Bootstrapping **Robust EPSI** with **coarsely** sampled data

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Outline

1. Intro/review of Robust EPSI algorithm
2. “Bootstrapping” by deliberate data decimation
3. Application to subsampled data
4. ... bonus slides? (if time permits)

Robust EPSI primer

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

true primary wavefield — SRME-produced primary

$$\mathbf{P_o} = \mathbf{P} - A(f)\mathbf{P_o}\mathbf{P}$$

$\mathbf{P}$	total up-going wavefield
$\mathbf{P_o}$	primary wavefield
$A(f)$	“matching” operator

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

true primary wavefield — SRME–produced primary

$$\mathbf{P_o} \approx \mathbf{P} - A(f)\mathbf{PP}$$

SRMP

$\mathbf{P}$	total up-going wavefield
$\mathbf{P_o}$	primary wavefield
$A(f)$	“matching” operator

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

adaptive subtraction

$$\min_{A} \sum_{f} \|\mathbf{P} - A(f)\mathbf{P}\mathbf{P}\|$$

SRMP

$\mathbf{P}$	total up-going wavefield
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true primary wavefield SRME–produced primary

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$\mathbf{P}$ total up-going wavefield

$\mathbf{P_o}$ primary wavefield

$A(f)$ "matching" operator

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

recorded data   predicted data from SRME

$$\mathbf{P} = \mathbf{P_o} + A(f)\mathbf{P_o}\mathbf{P}$$

$\mathbf{P}$	total up-going wavefield
$\mathbf{P_o}$	primary wavefield
$A(f)$	"matching" operator

From SRME to Robust EPSI

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recorded data predicted data from SRME

$$\mathbf{P} = \mathbf{P_o} + A(f)\mathbf{P_o}\mathbf{P}$$

$$\mathbf{P_o} = \mathbf{QG}$$
$$A(f) = -\mathbf{Q}^{-1}$$

$\mathbf{P}$ total up-going wavefield

$\mathbf{Q}$ down-going source signature

$\mathbf{G}$ primary impulse response

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

recorded data predicted data from SRME

$$\mathbf{P} = \mathbf{QG} - \mathbf{GP}$$

$\mathbf{P}$ total up-going wavefield

$\mathbf{Q}$ down-going source signature

$\mathbf{G}$ primary impulse response

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

recorded data predicted data from SRME

$$\mathbf{P} = \mathbf{QG} - \mathbf{GP}$$

Inversion objective:

$$f(\mathbf{G}, \mathbf{Q}) = \frac{1}{2}\|\mathbf{P} - (\mathbf{QG} - \mathbf{GP})\|_2^2$$

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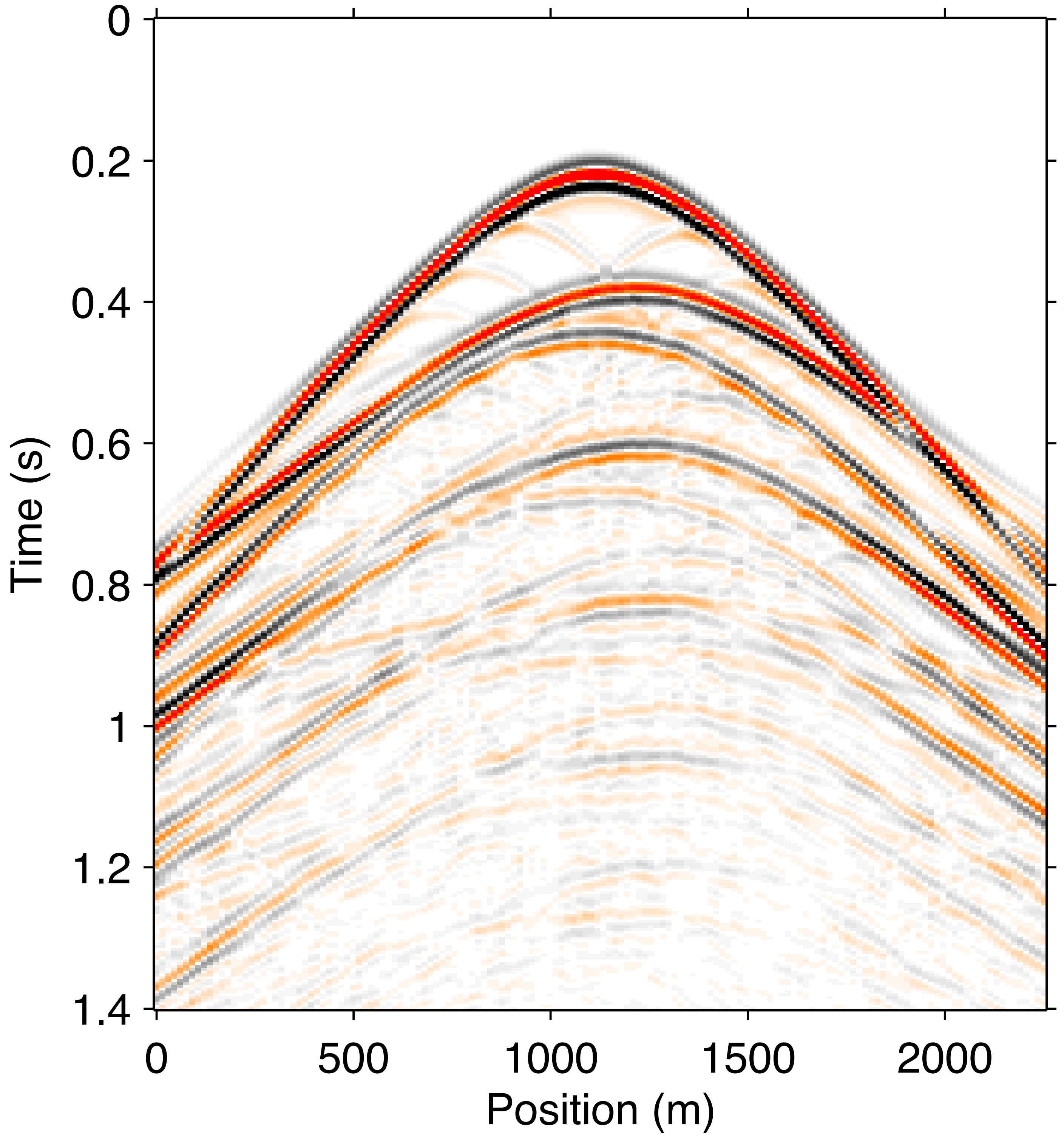
From SRME to Robust EPSI



Primaries by Sparse Inversion (van Groenestijn and Verschuur, 2009)

'ded data predicted data from SRME

$$\mathbf{P} = \mathbf{QG} - \mathbf{GP}$$

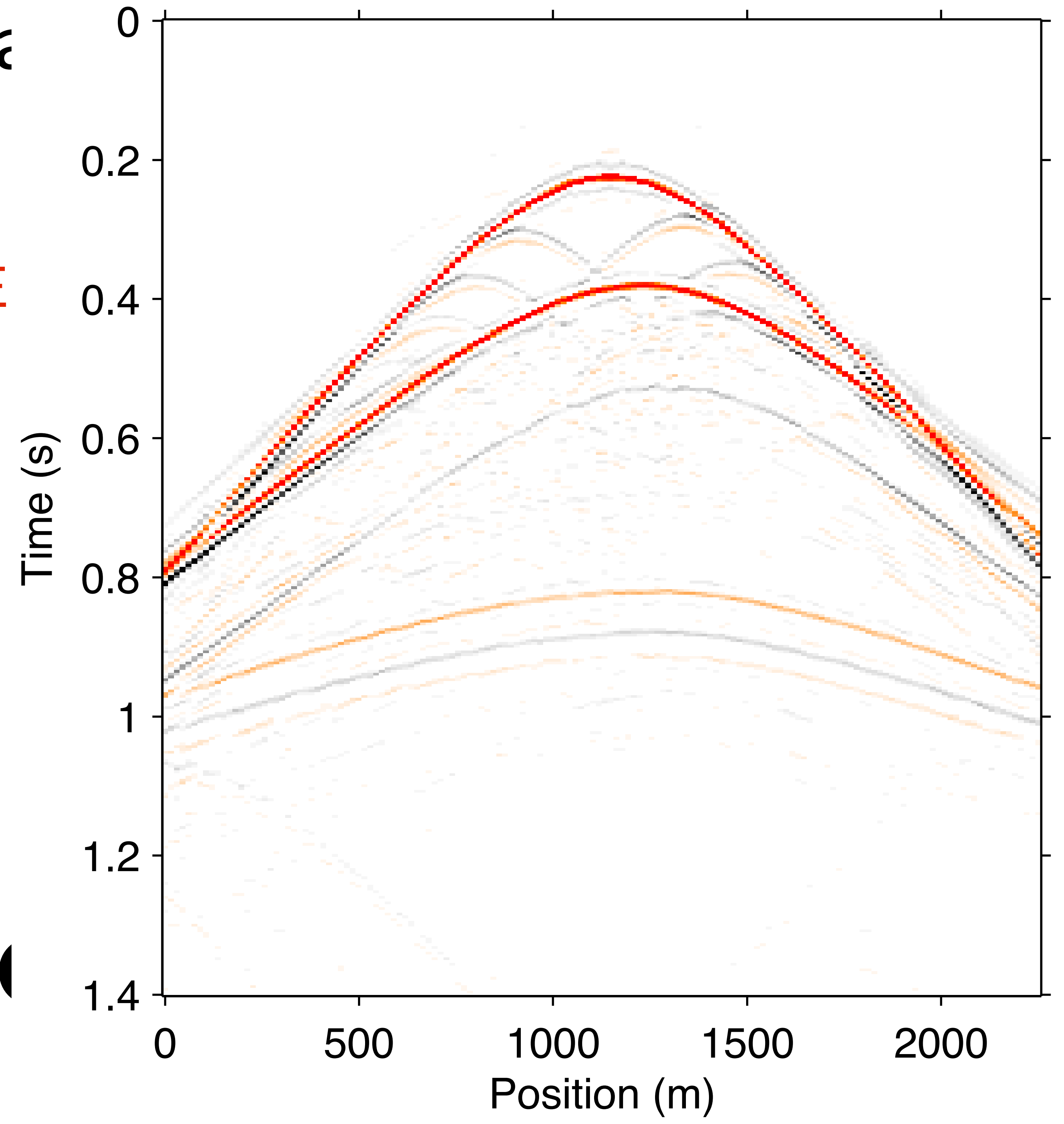
$$f(\mathbf{G}, \mathbf{Q}) = \frac{1}{2}\|\mathbf{P} - (\mathbf{QG} - \mathbf{GP})\|_2^2$$

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (va 9)

recorded data predicted data from SRME

$$\mathbf{P} = \mathbf{QG} - \mathbf{GP}$$



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From SRME to Robust EPSI

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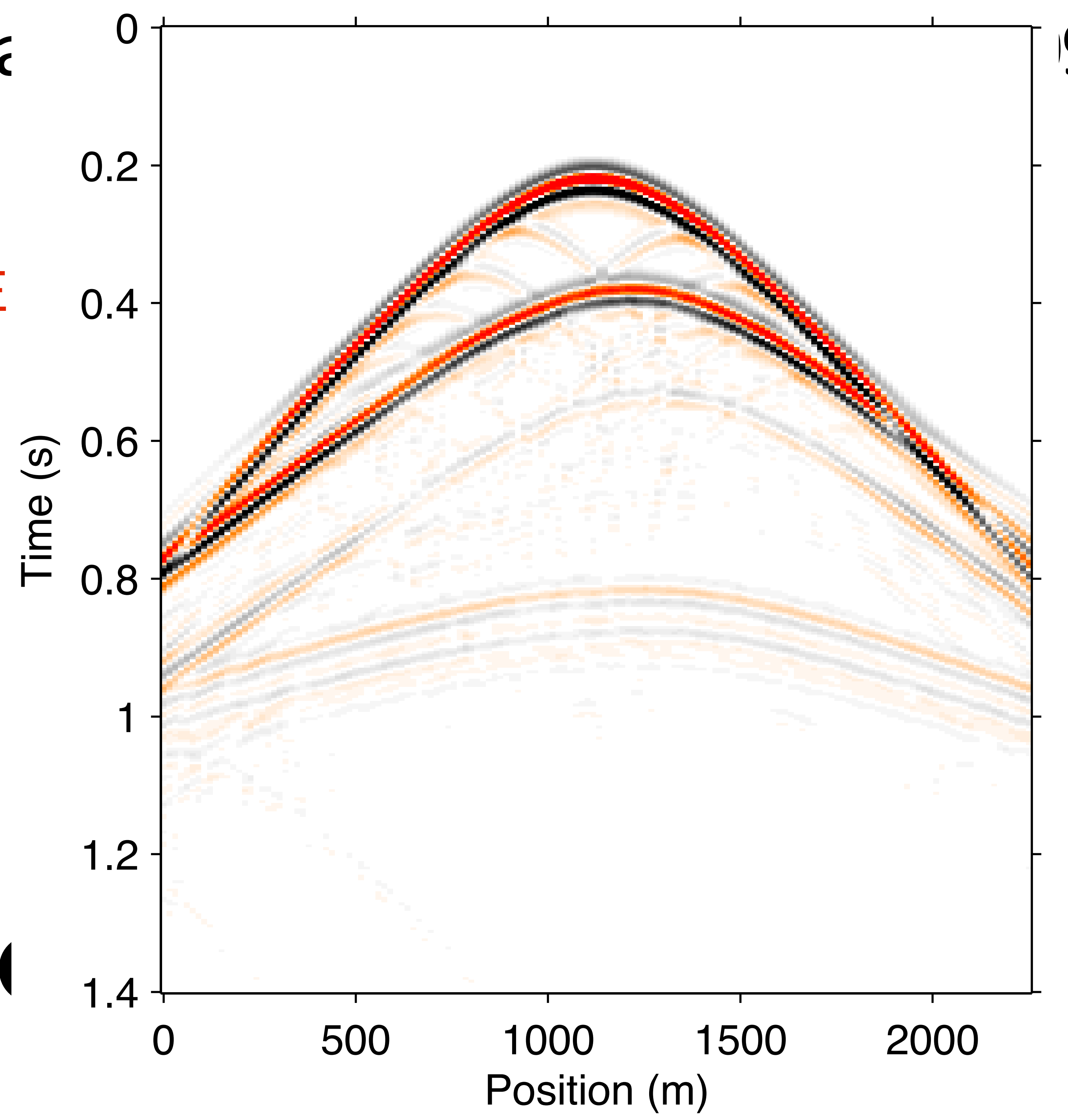


From SRME to Robust EPSI

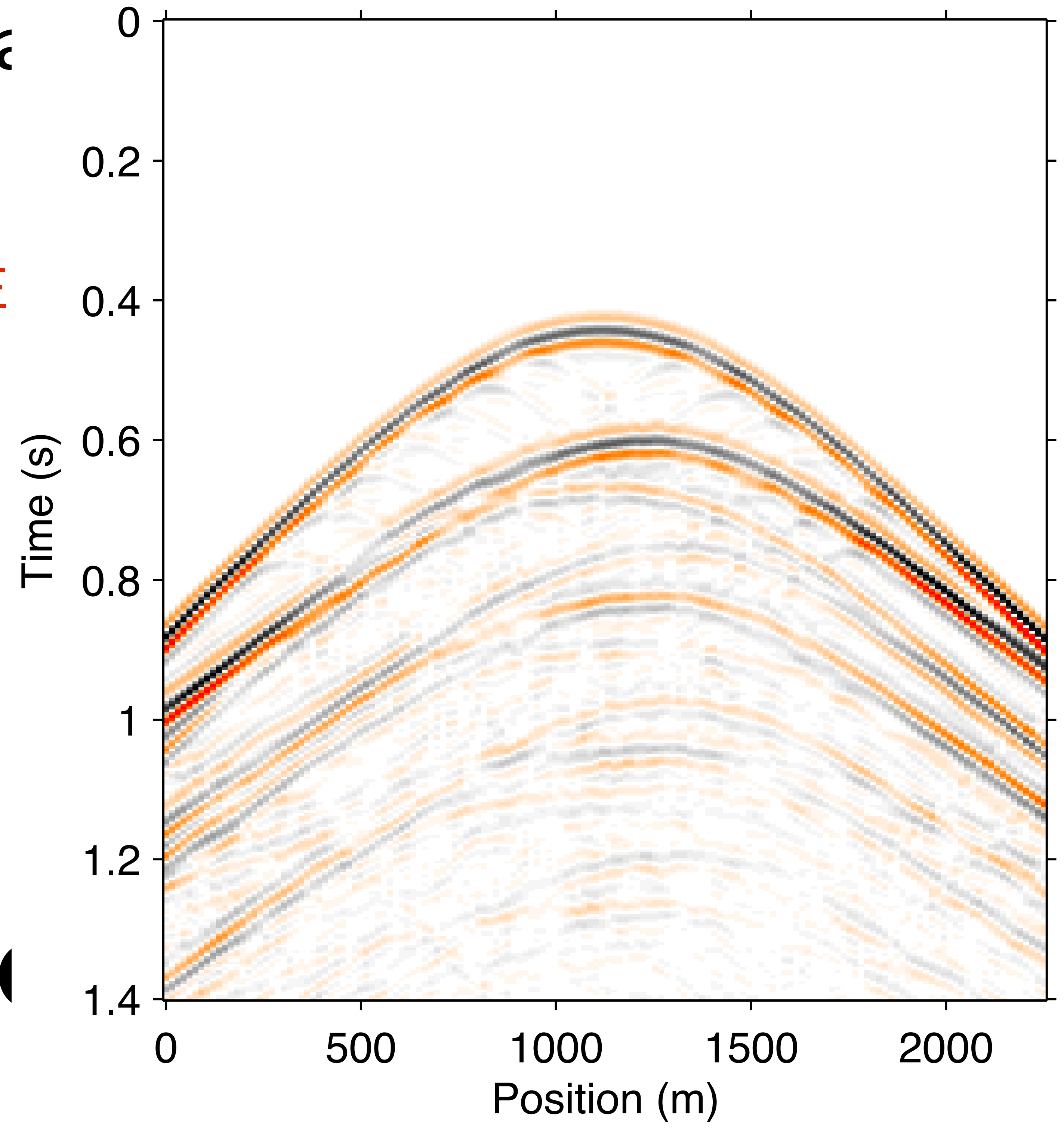
Based on **Estimation of Primaries by Sparse Inversion** (va   9)

recorded data   predicted data from SRME

$$\mathbf{P} = \mathbf{Q}\mathbf{G} - \mathbf{G}\mathbf{P}$$

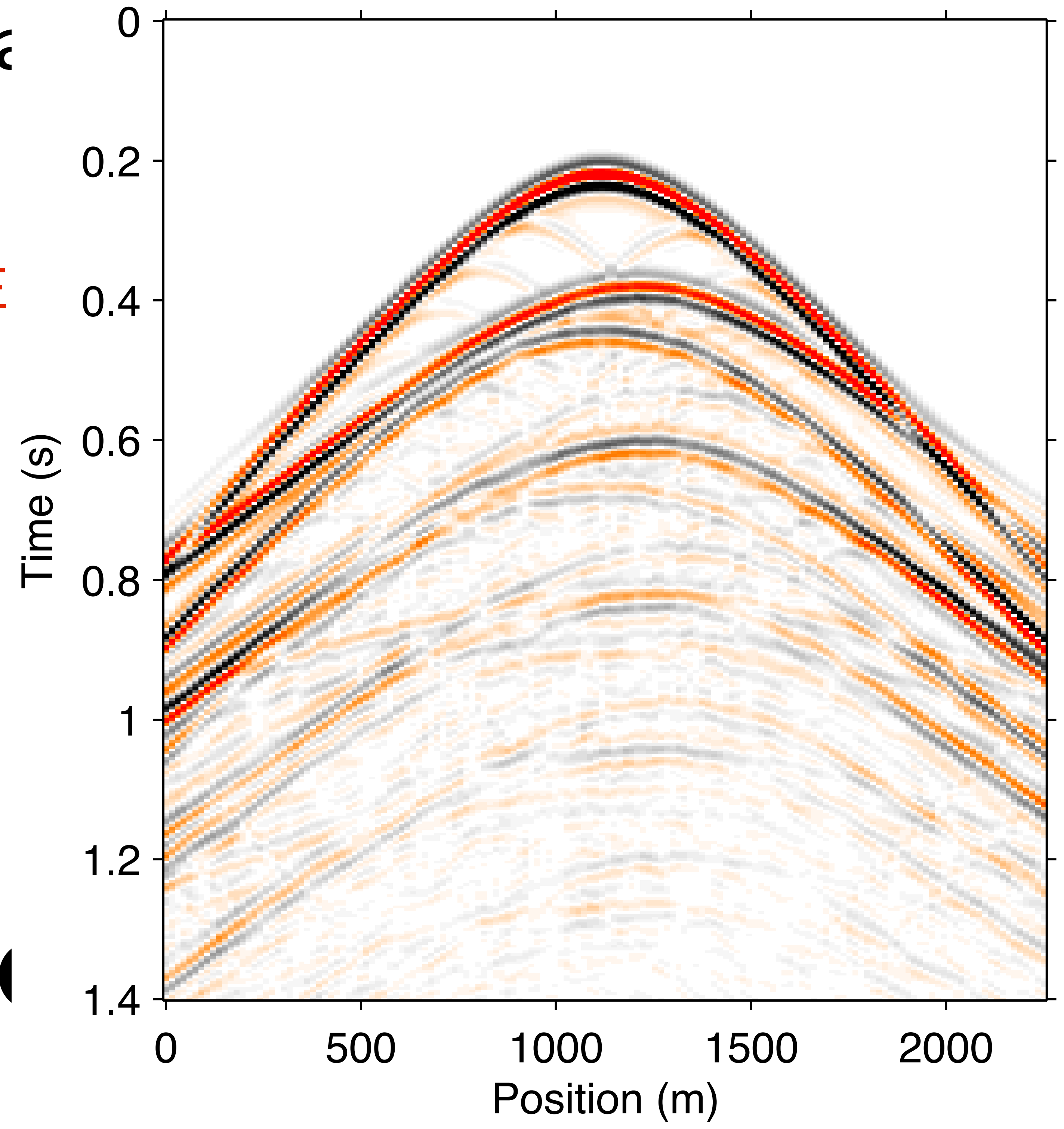
Inversion objective:

$$f(\mathbf{G}, \mathbf{Q}) = \frac{1}{2}\|\mathbf{P} - (\mathbf{Q}$$



From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (va



9)

recorded data

predicted data from SRME

$$\mathbf{P} = \mathbf{QG} - \mathbf{GP}$$

Inversion objective:

$$f(\mathbf{G}, \mathbf{Q}) = \frac{1}{2}\|\mathbf{P} - (\mathbf{Q}$$

From SRME to Robust EPSI

Based on **Estimation of Primaries by Sparse Inversion** (van Groenestijn and Verschuur, 2009)

recorded data predicted data from SRME

$$\mathbf{P} = \mathbf{Q}\mathbf{G} - \mathbf{G}\mathbf{P}$$

Inversion objective:

$$f(\mathbf{G}, \mathbf{Q}) = \frac{1}{2}\|\mathbf{P} - (\mathbf{Q}\mathbf{G} - \mathbf{G}\mathbf{P})\|_2^2$$

From SRME to Robust EPSI

Two ways to obtain the final primary wavefield

"Direct" Primary "Conservative" Primary

$$\mathbf{QG} = \mathbf{P} + \mathbf{GP}$$

Inversion objective:

$$f(\mathbf{G}, \mathbf{Q}) = \frac{1}{2}\|\mathbf{P} - (\mathbf{QG} - \mathbf{GP})\|_2^2$$

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From SRME to Robust EPSI

In time domain (lower-case: whole dataset in time domain)

recorded data predicted data from SRME

$$\mathbf{p} = \mathcal{M}(\mathbf{g}, \mathbf{q})$$

$$\mathcal{M}(\mathbf{g}, \mathbf{q}) := \mathcal{F}_{\mathrm{t}}^{\dagger} \mathrm{BlockDiag}_{\omega_1 \cdots \omega_{nf}} [(q(\omega)\mathbf{I} - \mathbf{P})^{\dagger} \otimes \mathbf{I}] \mathcal{F}_{\mathrm{t}} \mathbf{g}$$

Inversion objective:

$$f(\mathbf{g}, \mathbf{q}) = \frac{1}{2} \|\mathbf{p} - \mathcal{M}(\mathbf{g}, \mathbf{q})\|_2^2$$

Solving the EPSI problem

Linearizations

$$\mathbf{p} = \mathcal{M}(\mathbf{g}, \mathbf{q})$$

$$\mathbf{M}_{\tilde{q}} = \left(\frac{\partial \mathcal{M}}{\partial \mathbf{g}}\right)_{\tilde{q}}$$

$$\mathbf{M}_{\tilde{g}} = \left(\frac{\partial \mathcal{M}}{\partial \mathbf{q}}\right)_{\tilde{g}}$$

In fact it is bilinear:

$$\mathbf{M}_{\tilde{q}}\mathbf{g} = \mathcal{M}(\mathbf{g}, \tilde{\mathbf{q}}) \qquad \mathbf{M}_{\tilde{g}}\mathbf{q} = \mathcal{M}(\mathbf{q}, \tilde{\mathbf{g}})$$

Solving the EPSI problem

Linearizations

$$\mathbf{p} = \mathcal{M}(\mathbf{g}, \mathbf{q})$$

$$\mathbf{M}_{\tilde{q}} = \left(\frac{\partial \mathcal{M}}{\partial \mathbf{g}}\right)_{\tilde{q}}$$

$$\mathbf{M}_{\tilde{g}} = \left(\frac{\partial \mathcal{M}}{\partial \mathbf{q}}\right)_{\tilde{g}}$$

Associated objectives:

$$f_{\tilde{q}}(\mathbf{g}) = \frac{1}{2}\|\mathbf{p} - \mathbf{M}_{\tilde{q}}\mathbf{g}\|_2^2 \qquad f_{\tilde{g}}(\mathbf{q}) = \frac{1}{2}\|\mathbf{p} - \mathbf{M}_{\tilde{g}}\mathbf{q}\|_2^2$$

Solving the EPSI problem

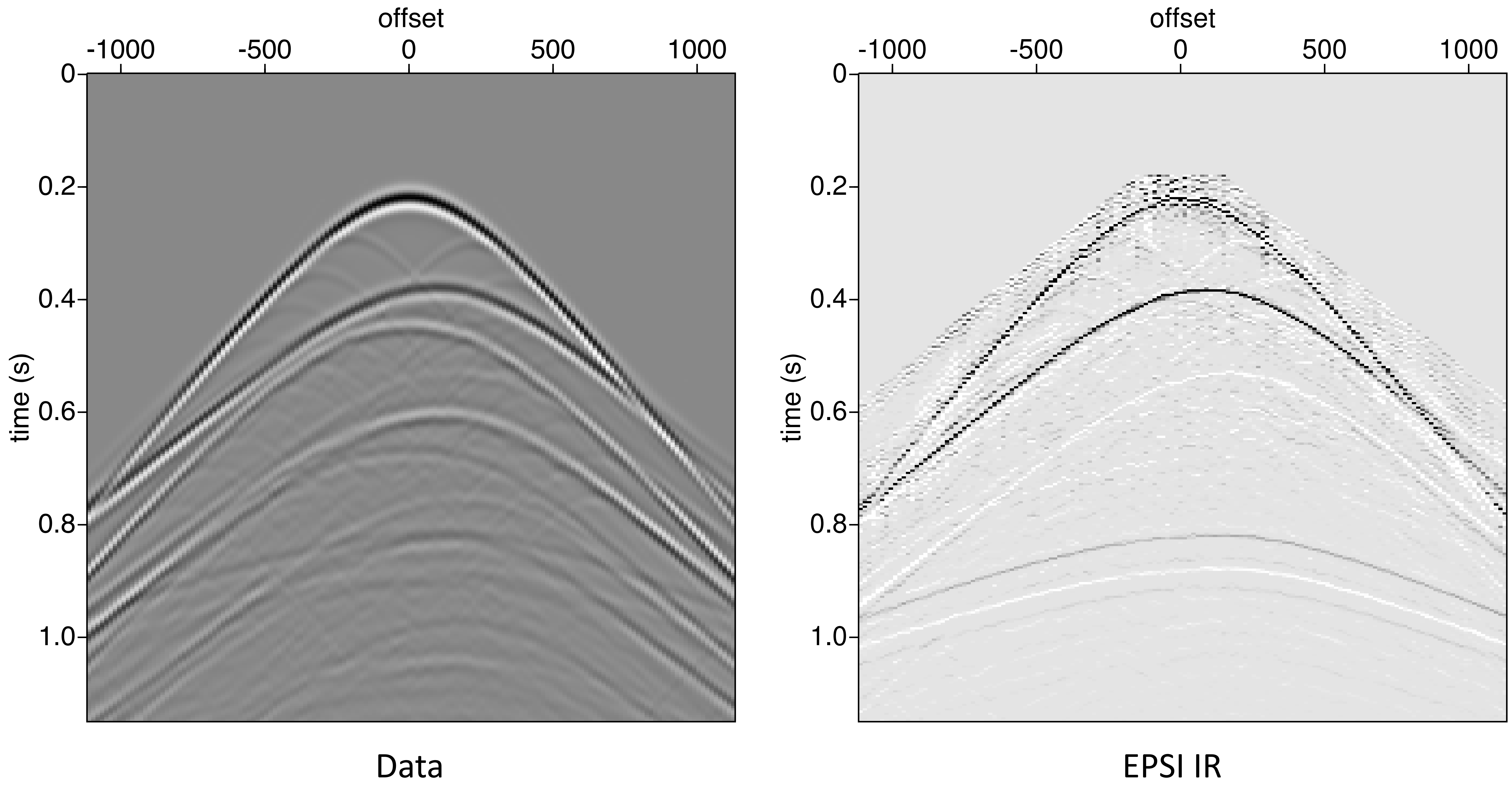
Do:

$$\mathbf{g}_{k+1} = \mathbf{g}_k + \alpha\mathcal{S}(\nabla f_{q_k}(\mathbf{g}_k))$$
$$\mathbf{q}_{k+1} = \mathbf{q}_k + \beta\nabla f_{g_{k+1}}(\mathbf{q}_k)$$

Gradient sparsity

$\mathcal{S}$: pick largest ρ elements per trace

Solving the EPSI problem



Robust EPSI
L1-minimization approach to the EPSI problem

[Lin and Herrmann, 2013 *Geophysics*]

While $\|\mathbf{p} - \mathcal{M}(\mathbf{g}_k, \mathbf{q}_k)\|_2 > \sigma$

determine new τ_k from the Pareto curve

$$\mathbf{g}_{k+1} = \arg\min_{\mathbf{g}} \|\mathbf{p} - \mathbf{M}_{q_k}\mathbf{g}\|_2 \text{ s.t. } \|\mathbf{g}\|_1 \leq \tau_k$$

(Solve with SPG part of SPGL1 until Pareto curve reached)

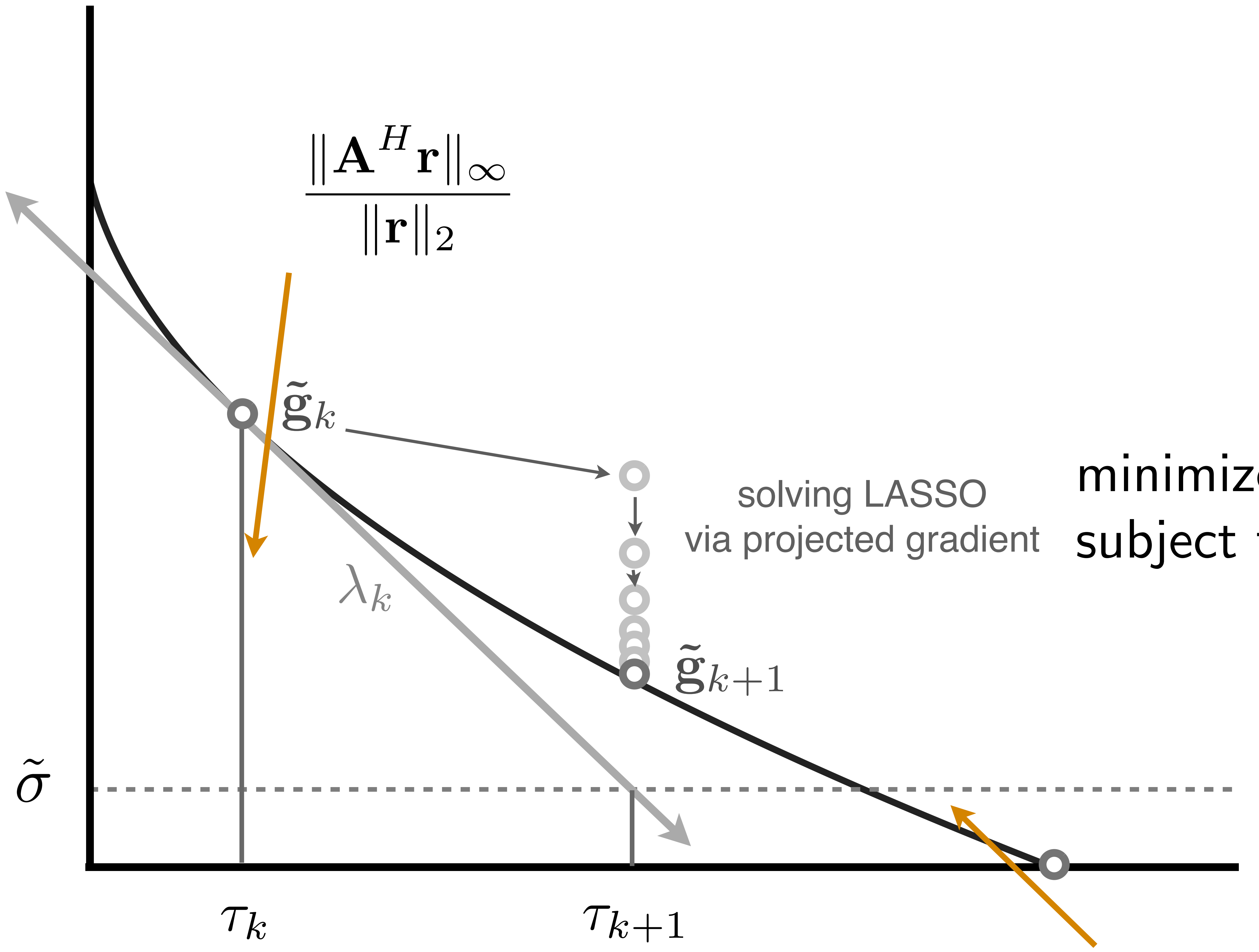
$$\mathbf{q}_{k+1} = \arg\min_{\mathbf{q}} \|\mathbf{p} - \mathbf{M}_{g_{k+1}}\mathbf{q}\|_2$$

(wavelet matching, solve with LSQR)

Choosing Tau from the Pareto curve

$$\begin{array}{ll}\text{minimize} & \|x\|_1 \\ \text{subject to} & \|Ax - b\|_2 \le \sigma\end{array}$$

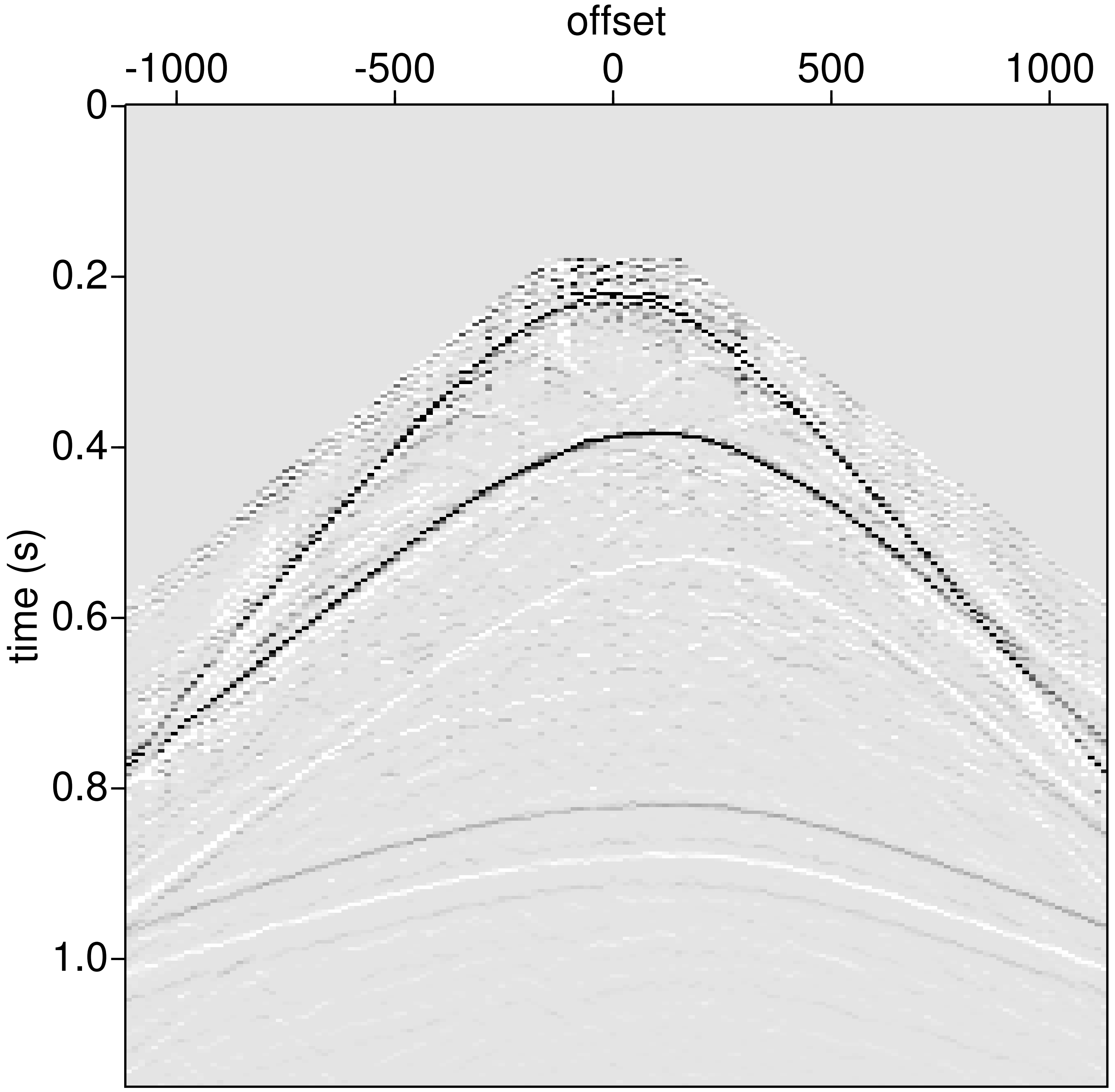
Look at the solution space and the line of optimal solutions (Pareto curve)



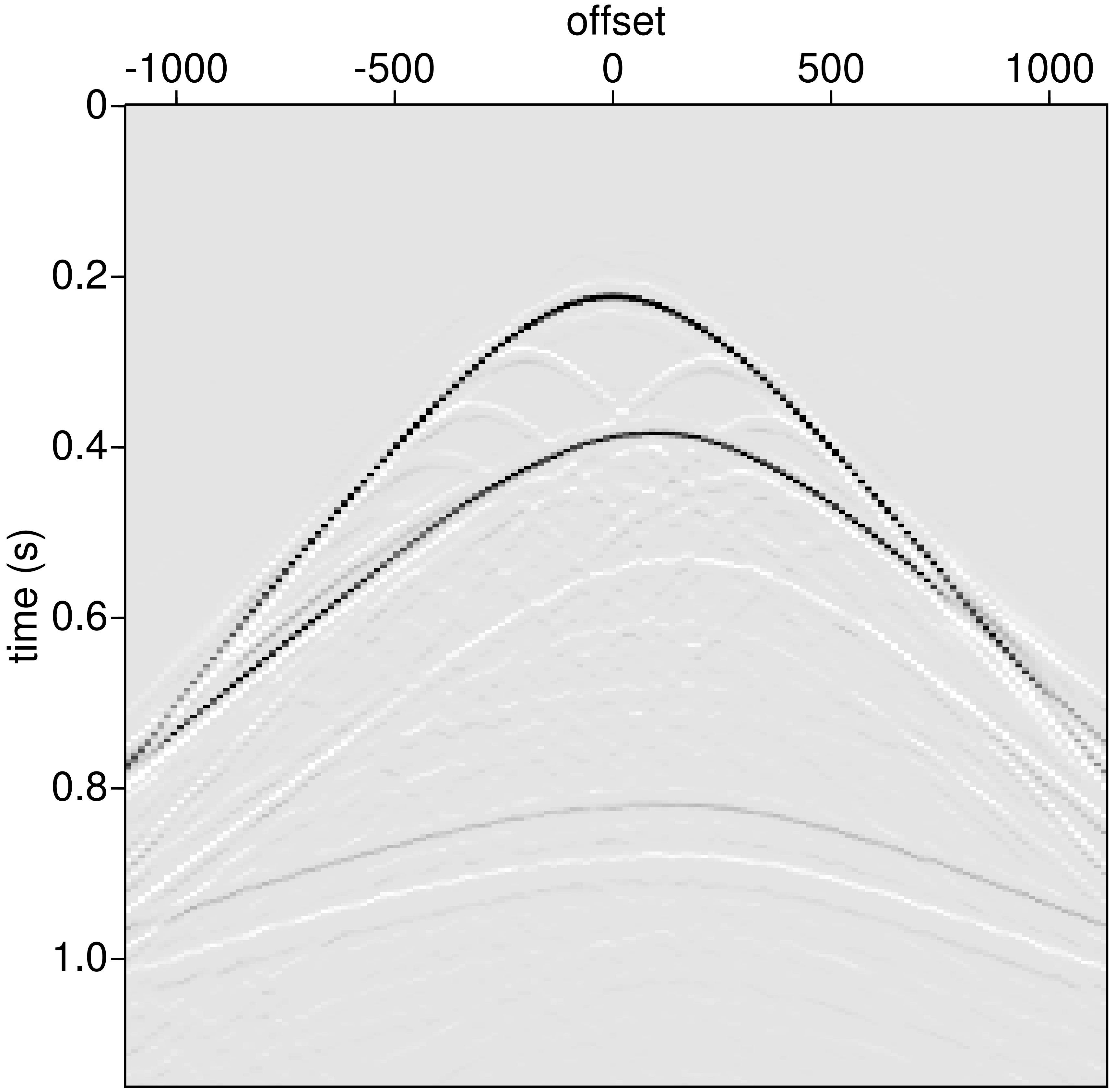
$$\begin{array}{ll}\text{minimize} & \|Ax - b\|_2 \\ \text{subject to} & \|x\|_1 \le \tau\end{array}$$

feasible solution with smallest $\|x\|_1$

Robust EPSI

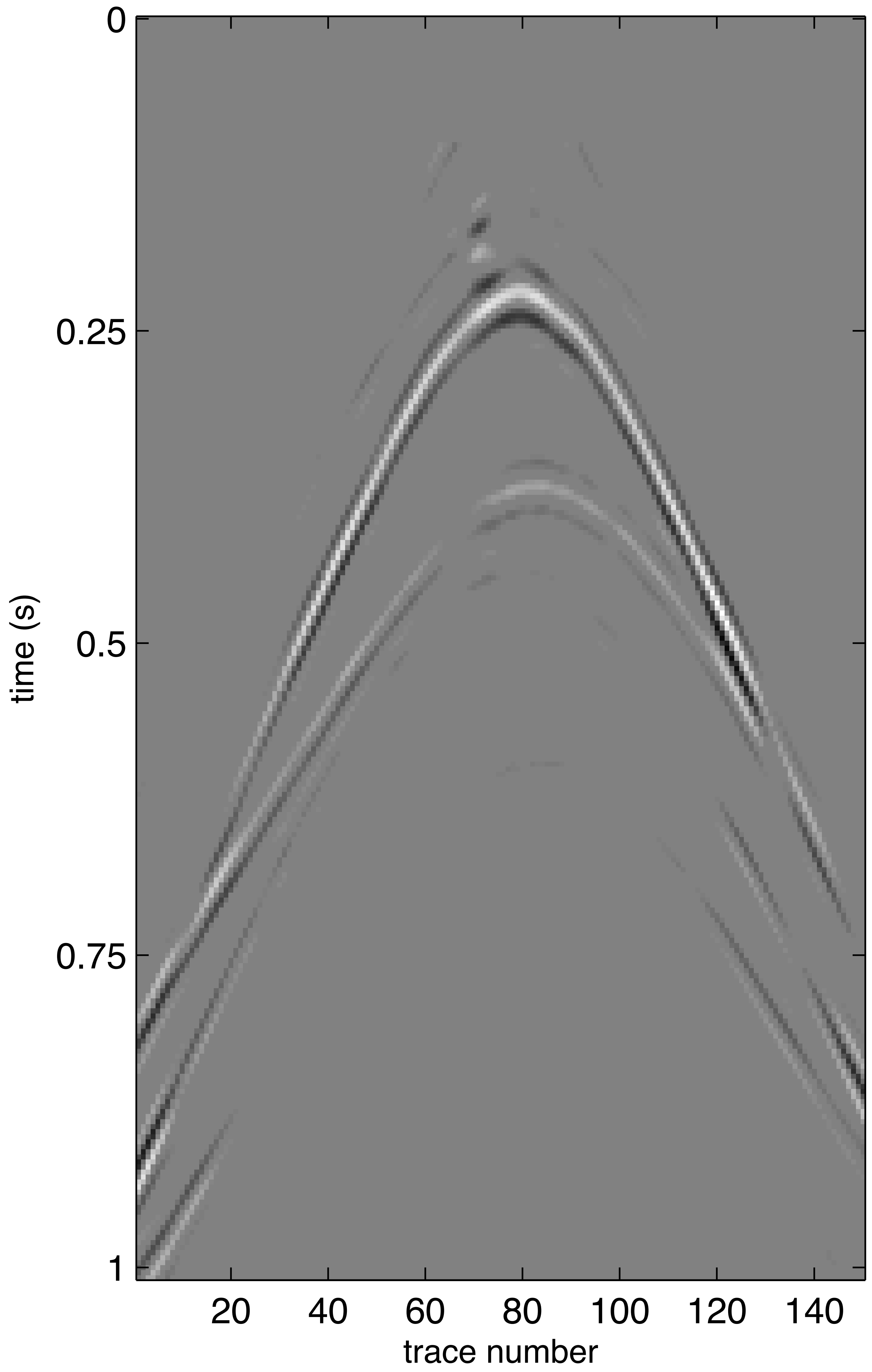


EPSI IR



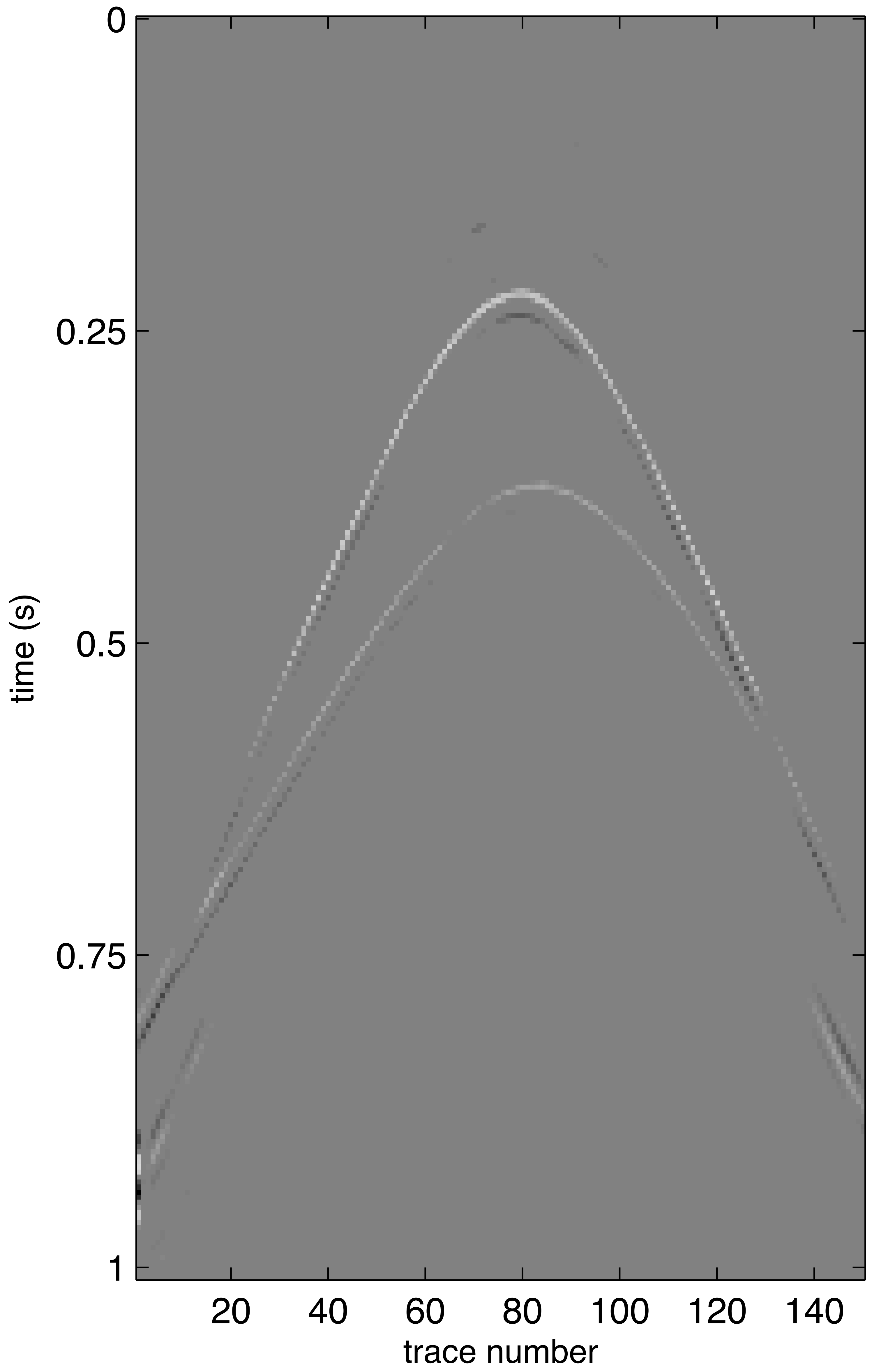
Robust EPSI IR

L1 projection and sparsity



Solution at beginning of SPG

L1 projection and sparsity



Solution at end of SPG (pareto-optimal)

L1 projection and sparsity

$$\begin{array}{ll} \text{minimize} & \|Ax-b\|_2 \\ \text{subject to} & \|x\|_1 \leq \tau \end{array}$$

L1 projection and sparsity

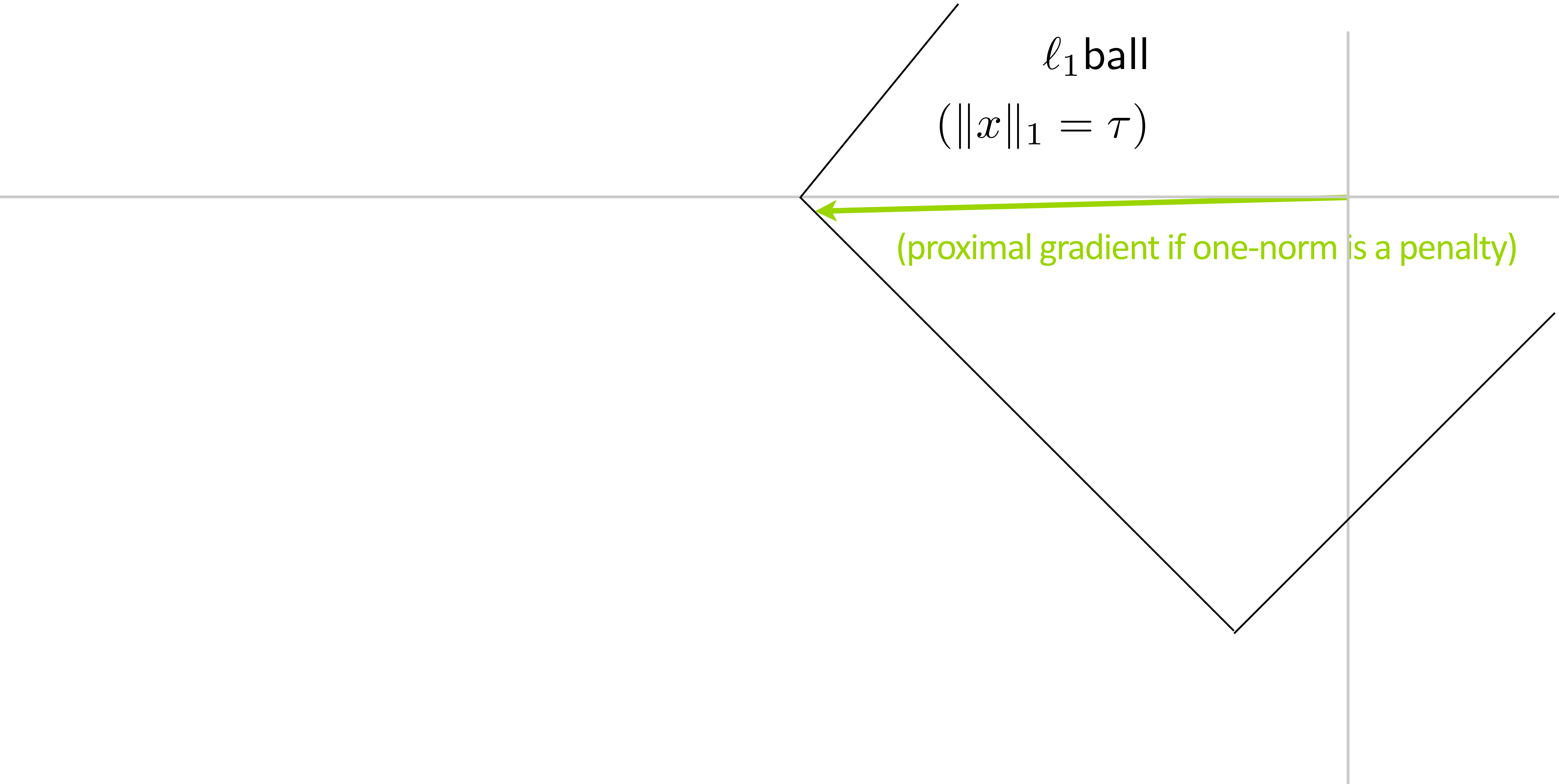
$$\begin{array}{ll}\text{minimize} & \|Ax-b\|_2 \\ \text{subject to} & \|x\|_1 \le \tau\end{array}$$

L1 projection and sparsity

$$\begin{array}{ll} \text{minimize} & \|Ax - b\|_2 \\ \text{subject to} & \|x\|_1 \leq \tau \end{array}$$

L1 projection and sparsity

minimize $\|Ax - b\|_2$
subject to $\|x\|_1 \leq \tau$



Robust EPSI summary

Benefits

- Formulation is more physical than SRME w/adaptive subtraction
- Provide useful estimates of both primary and multiple wavefields
- Mostly hands-free
- Much more accurate estimate of the multiples than single-pass SRMP
- Gives sparse impulse response of primary wavefield

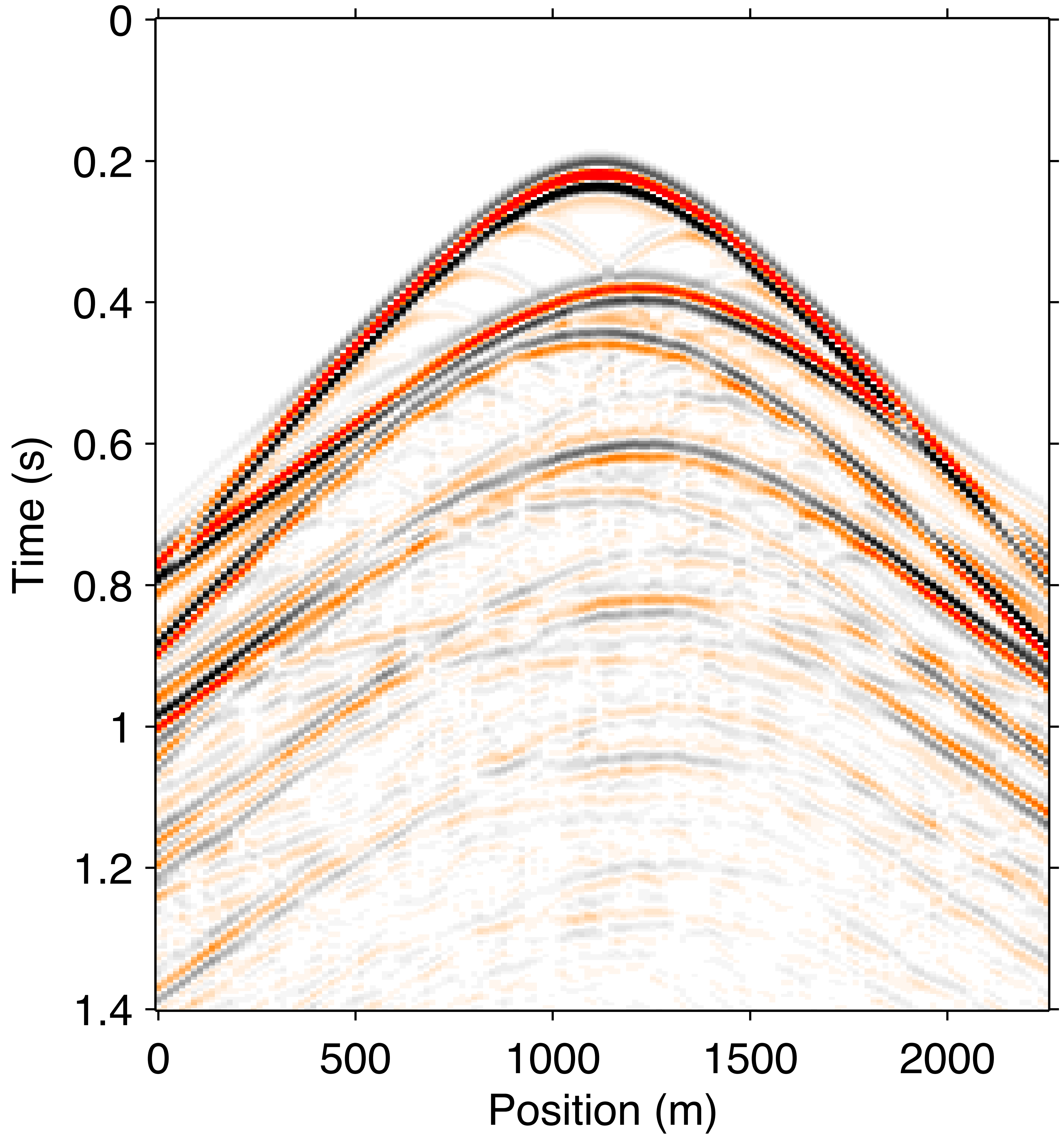
Challenges

- Cost roughly 100 to 200 SRMP
- Inversion approach means hard to QC until too late

Bootstrapping

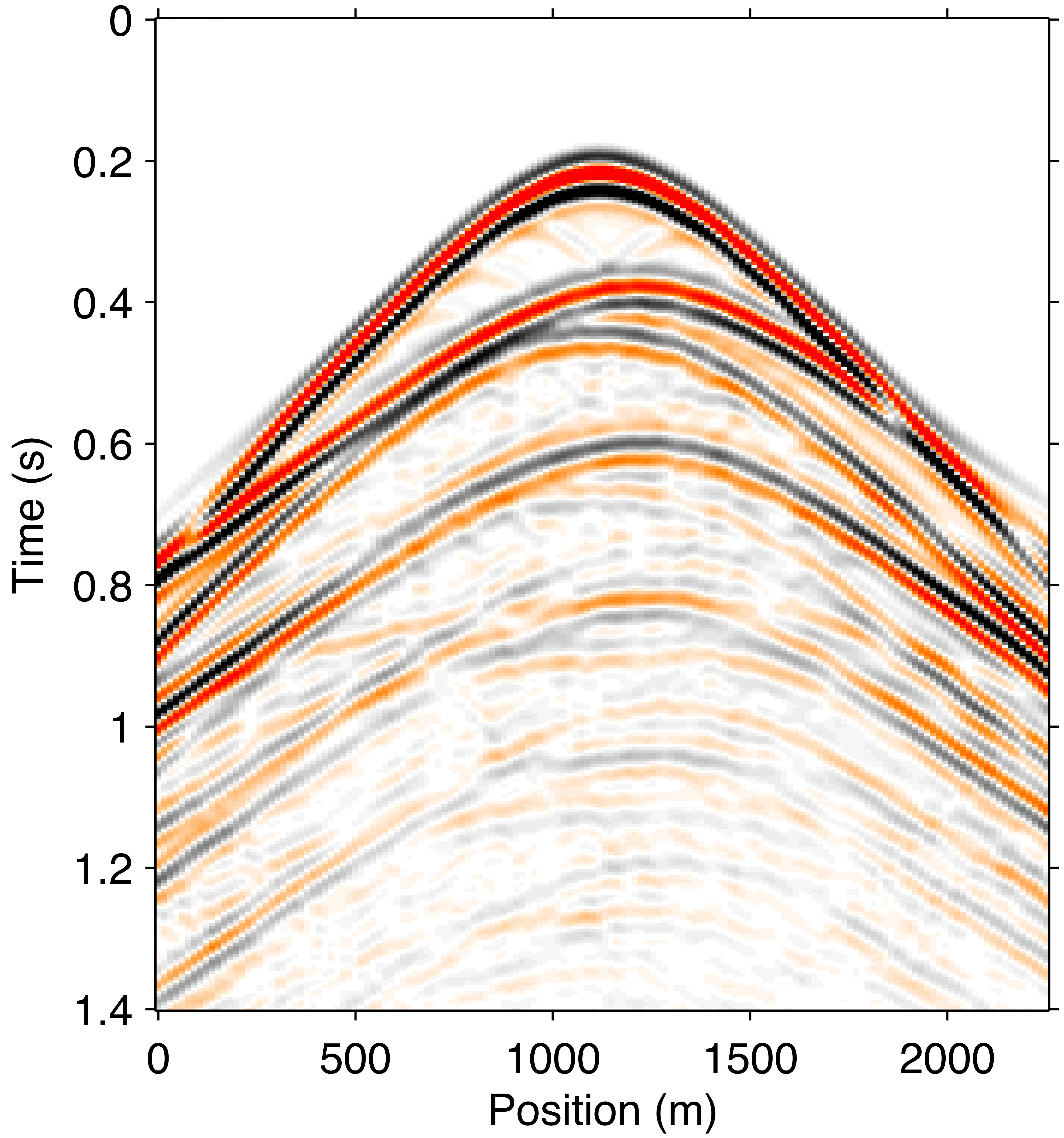
(continuation strategy for spatial sampling)

Motivation: G unchanged by global filters



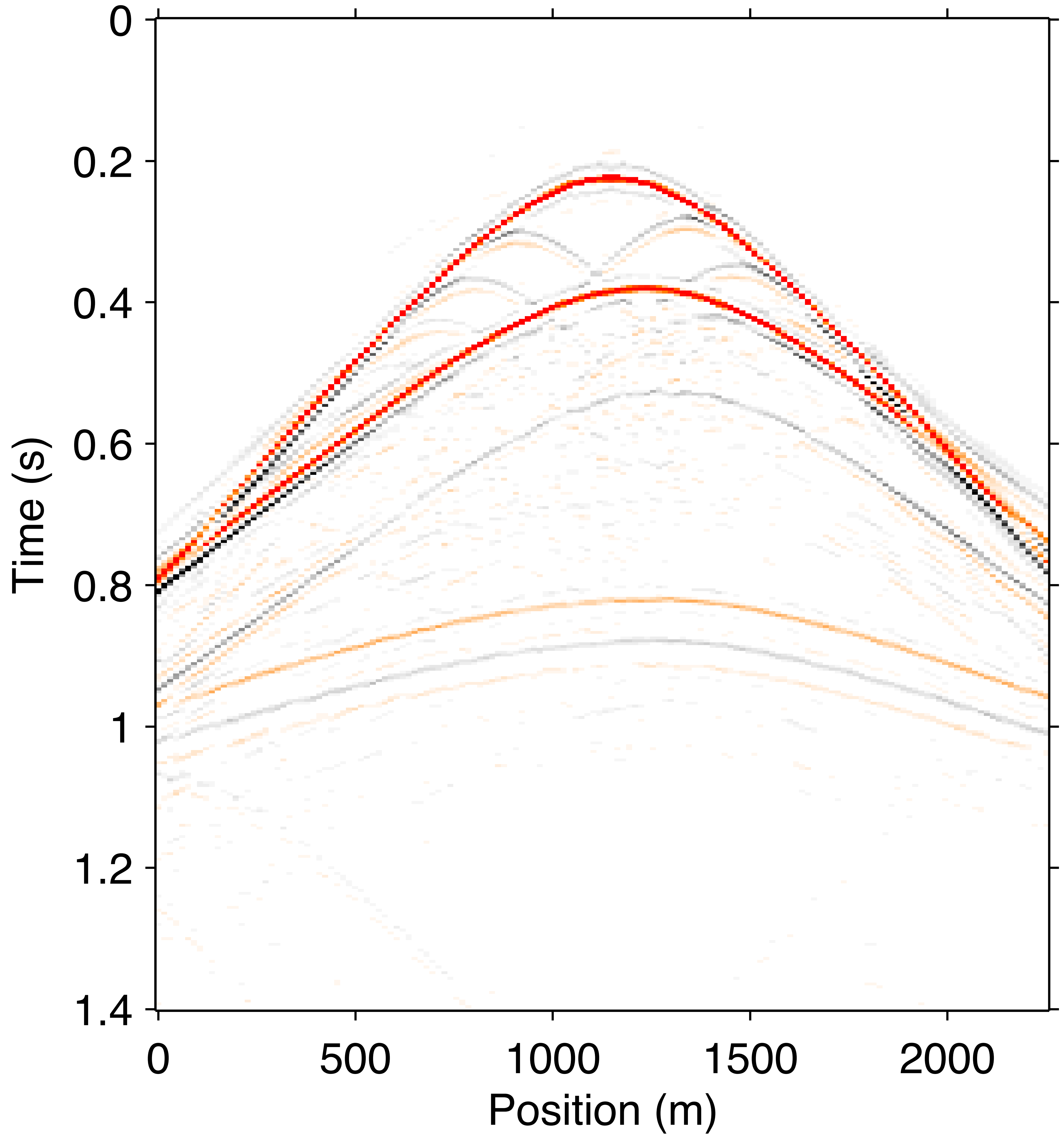
Data
modeled with Ricker 30Hz

Motivation: G unchanged by global filters



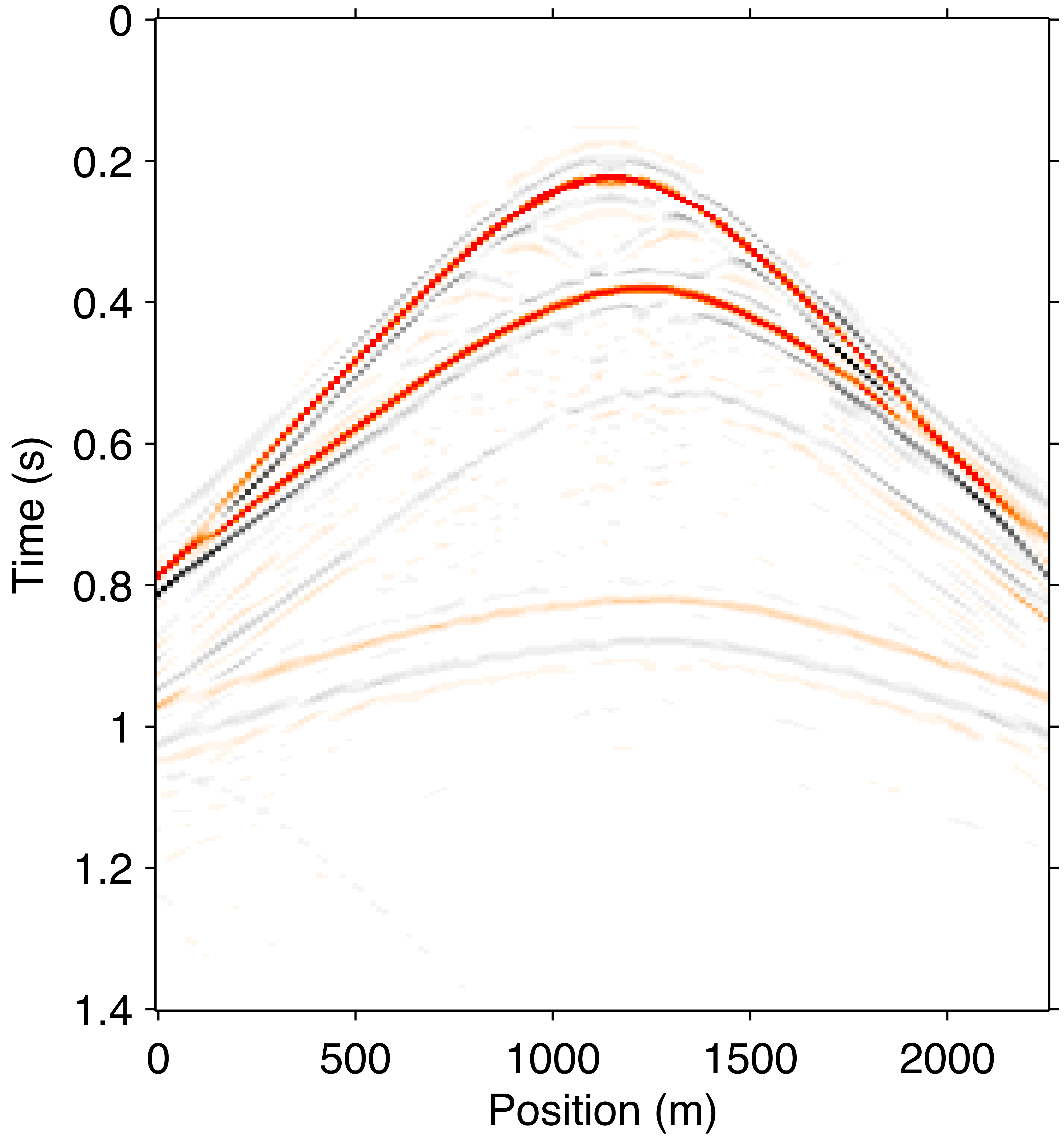
Lowpassed Data
modeled with Ricker 30Hz
lowpass at 40Hz
(zero-phase cosine window)

Motivation: G unchanged by global filters



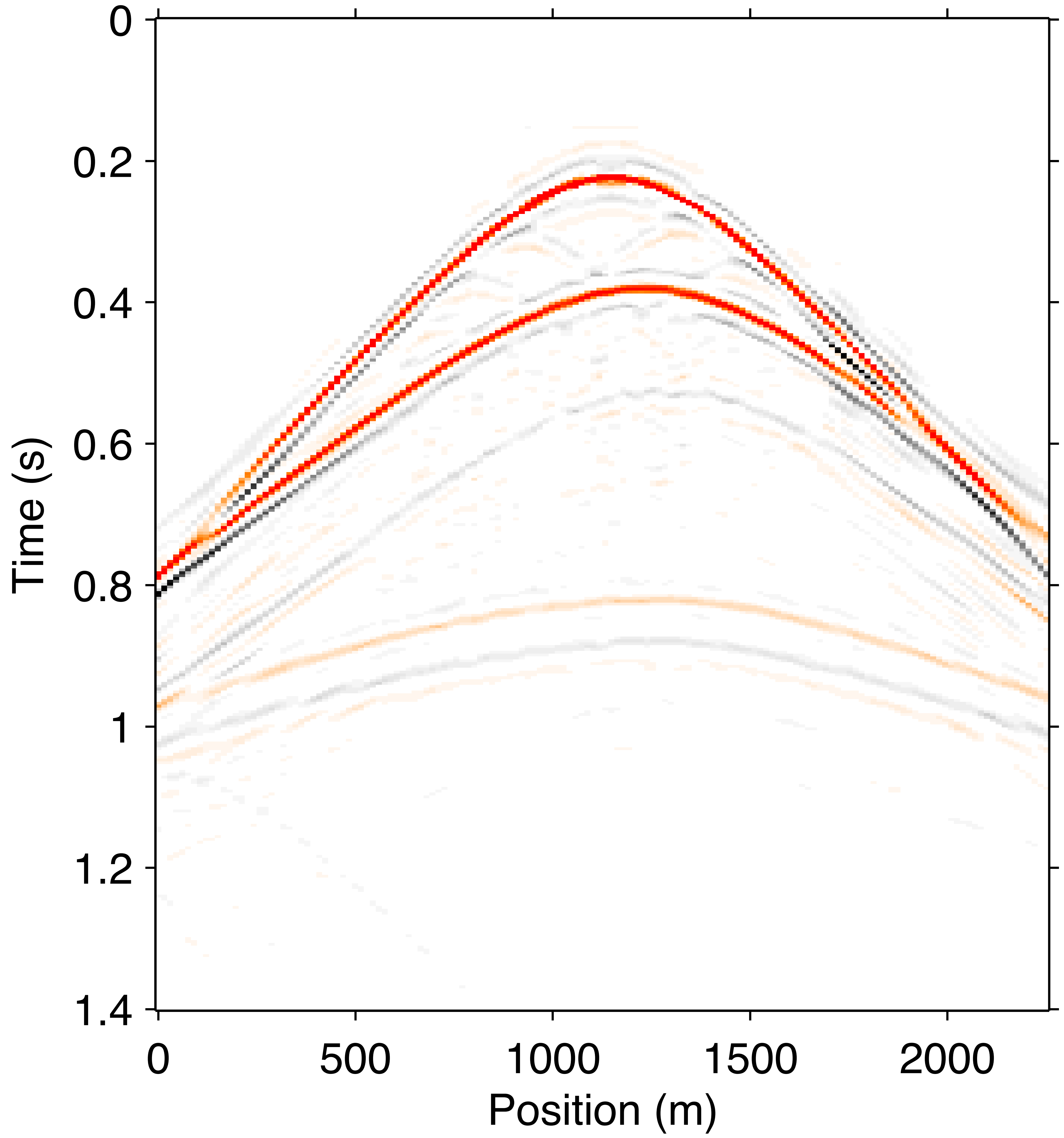
Reference REPSI primary IR
from original data

Motivation: G unchanged by global filters



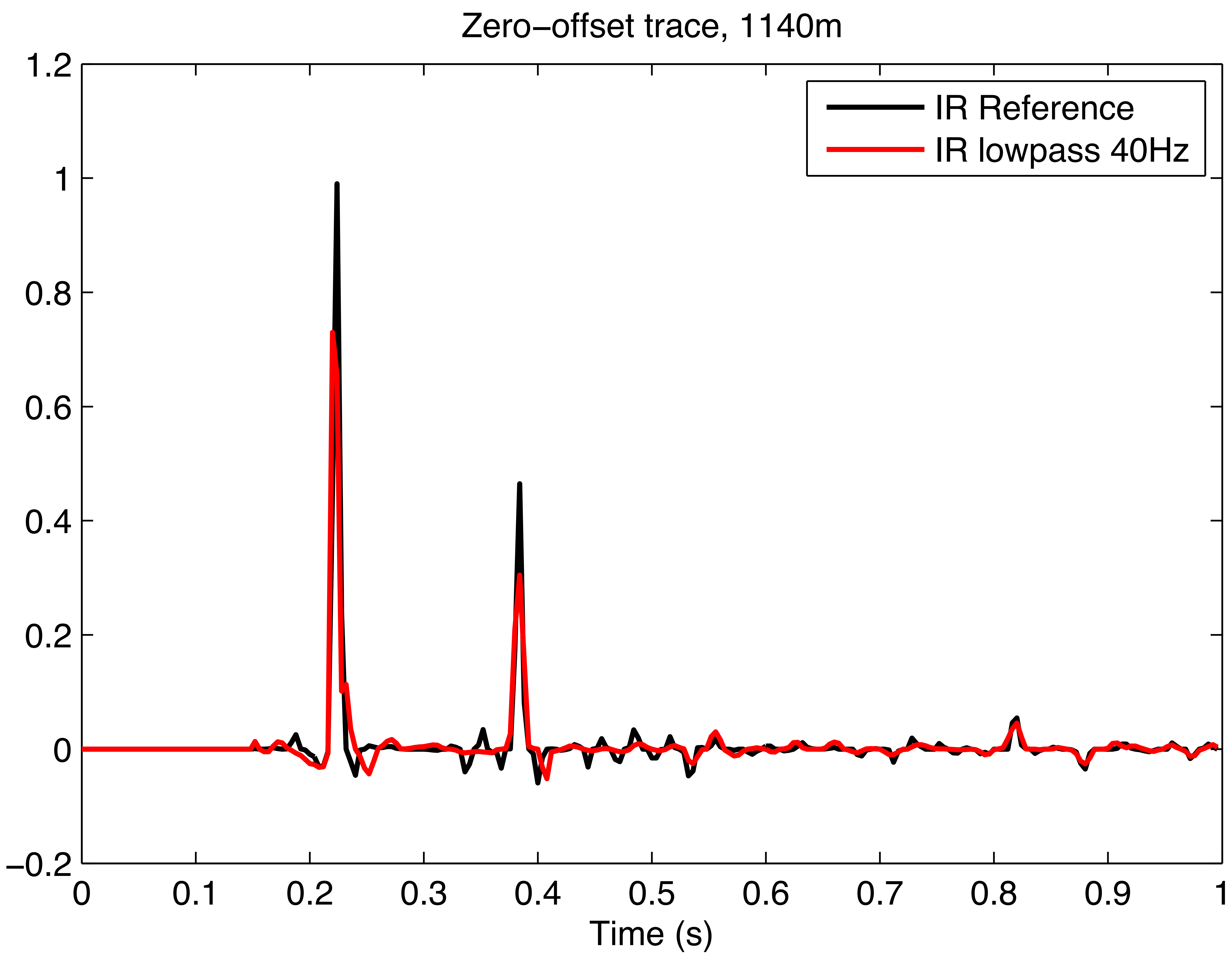
REPSI primary IR
from low-passed data @ 40Hz

Motivation: G tolerant to global filters



REPSI primary IR
from low-passed data @ 40Hz

Motivation: G tolerant to global filters



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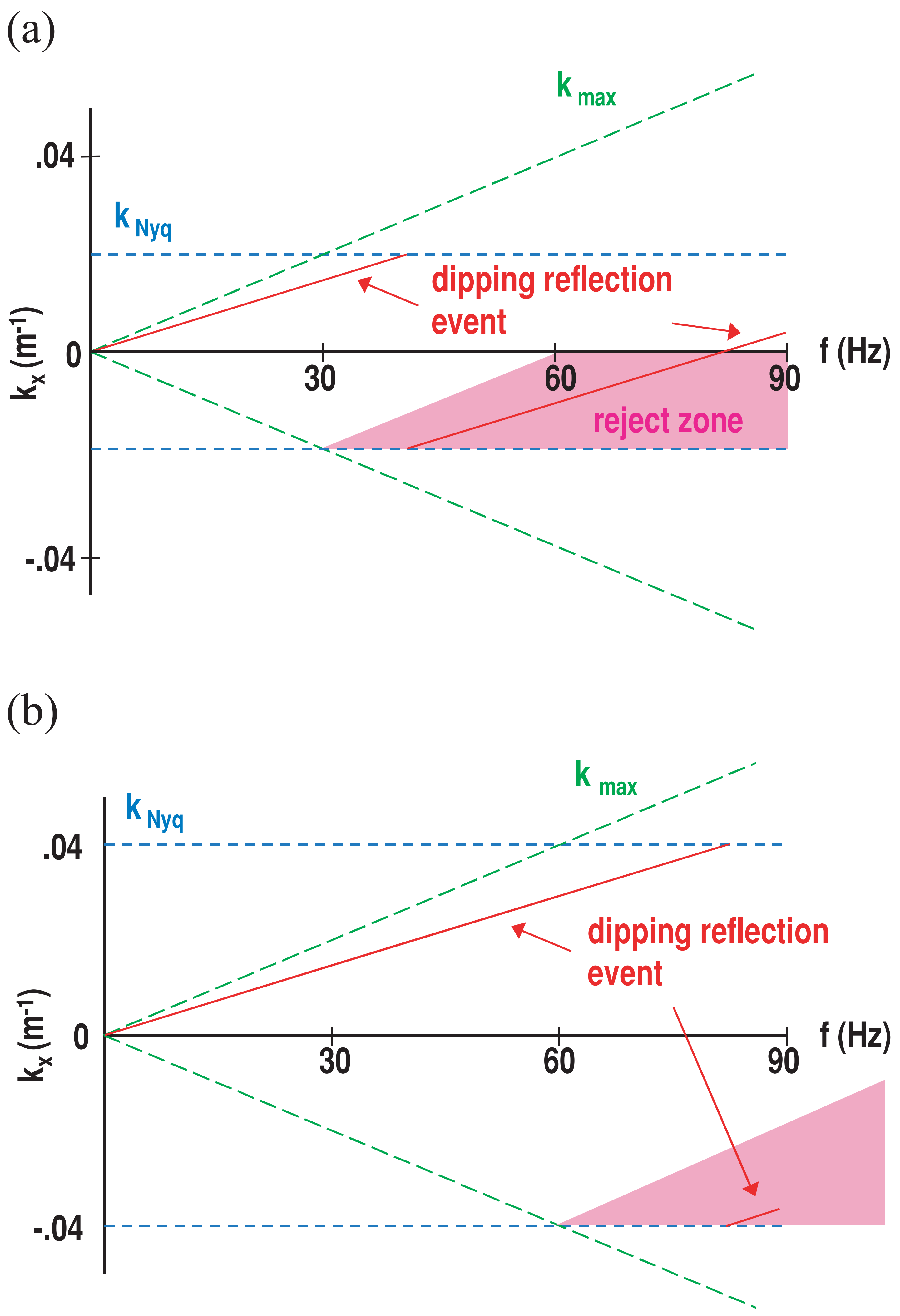
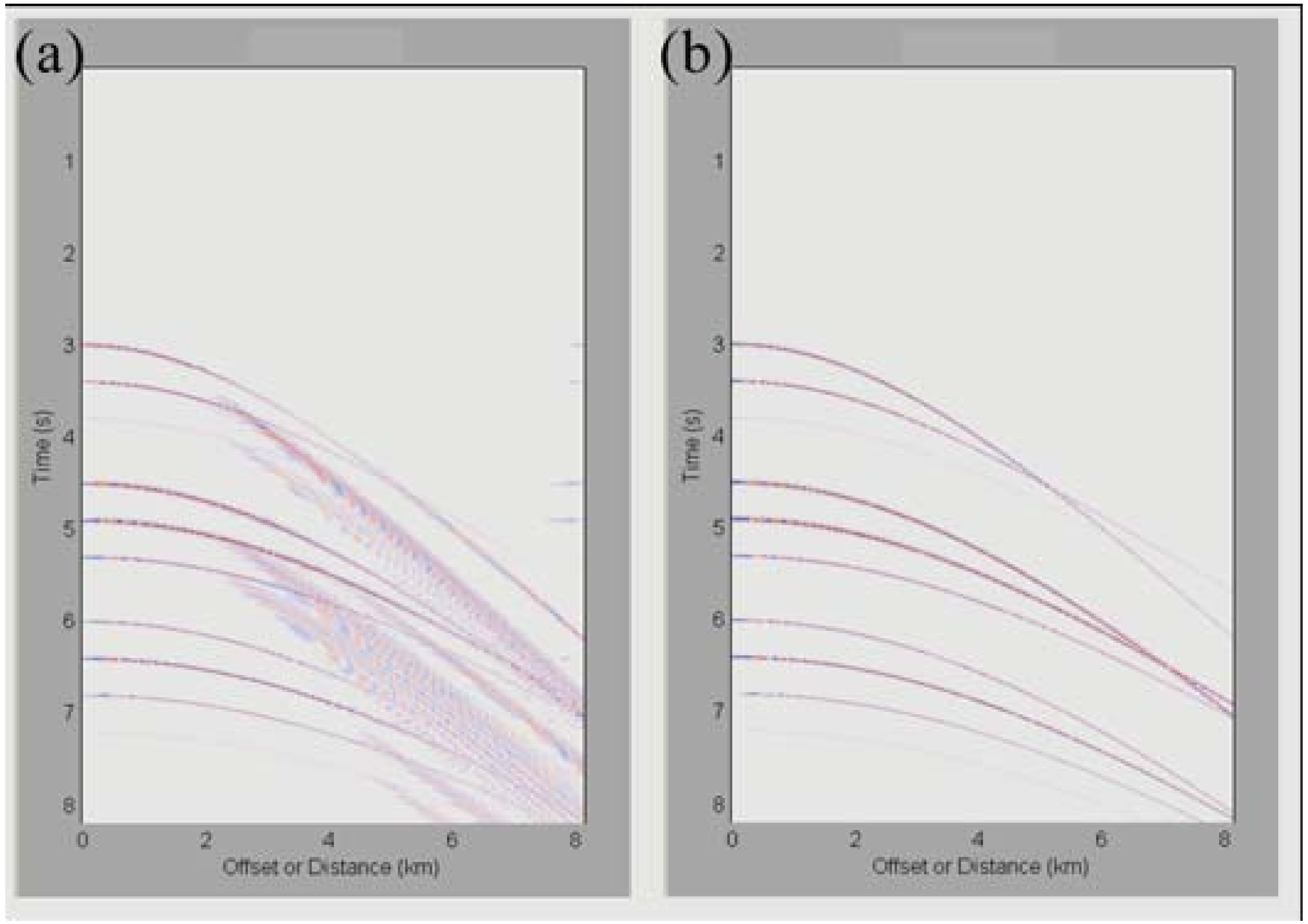
Sampling issue in multiple prediction = alias

“The impact of field-survey characteristics on surface-related multiple attenuation”
Dragoset, Moore, Kostov 2006



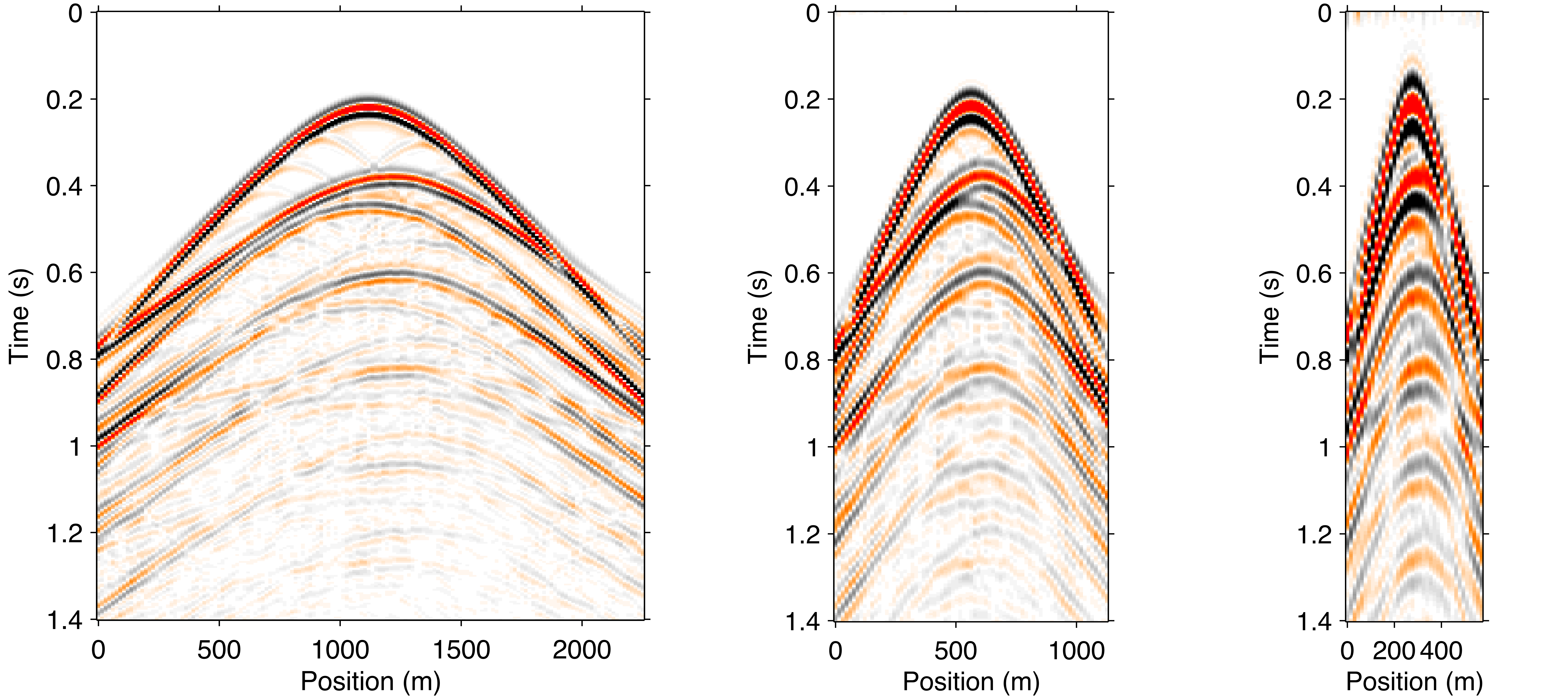


Idea 1: Solve REPSI on decimated dataset
(low-pass in temporal frequency)

Original (dx = 15m)

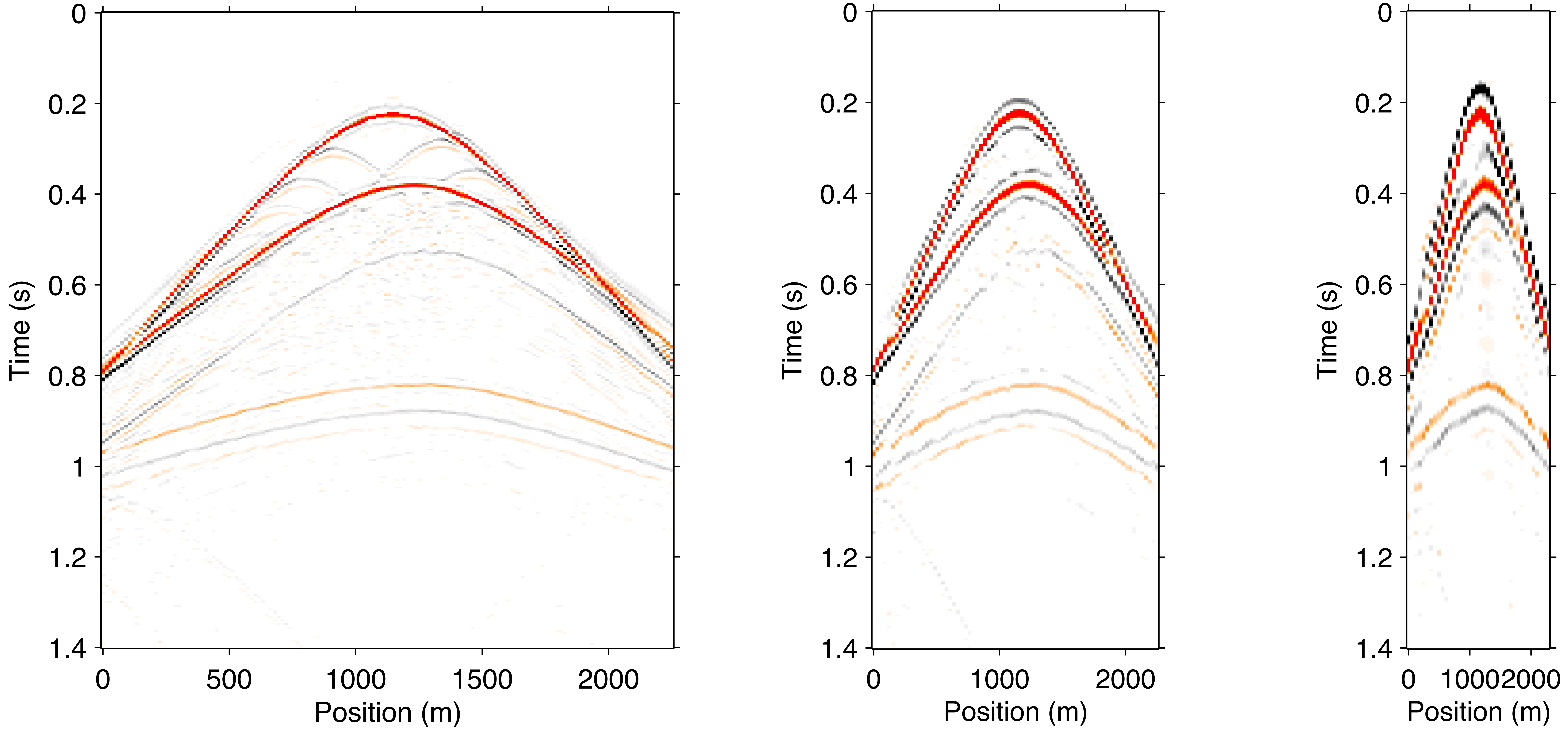
2x decimated
lowpass 30Hz

4x decimated
lowpass 60Hz



Idea 1: Solve REPSI on decimated dataset
(low-pass in temporal frequency)

Impulse response solutions



Idea 1: Solve REPSI on decimated dataset
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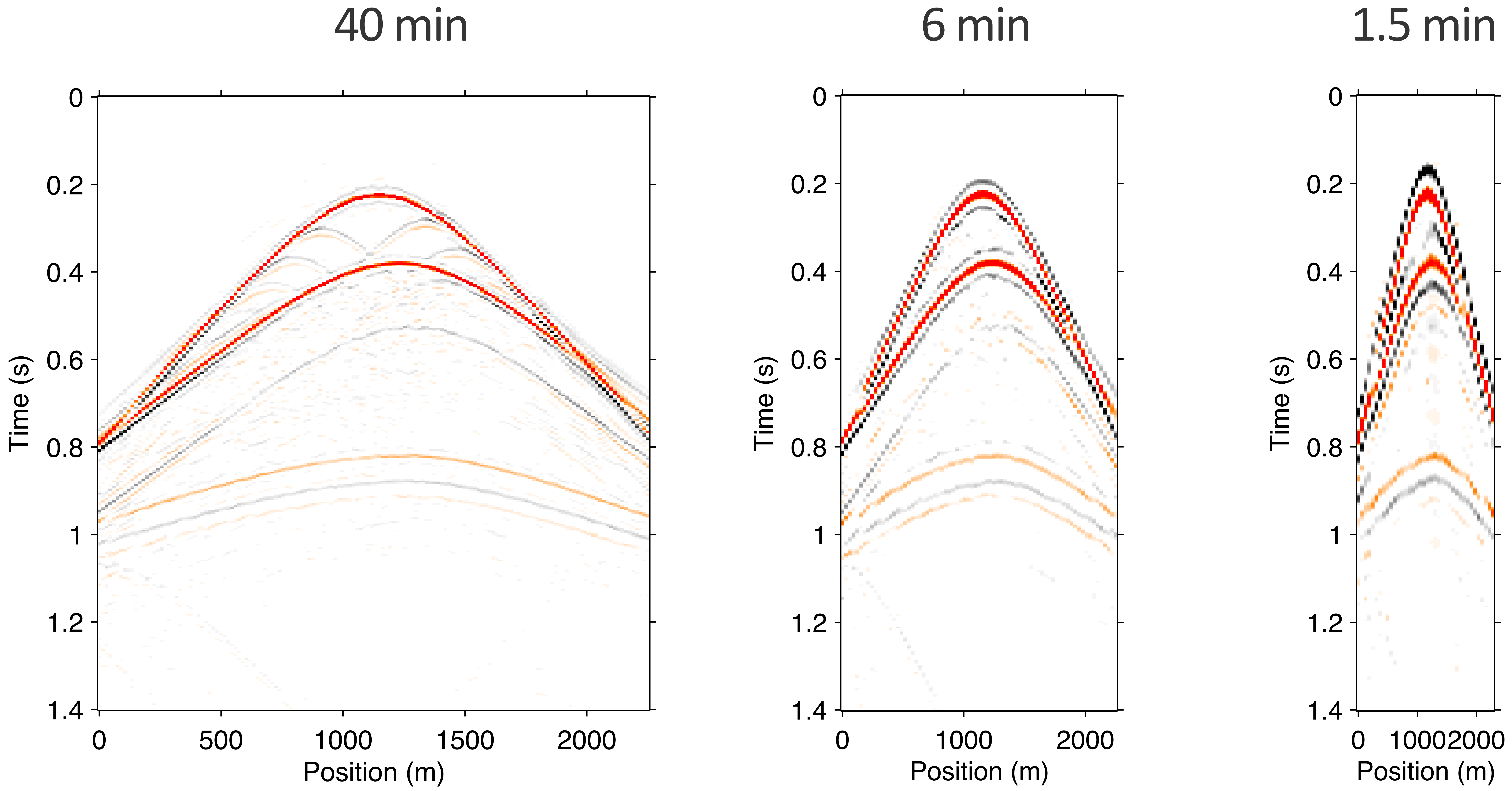

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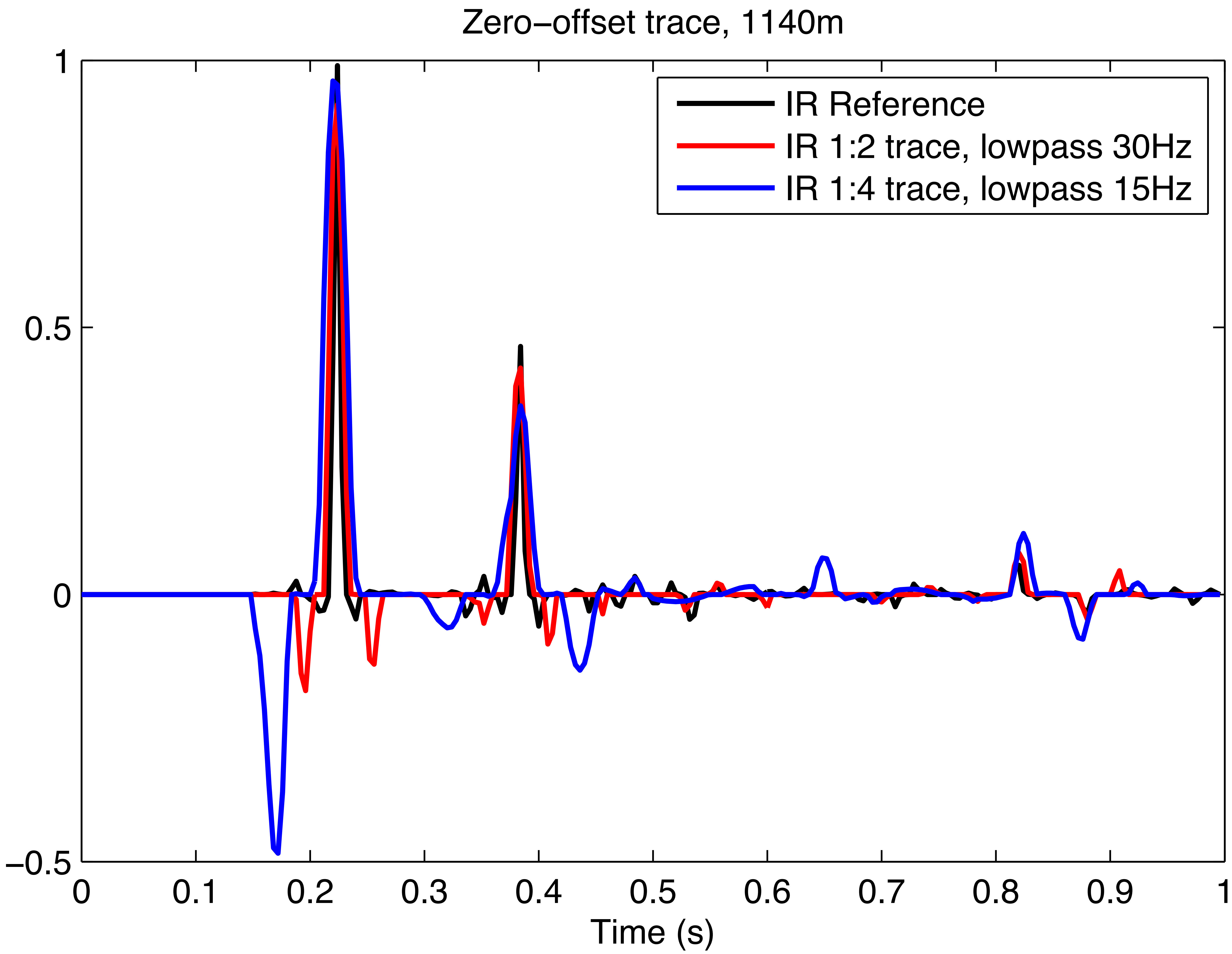
(low-pass in temporal frequency)



Idea 2: Warm-start with coarse data solutions

Since decimated datasets solve much faster, we use its (slightly inaccurate) results to replace early estimates to full problem

Initial τ_k (one-norm constraint) of full problem obtained by interpolating coarse solution, calculate one-norm, then scale back by some ratio

Previous Q is discarded

Interpolation method of G not important, just can't alias

Simple constant NMO (i.e., at water velocity) + linear interpolation works fine

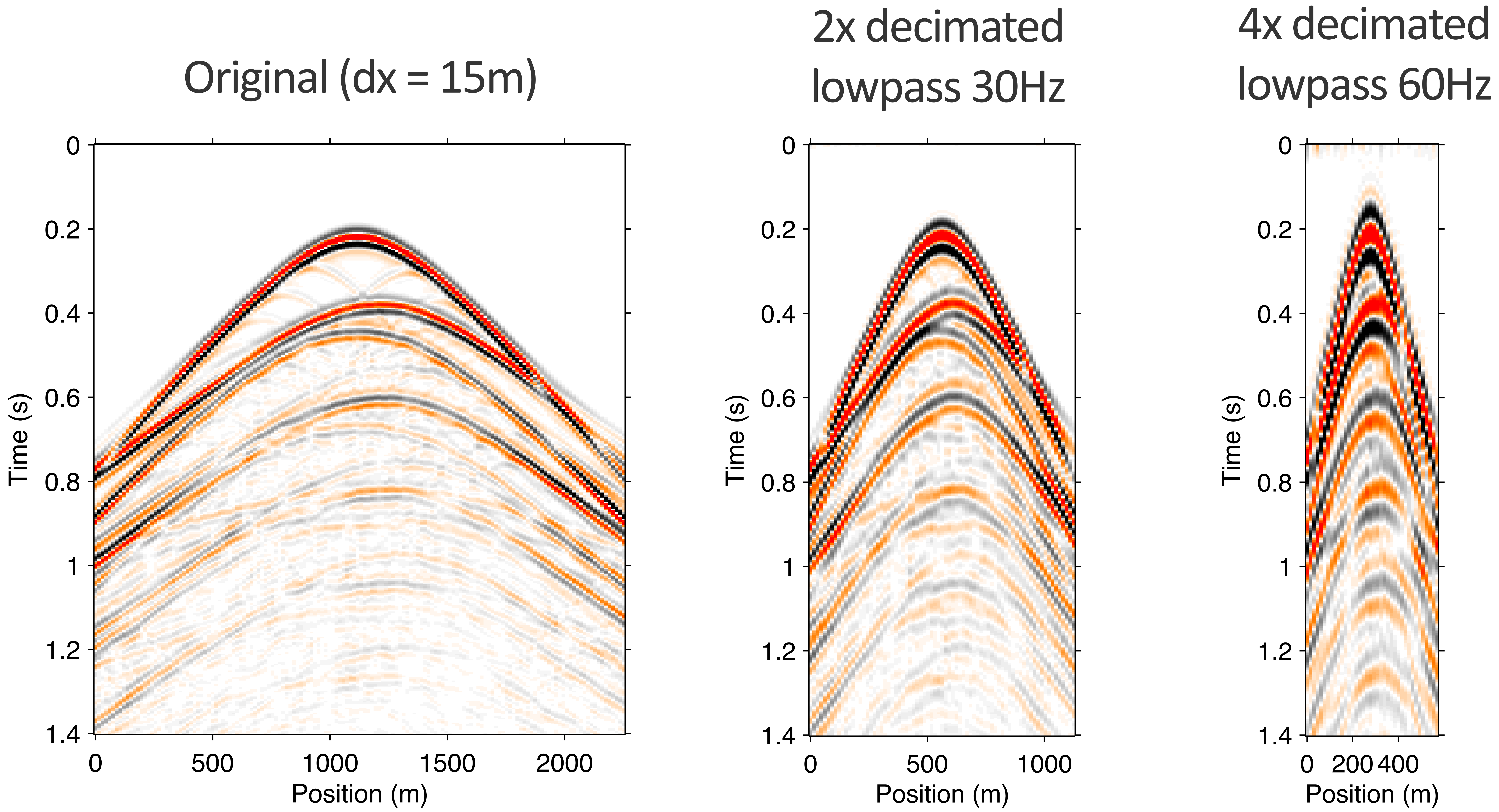
By the way...

If you hear any of these:

MNO
Animo
Animal
Asimov
Nemo
Anemone
Eminem
M&M's
Nominal
Dominos
Ememo
Wrarar
Waka-waka

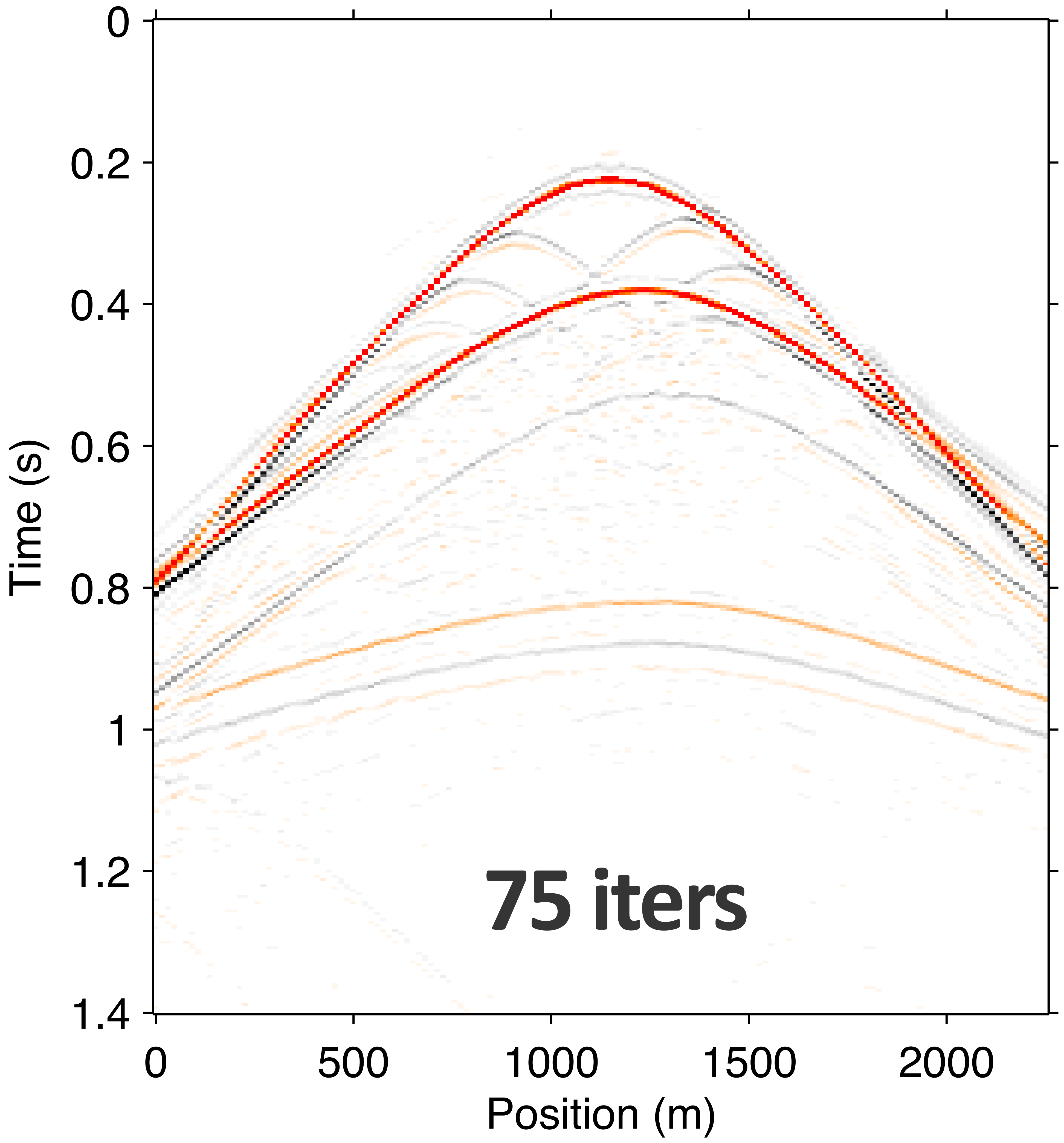
it's just me trying to say: **NMO** (very badly)

Warm-starting/continuation from coarse solution
Example

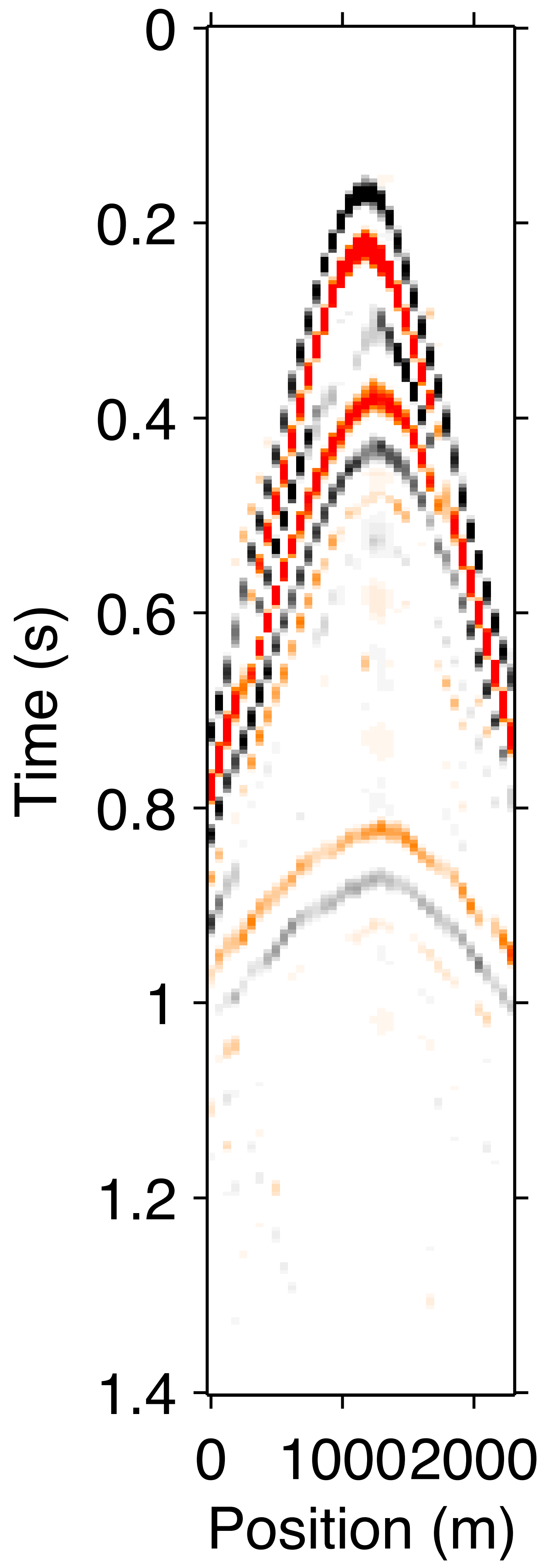


Warm-starting/continuation from coarse solution
Example

Solution of full data



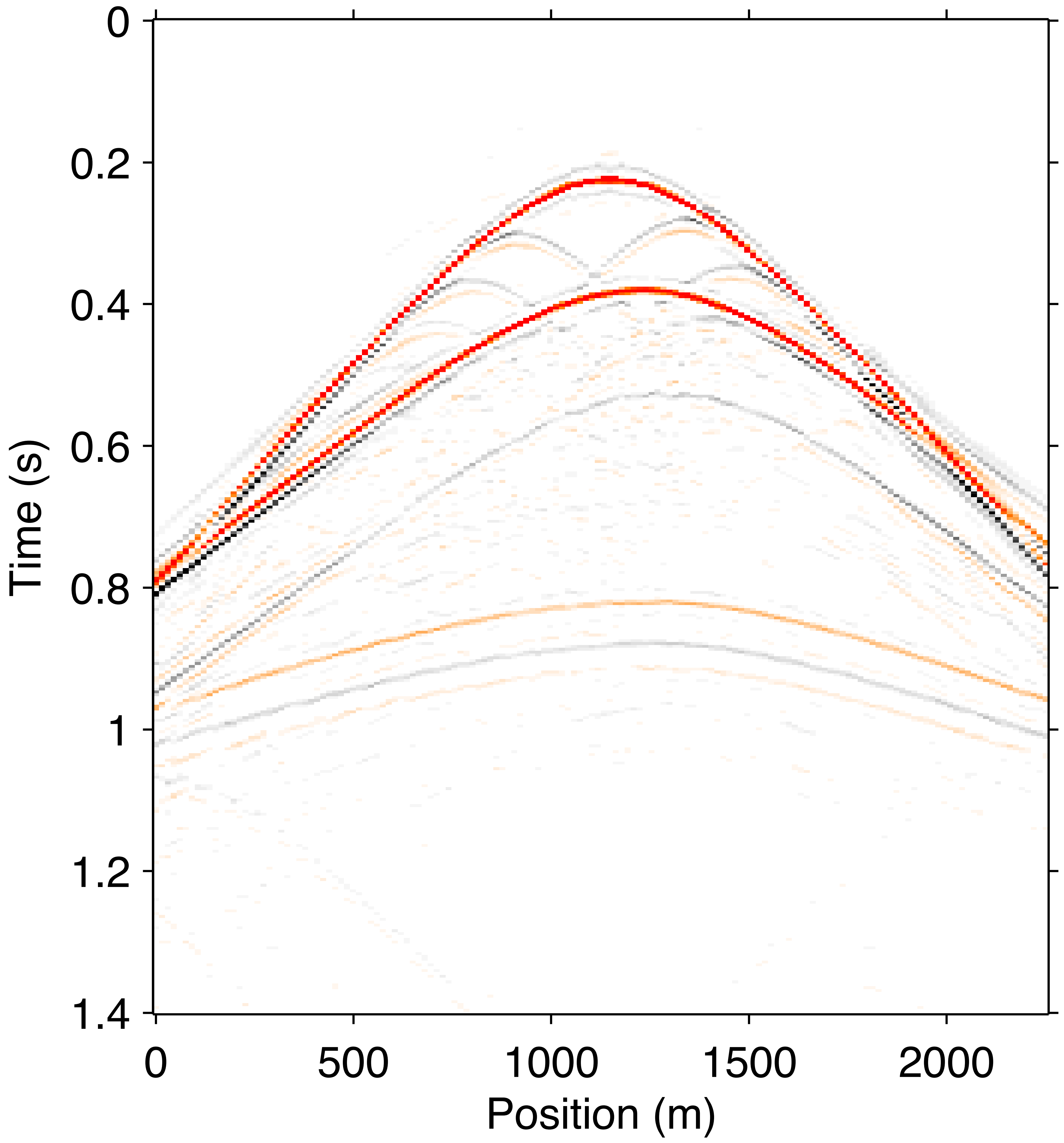
Solution of 4x decimated data



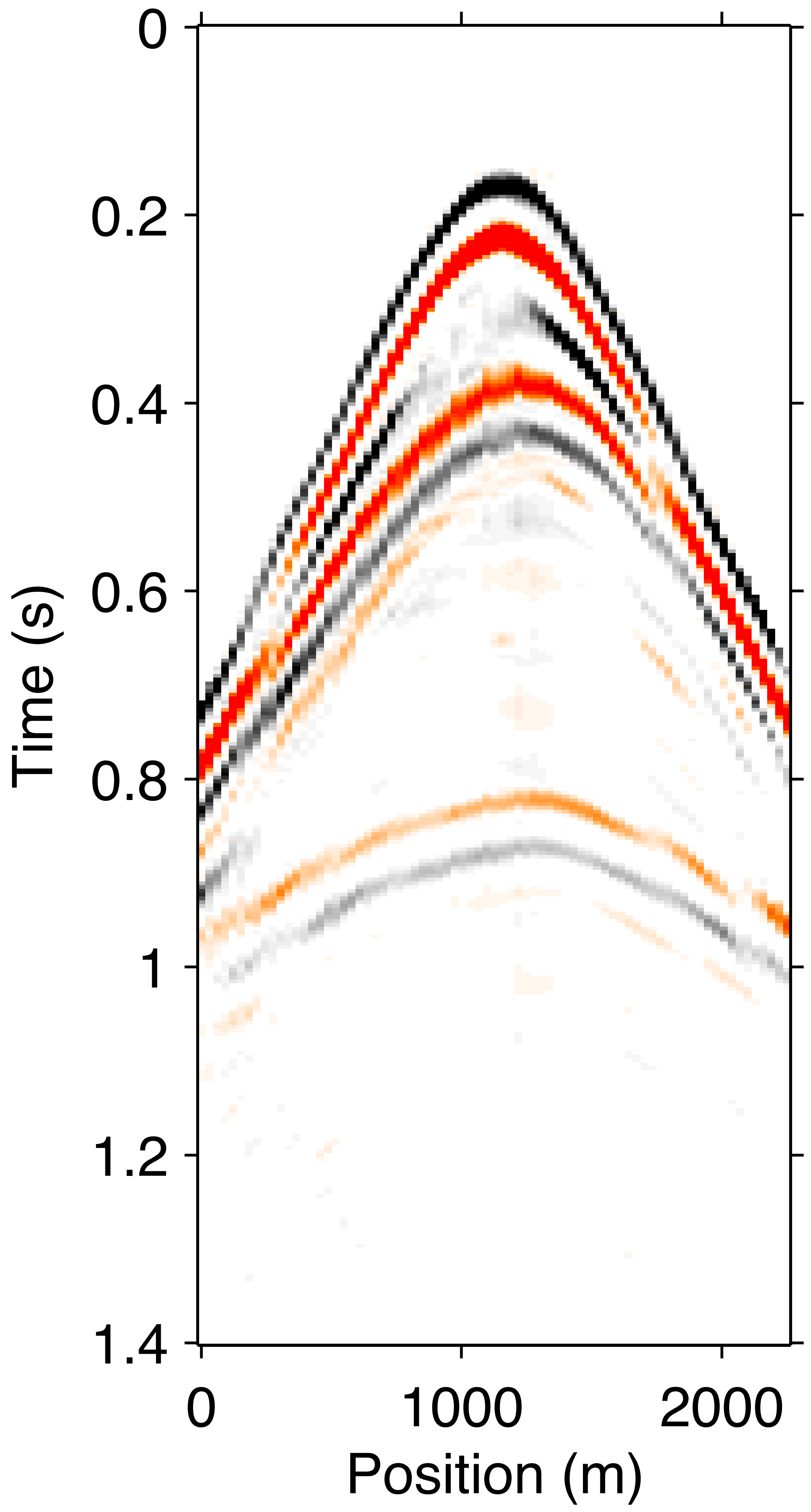
60 iters

Warm-starting/continuation from coarse solution
Example

Solution of full data



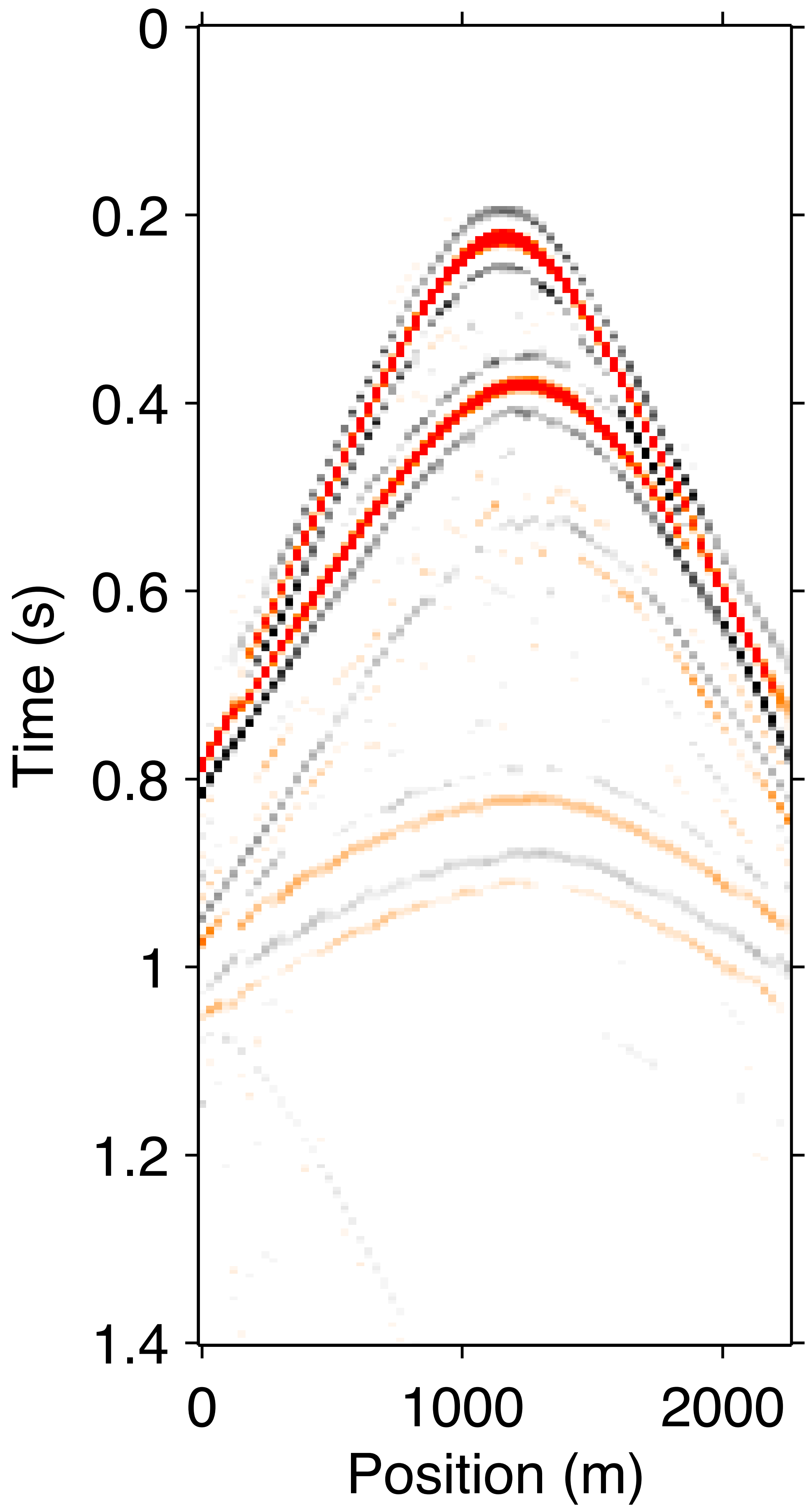
Solution of 4x decimated data
constant NMO linear interp 2x



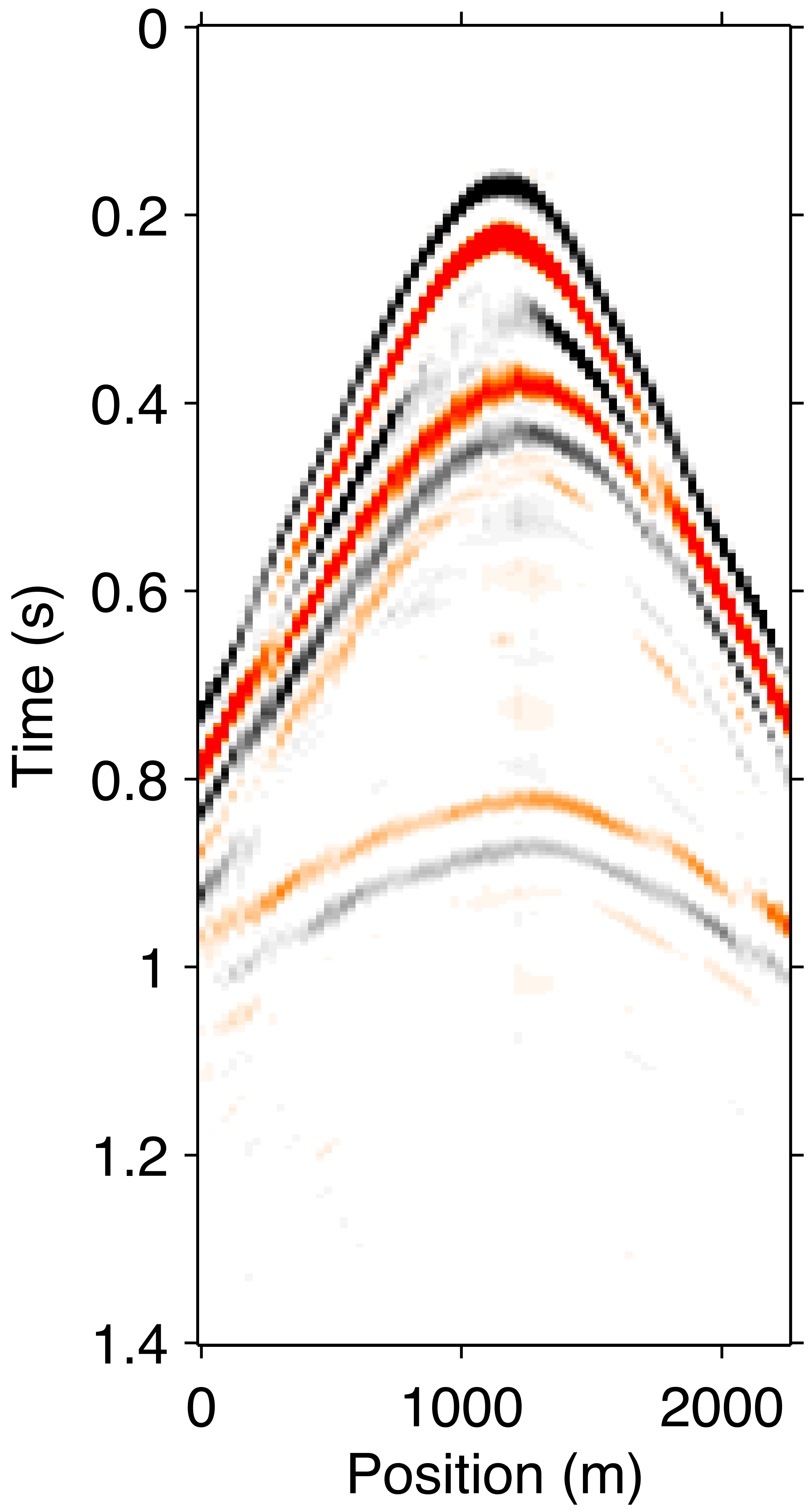
Warm-starting/continuation from coarse solution

Example

Solution of 2x decimated data

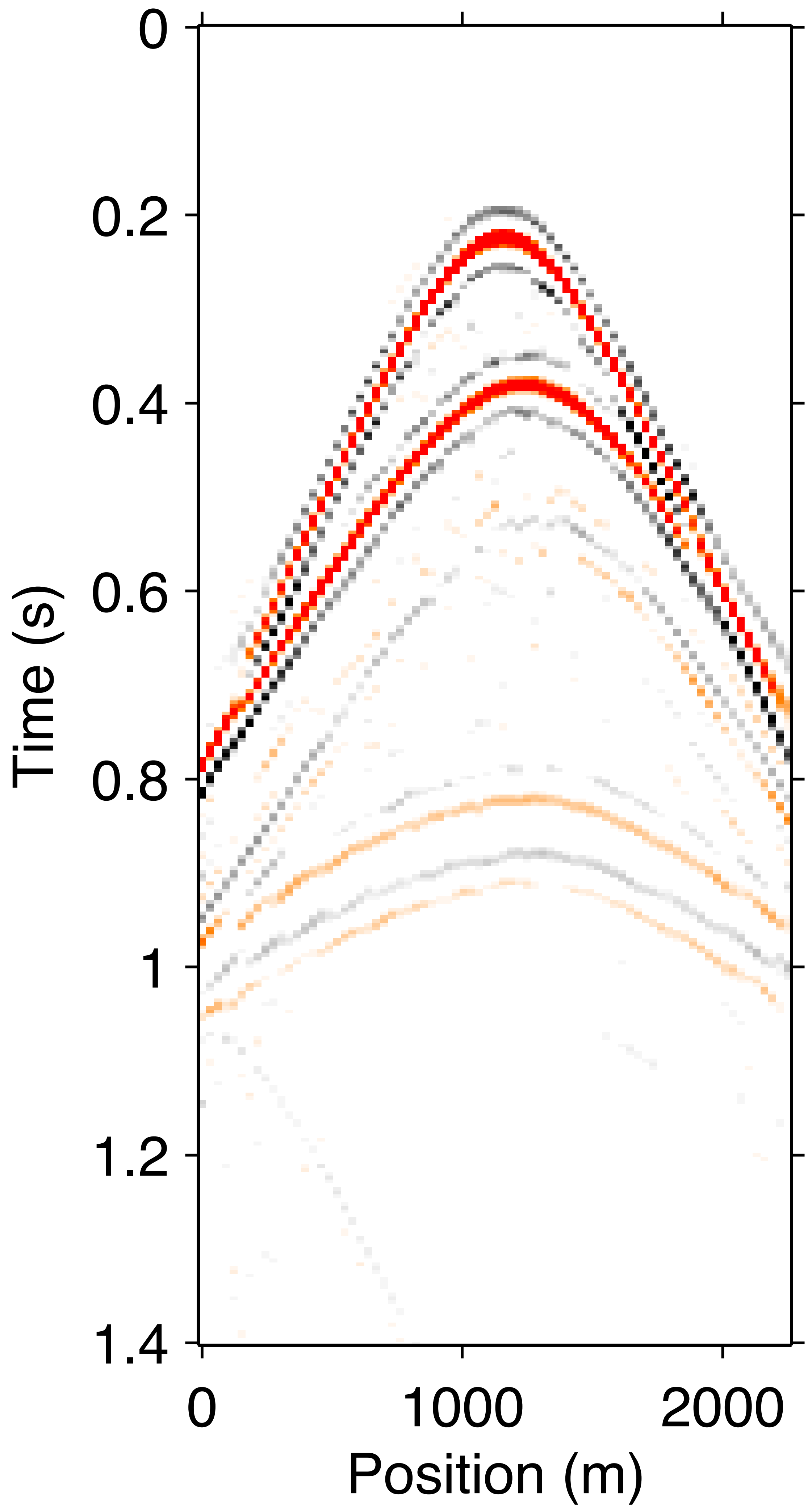


Solution of 4x decimated data
constant NMO linear interp 2x

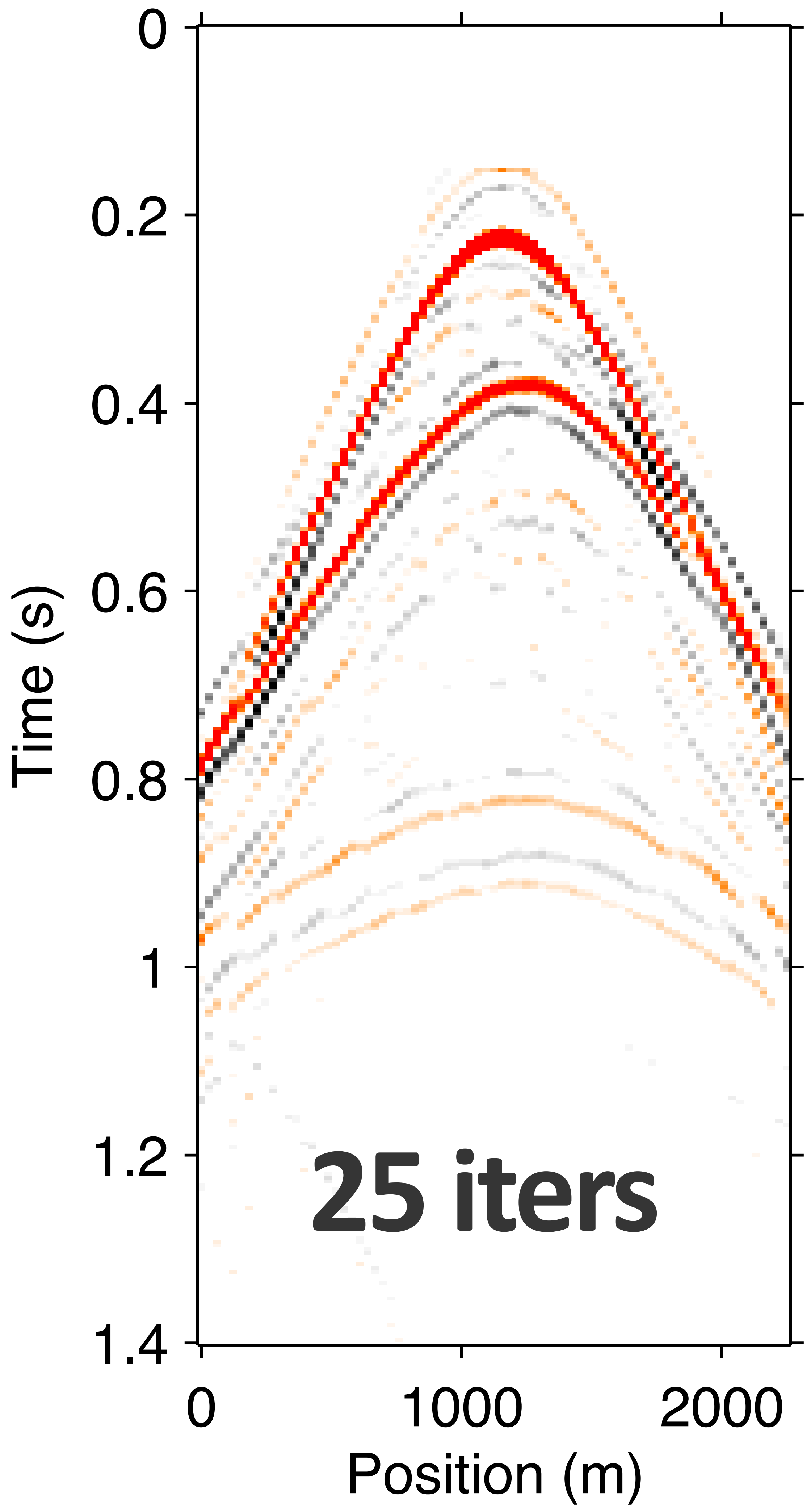


Warm-starting/continuation from coarse solution
Example

Solution of 2x decimated data

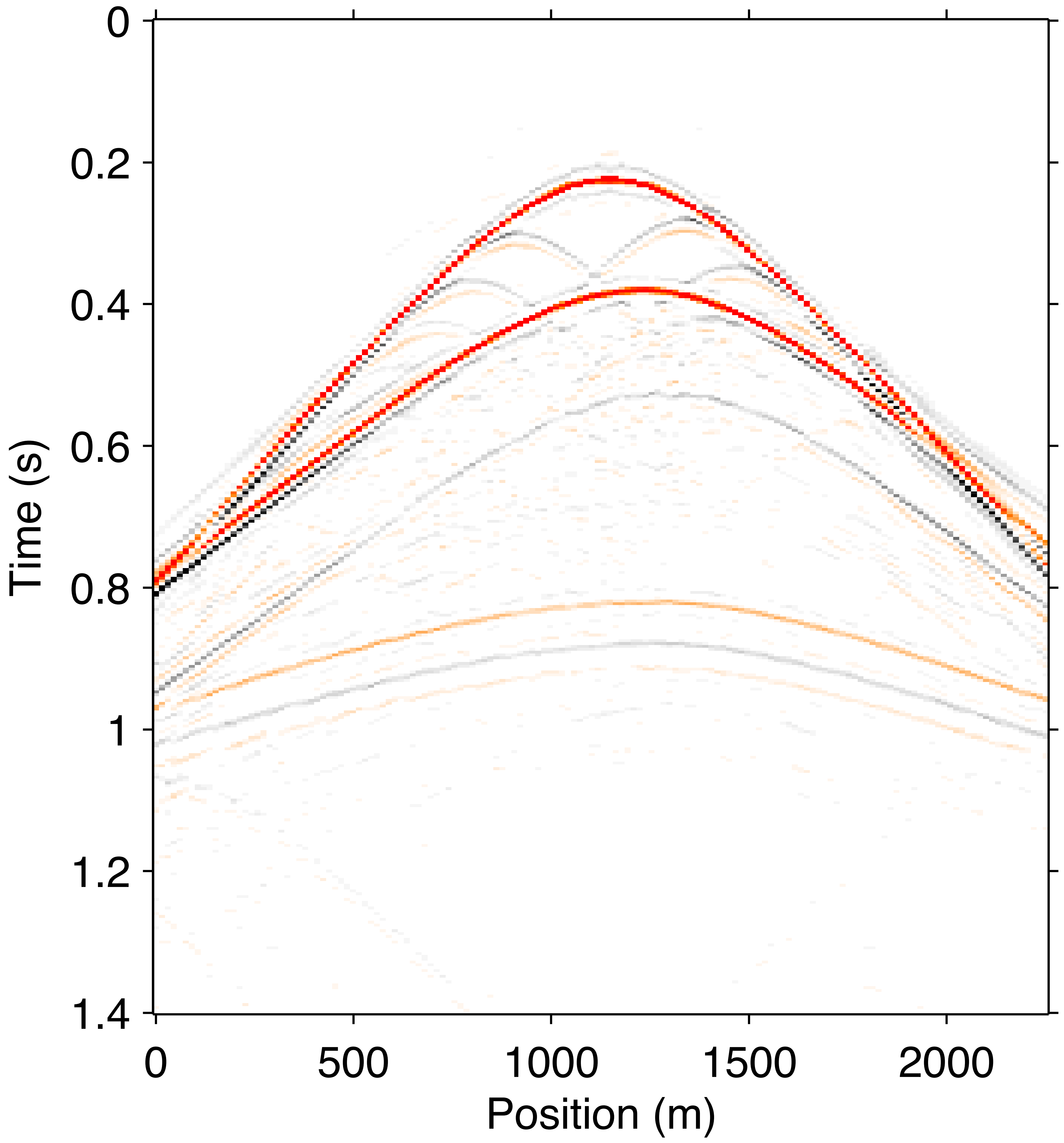


Solution on 2x dec data
continuation from 4x dec solution

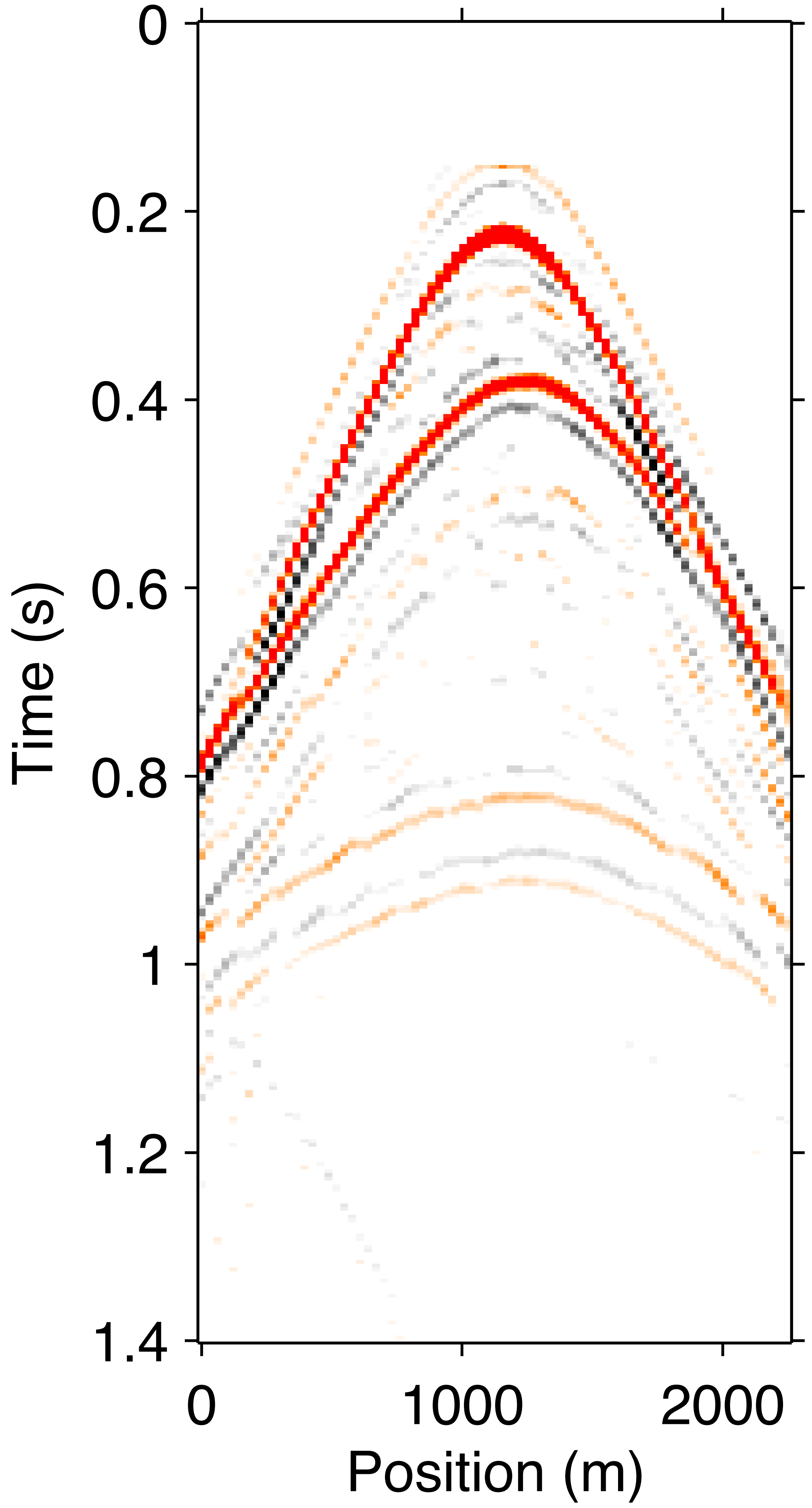


Warm-starting/continuation from coarse solution
Example

Solution of full data



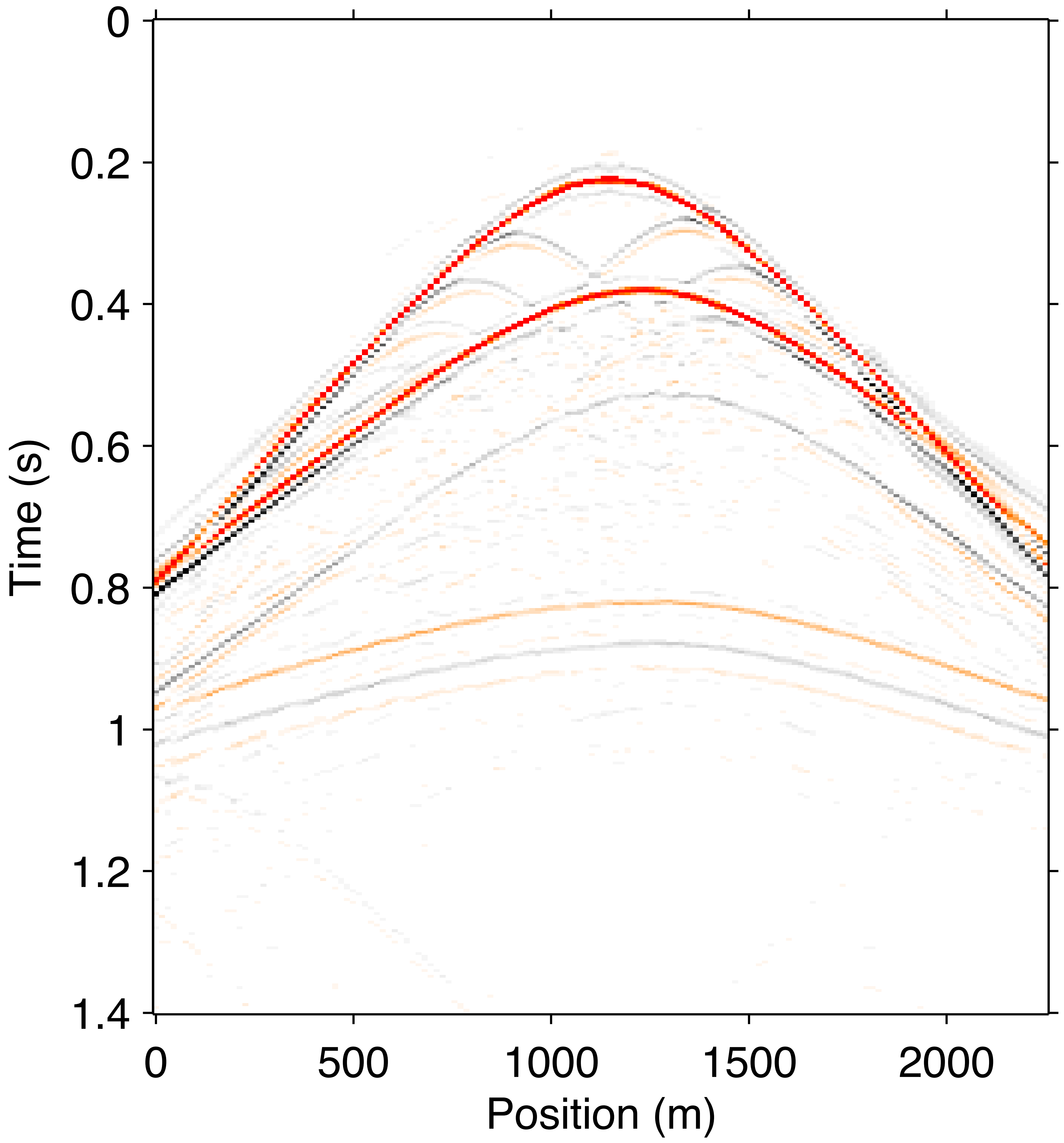
Solution on 2x dec data
continuation from 4x dec solution



Warm-starting/continuation from coarse solution

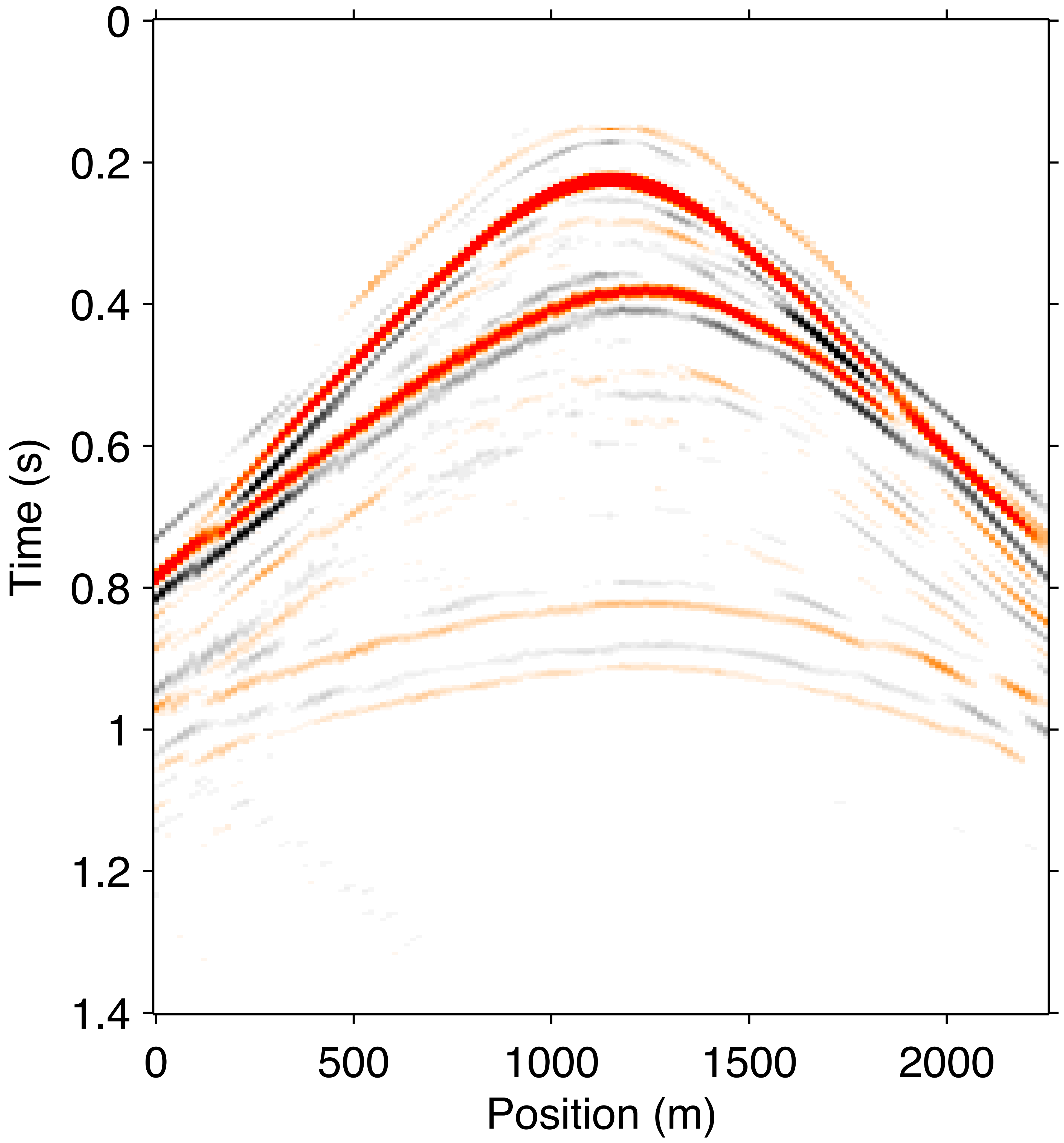
Example

Solution of full data



Solution on 2x dec data > interp 2x

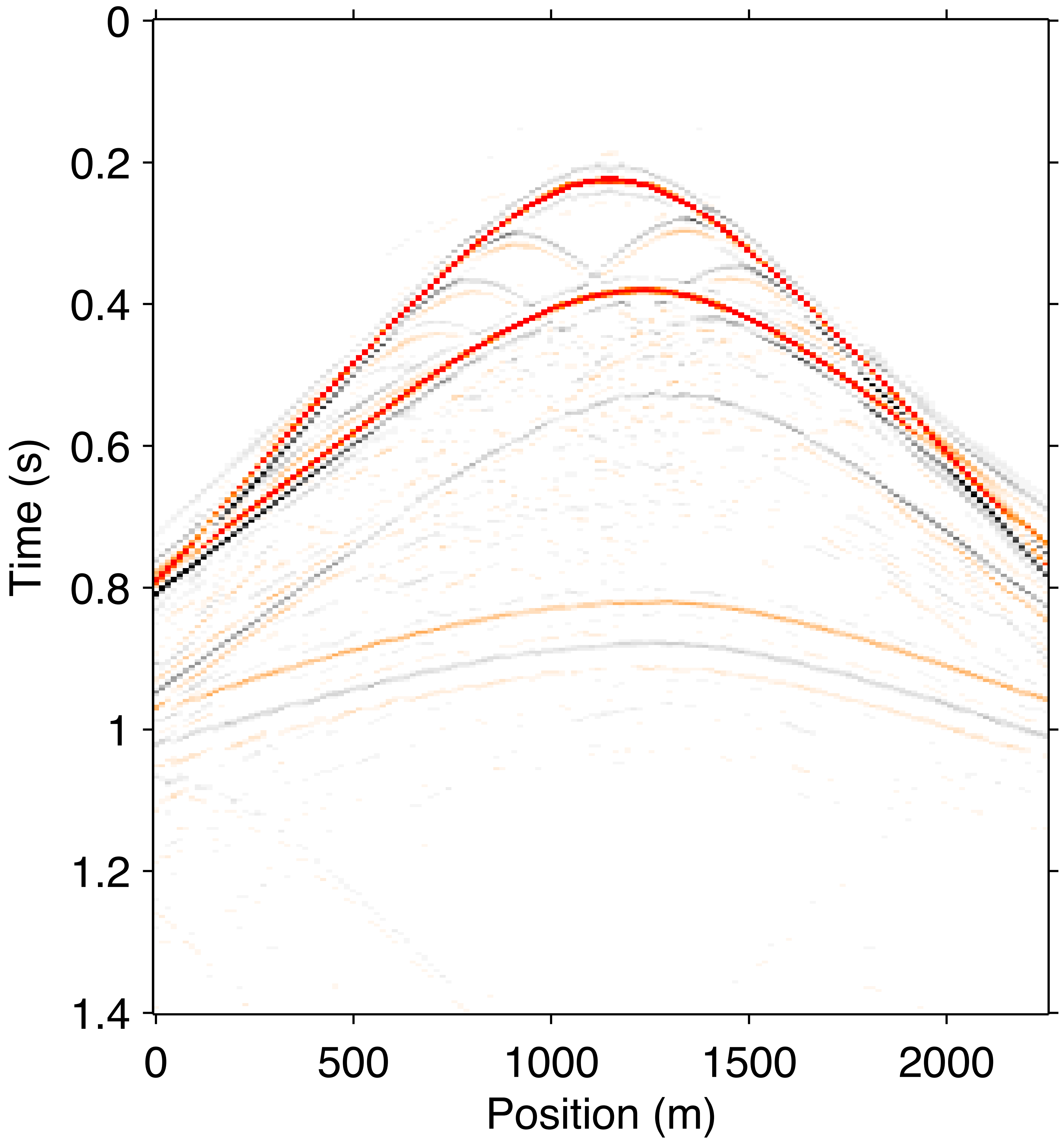
continuation from 4x dec solution



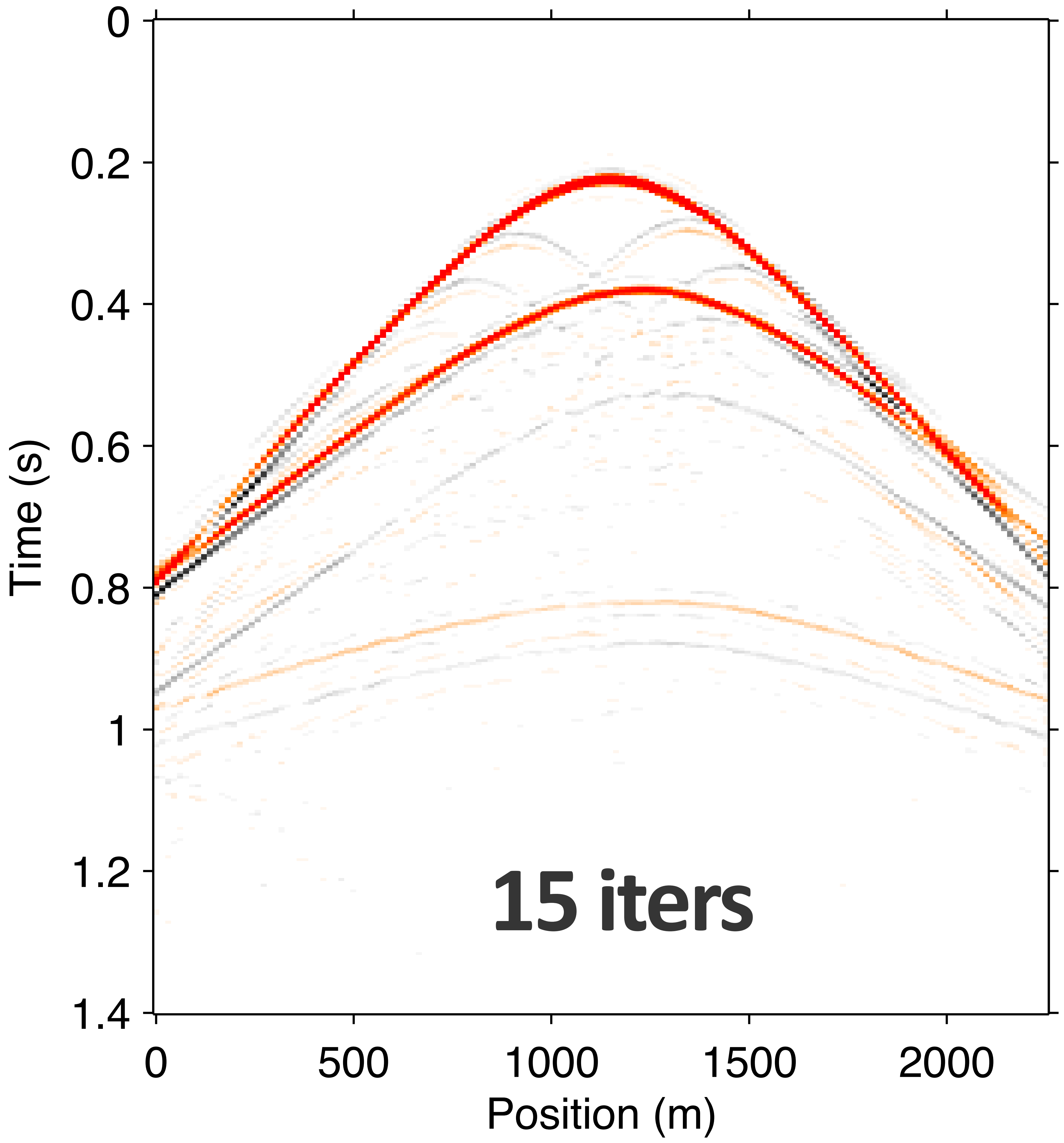
Warm-starting/continuation from coarse solution

Example

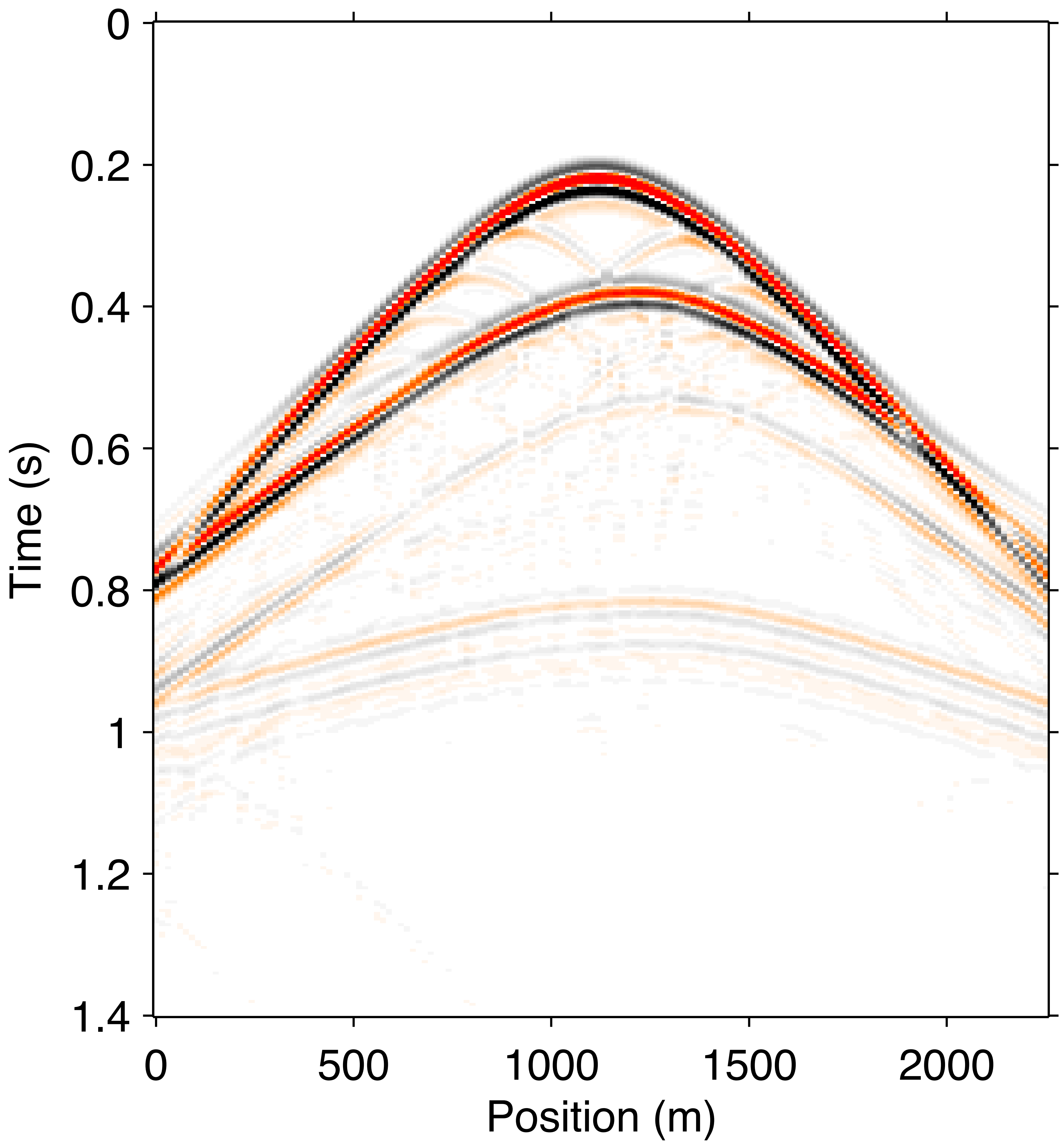
Solution of full data



Solution on 2x dec data > interp 2x
continuation from 4x thru 2x solution

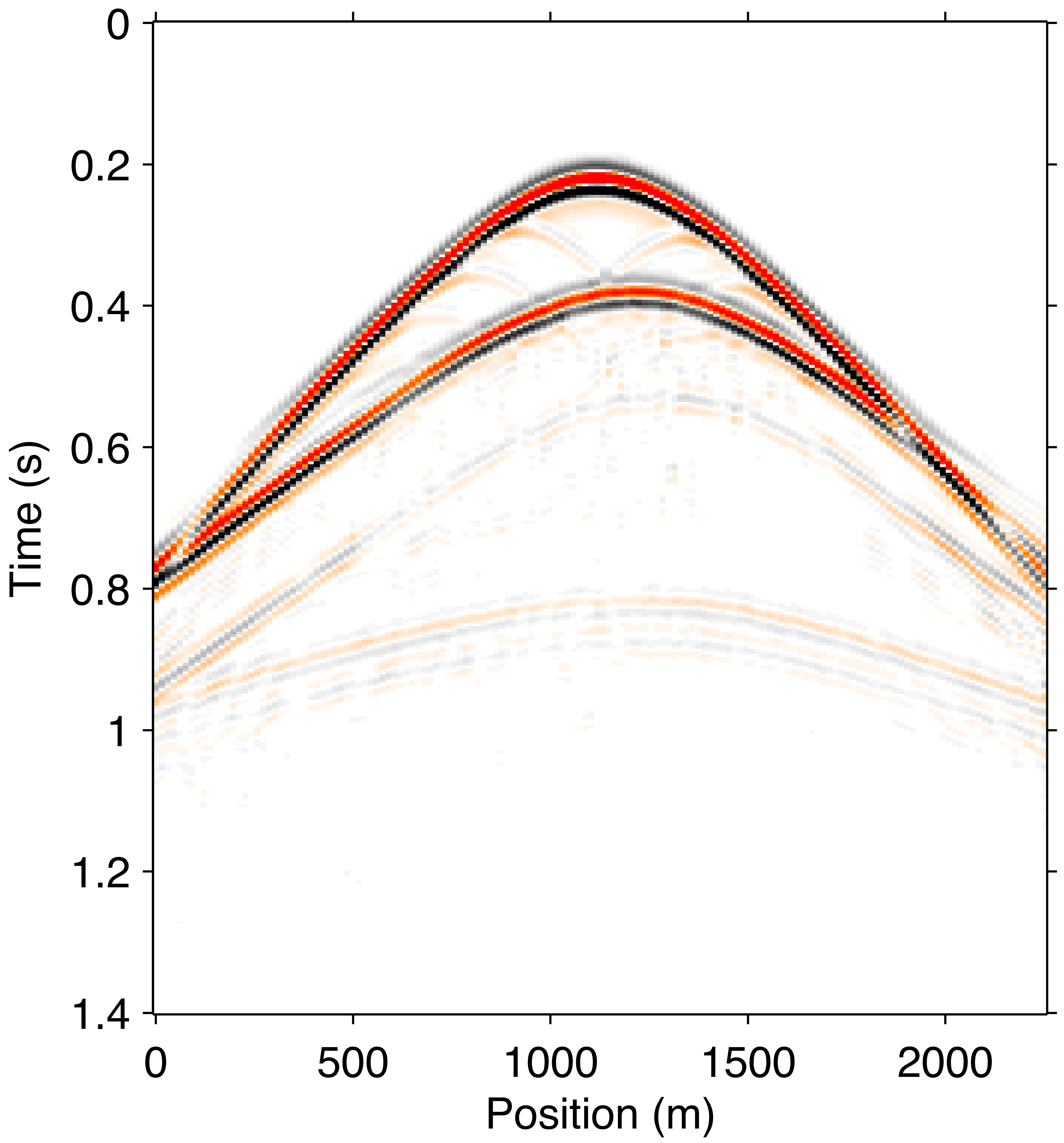


Warm-starting/continuation from coarse solution
Example



Direct Primary
Solved from full data

Warm-starting/continuation from coarse solution
Example

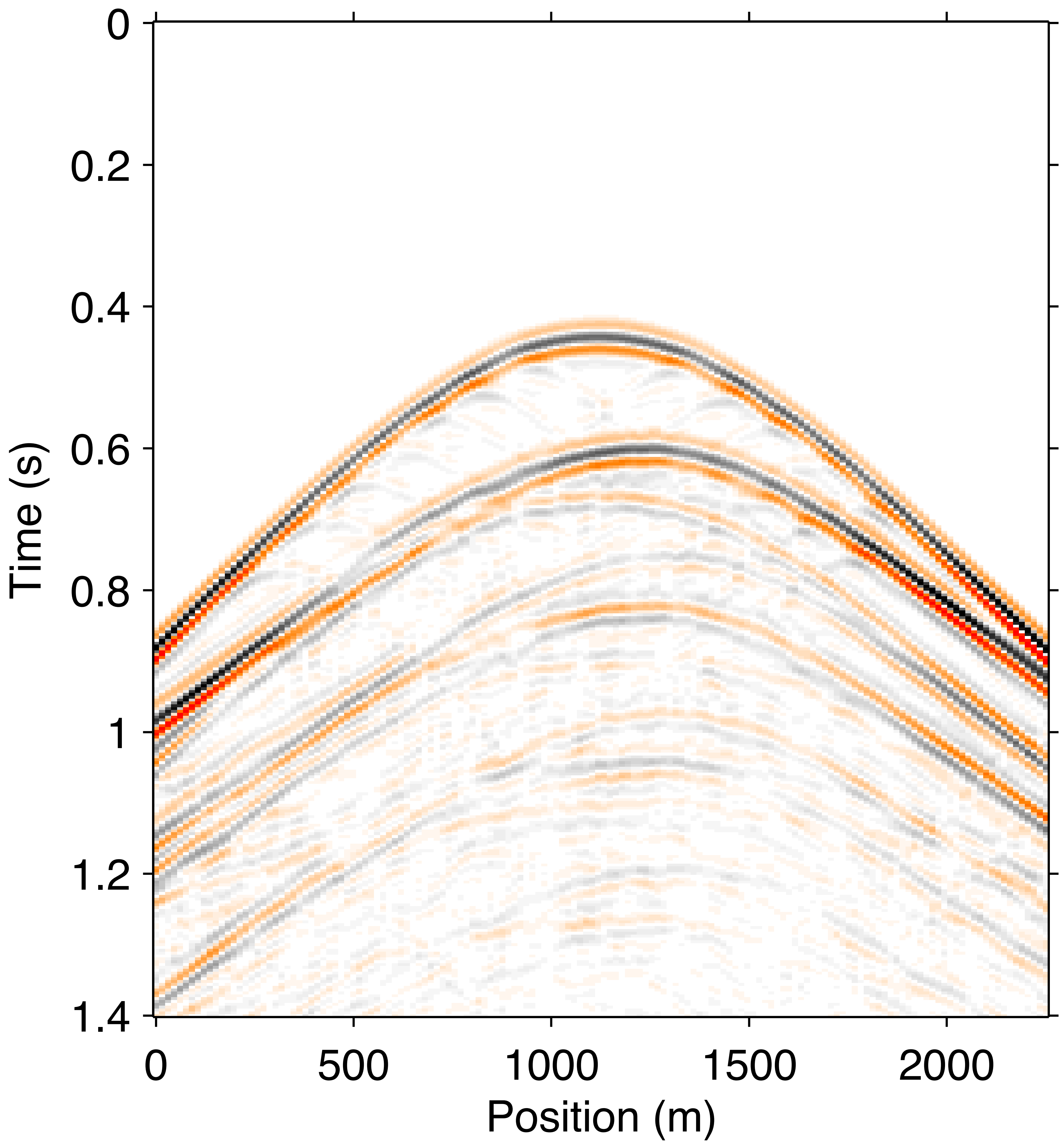


Direct Primary

Solved with spatial sampling continuation

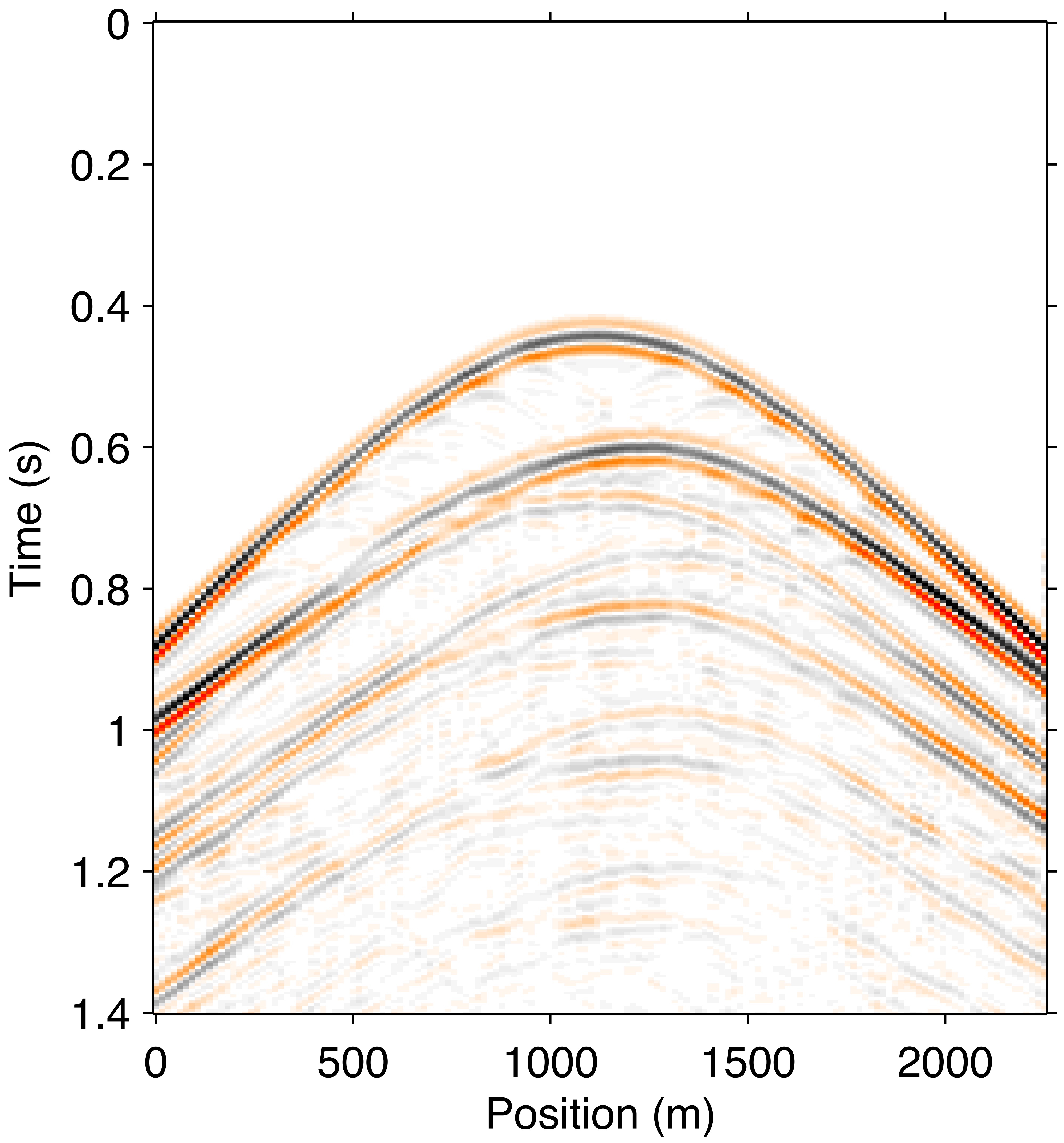
dx = 60m > 30m > 15m

Warm-starting/continuation from coarse solution
Example



REPSI Multiples
Solved from full data

Warm-starting/continuation from coarse solution
Example



REPSI Multiples

Solved with spatial sampling continuation

dx = 60m > 30m > 15m

Significant speedup from bootstrapping

Per-iteration FLOPs cost (one forward/adjoint): $n = n_{\mathrm{rcv}} = n_{\mathrm{src}}$

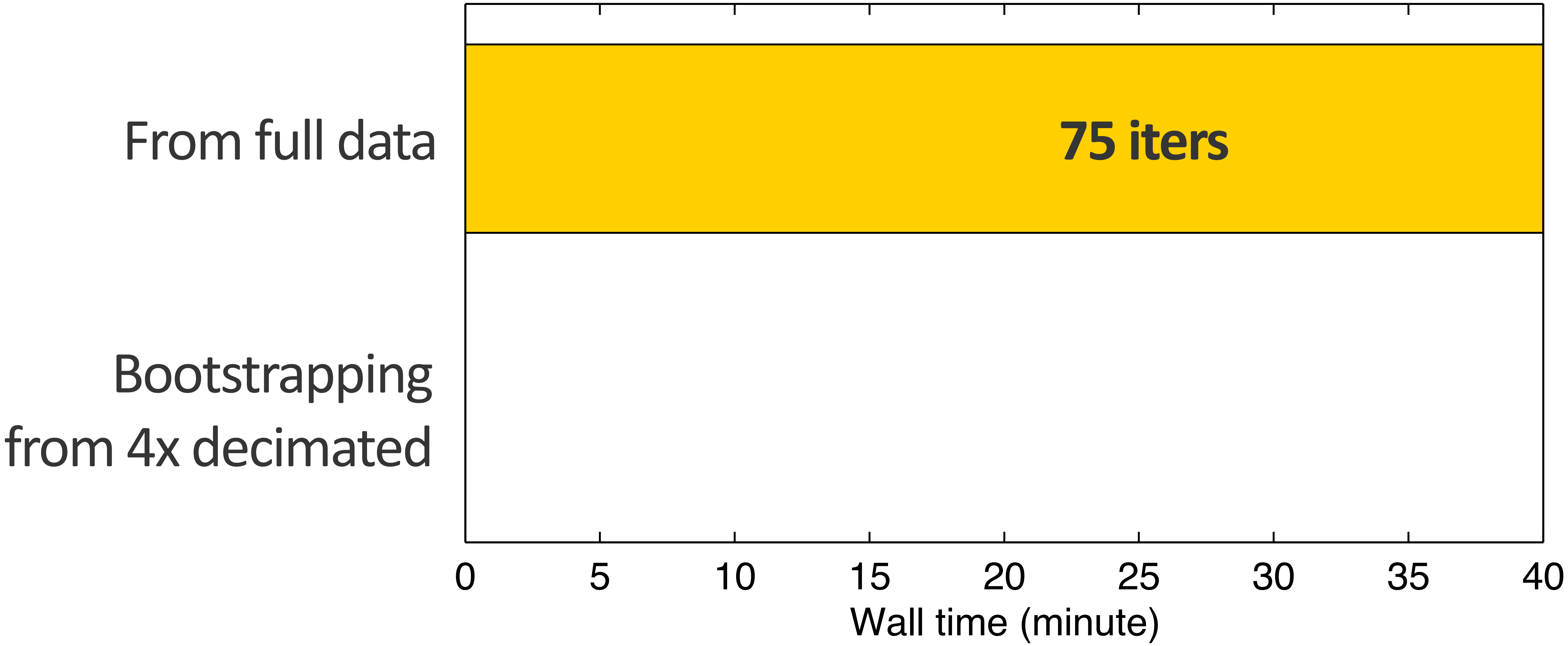
$$\text{Cost}(n) = \mathcal{O}(2n_t \log n_t n^2) + \mathcal{O}(n_t n^3)$$

2 times FFT — computing MCG & sum in FX

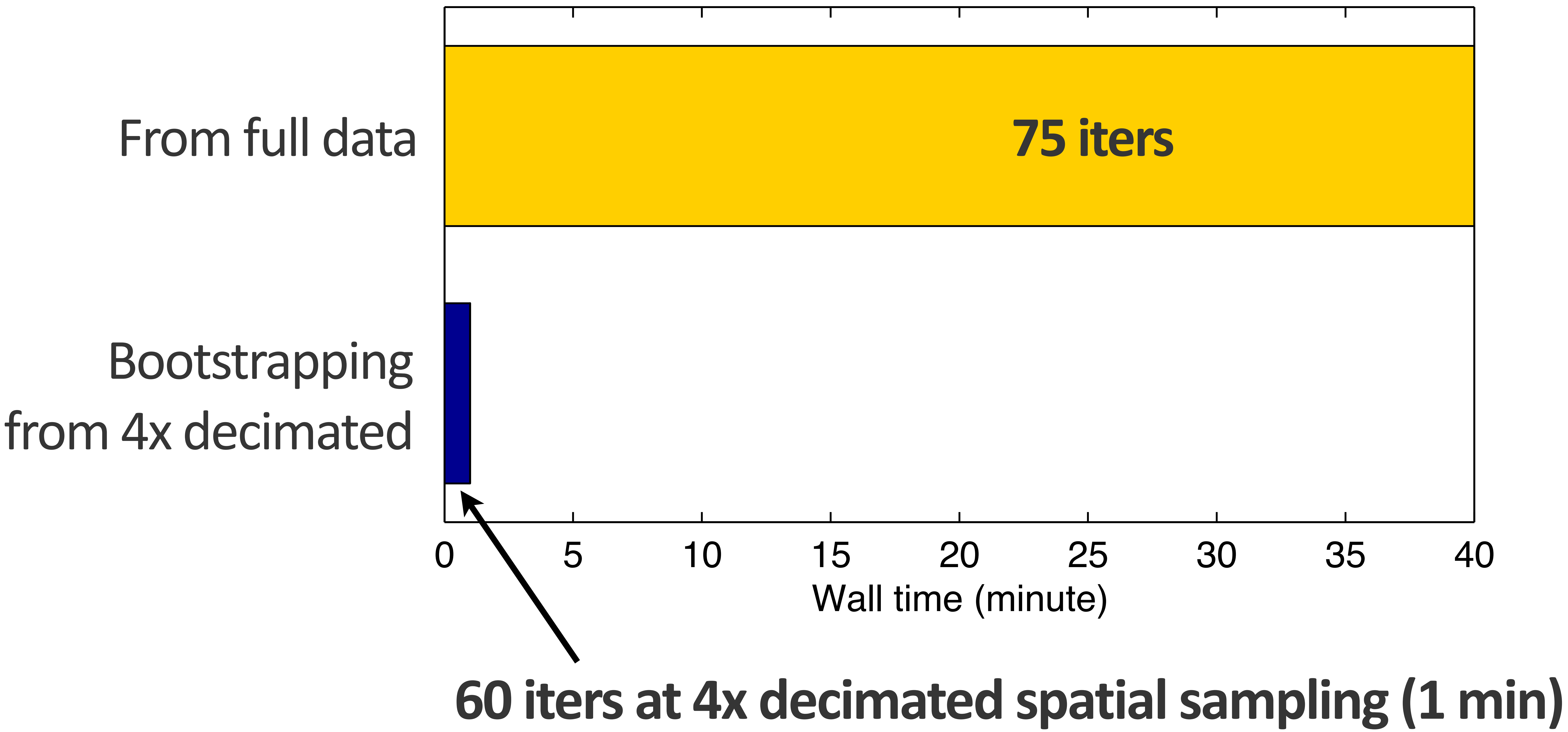
$$\text{Cost}\left(\frac{1}{2}n\right) = \frac{1}{4}\mathcal{O}(2n_t \log n_t n^2) + \frac{1}{8}\mathcal{O}(n_t n^3)$$

$$\text{Cost}\left(\frac{1}{4}n\right) = \frac{1}{16}\mathcal{O}(2n_t \log n_t n^2) + \frac{1}{64}\mathcal{O}(n_t n^3)$$

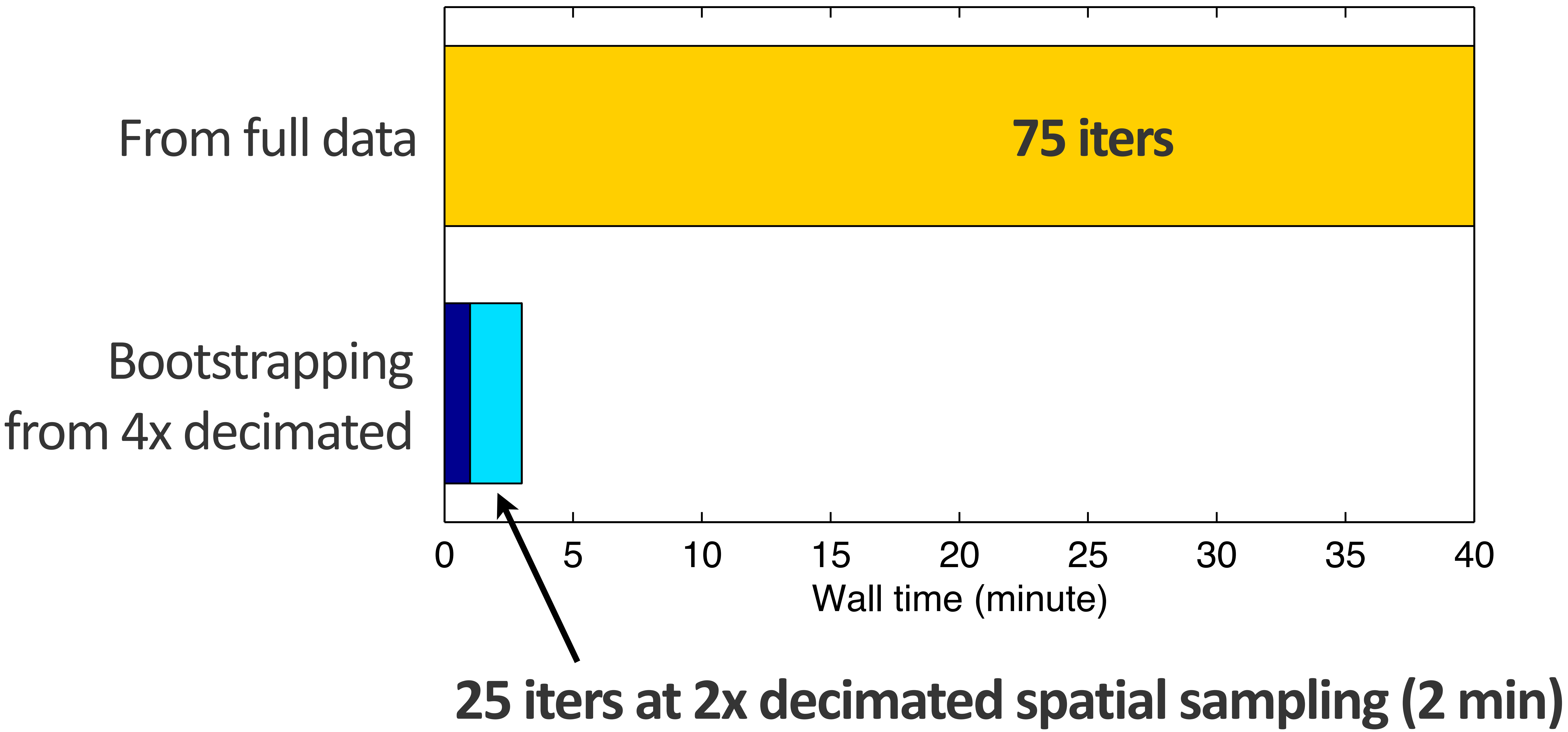
Significant speedup from bootstrapping
Wall times



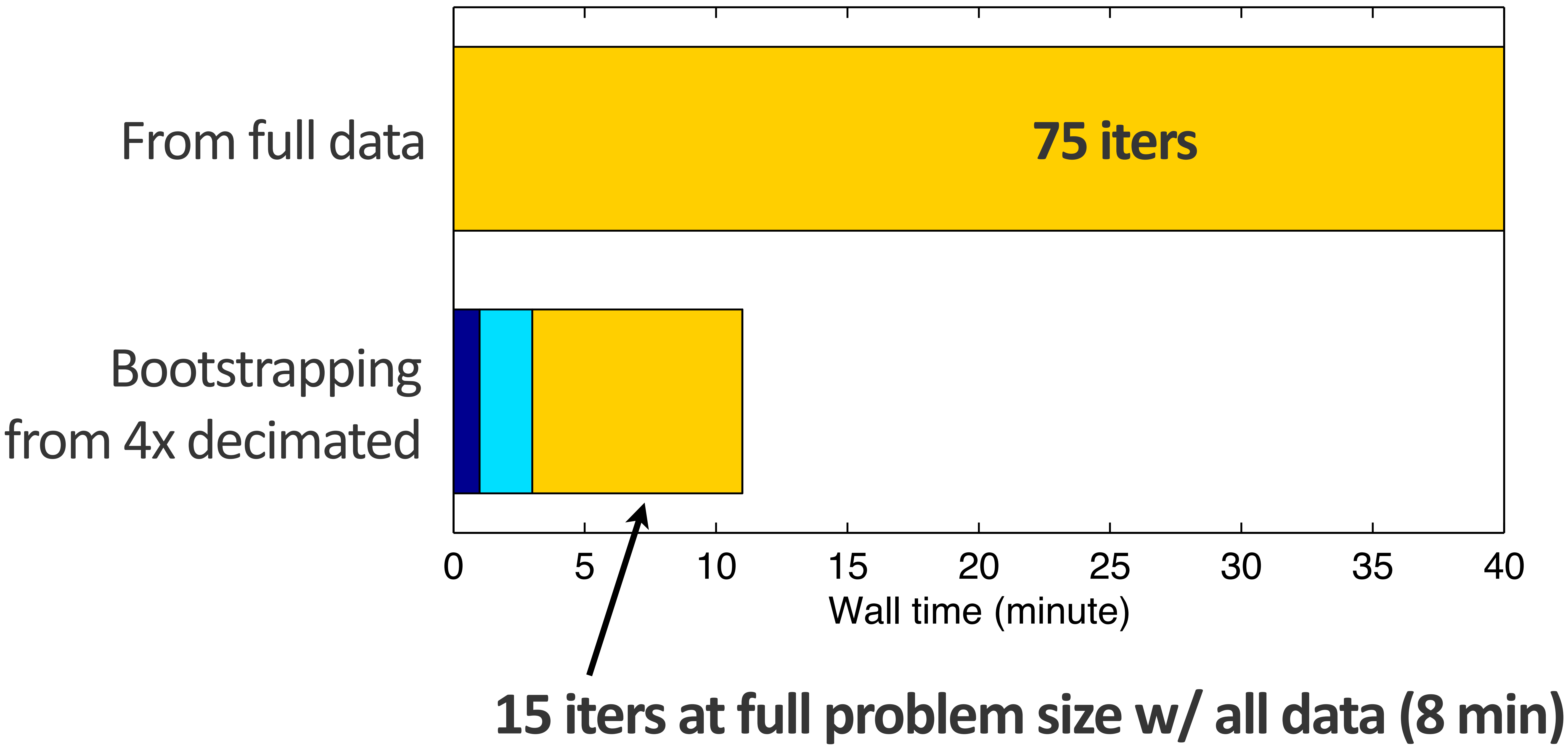
Significant speedup from bootstrapping
Wall times



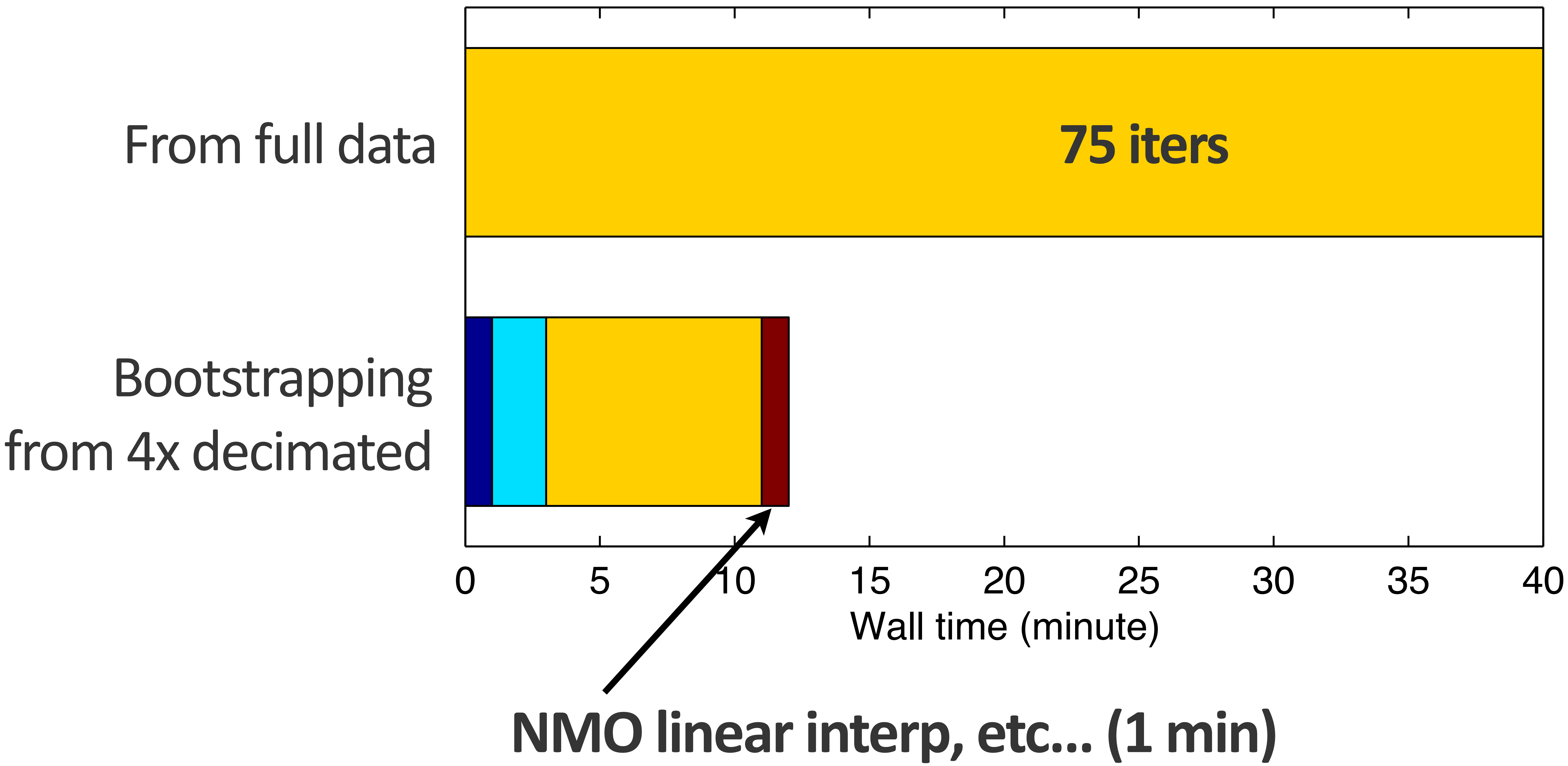
Significant speedup from bootstrapping
Wall times



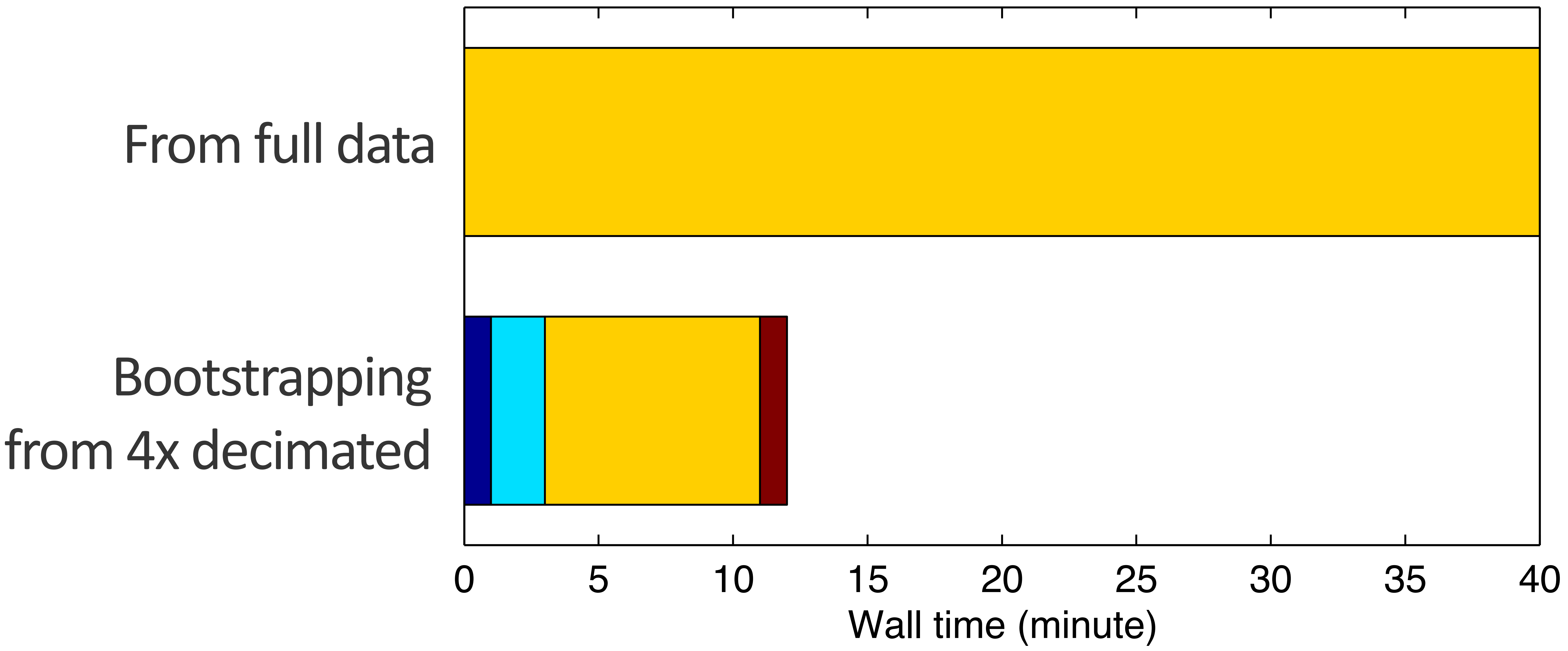
Significant speedup from bootstrapping
Wall times



Significant speedup from bootstrapping
Wall times



Significant speedup from bootstrapping
Wall times



Bootstrapping

application to under-sampled data

Robust EPSI
With updates to unknown data

While $\|\mathbf{p}_k - \mathcal{M}(\mathbf{g}_k, \mathbf{q}_k)\|_2 > \sigma$

determine new τ_k from the Pareto curve

$$\mathbf{g}_{k+1} = \arg\min_{\mathbf{g}} \|\mathbf{p}_k - \mathbf{M}_{q_k}\mathbf{g}\|_2 \text{ s.t. } \|\mathbf{g}\|_1 \leq \tau_k$$

(Solve with SPG part of SPGL1 until Pareto curve reached)

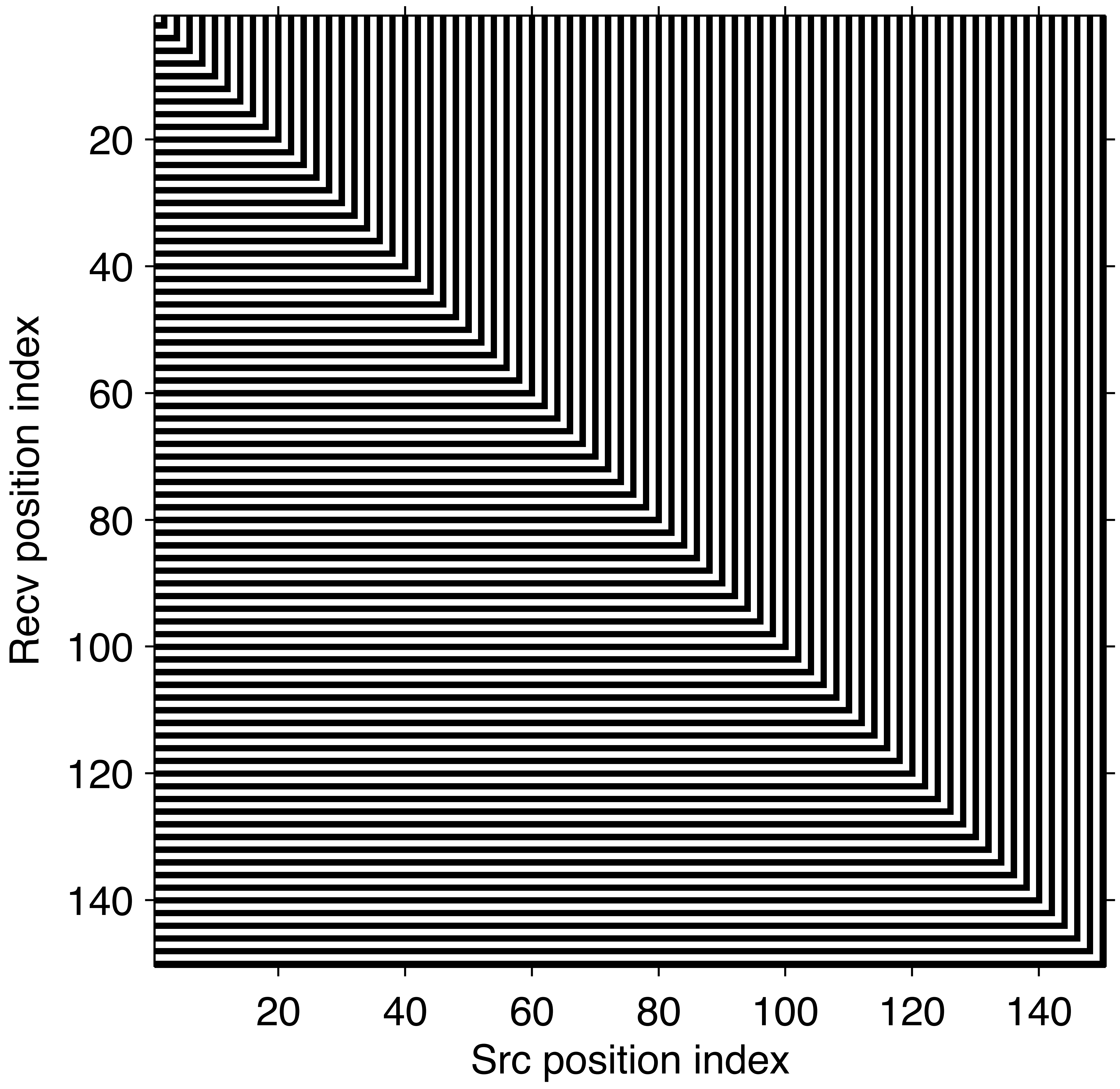
$$\mathbf{q}_{k+1} = \arg\min_{\mathbf{q}} \|\mathbf{p}_k - \mathbf{M}_{g_{k+1}}\mathbf{q}\|_2$$

(Solve with LSQR)

$$\mathbf{p}_{k+1} = \mathbf{p}_k + \alpha\Delta\mathbf{p}(\mathbf{g}_{k+1}, \mathbf{q}_{k+1}, \mathbf{p}_k)$$

(Gradient update on data)

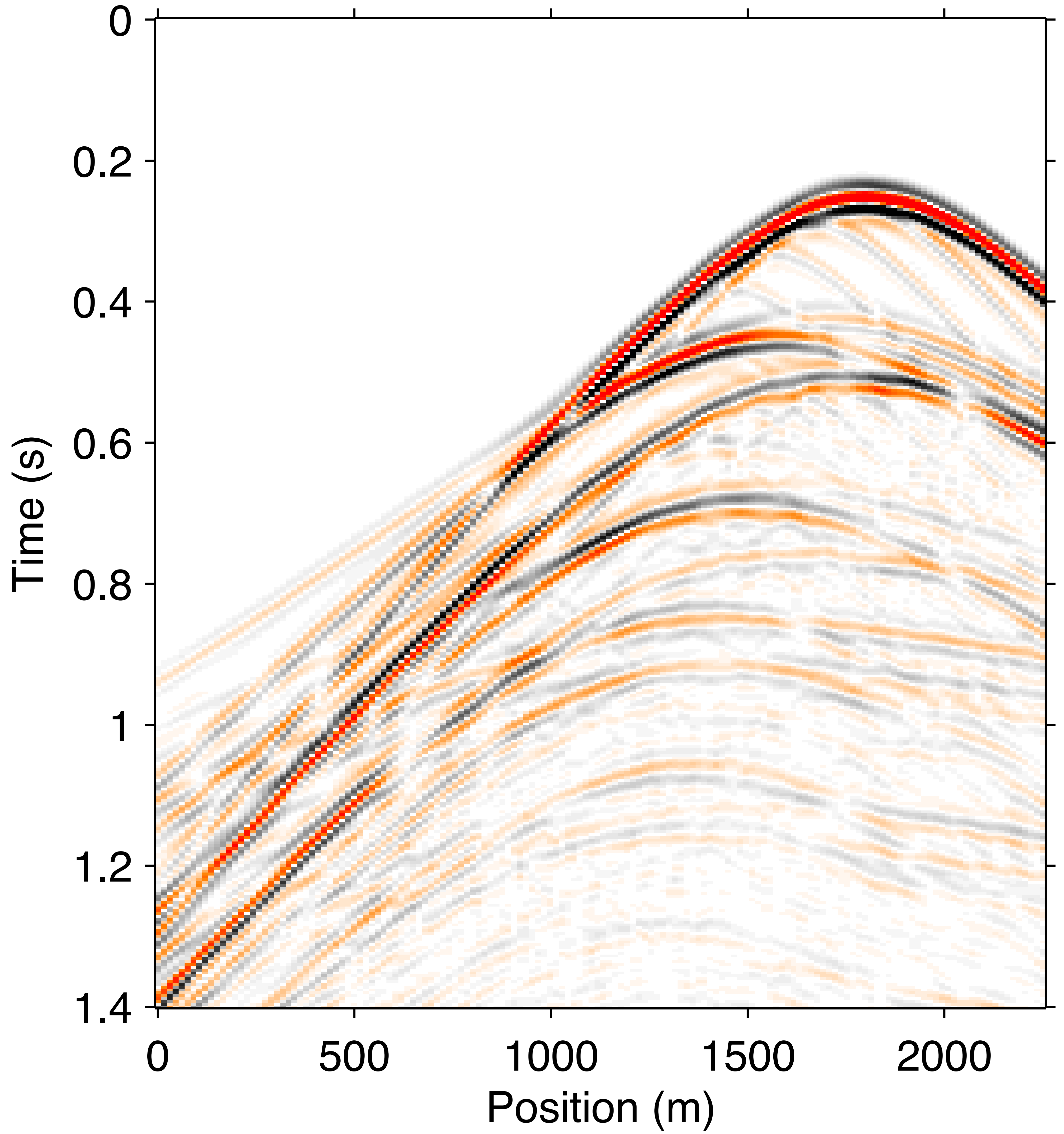
REPSI with 2:1 source undersampling



Trace mask
dRecv 15m
dSrc 30m
(assuming streamer acquisition)

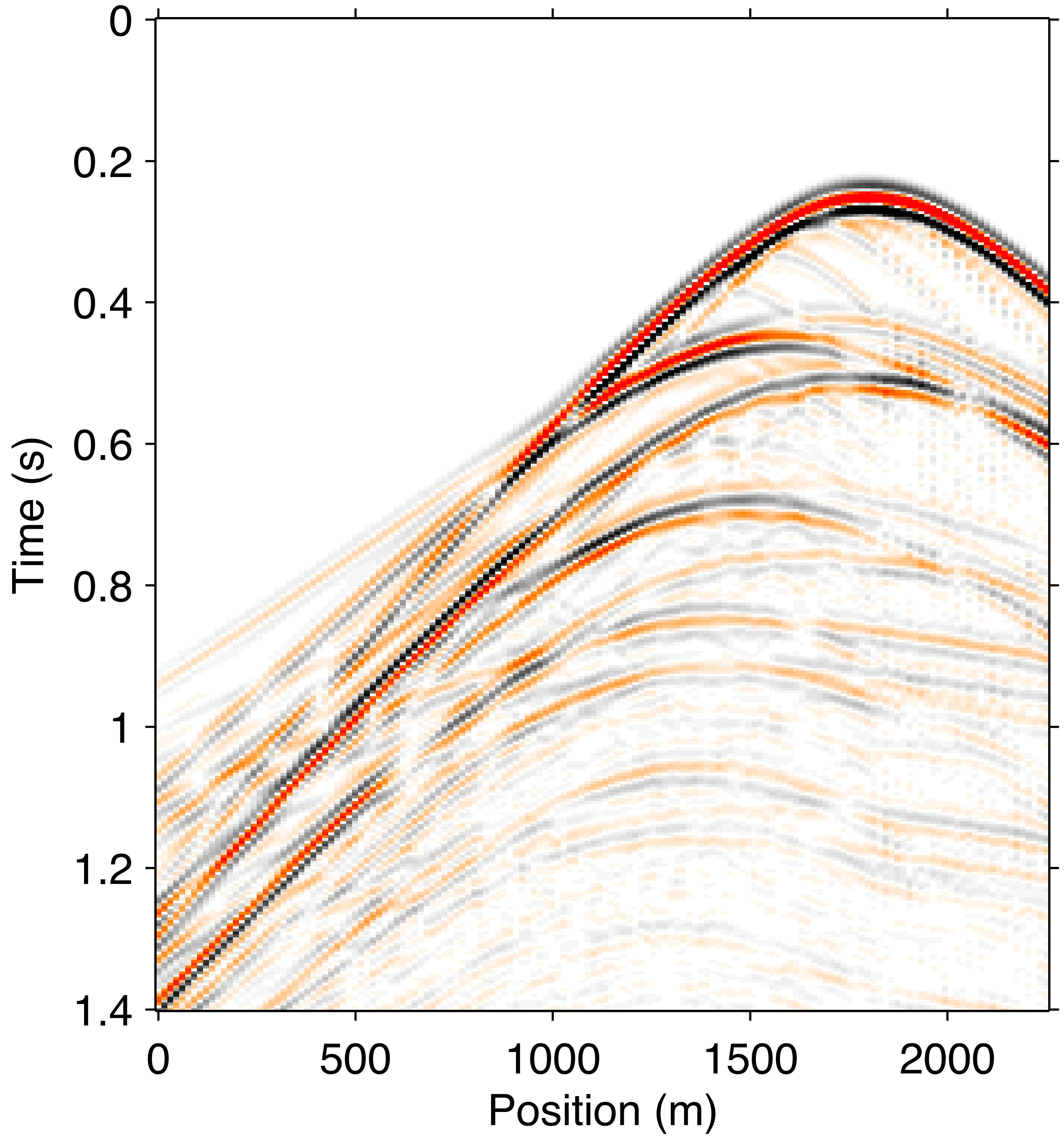
■ : missing data

REPSI with 2:1 source undersampling



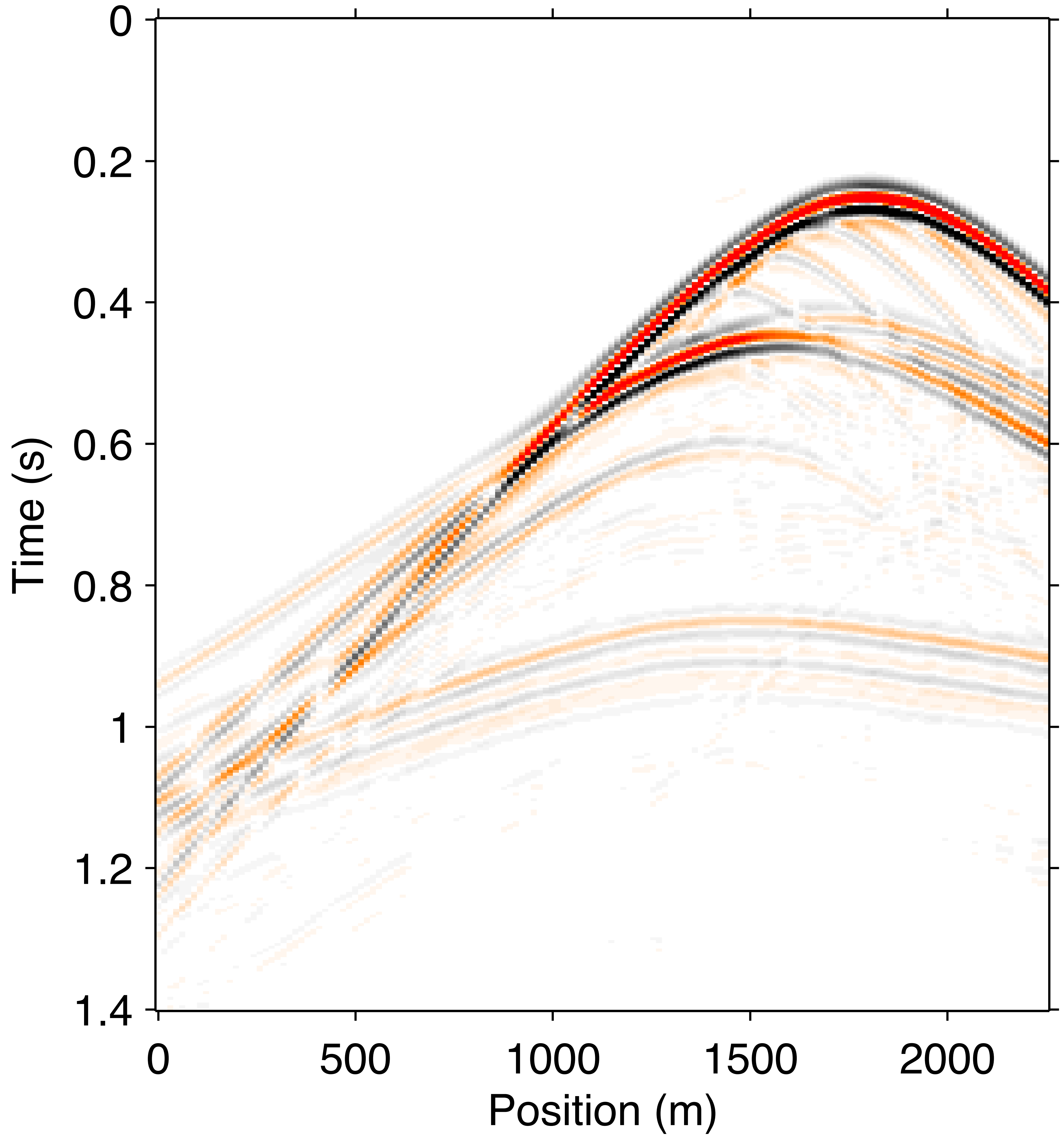
Fully-sampled data
shot gather
src at 1800m

REPSI with 2:1 source undersampling



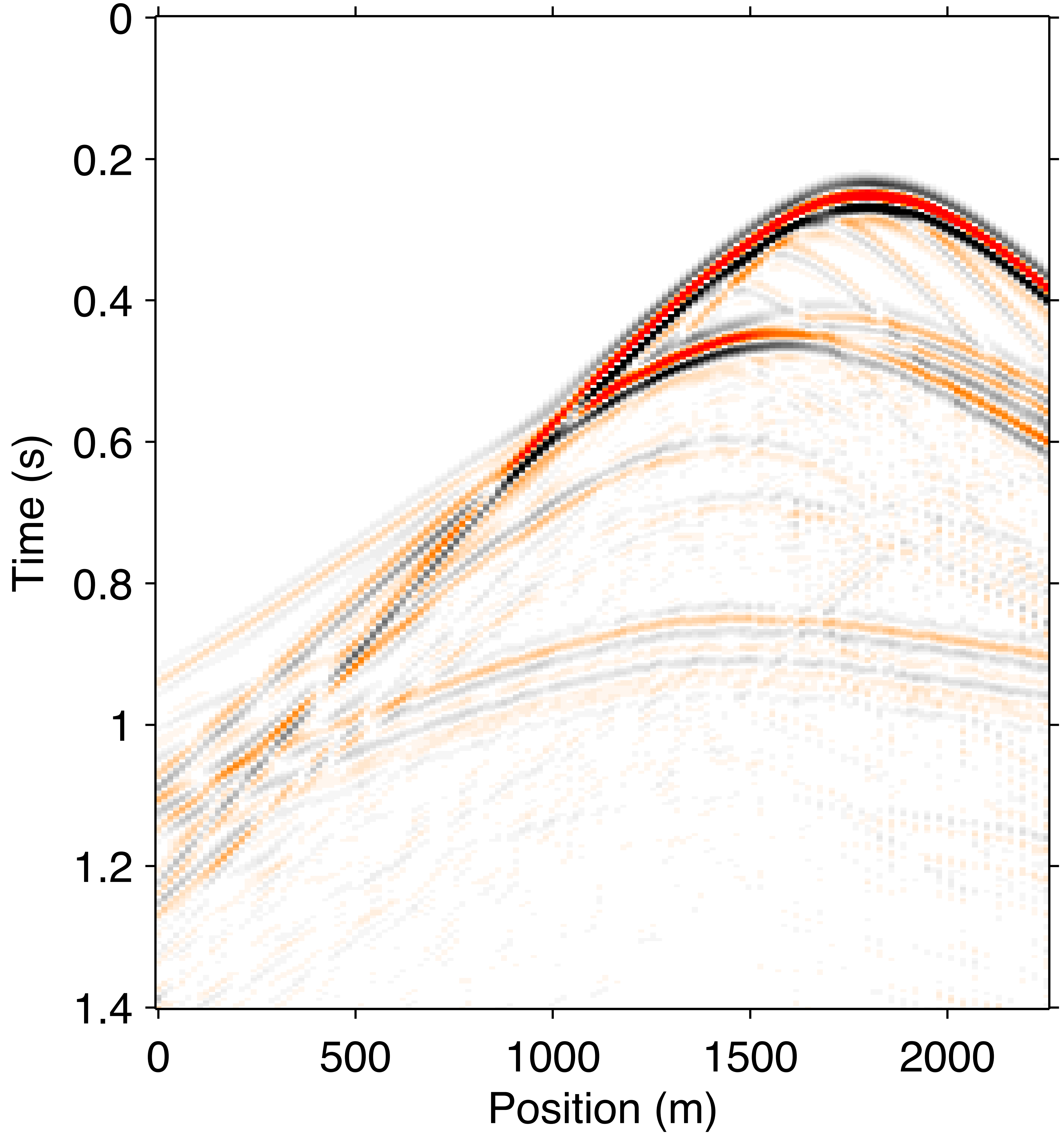
Interpolated data
via const NMO 1600m/s
natural-neighbor trace copy
negative offsets sampled
src at 1800m

REPSI with 2:1 source undersampling



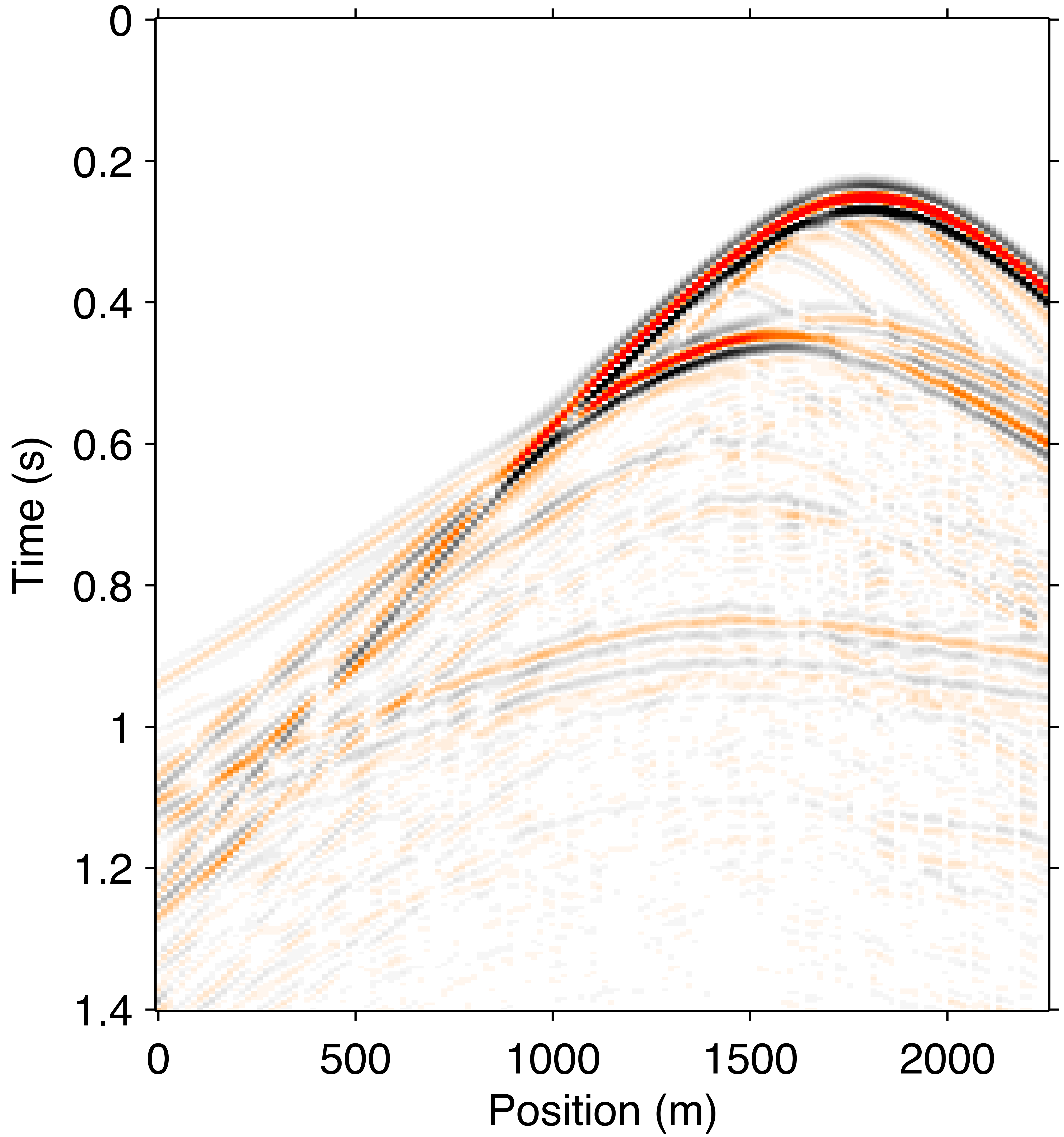
Reference solution
REPSI from fully-sampled data
(conservative primary)

REPSI with 2:1 source undersampling



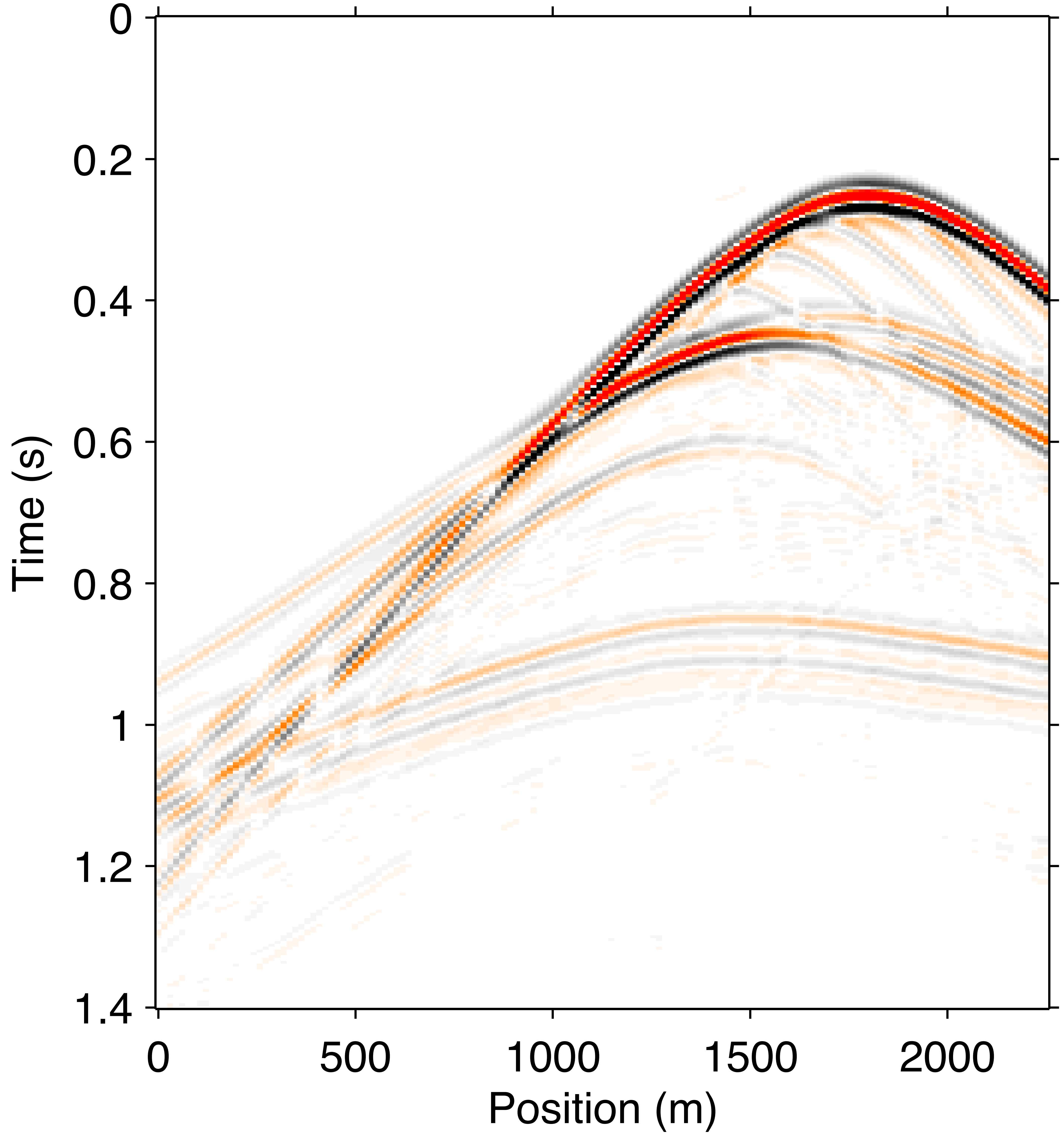
REPSI primary
from 2:1 source undersmapling
with data updates
dRecv = 15m, dSrc = 30m
(conservative primary)

REPSI with 4:1 source undersampling



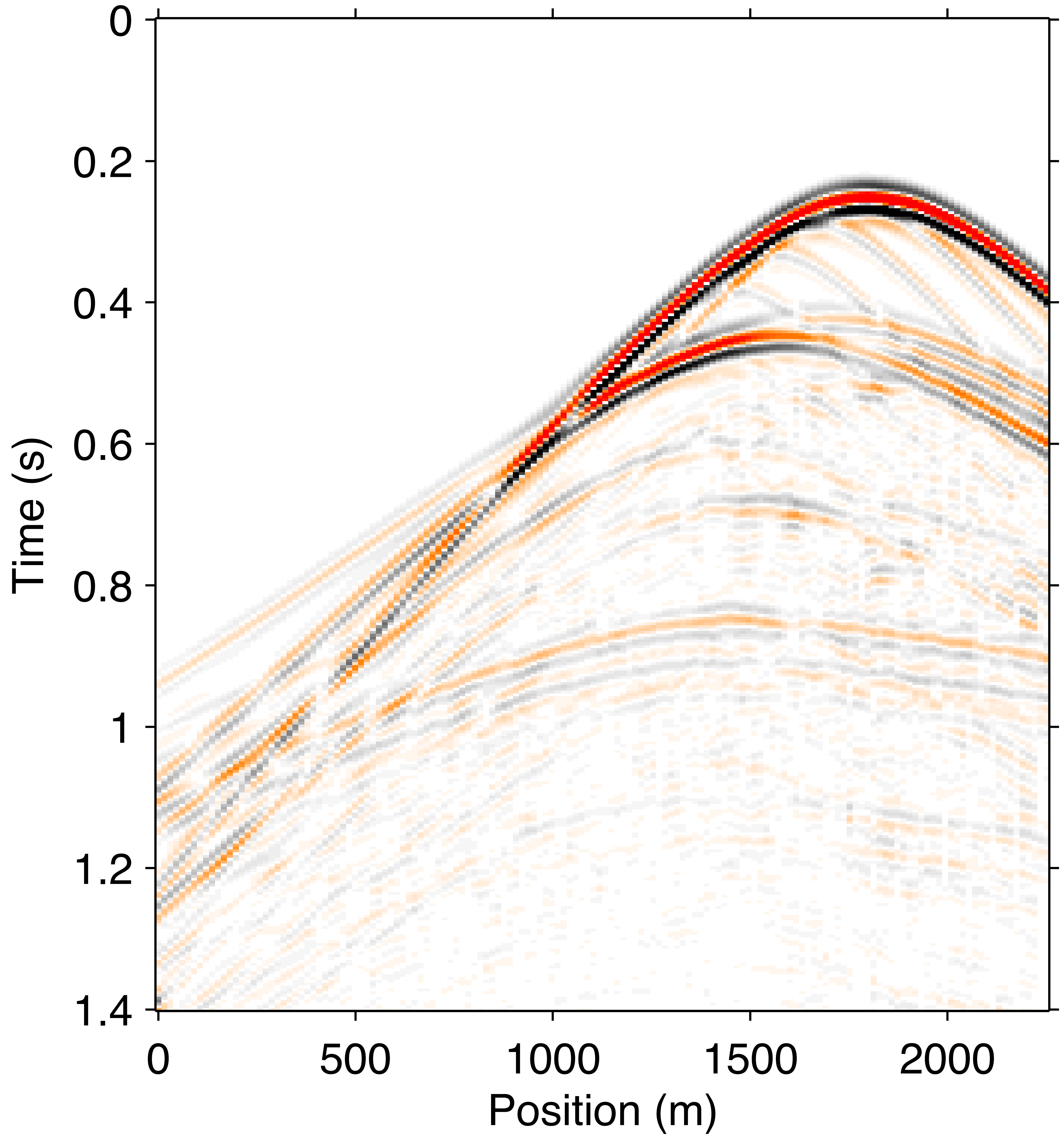
REPSI primary
from 4:1 source undersmapling
with data updates
dRecv = 15m, dSrc = 60m
(conservative primary)

REPSI with 2:1 source undersampling



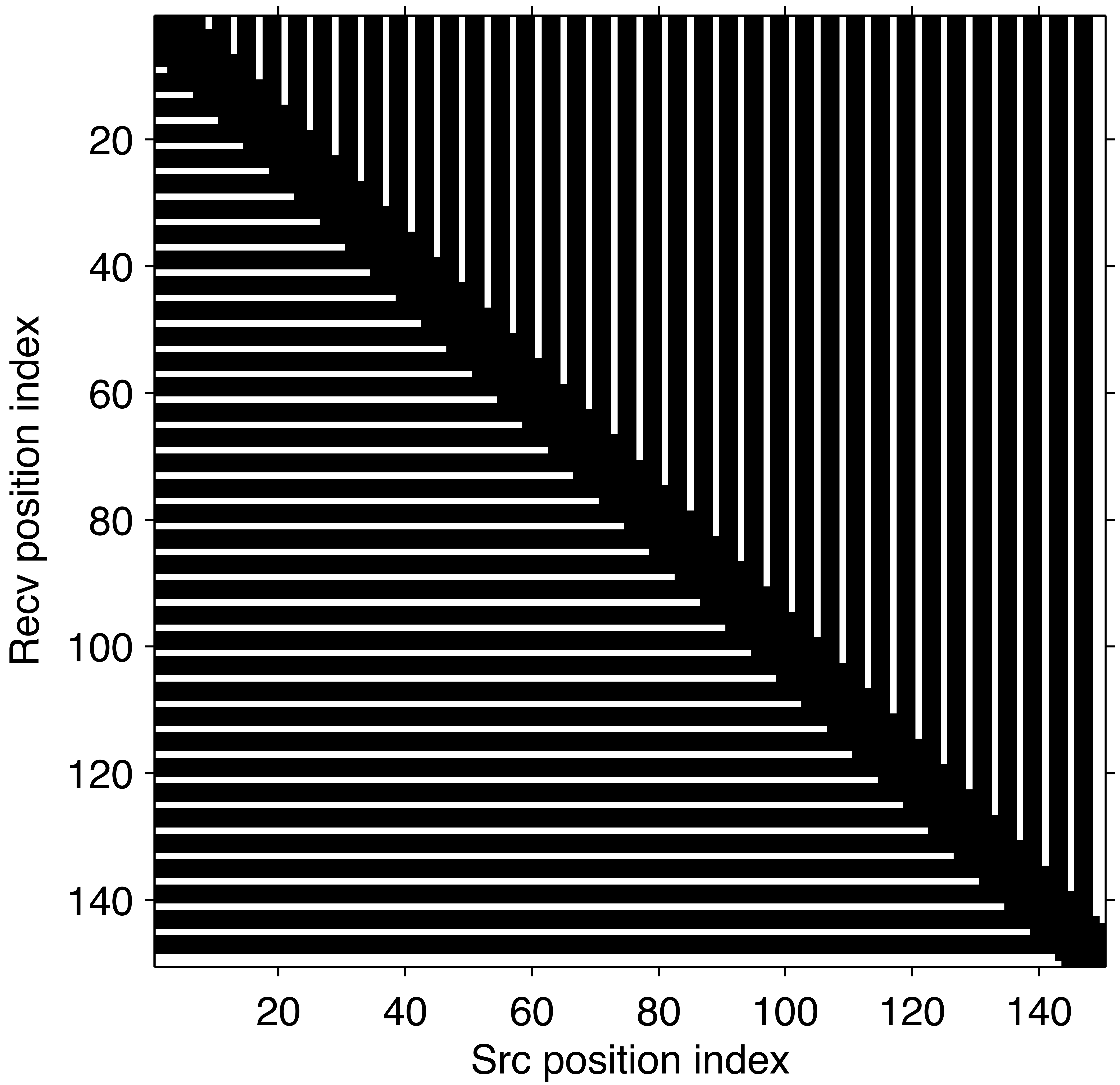
Reference solution
REPSI from fully-sampled data
(conservative primary)

REPSI with 4:1 source, nearest offset at 105m



REPSI primary
from 4:1 source undersmapling
nearest offset at 105m
with data updates
dRecv = 15m, dSrc = 60m
(conservative primary)

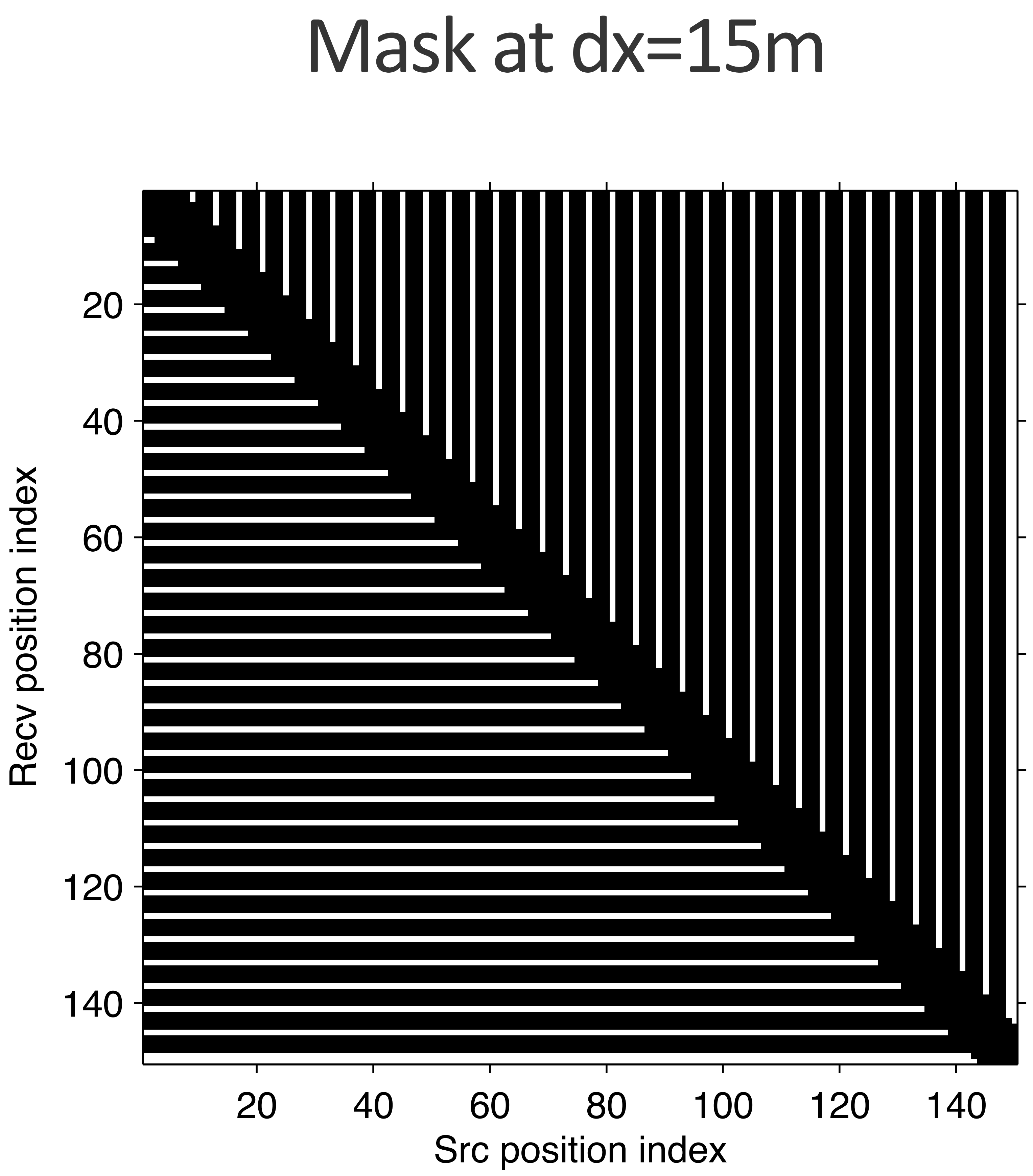
REPSI with 4:1 source, nearest offset at 105m

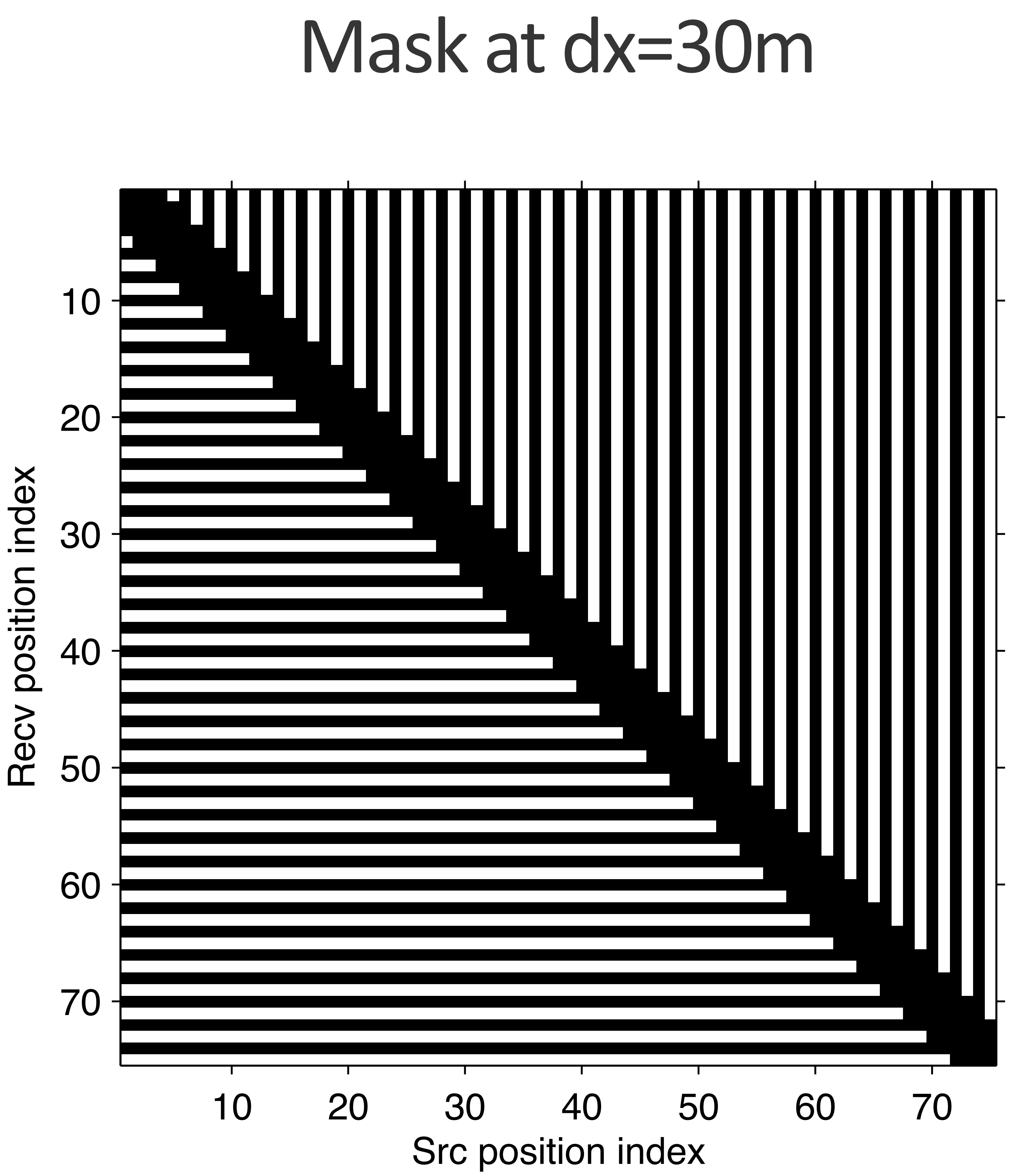


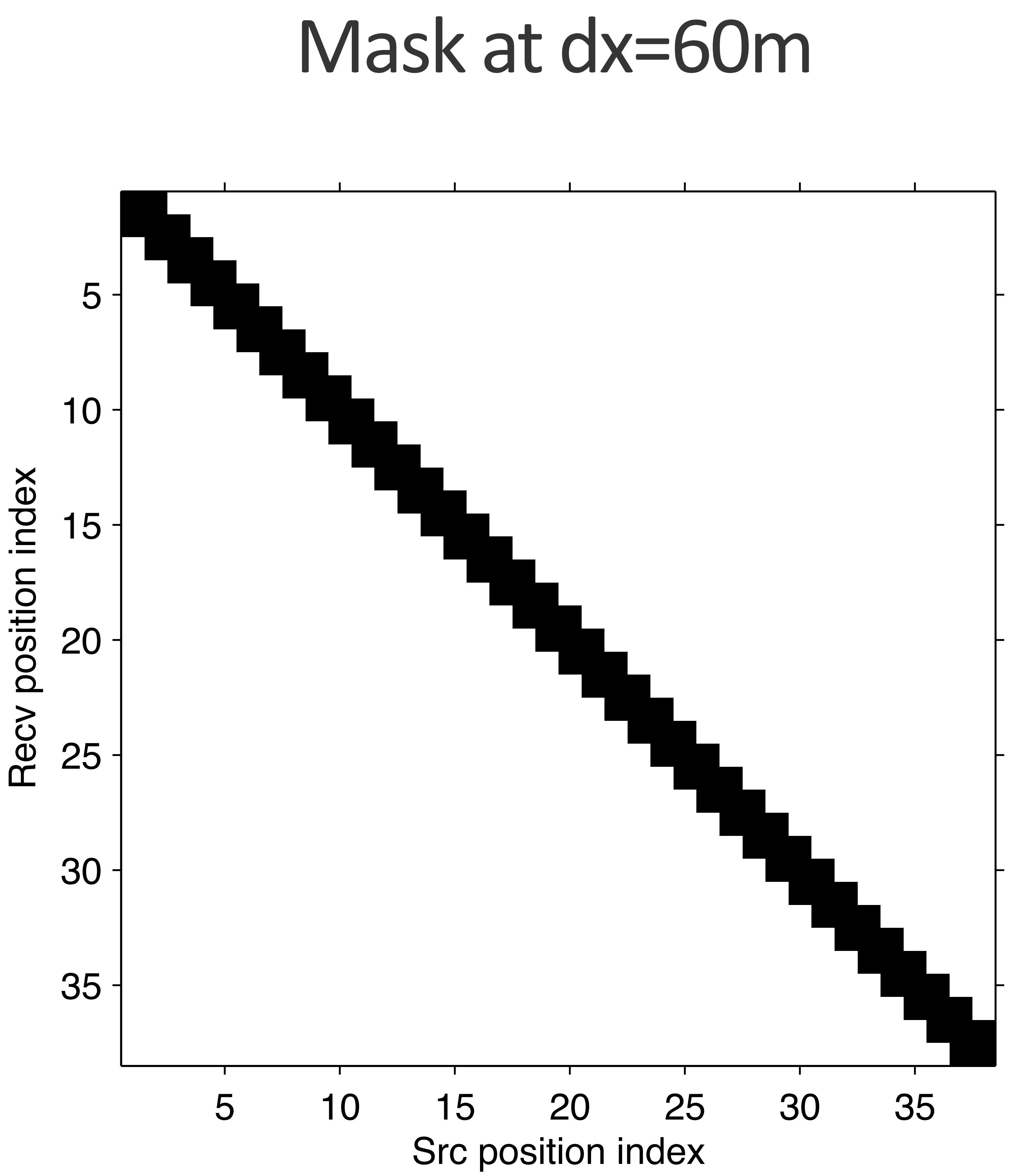
Trace mask
dRecv 15m
dSrc 60m
nearest offset 105m
(assuming streamer acquisition)

■ : missing data

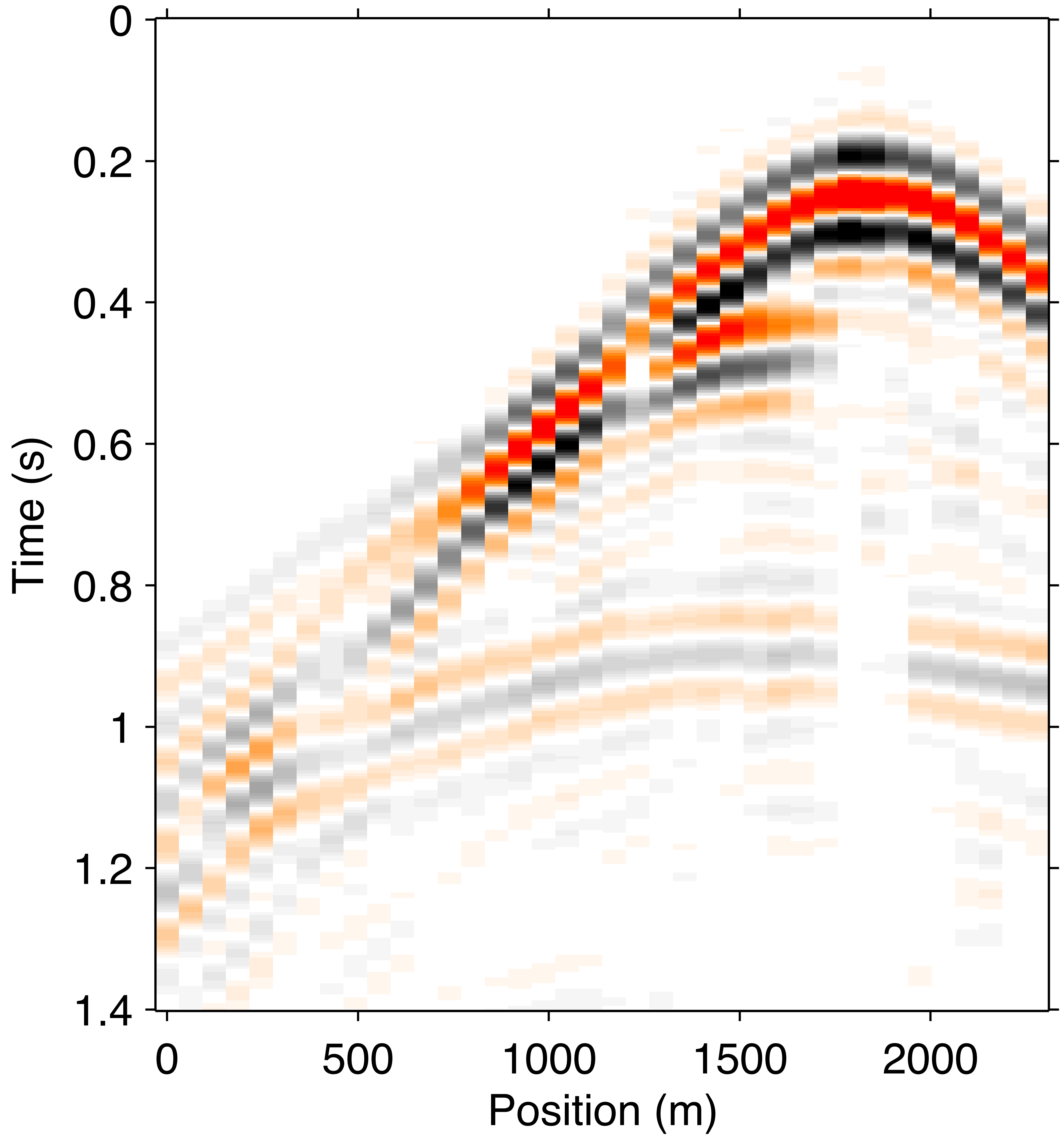
Bootstrapping, for unknown data





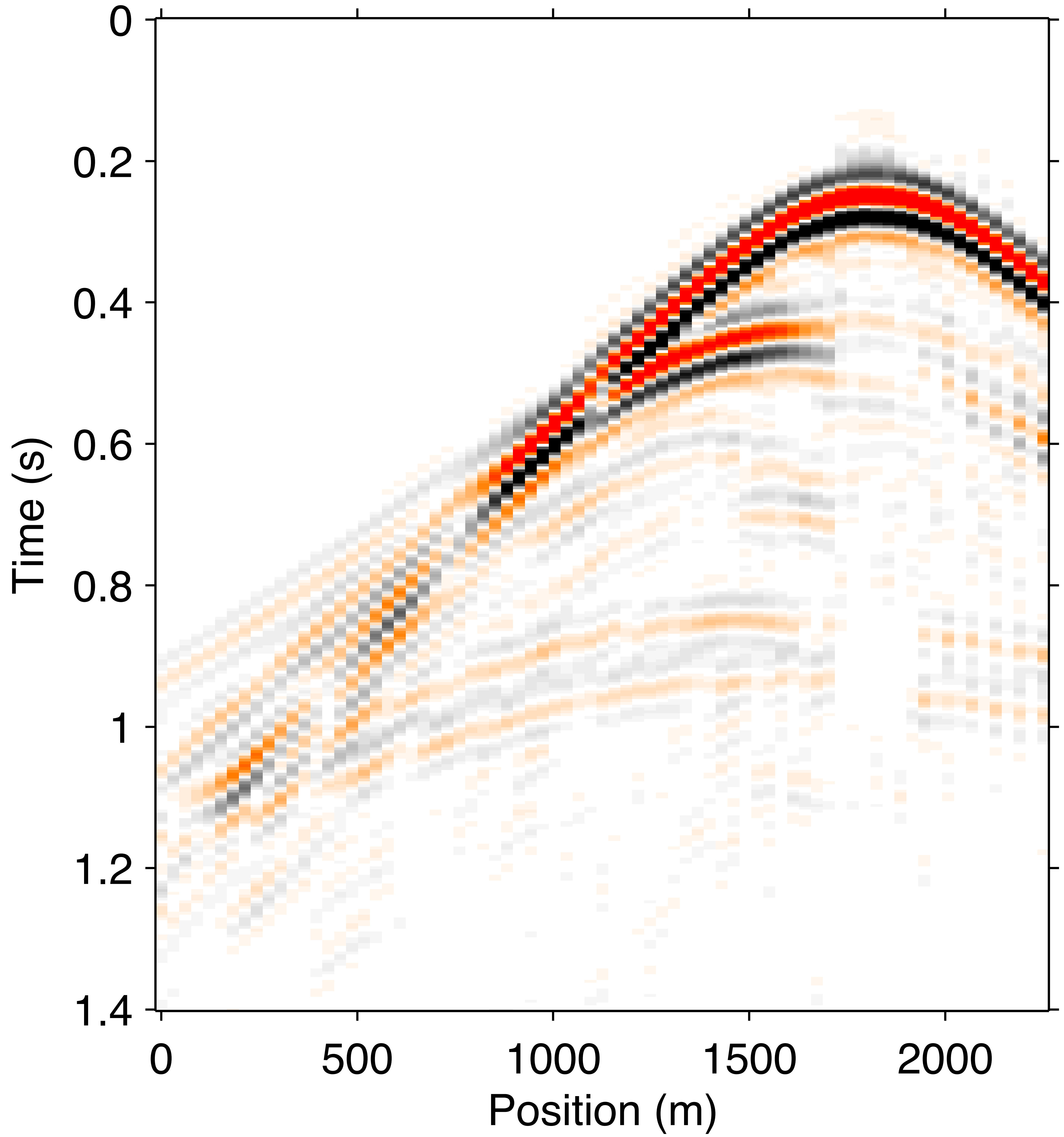


Bootstrap REPSI with 4:1 source, nearest offset at 105m



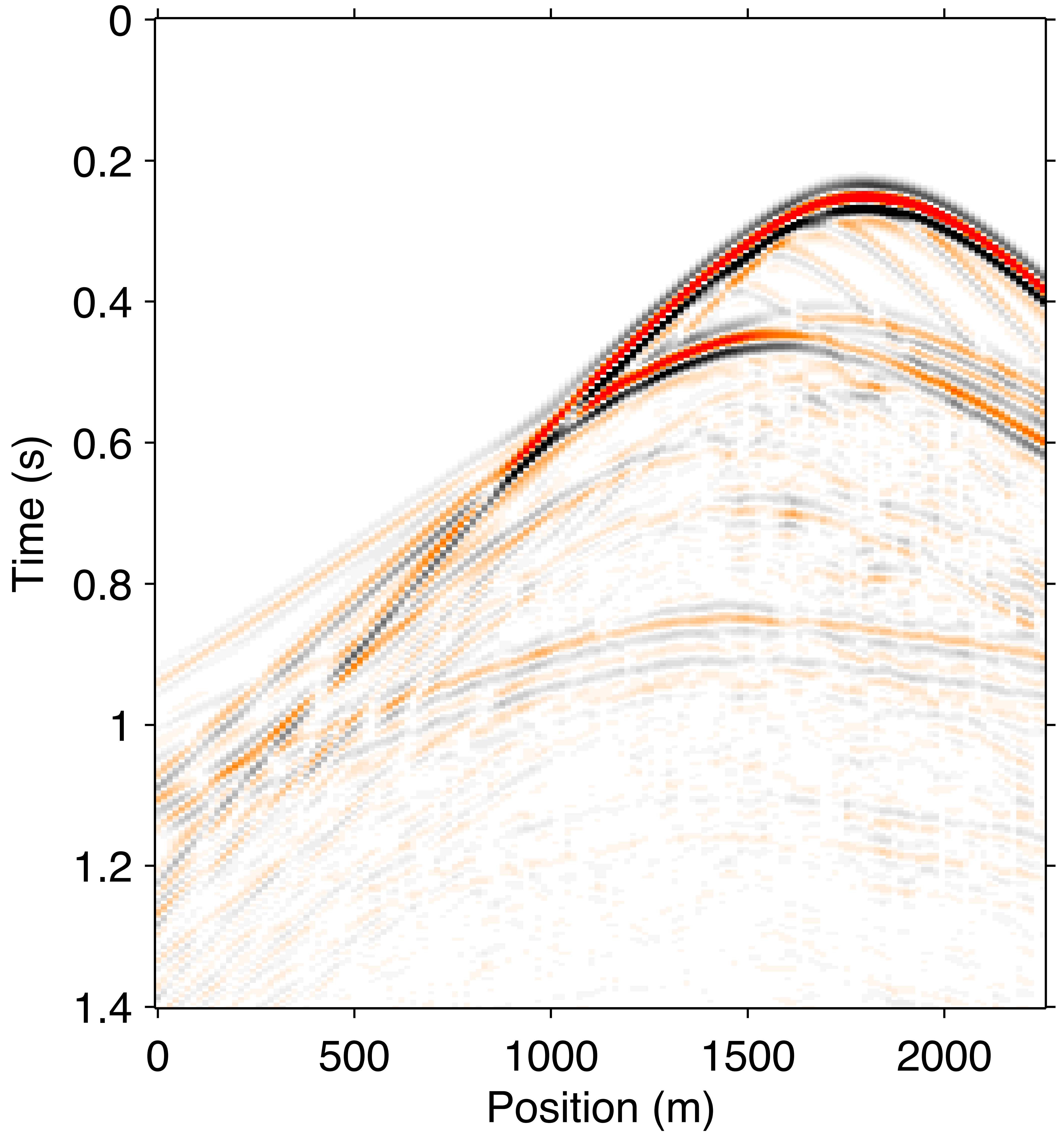
REPSI primary
from 4:1 source undersmapling
nearest offset at 105m
with data updates
dRecv = 60m, dSrc = 60m
(direct primary)

Bootstrap REPSI with 4:1 source, nearest offset at 105m



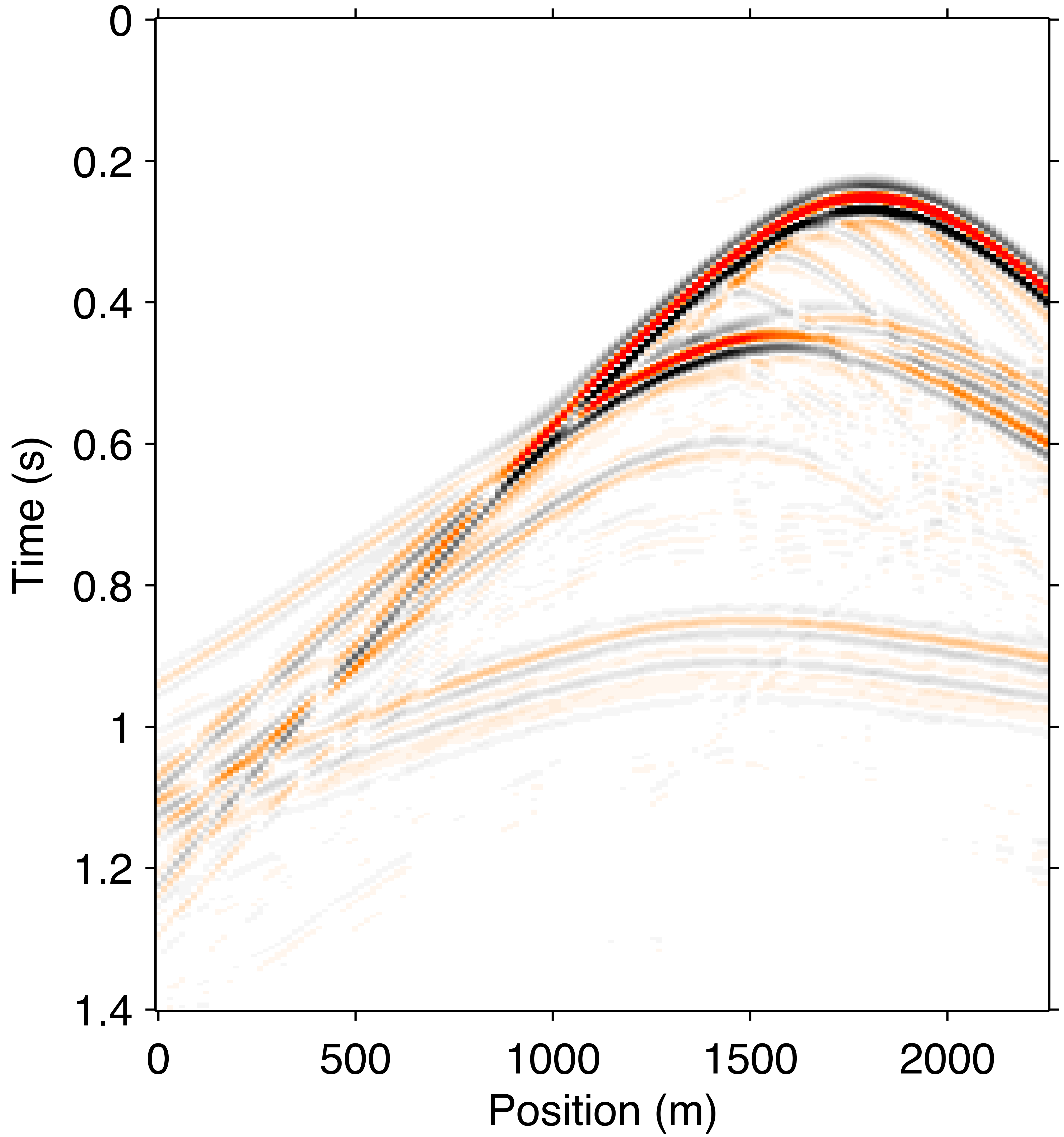
REPSI primary
from 4:1 source undersmapling
nearest offset at 105m
with data updates
starting from dx=60m solution
dRecv = 30m, dSrc = 60m
(direct primary)

Bootstrap REPSI with 4:1 source, nearest offset at 105m



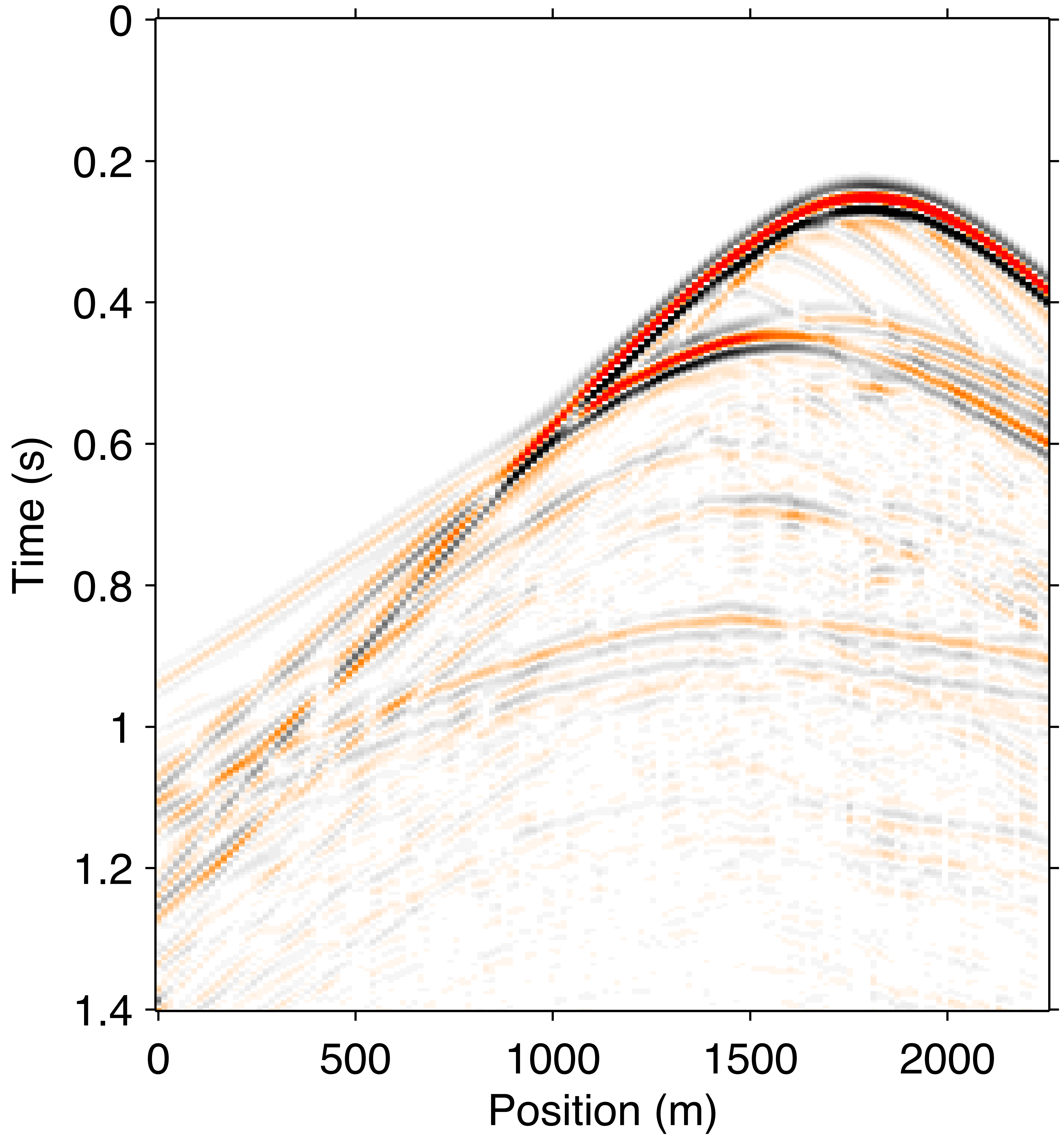
REPSI primary
from 4:1 source undersmapling
nearest offset at 105m
with data updates
starting from dx=30m solution (which started from dx=60m)
dRecv = 15, dSrc = 60m
(conservative primary)

REPSI with 2:1 source undersampling



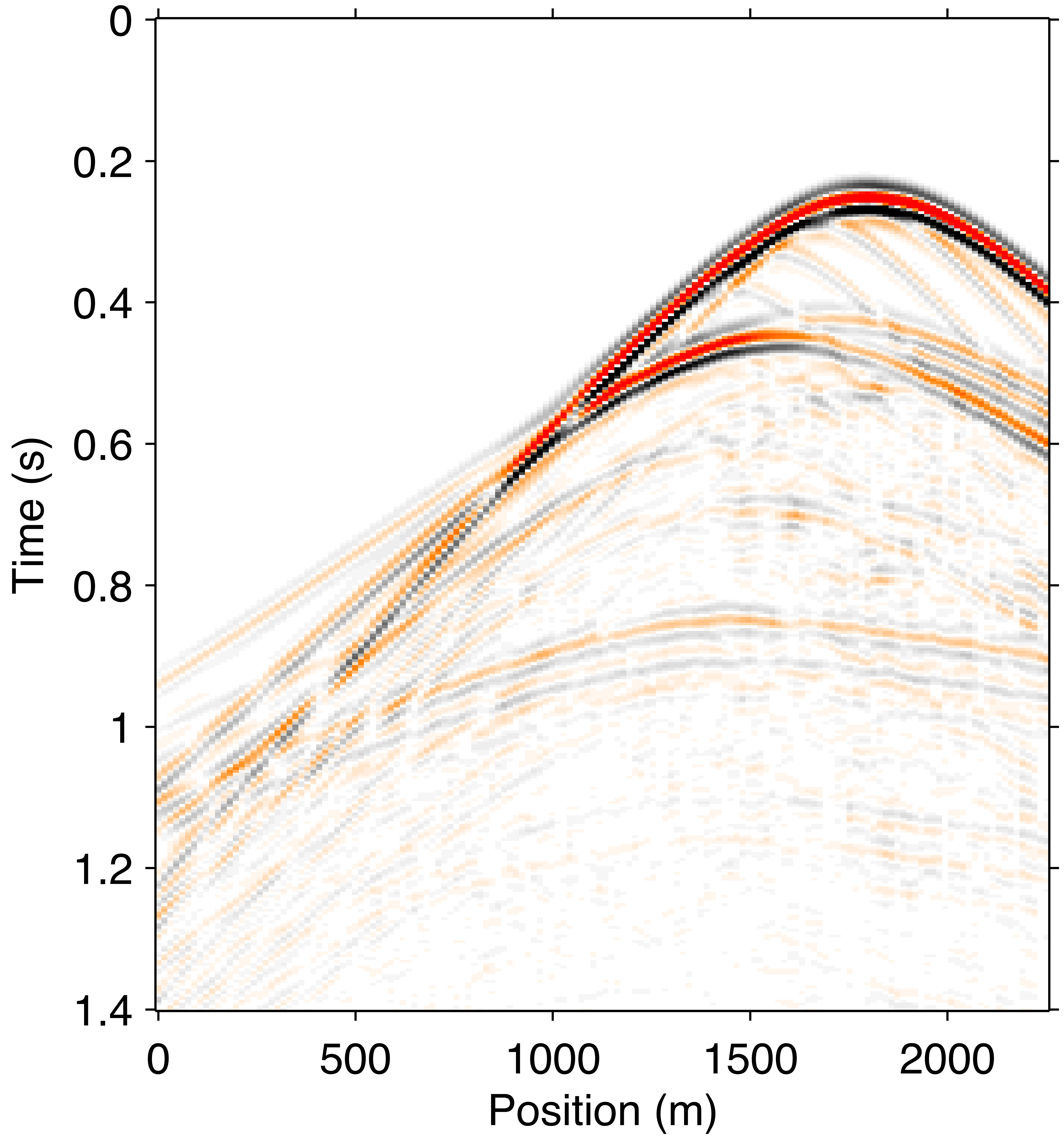
Reference solution
REPSI from fully-sampled data
(conservative primary)

REPSI with 4:1 source, nearest offset at 105m



REPSI primary
from 4:1 source undersmapling
nearest offset at 105m
with data updates
dRecv = 15m, dSrc = 60m
(conservative primary)

Bootstrap REPSI with 4:1 source, nearest offset at 105m



REPSI primary
from 4:1 source undersmapling
nearest offset at 105m
with data updates
starting from dx=30m solution
(which started from dx=60m)
dRecv = 15, dSrc = 60m
(conservative primary)

Sampling-continuation scheme summary

Start REPSI with decimated data, lowpass to avoid spatial aliasing; once "significant" progress is made, continue with less decimated problem

Significant saving in computation cost, 100x to 200x SRMP becomes more like 30x to 40x

Can keep ratio of unknown data at a controlled level

How low can we go? Two limits:

- Coarsest sampling interval in your datatype (crossline, OBN spacing, etc)
- Some lower-bound on feasible low-pass frequency, either from theory, data quality, or geophysical reasons (under investigation)

Remaining areas of investigation for REPSI

At coarsest levels, use more advanced/costly sparsifying methods? Go grid-free in the time domain? (*i.e., super-resolution methods)*

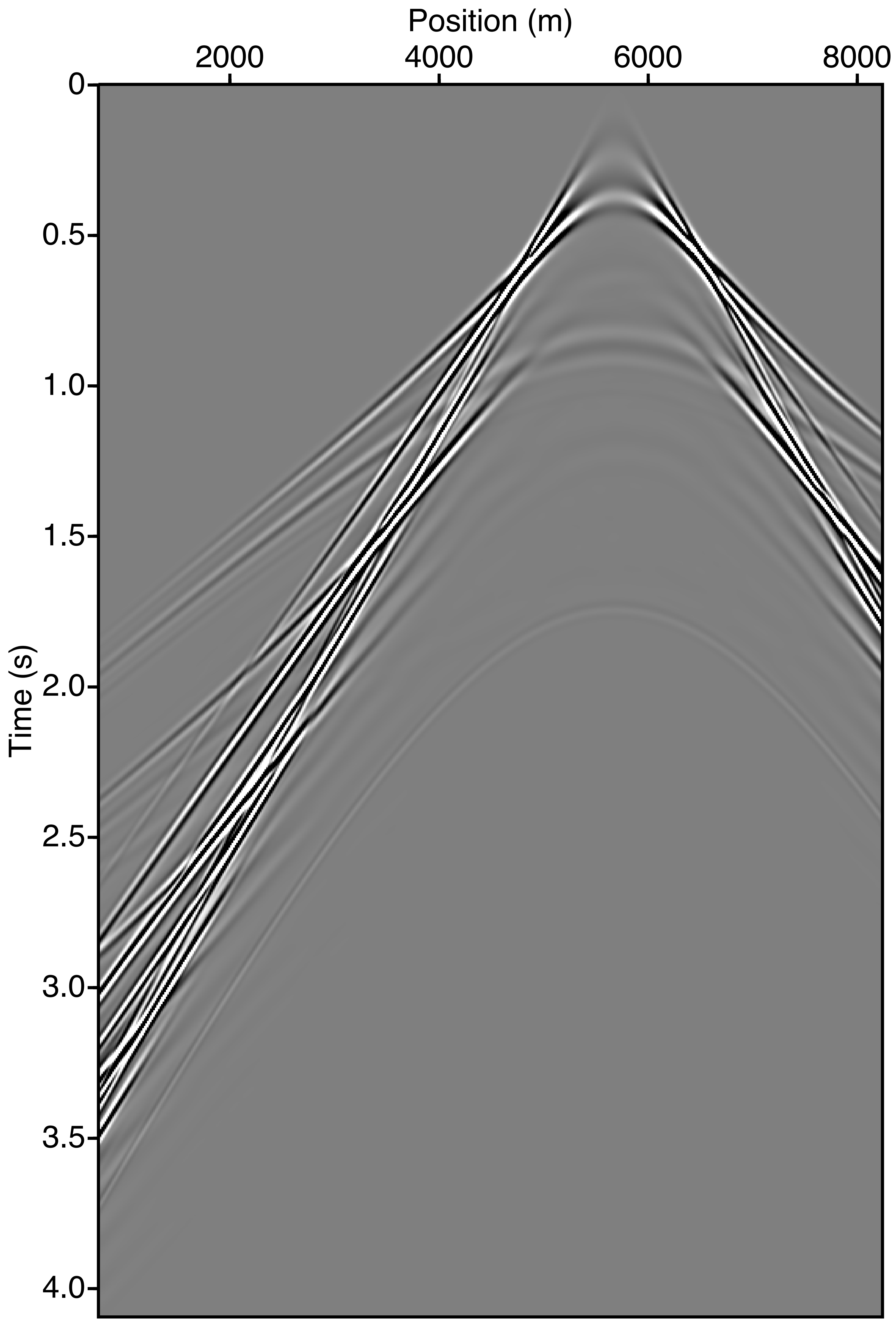
More sophisticated data-update method, less prone to local minima (use correlation between P and G, etc)

Incorporate up/down decomposition operator to work on P & Vz data

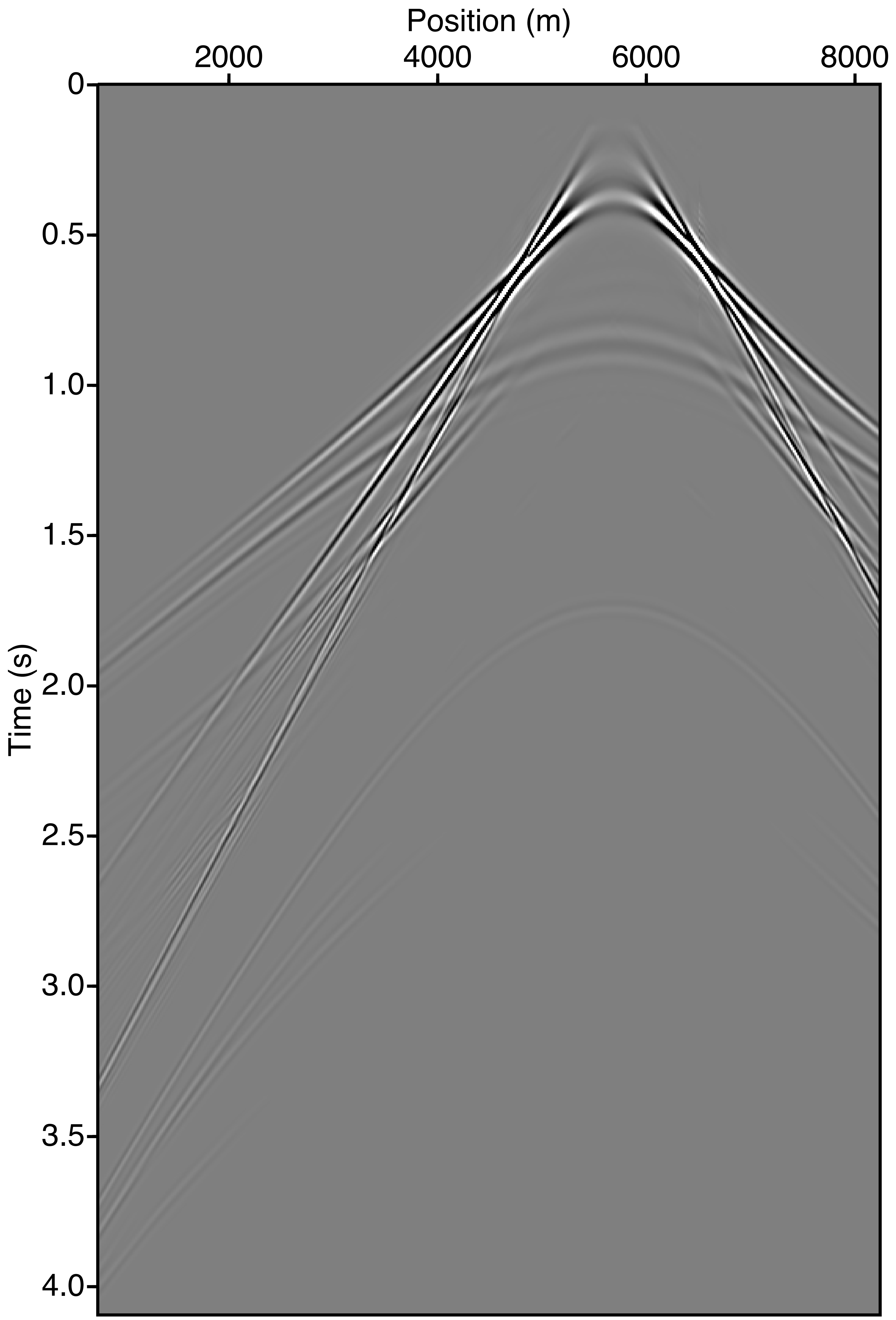
Potentially extract low-frequency information from G for diving-wave full-waveform inversion…?

Bonus presentation

Preliminary study in low-frequency recovery of diving waves using Robust EPSI



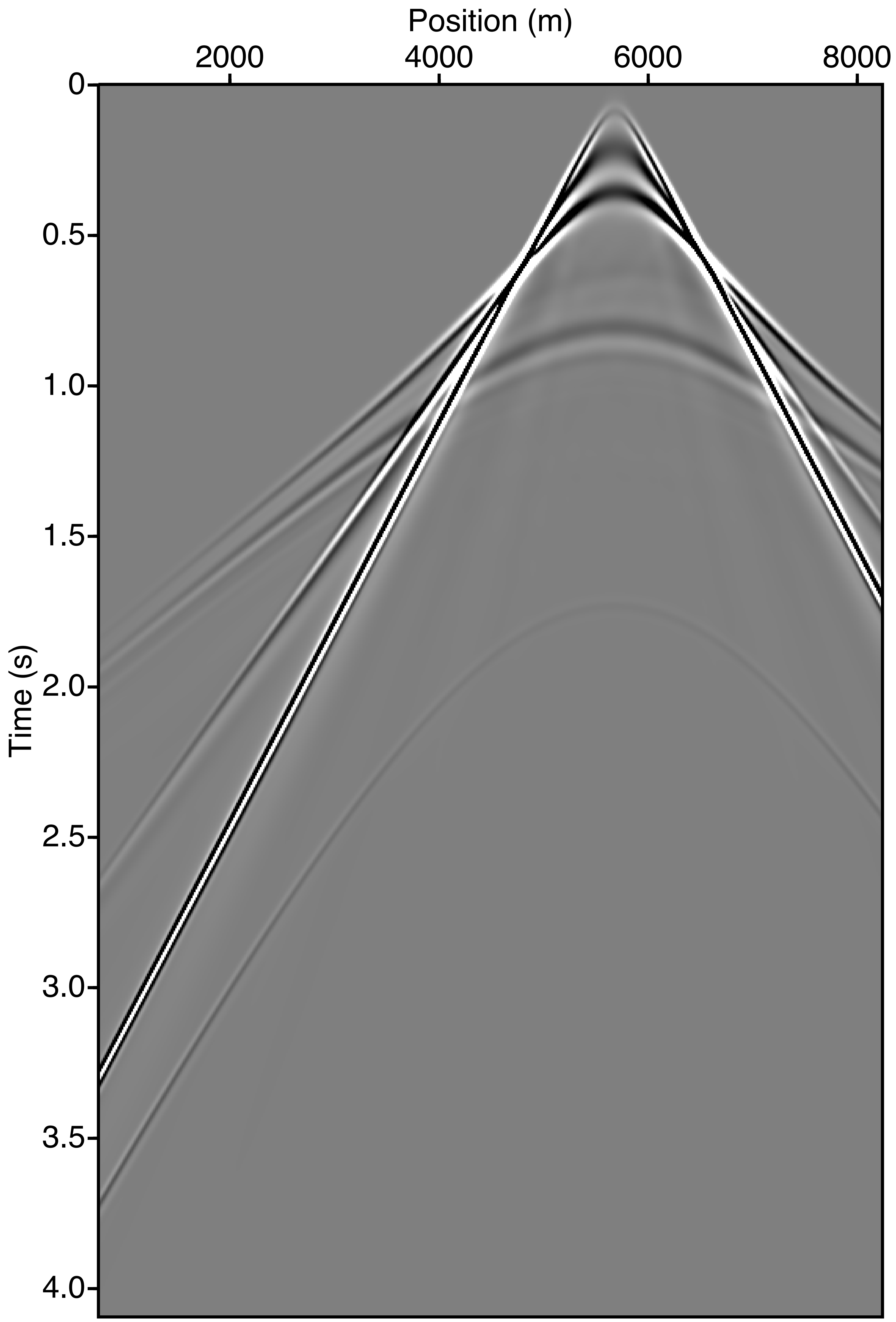
Data



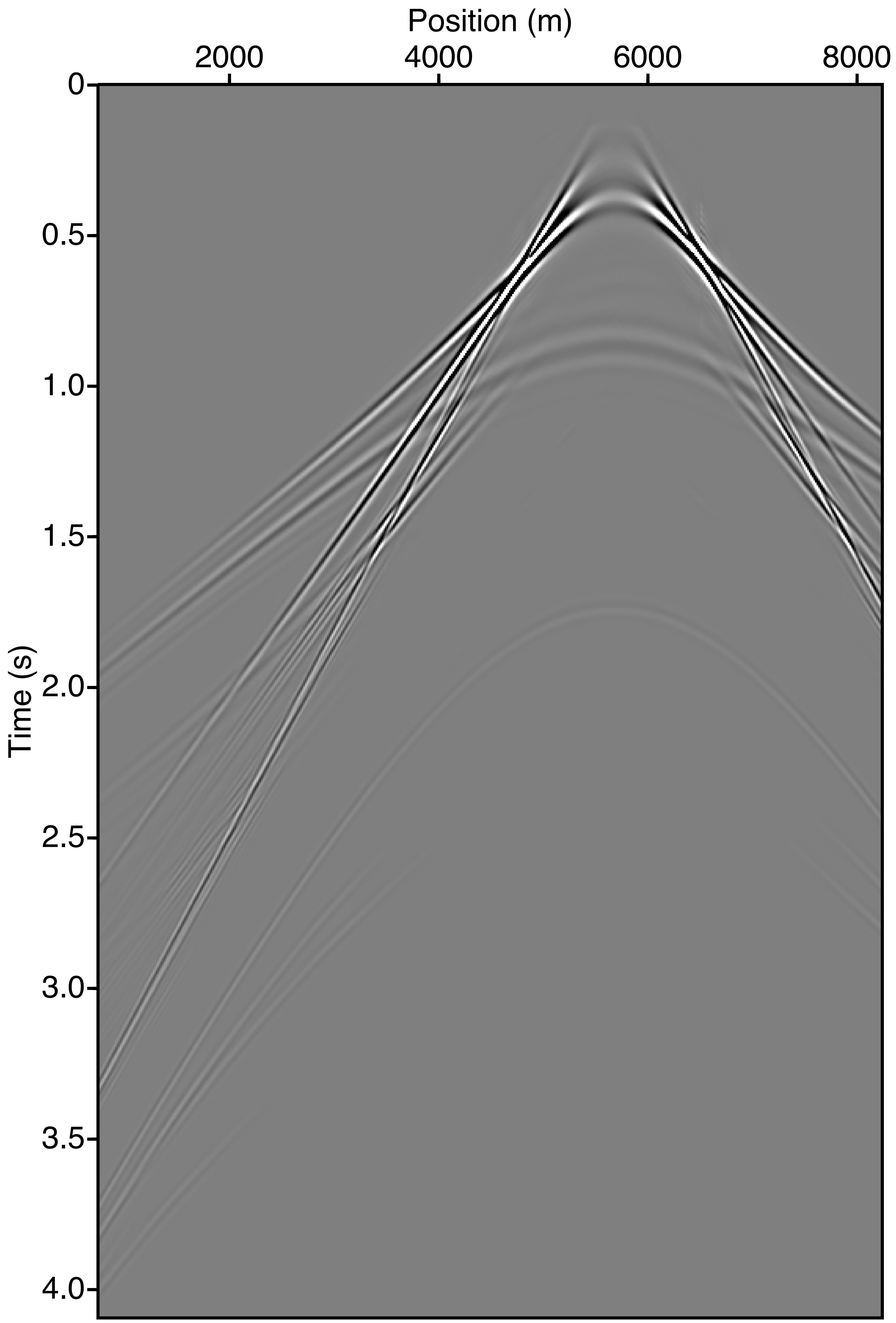
REPSI Primary

REPSI "full band"
(only diving wave)

fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, "full band"
modeled w/iWAVE

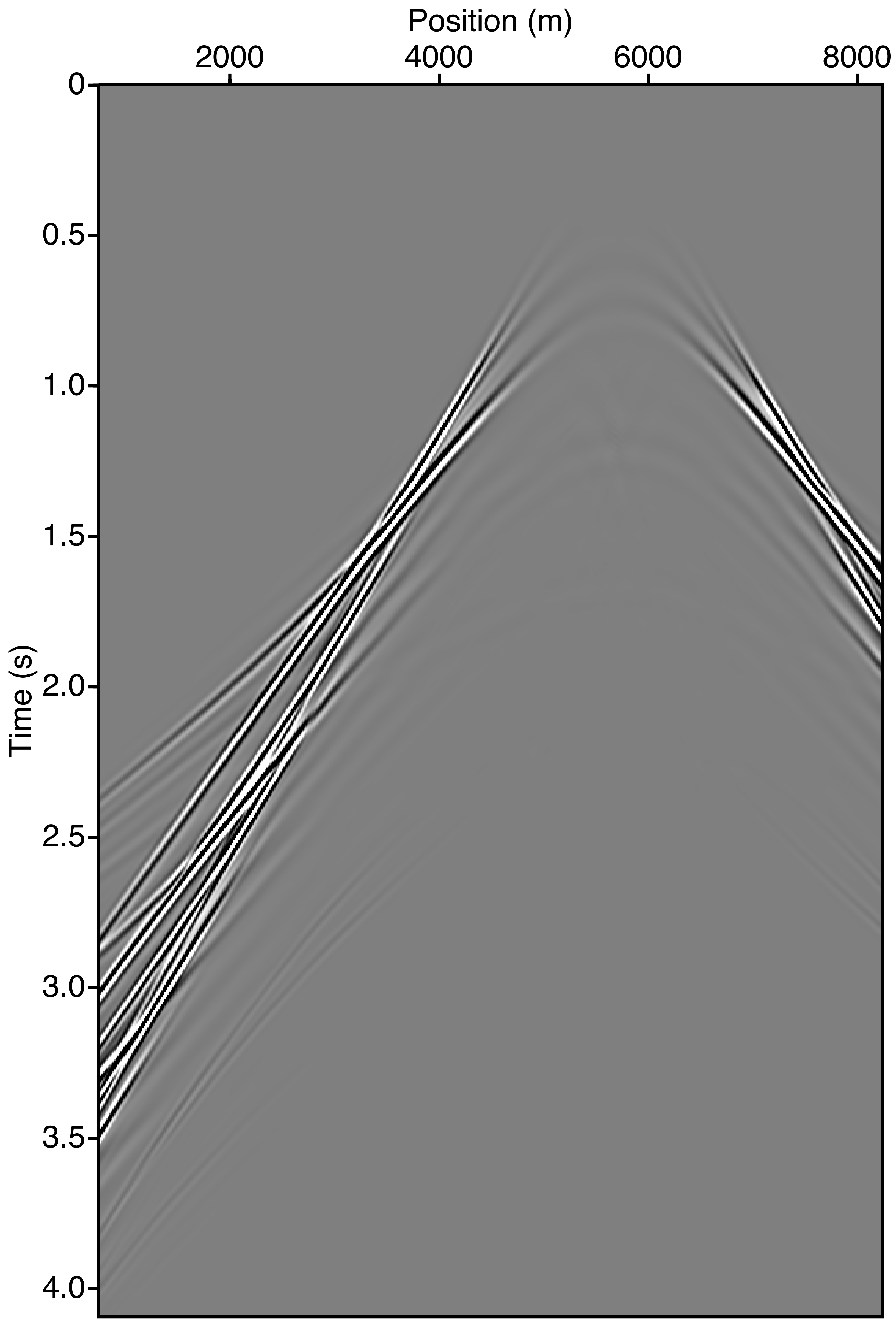


Modeled primary

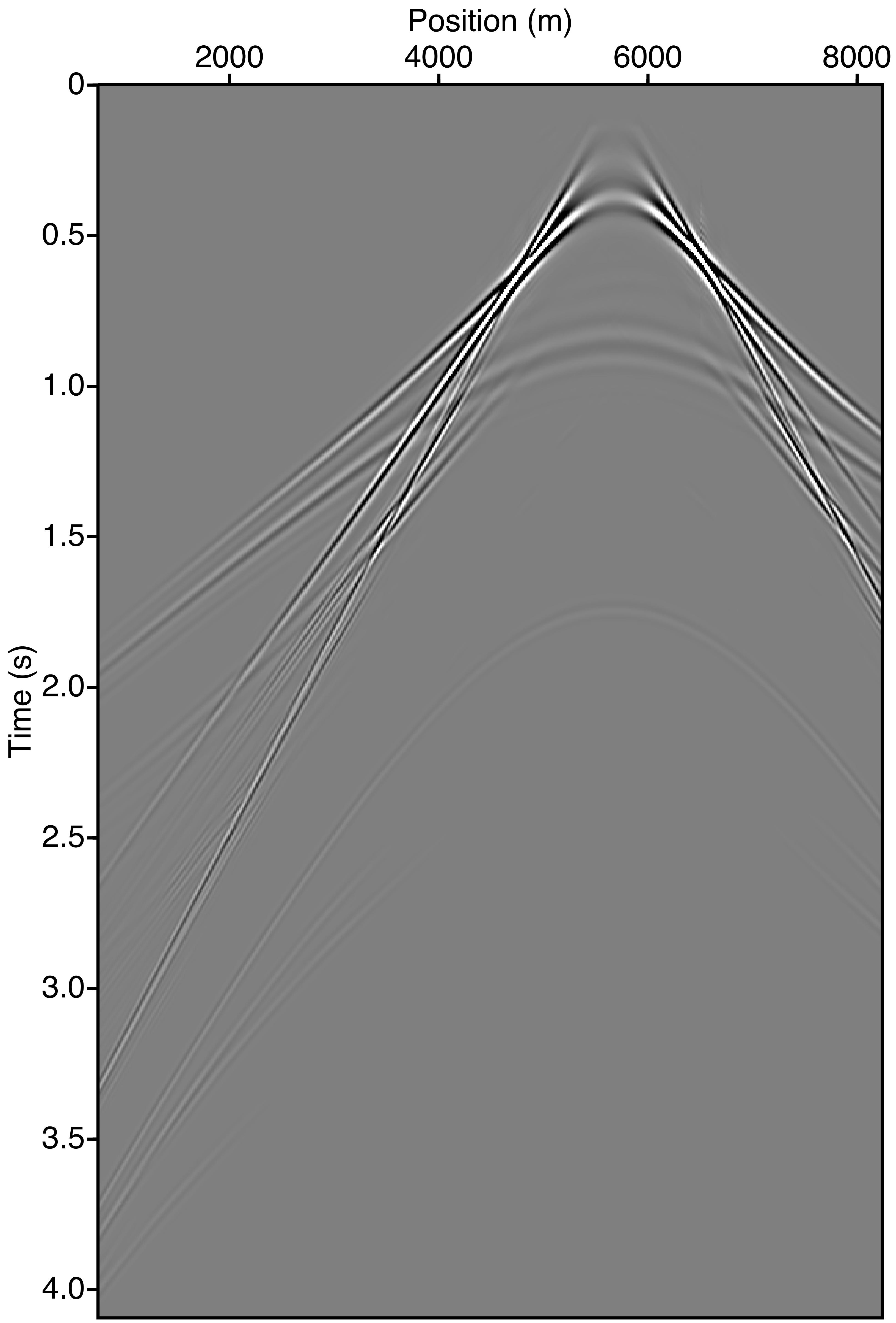


REPSI Primary

REPSI “full band”
(only diving wave)
fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, “full band”
modeled w/iWAVE

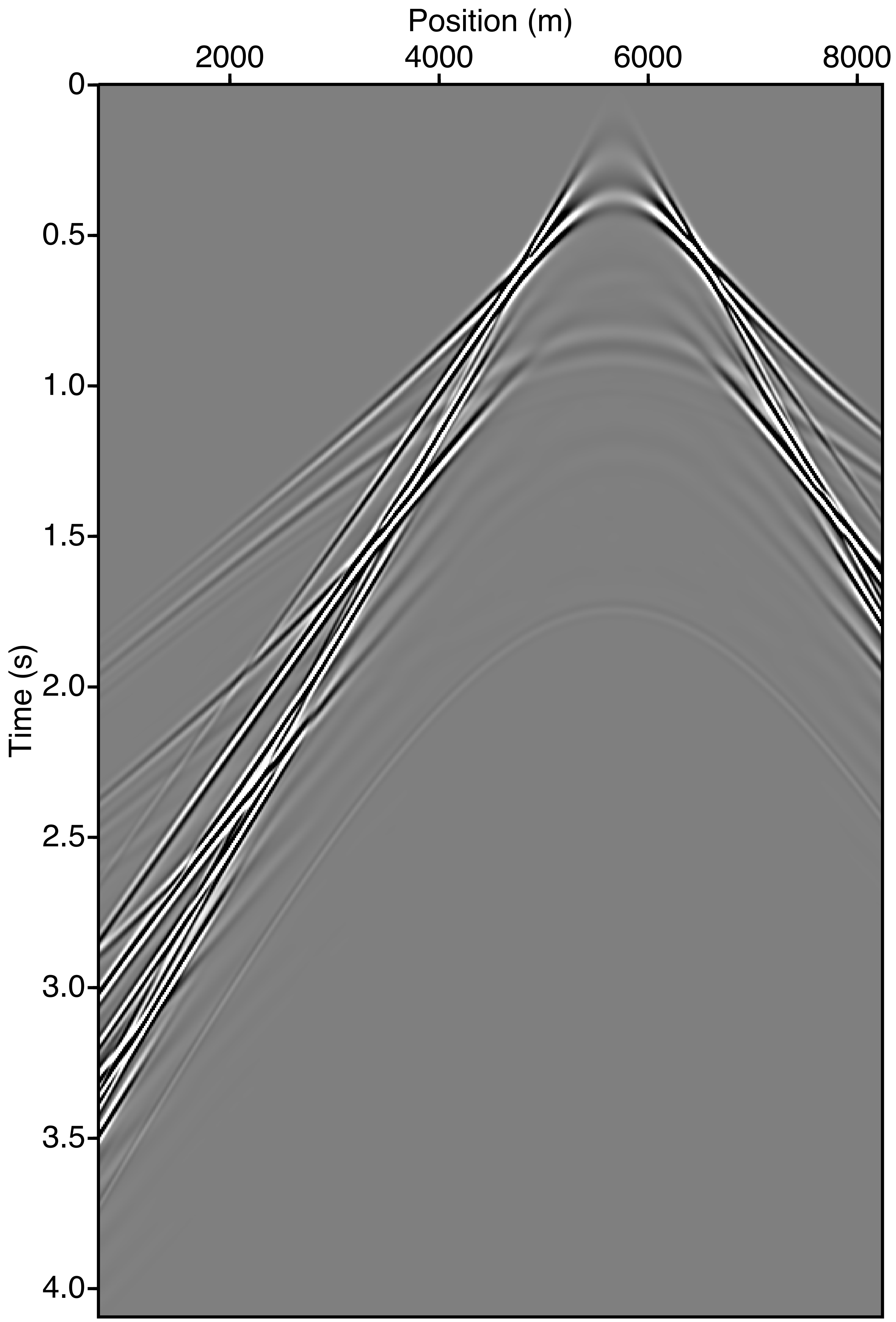


REPSI Multiples

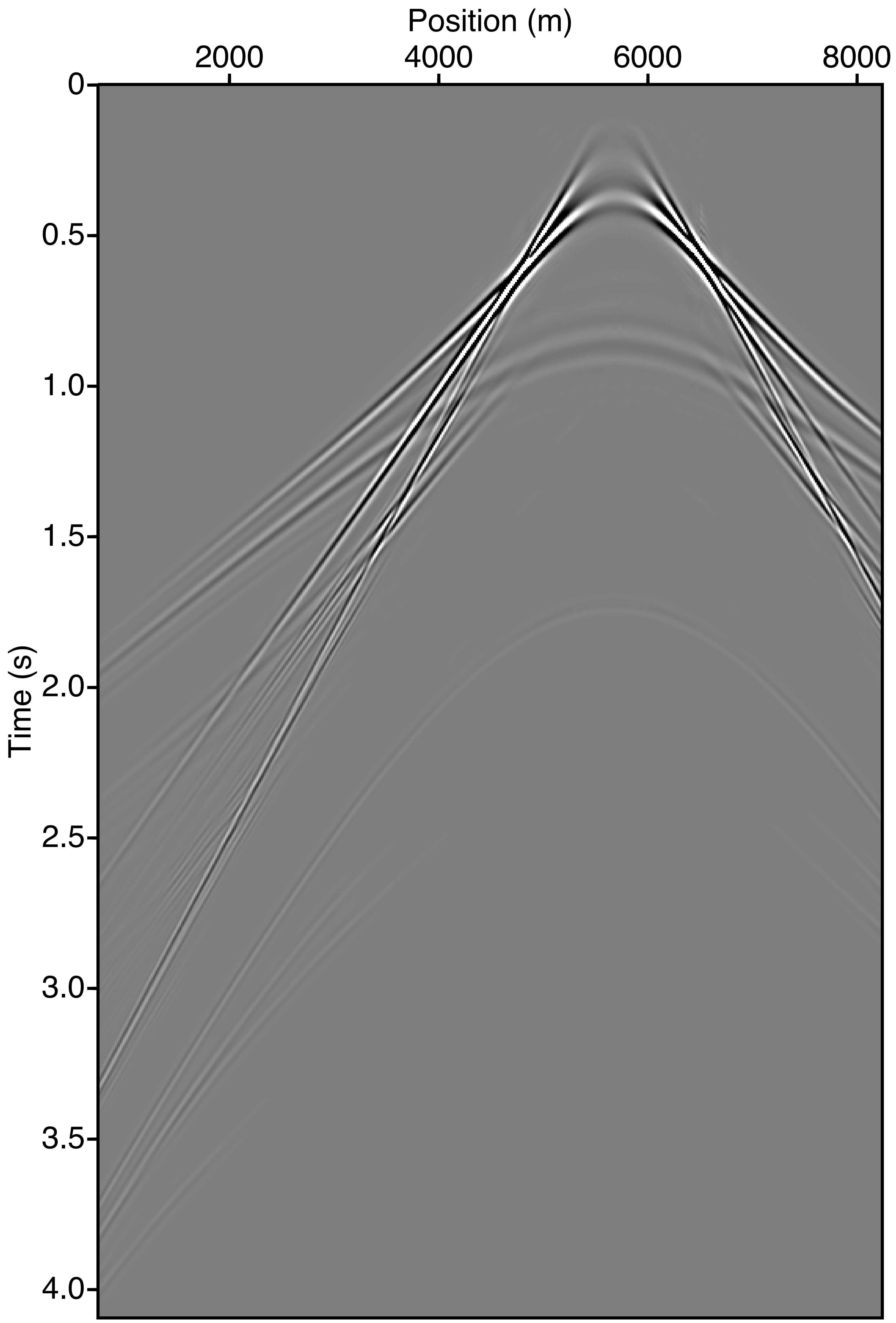


REPSI Primary

REPSI "full band"
(only diving wave)
fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, "full band"
modeled w/iWAVE



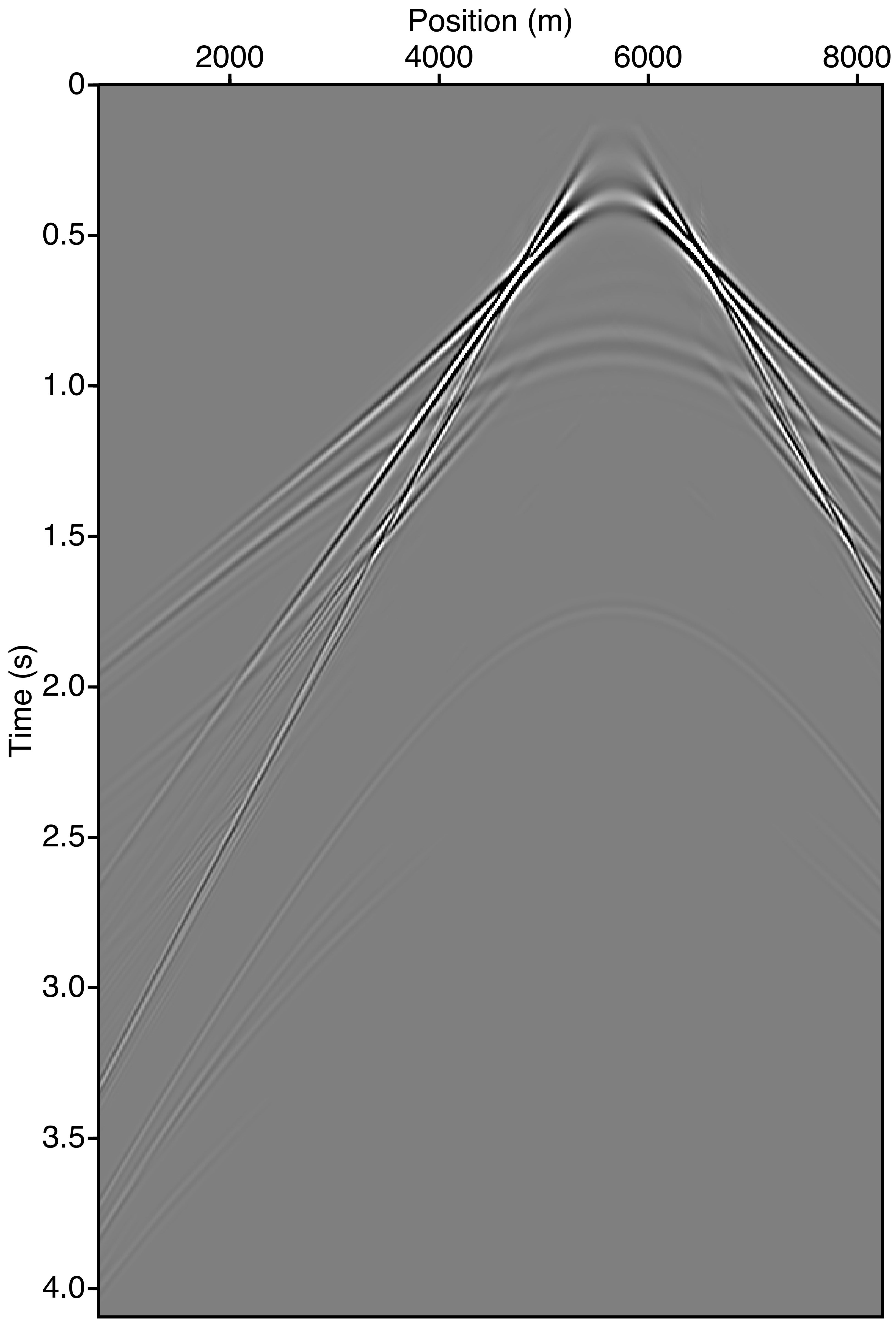
Data



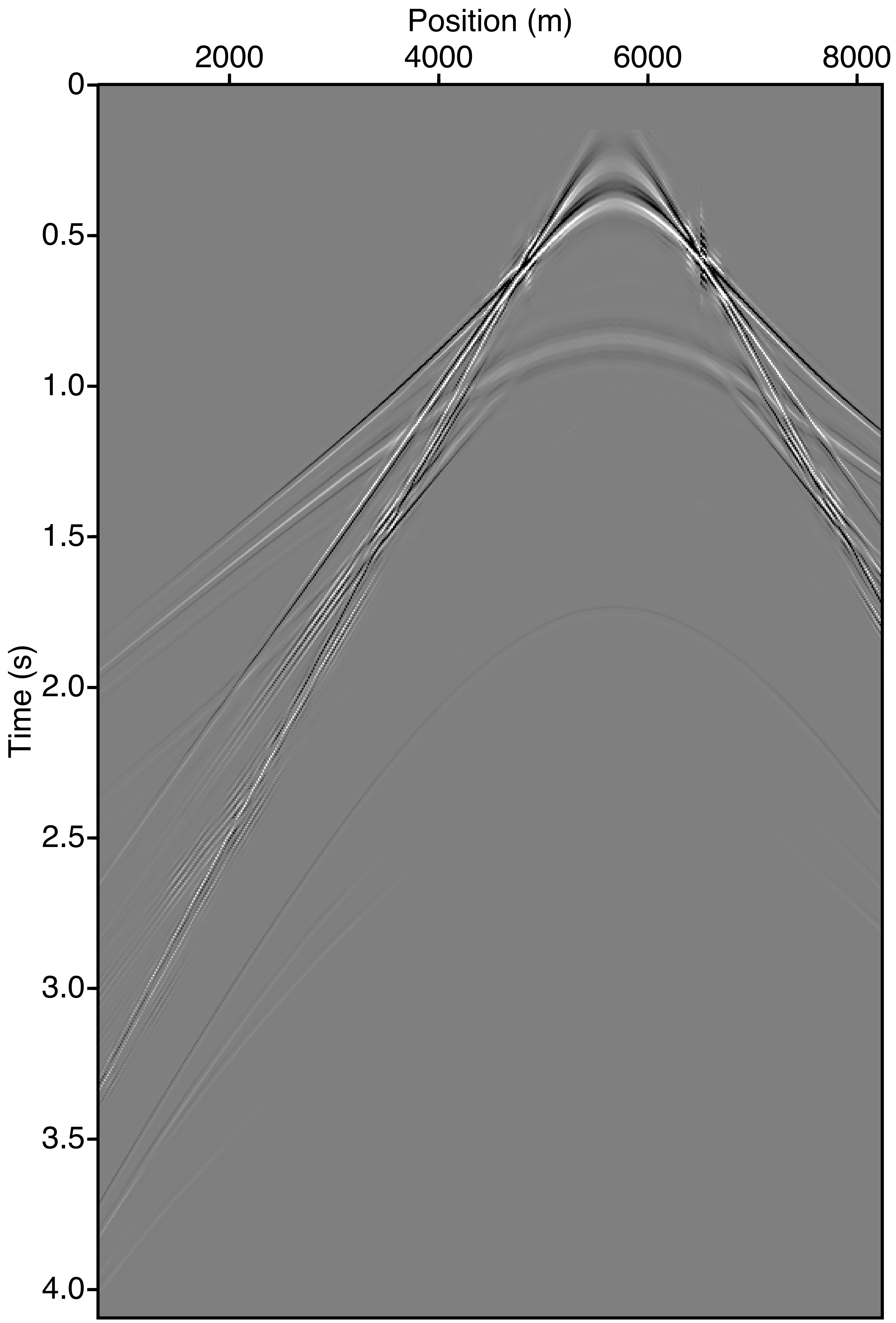
REPSI Primary

SLIM

REPSI "full band"
(only diving wave)
fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, "full band"
modeled w/iWAVE



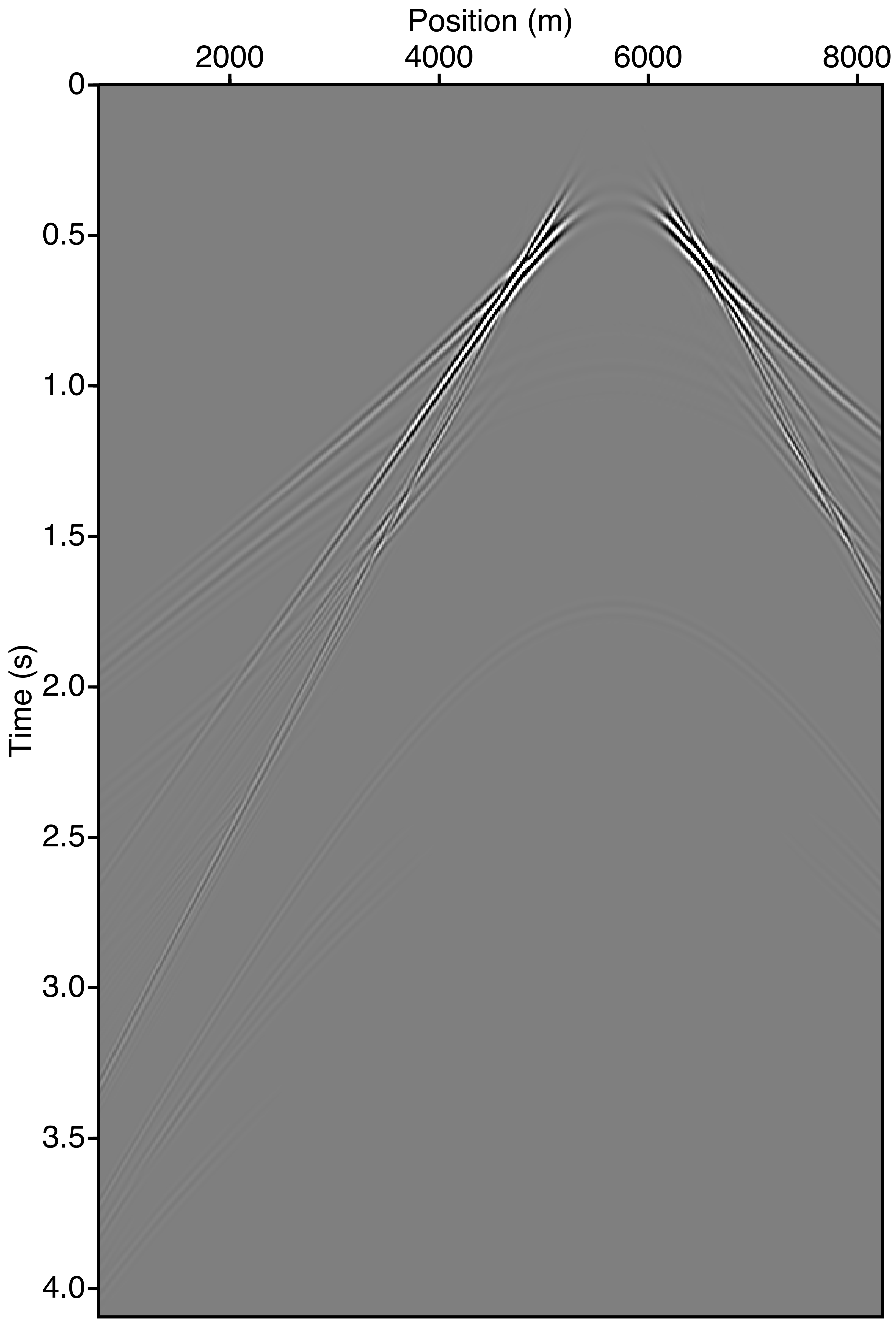
REPSI Primary



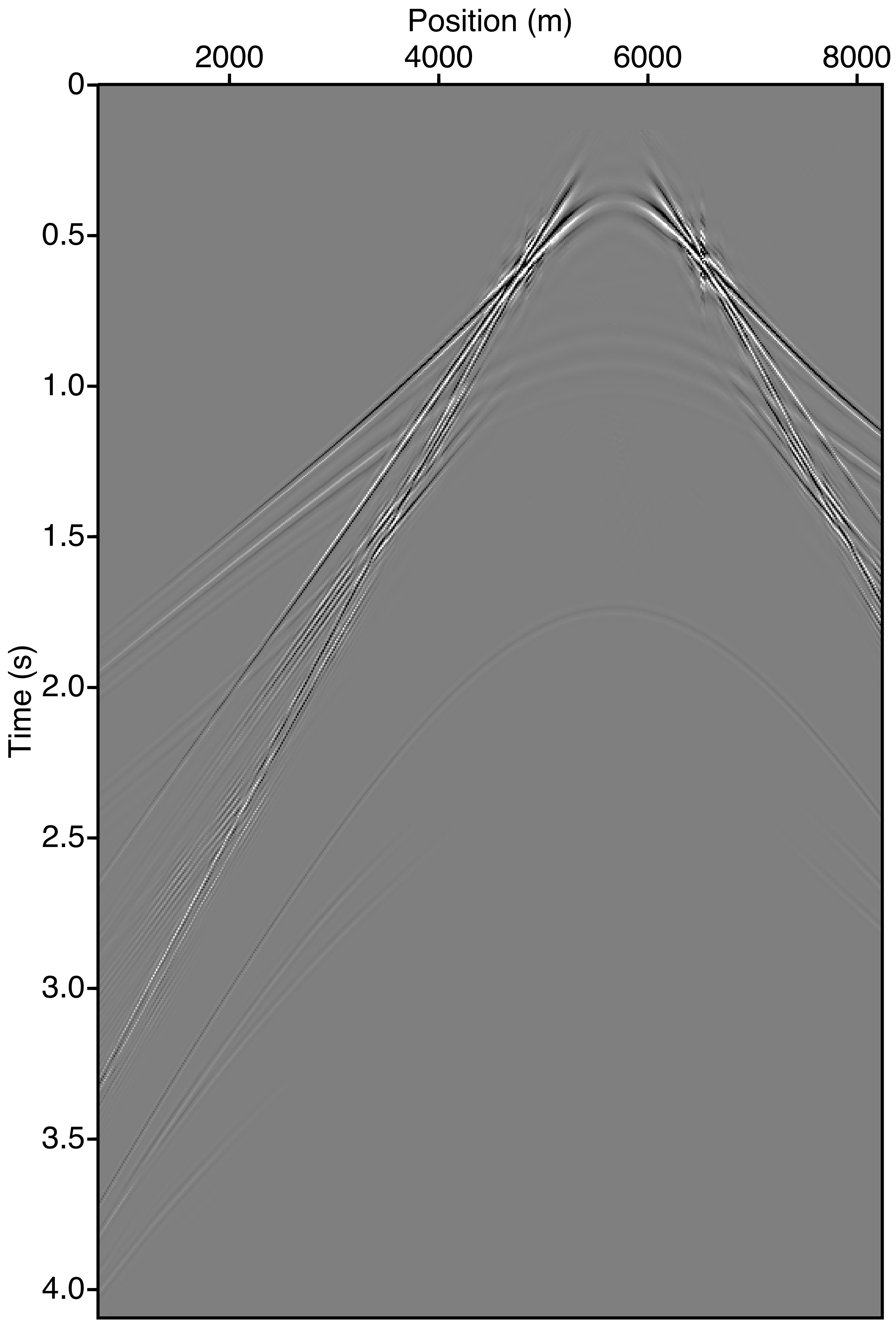
REPSI Primary IR

REPSI “full band”
(only diving wave)

fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, “full band”
modeled w/iWAVE



REPSI Primary

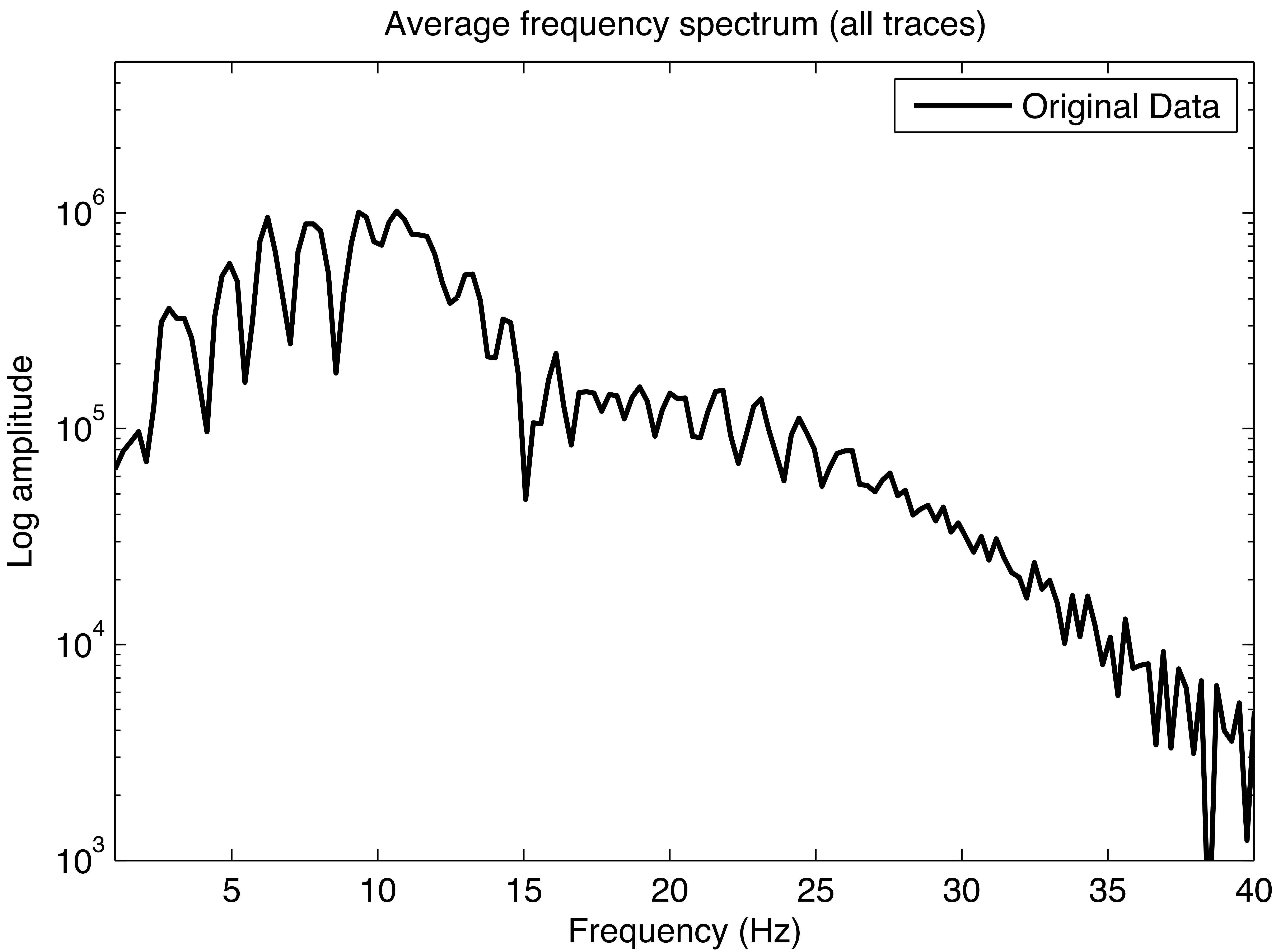


REPSI Primary IR

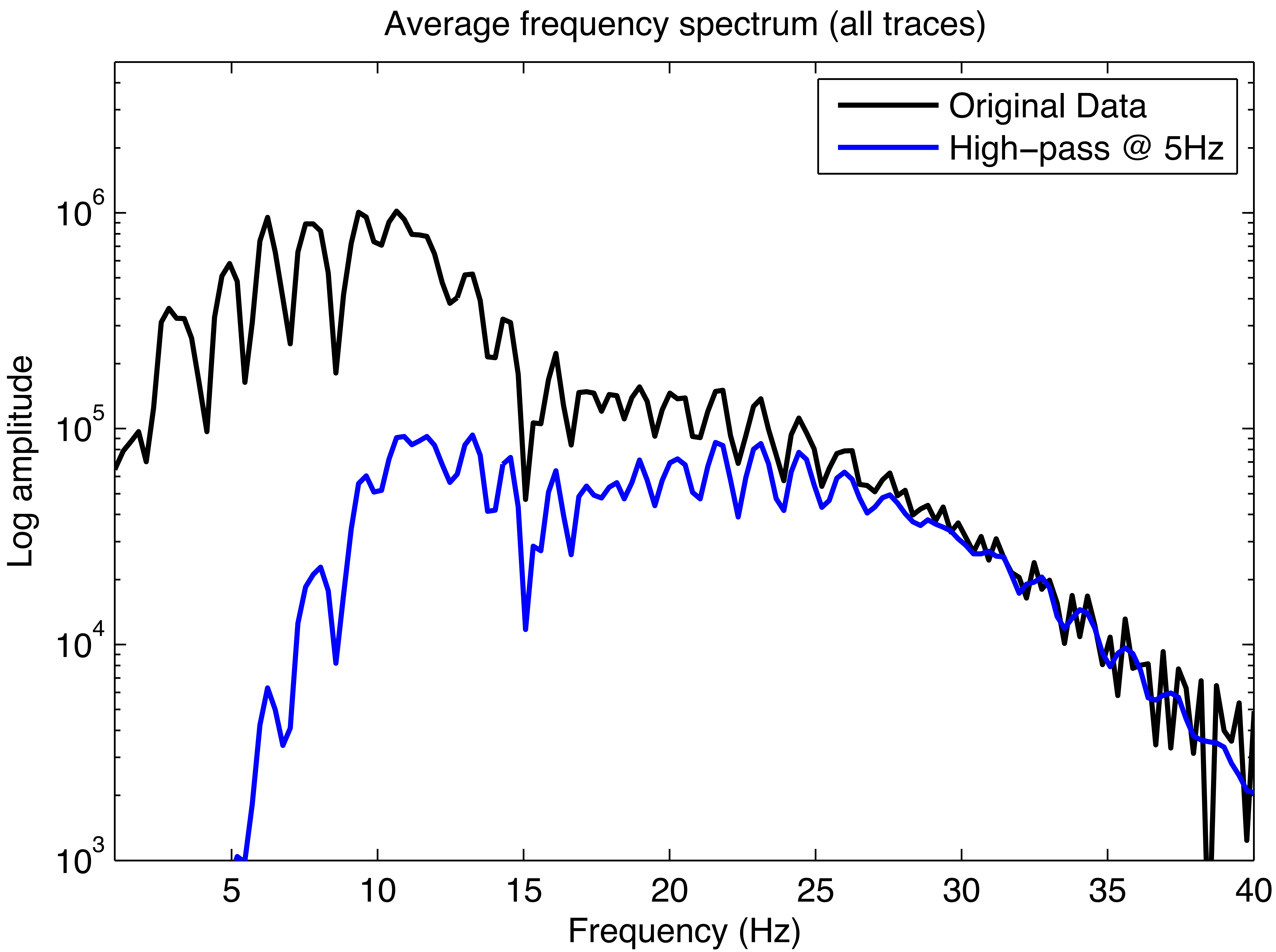
Low cut at 5Hz
(only diving wave)

fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, "full band"
modeled w/iWAVE
Low cut at 5Hz

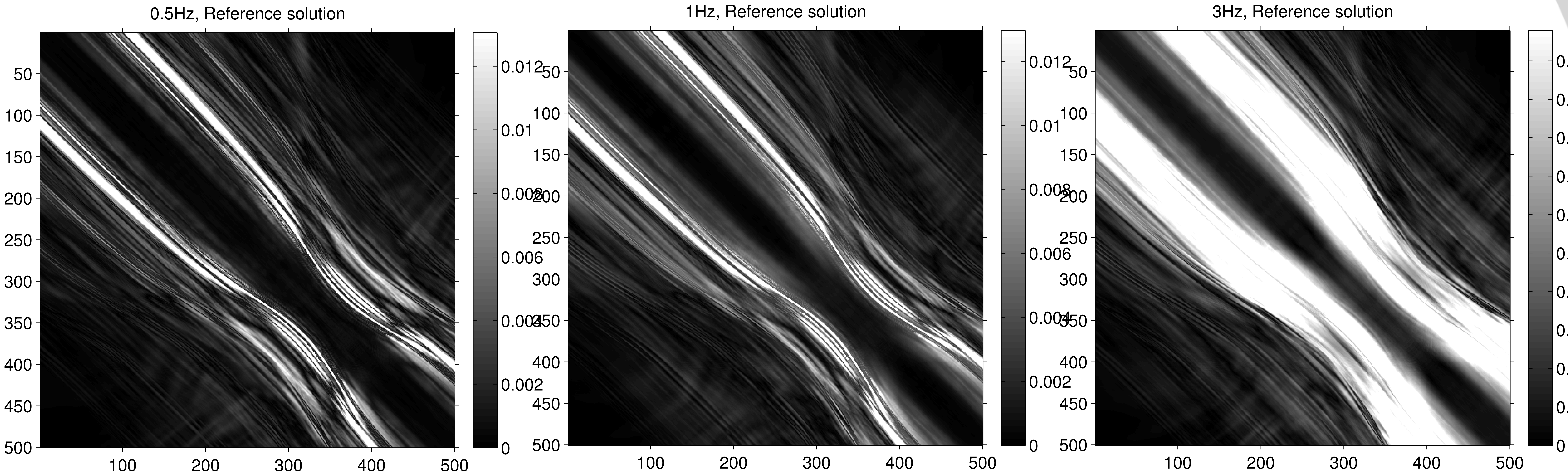
Average trace spectrum



Average trace spectrum



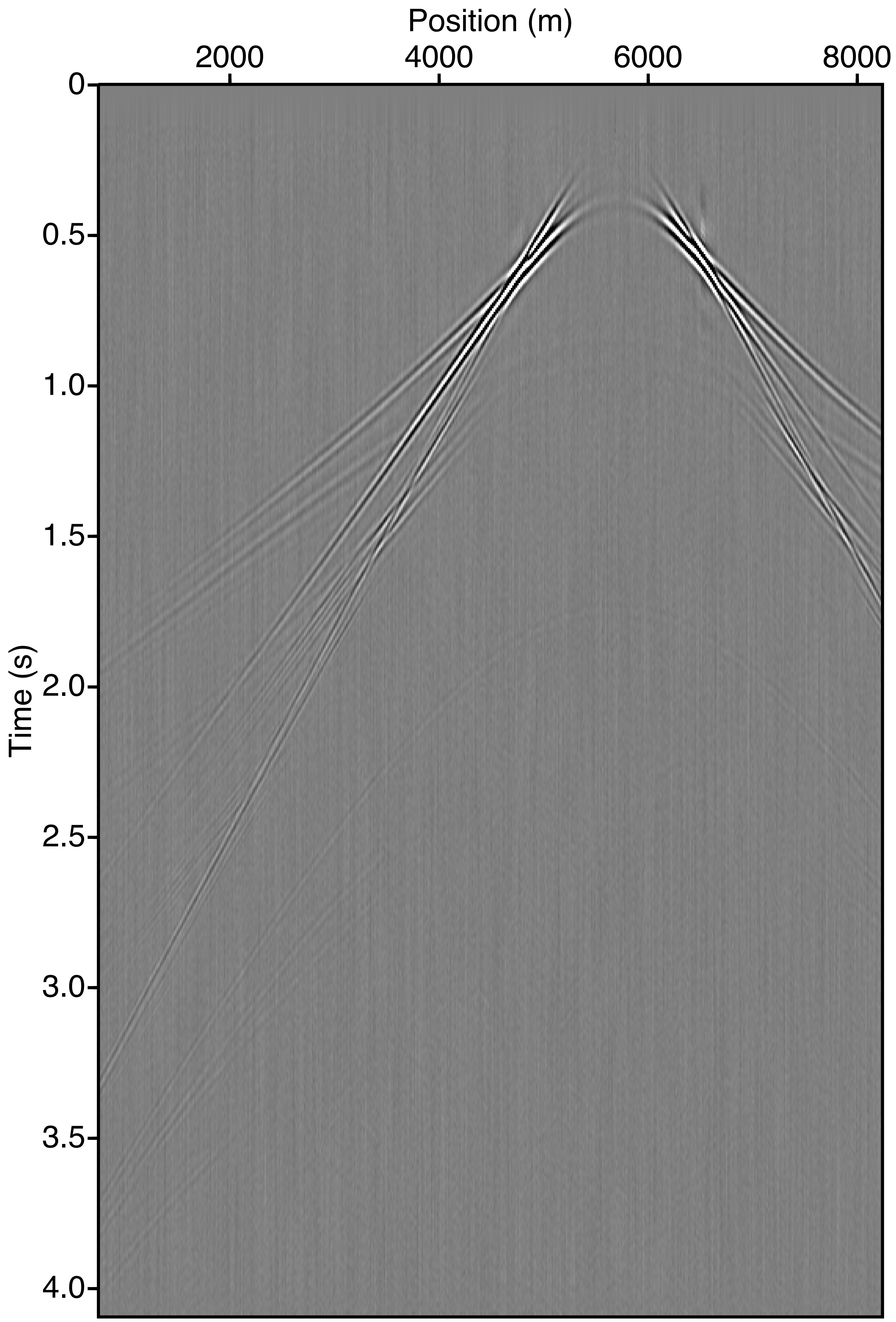
Amplitude Reference solution



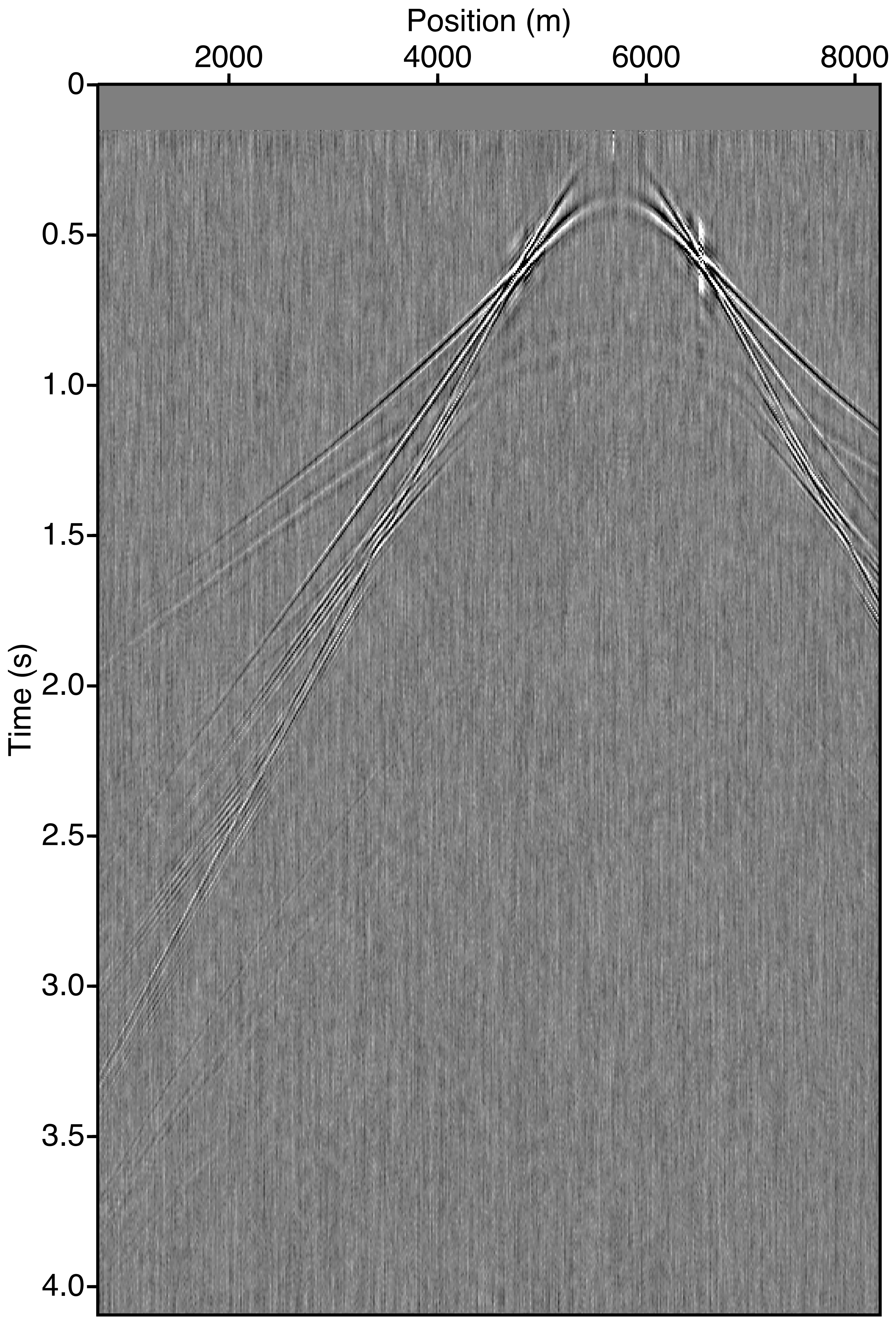
0.5Hz **1 Hz** **3 Hz**

Amplitude Low-cut at 5 Hz

0.5Hz **1 Hz** **3 Hz**



REPSI Primary



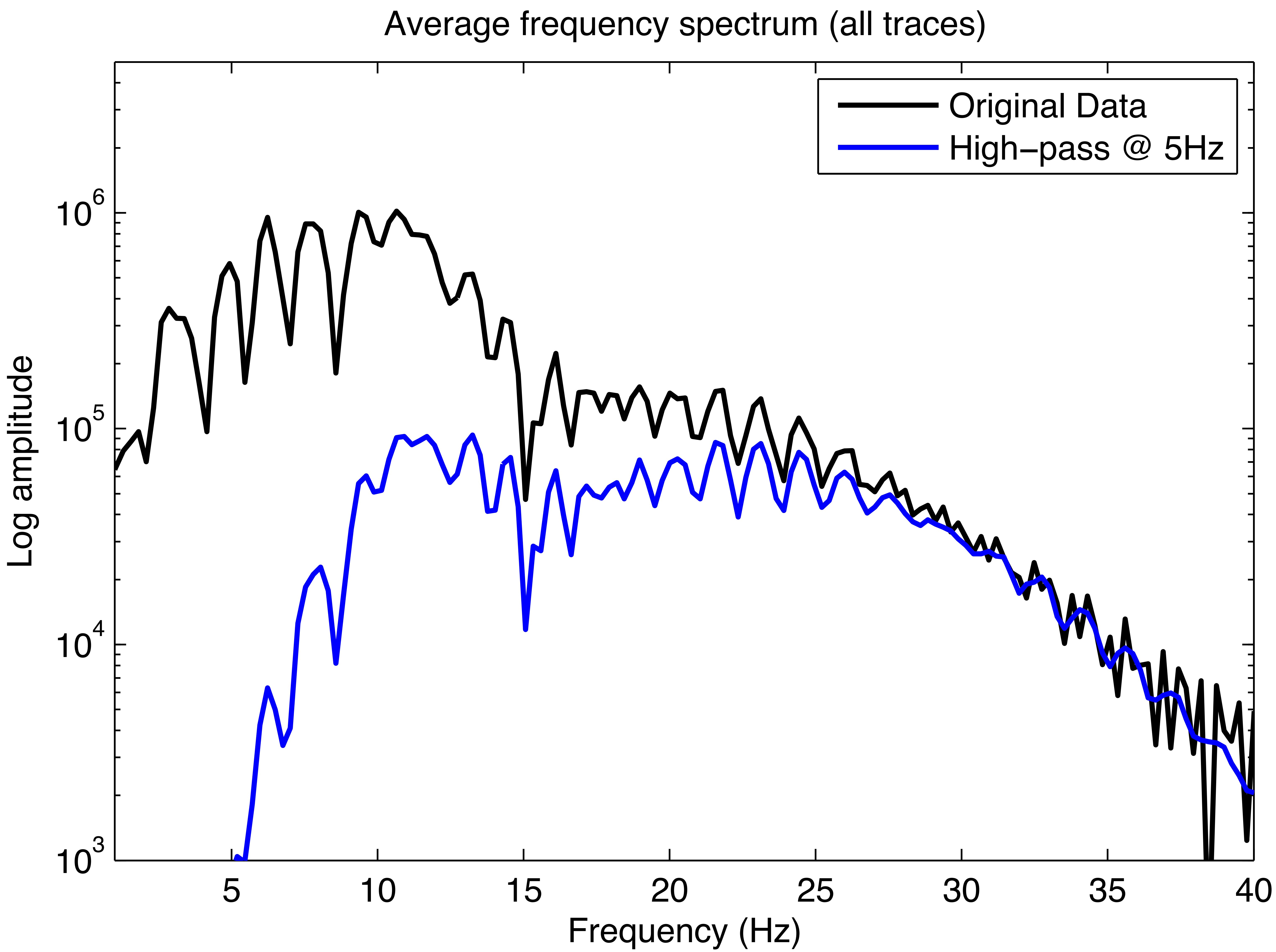
REPSI Primary IR

Low cut at 5Hz + Noise

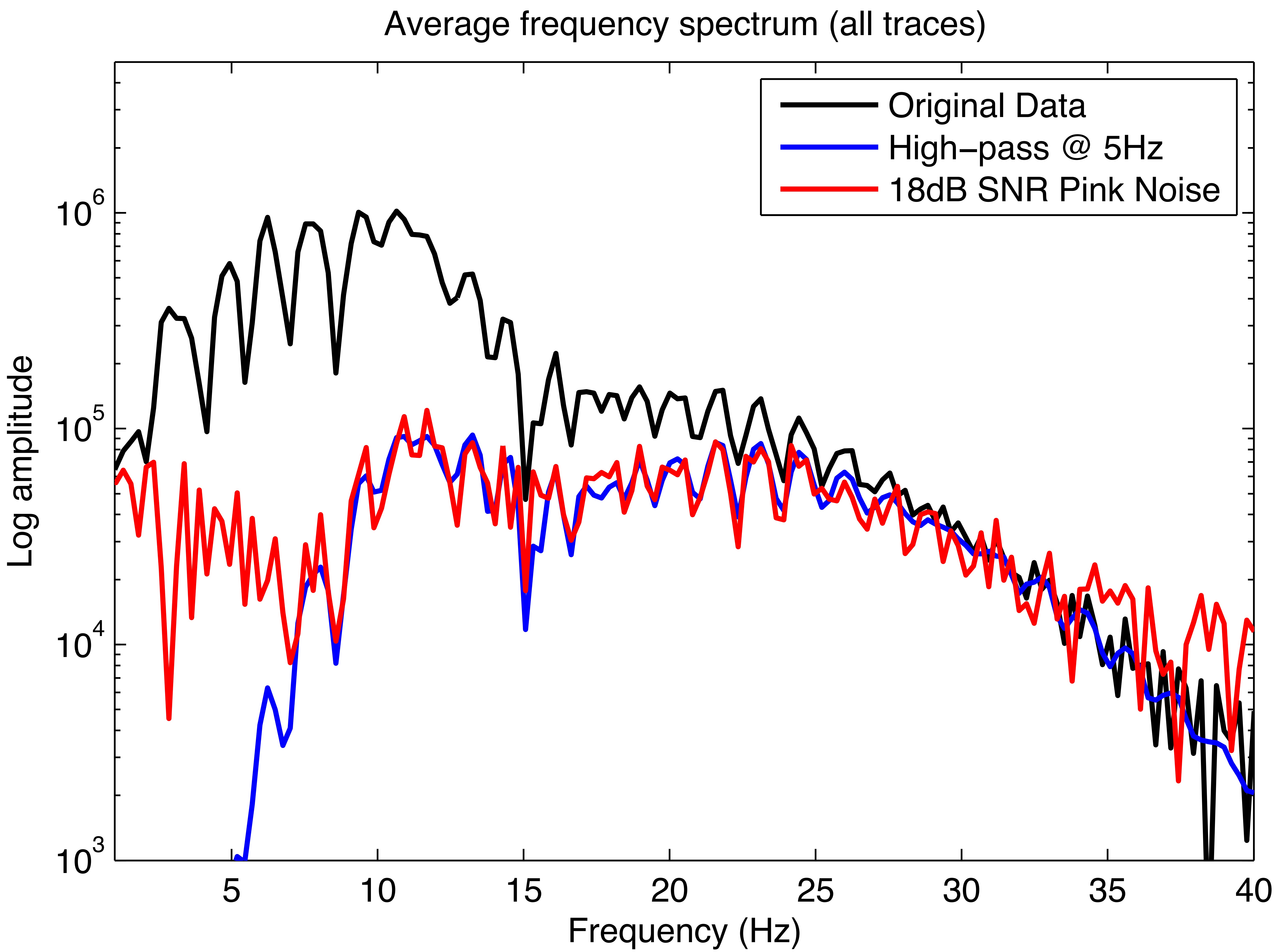
(only diving wave)

fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, "full band"
modeled w/iWAVE
Low cut at 5Hz
18dB pink noise added
(i.d.d. per trace)

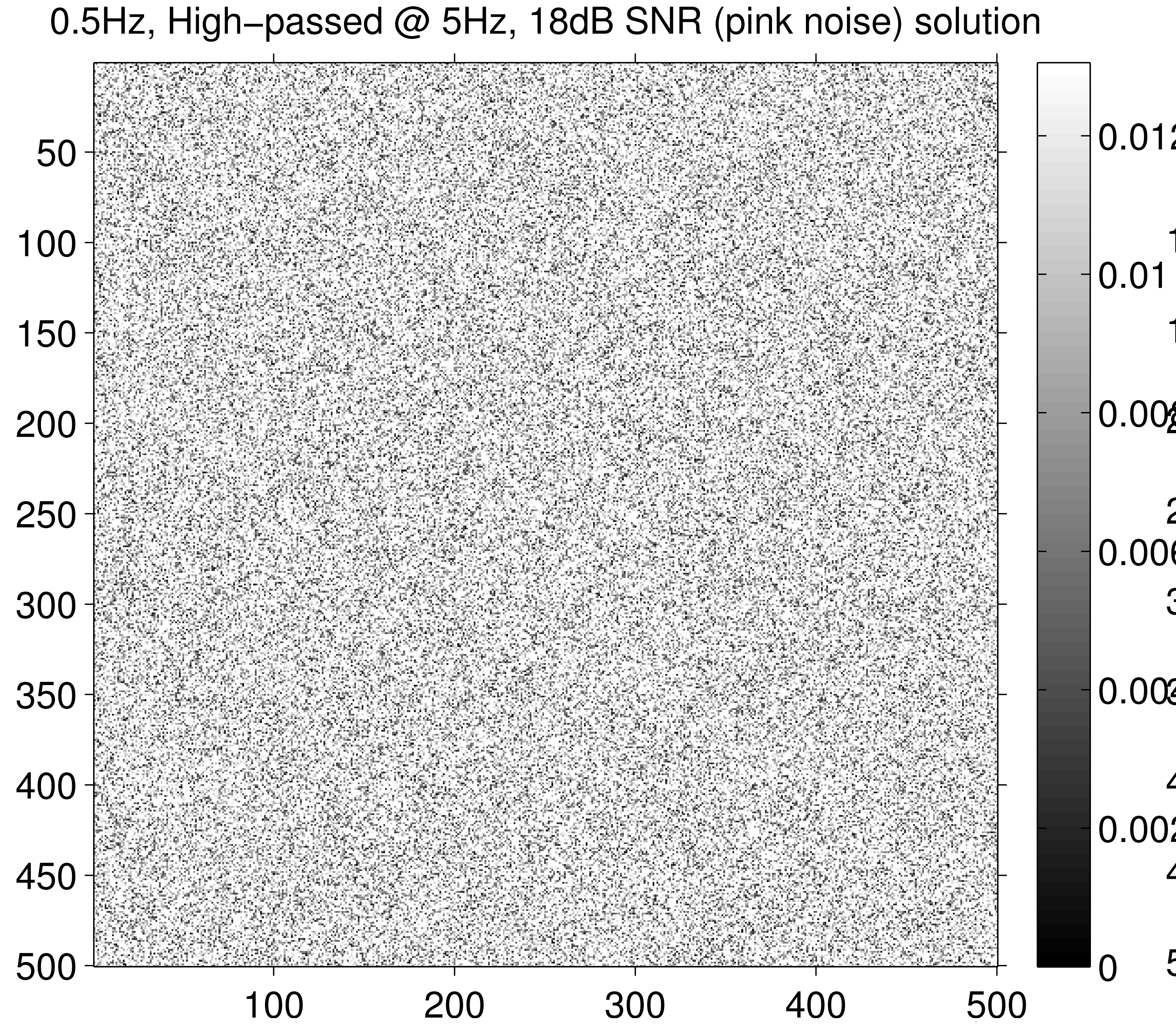
Average trace spectrum



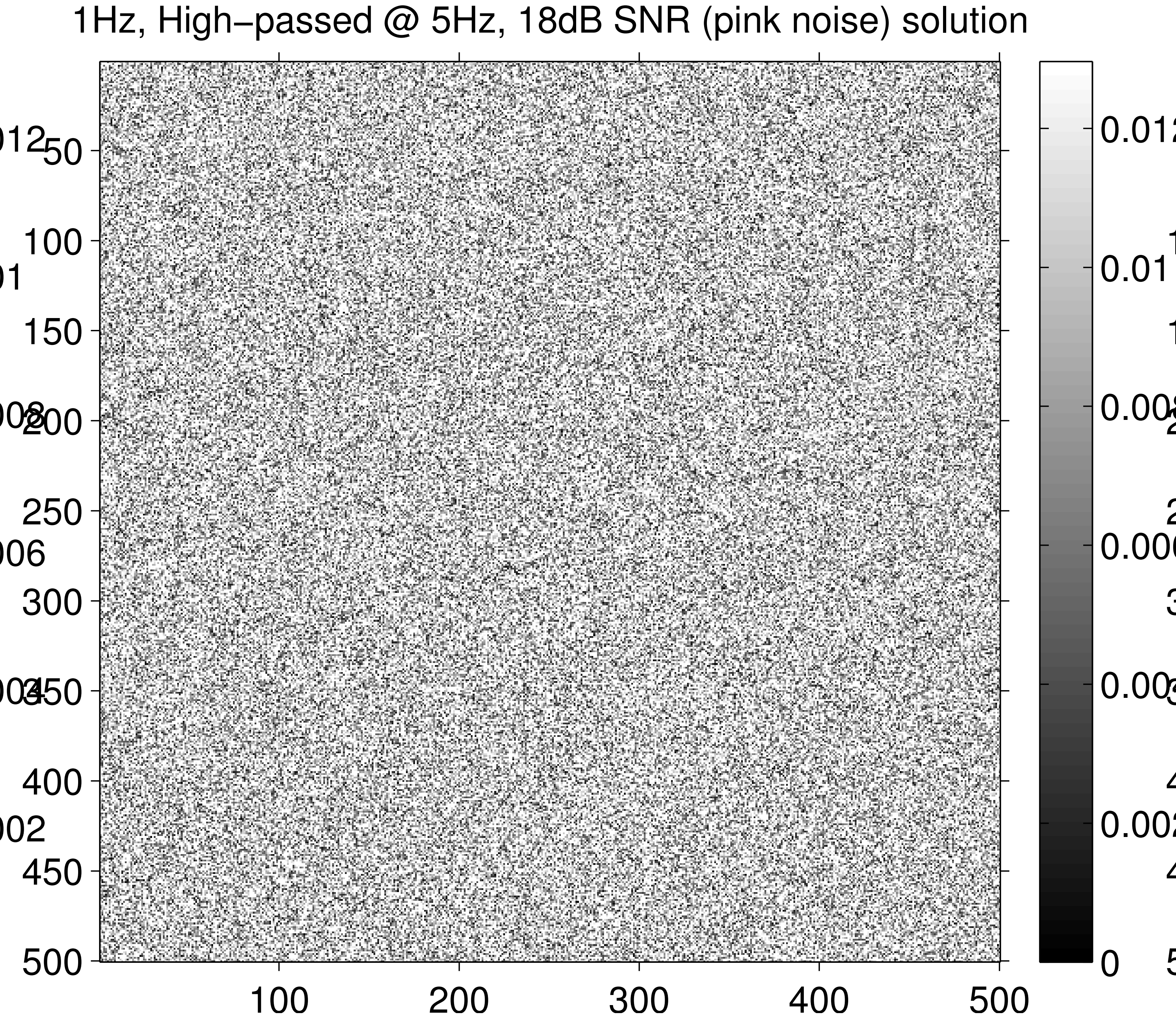
Average trace spectrum



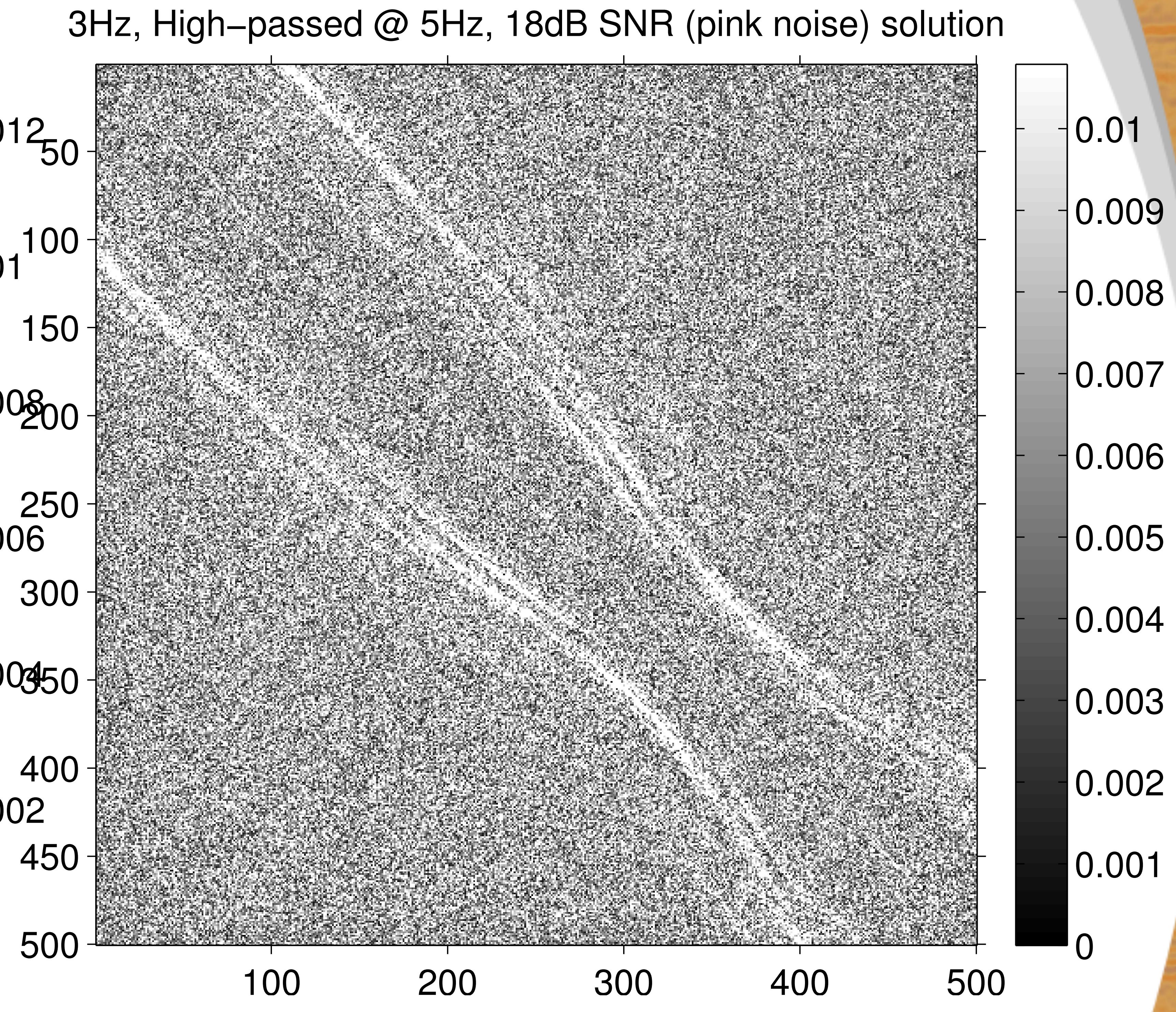
Amplitude Low-cut at 5 Hz, 18dB Pink noise added



0.5Hz

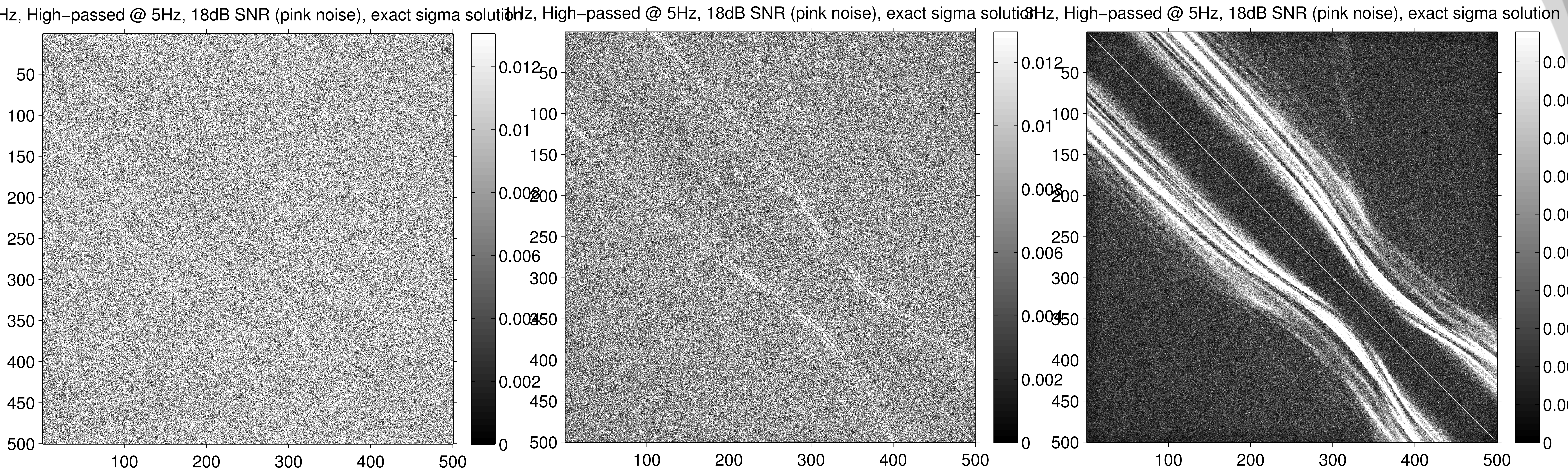


1 Hz

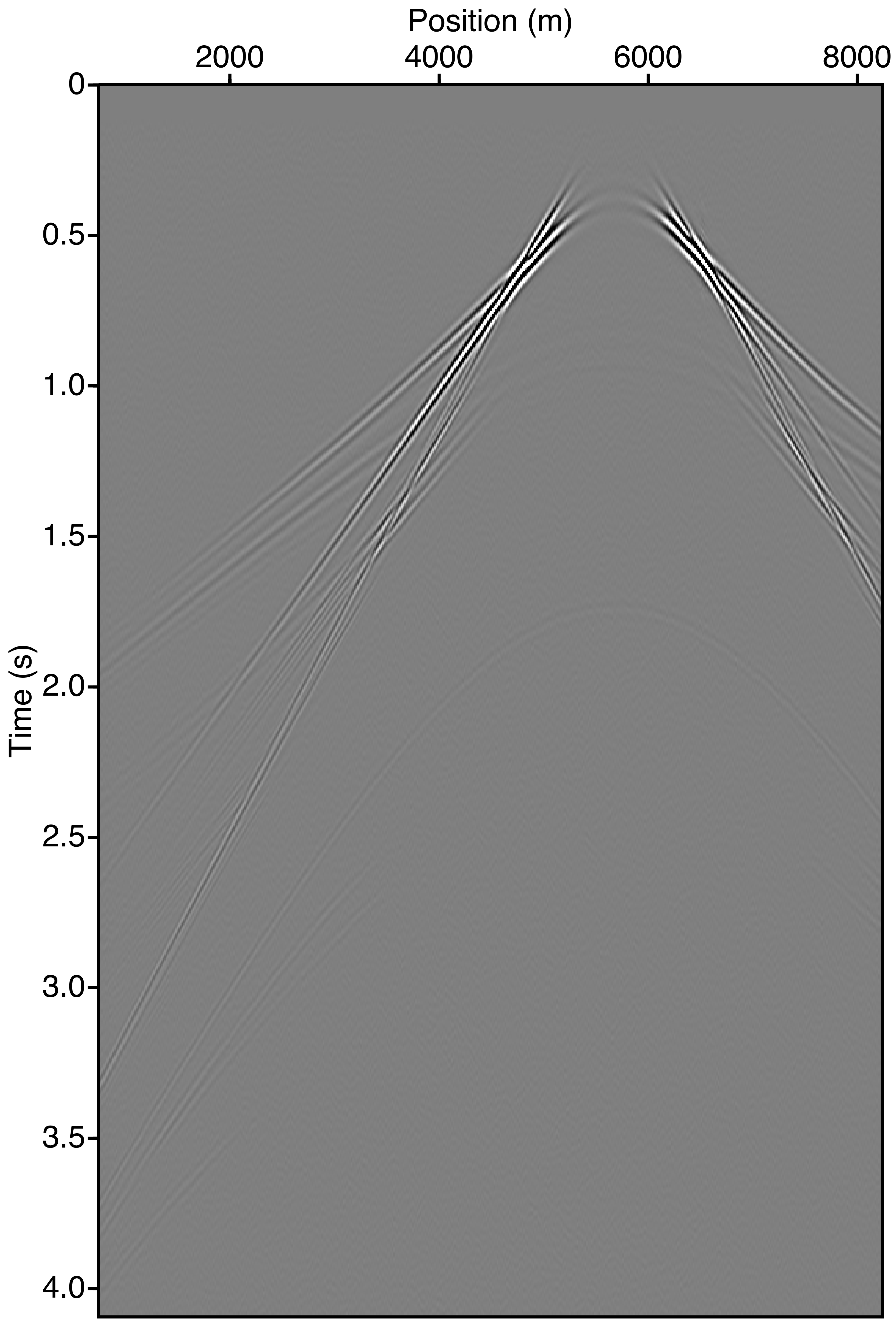


3 Hz

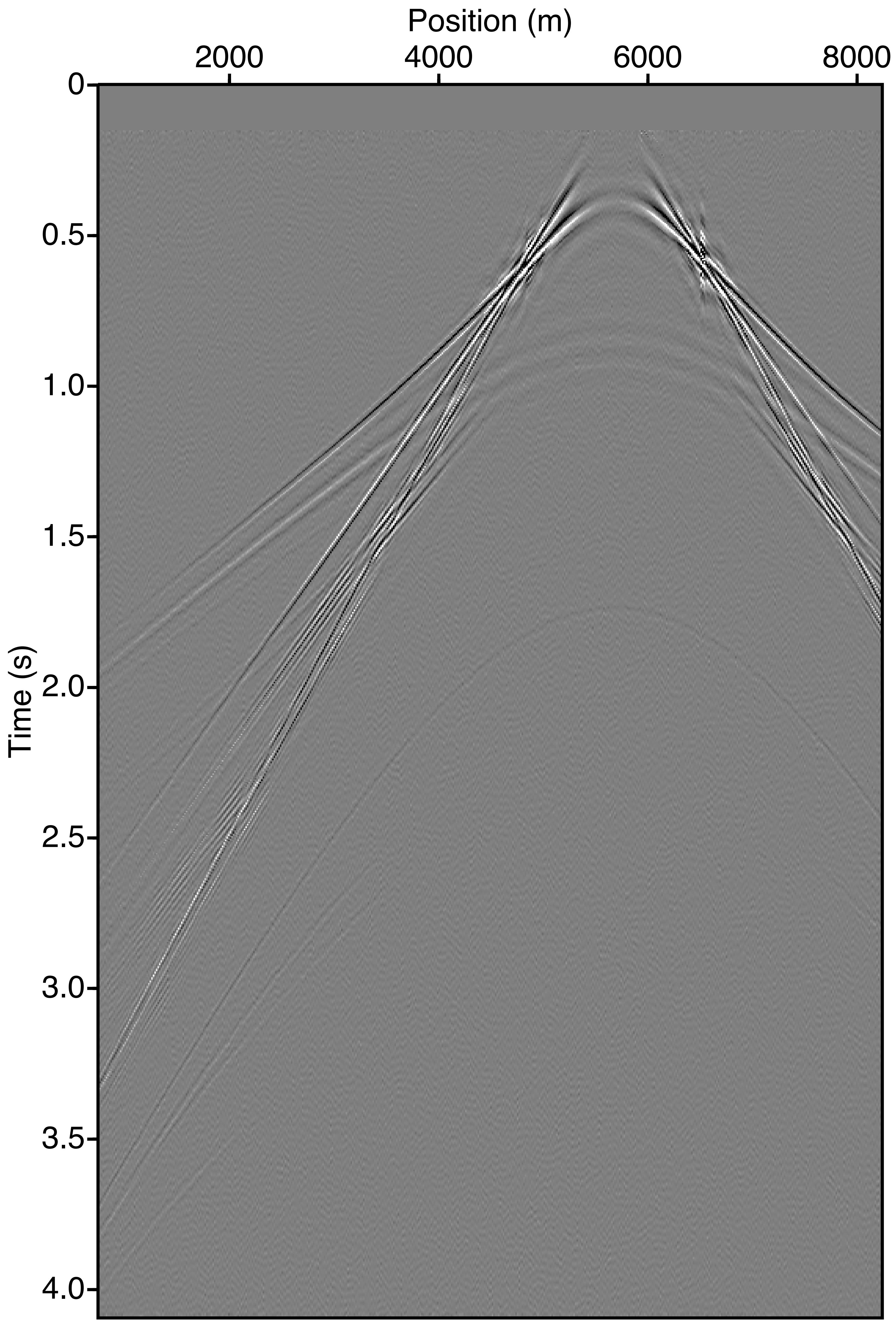
Amplitude Low-cut at 5 Hz, 18dB Pink noise added (solved to exact sigma)



0.5Hz **1 Hz** **3 Hz**



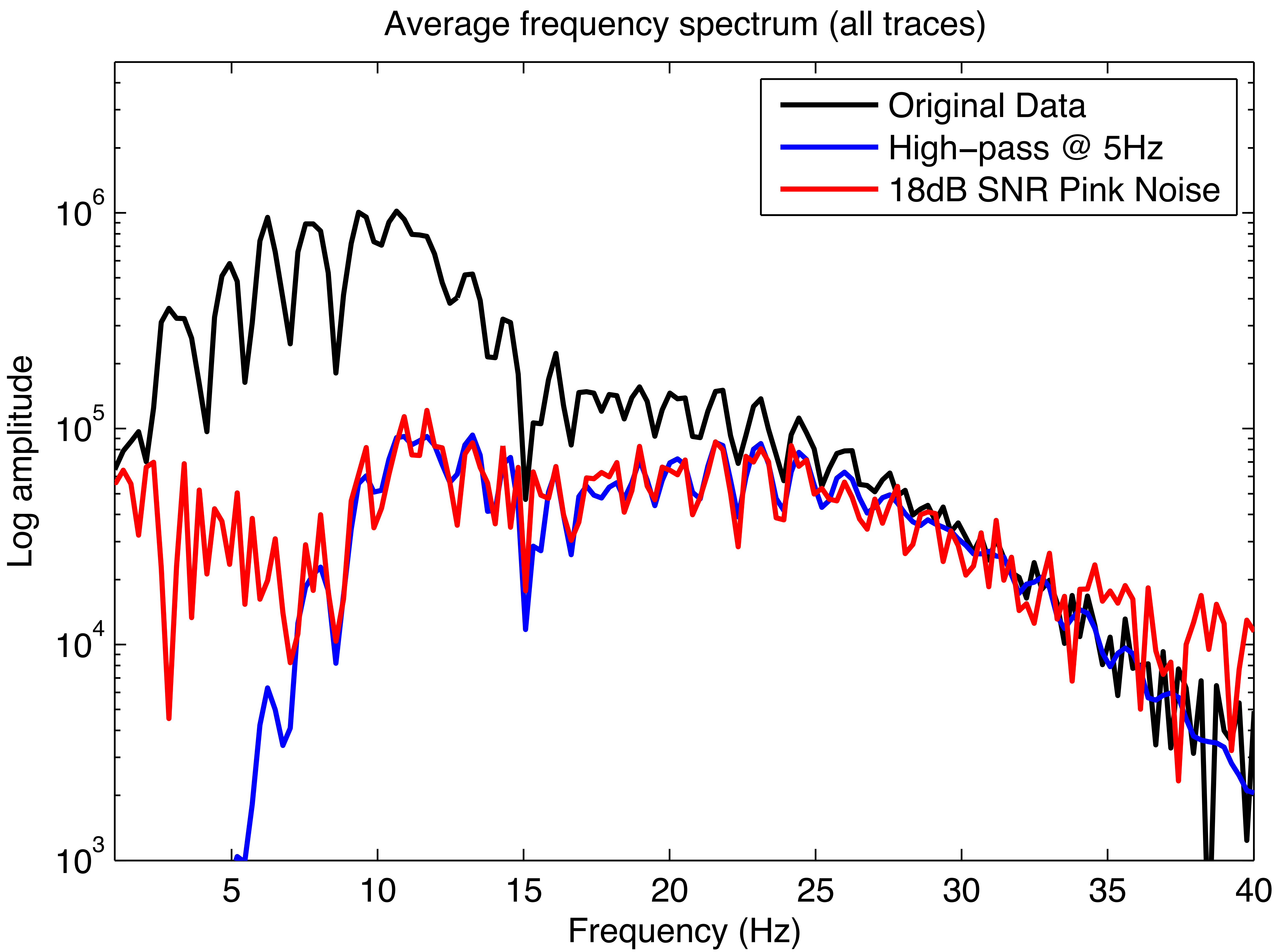
REPSI Primary



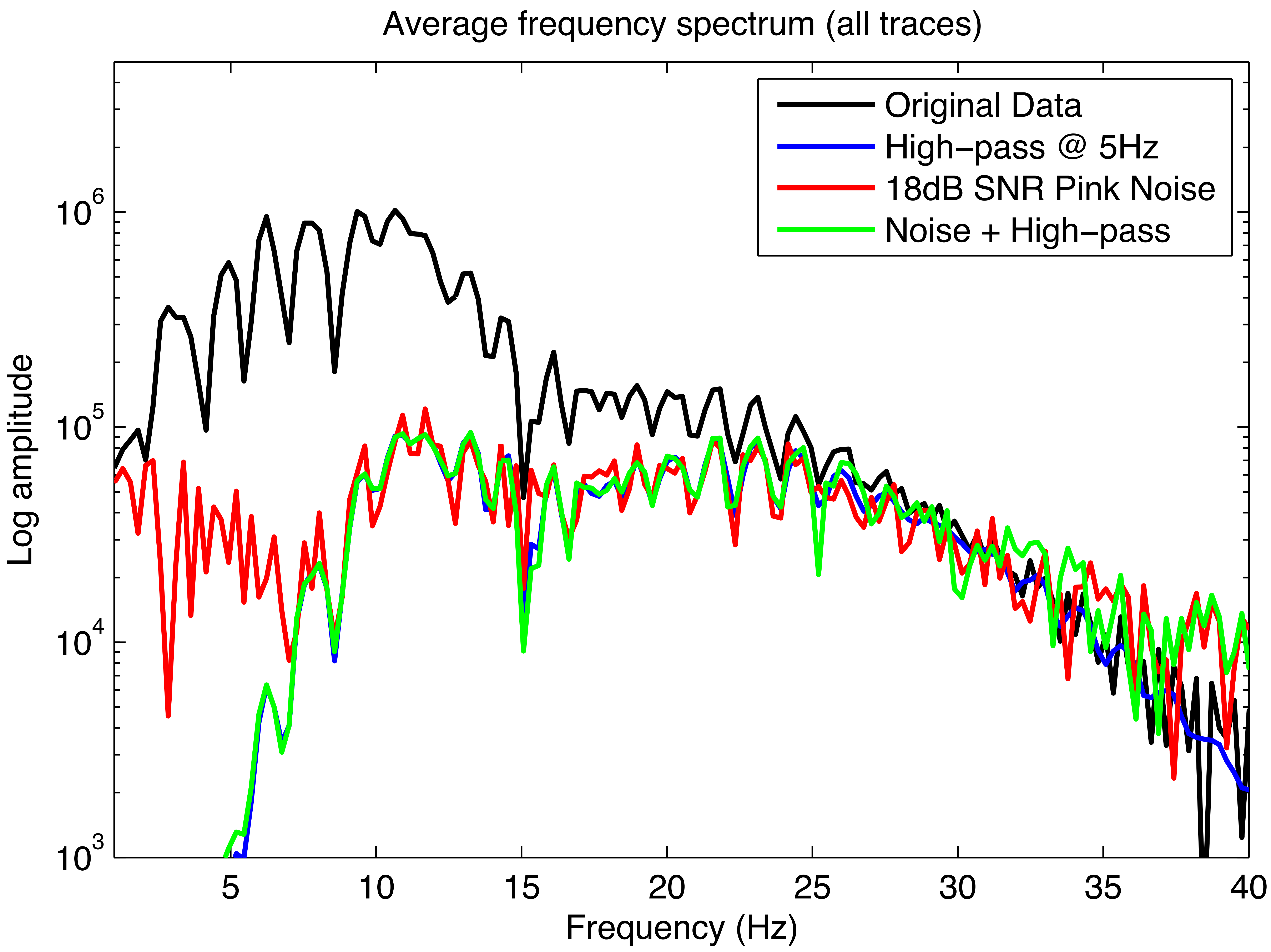
REPSI Primary IR

Noise + Low cut at 5Hz
(only diving wave)
fixed spread of 7.5km
ds=dr=15m
15Hz Ricker, “full band”
modeled w/iWAVE
18dB pink noise added (i.d.d. per trace)
Low cut at 5Hz
(low-cut *after* noise is added)

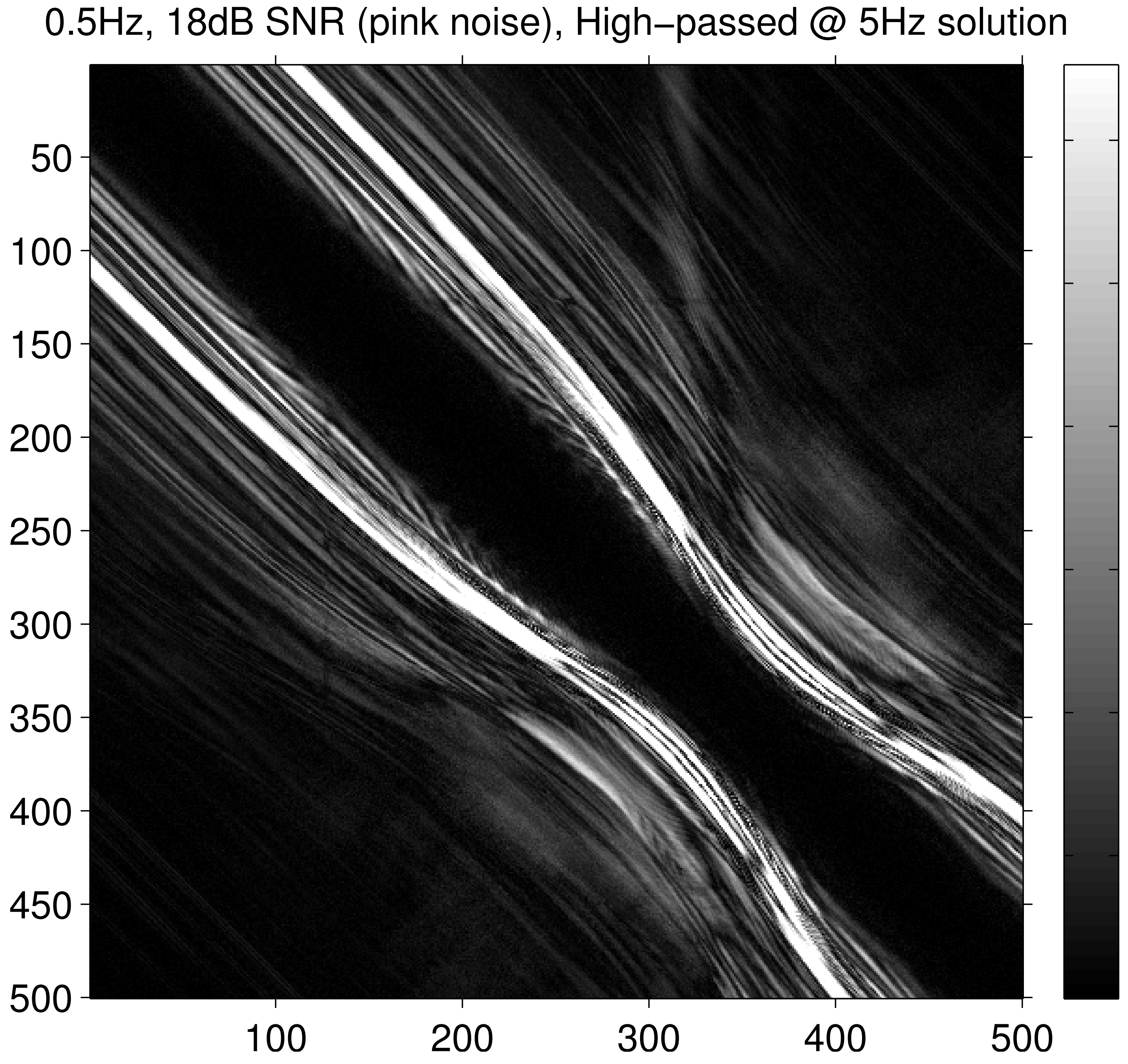
Average trace spectrum



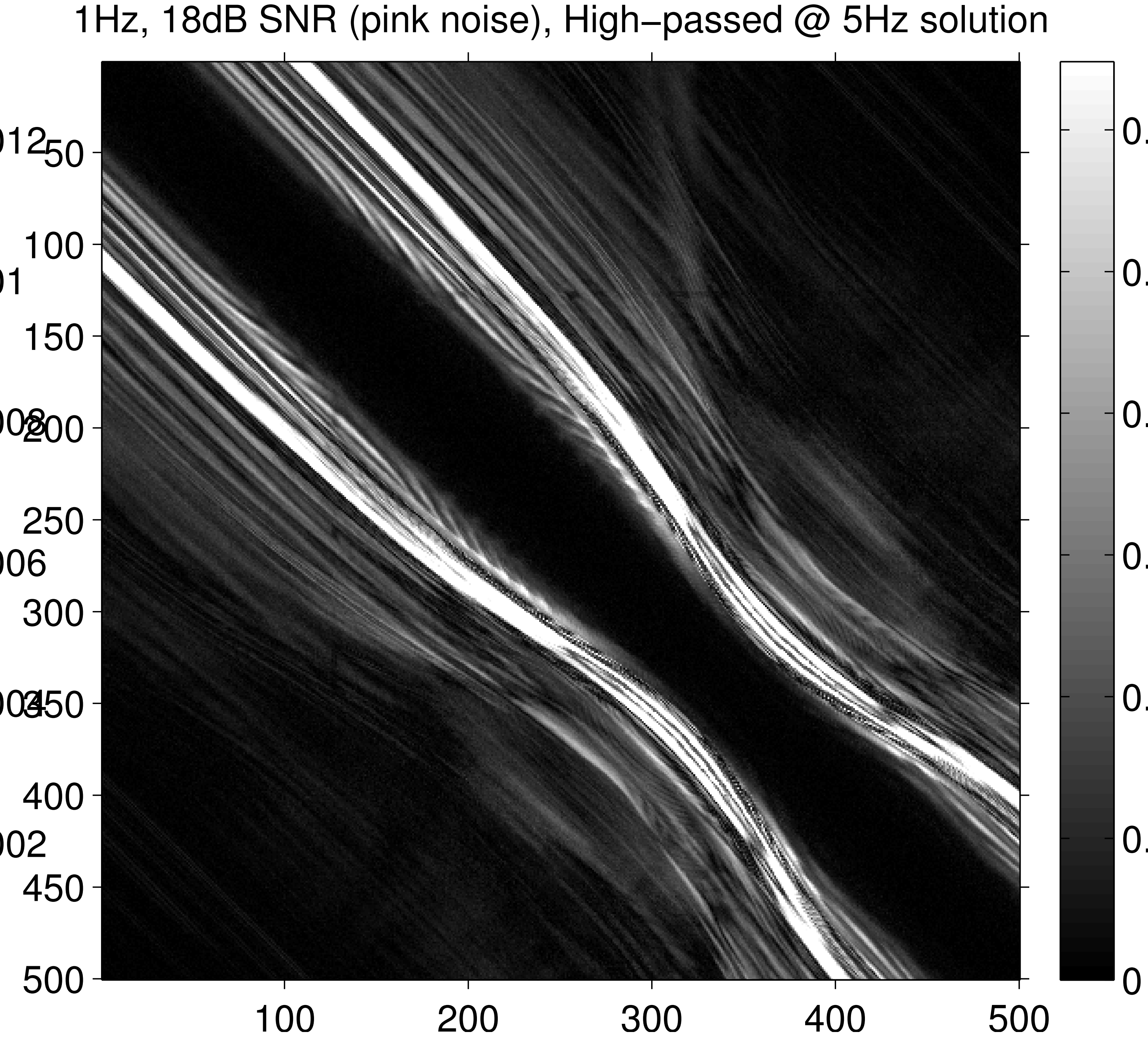
Average trace spectrum



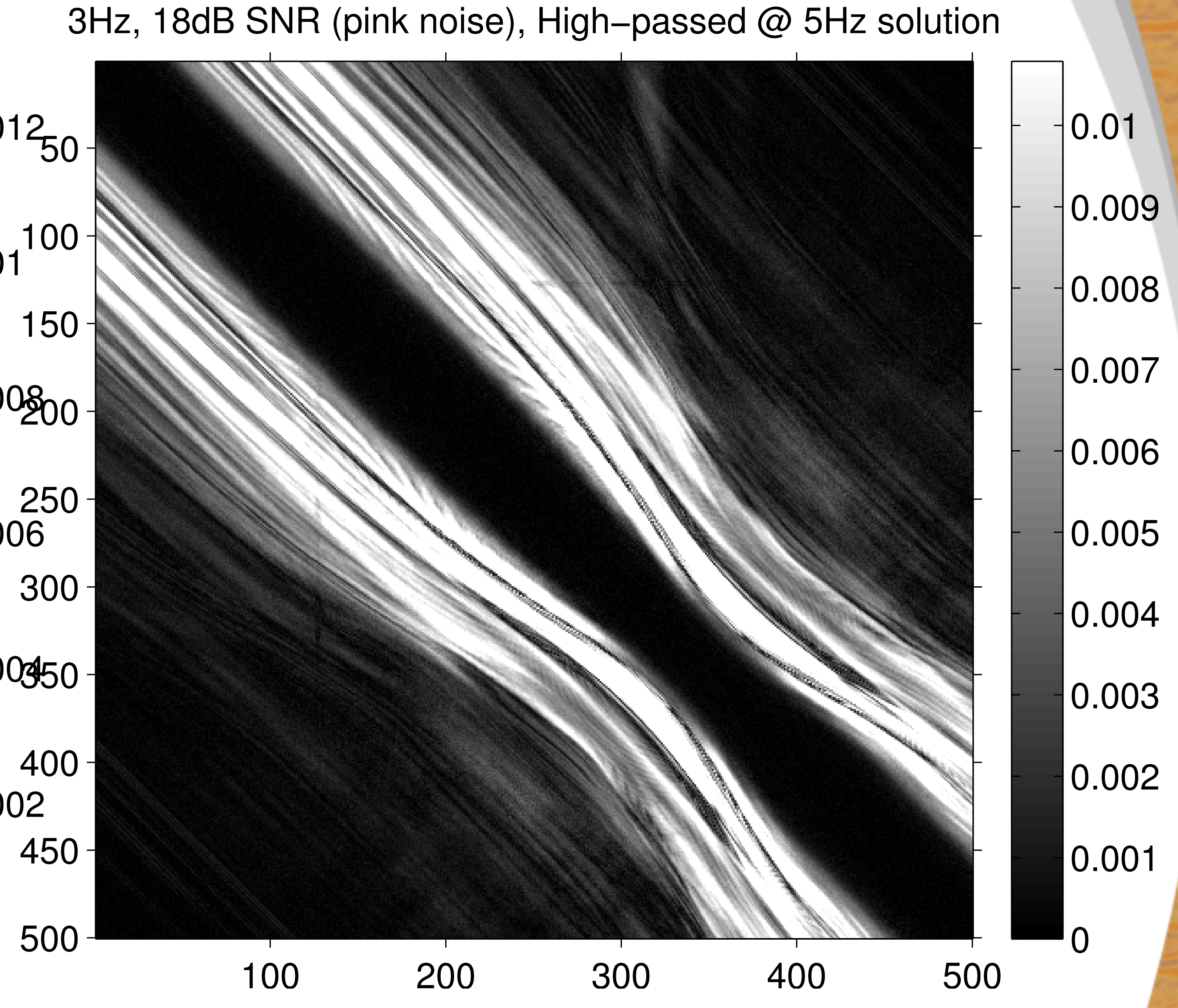
Amplitude 18dB Pink noise added, Low-cut at 5 Hz



0.5Hz

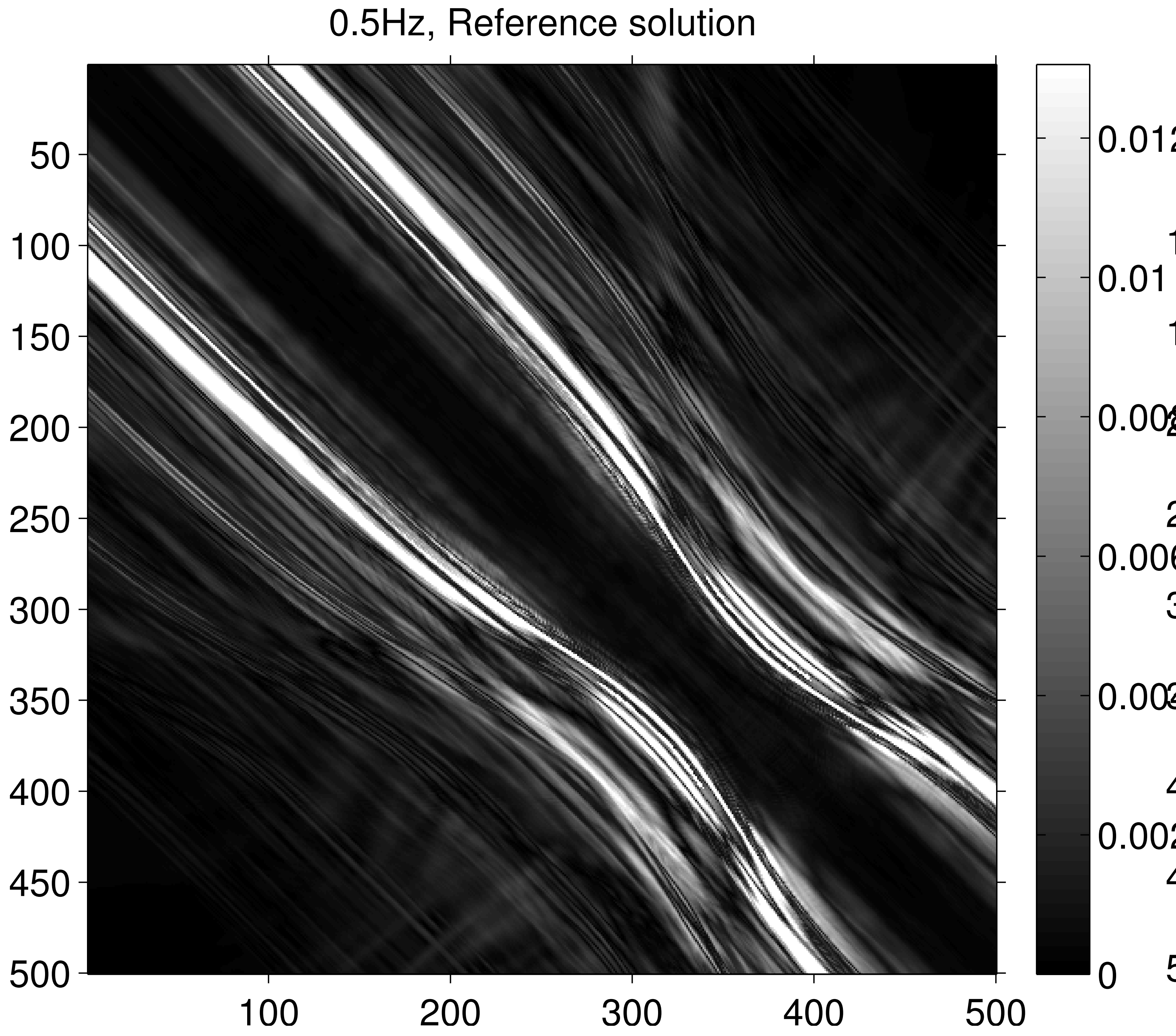


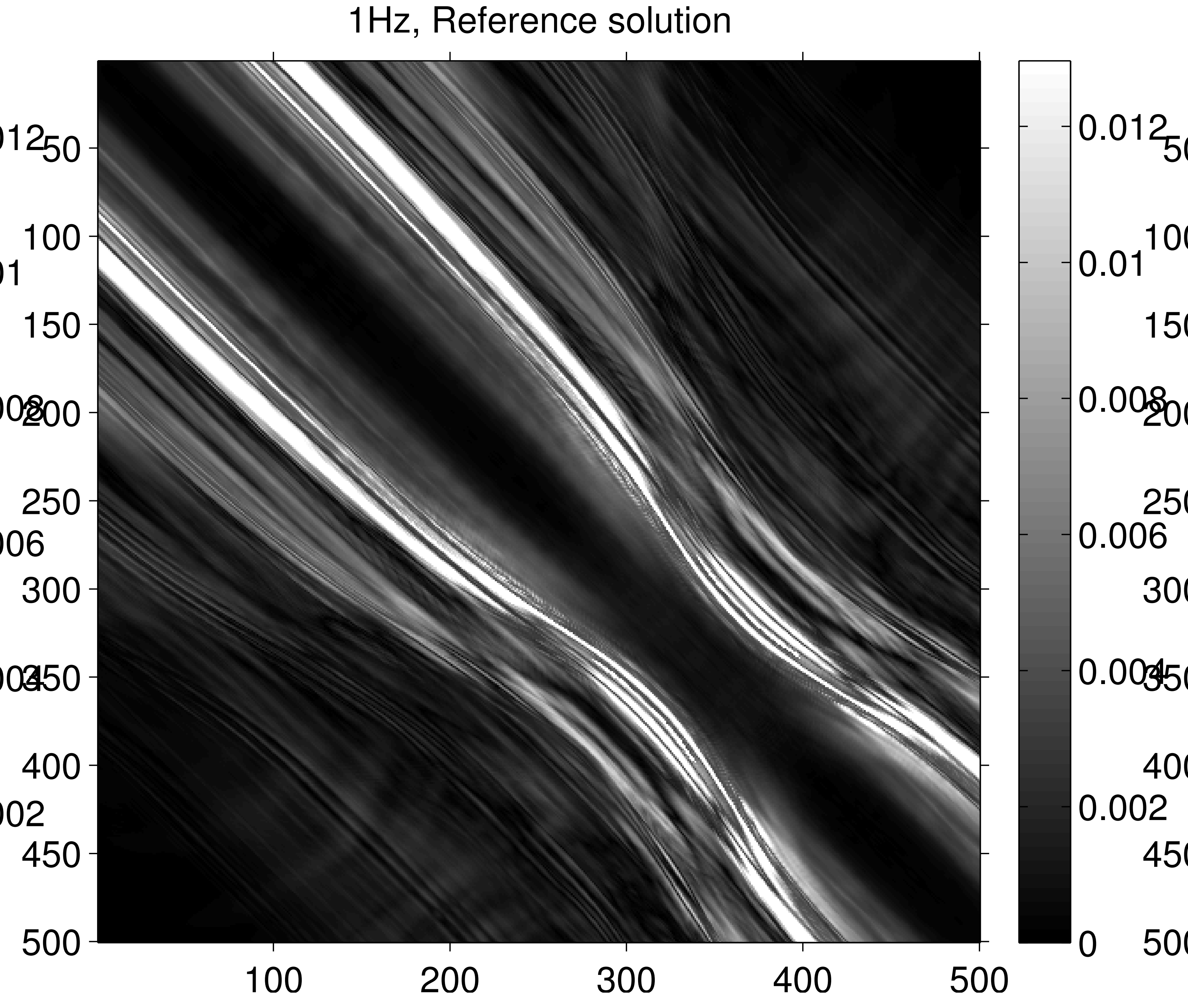
1 Hz

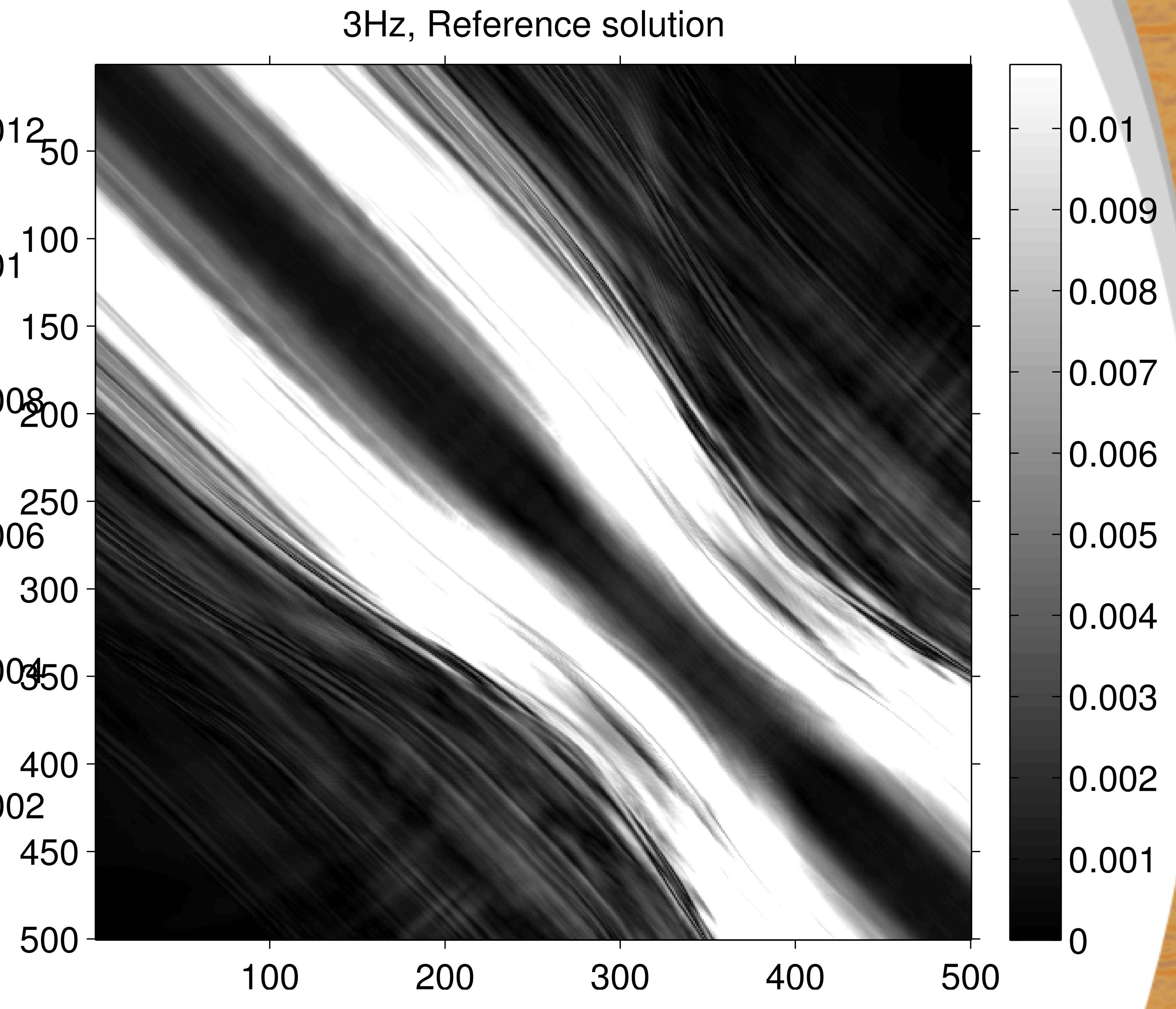


3 Hz

Amplitude Reference solution





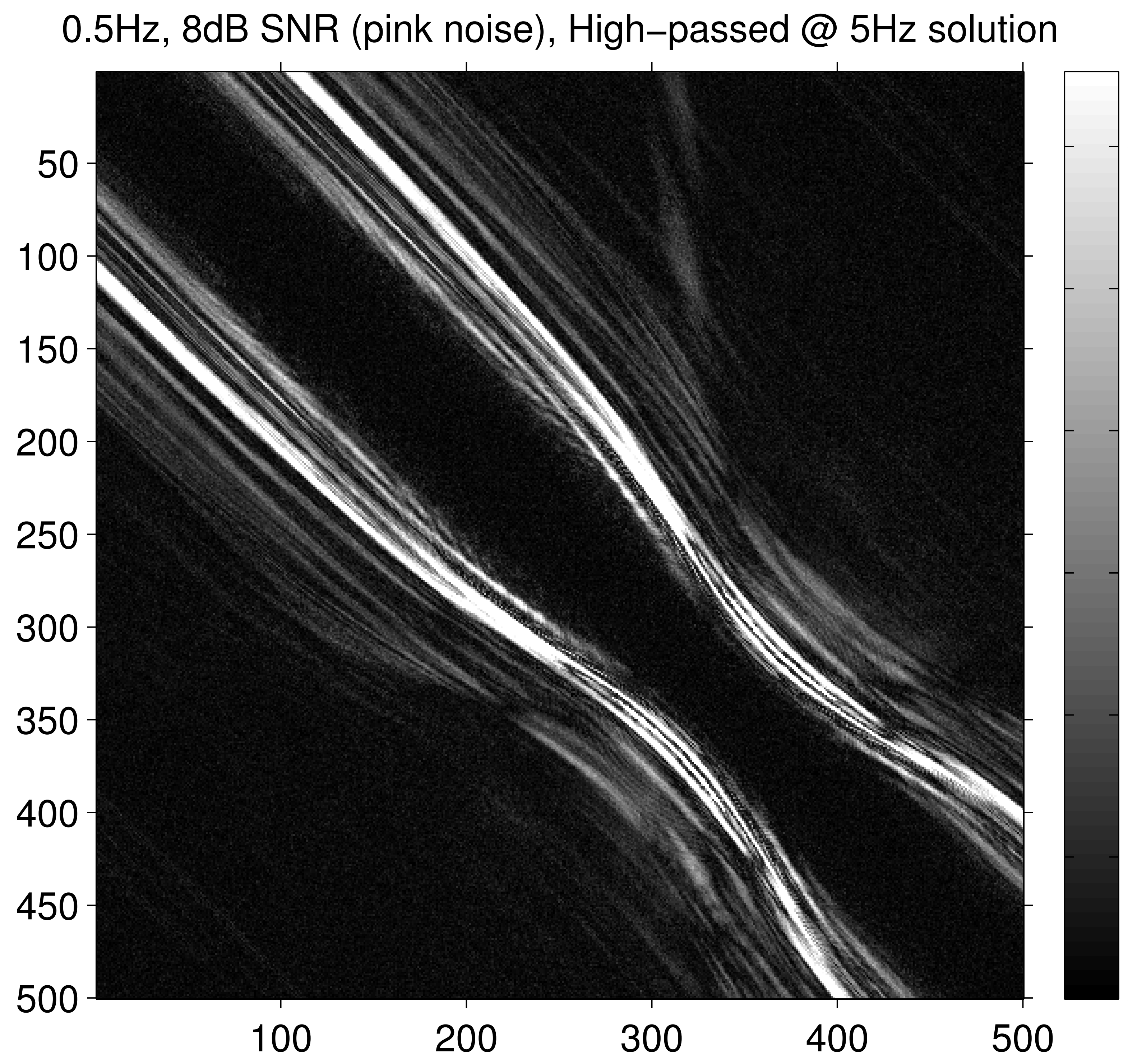


0.5Hz

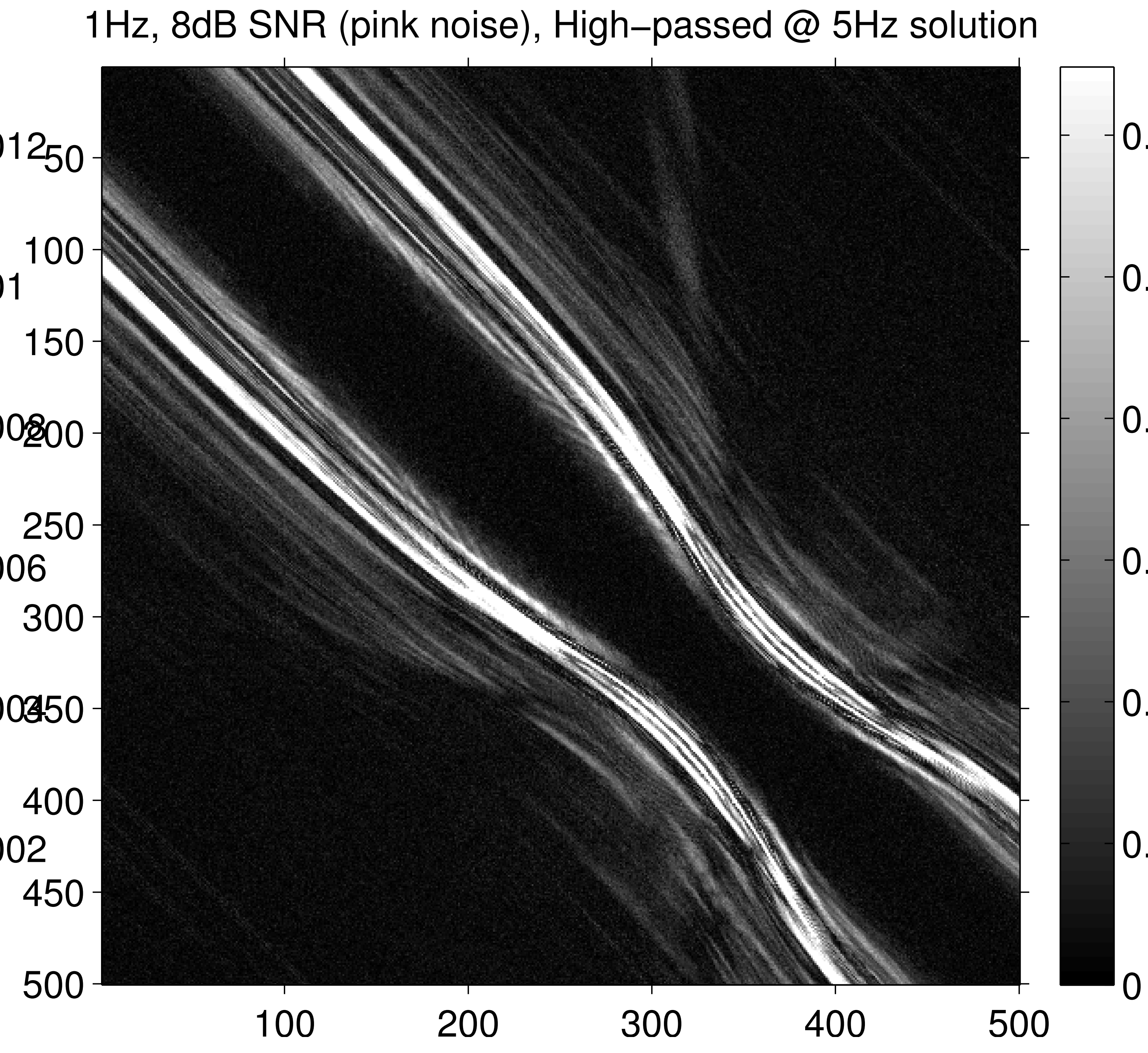
1 Hz

3 Hz

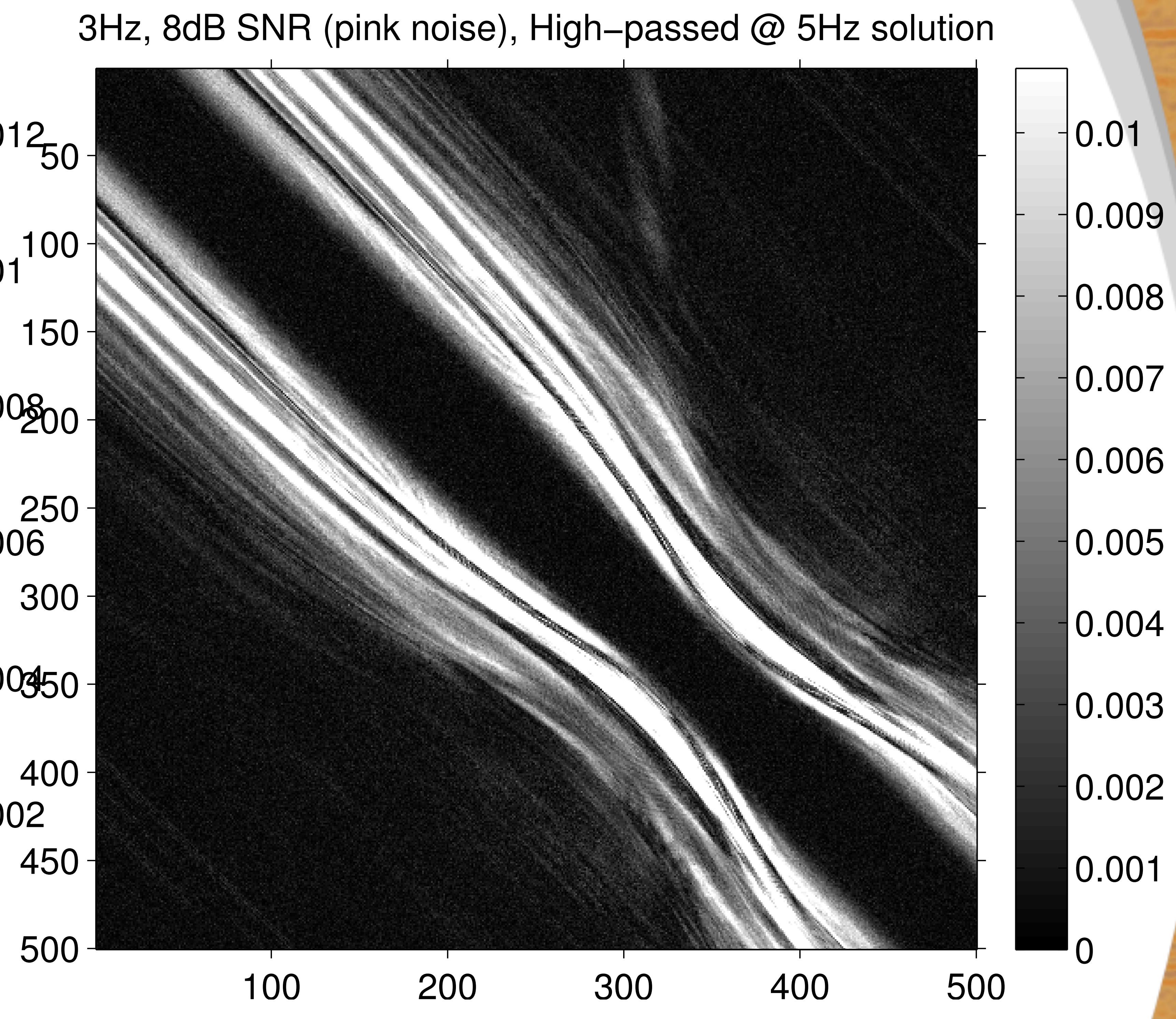
Amplitude 8dB Pink noise added, Low-cut at 5 Hz



0.5Hz

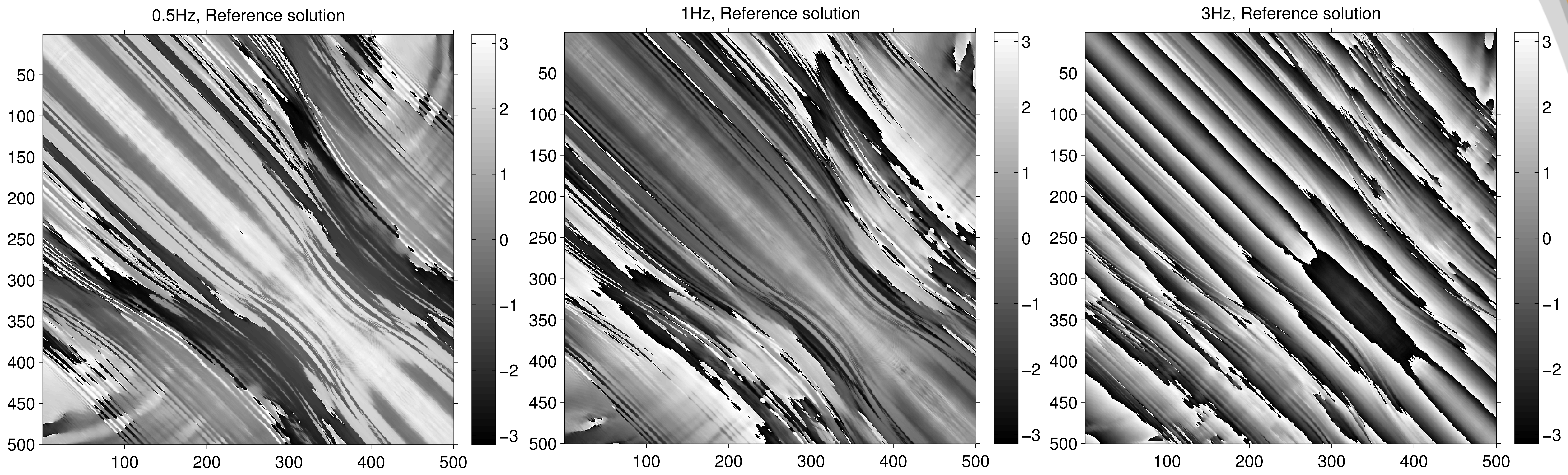


1 Hz



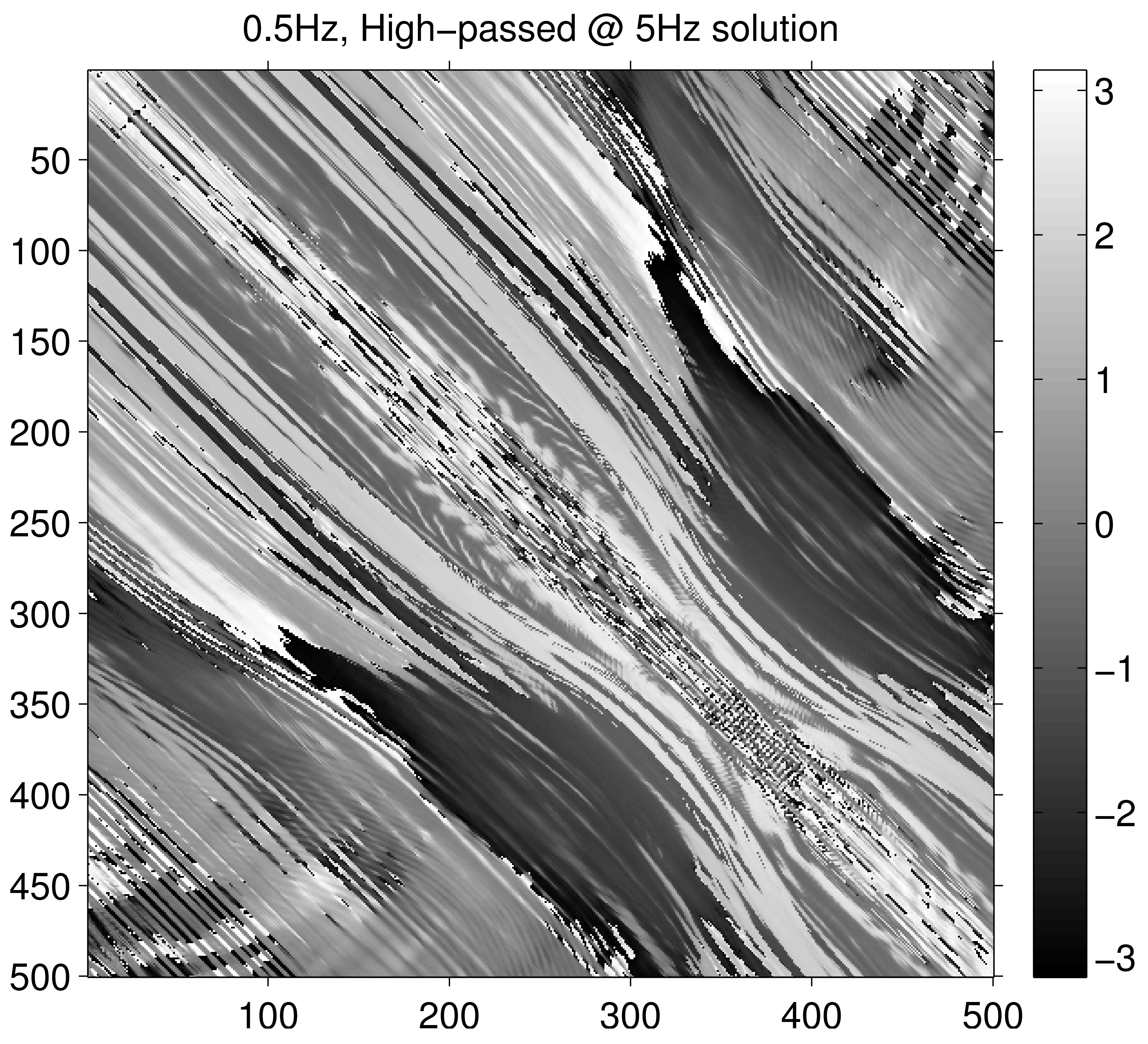
3 Hz

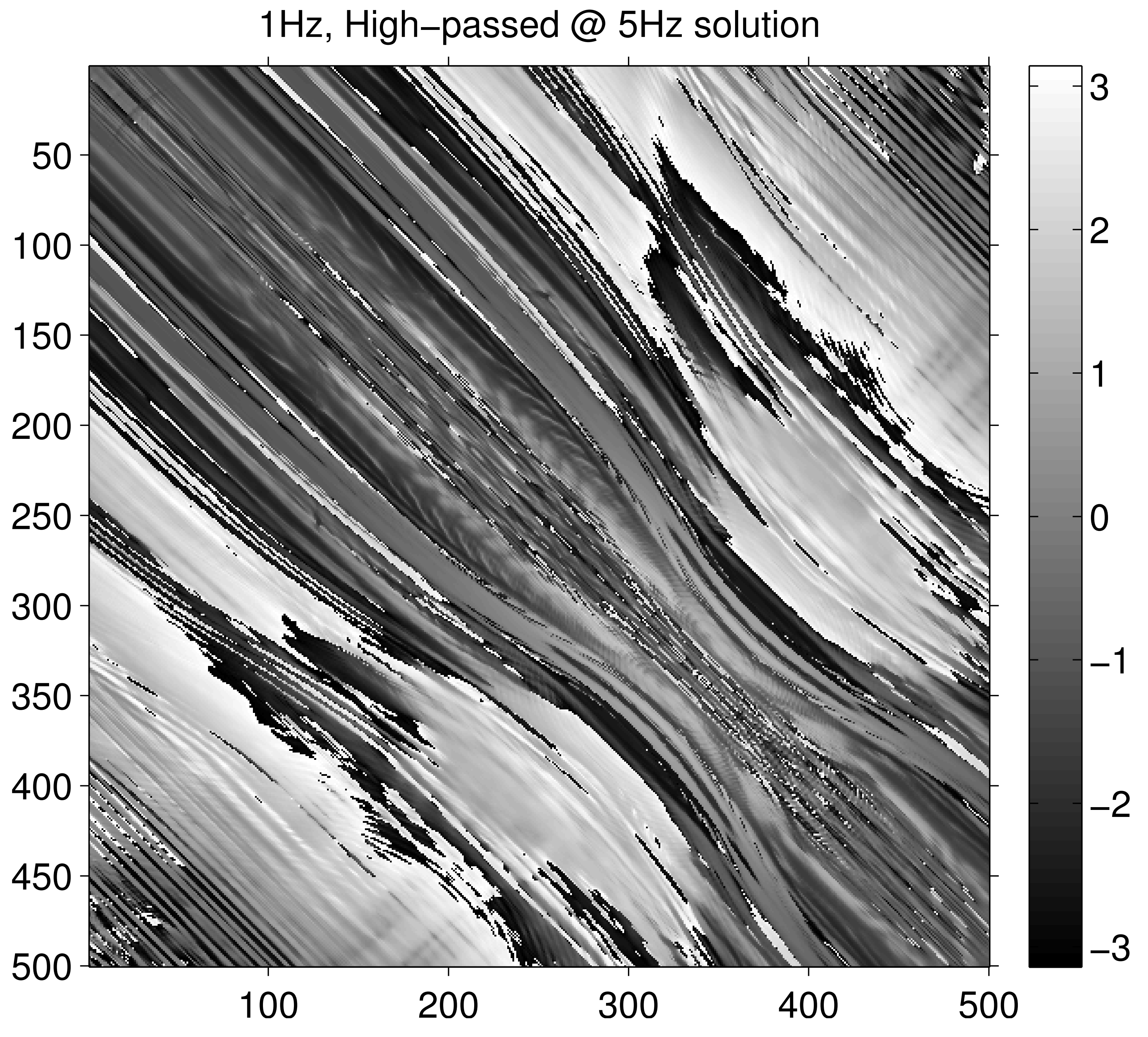
Phase Reference solution

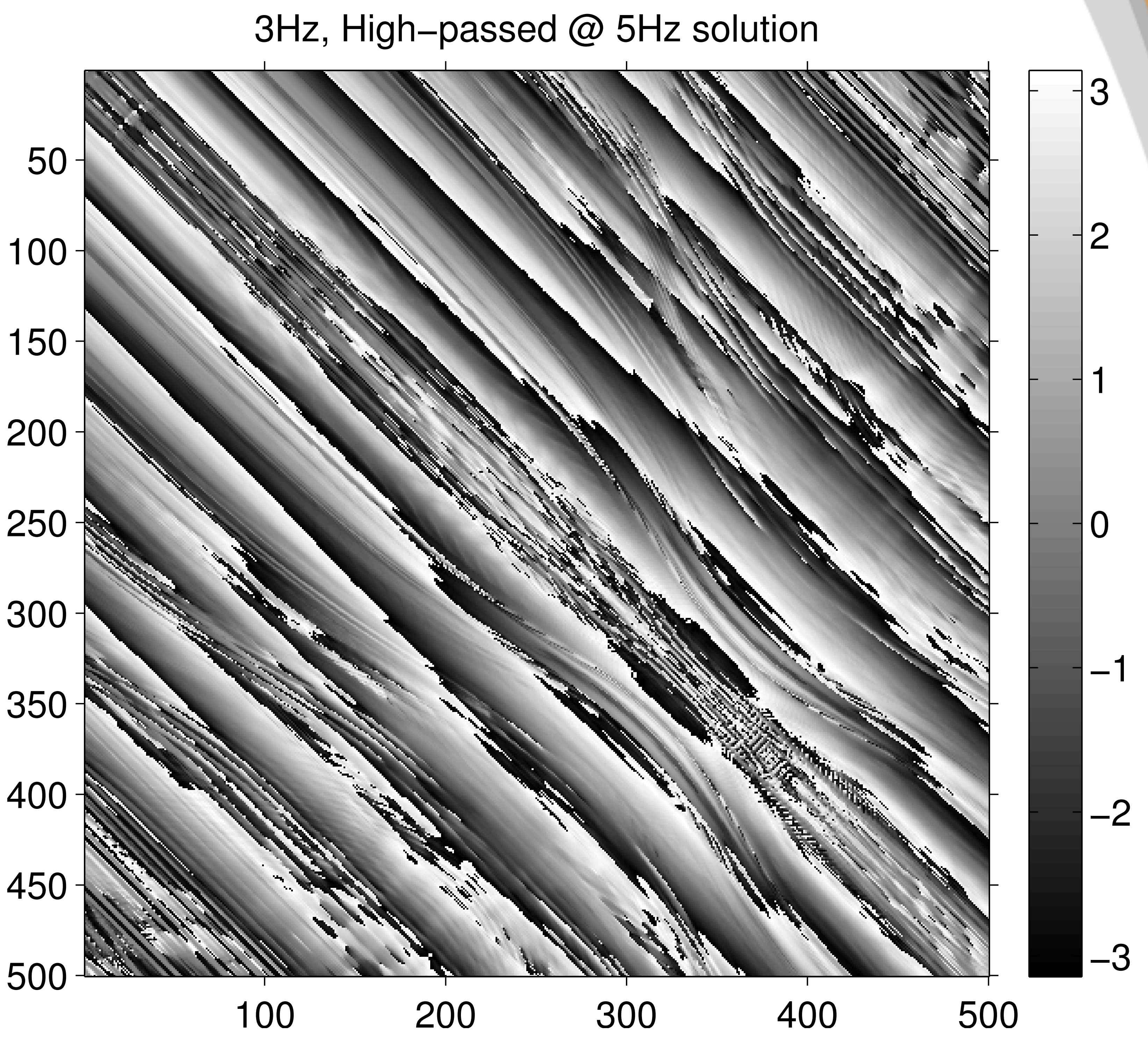


0.5Hz **1 Hz** **3 Hz**

Phase Low-cut at 5 Hz

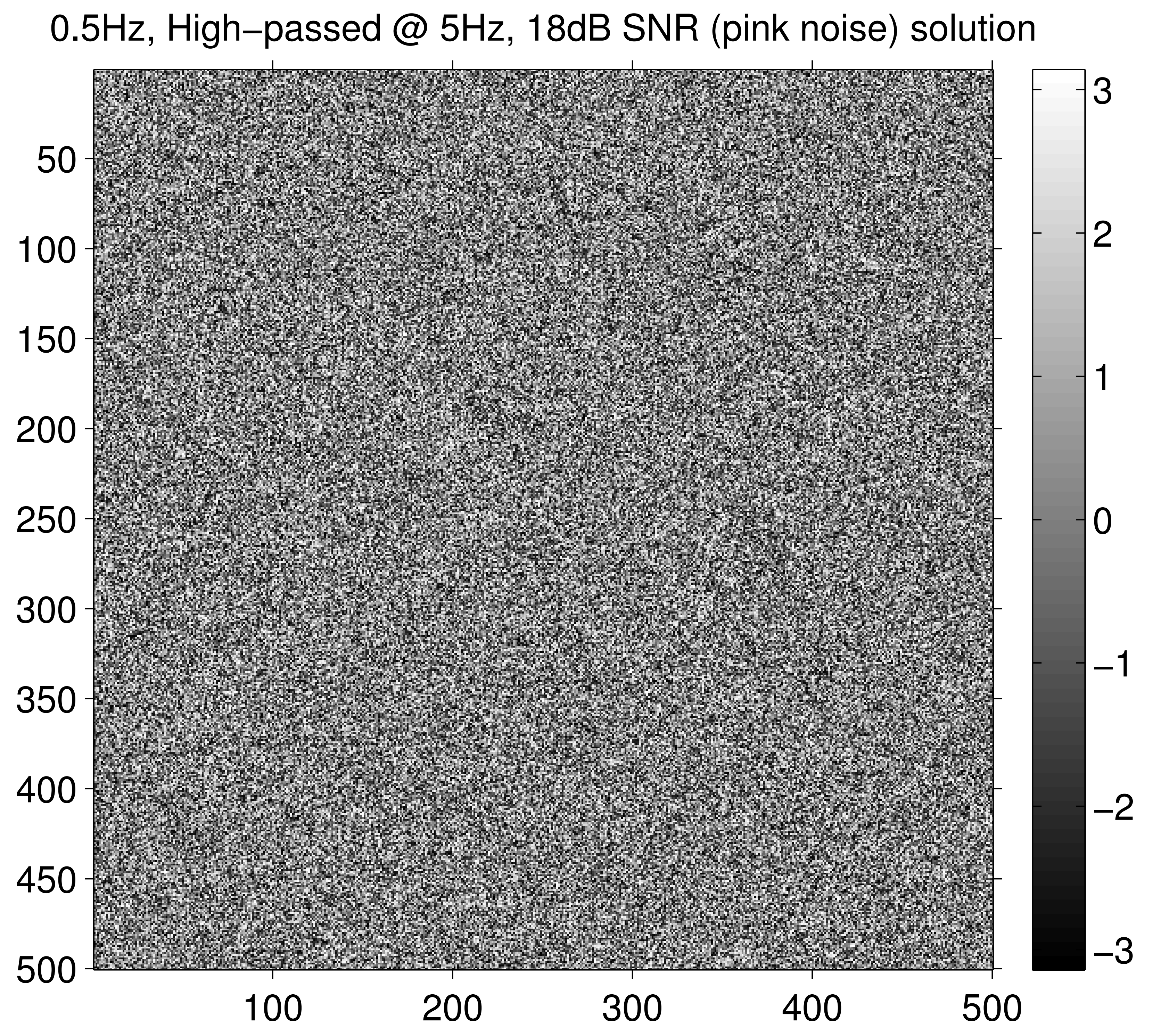




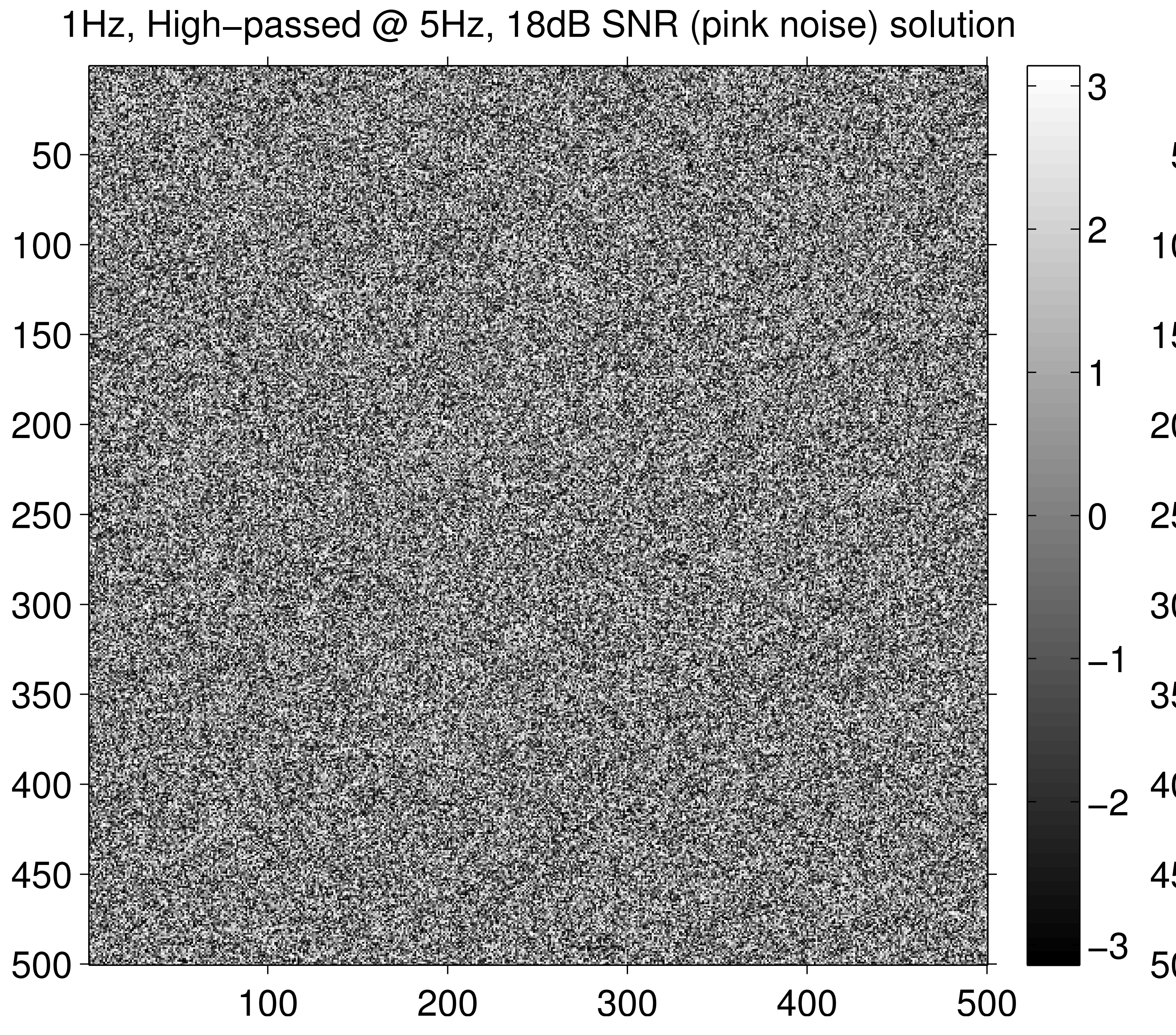


0.5Hz **1 Hz** **3 Hz**

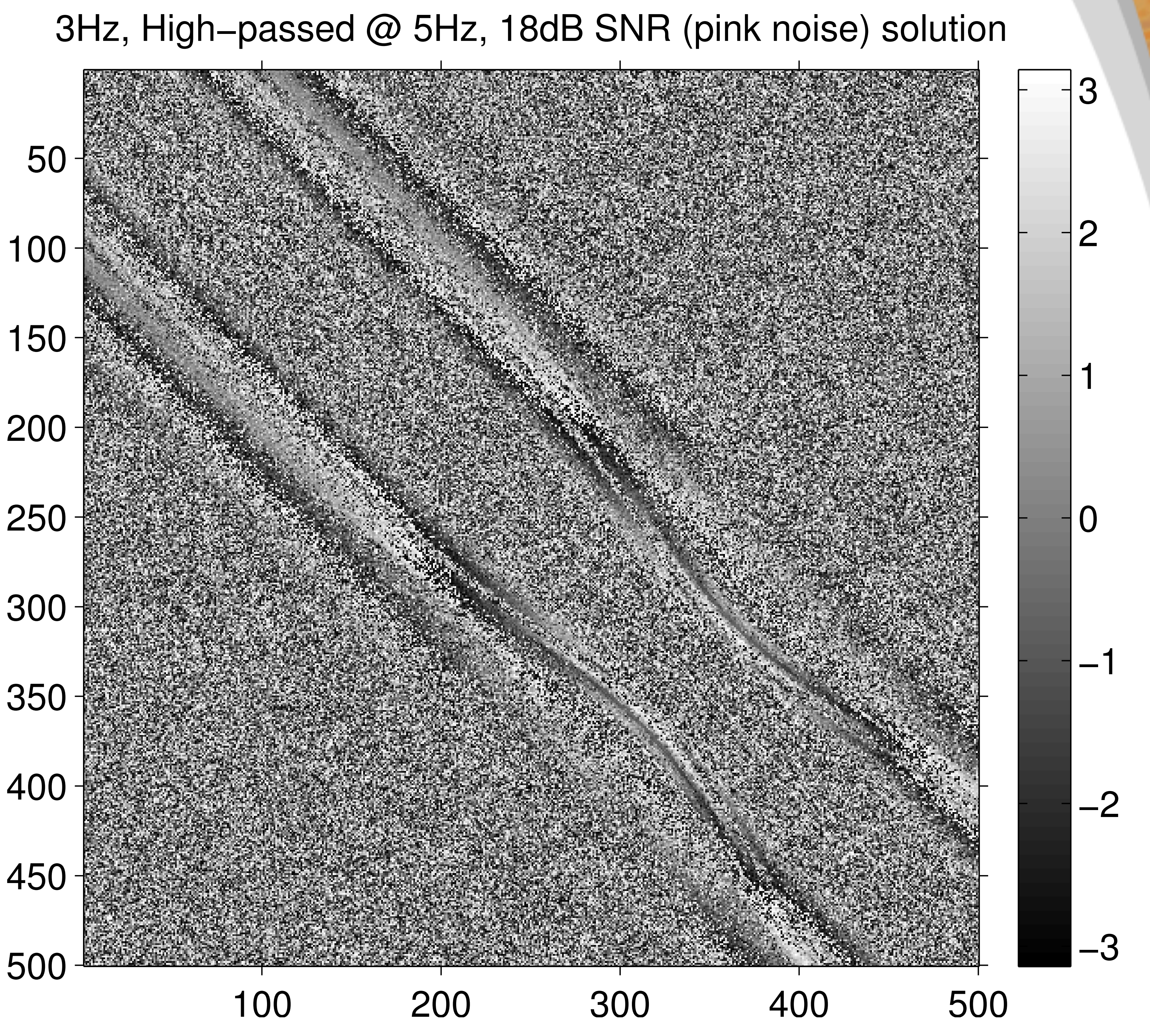
Phase Low-cut at 5 Hz, 18dB Pink noise added



0.5Hz

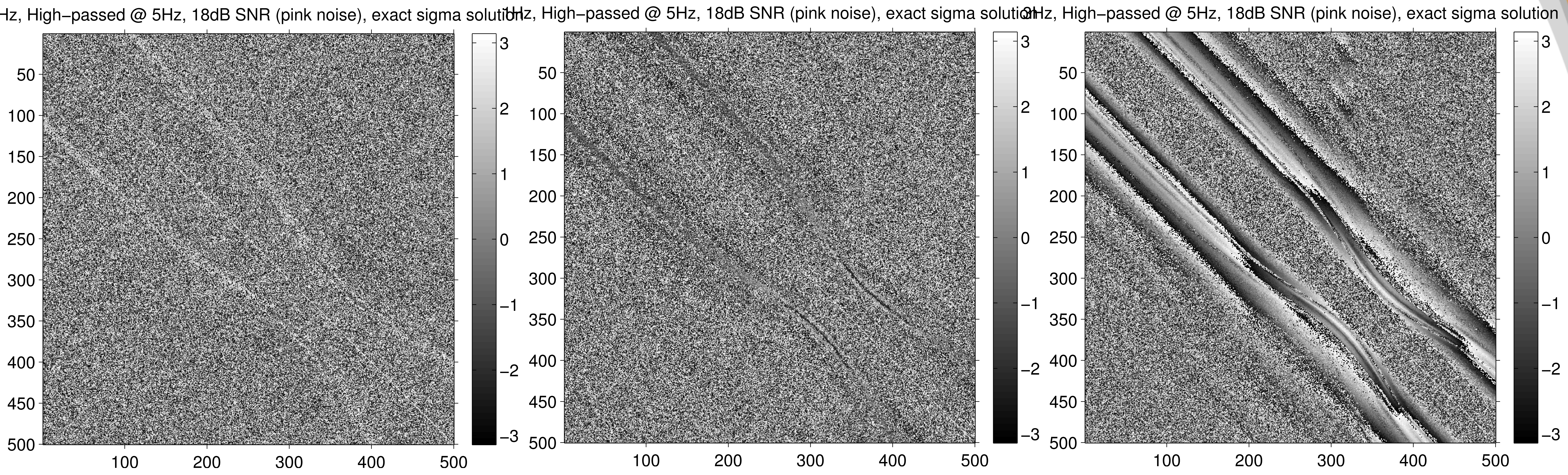


1 Hz



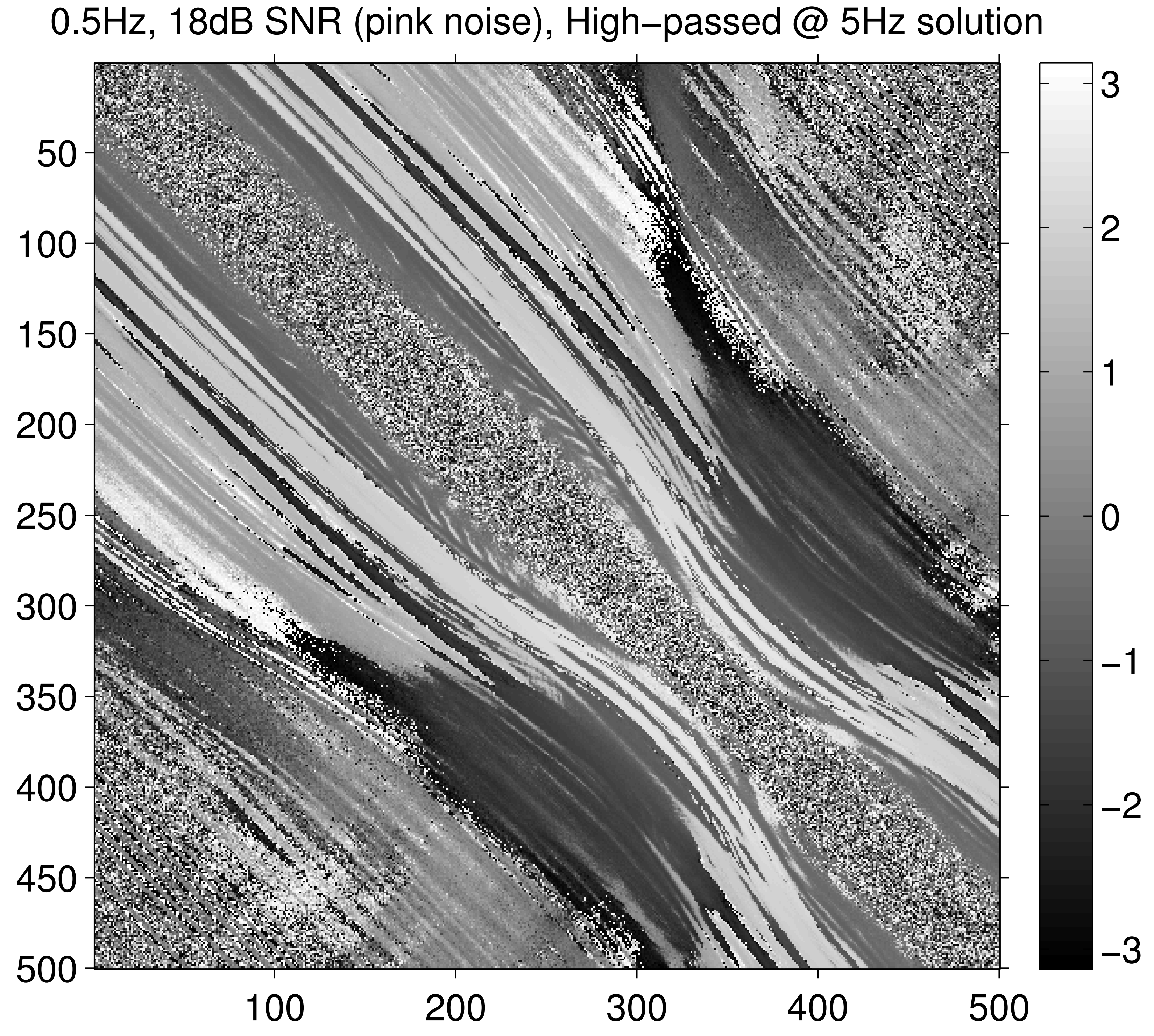
3 Hz

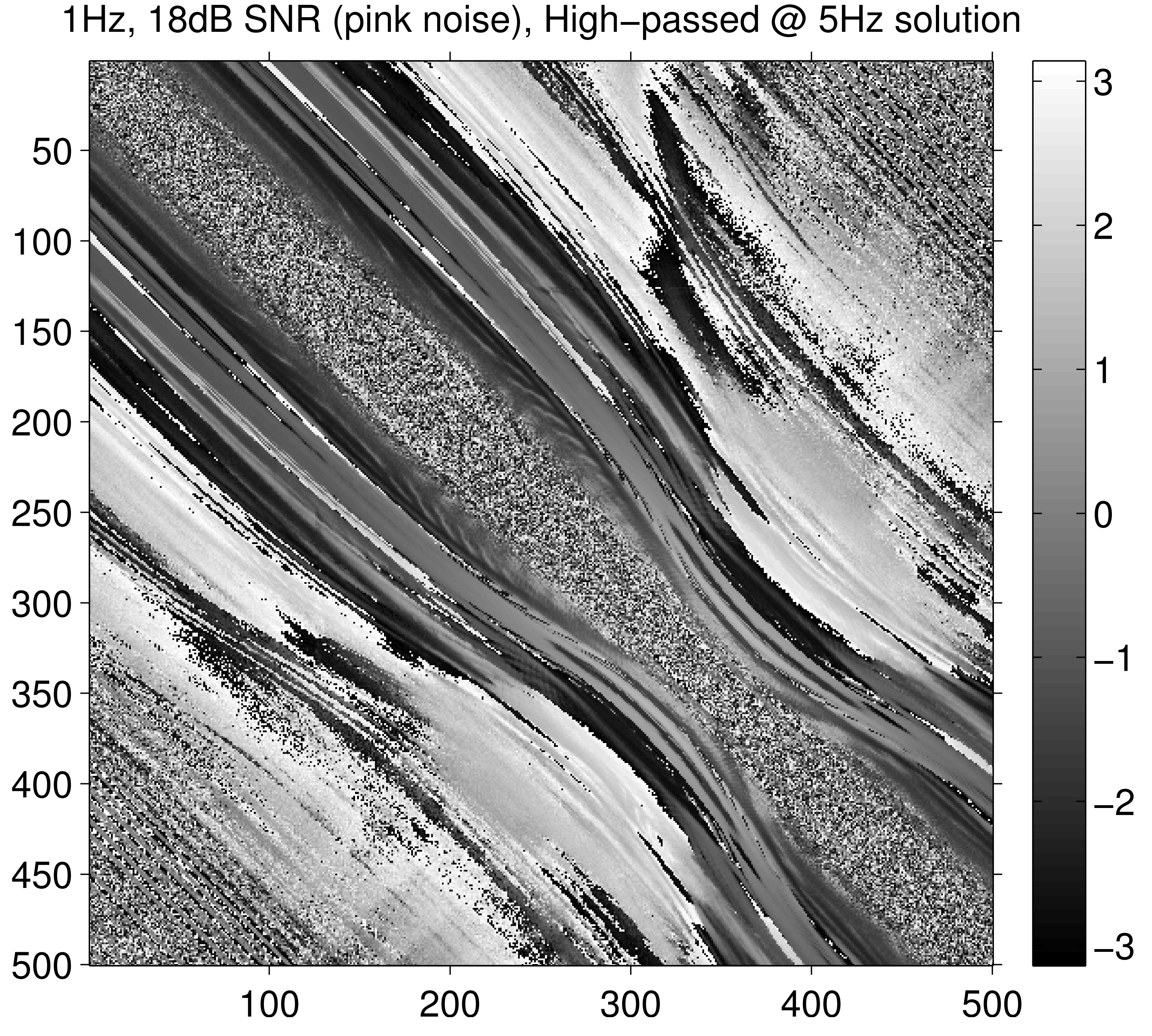
Phase Low-cut at 5 Hz, 18dB Pink noise added (solved to exact sigma)

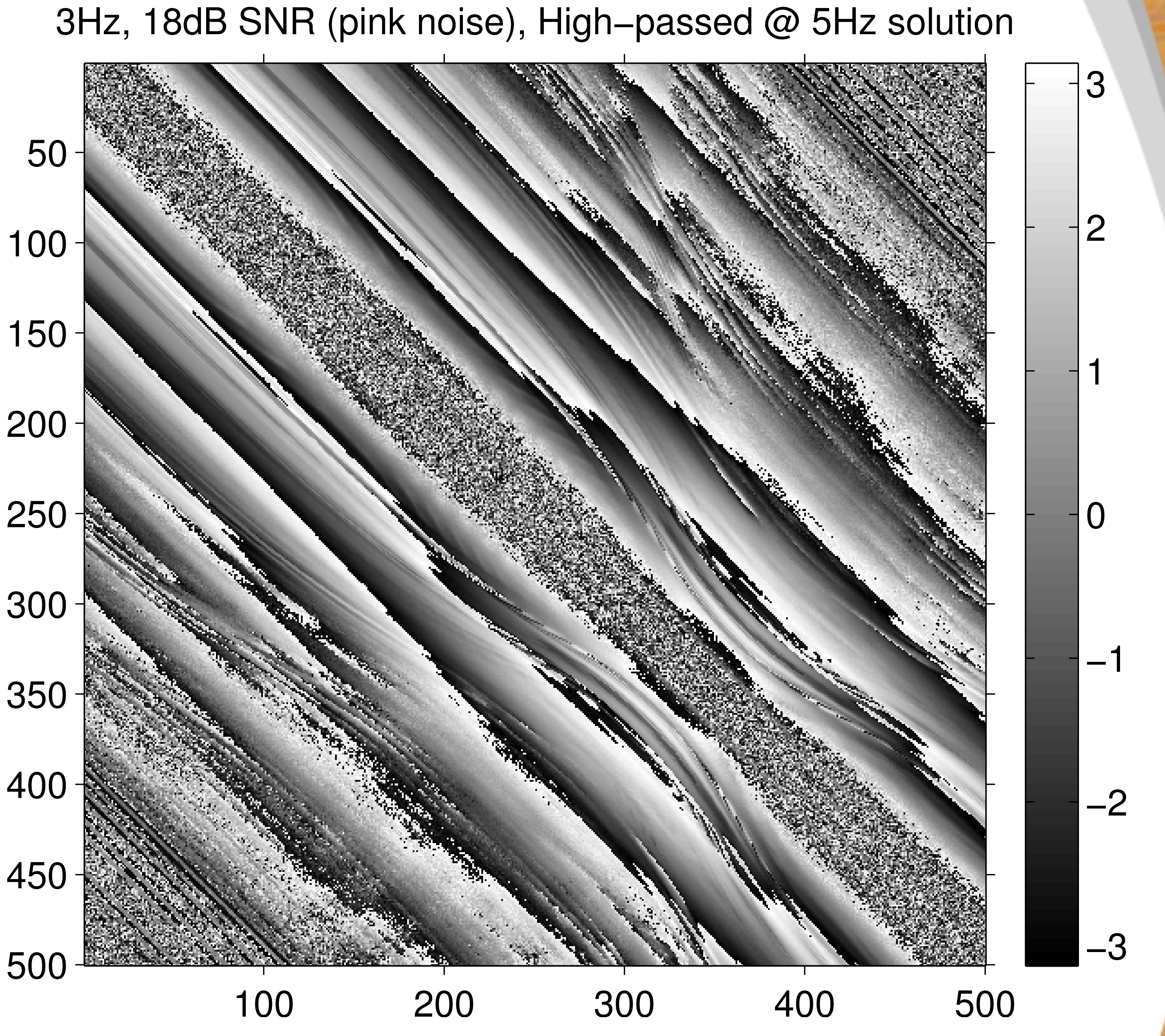


0.5Hz **1 Hz** **3 Hz**

Phase 18dB Pink noise added, Low-cut at 5 Hz

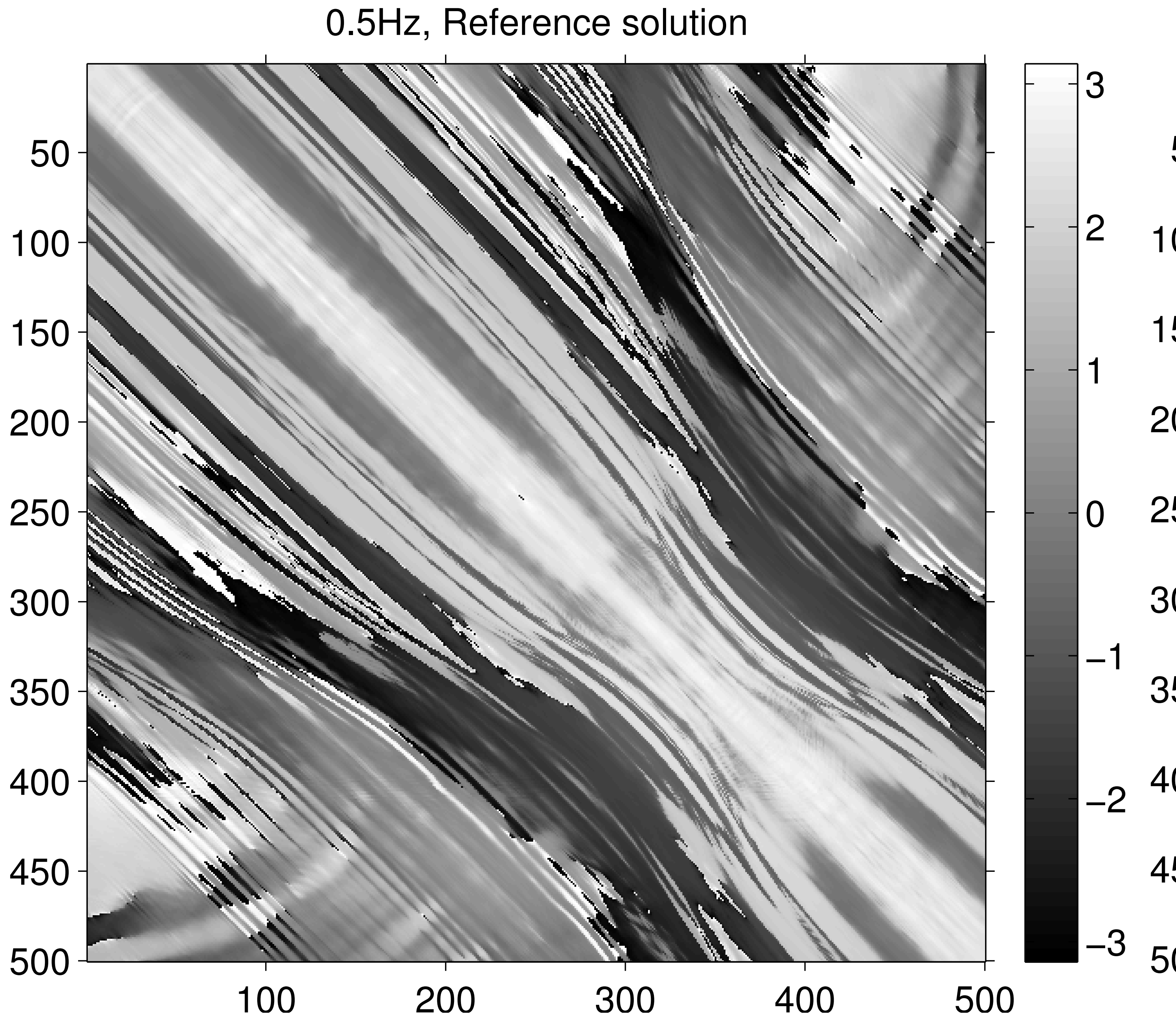




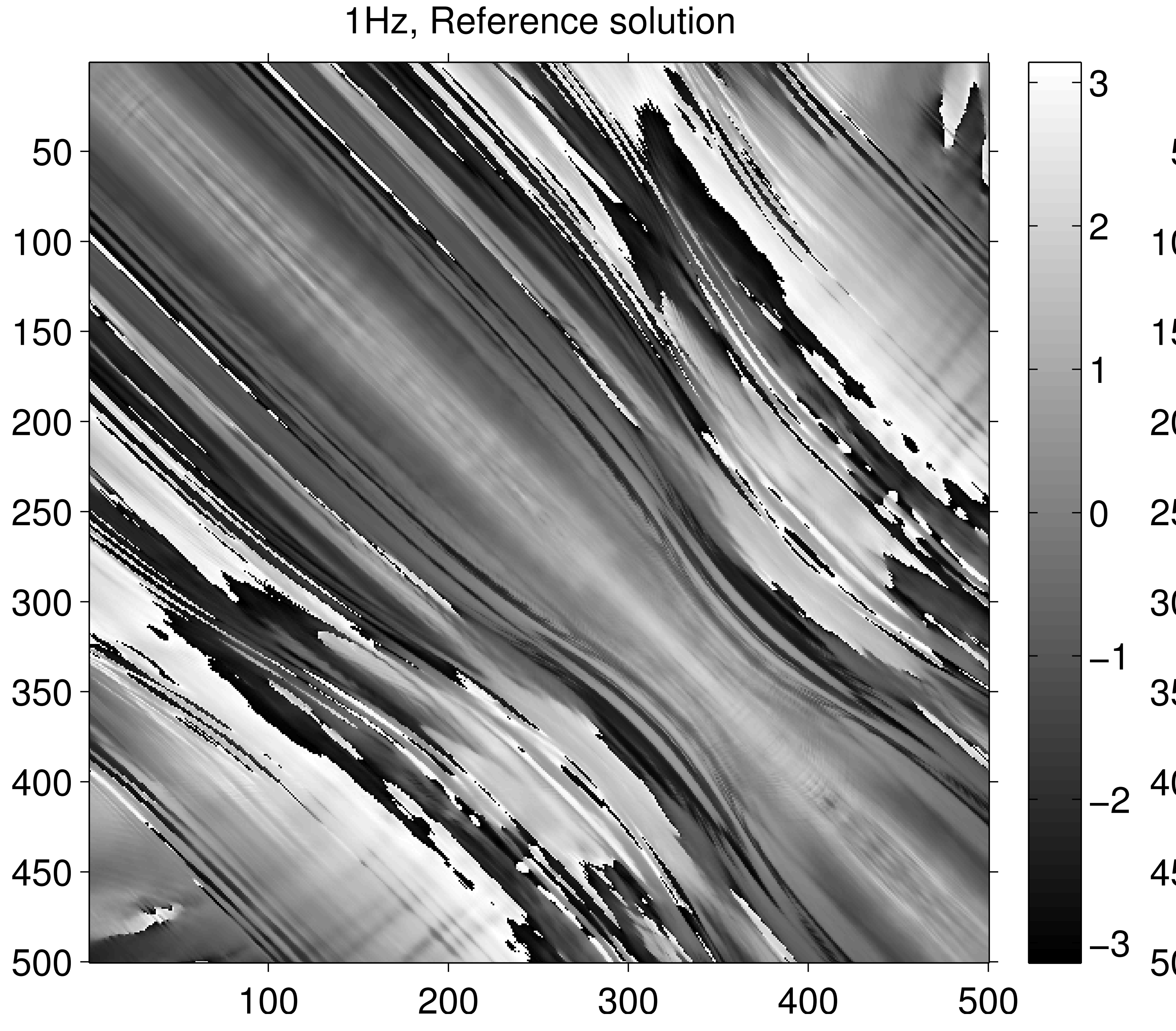


0.5Hz **1 Hz** **3 Hz**

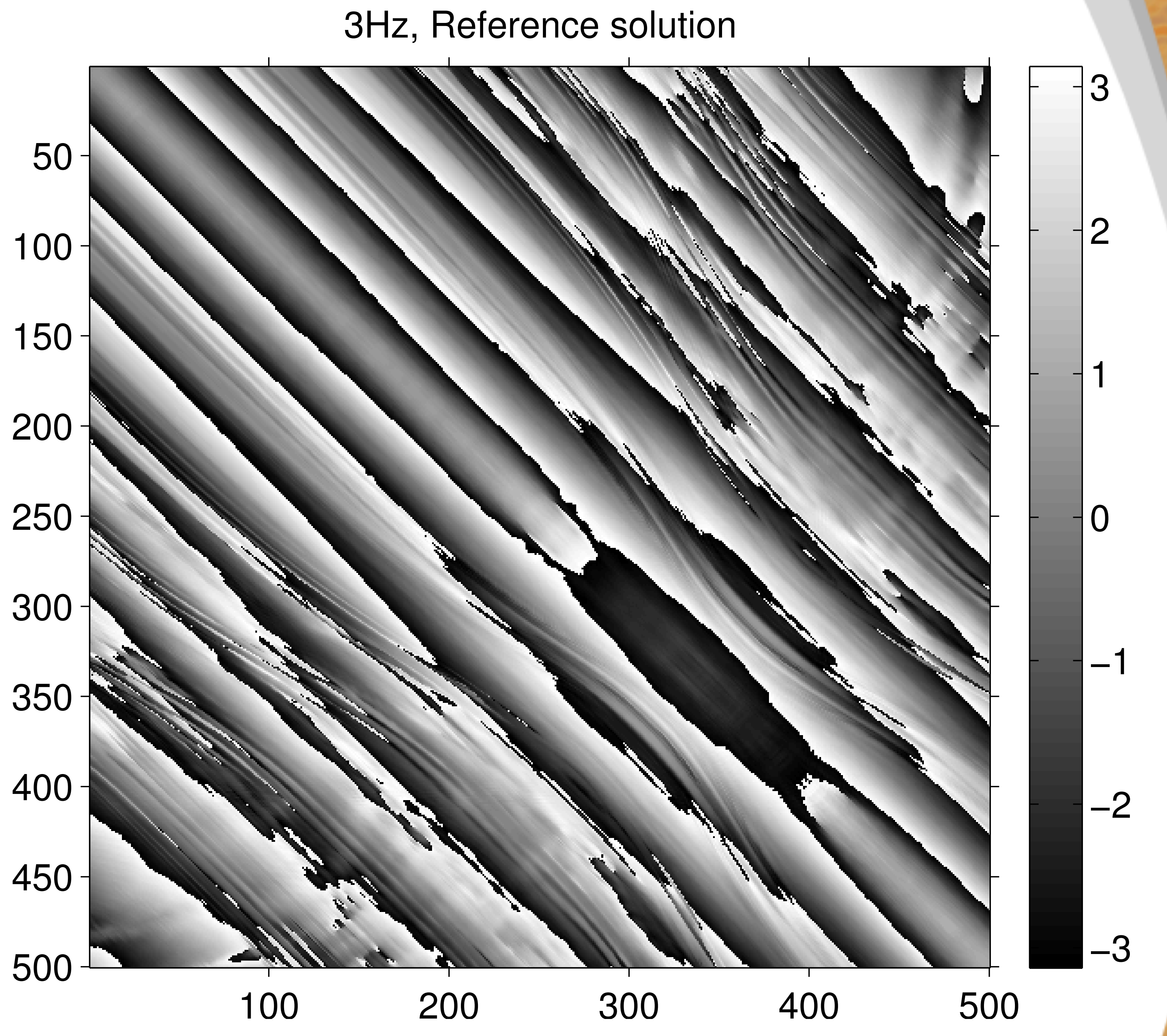
Phase Reference solution



0.5Hz

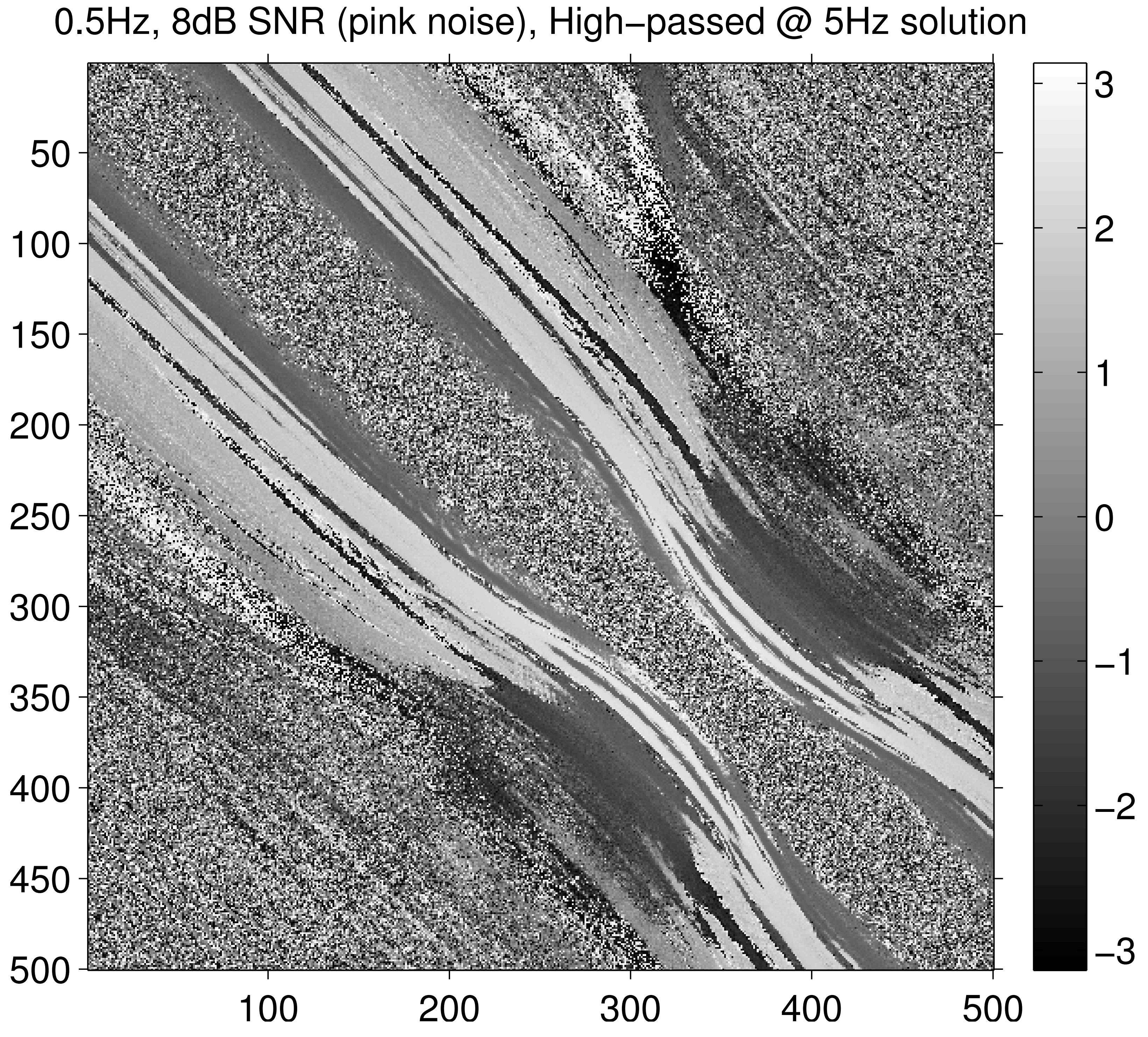


1 Hz

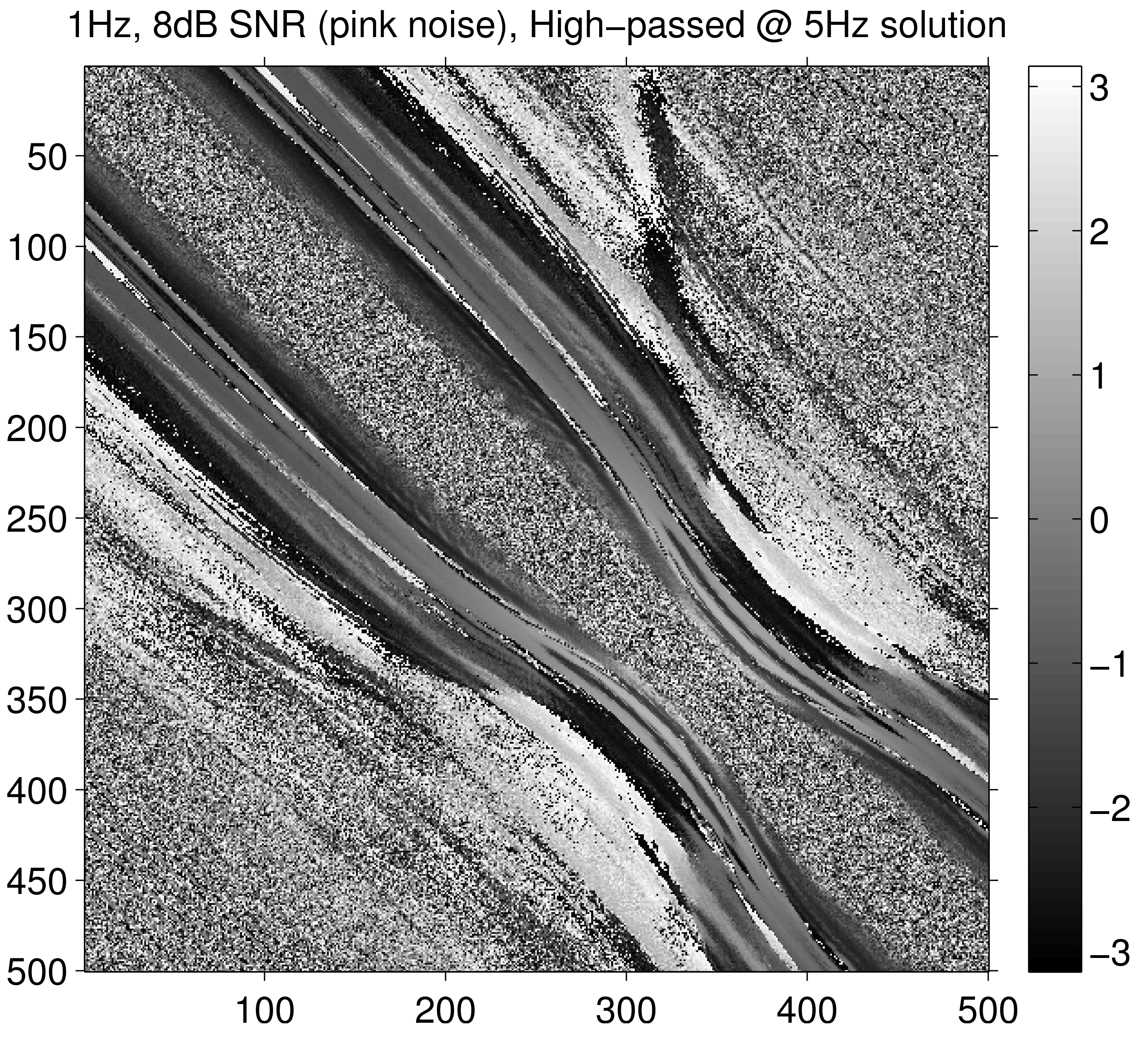


3 Hz

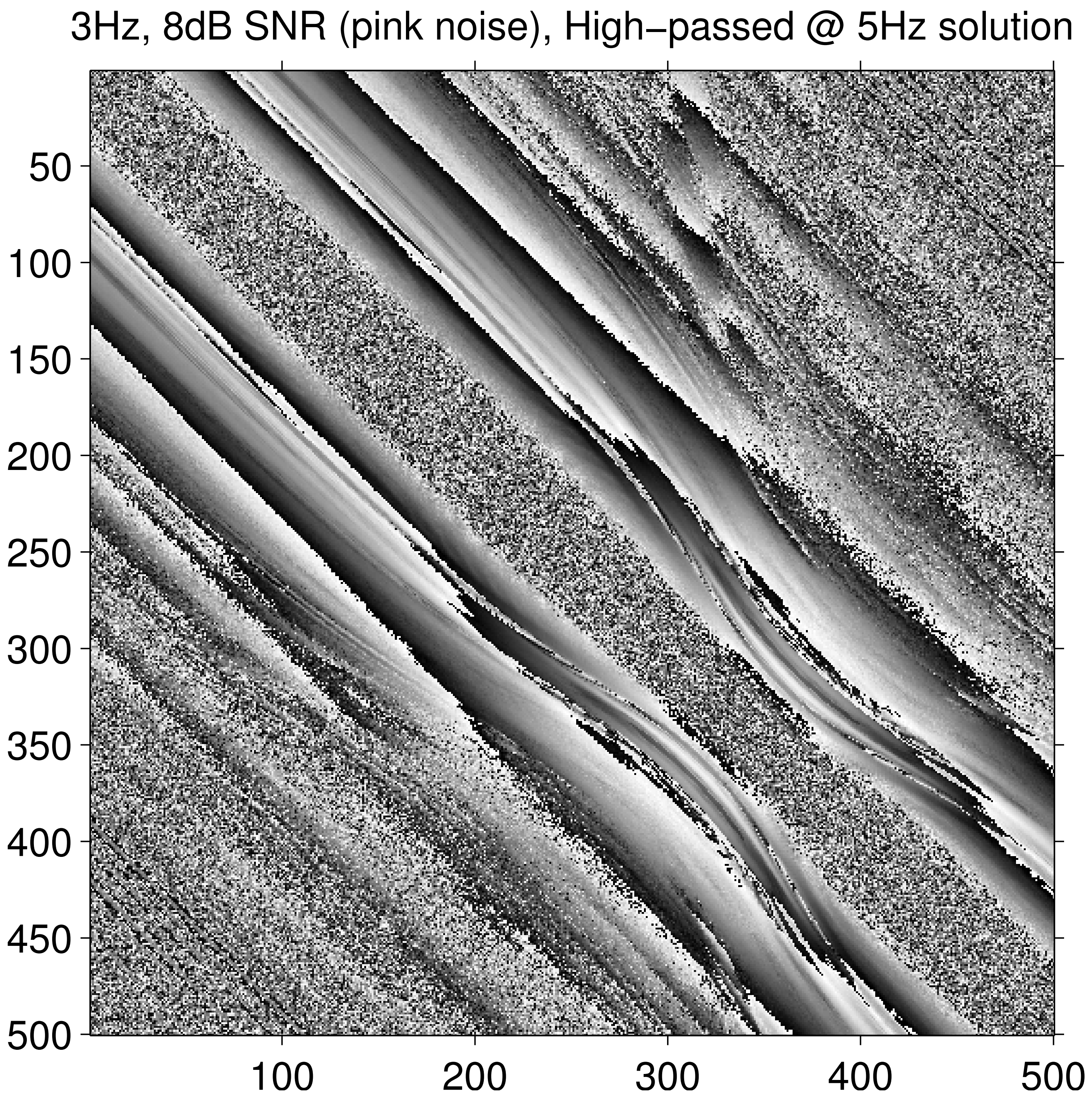
Phase 8dB Pink noise added, Low-cut at 5 Hz



0.5Hz



1 Hz



3 Hz

Remaining areas of investigation for REPSI

At coarsest levels, use more advanced/costly sparsifying methods? Go grid-free in the time domain? (*i.e., super-resolution methods)*

More sophisticated data-update method, less prone to local minima (use correlation between P and G, etc)

Incorporate up/down decomposition operator to work on P & Vz data

Potentially extract low-frequency information from G for diving-wave full-waveform inversion

Acknowledgements

Gratitude to everyone who have given me with advice on multiple removal over the years

Thank YOU! This talk had **117** slides!

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