Randomization of time-lapse marine surveys

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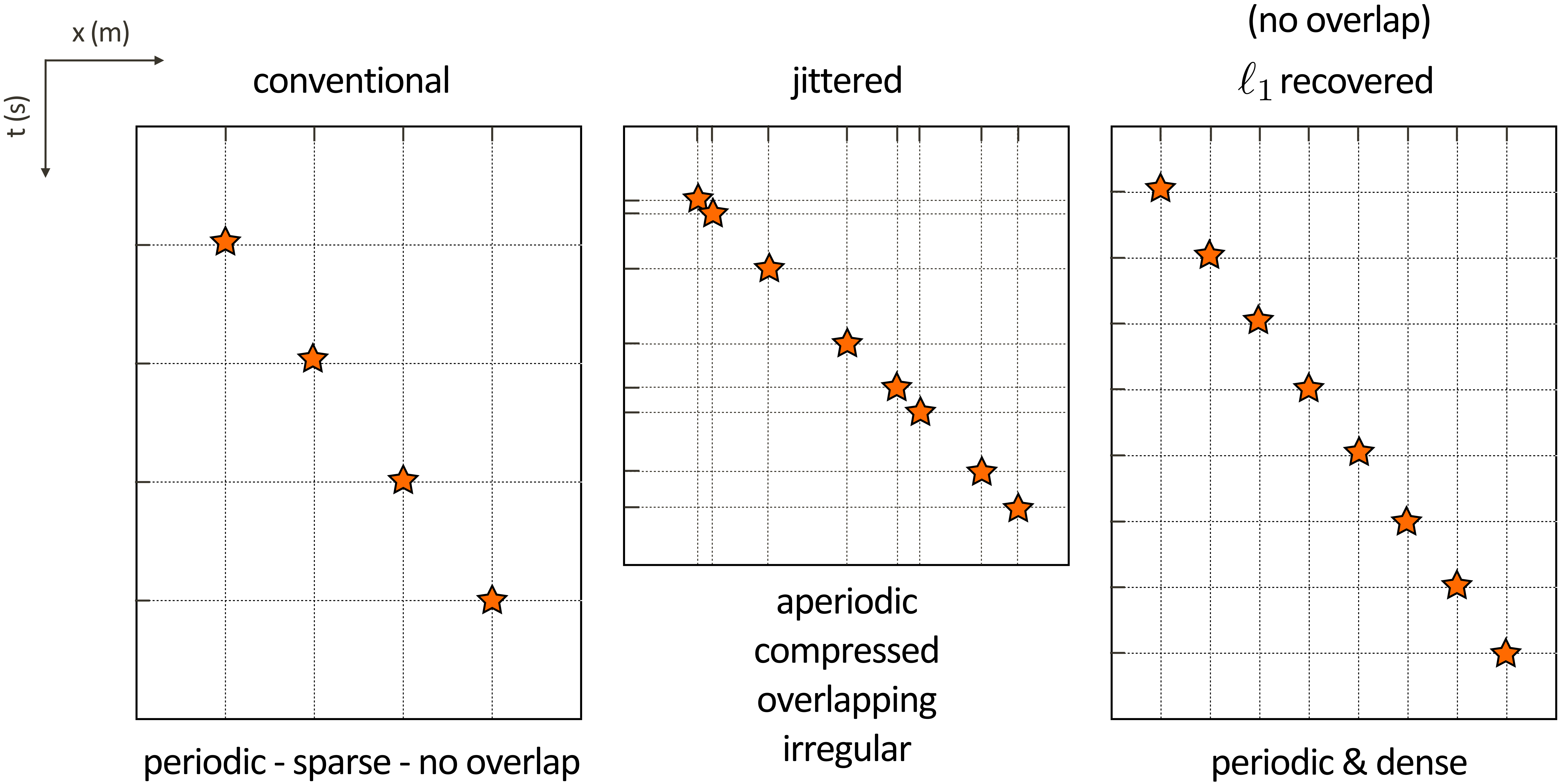
Randomized jitter sampling in marine



Motivation

What are the implications of randomization in time-lapse seismic?

Is it really possible to repeat time-lapse surveys?

Time-lapse seismic

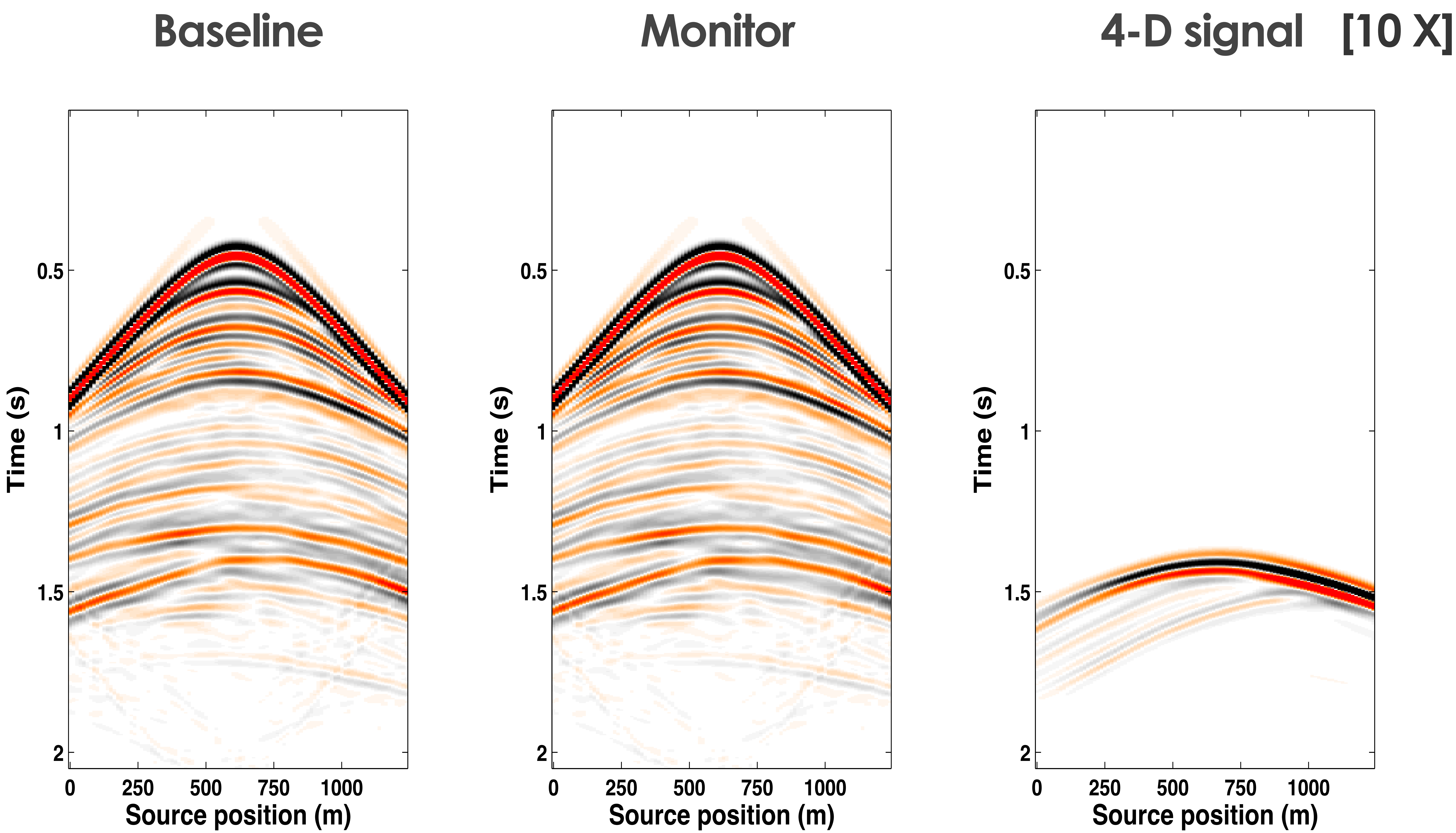
Current acquisition paradigm:

- 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
- may offer possibility to relax insistence on repeatability
- exploits insights from distributed compressed sensing

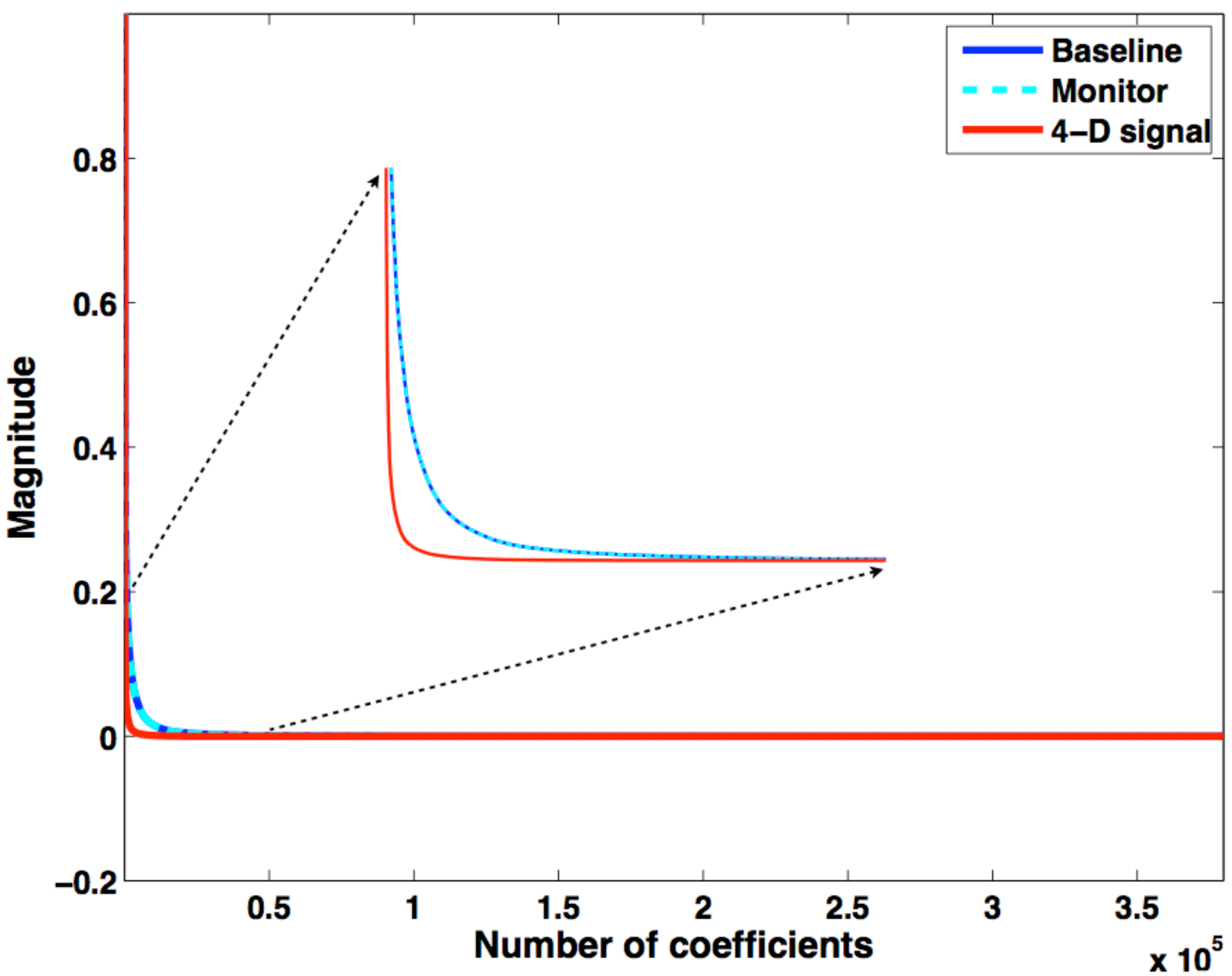
Time-lapse data



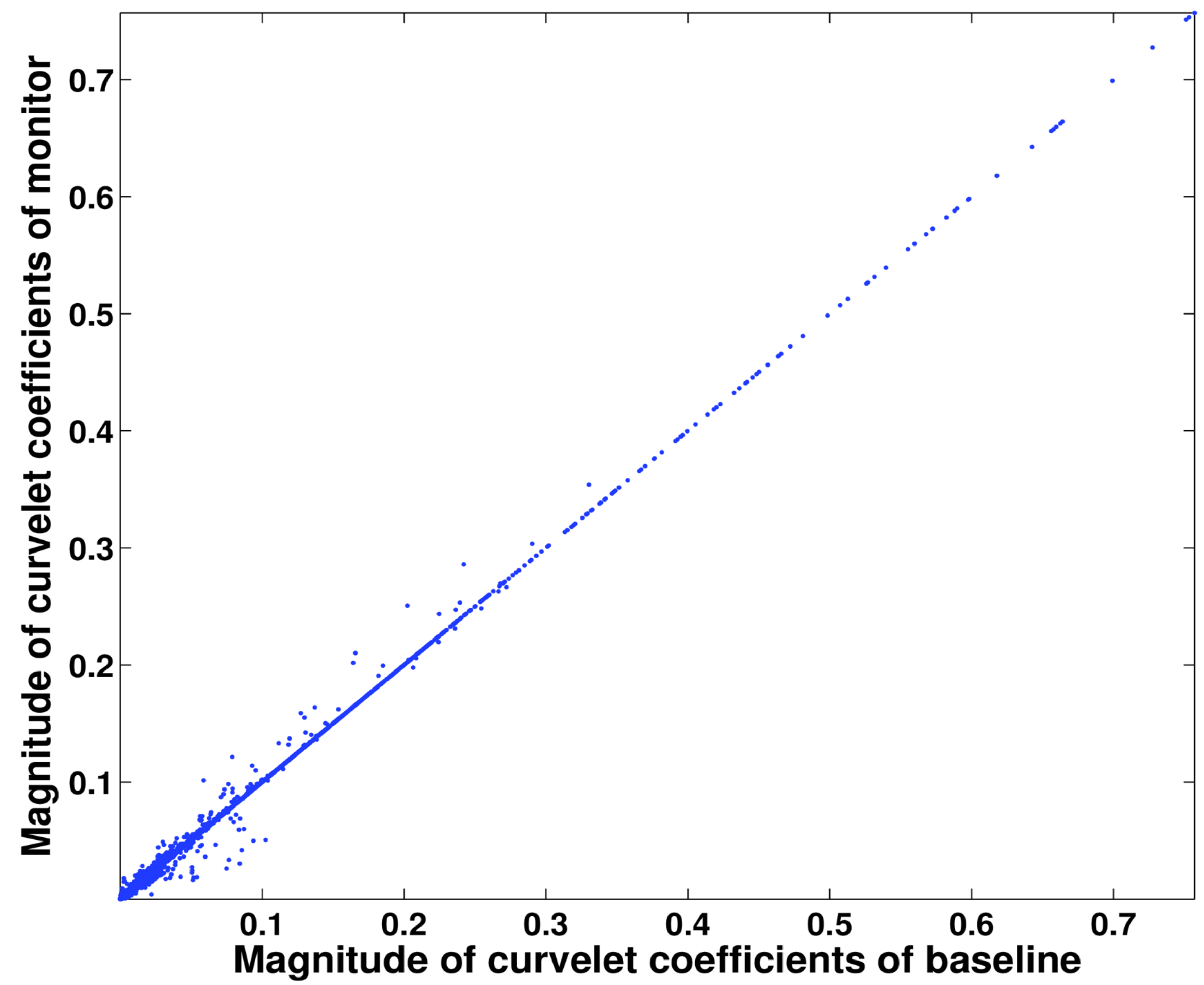
time samples: **512**
receivers: **100**
sources: **100**

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

Sparse structure via curvelets



significant correlation between the vintages



Dror Baron, Marco F. Duarte, Shriram Sarvotham, Michael B. Wakin, Richard G. Baraniuk, "**An Information-Theoretic Approach to Distributed Compressed Sensing**" (2005)

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Distributed compressed sensing
– joint recovery model (JRM)

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

baseline

monitor

vintages

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

differences

common component

different vintages share common information

Time-lapse seismic
– w/ & w/o repetition

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” repeatability…

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

- no absolute control on surveys
- errors in the shot/receiver positions
- noise…

Context

Acquire randomized subsamplings for the baseline and monitor surveys

Aim: recovery of both vintages & time-lapse signal from incomplete data

Questions:

- Process/recover independently or jointly to exploit common features of surveys?
- Should we repeat the surveys when doing randomized subsampling?

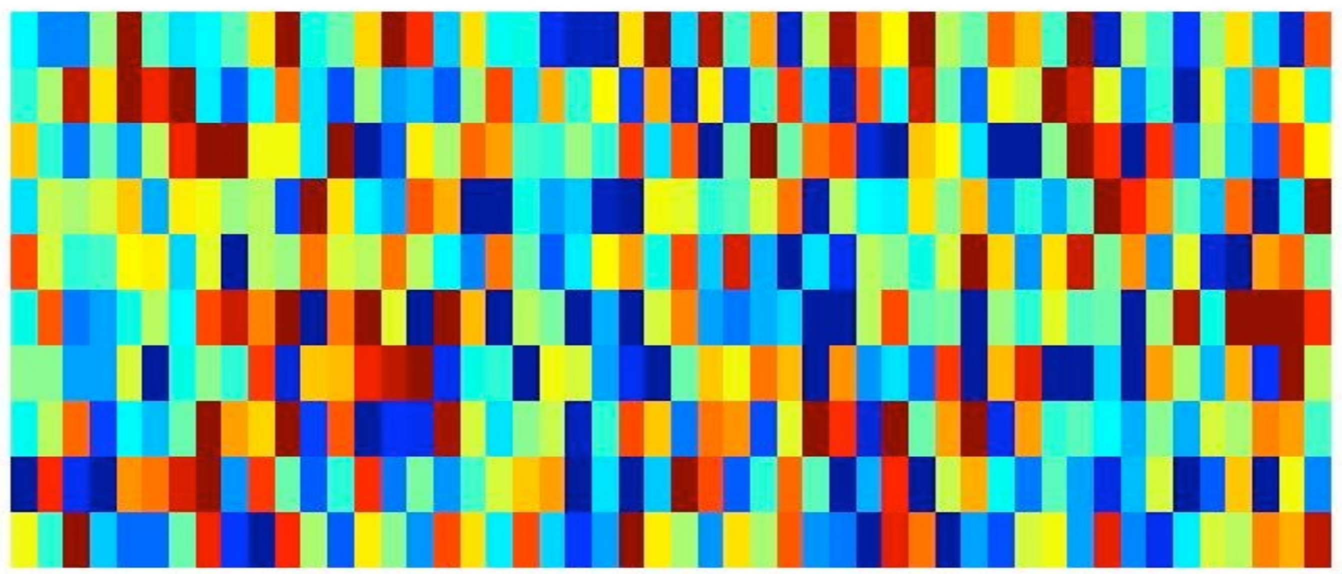
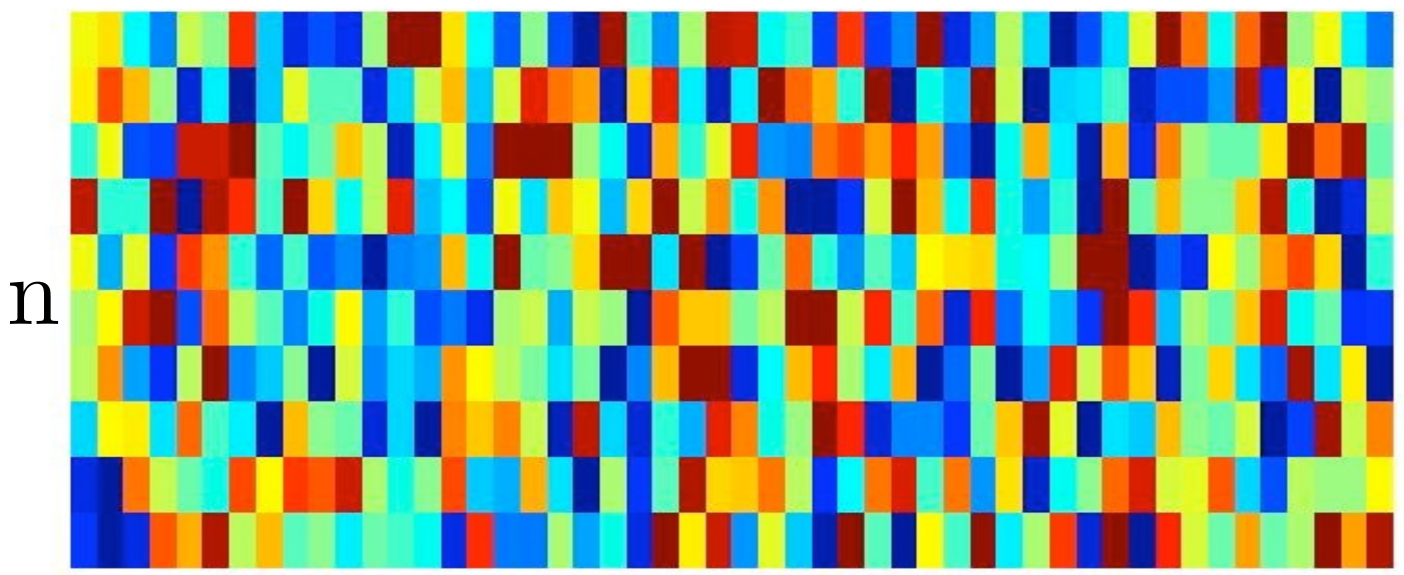
Stylized experiments

Stylized experiments

Conduct *many* CS experiments to compare

- *joint* vs *parallel* recovery of signals and the difference
- recovery with *same*, *partially* or *completely* independent matrices
- *random* acquisition with different numbers of samples

$\mathbf{A}_1$ $\quad\quad$ $\mathrm{n} = 10$ $\quad\quad$ $\mathbf{A}_2$

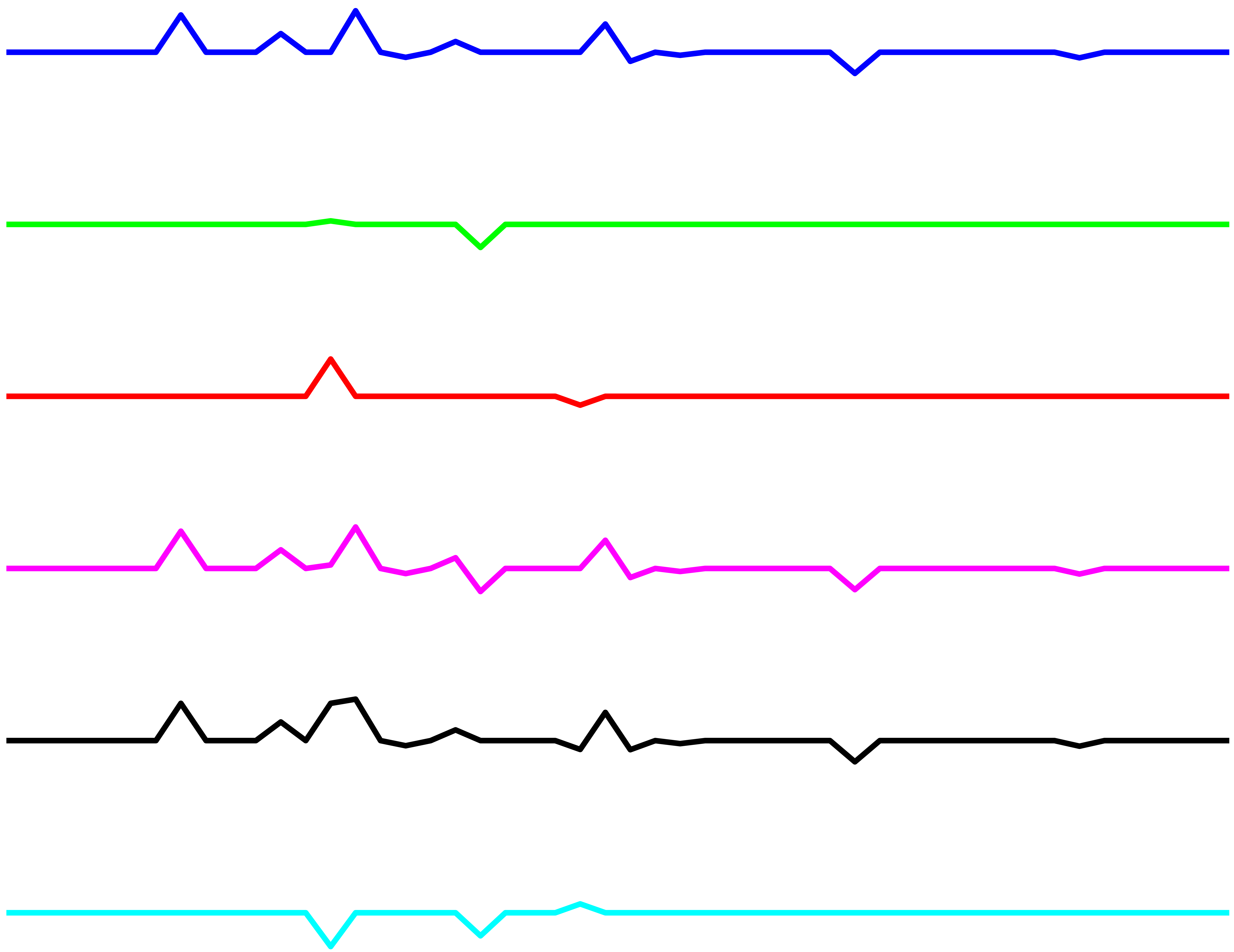
n  n 

N $\quad\quad$ N

$\mathbf{b}_1 = \mathbf{A}_1\mathbf{x}_1$ $\quad\quad$ $\mathbf{b}_2 = \mathbf{A}_2\mathbf{x}_2$

run 2000 different experiments & compute probability of recovery

Sparse signals



$\mathbf{z}_0$ common component

$\mathbf{z}_1$ “difference”

$\mathbf{z}_2$ “difference”

$\mathbf{x}_1$ baseline

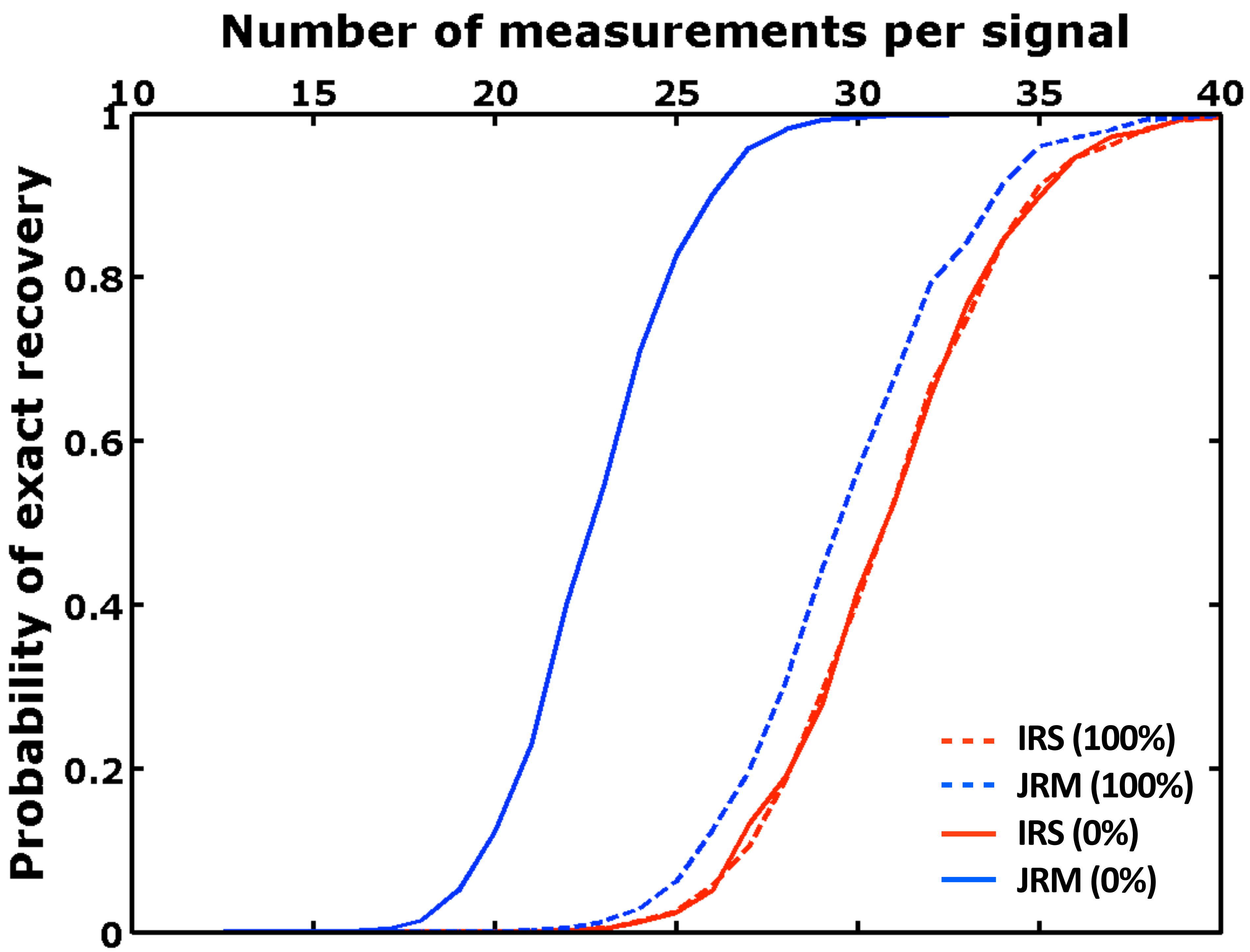
$\mathbf{x}_2$ monitor

$\left.\begin{array}{l}\mathbf{x}_1 \\ \mathbf{x}_2\end{array}\right\}$ vintages

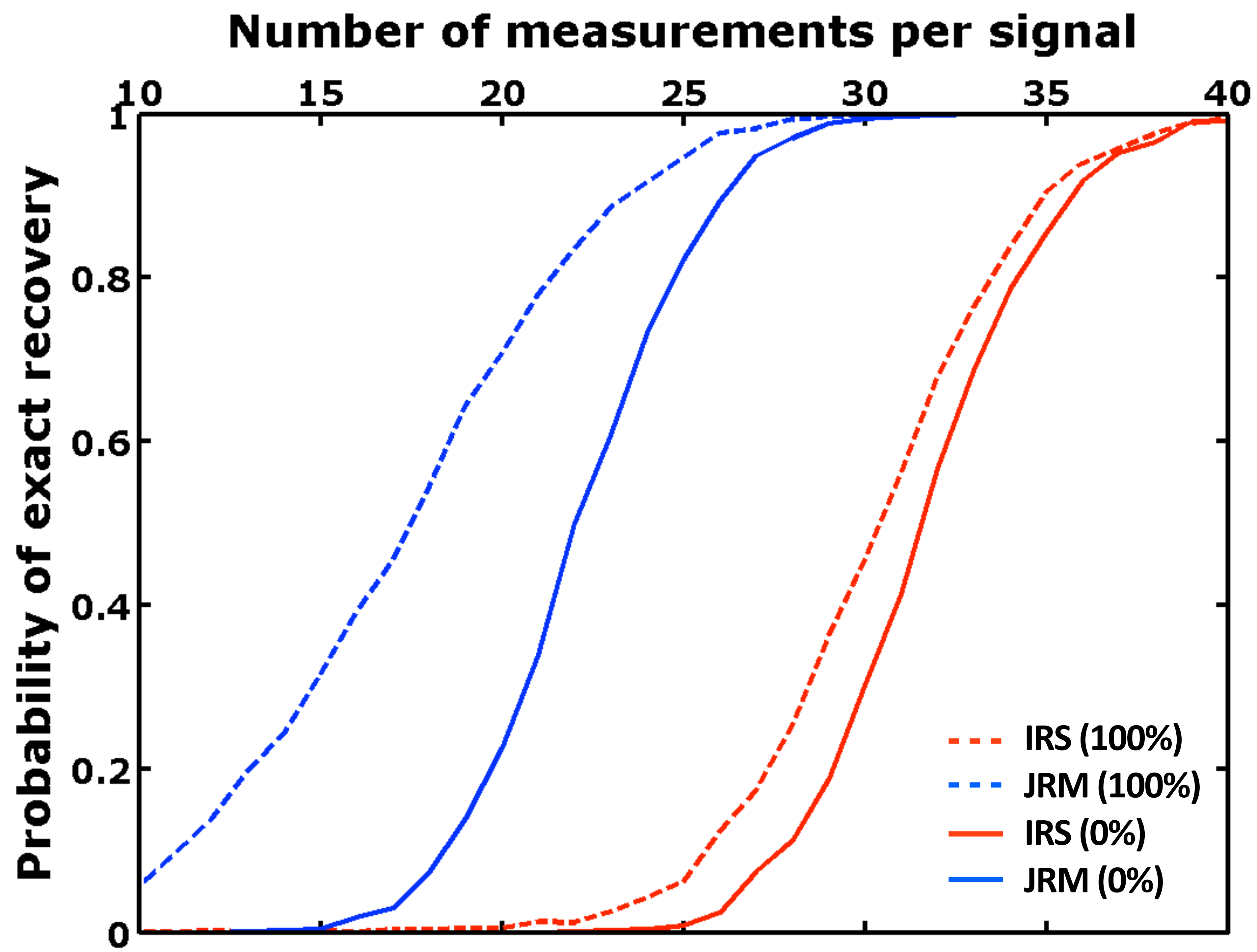
$\mathbf{x}_1$ - $\mathbf{x}_2$ time-lapse

Independent vs. joint recovery
– 100% & 0% overlap in acquisition matrices

100% => "exact" repeatability
(difficult to achieve in practice)



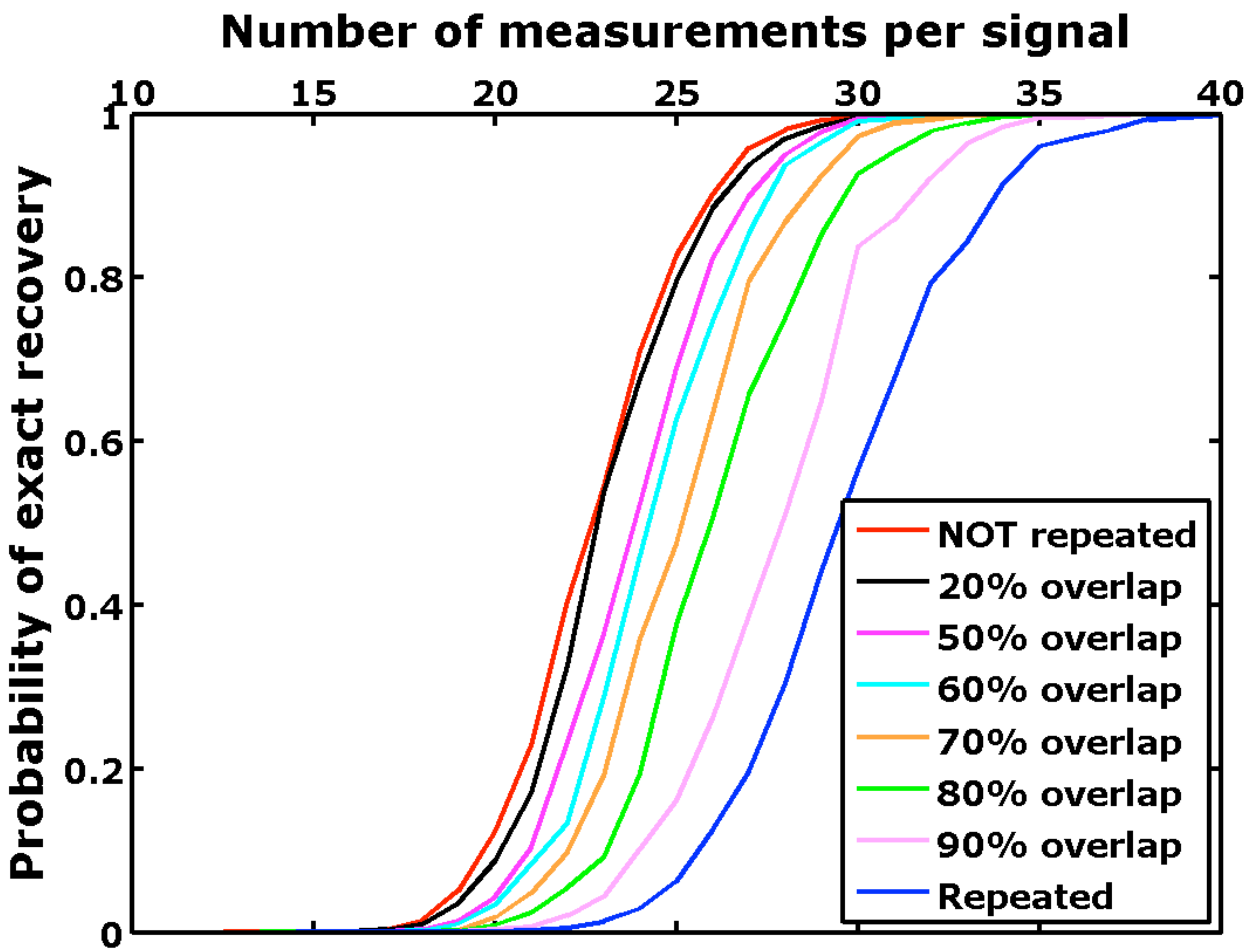
Vintages



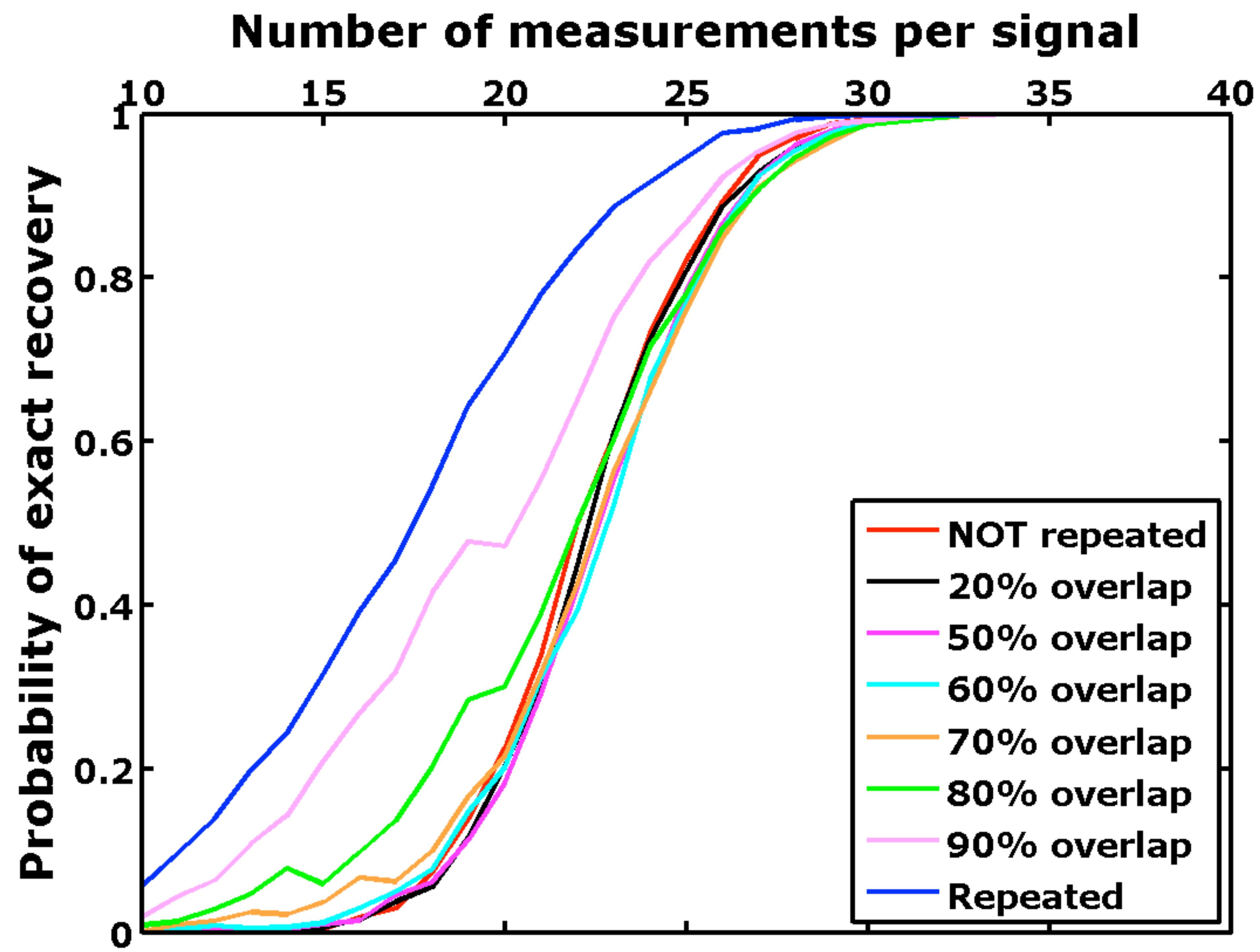
4-D signal

Joint recovery

– varying % of overlap in acquisition matrices



Vintages



4-D signal

Observations

Stylized synthetics give fundamental insights when recovering signals in 4-D seismic

The Joint Recovery Model (JRM) always gives superior results, since it exploits the shared information between the vintages

Aim: recovery of both vintages & time-lapse signal from incomplete data

Synthetic seismic case study

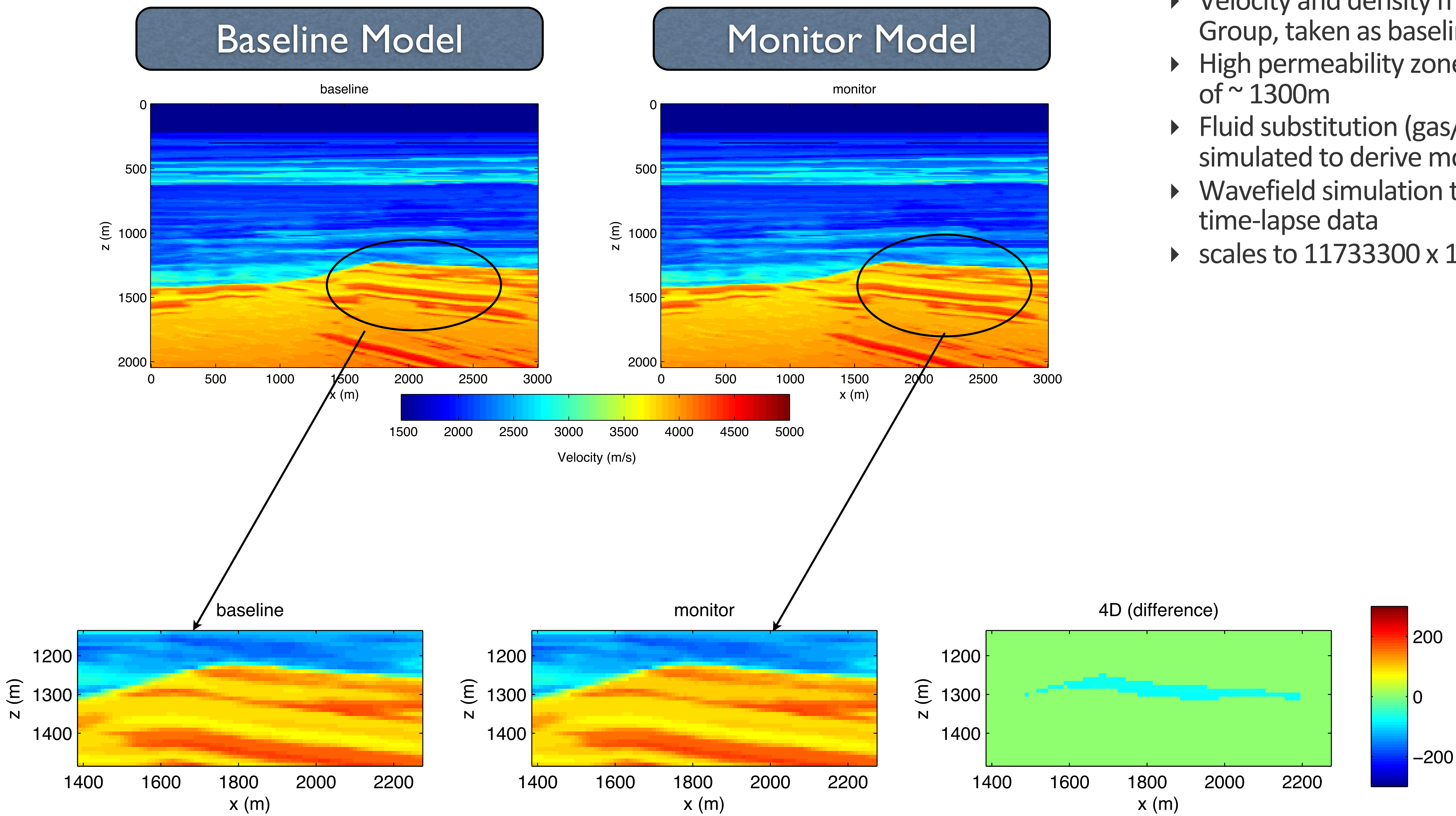
Time-jittered marine acquisition on the grid

% repetition => “exact” repetition

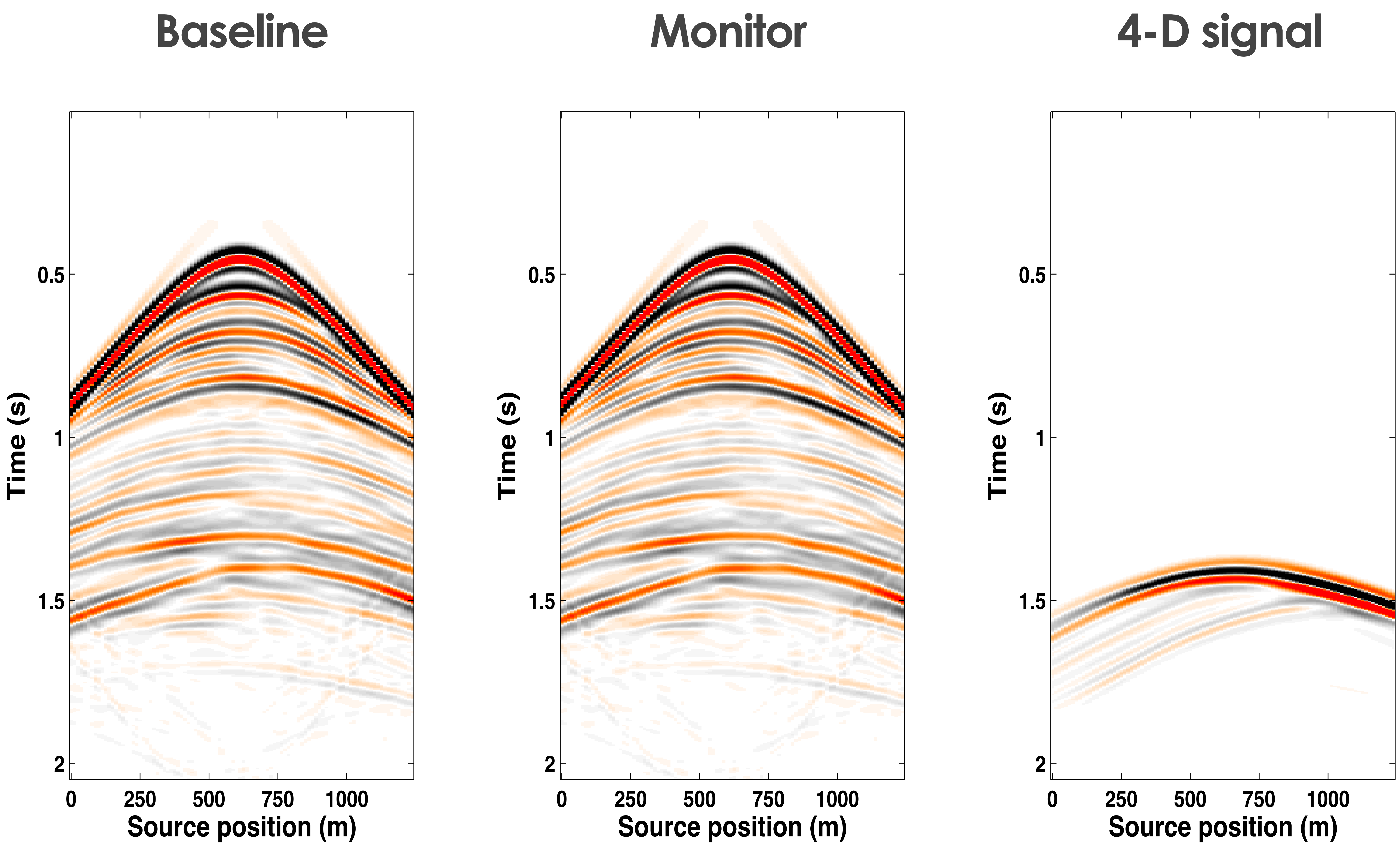
No errors in the shot/receiver locations

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

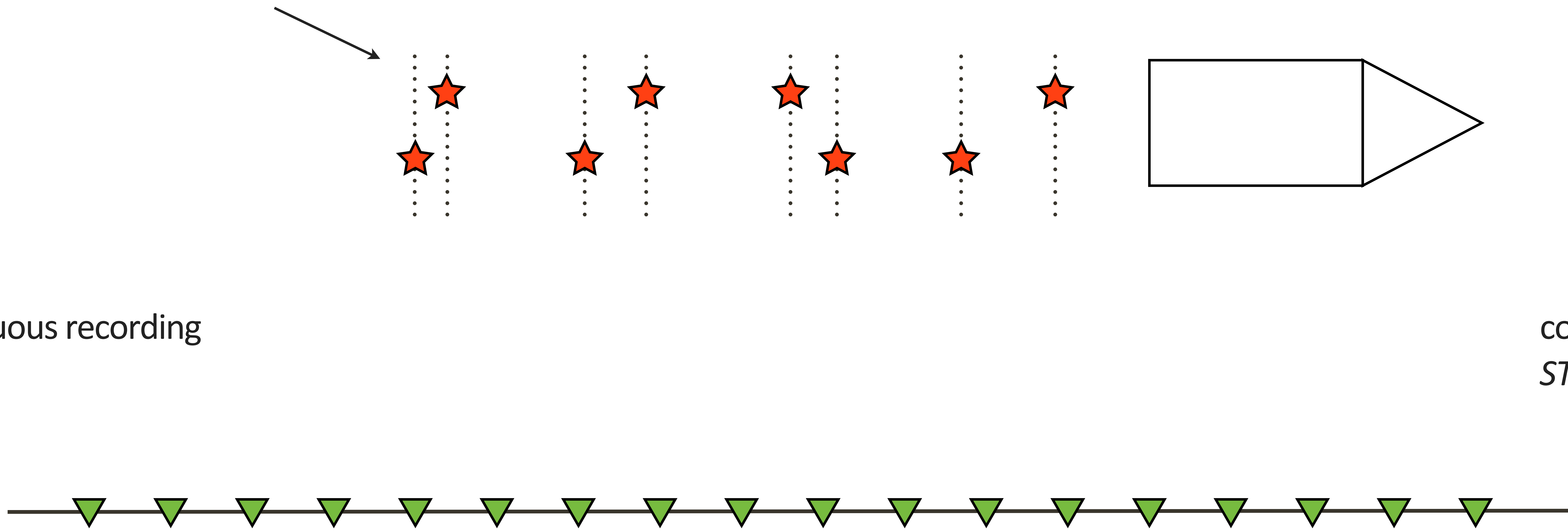


time samples: **512**
receivers: **100**
sources: **100**

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

Time-jittered marine acquisition

irregularly sampled spatial grid

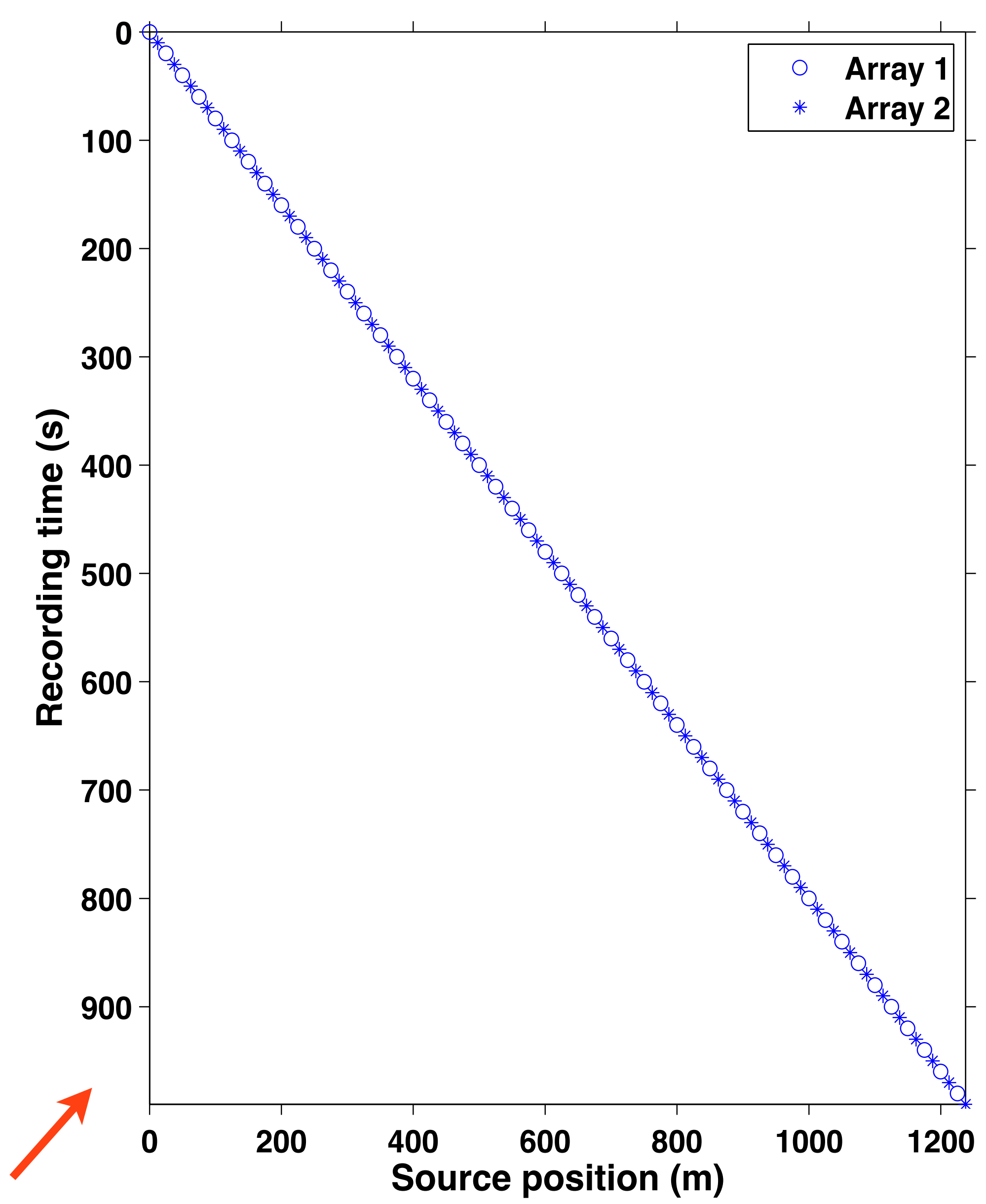


continuous recording
START

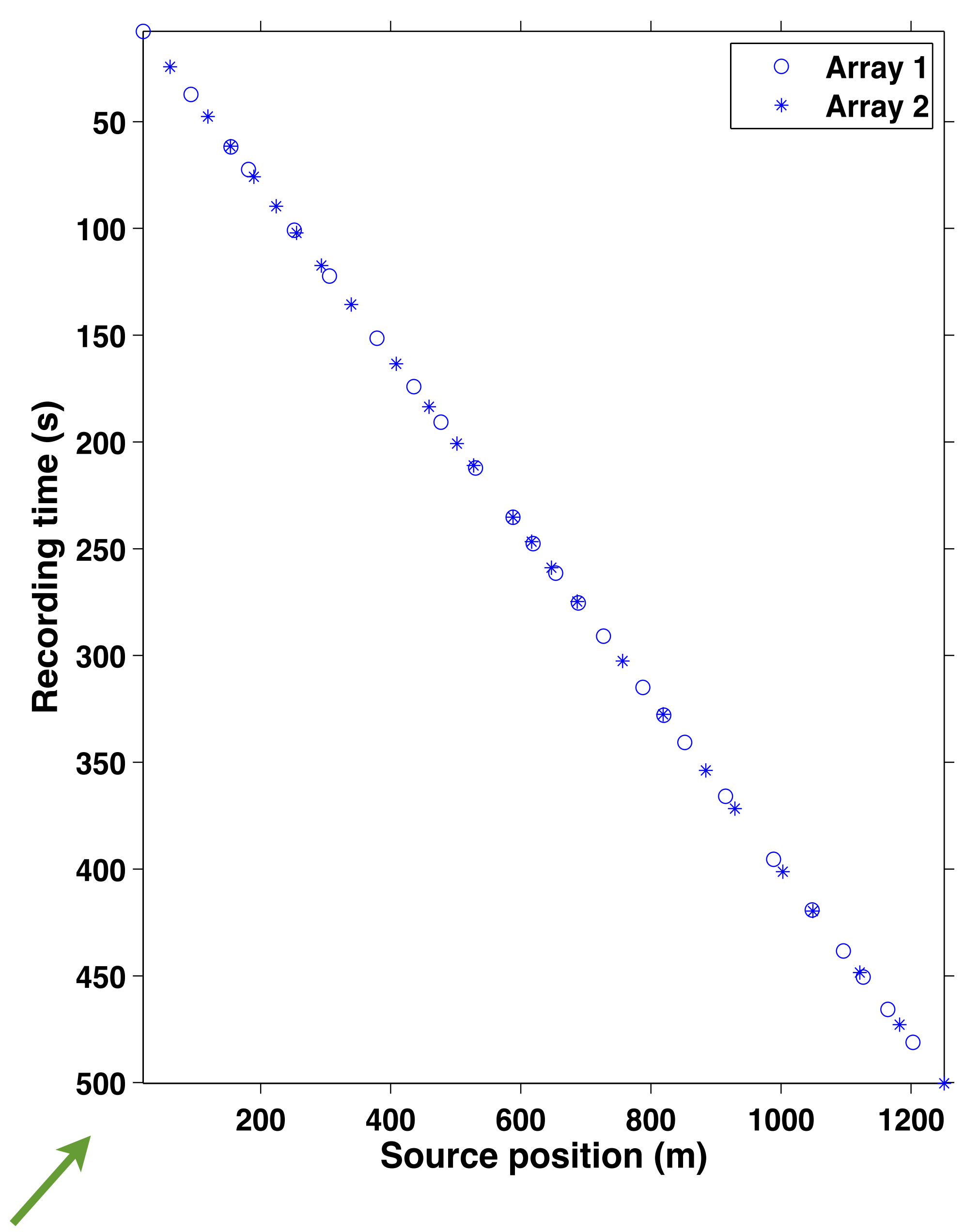
continuous recording
STOP

Conventional vs. time-jittered sources
– subsampling ratio = 2 (2 source arrays)

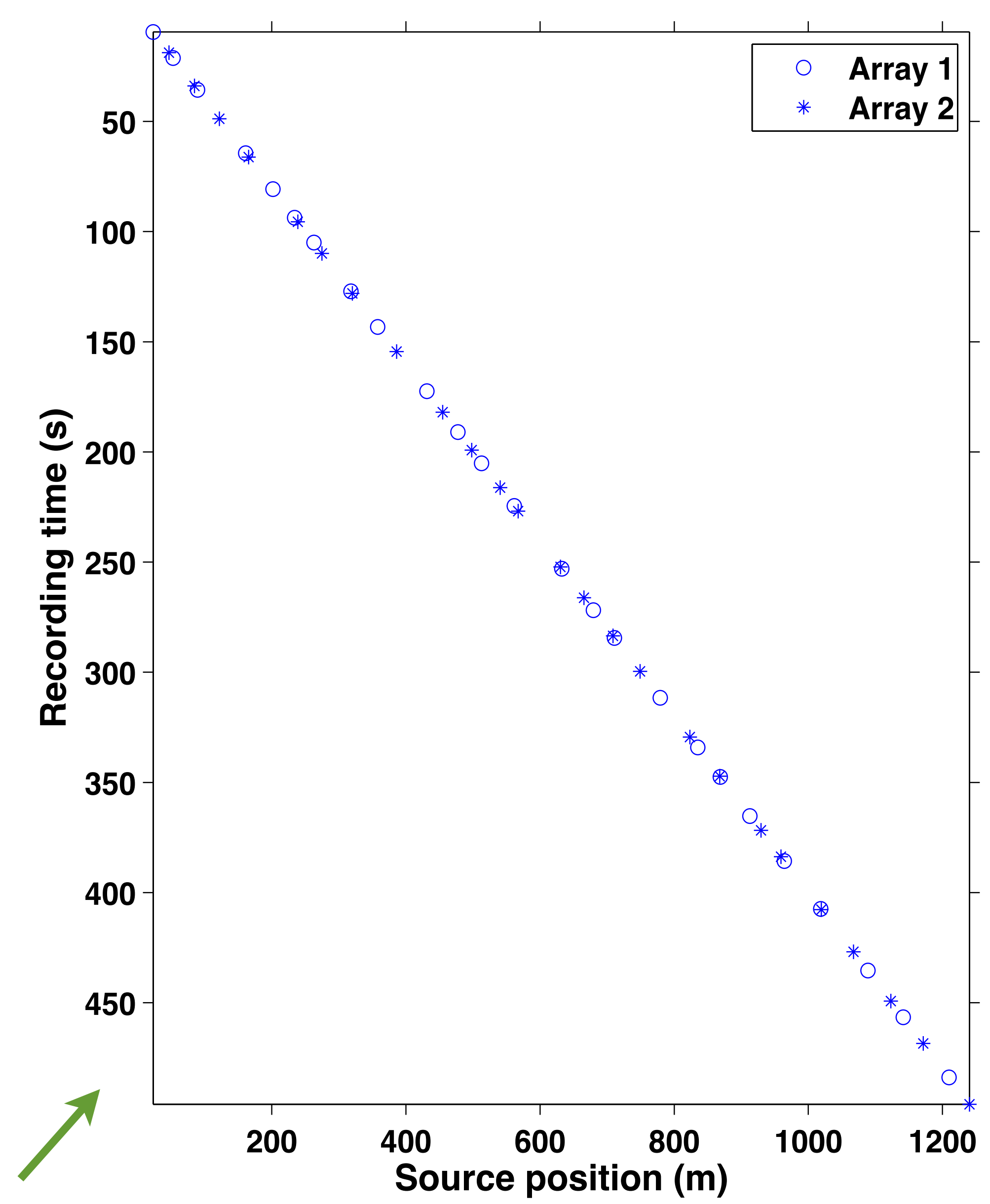
conventional



jittered acquisition 1 (baseline)



jittered acquisition 2 (monitor)



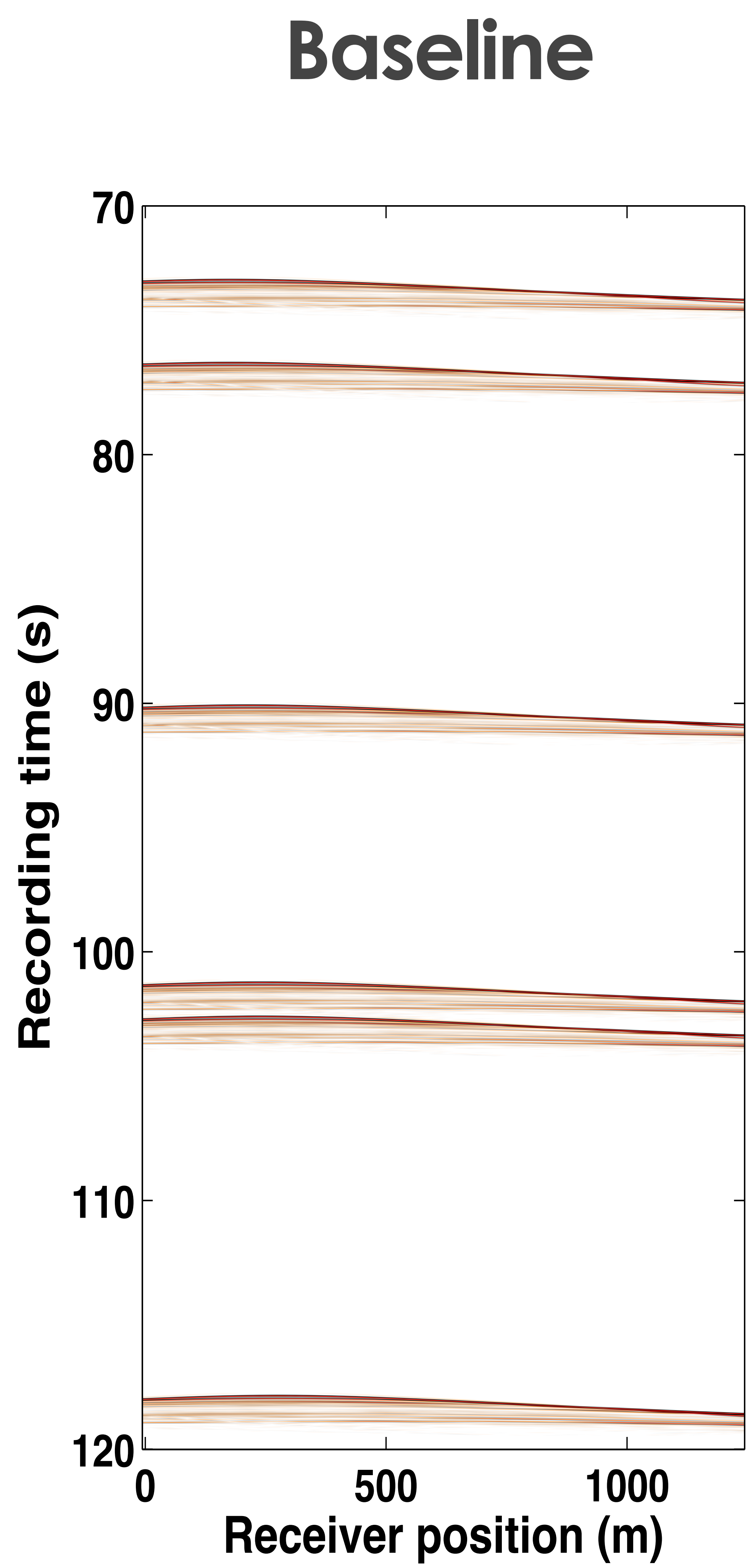
***"unblended"* shot gathers**
number of shots = **100** (per array)
shot record length: 10.0 s
spatial sampling: **12.5 m**
vessel speed: **1.25 m/s**
recording time = 100 x 10.0 = **1000.0 s**

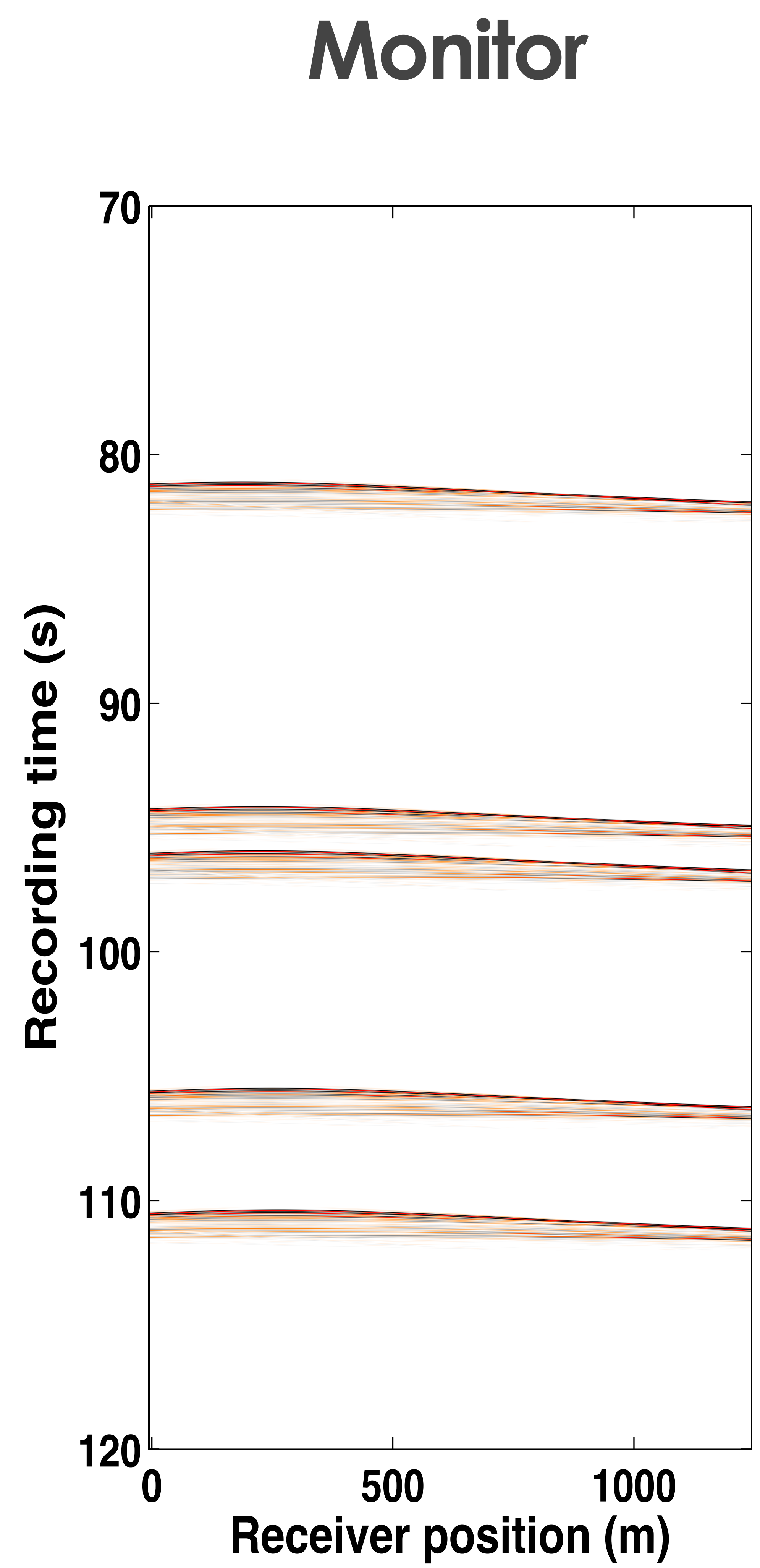
[BLENDING & SUBSAMPLING]
spatial subsampling factor = 2

spatial sampling **increase** factor = 2
[DEBLENDING & INTERPOLATION]

***"blended"* 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 blended





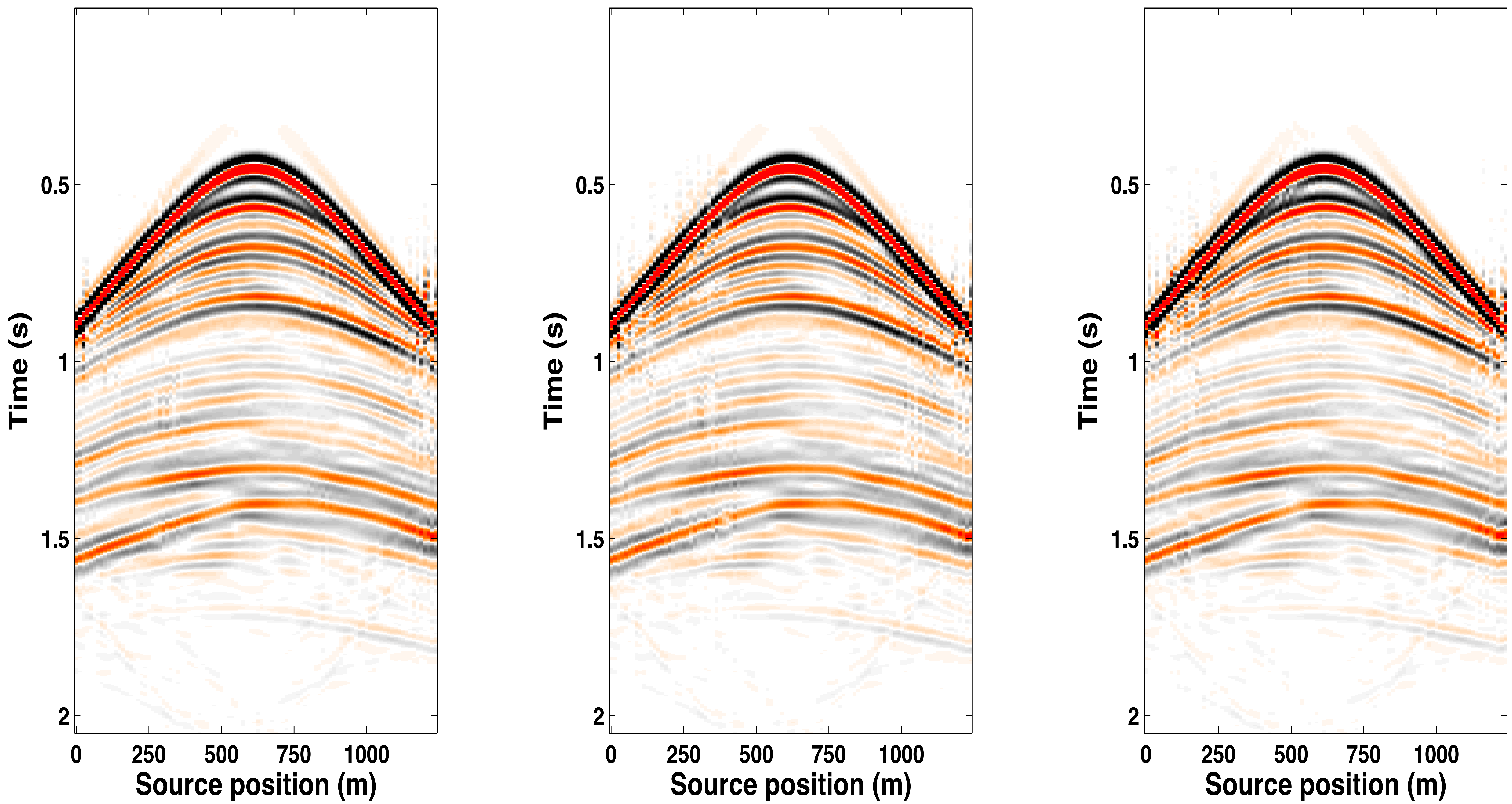
Monitor recovery

– Independent recovery

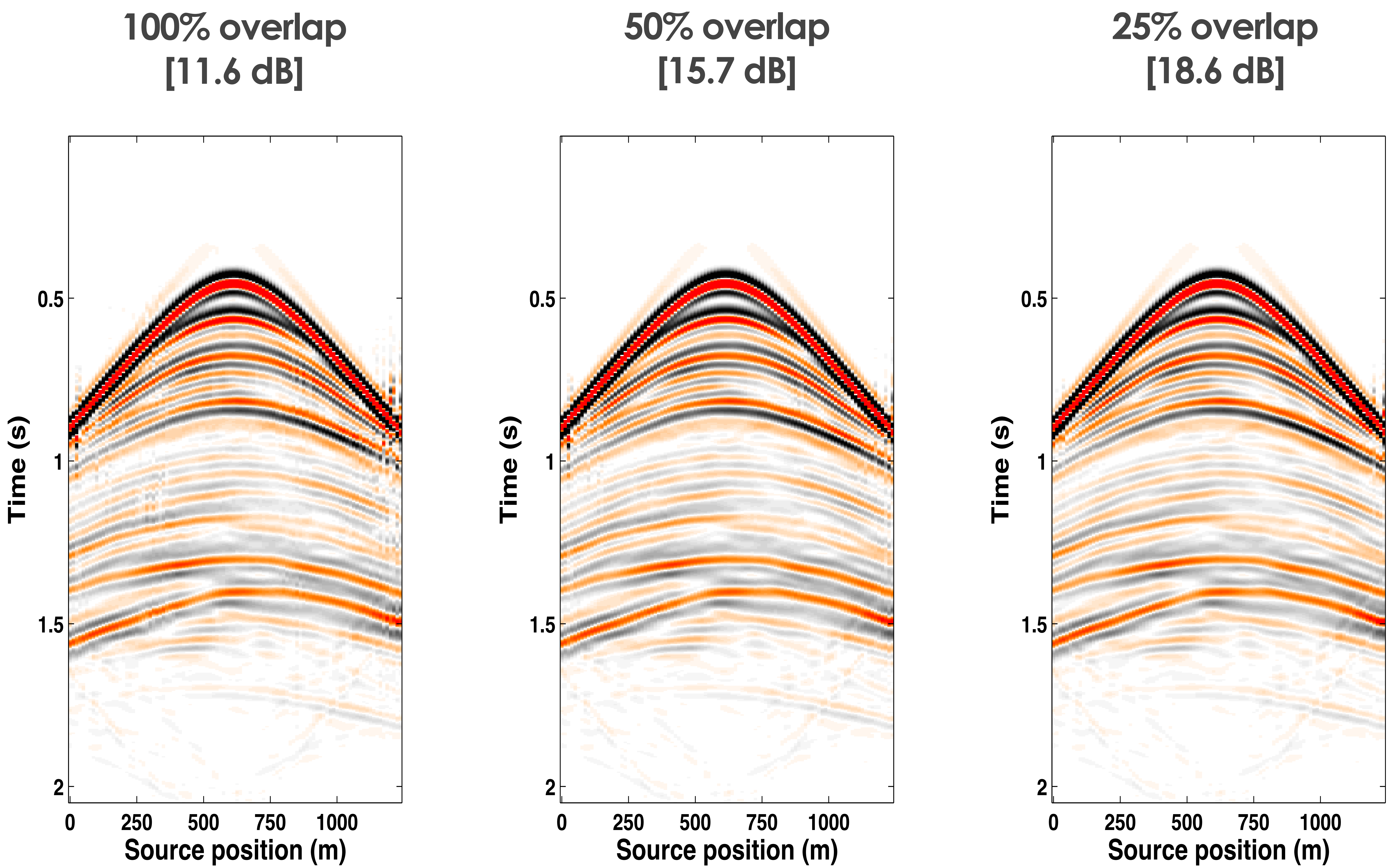
100% overlap [11.6 dB]

50% overlap [11.0 dB]

25% overlap [10.3 dB]

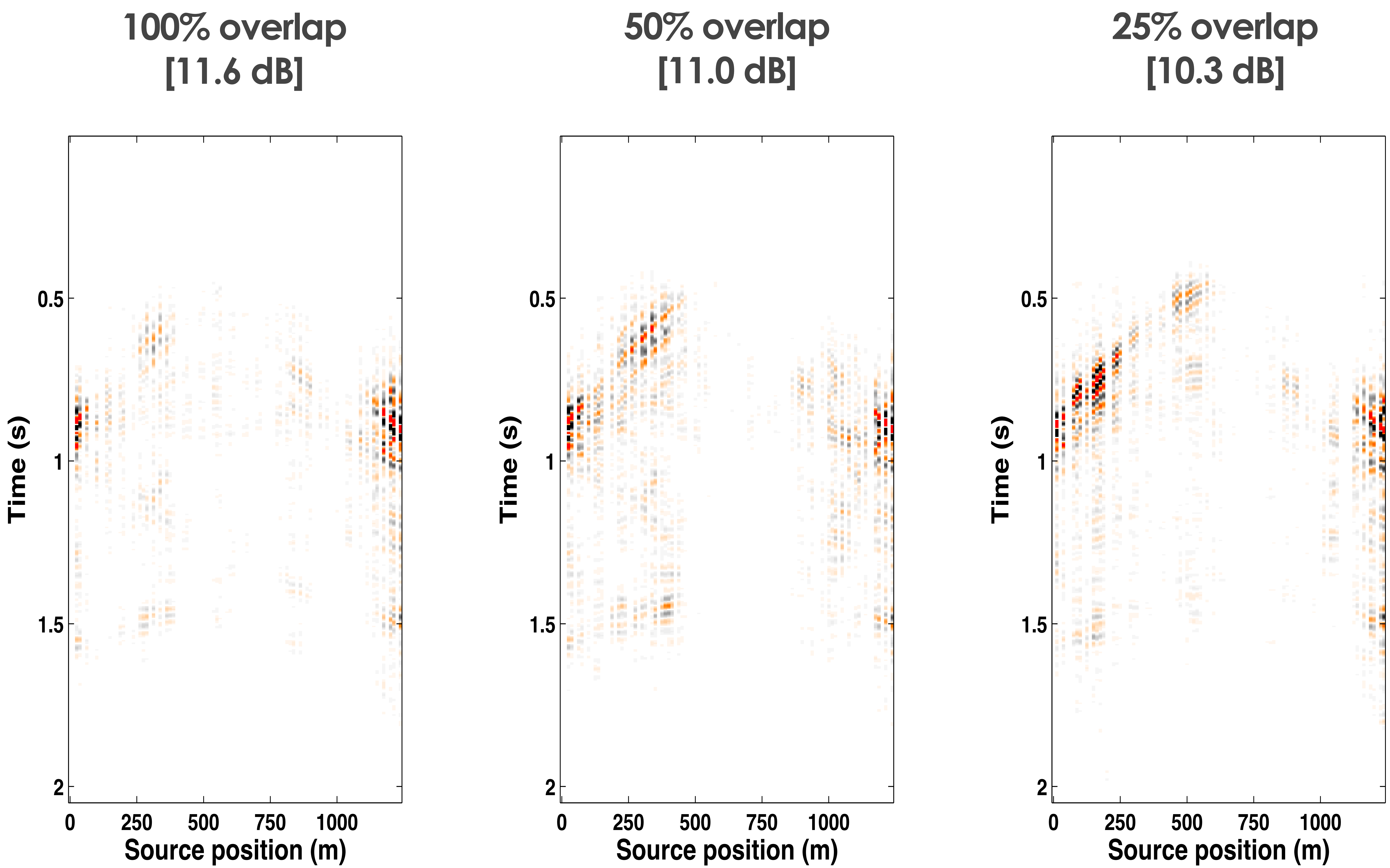


Monitor recovery
– Joint recovery



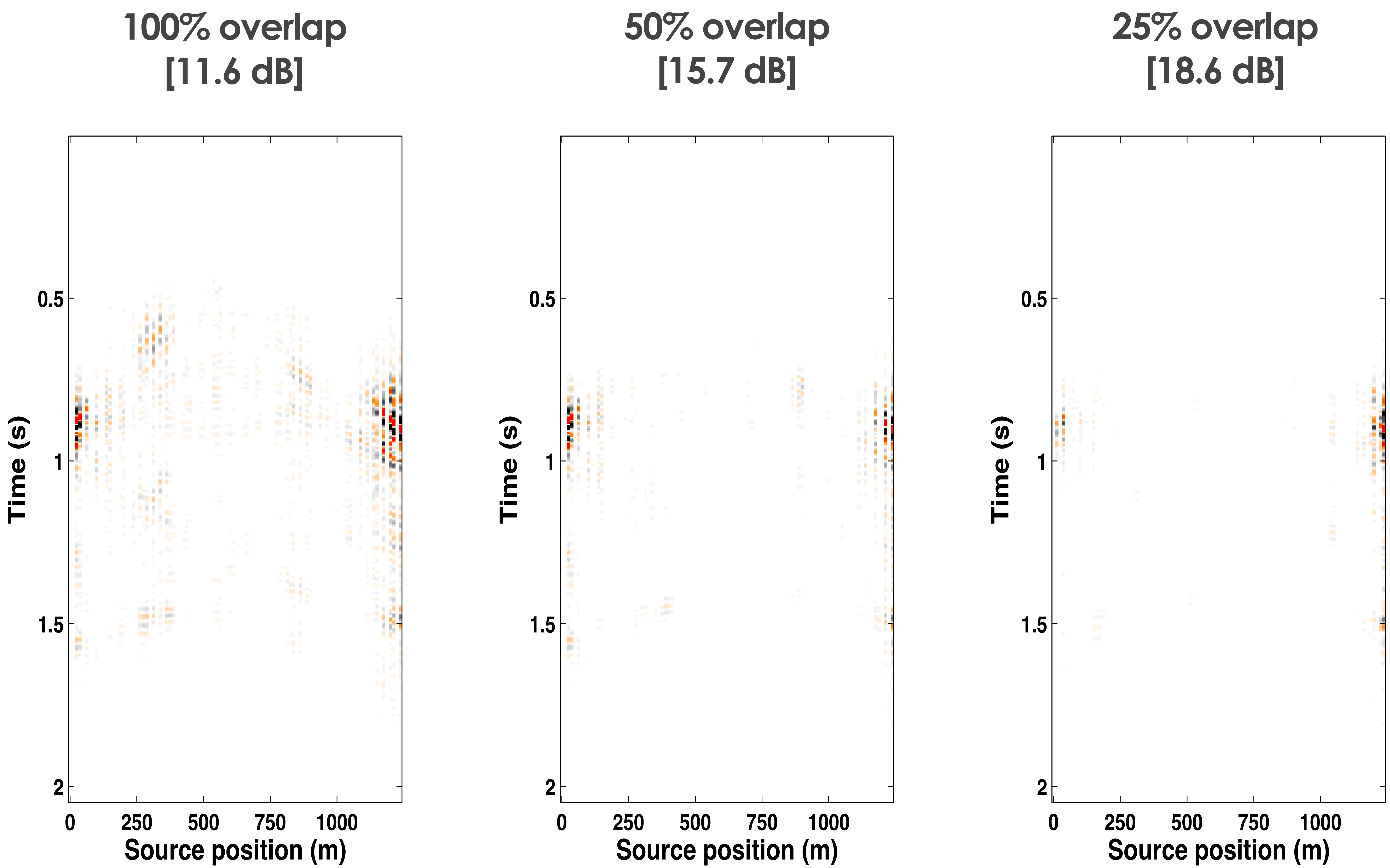
Monitor residual

– Independent residual



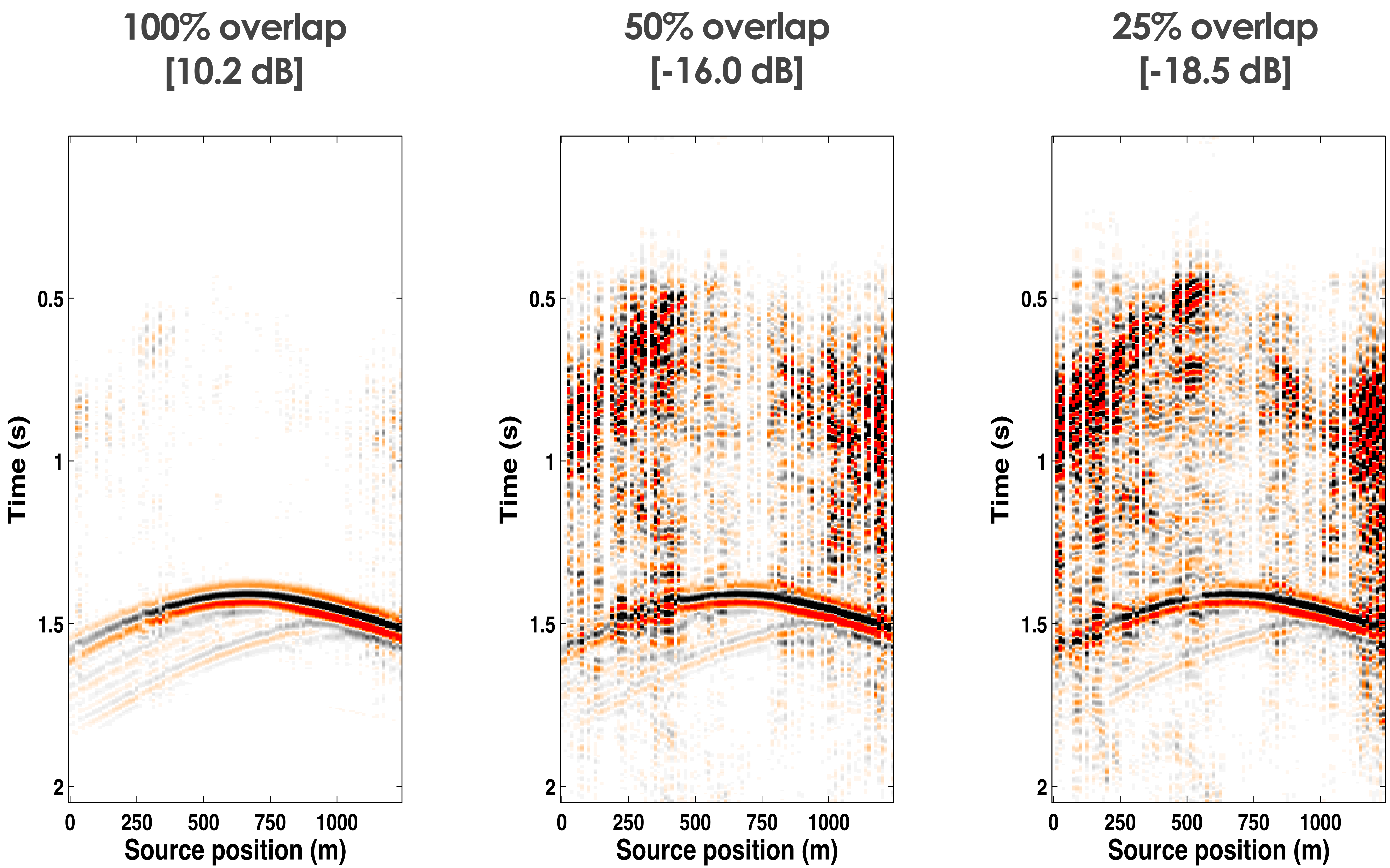
Monitor residual

– Joint residual



4-D recovery
– Independent recovery

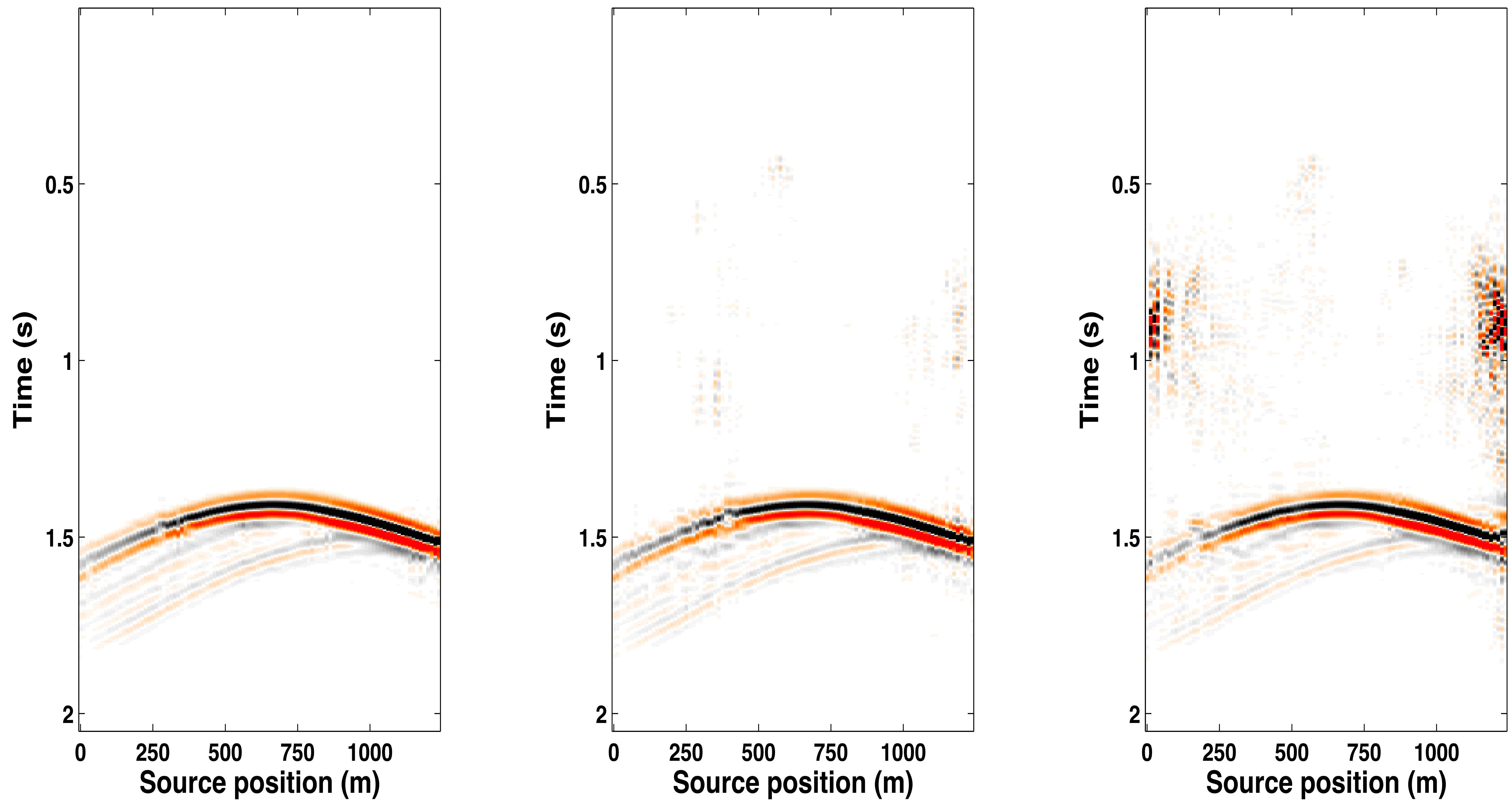
[colormap scale: 10 X]



4-D recovery
– Joint recovery

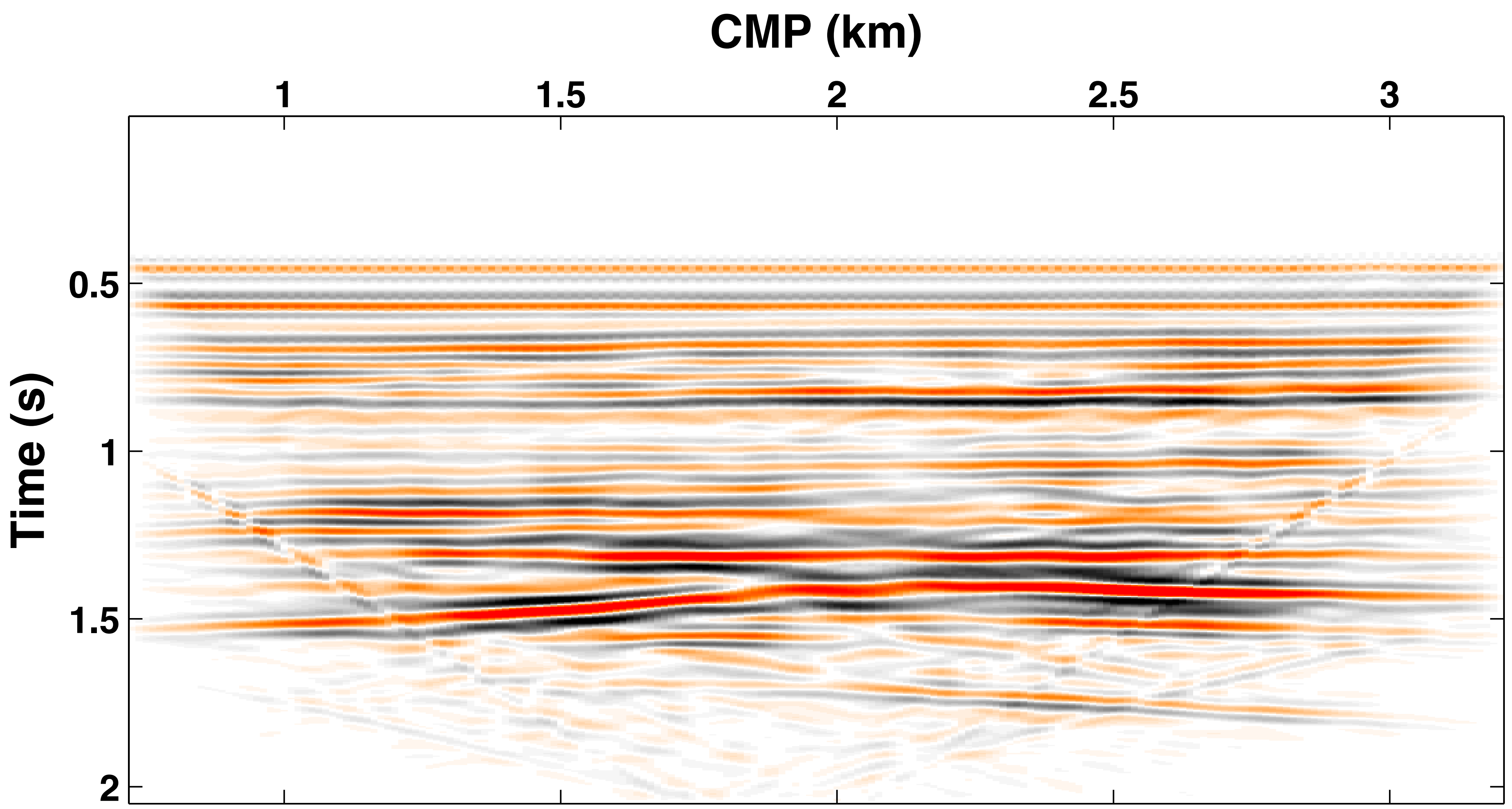
[colormap scale: 10 X]

100% overlap [12.8 dB] | 50% overlap [4.0 dB] | 25% overlap [-1.9 dB]

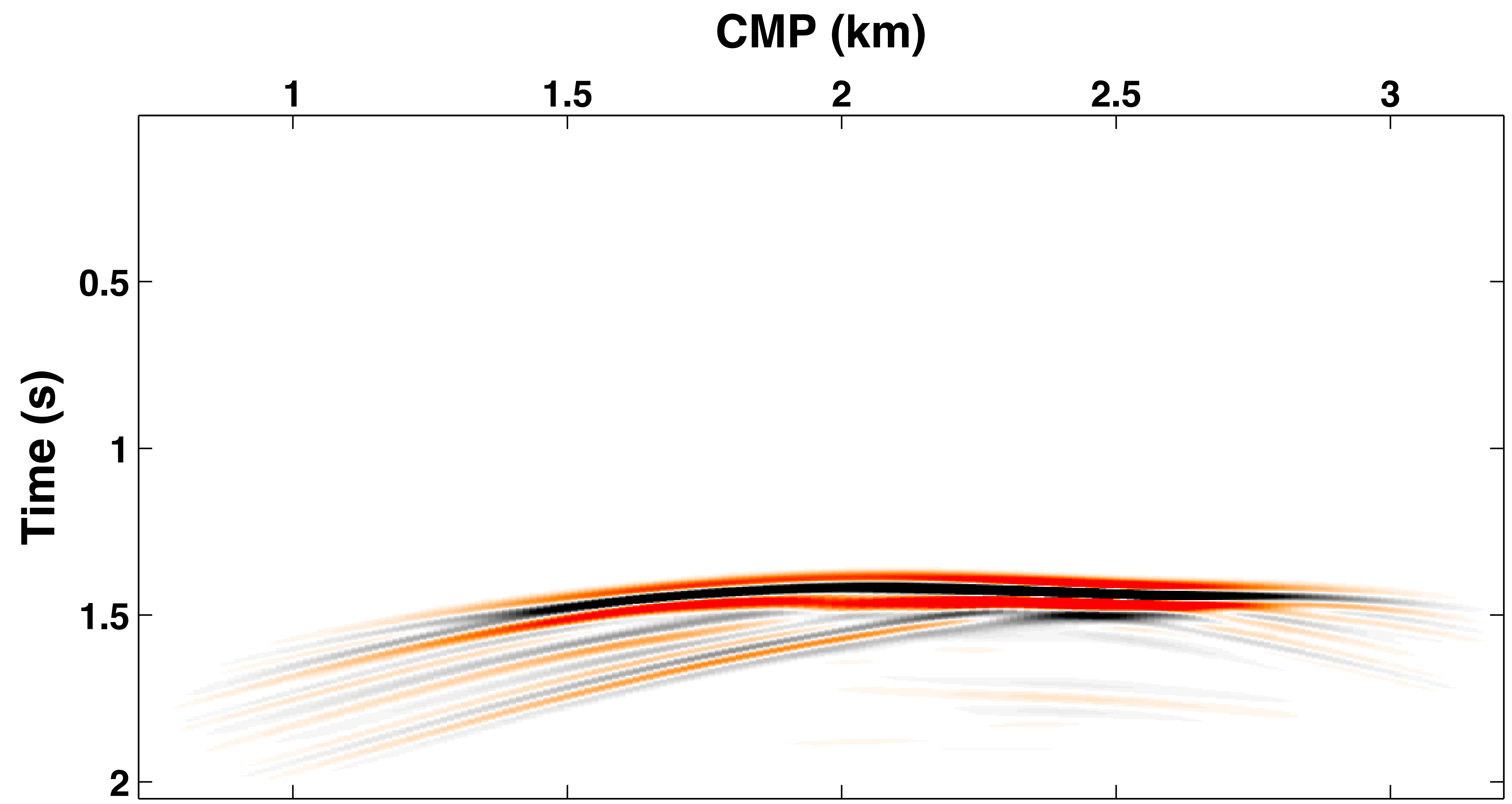


Stacked sections

Baseline



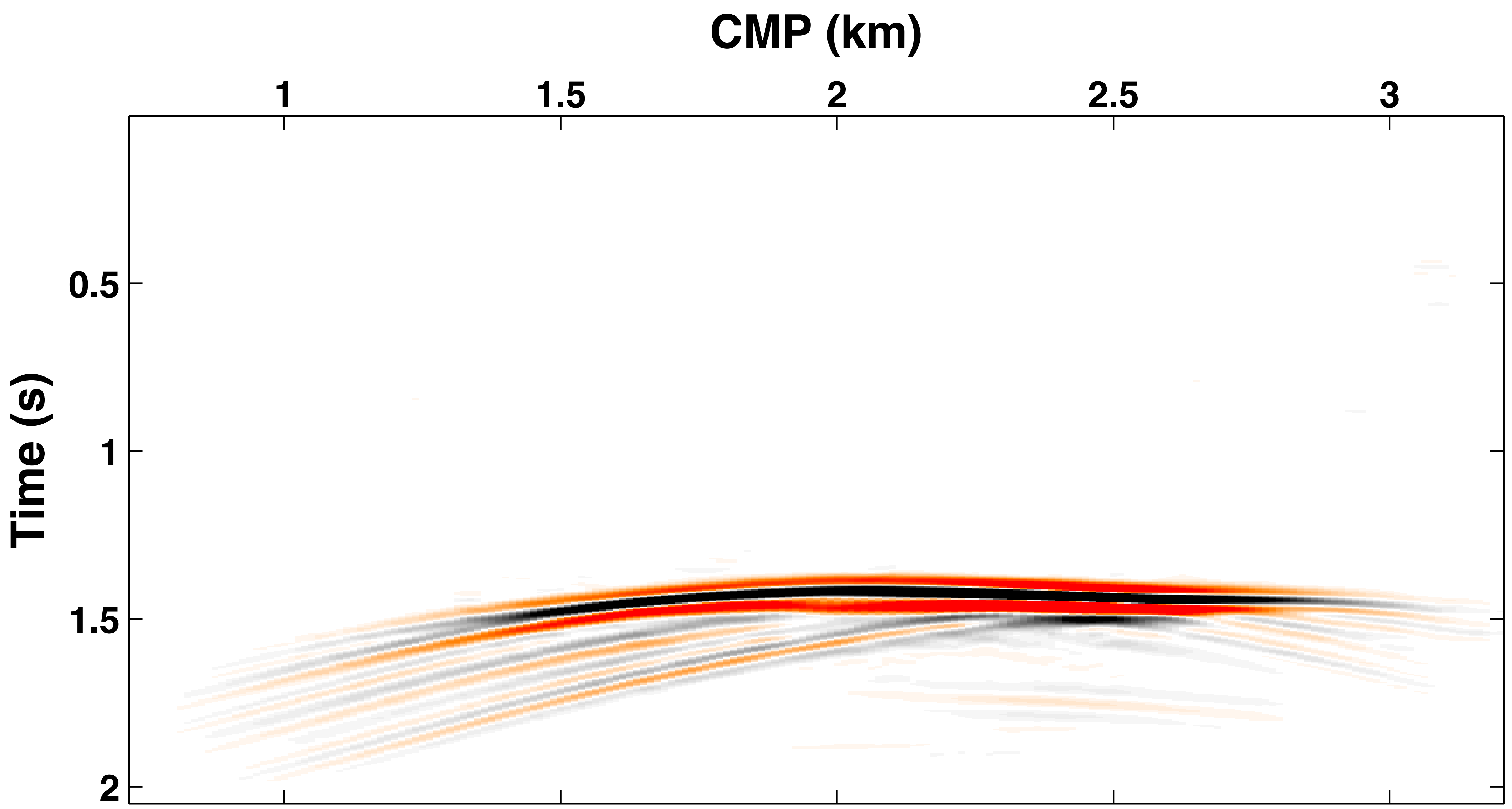
4-D signal
[10 X]



Stacked sections
– 100% overlap in acquisition matrices

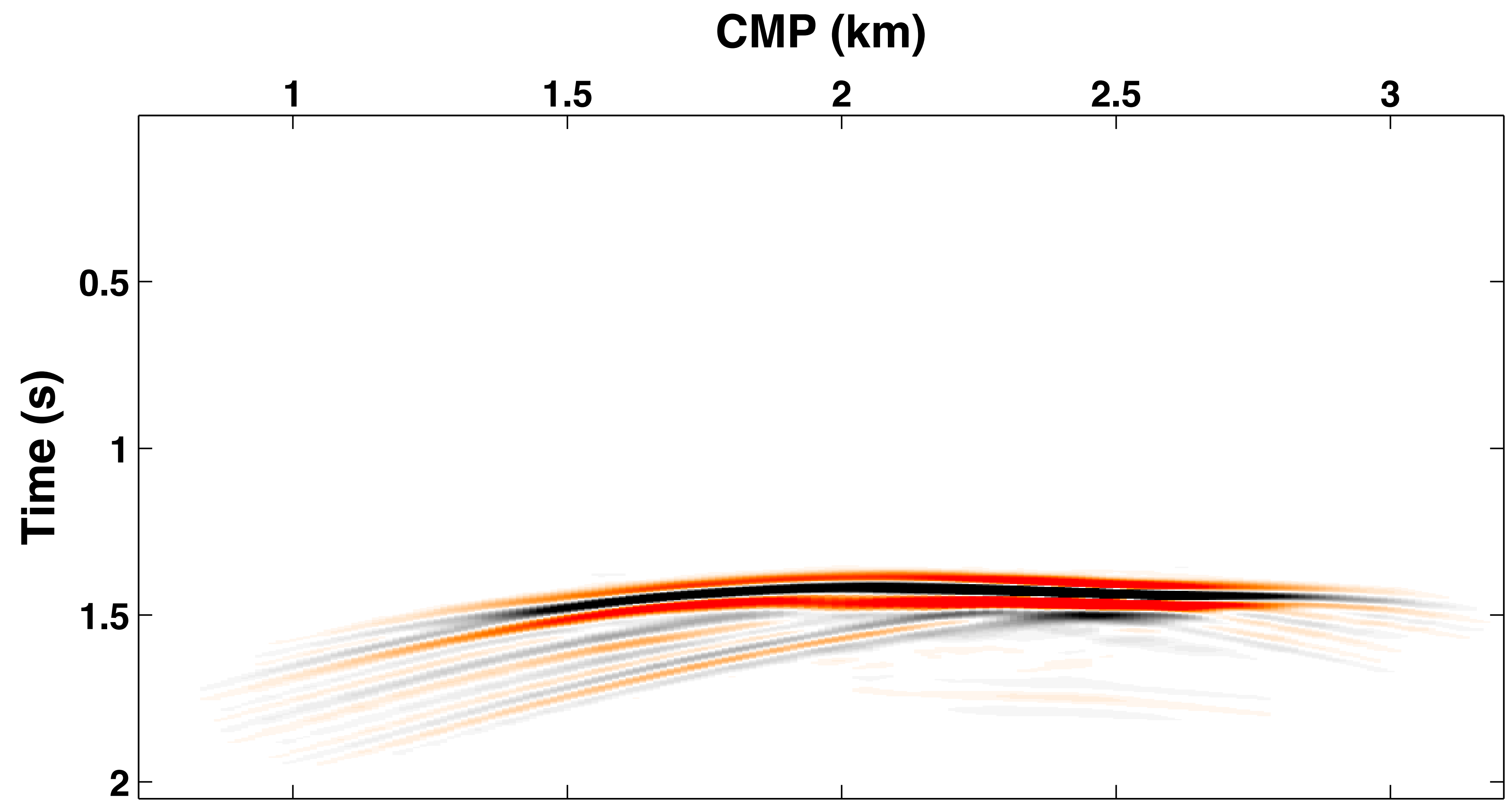
IRS

[25.2 dB]



JRM

[24.2 dB]

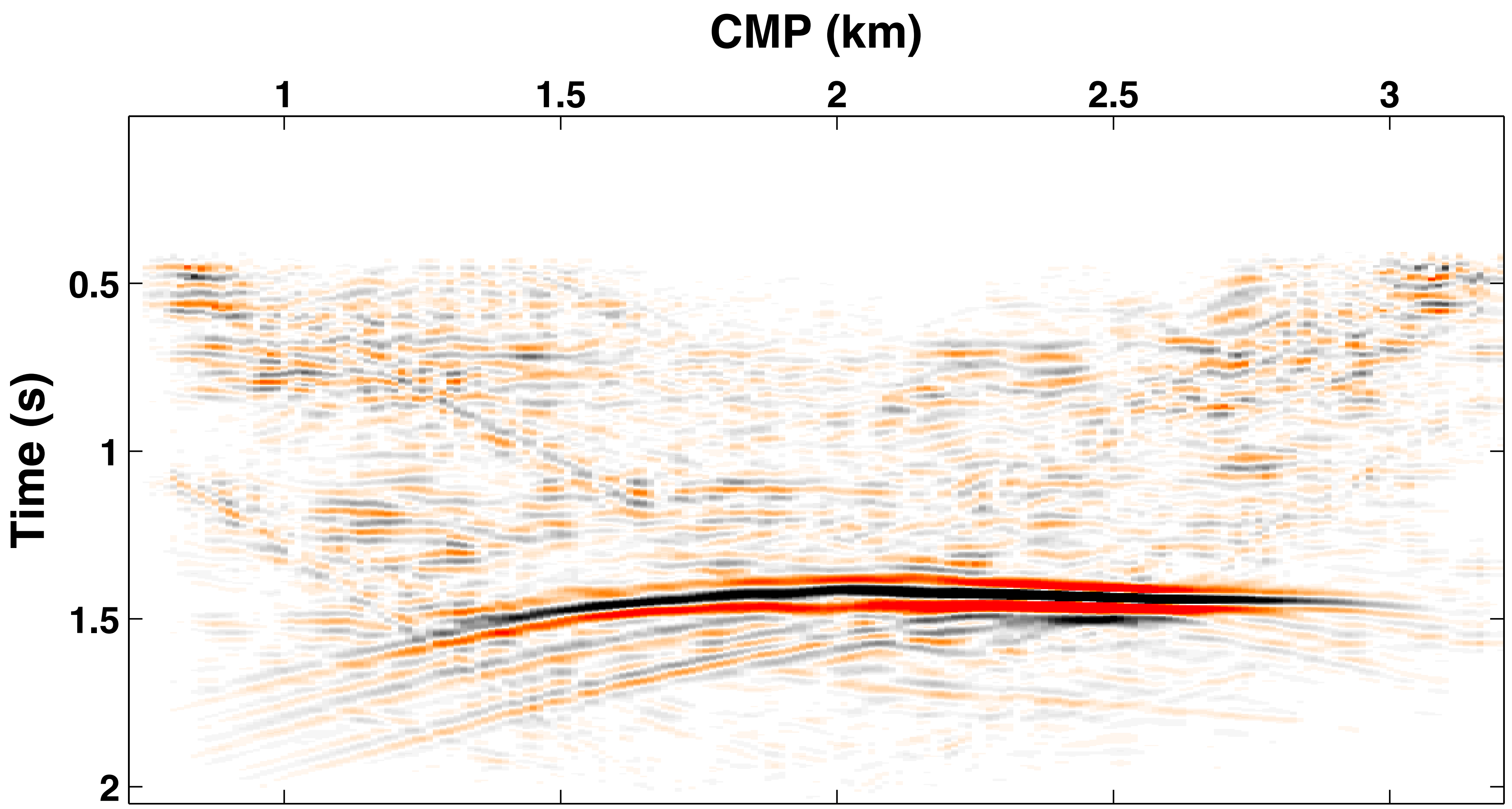


Stacked sections

– 50% overlap in acquisition matrices

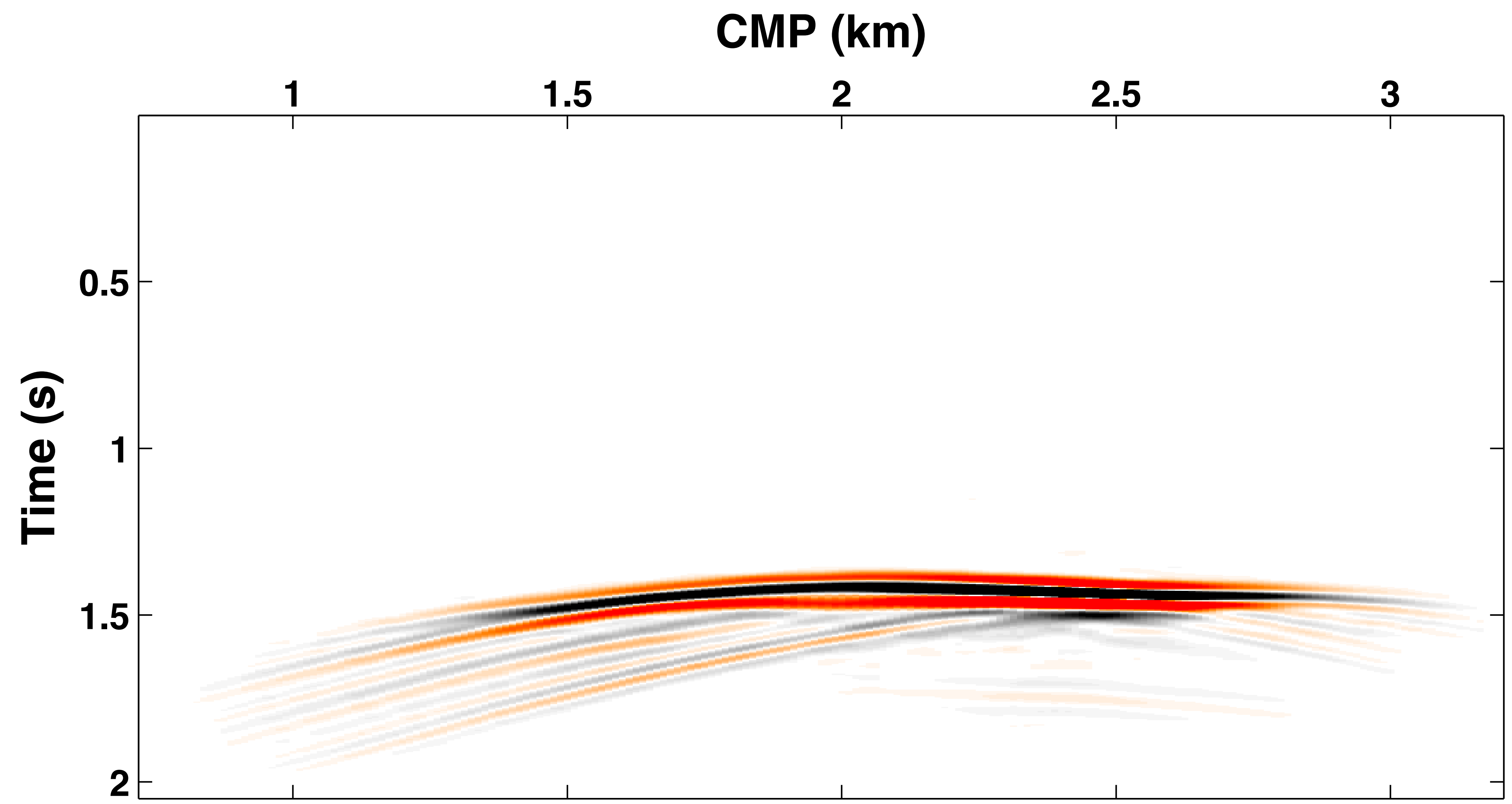
IRS

[9.7 dB]



JRM

[20.0 dB]

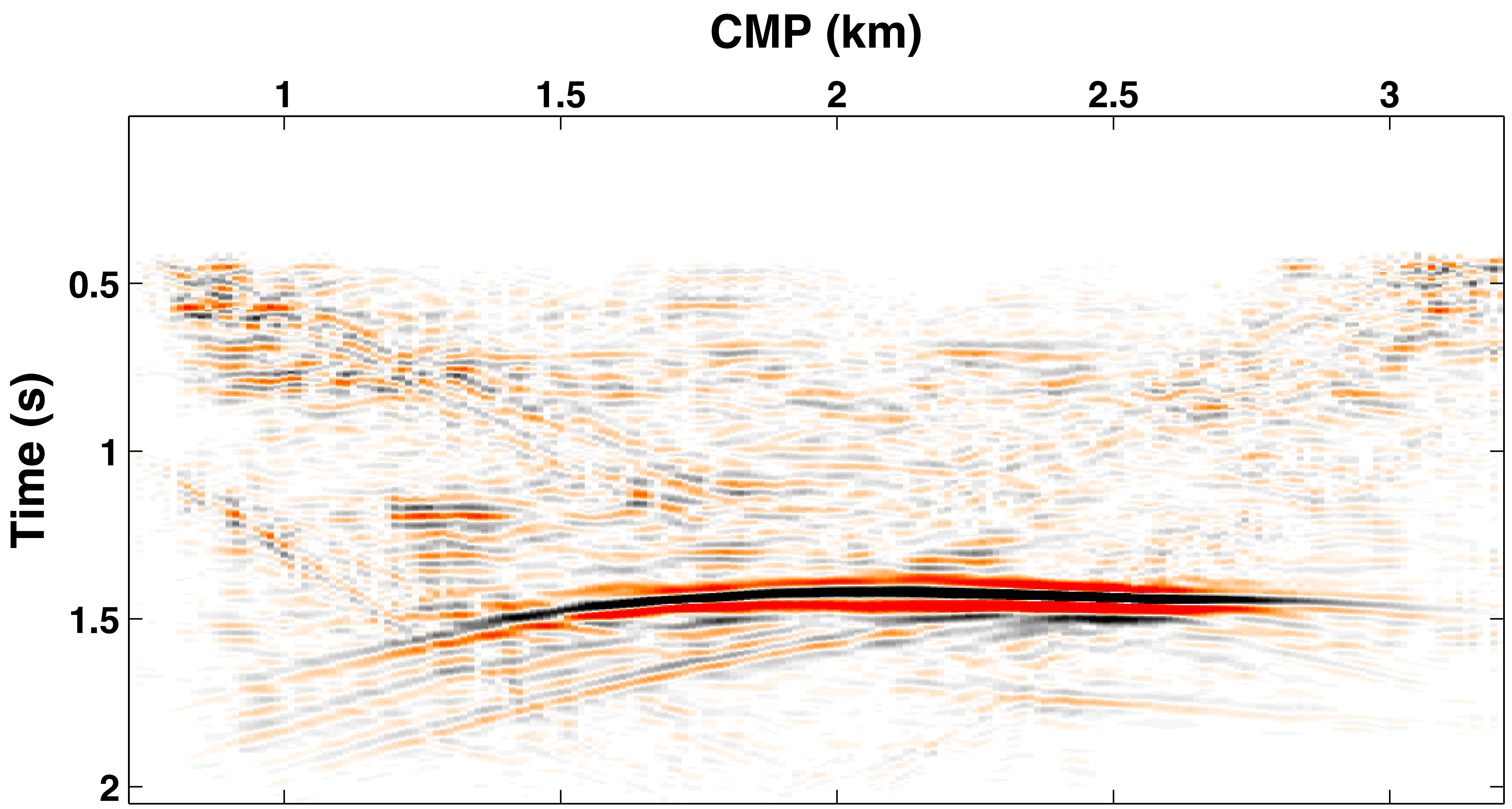


Stacked sections

– 25% overlap in acquisition matrices

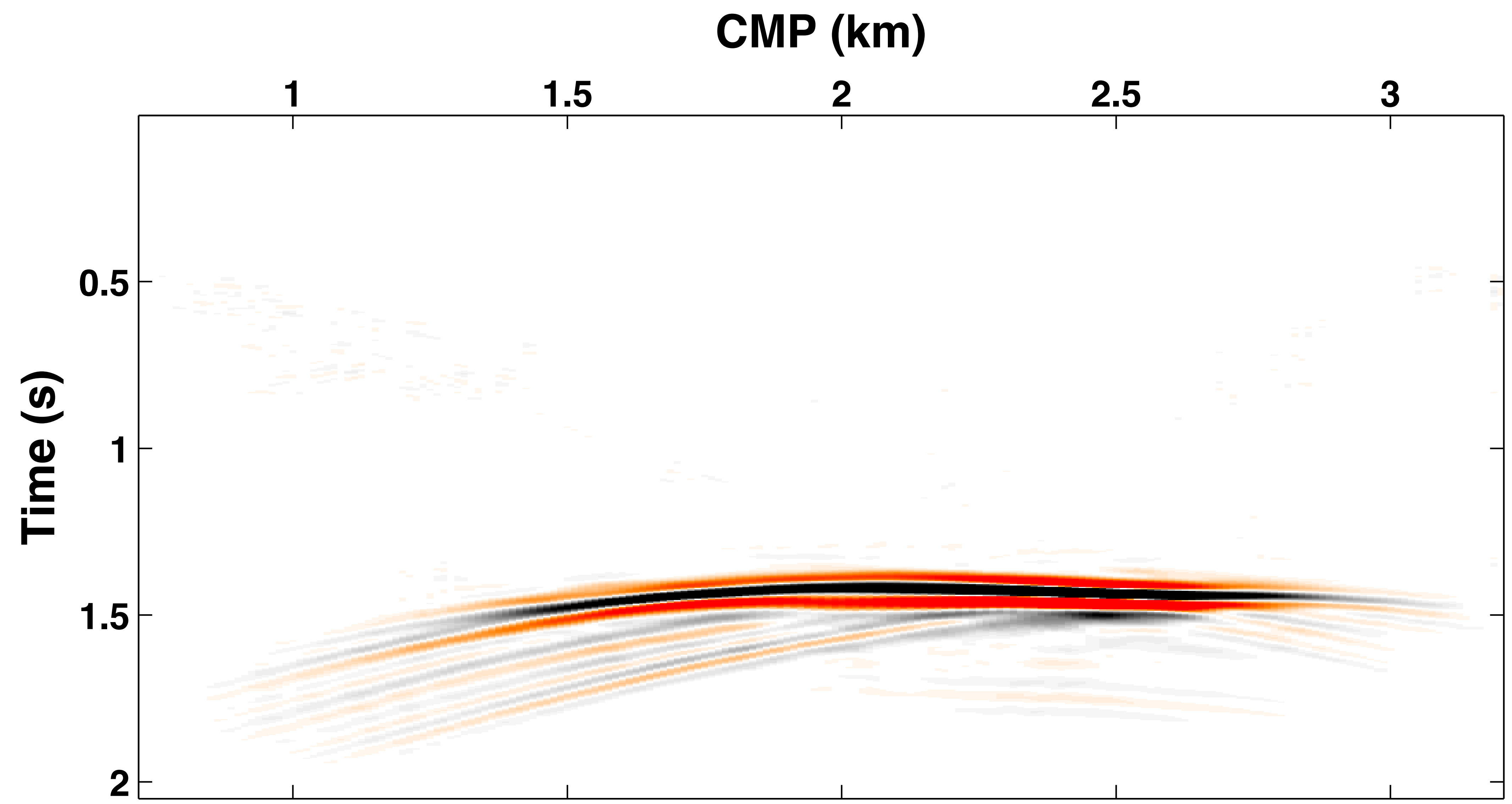
IRS

[9.5 dB]



JRM

[17.9 dB]



SNR (dB) for stacked sections
– average of 5 experiments

overlap	baseline		monitor		4-D signal	
	IRS	JRM	IRS	JRM	IRS	JRM
100%	25.6 ± 1.2	23.9 ± **1.0**	25.7 ± 1.1	24.0 ± **1.0**	25.0 ± 0.9	23.4 ± **0.8**
50%	25.6 ± 1.2	30.9 ± 1.3	24.3 ± 0.9	30.6 ± 1.4	10.1 ± 1.4	18.1 ± 0.9
25%	25.6 ± 1.2	**34.4 ± 0.9**	23.5 ± 1.3	**33.6 ± 0.8**	8.5 ± 1.3	**15.9 ± 0.7**

Observations

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

Questions:

Process/recover independently or jointly to exploit common features of surveys?

- processing jointly leads to improved recovery of **both** vintages & time-lapse signal

Should we repeat the surveys when doing randomized subsampling?

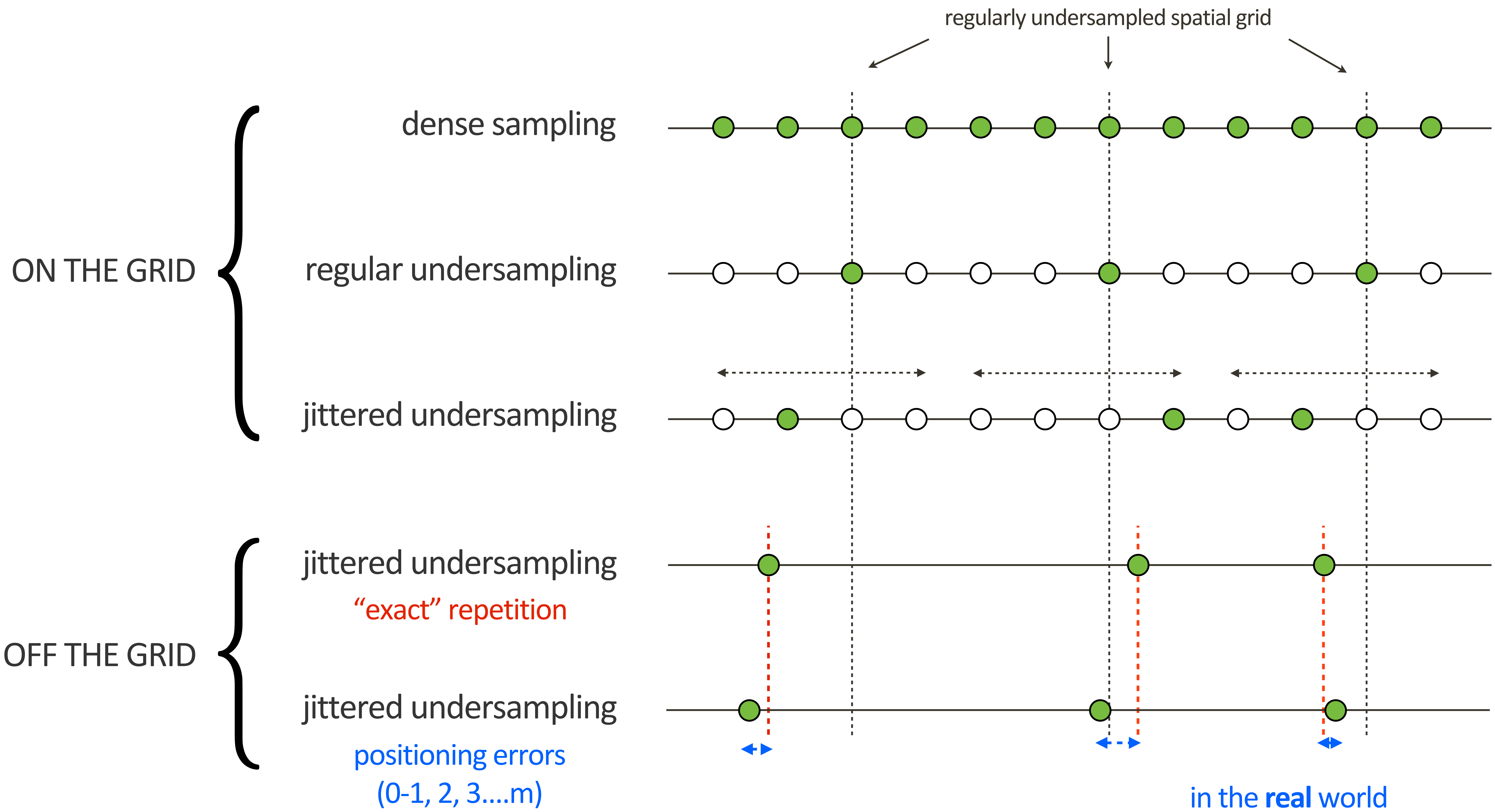
Is repetition in the field really possible?

Notion of repetition

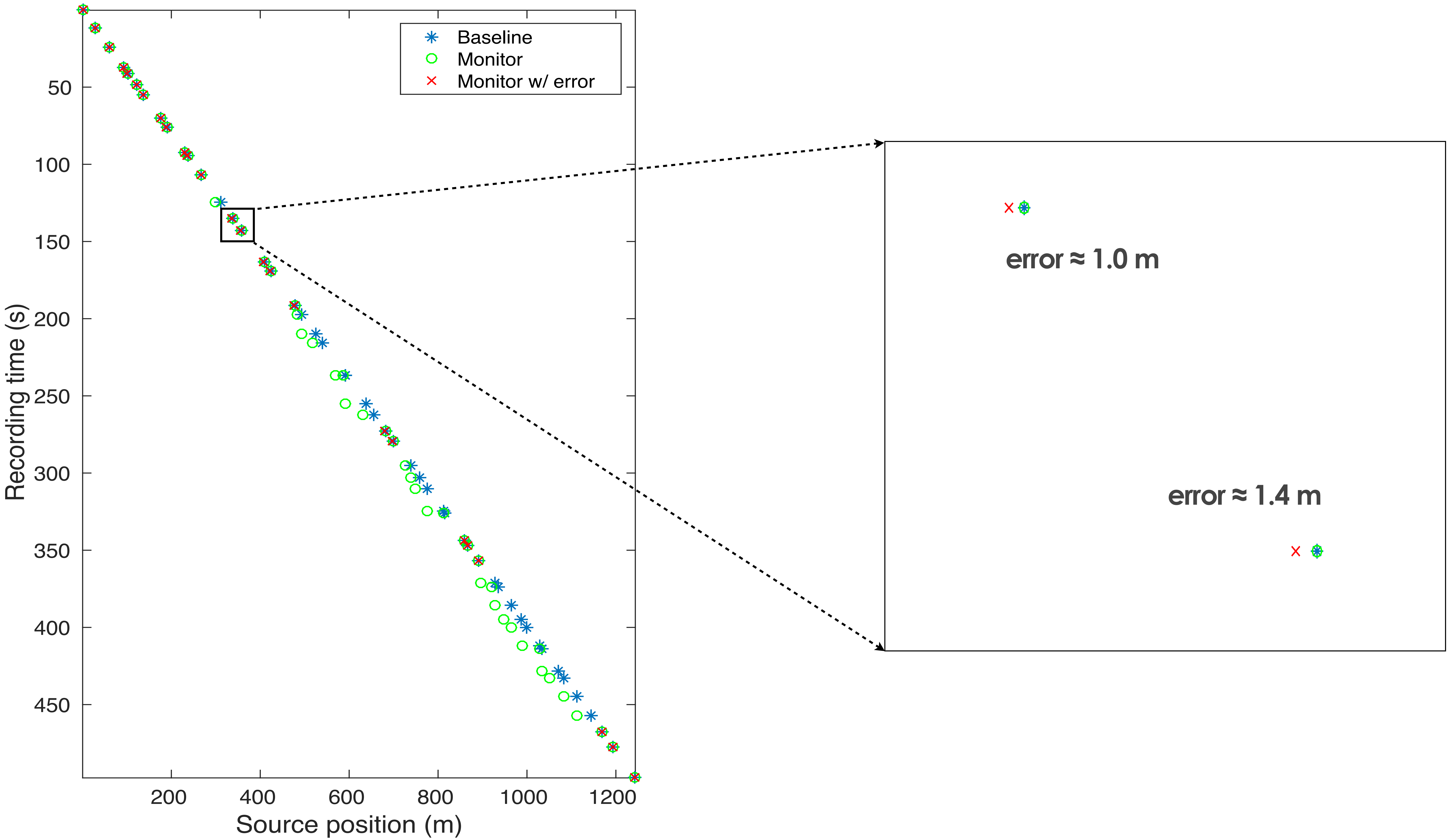
Time-jittered marine acquisition off the grid

With & without errors in shot locations

Randomized sampling in marine



4-D time-jittered marine acquisition

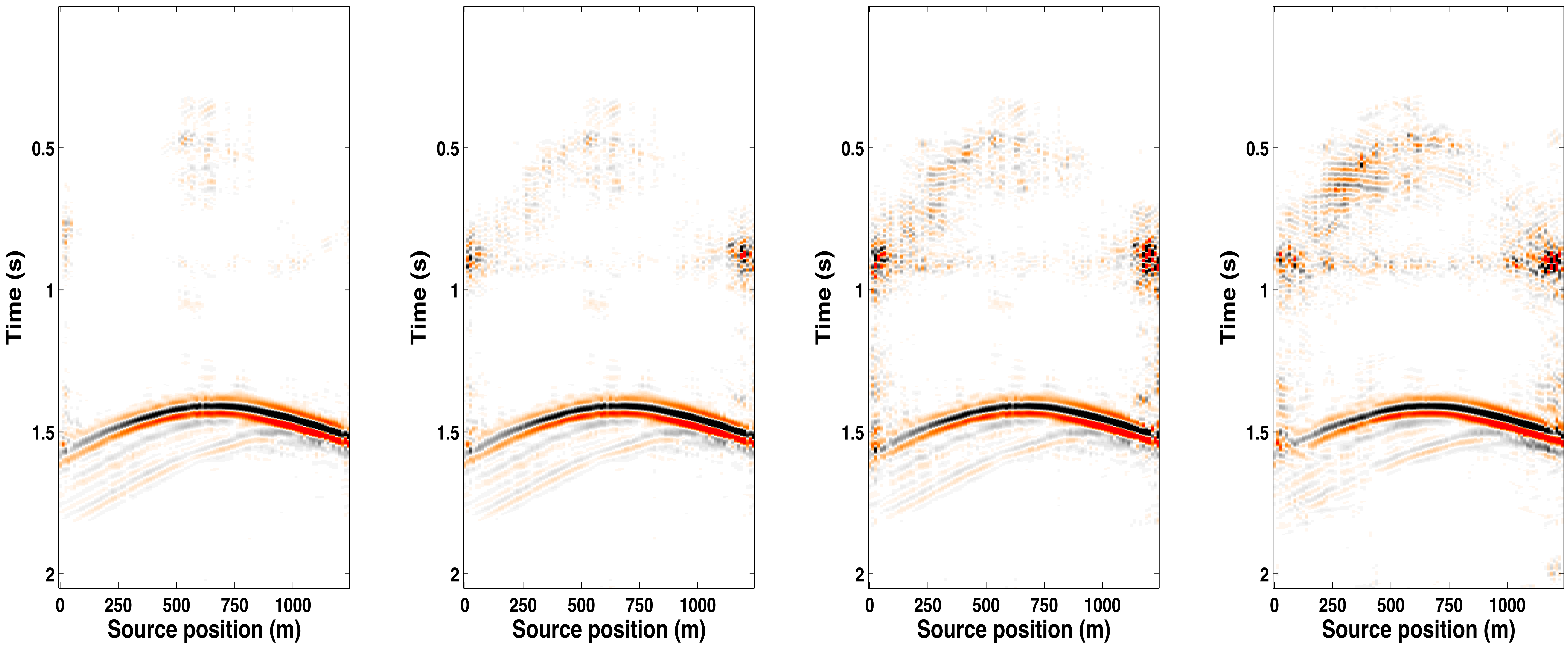


4-D recovery - JRM

– 50% overlap in acquisition matrices

0% overlap

no error [12.2 dB]	error ≈ 1.0 m [8.5 dB]	error ≈ 2.8 m [3.8 dB]	[2.0 dB]



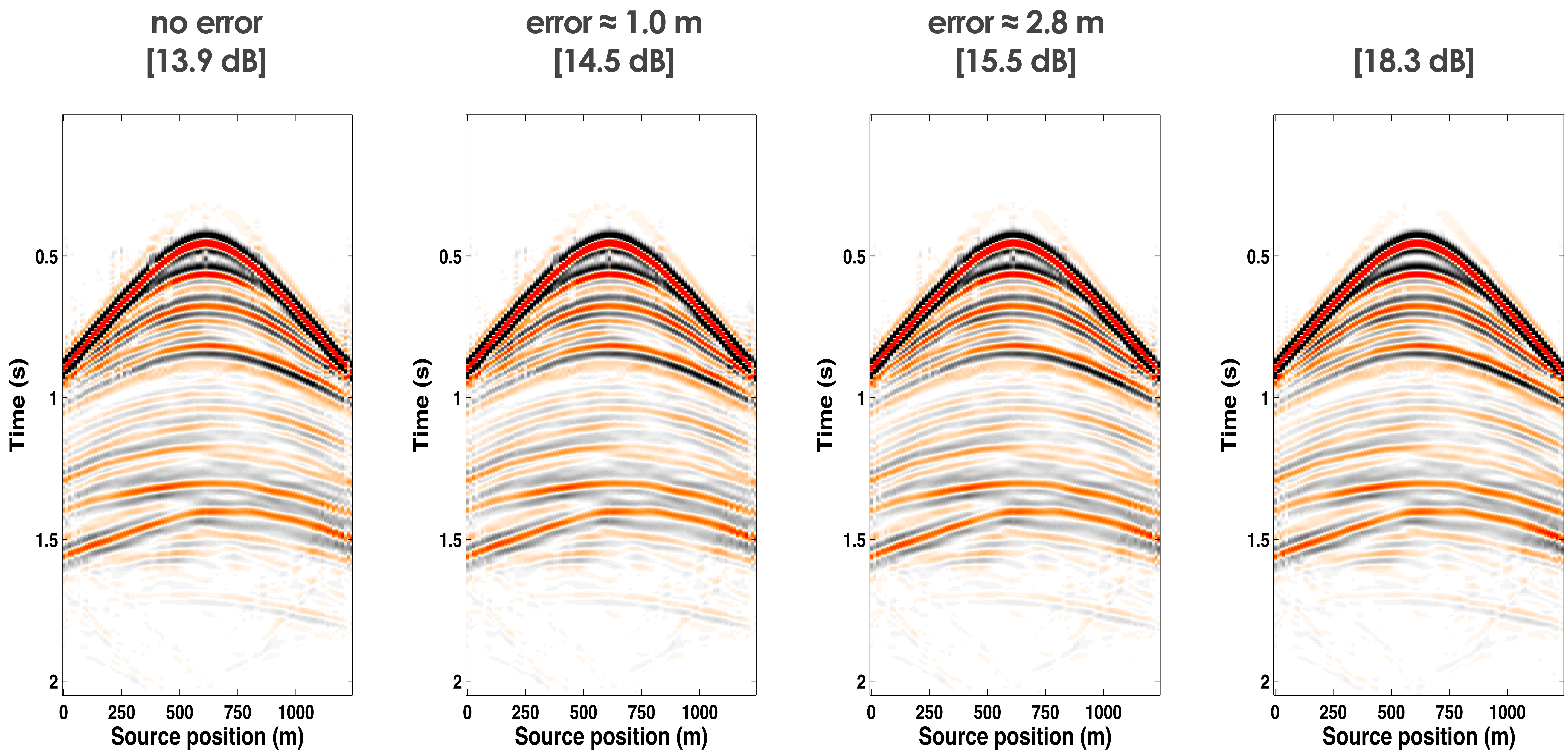
On the contrary,

calibration errors improve recovery of the vintages!

Monitor recovery - JRM

– 50% overlap in acquisition matrices

0% overlap

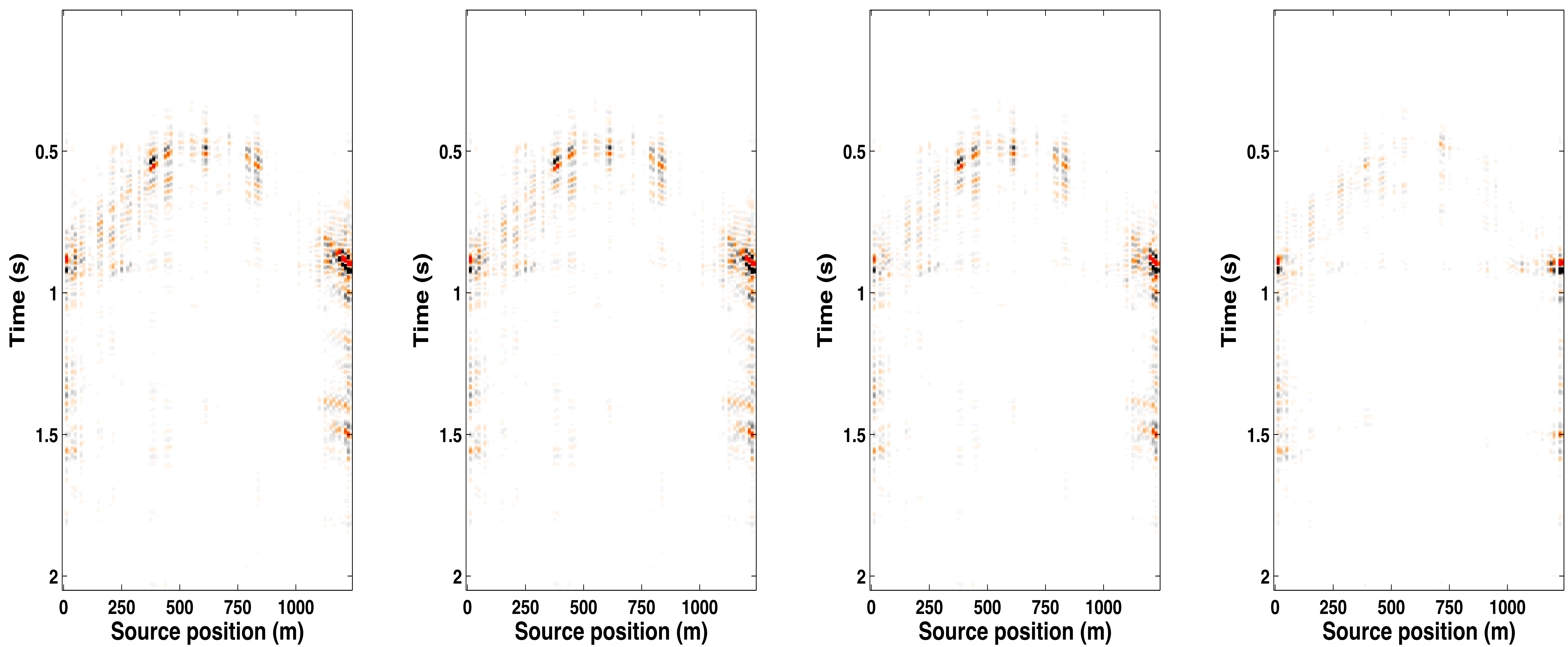


Monitor residual - JRM

– 50% overlap in acquisition matrices

0% overlap

no error | error ≈ 1.0 m | error ≈ 2.8 m



Observations

In the given context of randomized subsampling, errors in the shot locations

- deteriorate recovery of the time-lapse signal
- improve recovery of the vintages

“Exact” repeatability of the surveys seems essential for good recovery of the time-lapse signal

Summary

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

Processing time-lapse data jointly leads to improved recovery of both vintages & time-lapse signal

Since errors in the shot locations are inevitable in the real world, the insistence on repetition in time-lapse surveys can be relaxed

Current work

Application to more realistic 4-D data sets

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Acknowledgements

Thank you for your attention!

SINBAD

NSERC CRSNG

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