Randomization and repeatability in time-lapse marine acquisition

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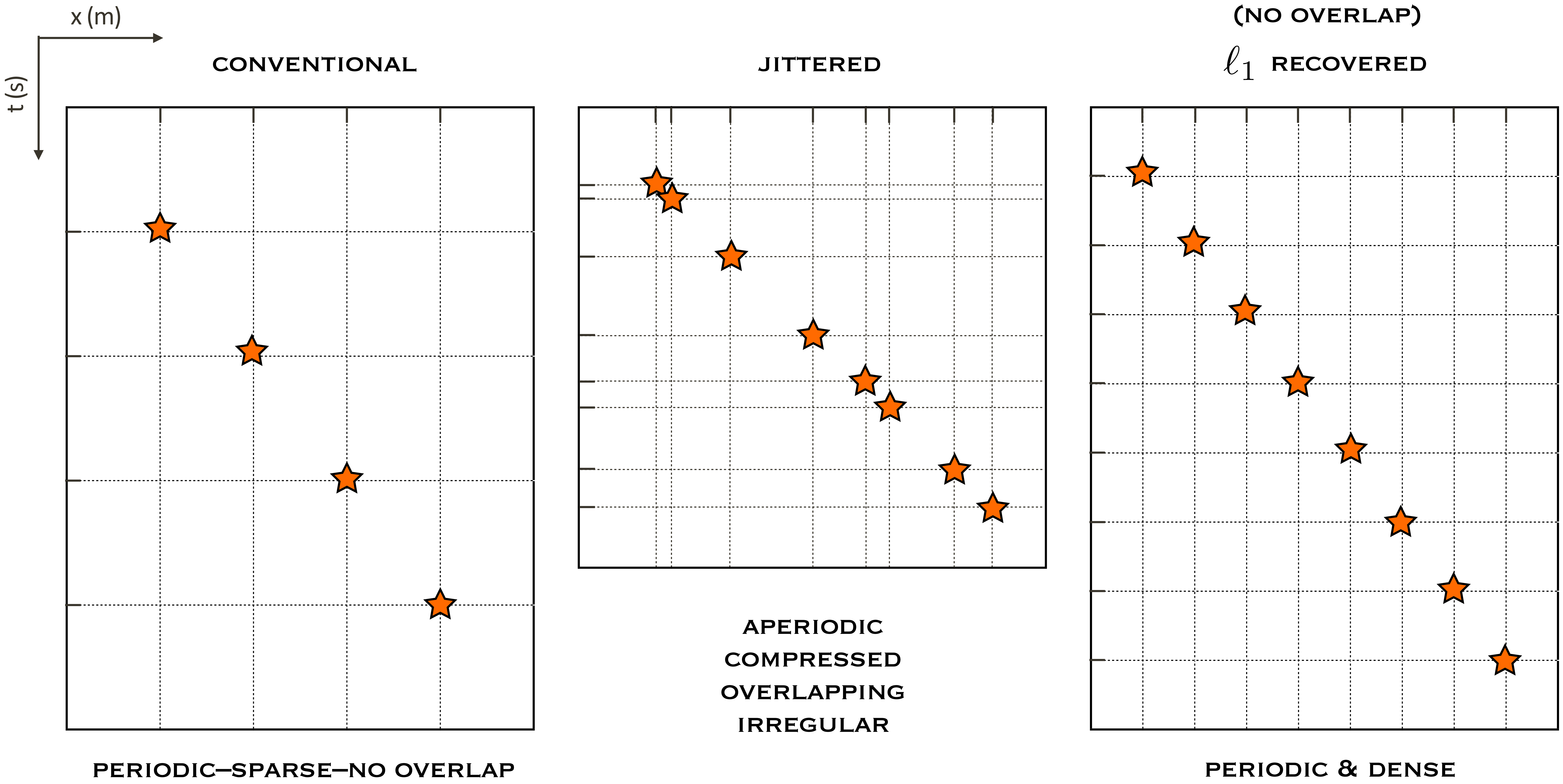
Randomized sampling in marine

[SINBAD 2013]



CONVENTIONAL

PERIODIC–SPARSE–NO OVERLAP

JITTERED

APERIODIC
COMPRESSED
OVERLAPPING
IRREGULAR

(NO OVERLAP)

ℓ_1 RECOVERED

PERIODIC & DENSE

Motivation

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

Should we repeat in randomized marine acquisition?

Felix Oghenekohwo, Haneet Wason, and Felix J. Herrmann, "**Compressive 4D---economic time-lapse seismic with randomized subsampling and joint recovery**", submitted to *Geophysics*, October 2014.
Haneet Wason, and Felix J. Herrmann, "**Time-jittered ocean bottom seismic acquisition**", in *SEG Technical Program Expanded Abstracts*, 2013, p. 1-6.
Hassan Mansour, Haneet Wason, Tim T.Y. Lin, and Felix J. Herrmann, "**Randomized marine acquisition with compressive sampling matrices**", *Geophysical Prospecting*, vol. 60, p. 648-662, 2012

Time-lapse seismic

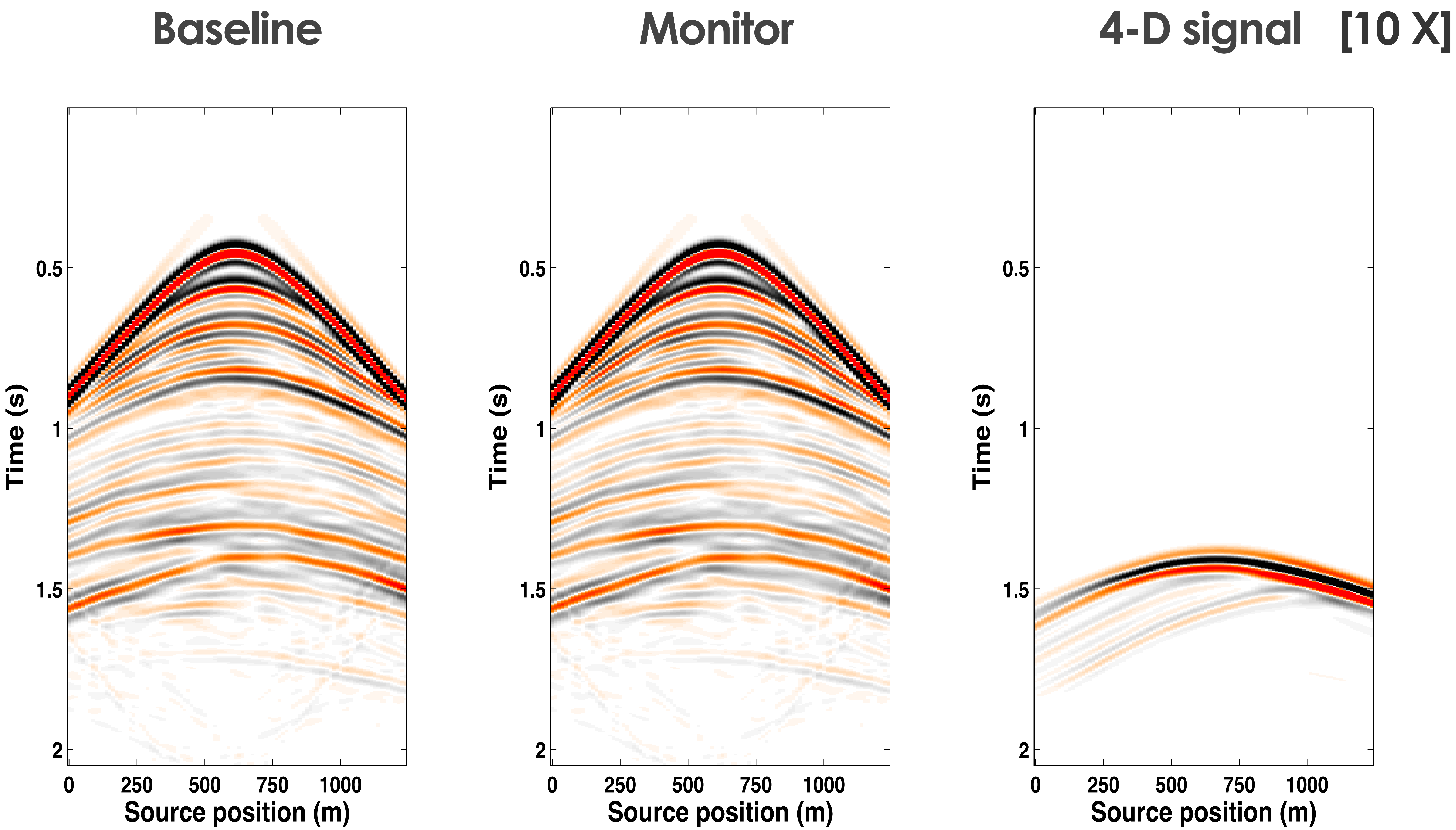
Current acquisition *paradigm*:

- *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** *sub*sampled acquisition, e.g. via time-*jittered* marine *sub*sampling
- may offer *possibility* to *relax* insistence on *repeatability*
- *exploits* insights from *distributed* compressed sensing

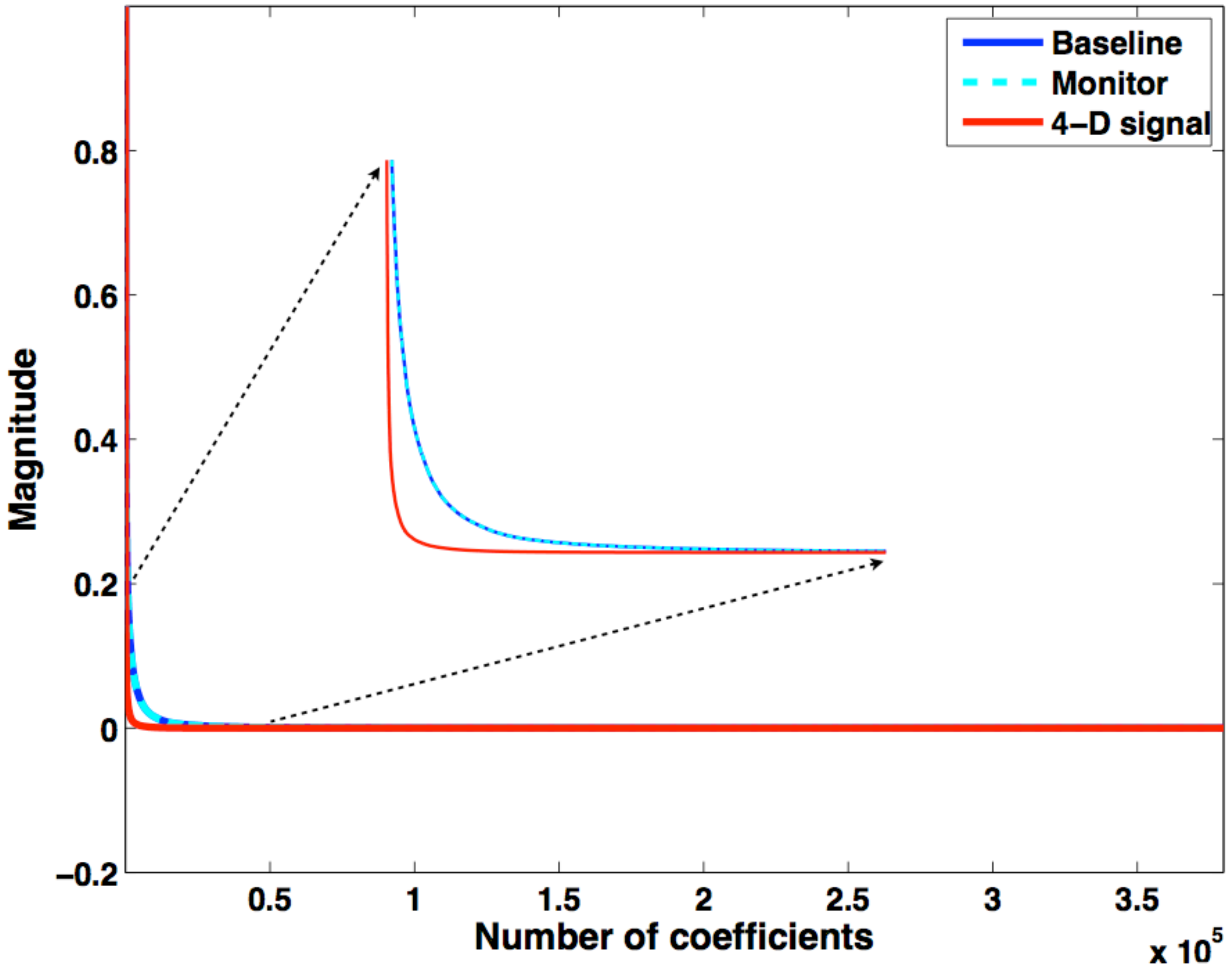
Time-lapse data



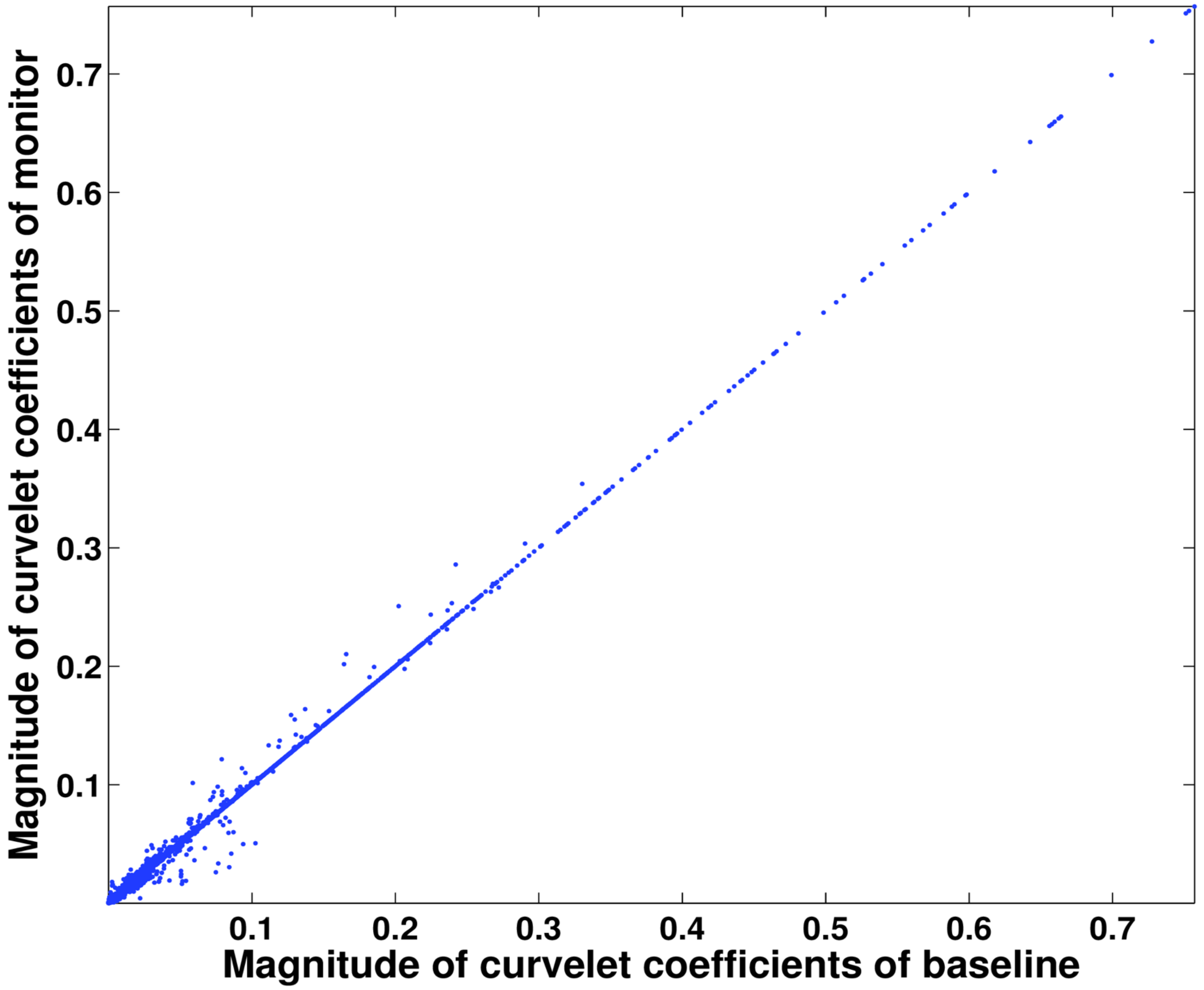
time samples: **512**
receivers: **100**
sources: **100**

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)

Distributed compressed sensing

– *joint* recovery model (JRM)

vintages

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

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

differences

***common* component**

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

baseline

monitor

Key idea:

- use the fact that *different* vintages *share* common information
- invert for *common* components & *differences* w.r.t. the *common* components with *sparse* recovery

Time-lapse seismic

– w/ & w/o *repetition*

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

- JRM *simplifies* to recovering the *difference* from $(\mathbf{b}_2 - \mathbf{b}_1) = \mathbf{A}_1(\mathbf{x}_2 - \mathbf{x}_1)$
- 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*
- *calibration* errors
- noise...

Time-lapse seismic

– w/ & w/o *repetition*

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

- no absolute *control* on *surveys*
- *calibration* errors
- noise...

What does repetition really mean?

Context

Acquire randomized subsamplings for the baseline and monitor surveys

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

Questions:

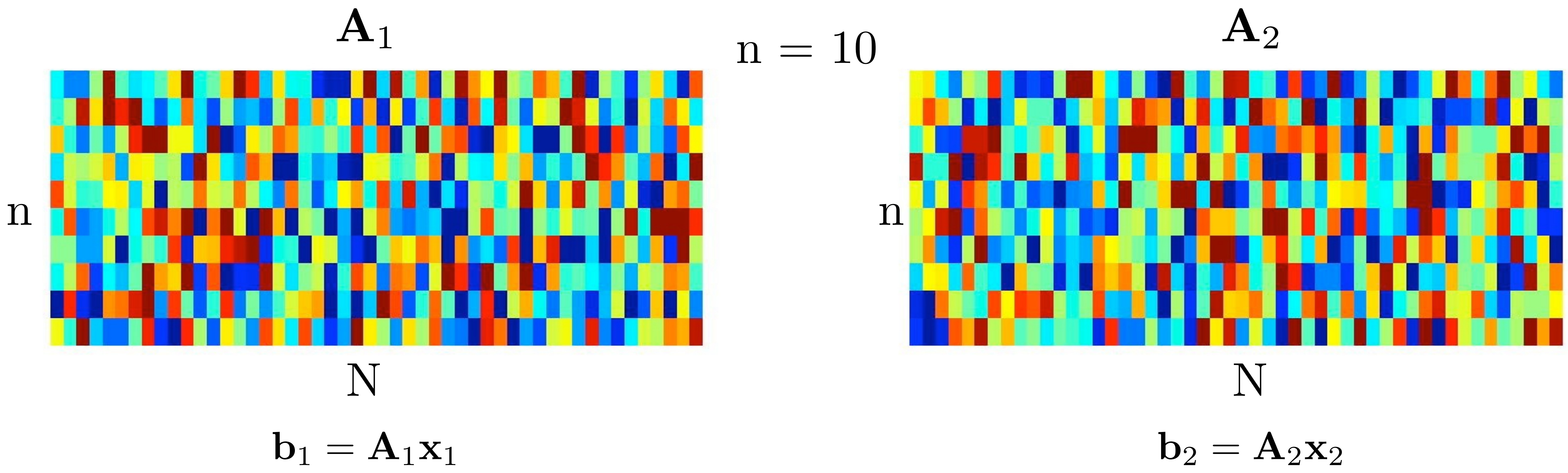
- Process/recover *independently* or *jointly* to exploit *common* features of surveys?
- Should we *repeat* the surveys when doing *randomized sub*sampling?

Stylized experiments

Stylized experiments

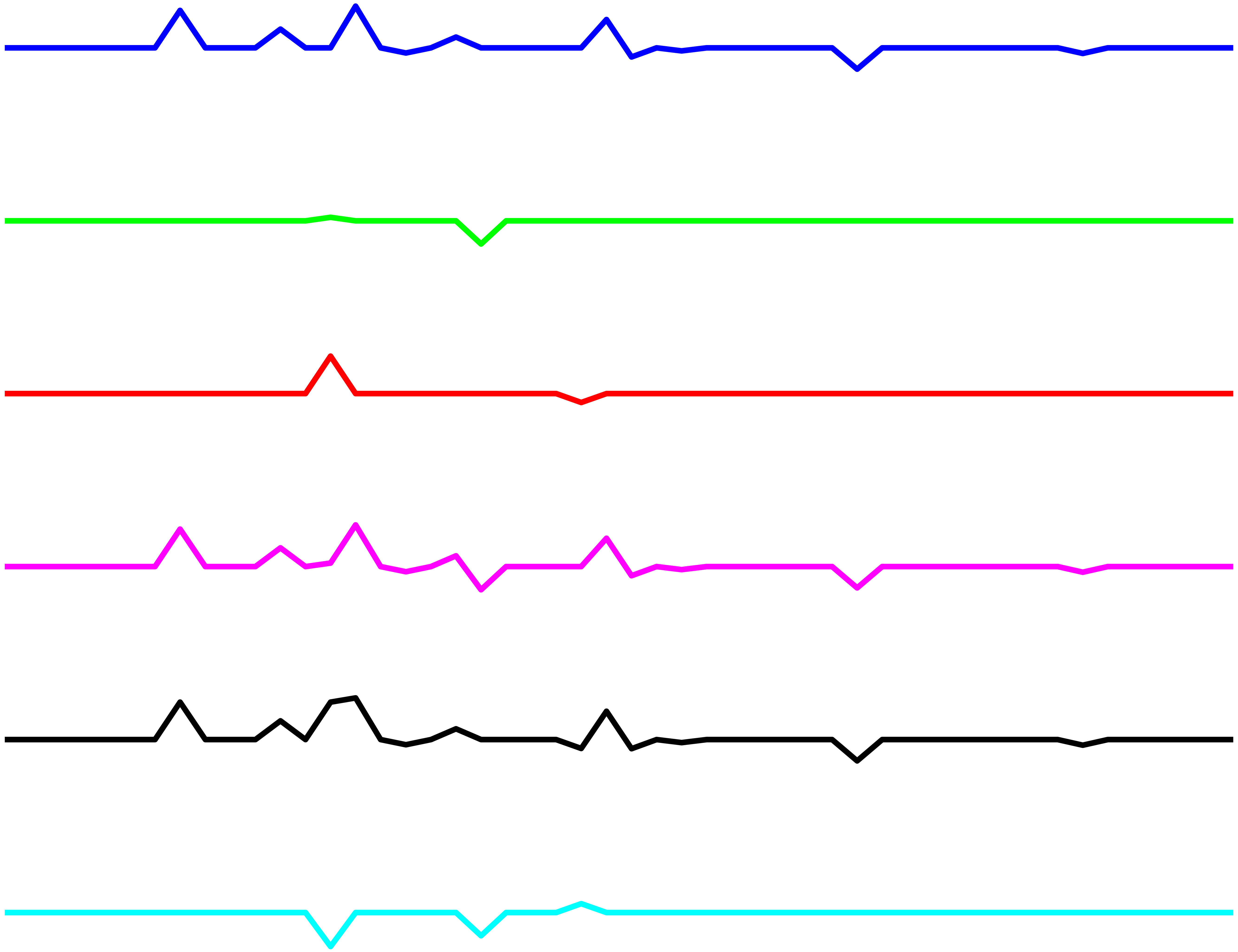
Conduct *many* CS experiments to compare

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



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***

} ***vintages***

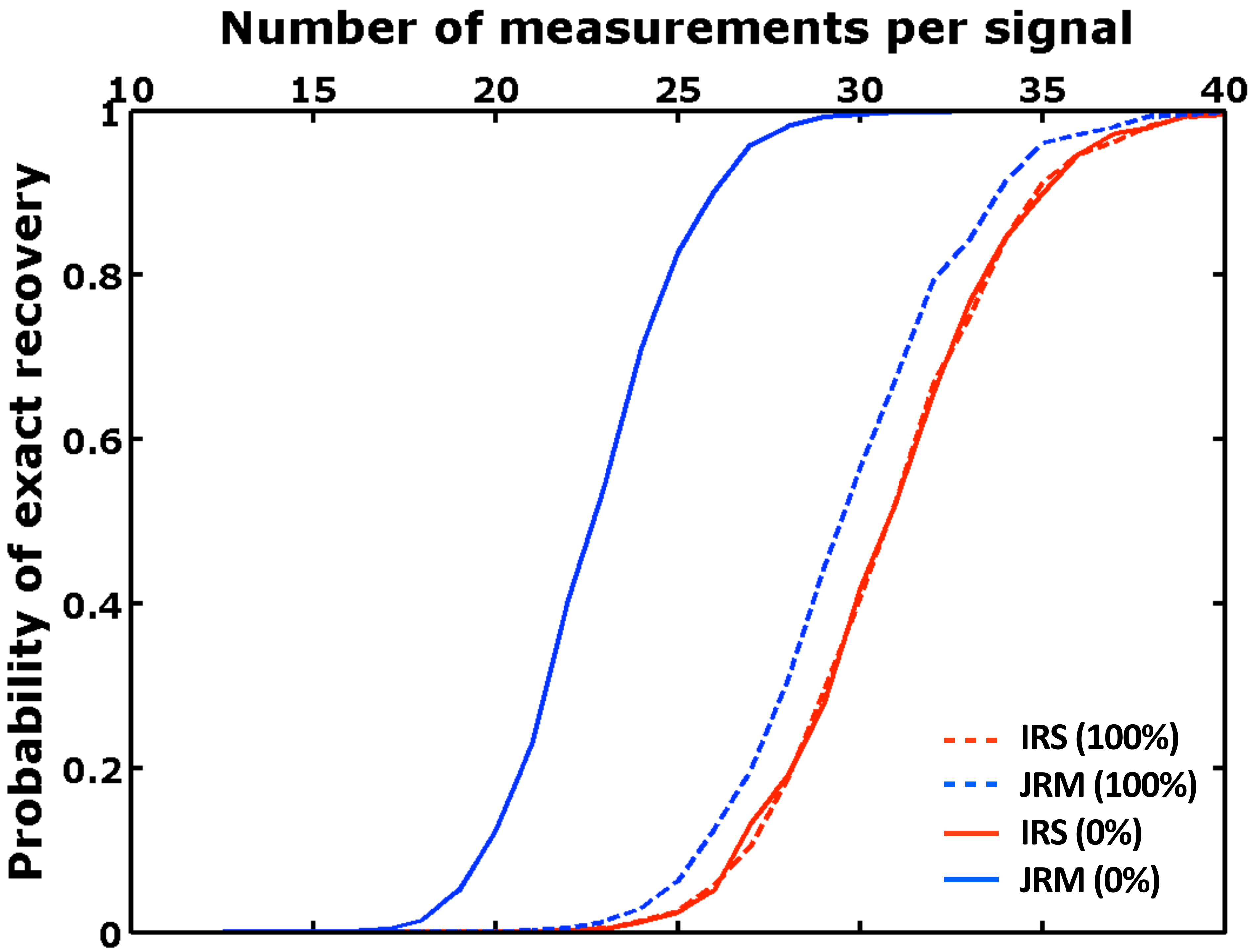
$\mathbf{x}_2$ ***monitor***

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

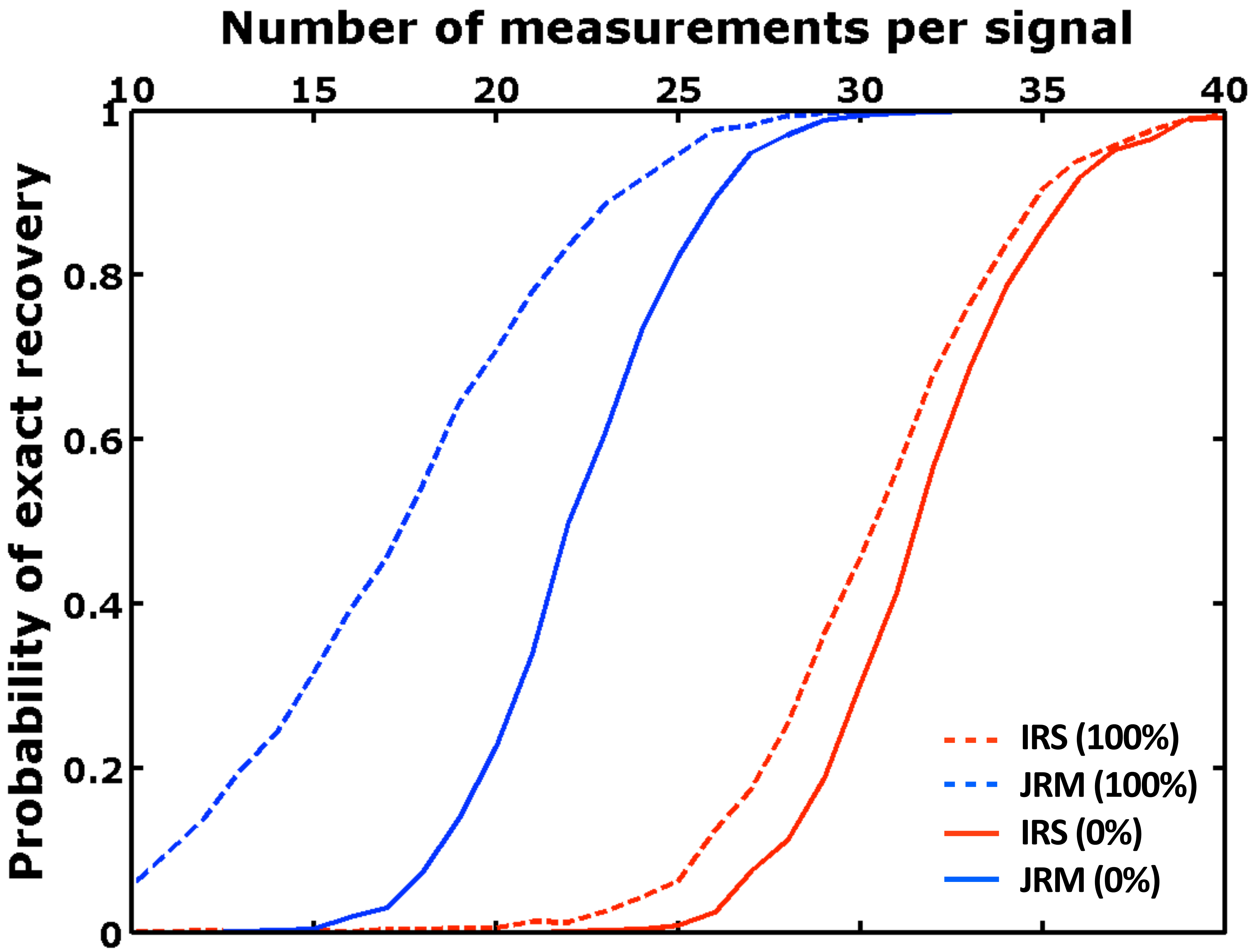
Independent vs. *joint* recovery

– 100% & 0% overlap in *acquisition* matrices

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



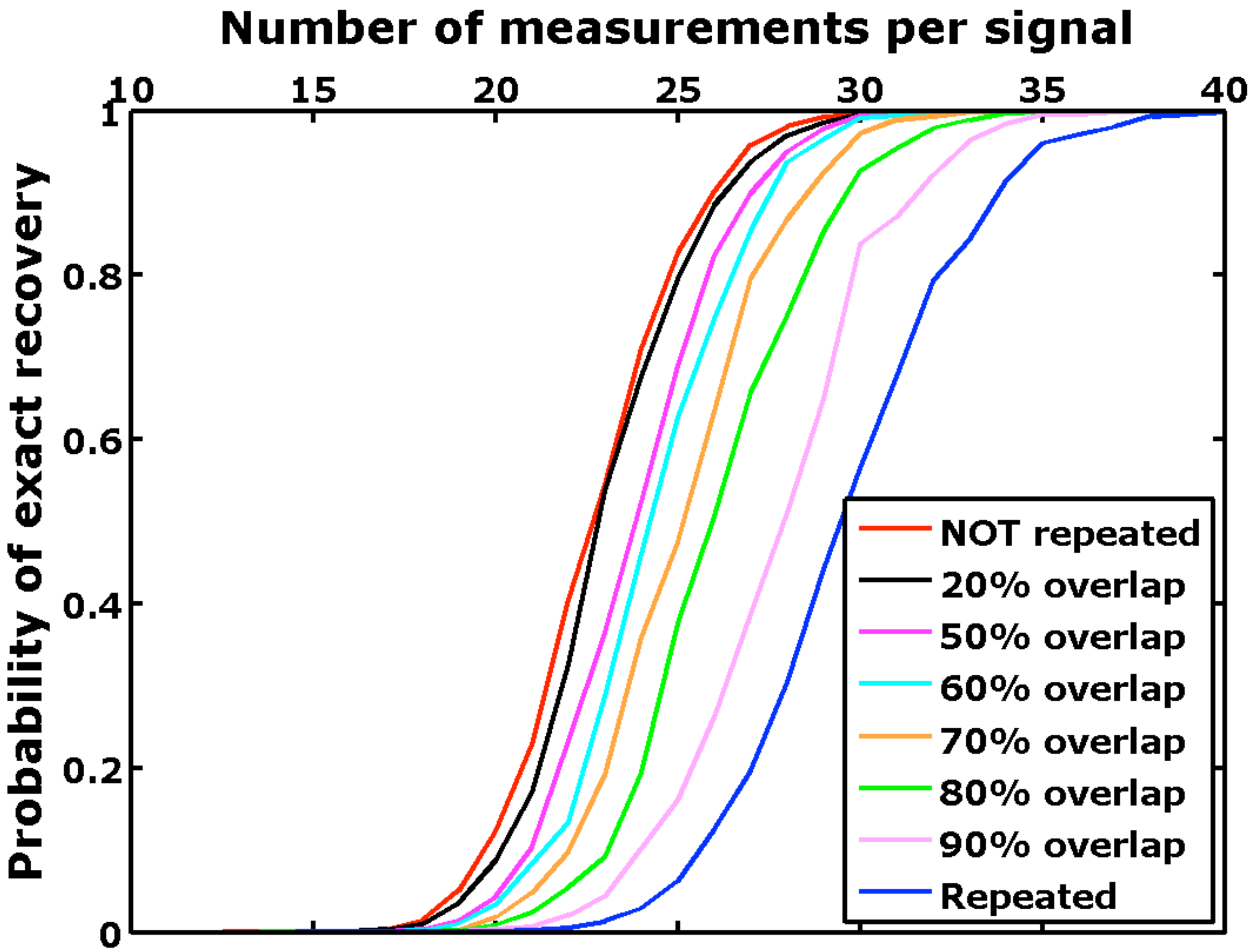
Vintages



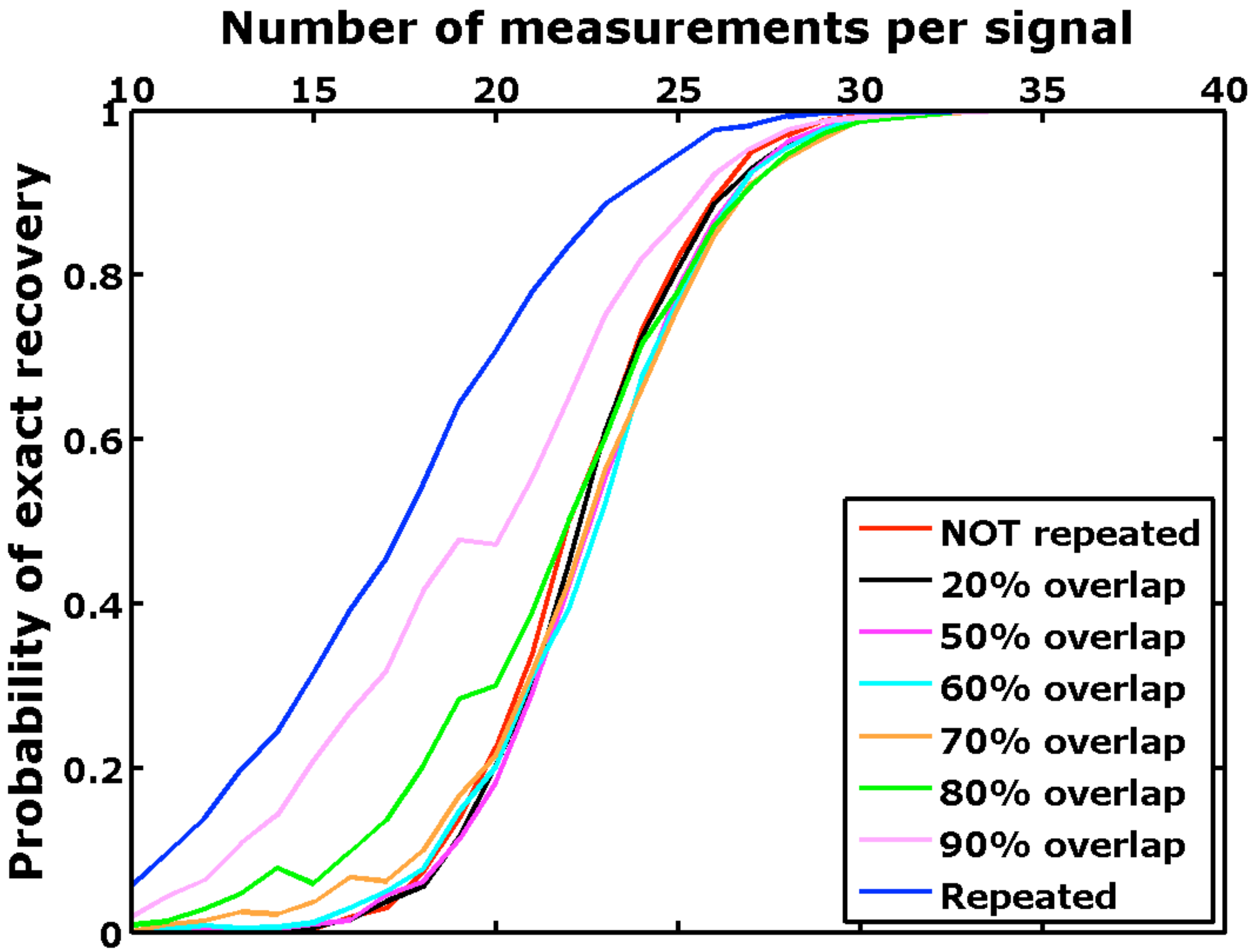
4-D signal

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

- exploits *shared* information between the vintages

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

Question:

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

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

Synthetic seismic case study

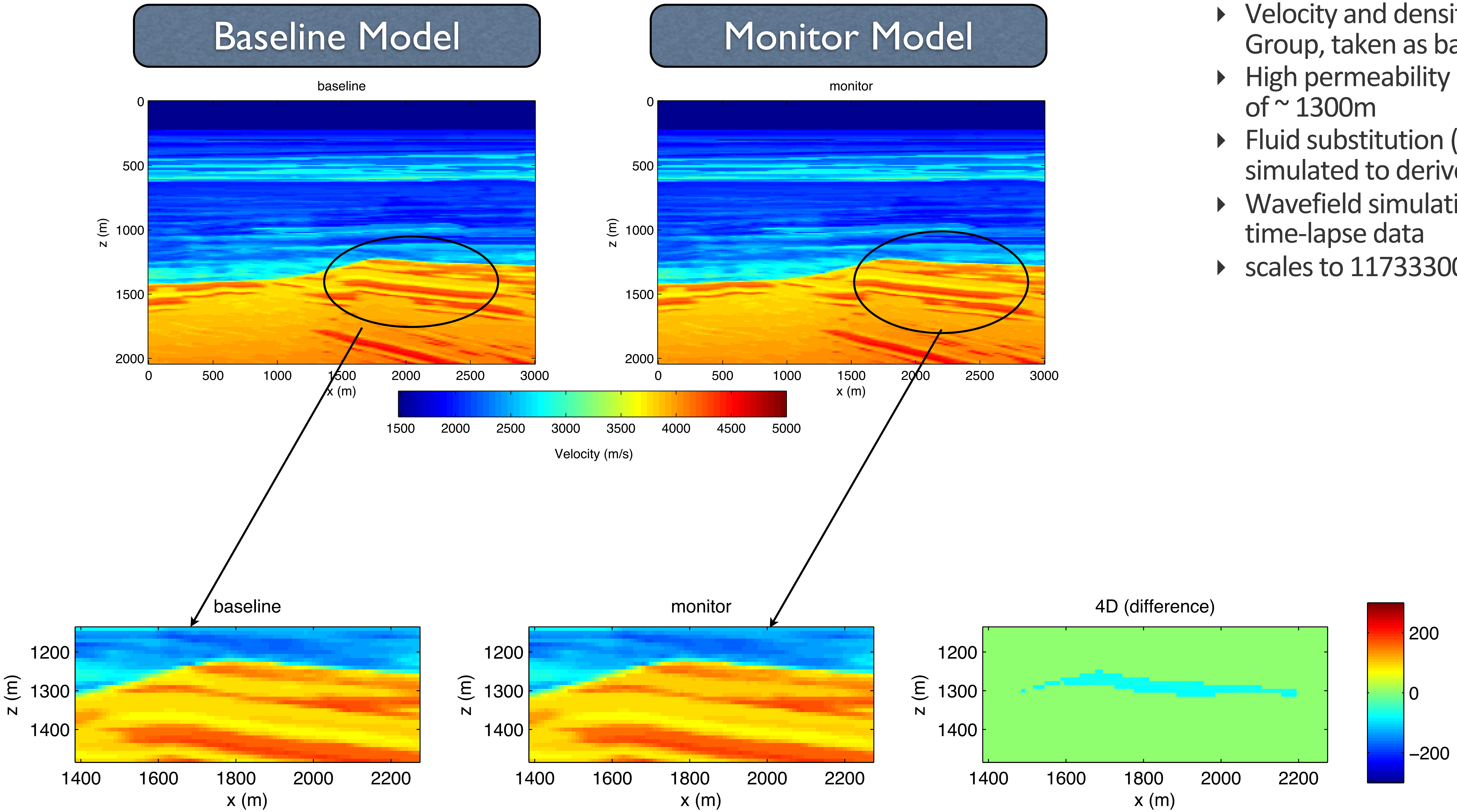
Time-jittered marine acquisition on the grid

% repetition => "*exact*" repetition

No calibration errors

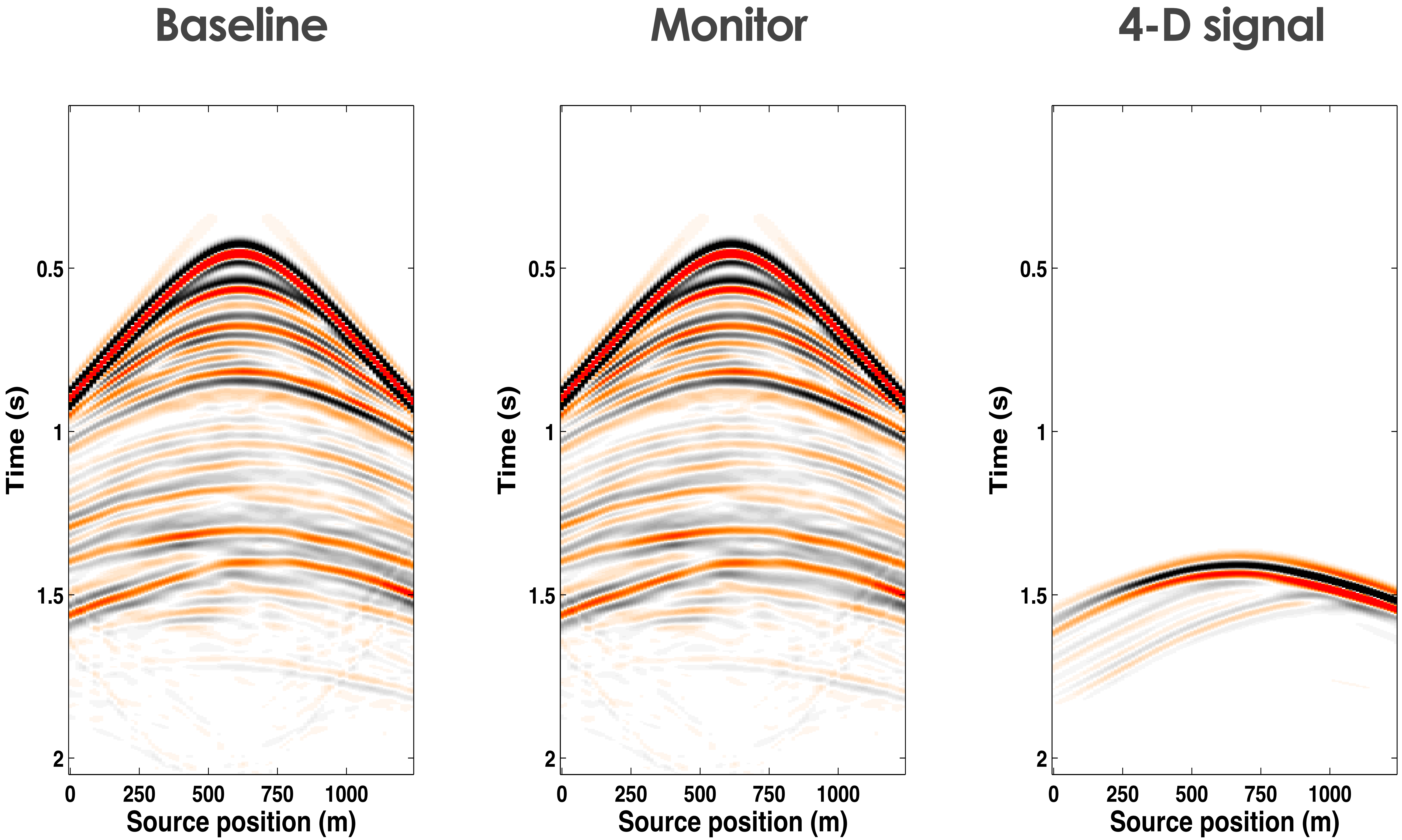
Method

- 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



Baseline

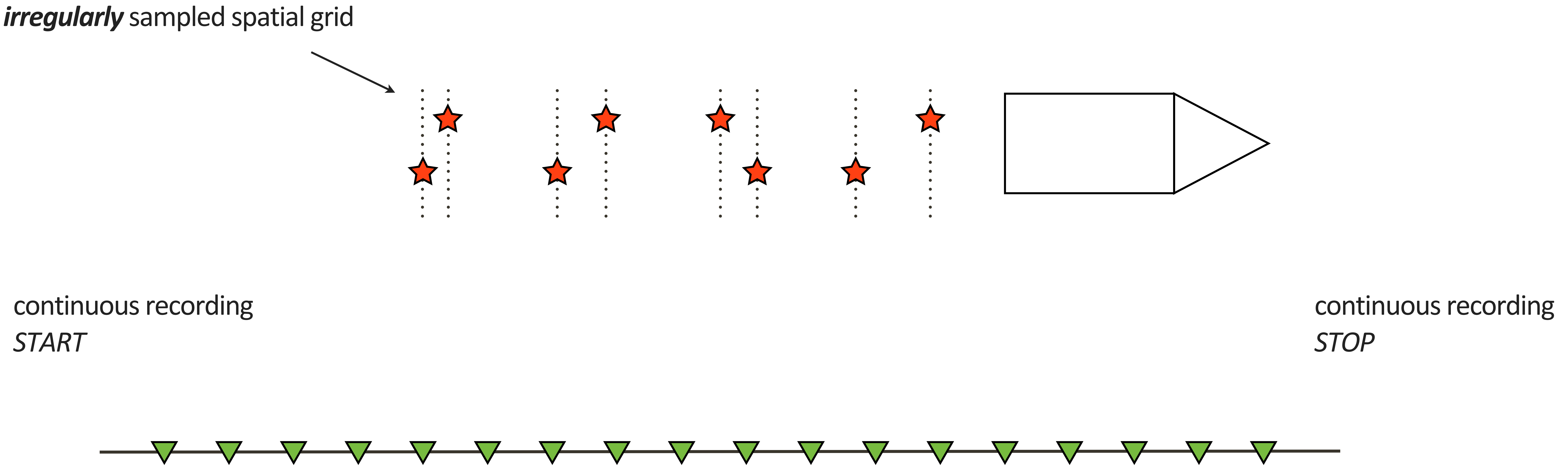
Monitor

4-D signal

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

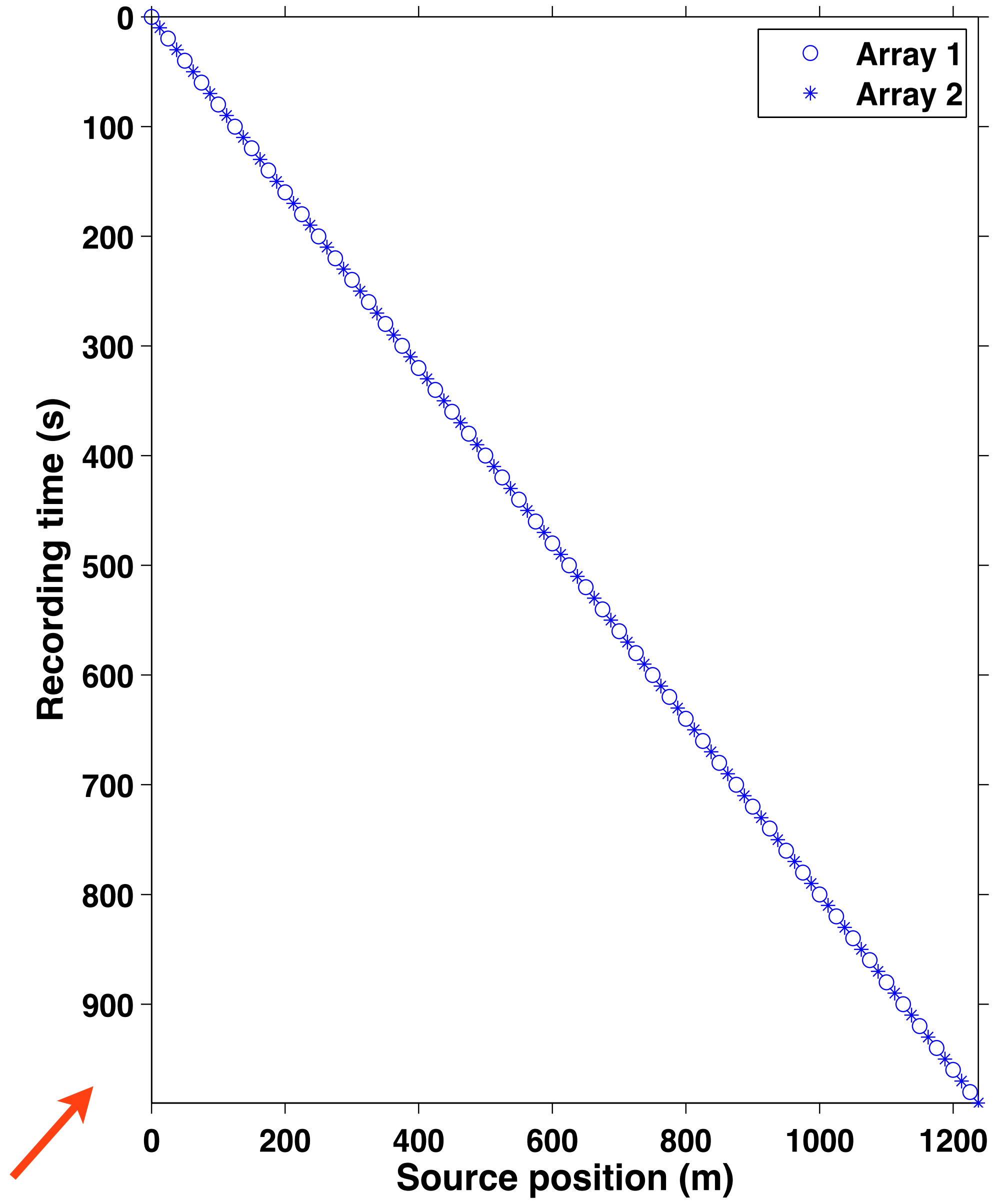
continuous recording
START

continuous recording
STOP

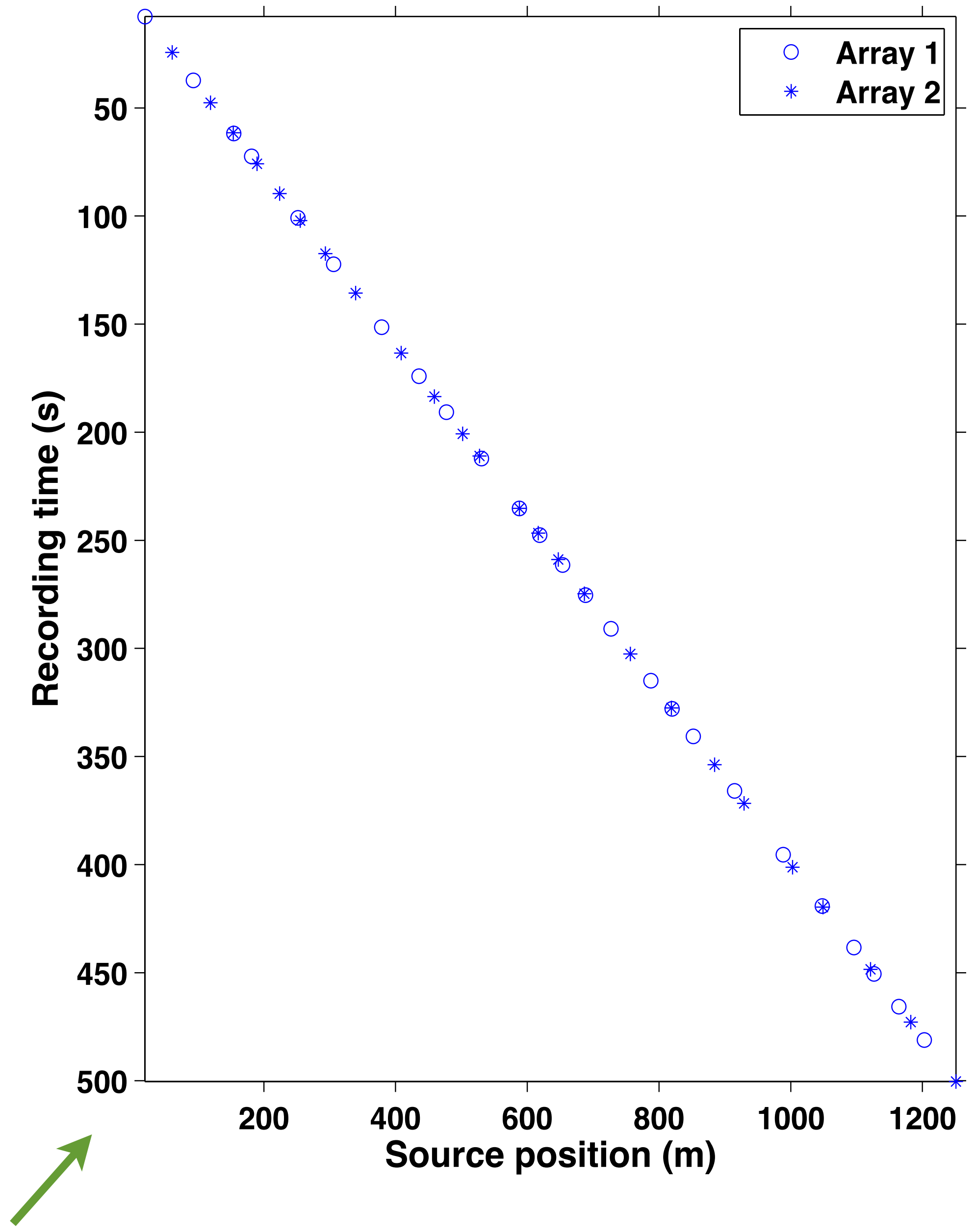
Conventional vs. *time-jittered* sources

– *subsampling* ratio = 2, 2 source arrays

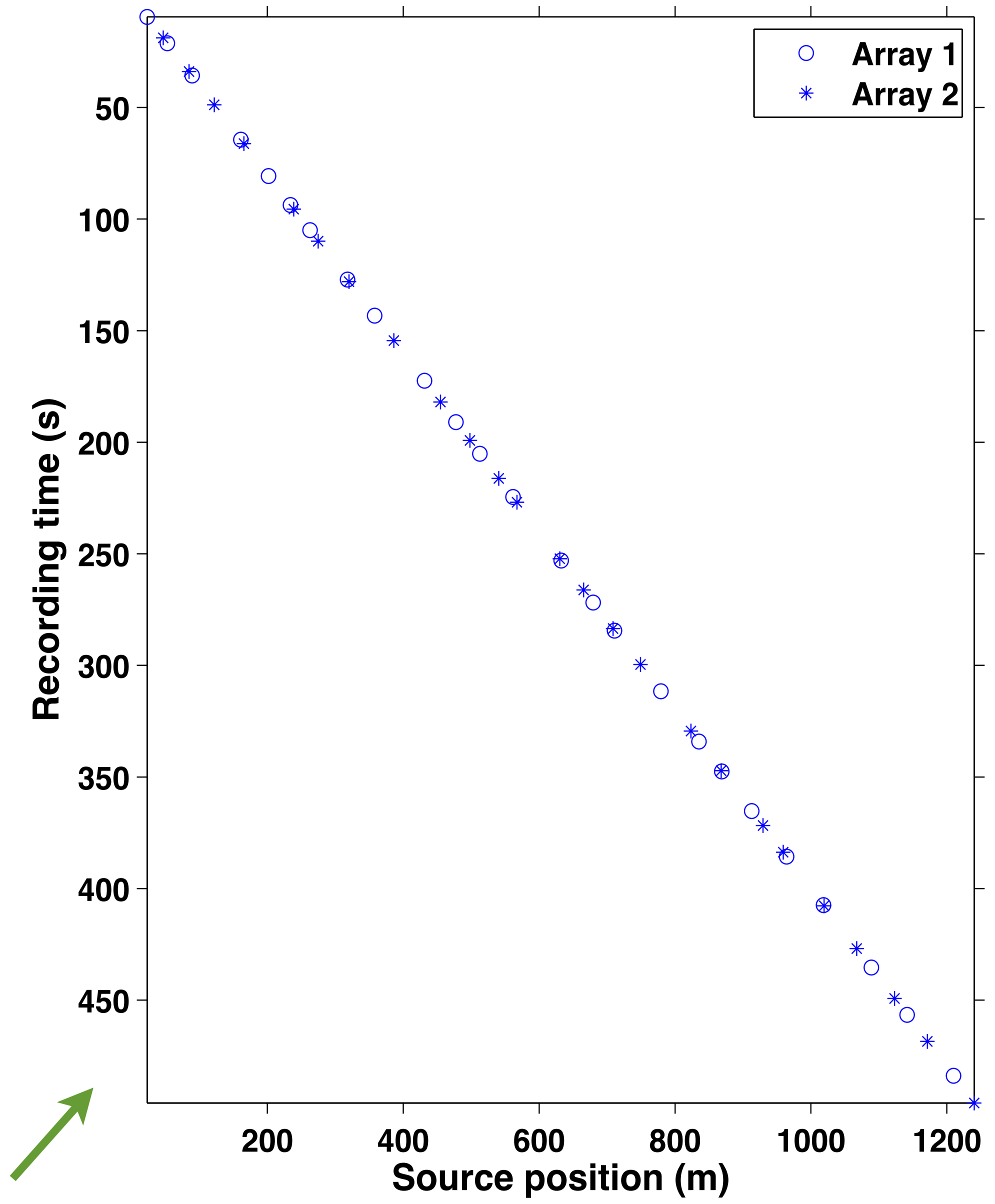
conventional



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**

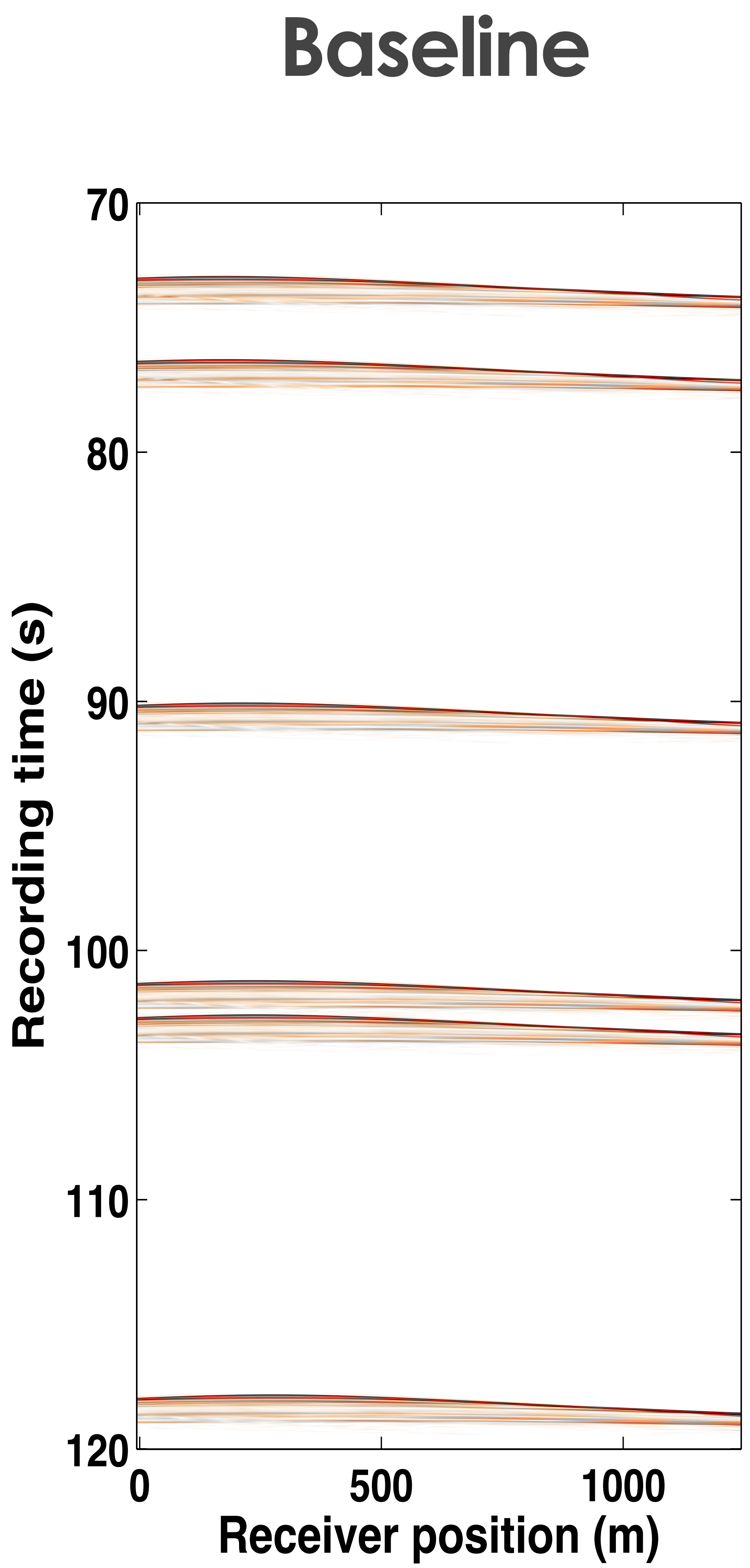
[BLENDING & SUBSAMPLING]
spatial subsampling factor = 2

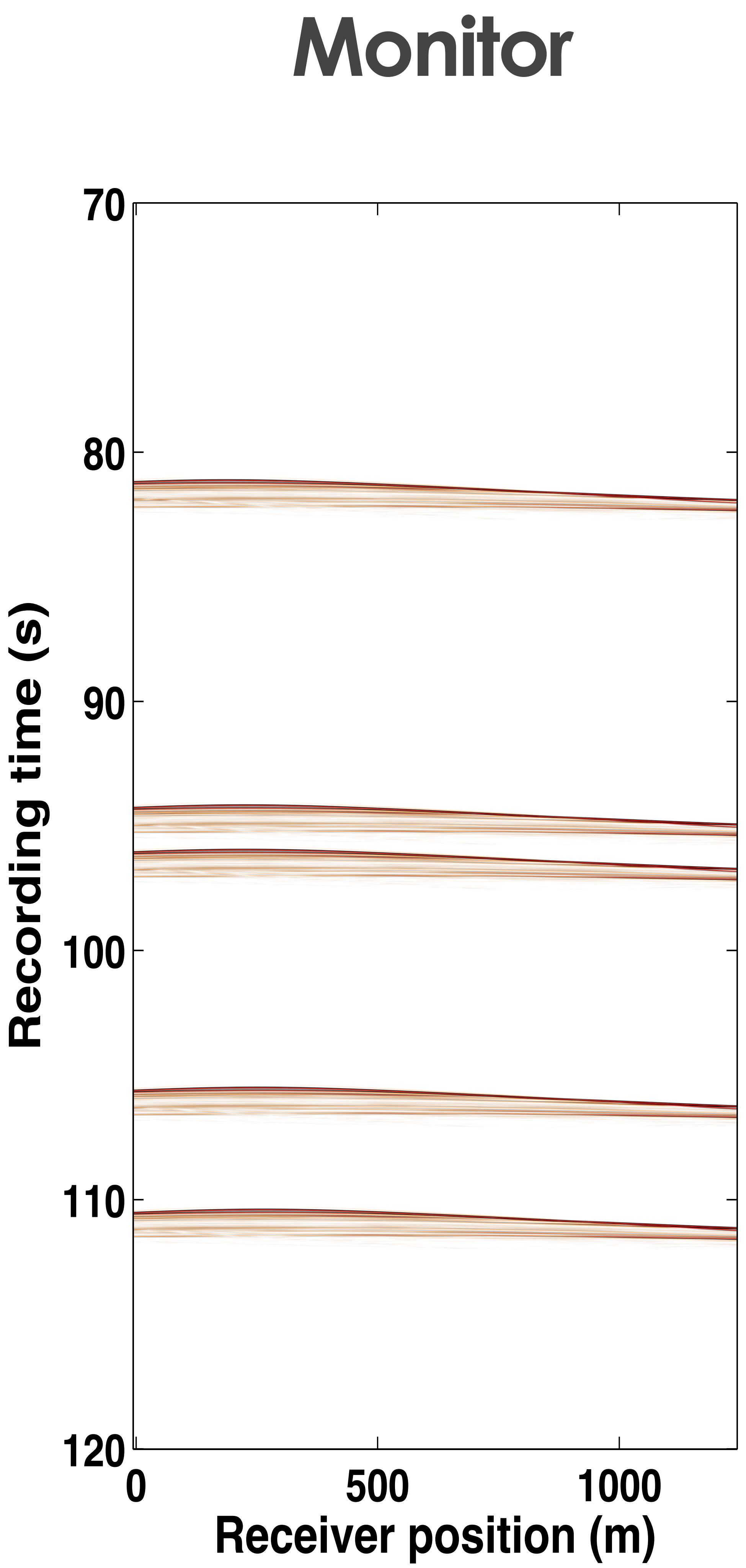
spatial sampling ***increase*** factor = 2
[DEBLENDING & INTERPOLATION]

***"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

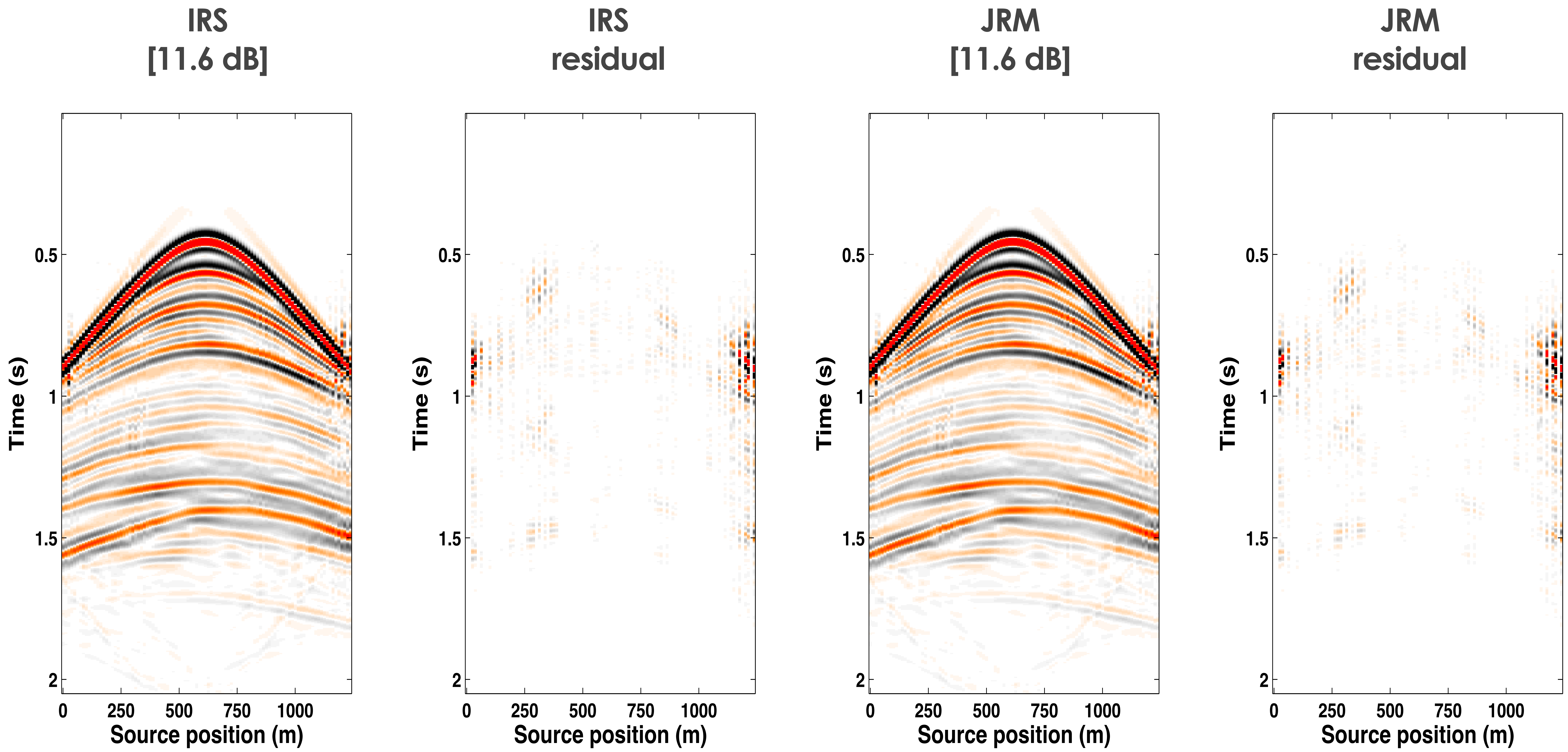
– *subsampled* and *blended*





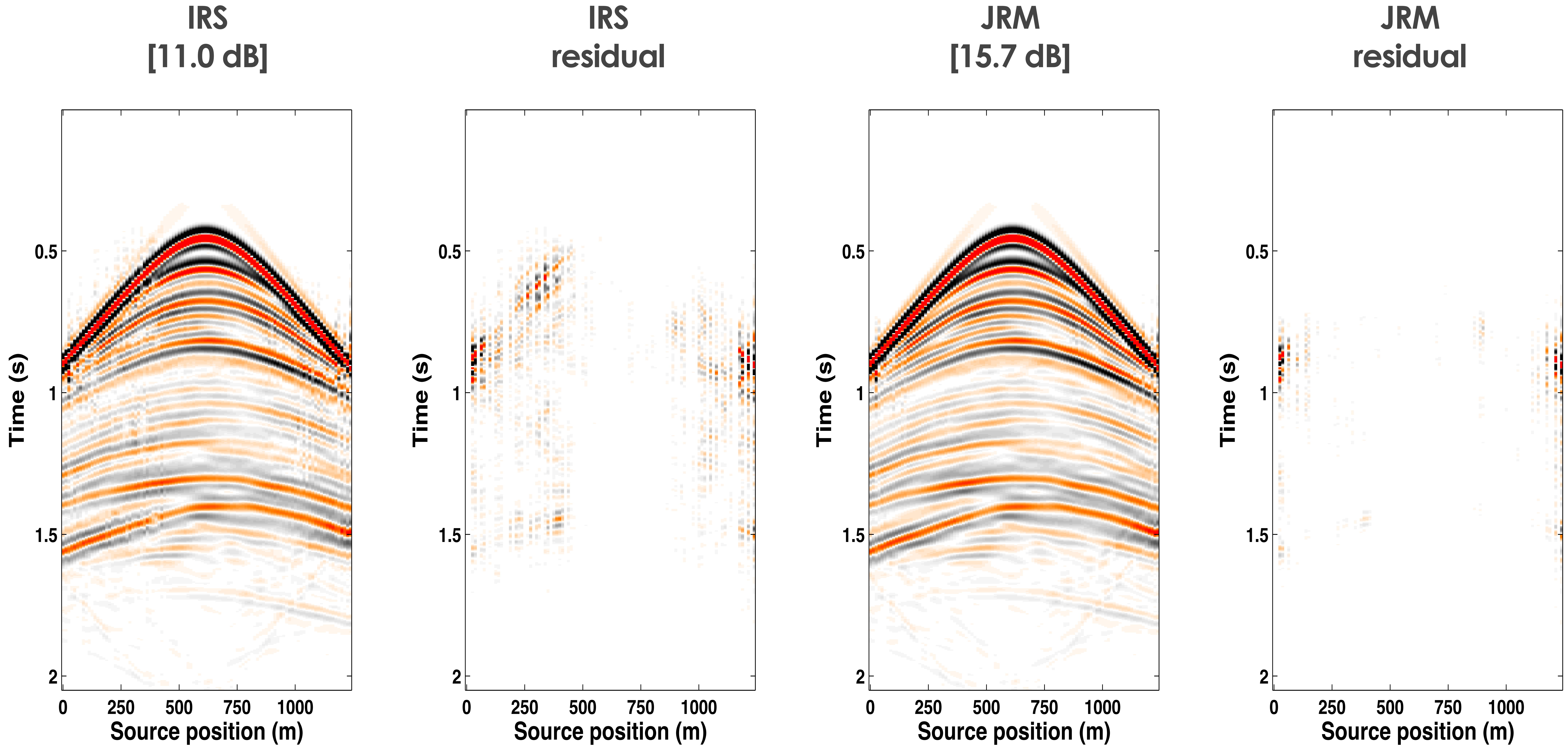
Monitor recovery

– **100% overlap** in *acquisition* matrices



Monitor recovery

– 50% overlap in *acquisition* matrices


IRS [11.0 dB]

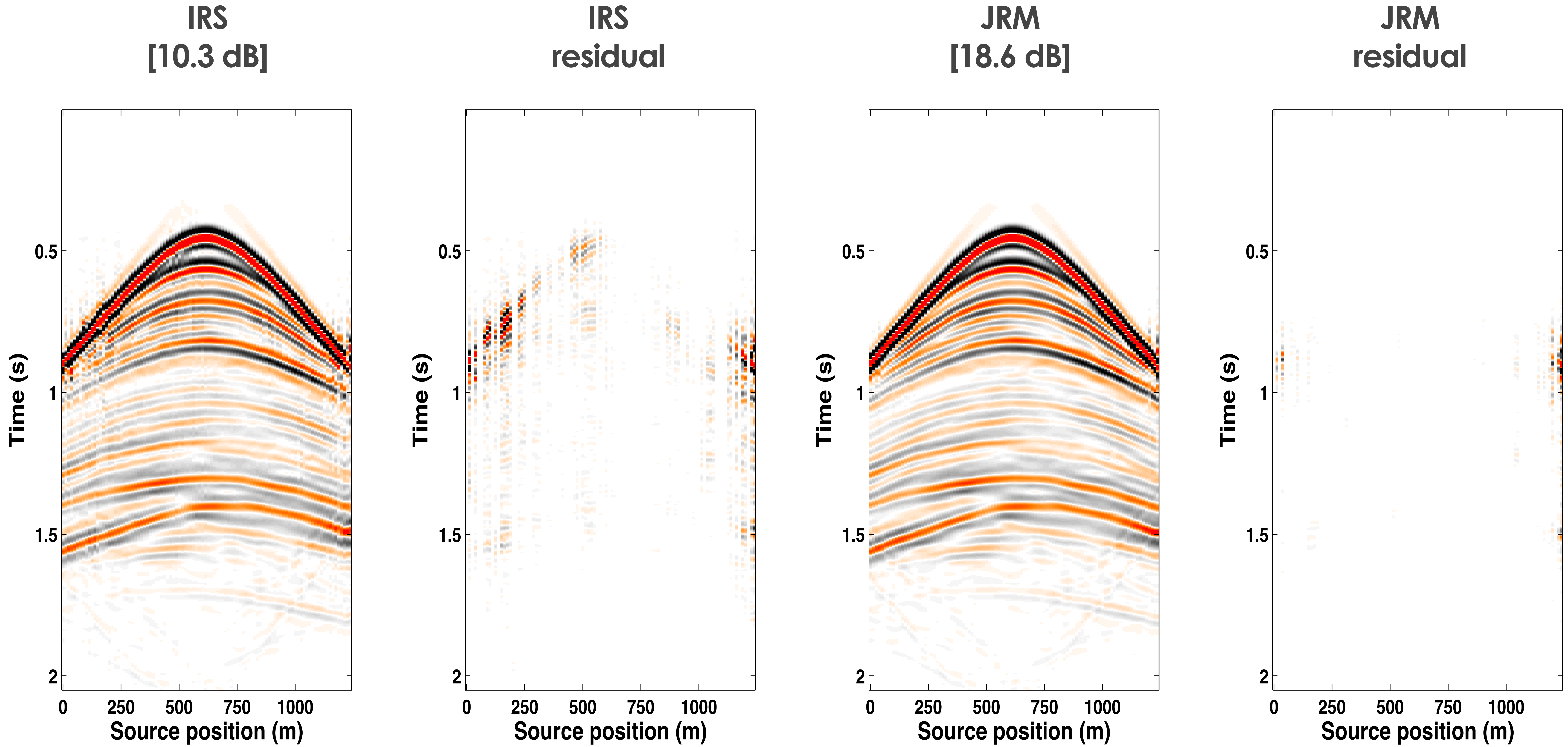
IRS residual

JRM [15.7 dB]

JRM residual

Monitor recovery

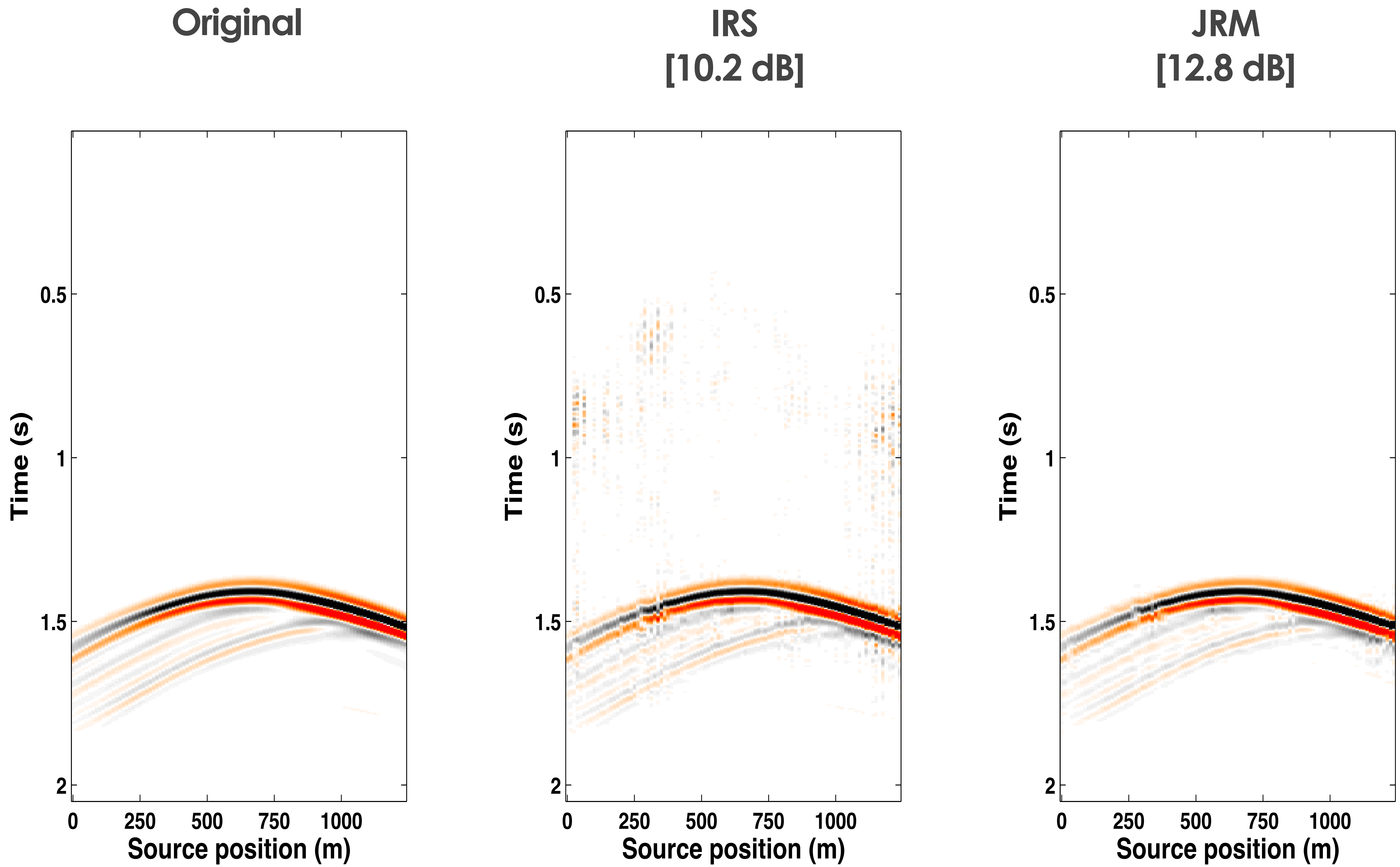
– **25% overlap** in *acquisition* matrices



4-D recovery

– **100% overlap** in *acquisition* matrices

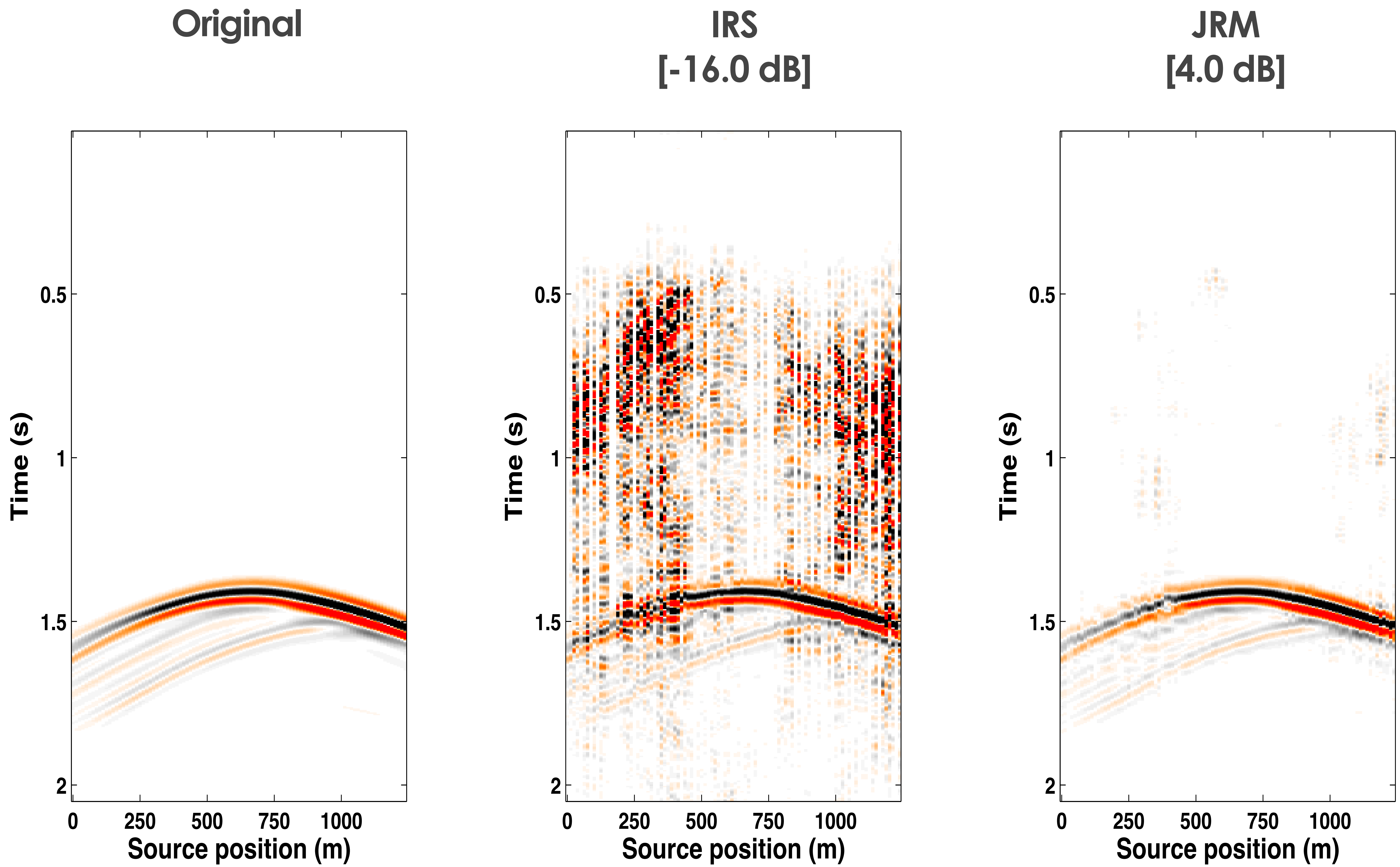
[colormap scale: 10 X]



4-D recovery

– **50% overlap** in *acquisition* matrices

[colormap scale: 10 X]



Original

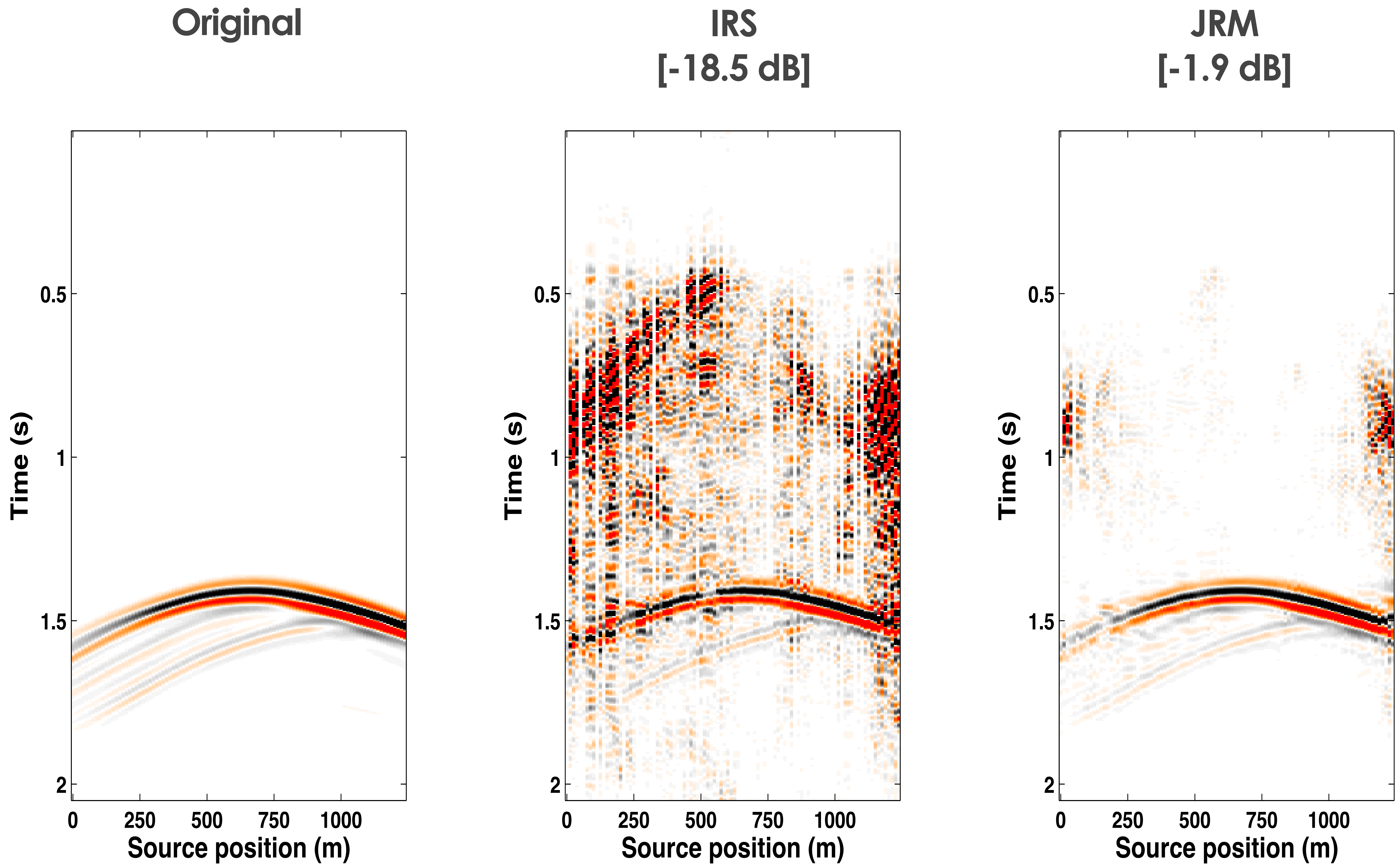
IRS
[-16.0 dB]

JRM
[4.0 dB]

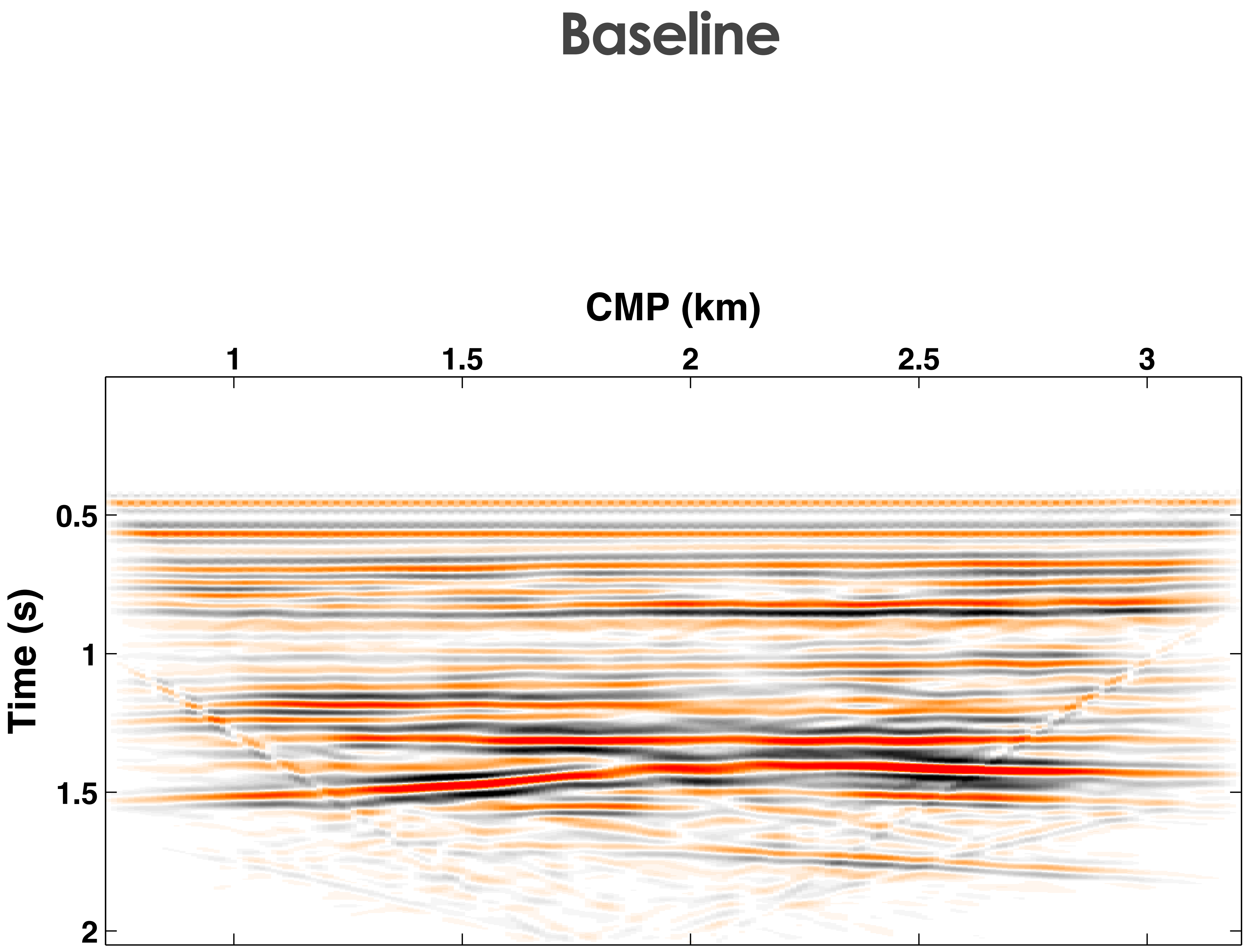
4-D recovery

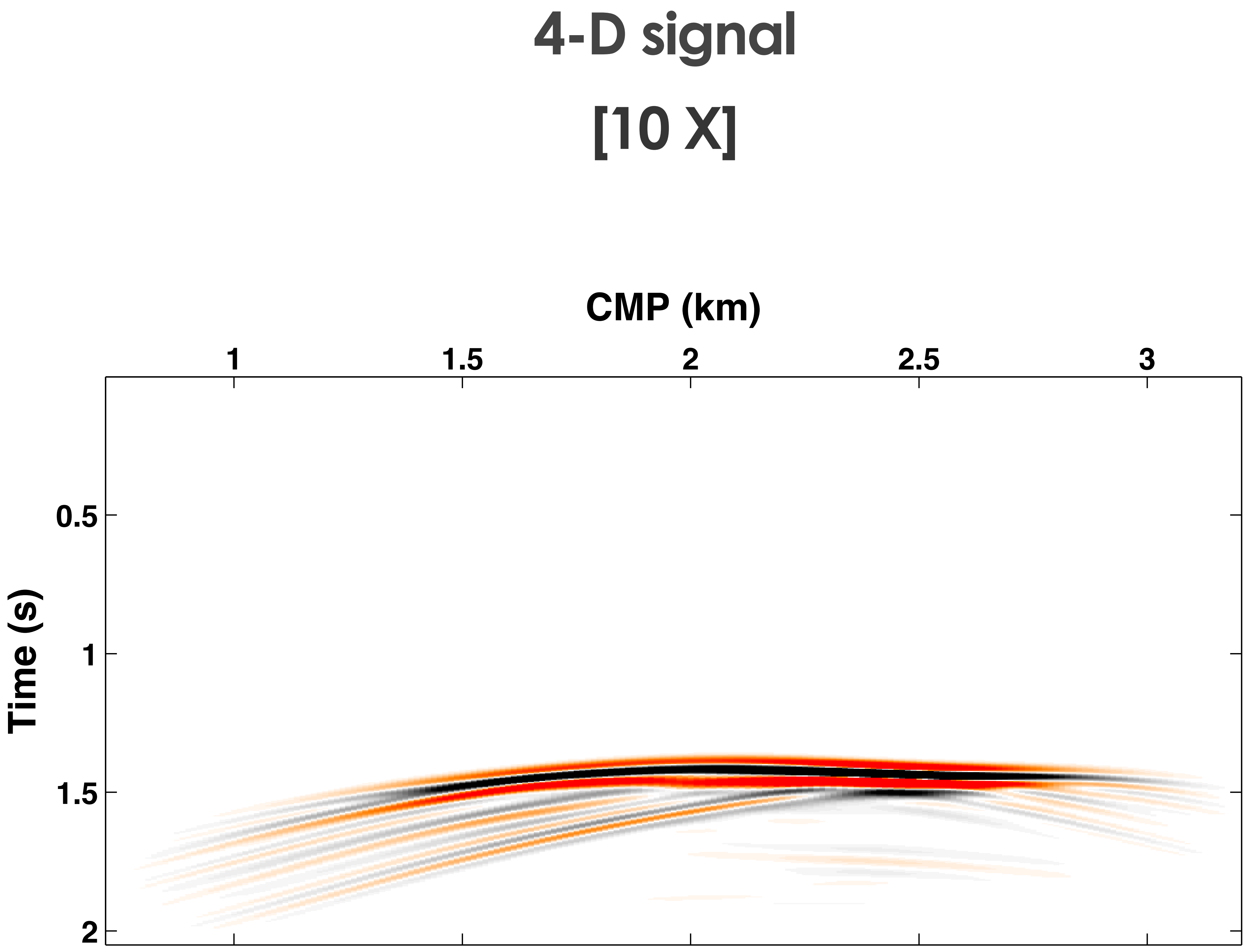
– 25% overlap in *acquisition* matrices

[colormap scale: 10 X]



Stacked sections



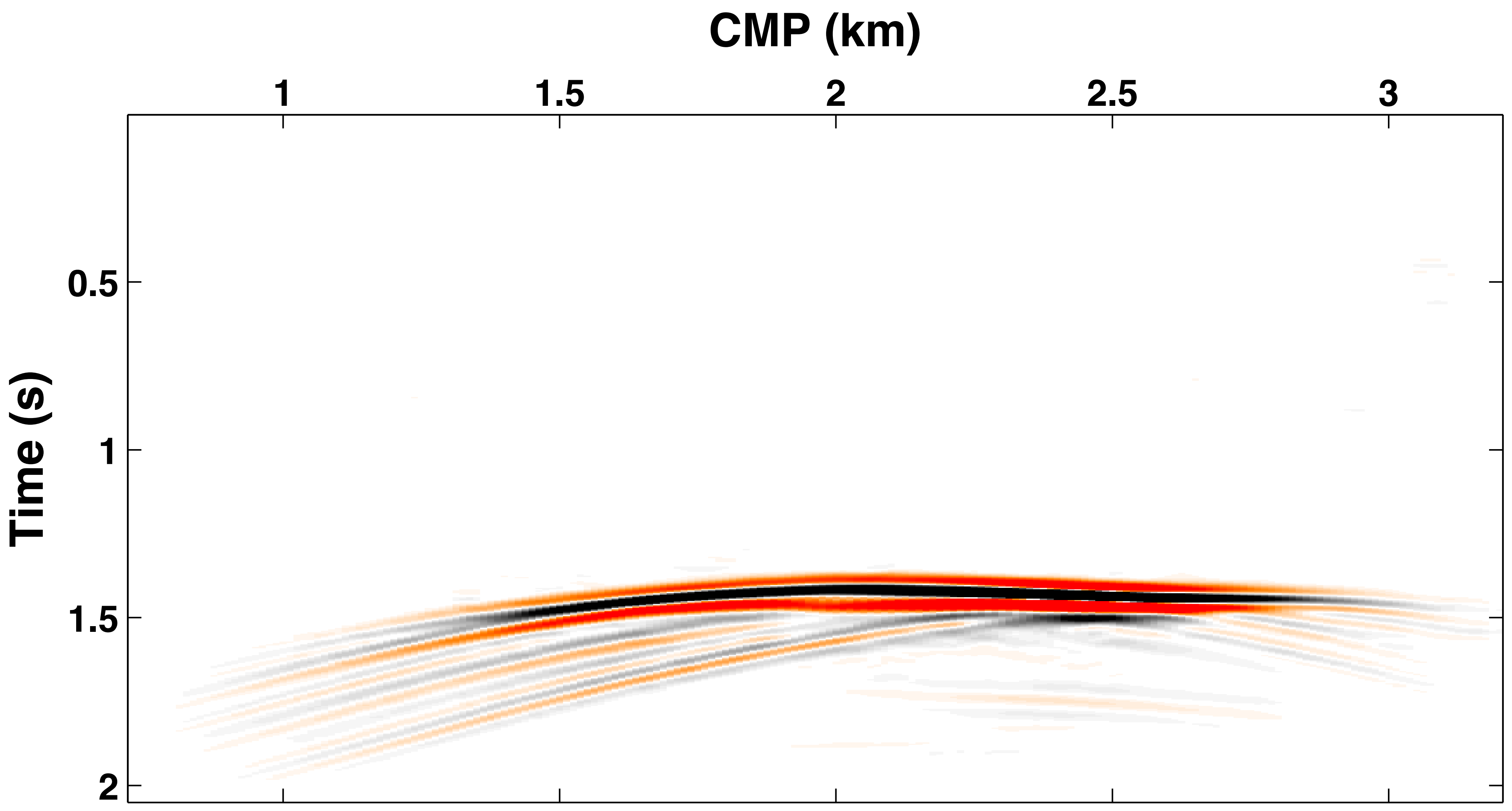


Stacked sections

– **100% overlap** in *acquisition* matrices

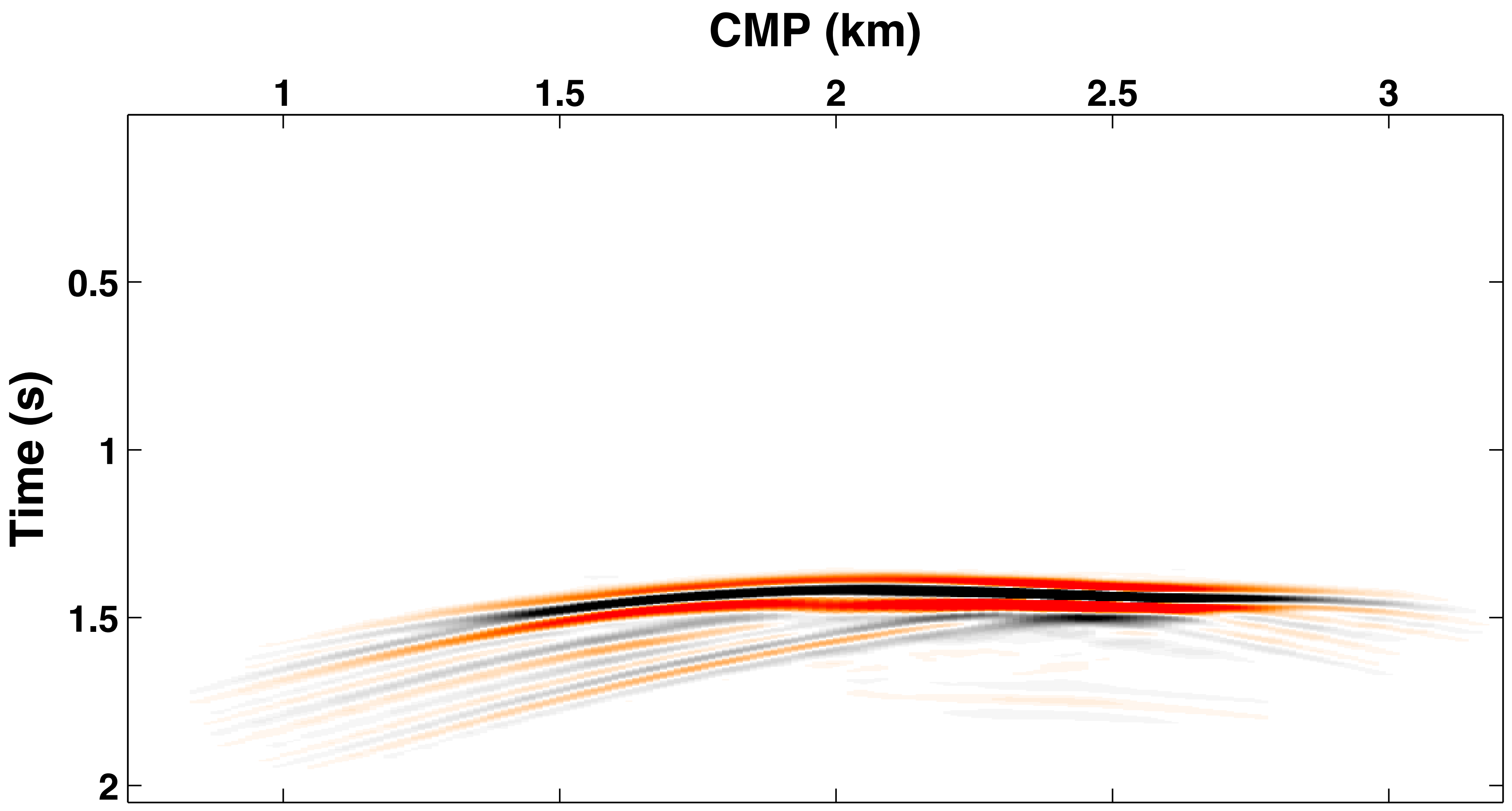
IRS

[25.2 dB]



JRM

[24.2 dB]



Stacked sections

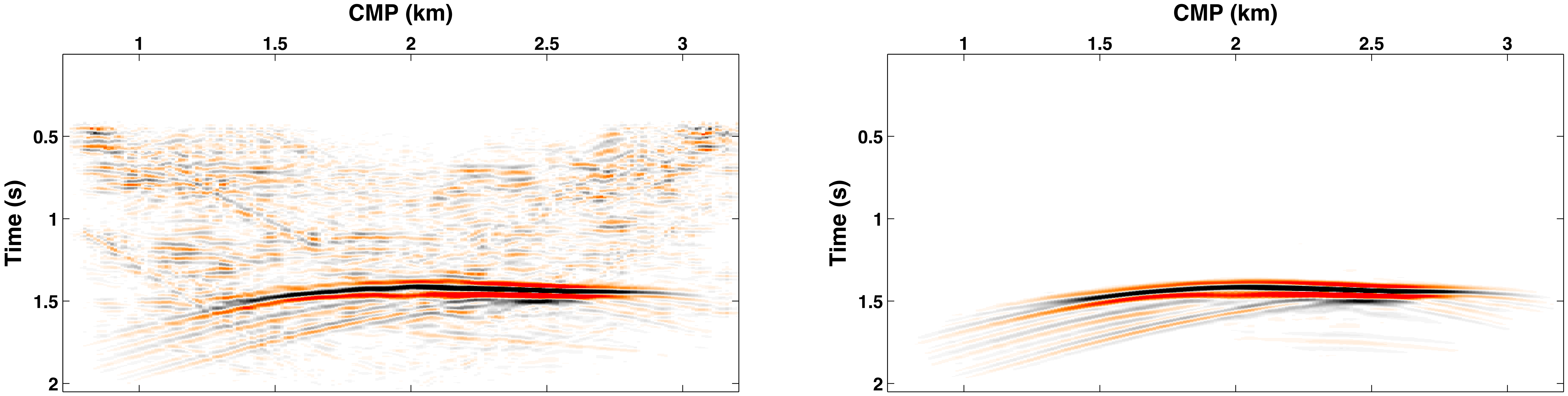
– **50% overlap** in *acquisition* matrices

IRS

[9.7 dB]

JRM

[20.0 dB]

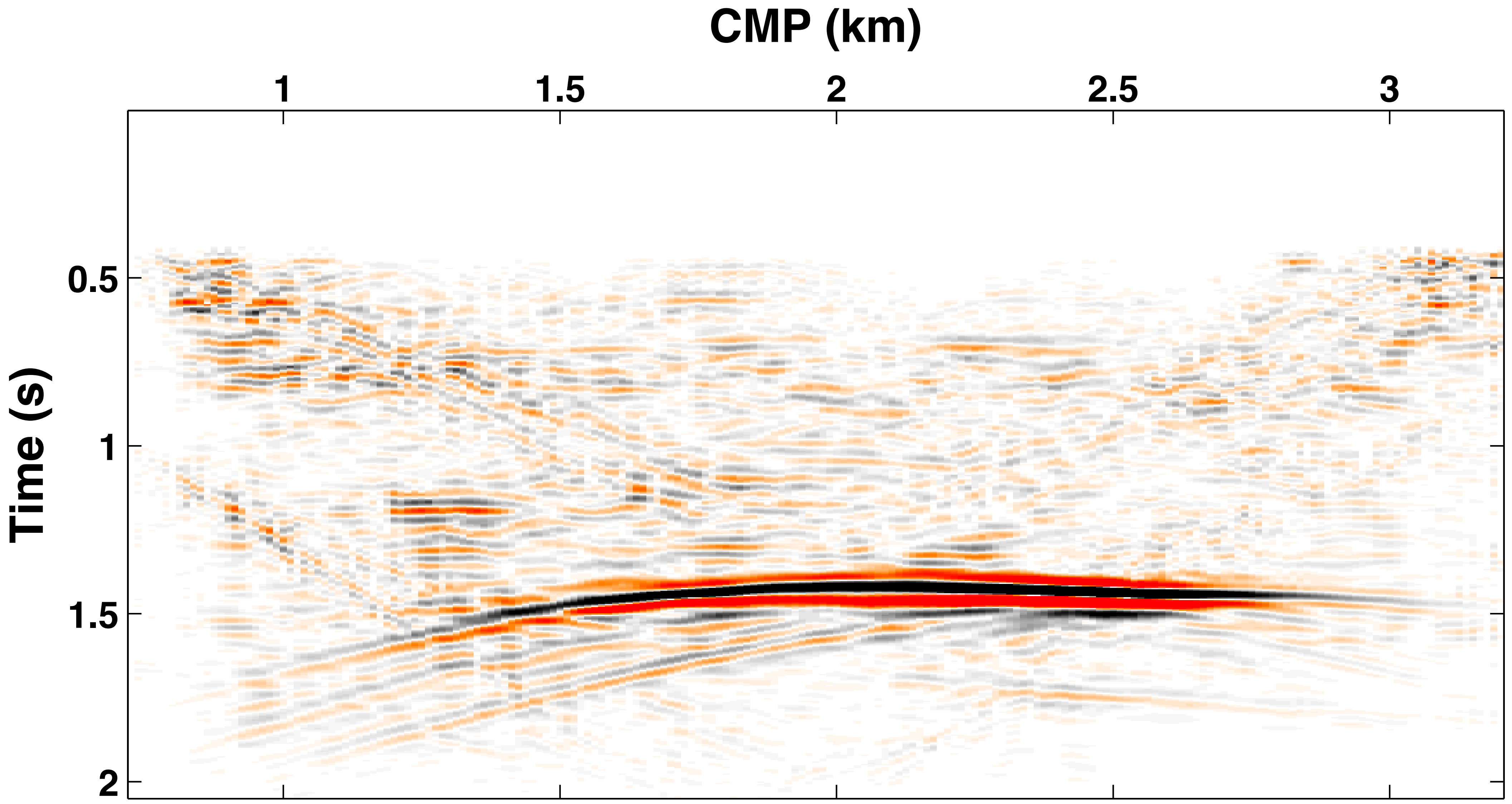


Stacked sections

– **25% overlap** in *acquisition* matrices

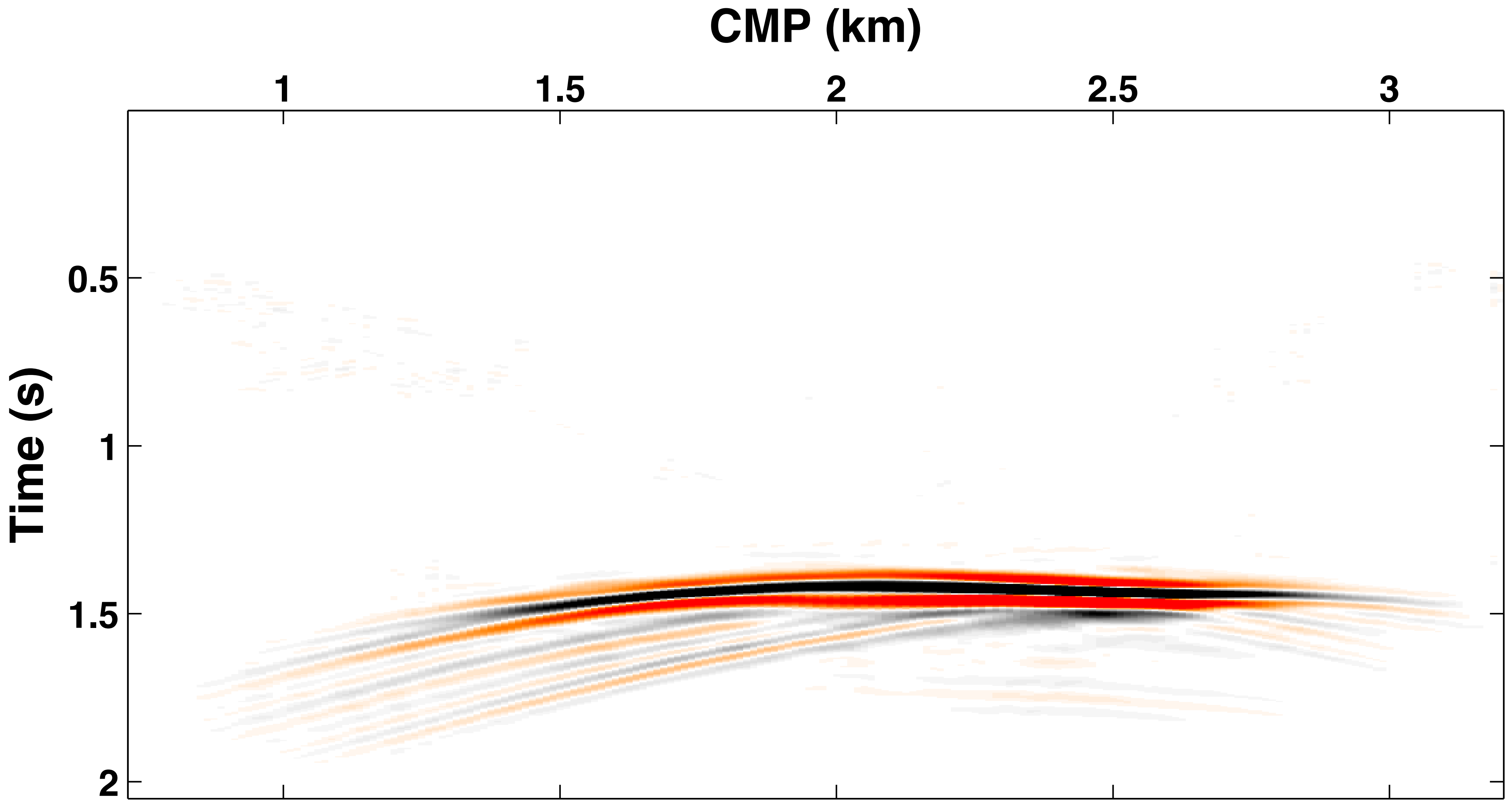
IRS

[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 sub*sampling?

Observations

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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 sub*sampling?

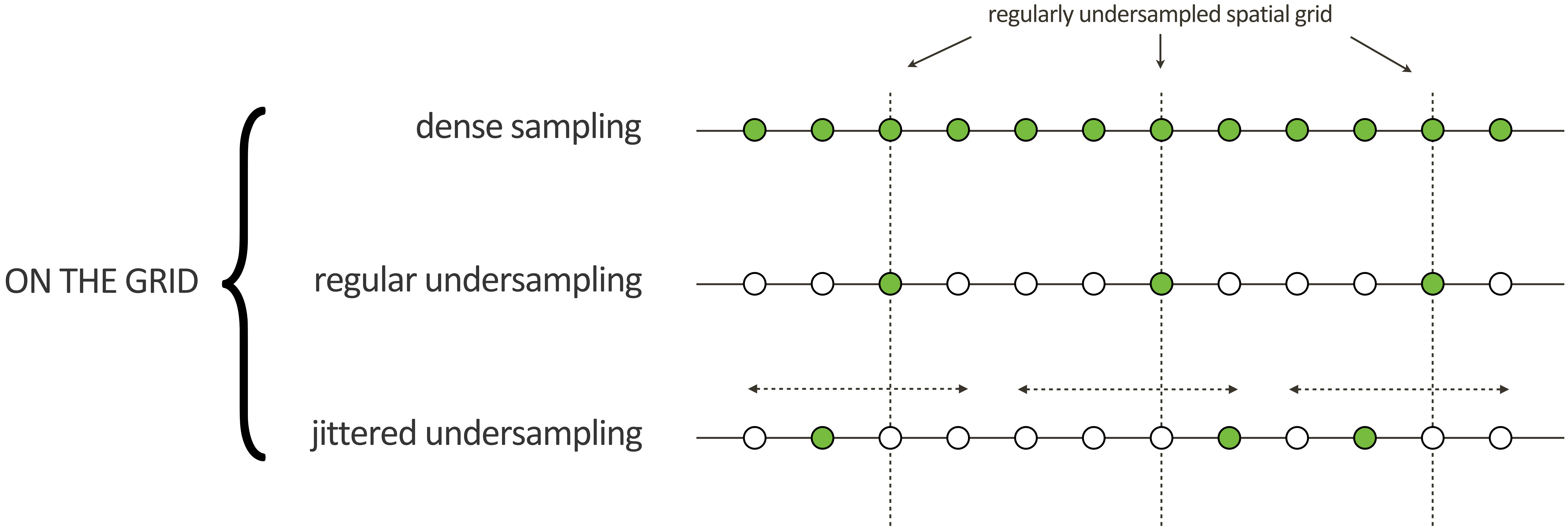
What does repetition "in-the-field" mean?

Notion of repetition

Time-jittered marine acquisition off the grid

With & without calibration errors

Randomized sampling in marine



regularly undersampled spatial grid

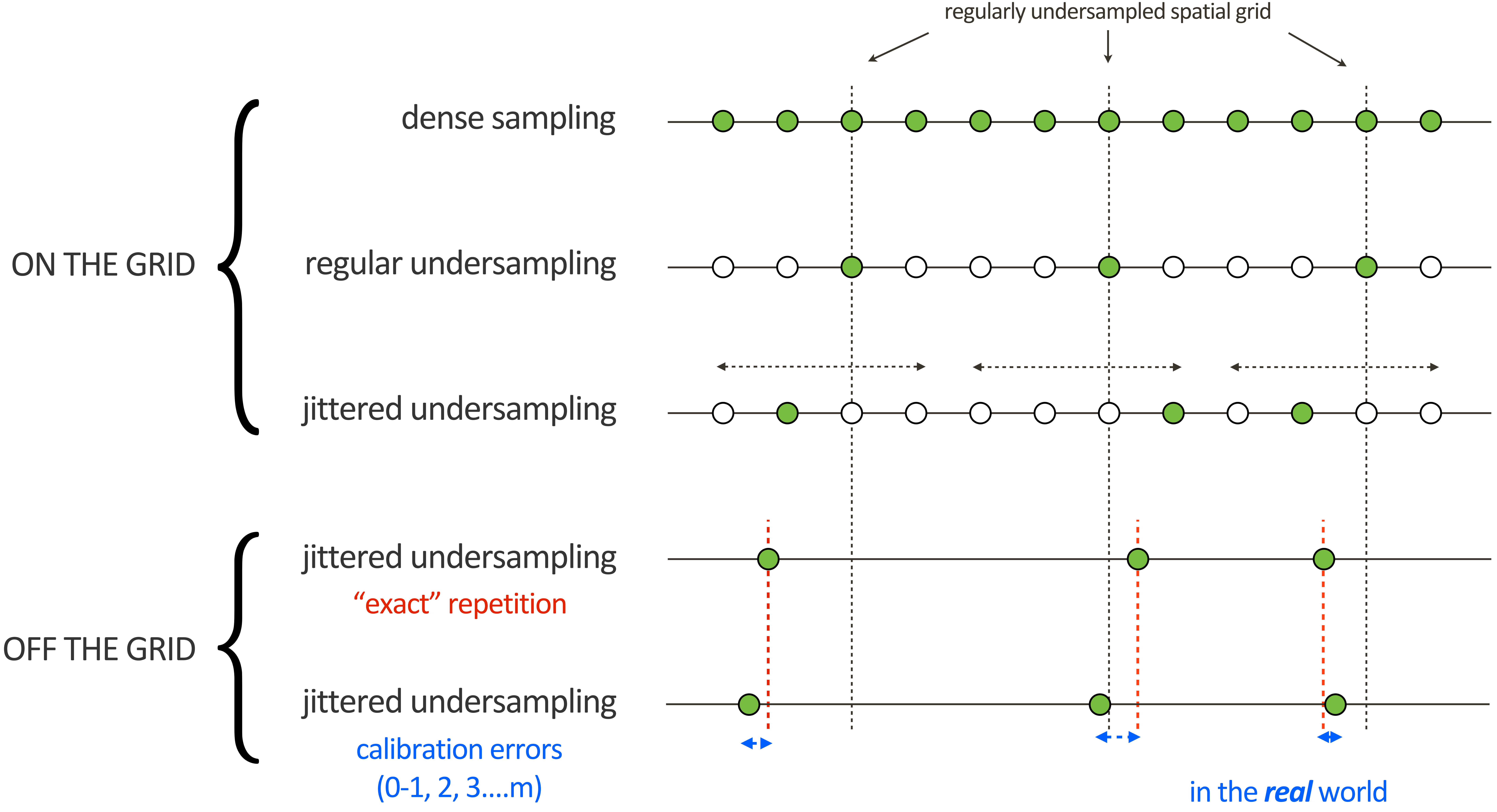
ON THE GRID

dense sampling

regular undersampling

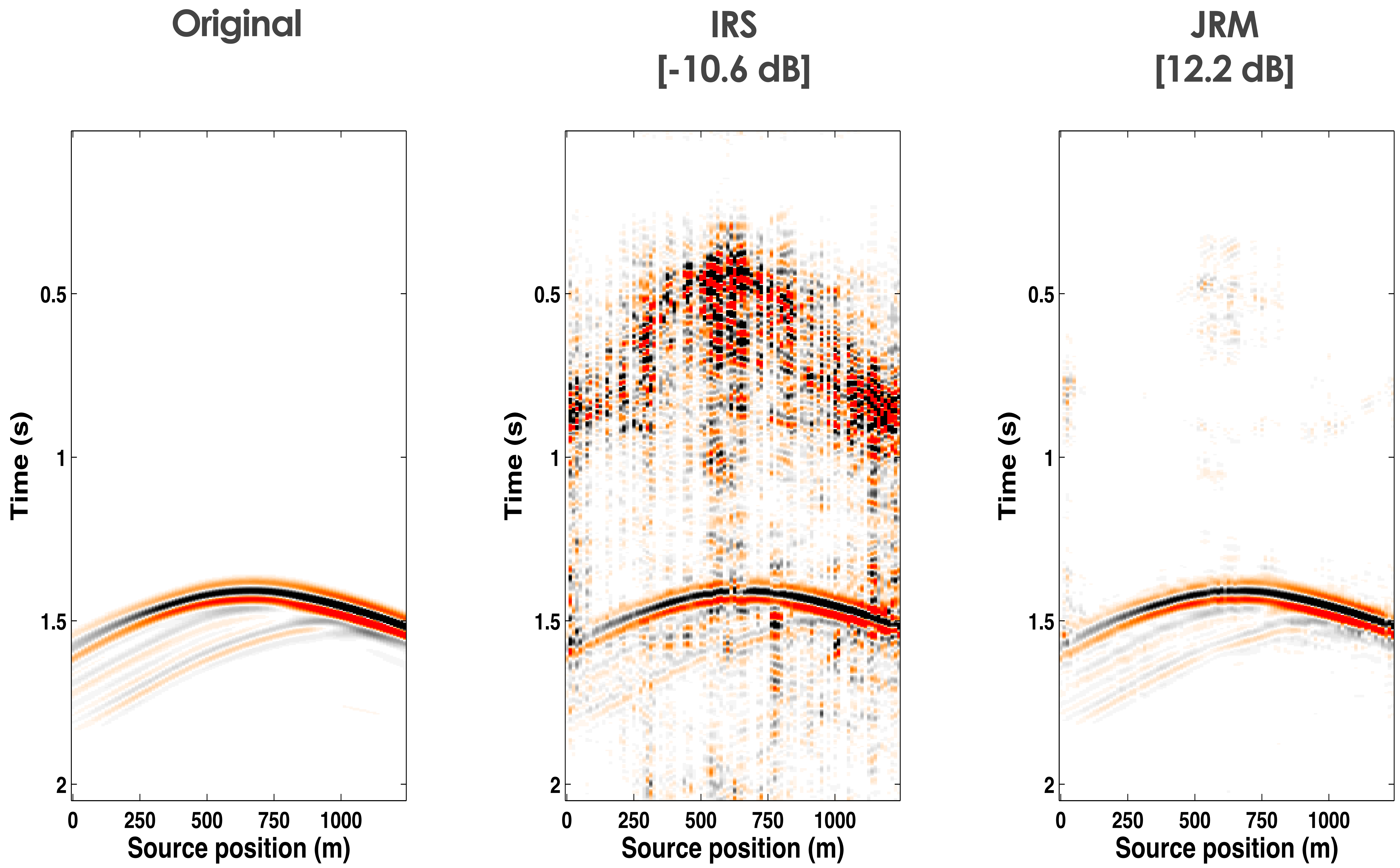
jittered undersampling

Randomized sampling in marine



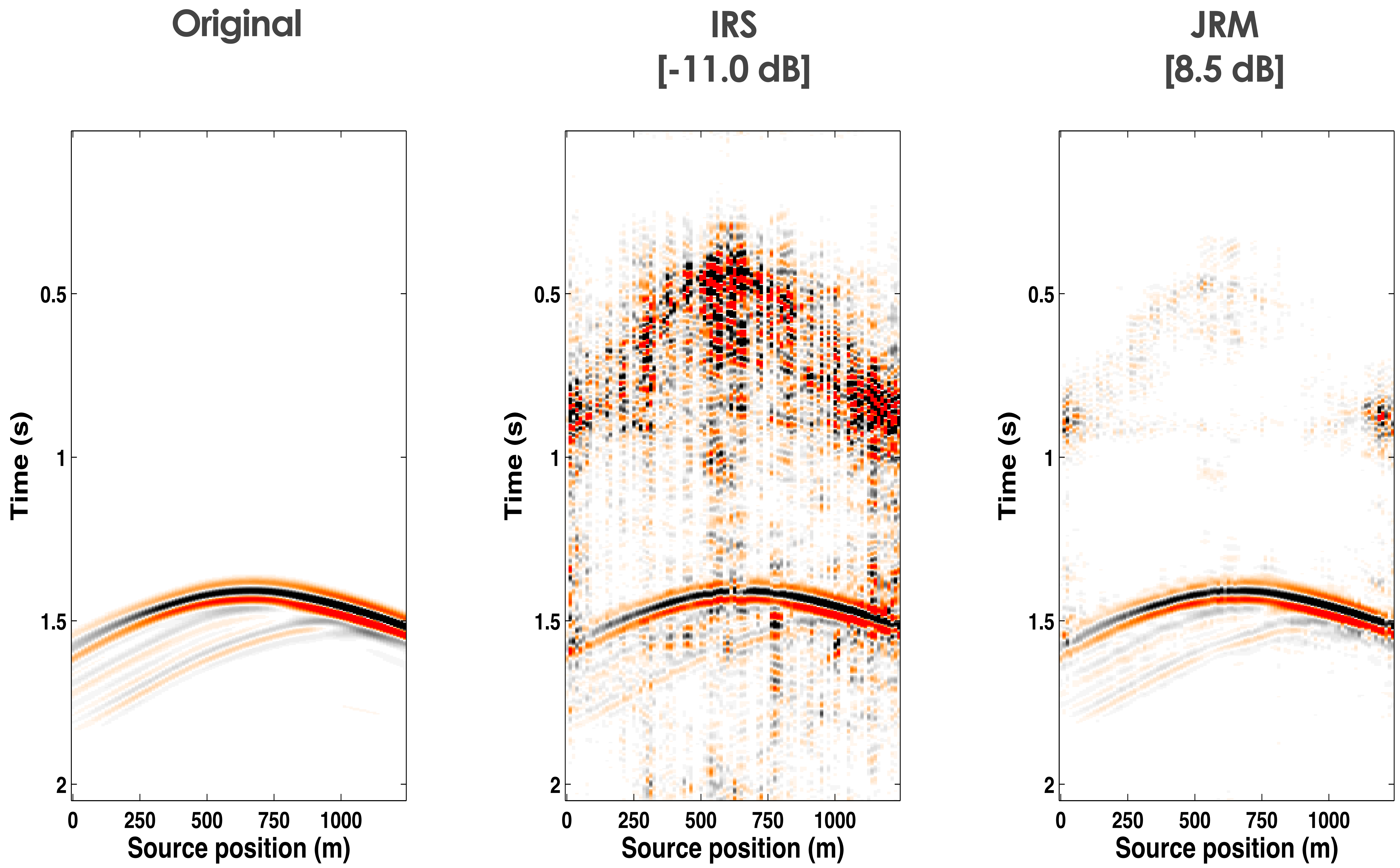
4-D recovery

– **50% overlap** in *acquisition* matrices, **no calibration errors**



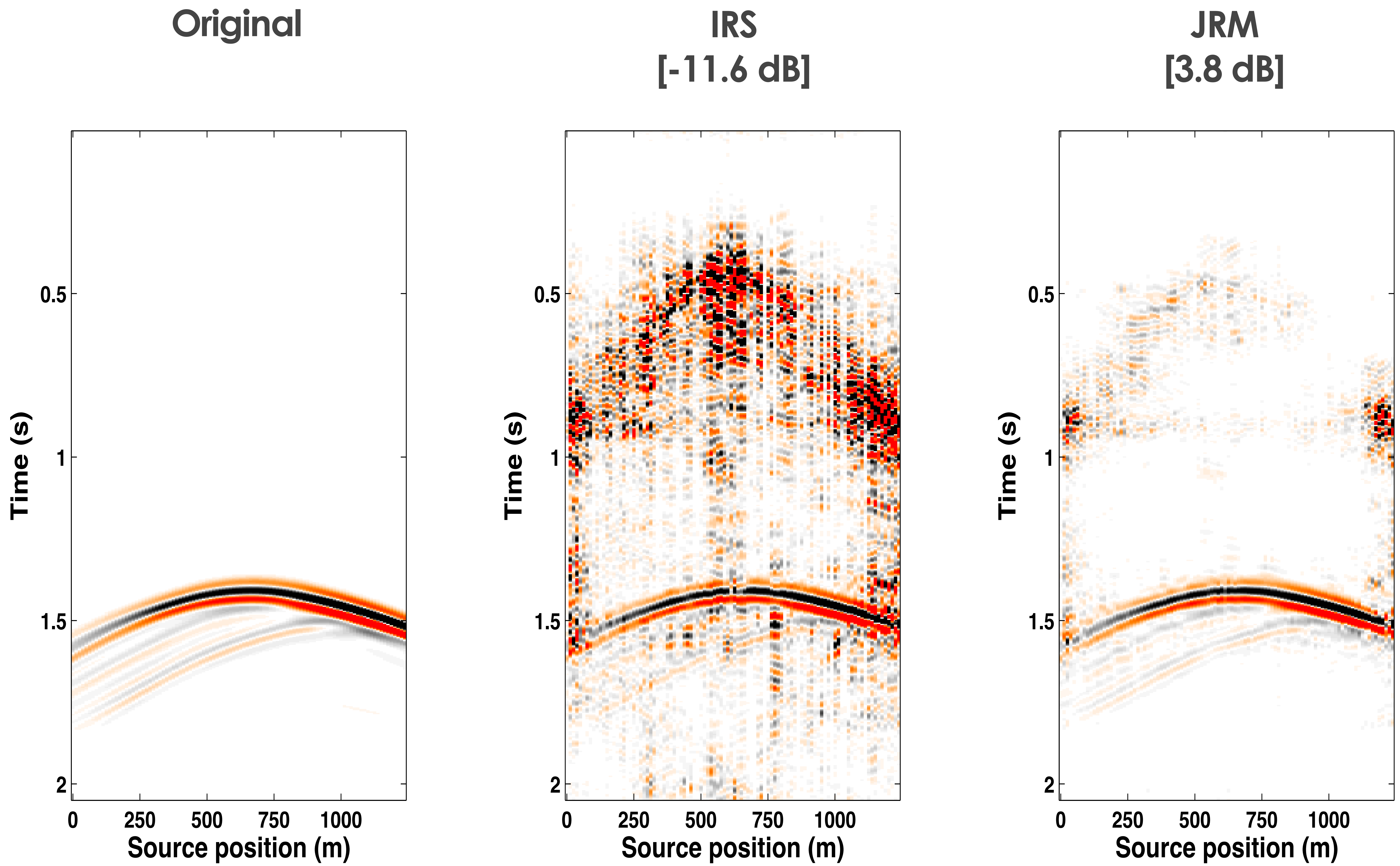
4-D recovery

– **50% overlap** in *acquisition* matrices, **calibration errors ≈ 1.0 m (avg.)**



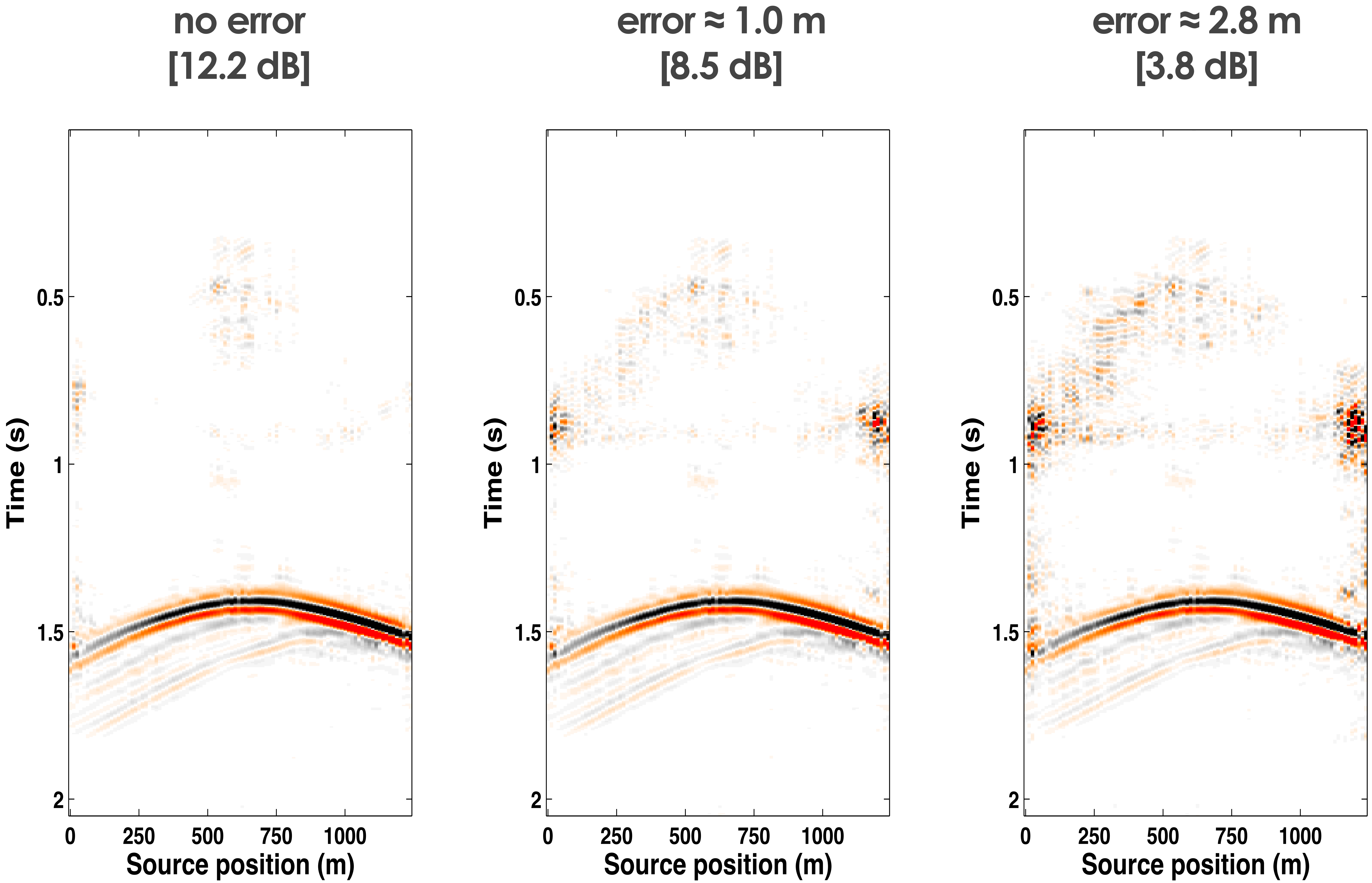
4-D recovery

– **50% overlap** in *acquisition* matrices, **calibration errors ≈ 2.8 m (avg.)**



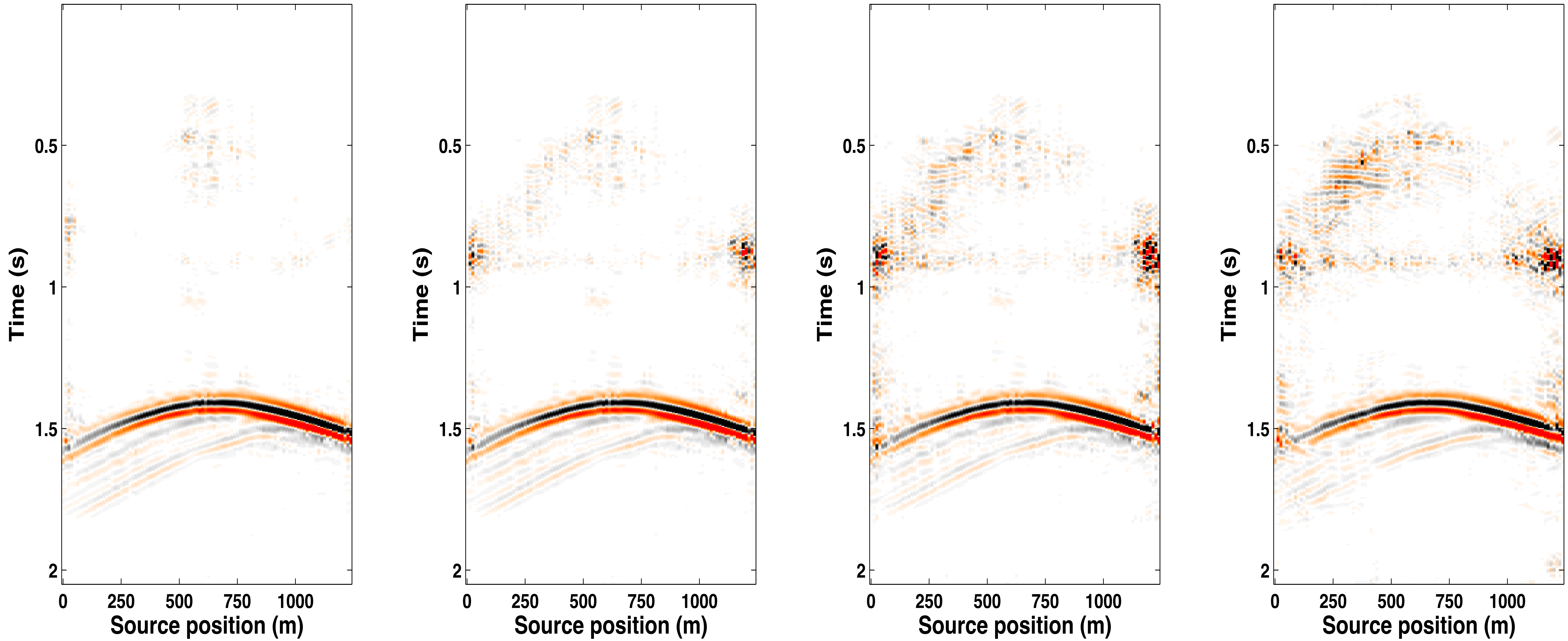
4-D recovery - JRM

– 50% overlap in *acquisition* matrices, w/ & w/o calibration errors



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]

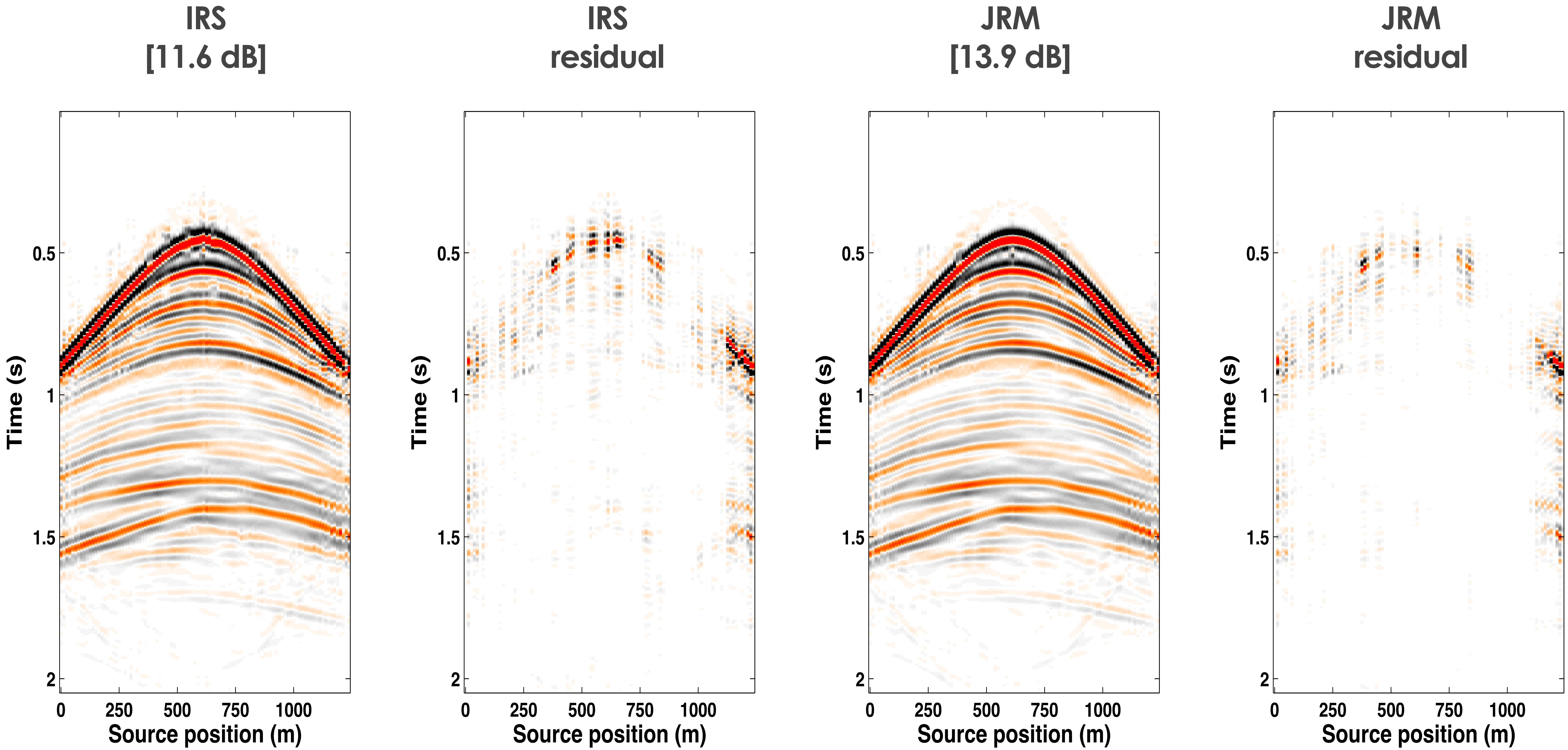
[2.0 dB]

On the contrary,

calibration errors improve recovery of the vintages!

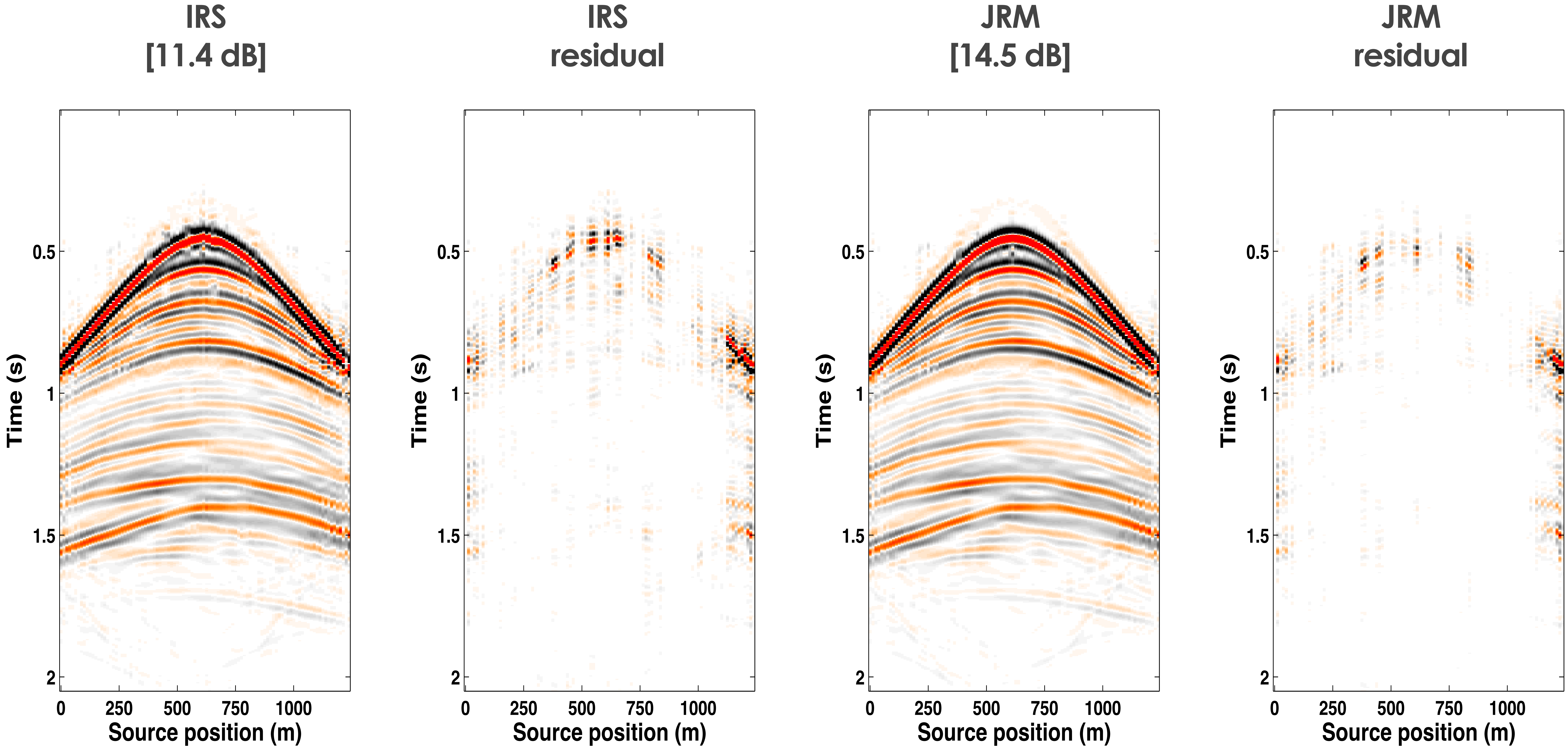
Monitor recovery

– 50% overlap in *acquisition* matrices, no calibration errors



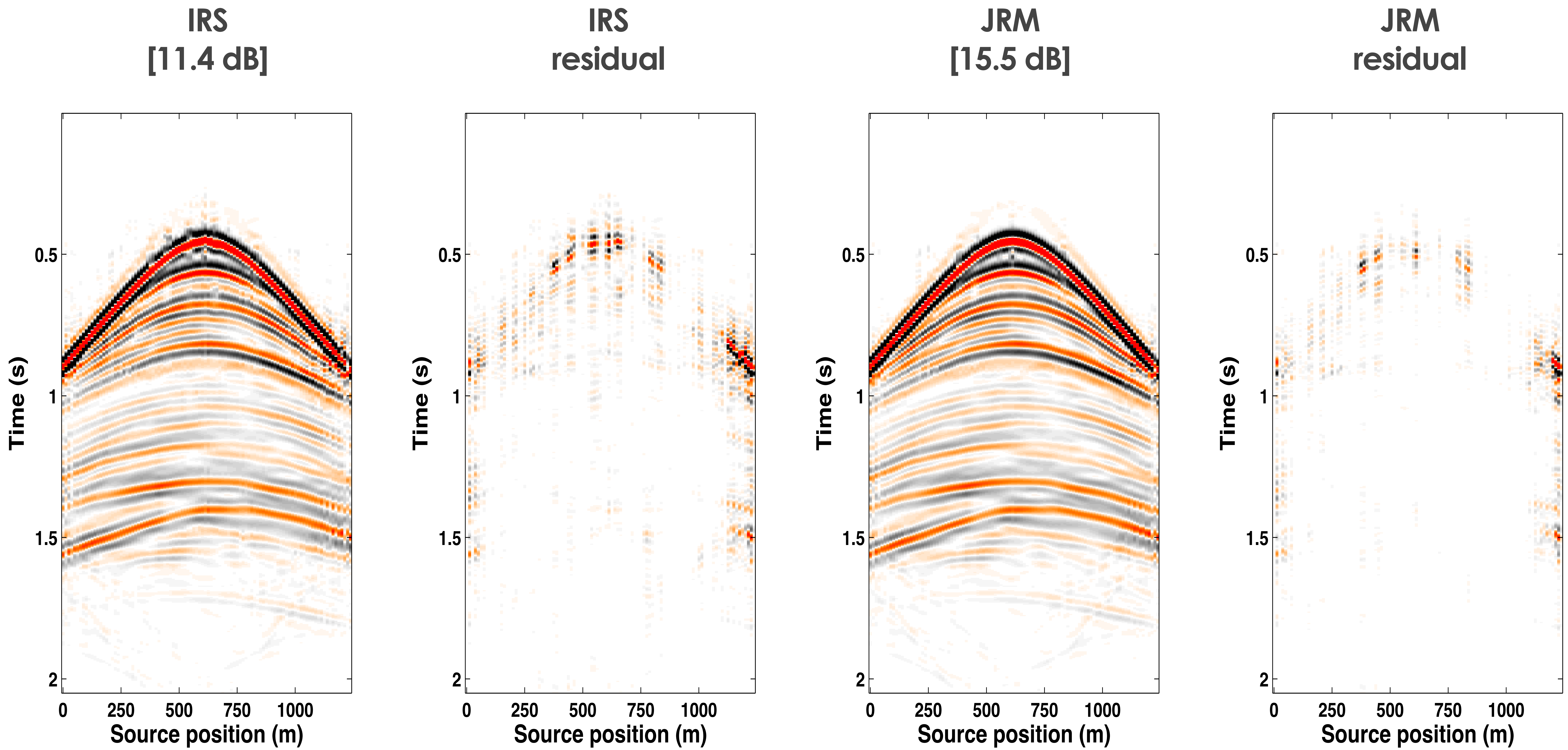
Monitor recovery

– 50% overlap in *acquisition* matrices, calibration errors ≈ 1.0 m (avg.)



Monitor recovery

– 50% overlap in *acquisition* matrices, calibration errors ≈ 2.8 m (avg.)



IRS [11.4 dB]

IRS residual

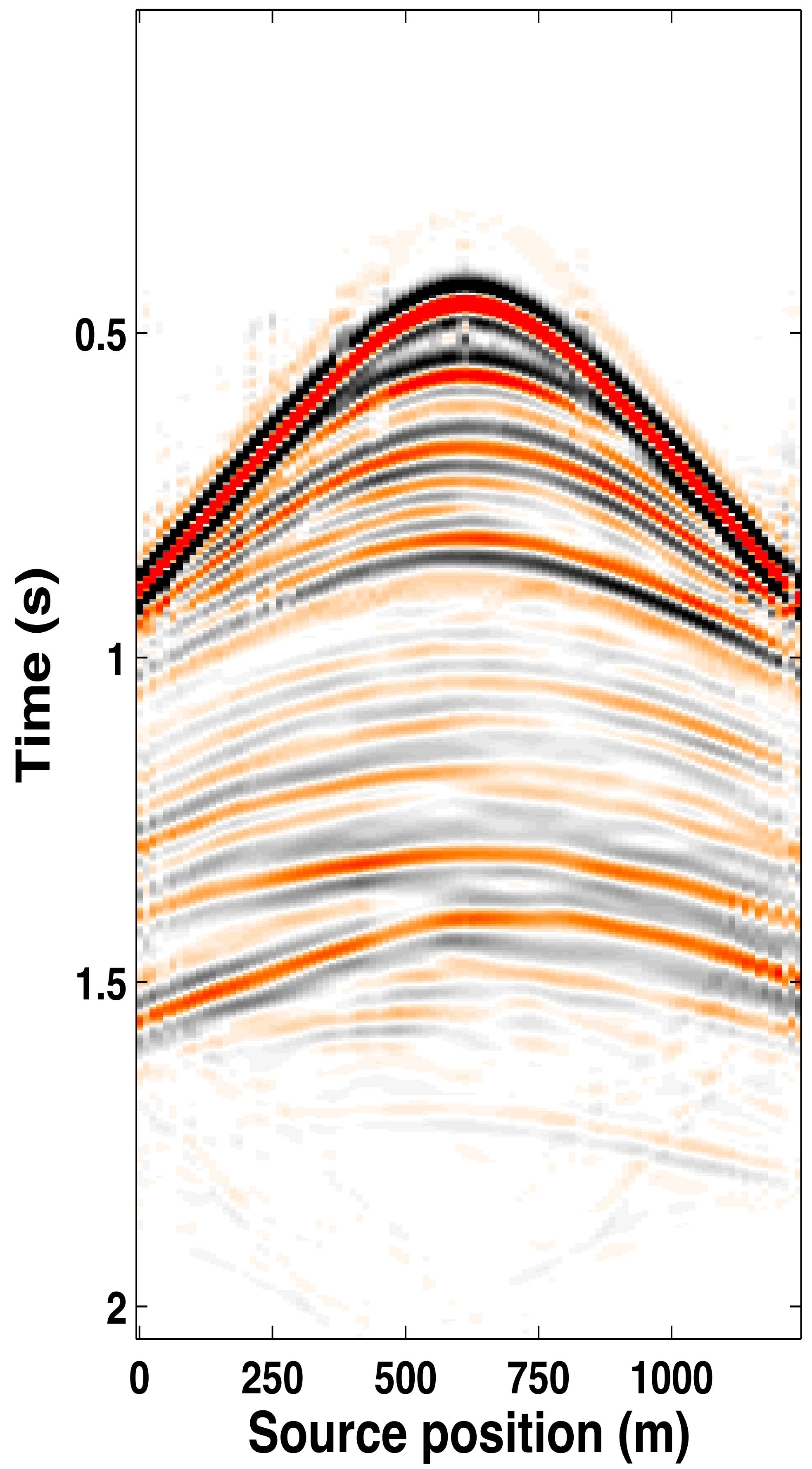
JRM [15.5 dB]

JRM residual

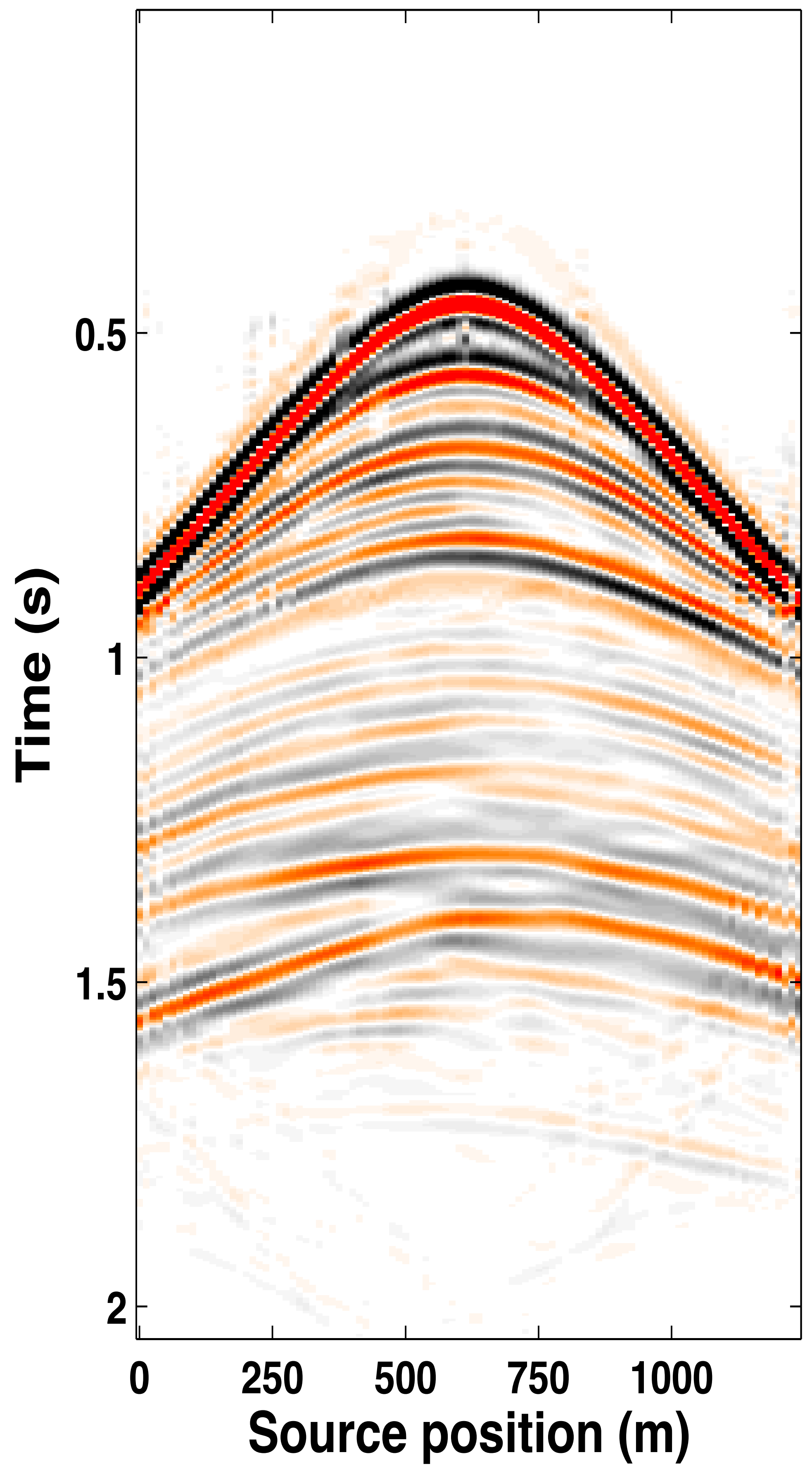
Monitor recovery - JRM

– **50% overlap** in *acquisition* matrices

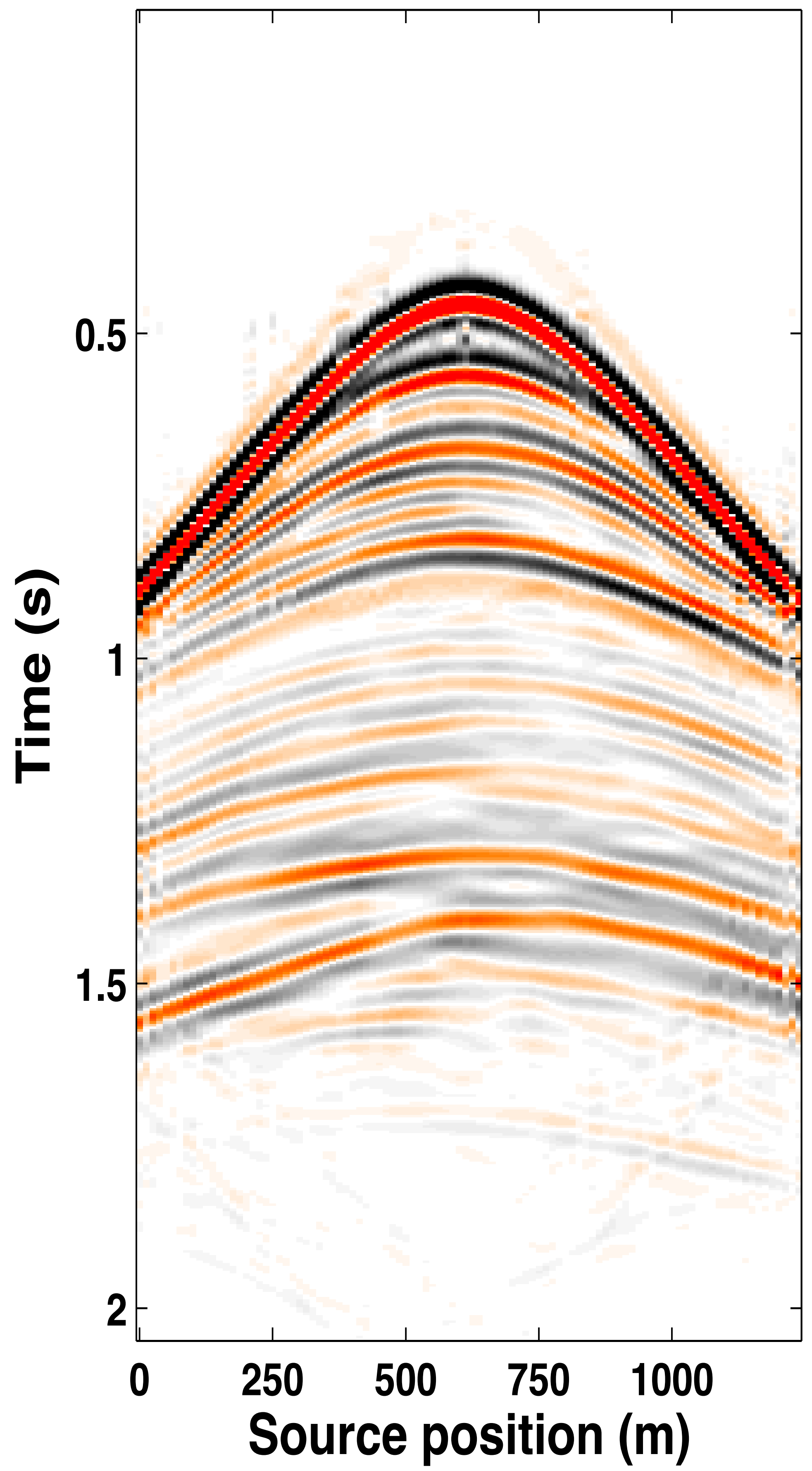
no error
[13.9 dB]



error ≈ 1.0 m
[14.5 dB]

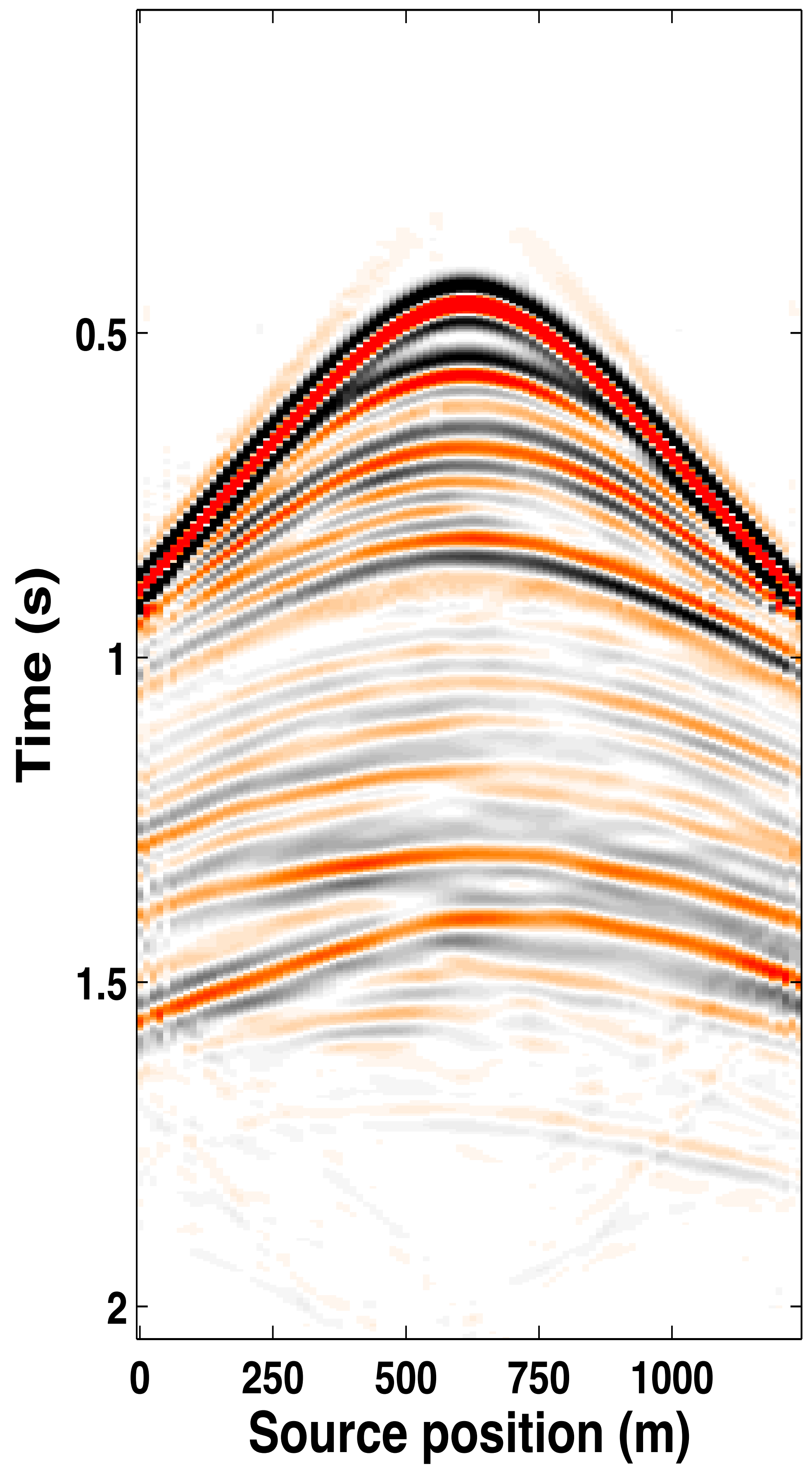


error ≈ 2.8 m
[15.5 dB]



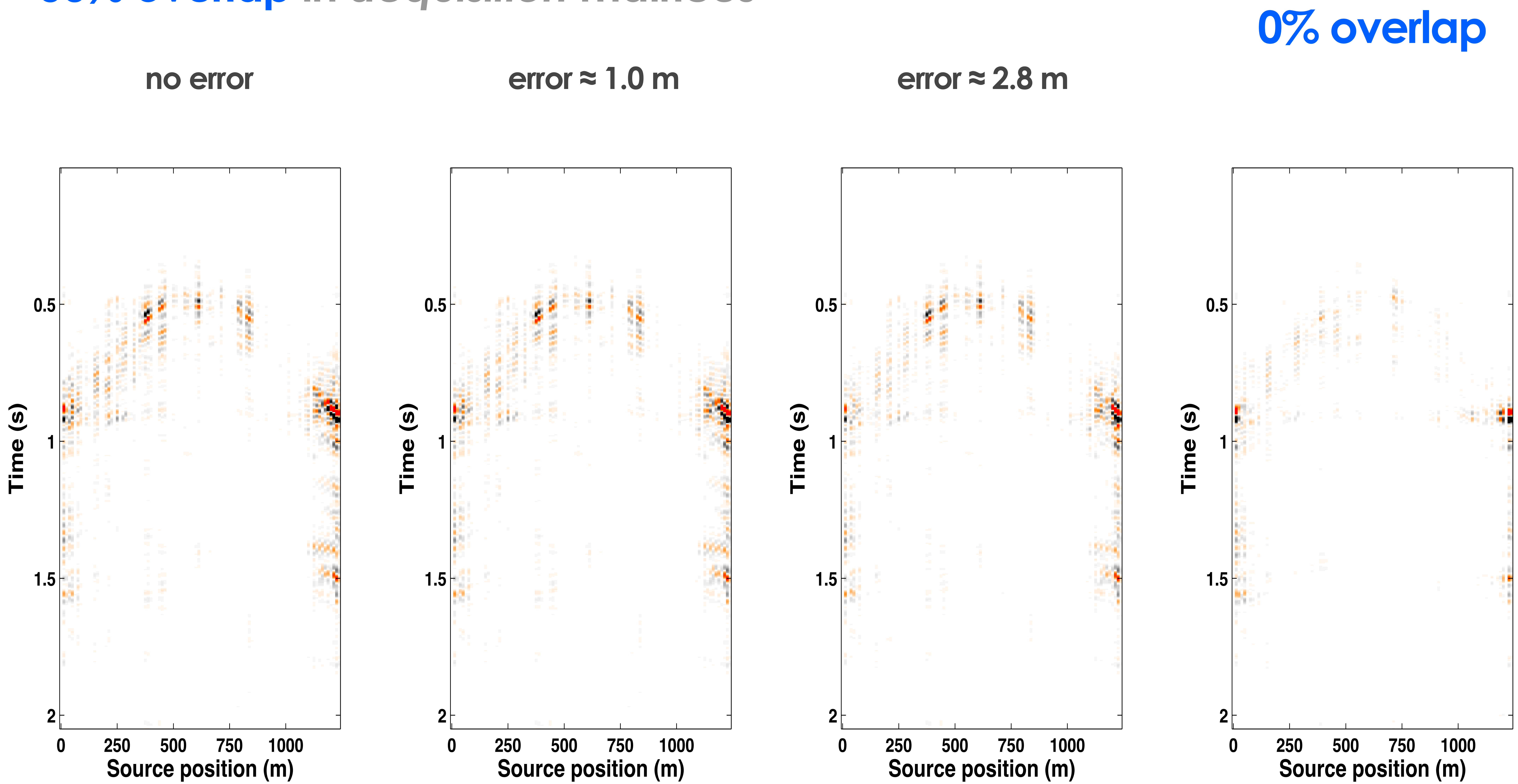
0% overlap

[18.3 dB]



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, calibration errors

- *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

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 sub*sampling?

- no, as long as one samples *sufficiently* to recover *both vintages* jointly
- calibration errors do *not* allow "*exact*" repeatability which is essential for good recovery of the time-lapse signal

Future work

Application to field datasets

Software release: *Time-jittered marine acquisition “off-the-grid”*

Acknowledgements

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