Creating virtual receivers from drill-bit noise using seismic interferometry

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Motivation

- A data-driven redatuming method
- Can improve migrated images in the presence of velocity errors
- Suitable for deep local imaging

Use drill-bit noise data acquired while drilling for such local imaging?

Outline

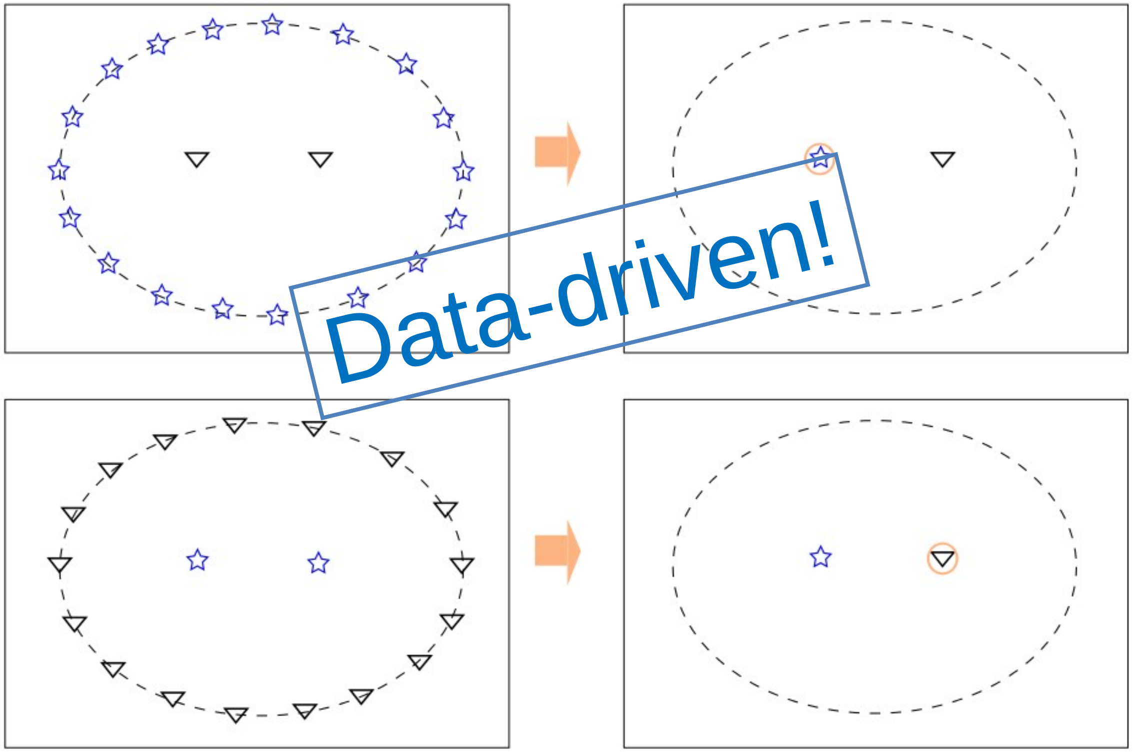
- Introduction
- Inter-source seismic interferometry (SI)
- Inter-source SI with non-transient sources
- Synthetic results
- Discussion and conclusion

Seismic interferometry (SI)

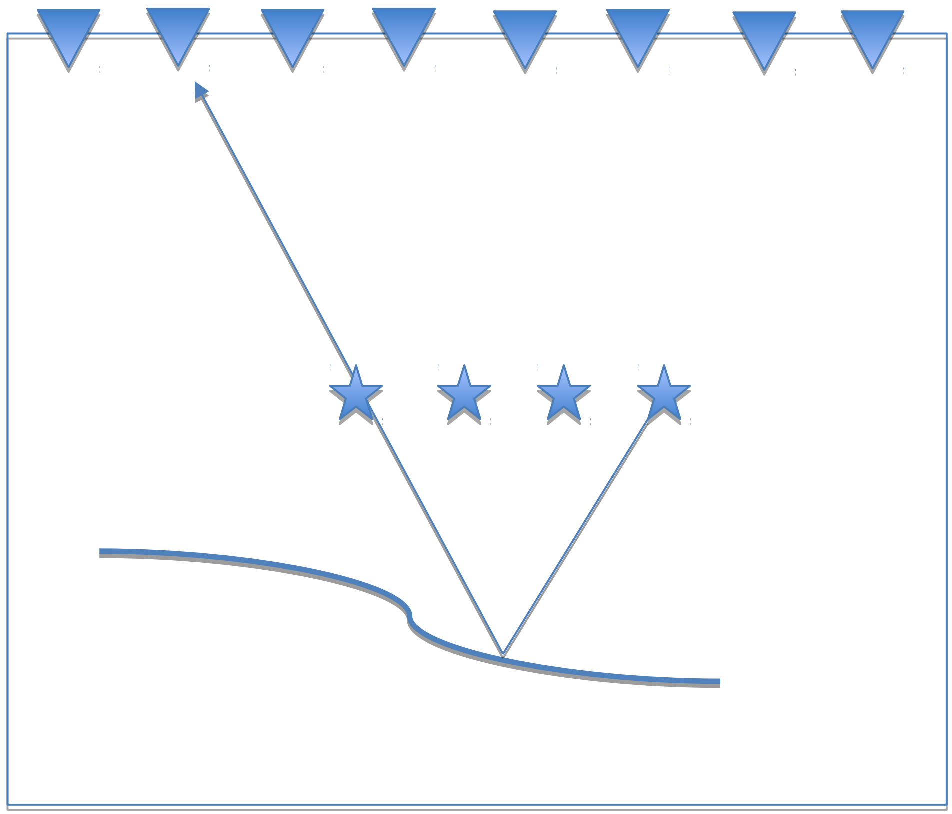
- Green's function retrieval
- Any arbitrary 3D inhomogeneous lossless medium
- Integral (Summation) of crosscorrelation of wavefield observations

• Inter-receiver SI

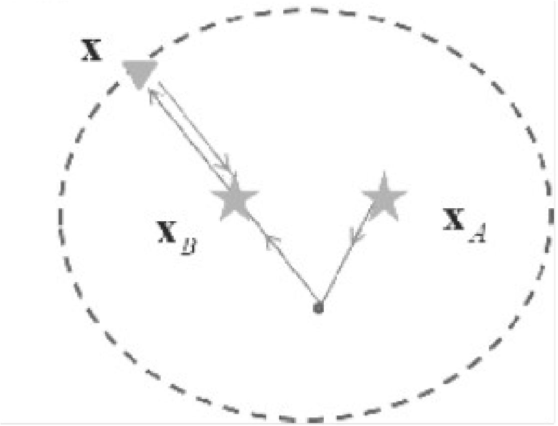
• Inter-source SI



for our drill-bit situation:



Simplified form of inter-source SI



$$G(\mathbf{x}_A \mid \mathbf{x}_B) + G^*(\mathbf{x}_A \mid \mathbf{x}_B) \propto \oint_{\partial D} G^*(\mathbf{x} \mid \mathbf{x}_A) G(\mathbf{x} \mid \mathbf{x}_B) d\mathbf{x}$$

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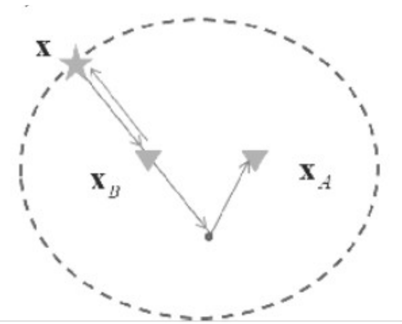
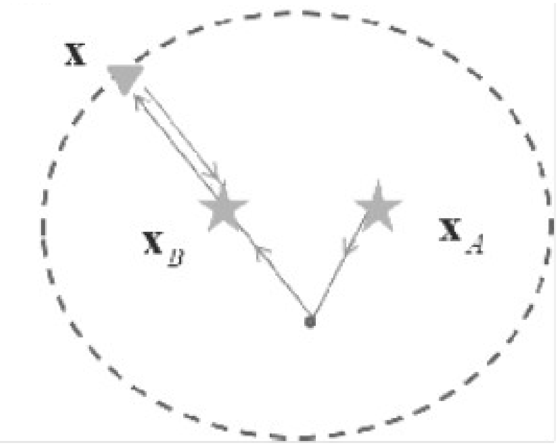
Inter-source SI with non-transient sources



$$G(\mathbf{x}_A|\mathbf{x}_B) + G^*(\mathbf{x}_A|\mathbf{x}_B) \propto \oint_{\partial D} G^*(\mathbf{x}|\mathbf{x}_A) G(\mathbf{x}|\mathbf{x}_B) d\mathbf{x}$$

- Non-transient source S($\mathbf{x}_i$)



$$Y(\mathbf{x}|\mathbf{x}_i) = G(\mathbf{x}|\mathbf{x}_i) S(\mathbf{x}_i)$$

$$C_{AB}(\mathbf{x}) = Y^*(\mathbf{x}|\mathbf{x}_A) Y(\mathbf{x}|\mathbf{x}_B)$$

$$\int_{\partial D_0} C_{AB}(\mathbf{x}) d\mathbf{x} = S^*(\mathbf{x}_A) S(\mathbf{x}_B) \int_{\partial D_0} G^*(\mathbf{x}|\mathbf{x}_A) G(\mathbf{x}|\mathbf{x}_B) d\mathbf{x}$$

$$\int_{\partial D_0} C_{AB}(\mathbf{x}) d\mathbf{x} \propto S^*(\mathbf{x}_A) S(\mathbf{x}_B) (G(\mathbf{x}_A|\mathbf{x}_B) + G^*(\mathbf{x}_A|\mathbf{x}_B))$$

Inter-source SI with non-transient sources

- Same noise signal s(t):
  - SI by crosscorrelation (CC): $\int_{\partial D_0} C_{AB}(\mathbf{x})d\mathbf{x} \propto |S|^2 \left(G(\mathbf{x}_A|\mathbf{x}_B) + G^*(\mathbf{x}_A|\mathbf{x}_B)\right)$
  - SI by deconvolution (DC):

$$D_{AB}(\mathbf{x}) = \frac{Y(\mathbf{x}|\mathbf{x}_B)}{Y(\mathbf{x}|\mathbf{x}_A)} = \frac{Y^*(\mathbf{x}|\mathbf{x}_A)Y(\mathbf{x}|\mathbf{x}_B)}{|Y(\mathbf{x}|\mathbf{x}_A)|^2} = \frac{G^*(\mathbf{x}|\mathbf{x}_A)G(\mathbf{x}|\mathbf{x}_B)}{|G(\mathbf{x}|\mathbf{x}_A)|^2}$$

$$\int_{\partial D_0} D_{AB}(\mathbf{x})d\mathbf{x} = \int_{\partial D_0} \frac{G^*(\mathbf{x}|\mathbf{x}_A)G(\mathbf{x}|\mathbf{x}_B)}{|G(\mathbf{x}|\mathbf{x}_A)|^2}d\mathbf{x}$$

  - SI by crosscoherence (CH):

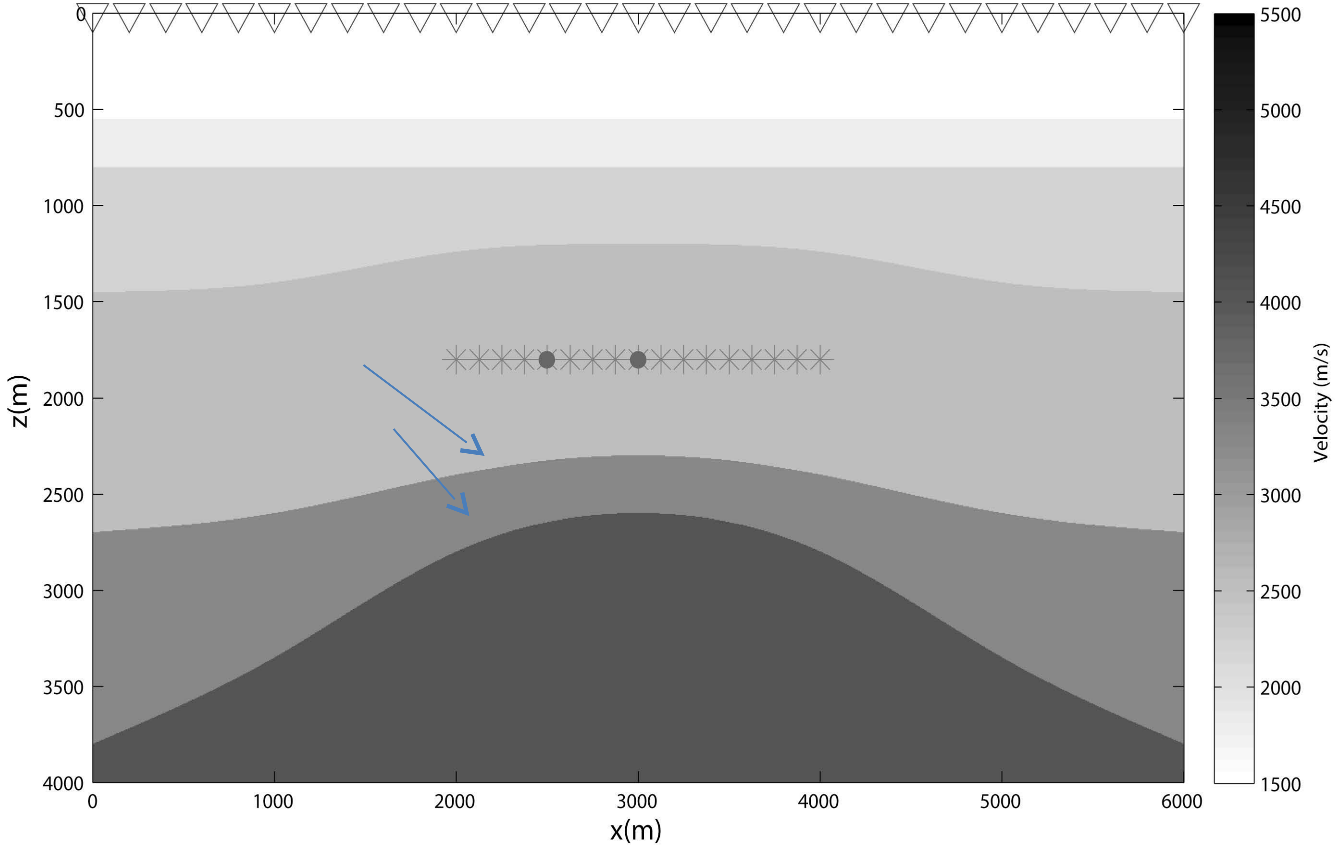
$$H_{AB}(\mathbf{x}) = \frac{Y^*(\mathbf{x}|\mathbf{x}_A)Y(\mathbf{x}|\mathbf{x}_B)}{|Y(\mathbf{x}|\mathbf{x}_A)||Y(\mathbf{x}|\mathbf{x}_B)|} = \frac{G^*(\mathbf{x}|\mathbf{x}_A)G(\mathbf{x}|\mathbf{x}_B)}{|G(\mathbf{x}|\mathbf{x}_A)||G(\mathbf{x}|\mathbf{x}_B)|}$$

$$\int_{\partial D_0} H_{AB}(\mathbf{x})d\mathbf{x} = \int_{\partial D_0} \frac{G^*(\mathbf{x}|\mathbf{x}_A)G(\mathbf{x}|\mathbf{x}_B)}{|G(\mathbf{x}|\mathbf{x}_A)||G(\mathbf{x}|\mathbf{x}_B)|}d\mathbf{x}$$

- Different s(t):

$$\tilde{G}(\mathbf{x}|\mathbf{x}_A) = \frac{Y(\mathbf{x}|\mathbf{x}_A)\tilde{S}^*(\mathbf{x}_A)}{|\tilde{S}(\mathbf{x}_A)|^2}.$$

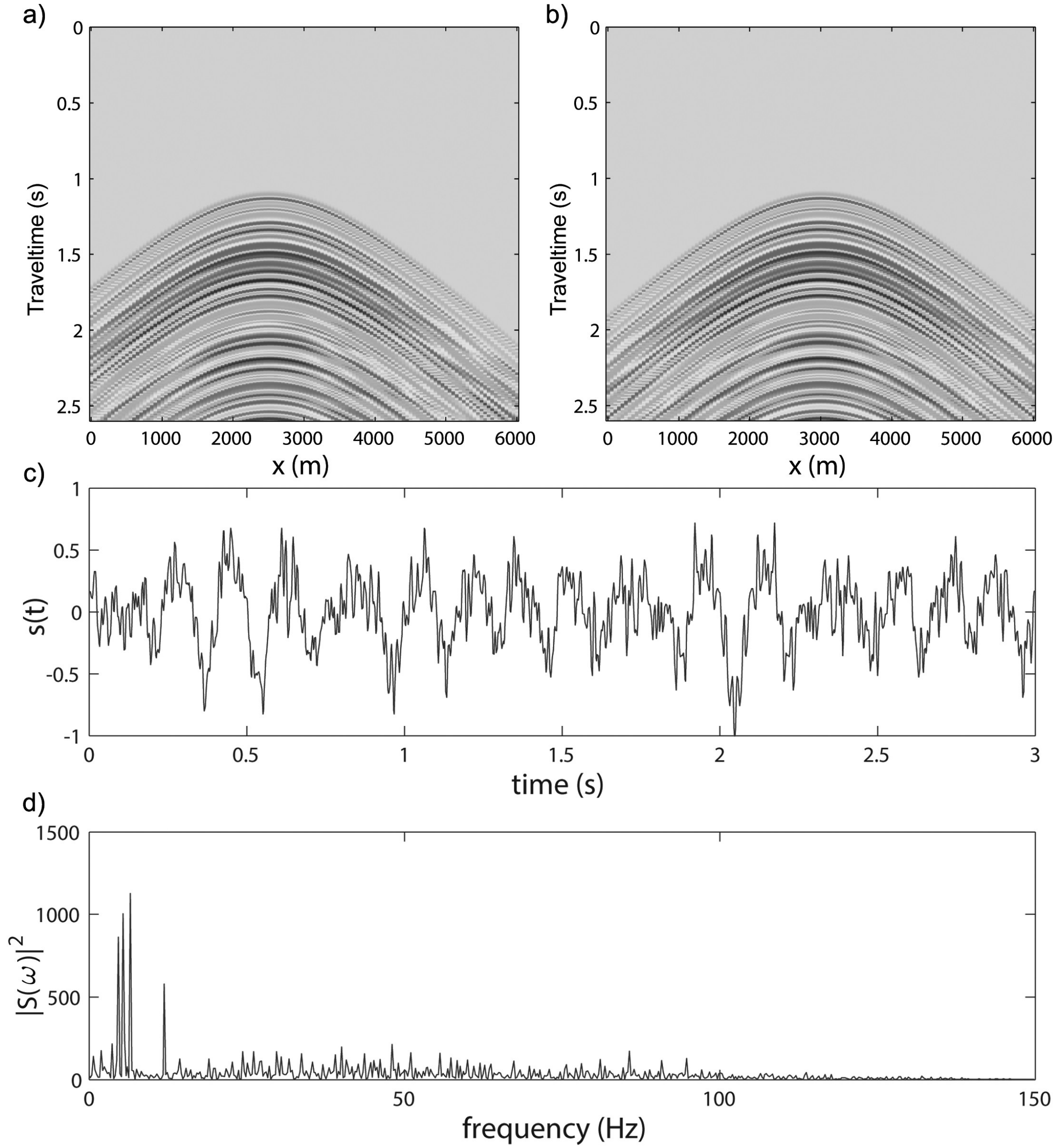
Synthetic example



Synthetic Vp model. The stars denote drill-bit positions and triangles denote receivers at the surface level. The dots indicate two reference source positions for trace comparison.

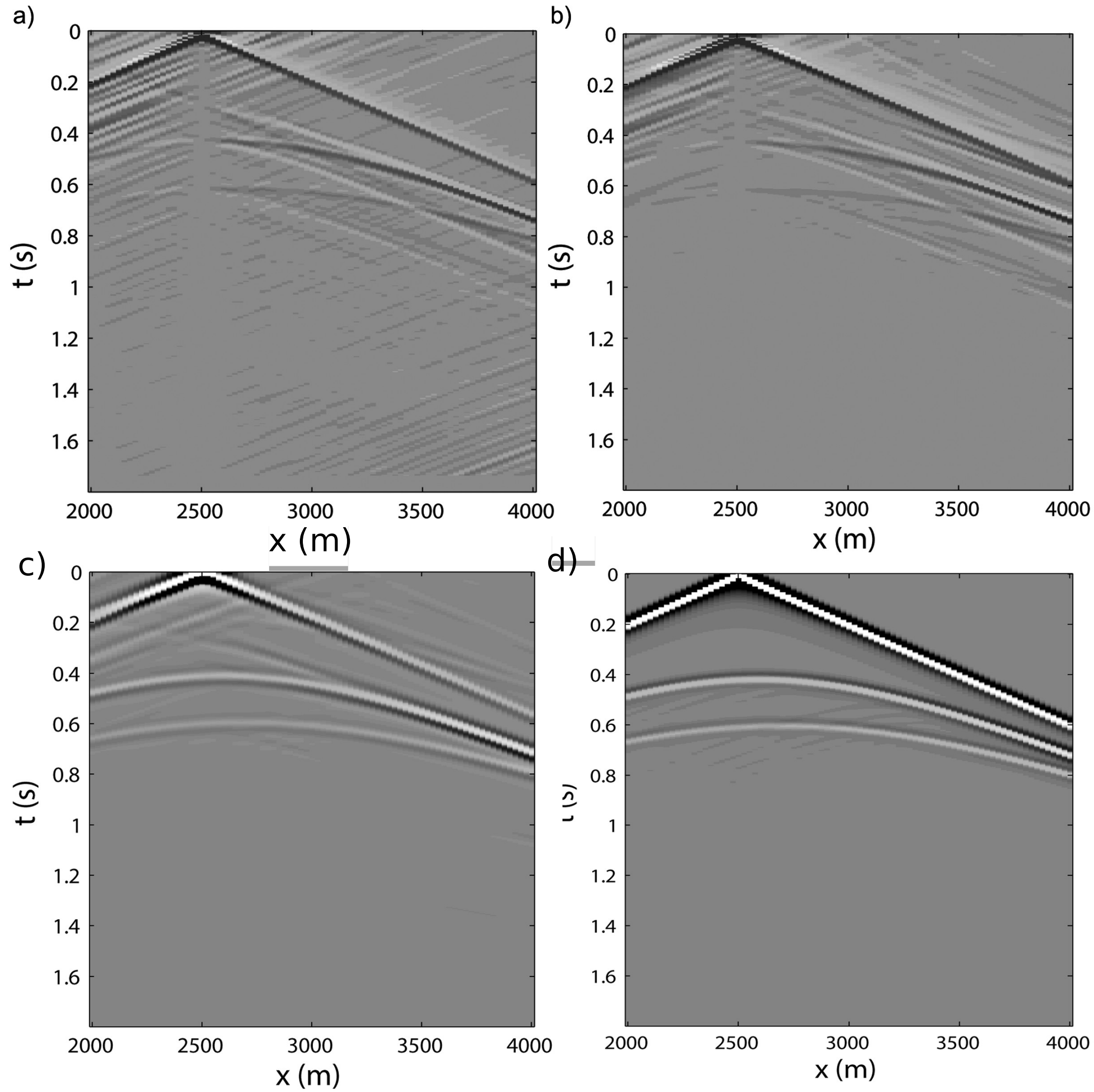
nsrc=81, nrcv=121

Same s(t)



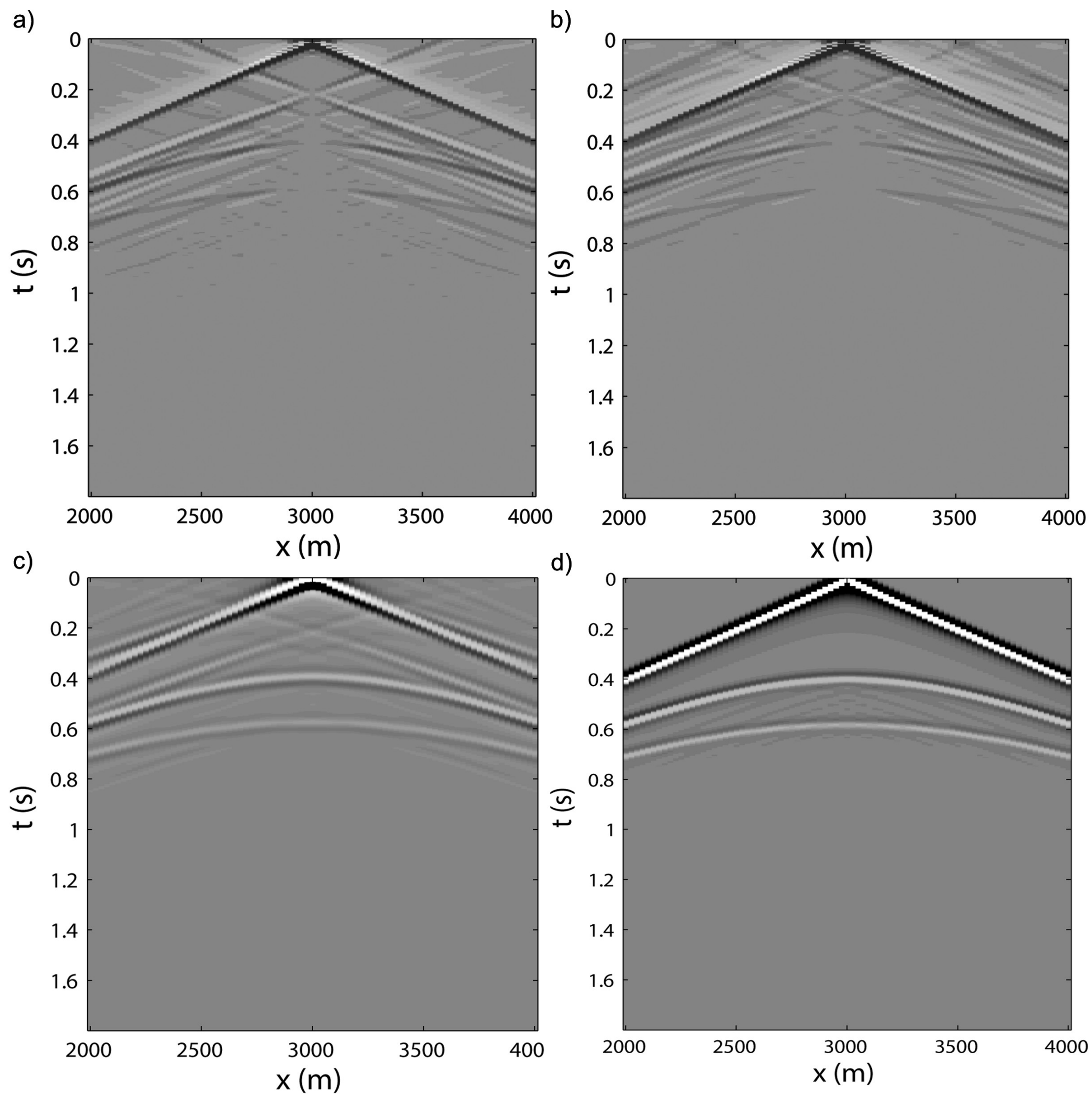
Drill-bit source function and recorded common-source gathers. a) Common-source gather at x = 2500 m and b) at x=3000 m. c) Modelled drill-bit source function. d) Power spectrum of the modelled drill-bit function.

Comparison of the retrieved responses with the reference response



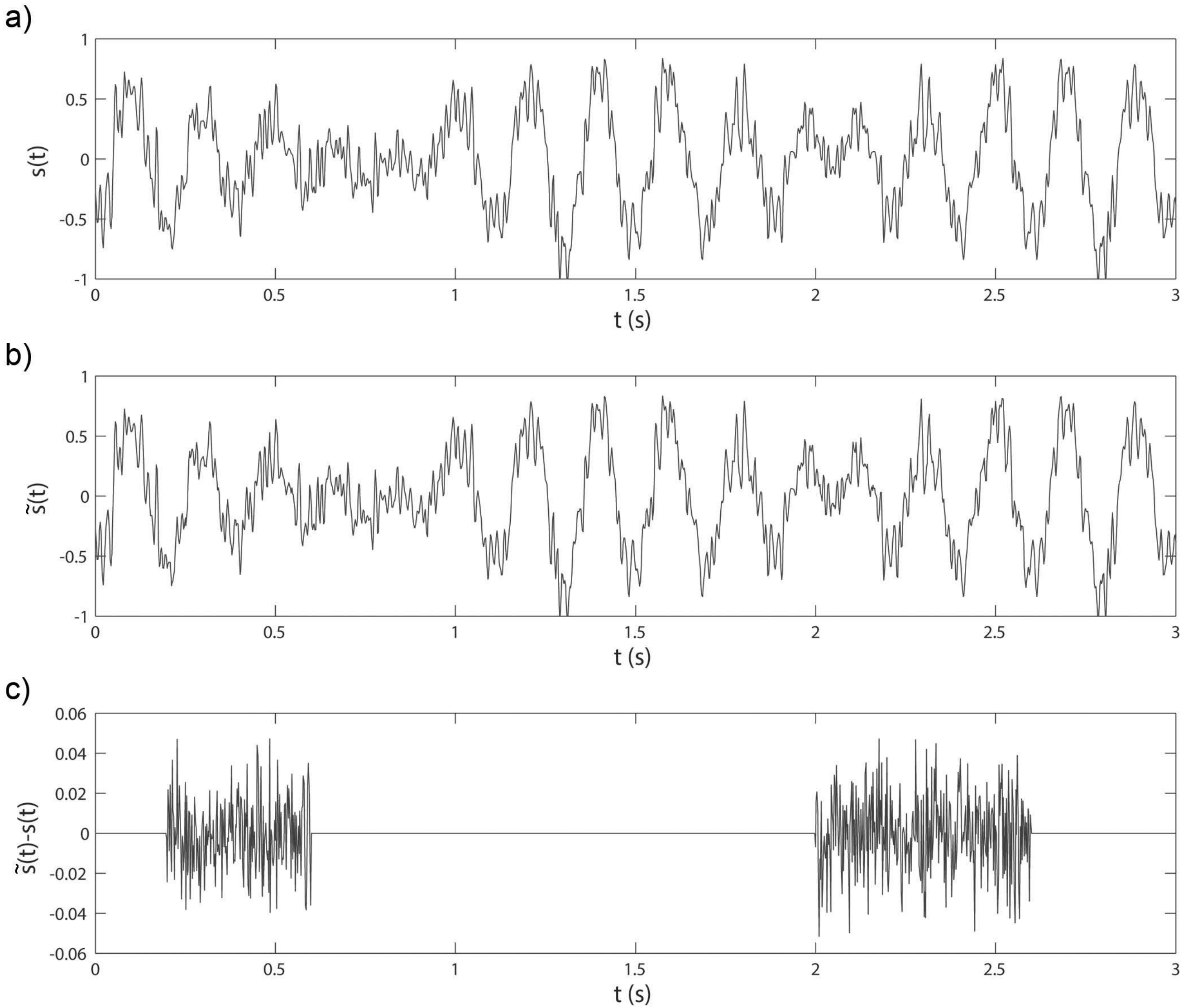
The virtual response of the source at x= 2500m retrieved by a) DC, b) CH and c) CC. d) The reference response modelled with a homogeneous overburden.

Comparison of the retrieved responses with the reference response



As the previously, but with the virtual response of the source at x= 3000 m.

Different s(t)



An example of the modelled drill-bit signals. a) The exact drill-bit source function s(t). b) Estimate of the signal. c) The noise added to the estimated signal, which is up to 5% of the drill-bit signal.

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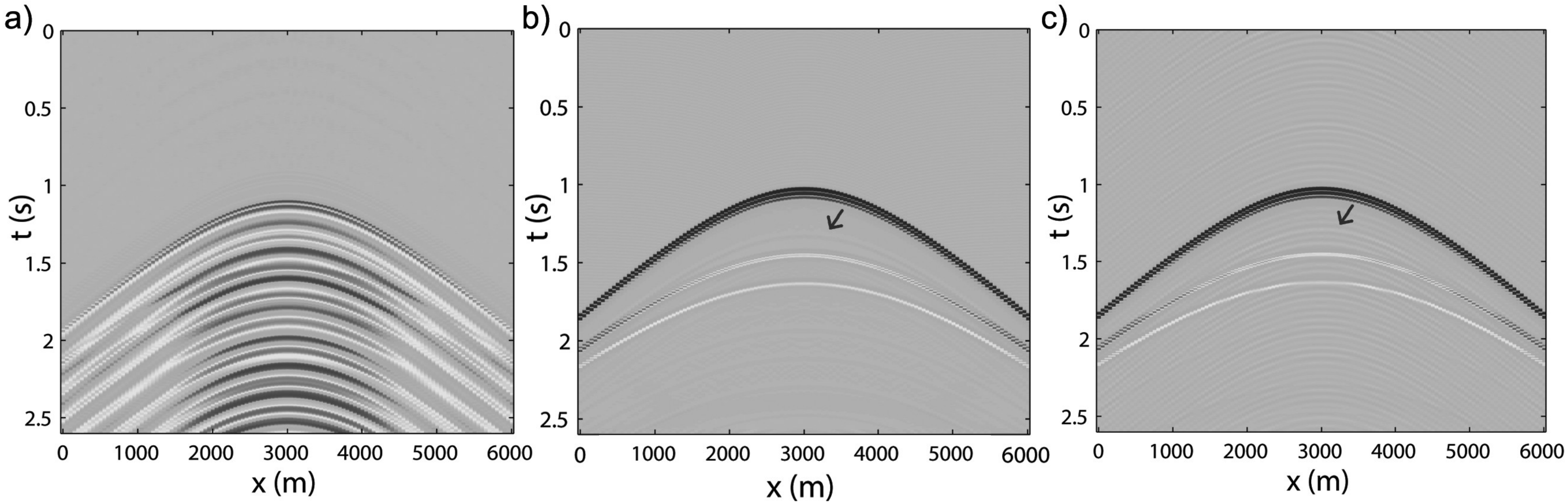
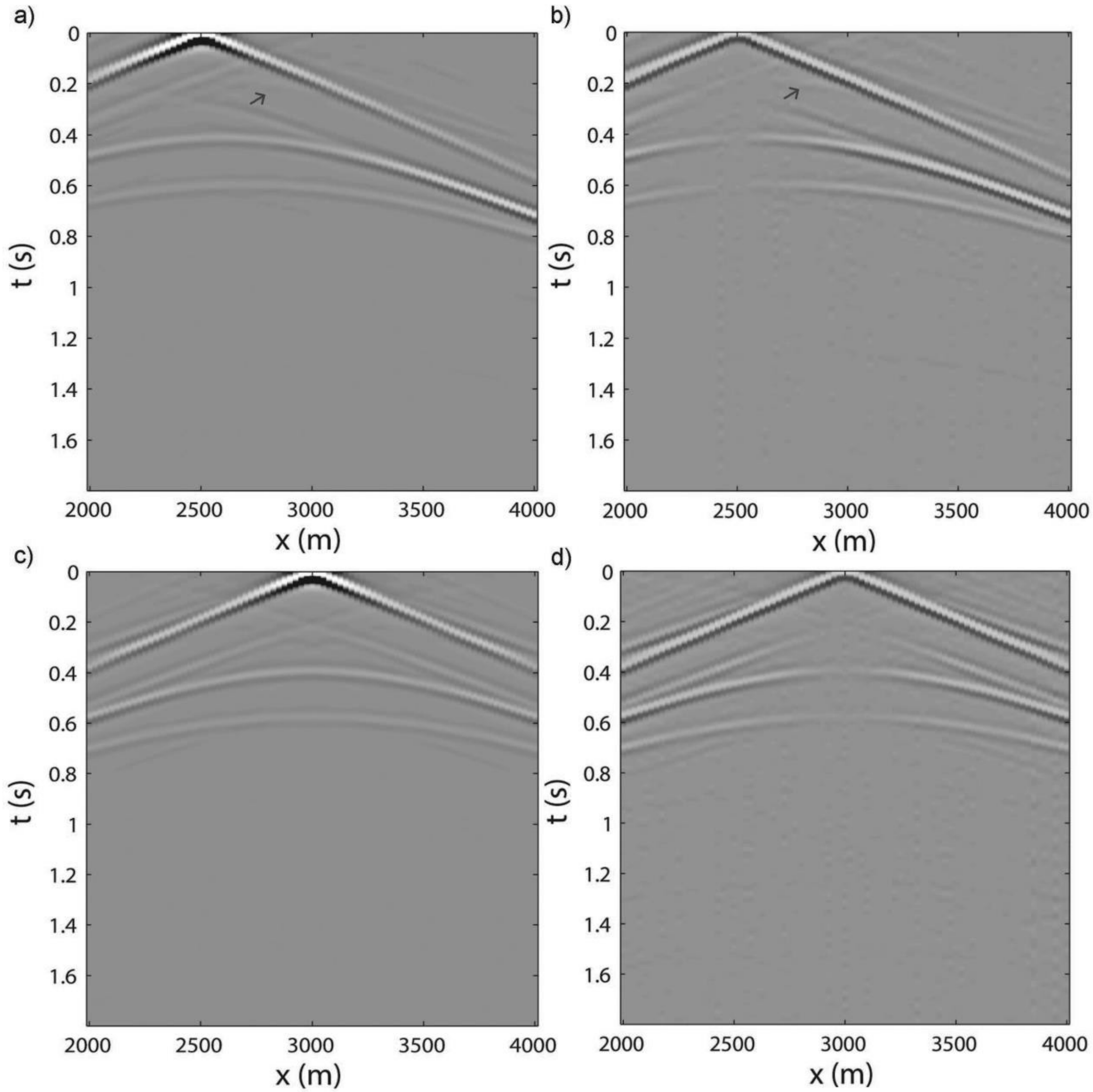
Modelled common-source gather and pilot-deconvolved results.



a) Raw common-source gather from drilling noise at x=3000 m. Pilot-deconvolved common-source gathers using b) the exact source signal and c) the noise-contaminated pilot signal. The arrow indicates the internal multiple from the second layer, which arrives about 0.2 seconds after the direct waves.

Retrieved common-source response at the drill-bit positions.



a) and c) used s(t) for pilot deconvolution. b) and d) use $\tilde{s}(t)$, and energy normalization is applied afterwards. The arrow indicates the non-physical reflection identified as the crosscorrelation of the direct waves and the internal multiples.

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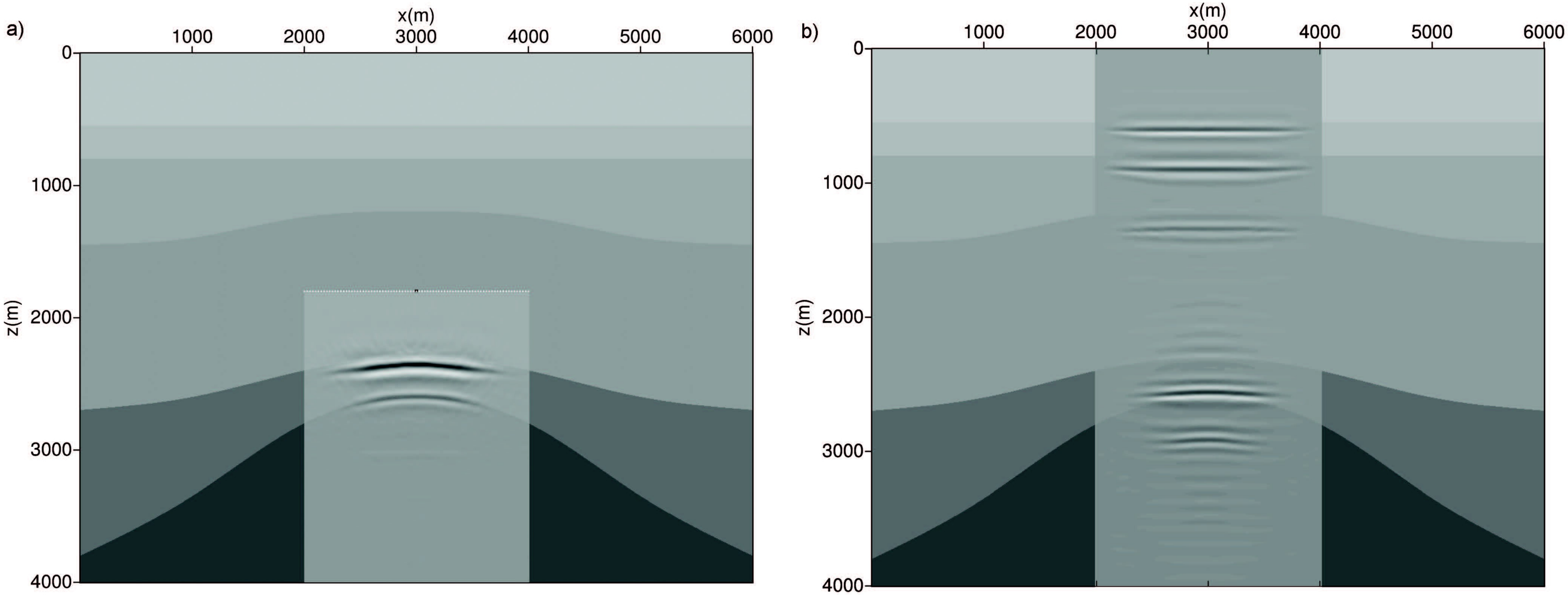
Migration images



a) using retrieved virtual reflection responses at the drill-bit positions, and b) using conventional surface seismic reflection data. The background indicates the true velocity model. Image a) is obtained using a homogeneous velocity model of 2750 m/s (2500 m/s+10% error), while image b) is obtained using the 10-percent erroneous velocities of the whole model.

Discussion and conclusion

- Create vitual receivers from drill-bit noise using pilot-deconvolved drill-bit data;

- The retrieved responses are useful for imaging as they have been interferometrically redatumed to the borehole level, thus independent of the velocity accuracy of the overburden.

- Information about the drill-bit noise is essential;

- Pilot signals need to have sufficient signal-to-noise ratios;

- Receiver arrays on land or with ocean-bottom stations or cables, with sufficient spacing to avoid aliasing;

- The length of the receiver array also matters.

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