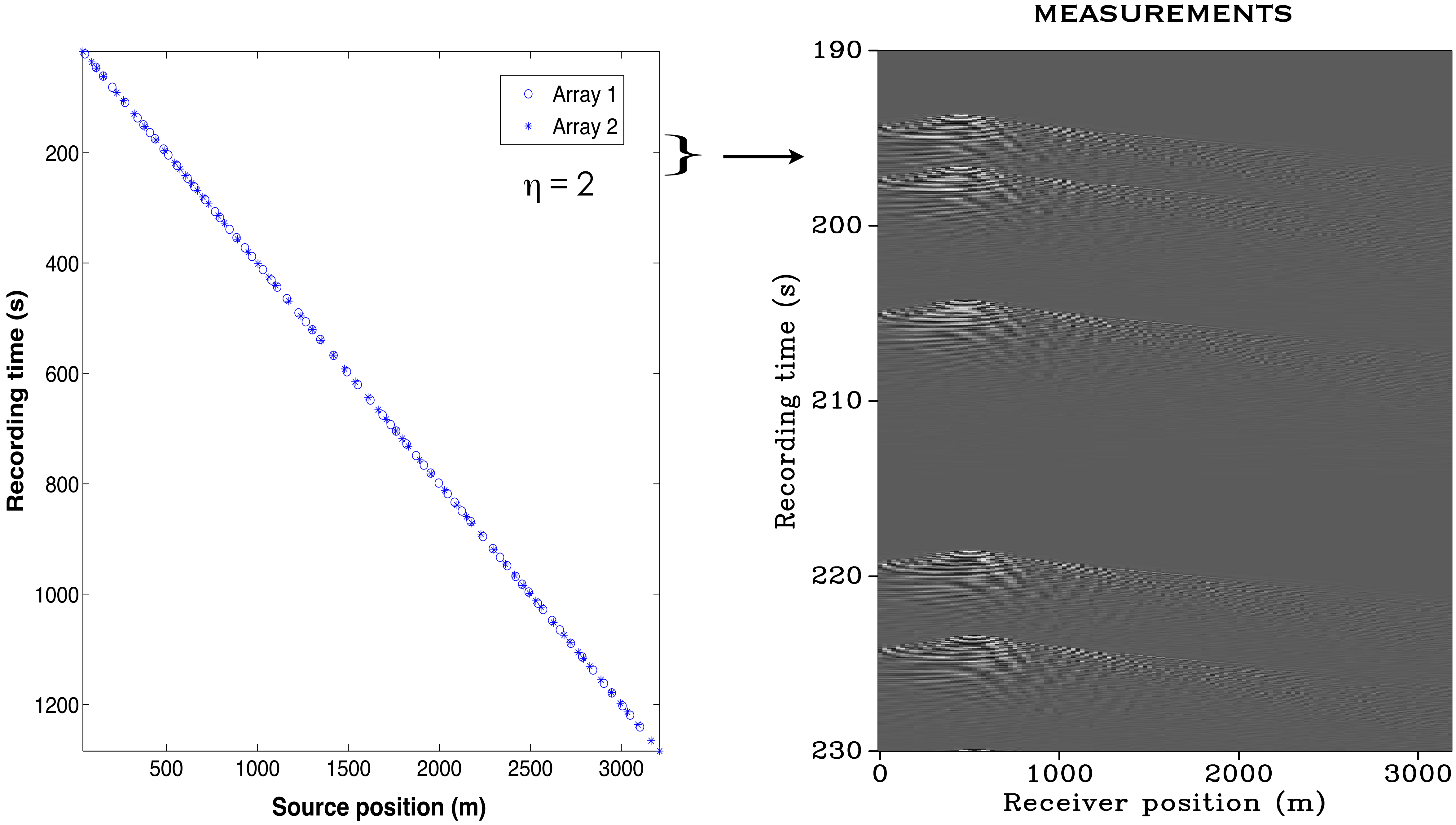
Gulf of Suez

1024 time samples
128 sources
128 receivers

Shot interval: **25 m**
Receiver/group interval: **25 m**

Time-jittered OBC acquisition

[1 source vessel, speed = 2.5 m/s, underlying grid: 25 m]



Recovery

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 25m grid]

CONVENTIONAL PROCESSING

Apply the adjoint of the sampling operator

+

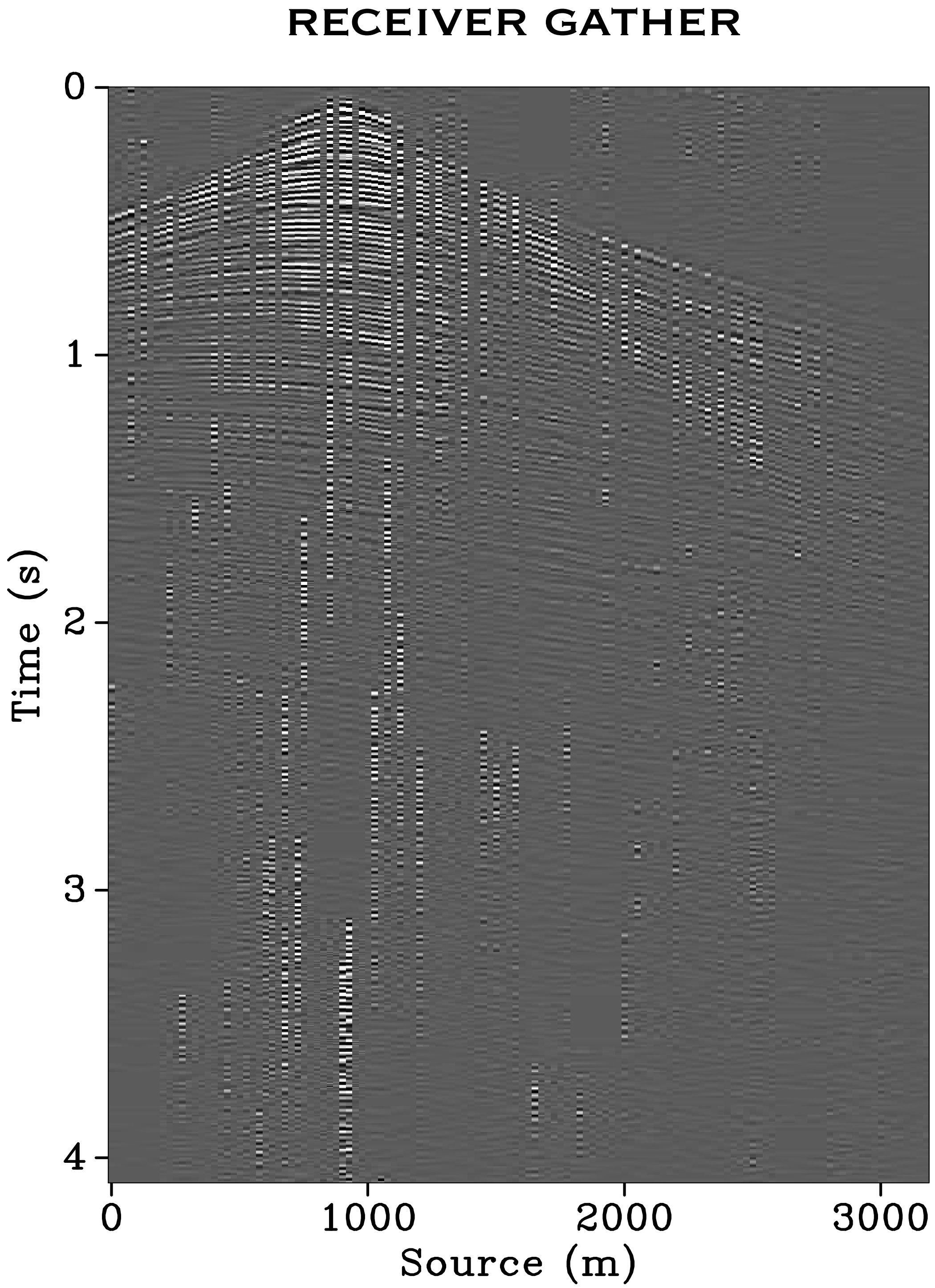
Median filtering in the midpoint-offset domain

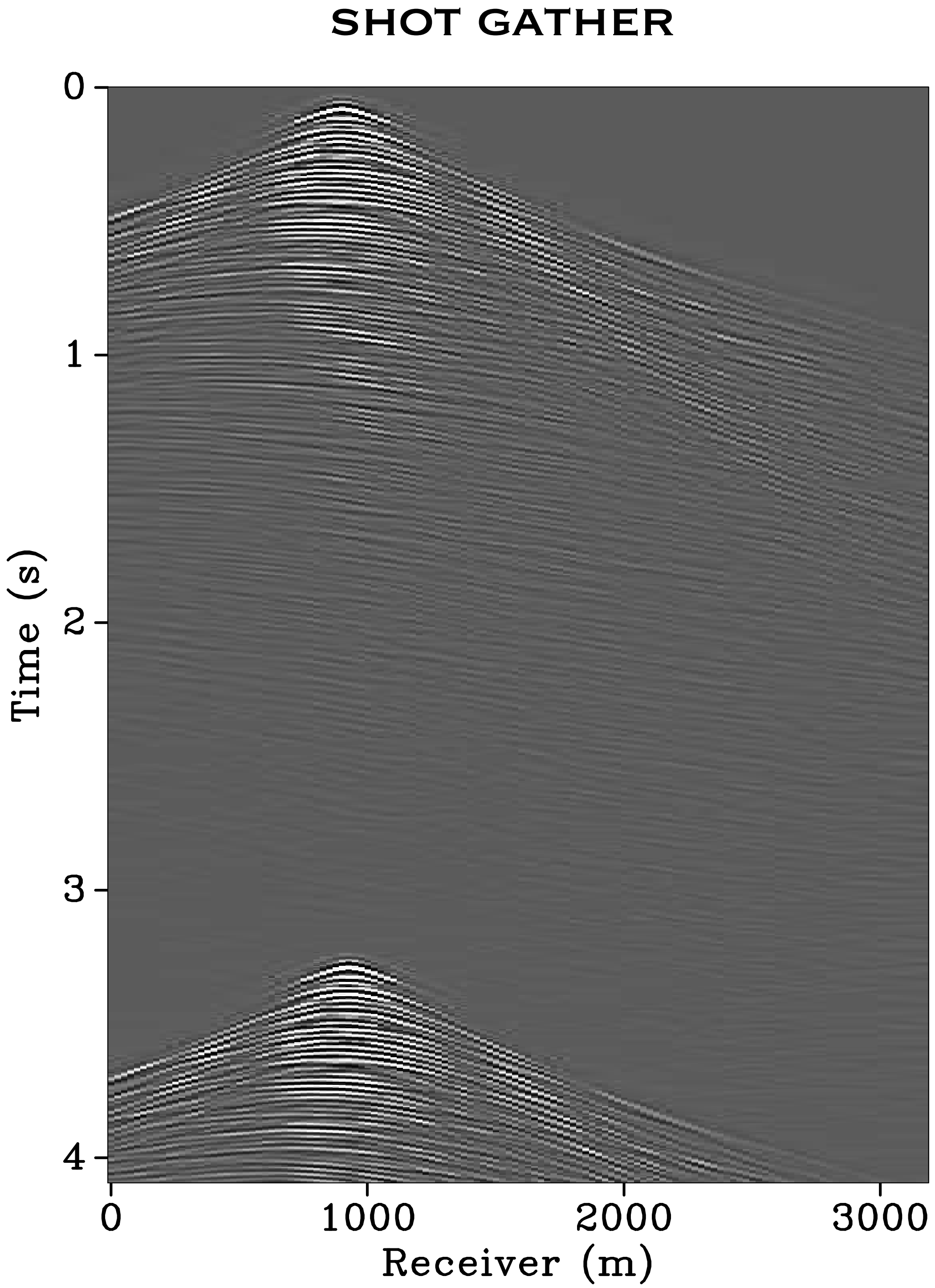
CURVELET-DOMAIN SPARSITY-PROMOTION

Solve an optimization problem (e.g., one-norm minimization)

Conventional processing

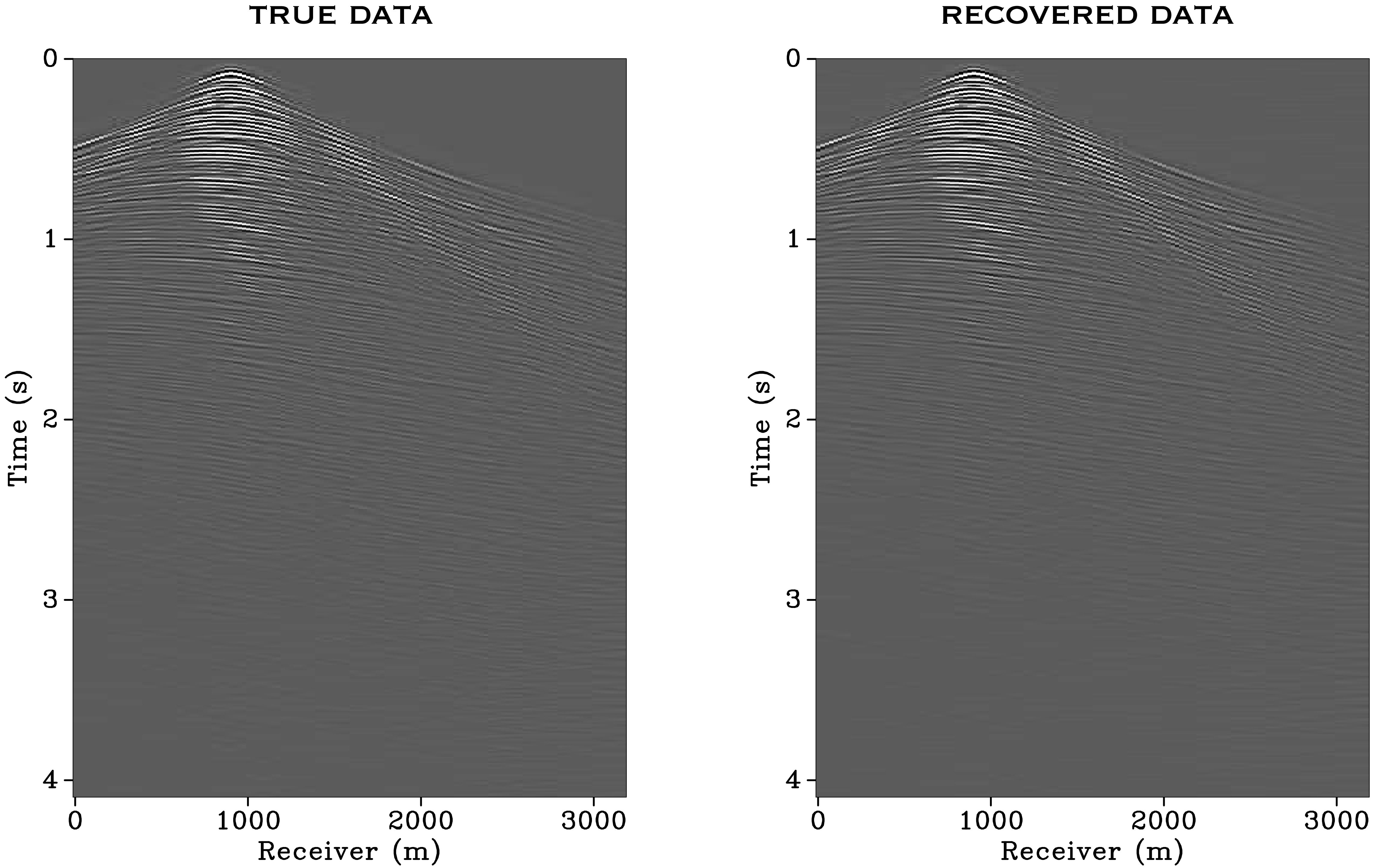
[Adjoint applied]





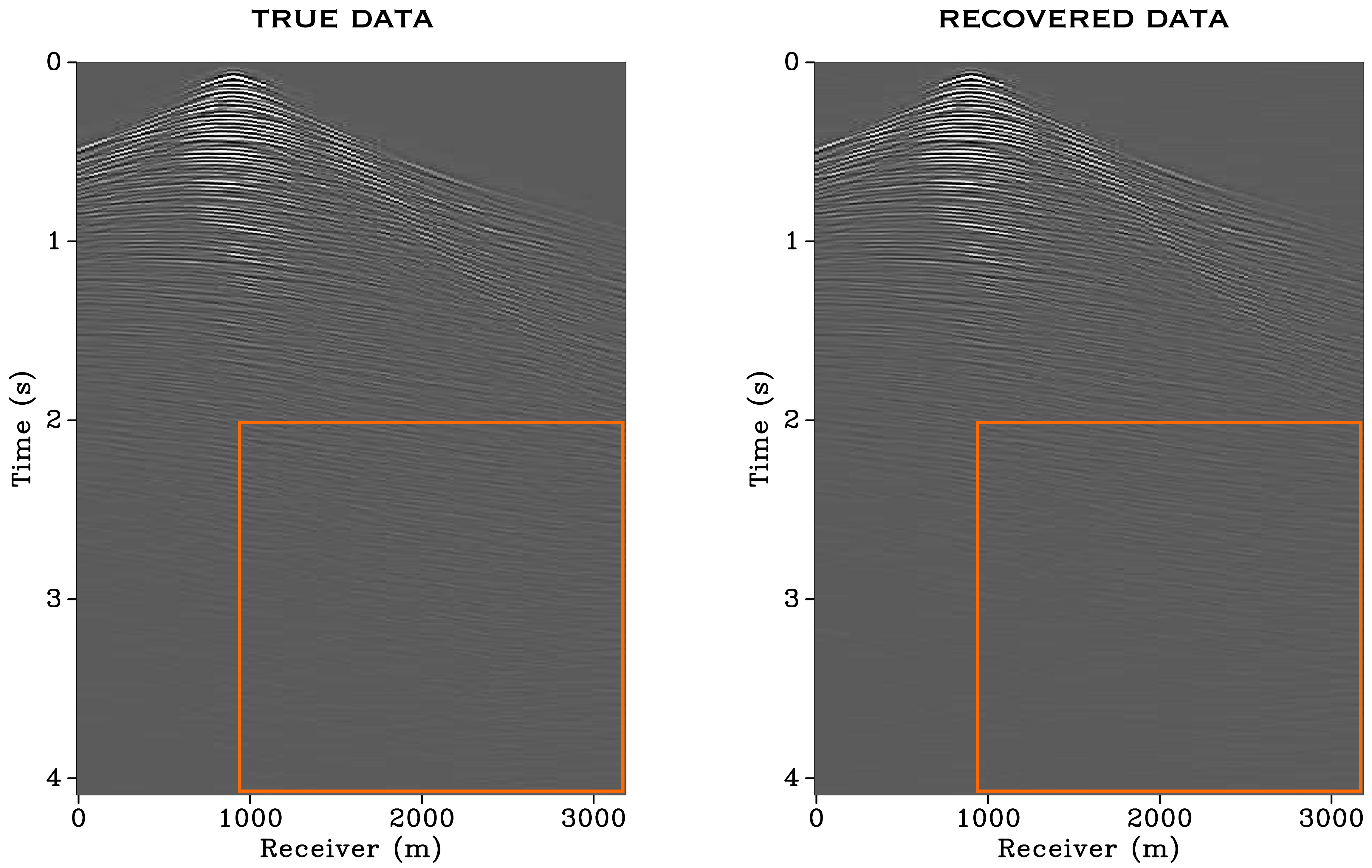
Sparsity-promoting recovery (15.4 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 25m grid]



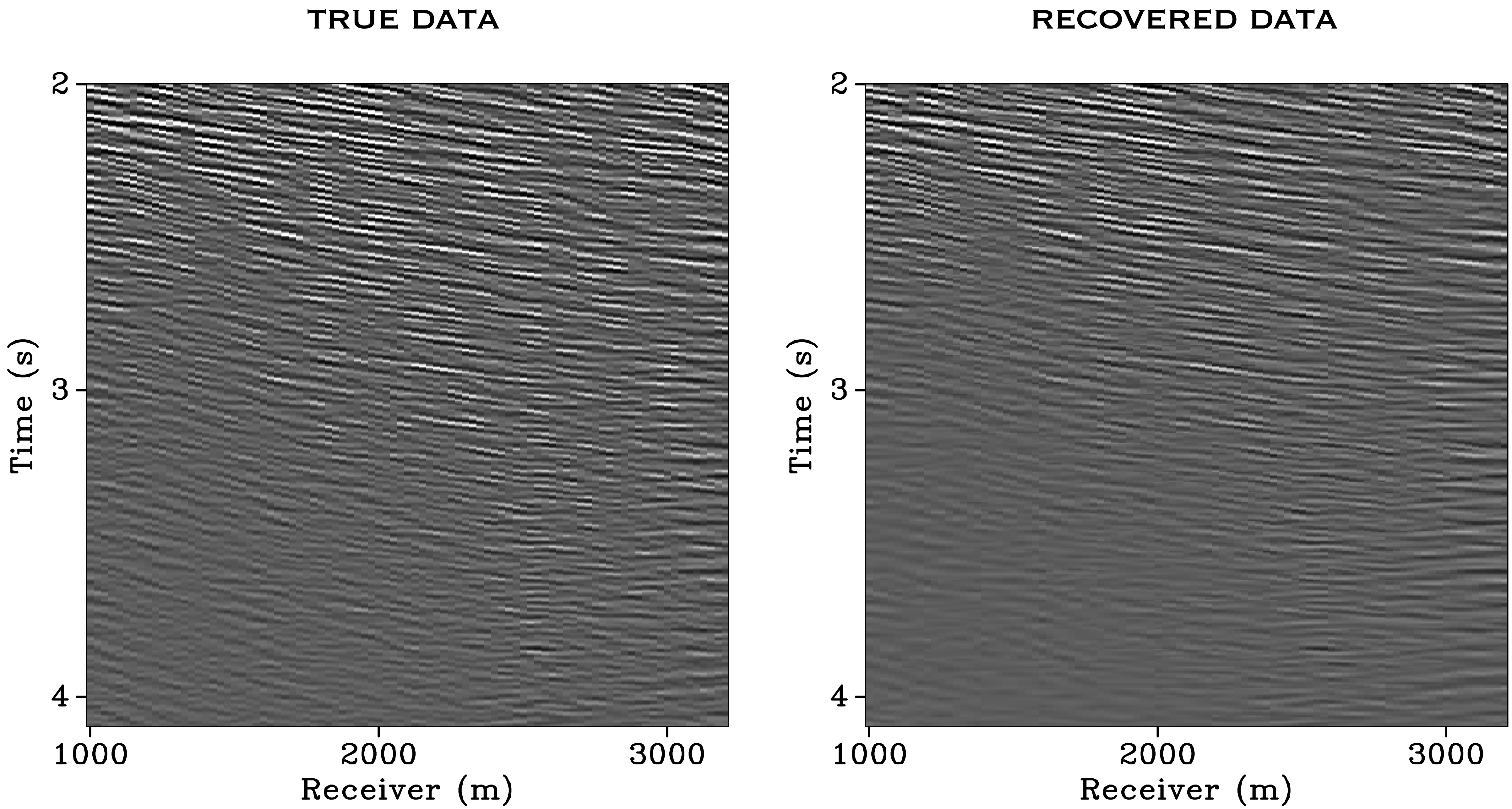
Sparsity-promoting recovery (15.4 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 25m grid]



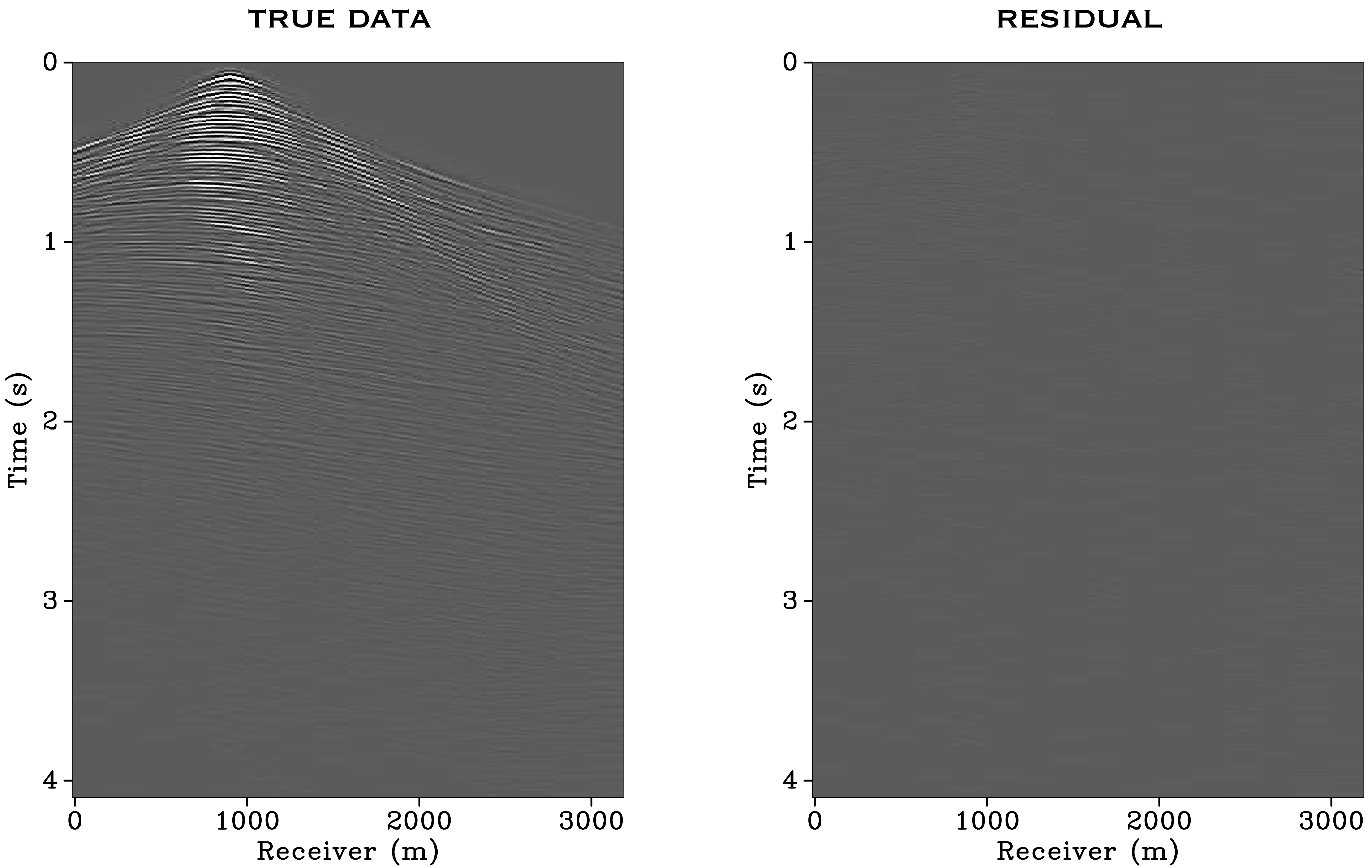
Sparsity-promoting recovery (15.4 dB)

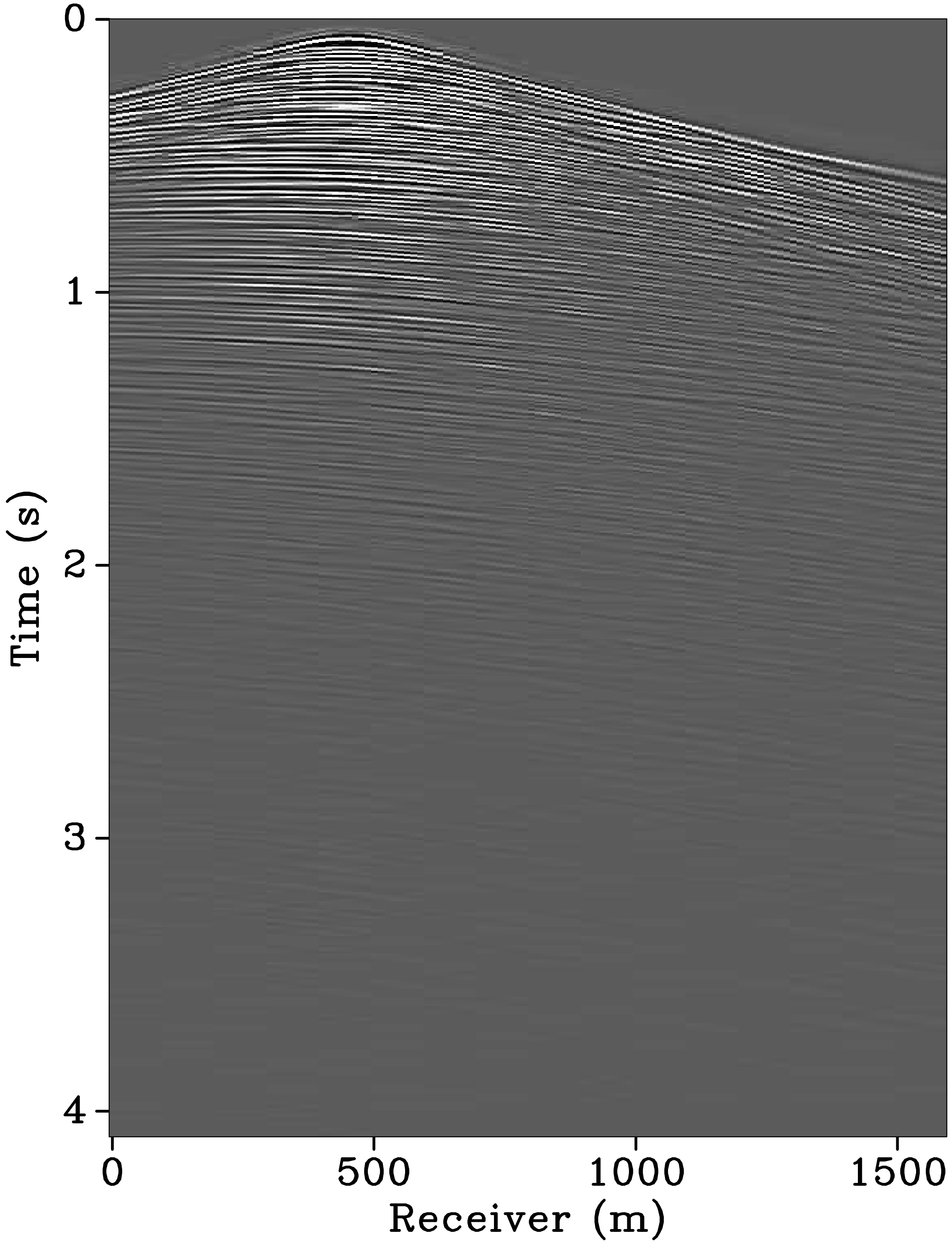
[Demultiplexing +
Interpolation from *jittered* 50m grid to *regular* 25m grid]



Sparsity-promoting recovery (15.4 dB)

[Demultiplexing +
Interpolation from *jittered* 50m grid to *regular* 25m grid]





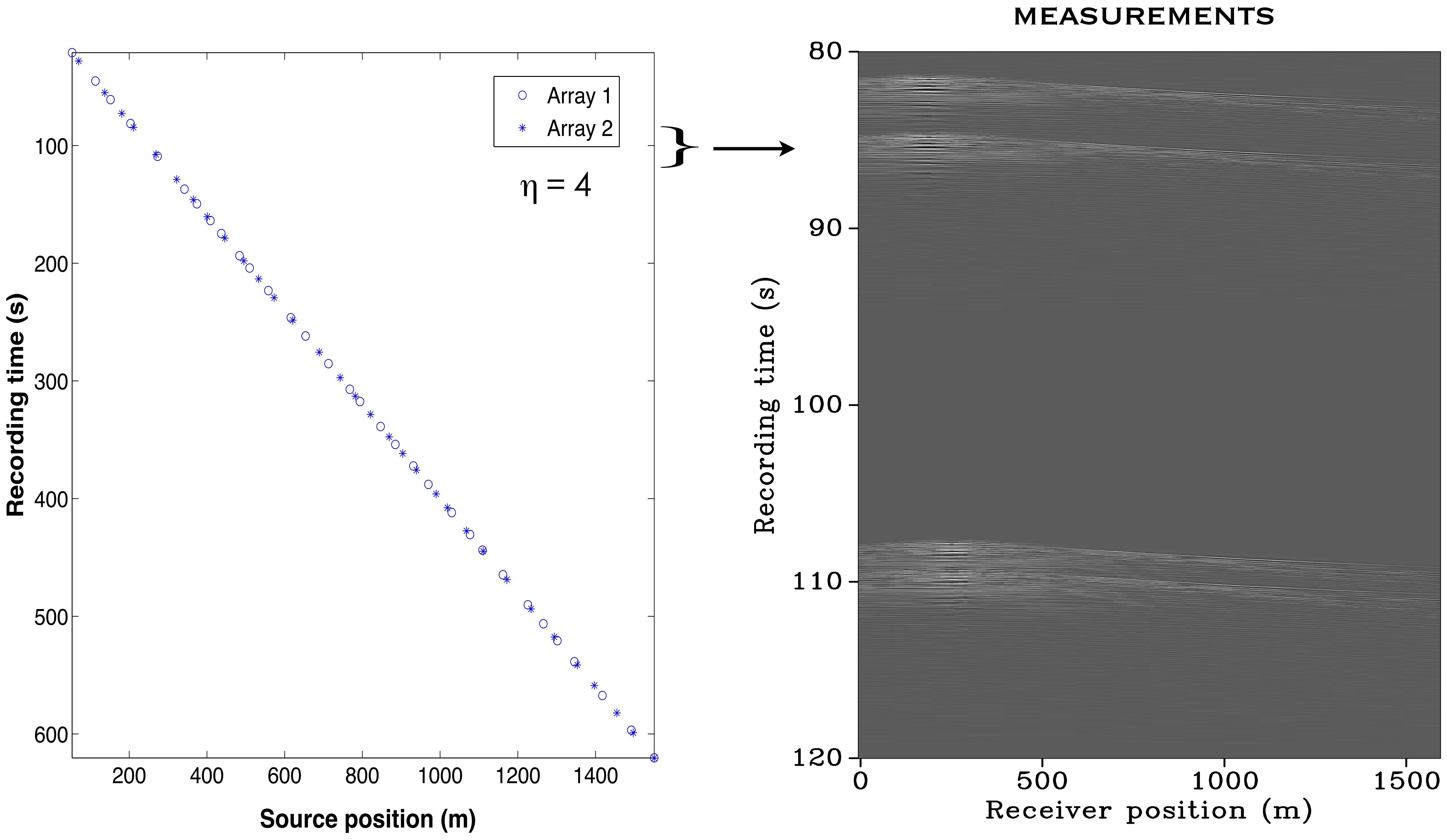
Gulf of Suez

1024 time samples
128 sources
128 receivers

Shot interval: **12.5 m**
Receiver/group interval: **12.5 m**

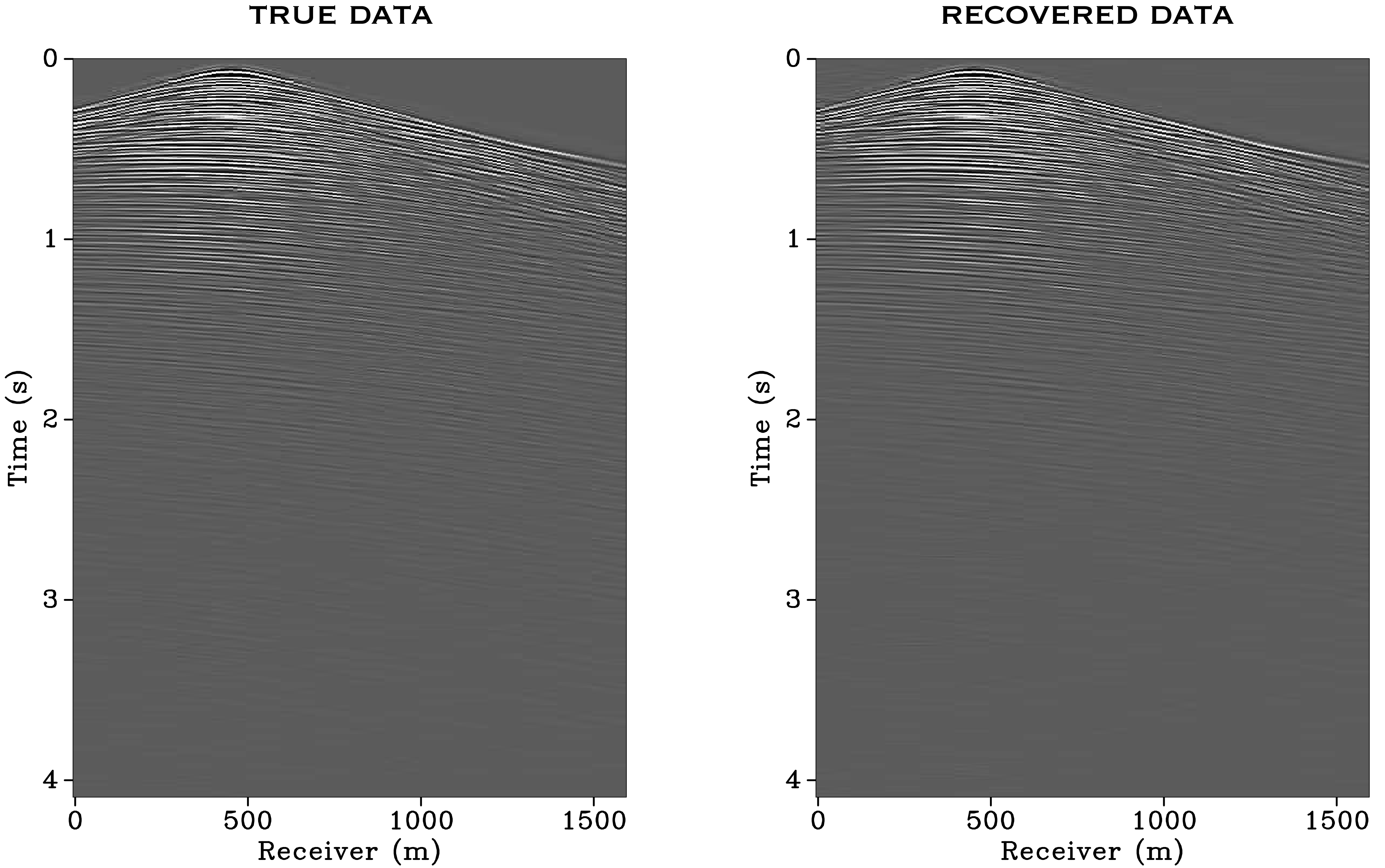
Time-jittered OBC acquisition

[1 source vessel, speed = 2.5 m/s, underlying grid: 12.5 m]



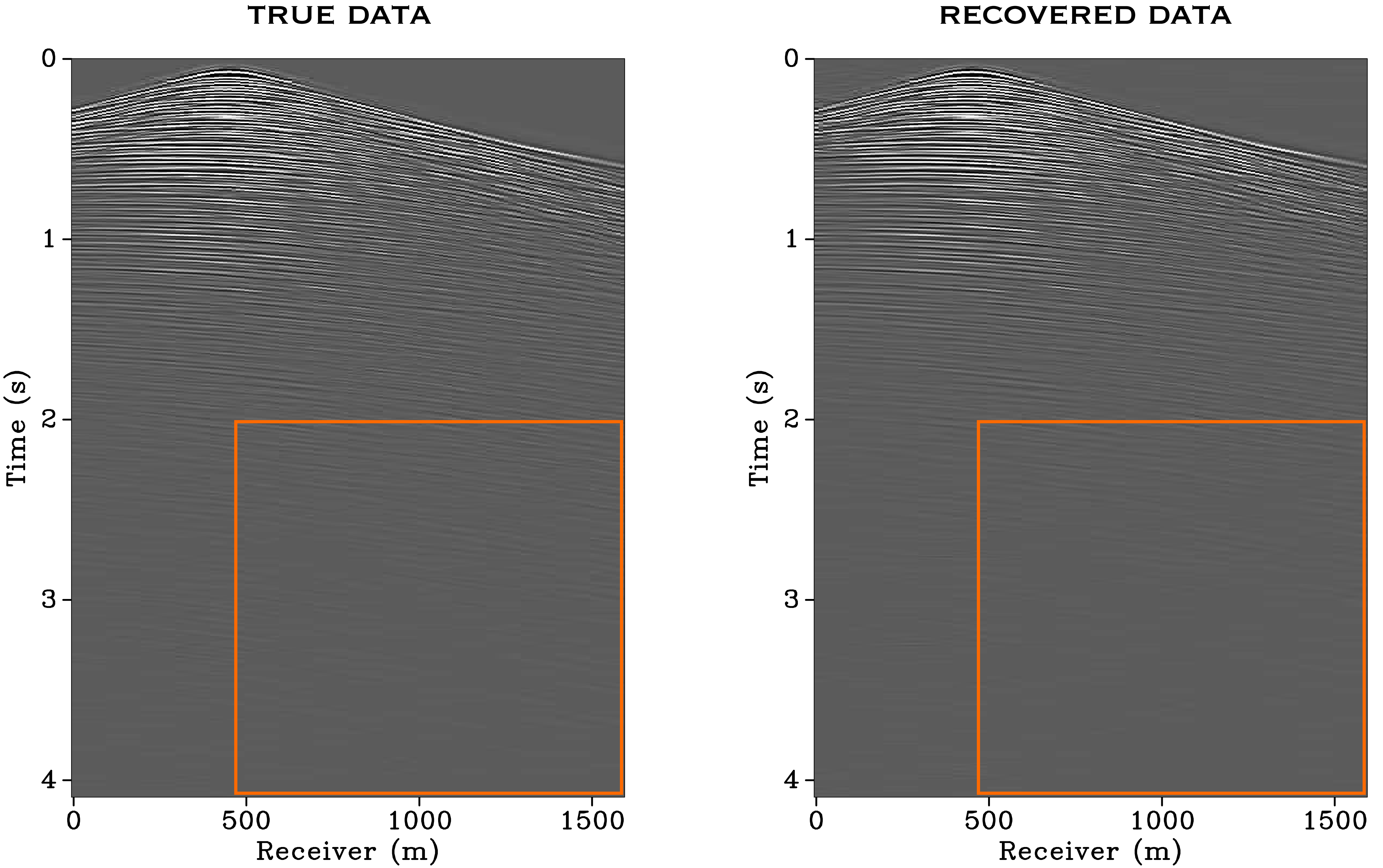
Sparsity-promoting recovery (10.8 dB)

[Demultiplexing +
Interpolation from *jittered* 50m grid to *regular* 12.5m grid]



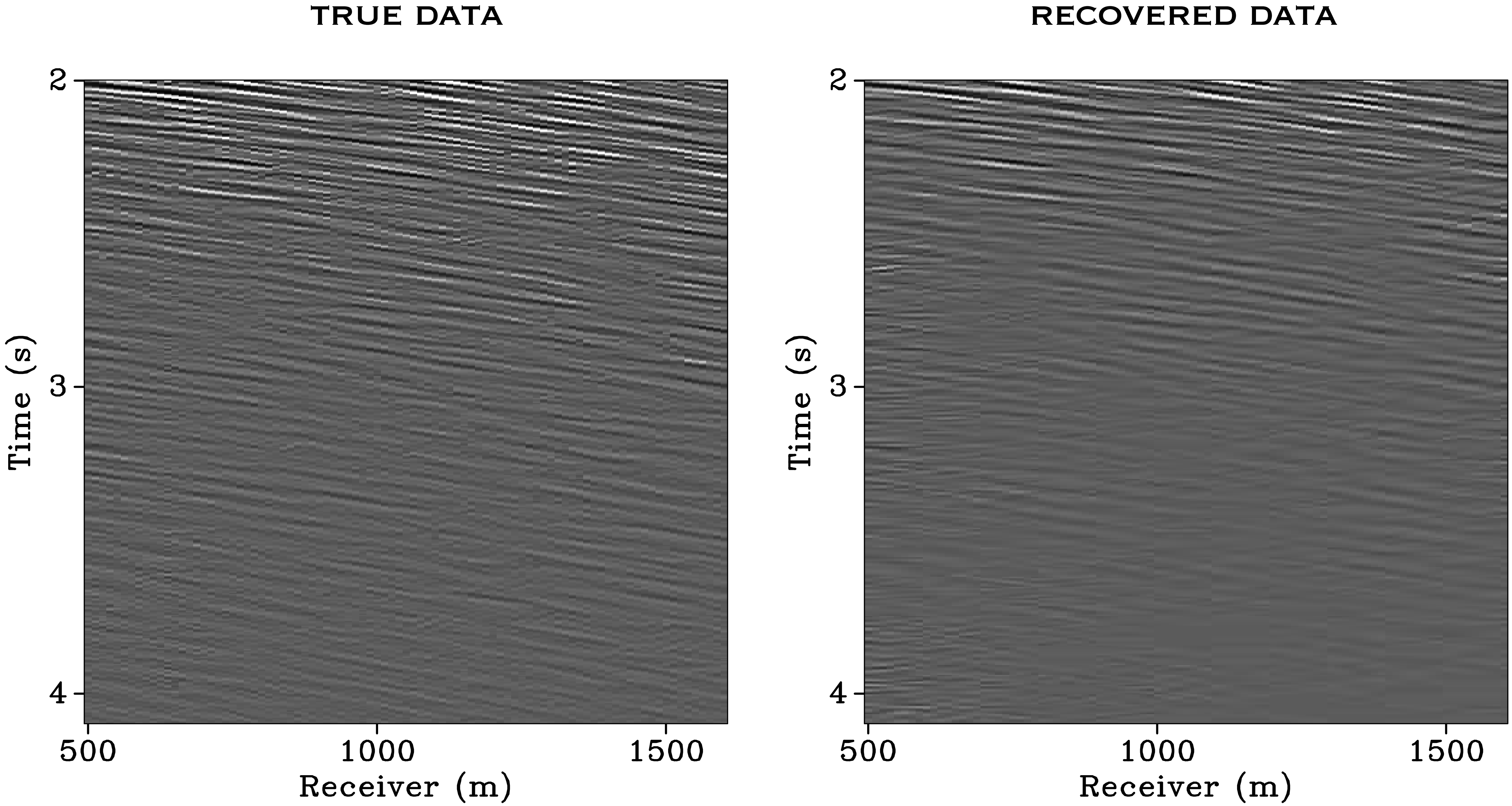
Sparsity-promoting recovery (10.8 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 12.5m grid]



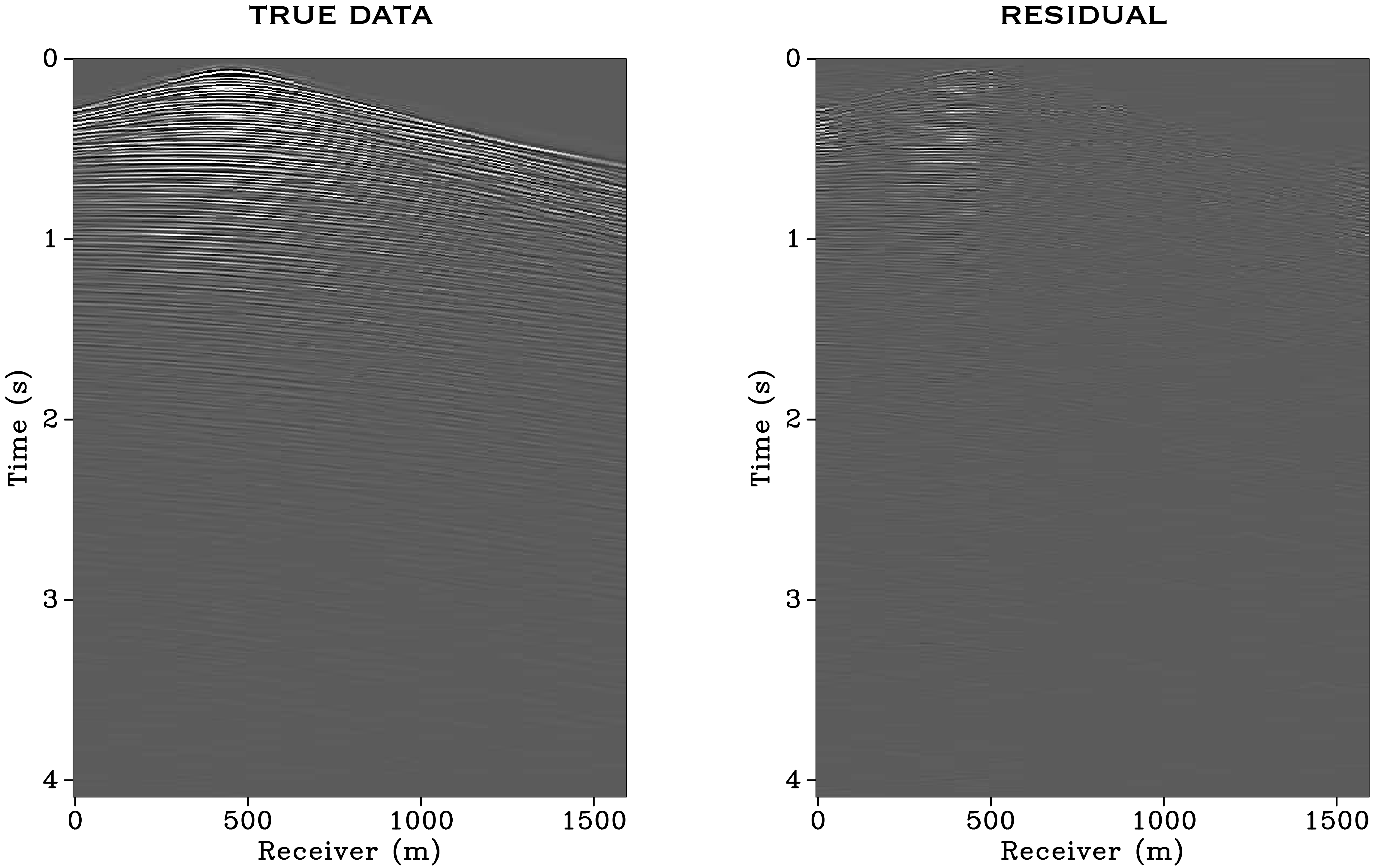
Sparsity-promoting recovery (10.8 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 12.5m grid]



Sparsity-promoting recovery (10.8 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 12.5m grid]

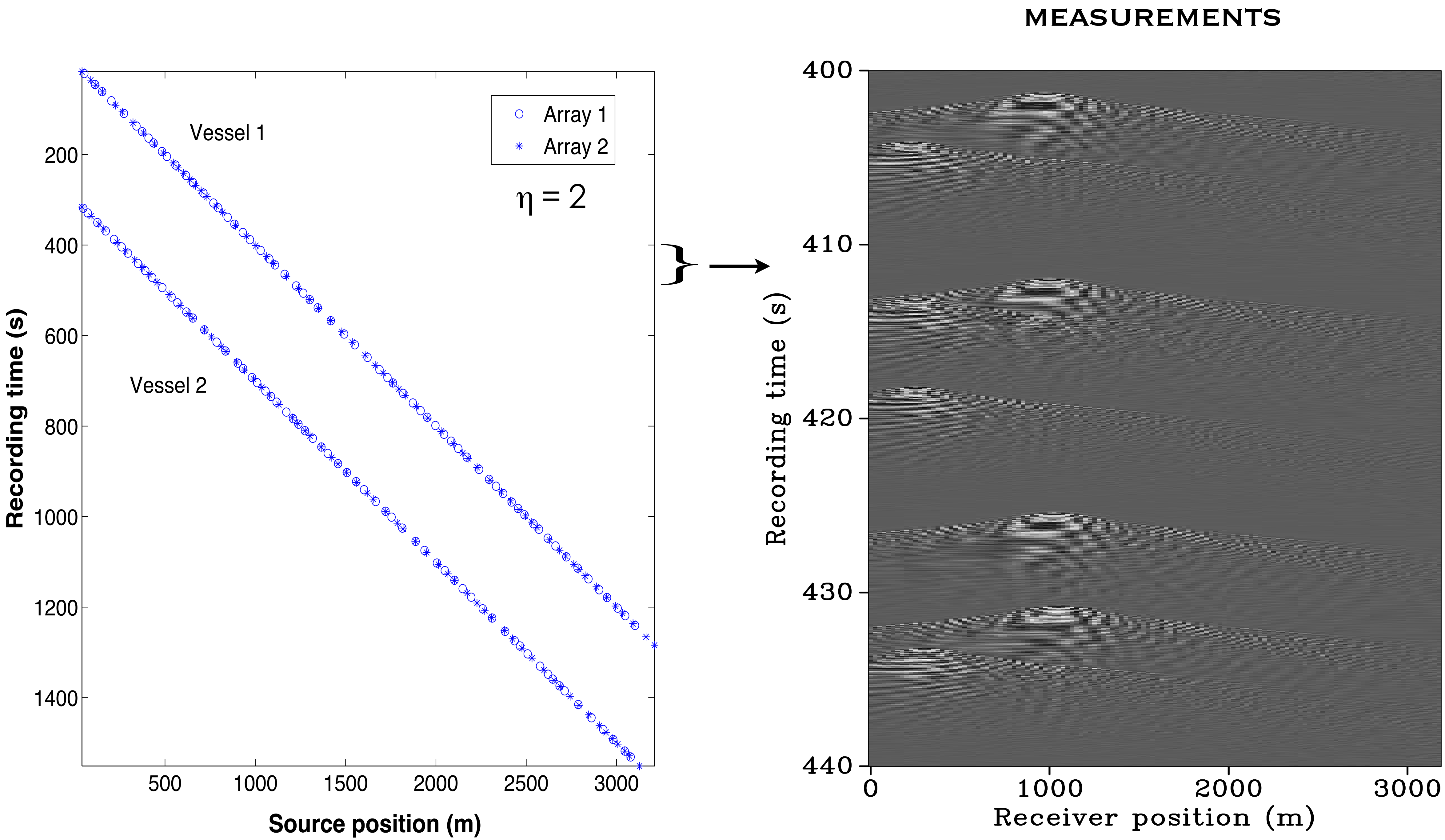


Summary

	interpolate (jittered to regular)	sparsity-promoting recovery [snr (dB)]
1 source vessel (2 airgun arrays)	50m to 25m	15.4
	50m to 12.5m	10.8
2 source vessels (2 airgun arrays per vessel)	50m to 25m	?
	50m to 12.5m	?

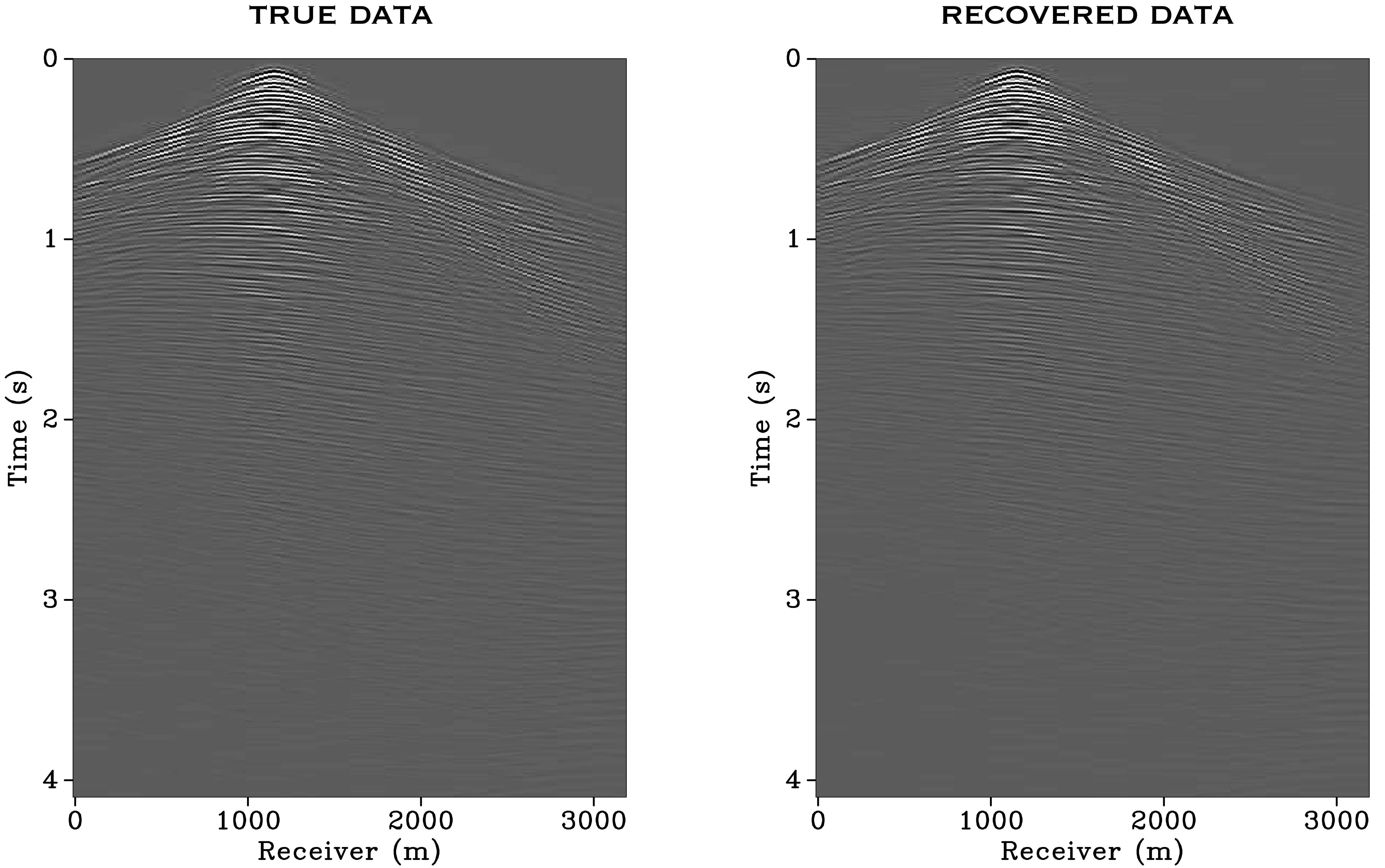
Time-jittered OBC acquisition

[2 source vessels, speed = 2.5 m/s, underlying grid: 25 m]



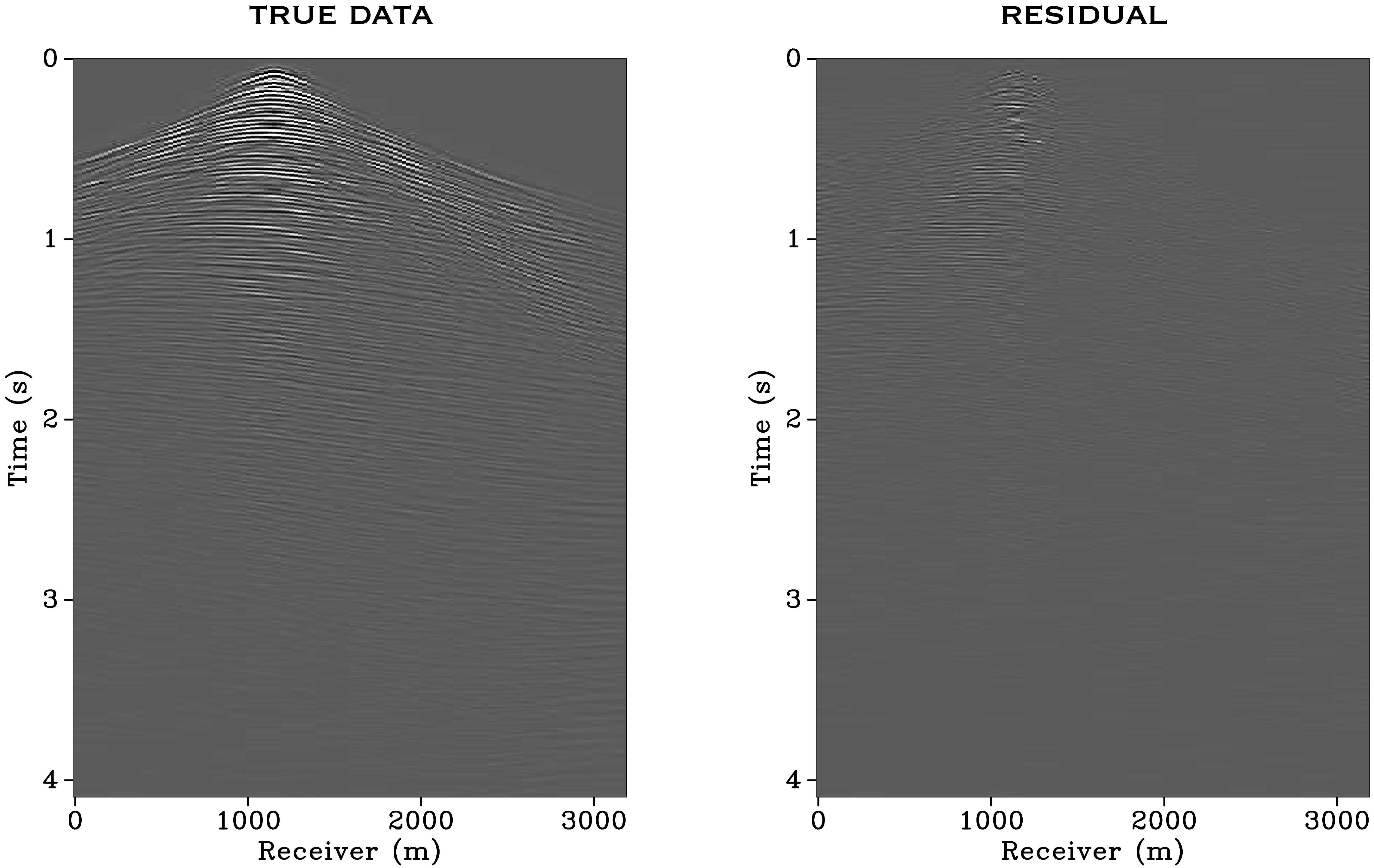
Sparsity-promoting recovery (20.5 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 25m grid]



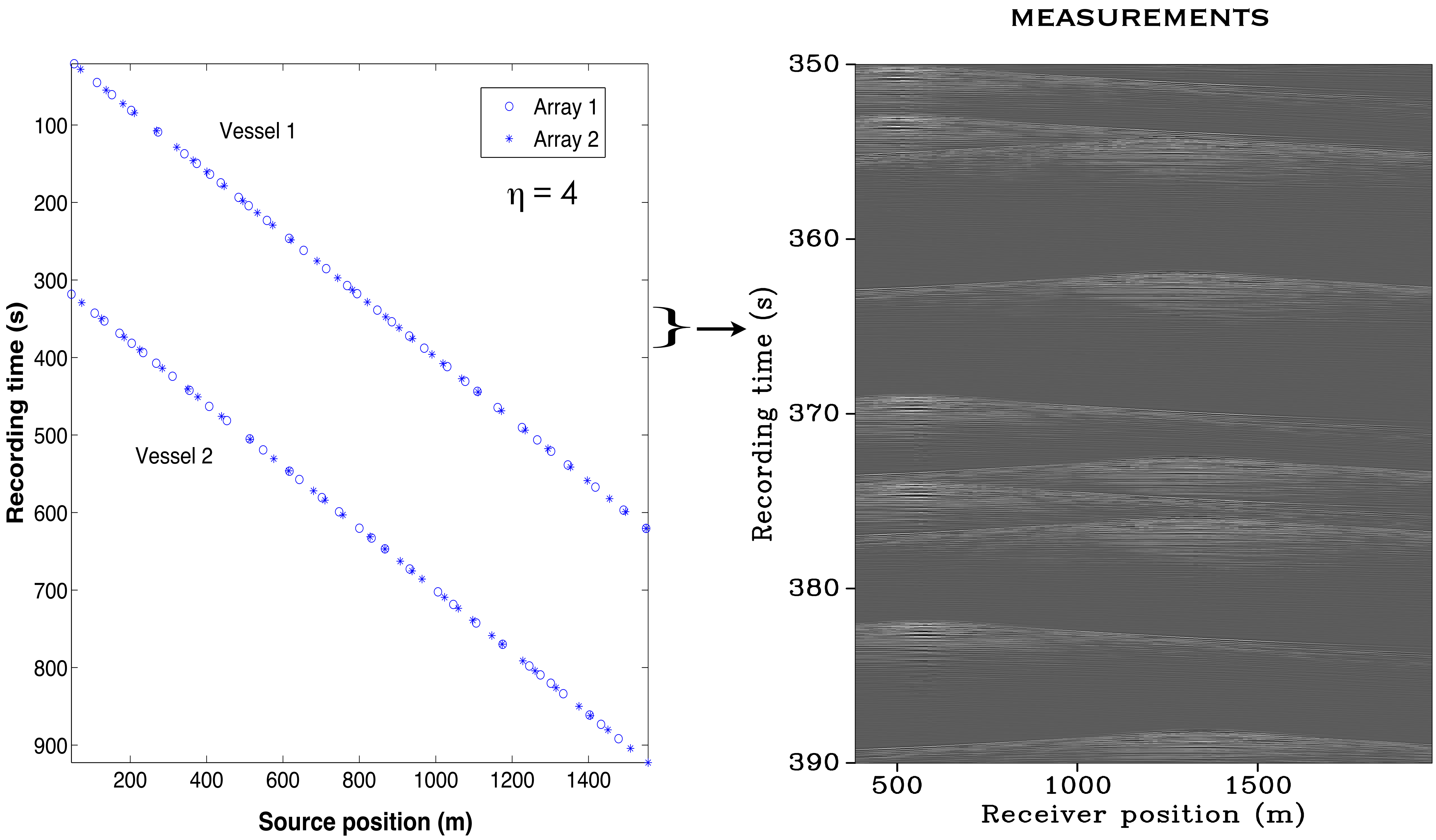
Sparsity-promoting recovery (20.5 dB)

[Demultiplexing +
Interpolation from *jittered* 50m grid to *regular* 25m grid]



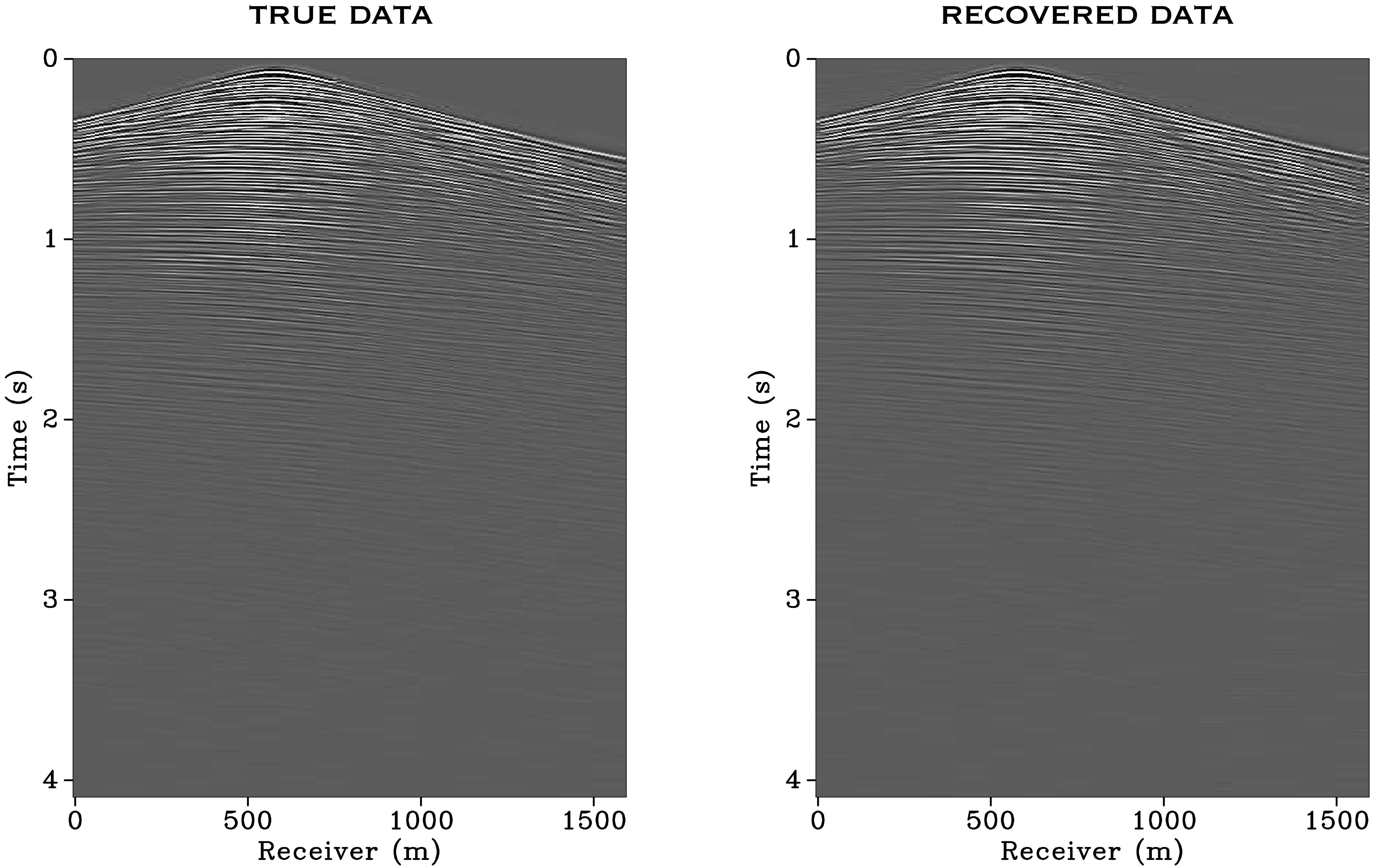
Time-jittered OBC acquisition

[2 source vessels, speed = 2.5 m/s, underlying grid: 12.5 m]



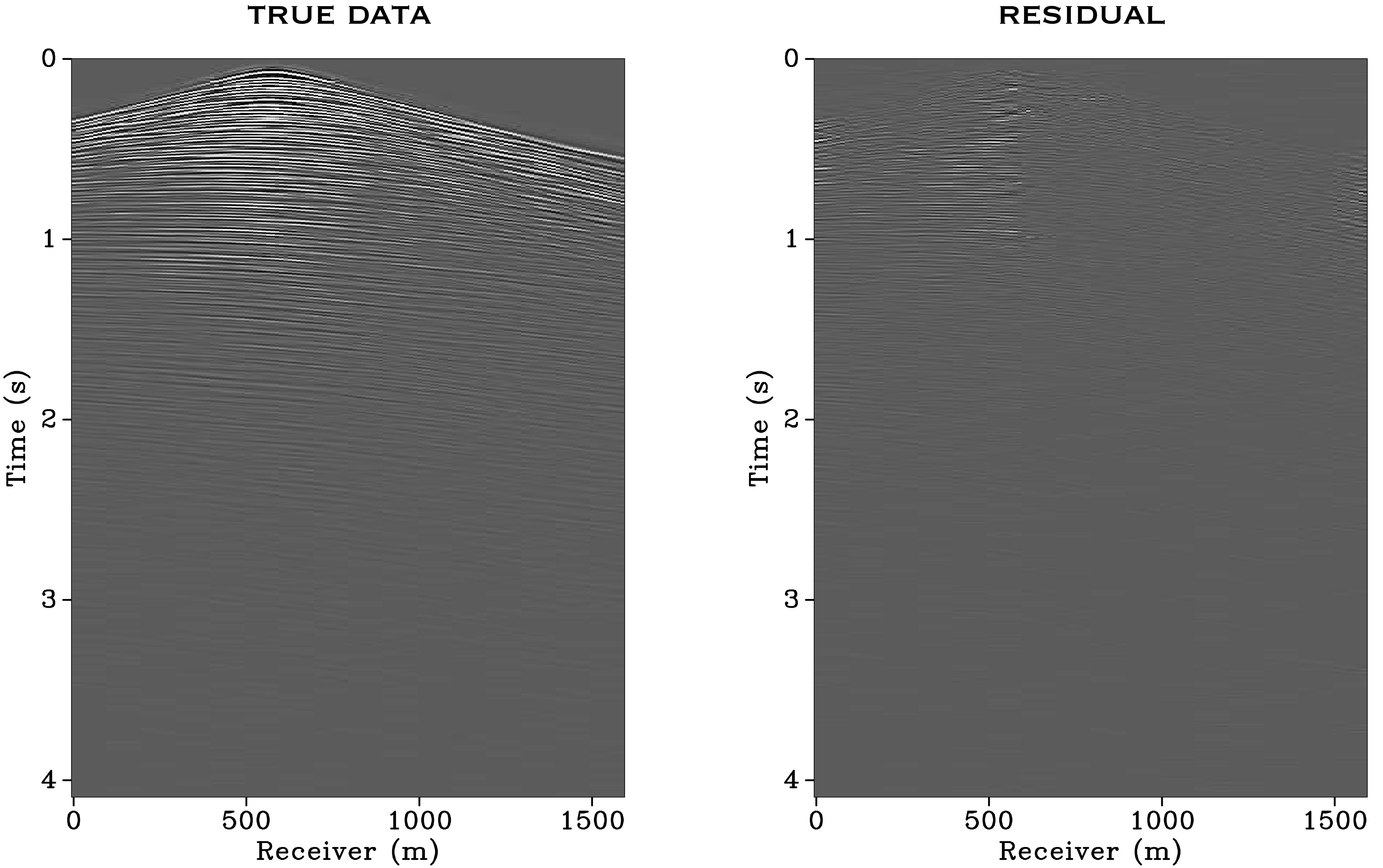
Sparsity-promoting recovery (14.7 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 12.5m grid]



Sparsity-promoting recovery (14.7 dB)

[Demultiplexing + Interpolation from *jittered* 50m grid to *regular* 12.5m grid]



Summary

	interpolate (jittered to regular)	sparsity-promoting recovery [snr (dB)]
1 source vessel (2 airgun arrays)	50m to 25m	15.4
	50m to 12.5m	10.8
2 source vessels (2 airgun arrays per vessel)	50m to 25m	20.5
	50m to 12.5m	14.7

Observations

- *Time*-jittered (simultaneous) marine acquisition is an instance of compressive sensing

- With *sparsity*-promoting recovery we can:
  - *demultiplex*, and
  - *interpolate* from a coarser (50m) grid to a finer grid (25m, 12.5m)

Observations

- Survey-time ratio, [Berkhout, 2008]

$$\mathrm{STR} = \frac{\text{time of the conventional recording}}{\text{time of the simultaneous recording}}$$

  - shot interval $= 12.5\mathrm{m}$, record length (shot gather) $= 10.0\mathrm{s}$, with no overlap $\Longrightarrow$
    decreased speed of the source vessel $= 1.25\mathrm{m/s}$

$$\mathrm{STR} = \frac{1600\mathrm{m}/1.25\mathrm{m/s}}{1600\mathrm{m}/2.5\mathrm{m/s}} = 2$$

Observations

- Source-density ratio,

[Berkhout, 2008]

$$\text{SDR} = \frac{\text{\# of sources in the simultaneous survey (after recovery)}}{\text{\# of sources in the conventional survey}}$$

$$= (2*128) / (2*32) = 4$$

Future work

- 3D acquisition – innovative geometries
  - jittered shots *and* receivers
  - ocean bottom nodes

- Processing with simultaneous data

References

Beasley, C. J., 2008, A new look at marine simultaneous source, *The Leading Edge, 27, 914-917.*

van den Berg, E., and Friedlander, M.P., 2008, Probing the Pareto frontier for basis pursuit solutions, *SIAM Journal on Scientific Computing, 31, 890-912.*

Berkhout, A. J., 2008, Changing the mindset in seismic data acquisition, *The Leading Edge, 27, 924-938.*

Candès, E., J. Romberg, and T. Tao, 2006, Stable signal recovery from incomplete and inaccurate measurements: *Comm. Pure Appl. Math., 59, 1207–1223*.

Candès, E. J., and L. Demanet, 2005, The curvelet representation of wave propagators is optimally sparse: *Comm. Pure Appl. Math, 58, 1472–1528*.

Candès, E. J., L. Demanet, D. L. Donoho, and L. Ying, 2006, Fast discrete curvelet transforms: *Multiscale Modeling and Simulation, 5, 861–899*.

Donoho, D. L., 2006, Compressed sensing: *IEEE Trans. Inform. Theory, 52, 1289–1306*.

Donoho, P., R. Ergas, and R. Polzer, 1999, Development of seismic data compression methods for reliable, low-noise performance: *SEG International Exposition and 69th Annual Meeting, 1903–1906*.

Hennenfent, G., and Felix J. Herrmann, 2008, Simply denoise: wavefield reconstruction via jittered undersampling, *Geophysics, 73, 19-28.*

Herrmann, F. J., Y. A. Erlangga, and T. Lin, 2009, Compressive simultaneous full-waveform simulation: *Geophysics, 74, A35*.

Mansour, H., Haneet Wason, Tim T. Y. Lin, and Felix J. Herrmann, 2012, Randomized marine acquisition with compressive sampling matrices: *Geophysical Prospecting, 60, 648–662*.

Romberg, J., 2009, Compressive sensing by random convolution: *SIAM Journal on Imaging Sciences, 2, 1098–1128*.

Acknowledgements

E. J. Candès, L. Demanet, D. L. Donoho, and L. Ying for CurveLab (www.curvelet.org)

E. van den Berg and M. P. Friedlander for SPGl1 (www.cs.ubc.ca/labs/scl/spgl1)

This work was in part financially supported by the Natural Sciences and Engineering Research Council of Canada Discovery Grant (22R81254) and the Collaborative Research and Development Grant DNOISE II (375142-08). This research was carried out as part of the SINBAD II project with support from the following organizations: BG Group, BGP, BP, Chevron, ConocoPhillips, Petrobras, PGS, Total SA, and WesternGeco.