Latest developments in marine (4D) acquisition

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Carry home messages

Randomization of field-data acquisition

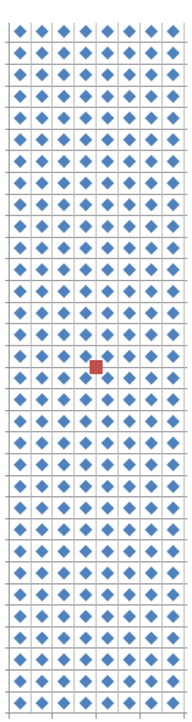
- has solid theoretical underpinnings from compressive sensing
- can lead to improved wavefield reconstruction from low-cost acquisitions
- fundamental new insights how to acquire data

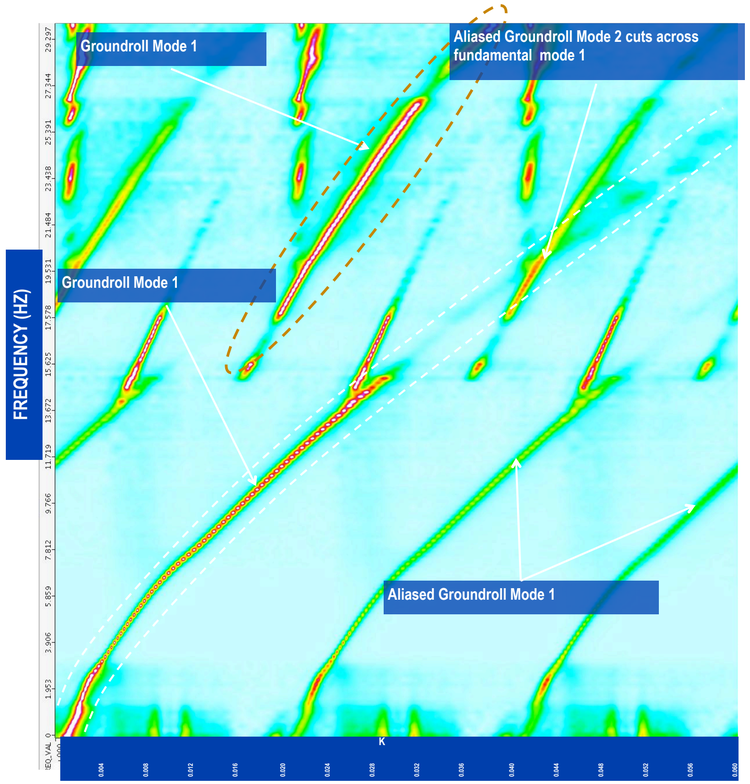
Randomization and repeatability in time-lapse acquisition

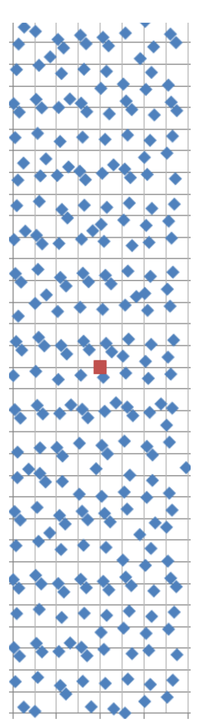
- could put an end to insisting on repeatability
- exploits what time-lapse surveys have in common rather than how they differ
- significantly improved time-lapse signals from severely undersampled data

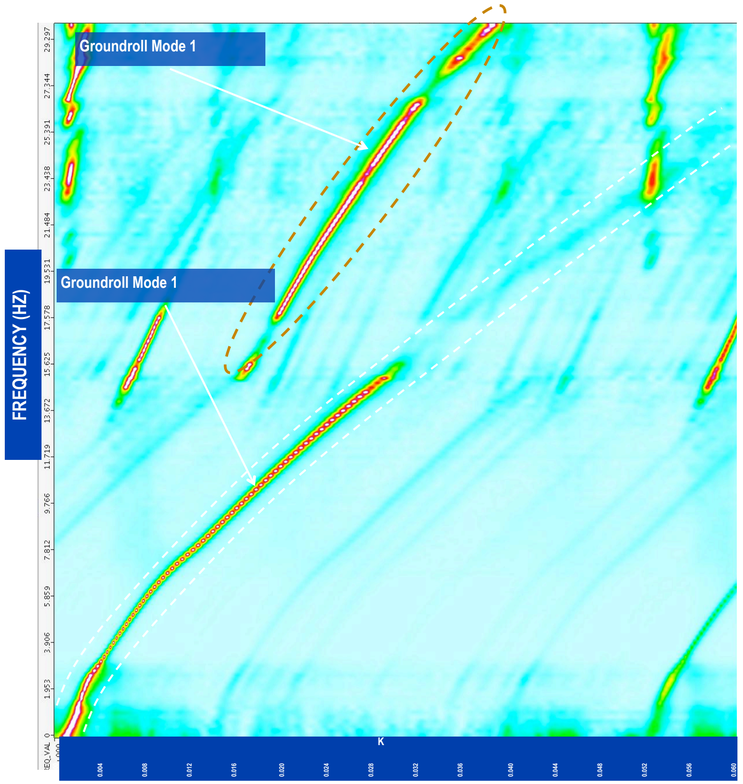
Randomized sampling
– examples from industry (WesternGeco)

Random *source* locations
(thanks Nick Moldoveanu)



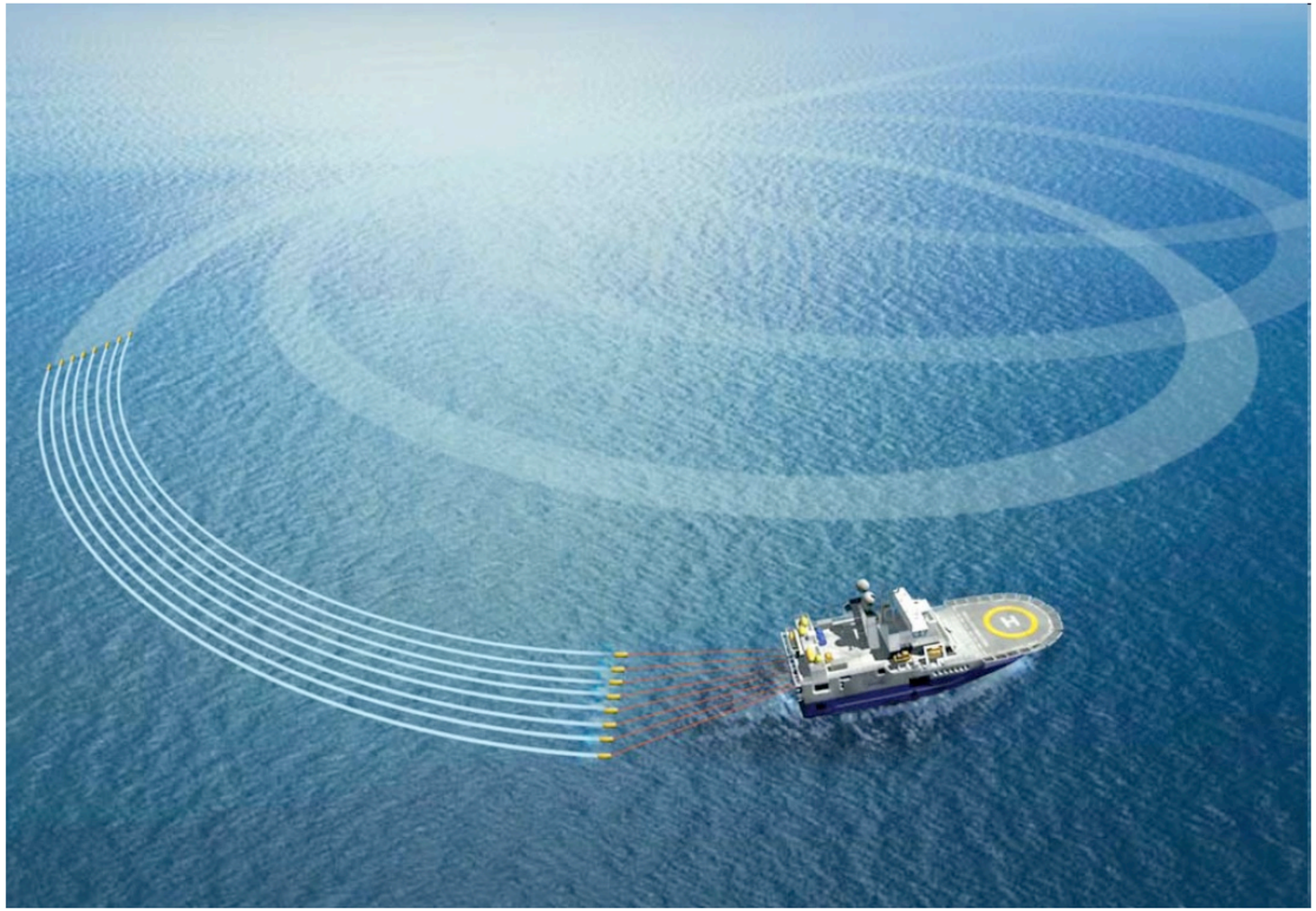






Coil sampling

– examples from industry (WesternGeco)



Coil sampling

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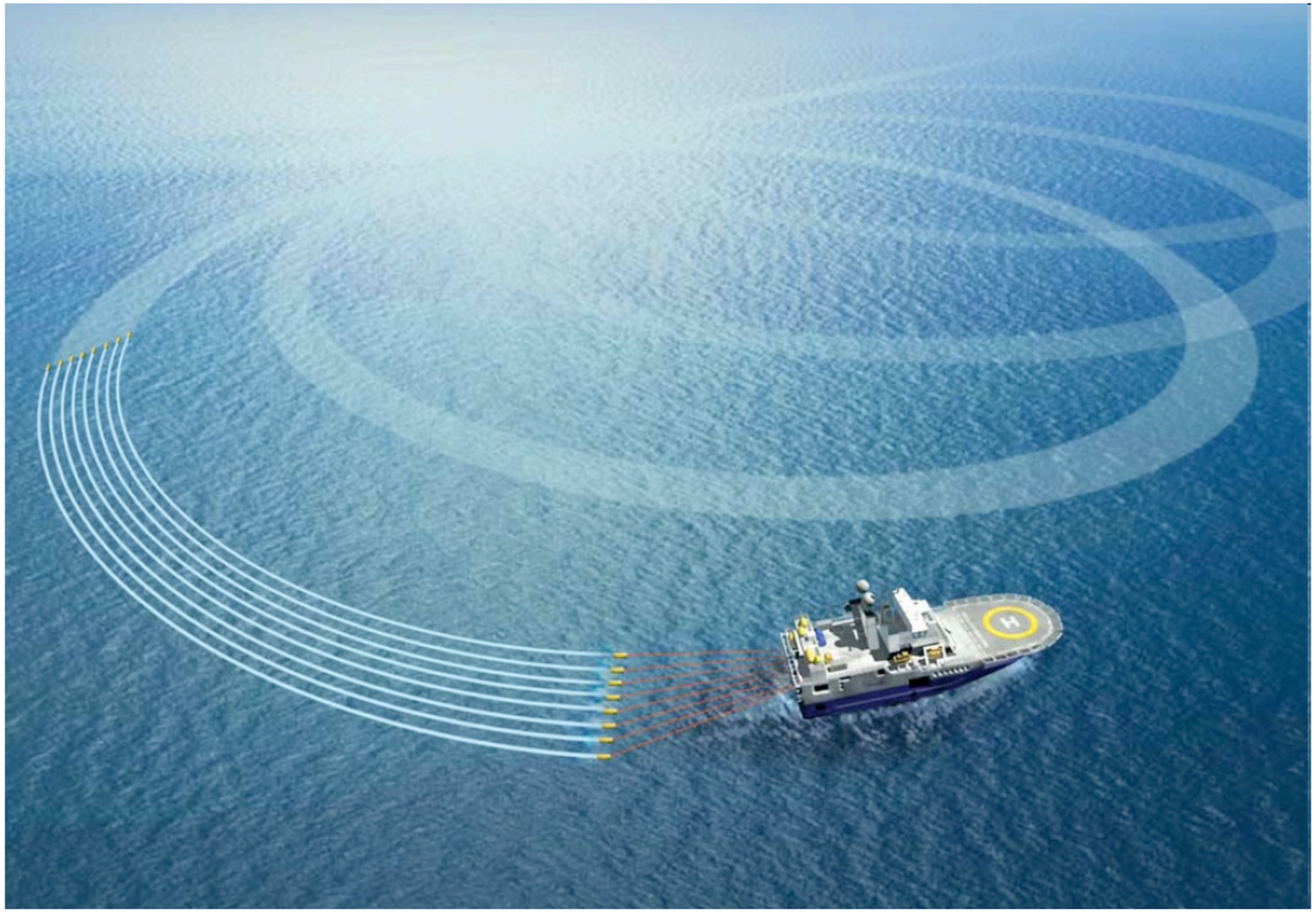
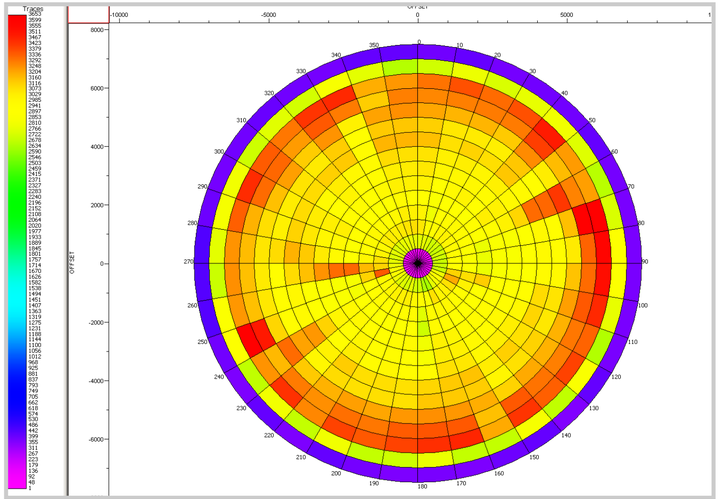




Mosher, C. C., Keskula, E., Kaplan, S. T., Keys, R. G., Li, C., Ata, E. Z., ... & Sood, S. (2012, November). Compressive Seismic Imaging. In *2012 SEG Annual Meeting*. Society of Exploration Geophysicists.

Randomized undersampling

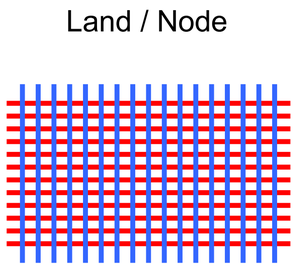
– examples from industry (ConocoPhilips)

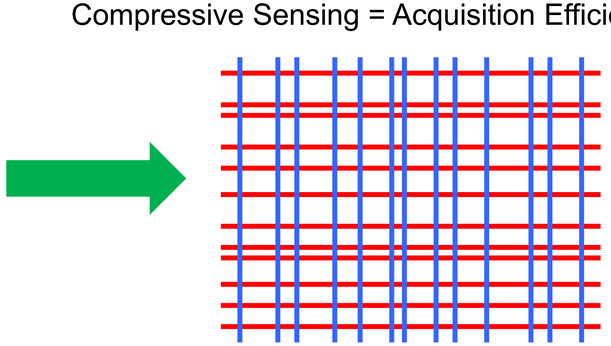
Deliberate & natural randomness in acquisition

(thanks to Chuck Mosher)

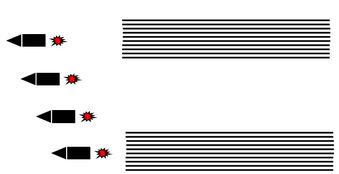
Land / Node

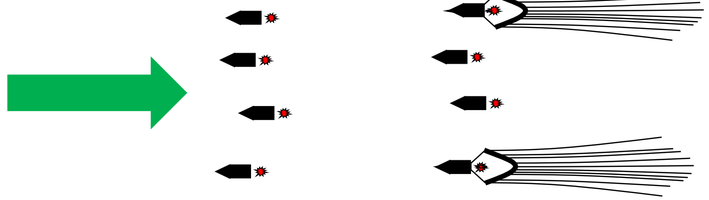
Compressive Sensing = Acquisition Efficiency

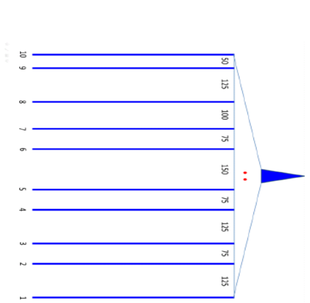




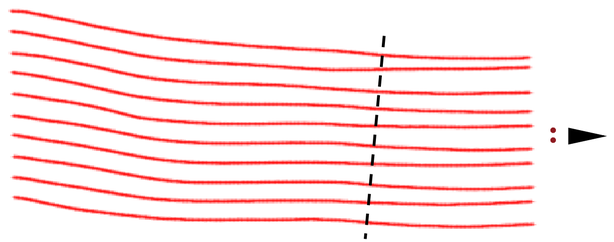
Marine







Designed



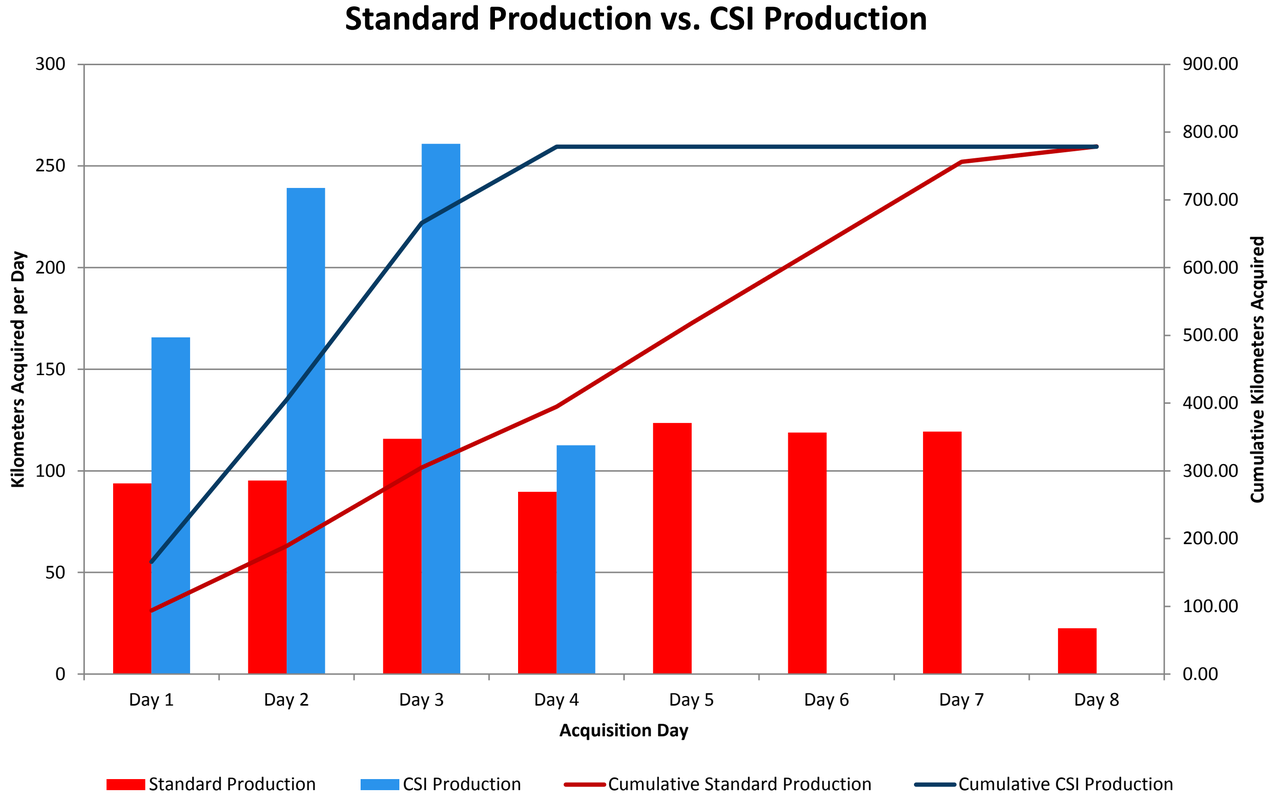
Actually Acquired

Bottom line

– examples from industry (ConocoPhilips)

Economics

(thanks to Chuck Mosher)



add refes to Craig and Nick

Observations

Randomized *coil* sampling:

- renders coherent *aliases* harmless by turning them into *incoherent* noise
- *"noise"* removed by stacking over relatively high *fold*
- major *improvements* in RTM

CSI Houston:

- renders coherent *aliases* harmless by turning them into *incoherent* noise
- *"noise"* removed by exploiting *structure* through *convex* optimization
- *deliberate under*sampling major cost *reductions* in acquisition

Other examples of *randomized* sampling include

- *missing*-trace interpolation of various sorts
- *simultaneous* or *blended* marine & land acquisition

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

Compressive sensing *paradigm*

Find representations that reveal _structure_

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

Sample to _break_ the _structure_

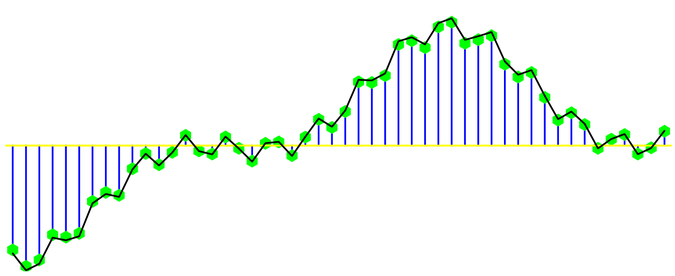
- *randomized* acquisition (e.g., *jittered* sampling, time *dithering*, *encoding*, etc.)
- destroy *sparsity*

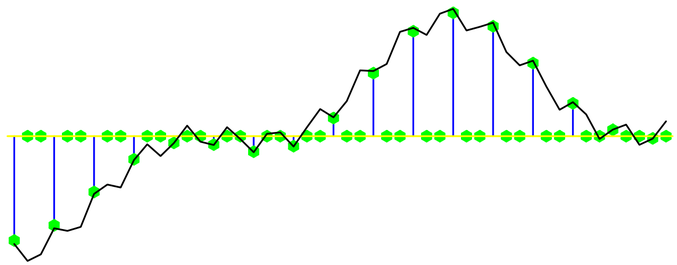
Recover _structure_ by promoting

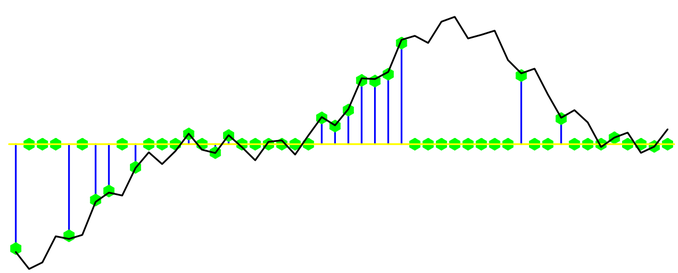
- *sparsity* via *one*-norm *minimization*

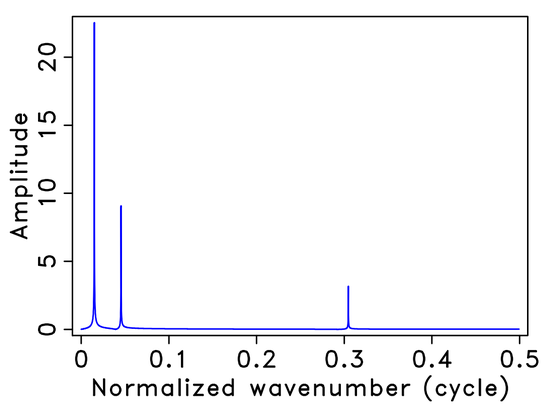
Felix J. Herrmann and Gilles Hennenfent, "**Non-parametric seismic data recovery with curvelet frames**", *GJI*, vol. 173, p. 233-248, 2008.
Gilles Hennenfent and Felix J. Herrmann, "**Simply denoise: wavefield reconstruction via jittered undersampling**", *Geophysics*, vol. 73, p. V19-V28, 2008.
Felix J. Herrmann, "**Randomized sampling and sparsity: Getting more information from fewer samples**", *Geophysics*, vol. 75, p. WB173-WB187, 2010.

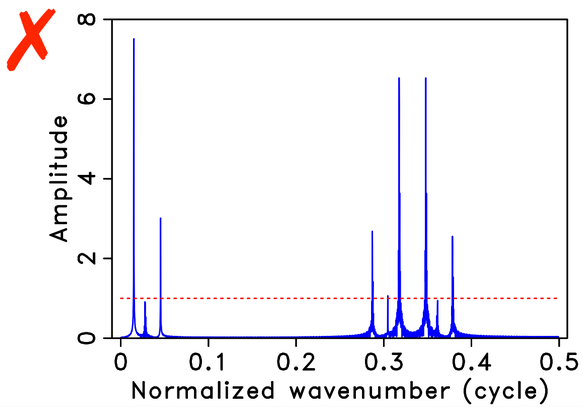
Golden oldies
– sparse time-harmonic signals

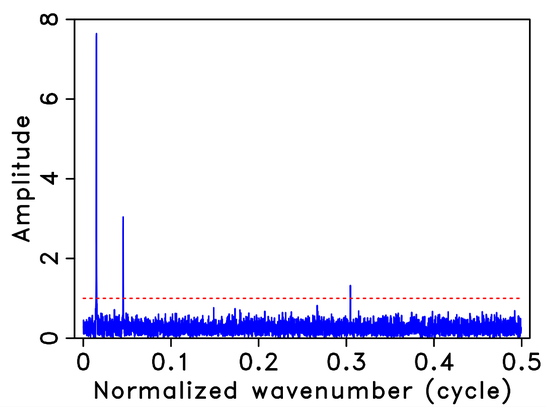






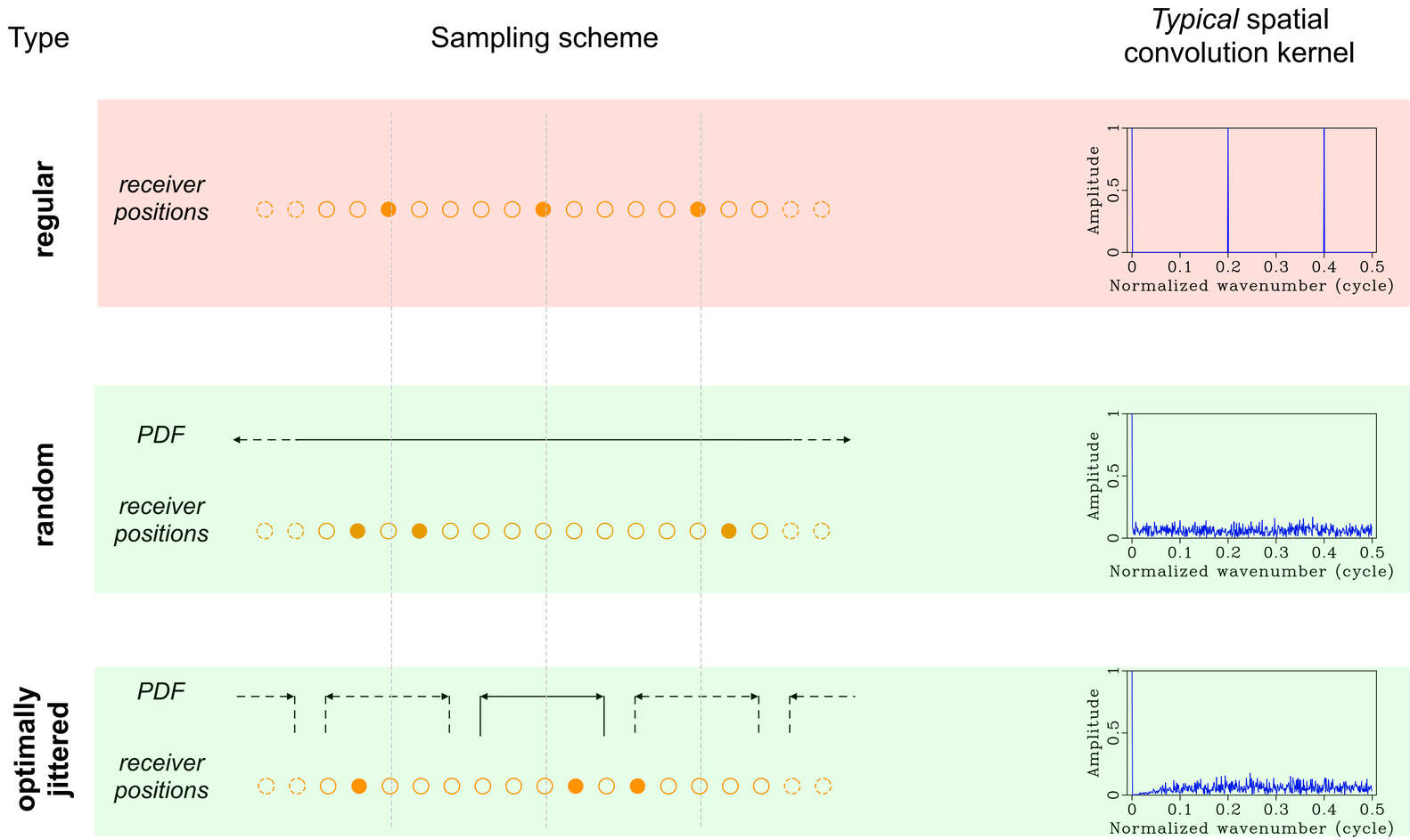




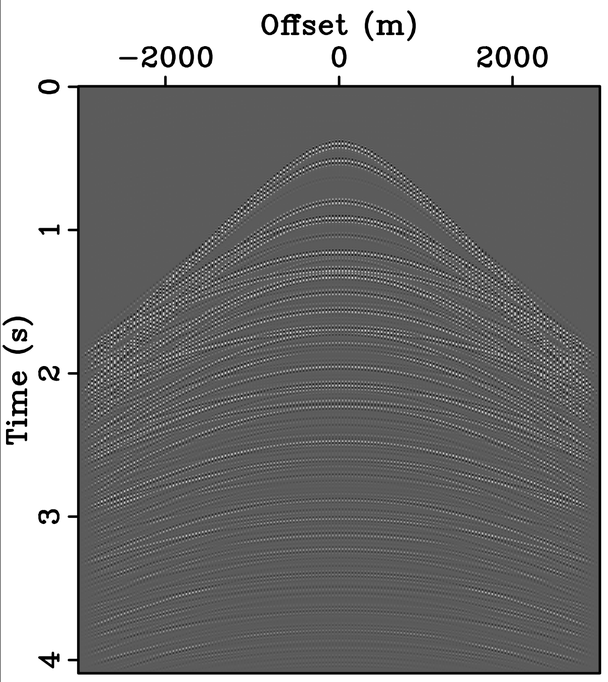


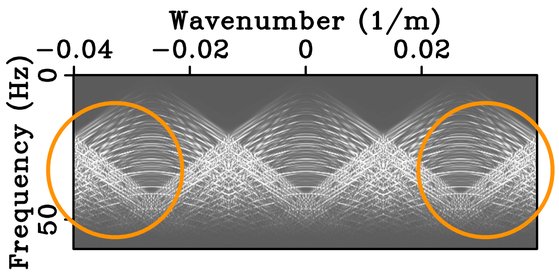
Gilles Hennenfent and Felix J. Herrmann, "**Simply denoise: wavefield reconstruction via jittered undersampling**", *Geophysics*, vol. 73, p. V19-V28, 2008.

Jittered sampling

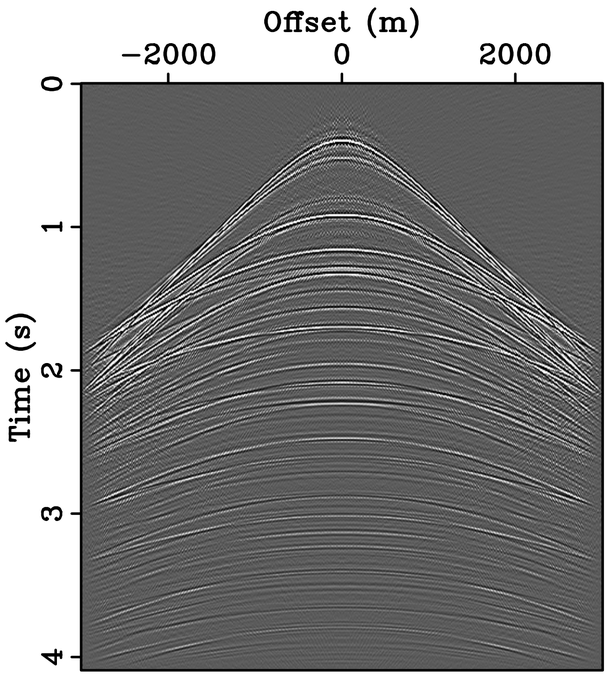


Periodic sampling

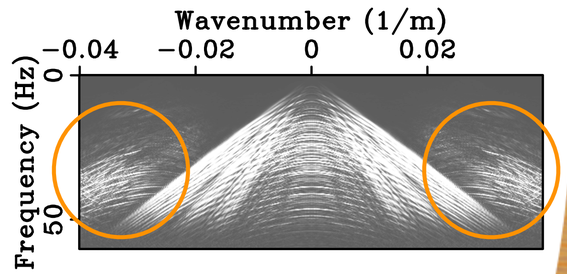




*3-fold under*sampled

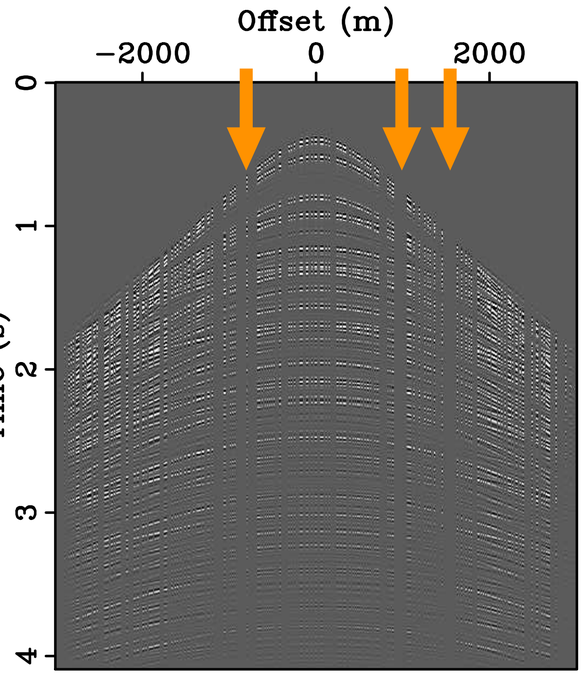


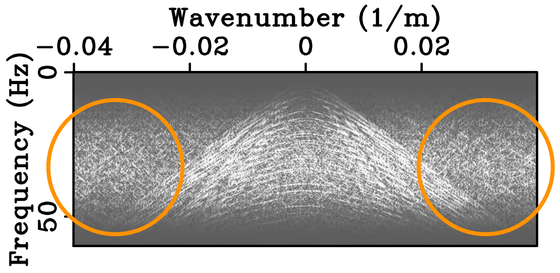
SNR = 6.92 dB



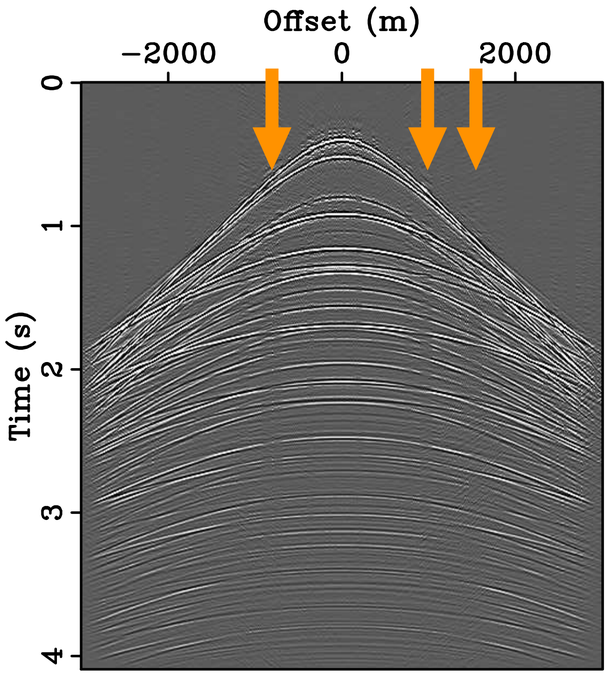
recovered

Uniform random sampling

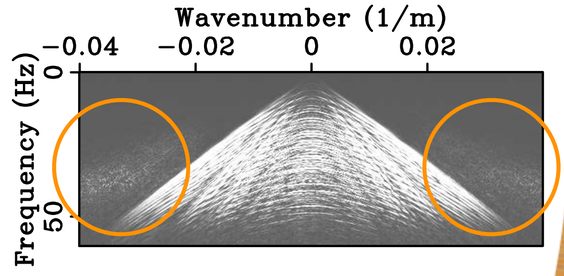




3-fold undersampled

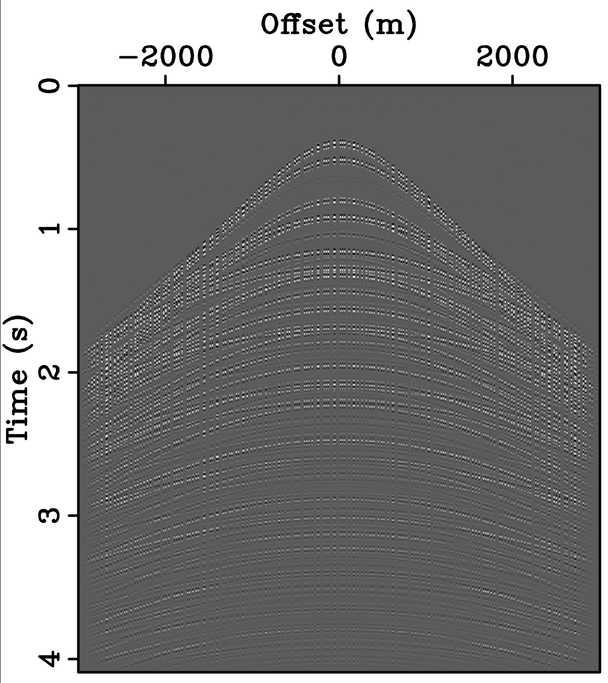


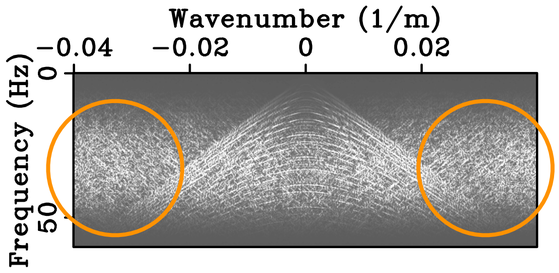
SNR = 9.72 dB



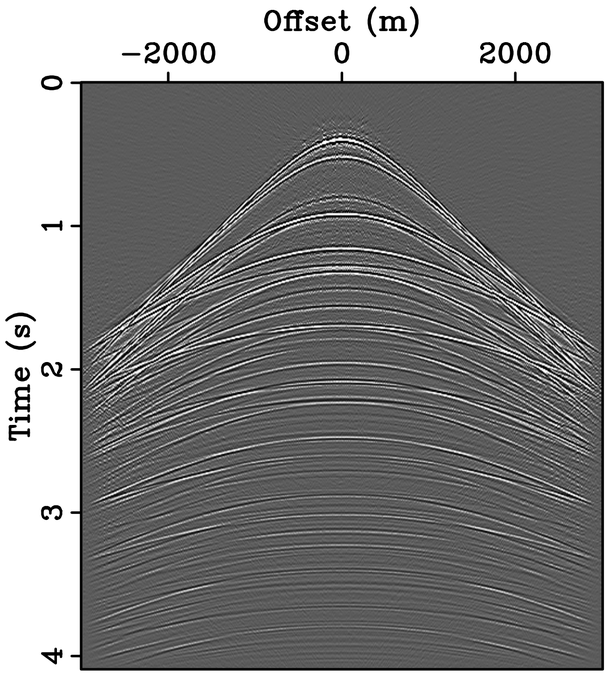
recovered

Jittered sampling

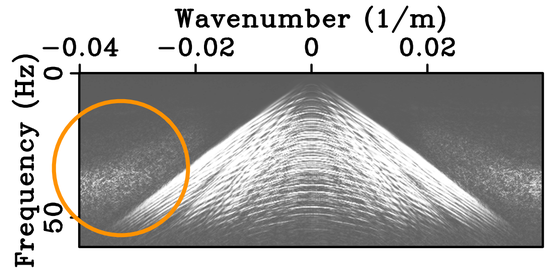




***3-fold under*sampled**



SNR = 10.42 dB



recovered

Time-*jittered* marine acquisition

SLIM
University of British Columbia

Objective

Shorten marine acquisition times & increase source sample density.

Question:

Does increased variability of firing times improve recovery?

Objective

Shorten marine acquisition times & increase source sample density.

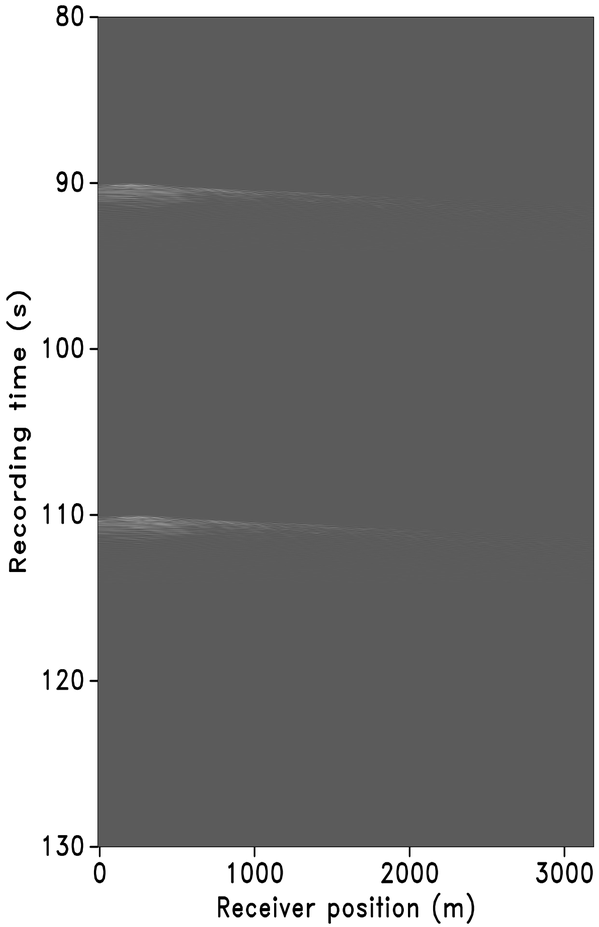
Questions:

Does increased randomized variability of firing times improve recovery?

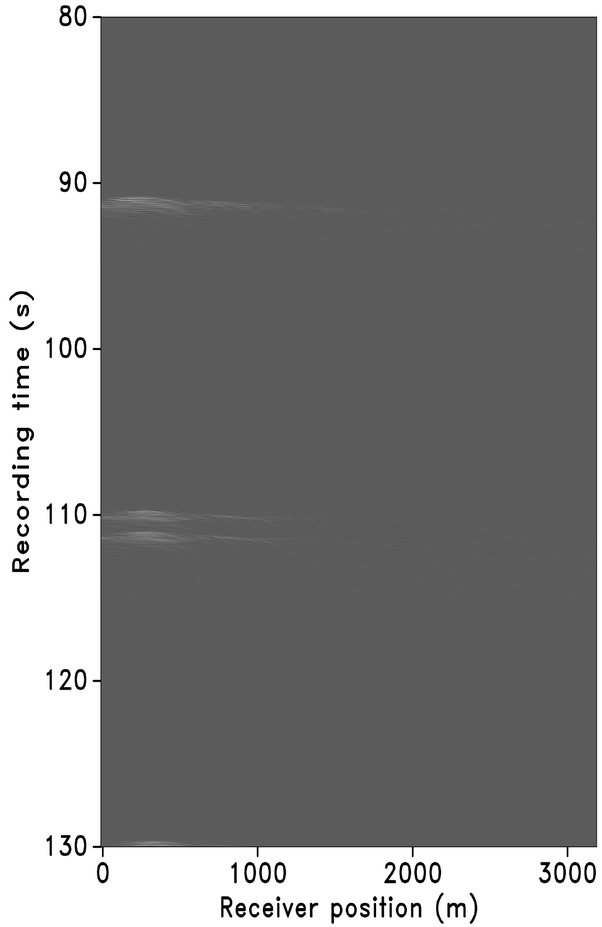
If transform-domain recovery fails are there alternatives?

Measurements

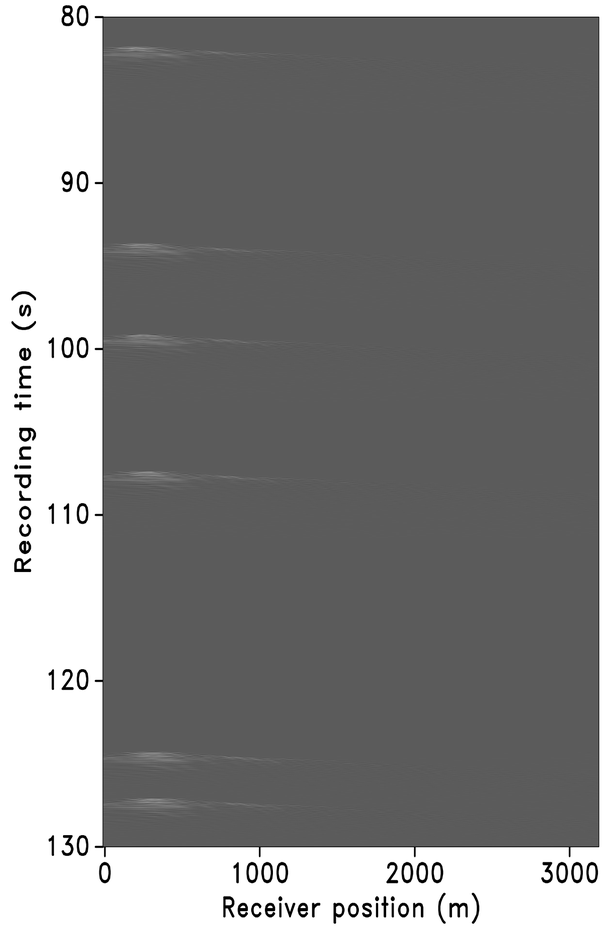
periodic



low variability

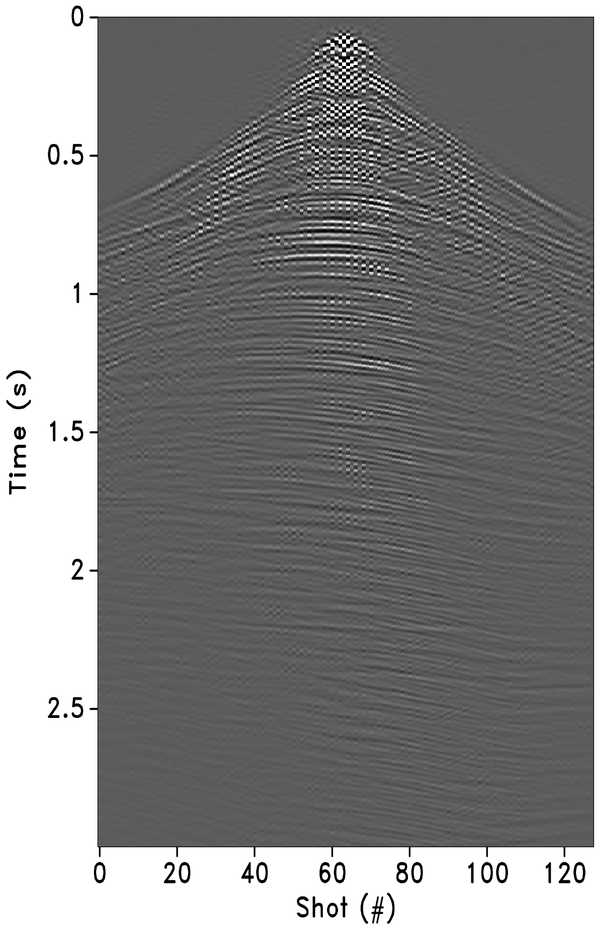


high variability

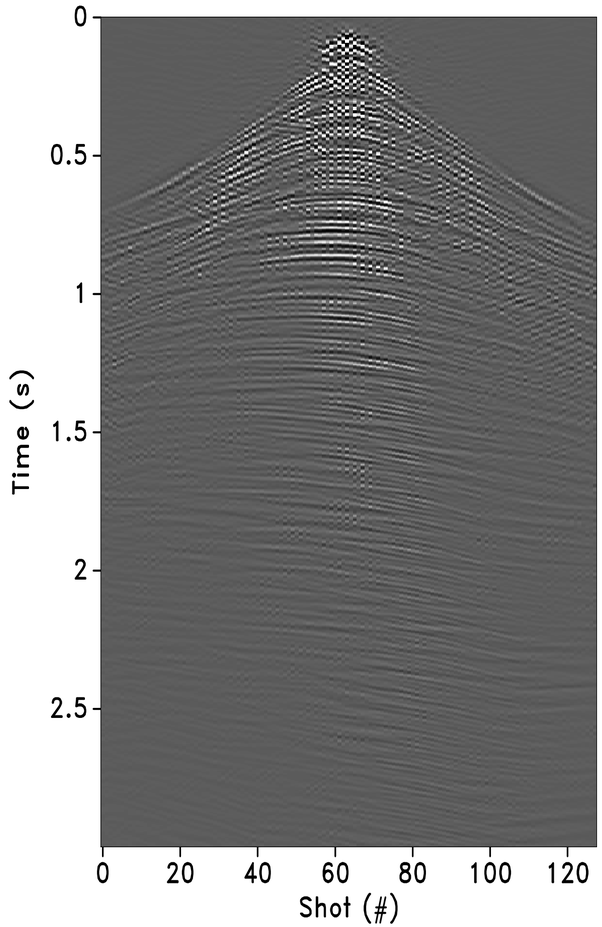


Recovery

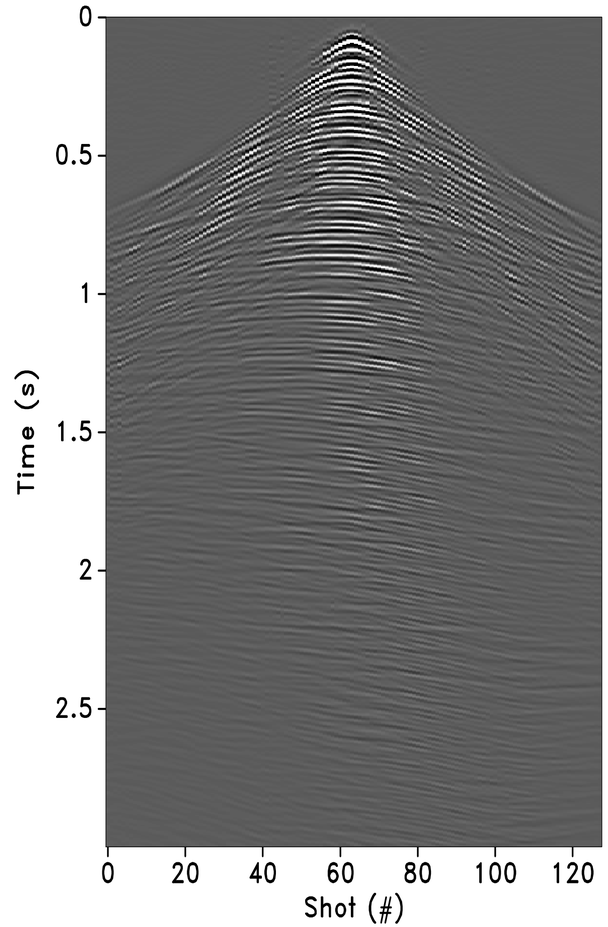
periodic



low variability

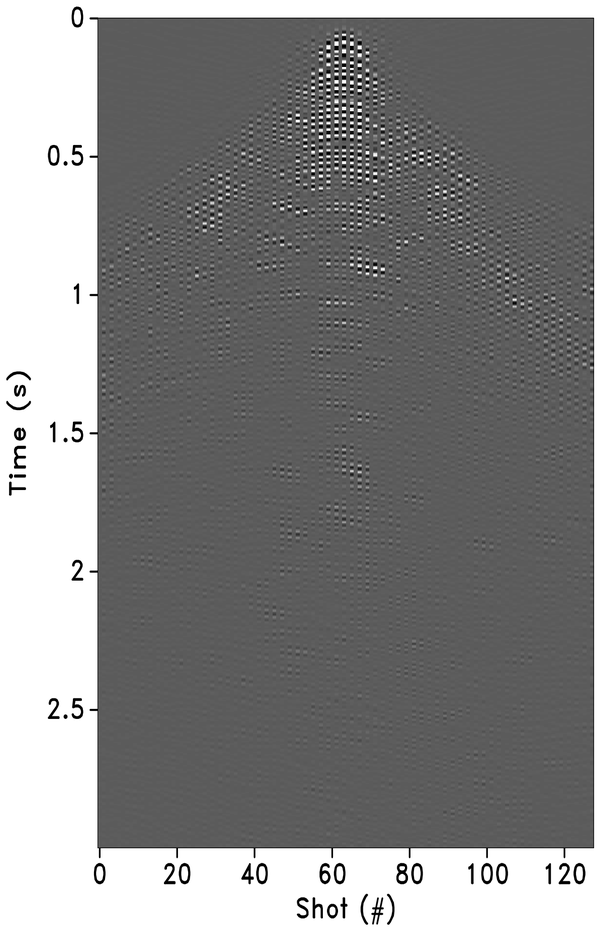


high variability

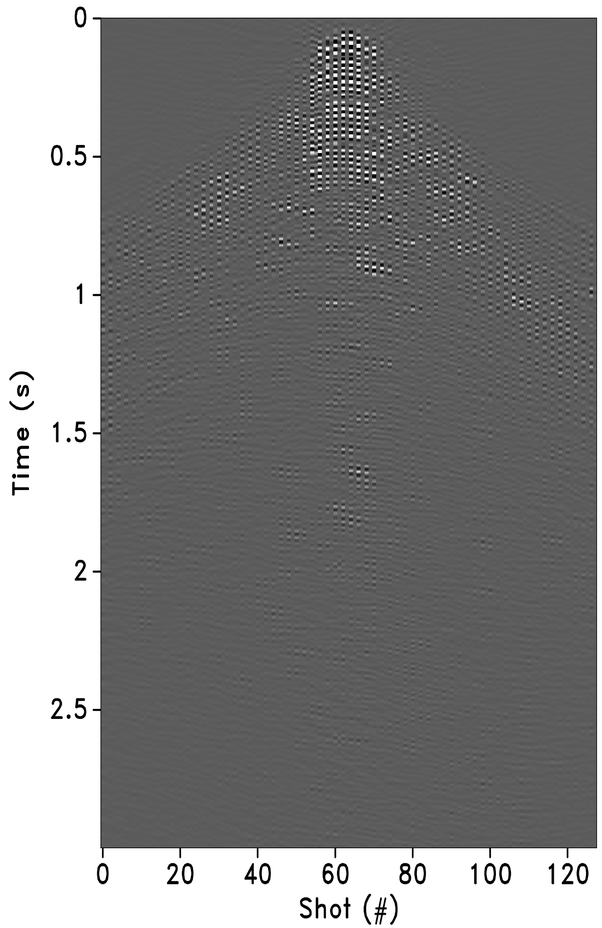


Difference

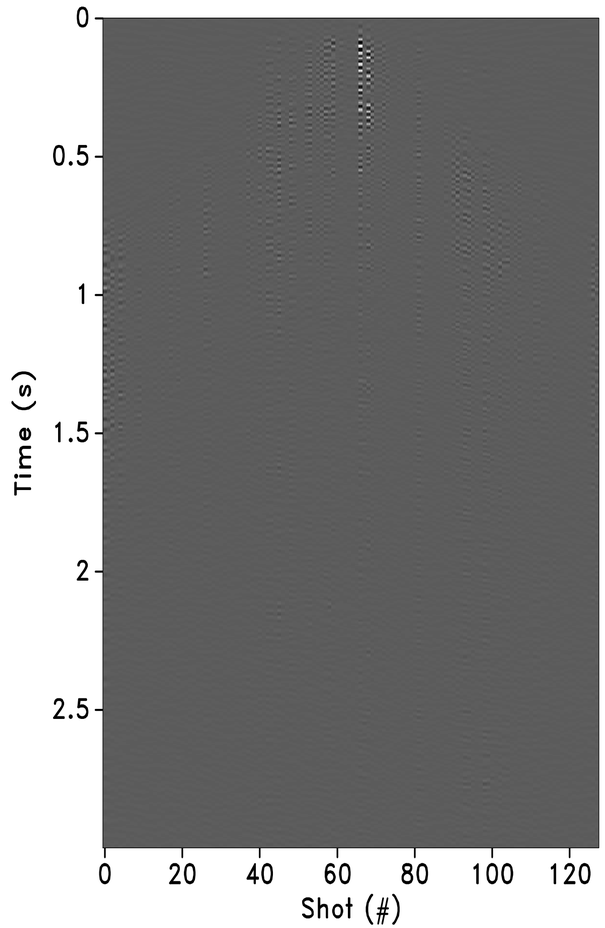
periodic



low variability



high variability



Haneet Wason and Felix J. Herrmann, "**Time-jittered ocean bottom seismic acquisition**", SEG, 2013
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

Observations

Recoveries entail joint interpolations & deblendings/source separations

Question:

Does increased variability of firing times improve curvelet recovery?

- ✓ yes, but only for ocean bottom acquisition – towed arrays are more challenging

Haneet Wason and Felix J. Herrmann, "Time-jittered ocean bottom seismic acquisition", SEG, 2013
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
Haneet Wason, Rajiv Kumar, Aleksandr Y. Aravkin, and Felix J. Herrmann, "Source separation via SVD-free rank minimization in the hierarchical semi-separable representation". 2014.

Observations

Recoveries entails joint interpolations & deblendings

Questions:

Does increased variability of firing times improve curvelet recovery?

- ✓ yes, but only for node acquisition since it is challenging for towed arrays

If transform-domain recovery fails are there alternatives?

- ✓ yes, rank revealing techniques succeed where curvelet-domain fail
- ✓ yes, rank revealing techniques give curvelet techniques a "run for their money" with drastically improved run times & reduced memory use

Randomized time-*lapse* seismic

SLIM
University of British Columbia

Motivation

Seemingly *innocent* remark by Craig J. Beasley at SBGf meeting:

"Should we repeat or not repeat in randomized marine acquisition?"

Motivation

Seemingly *innocent* remark by Craig J. Beasley at SBGf meeting:

"Should we repeat or not repeat in randomized marine acquisition?"

"How sensitive is the recovery to minor errors in exact repeatability?"

Disclaimer

Assumptions:

- you are a *believer* in *randomized* acquisition & *sparse* recovery
- *seismic* data & *time*-lapse signal *both* permit *sparse* representations
- *degree* repetition refers to *percentage* of a *survey* that is repeated *exactly*

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

Disclaimer

Assumptions:

- you are a *believer* in *randomized* acquisition & *sparse* recovery
- *seismic* data & *time*-lapse signal *both* permit *sparse* representations
- allow for minor *known* errors in the repetition

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

Findings – a preview

Increased exact repetition amongst surveys leads to

- deteriorated recovery of the vintages themselves
- improved recovery of time-laps differences

Small and known errors lead to

- improved recovery of the vintages
- deteriorated recovery of time-lapse differences

Tentative conclusions

- do not bother to repeat as long as you know where you were
- instead aim to increase variability albeit natural variability already helps…