Asymmetric sampling in time-lapse seismic acquisition

Felix Oghenekohwo

SLIM
University of British Columbia

Asymmetric sampling in time-lapse seismic acquisition

Felix Oghenekohwo*, Haneet Wason, Felix J. Herrmann

SLIM
University of British Columbia

Challenges

- Expensive dense multi-azimuth surveys
- Source/receiver replication among time-lapse (4D) surveys
- Need for high-fidelity 4D data repeatability

Solution

- Compressed sensing inspired cheap acquisition
- Avoid source/receiver replication
- Exploit common information in vintages
- Improve 4D data repeatability using the joint recovery model (JRM)

Joint recovery model (JRM)

- Distributed compressed sensing [Baron et al., (2009)]
- Enable low-cost time-lapse acquisition design & processing
- Time-lapse imaging (w/ multiples) & FWI

Felix Oghenekohwo, Haneet Wason, Ernie Esser and Felix J. Herrmann "Low-cost time-lapse seismic with distributed Compressive Sensing---exploiting common information amongst the vintages" (To appear in Geophysics)

Haneet Wason, **Felix Oghenekohwo**, and Felix J. Herrmann " Cheap time-lapse with distributed Compressive Sensing---impact on repeatability" (To appear in Geophysics)

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

forward model baseline

forward model monitor

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

baseline

monitor

Key idea:

- invert for common components & innovation w.r.t. common components with sparse recovery
- common component observed by all surveys

Joint recovery model (JRM)

sparsity-promoting minimization:

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

$$\tilde{\mathbf{z}} = \left.\begin{bmatrix} \tilde{\mathbf{z}}_0 \\ \tilde{\mathbf{z}}_1 \\ \tilde{\mathbf{z}}_2 \end{bmatrix}\right\} \text{time-lapse}$$

Key idea:

- invert for common components & innovation w.r.t. common components with sparse recovery
- common component observed by all surveys

Acquisition design : examples

- Time-jittered sources a.k.a. Sim. src. or blended acquisition

  (Wason and Herrmann, 2013)

- Simultaneous long offset (SLO)

  (Long et al., 2010)

- Coil shooting

  (Moldoveanu et al., 2010)

- Randomized (jittered) source sampling

  (Hennenfent and Herrmann, 2008)

- ... any design w/ randomness

Acquisition design : examples

- Time-jittered sources a.k.a. Sim. src. or blended acquisition
  (Wason and Herrmann, 2013)
- Simultaneous long offset (SLO)
  (Long et al., 2010)
- Coil shooting
  (Moldoveanu et al., 2010)
- Randomized (jittered) source sampling
  (Hennenfent and Herrmann, 2008)

  → **Randomly missing sources**
- ... any design w/ randomness

Seismic example

NRMS: [Kragh and Christie (2002)]

Context

Time-lapse AVO is of interest - for inversion purposes

Pre-stack (repeatability) data analysis is desirable

NRMS is a suitable metric to validate repeatability

Optimize cost of time-lapse surveys to meet 4D objectives

SLIM

NRMS

Metric for quantifying repeatability

$$\mathrm{NRMS}(\mathbf{x_1}, \mathbf{x_2}) = \frac{200 \times \mathrm{RMS}(\mathbf{x_1} - \mathbf{x_2})}{\mathrm{RMS}(\mathbf{x_1}) + \mathrm{RMS}(\mathbf{x_2})}$$

$$\mathrm{RMS}(\mathbf{x}_t) = \sqrt{\frac{\sum_{t_1}^{t_2} (\mathbf{x}_t)^2}{N}}$$

N : number of samples in interval

NRMS : similarity between two signals

0% : ideal, perfect repeatability

$\ll 10\%$: acceptable repeatability

Time-lapse seismic acquisition & repeatability

Experiment

One common receiver gather (OBN)

4secs record length @ 4ms sample interval

150 shots per receiver gather

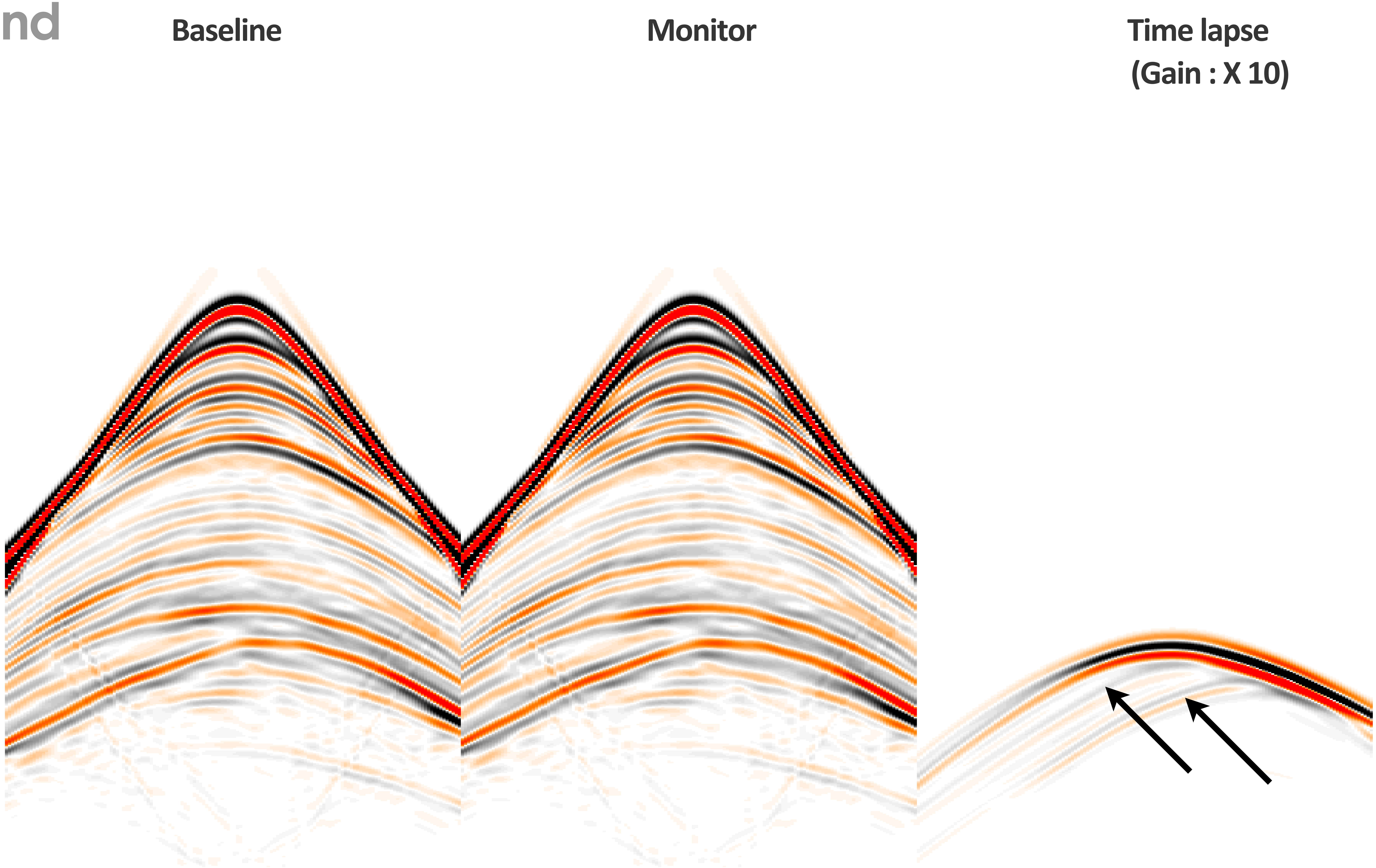
Time-lapse amplitude scaled by factor of 10

Randomly subsample shots & recovery

Validate repeatability & time-lapse fidelity

Extendable to other randomized sampling acquisition scenarios

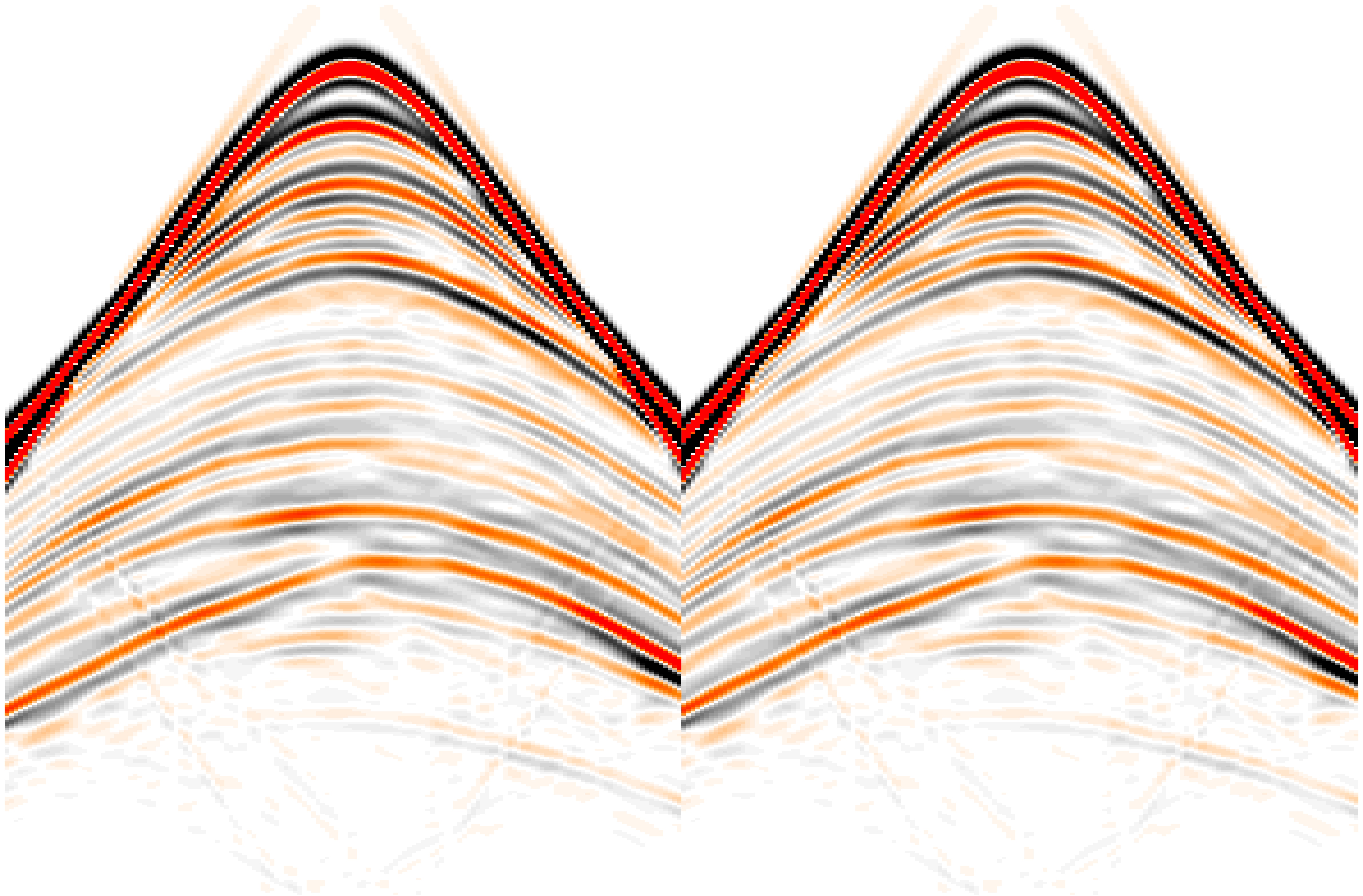
Ground truth



Assuming no time-lapse (Earth model doesn't change)

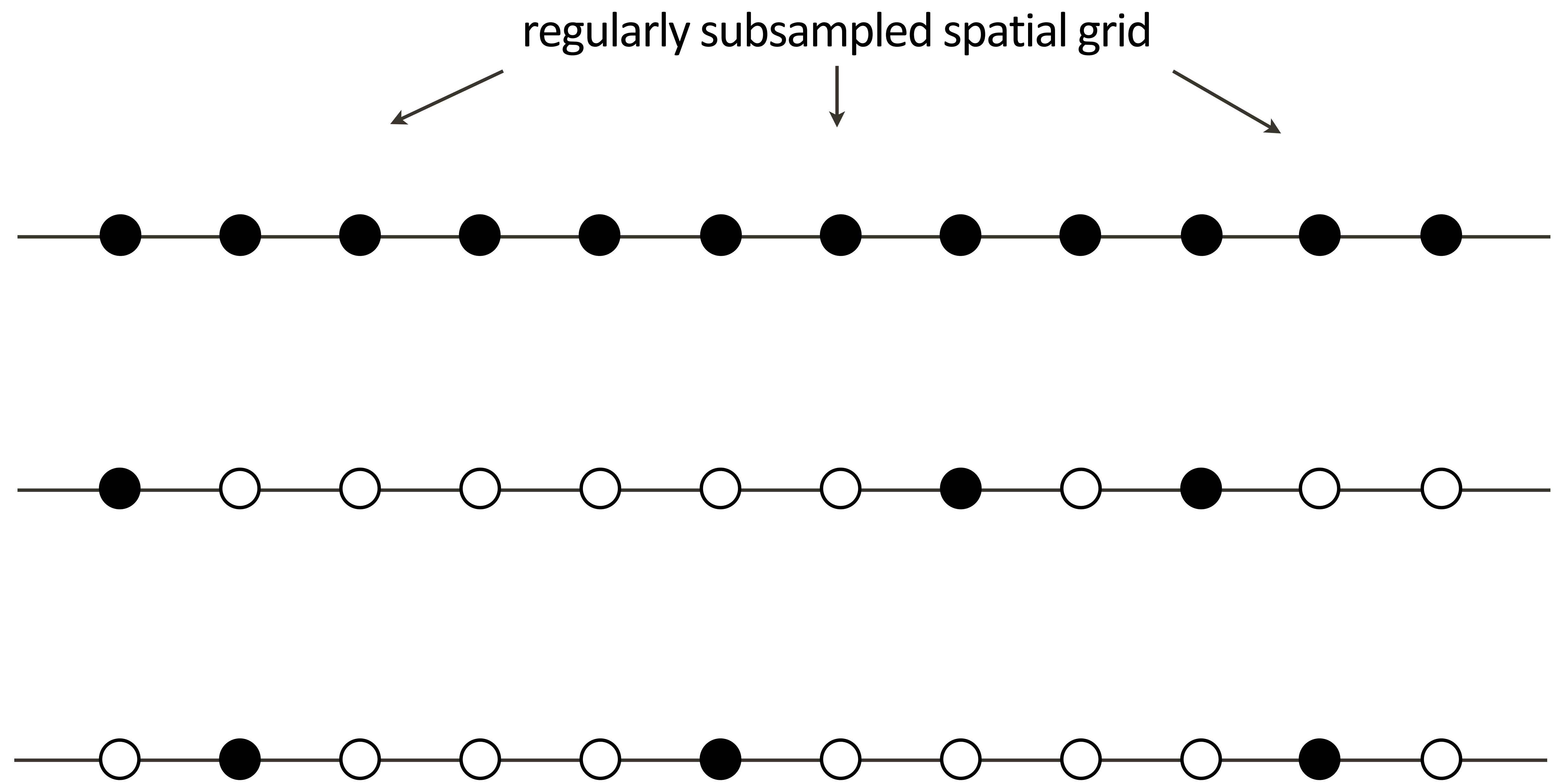
Ground truth

Baseline **Monitor** **Time-lapse**



Sampling scheme

ON-THE-GRID SAMPLING
("exact" replication)



(a) dense sampling

(b) first random subsampling

(c) second randomly subsampling
(NO overlap with (b))

Assume no time-lapse

Acquire and recover data

- with first (50% missing), then second (65% missing) sampling

Compare Independent recovery (IRS) with our JRM

Measure the repeatability (NRMS) of recovered data

Pre-stack (repeatability) data analysis may be desirable

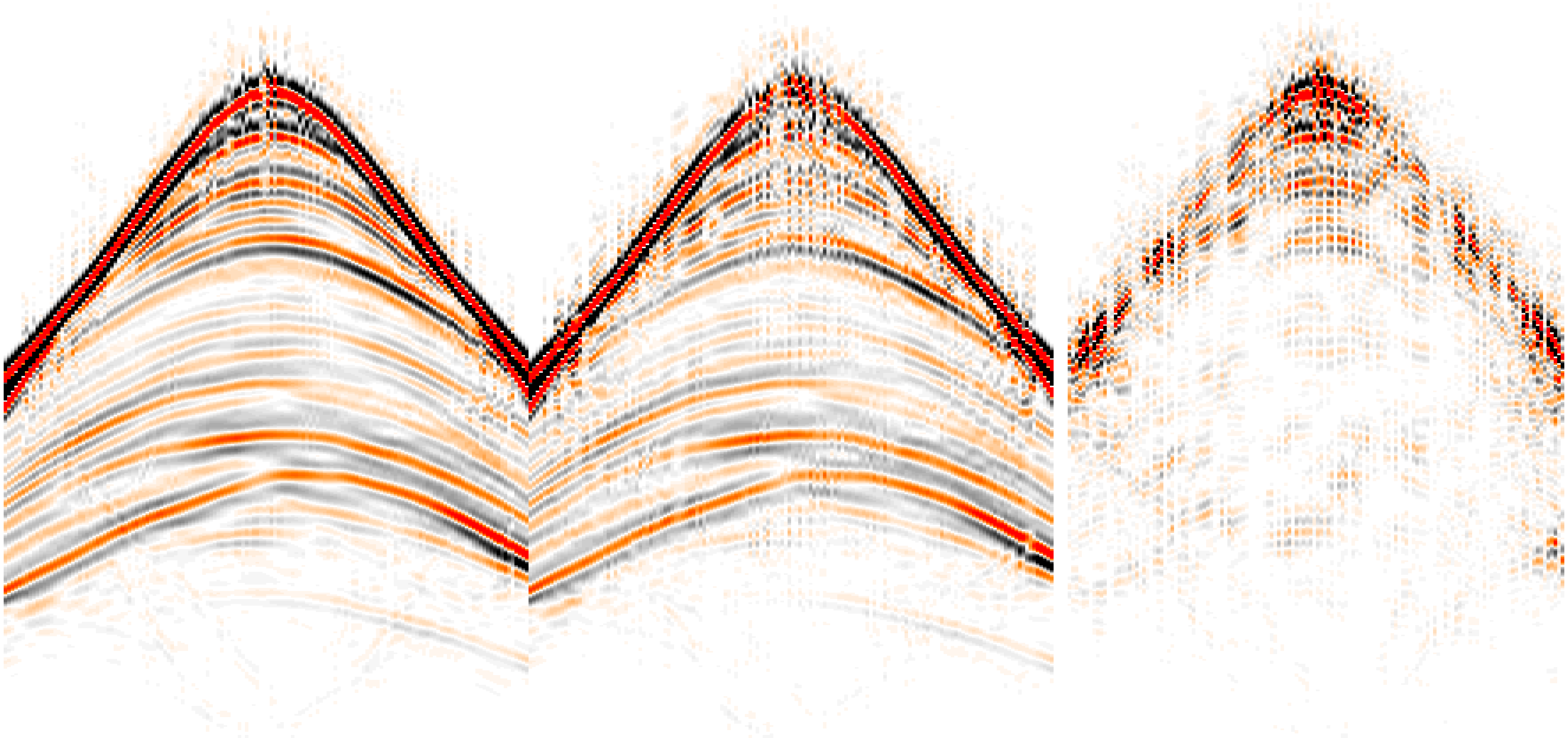
Recovery (IRS)

Baseline (50% missing)

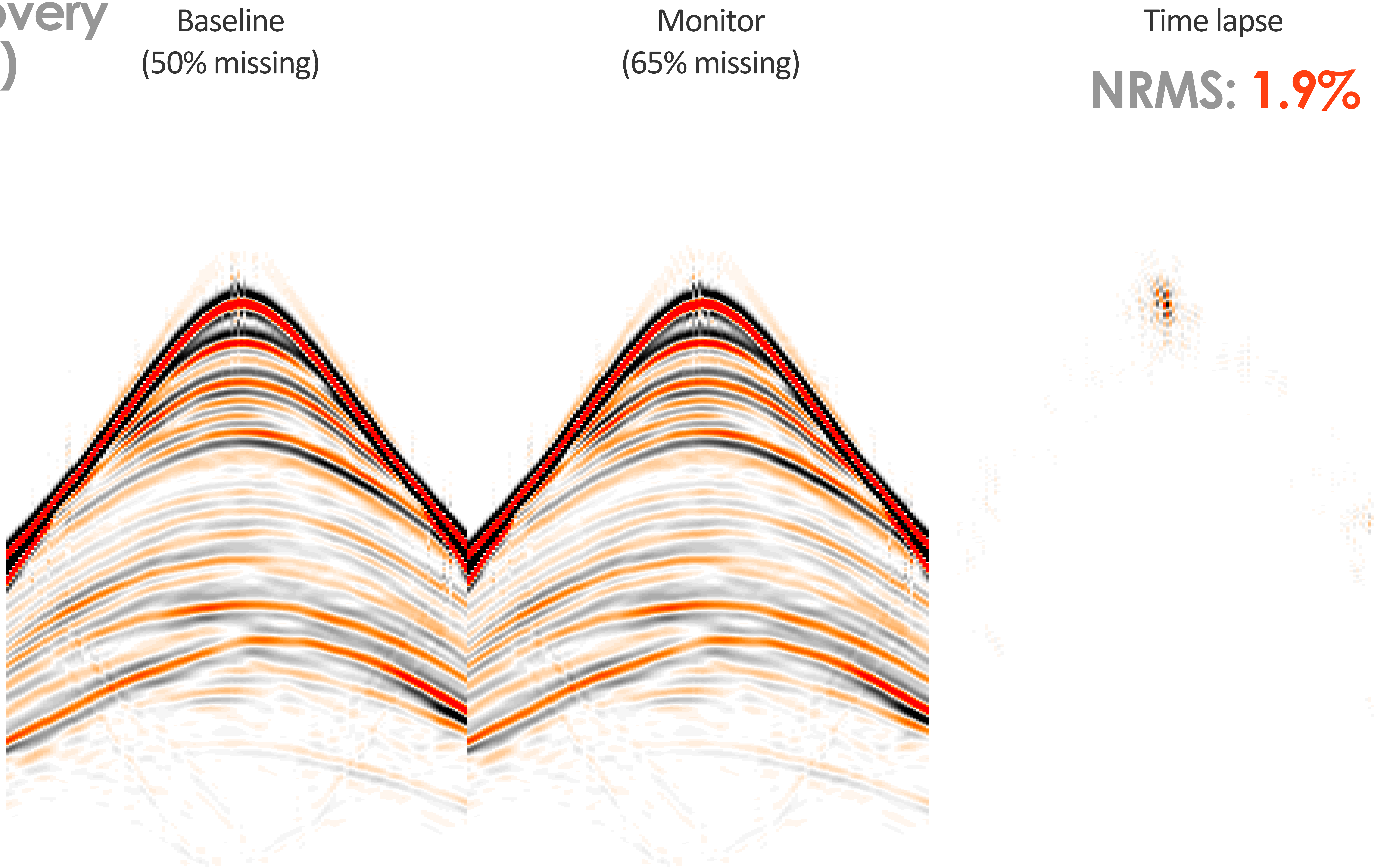
Monitor (65% missing)

Time lapse

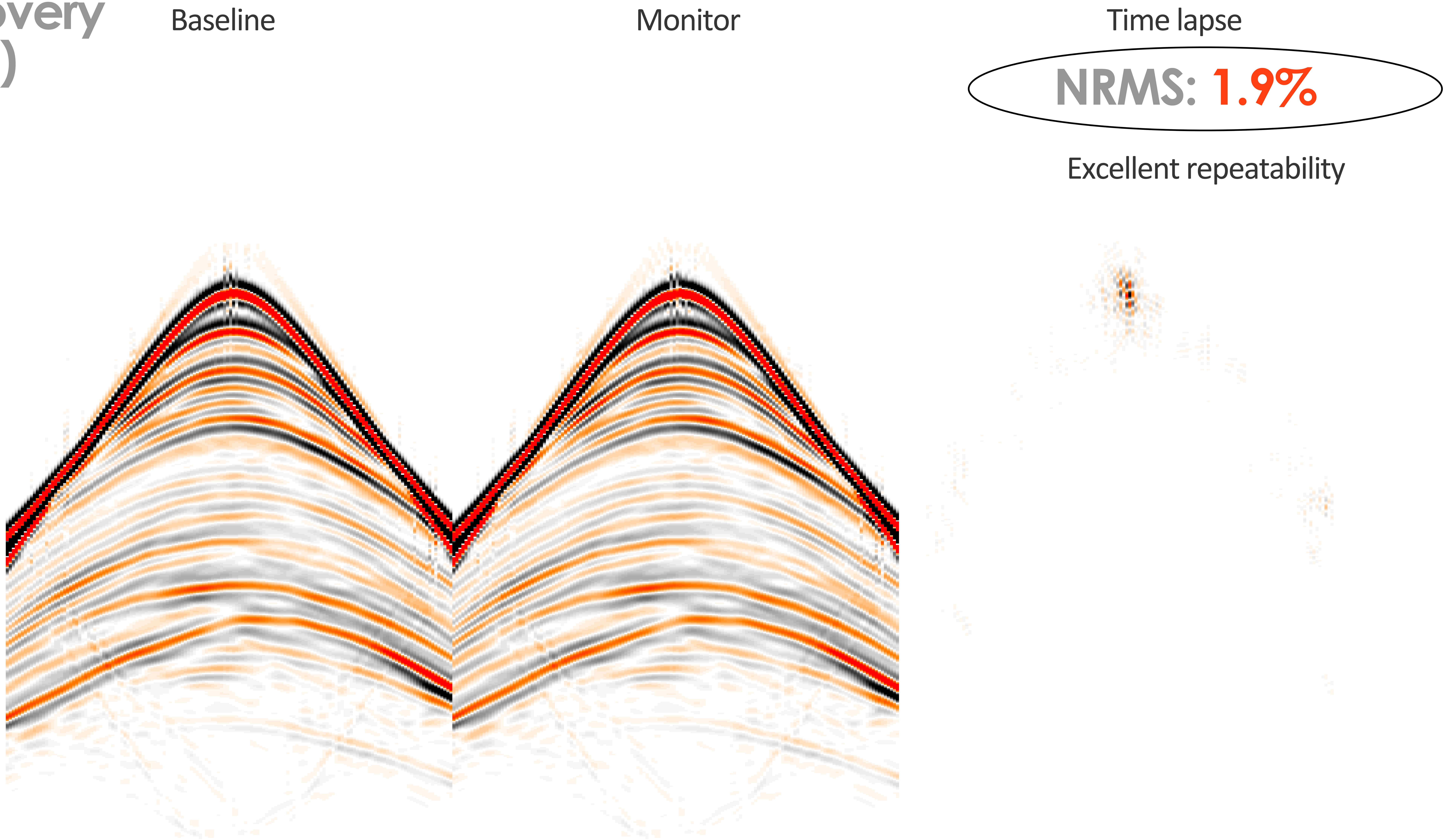
NRMS: 20%



Recovery (JRM)



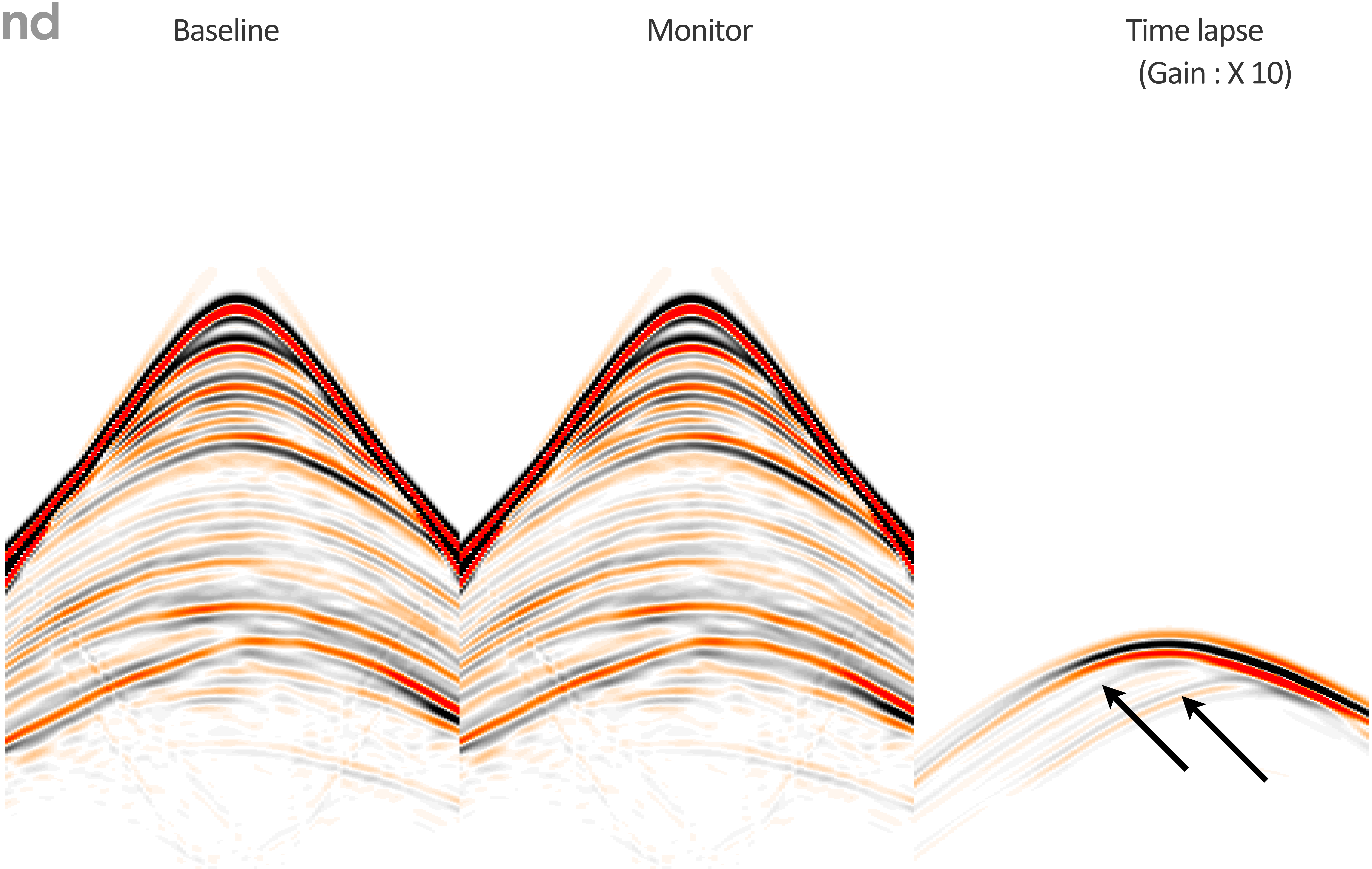
Recovery (JRM)



Should we acquire more data for the baseline or vice-versa?

Asymmetric sampling & JRM

Ground truth



Experiments w/ Asymmetric sampling

Acquire and recover data

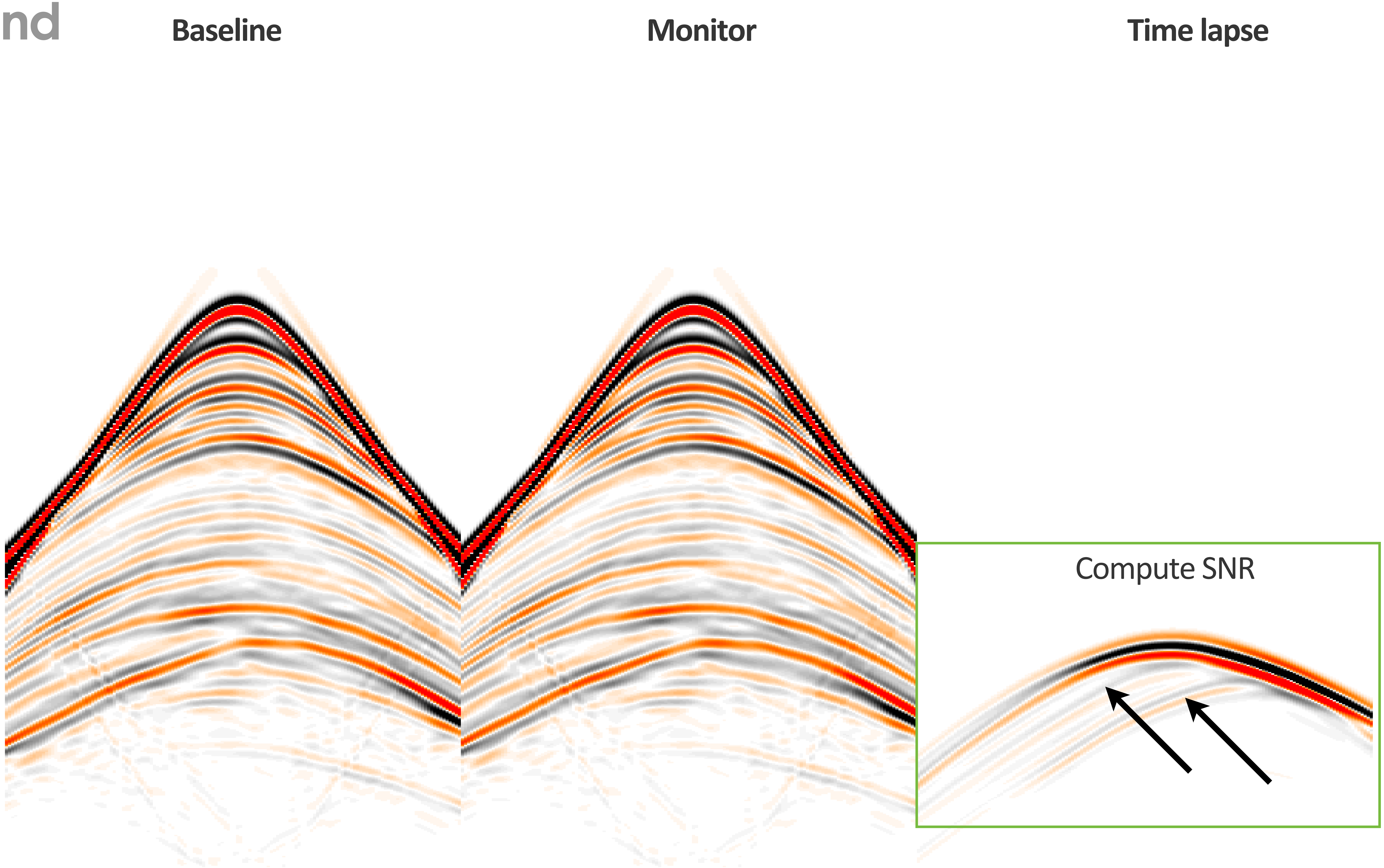
- with baseline (50% missing), monitor (65% missing)
- with baseline (60% missing), monitor (55% missing)

Recovery with only JRM

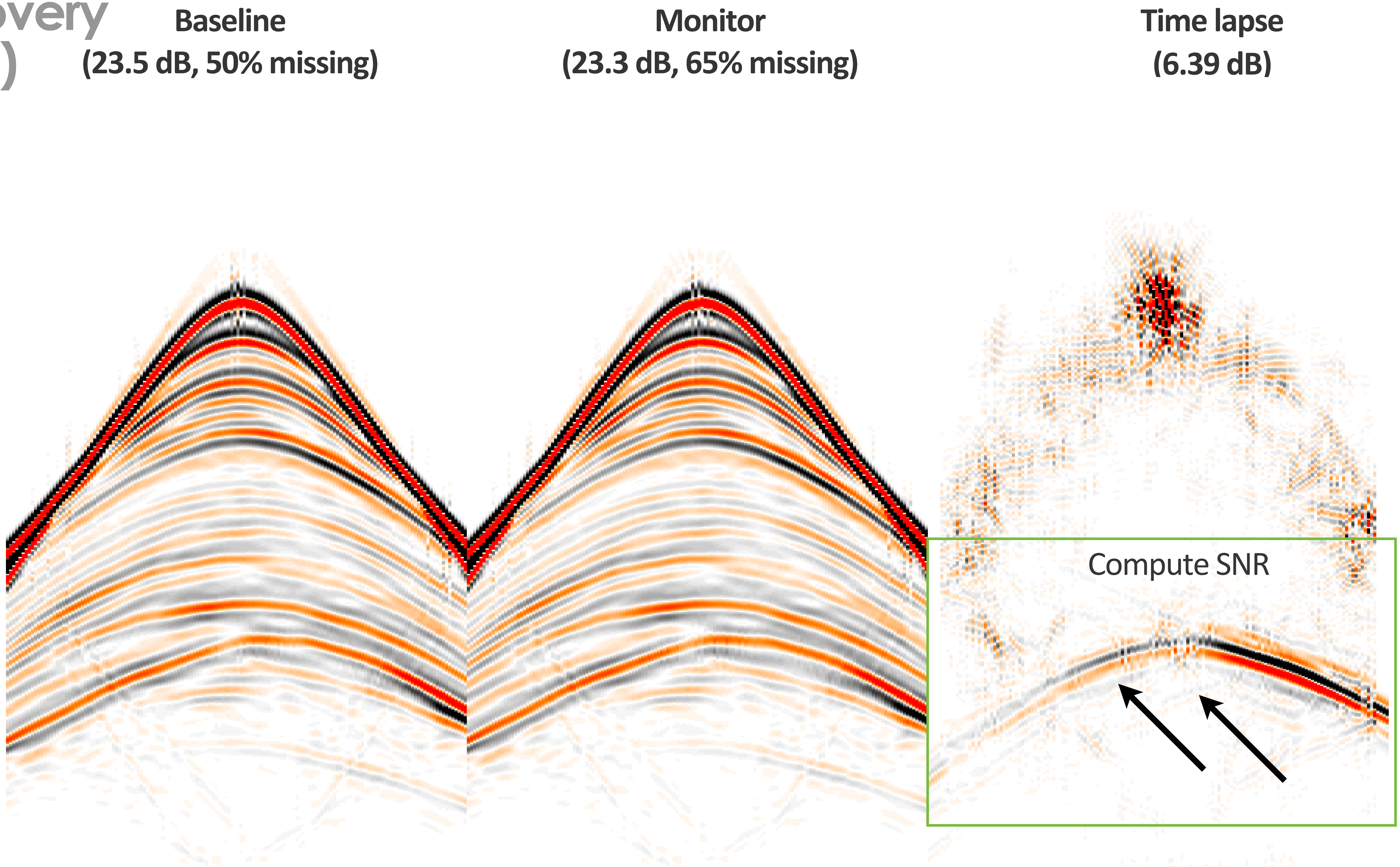
Measure the recovery quality (SNR)

Compute time-lapse SNR in area of interest

Ground truth



Recovery (JRM)

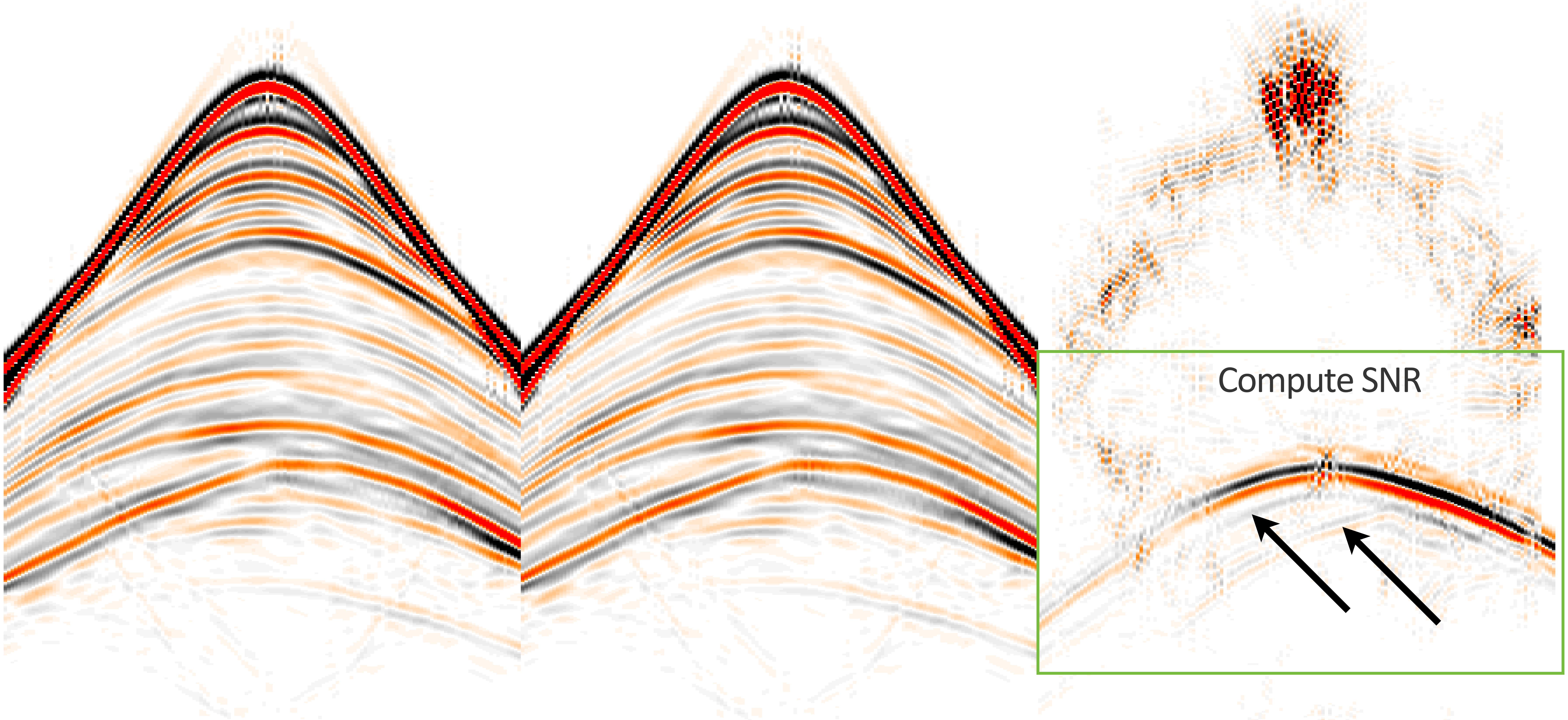


Recovery (JRM)

Baseline (25.4 dB, 60% missing)

Monitor (25.1 dB, 55% missing)

Time lapse (6.65 dB)



SLIM

Summary

- Time-lapse acquisition design & recovery w/ JRM
- Repeatability w/ JRM, measured by NRMS, can serve as yardstick for survey validation
- Preserve pre-stack time-lapse signal
- More in-depth study on more realistic acquisitions on different geological models need to be investigated

SLIM

Next step

- Simulation-based 3D time-lapse acquisition (static/ dynamic) design , and QC on two realistic geological settings
  - preliminary results promising (next talk)

- Validation on field data

Acknowledgements

This research was carried out as part of the SINBAD project with the support of the member organizations of the SINBAD Consortium.