Simultaneous-source seismic data acquisition and processing with compressive sensing

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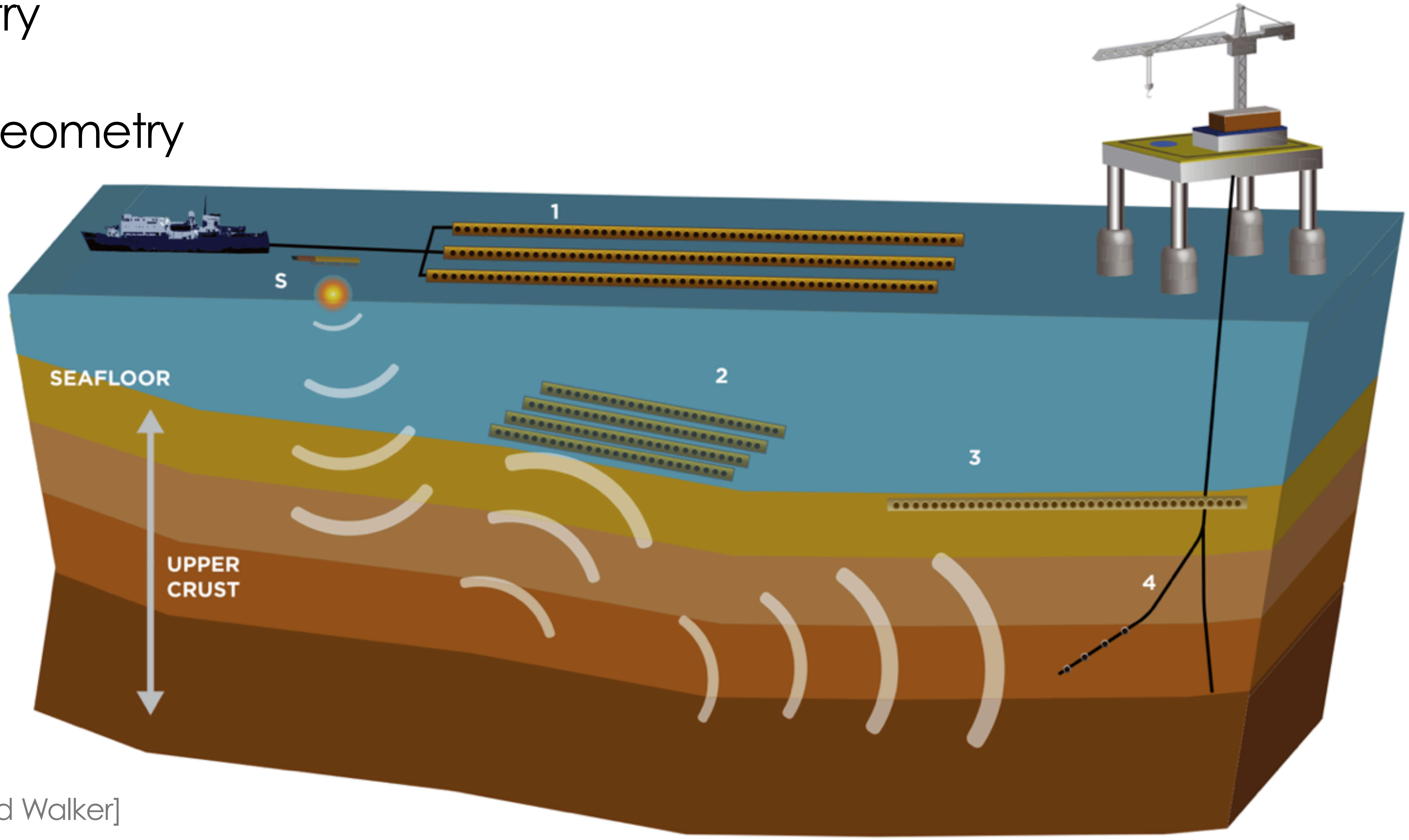
Introduction

Seismic data acquisition
- marine surveys
- static vs. dynamic geometries
- time-lapse surveys

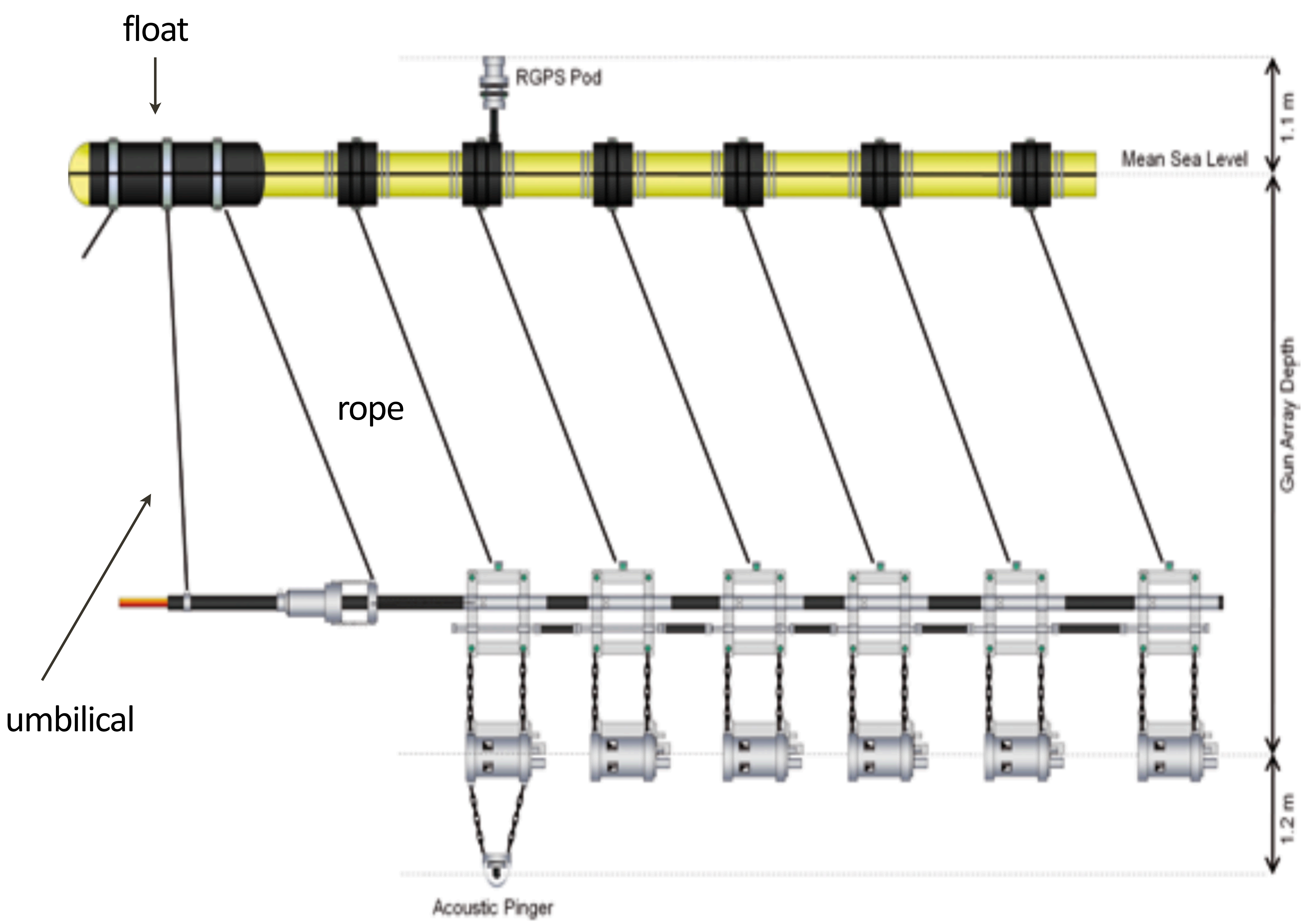
Marine seismic surveys

S : seismic source (air-gun arrays)
• : receivers (hydrophones and/or geophones)
1 : towed-streamer geometry (**moving receivers => dynamic geometry**)
2 : ocean-bottom geometry
3 : buried seafloor array
4 : vertical seismic profile geometry
2 - 4: **fixed receivers**
=> static geometries

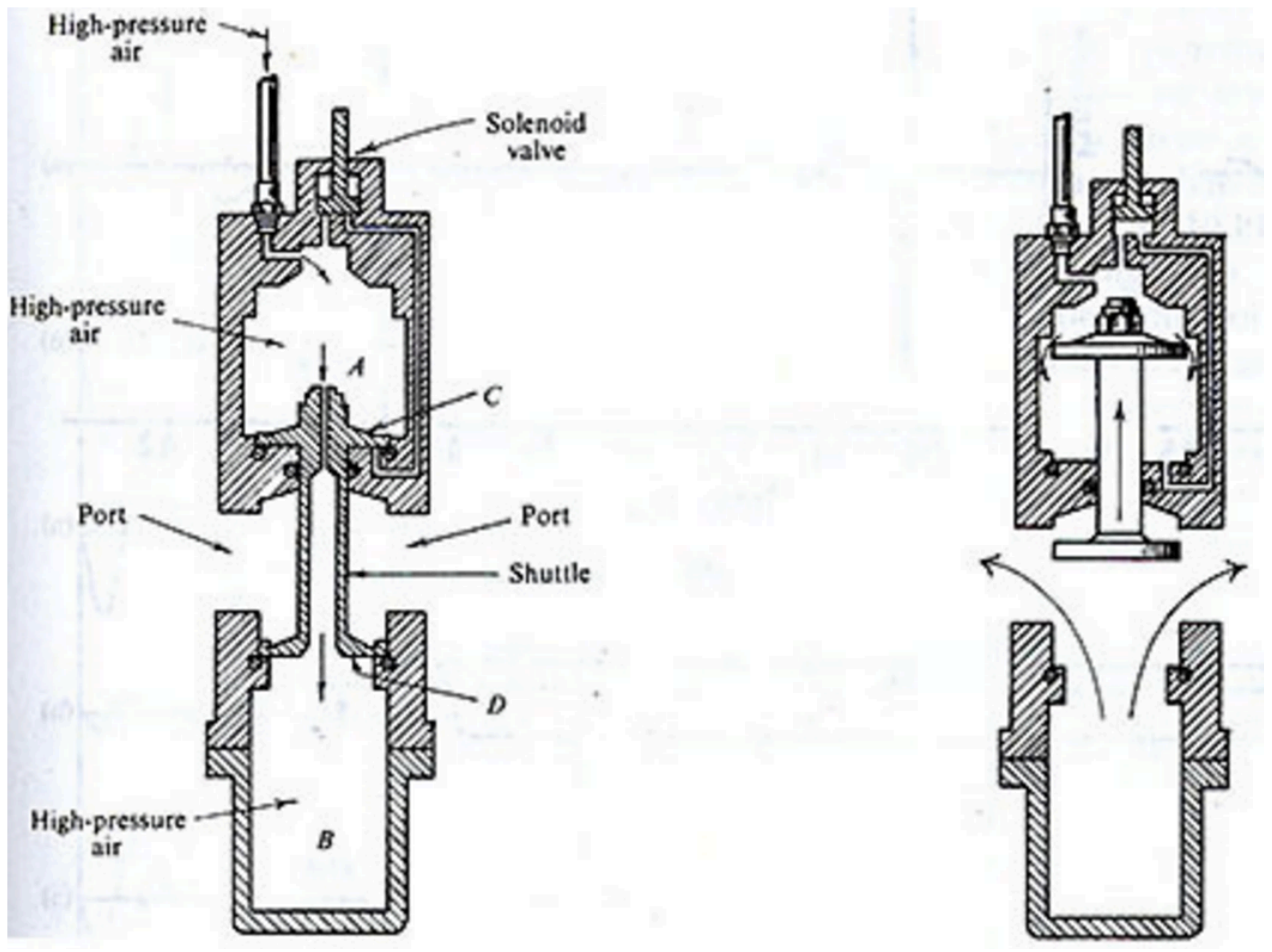


[Caldwell and Walker]

Marine seismic source



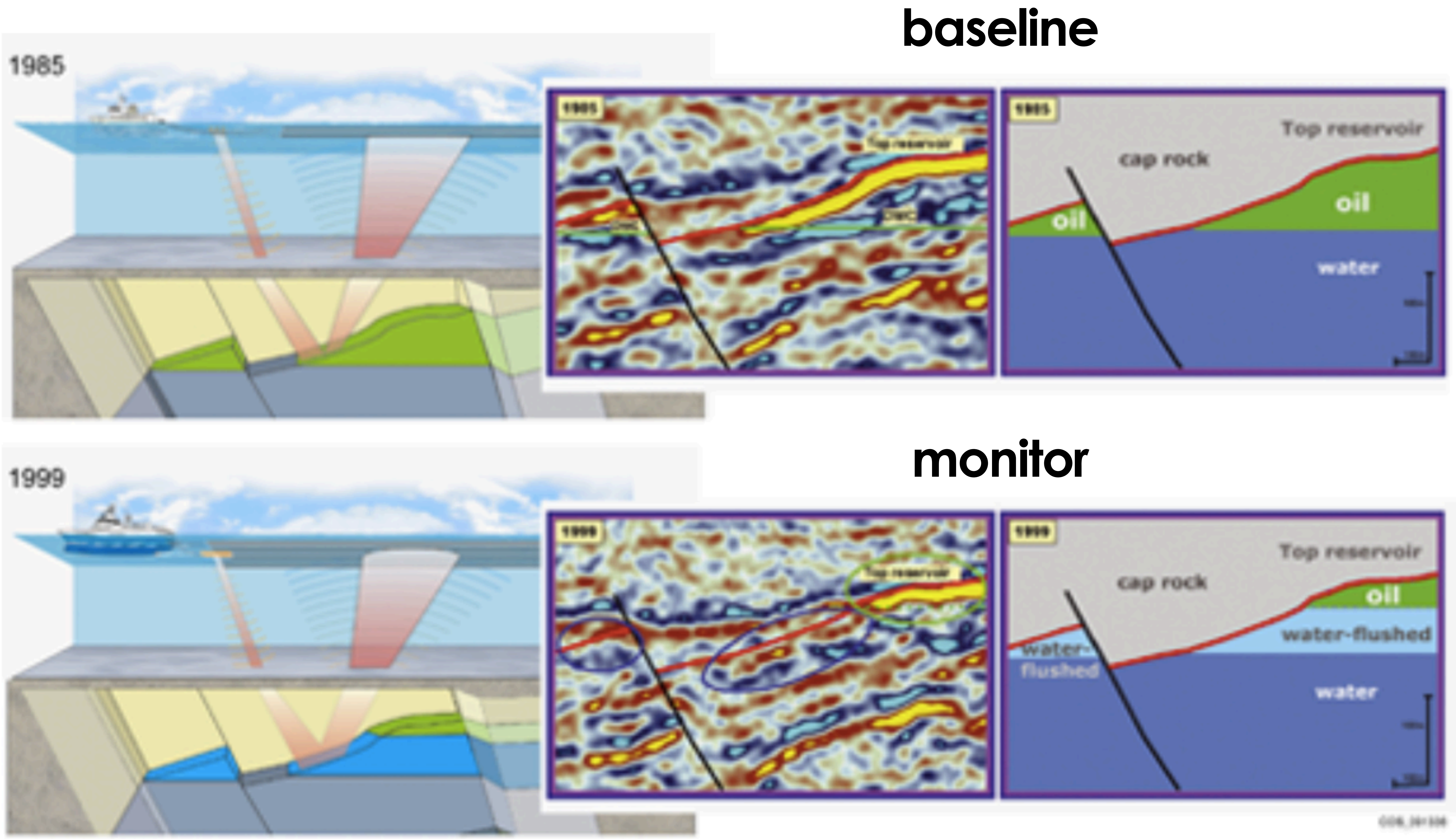
side view of an air-gun array



schematic of air gun primed (left) and firing (right)

[Left -- Caldwell and Walker; Right -- http://www.geol.lsu.edu/jlorenzo/ReflectSeismol97/eczimmermann/WWW/eczimmermann.html]

Time-lapse (or 4D) surveys



Principle of 4D acqusition

Gullfaks field

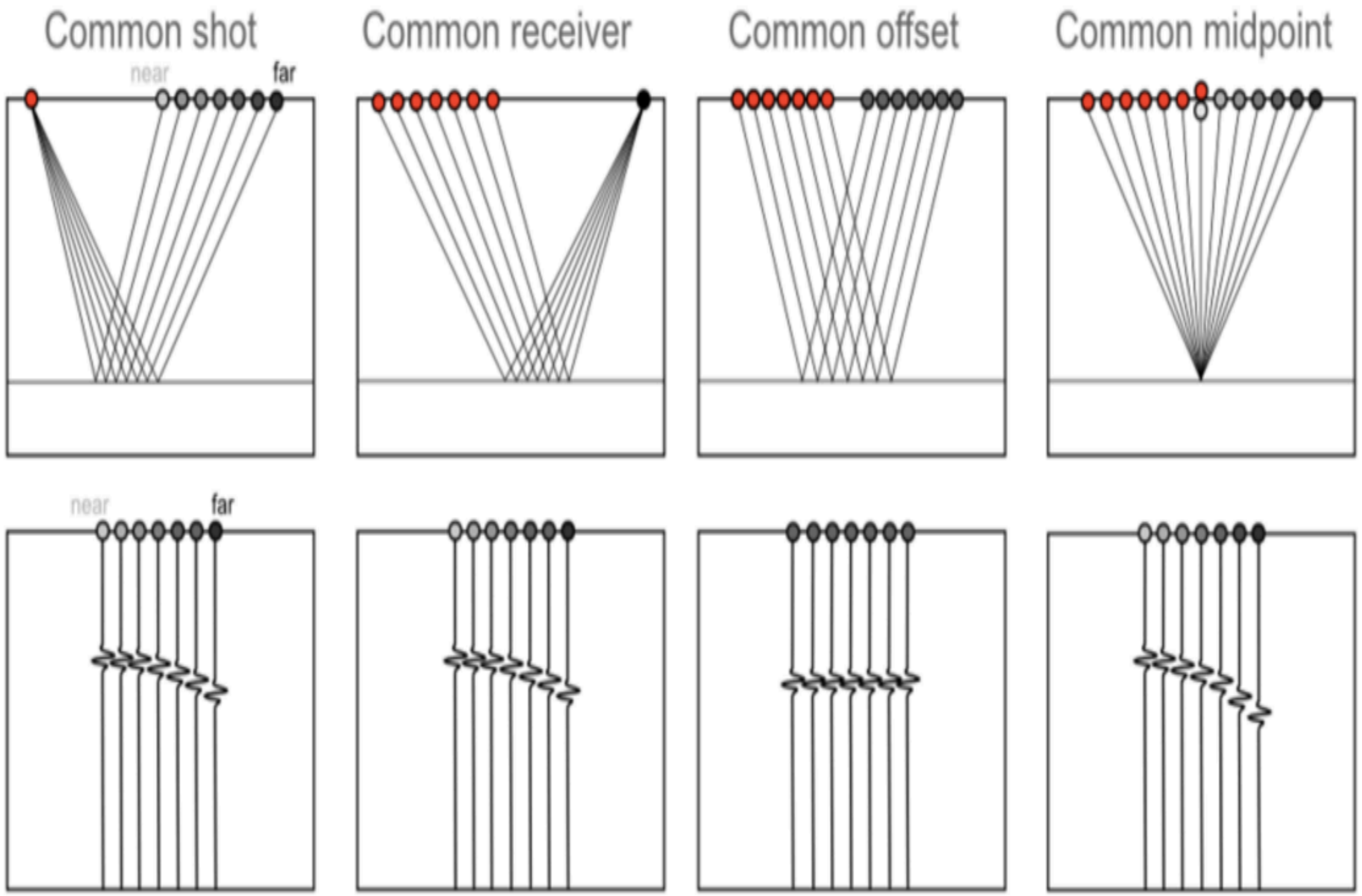
Seismic reservoir monitoring

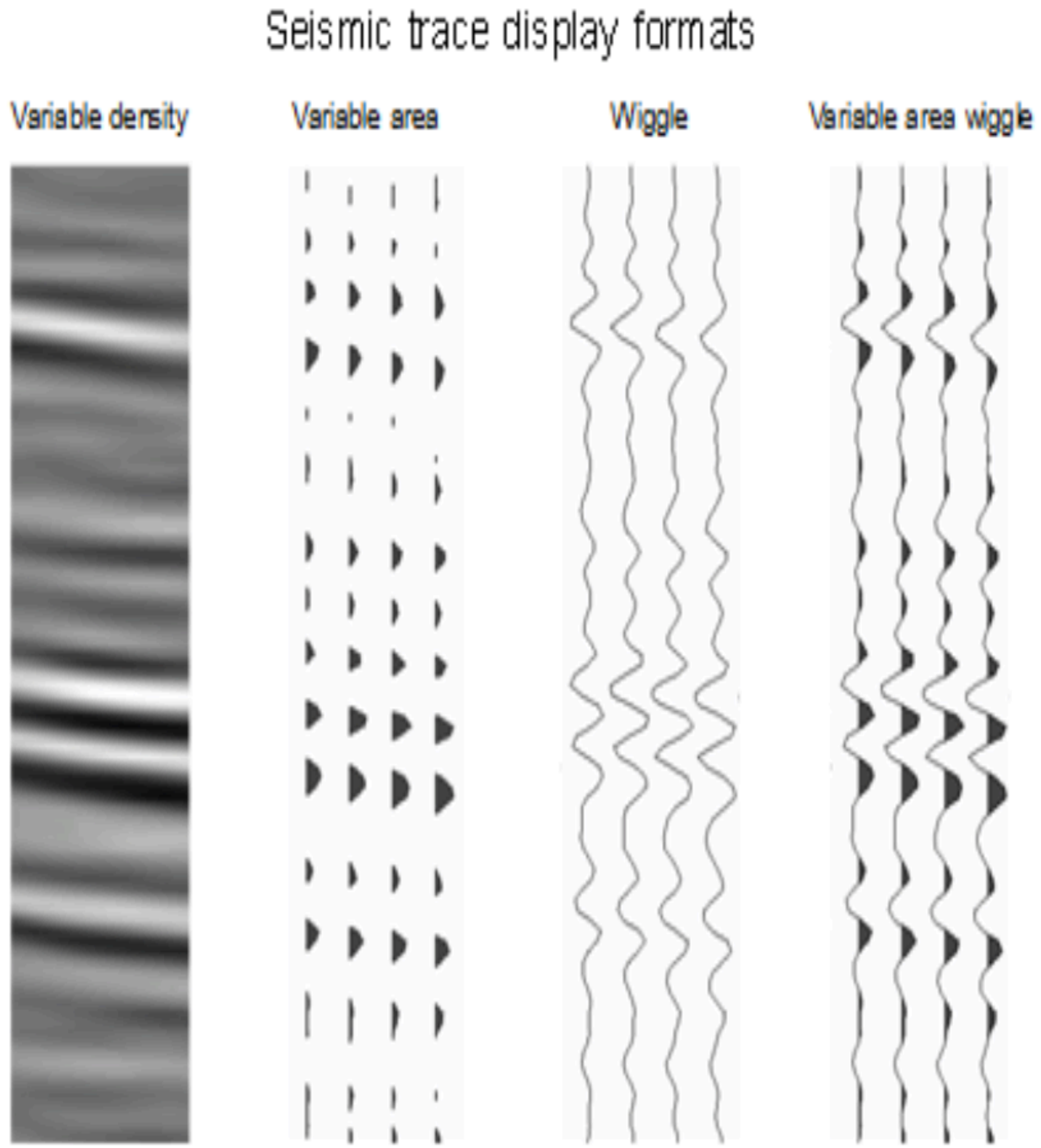
- compare seismic surveys re-run some time apart (order of months or years) over the same area

- monitor changes in the reservoir over time due to production

[http://www.geoexpro.com/articles/2009/05/4d-geophysical-data]

Types of gathers & trace display formats





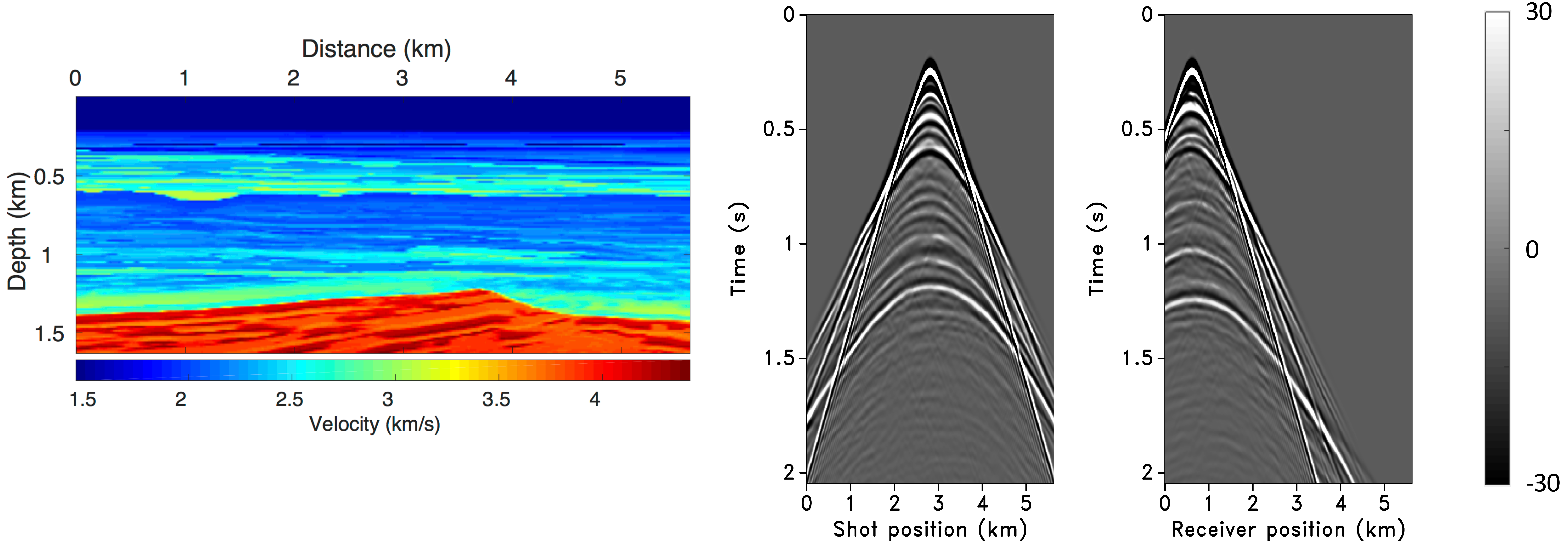
[Left -- http://www.agilegeoscience.com/blog/2011/9/14/g-is-for-gather.html; Right -- SEG Wiki]

Types of gathers

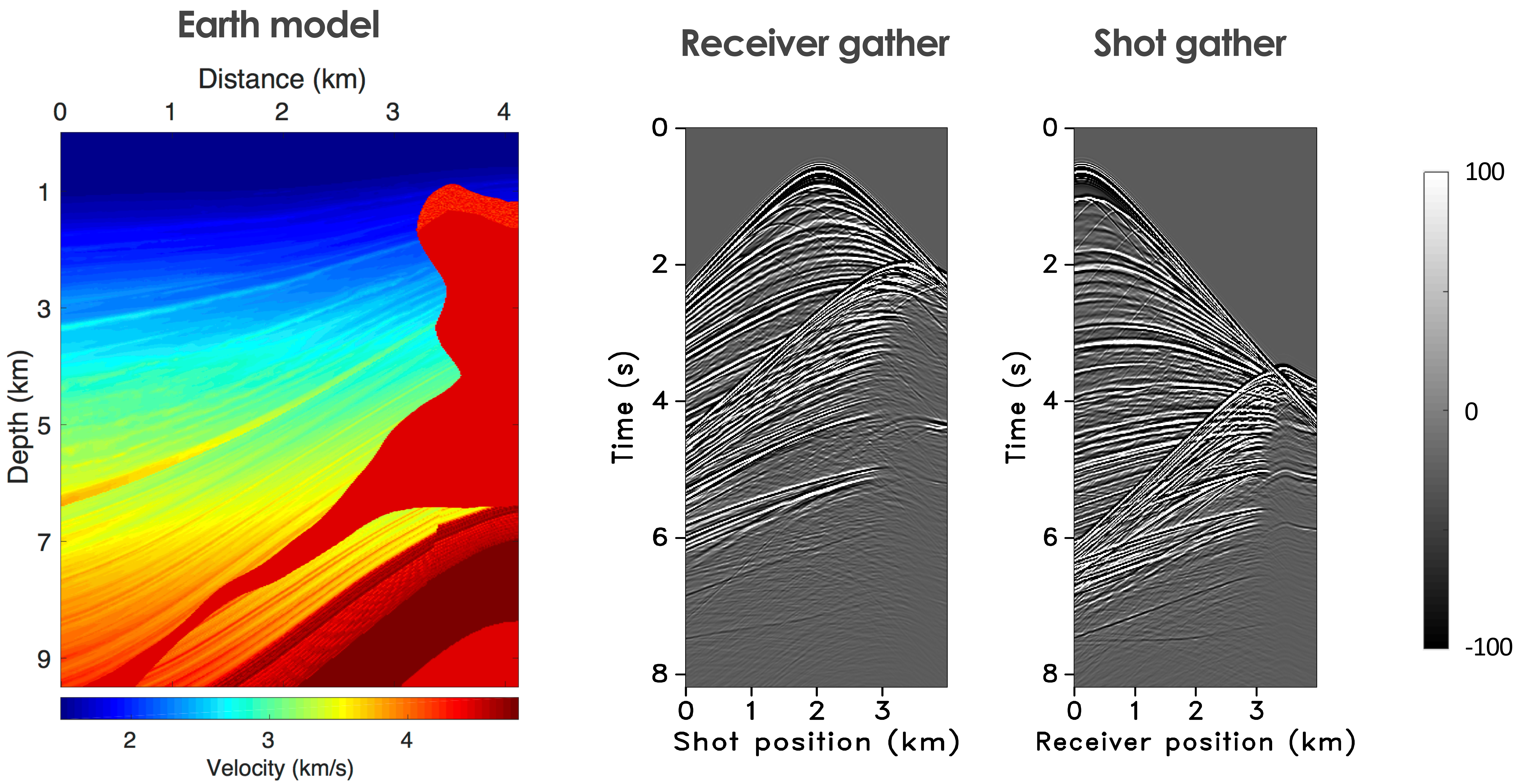
Earth model

Receiver gather

Shot gather



Types of gathers



Challenges

Expensive dense and **full-azimuthal** sampling to produce high-resolution images of the subsurface

- deploy multiple source vessels for full azimuthal coverage
- simultaneous-source (or blended) acquisition; **problem:** source separation
- leads to uneven sampling: coarse source and dense receiver sampling or vice-versa

Time-lapse seismic acquisition

- **repeat expensive** dense acquisitions & “independent” processing
- hampered by practical challenges to ensure repetition

Our solutions

Adapt ideas from Compressive Sensing (CS)

- **design economic** (or low-cost), **randomly subsampled** acquisitions
- surveys acquired with **small** environmental **imprint**
- **recover** dense, periodically sampled data via **structure promotion**

Adapt ideas from Distributed Compressive Sensing (DCS)

- **economic**, randomly subsampled **time-lapse** acquisition
- offers possibility to **relax** insistence on survey **replicability**
- **recover** dense, periodically sampled time-lapse vintages and difference by **exploiting common information** among the vintages

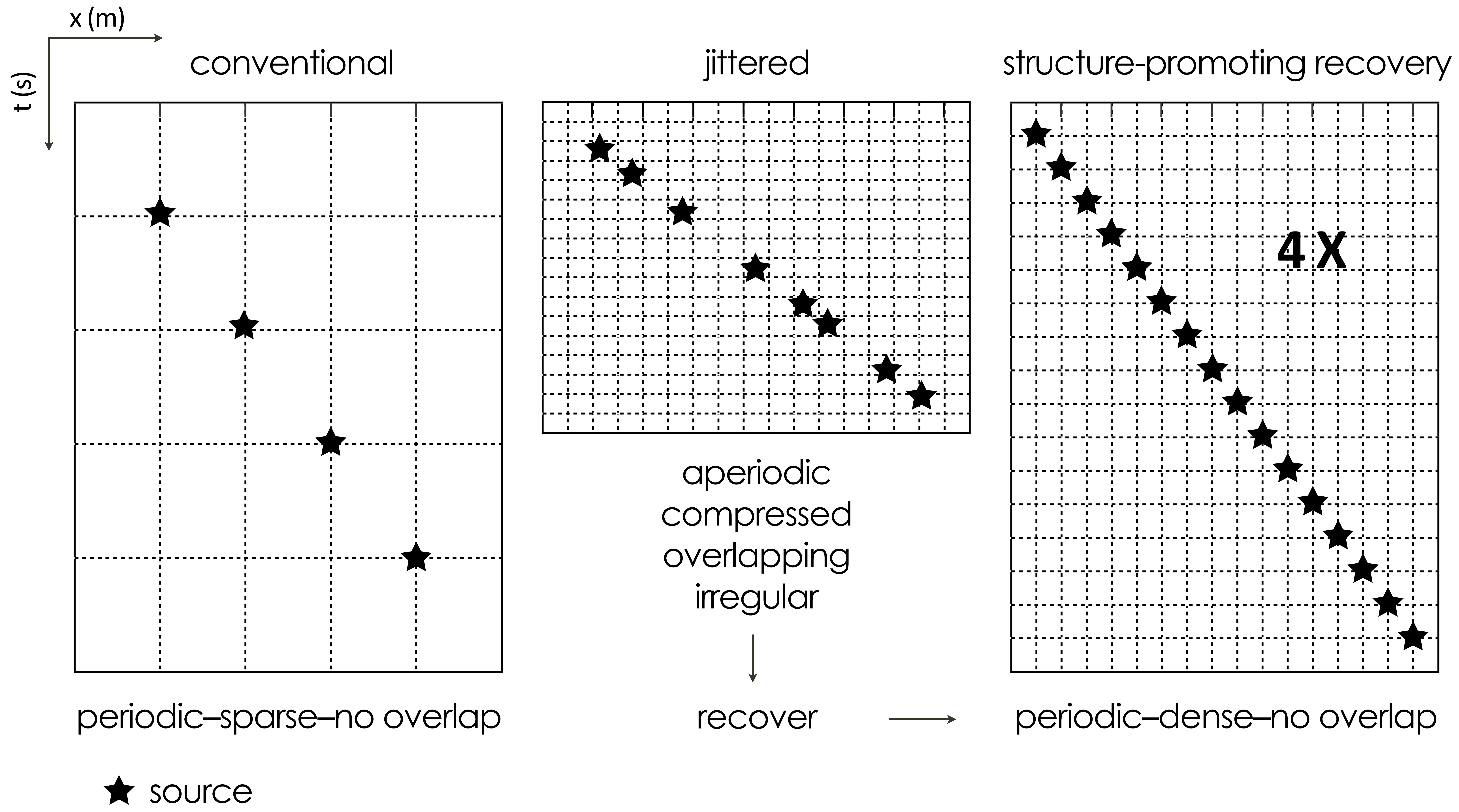
The impact

Special Section: Impact of compressive sensing on seismic data acquisition and processing

Chapters 2 & 3

Compressive sensing in seismic exploration
- simultaneous-source marine acquisition
- static acquisition geometry

Conventional vs. compressive acquisition



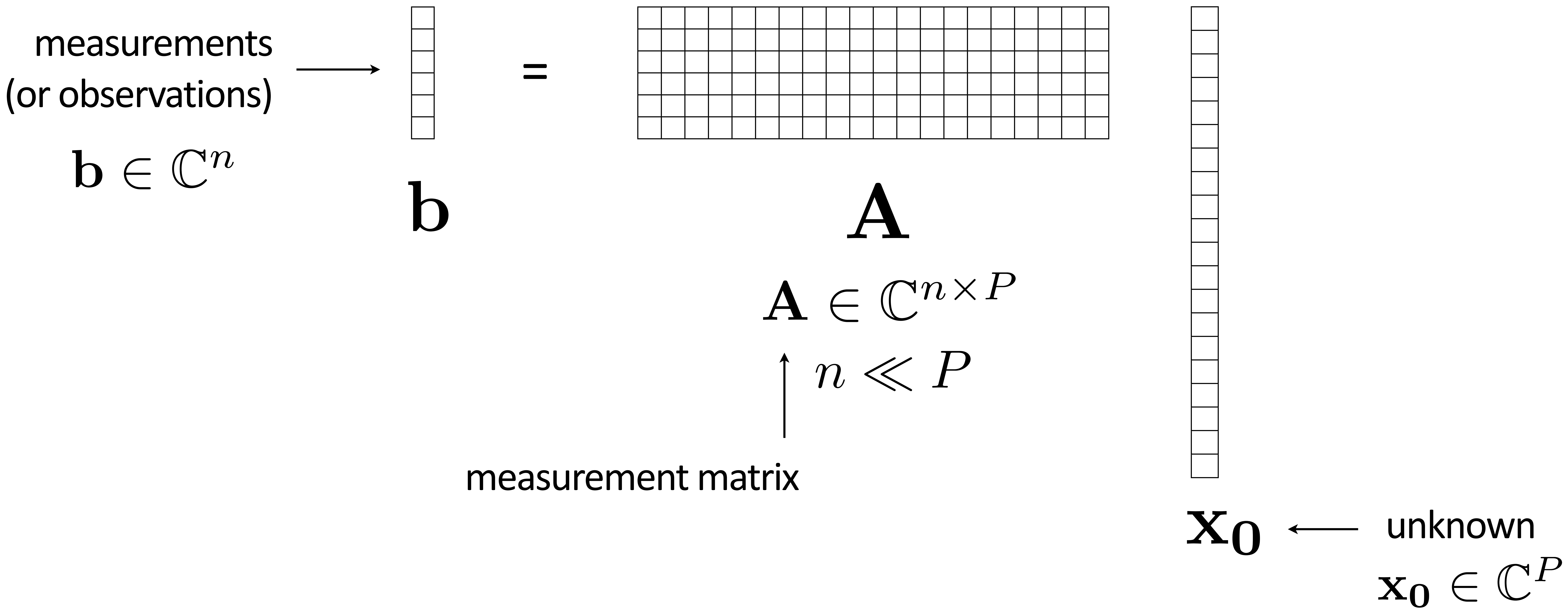
Compressive sensing

Powerful sensing paradigm

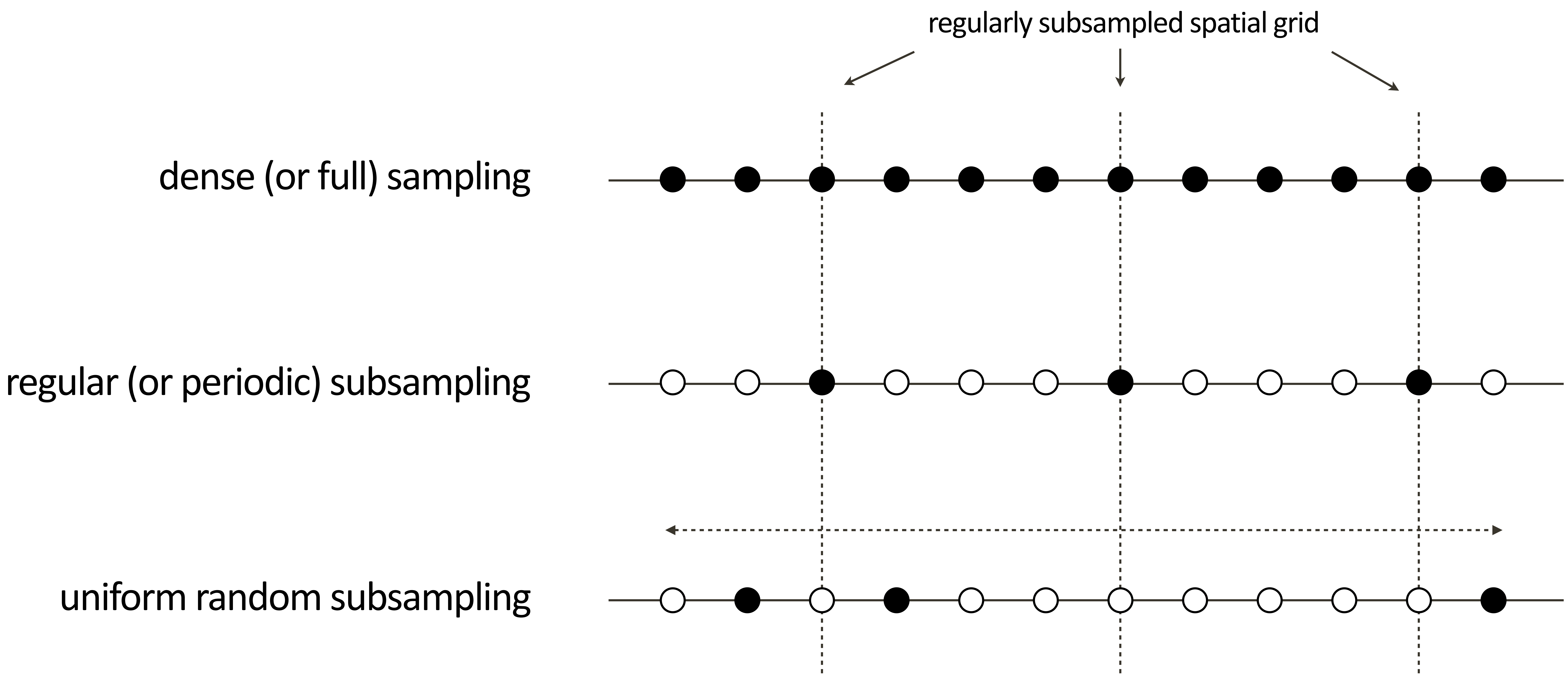
- **find representations that reveal structure**
  - transform-domain sparsity (e.g., Fourier, curvelets, etc.)
- **sample to break structure**
  - randomized acquisition (e.g., time-jittered, over/under, SLO, etc.)
  - destroys sparsity
- **recover by structure promotion**
  - sparsity via one-norm minimization

Compressive sensing

Solve an underdetermined system of linear equations:

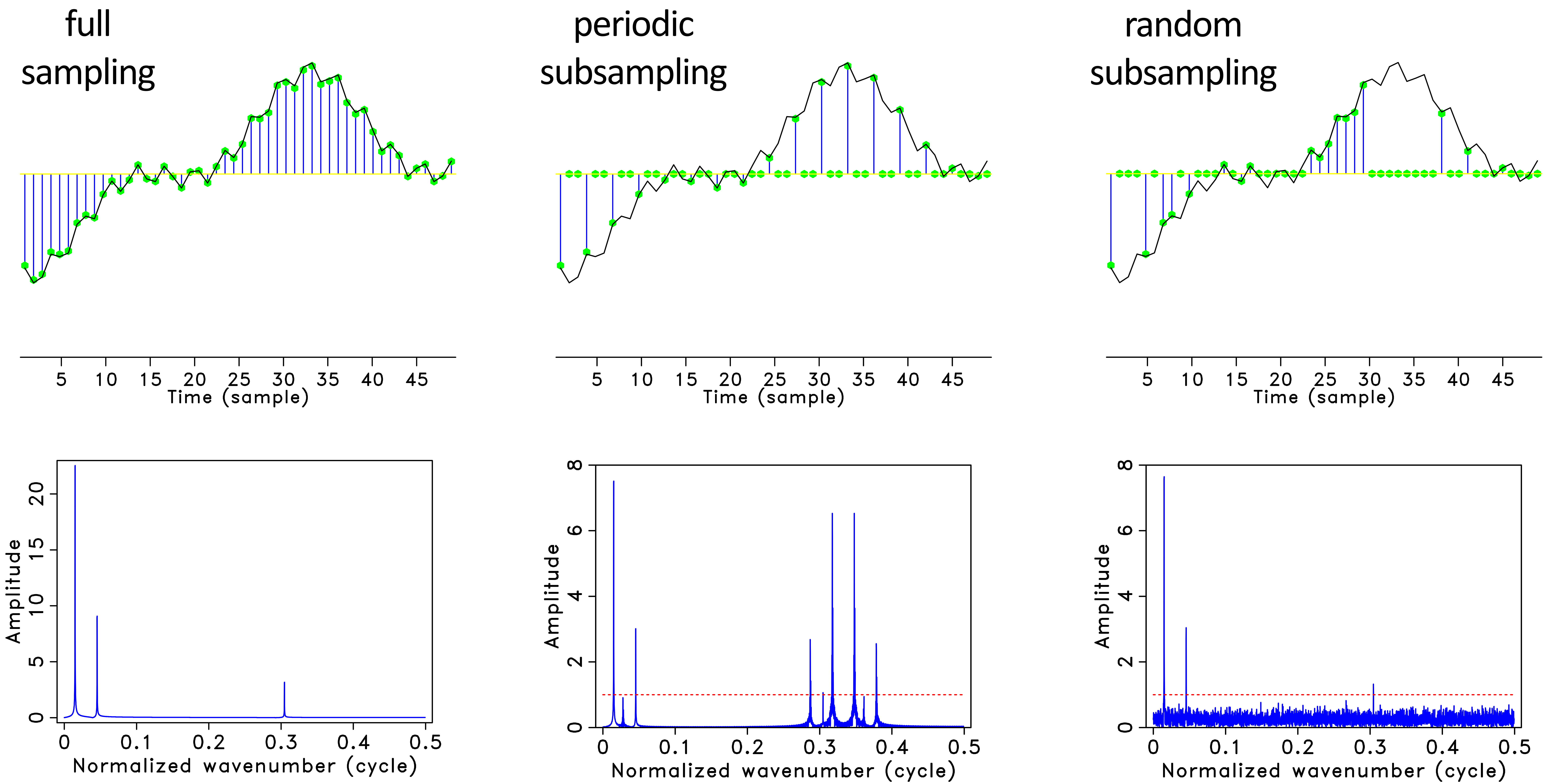


Sampling schemes



[adapted from Hennenfent and Herrmann, 2008]

Random vs. periodic subsampling



[Hennenfent and Herrmann, 2008]

Adapt CS ideas to seismic acquisition

- design simultaneous-source marine acquisition
- source separation via structure ("sparsity") promotion

Simultaneous-source marine acquisition

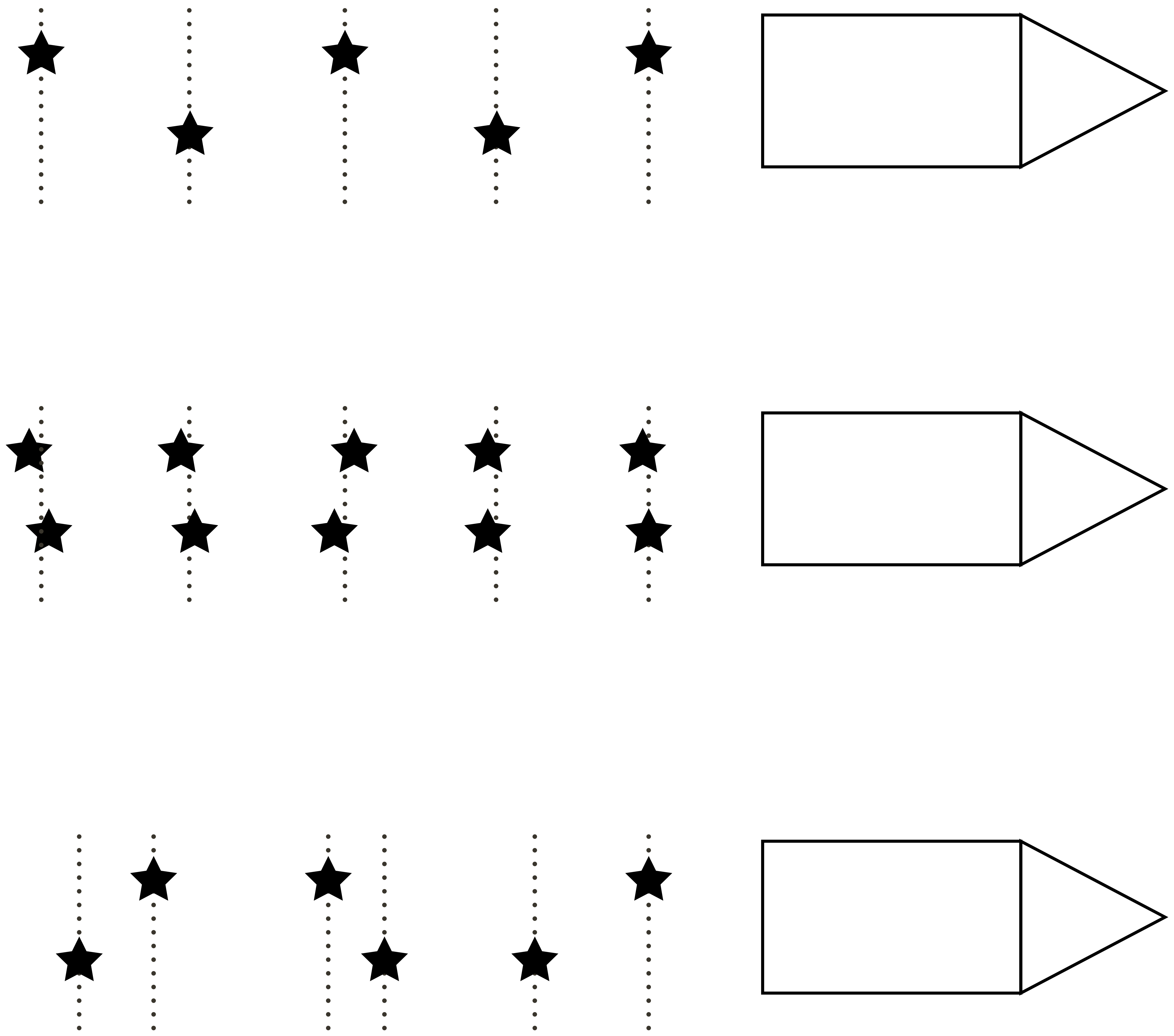
random vs. periodic

shot-time randomness

periodically sampled spatial grid (**static/dynamic** acquisition geometry: conventional acquisition) — NONE

almost periodically sampled spatial grid (**dynamic** acquisition geometry: towed arrays) — SMALL

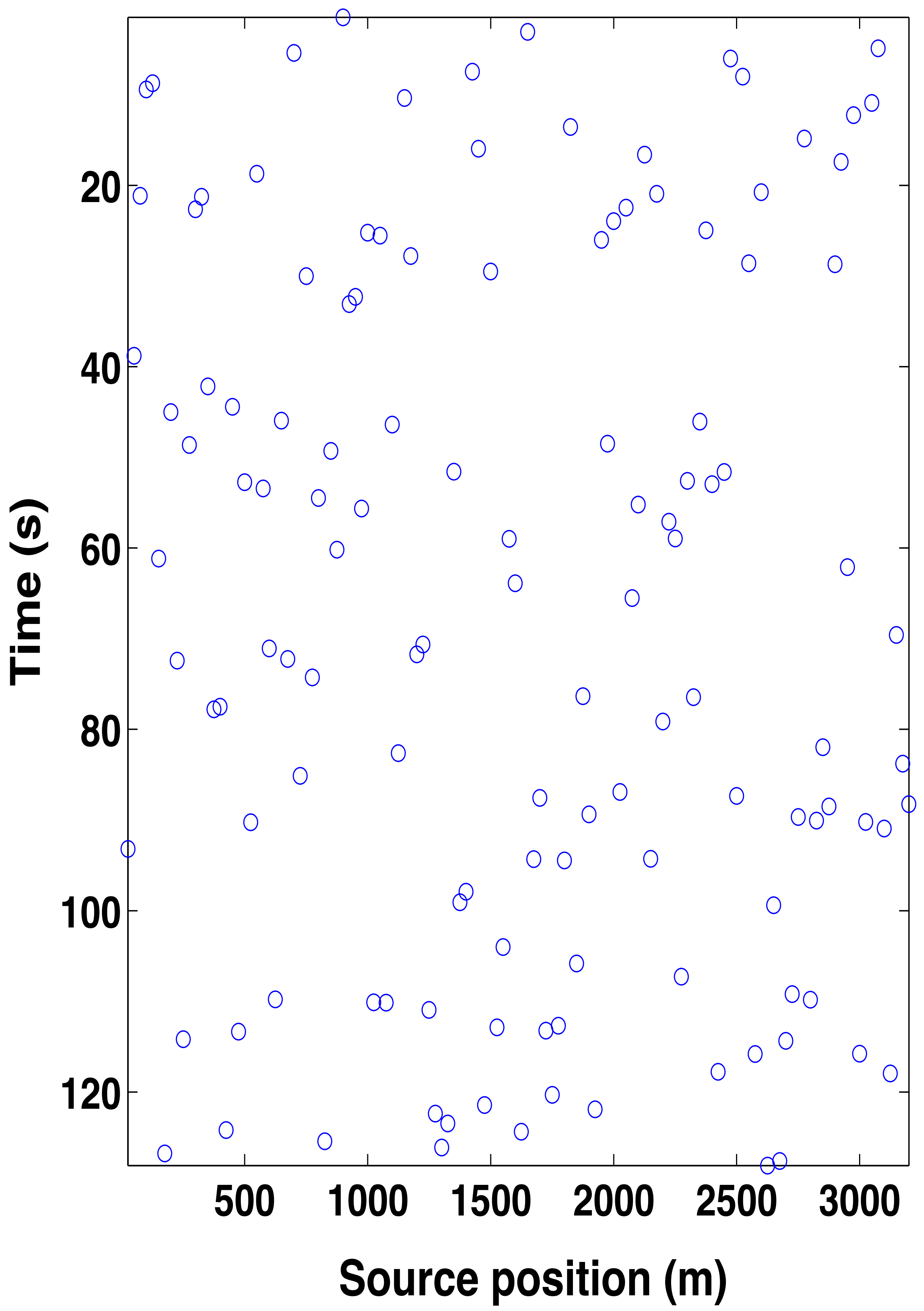
randomly jittered sampled spatial grid (**static** acquisition geometry: OBC/OBN; “time-jittered” acquisition) — LARGE



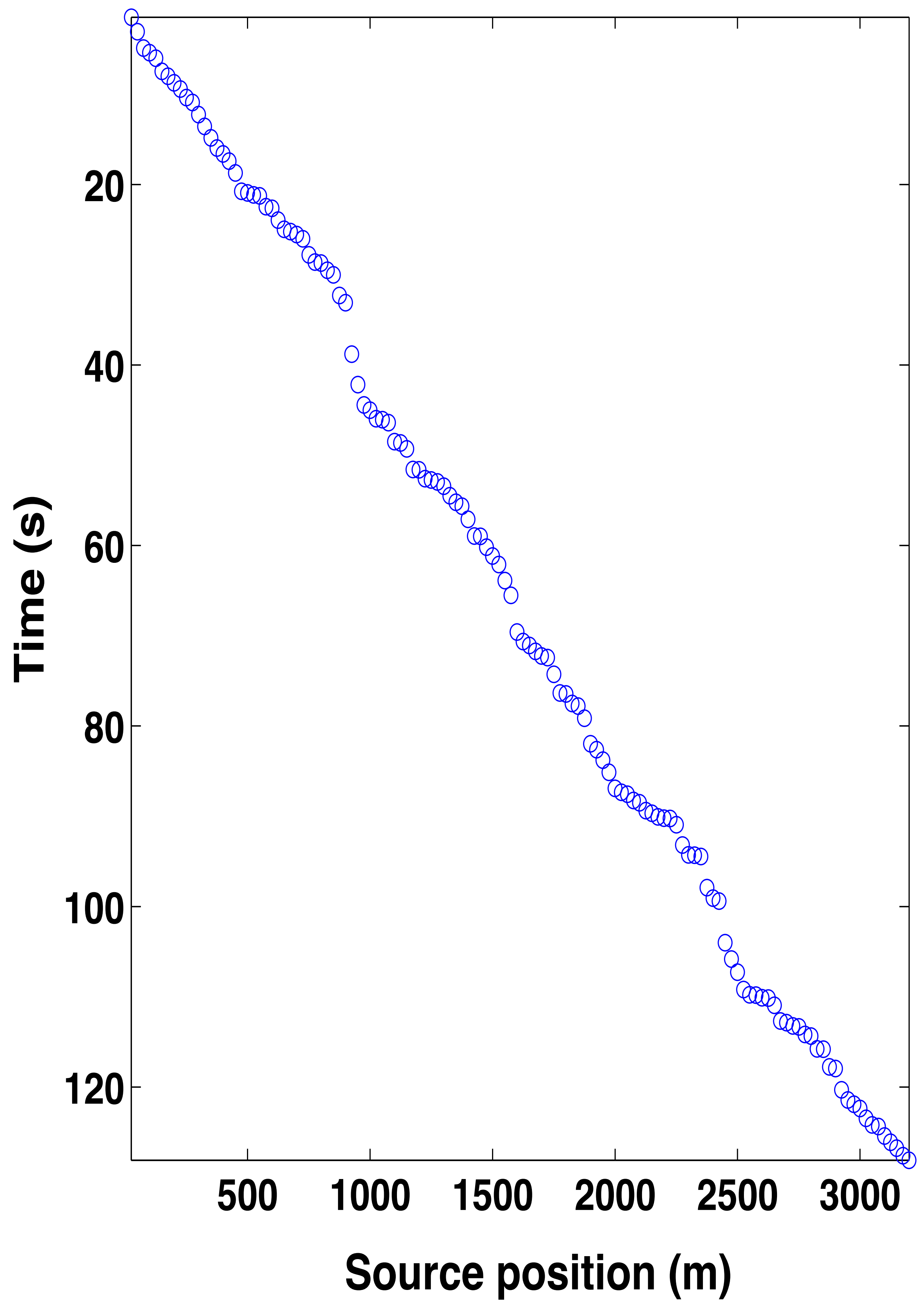
Simultaneous-source marine acquisition

random vs. periodic

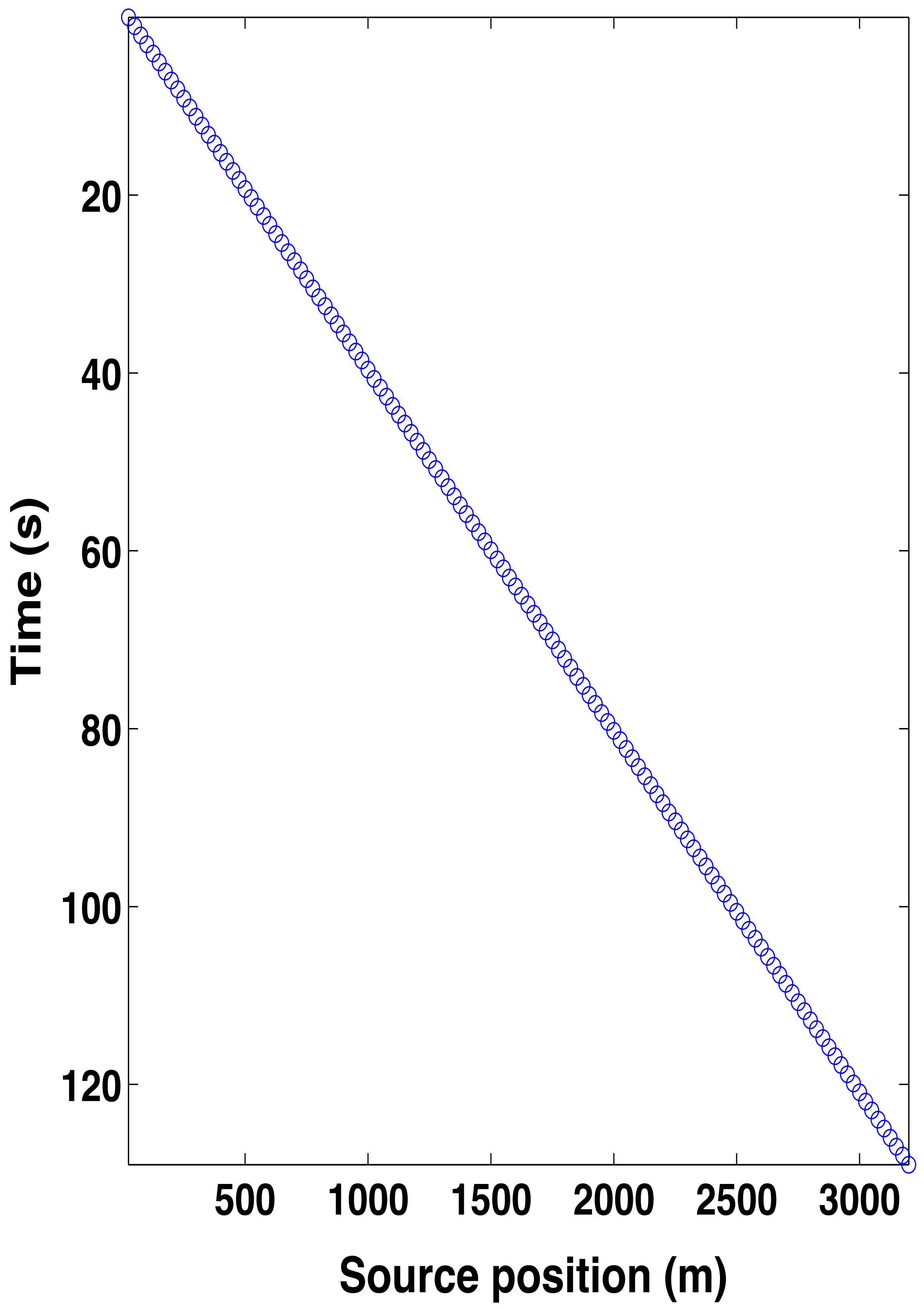
“Ideal” simultaneous acquisition



Random time dithering



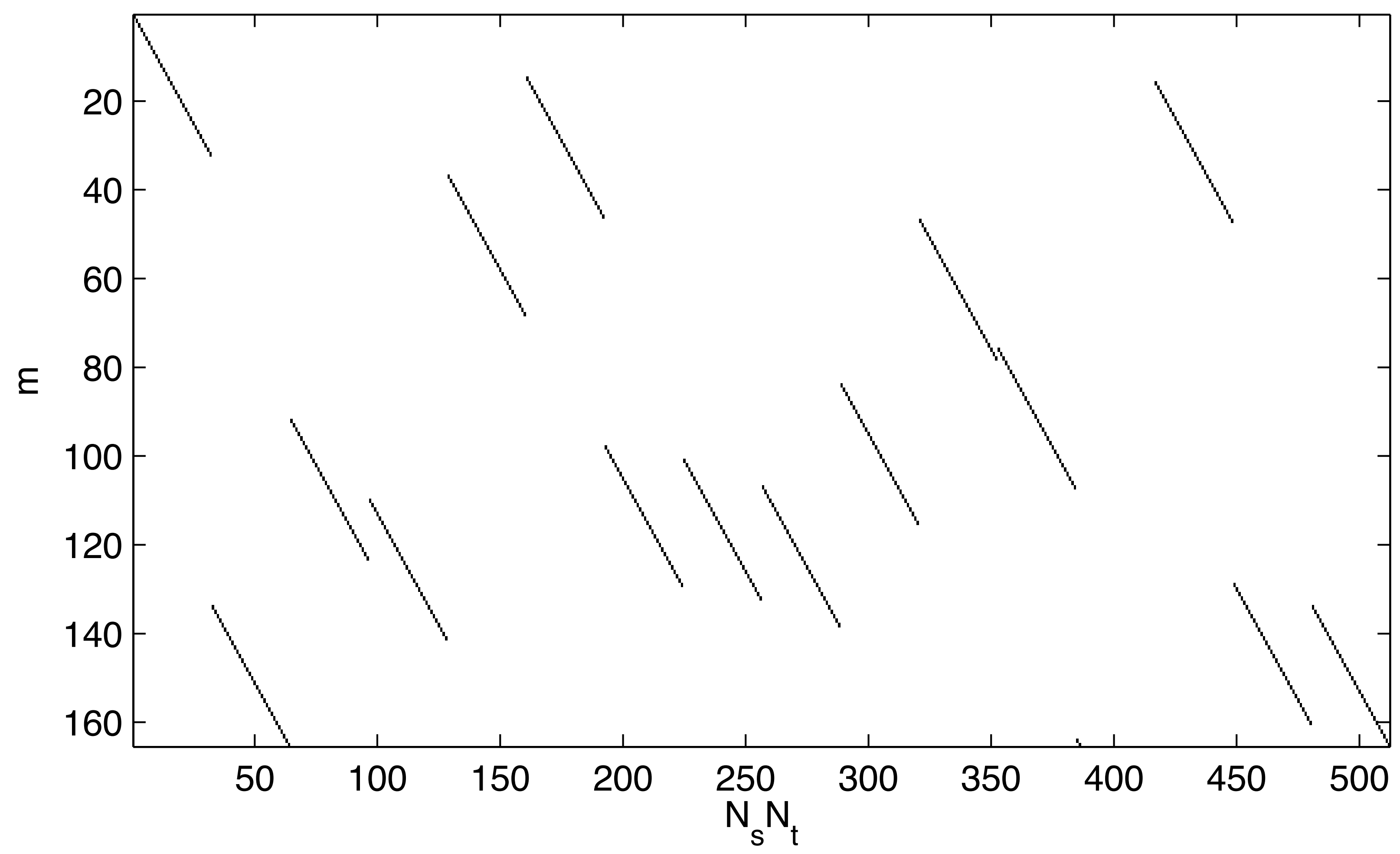
Periodic time dithering



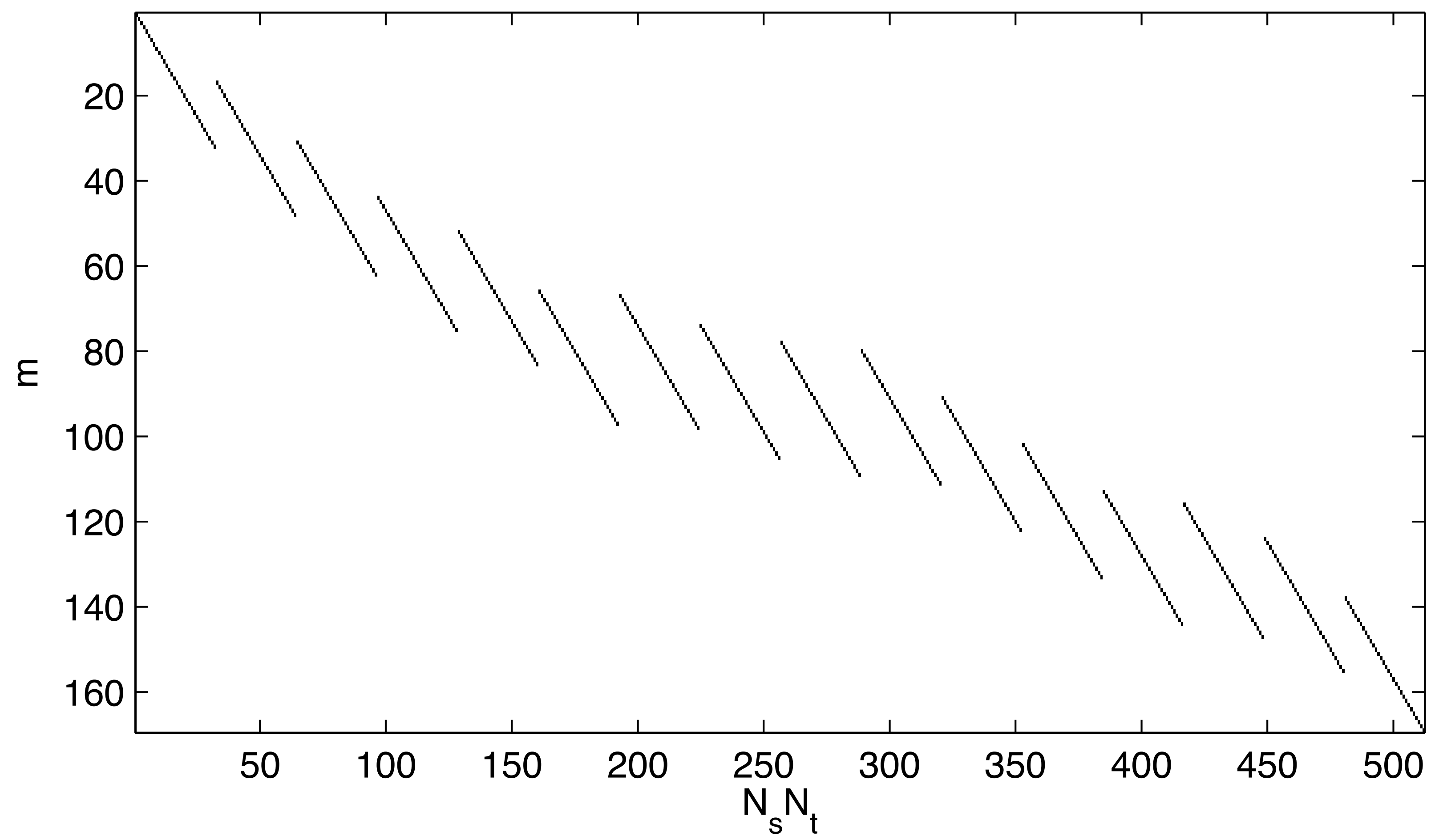
Simultaneous-source sampling operators

random vs. periodic

"Ideal" simultaneous acquisition

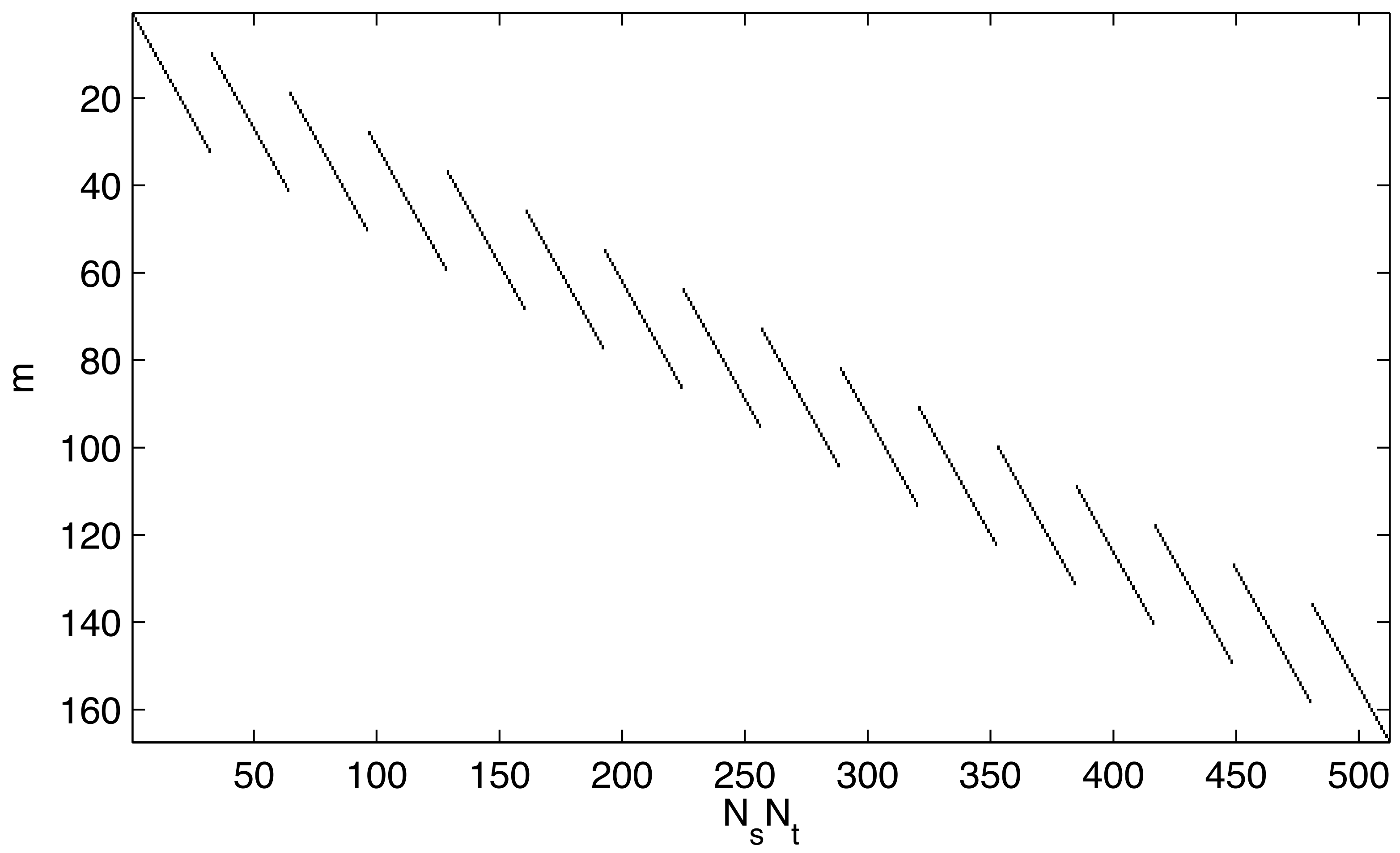


Random time dithering



samples recorded at each receiver during conventional acquisition

Periodic time dithering

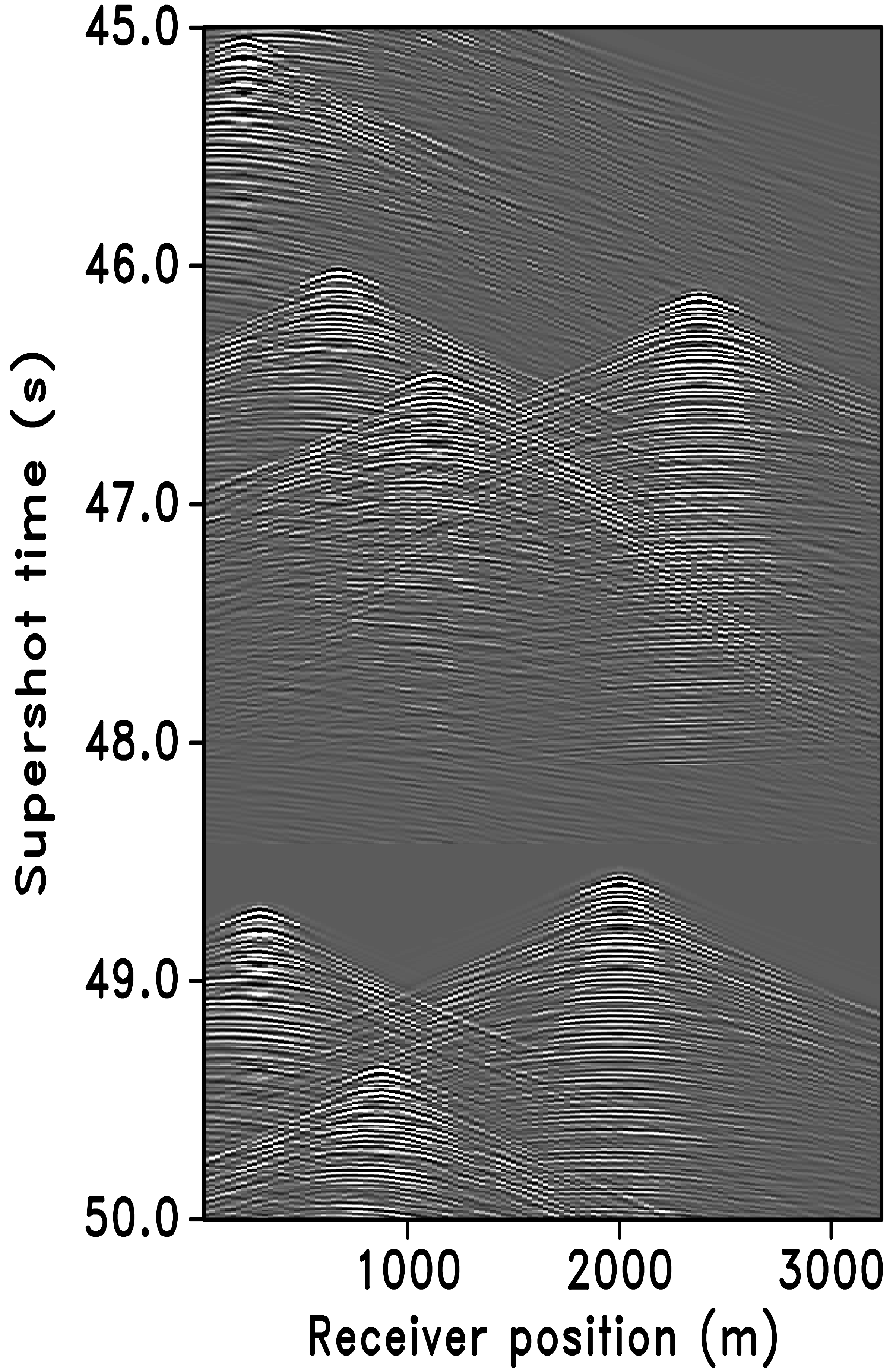


samples recorded at each receiver during simultaneous acquisition

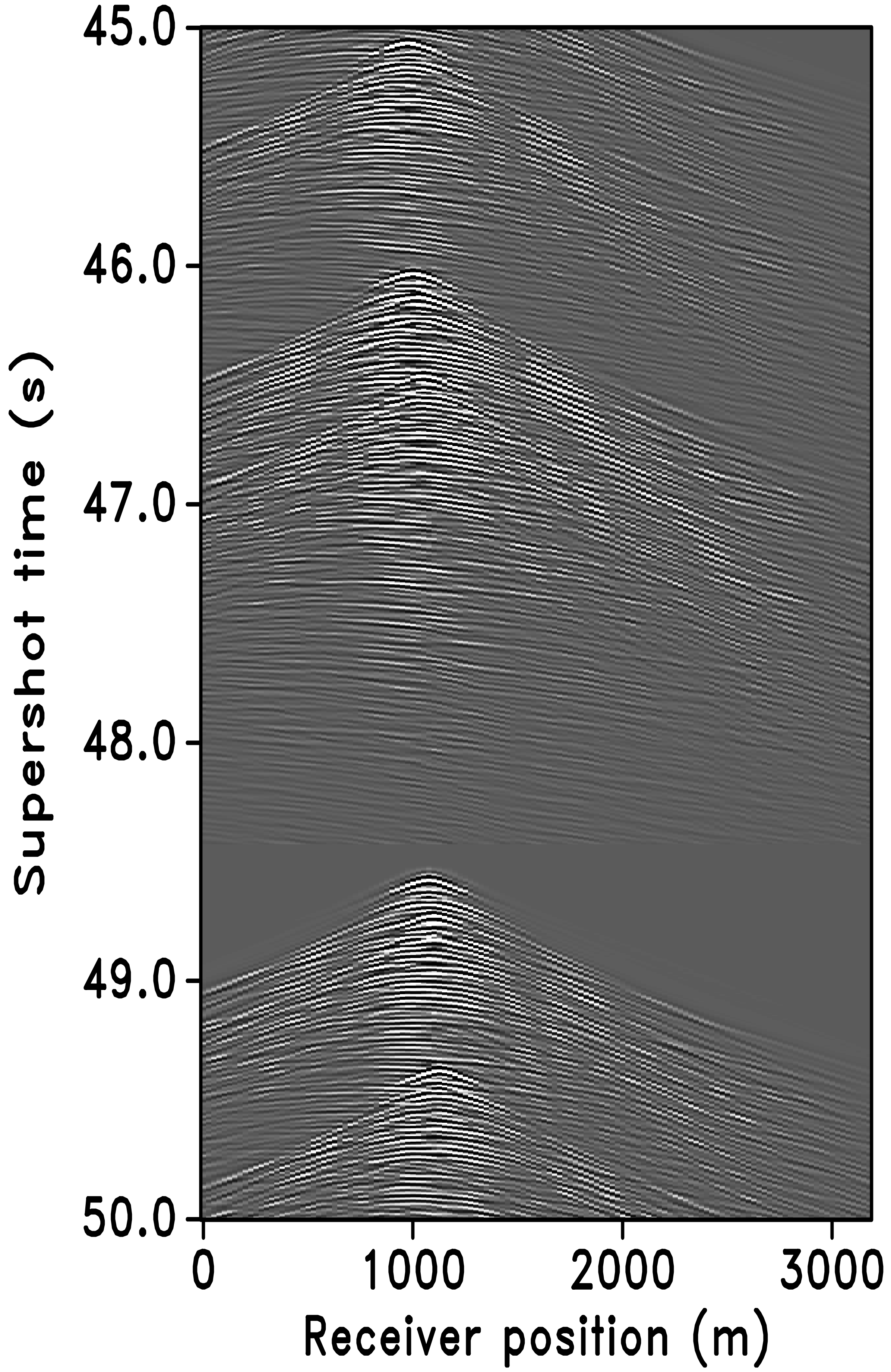
Ns: number of sources
Nt: number of time samples
Nr: number of receivers

Measurements
– overlapping shots

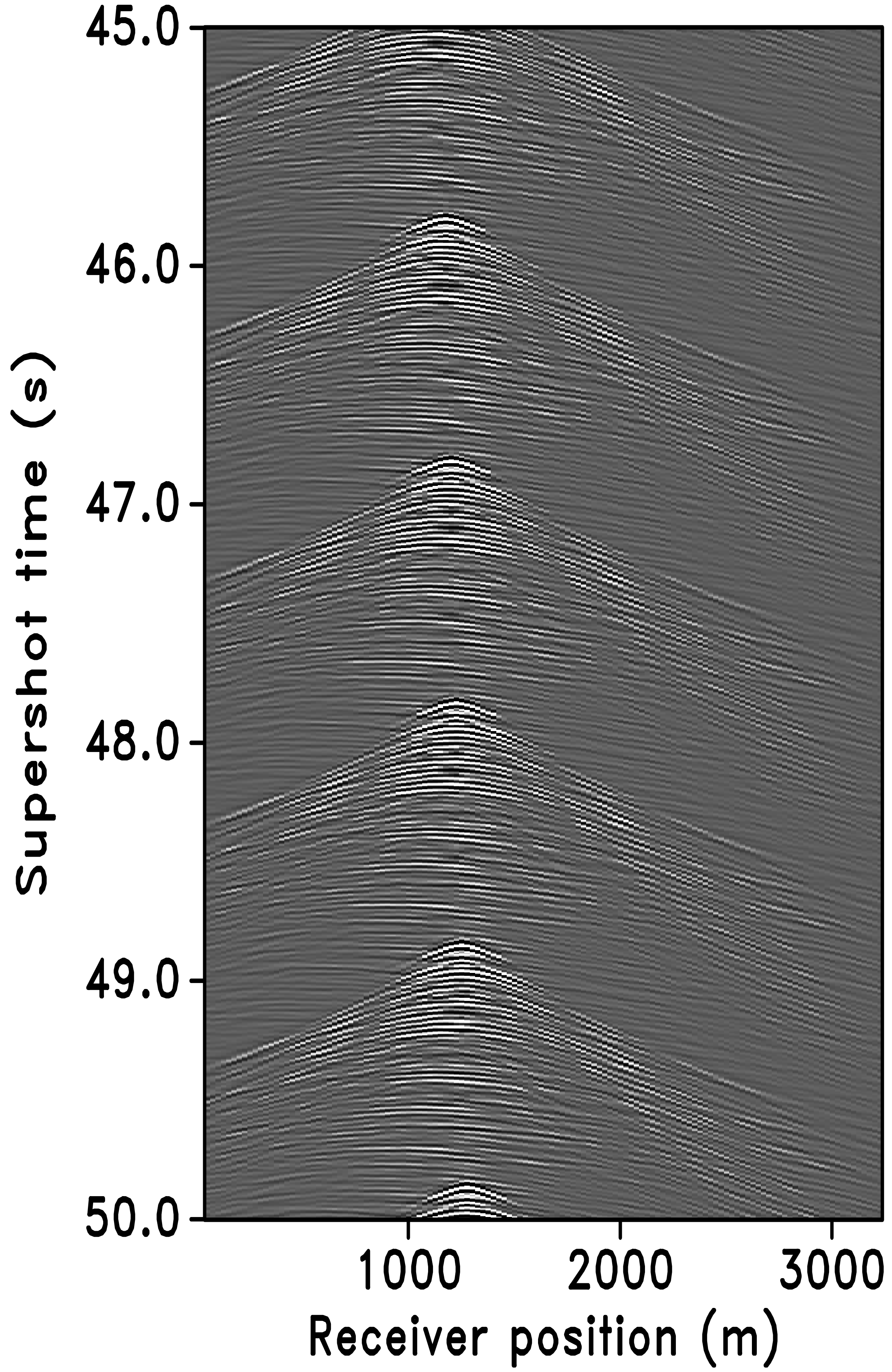
"Ideal" simultaneous acquisition



Random time dithering



Periodic time dithering



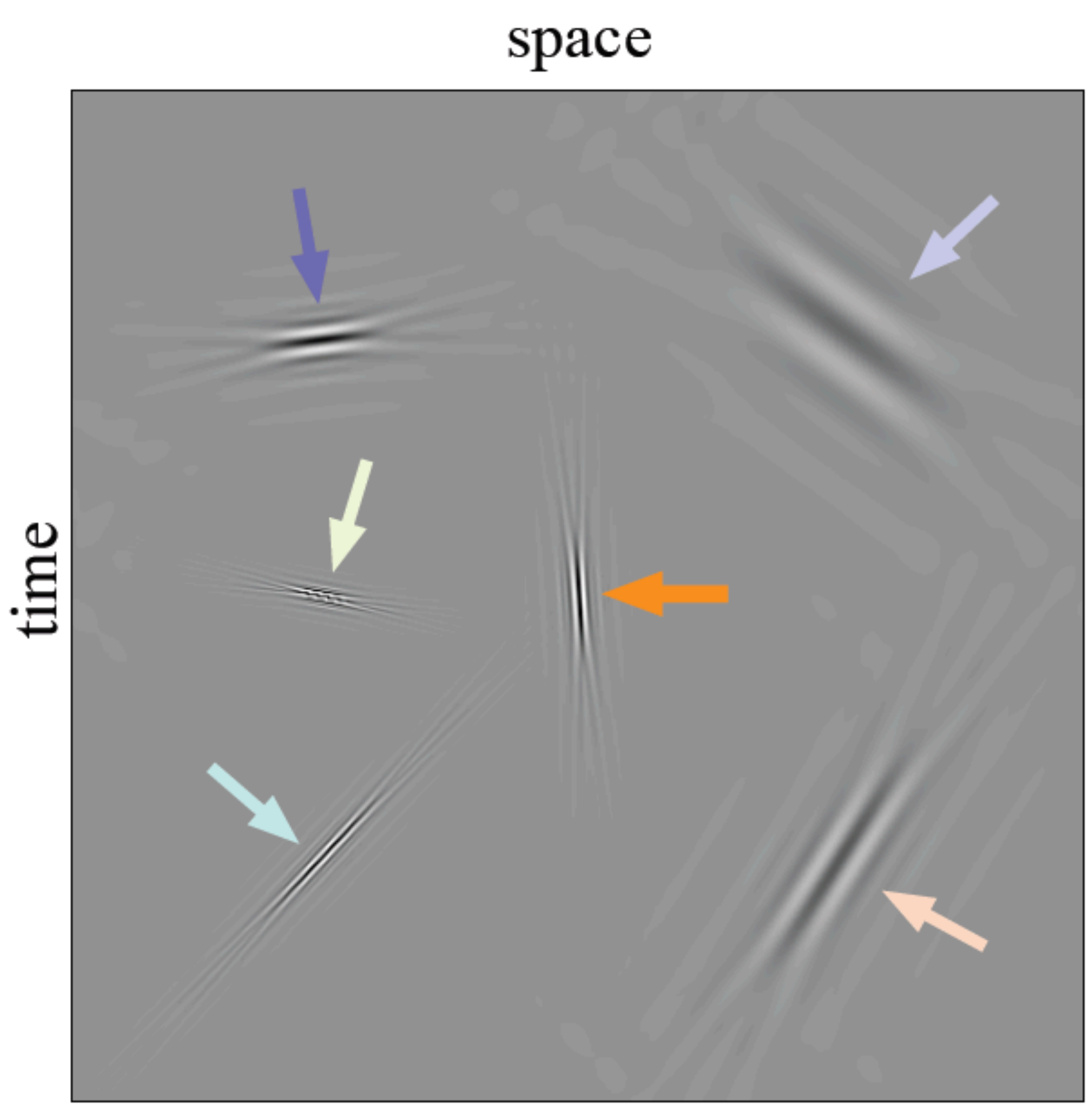
Source separation via sparsity promotion

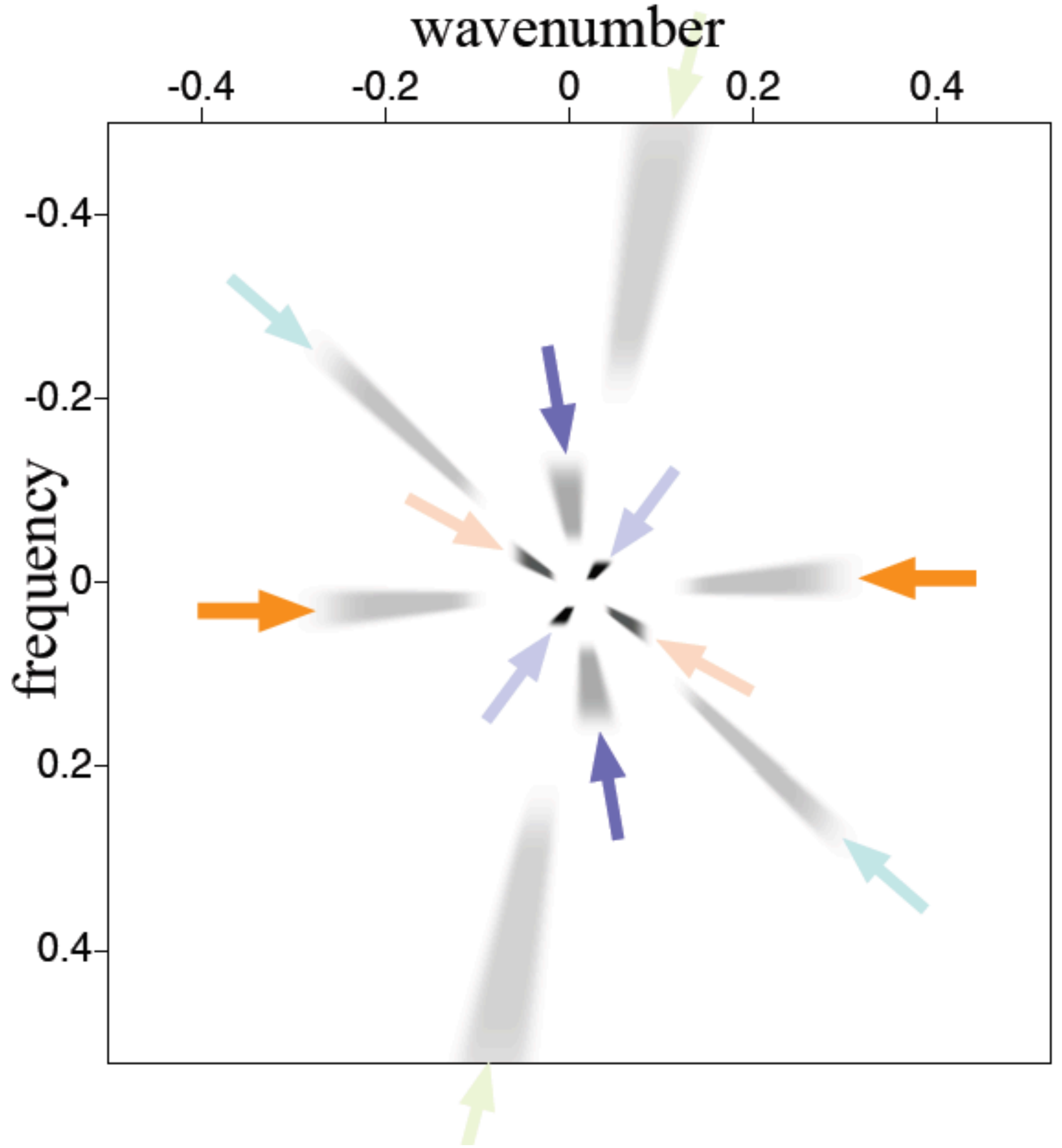
$$\mathbf{d} = \mathbf{S^H}\mathbf{x}$$

$$\tilde{\mathbf{x}} = \arg\min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{subject to} \quad \mathbf{A}\mathbf{x} = \mathbf{b}$$

$\mathbf{x}$	a choice of curvelet coefficients for $\mathbf{d}$
$\mathbf{S^H}$	a transform domain synthesis (curvelet)
$\mathbf{A}$	measurement operator : $\mathbf{M}\mathbf{S^H}$, $\mathbf{M}$: acquisition (or mixing) operator
$\mathbf{b}$	simultaneous data
$\tilde{\mathbf{x}}$	estimated curvelet coefficients for source separated wavefield
$\tilde{\mathbf{d}}$	($= \mathbf{S^H}\tilde{\mathbf{x}}$) estimated source separated wavefield

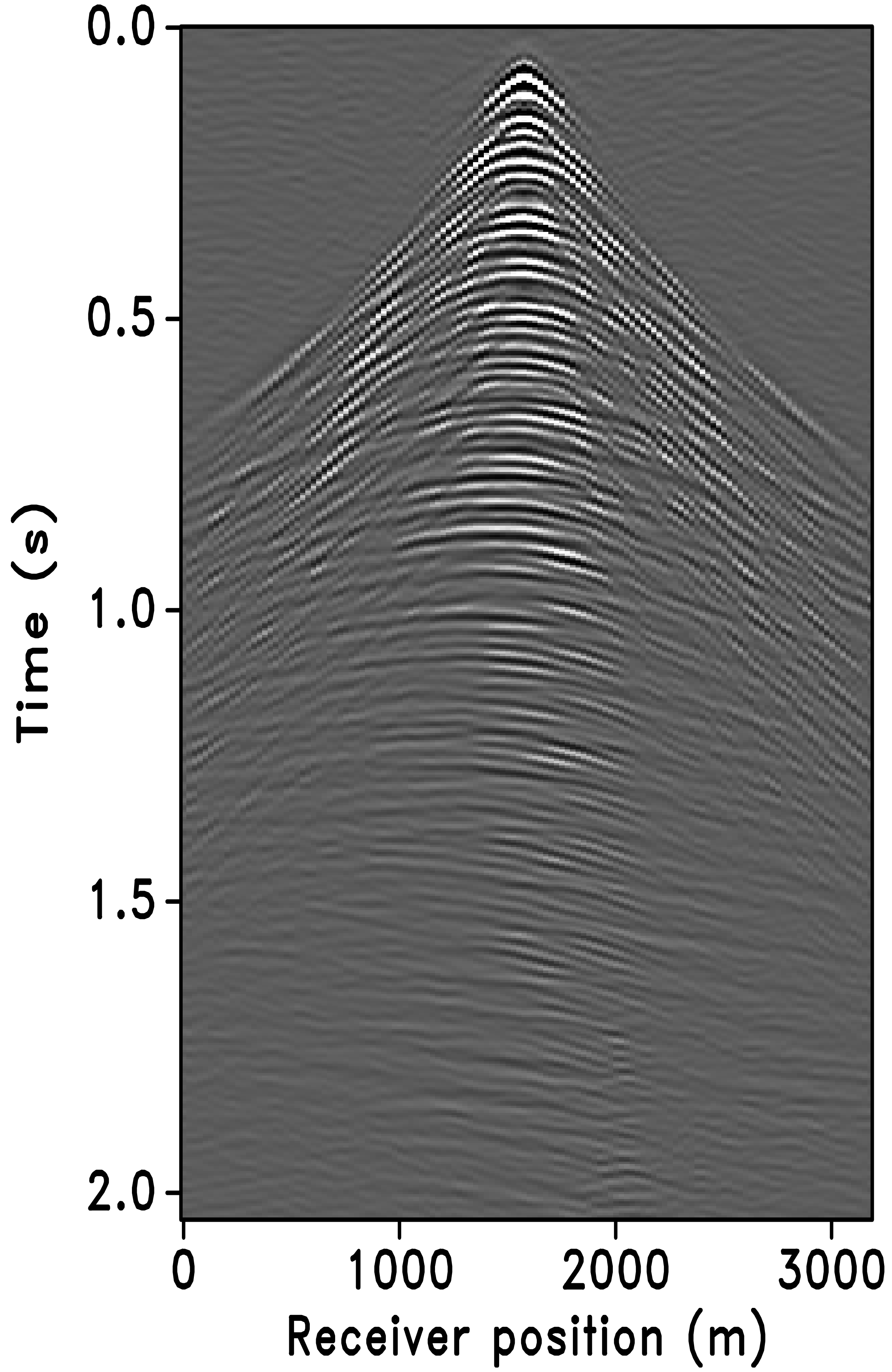
Curvelets



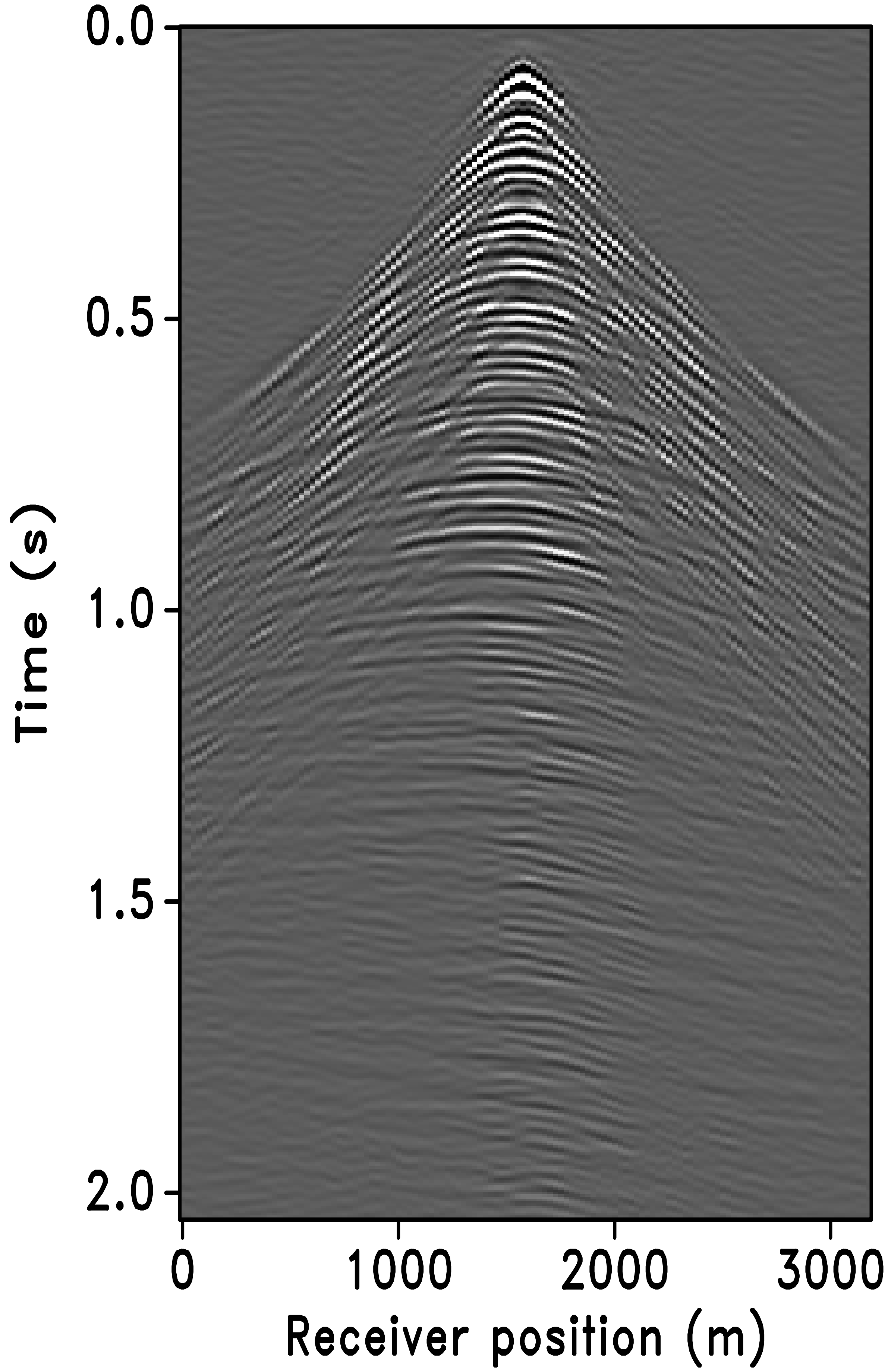


Source separation
– subsampling factor = 2

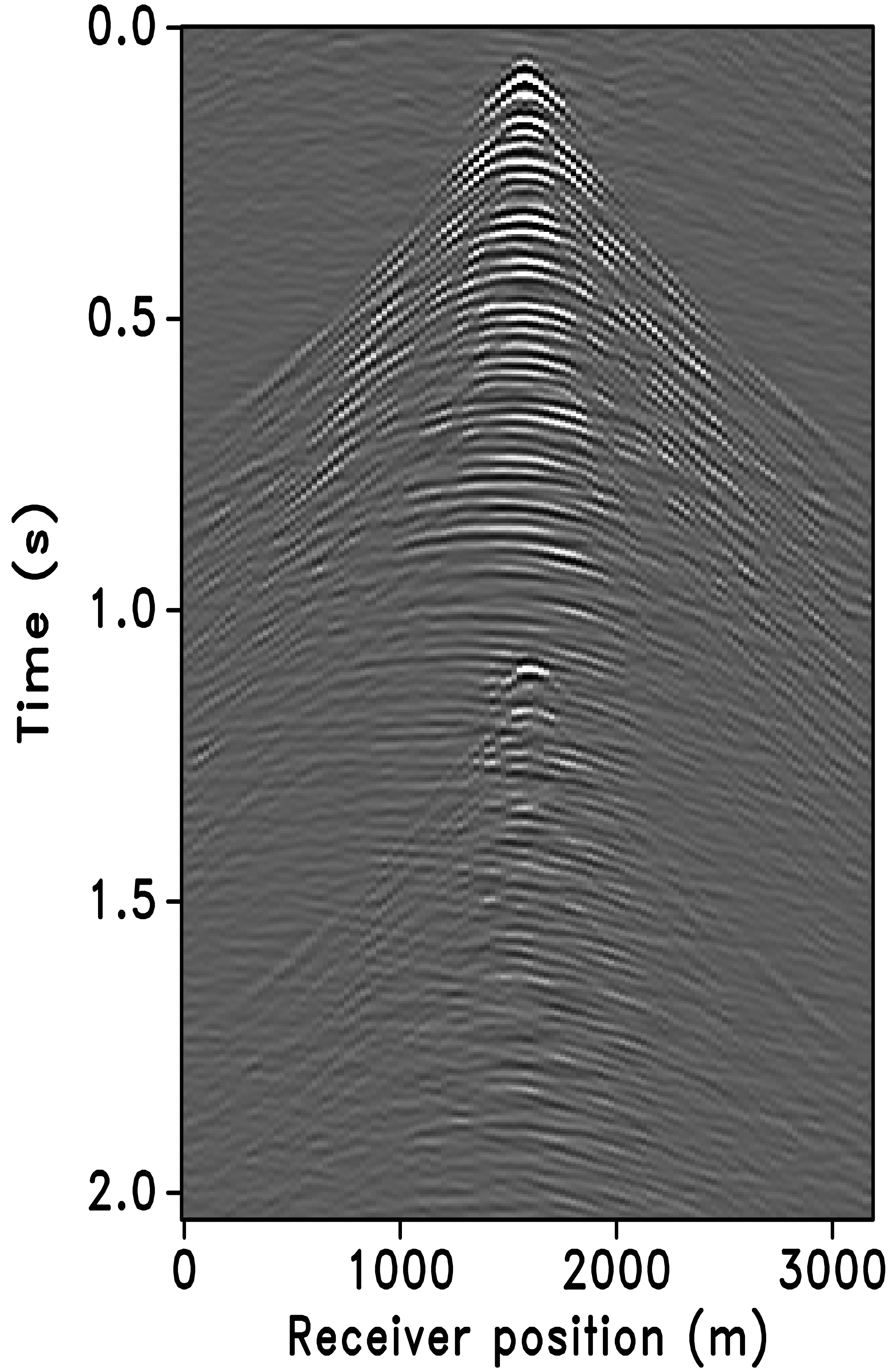
"Ideal" simultaneous acquisition



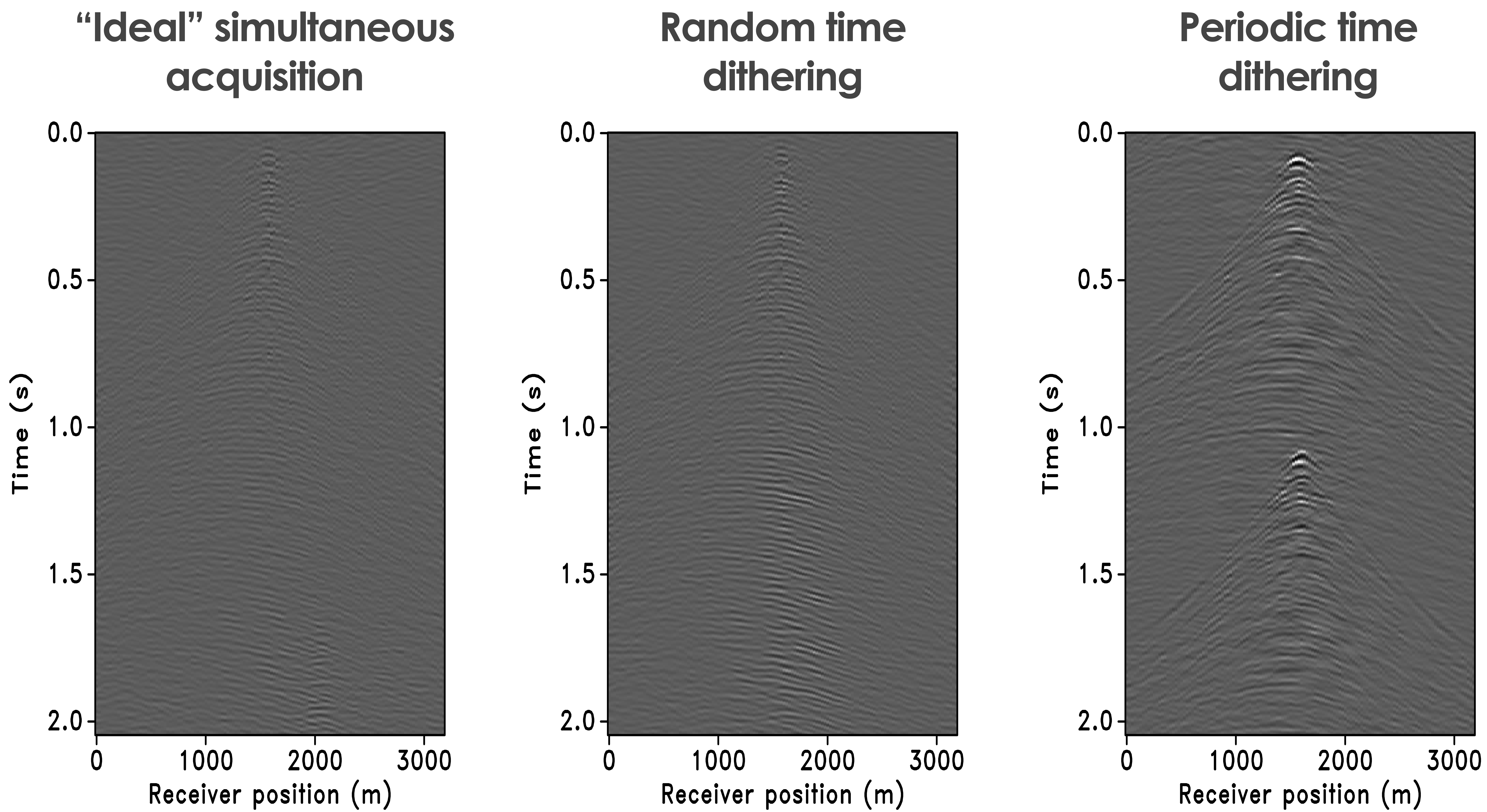
Random time dithering



Periodic time dithering



Residual
– subsampling factor = 2



Conclusions

CS ideas can be **successfully** adapted to seismic data acquisition

Three **key** components:

- find representations that reveal structure, e.g., transform-domain sparsity
- sample to break structure, e.g., randomized acquisitions
- recover by structure promotion, e.g., sparsity via one-norm minimization

Curvelets lead to compressible representation of seismic data

Simultaneous-source acquisition is an instance of compressive sensing

CS offers new **design** perspectives for seismic data acquisition schemes

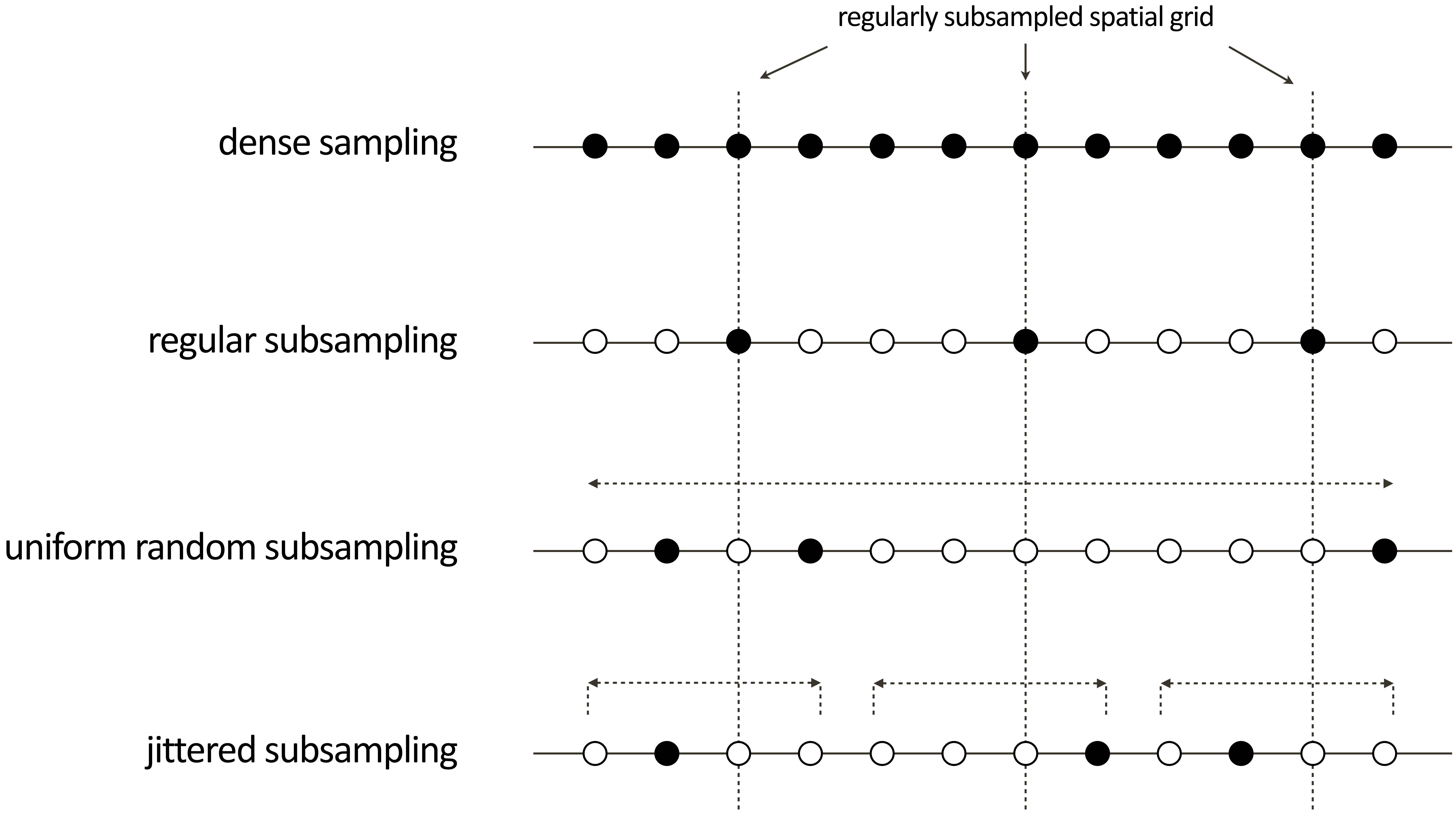
Chapter 4

Compressive marine seismic acquisition

- **pragmatic** simultaneous-source “time-jittered” marine

- static acquisition geometry

Sampling schemes

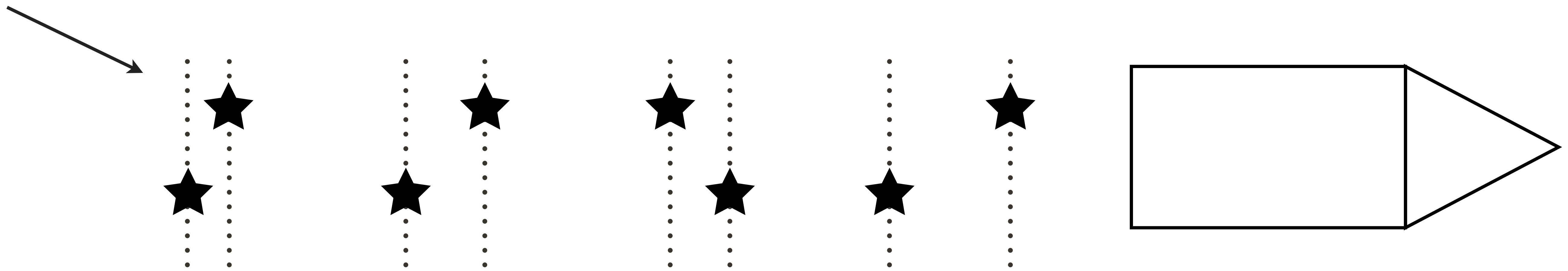


[adapted from Hennenfent and Herrmann, 2008]

Time-jittered marine acquisition

shot-time randomness: **LARGE**

irregularly sampled spatial grid



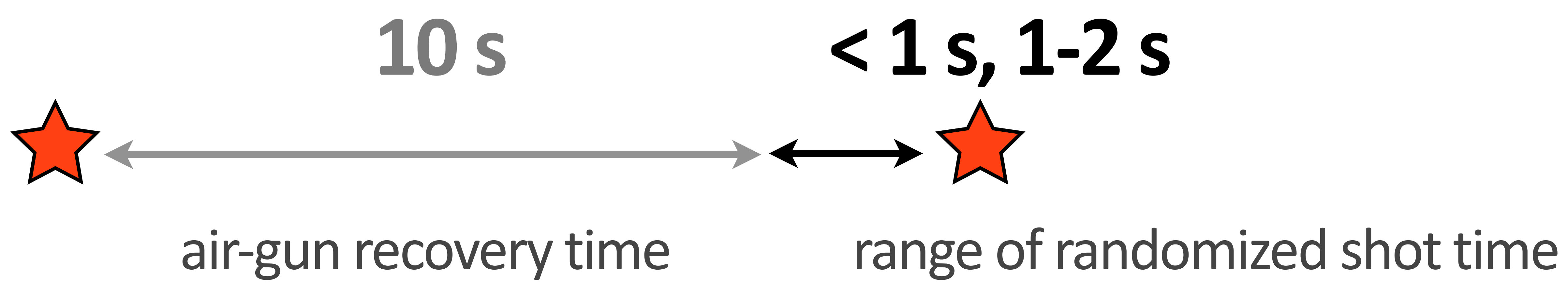
continuous recording
START

continuous recording
STOP

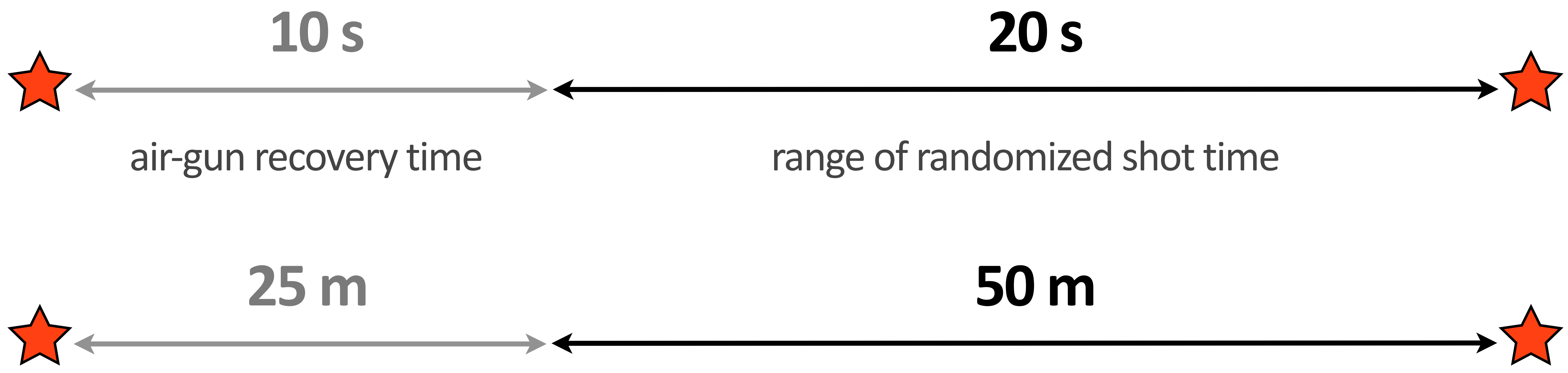
ocean-bottom cable

Design of time-jittered shots

Low variation



High variation

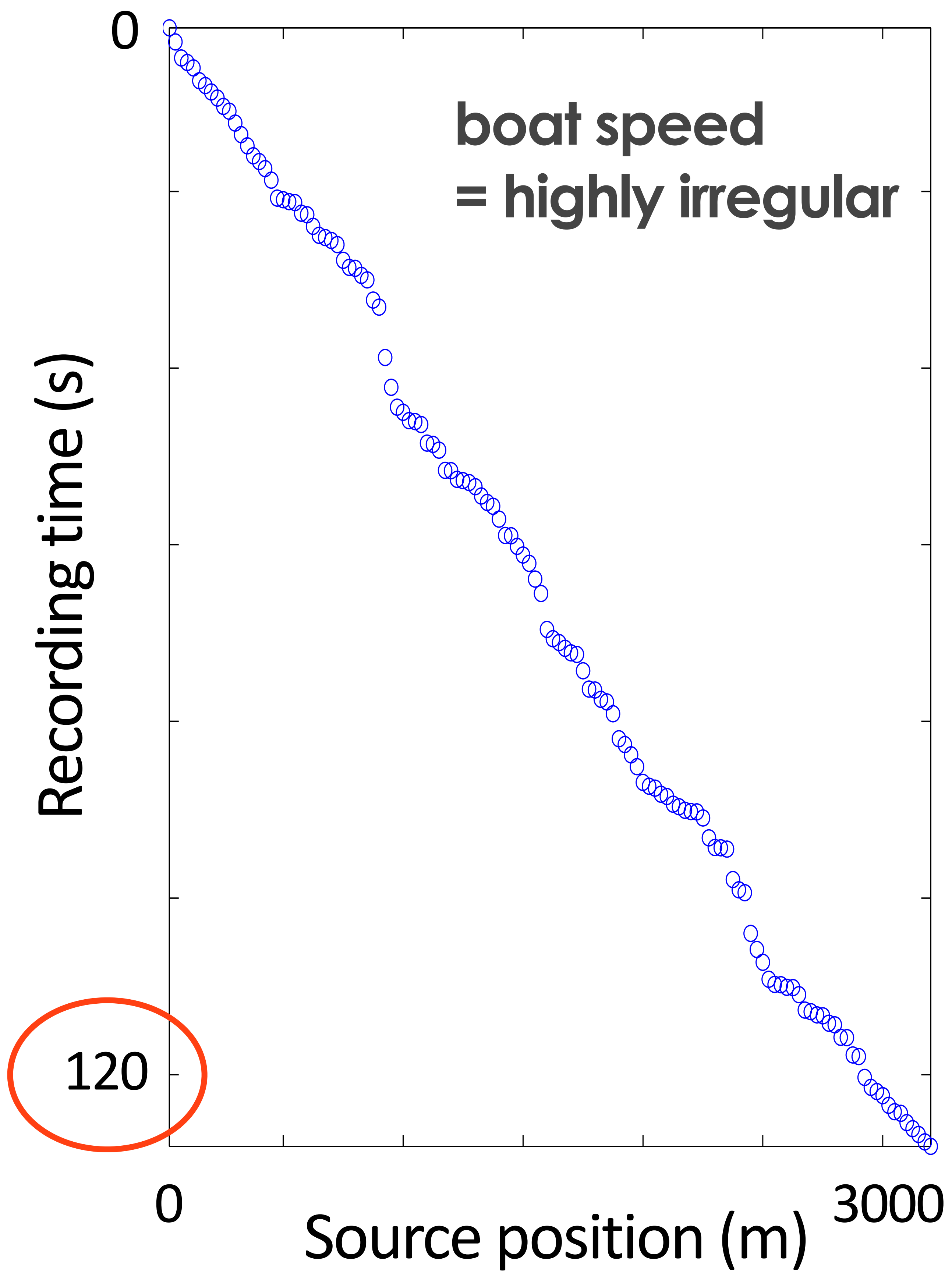


assume boat speed of 2.5m/s (≈ 5 knots)

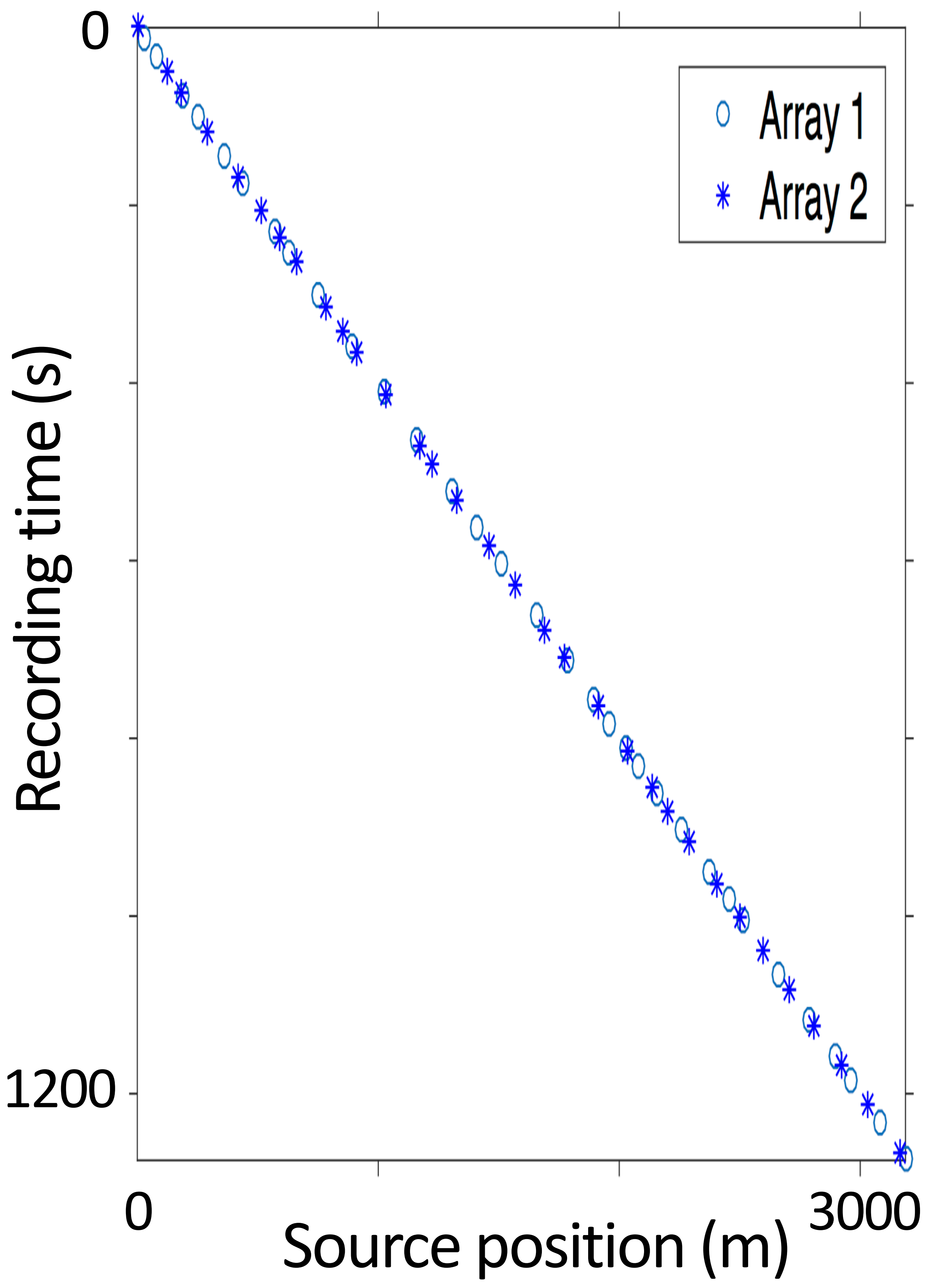
Pragmatic compressive simultaneous acquisition

SLIM

Random time dithering (nonrealistic)



Time-jittered marine (realistic)



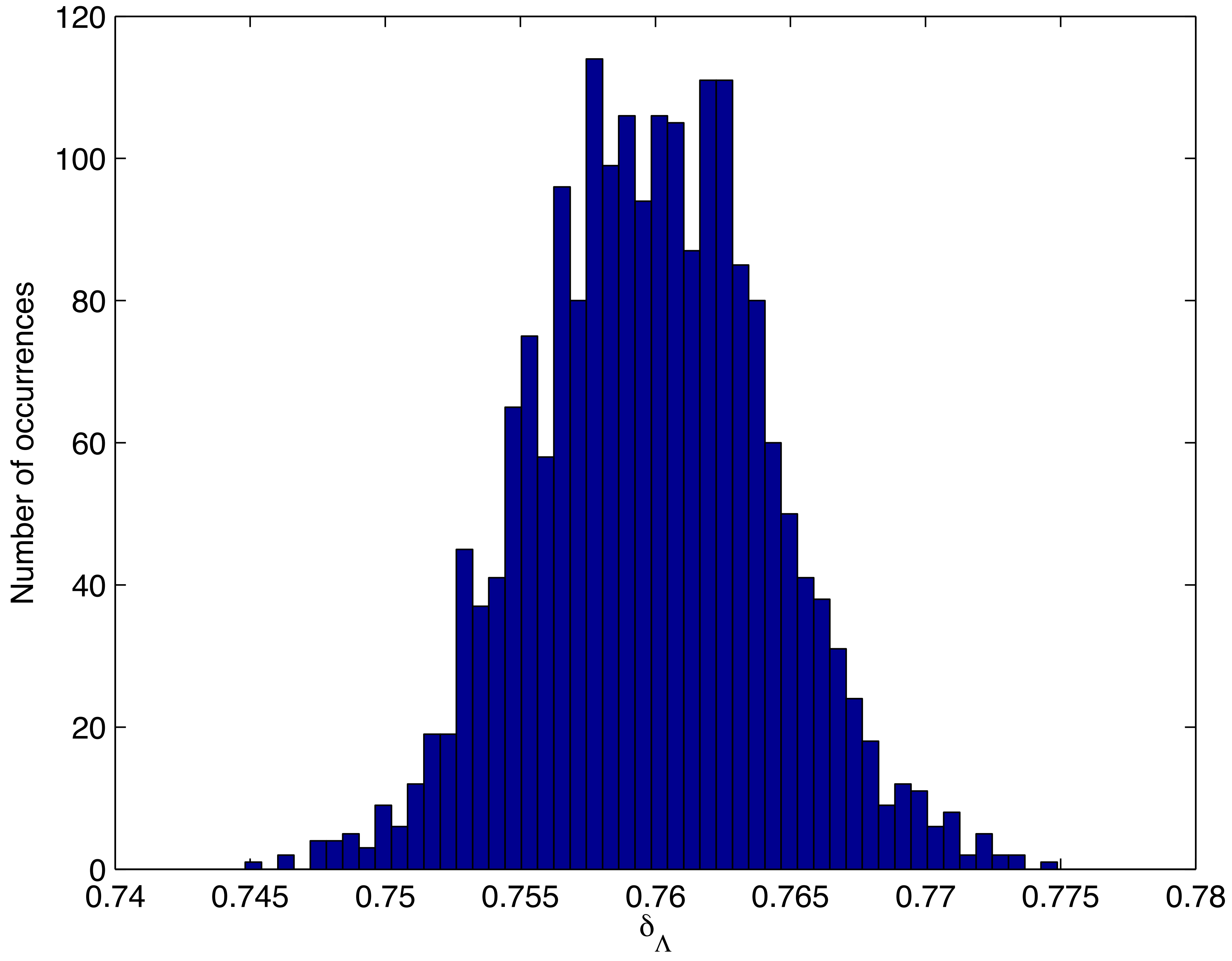
boat speed
≈ constant

Restricted Isometry Property (RIP)

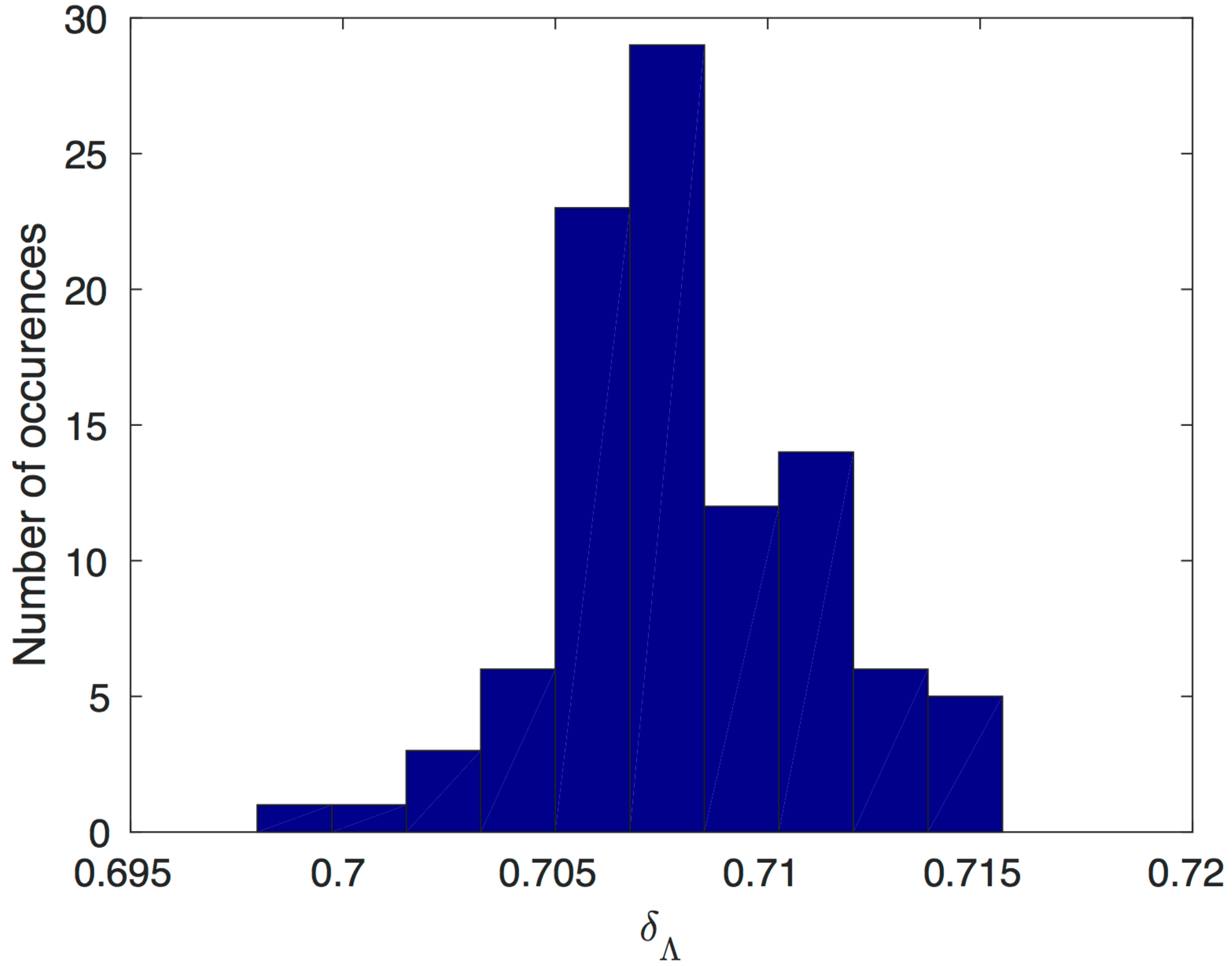
- indicates whether every group of k columns of $\mathbf{A}$ are nearly orthogonal
- restricted isometry constant $0 < \delta_k < 1$ for which

$$(1-\delta_k)\|\mathbf{u}\|_2^2 \leq \|\mathbf{A}_\Lambda \mathbf{u}\|_2^2 \leq (1+\delta_k)\|\mathbf{u}\|_2^2$$

nonrealistic

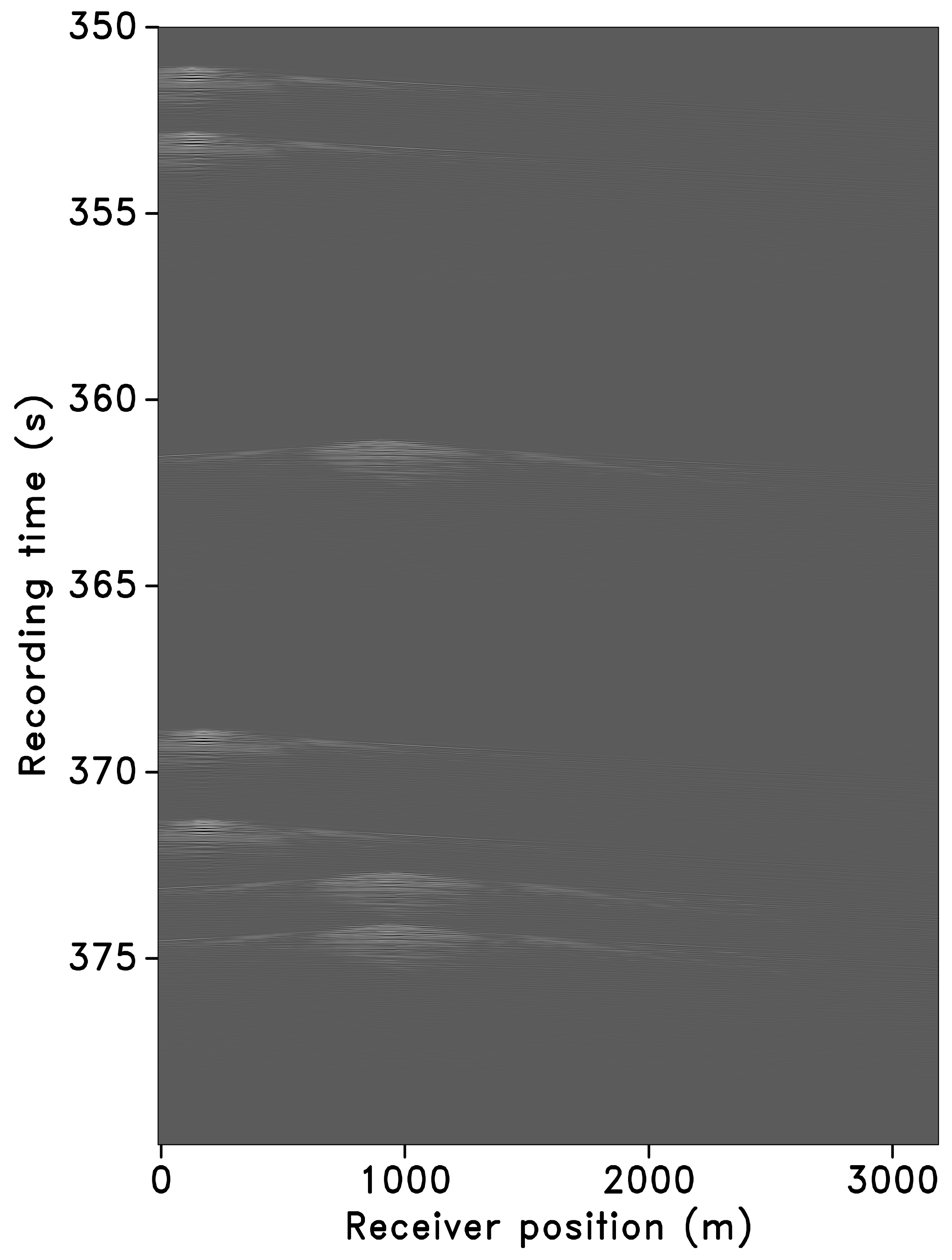


realistic



Time-jittered marine acquisition

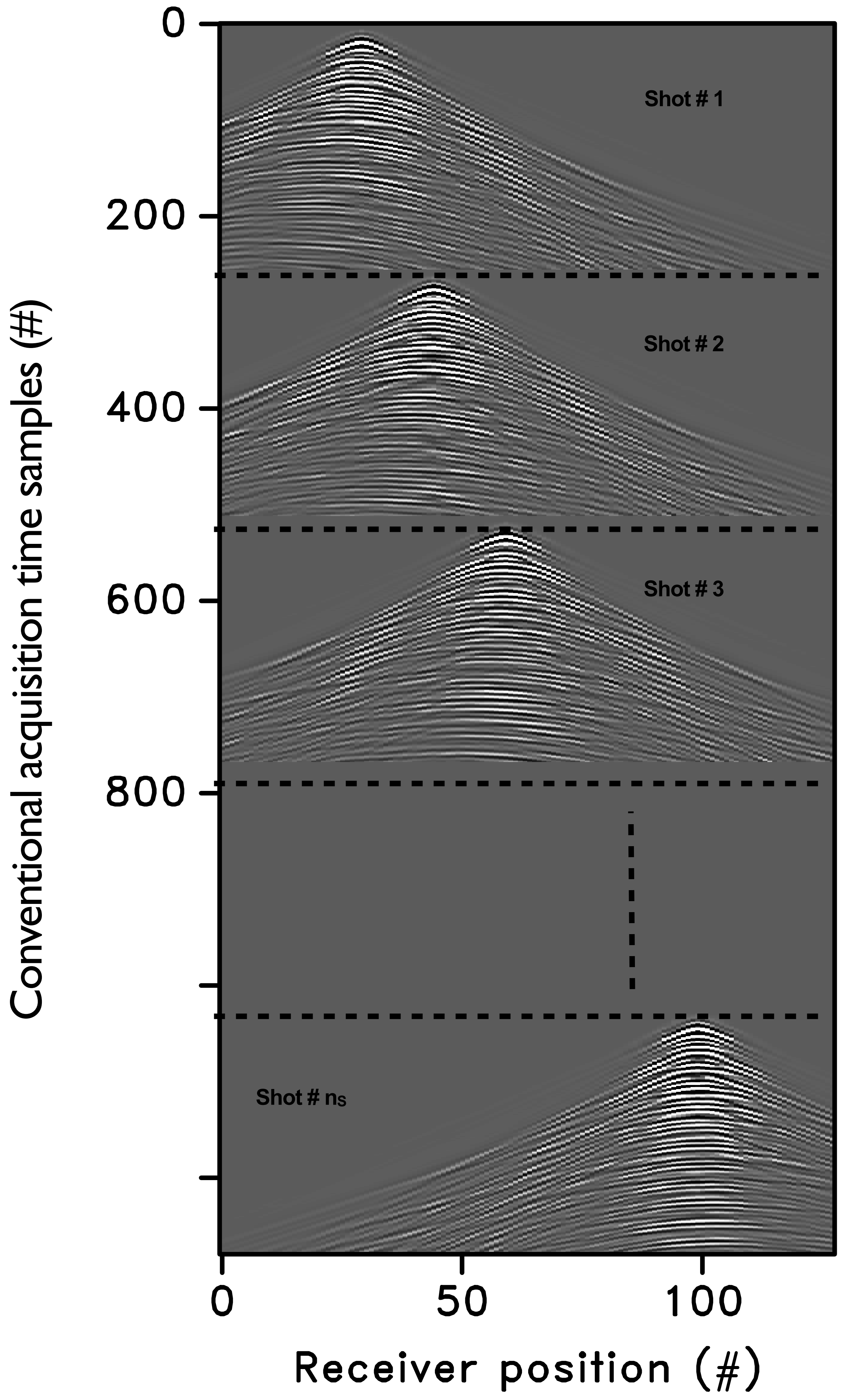
subsampled shots **with overlap** between shot records



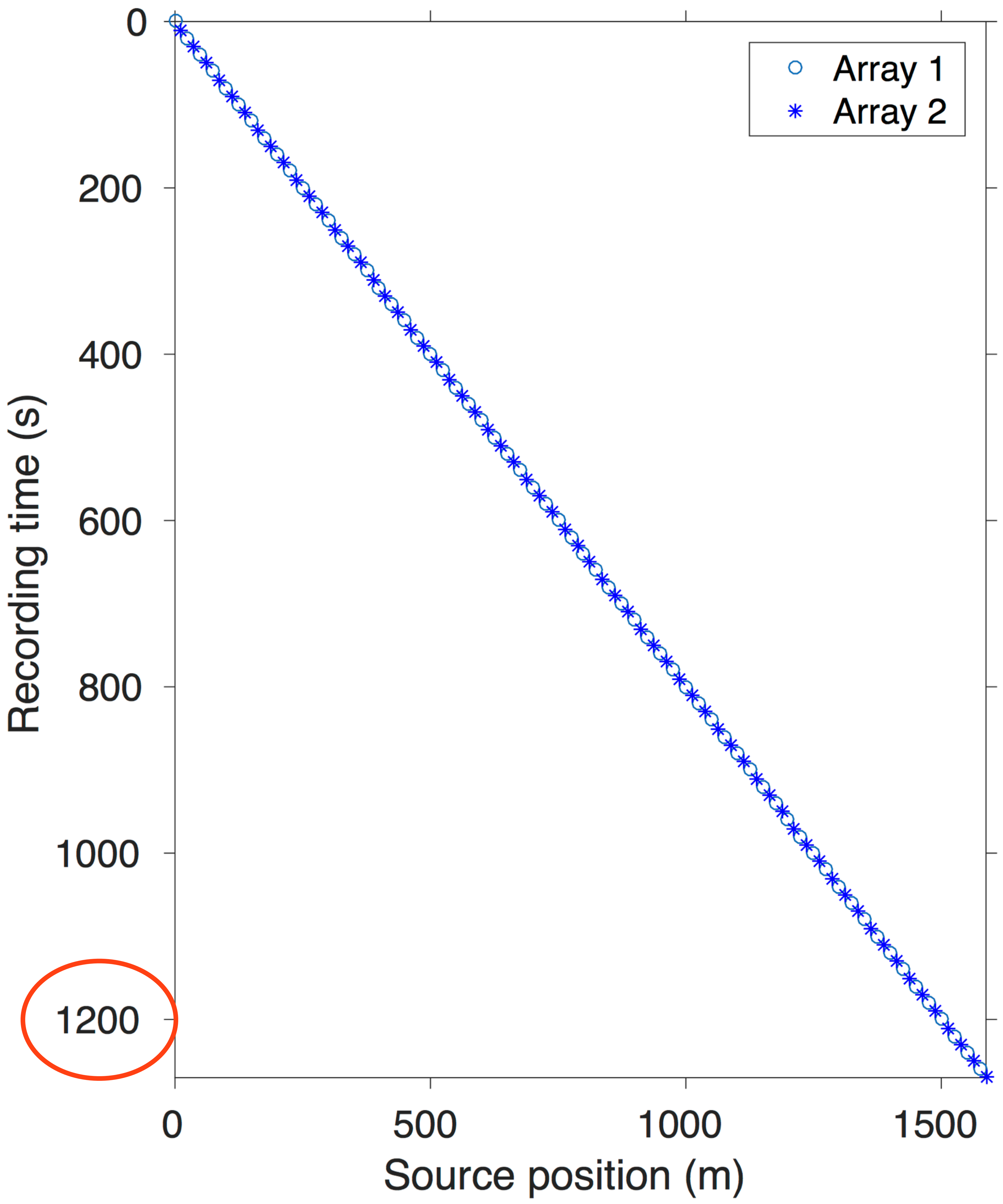
source fires at jittered times and jittered positions

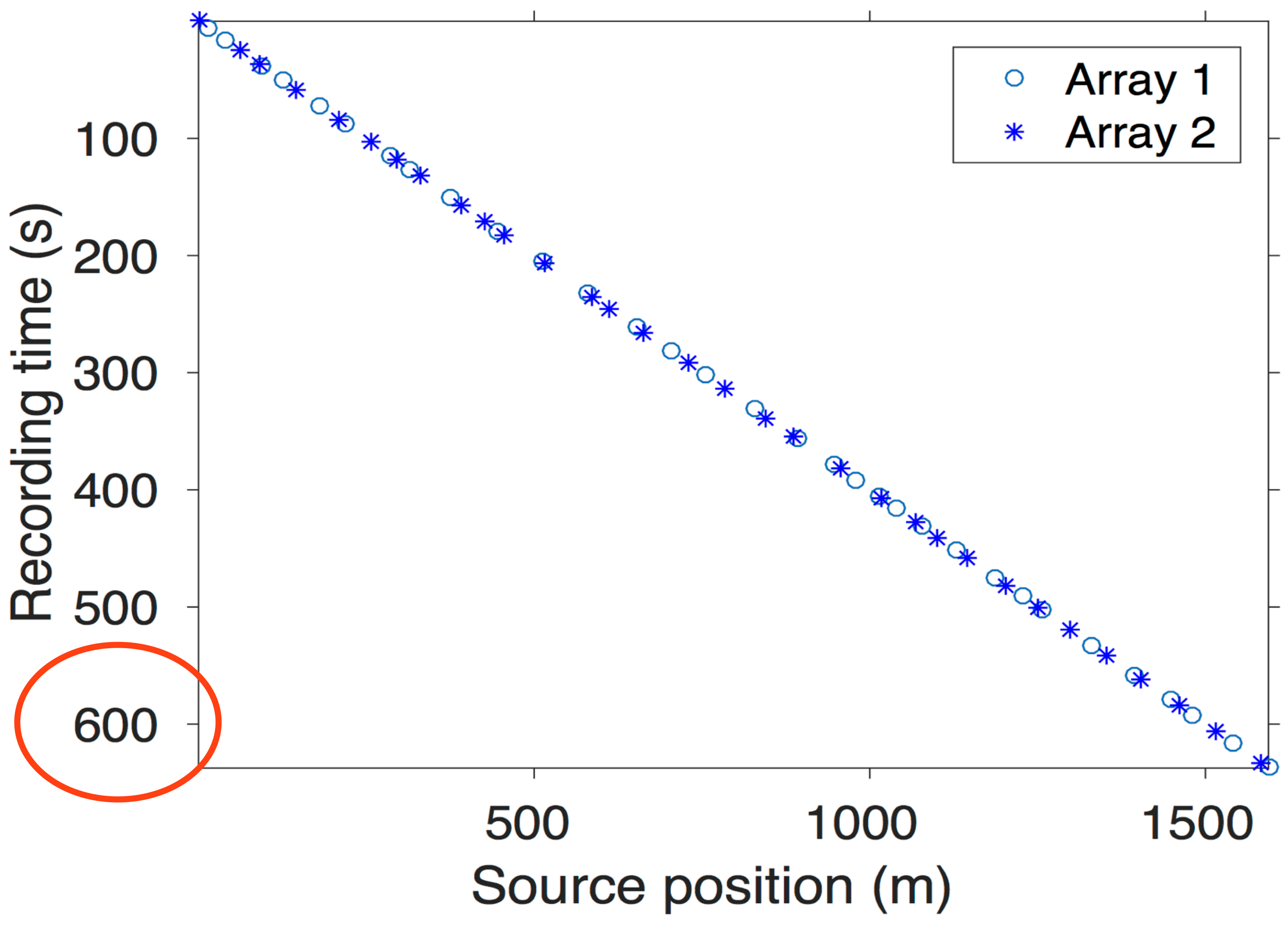
sum

all shots **without overlap** between shot records



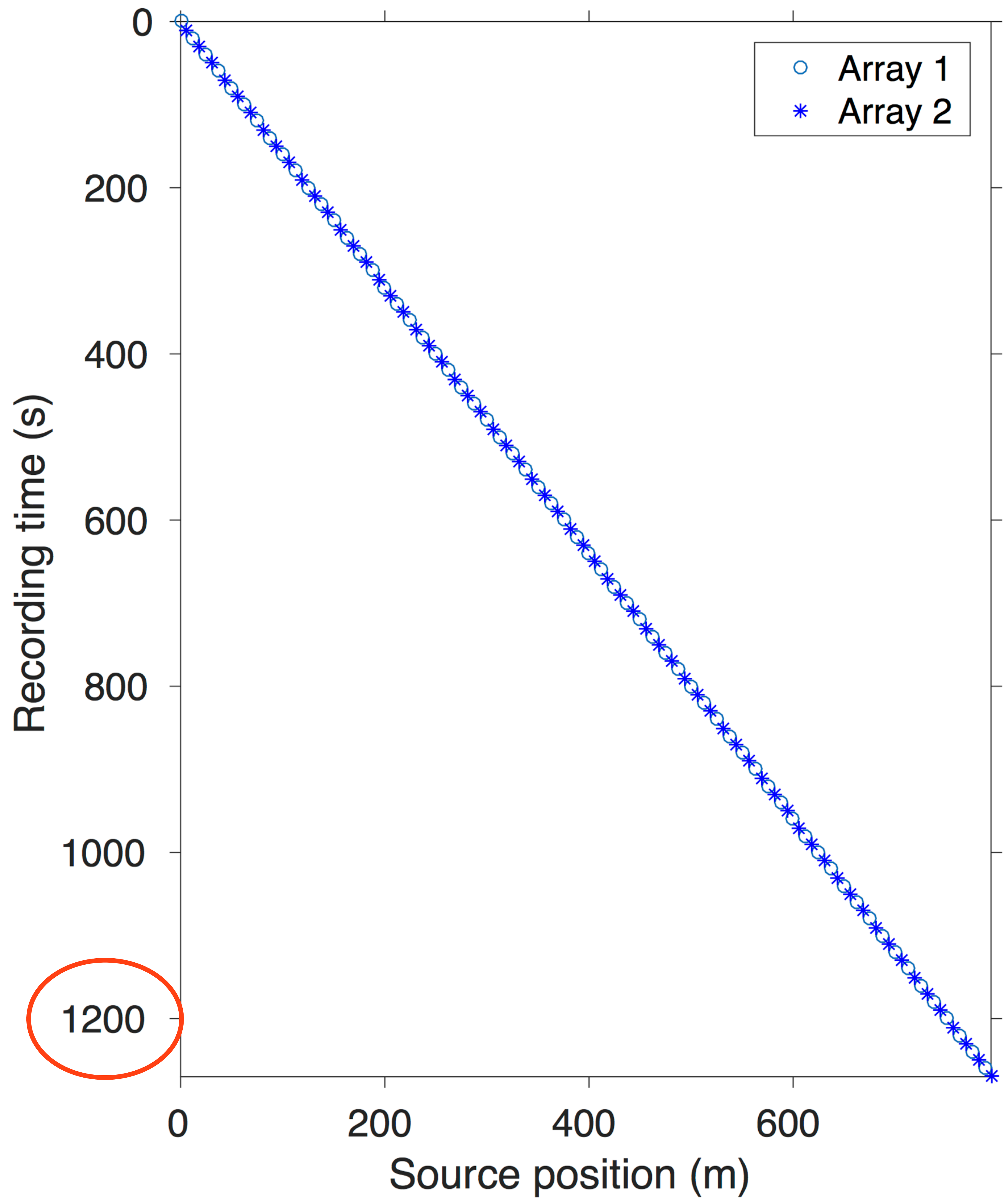
Conventional vs. time-jittered marine acquisition
– subsampling factor = 2

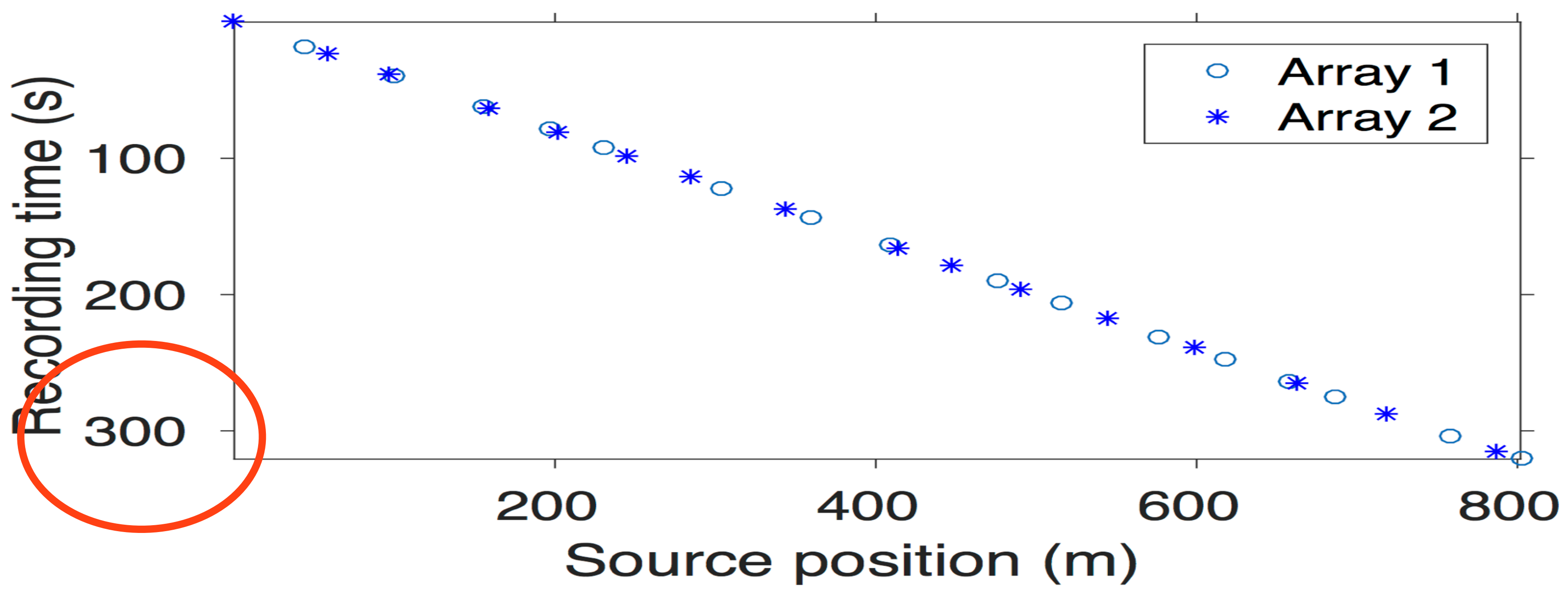




Conventional vs. time-jittered marine acquisition

– subsampling factor = 4





Compressive simultaneous acquisition

subsampling factor

$$\eta = \frac{1}{\text{number of air-gun arrays}} \times \frac{\text{jittered spatial grid interval}}{\text{conventional spatial grid interval}}$$

for spatial sampling = 12.5 m

$$\eta = \frac{1}{2} \times \frac{50.0 \text{ m}}{12.5 \text{ m}} = 2$$

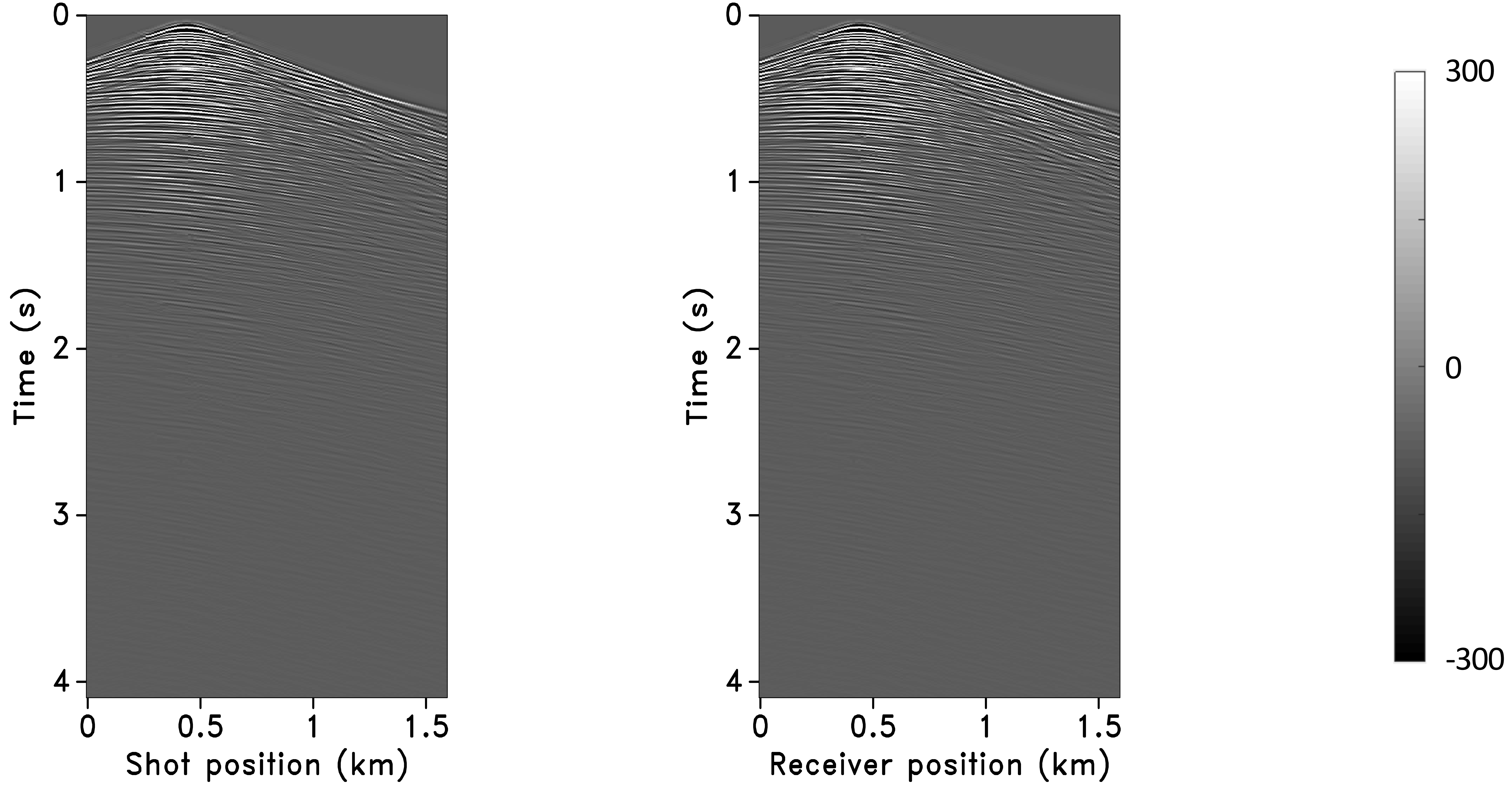
for spatial sampling = 6.25 m

$$\eta = \frac{1}{2} \times \frac{50.0 \text{ m}}{6.25 \text{ m}} = 4$$

Conventional data

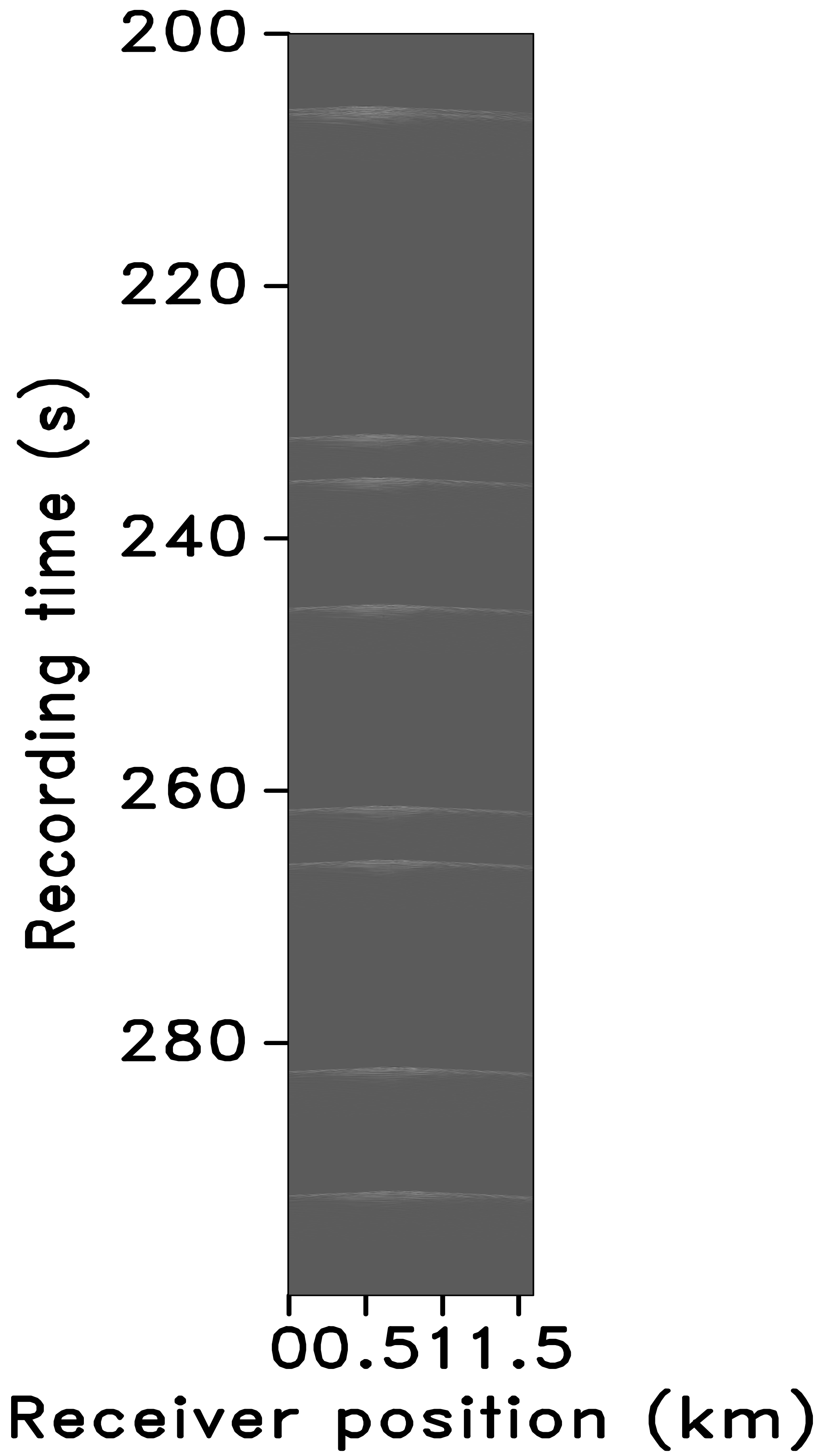
Receiver gather

Shot gather

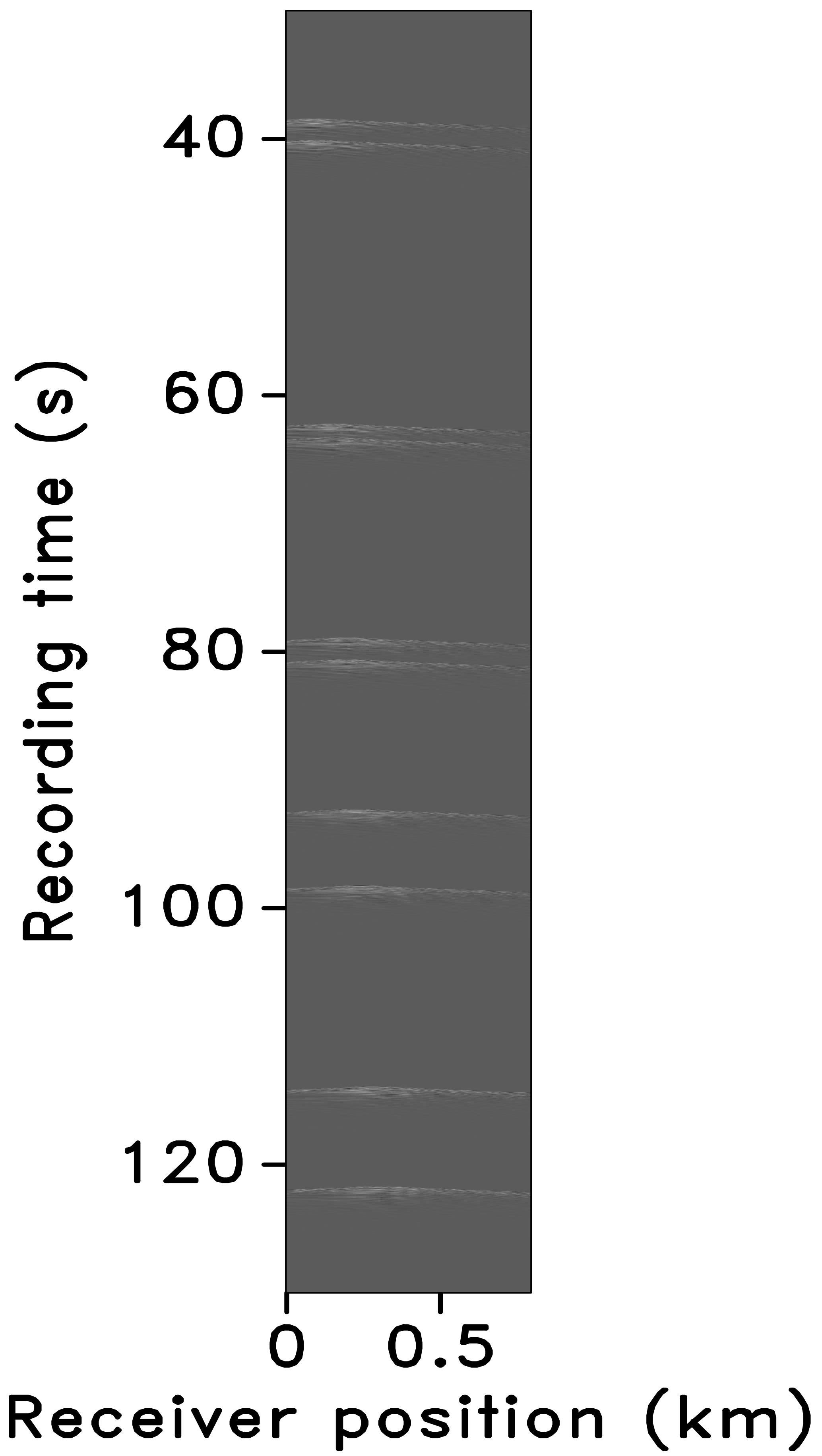


Measurements
– subsampled and overlapping shots

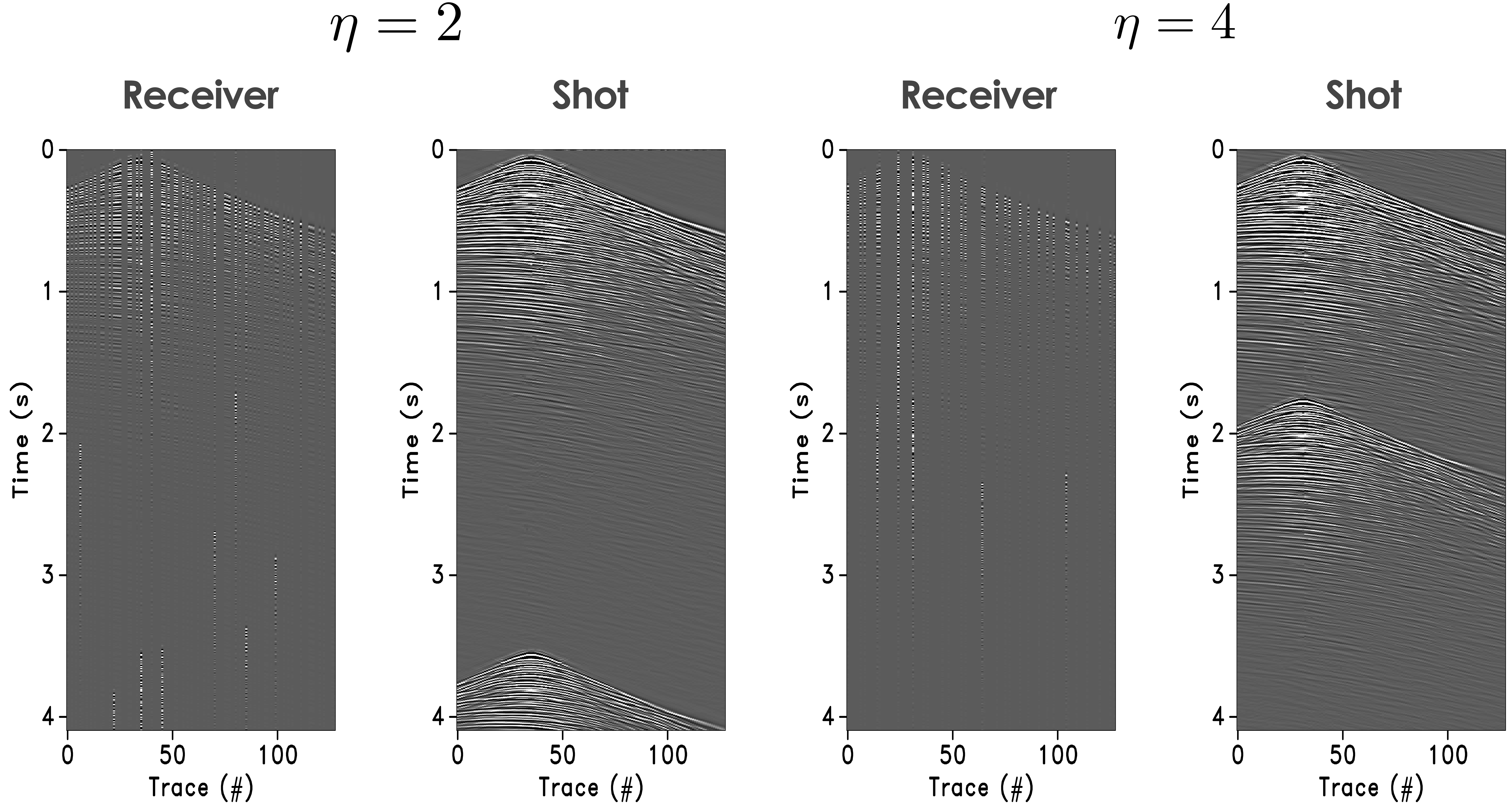
$\eta = 2$



$\eta = 4$

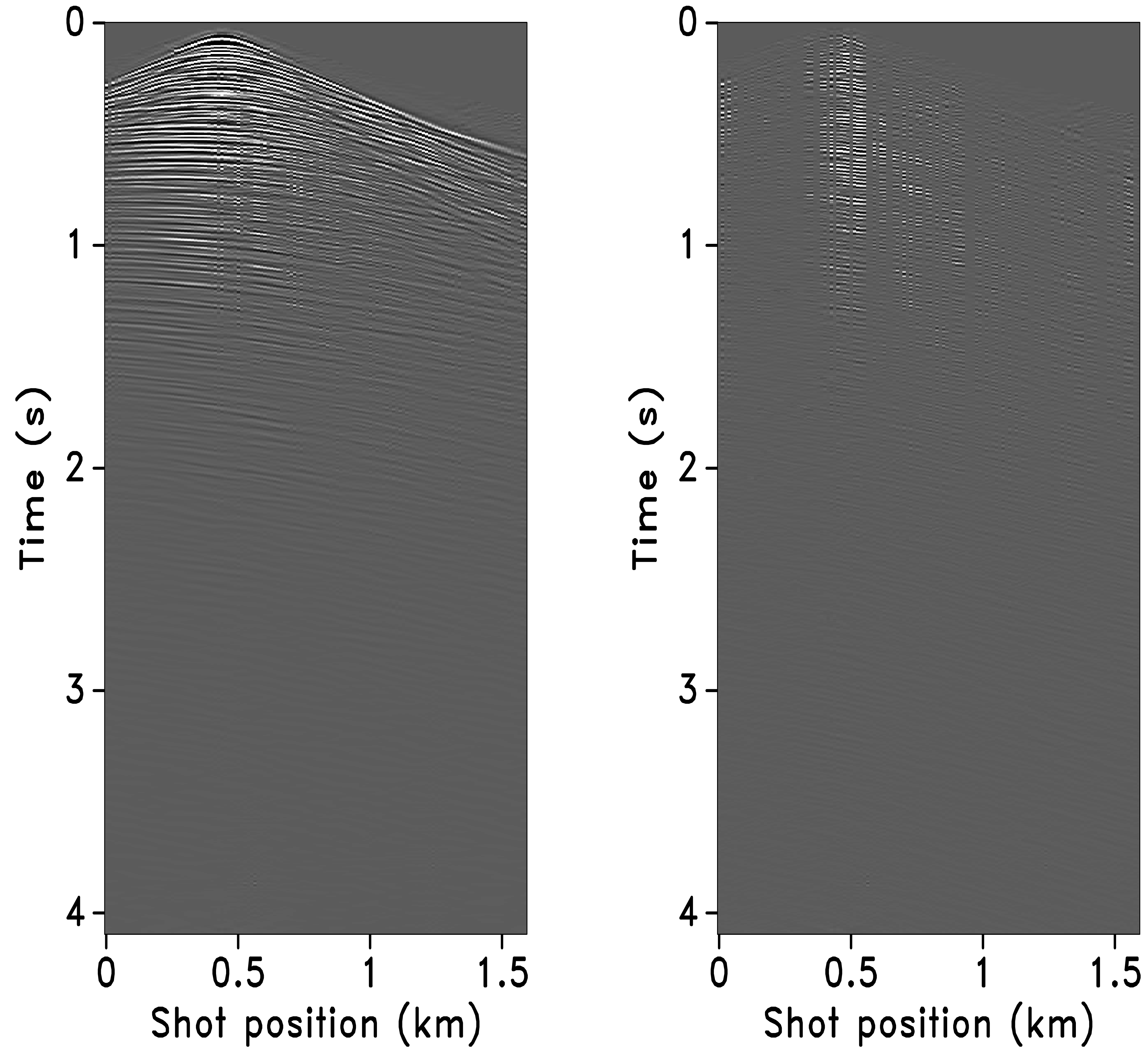


Adjoint of acquisition operator ($\mathbf{M^H b}$)

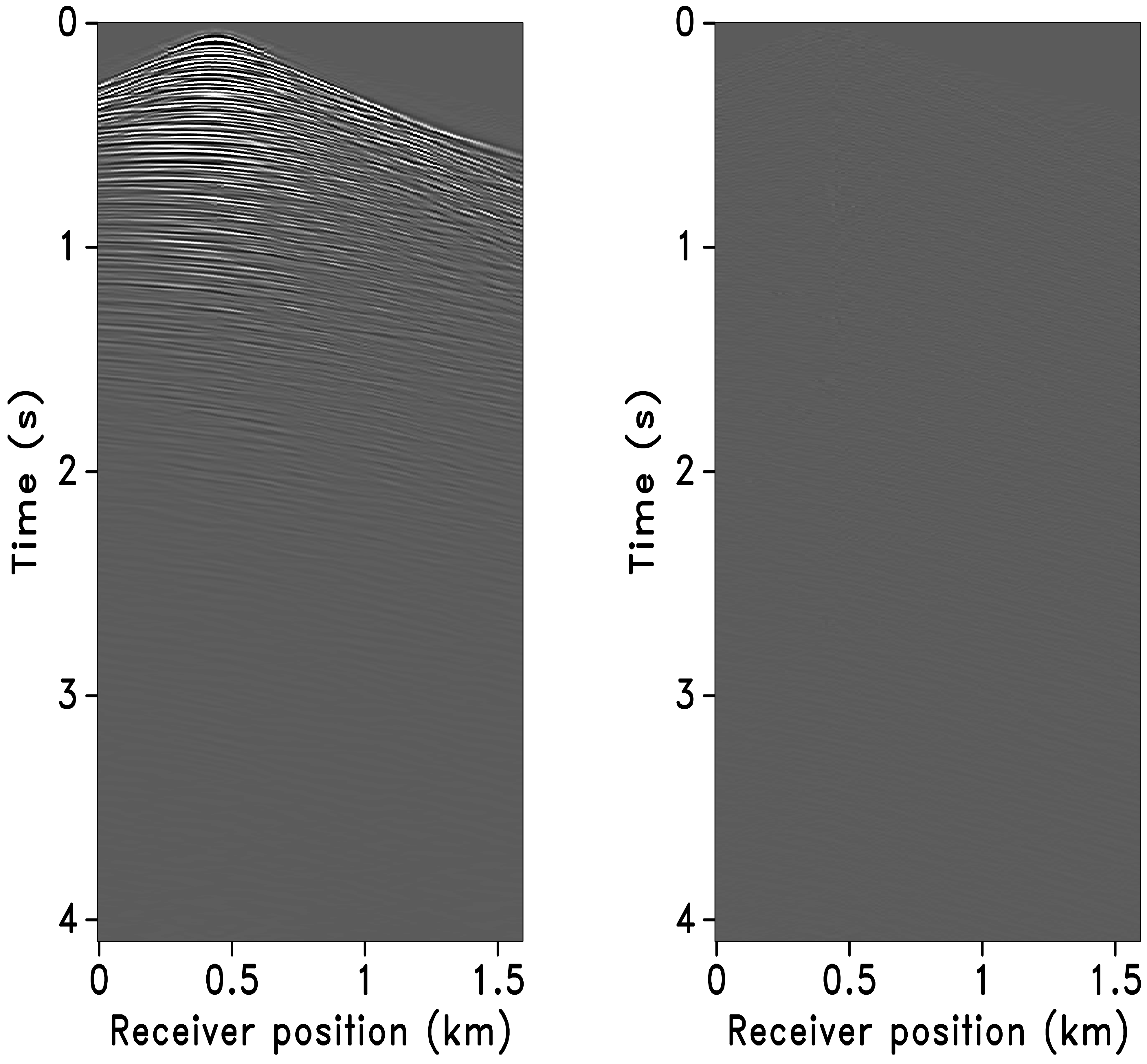


Sparsity-promoting recovery & residual
– 2D curvelets; subsampling factor = 2

Receiver gather

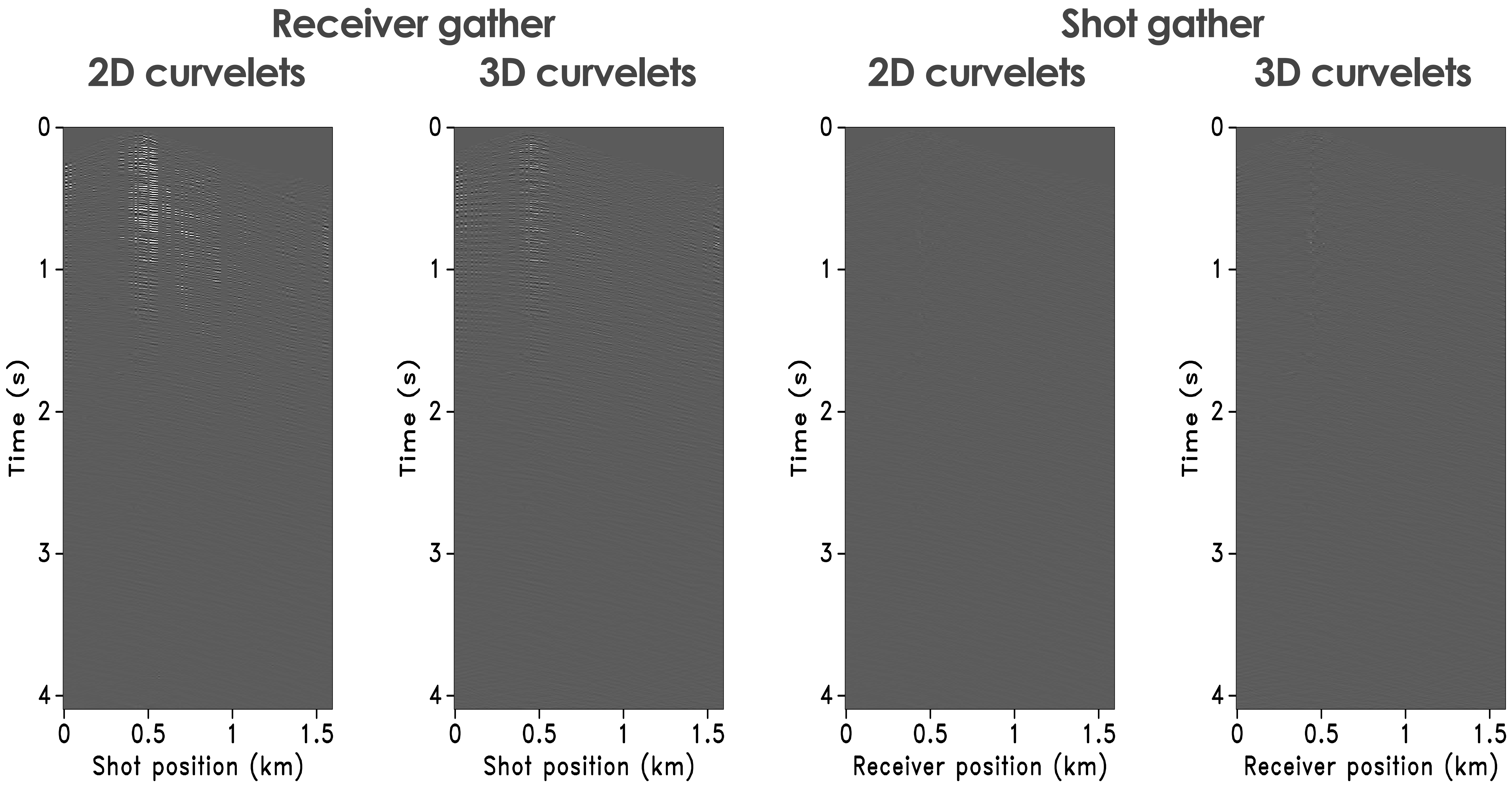


Shot gather



Residual

– 2D vs. 3D curvelets; subsampling factor = 2

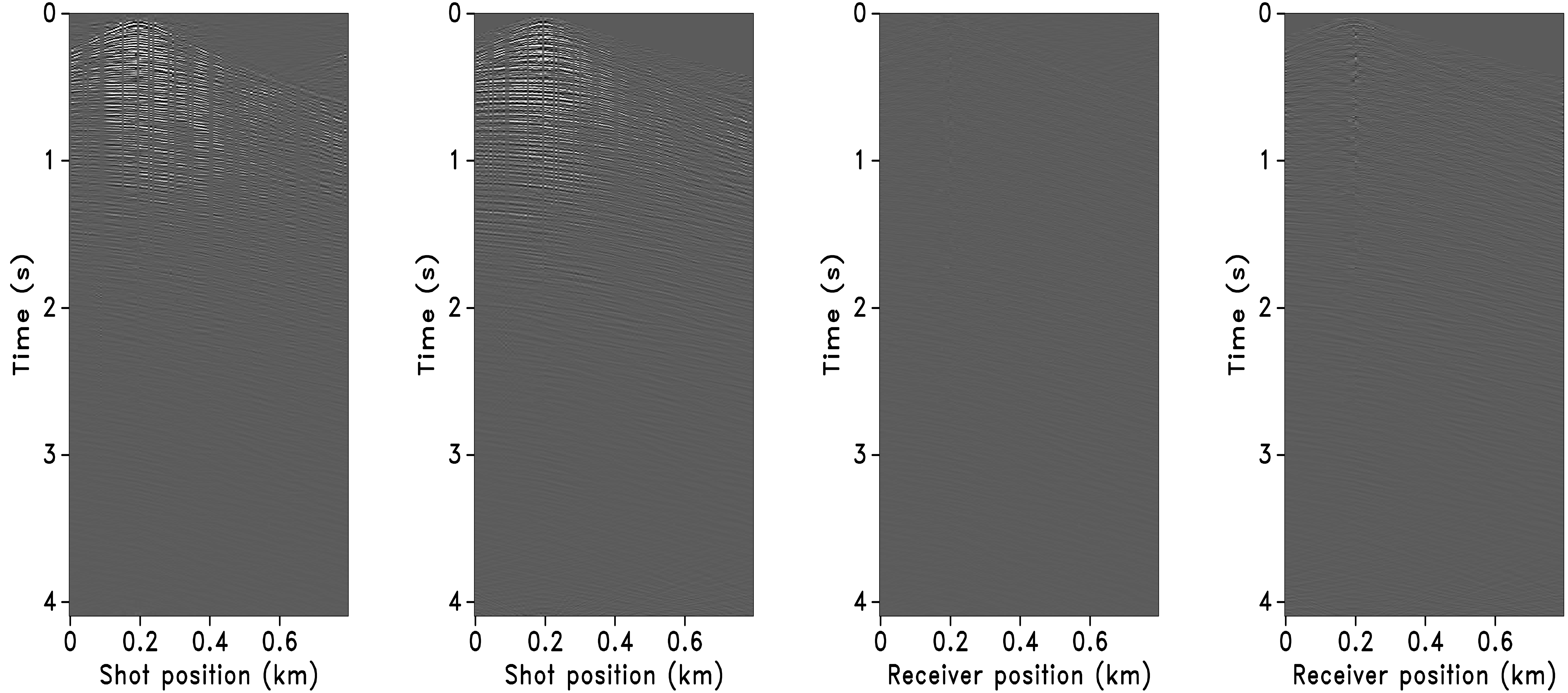


Residual

– 2D vs. 3D curvelets; subsampling factor = 4

Receiver gather | **Shot gather**

2D curvelets | **3D curvelets** | **2D curvelets** | **3D curvelets**



Summary (S/N (dB))

$$S/N(\mathbf{f}, \widetilde{\mathbf{f}}) = -20 \log_{10} \frac{\|\mathbf{f} - \widetilde{\mathbf{f}}\|_2}{\|\mathbf{f}\|_2}$$

	jittered to regular (m), subsampling (η)	recovery with 2D FDCT*	recovery with 3D FDCT*
1 source vessel (2 air-gun arrays)	50 to 12.5, 2	11.5	12.4
	50 to 6.25, 4	4.9	5.7

* FDCT : Fast Discrete Curvelet Transform

Economic performance indicators

Improved spatial-sampling ratio (ISSR):

$$\text{ISSR} = \frac{\text{number of shots recovered via sparsity-promoting inversion}}{\text{number of shots in simultaneous-source acquisition}}$$

for η = 2, 4, etc., gain in spatial sampling by the same factor

Survey-time ratio (STR): [Berkhout, 2008]

$$\text{STR} = \frac{\text{time of conventional acquisition}}{\text{time of simultaneous-source acquisition}}$$

for η = 2, 4, etc., reduction in survey time by $\frac{1}{\eta}$

Conclusions

Simultaneous-source **time-jittered marine** acquisition is an instance of compressive sensing

- **economic** acquisition with **reduced** environmental **imprint**

Jittered (sub)sampling shares the benefits of random sampling while offering control on maximum acquisition gap

3D FDCT slightly **improves** sparse recovery; however, its redundancy (about 24 x) renders large-scale processing extremely **memory intensive**, and hence **impractical**

Chapter 5

Compressive time-lapse seismic acquisition
- distributed compressive sensing
- static acquisition geometry
- **on-the-grid** marine surveys
- % overlap => **exact** replication of shot positions

Time-lapse seismic

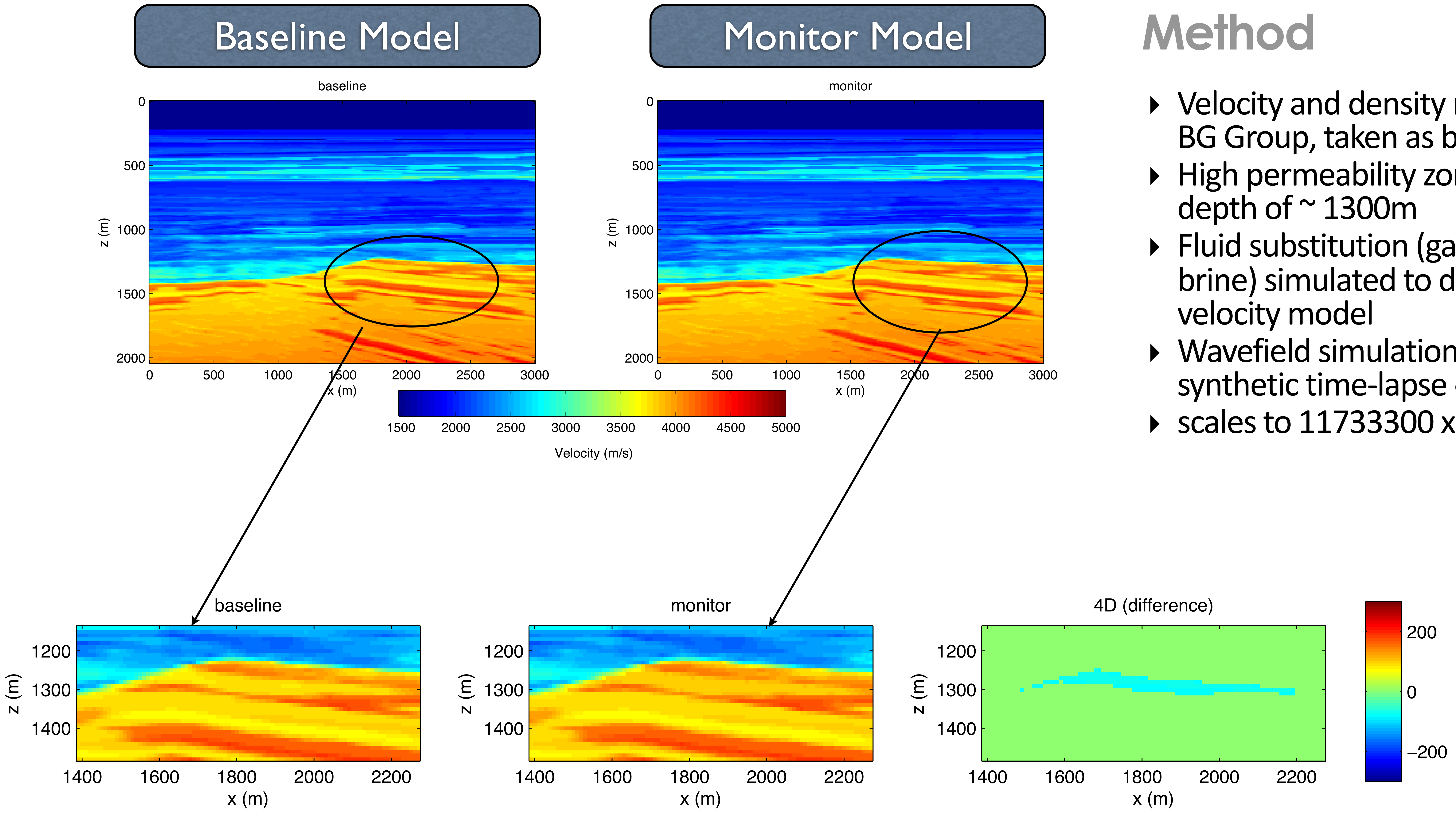
Current acquisition paradigm:

- repeat **expensive** dense acquisitions & “independent” processing
- compute differences between baseline & monitor survey(s)
- hampered by practical challenges to ensure repetition

New compressive sampling paradigm:

- **cheap** subsampled acquisition, e.g., via time-jittered marine subsampling
- offers possibility to relax insistence on replicability
- exploits insights from distributed compressive sensing

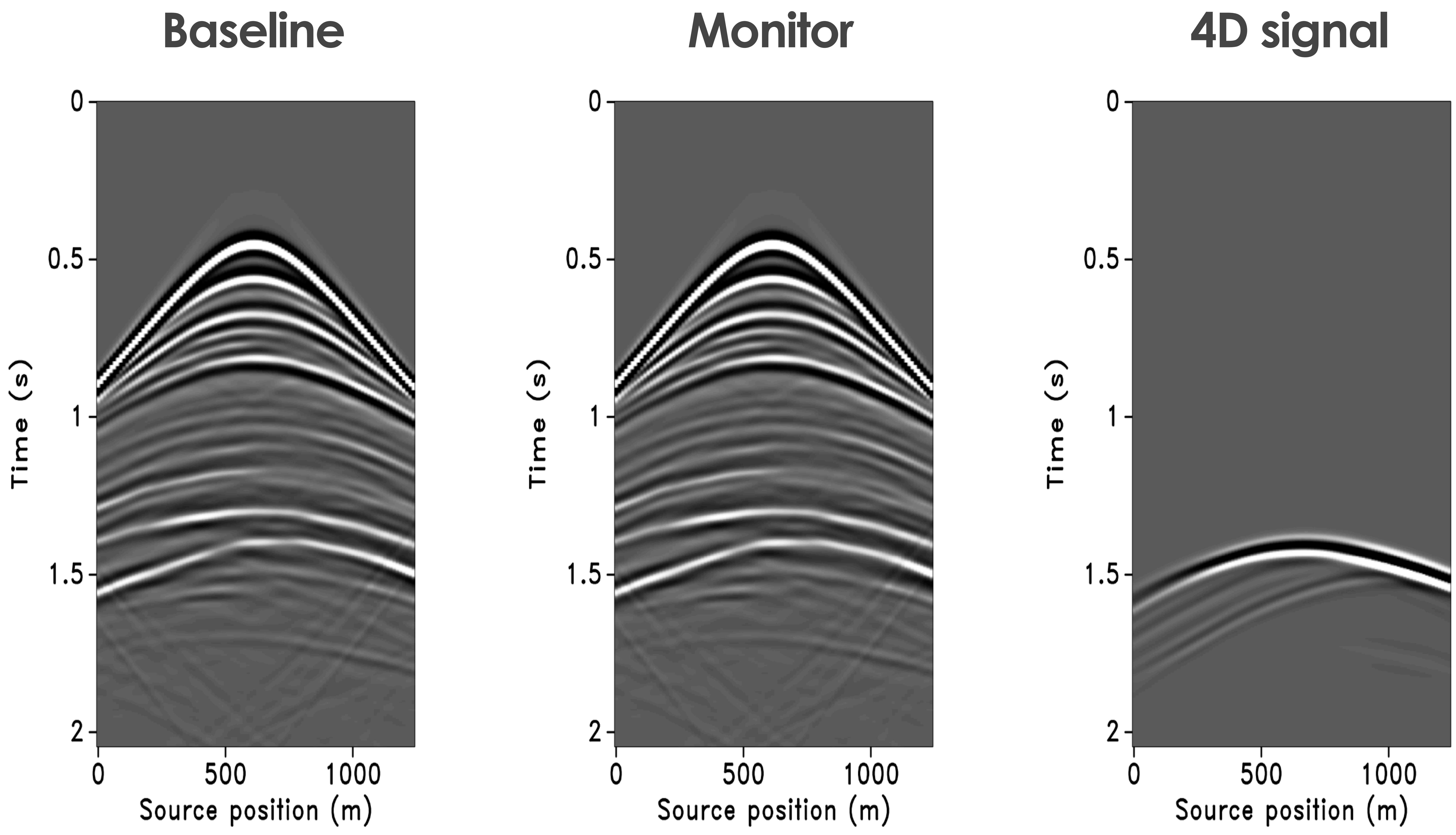
Time-lapse model



Method

- Velocity and density model provided by BG Group, taken as baseline
- High permeability zone identified at a depth of ~ 1300m
- Fluid substitution (gas/oil replaced with brine) simulated to derive monitor velocity model
- Wavefield simulation to generate synthetic time-lapse data
- scales to 11733300 x 114882048

Simulated time-lapse data
– time-domain finite differences

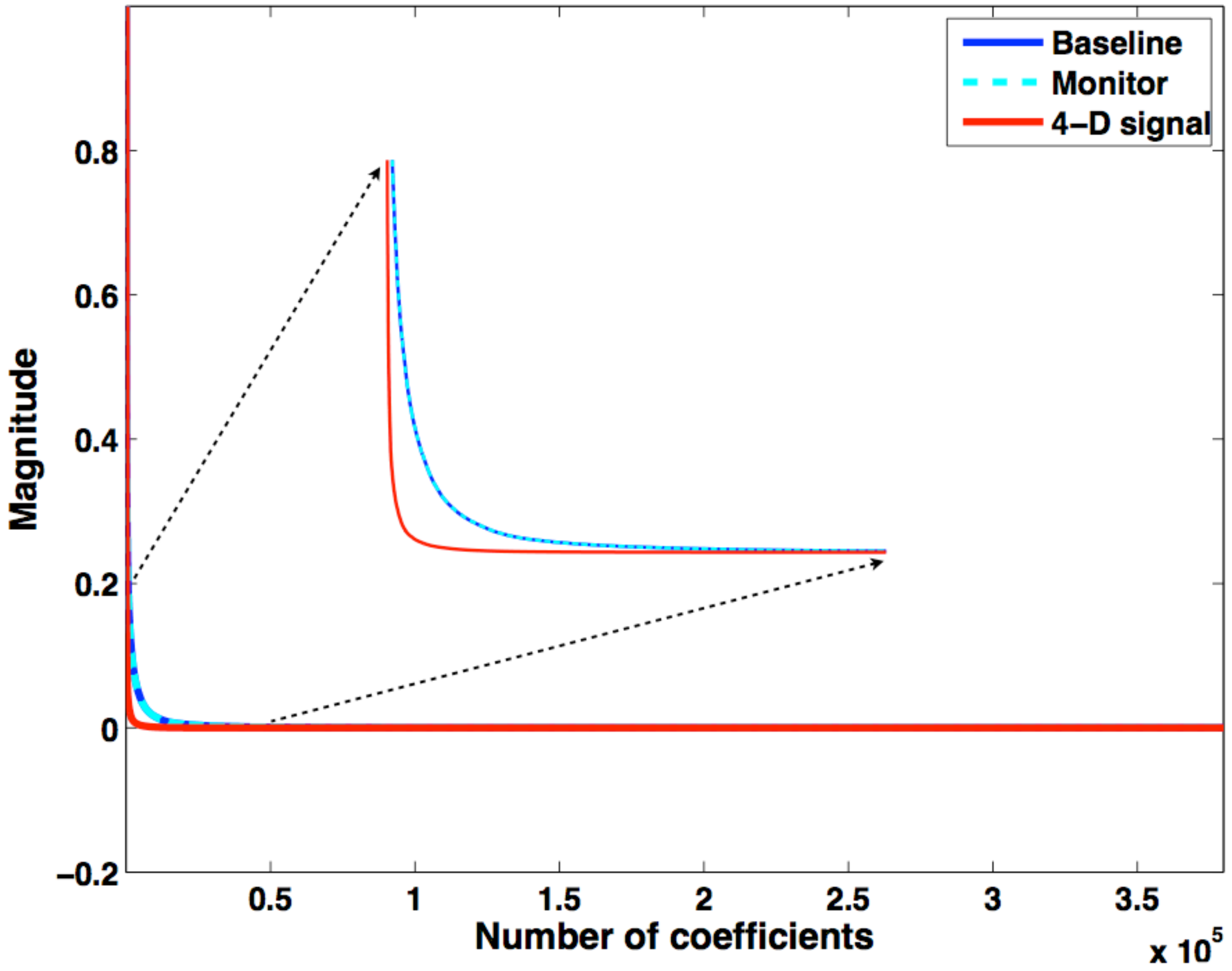


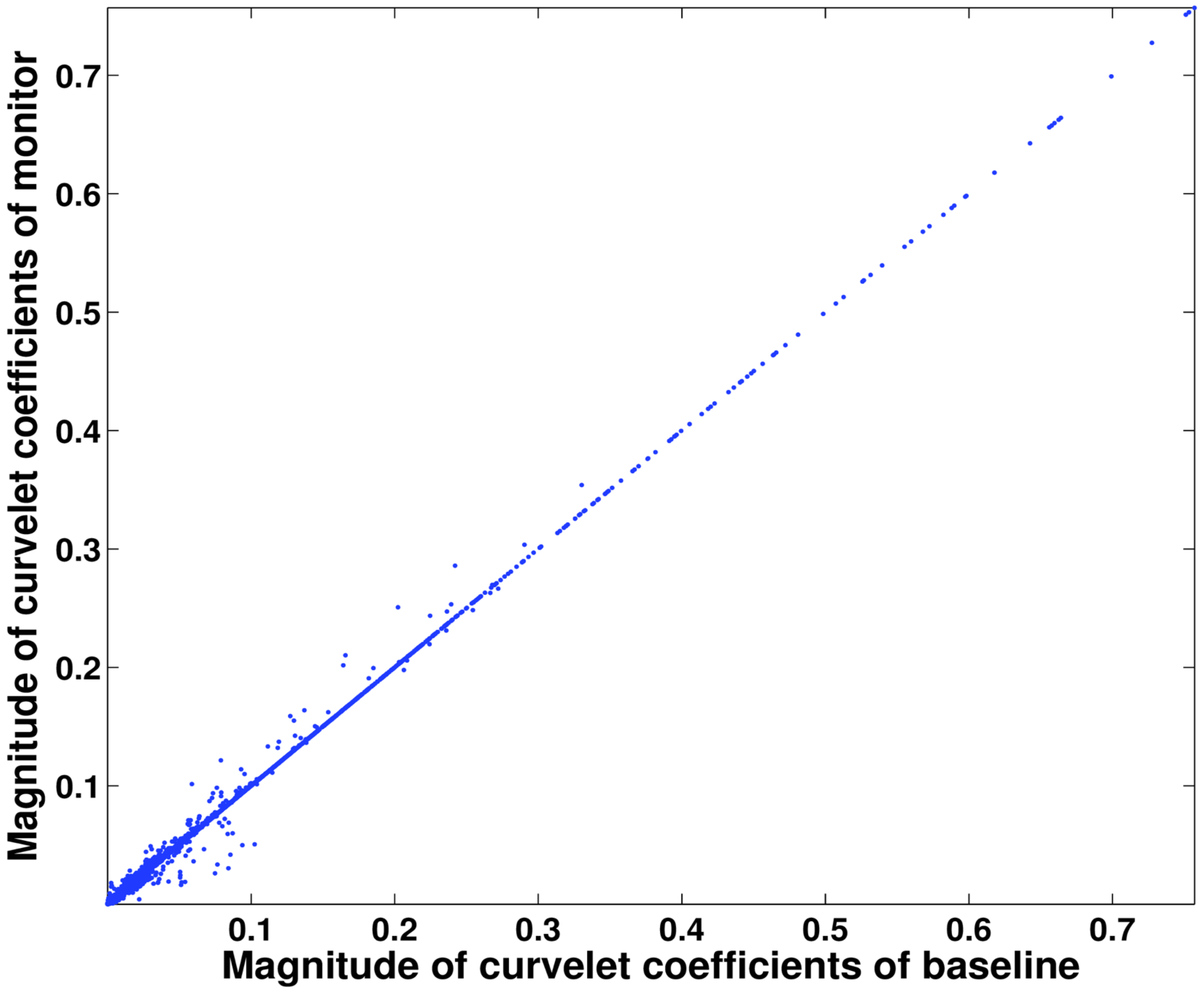
time samples: **512**
receivers: **100**
sources: **100**

sampling
time: **4.0 ms**
receiver: **12.5 m**
source: **12.5 m**

Sparse structure via curvelets

significant correlation between the vintages





Distributed compressive sensing
– joint recovery model (JRM)

$$\overbrace{\begin{bmatrix} \color{red}{\mathbf{A}_1} & \mathbf{A}_1 & \mathbf{0} \\ \color{red}{\mathbf{A}_2} & \mathbf{0} & \mathbf{A}_2 \end{bmatrix}}^{\mathbf{A}} \overbrace{\begin{bmatrix} \color{red}{\mathbf{z}_0} \\ \mathbf{z}_1 \\ \mathbf{z}_2 \end{bmatrix}}^{\mathbf{z}} = \overbrace{\begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix}}^{\mathbf{b}}$$

→ baseline
→ monitor

vintages ↓

$$\mathbf{x}_1 = \color{red}{\mathbf{z}_0} + \mathbf{z}_1$$
$$\mathbf{x}_2 = \color{red}{\mathbf{z}_0} + \mathbf{z}_2$$

→ differences

↓ common component

- different vintages share common information
- common component observed by all surveys
- invert for common component & vintages w.r.t. common component with sparse recovery

Time-lapse seismic
– with & without replication

In an **ideal** world $(\mathbf{A}_1 = \mathbf{A}_2)$

- JRM simplifies to $(\mathbf{b}_2 - \mathbf{b}_1) = \mathbf{A}_1(\mathbf{x}_2 - \mathbf{x}_1)$
- expect good recovery when difference is sparse
- but relies on “exact” replicability of surveys...

In the **real** world $(\mathbf{A}_1 \neq \mathbf{A}_2)$

- no absolute control on surveys
- deviations in shot/receiver positions
- noise...

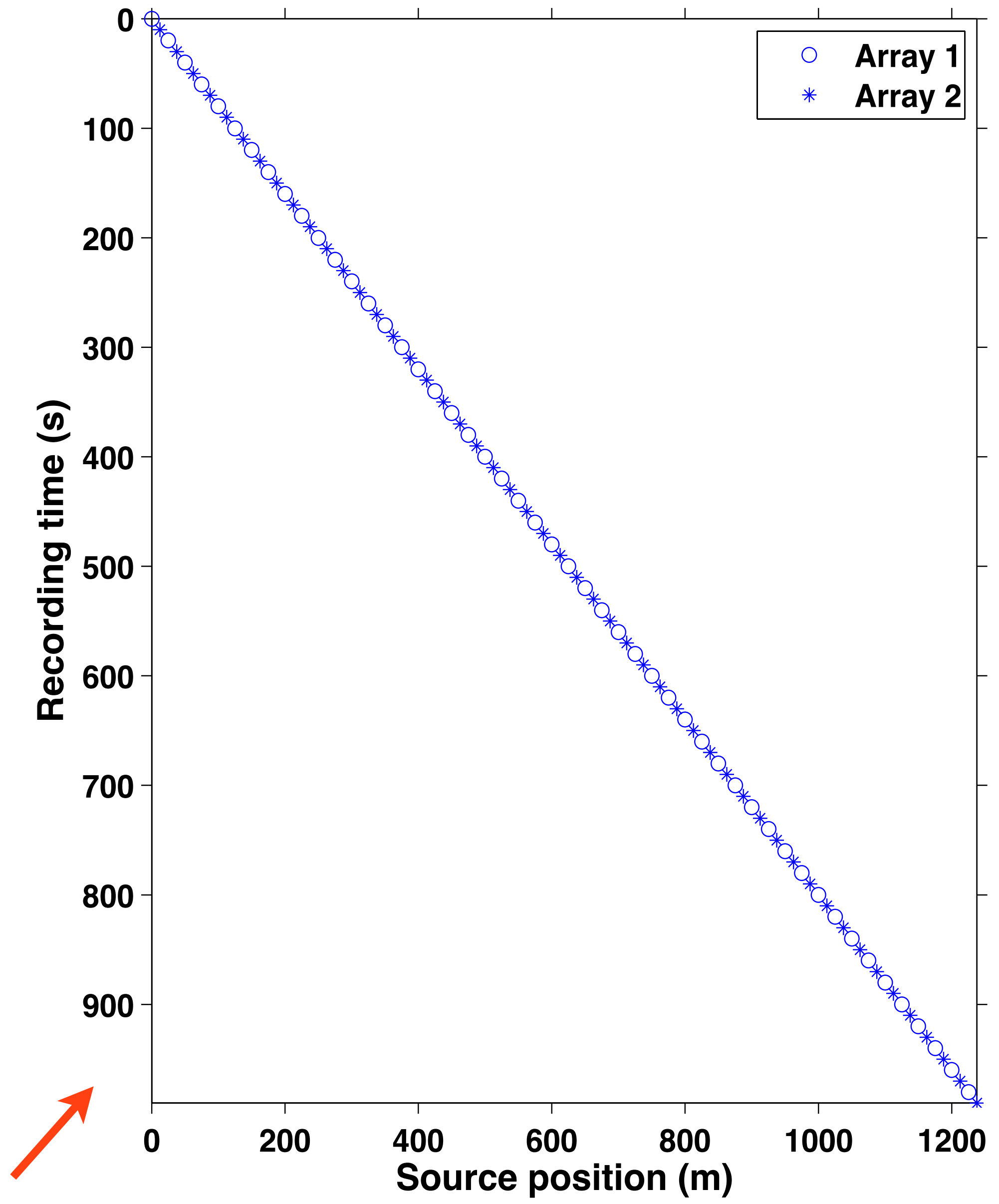
Synthetic seismic case study

Time-jittered marine acquisition **on the grid**
- % overlap => **exact** replication of shot positions

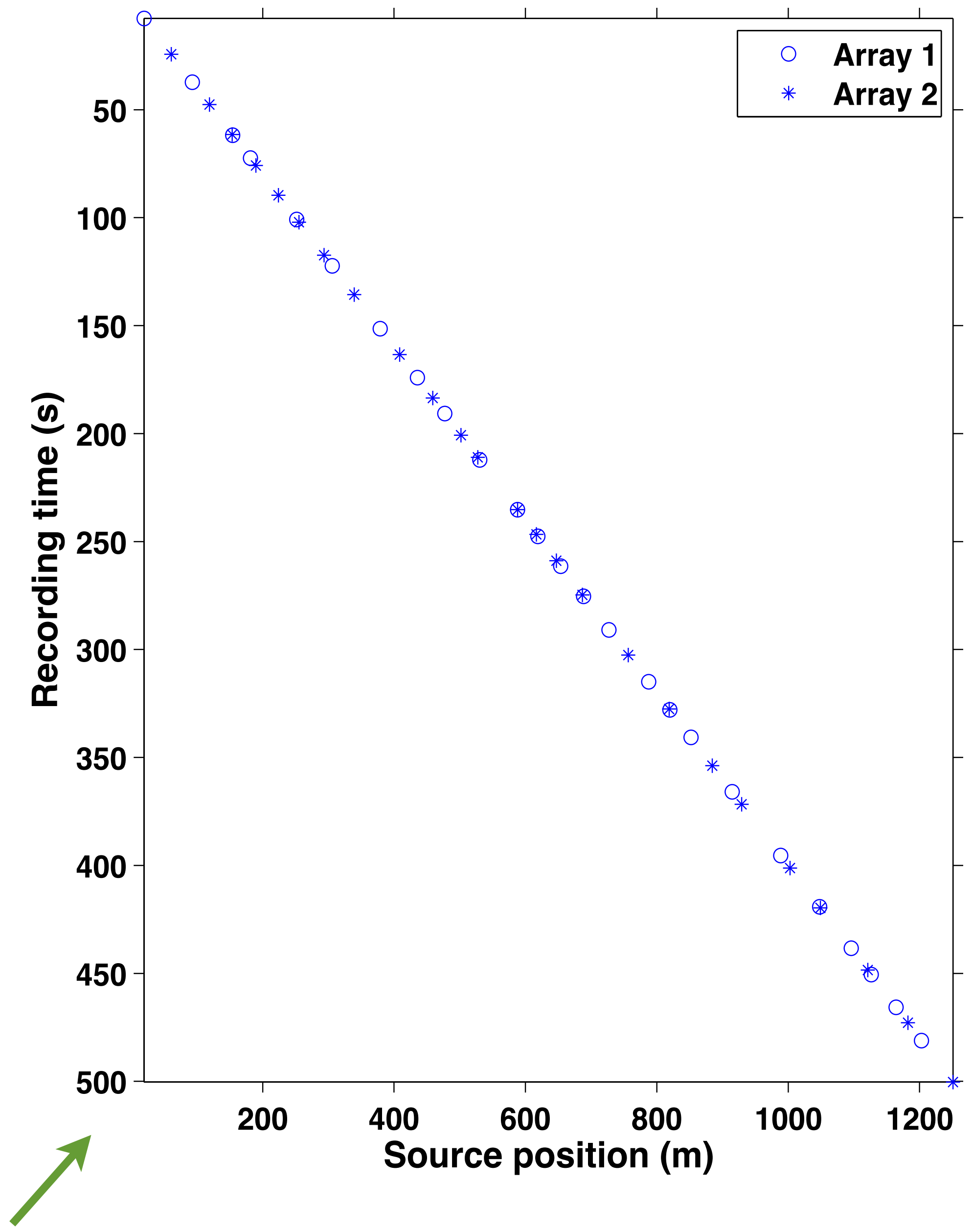
Conventional vs. time-jittered sources

– subsampling factor = 2 (2 source arrays)

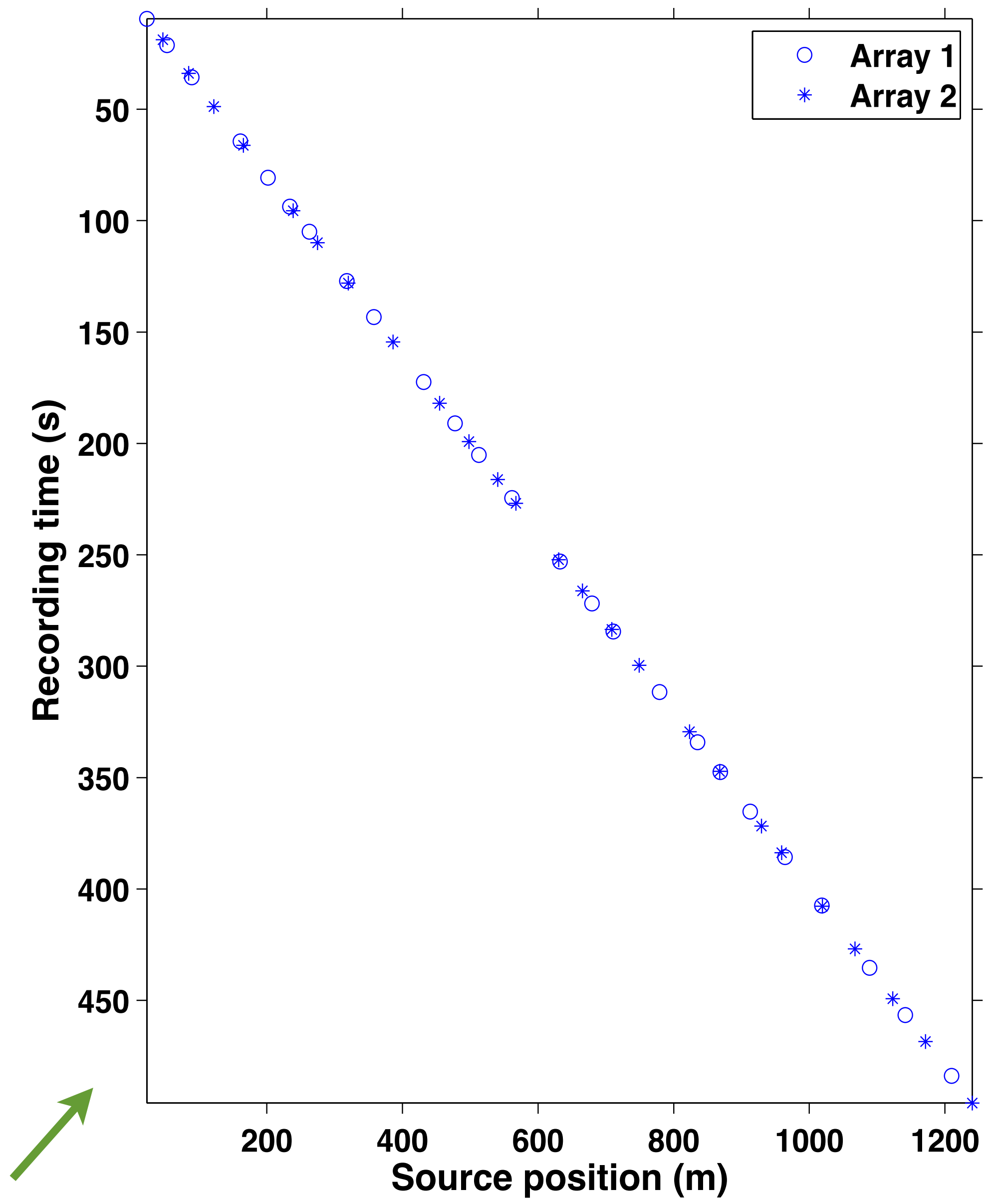
conventional



jittered acquisition 1 (baseline)



jittered acquisition 2 (monitor)



conventional shot gathers
number of shots = **100** (per array)
shot record length: 10.0 s
spatial sampling: **12.5 m**
vessel speed: **1.25 m/s**
recording time = 100 x 10.0 = **1000.0 s**

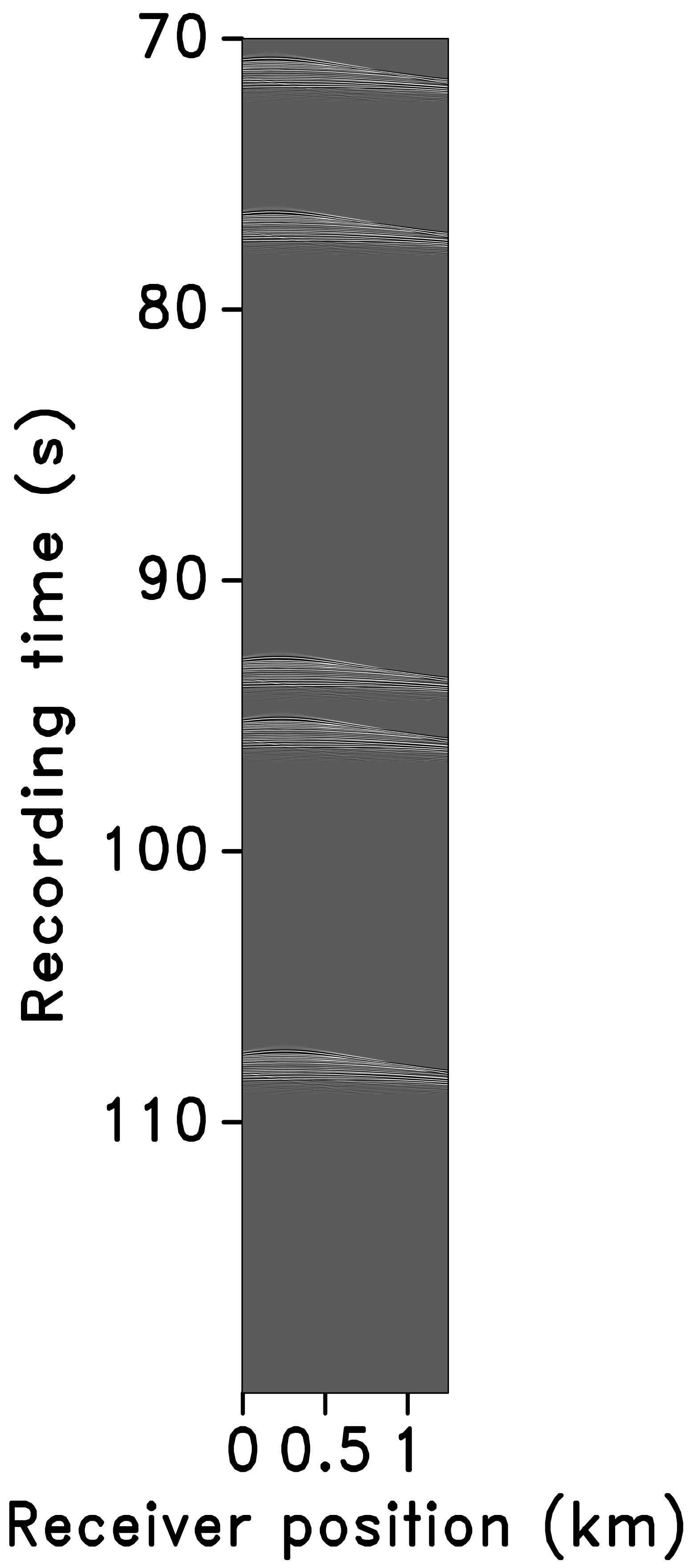
[MIXING & SUBSAMPLING]
spatial subsampling factor = 2

increase in spatial sampling factor = 2
[SOURCE SEPARATION & INTERPOLATION]

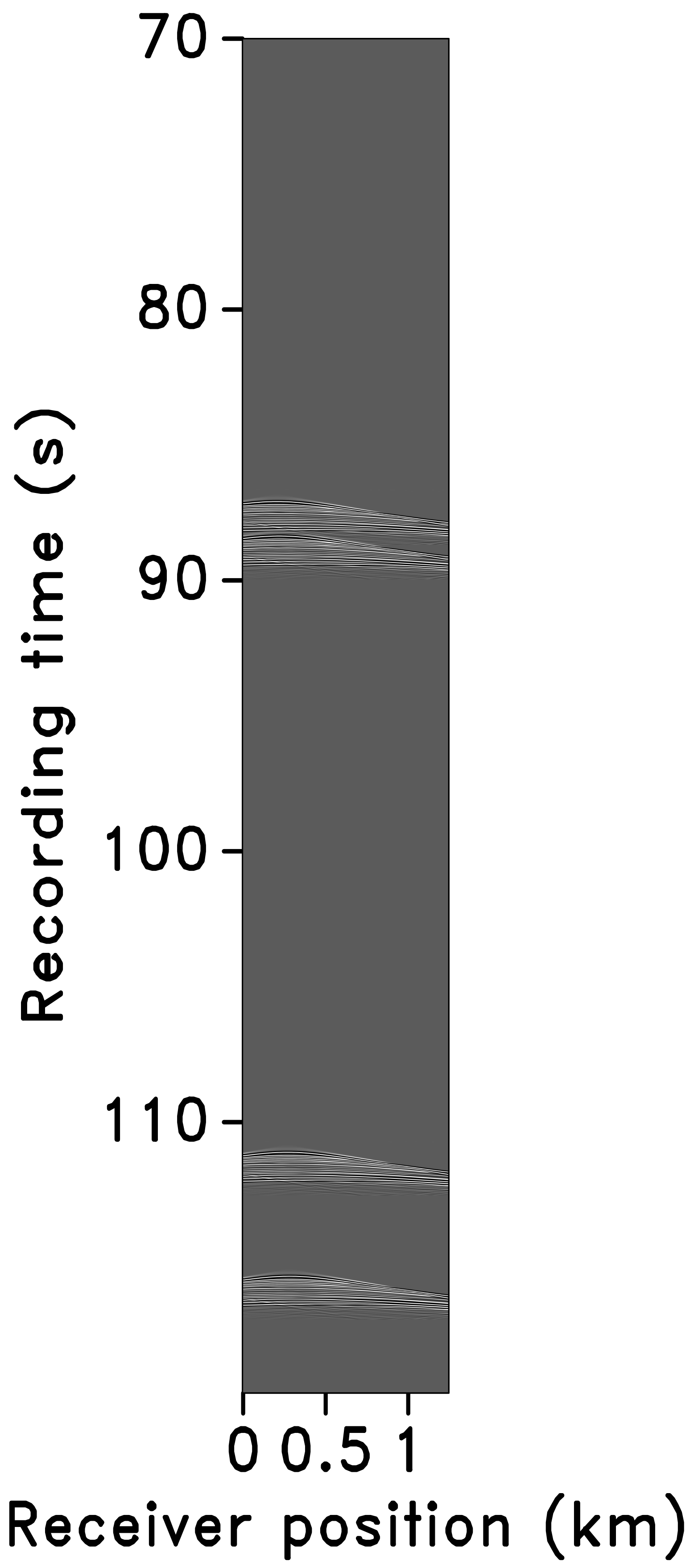
simultaneous shot gathers
number of shots = 100/2 = **50** (25 per array)
spatial sampling: **50.0 m (*jittered*)**
vessel speed: **2.50 m/s**
recording time ≈ 1000.0 s/2 = **500.0 s**

Measurements
– subsampled and overlapping shots

Baseline



Monitor

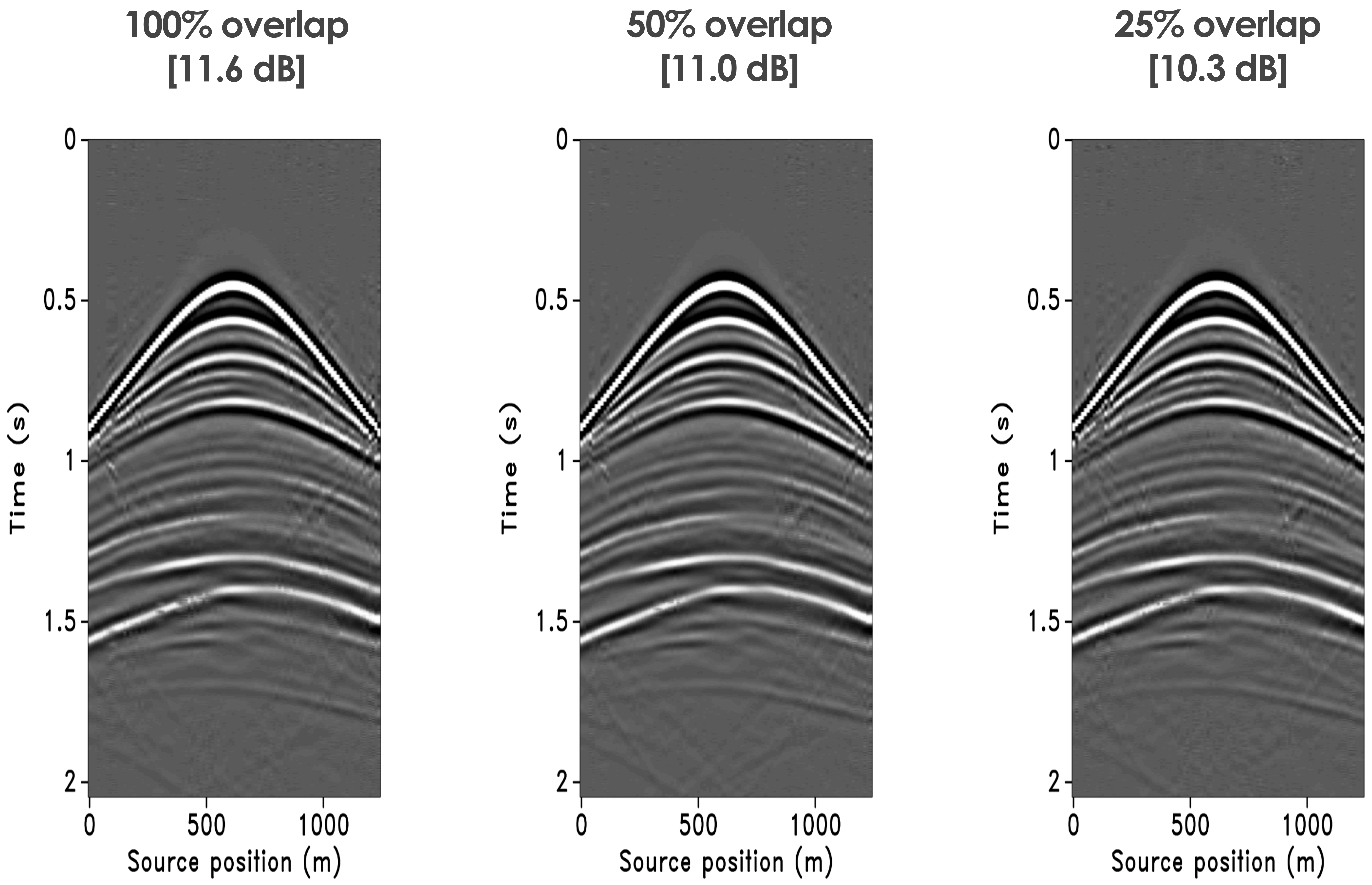


Monitor recovery

– Independent recovery

“on-the-grid” sampling

% overlap => “exact” replication of shot positions



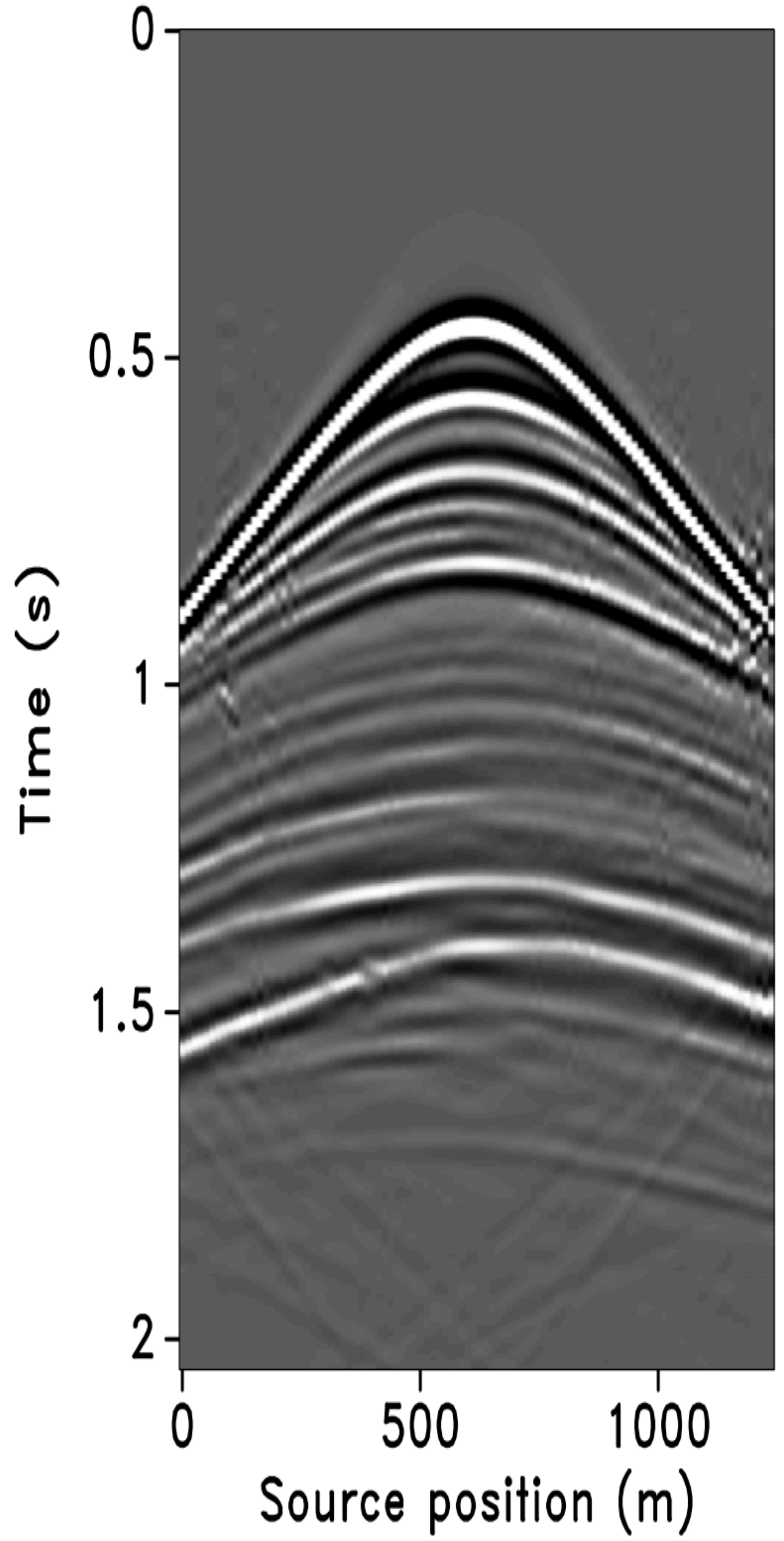
Monitor recovery

– Joint recovery

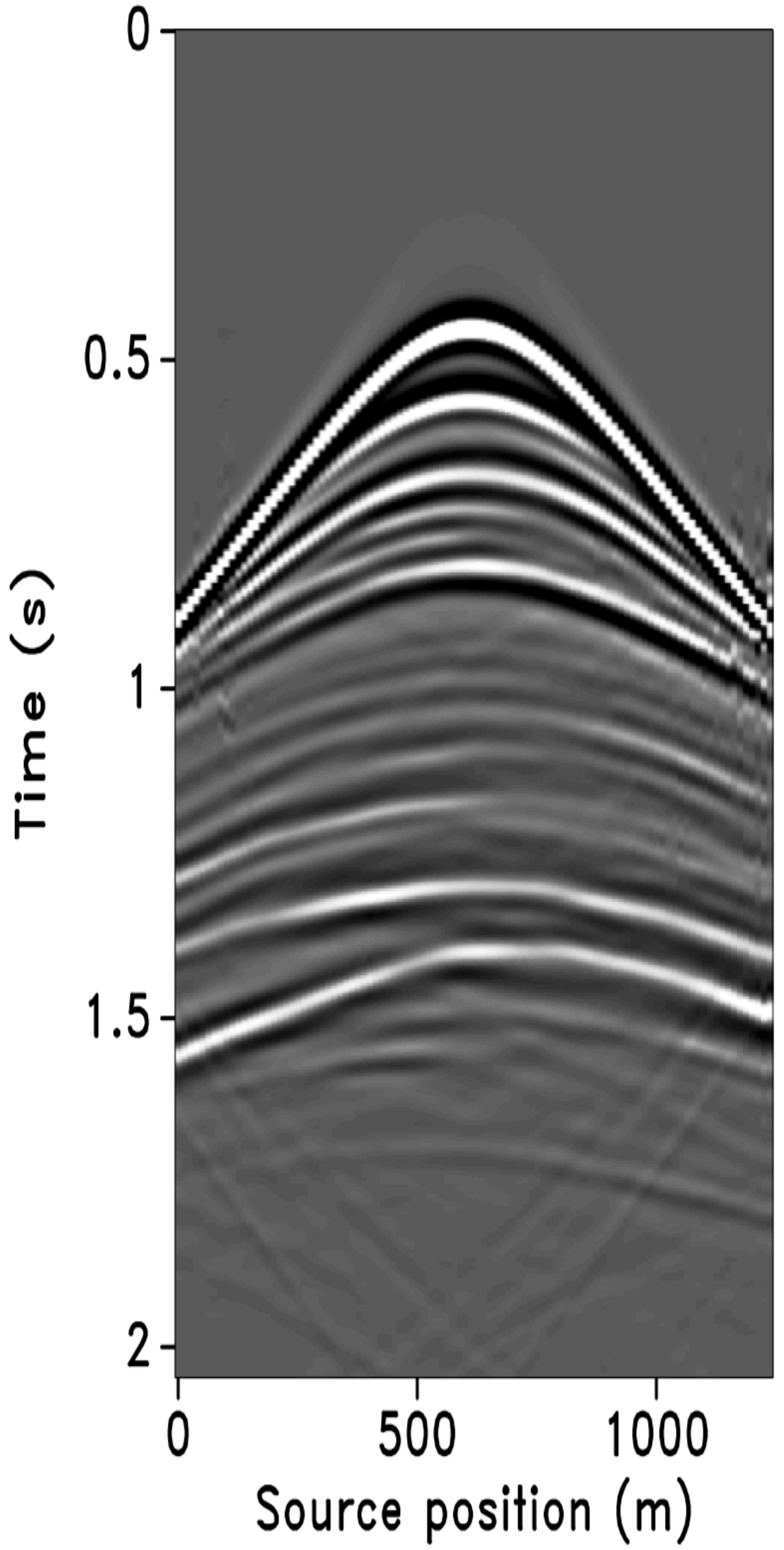
“on-the-grid” sampling

% overlap => “exact” replication of shot positions

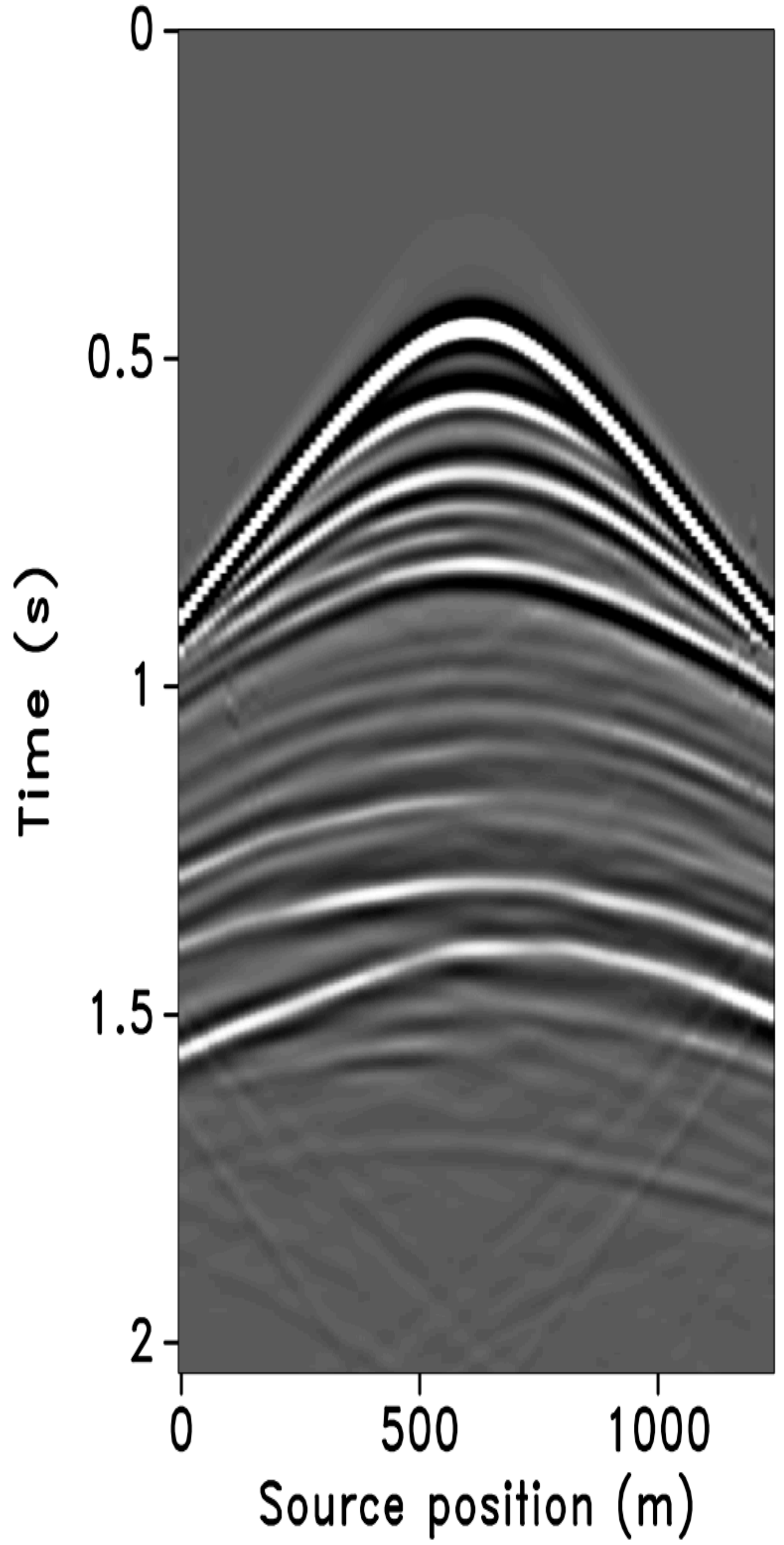
100% overlap
[11.6 dB]



50% overlap
[15.7 dB]

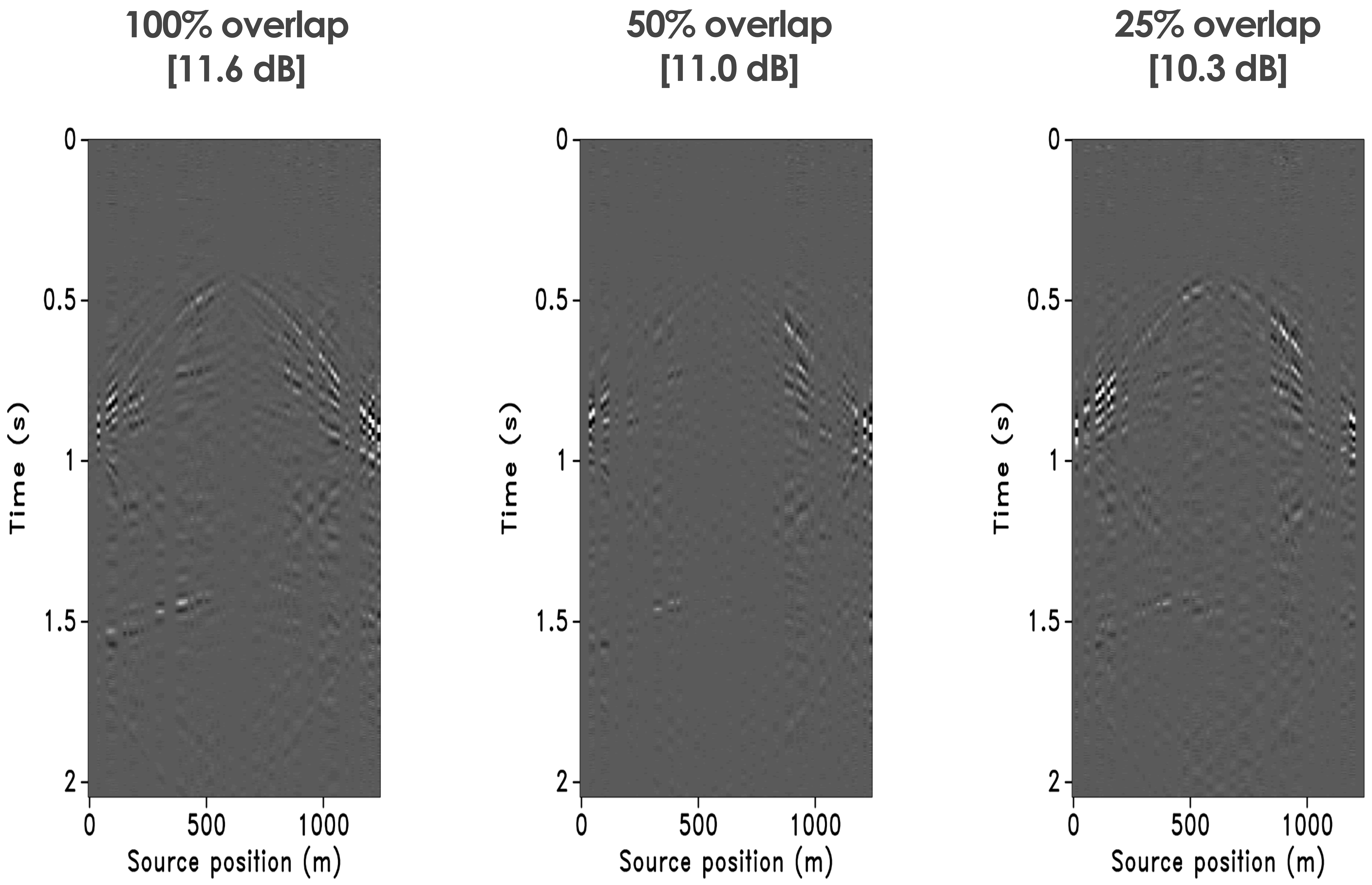


25% overlap
[18.6 dB]



Monitor residual

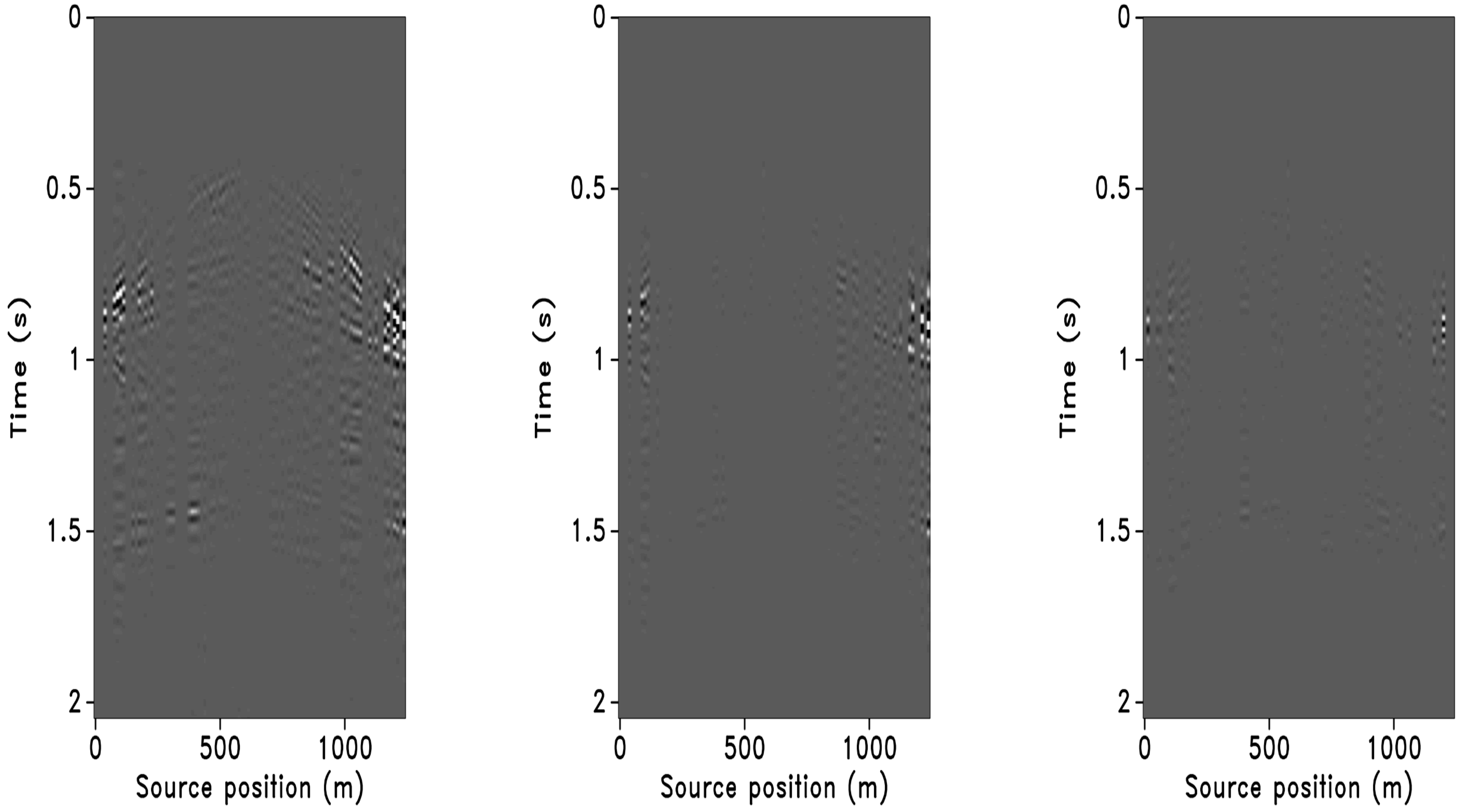
– Independent residual



Monitor residual

– Joint residual

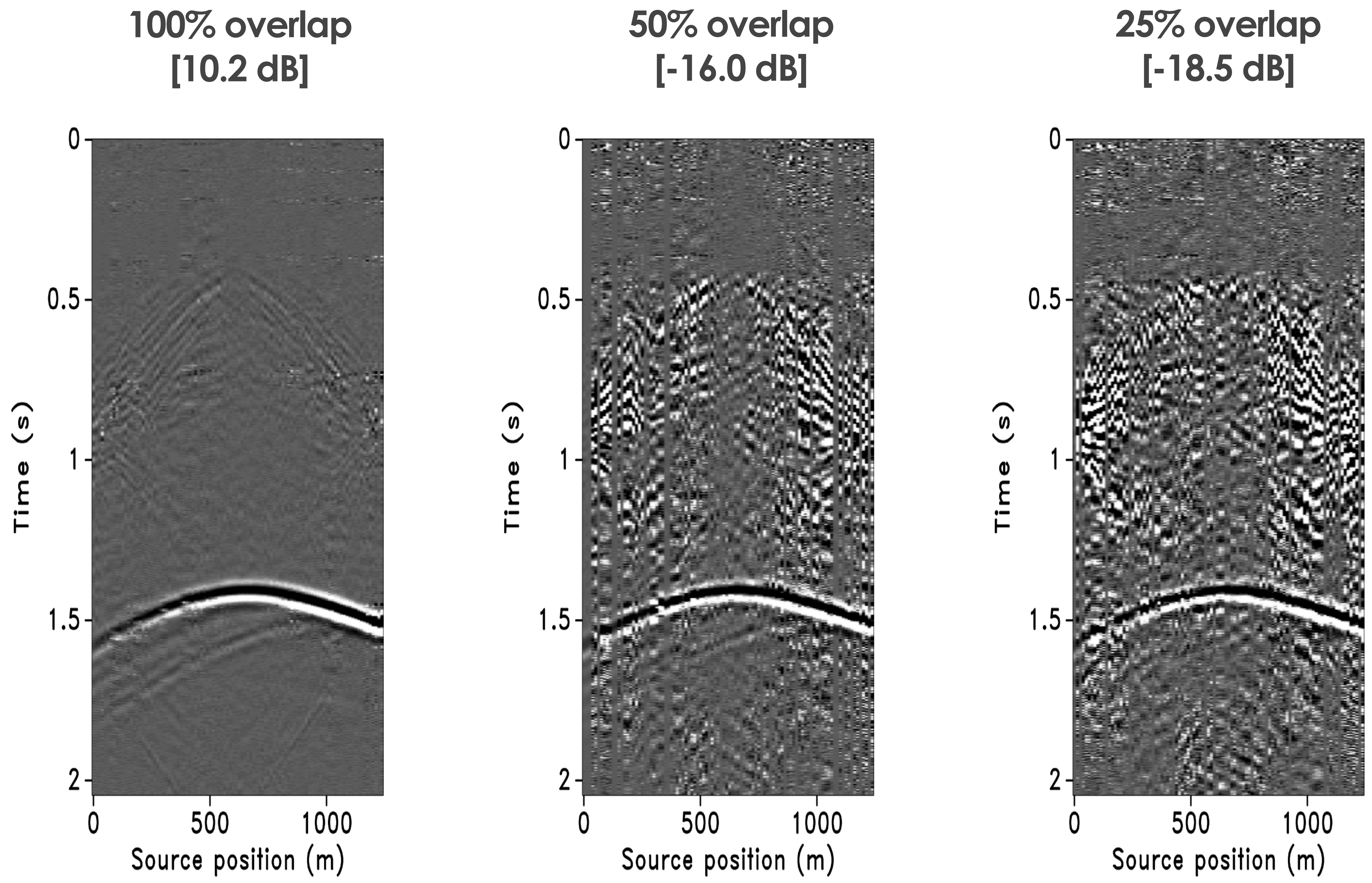
100% overlap [11.6 dB] | 50% overlap [15.7 dB] | 25% overlap [18.6 dB]



4D recovery

– Independent recovery

[colormap scale: 10 X]

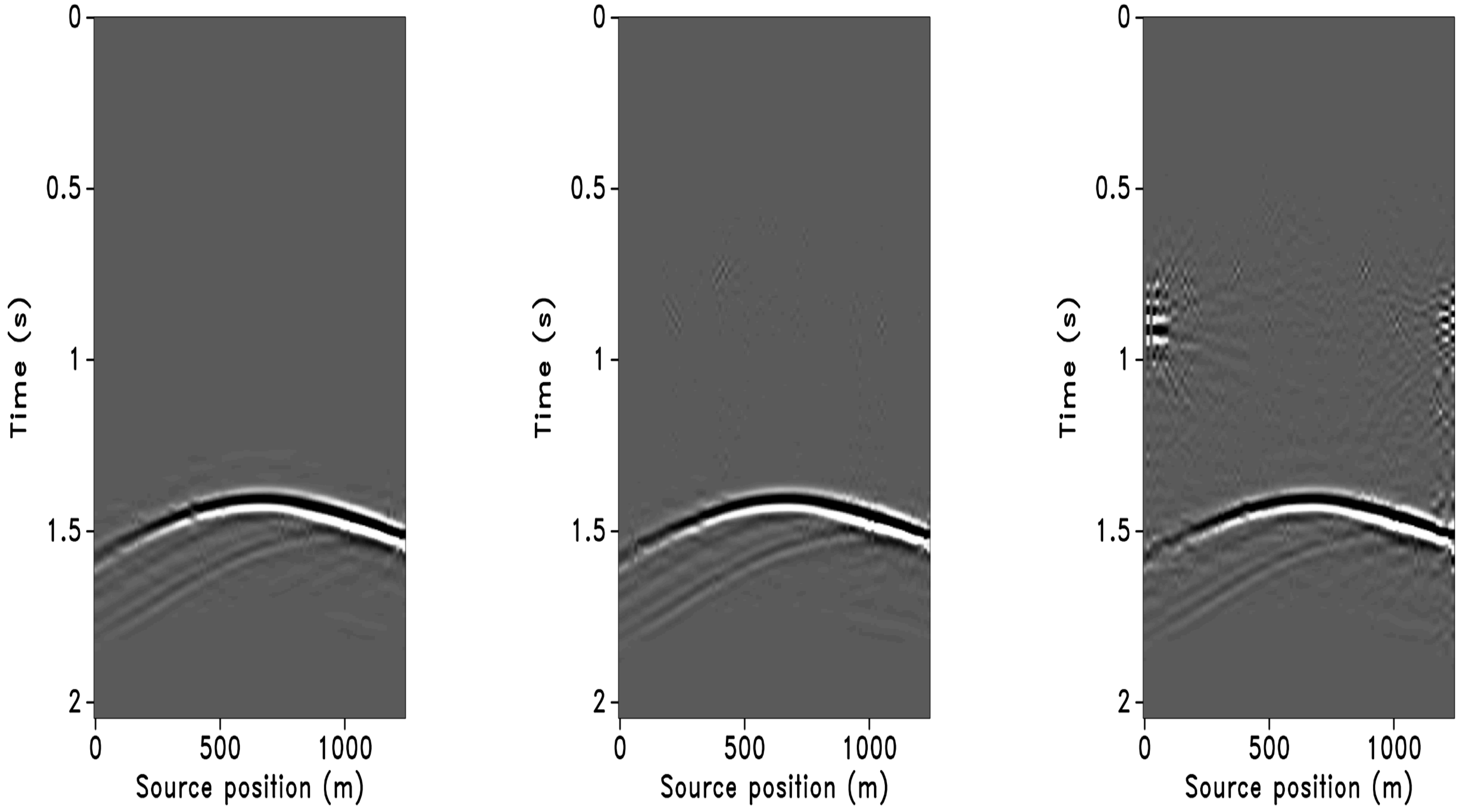


4D recovery

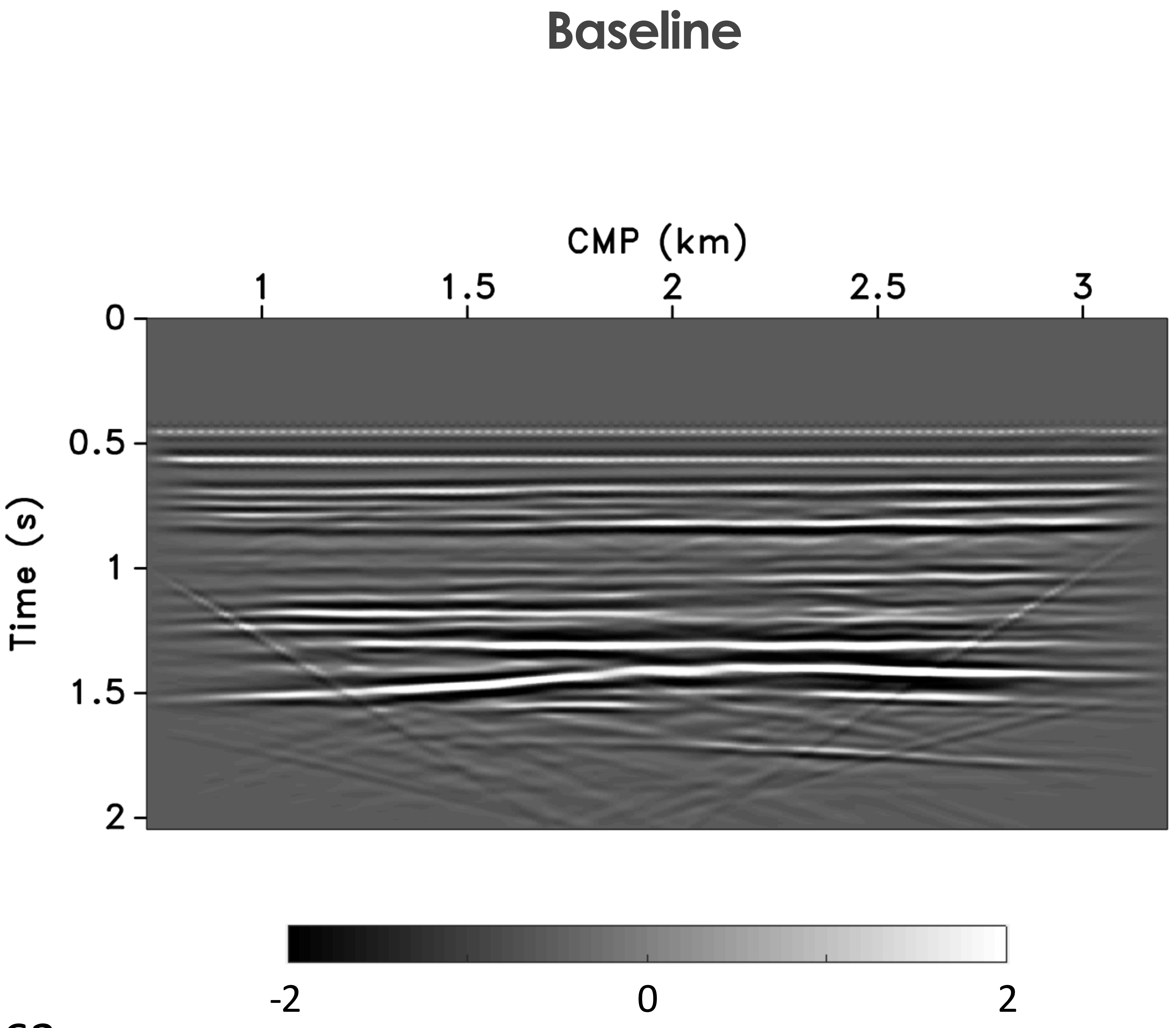
– Joint recovery

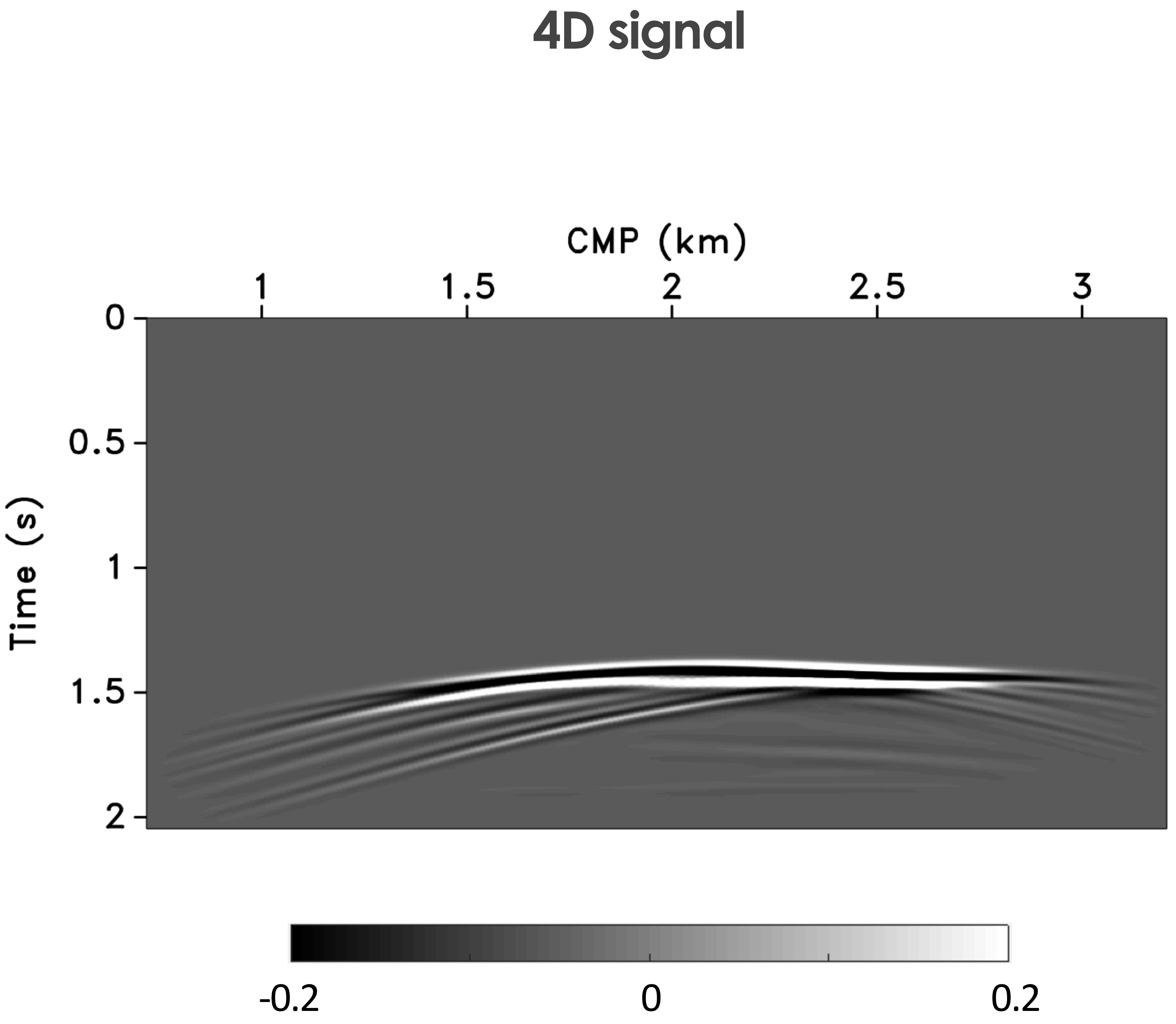
[colormap scale: 10 X]

100% overlap [12.8 dB] | 50% overlap [5.0 dB] | 25% overlap [2.0 dB]



Stacked sections



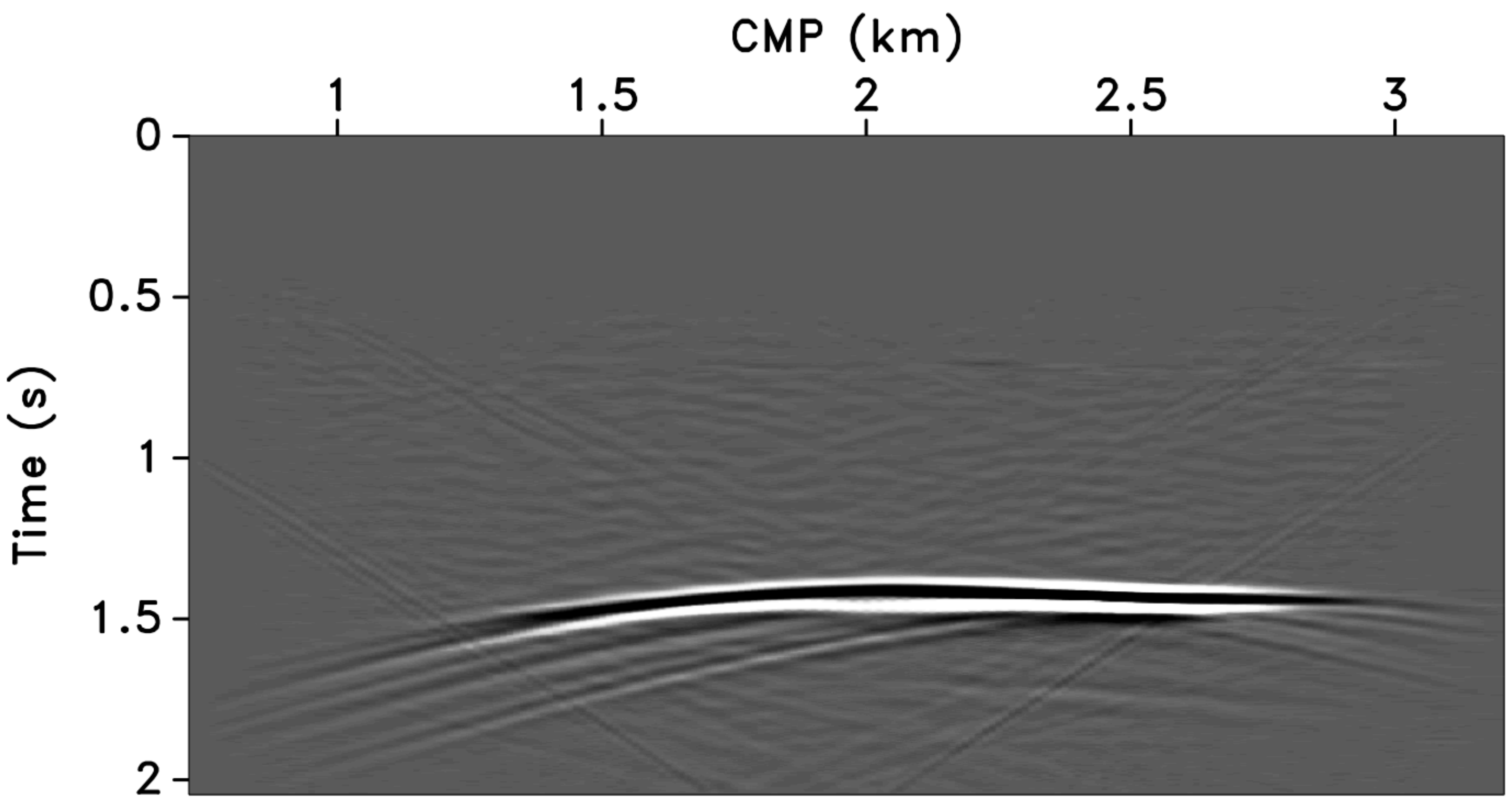


Stacked sections

– 100% overlap in acquisition matrices

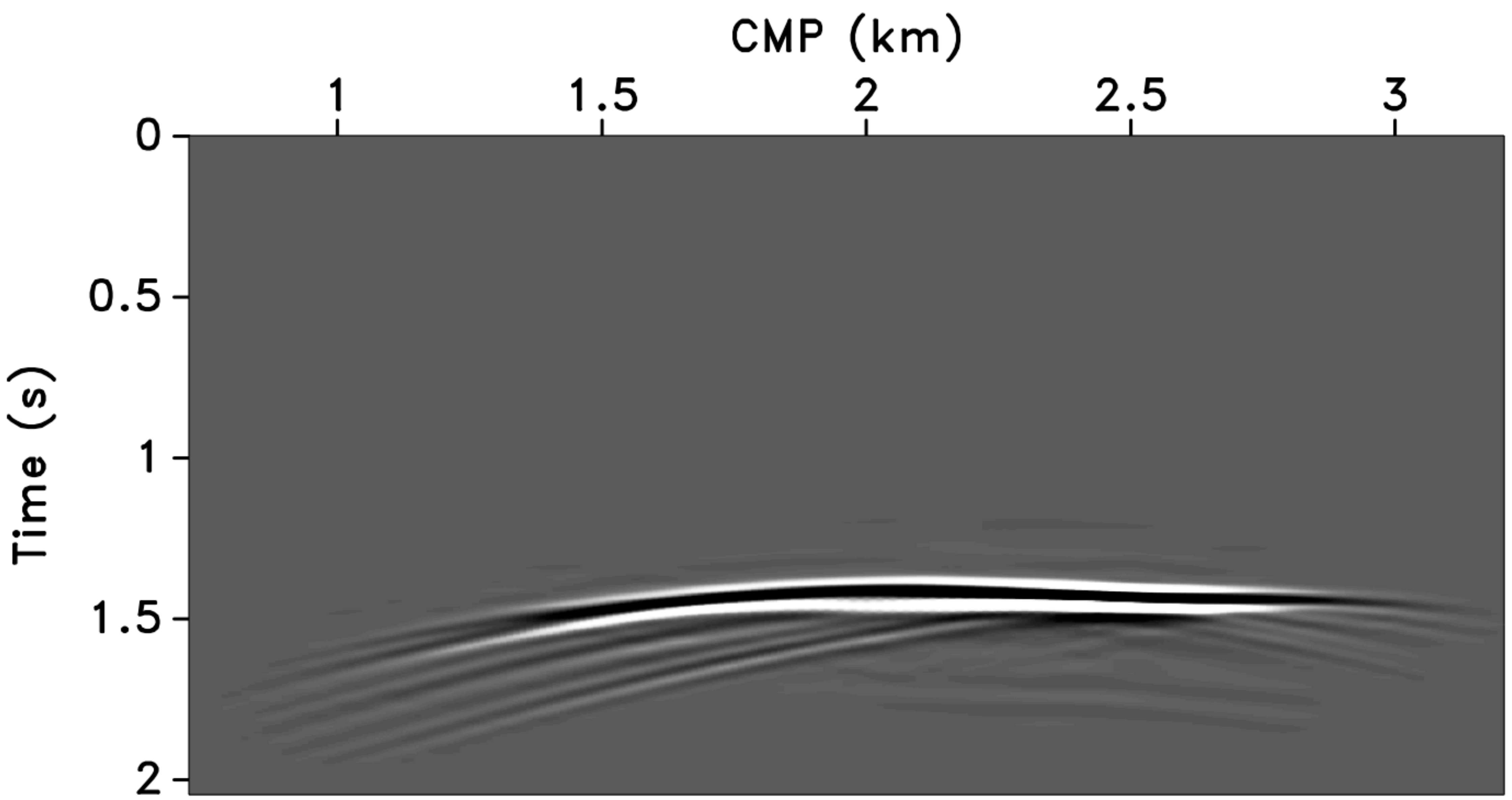
IRS

[21.4 dB]



JRM

[23.4 dB]

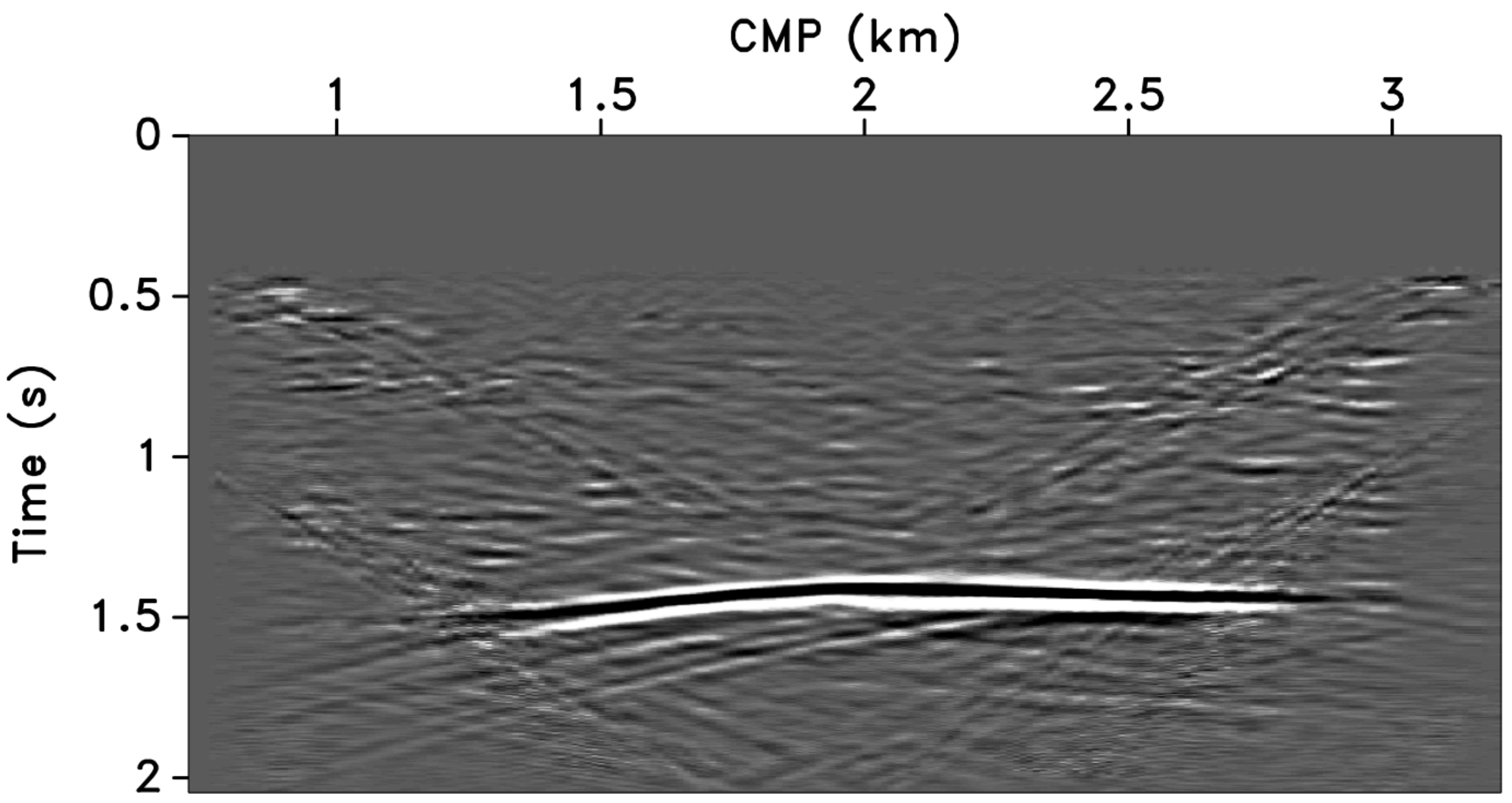


Stacked sections

– **50% overlap** in acquisition matrices

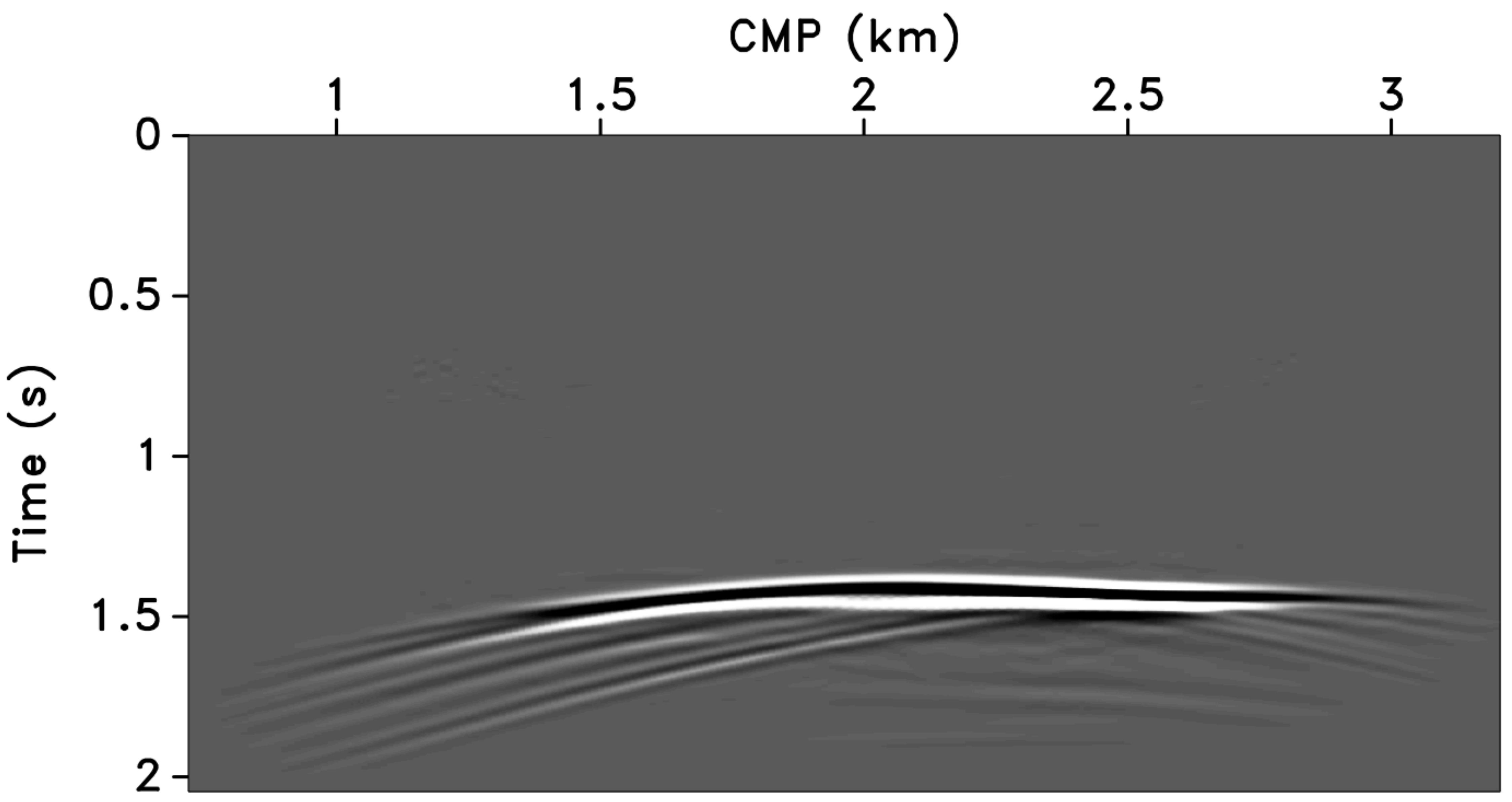
IRS

[9.1 dB]



JRM

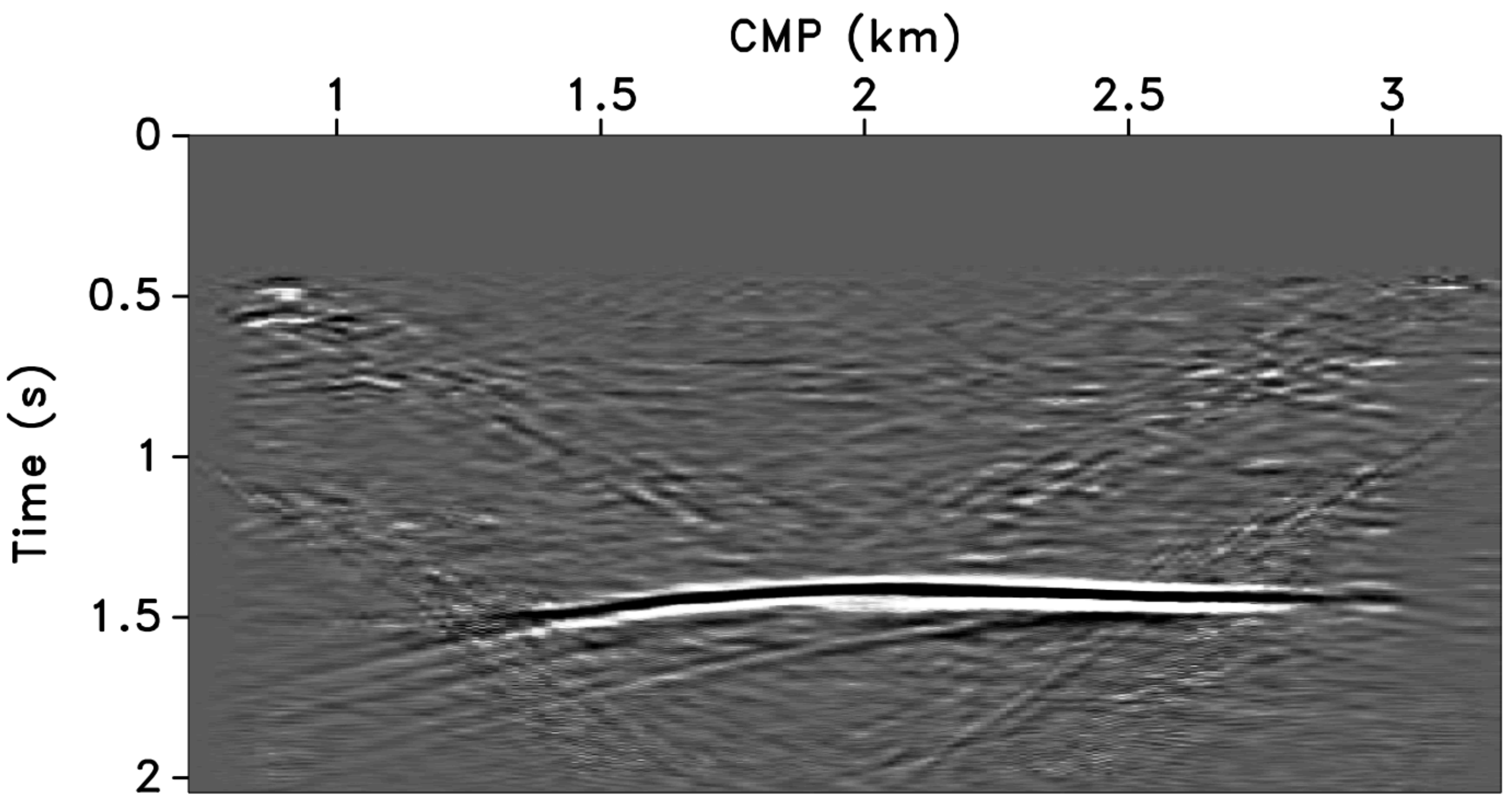
[20.2 dB]



Stacked sections
– 25% overlap in acquisition matrices

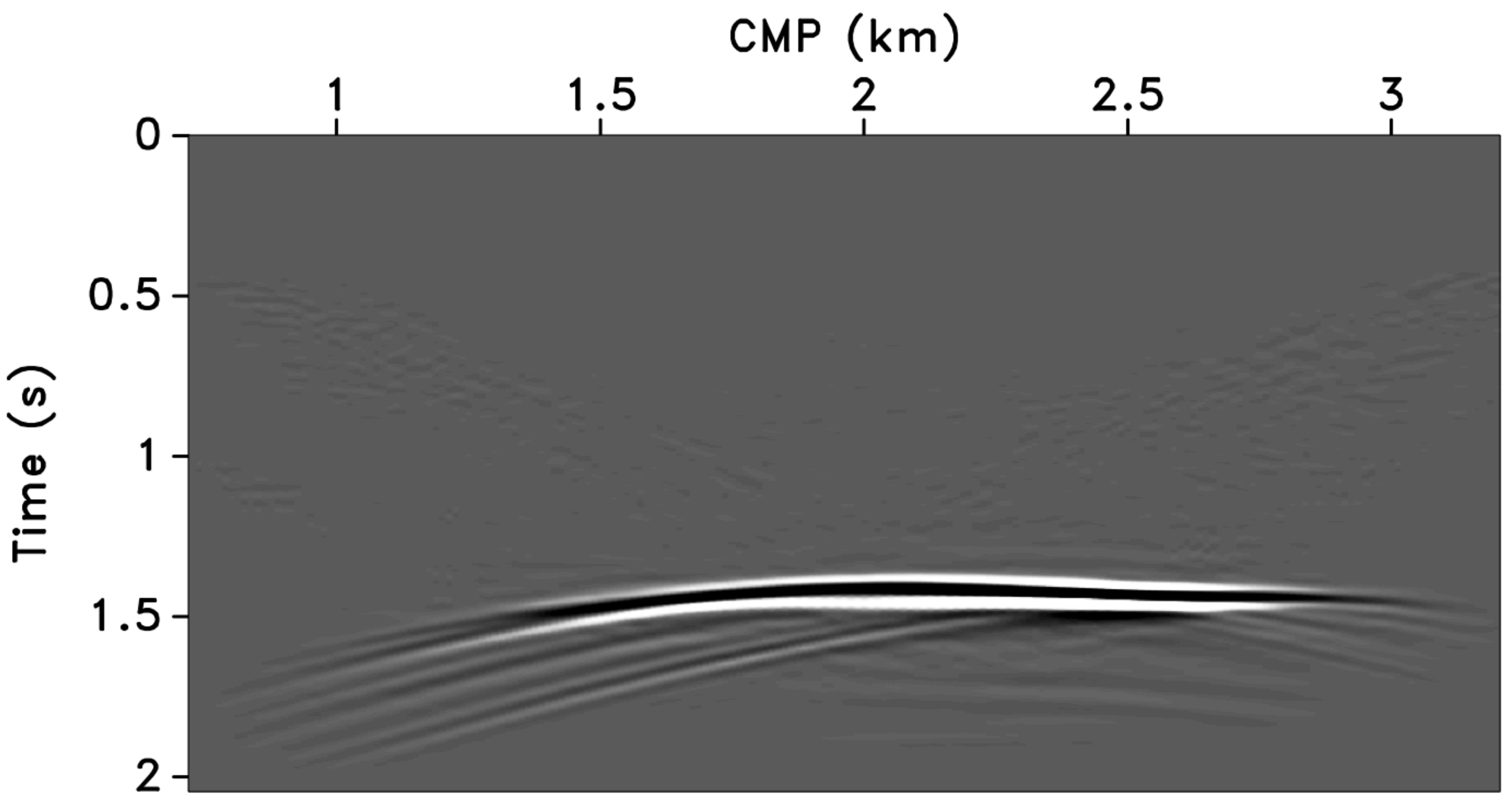
IRS

[7.8 dB]



JRM

[18.0 dB]



SNR (dB) for stacked sections
– average of 100 experiments

overlap	baseline		monitor		4D signal	
	IRS	JRM	IRS	JRM	IRS	JRM
100%	23.1 ± 1.2	24.8 ± 1.2	23.1 ± 1.3	24.8 ± 1.2	21.4 ± 1.8	**23.4 ± 2.1**
50%	23.1 ± 1.2	32.8 ± 1.6	23.4 ± 1.2	32.8 ± 1.6	9.1 ± 1.2	20.2 ± 1.3
25%	23.1 ± 1.2	**35.3 ± 1.5**	22.0 ± 1.1	**35.0 ± 1.5**	7.8 ± 1.3	**18.0 ± 1.1**

Conclusions

Seismic synthetics show that we do **not** necessarily have to insist on full replication of surveys depending on the recovery of the vintages

Processing time-lapse data **jointly** leads to improved recovery of the vintages with little variability in the time-lapse difference

Recall: we are still **on the grid** => exactly replicated (subsampled) shot locations …… **not realistic!**

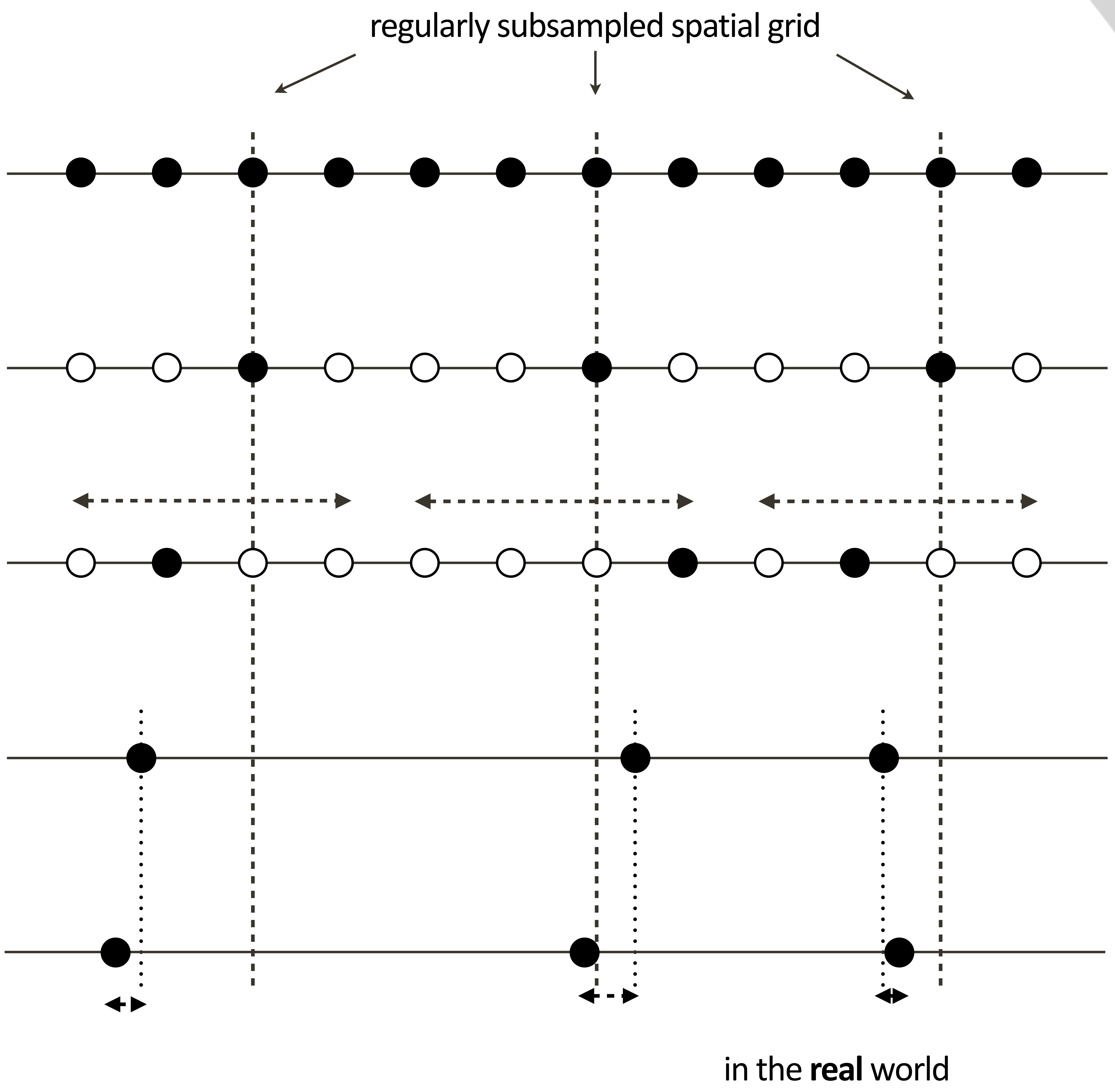
Chapter 6

Compressive time-lapse marine acquisition
- static acquisition geometry
- **off-the-grid** (or irregular) marine surveys
- with & without **deviations** in shot positions

Sampling schemes

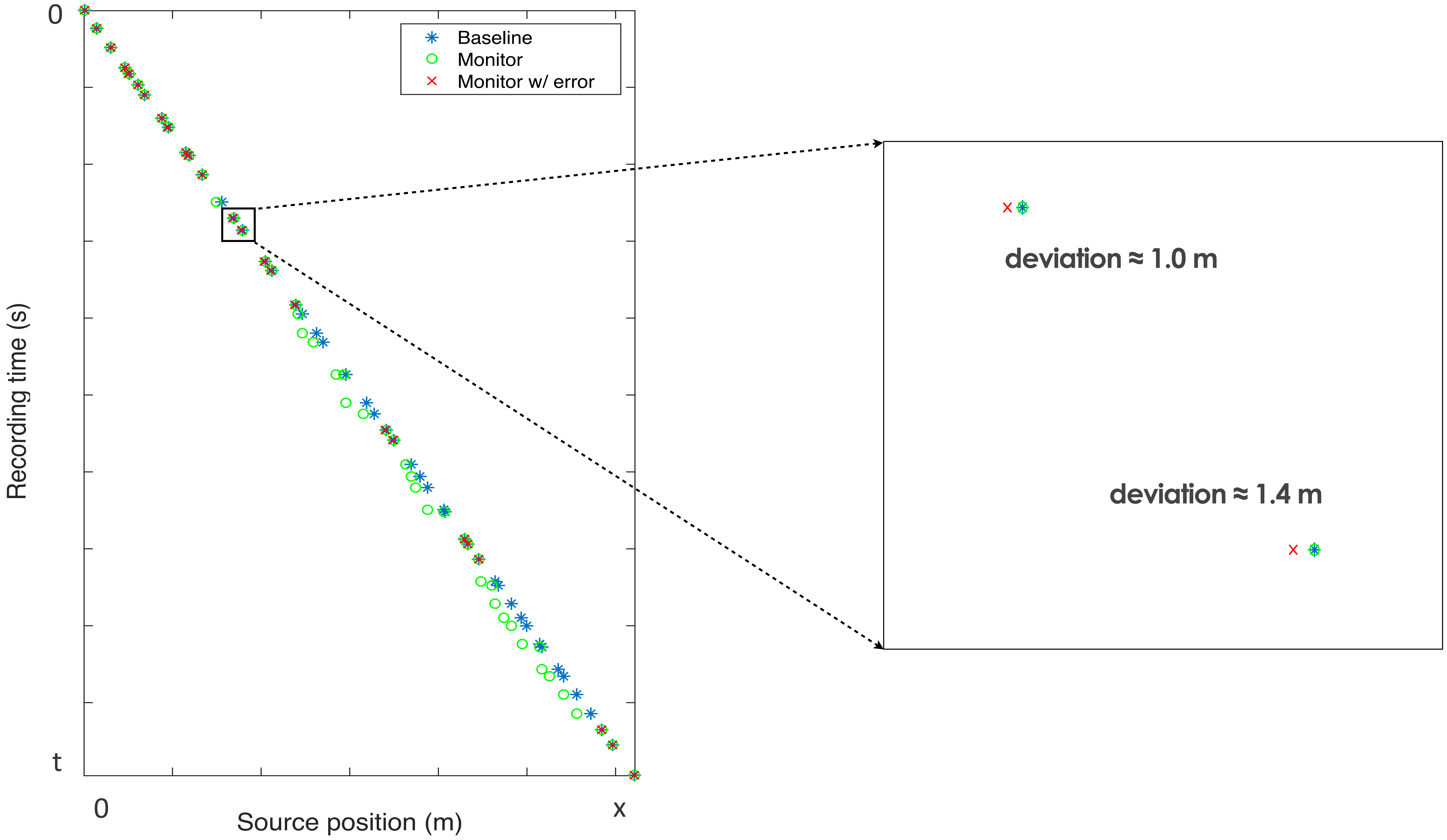
ON THE GRID
- dense sampling
- regular subsampling
- jittered subsampling

OFF THE GRID
- jittered subsampling (“exact” replication)
- jittered subsampling (deviations: 0-1, 2, 3...m)

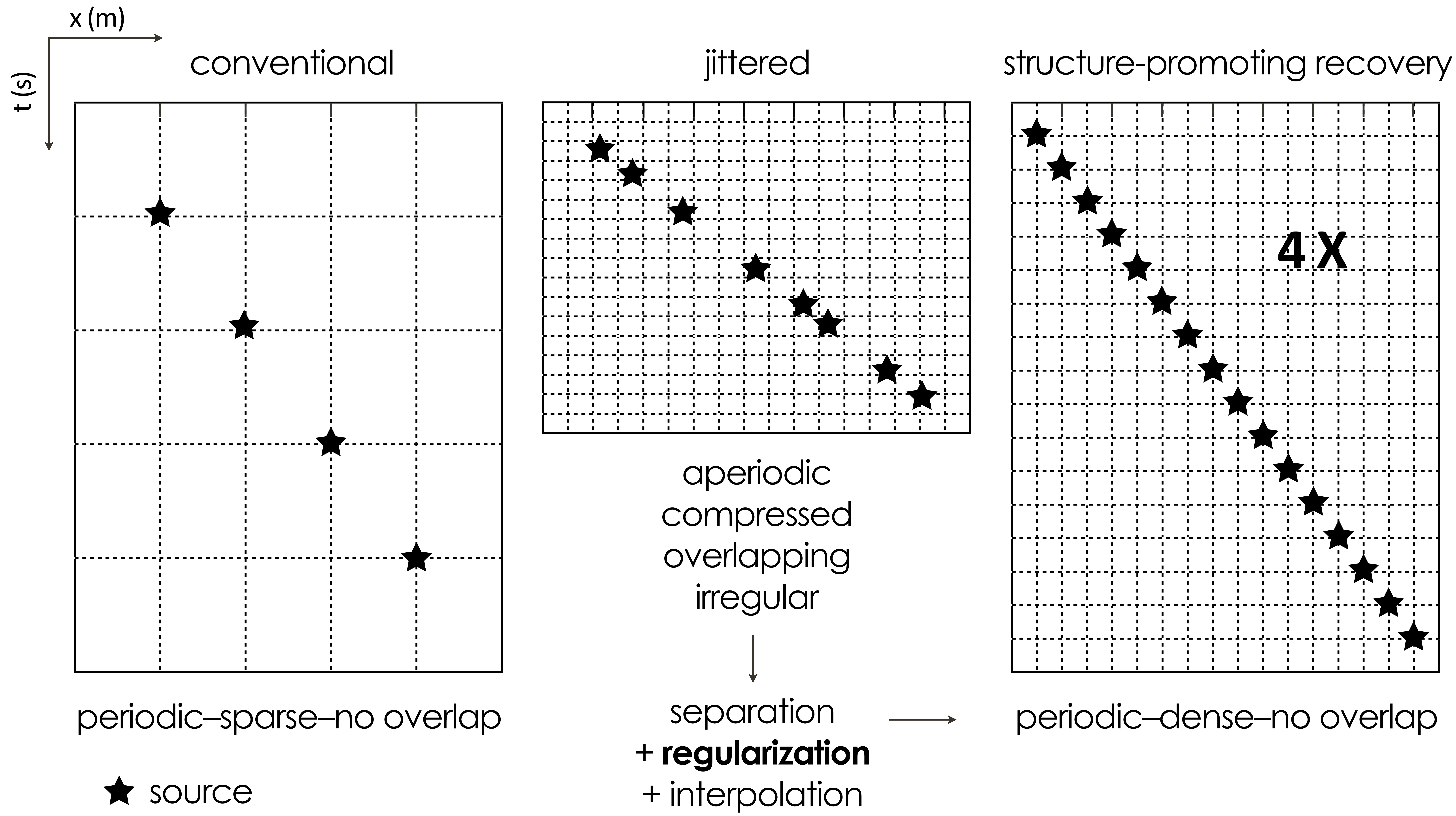


[adapted from Hennenfent and Herrmann, 2008]

4D time-jittered marine acquisition

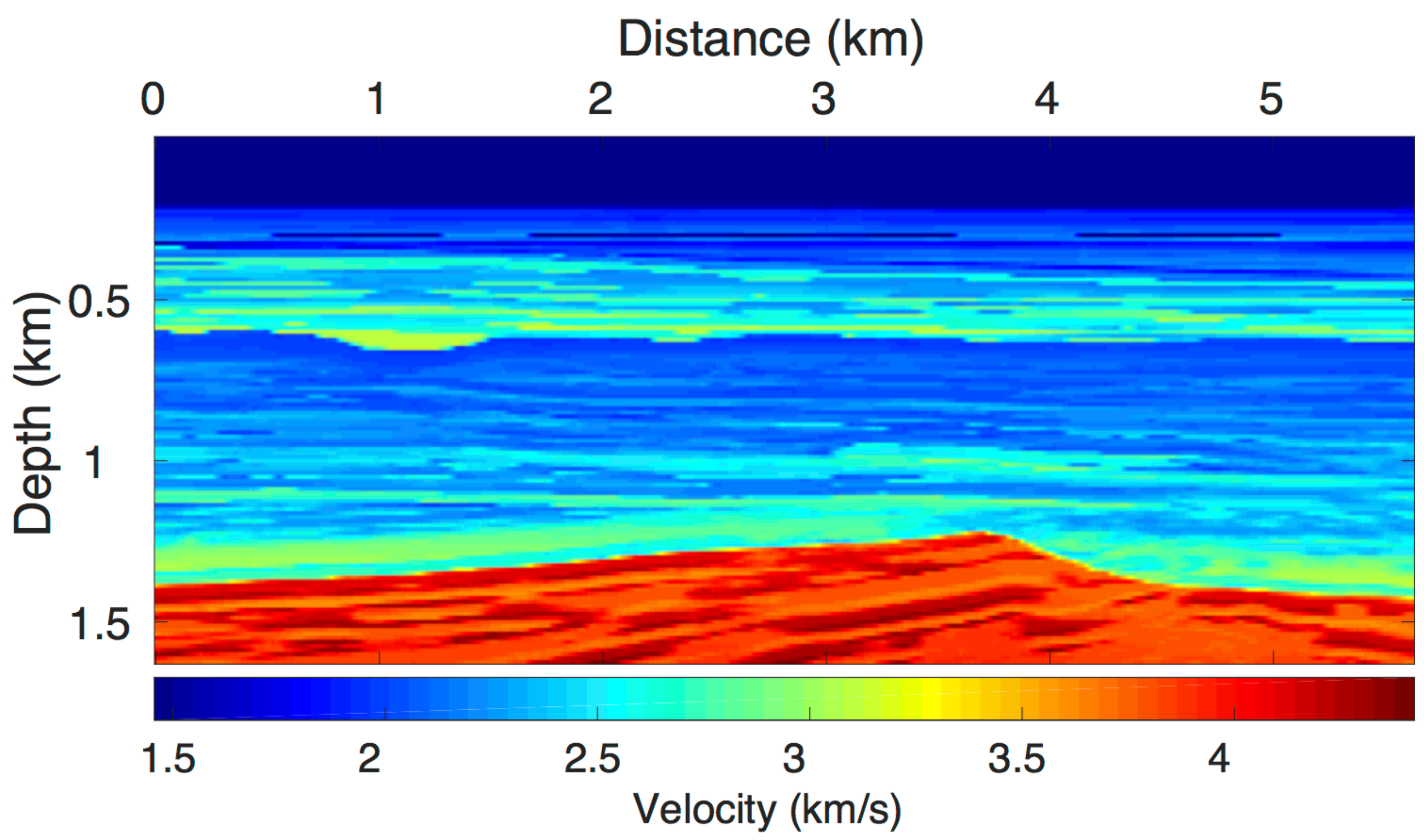


Conventional vs. compressive acquisition

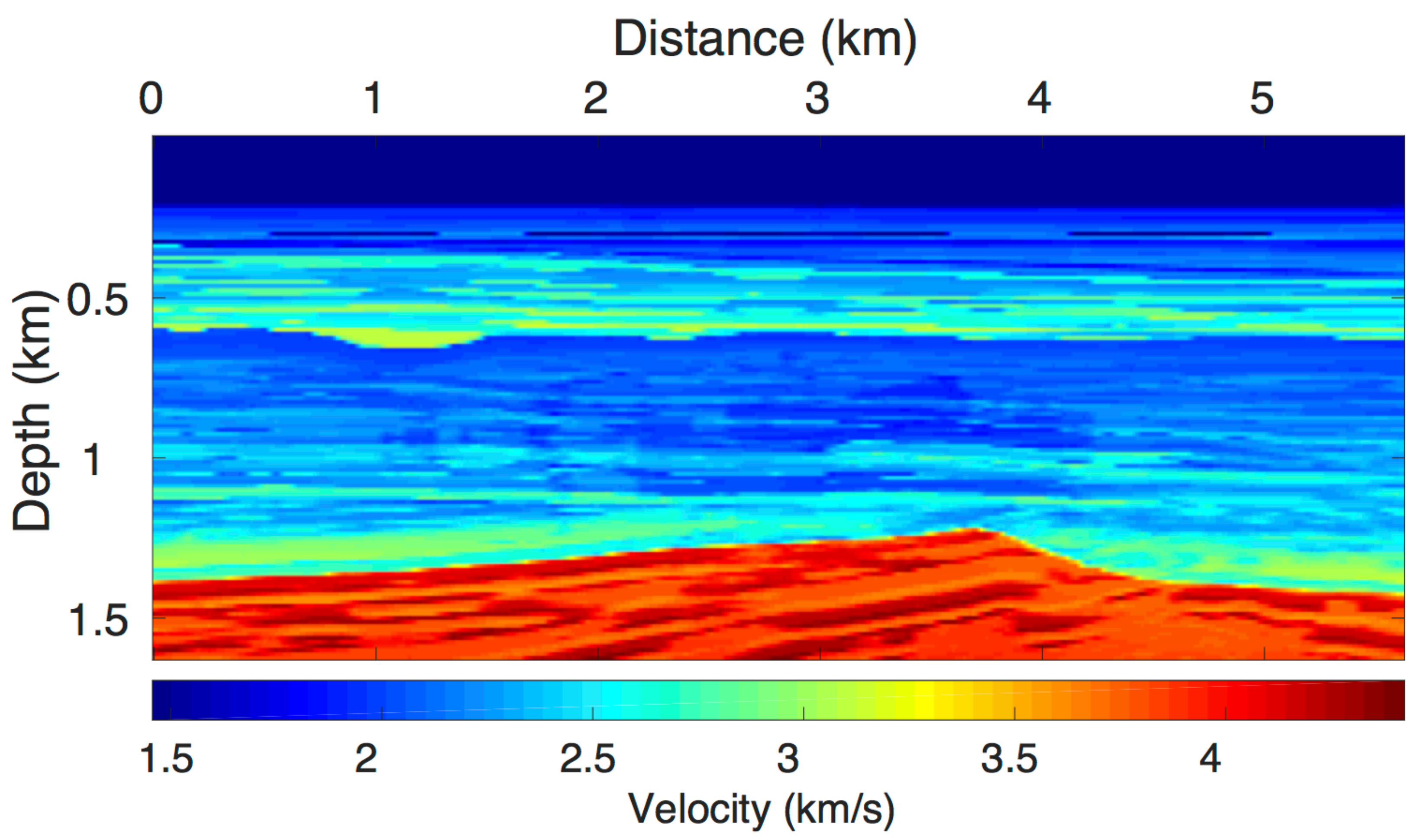


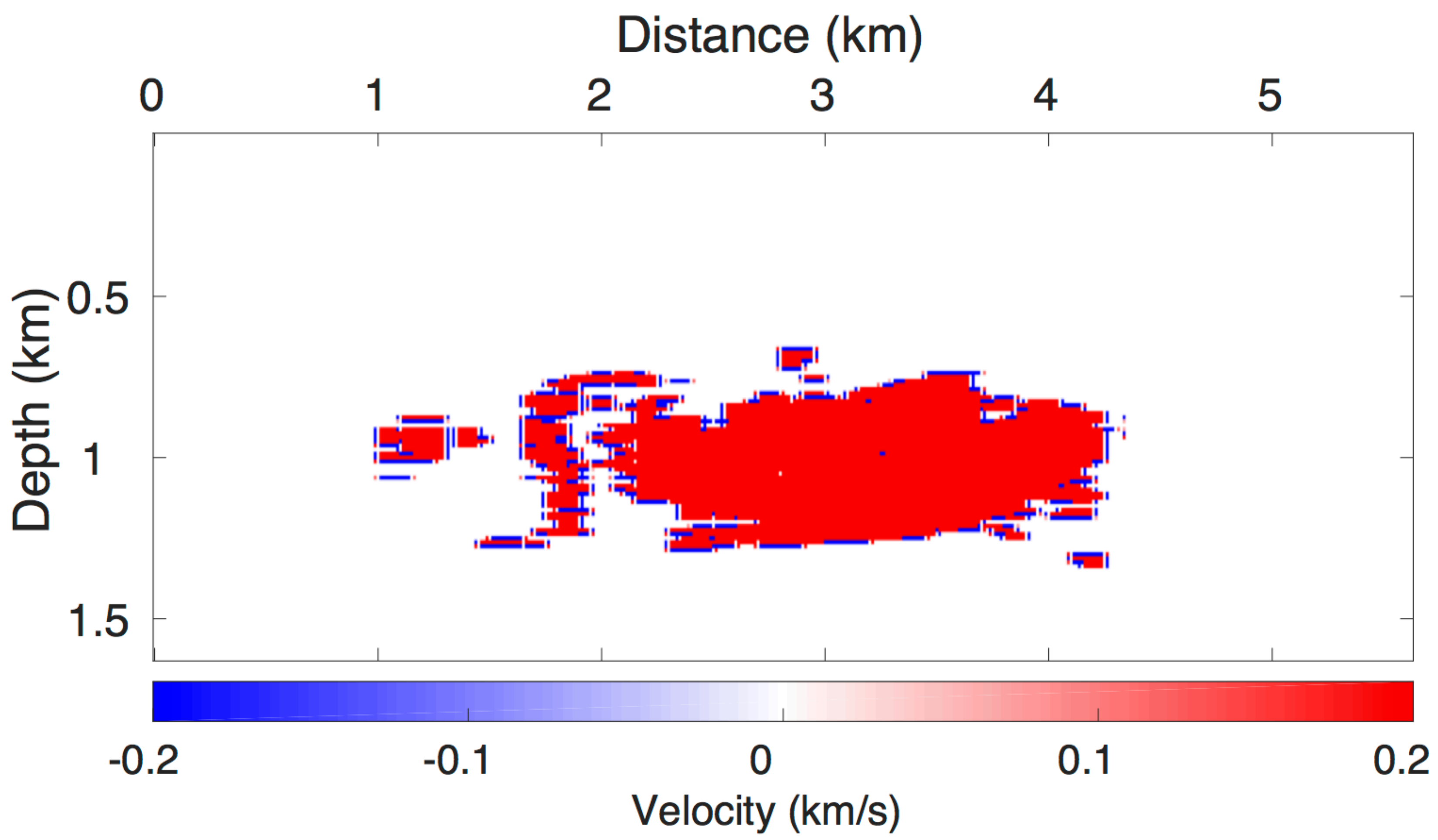
BG Compass model
– contains gas cloud

Baseline



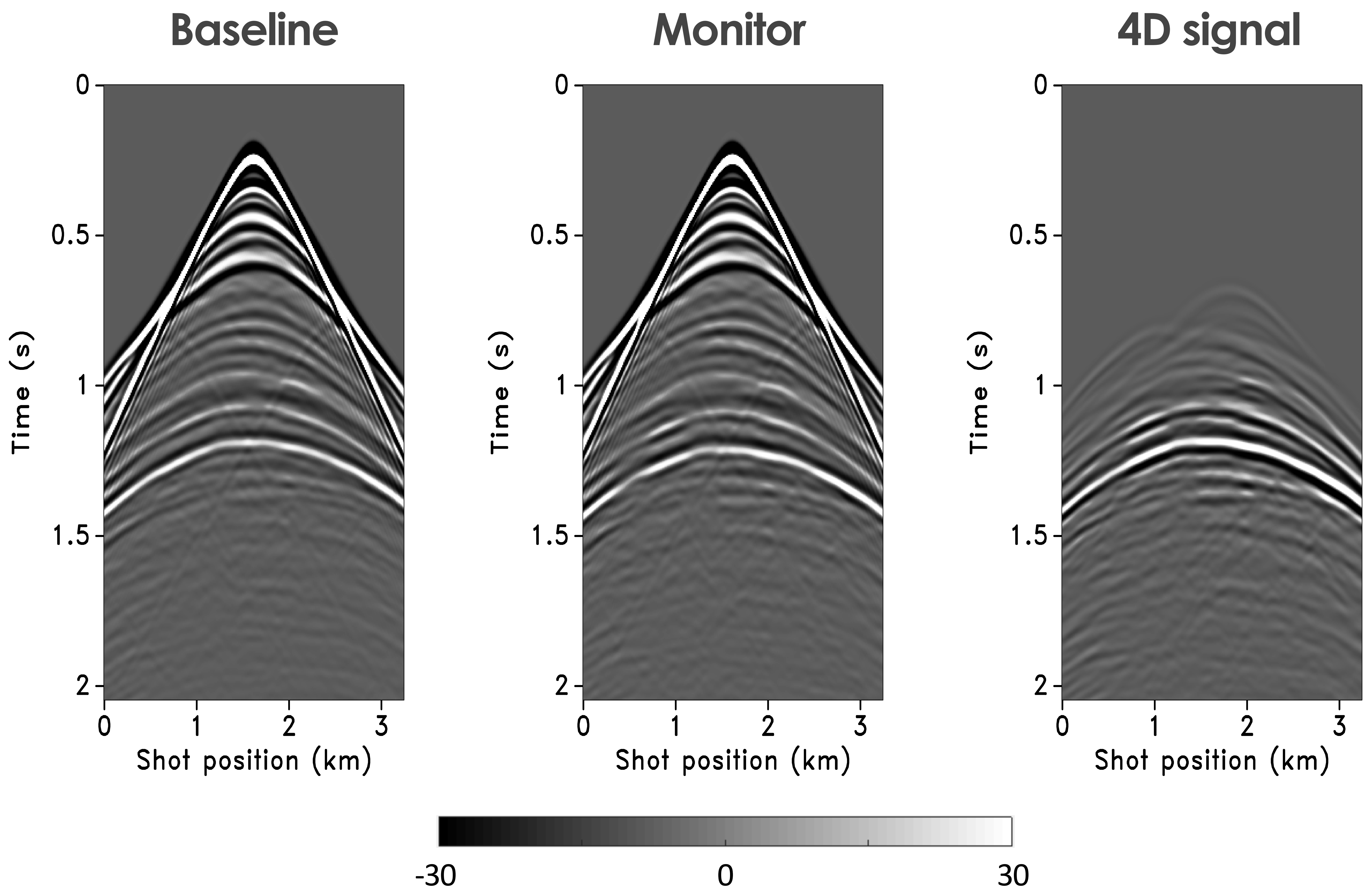
Monitor





Time-lapse difference

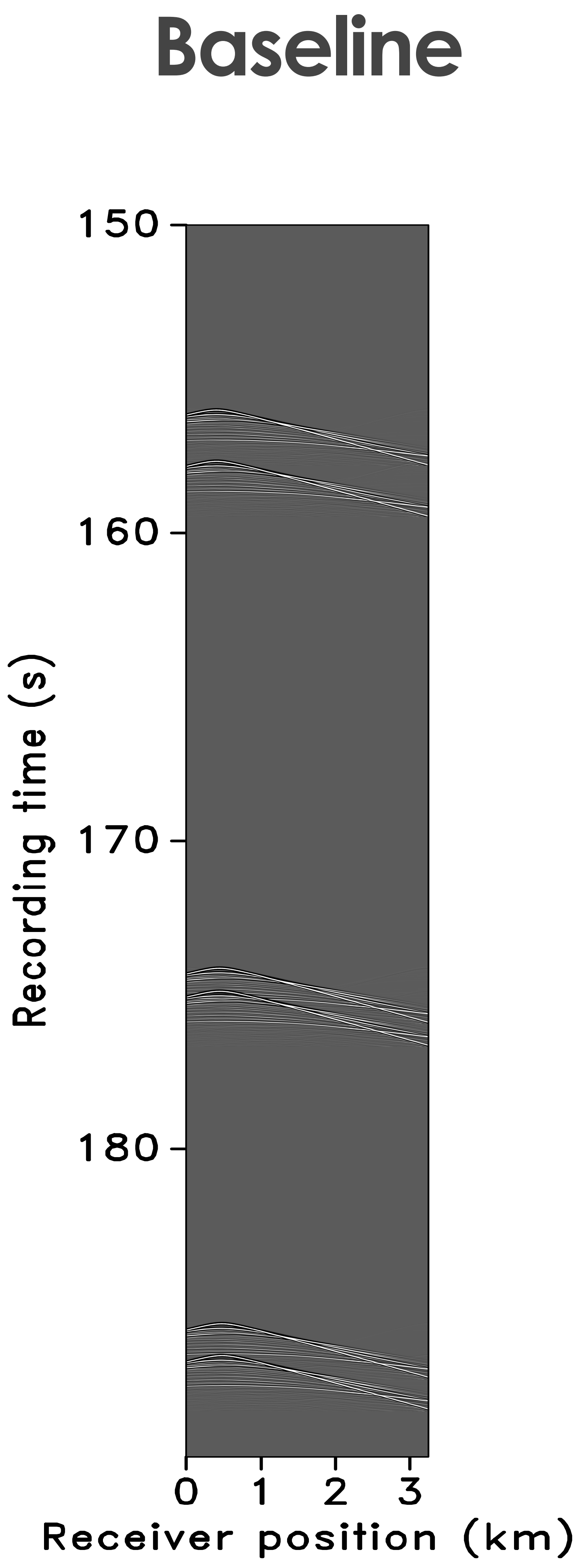
Simulated time-lapse data
– time-domain finite differences

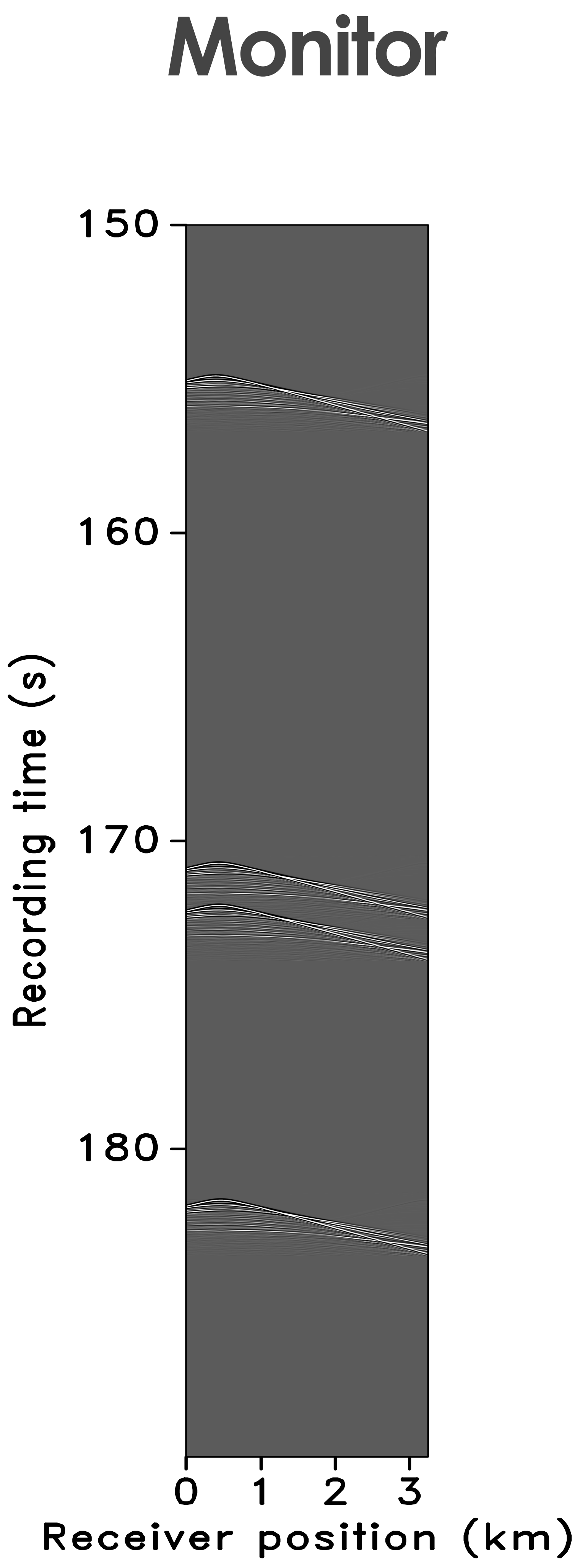


time samples: **512**
receivers: **260**
sources: **260**

sampling
time: **4.0 ms**
receiver: **12.5 m**
source: **12.5 m**

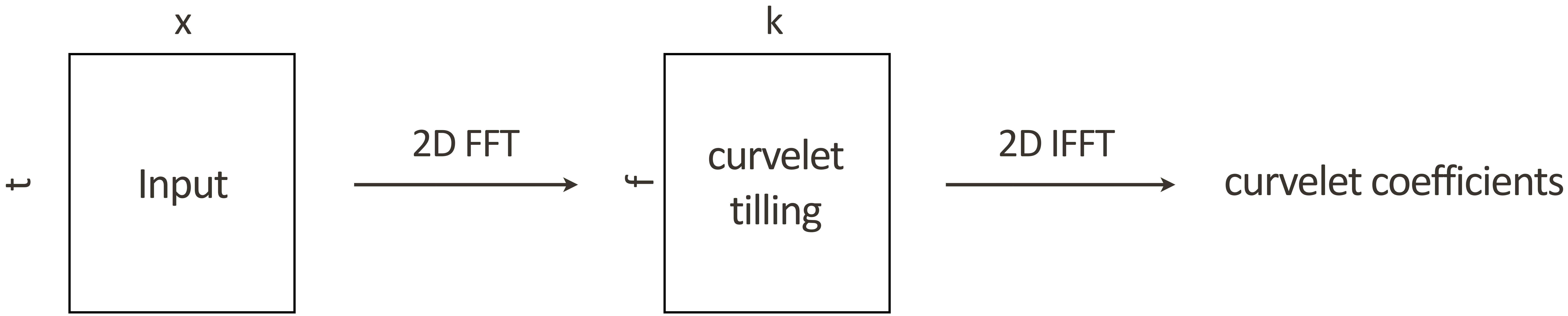
Measurements
– subsampled, overlapping and irregular shots



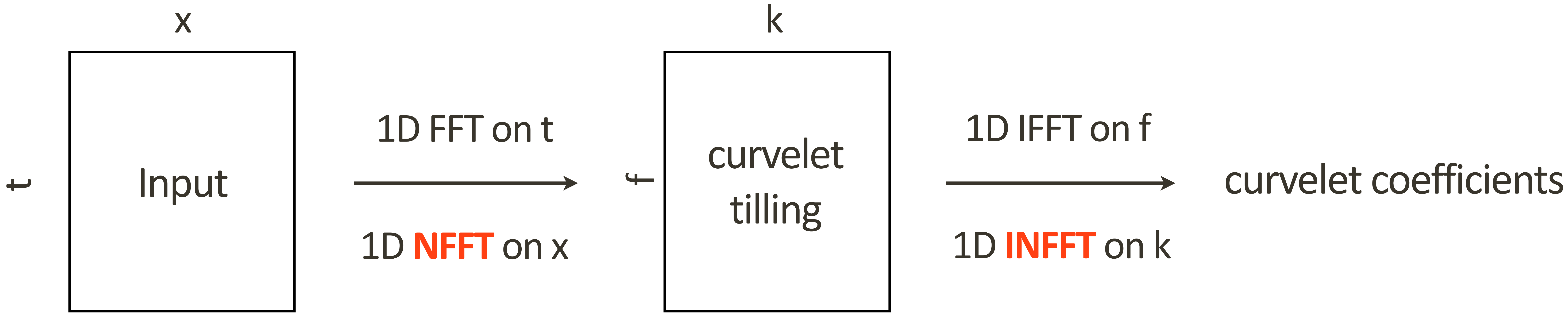


FDCT vs. NFDCT

Fast Discrete Curvelet Transform (FDCT)



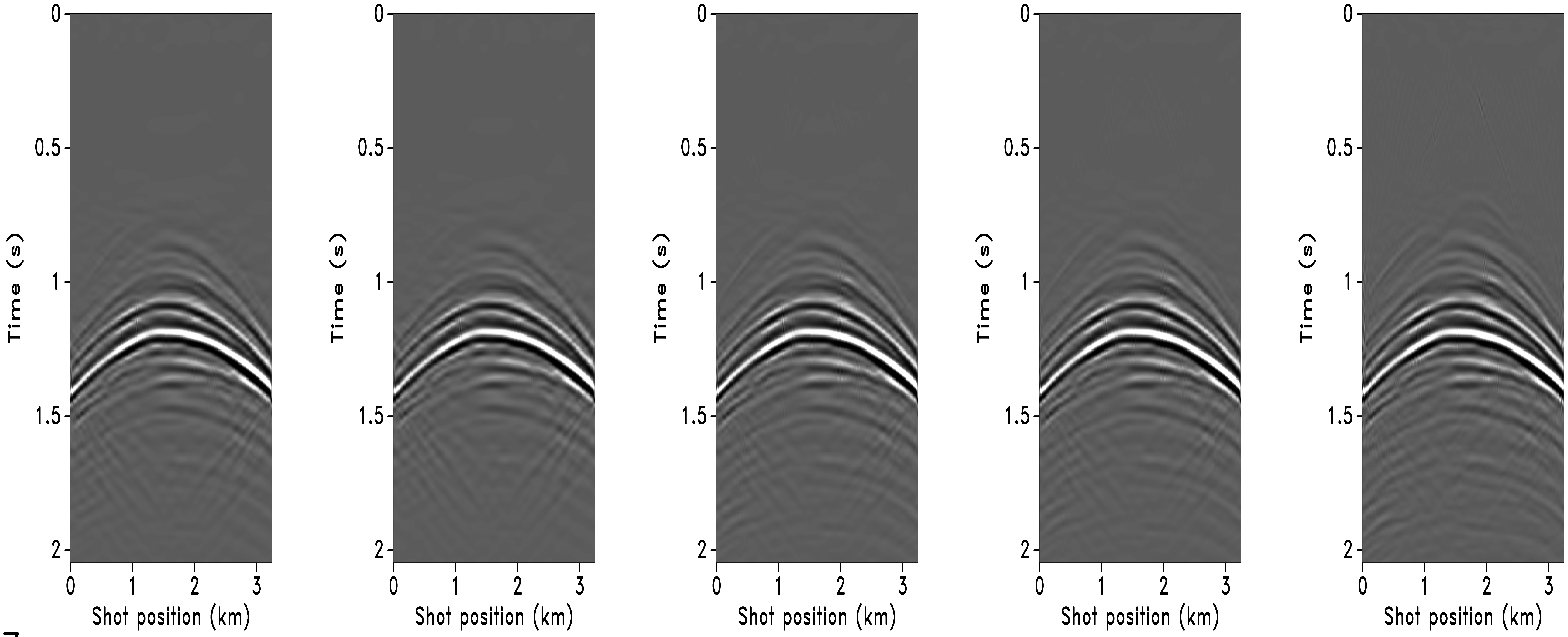
Nonequispaced Fast Discrete Curvelet Transform (NFDCT)



4D recovery

– Joint recovery; subsampling factor = 2

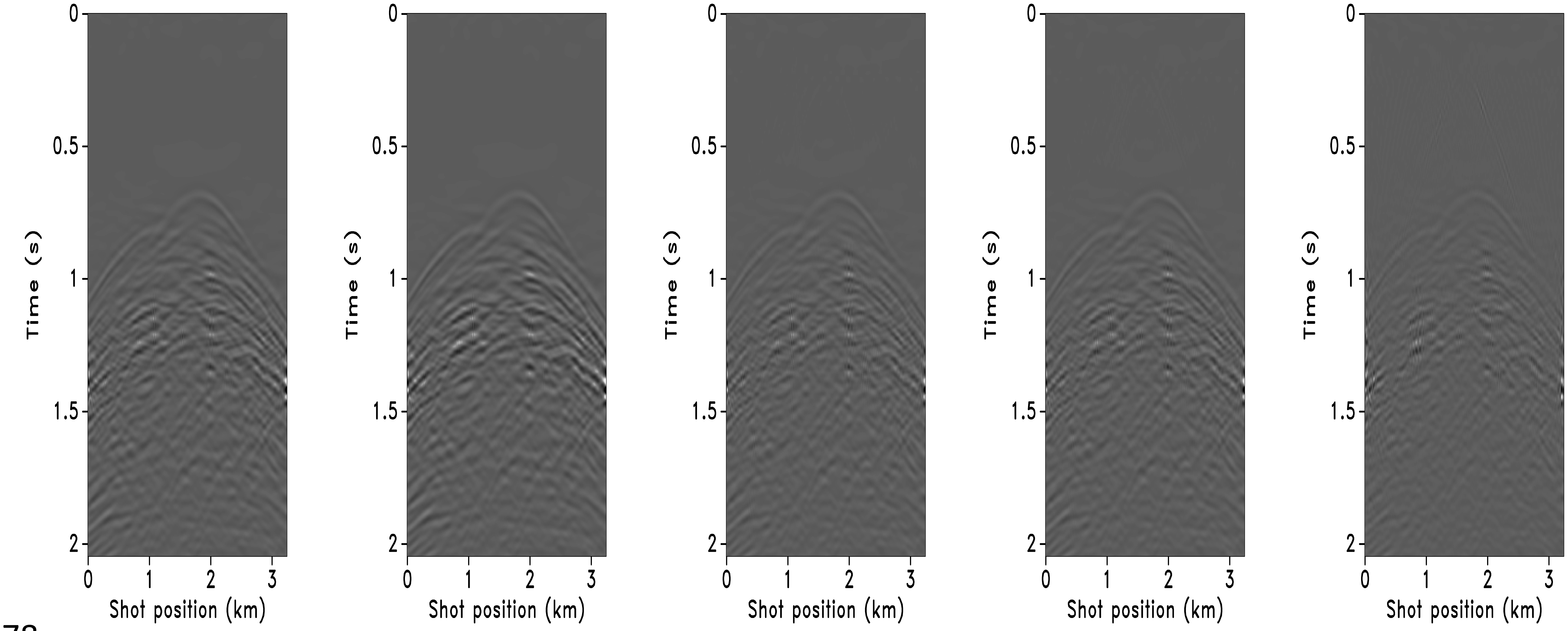
100% overlap [9.4 dB] | 100% ± 1.0 m [10.4 dB] | 100% ± 2.0 m [10.7 dB] | 100% ± 3.0 m [11.1 dB] | < 15% overlap [10.8 dB]



4D residual

– **Joint recovery**; subsampling factor = 2

100% overlap [9.4 dB] | 100% ± 1.0 m [10.4 dB] | 100% ± 2.0 m [10.7 dB] | 100% ± 3.0 m [11.1 dB] | < 15% overlap [10.8 dB]

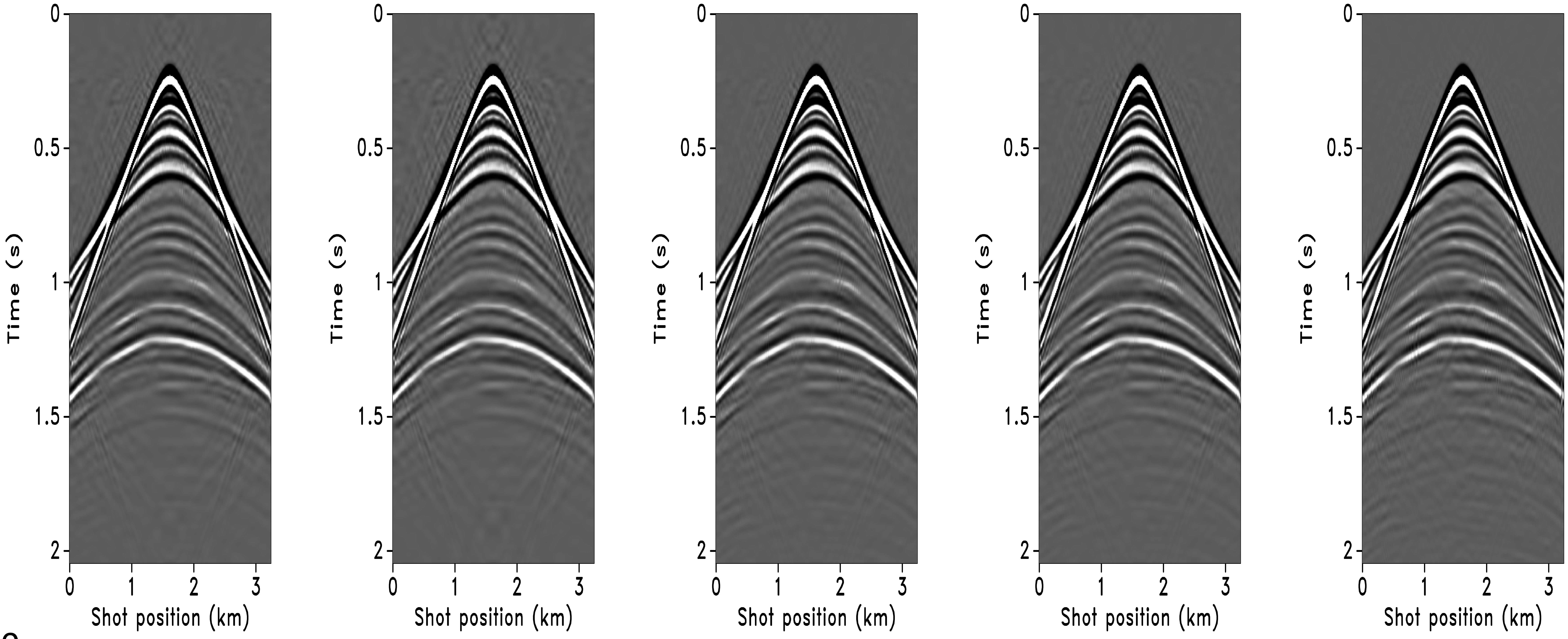


position deviations **improve** recovery of the vintages

Monitor recovery

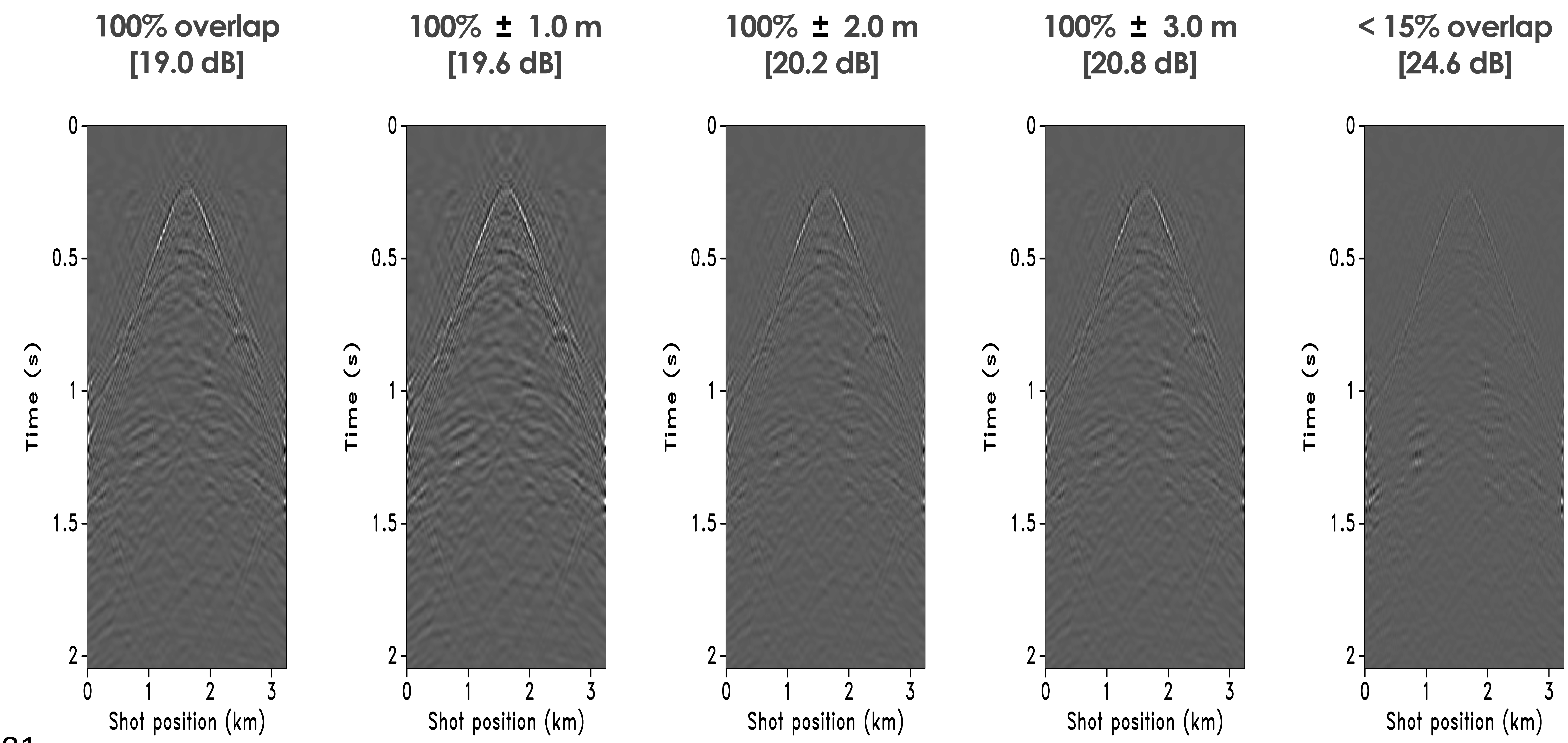
– **Joint recovery**; subsampling factor = 2

100% overlap [19.0 dB] | 100% ± 1.0 m [19.6 dB] | 100% ± 2.0 m [20.2 dB] | 100% ± 3.0 m [20.8 dB] | < 15% overlap [24.6 dB]



Monitor residual

– Joint recovery; subsampling factor = 2



SNR (dB) for data recovered via JRM

– average of 10 experiments; subsampling factor = 2

overlap ± deviation	Baseline	Monitor	4D signal
100%	19.1 ± 0.9	19.0 ± 0.9	9.4 ± 1.8
100% ± 1.0 m	19.7 ± 0.7	19.6 ± 0.7	10.4 ± 1.3
100% ± 2.0 m	20.3 ± 1.5	20.2 ± 1.5	10.7 ± 1.9
100% ± 3.0 m	21.0 ± 1.5	20.8 ± 1.5	11.1 ± 1.8
< 15 % *	**24.8 ± 1.8**	**24.6 ± 1.7**	10.8 ± 0.9

* least possible overlap range > 0% and < 15% (depends on simultaneous acquisition design and subsampling factor)

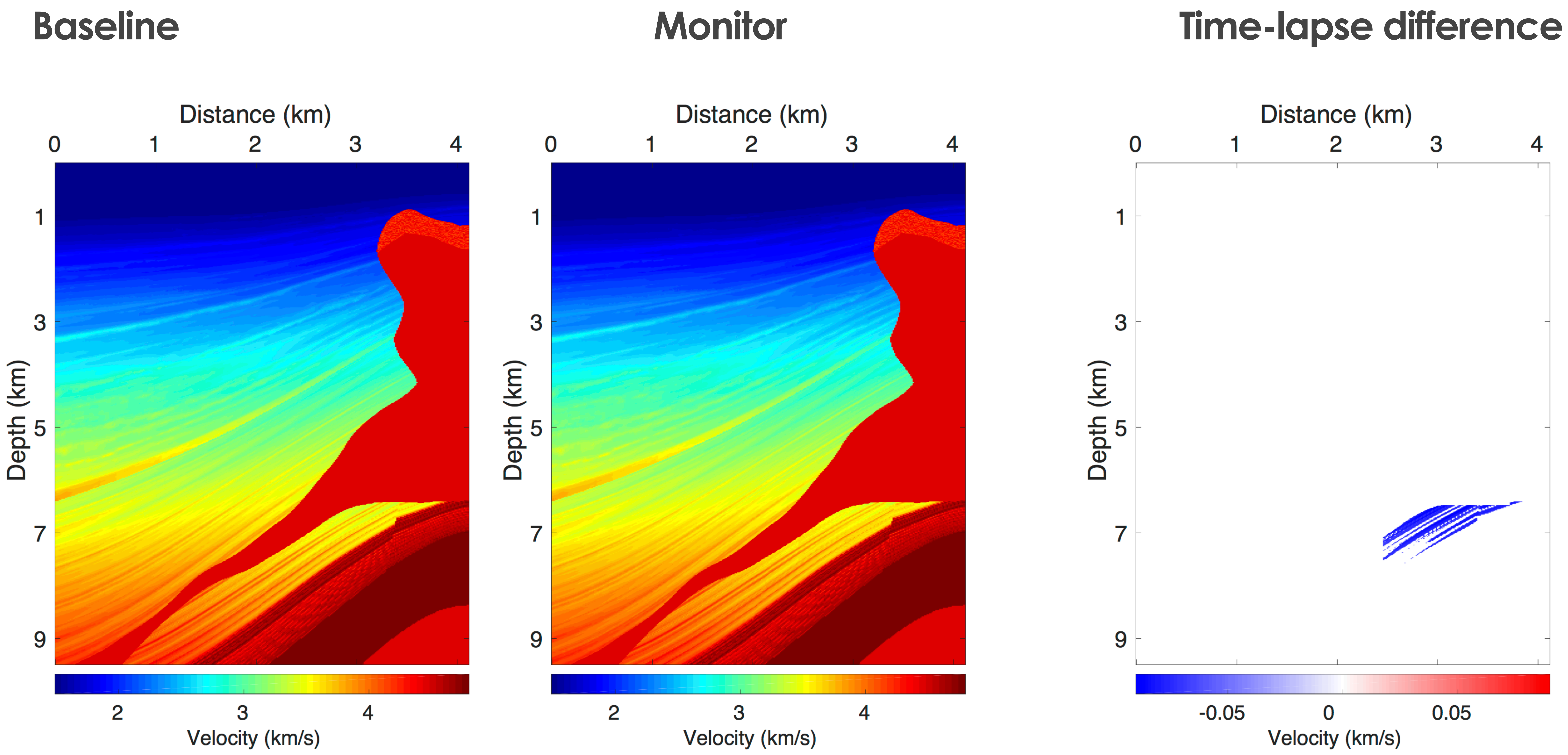
SNR (dB) for data recovered via JRM

– average of 10 experiments; subsampling factor = 4

overlap ± deviation	Baseline	Monitor	4D signal
100%	14.1 ± 0.7	13.9 ± 0.7	6.1 ± 0.8
100% ± 1.0 m	14.5 ± 0.8	14.3 ± 0.8	5.6 ± 0.8
100% ± 2.0 m	15.6 ± 0.7	15.5 ± 0.7	6.4 ± 0.7
100% ± 3.0 m	16.2 ± 0.7	16.0 ± 0.7	6.0 ± 0.6
< 5 % *	**18.0 ± 0.9**	**17.7 ± 0.8**	5.2 ± 0.5

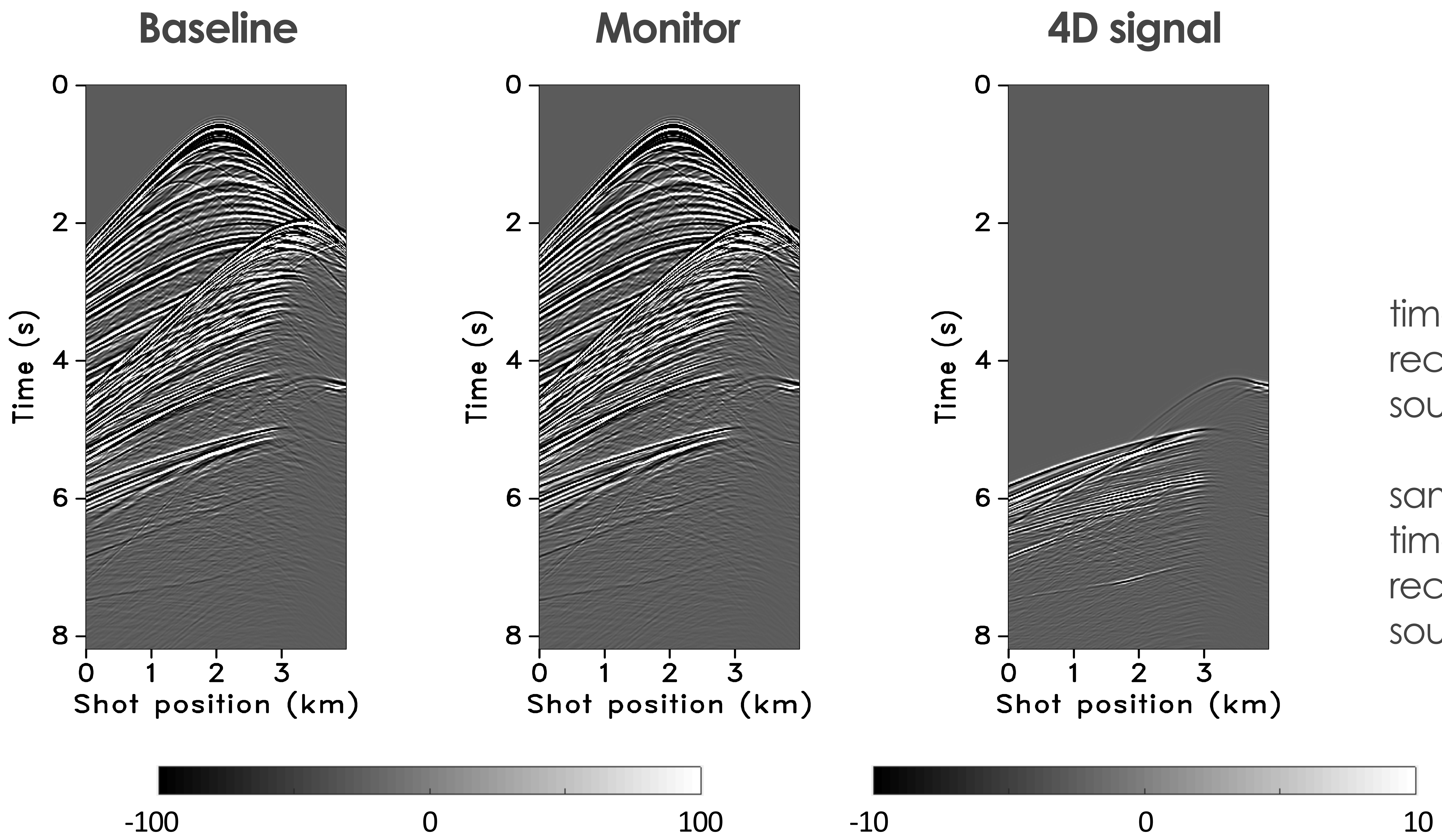
* least possible overlap range > 0% and < 5% (depends on simultaneous acquisition design and subsampling factor)

SEAM Phase 1 model
– time-lapse difference via fluid substitution



Simulated time-lapse data

– time-domain finite differences

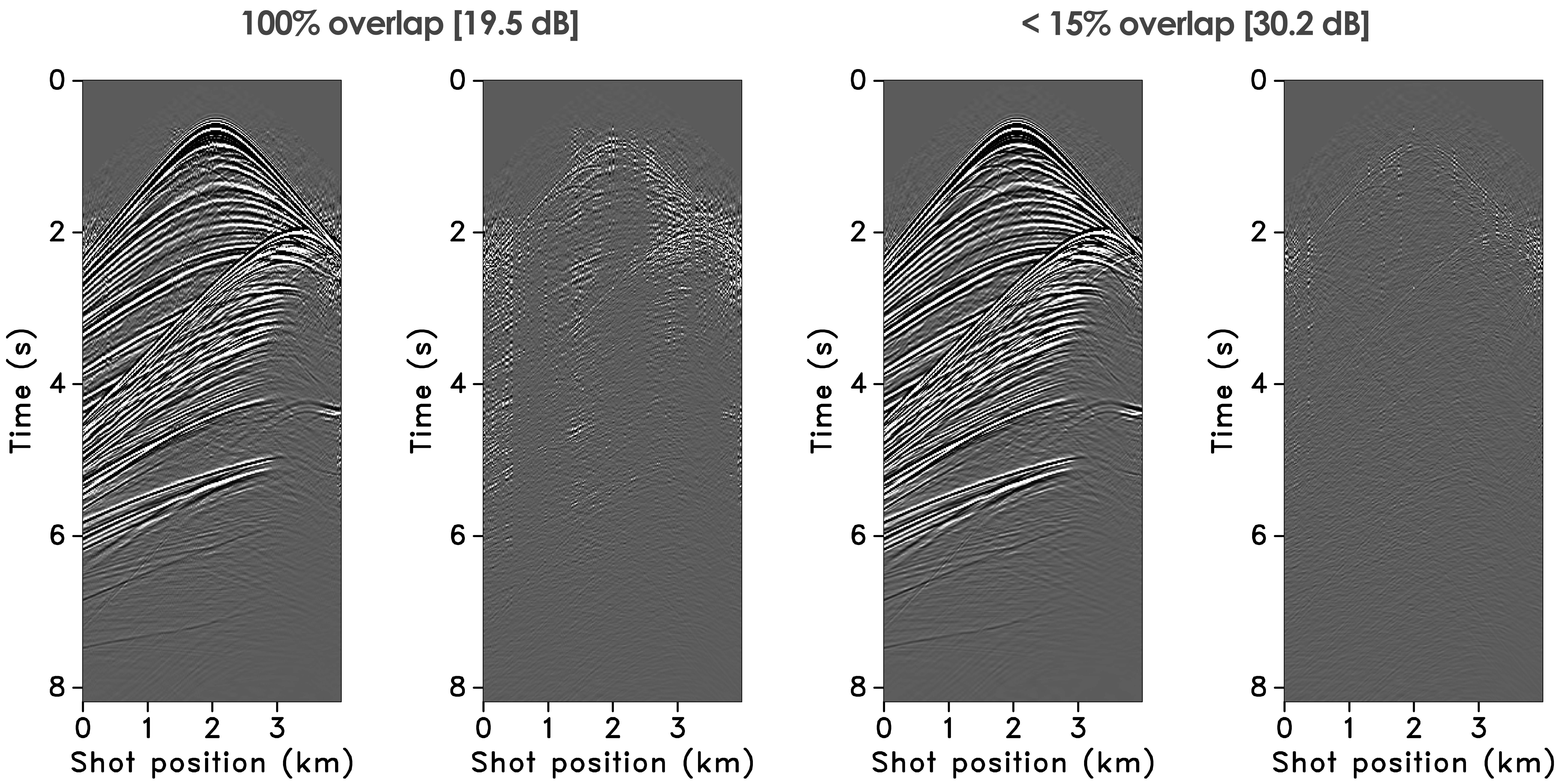


time samples: **2048**
receivers: **330**
sources: **330**

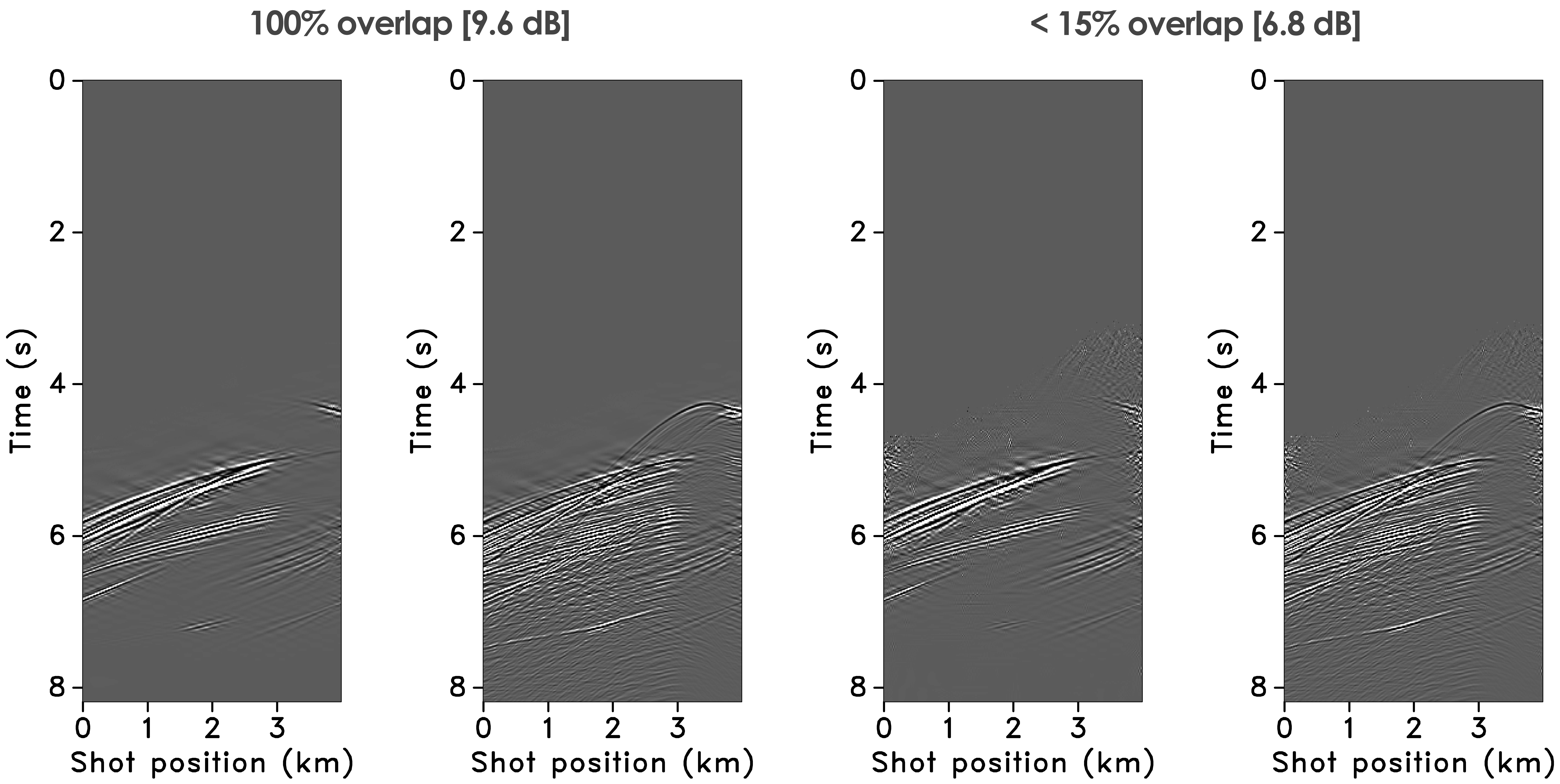
sampling
time: **4.0 ms**
receiver: **12.5 m**
source: **12.5 m**

Monitor recovery & residual

– Joint recovery; subsampling factor = 2



4D recovery & residual
– Joint recovery; subsampling factor = 2



Conclusions

In the given context of randomized subsampling, position deviations

- have **little variability** on recovery of the time-lapse **difference**
- **improve** recovery of the **vintages**

Should we repeat compressive randomized time-lapse surveys?

- **Irregular sampling is inevitable in the real world** => “exact” replicability of surveys is naturally not possible
- Better to focus on knowing the shot positions post acquisition

Embrace natural **randomness** in the field or better purposefully randomize acquisitions to maximize collection of information

Main contributions

Design of **pragmatic** simultaneous-source **time-jittered marine** acquisition

Adaptation of **NFDCT** for simultaneous-source acquisition and source separation

Design of **pragmatic** simultaneous-source **time-jittered time-lapse marine** acquisition with different overlaps between baseline & monitor surveys

Main conclusions

CS ideas can be **successfully** adapted to seismic data acquisition

CS offers new **design** perspectives for seismic data acquisition schemes

Three **key** components:

- find representations that reveal structure, e.g., transform-domain sparsity
- sample to break structure, e.g., randomized acquisitions
- recover by structure promotion, e.g., sparsity via one-norm minimization

Simultaneous-source acquisition is an instance of compressive sensing

- **economic** acquisitions with **reduced** environmental **imprint**

Main conclusions

Time-lapse seismic

- **processing** time-lapse data **jointly** leads to improved recovery of the vintages with little variability in the time-lapse difference
- **irregular** sampling is **inevitable** in the real world => better to focus on knowing the shot positions post acquisition

Embrace natural **randomness** in the field or better purposefully randomize acquisitions to maximize collection of information

Summary of publications

Journal papers

Low-cost time-lapse seismic with distributed compressive sensing --- Impact on repeatability, Haneet Wason, Felix Oghenekohwo, and Felix. J. Herrmann, Geophysics, 82, P15--P30.

Low-cost time-lapse seismic with distributed compressive sensing --- Exploiting common information among the vintages, Felix Oghenekohwo, Haneet Wason, Ernie Esser, and Felix J. Herrmann, Geophysics, 82, P1--P13.

Source separation for simultaneous towed-streamer marine acquisition --- A compressed sensing approach, Rajiv Kumar*, Haneet Wason*, and Felix J. Herrmann, Geophysics, 80, WD73--WD88. *Equal contribution.

Randomized marine acquisition with compressive sampling matrices, Hassan Mansour, Haneet Wason, Tim T.Y. Lin, and Felix J. Herrmann, Geophysical Prospecting, 60, 648--662.

Compressive sensing in seismic exploration: An outlook on a new paradigm, Felix J. Herrmann, Haneet Wason, and Tim T.Y. Lin, CSEG Recorder, 36, Part I [April Edition], 19--33; Part II [June Edition], 34--39.

Summary of publications

Conference proceedings

Compressed sensing in 4D marine --- Recovery of dense time-lapse data from subsampled data without repetition, Haneet Wason, Felix Oghenekohwo, and Felix. J. Herrmann, EAGE Conference & Exhibition 2015.

SVD-free matrix completion in randomized marine acquisition, Oscar Lopez, Haneet Wason, Curt Da Silva, Rajiv Kumar, and Felix. J. Herrmann, SEG Annual Meeting Workshop 2015.

Randomization and repeatability in time-lapse marine acquisition, Haneet Wason, Felix Oghenekohwo, and Felix. J. Herrmann, SEG Annual Meeting 2014.

Source-separation via SVD-free rank minimization in the hierarchical semi-separable representation, Haneet Wason, Rajiv Kumar, and Felix. J. Herrmann, SEG Annual Meeting 2014.

Time-jittered ocean bottom seismic acquisition, Haneet Wason, and Felix. J. Herrmann, SEG Annual Meeting 2013.

Only dither: efficient simultaneous marine acquisition, Haneet Wason, and Felix. J. Herrmann, EAGE Conference & Exhibition 2012.

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Future research directions

Develop a computationally faster and memory efficient implementation of 2D & 3D curvelet transforms

Improve recovery of weak late-arriving events with weighted one-norm minimization

Develop robust algorithms to use simultaneous-source data directly in imaging and inversion

Improve sparse time-lapse data recoveries with γ-weighted one-norm formulation for DCS:

$$\widetilde{\mathbf{z}} = \arg\min_{\mathbf{z}} \gamma_0 \|\mathbf{z_0}\|_1 + \gamma_1 \|\mathbf{z_1}\|_1 + \gamma_2 \|\mathbf{z_2}\|_1 \quad \text{subject to} \quad \mathbf{y} = \mathbf{A}\mathbf{z}$$

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