Randomization and repeatability in time-lapse marine acquisition

Haneet Wason, Felix Oghenekohwo, and Felix J. Herrmann

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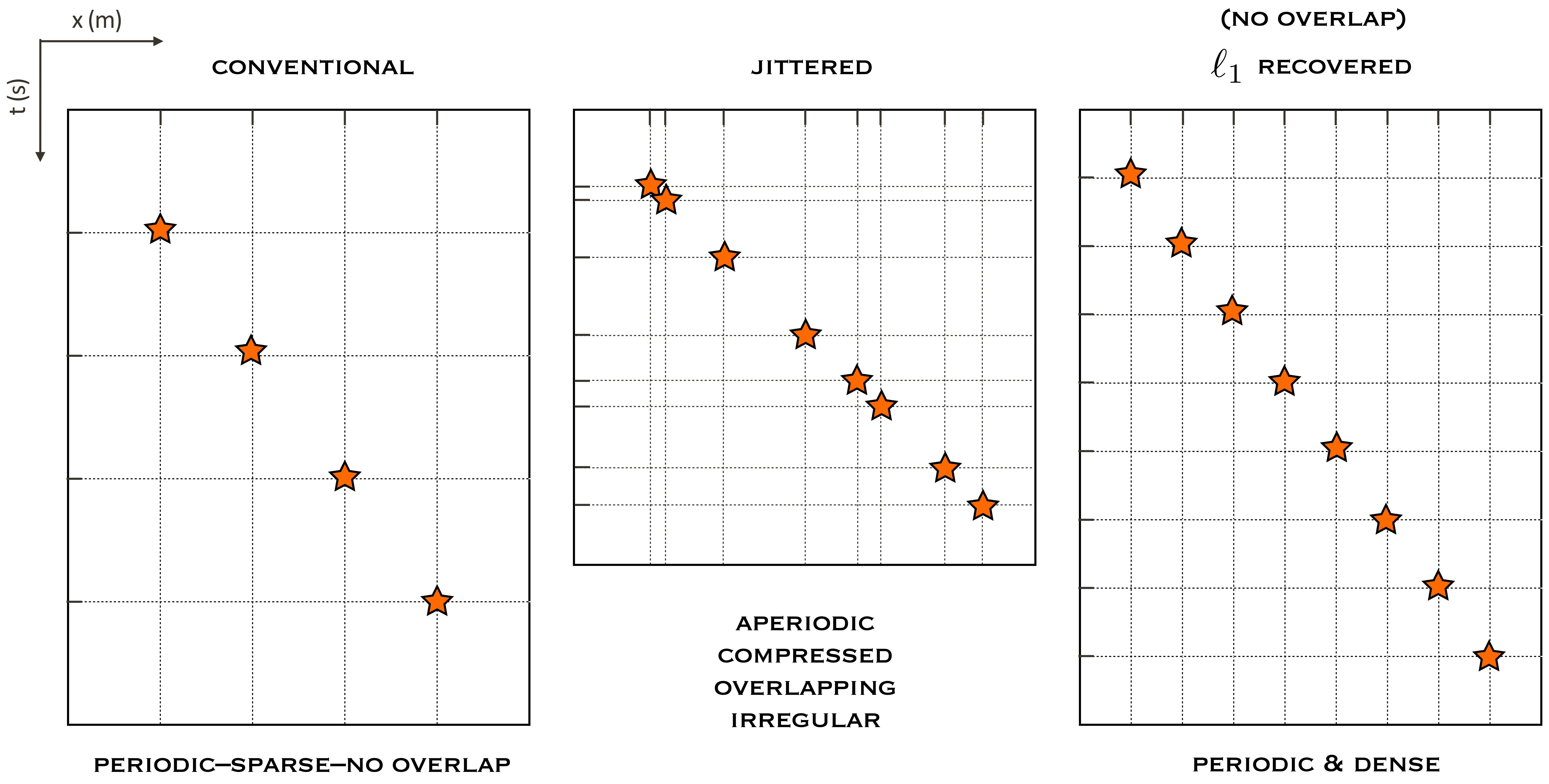
Randomized sampling in marine
[SEG 2013]



Motivation

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

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

Should we repeat in randomized marine acquisition?

Disclaimer

Assumptions:

- you are a *believer* in *randomized* acquisition & *sparse* recovery
- *seismic* data & *time*-lapse signal *both* permit *sparse* representations
- there are *no* calibration *errors but* there can be *additive* noise
- *degree* of repetition refers to *percentage* of a *survey* that is repeated *exactly*

All observations are based on *synthetic* ocean bottom data...

Felix Oghenekohwo, Ernie Esser, and Felix J. Herrmann, "**Time-lapse seismic without repetition: reaping the benefits from randomized sampling and joint recovery**", in *EAGE Annual Conference Proceedings*, 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*

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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

Felix J. Herrmann, Michael P. Friedlander, and Ozgur Yilmaz, "Fighting the Curse of Dimensionality: Compressive Sensing in Exploration Seismology", *Signal Processing Magazine, IEEE*, vol. 29, p. 88-100, 2012
Felix J. Herrmann, "Randomized sampling and sparsity: Getting more information from fewer samples", *Geophysics*, vol. 75, p. WB173-WB187, 2010

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Compressed sensing *paradigm*

Find **representations that reveal** ***structure***

- *transform*-domain *sparsity* (e.g., Fourier, curvelets, etc.)

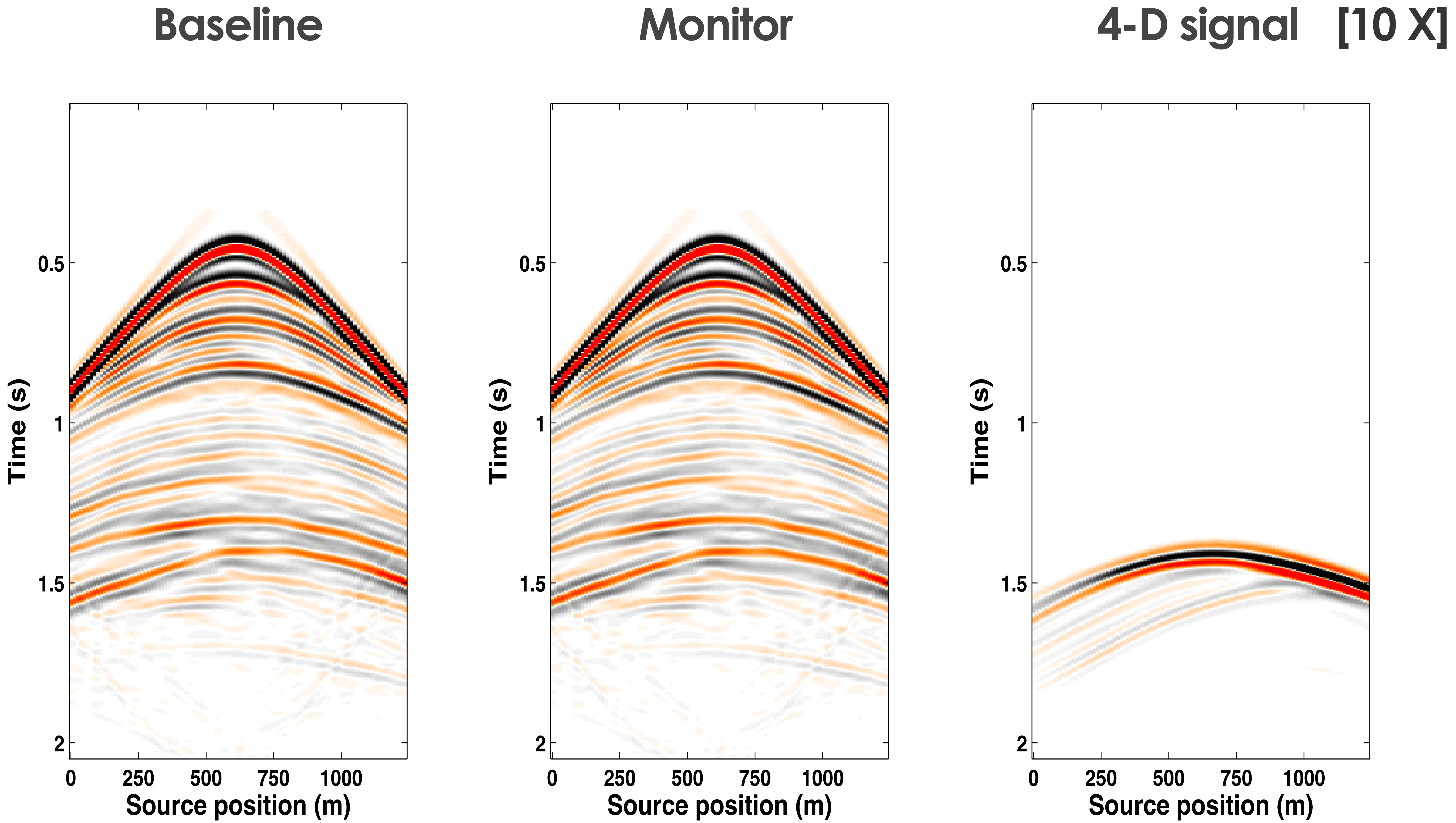
Sample **to** ***break*** **the** ***structure***

- *randomized* acquisition (e.g., *jittered* sampling, time *dithering*, *encoding*, etc.)
- destroy *sparsity*

Recover ***structure*** **by promoting**

- *sparsity* via *one*-norm *minimization*

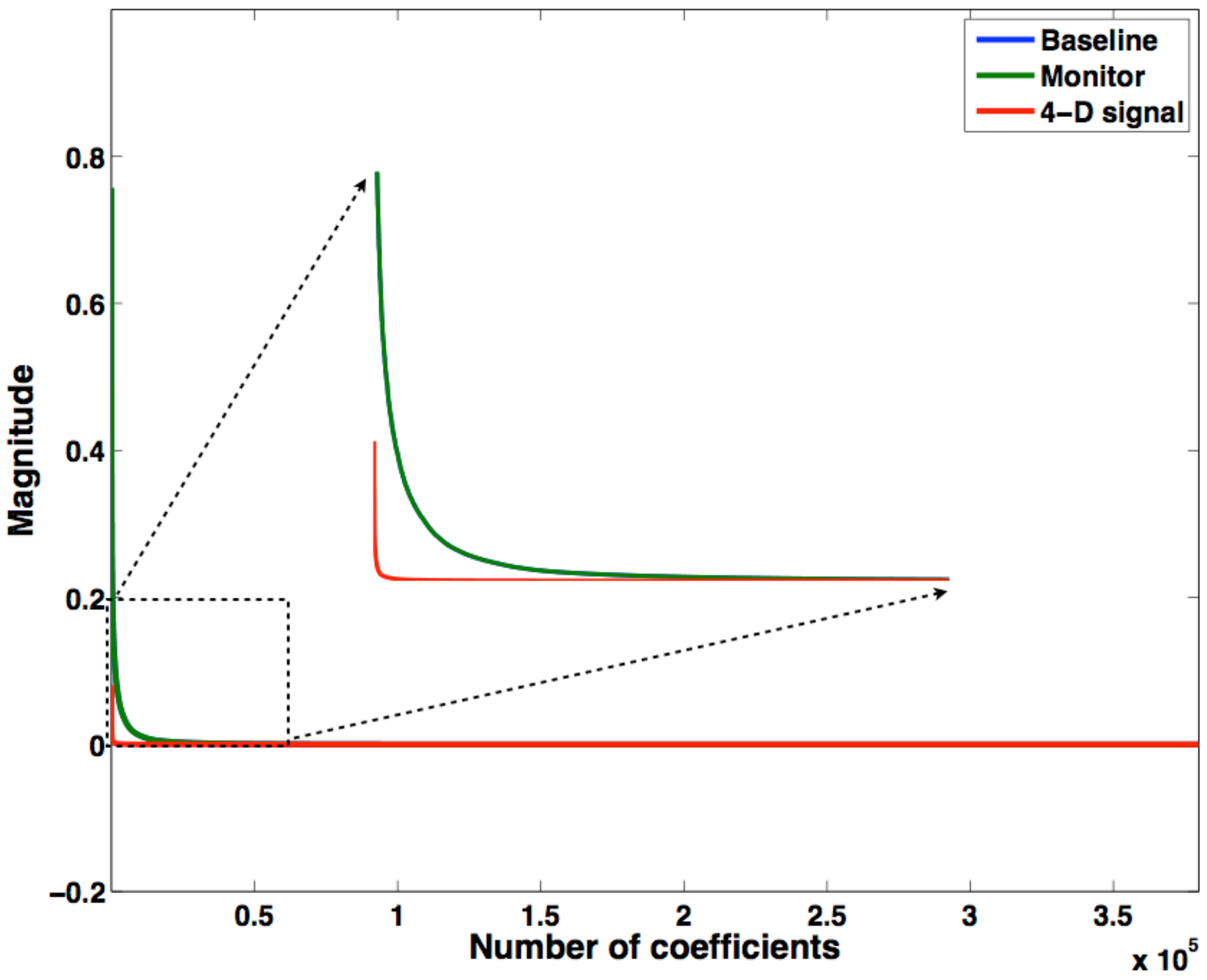
Time-lapse data



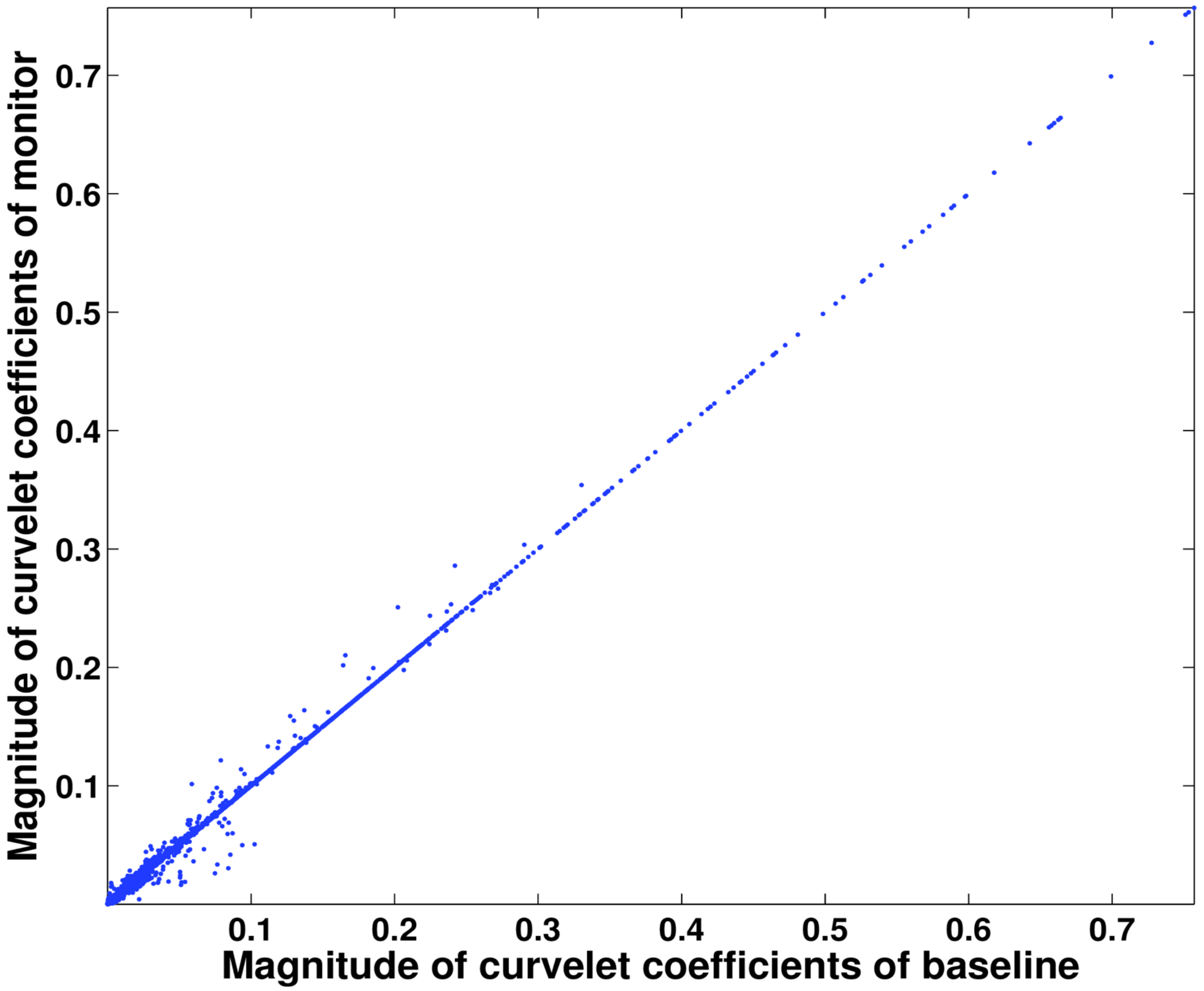
time samples: **512**
receivers: **100**
sources: **100**

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)

vintages

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

differences

common component

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

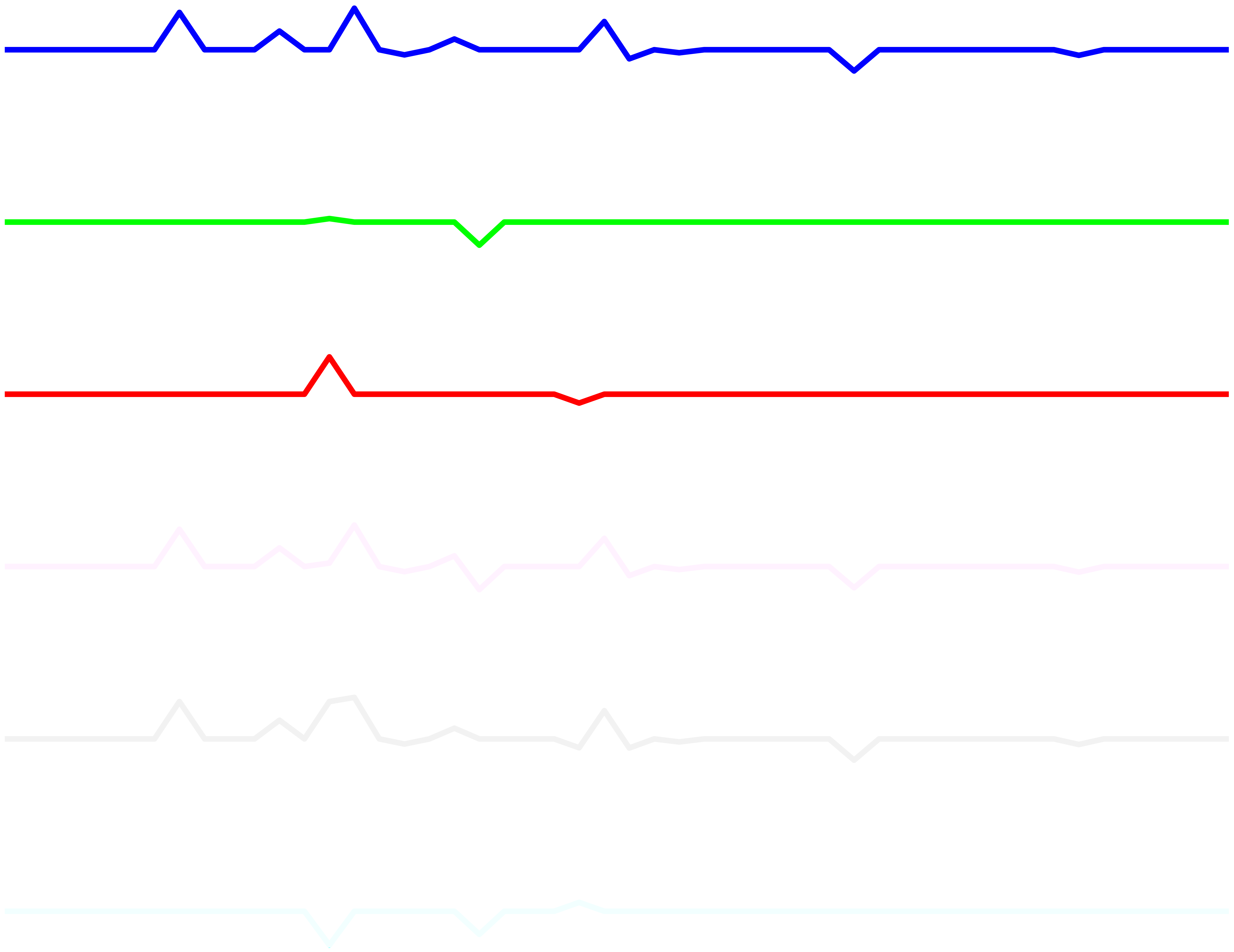
baseline

monitor

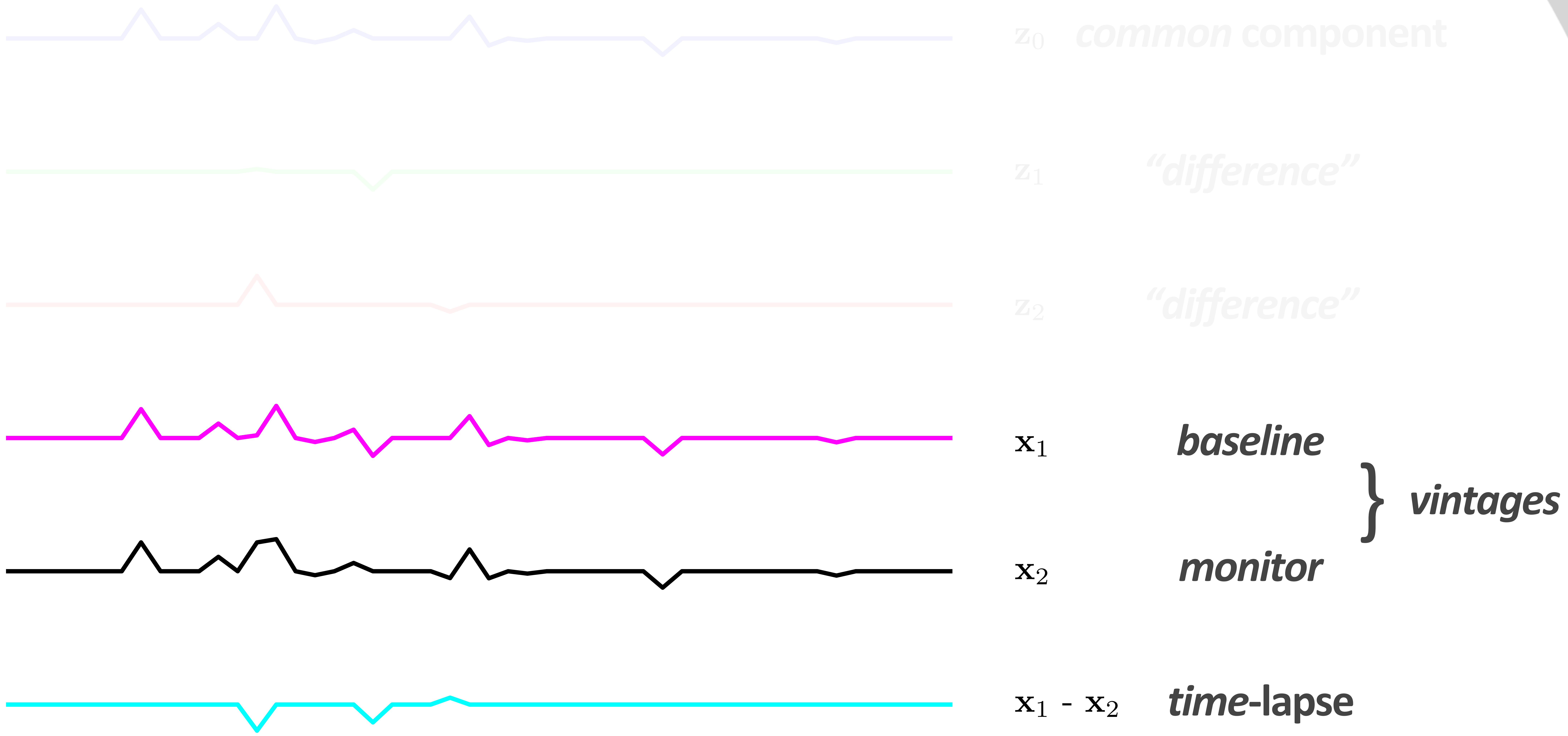
Key idea:

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

Sparse Joint Recovery Model (JRM)



Sparse baseline, monitor & time-lapse signals



Time-lapse
– 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…

Question: To *repeat* or *not* to repeat?

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?

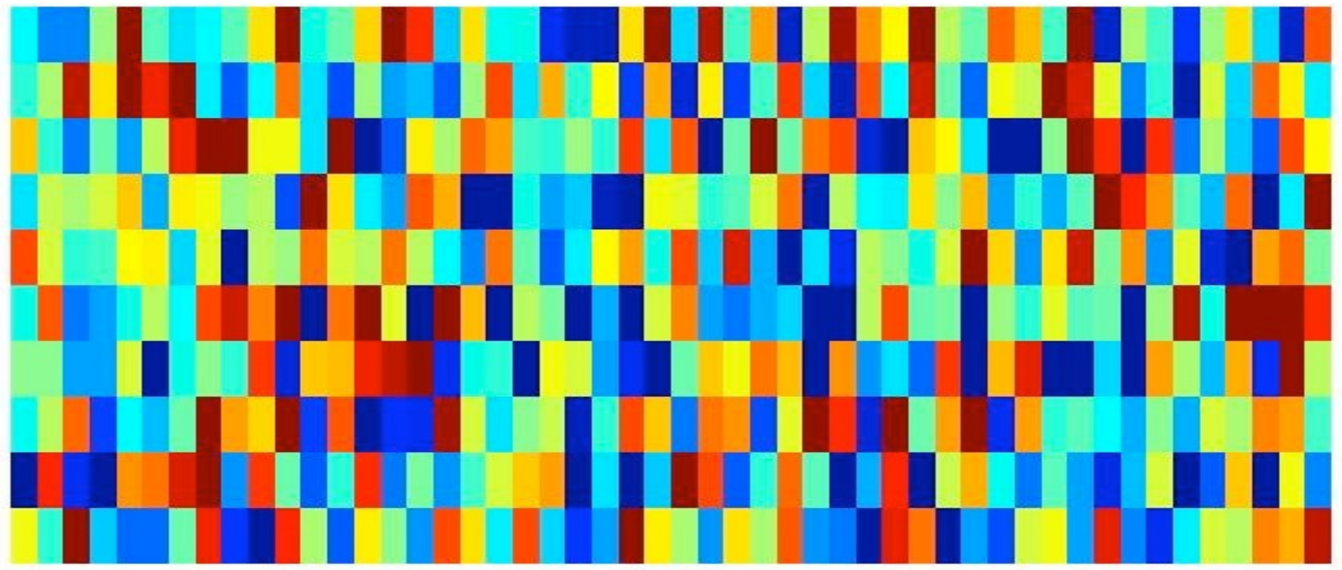
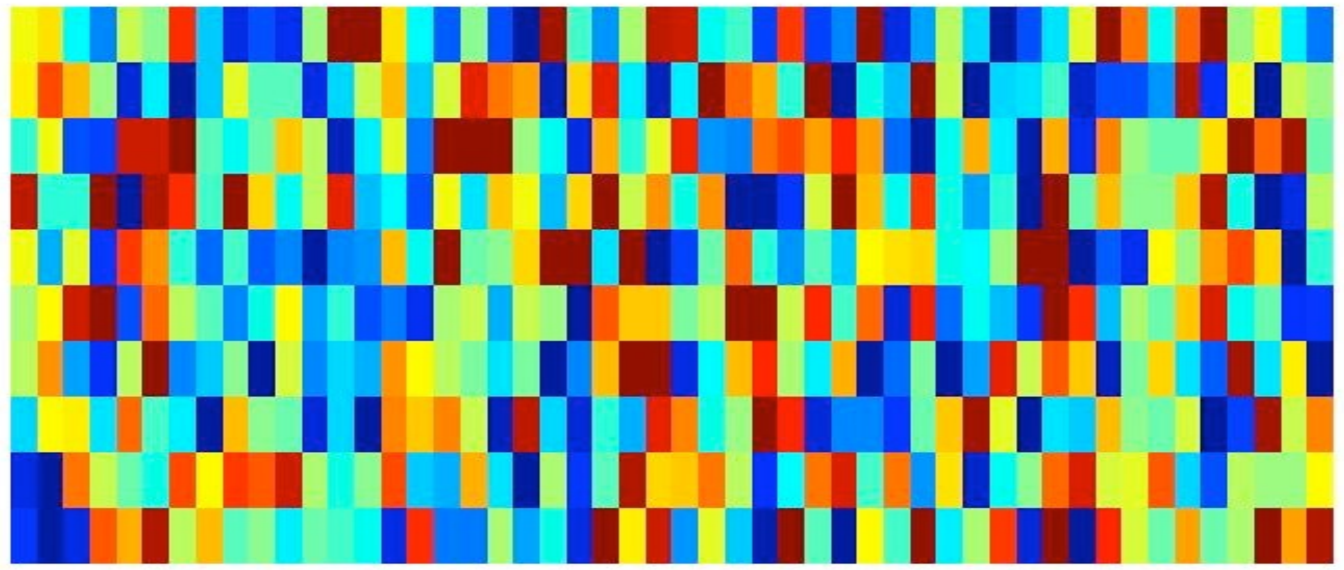
Stylized experiments

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

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

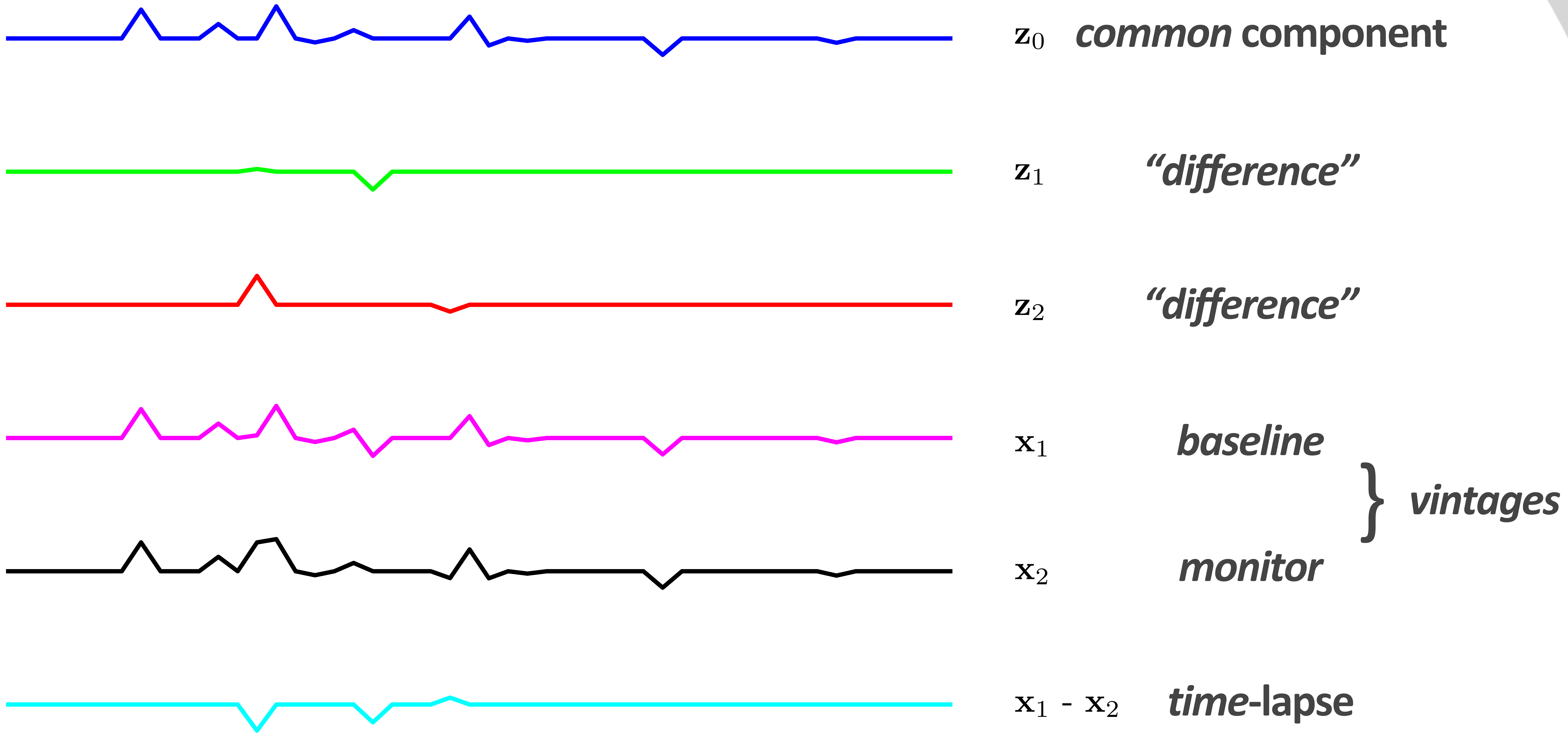
n  n 

N $\quad$ N

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

run 2000 different experiments & compute probability of recovery

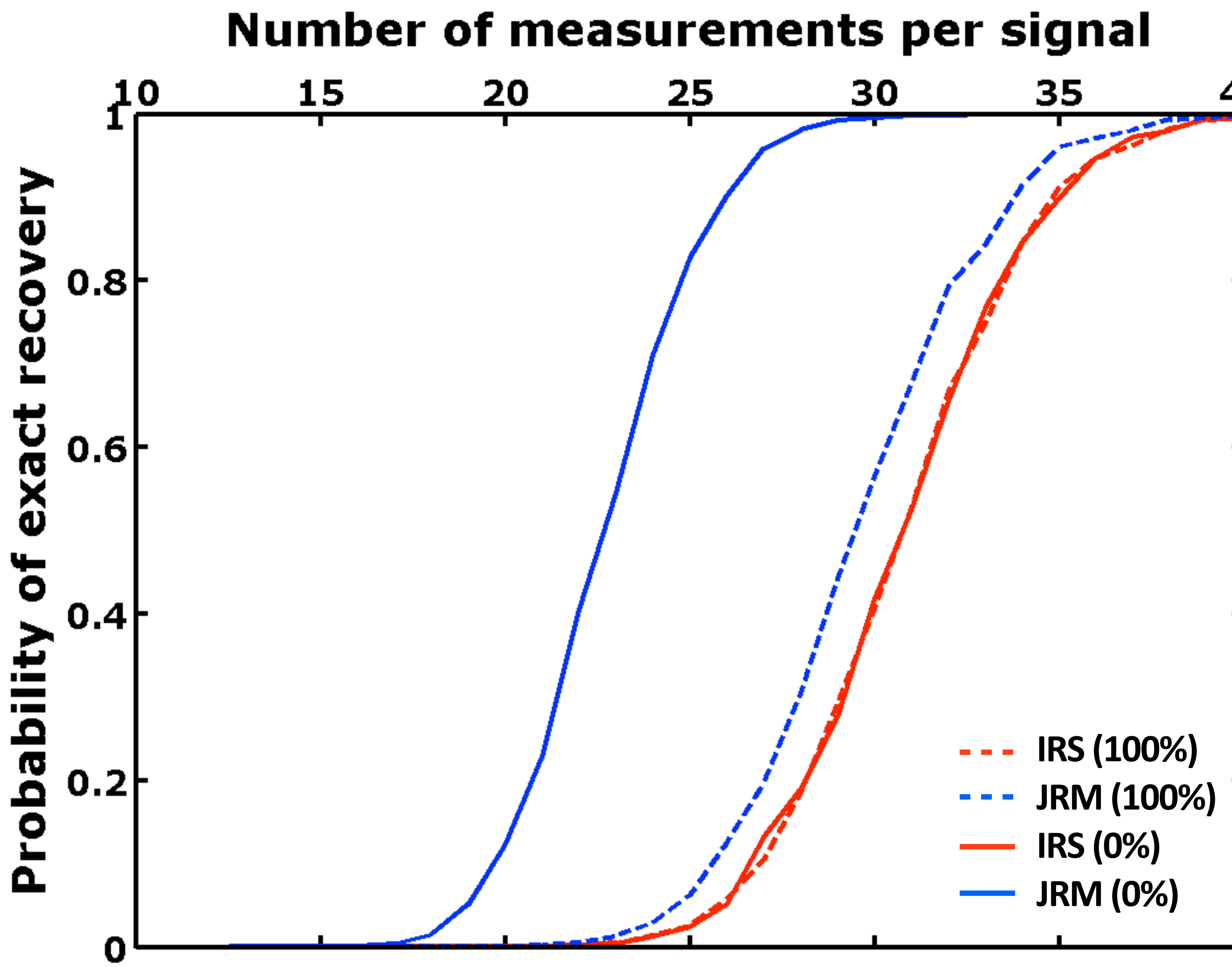
Sparse signals



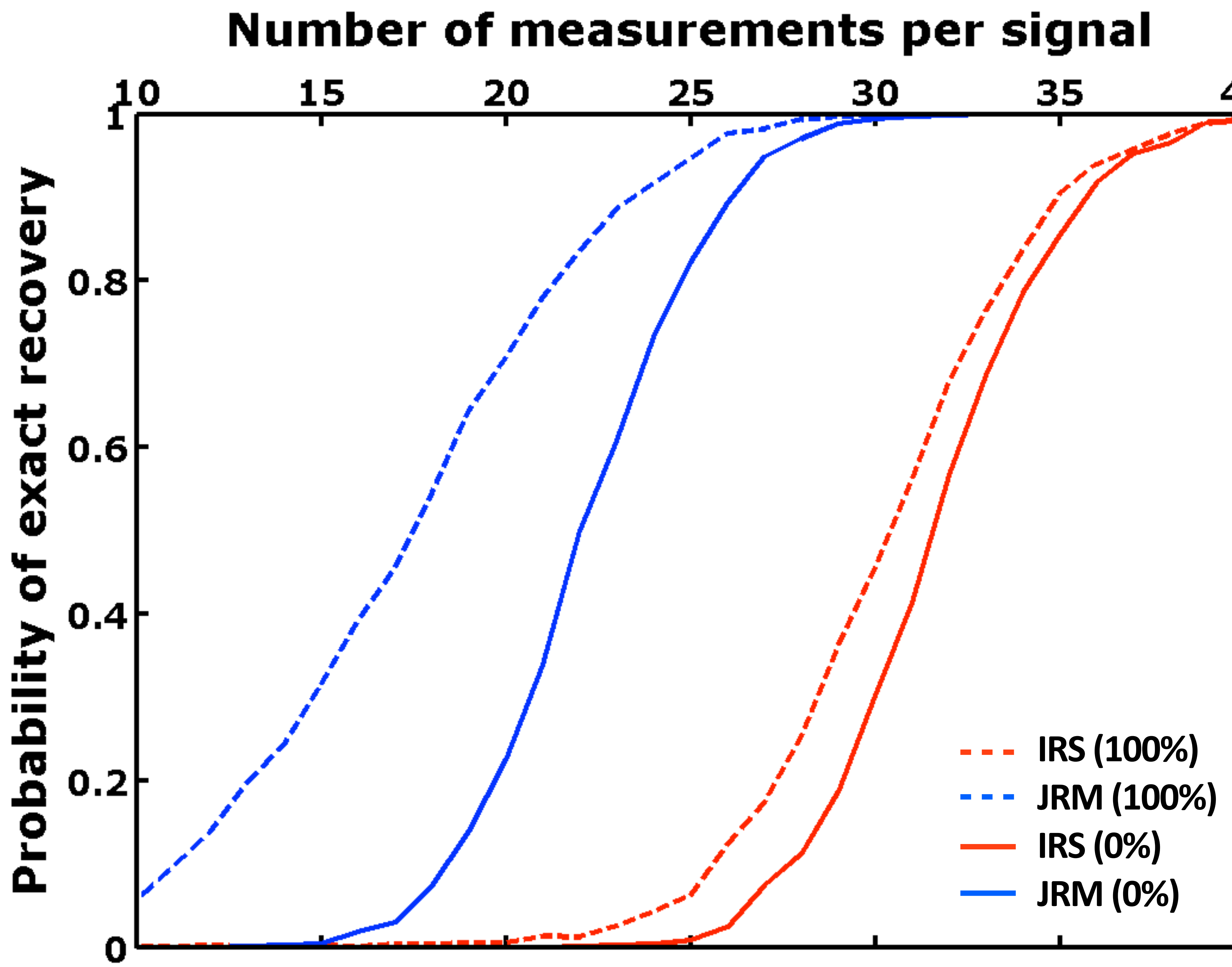
Independent vs. *joint* recovery

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

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

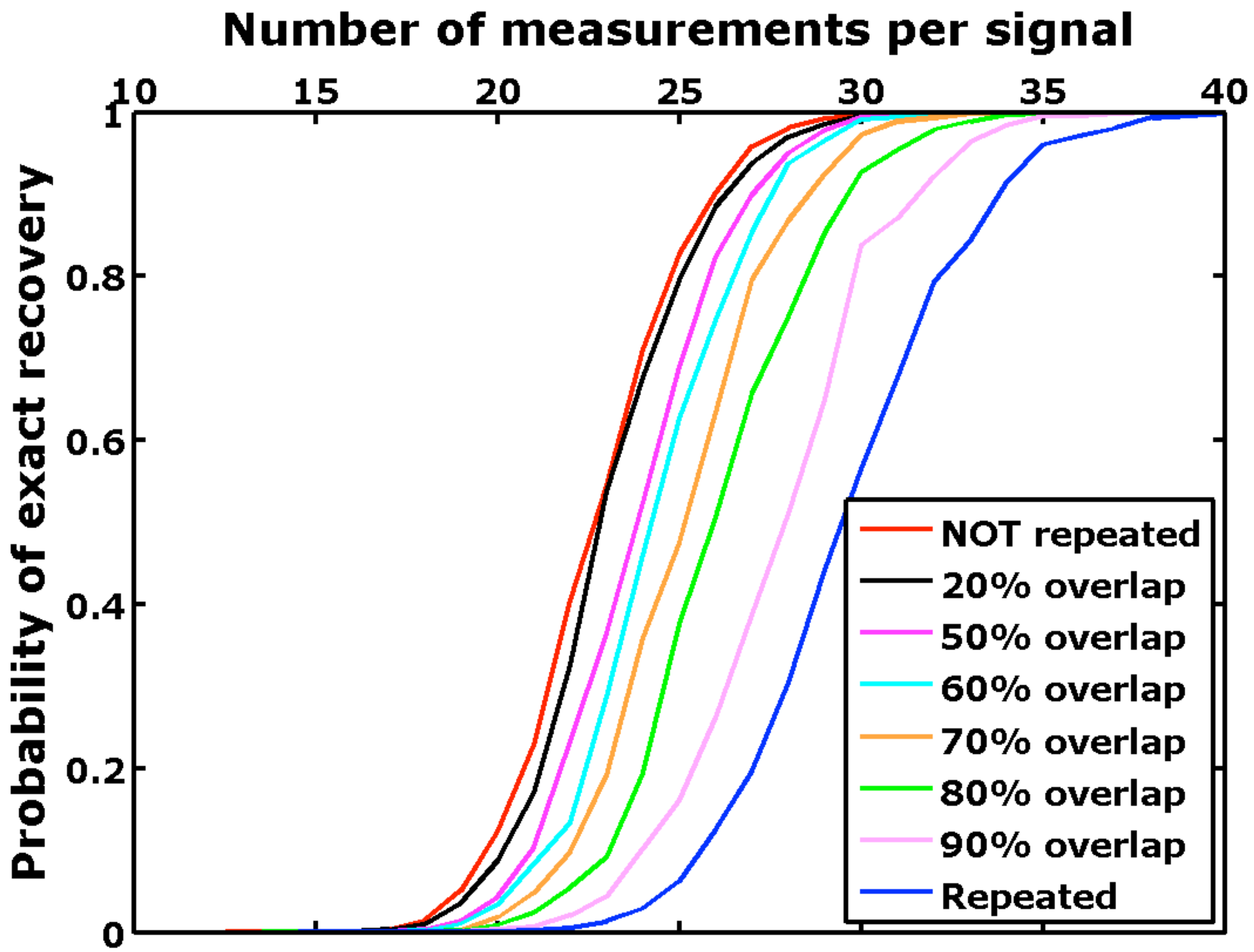


Vintages

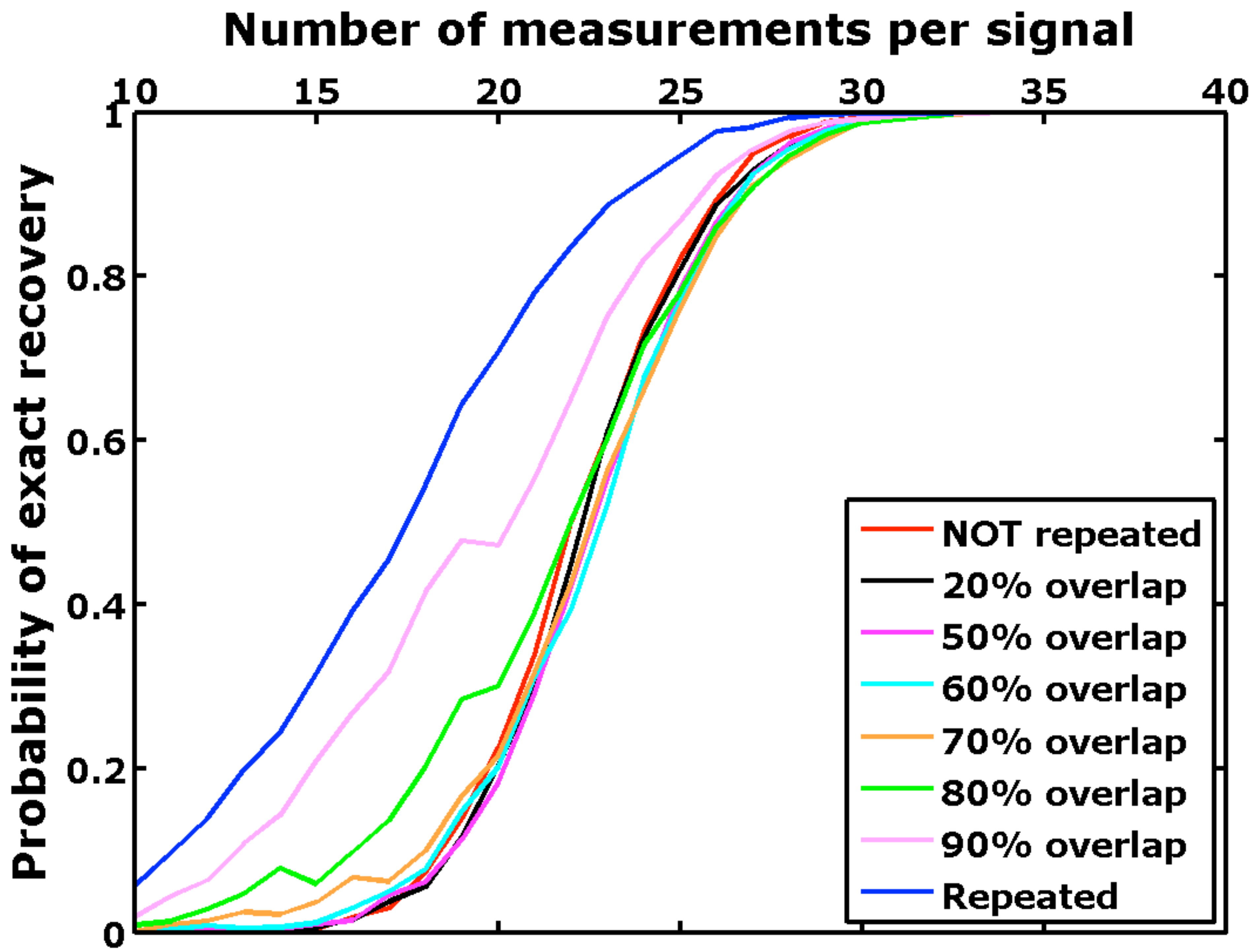


4-D signal

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?

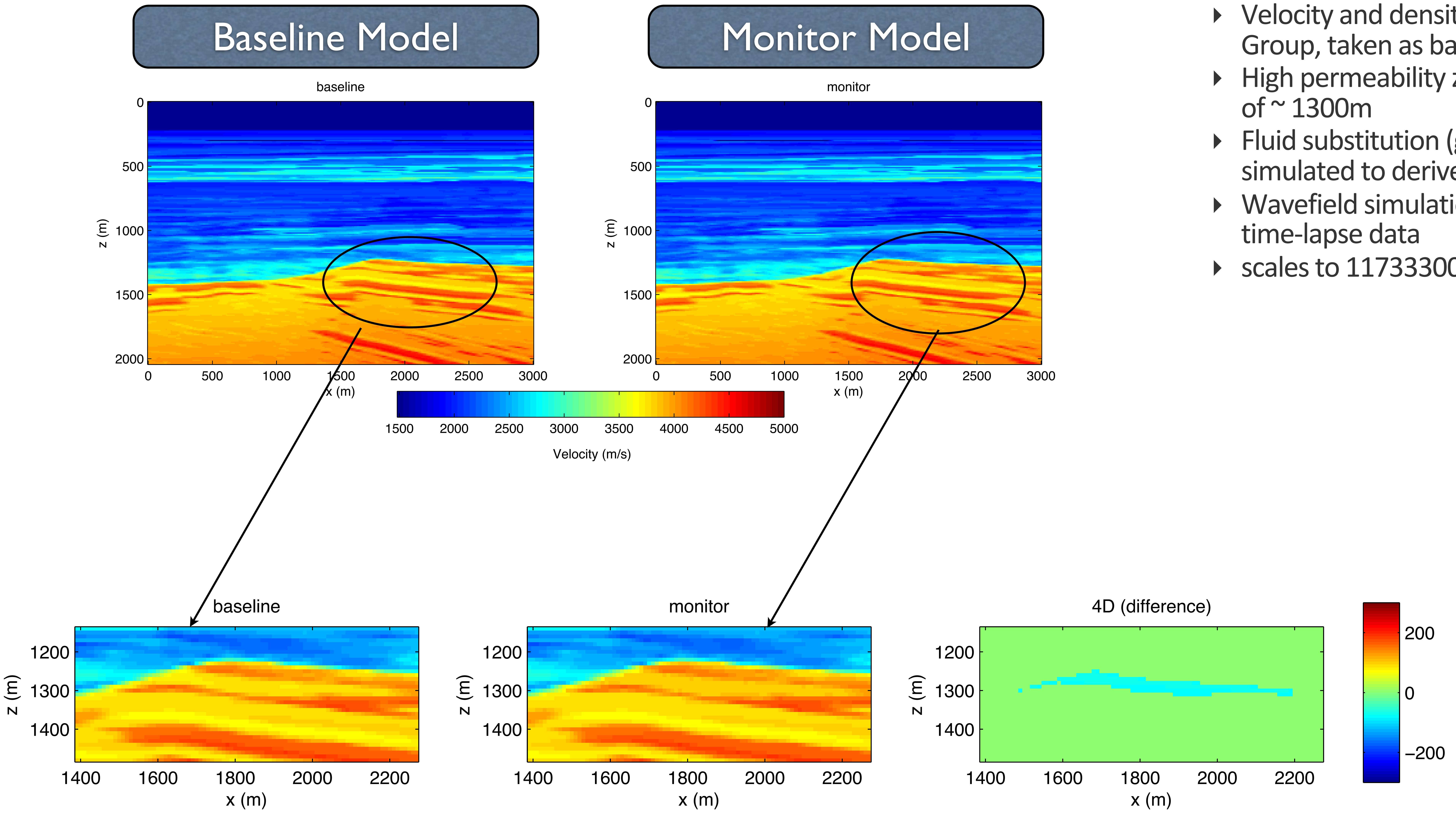
- processing *jointly* leads to *improved* recovery of ***both*** *vintages* & *time*-lapse signal

Synthetic seismic case study

Time-jittered marine acquisition

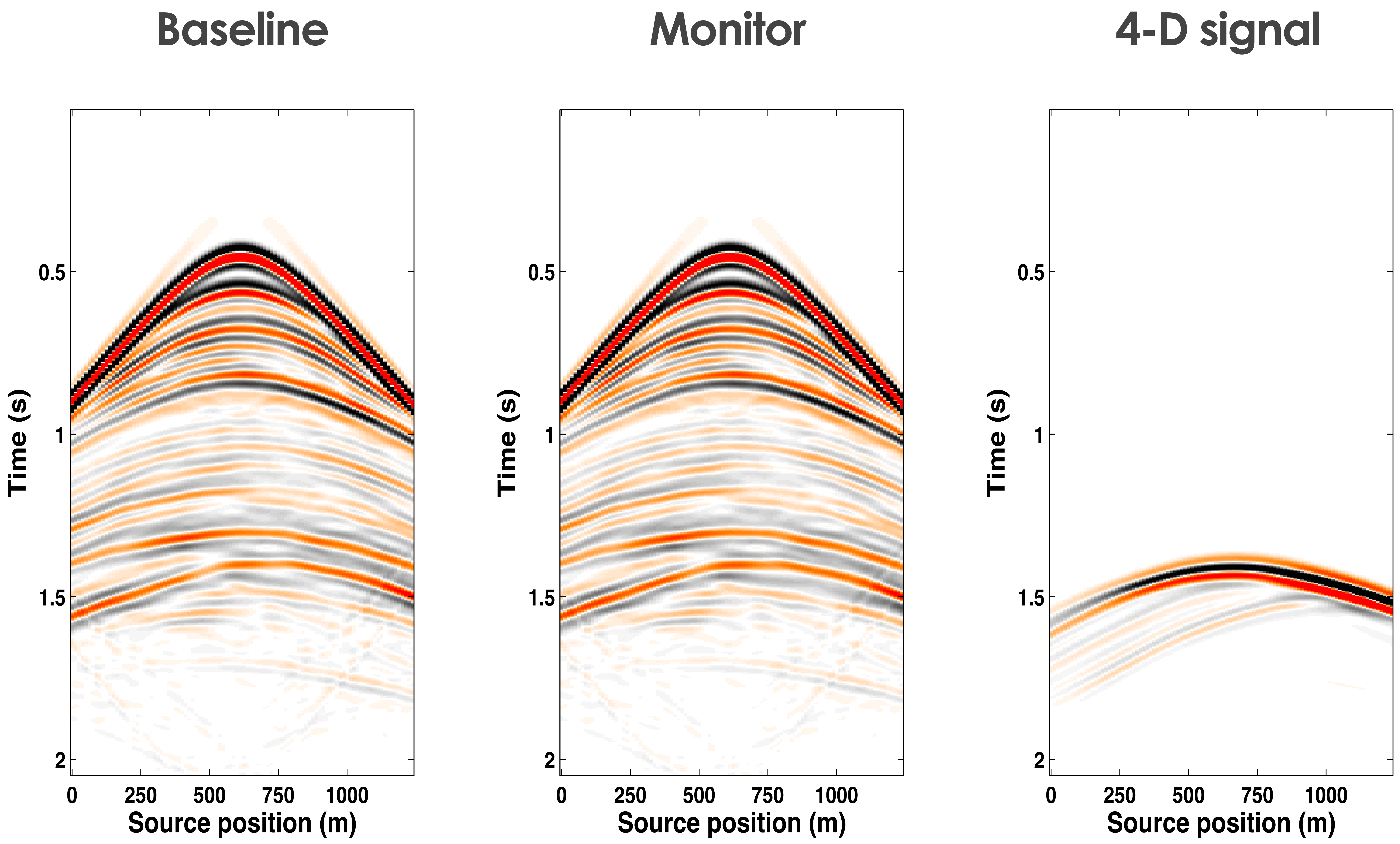
Method

- 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



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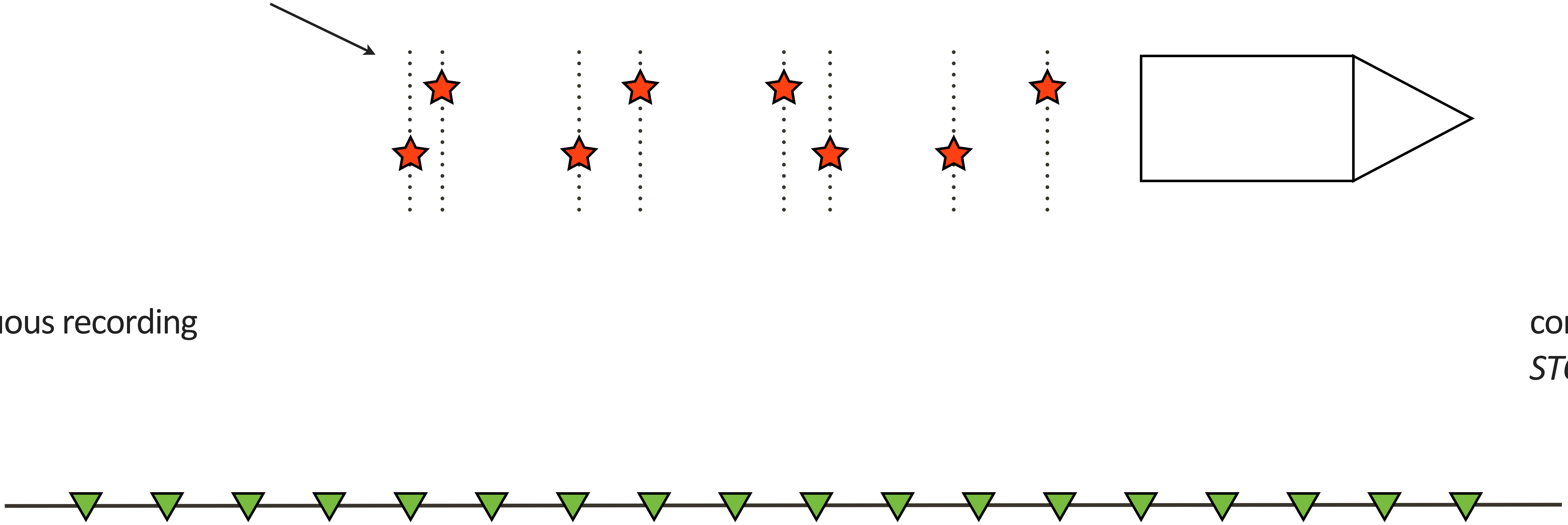
sources: **100**

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

Time-jittered marine acquisition

irregularly sampled spatial grid



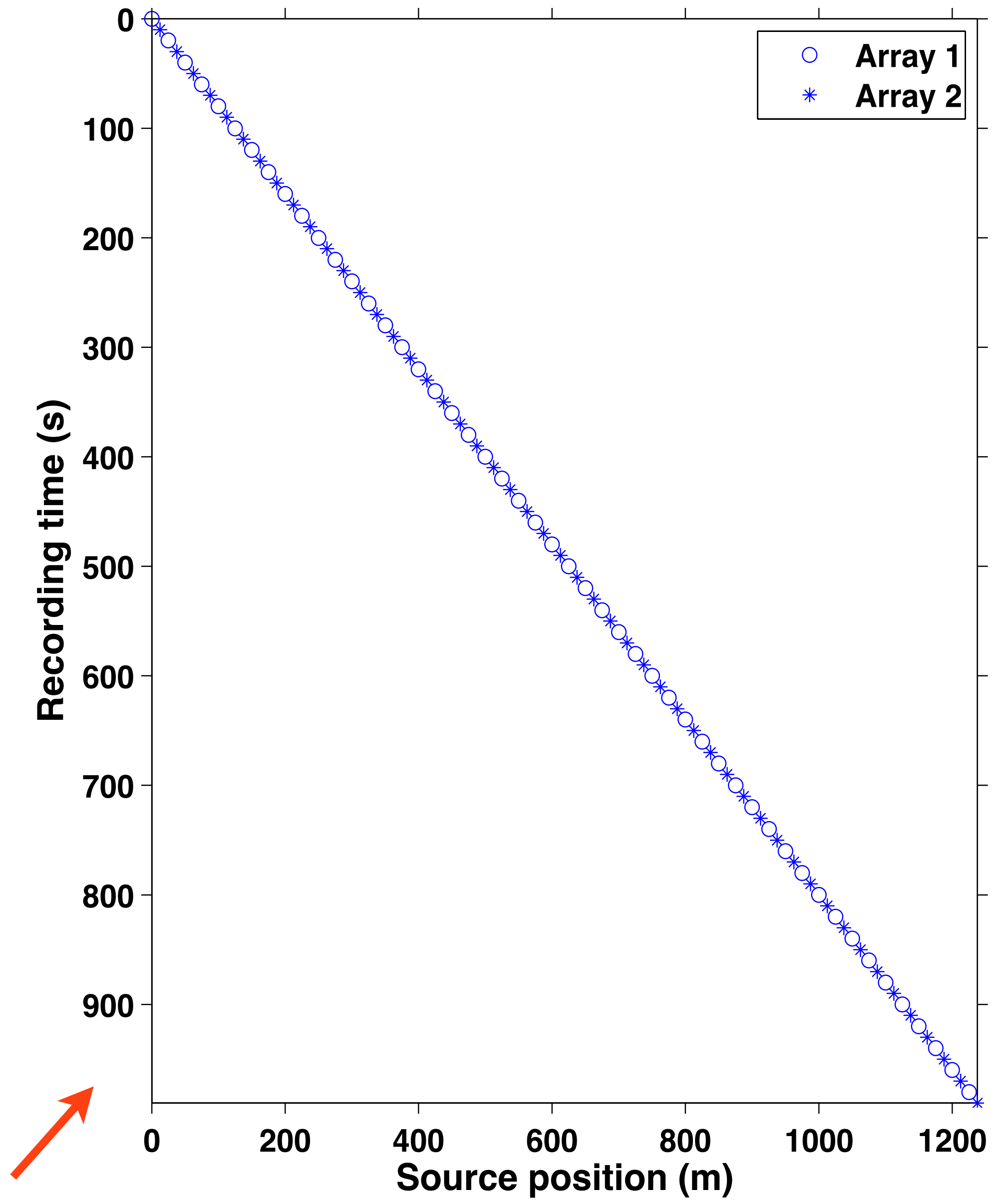
continuous recording
START

continuous recording
STOP

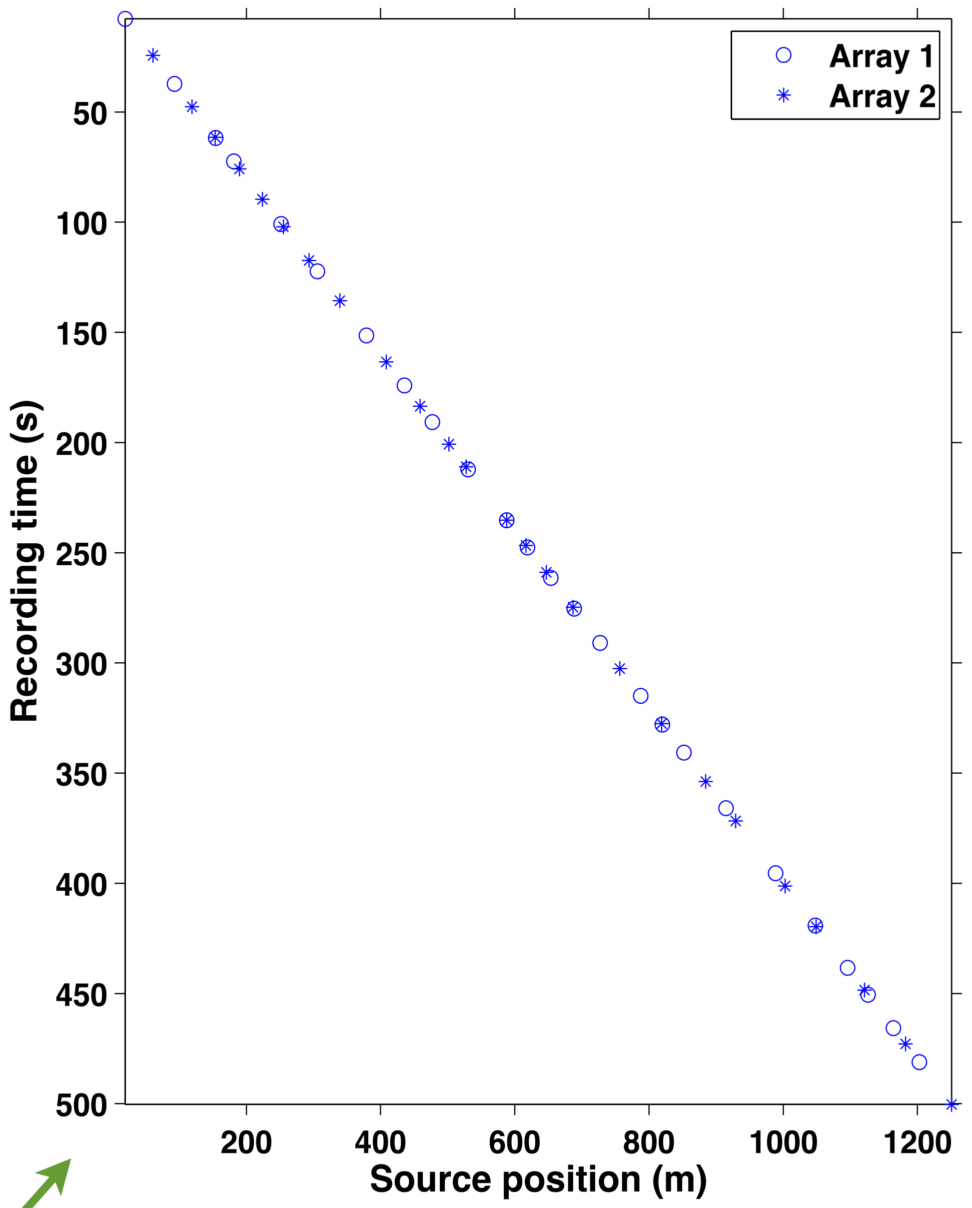
Conventional vs. *time-jittered* sources

– *subsampling* ratio = 2, 2 source arrays

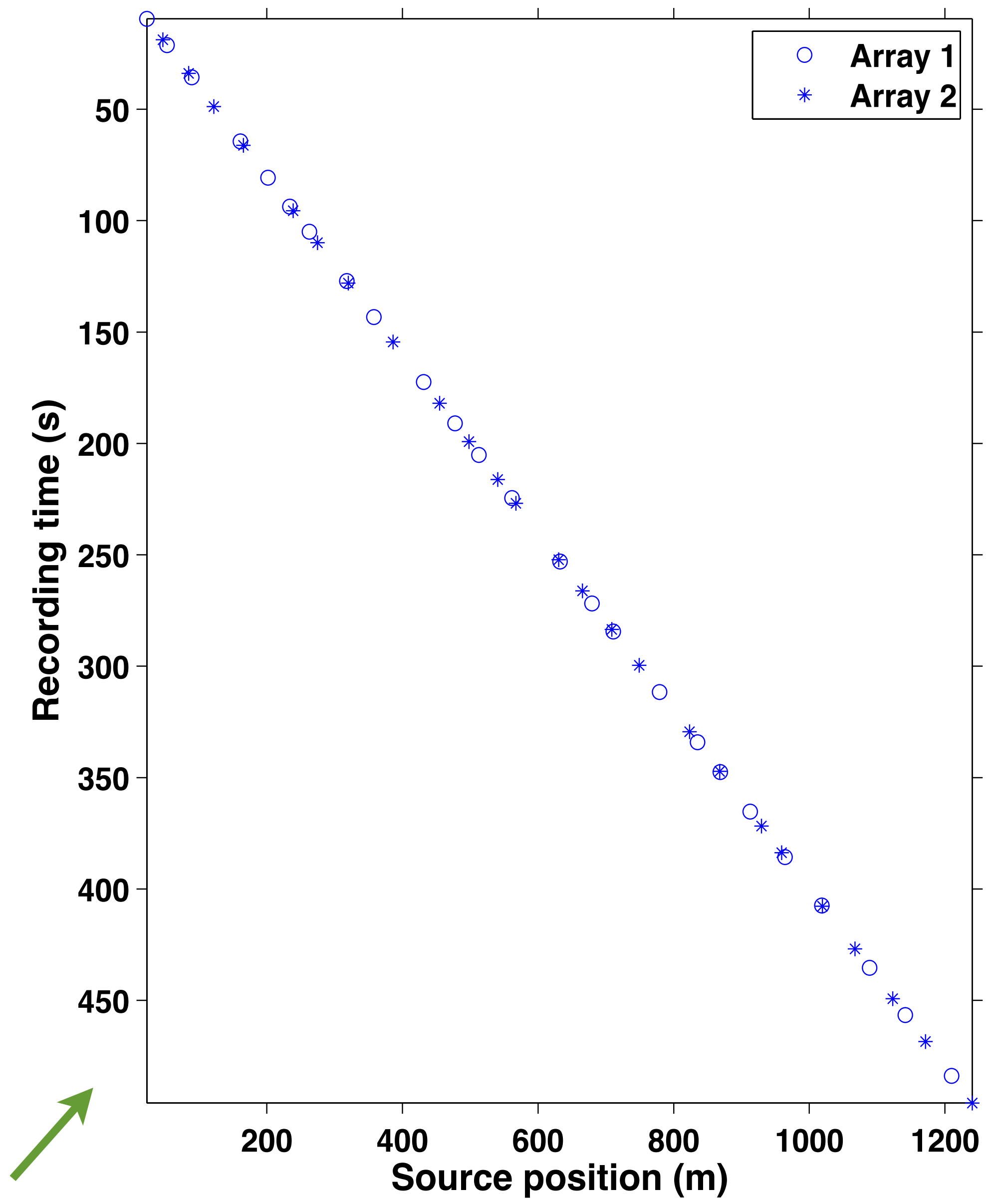
conventional



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**

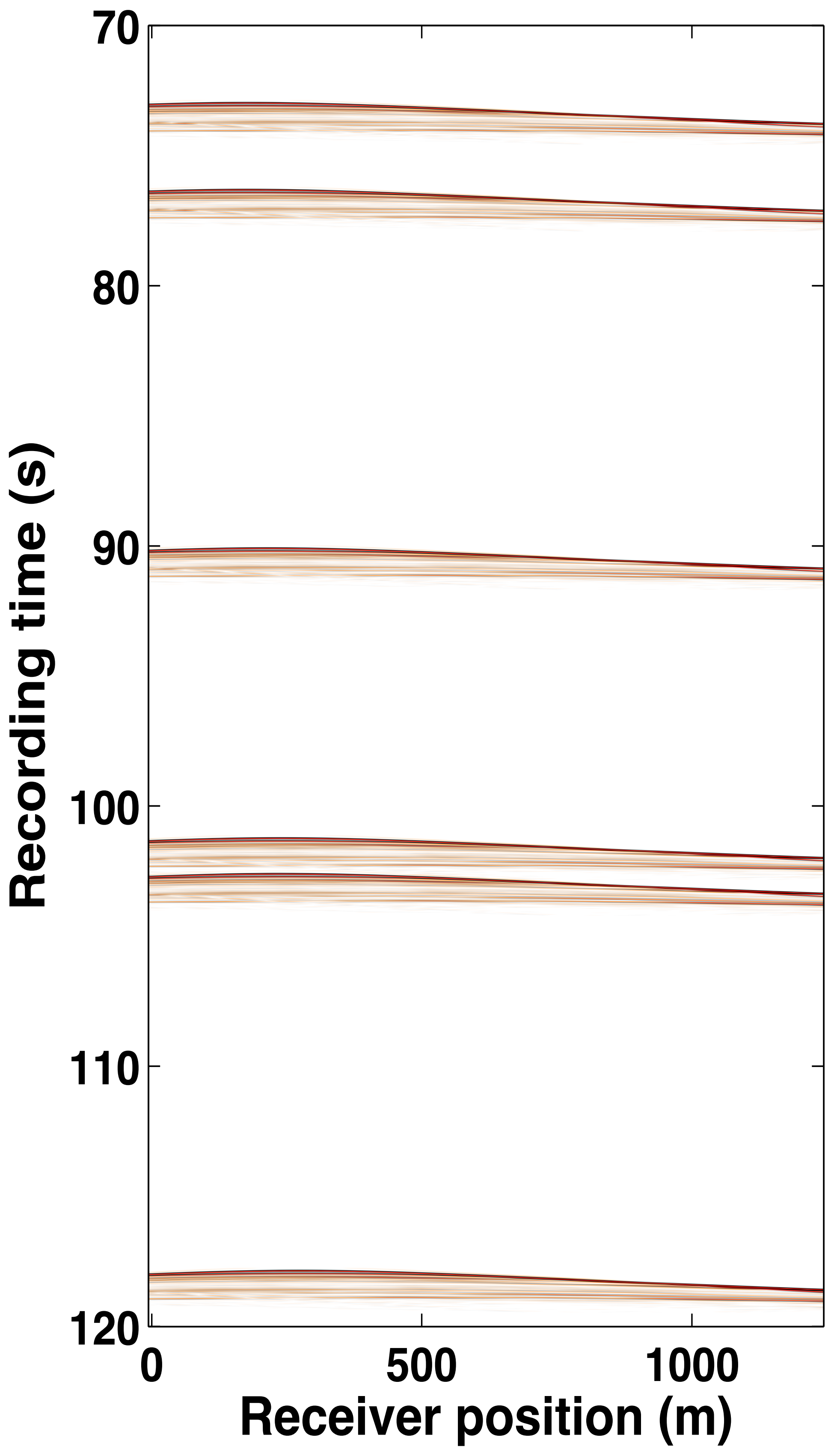
[BLENDING & SUBSAMPLING]
spatial subsampling factor = 2

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

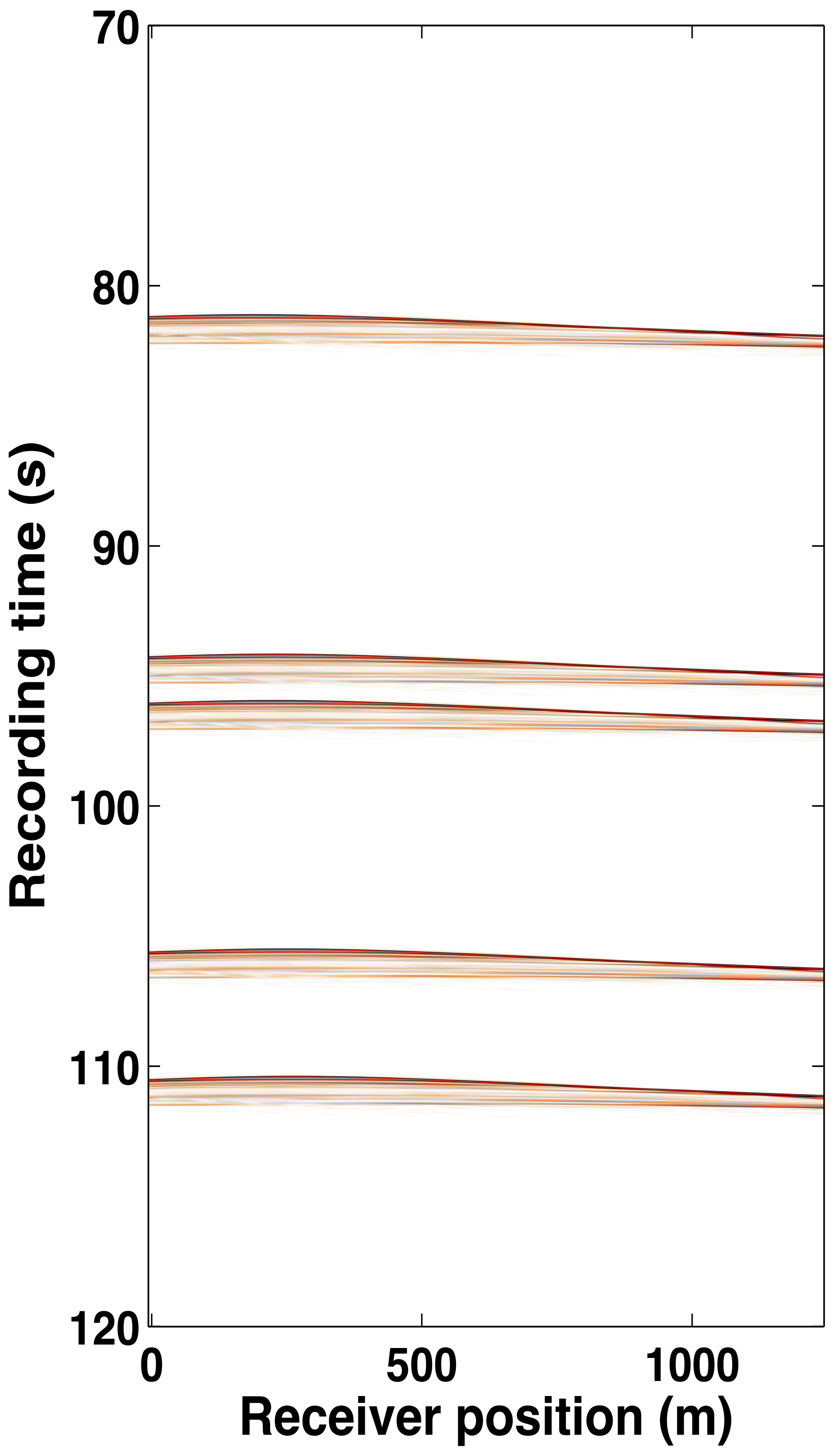
***"blended"* shot gathers**
number of shots = 100/2 = **50** (25 per array)
spatial sampling: **50.0 m (*jittered*)**
vessel speed: **2.50 m/s**
recording time ≈ 1000.0 s/2 = **500.0 s**

Measurements
– *subsampled* and *blended*

Baseline



Monitor



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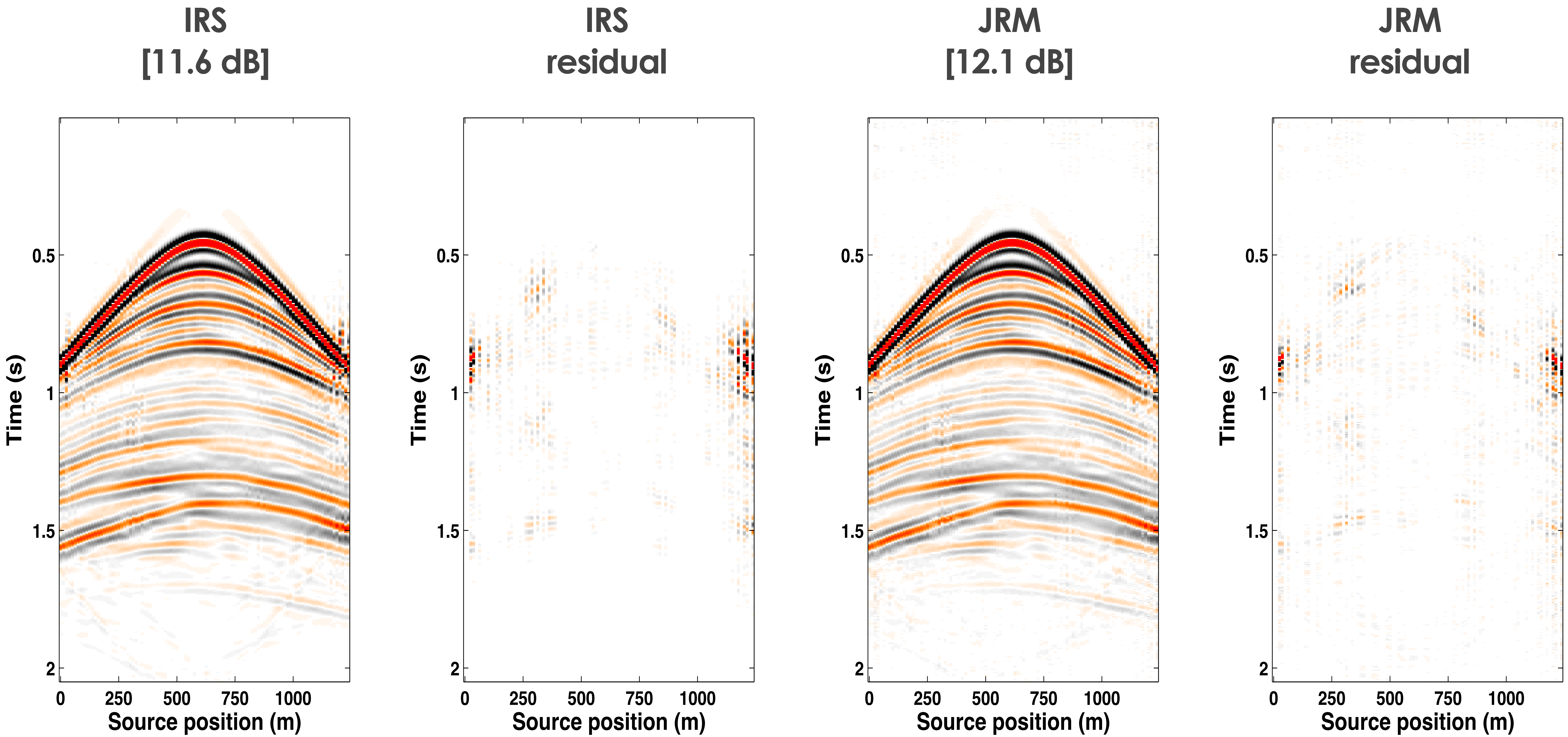
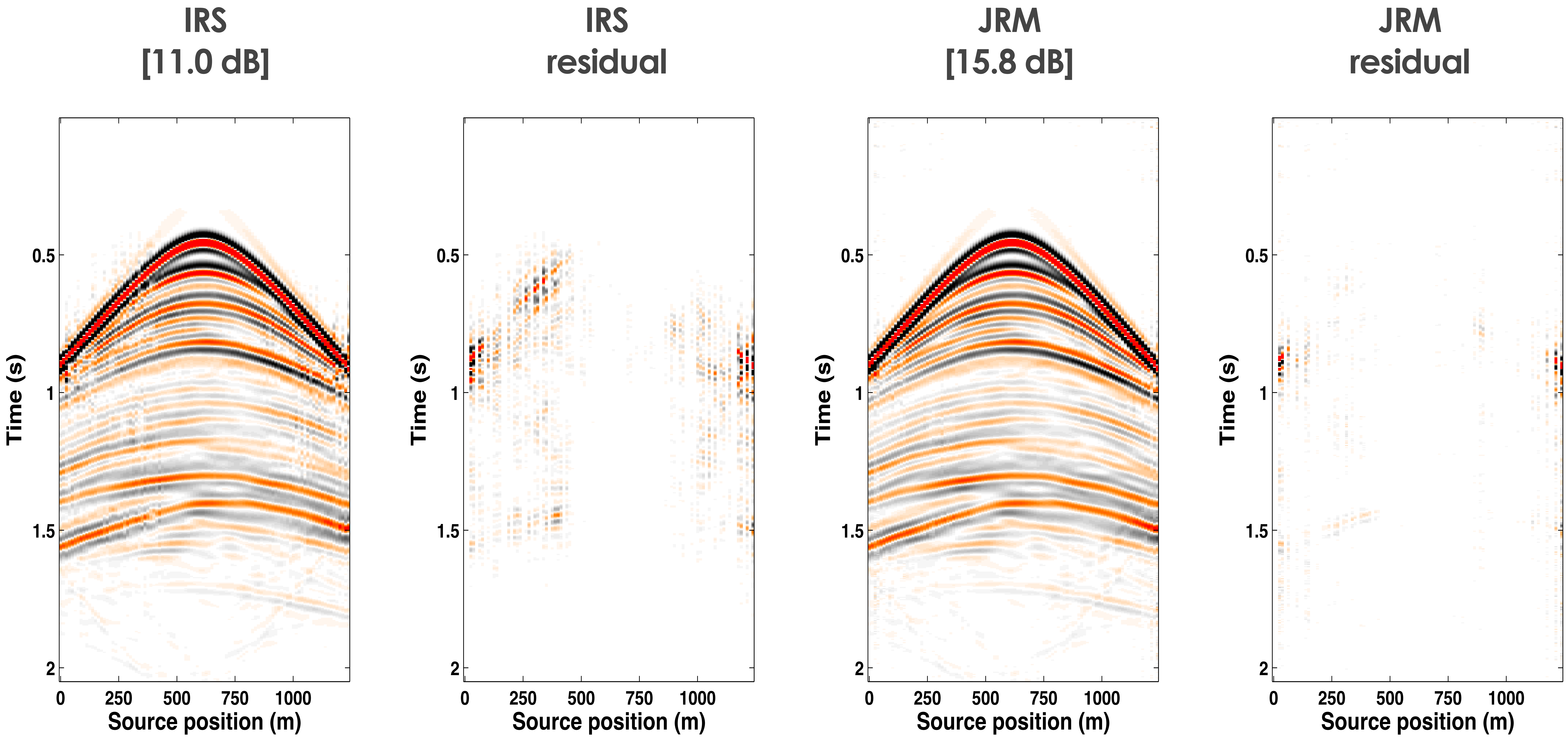
Monitor recovery

– 100% overlap in *acquisition* matrices



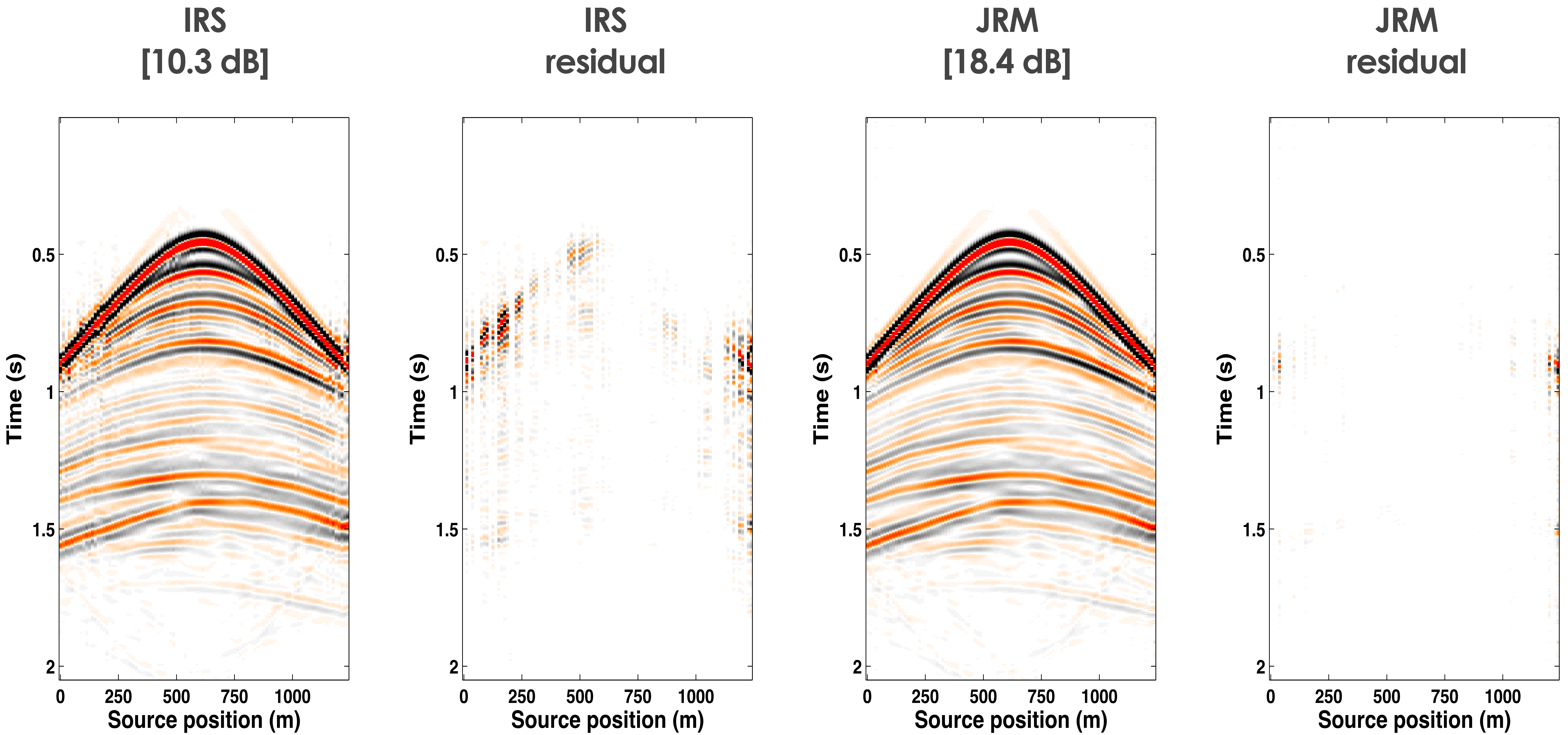
Monitor recovery

– 50% overlap in *acquisition* matrices



Monitor recovery

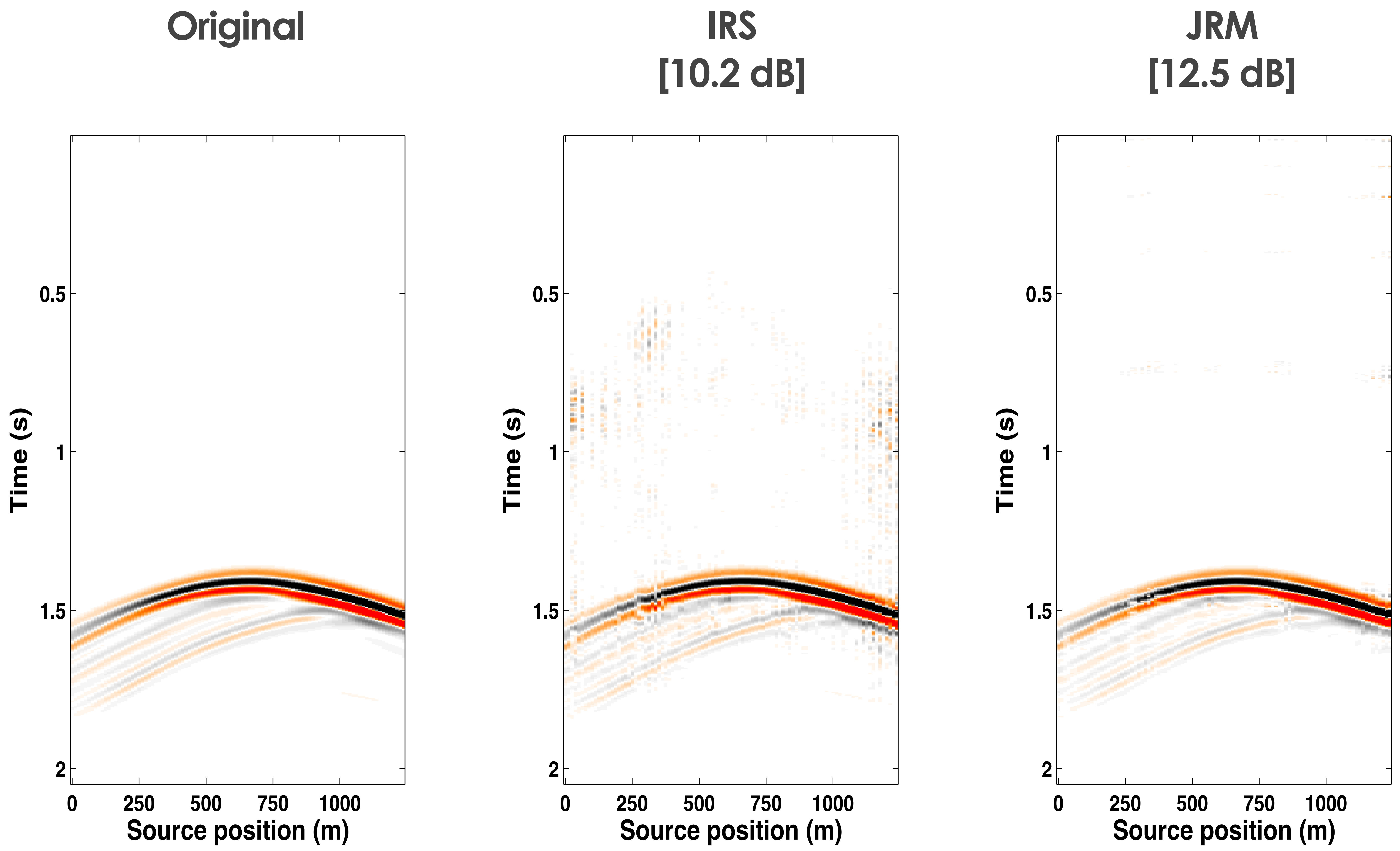
– **25%** overlap in *acquisition* matrices



4-D recovery

– 100% overlap in *acquisition* matrices

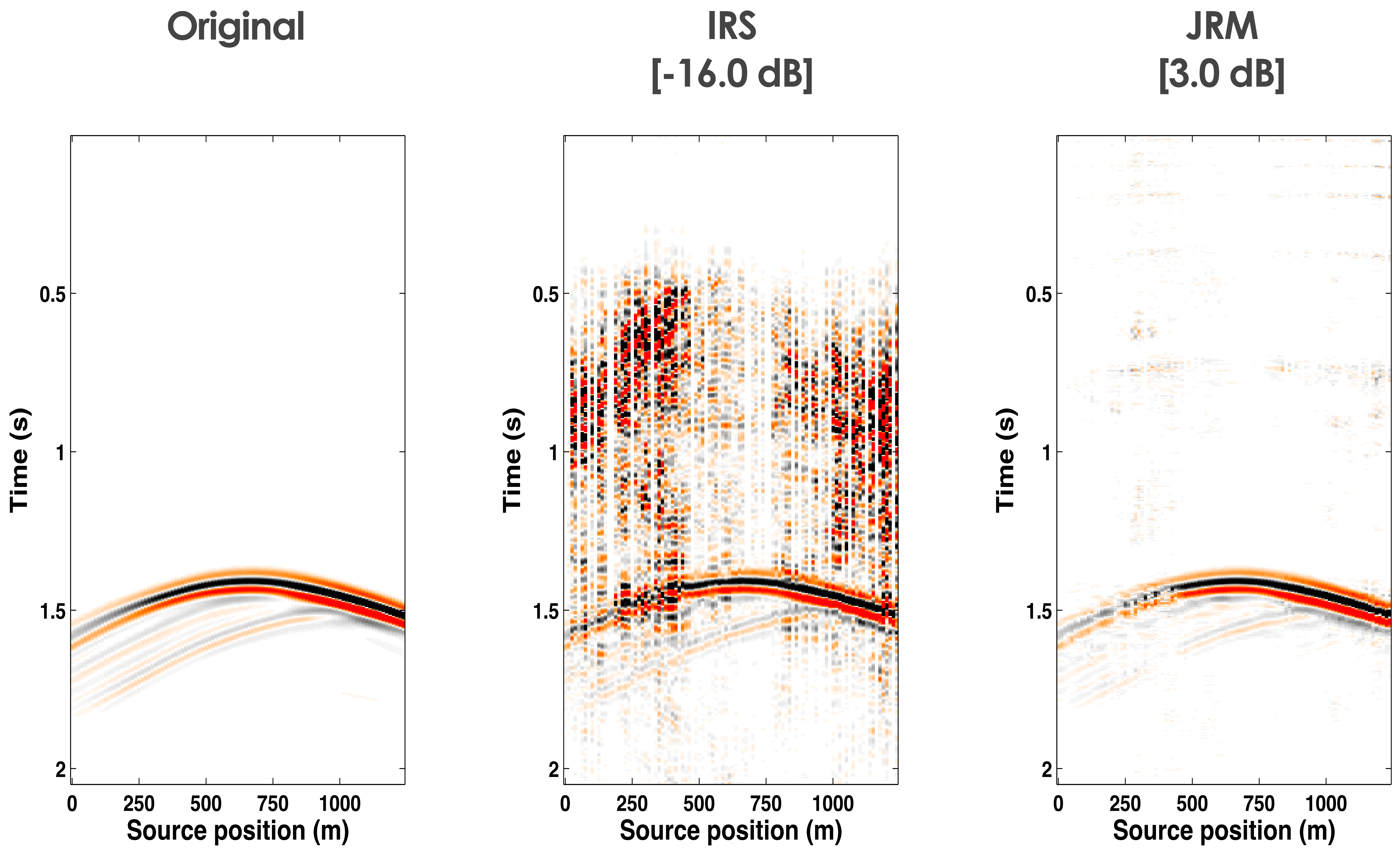
[colormap scale: 10 X]



4-D recovery

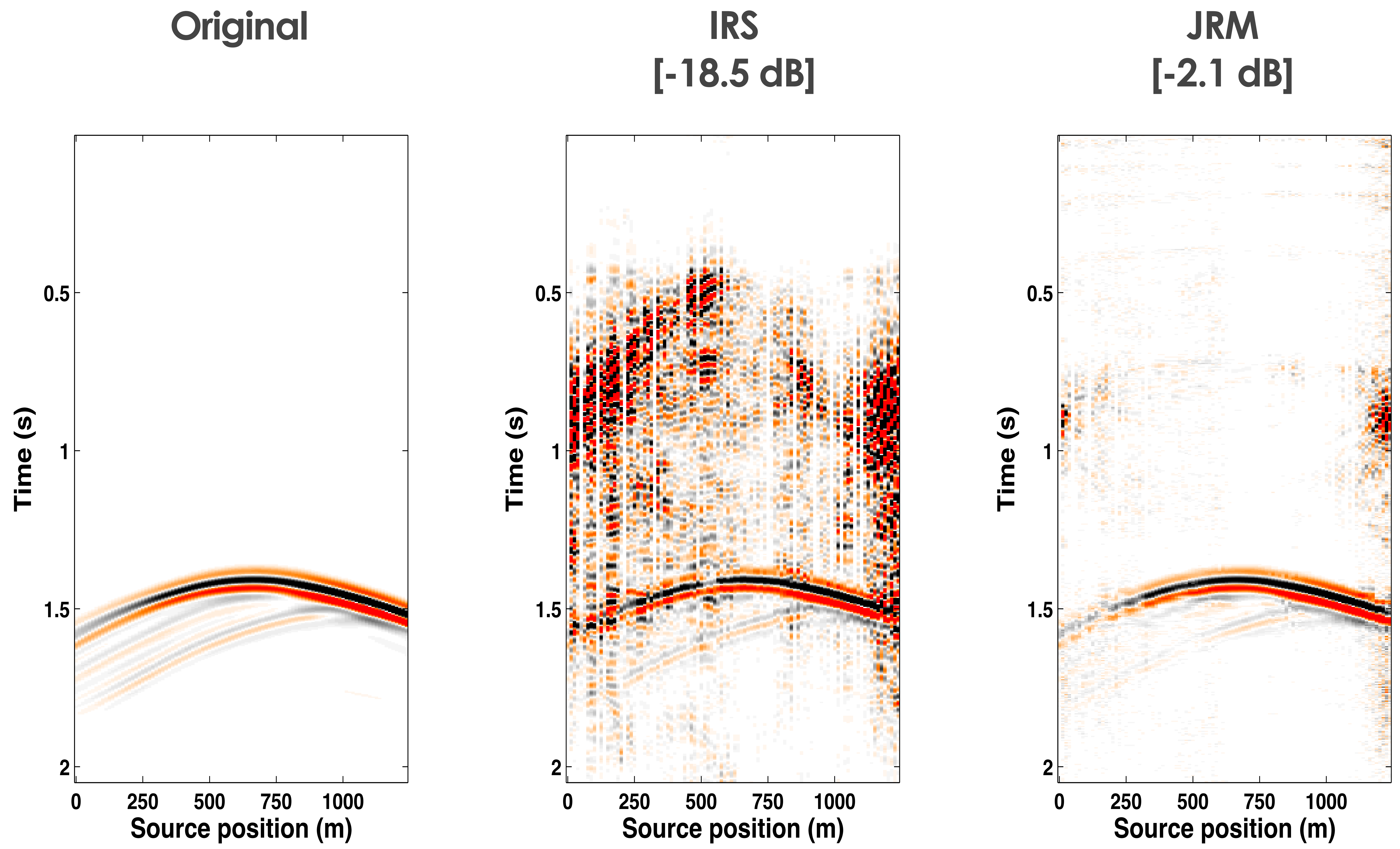
– 50% overlap in *acquisition* matrices

[colormap scale: 10 X]



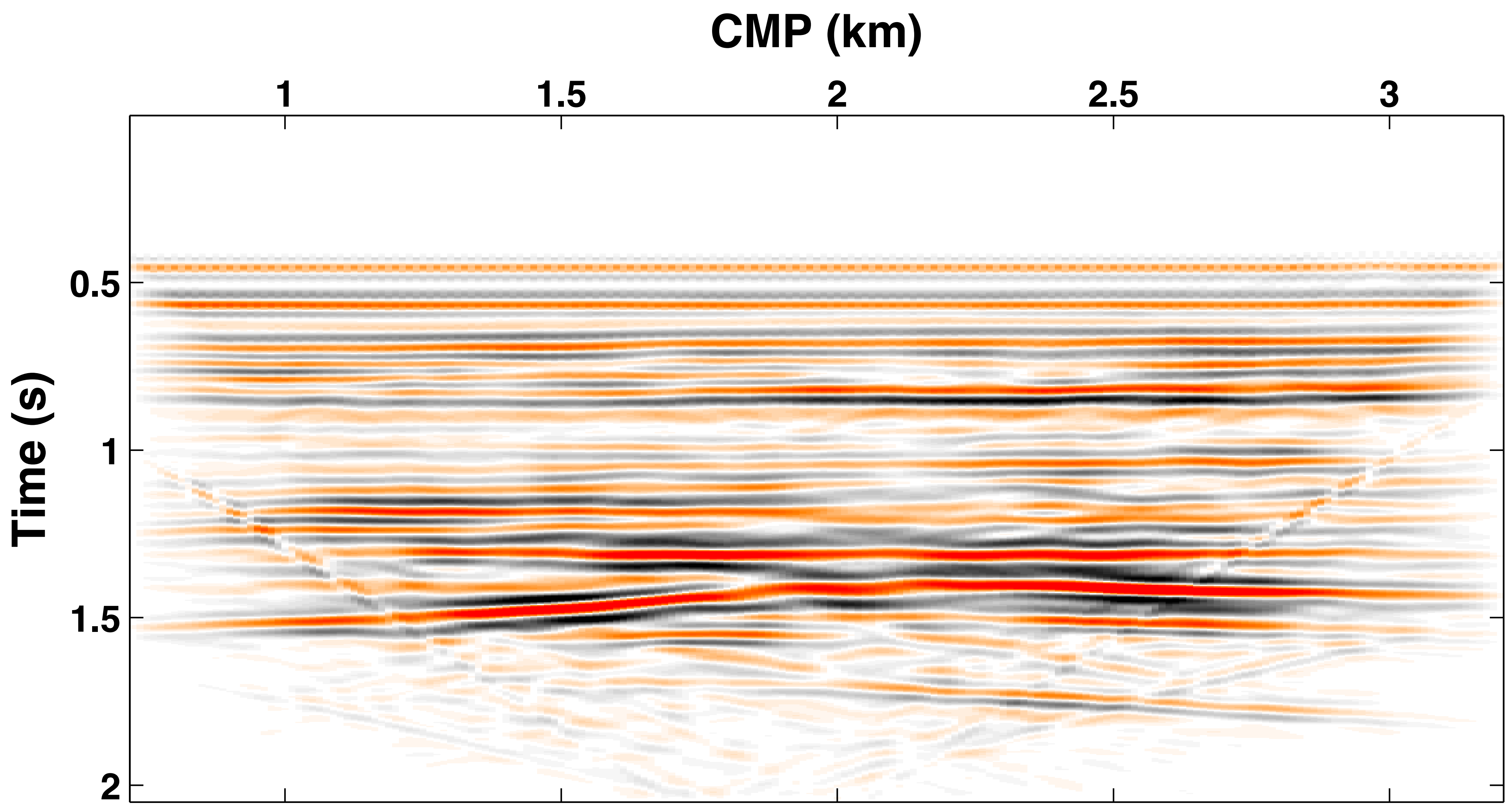
4-D recovery
– 25% overlap in *acquisition* matrices

[colormap scale: 10 X]

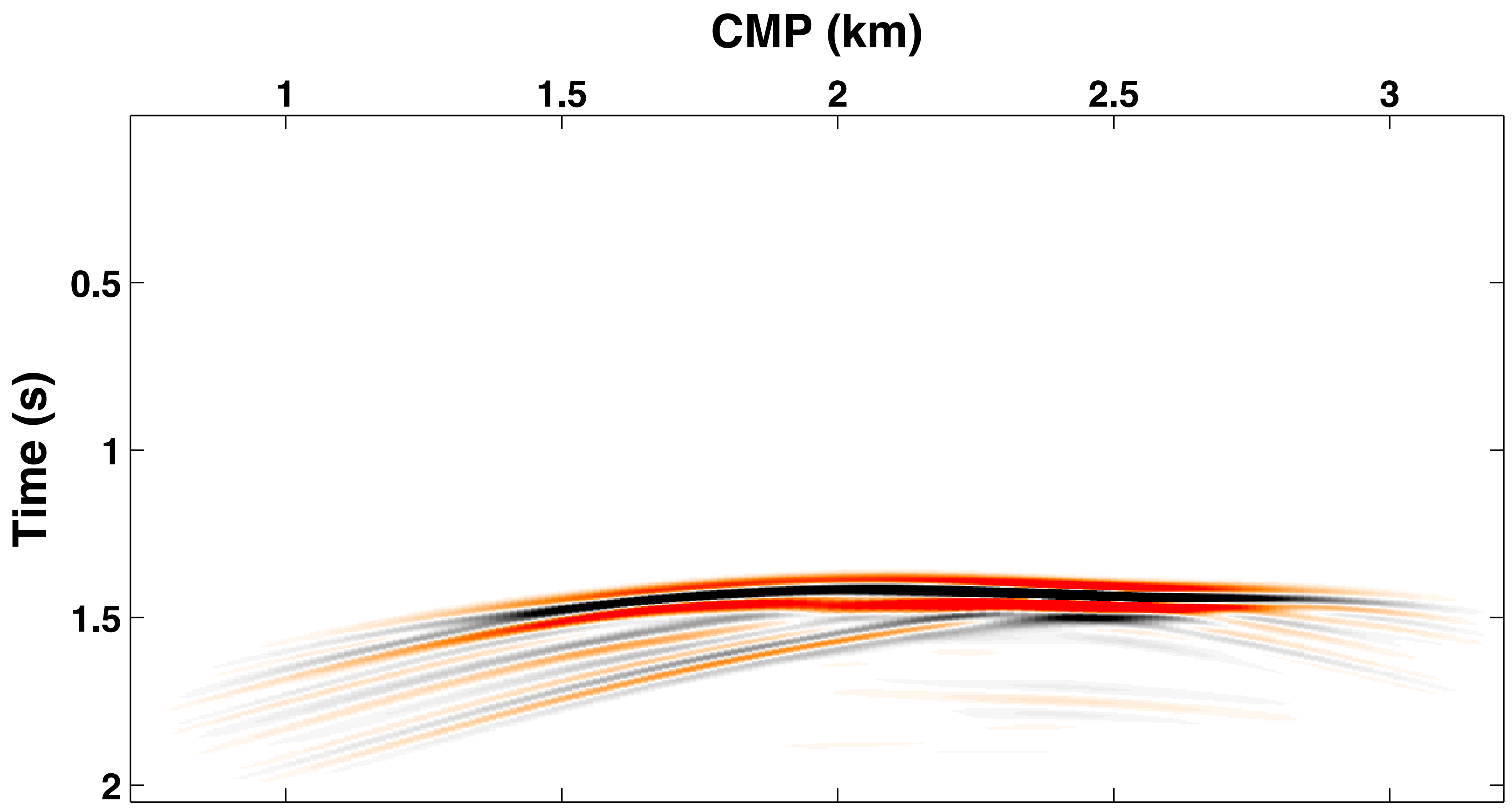


Stacked sections

Baseline



4-D signal [10 X]

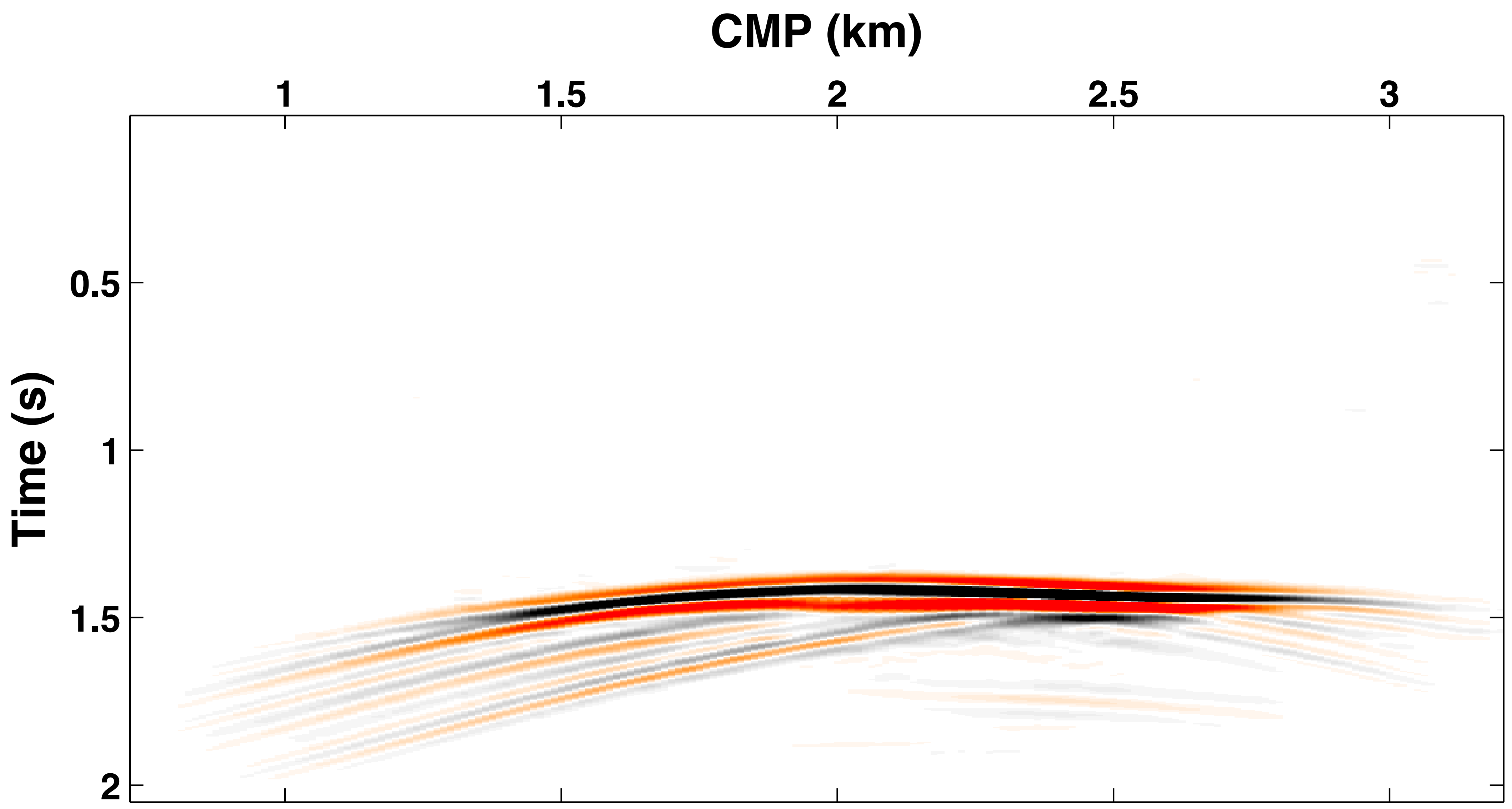


Stacked sections

– 100% overlap in *acquisition* matrices

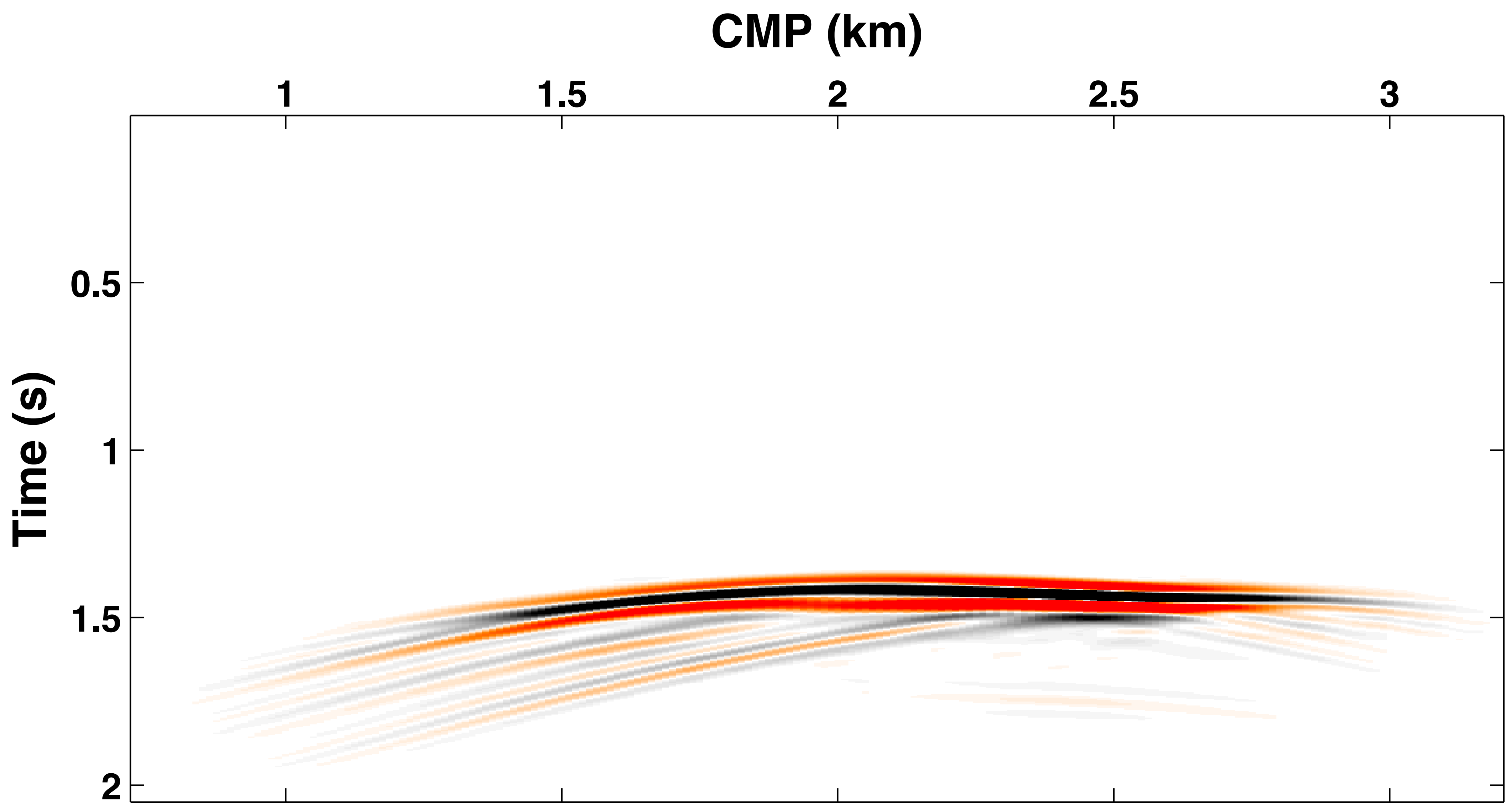
IRS

[25.2 dB]



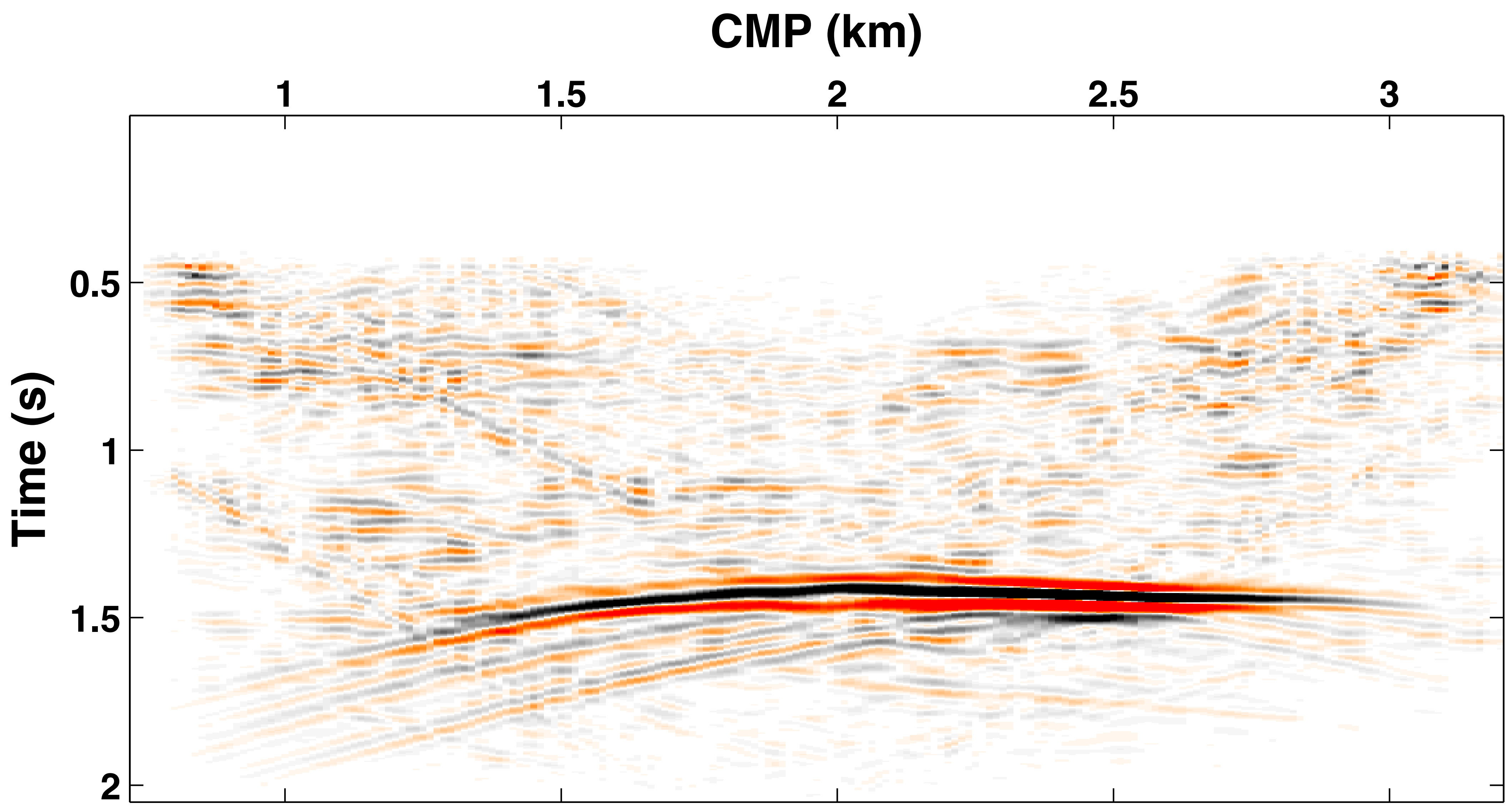
JRM

[23.6 dB]

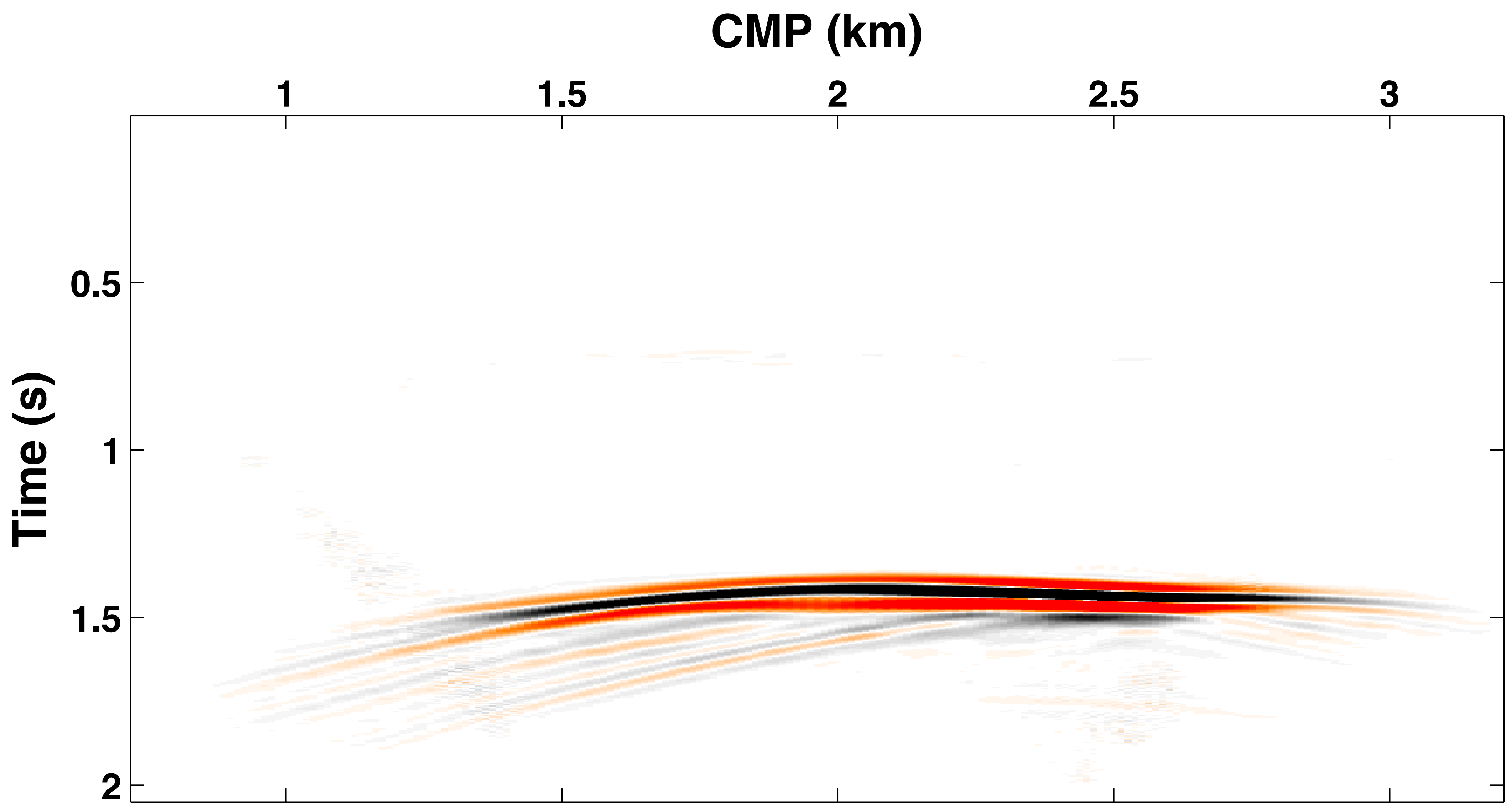


Stacked sections
– 50% overlap in *acquisition* matrices

IRS
[9.7 dB]



JRM
[17.1 dB]

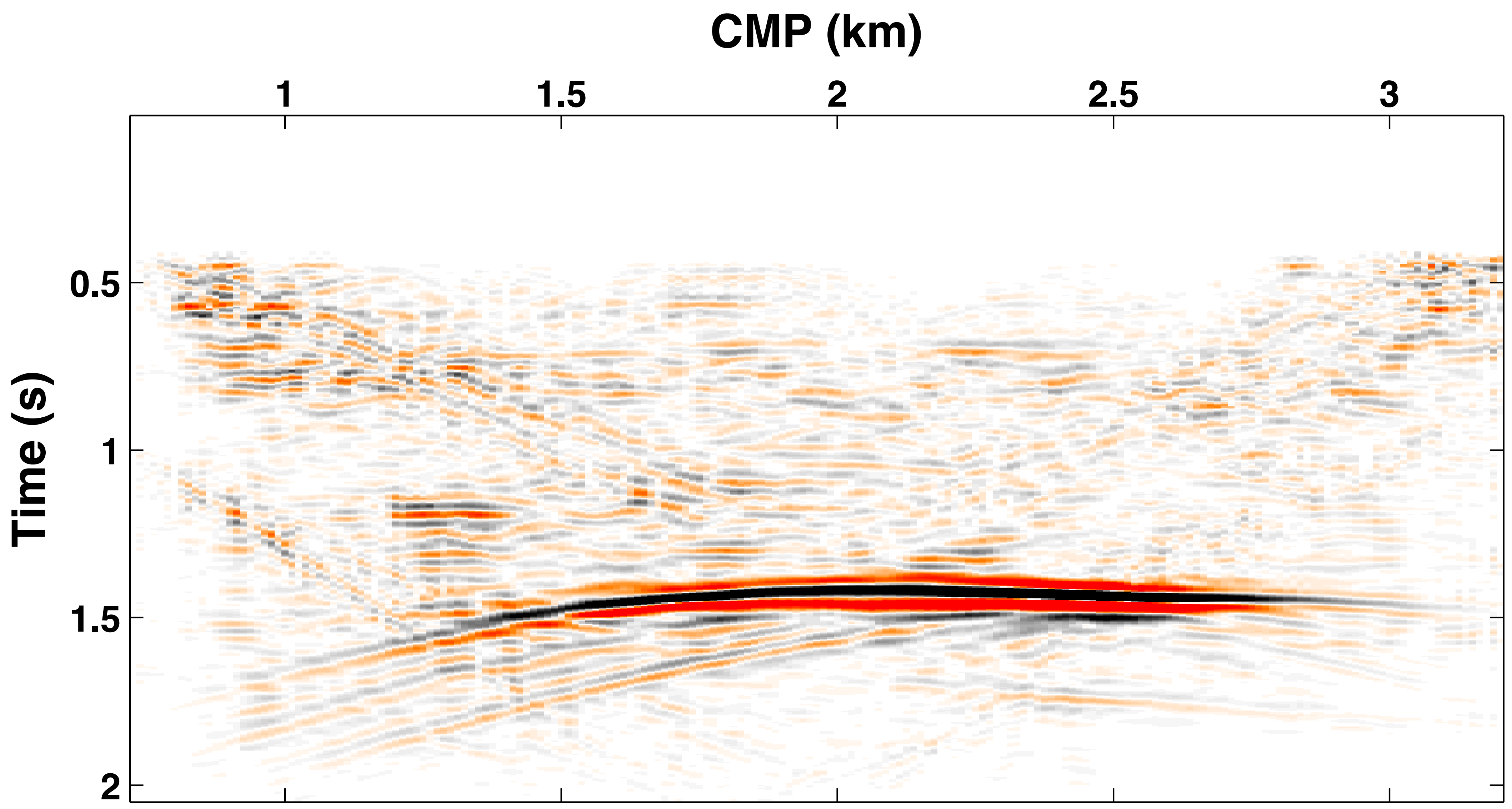


Stacked sections

– 25% overlap in *acquisition* matrices

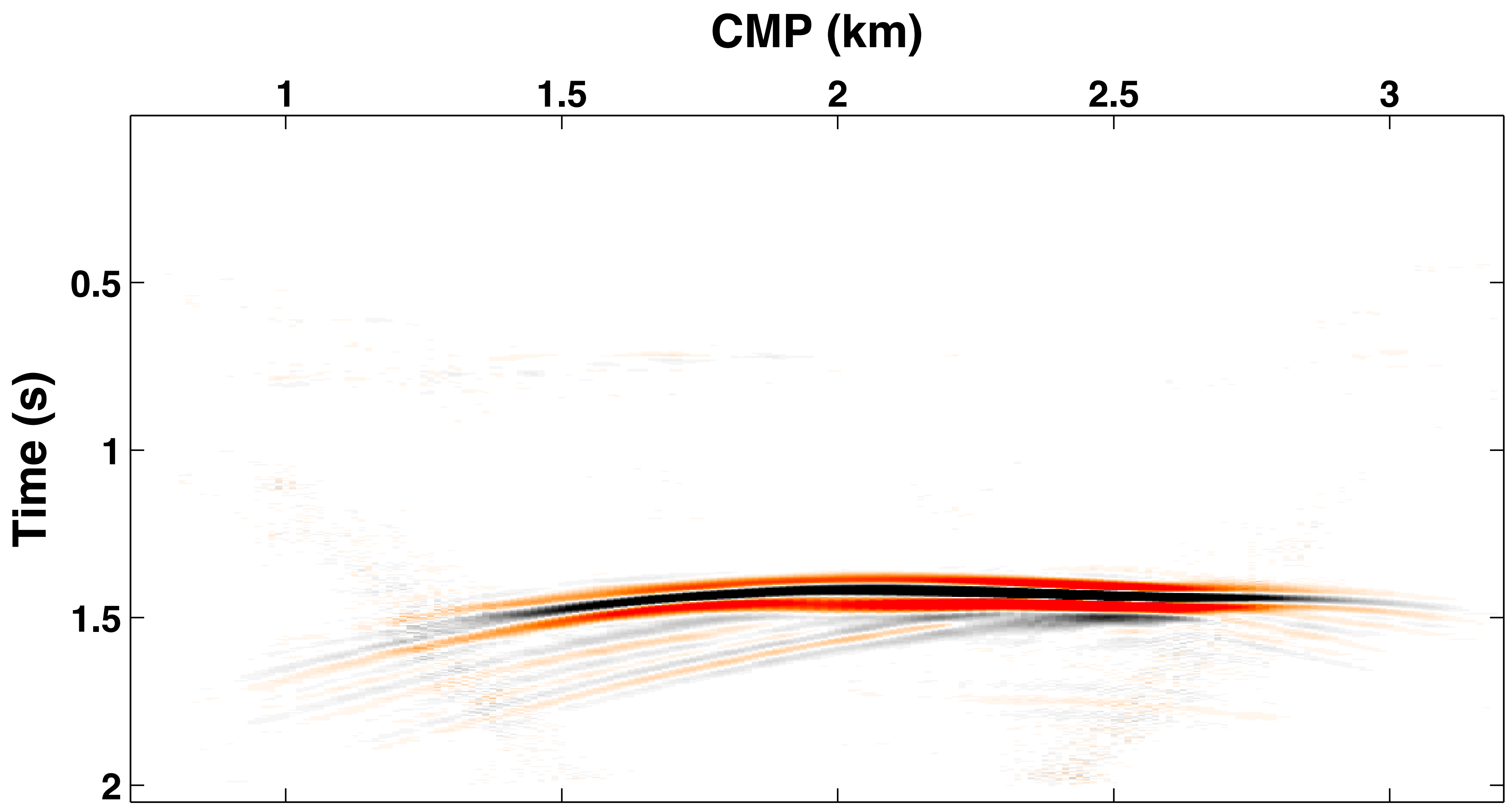
IRS

[9.5 dB]



JRM

[16.0 dB]



SNR (dB)
– 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

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

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

Approach is *trivially* extendable to *multiple* vintages & *image* space*

[*Felix Oghenekowho, "Randomized sampling without repetition in time-lapse seismic surveys". Wednesday 08:55 AM, Room: 4EF]

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
- ✓ yes, if recovery of vintages *fails* and *one* has a *high* degree of *repetition* then the *only* hope is to recover the *difference*, *not* recommended

Acknowledgements

Thank you for your attention!

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