Utrecht University

03 May 2019

Compressed Acquisition and Imaging for Ocean Turbulence Monitoring

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- *Seismic Oceanography*
- *Seismic acquisition*

- *Multicomponent reconstruction*

- *Sediment model*
  —regular sampling & irregular sampling

- *Turbulence model*
  —preconditioning
  —multi-source & multi-receiver (3D)

- *Seismic Oceanography*
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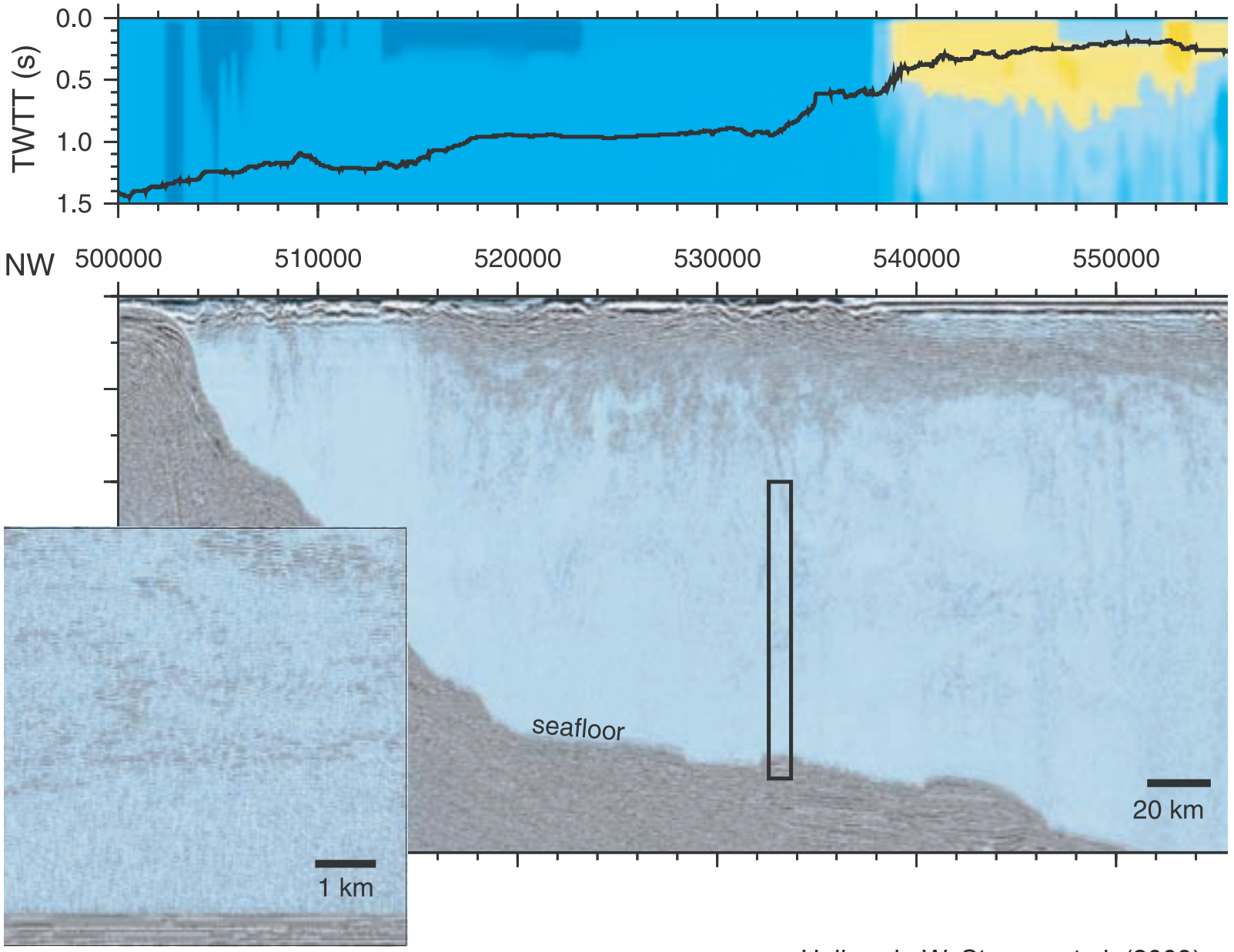
Seismic Oceanography (SO)

Fronts, internal waves, eddies, etc.

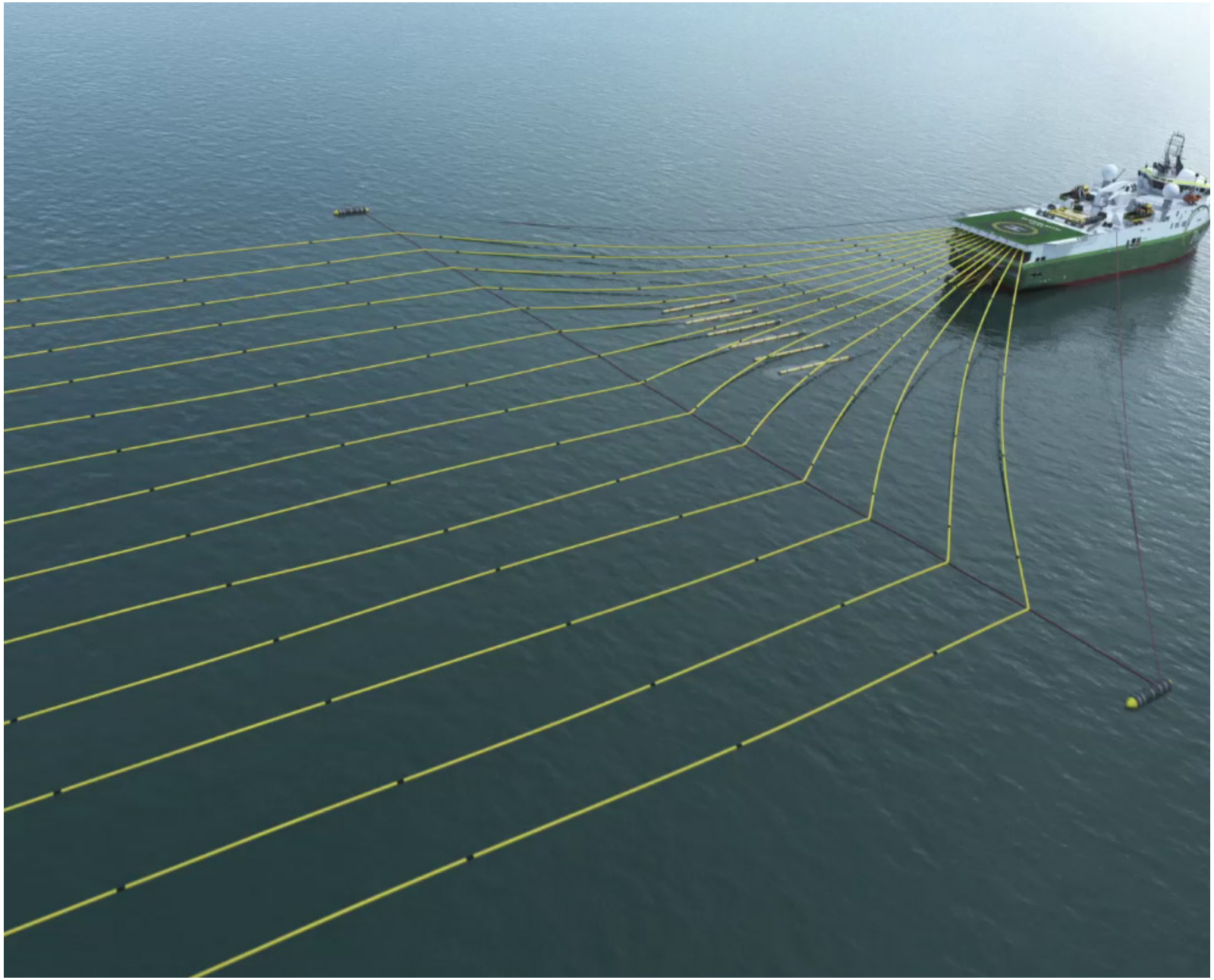


Holbrook, W. Steven, et al. (2003)

Multichannel Seismic systems (MSC)

Dense lateral sampling

Expensive

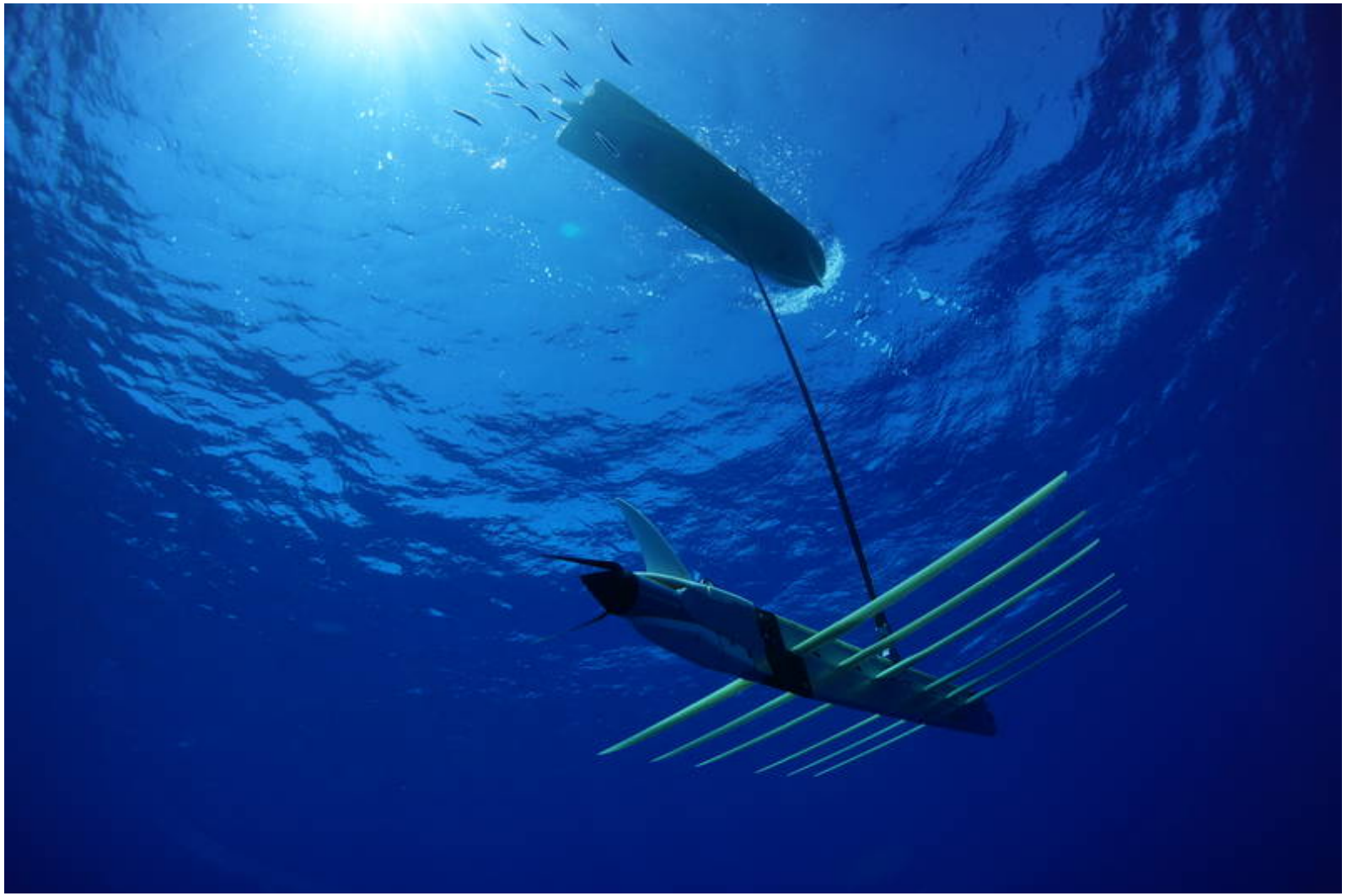


Multichannel Seismic systems (MSC)

~~Dense lateral sampling~~

~~Expensive~~

Autonomous platform



Sampling scheme

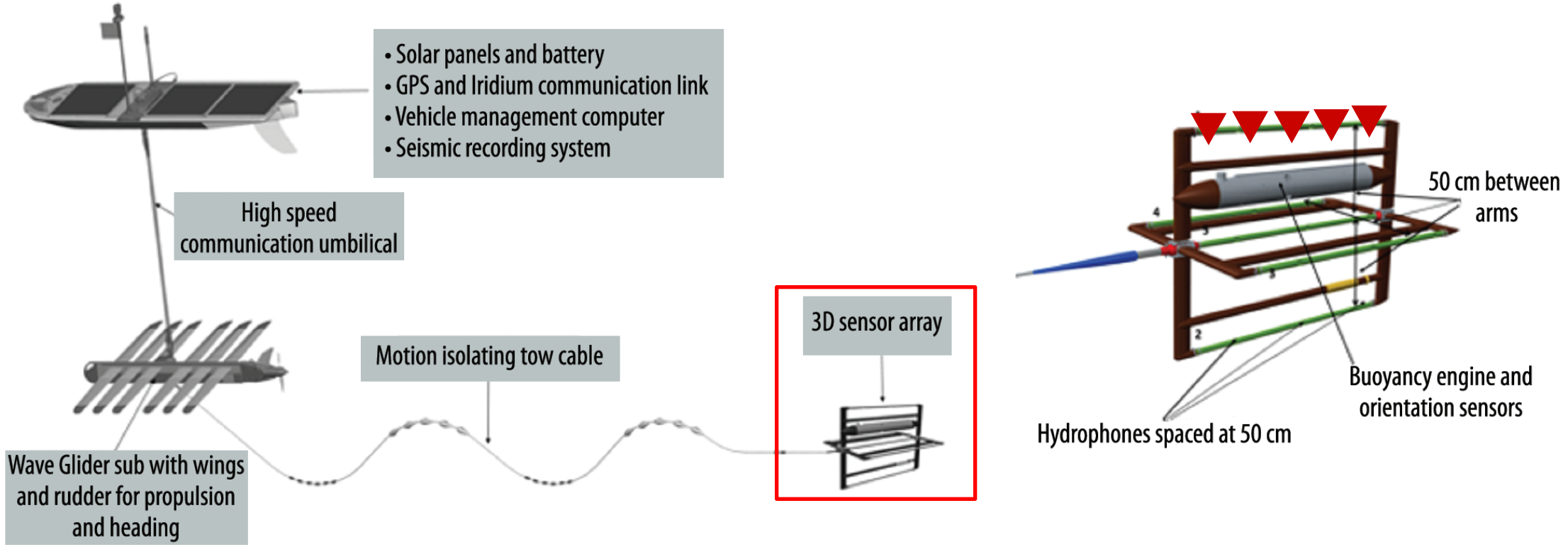
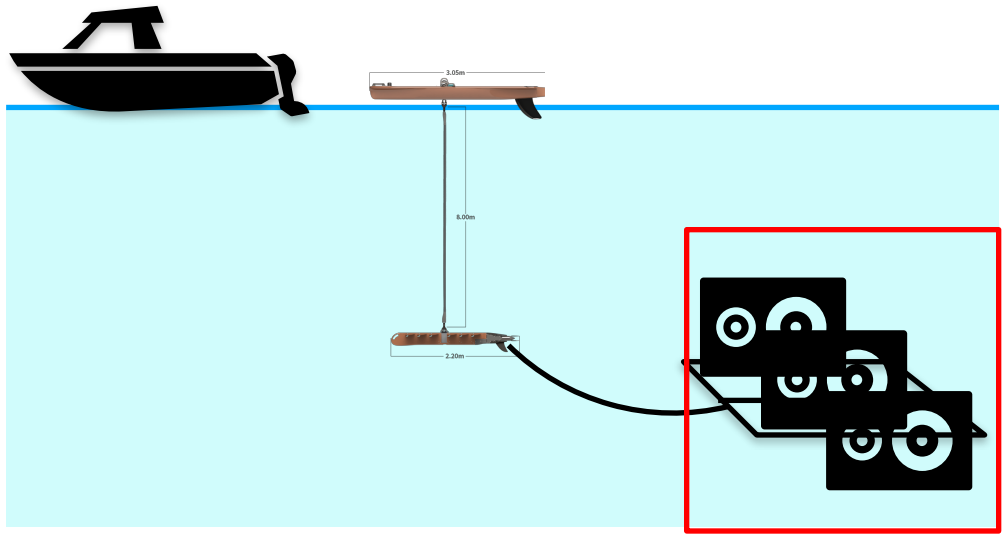


Figure 1. (a) AMV components, decoupling cable, and the 3DSA. (b) Enlarged view of the 3DSA.

Measurements of pressure data and its derivatives in receiver direction.

Sampling scheme



Marine Vibrator

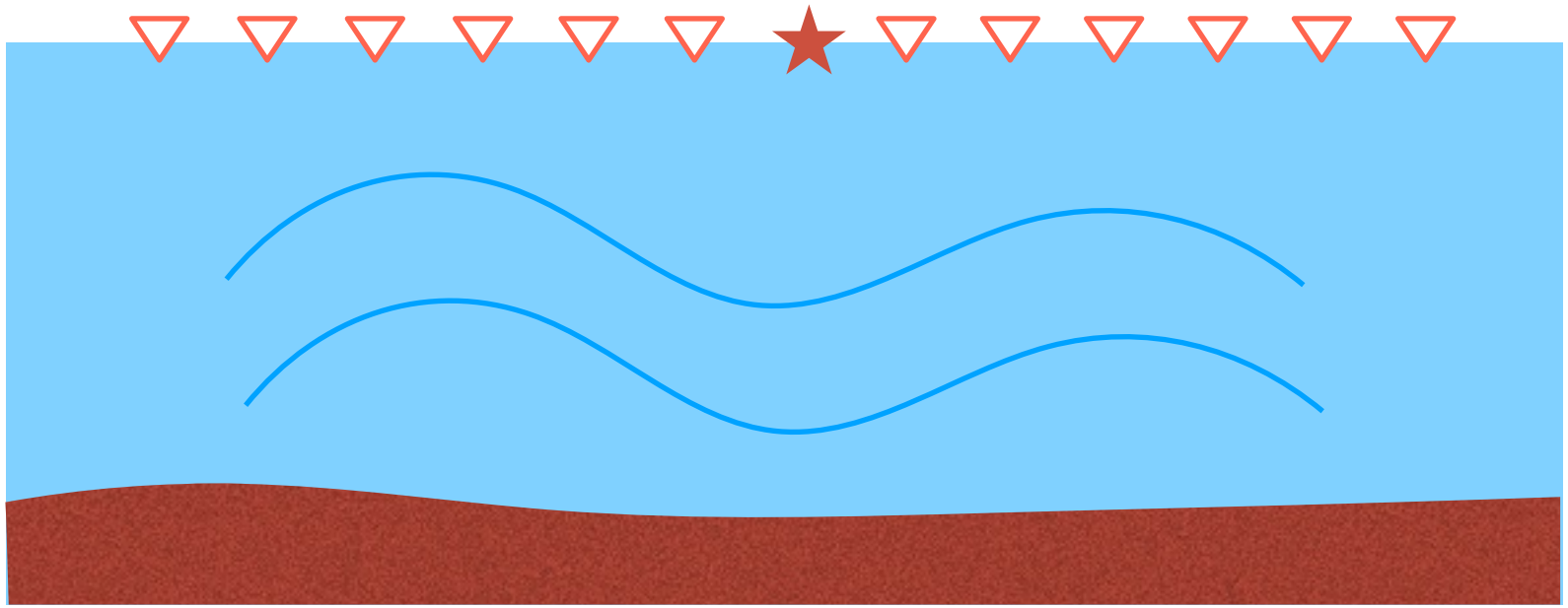
Phase & frequency control

Measurements of derivatives in source direction.

Sampling scheme

Autonomous platform

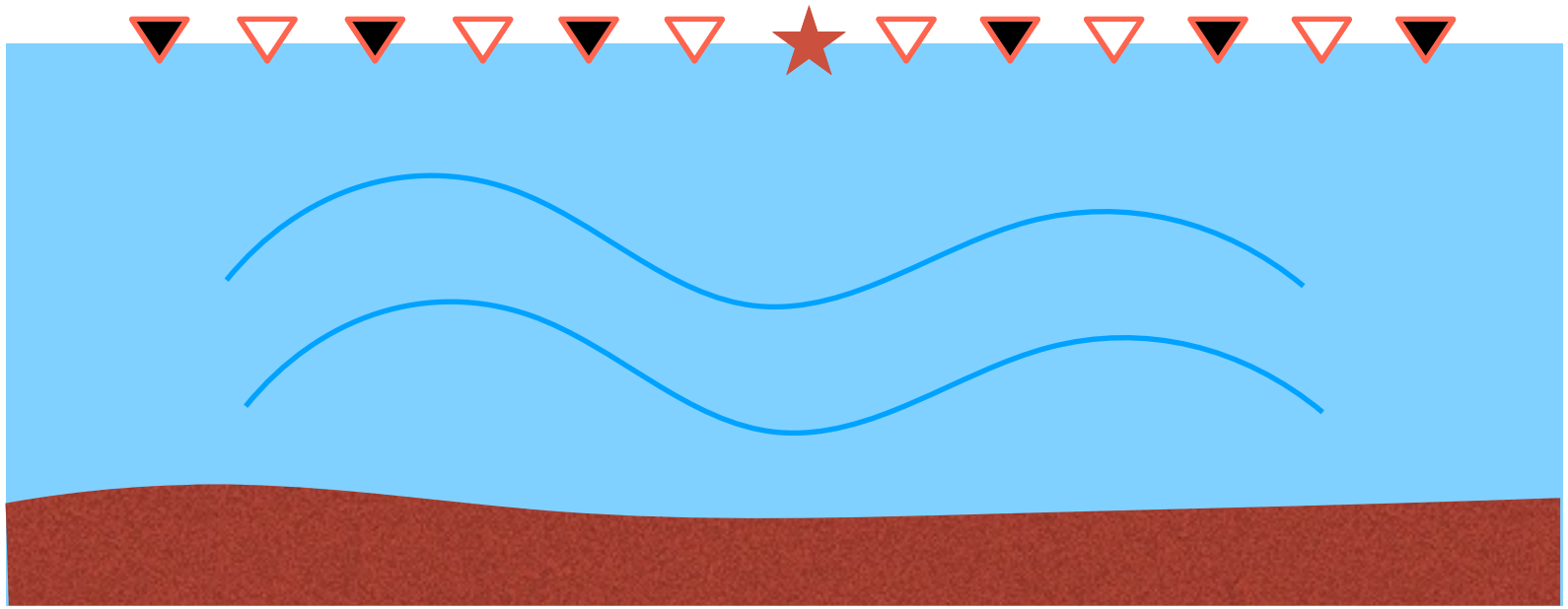
Sampling scheme:



Sampling scheme

Autonomous platform

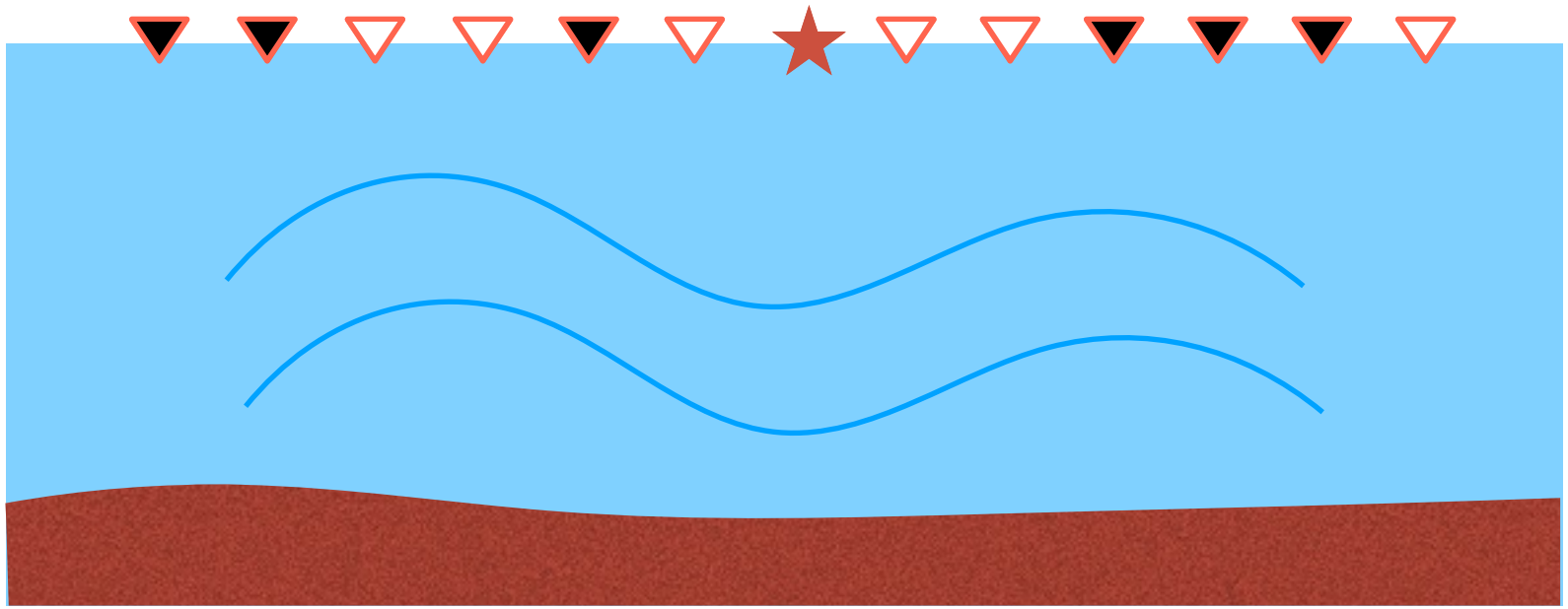
Sampling scheme:
—regular sampling



Sampling scheme

Autonomous platform

Sampling scheme:
—regular sampling
—irregular sampling

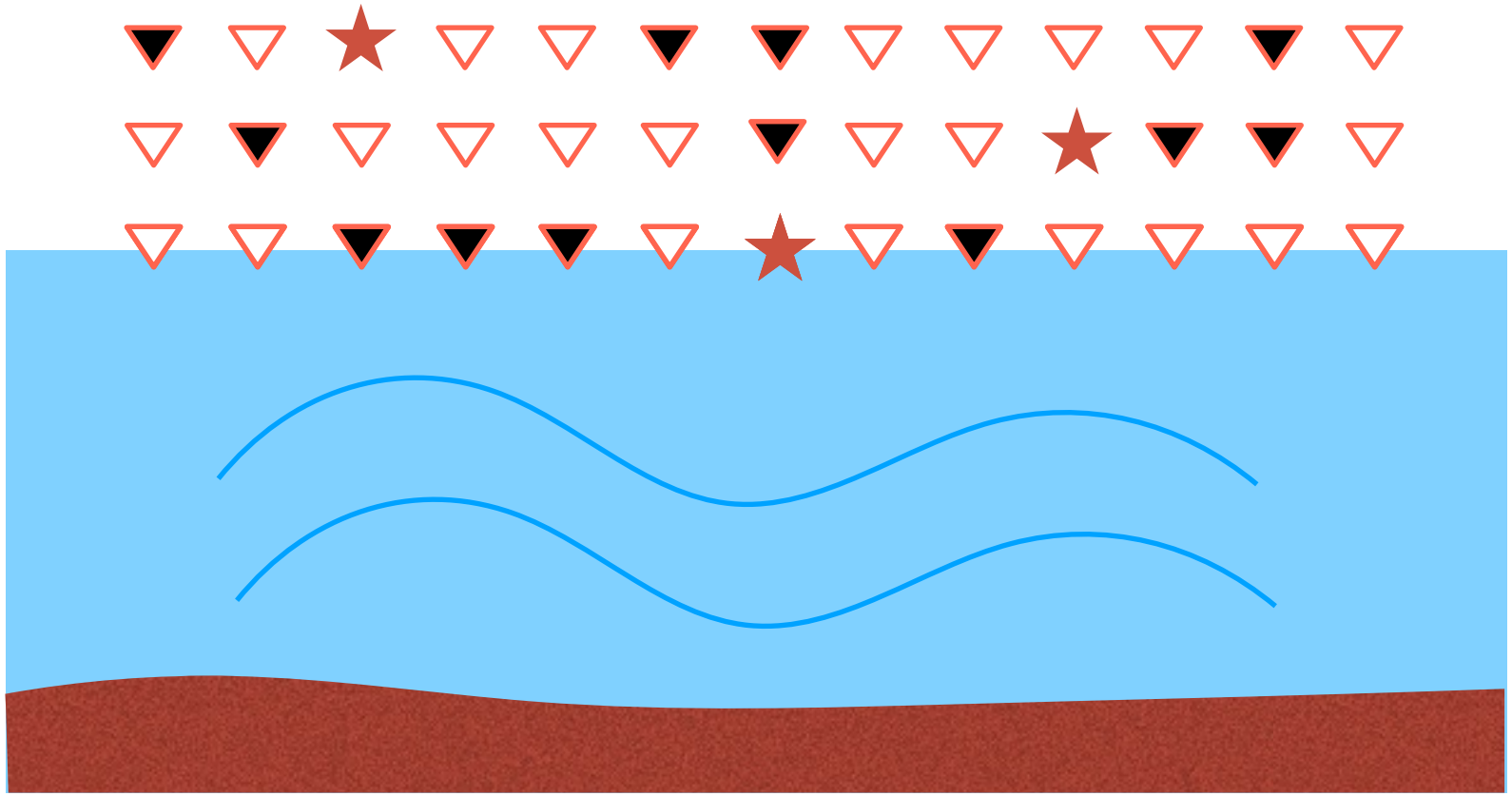


Sampling scheme

Autonomous platform

Sampling scheme:
—regular sampling
—irregular sampling

Multi-source



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Equations

Sinc interpolator

$$p(y_0) = \sum_{m=-\infty}^{\infty} p\left(\frac{m}{\sigma}\right) sinc(\sigma y_0 - m)$$

Multichannel sampling theorem (Linden, 1959; Robertsson, 2008)

$$p(y_0) = \sum_{m=-\infty}^{\infty} \left\{p\left(\frac{2m}{\sigma}\right) + \left(y_0 - \frac{2m}{\sigma}\right) \times \partial_y p\left(\frac{2m}{\sigma}\right)\right\} sinc^2\left(\sigma \frac{y_0}{2} - m\right)$$

Multicomponent reconstruction

With data and its first-order spatial derivatives

$$d_{obs} = S d_{model}$$

$$d_{obs} = \begin{pmatrix} d_t \\ d_1 \end{pmatrix} \quad and \quad S = \begin{pmatrix} R_r \\ D_1 \end{pmatrix}$$

$$D_1 = R_r * F^{-1} * diag(ik_n) * F$$

Multicomponent reconstruction

With data, its first- and second-order spatial derivatives

$$d_{obs} = S d_{model}$$

$$d_{obs} = \begin{pmatrix} d_t \\ d_1 \\ d_2 \end{pmatrix} \quad and \quad S = \begin{pmatrix} R_r \\ D_1 \\ D_2 \end{pmatrix}$$

$$D_1 = R_r * F^{-1} * diag(ik_n) * F$$

$$D_2 = R_r * F^{-1} * diag[(ik_n)^2] * F$$

Choice of the solvers& their Preconditioning

Solvers: LSQR, SPGL1

Domains: Fourier, Curvelet

Packages: Pylops(Python)
SPOT(MATLAB)

$$d_{mod} = F^{-1} d_f$$

$$d_{obs} = S F^{-1} d_f$$

$$LSQR: \quad min \quad \| d_{obs} - S F^{-1} d_{mod} \|_2$$

$$SPGL1(BPDN): \quad min \quad \| d_{mod} \|_1 \quad s.t. \quad \| d_{obs} - S F^{-1} d_{mod} \|_2 < \tau$$

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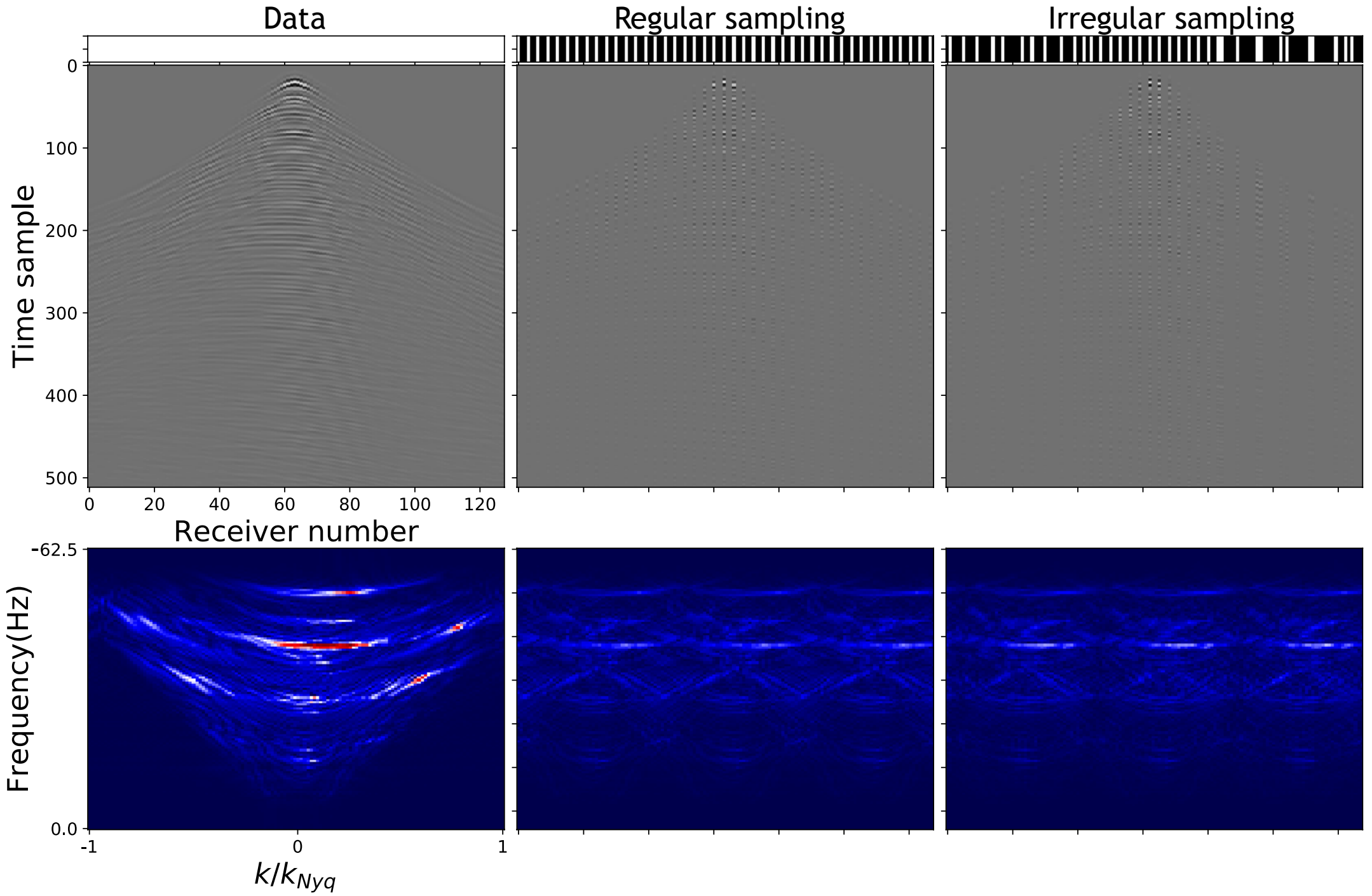
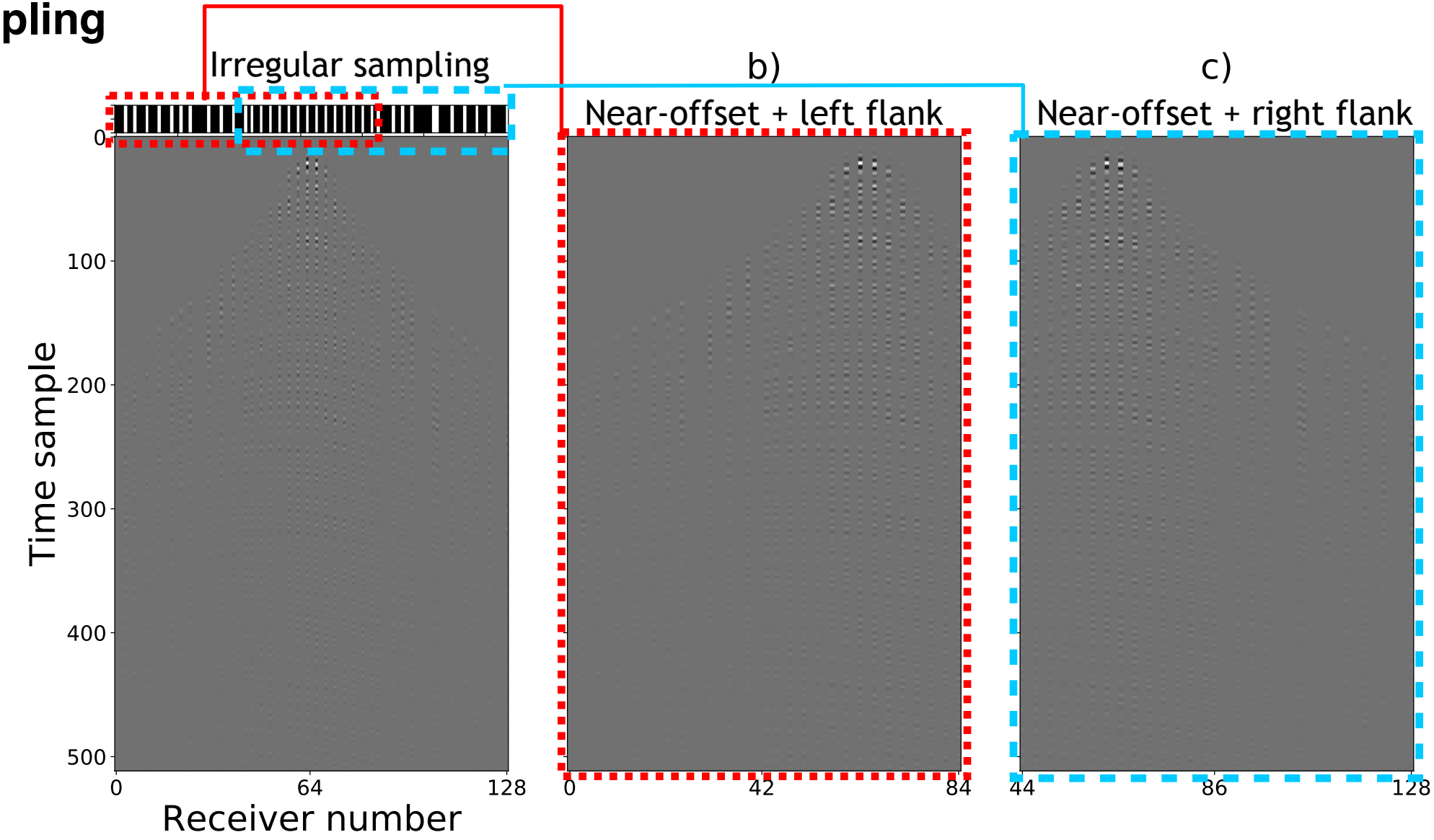

Data
Regular sampling
Irregular sampling
Time sample
Receiver number
Frequency(Hz)
k/k_{Nyq}
0
100
200
300
400
500
0
20
40
60
80
100
120
-62.5
0.0
-1
0
1

Partitioned sampling

$$d_{obs}^{L} = P d_{f}^{L}$$

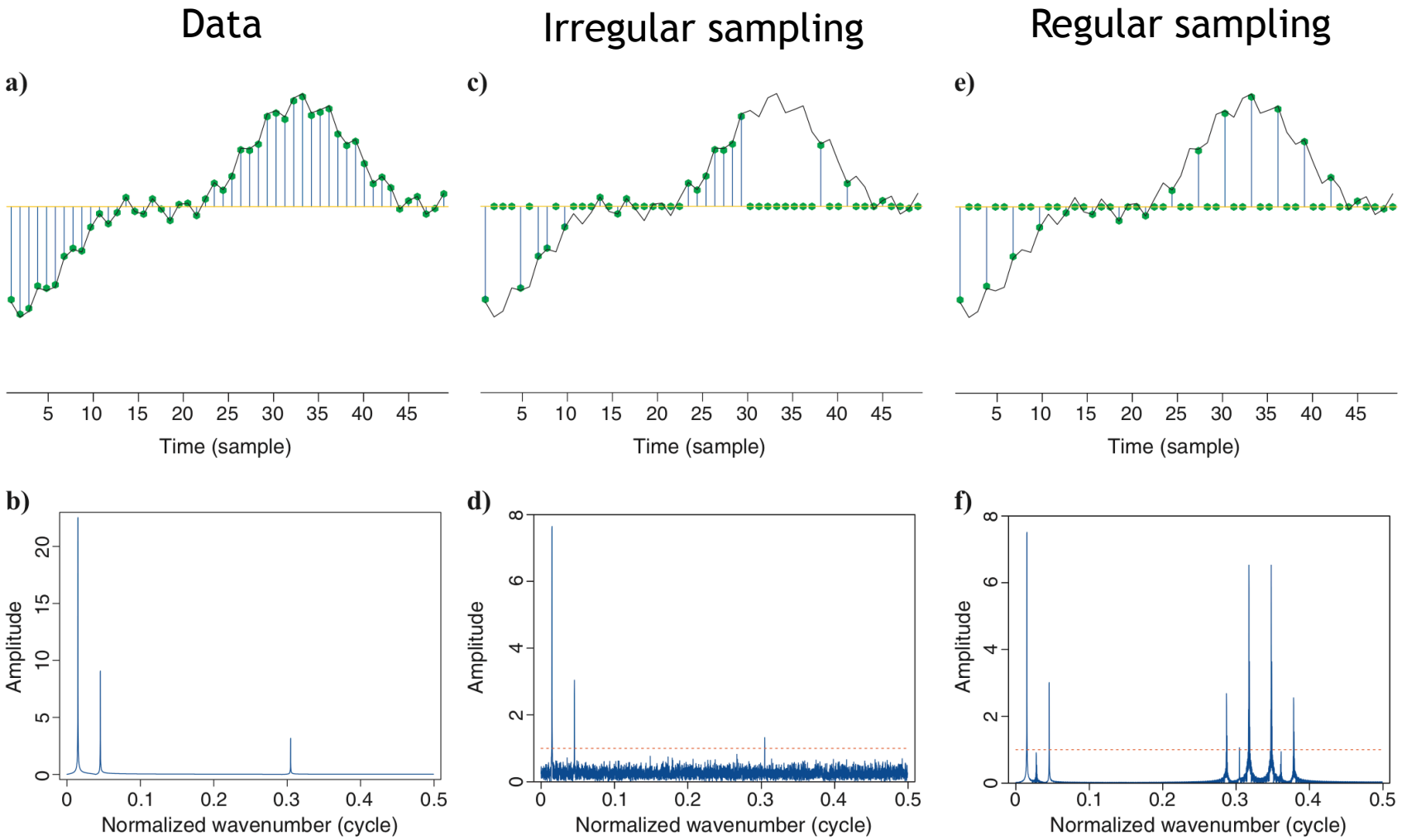
$$d_{obs}^{R} = P d_{f}^{R}$$



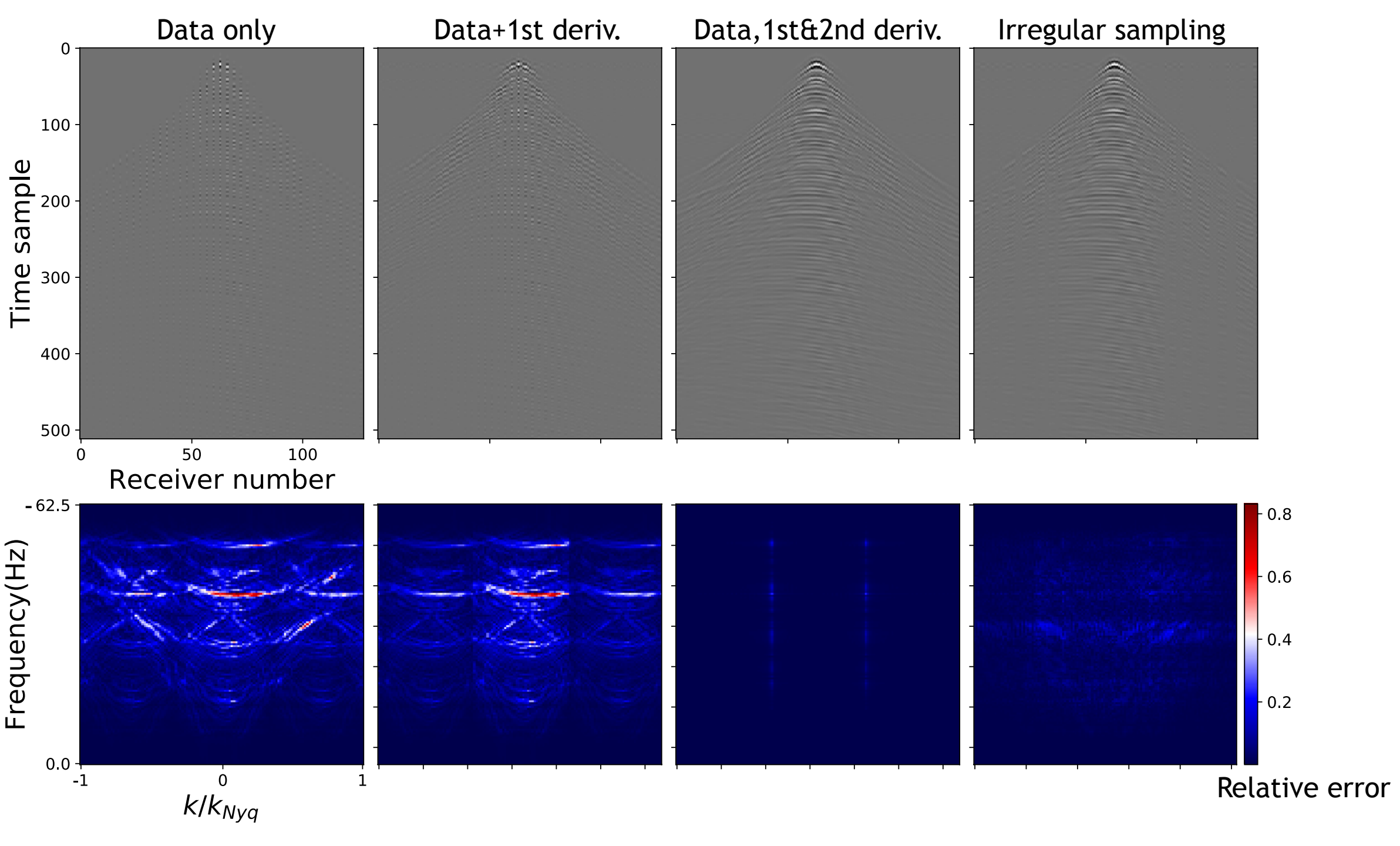
Irregular sampling

Regular sampling: strong imprint

Irregular sampling: weak imprint



Felix J. Herrmann(2010)


Data only
Data+1st deriv.
Data,1st&2nd deriv.
Irregular sampling
Time sample
0
100
200
300
400
500
0
50
100
Receiver number
Frequency(Hz)
62.5
0.0
-1
0
1
k/k_{Nyq}
0.8
0.6
0.4
0.2
Relative error

- *Seismic Oceanography*
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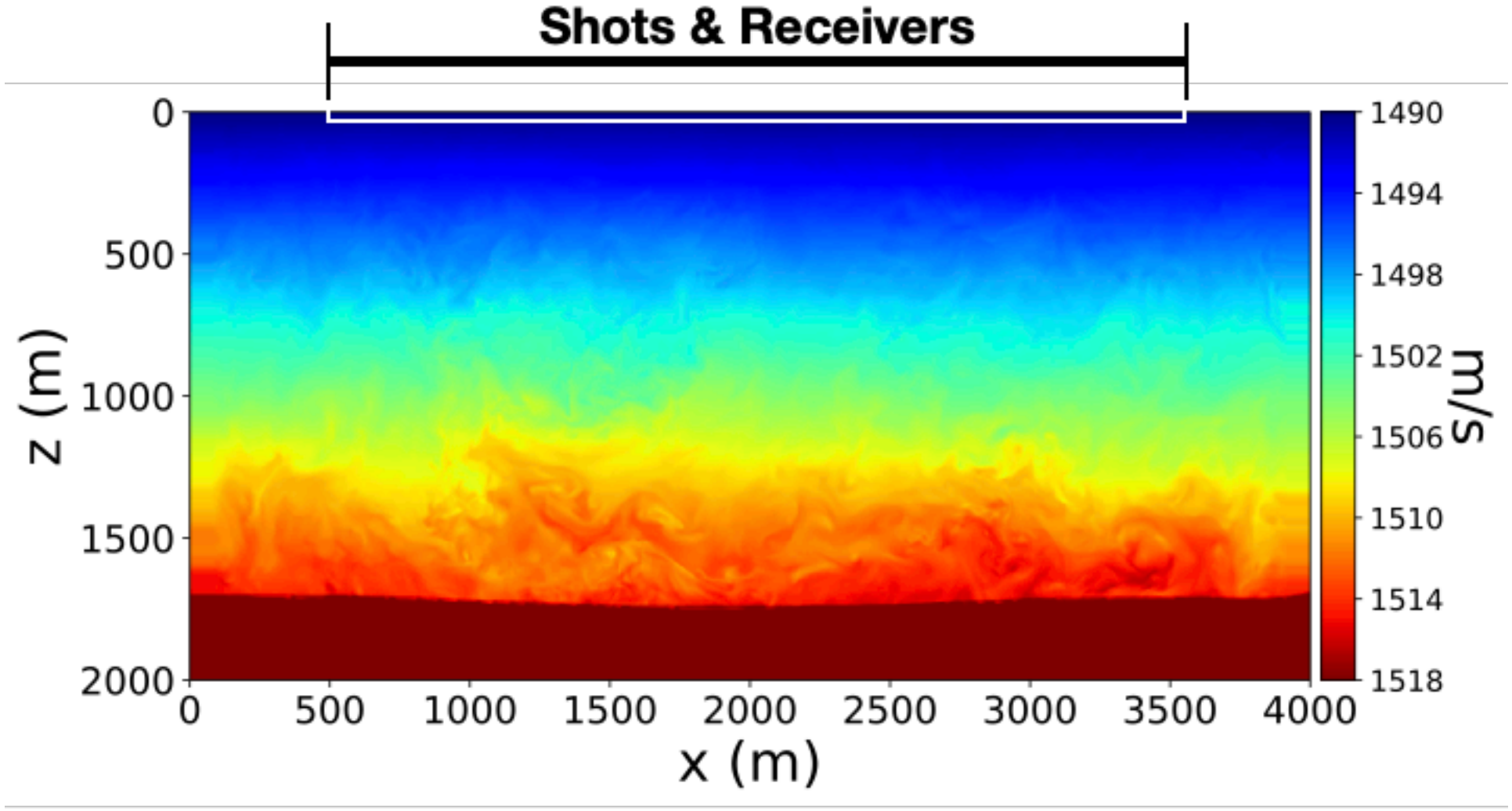
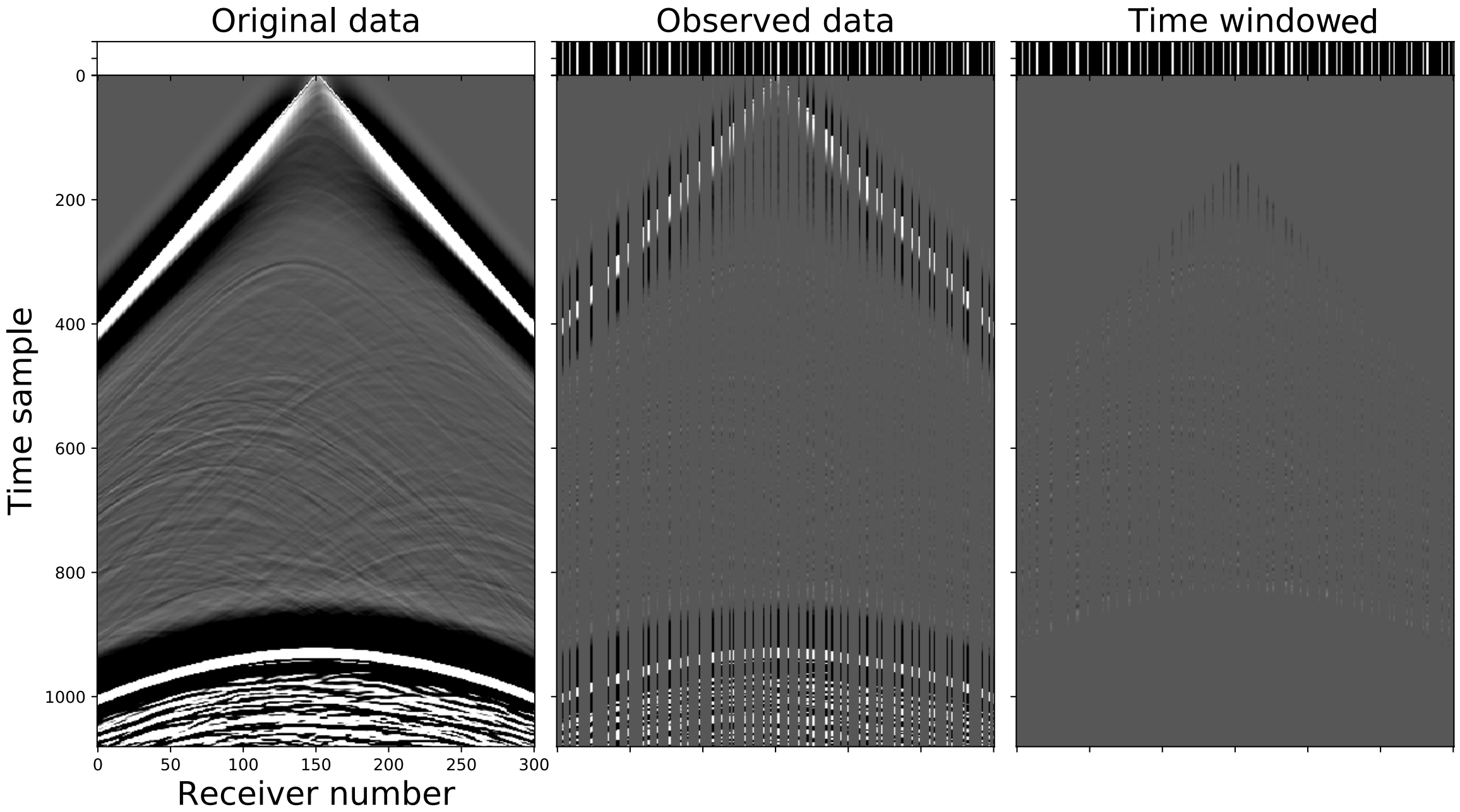
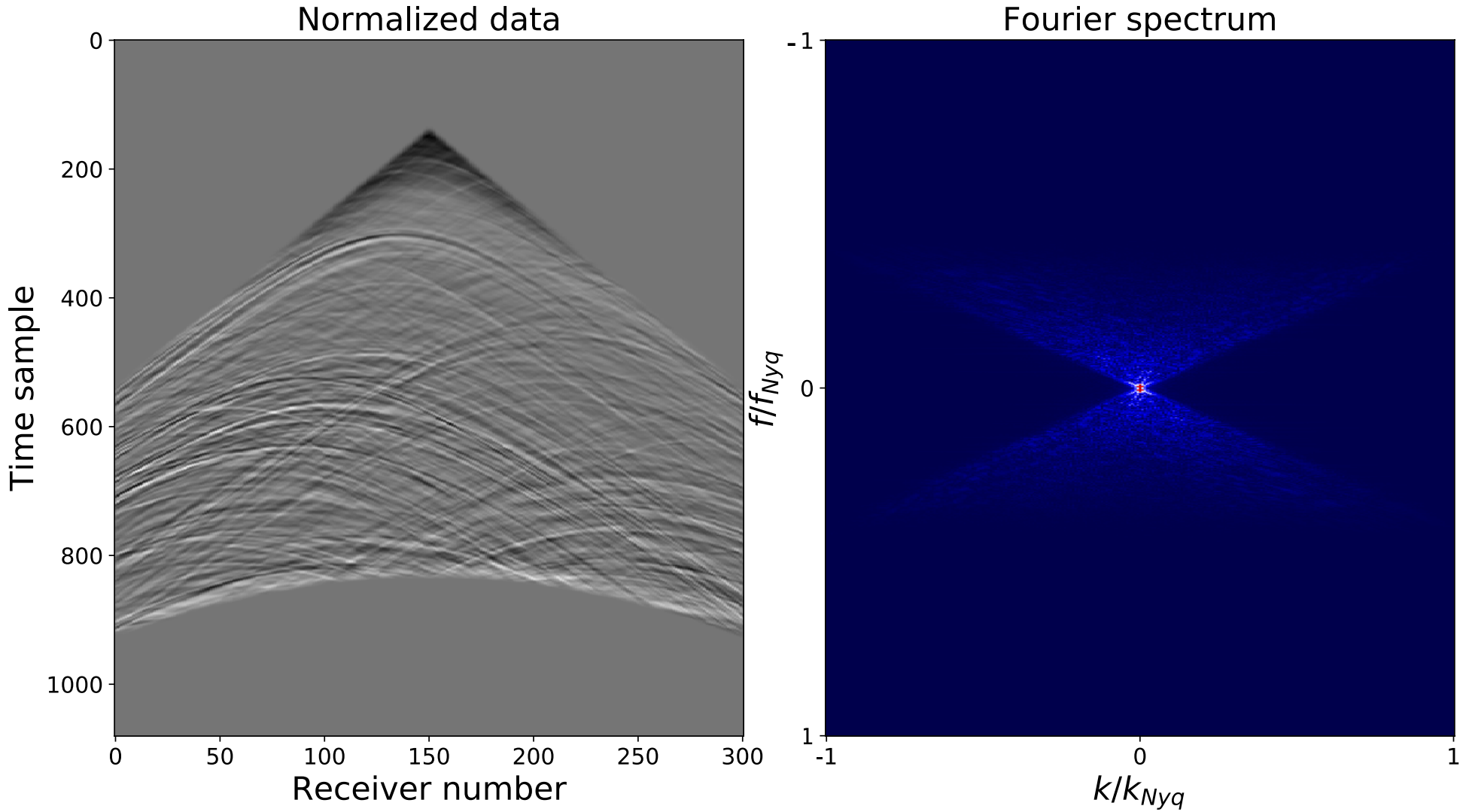
Turbulence model



Sampling—1/6 traces



Normalized data and its wavenumber-frequency spectrum



Preconditioning for ocean turbulence wavefield

Prior information:

P_{xt}: space-time domain

$P_{k\omega}$: Fourier domain

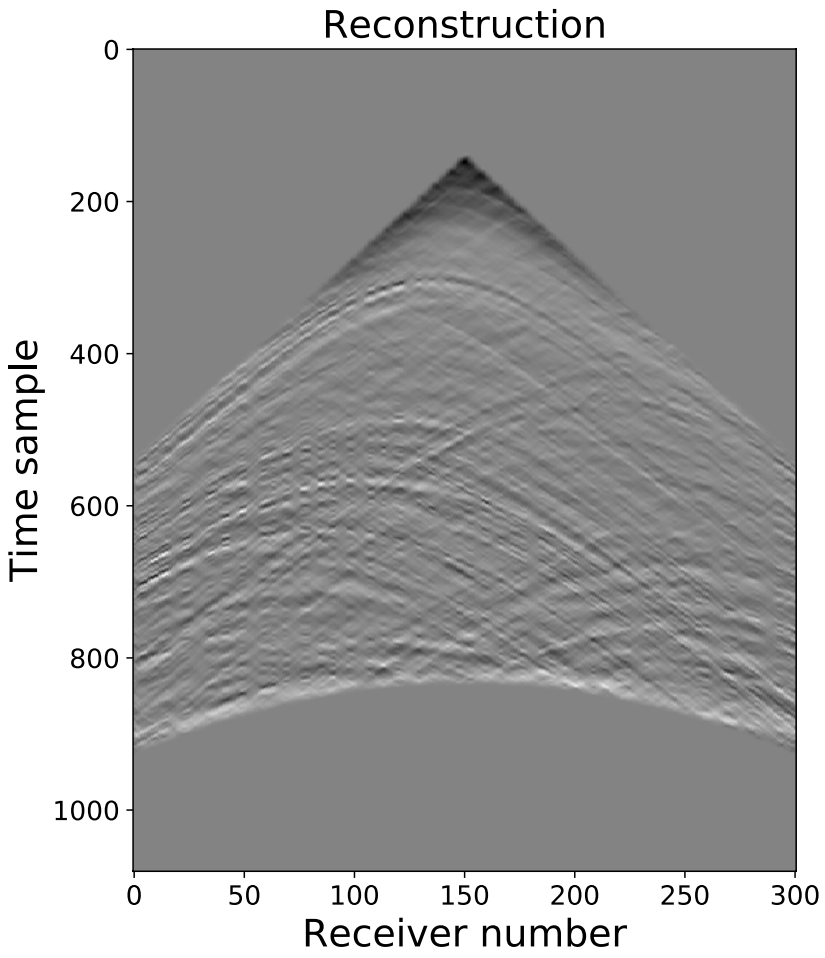
$$d_{mod} = F^{-1} d_f$$

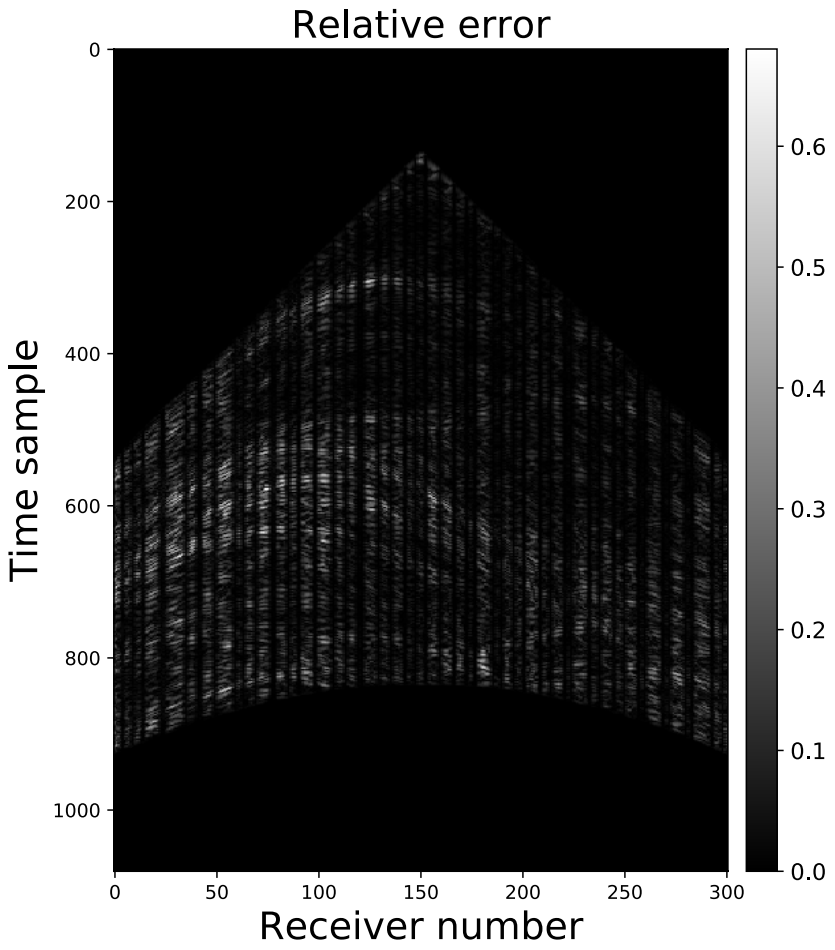
$$d_{obs} = S F^{-1} d_f$$

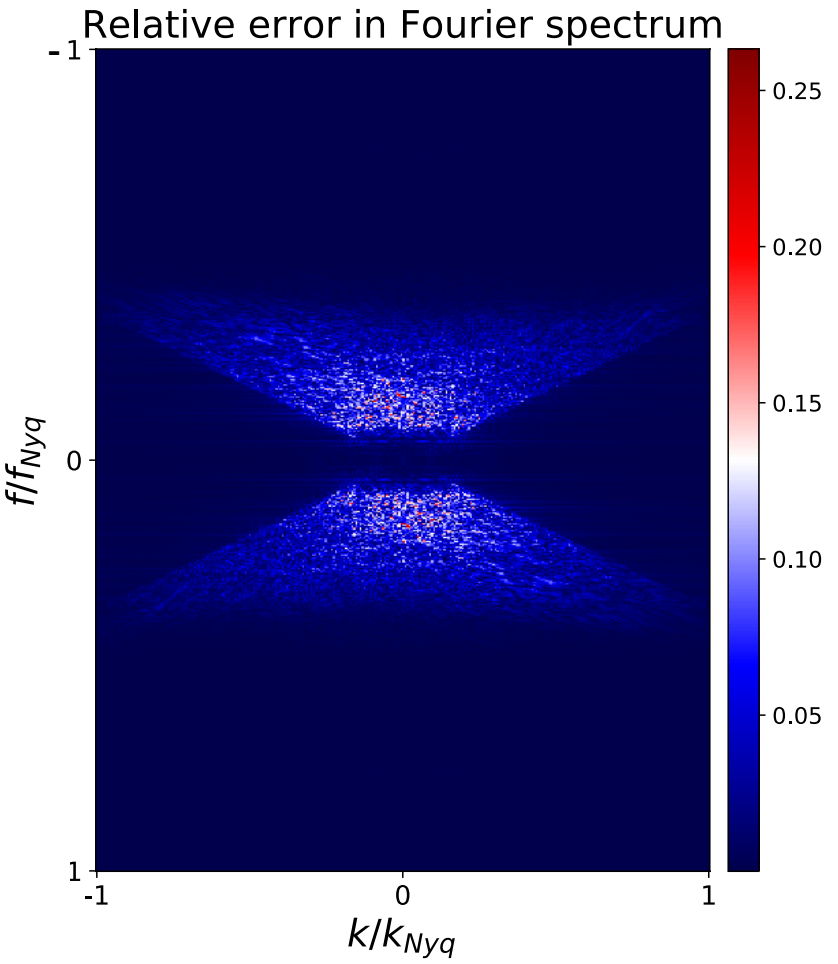
$$d_{obs} = S P_{xt} F^{-1} P_{k\omega} \hat{d}_f$$

$$d^P_{mod} = P_{xt} F^{-1} P_{k\omega} \hat{d}_f$$

Reconstruction

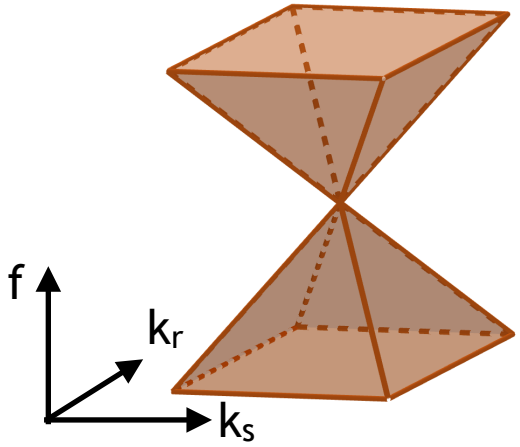






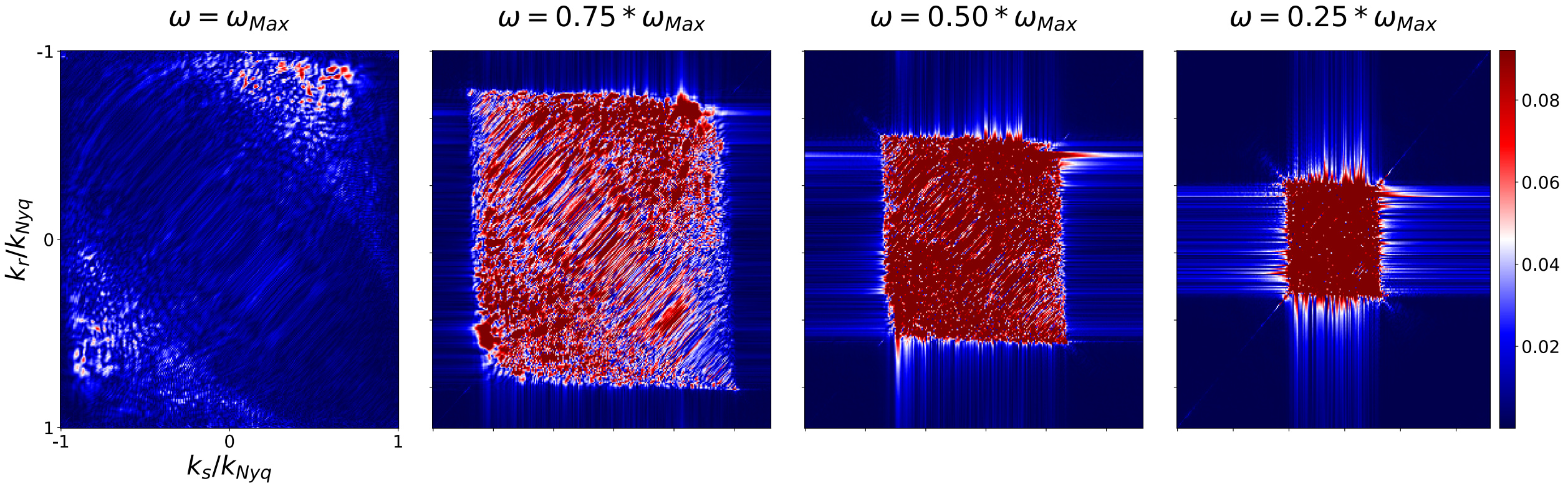
3D Reconstruction: multi-source, multi-receiver

Preconditioner in Fourier domain



281 shots & 281 receivers

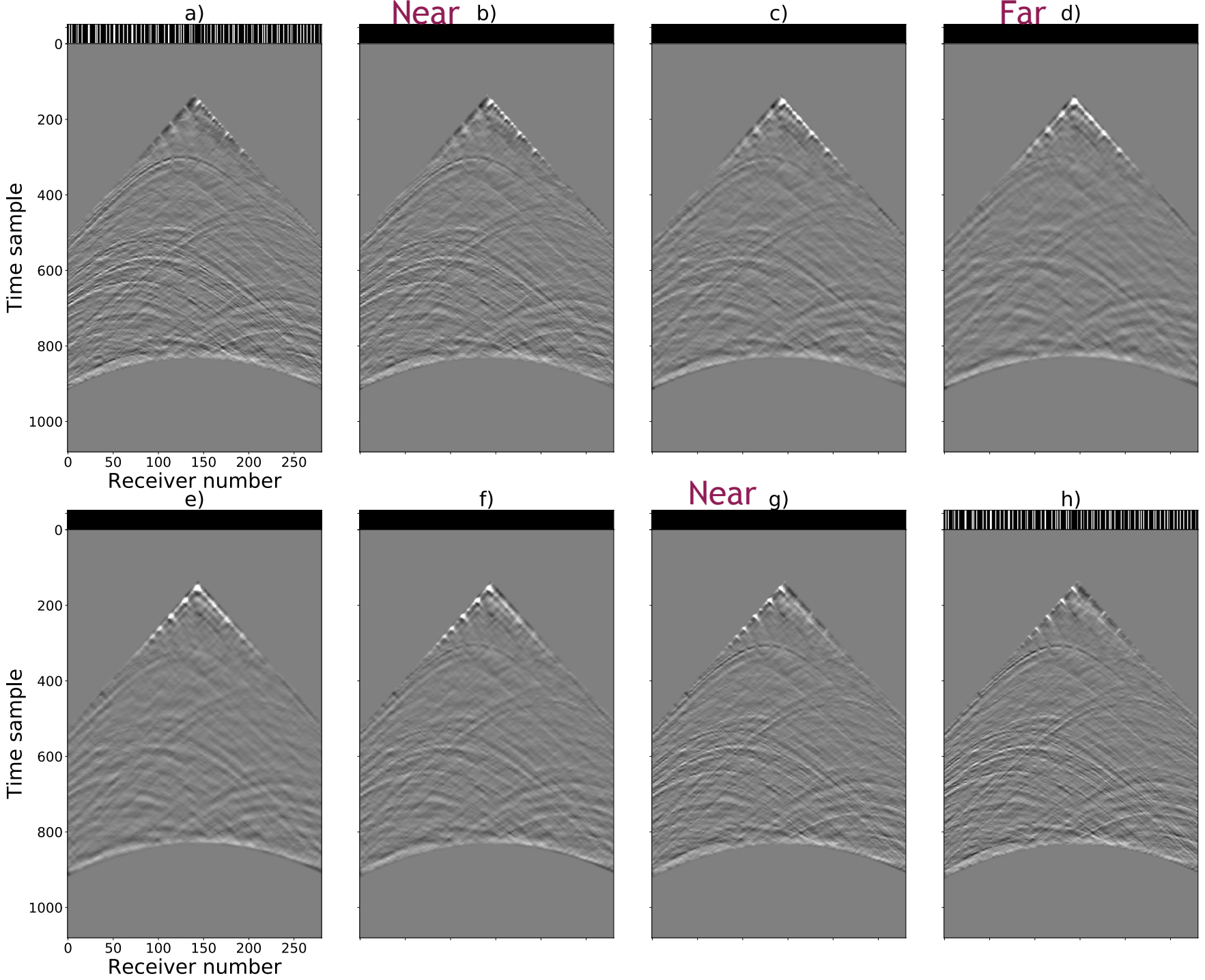
Fourier Spectrum



3D Reconstruction

Irregular sampling
&
1/4 decimation

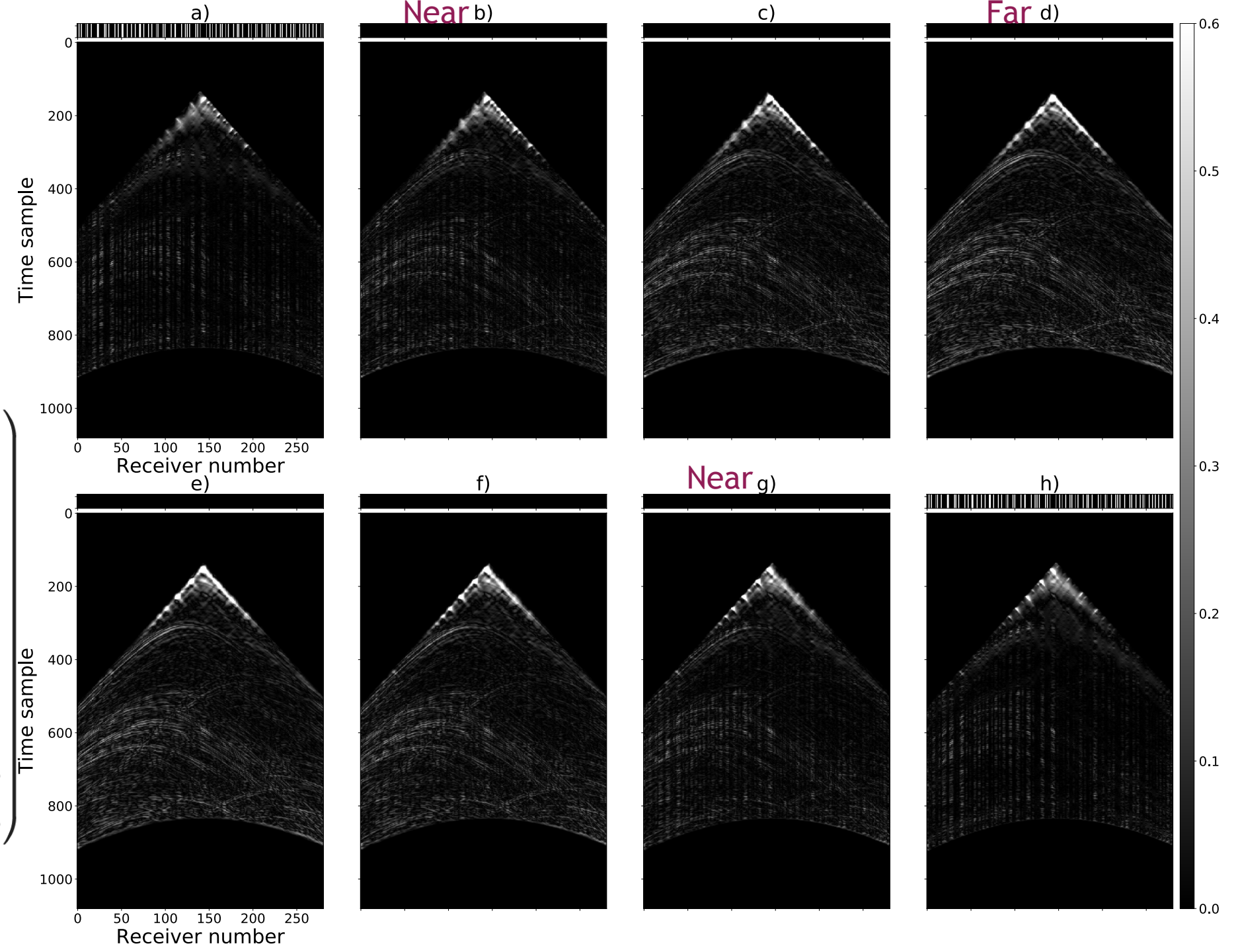
$$d_{obs} = \begin{pmatrix} d_t \\ d_{r1} \\ d_{r2} \\ d_{s1} \\ d_{s2} \\ d_{r1s1} \\ d_{r2s1} \\ d_{r1s2} \\ d_{r2s2} \end{pmatrix} \quad and \quad S = \begin{pmatrix} R_r \\ D_{r1} \\ D_{r1} \\ D_{s1} \\ D_{s2} \\ D_{r1s1} \\ D_{r2s1} \\ D_{r1s2} \\ D_{r2s2} \end{pmatrix}$$



3D Reconstruction

Irregular sampling
&
1/4 decimation

$$d_{obs} = \begin{pmatrix} d_t \\ d_{r1} \\ d_{r2} \\ d_{s1} \\ d_{s2} \\ d_{r1s1} \\ d_{r2s1} \\ d_{r1s2} \\ d_{r2s2} \end{pmatrix} \quad and \quad S = \begin{pmatrix} R_r \\ D_{r1} \\ D_{r1} \\ D_{s1} \\ D_{s2} \\ D_{r1s1} \\ D_{r2s1} \\ D_{r1s2} \\ D_{r2s2} \end{pmatrix}$$



Conclusion

- *Reconstruction*
  - —derivatives
  - —irregular sampling & preconditioning
- *Using data structure*
  - —space-time domain
  - —Fourier domain …
- *Source and receiver reconstruction*
- *Promising for turbulence monitoring*

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