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Automatic Statics Correction with Low-Rank Approximation

Ali M. Alfaraj, Rajiv Kumar, Felix J. Herrmann

June 13, 2018

Outline

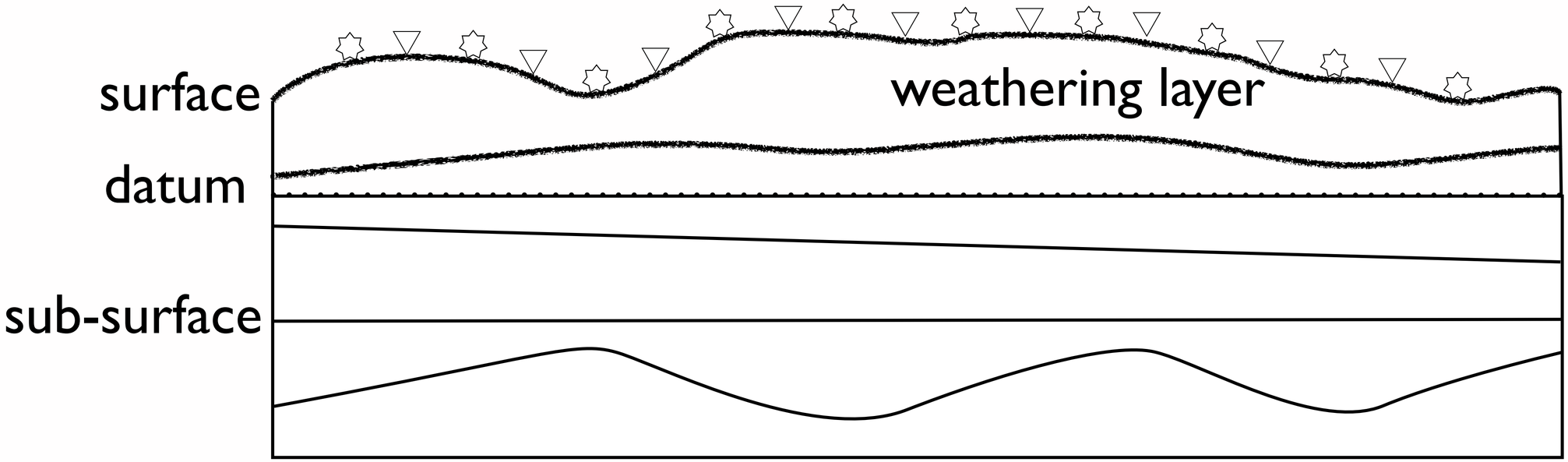
- Introduction
- Rank-based processing
- Low-rank approximation for statics correction
- Numerical examples
- Conclusions

Introduction

Sheriff, R.E. and Geldart, L.P. [1995] Seismic velocity. Cambridge University Press, 2 edn., 107–144.

Near-surface

- Loose material characterized by a low-velocity layer
- 250 to 1000 m/s, heterogeneous, rapidly changing and season dependent



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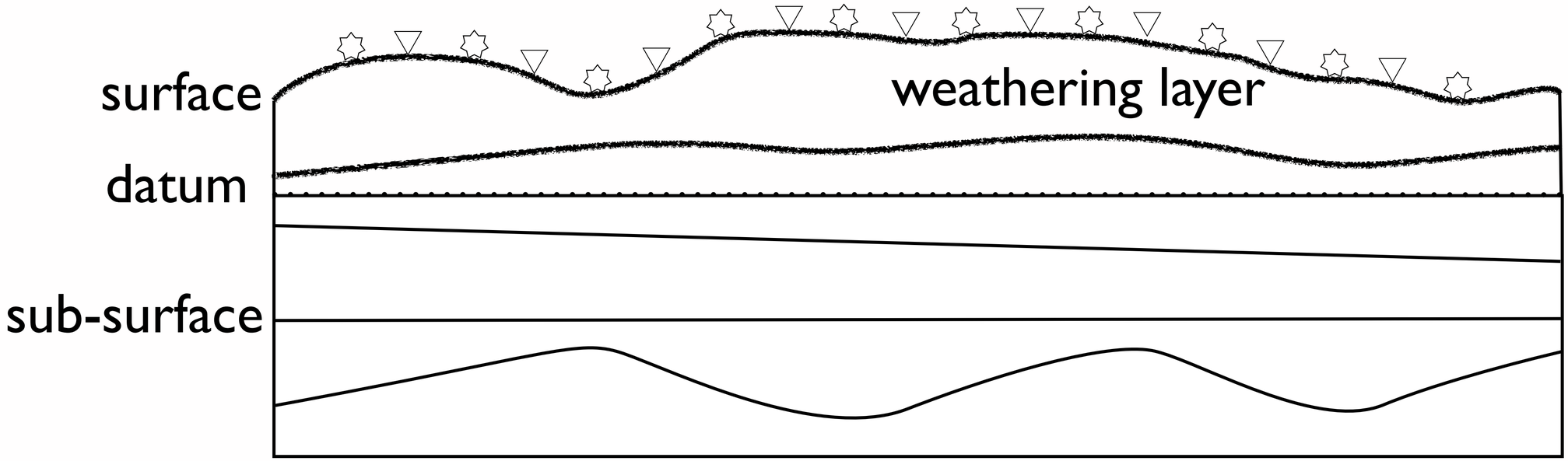
Near-surface

- Loose material characterized by a low-velocity layer
- 250 to 1000 m/s, heterogeneous, rapidly changing and season dependent → Statics (time-shifts)

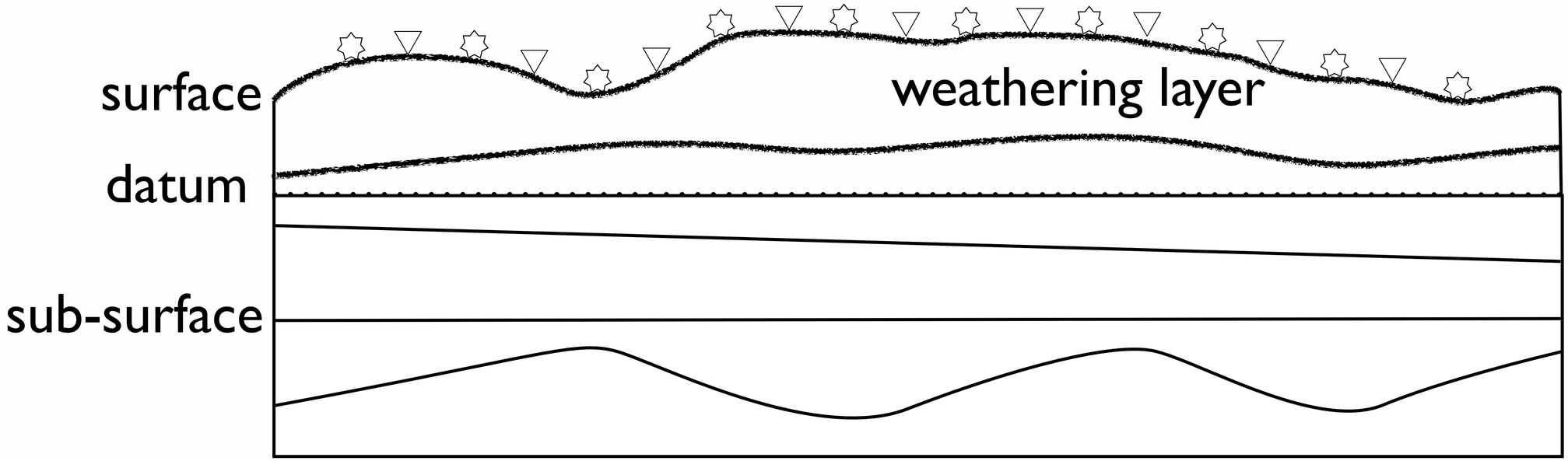


Yilmaz, O. [2001] Seismic Data Analysis. Society of Exploration Geophysicists.

Statics

(i) Long wavelength statics generated by the lateral variations in the weathering layer

(ii) Short wavelength statics (residual statics)



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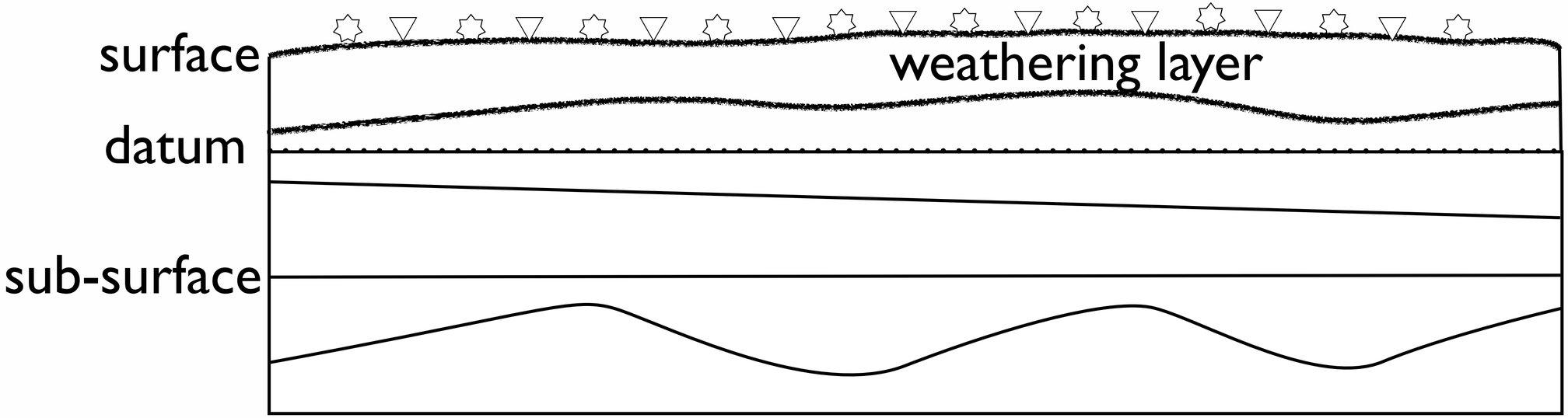

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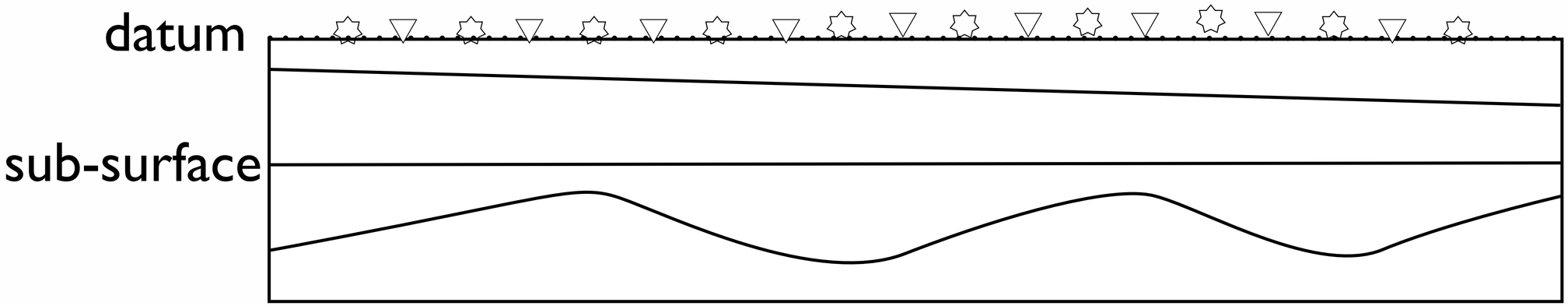

Statics correction methods

- Model-based methods:
  - Uphole surveys

Zhu, X., Sixta, D.P. and Angstman, B.G. [1992] Tomostatics: Turning-ray tomography + static corrections.The Leading Edge, 11(12), 15–23.

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- Cost and time consuming
- Unsatisfactory results when violating assumptions

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Residual statics

- Errors in estimated models
- Long wavelength methods do not account for:
  - Rapid changes in elevation
  - Base of weathering
  - Weathering velocity

Ronen, J. and Claerbout, J.F. [1985] Surface-consistent residual statics estimation by stack-power maximization. GEOPHYSICS, 50(12), 2759–2767.

Residual statics correction methods

- Data-driven methods:
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Rank-based processing

Ulrych, T.J., Freire, S. and Siston, P. [1988] Eigenimage processing of seismic sections. In: SEG Technical Program Expanded Abstracts 1988, Society of Exploration Geophysicists, 1261–1265.
Alfaraj, A.M., Kumar, R. and Herrmann, F.J. [2017] Shear wave reconstruction from low cost randomized acquisition. 79h EAGE Annual Conference Proceedings.
Kumar, R., Silva, C.D., Akalin, O., Aravkin, A.Y., Mansour, H., Recht, B. and Herrmann, F.J. [2015] Efficient matrix completion for seismic data reconstruction. Geophysics, 80(05), V97–V114. (Geophysics).
Wason, H., Kumar, R., Aravkin, A.Y. and Herrmann, F.J. [2014] Source separation via SVD-free rank minimization in the hierarchical semi-separable representation. SEG Technical Program Expanded Abstracts, 120–126. (SEG).
Trickett, S. and Burroughs, L. [2009] Prestack rank-reduction-based noise suppression. CSEG Recorder, 34(9), 24–31.

Rank-based processing

- Eigenimage processing
- Interpolation
- Source-separation
- Denoising

Alfaraj, A.M., Kumar, R. and Herrmann, F.J. [2017] Shear wave reconstruction from low cost randomized acquisition. 79h EAGE Annual Conference Proceedings.
Kumar, R., Silva, C.D., Akalin, O., Aravkin, A.Y., Mansour, H., Recht, B. and Herrmann, F.J. [2015] Efficient matrix completion for seismic data reconstruction. Geophysics, 80(05), V97–V114. (Geophysics).
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Rank-based processing

For a successful rank-based solution in a transform domain:

1. **Low-rank signal structure**

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2. **Structure destruction**

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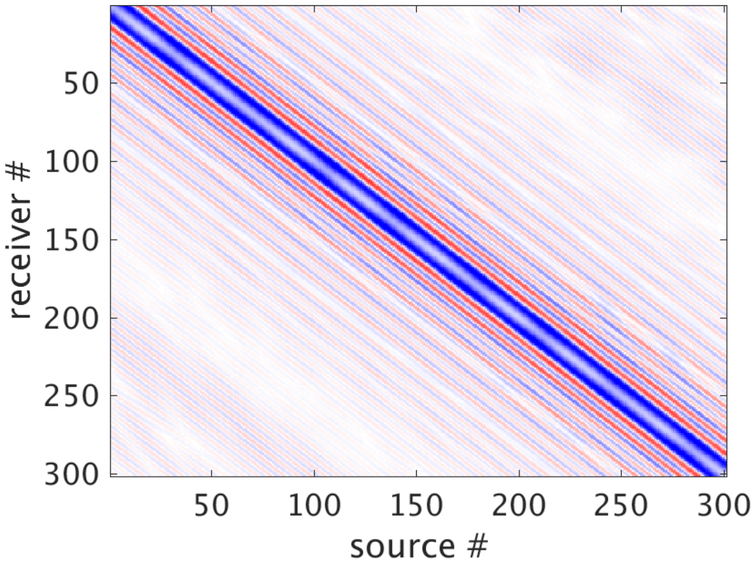
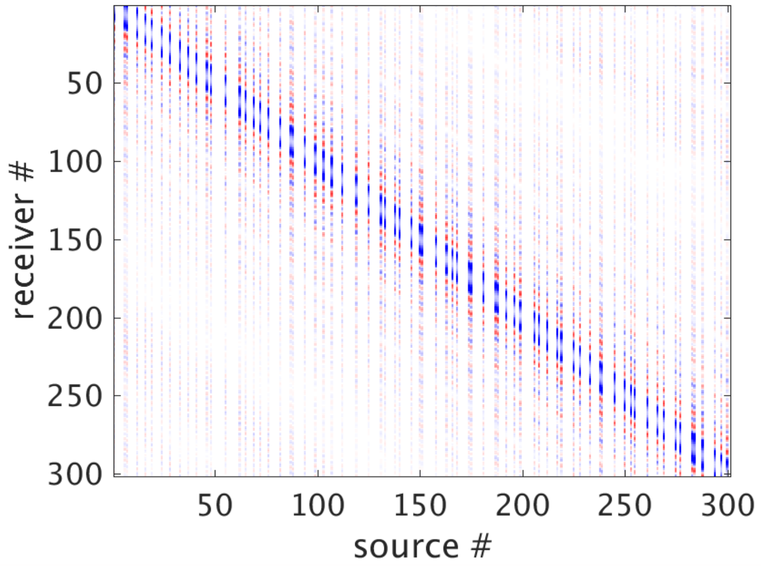
For a successful rank-based solution in a transform domain:

1. **Low-rank signal structure**
2. **Structure destruction**
3. **Structure promotion**

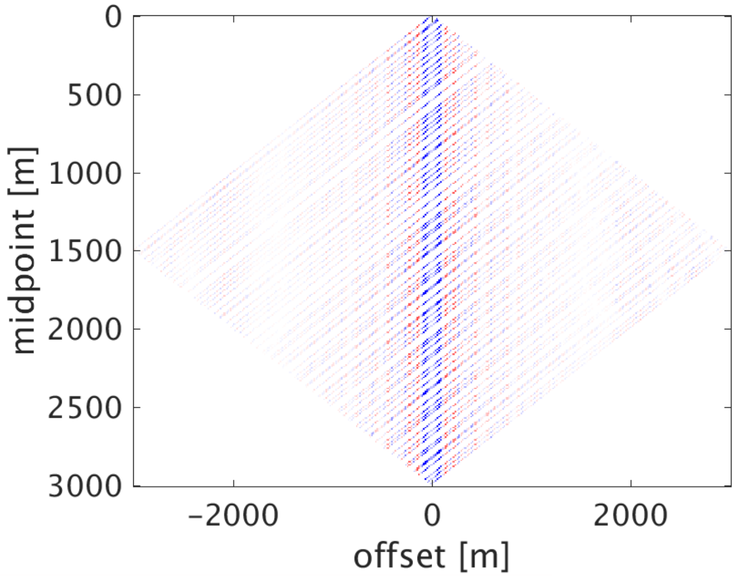
Rank-based processing



source-receiver domain

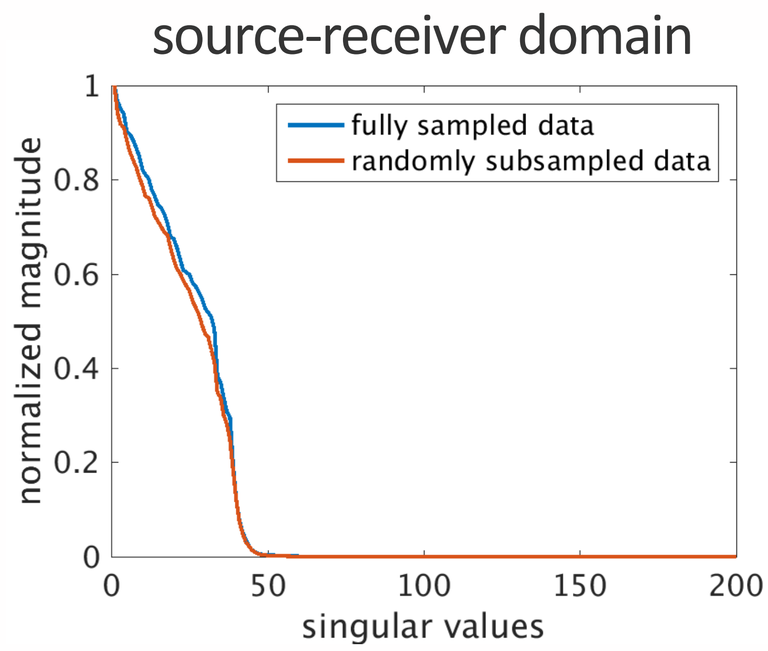


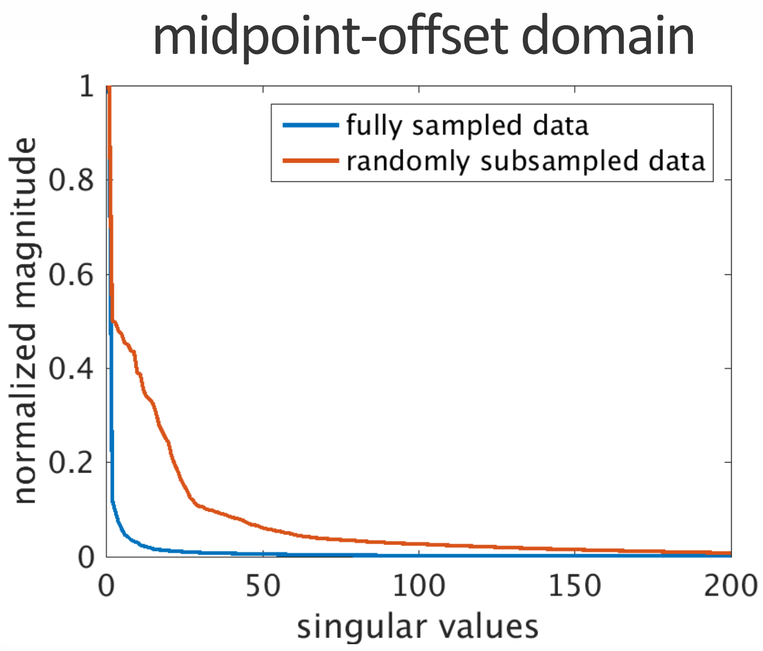
75% missing sources



midpoint-offset domain

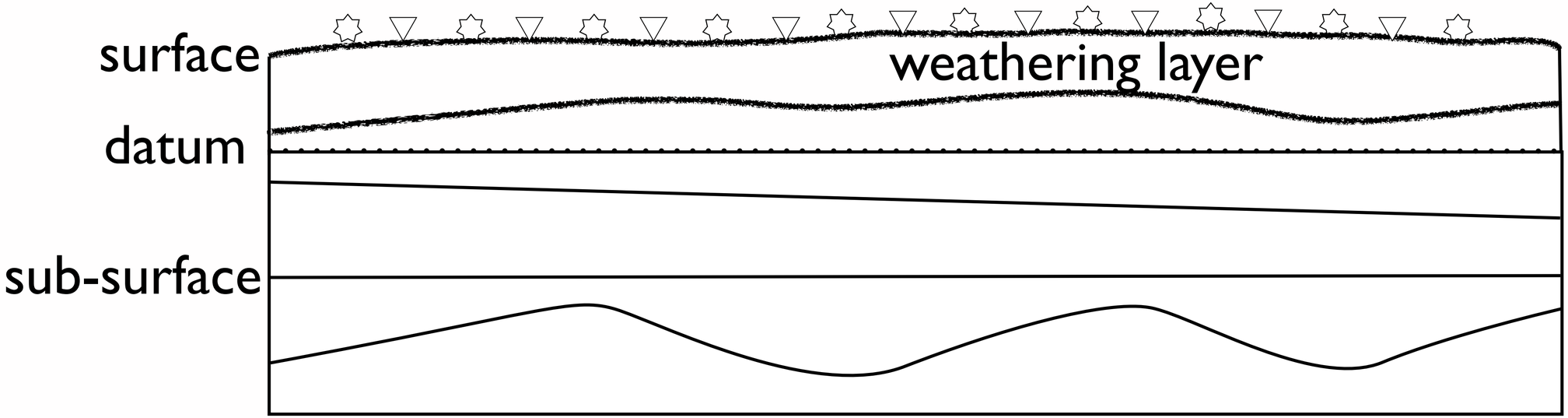
Singular values decay





Low-rank approximation for statics correction

Rank-based statics correction



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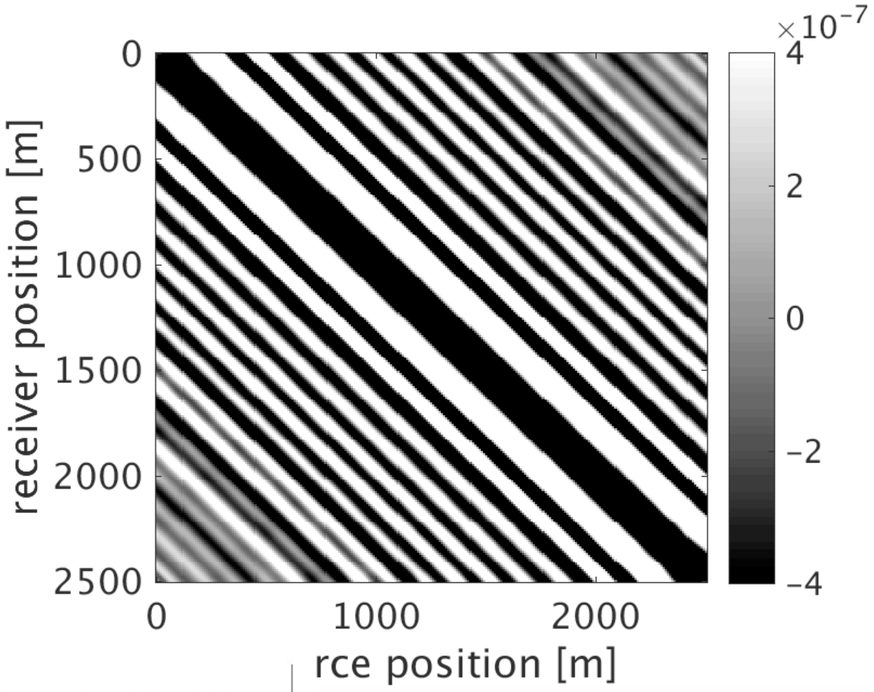
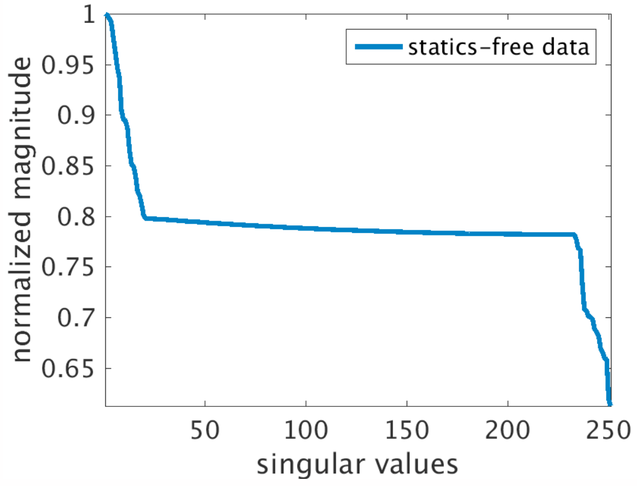
1. **Low-rank signal structure (statics-free data)**

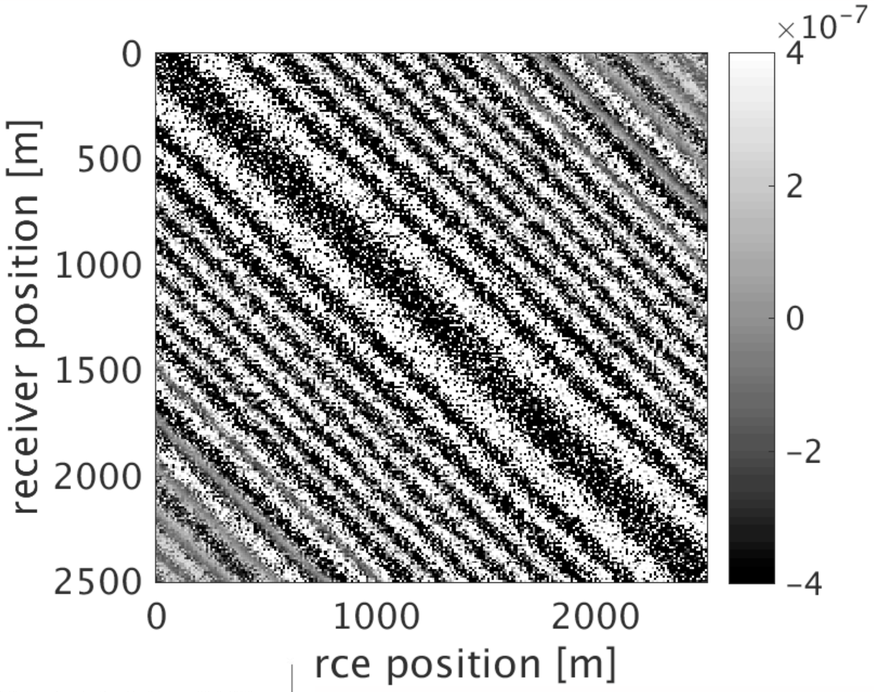


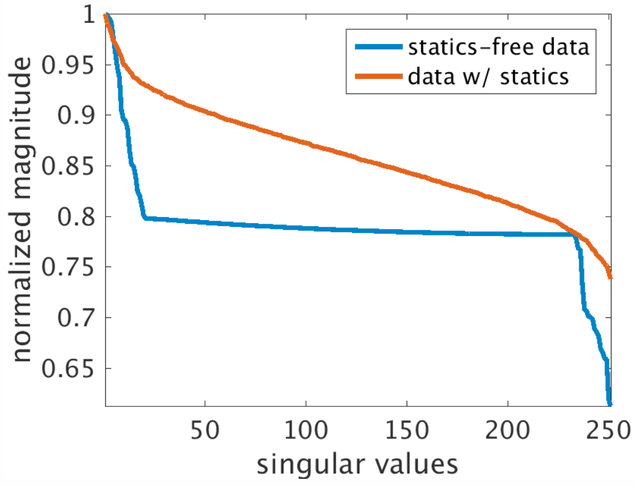


Rank-based statics correction

For a successful rank-based solution:

2. Structure destruction (data w/ statics)

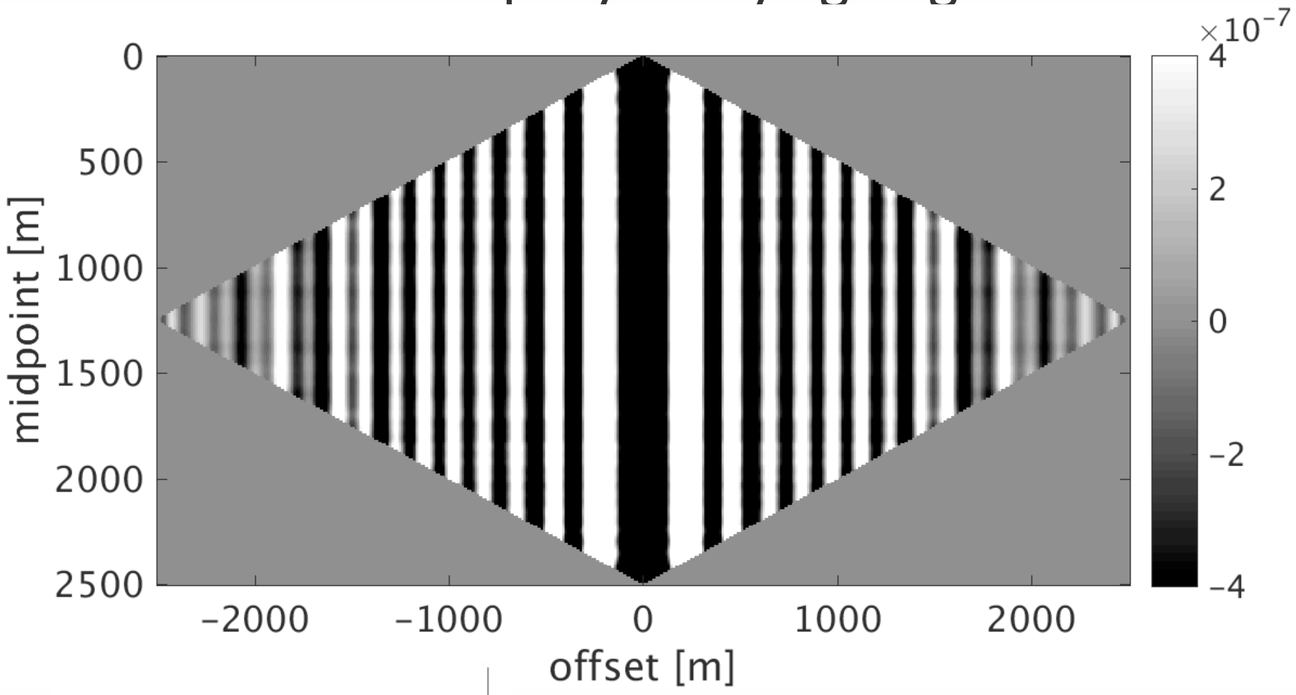


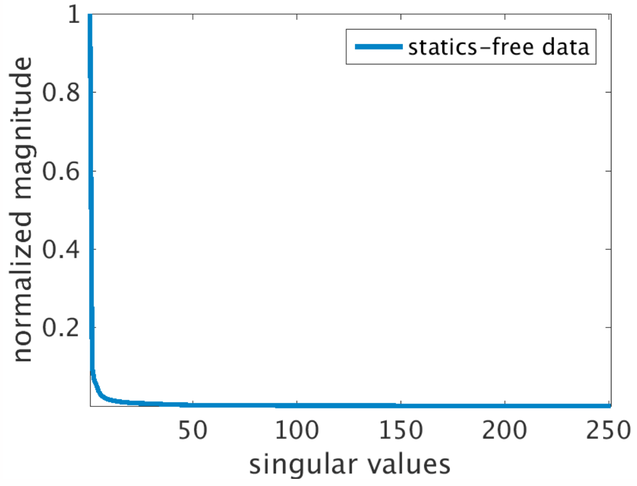


Rank-based statics correction

For a successful rank-based solution in the **(m-h) domain**:

1. **Low-rank signal structure (statics-free data)**
   - Rapidly decaying singular values



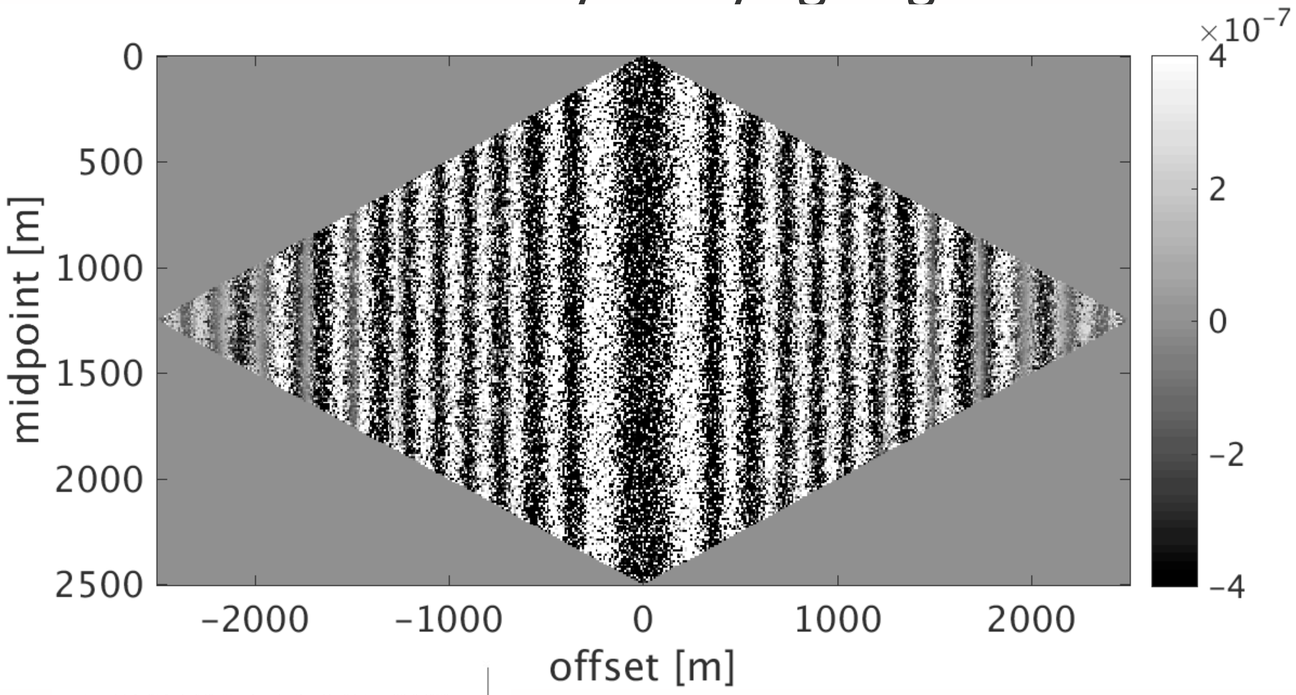


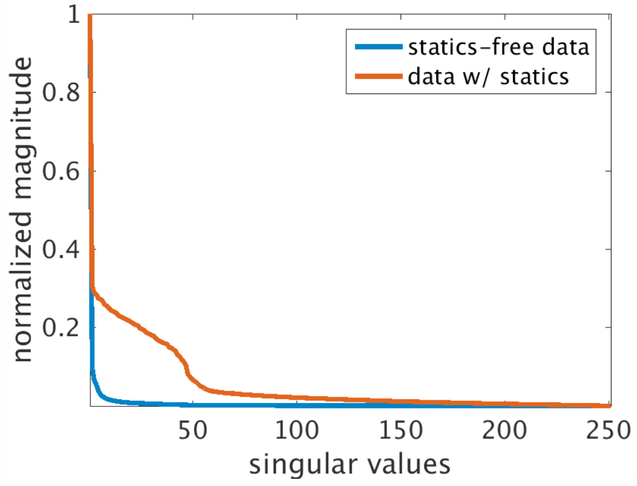
Rank-based statics correction

For a successful rank-based solution in the **(m-h) domain**:

2. Structure destruction (data w/ statics)

- Slowly decaying singular values





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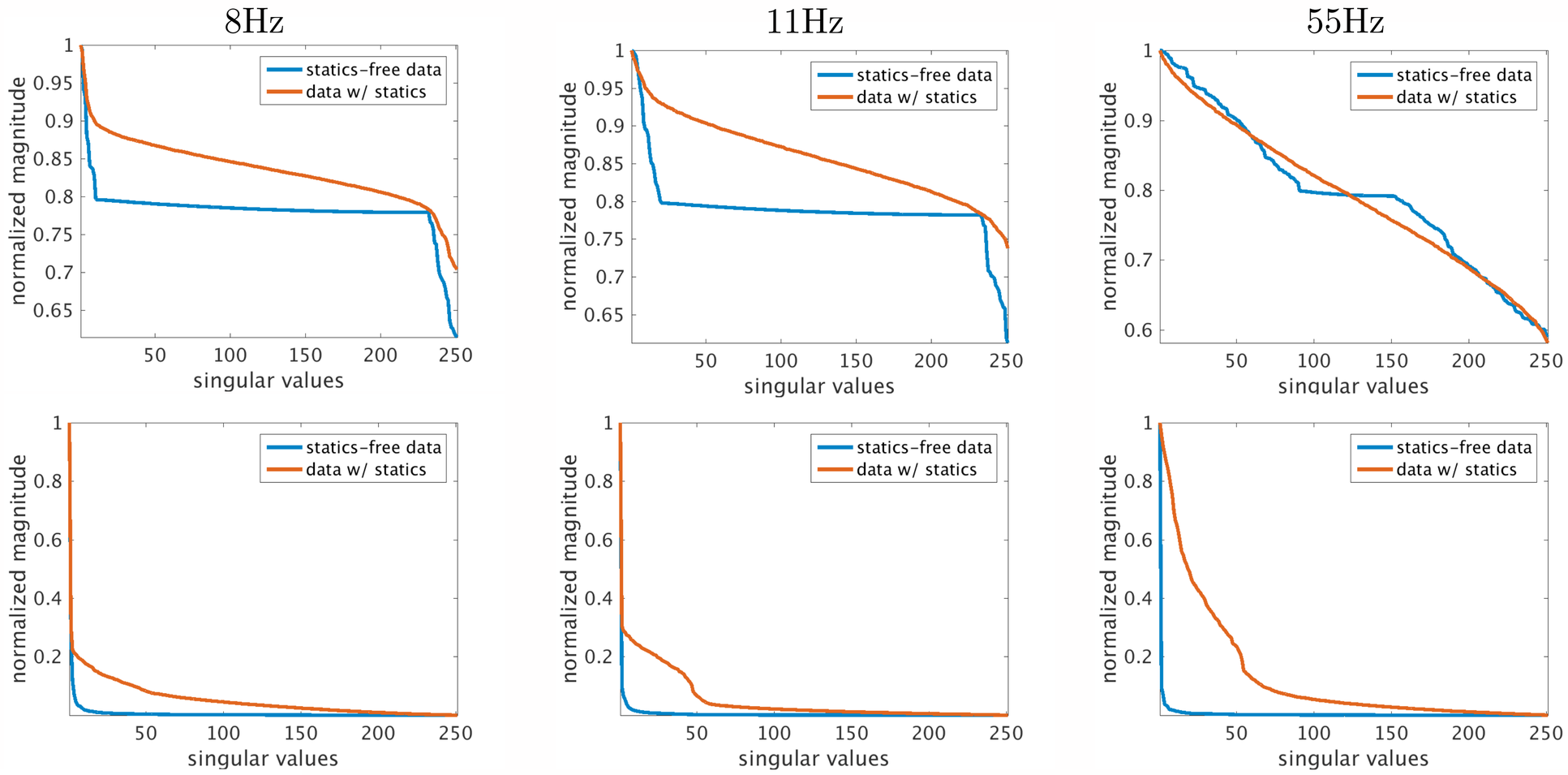


(s-r)

(m-h)

Rank-based statics correction

For a successful rank-based solution in the **(m-h) domain**:

3. **Structure promotion**
    - **Low-rank approximation**: Approximate data by a **small number of singular vectors** associated w\ the relatively **few largest singular values**

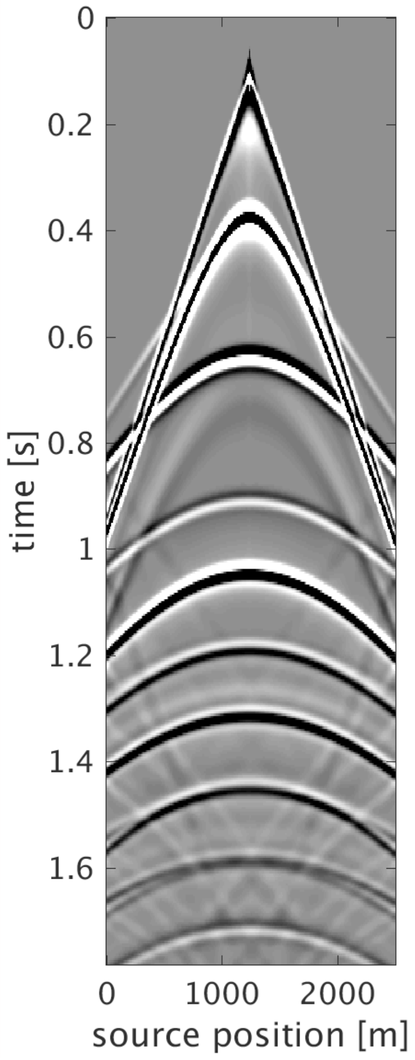
Low-rank approximation for statics correction

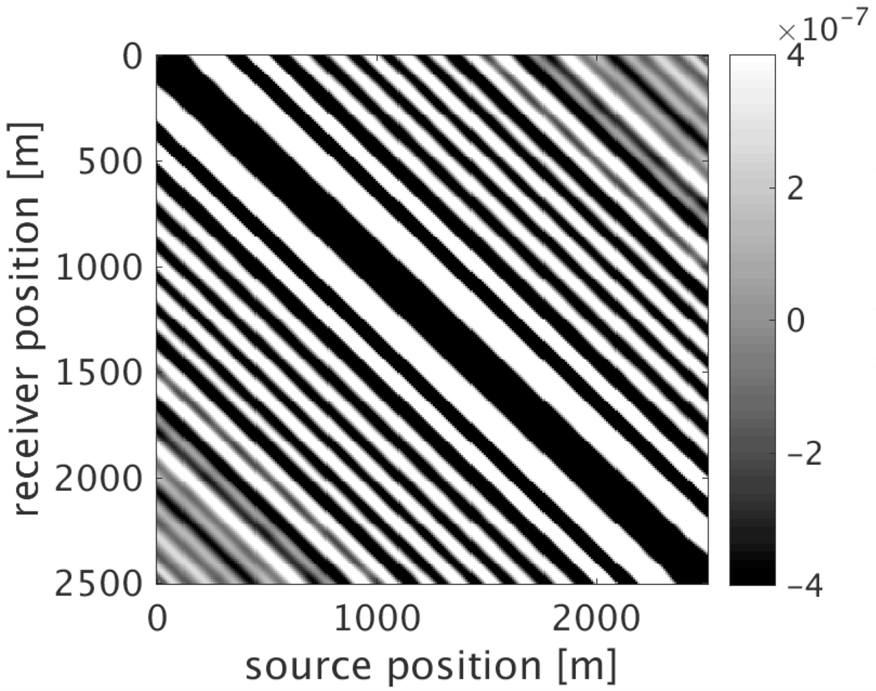
Algorithm 1 Automatic statics correction using low-rank approximation.

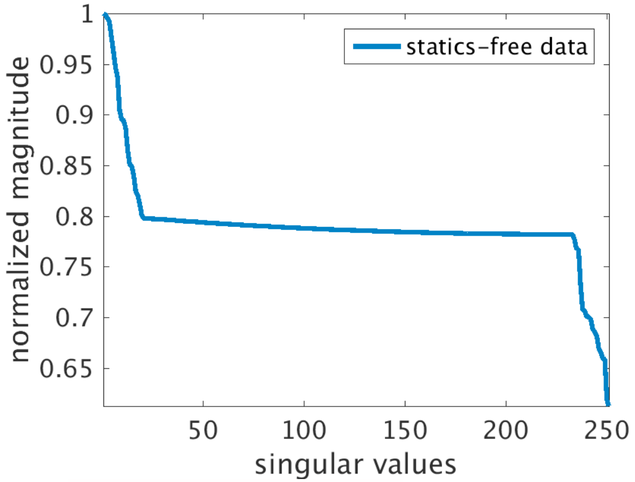
1. Rank k and data $\mathbf{D}(\mathbf{t},\mathbf{r},\mathbf{s})$ `//Input`,
2. Transform the data to the $(\mathbf{m}-\mathbf{h})$ domain to obtain $\mathbf{D}(\mathbf{t},\mathbf{h},\mathbf{m})$,
3. Pick NMO velocity and apply NMO correction,
4. Fourier transform the data to the frequency domain $(\mathbf{f})$,
5. Solve $\hat{\mathbf{X}} = \mathbf{USV}^H$ using rank k for each frequency slice,
6. Inverse Fourier transform to the time domain to obtain the estimated data with statics correction applied $\hat{\mathbf{D}}(\mathbf{t},\mathbf{h},\mathbf{m})$ `//output` .

Numerical examples
Synthetic data

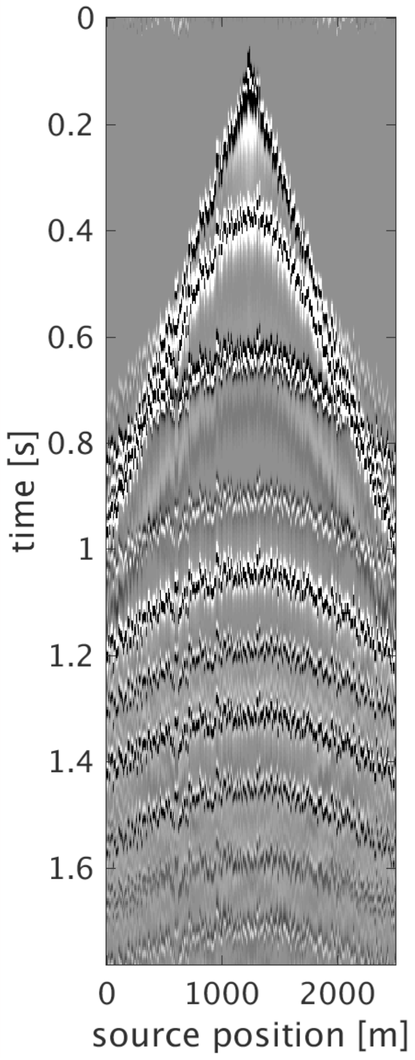
Example (i): statics-free data

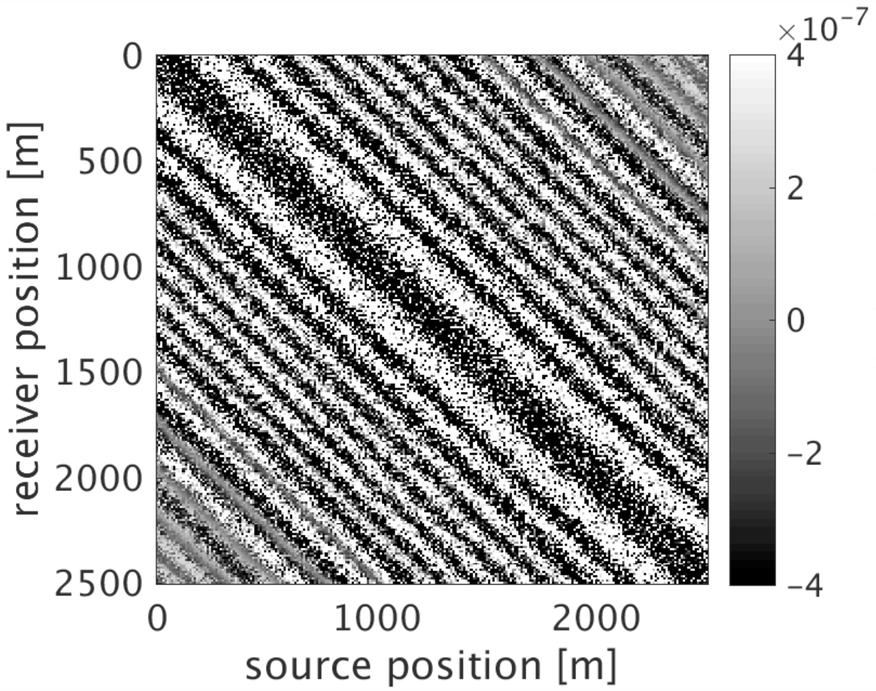


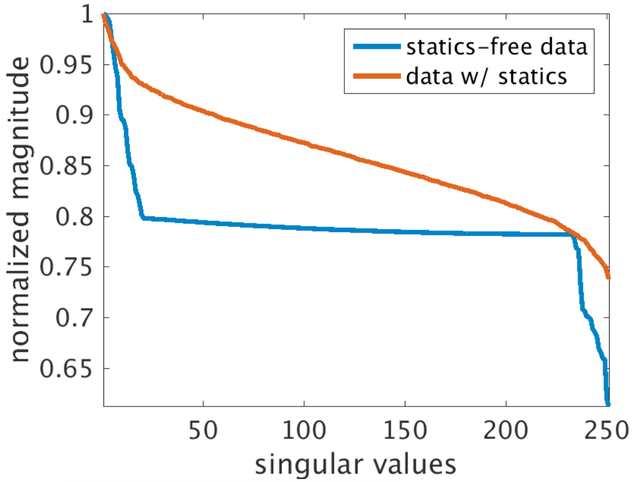




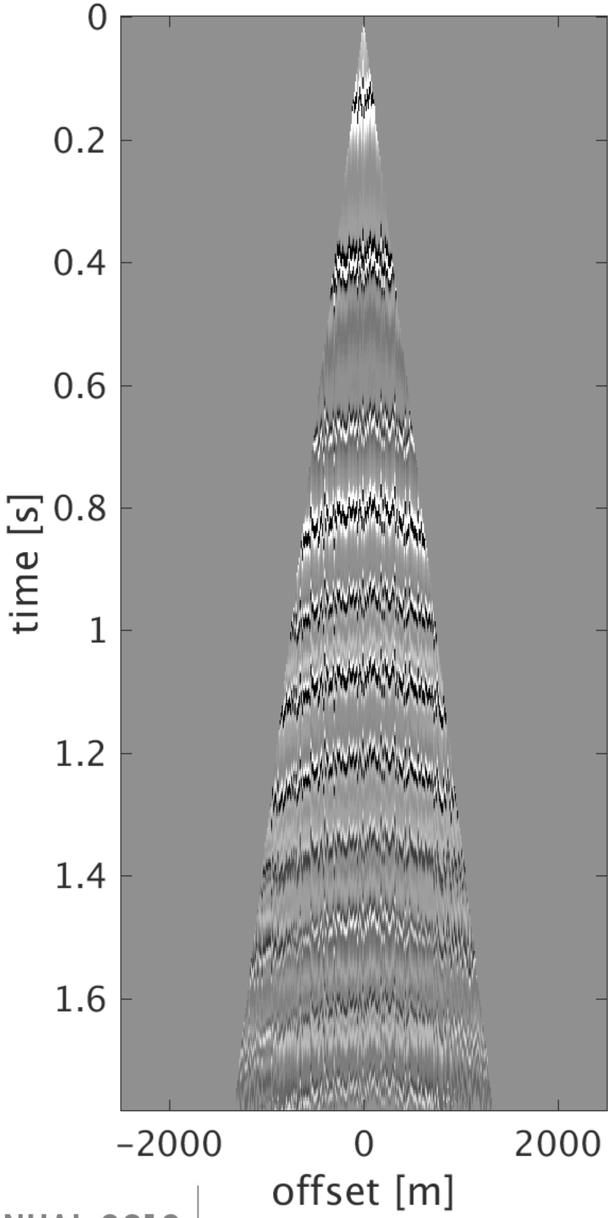
Example (i): data w/ statics $\pm 100\text{ms}$

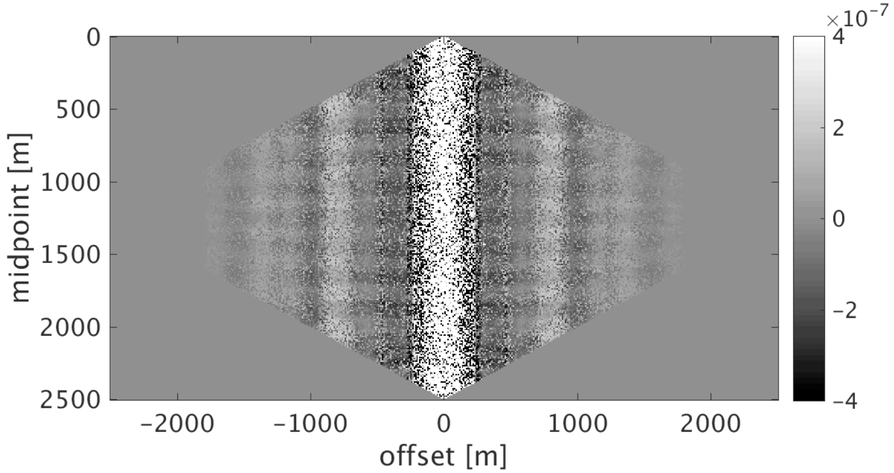


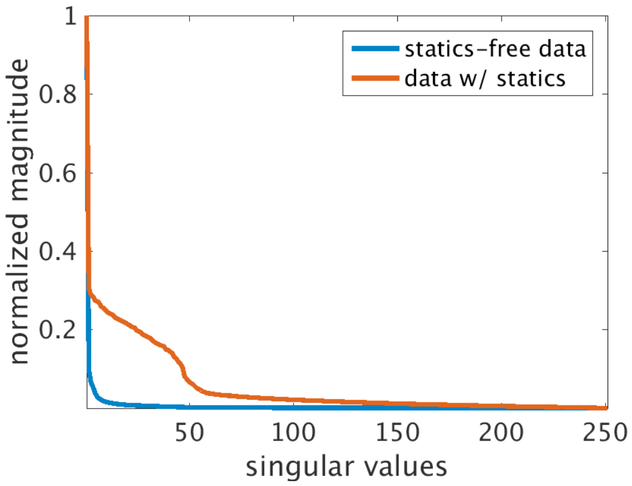




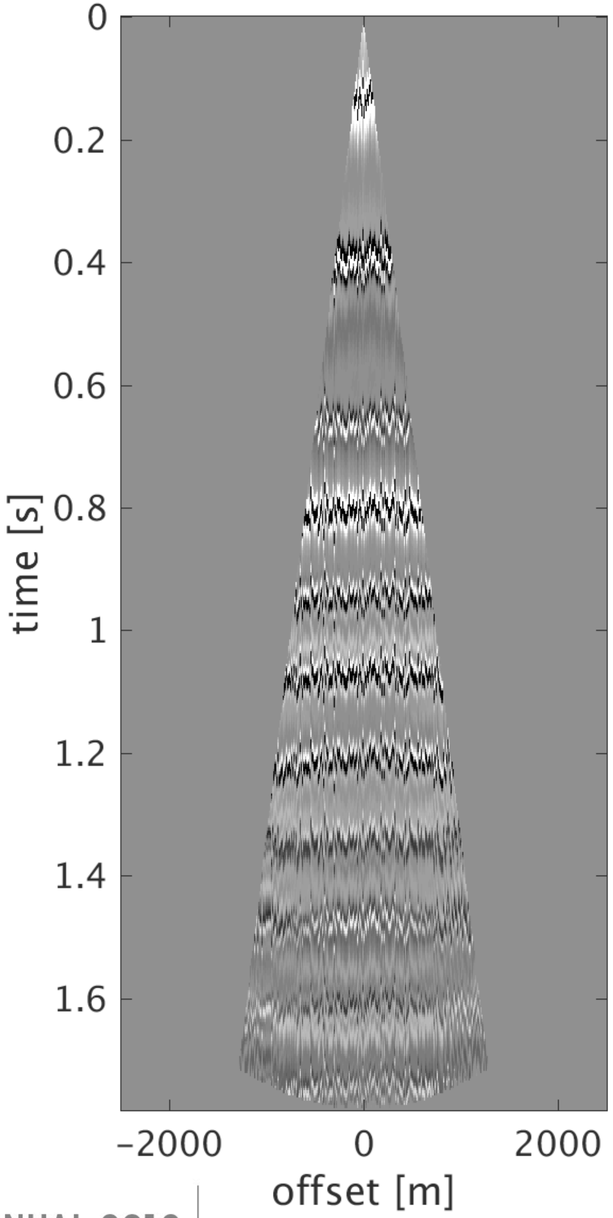
Example (i): m-h domain

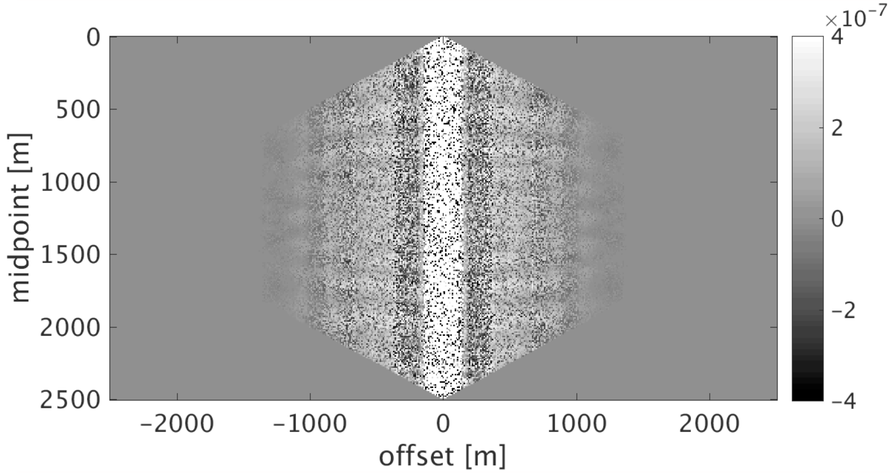


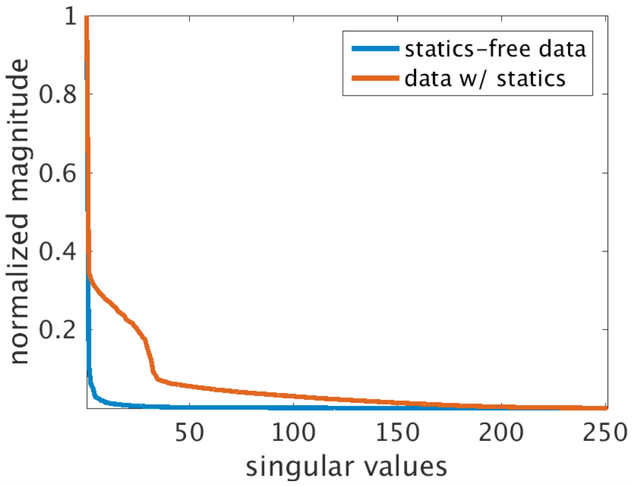




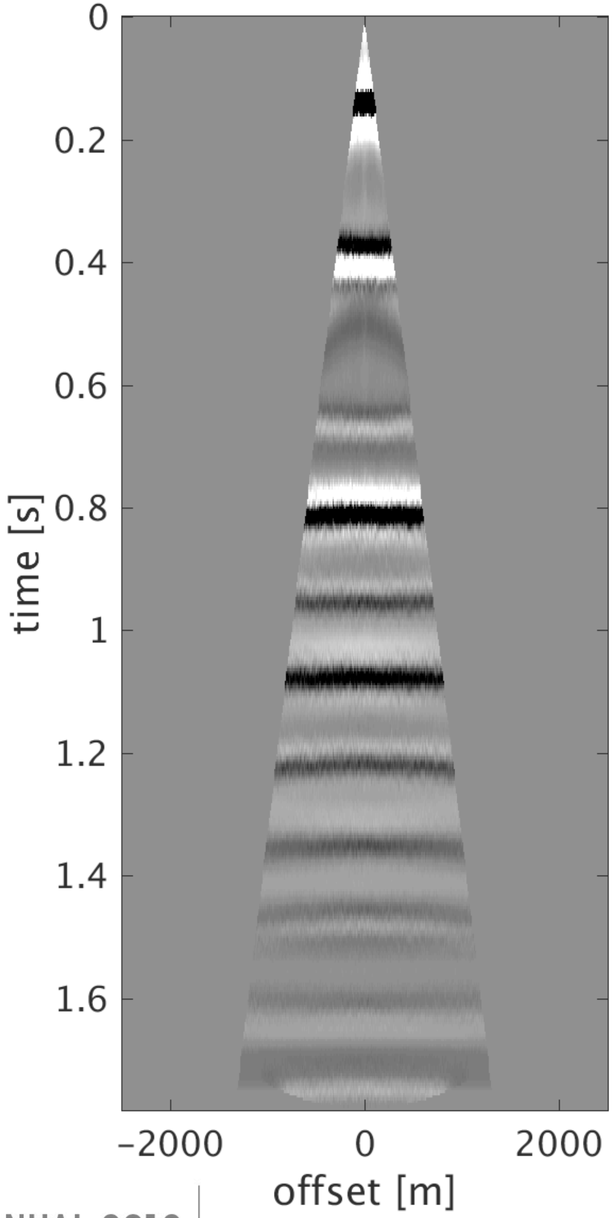
Example (i): NMO

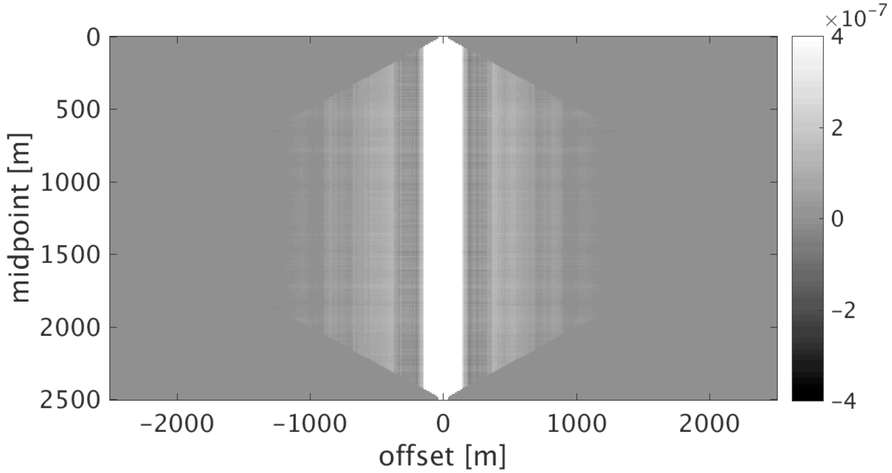




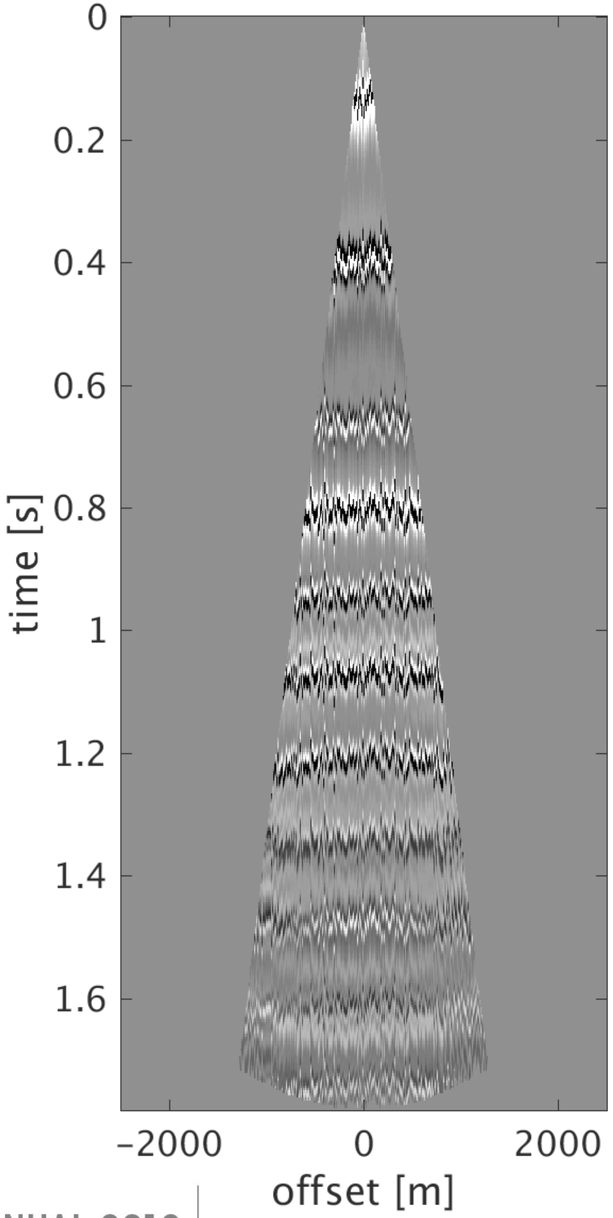


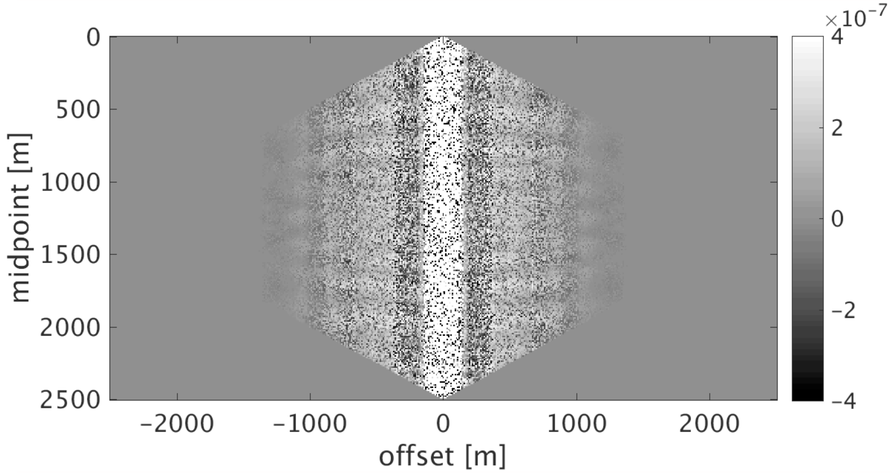
Example (i): Statics correction



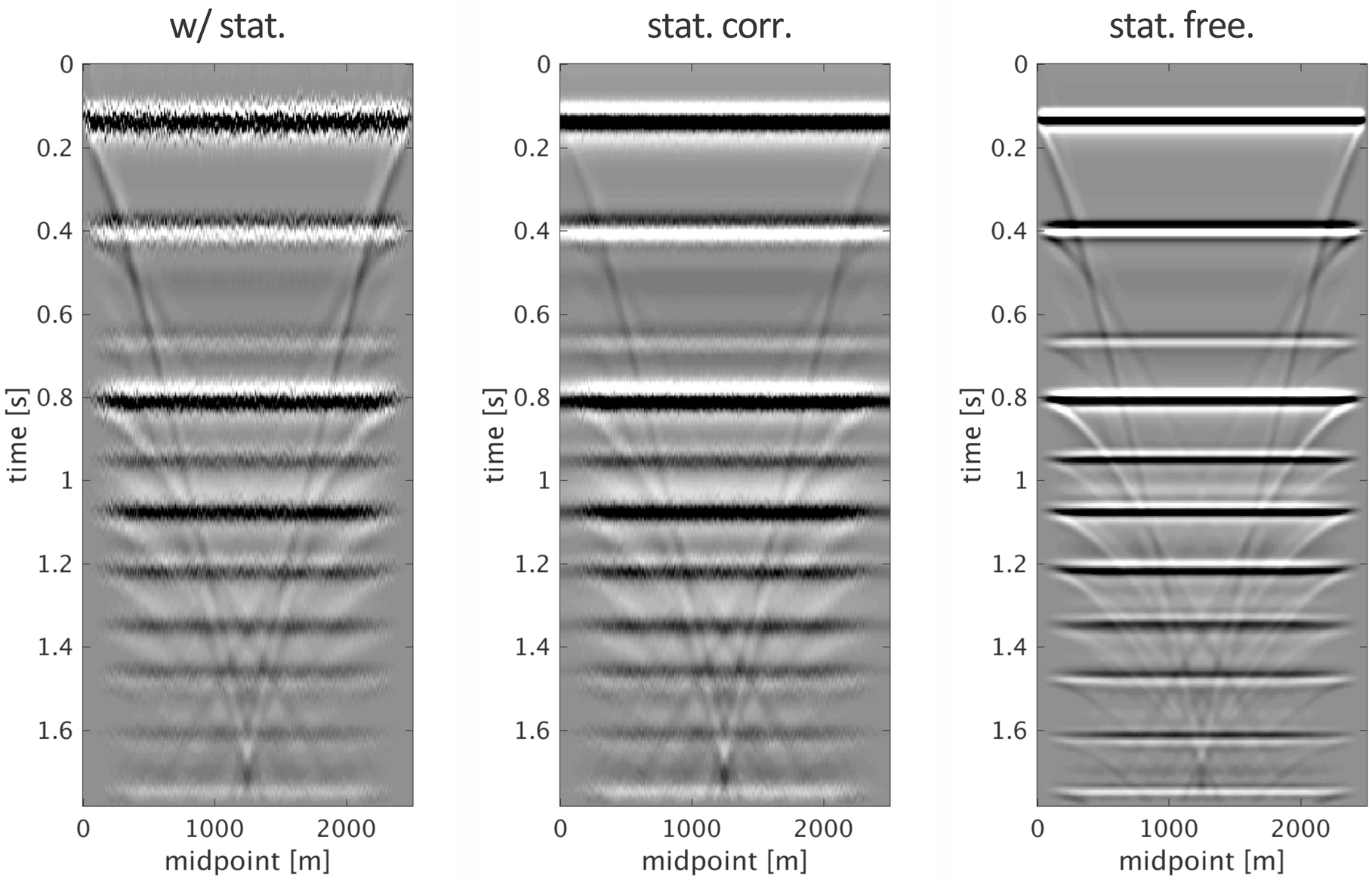


Example (i): NMO

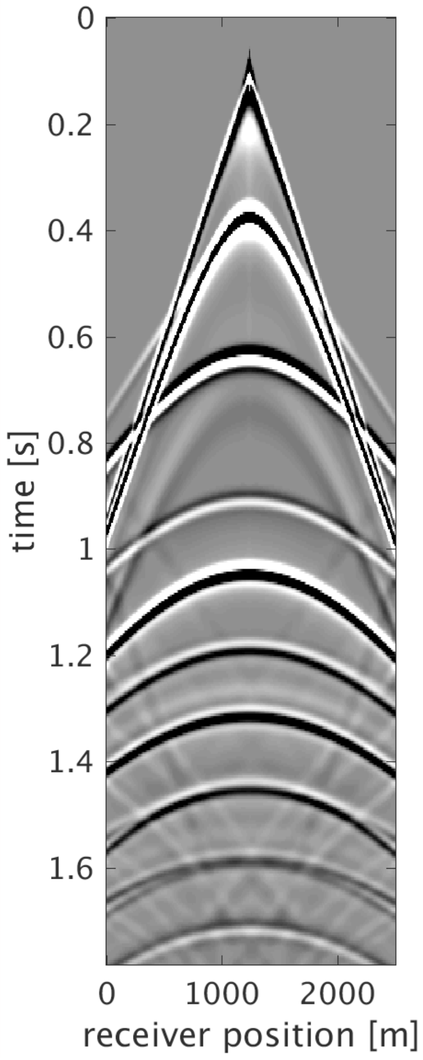


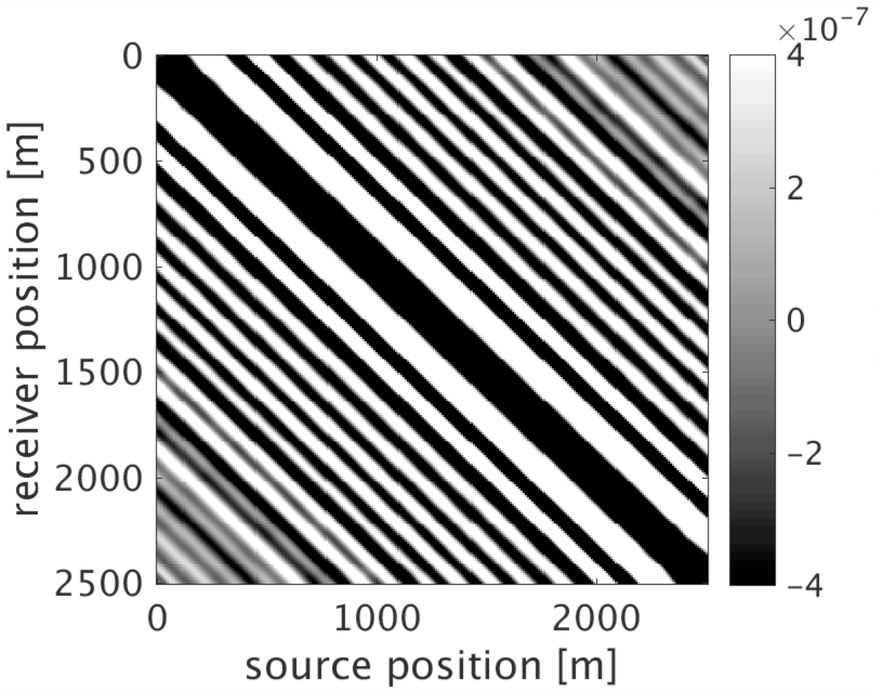


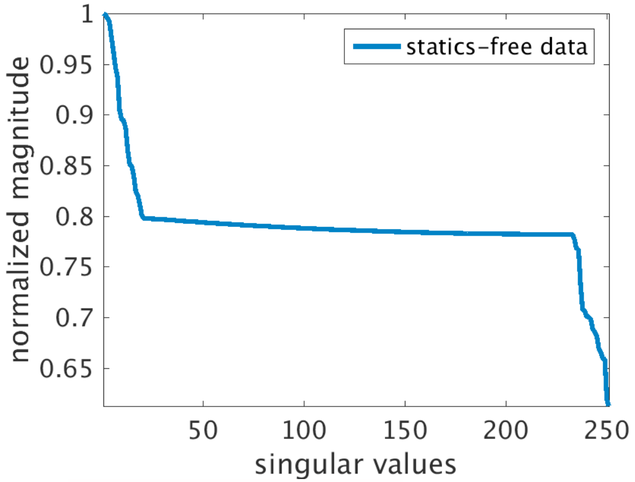
Example (i): Stack



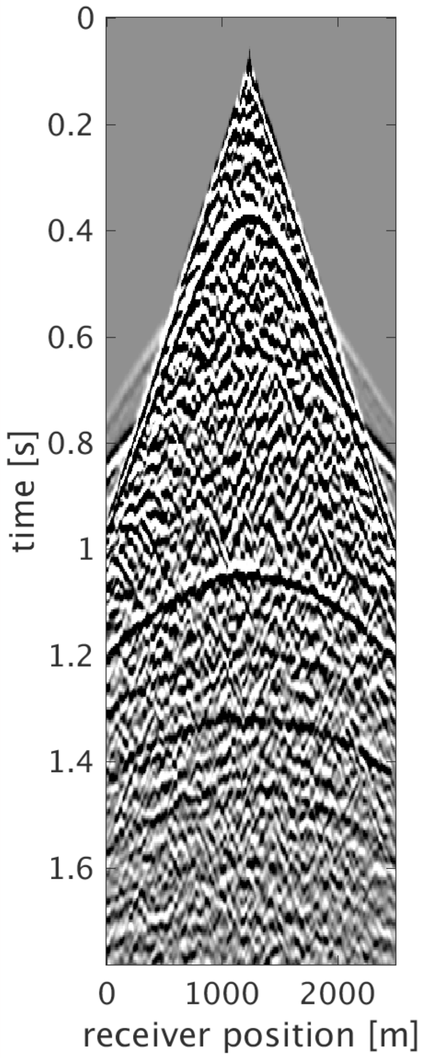
Example (ii): statics-free data

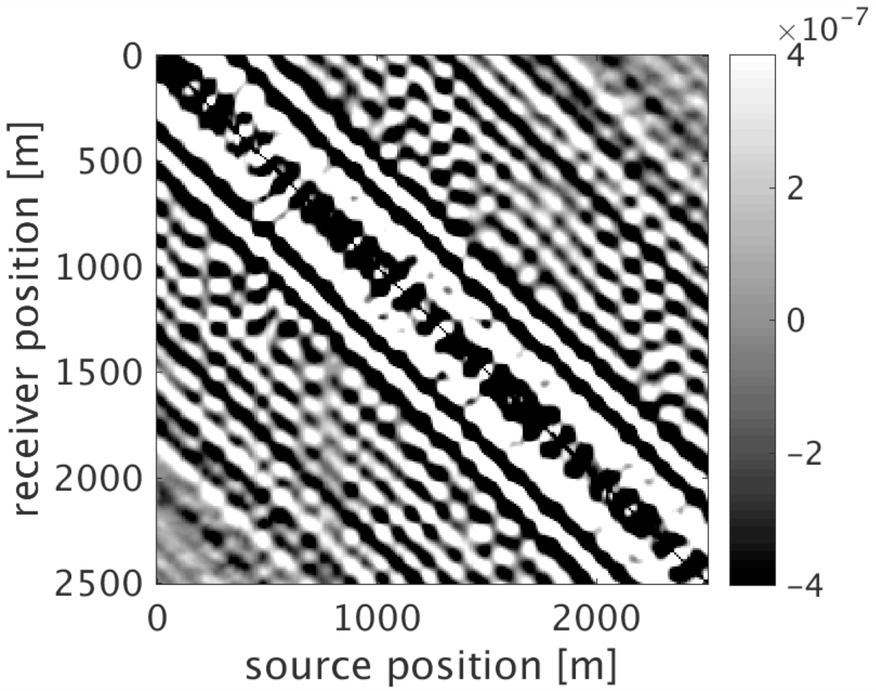


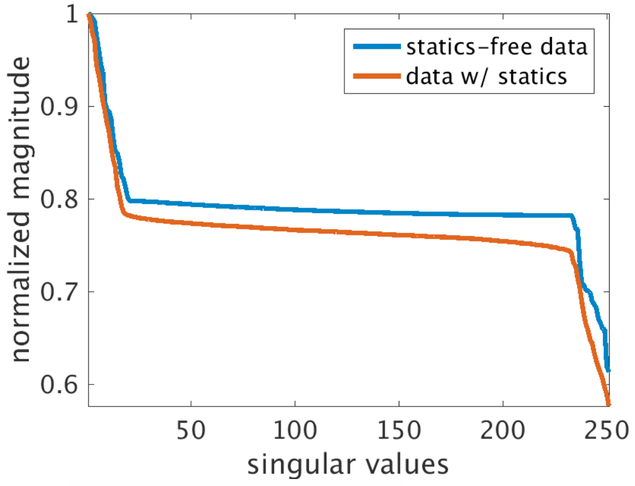




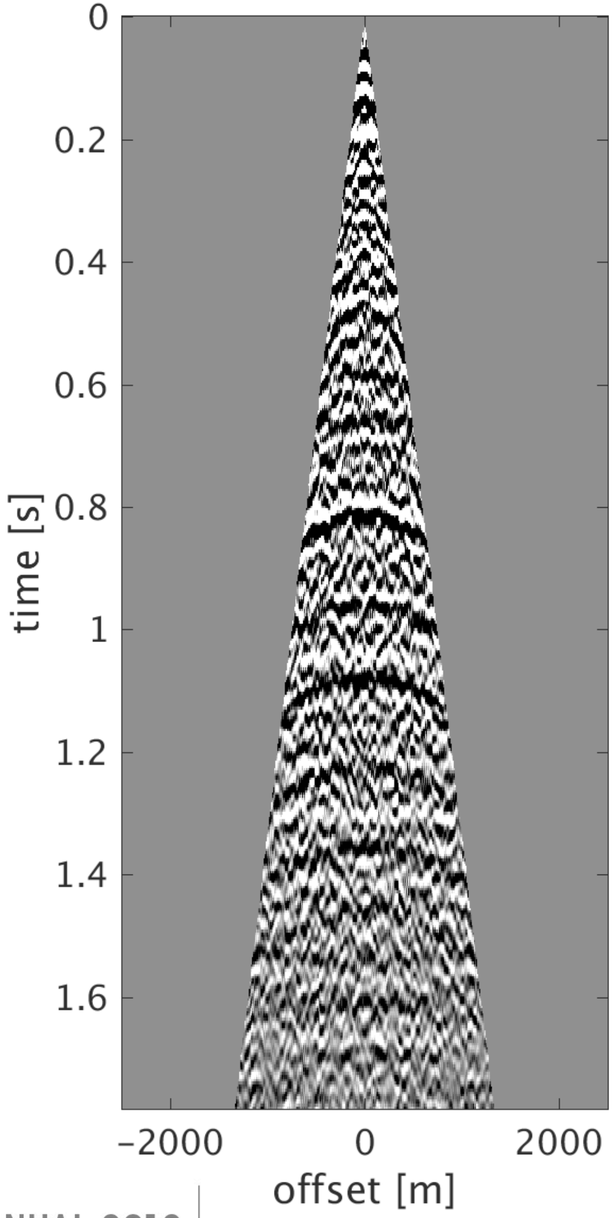
Example (ii): data w/ statics

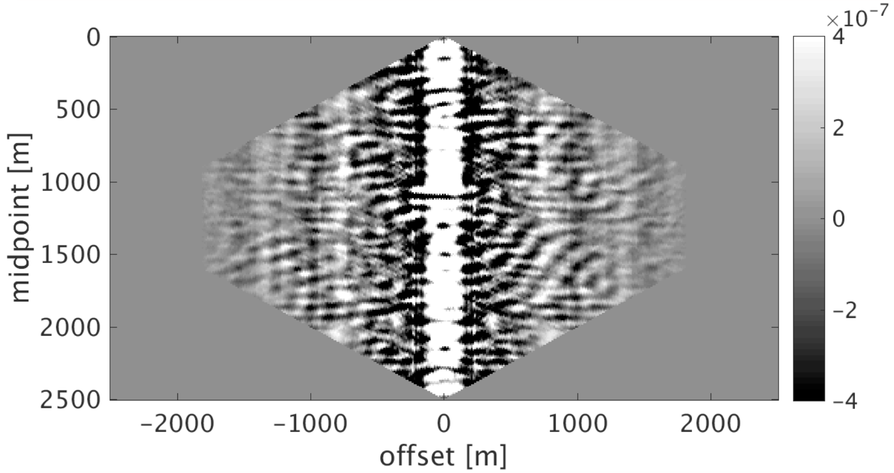


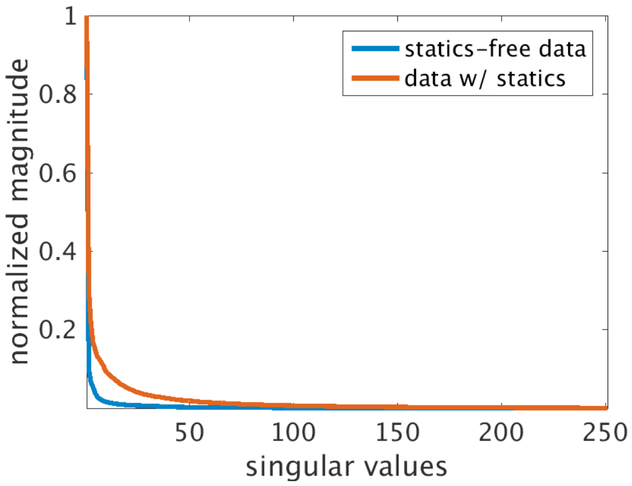




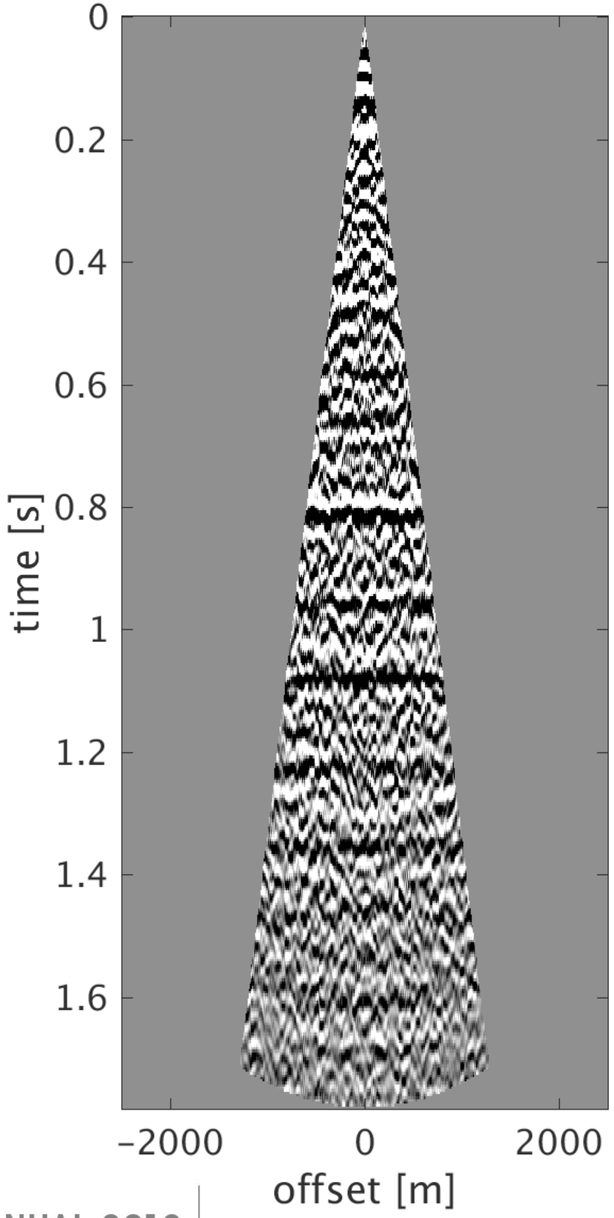
Example (ii): m-h domain

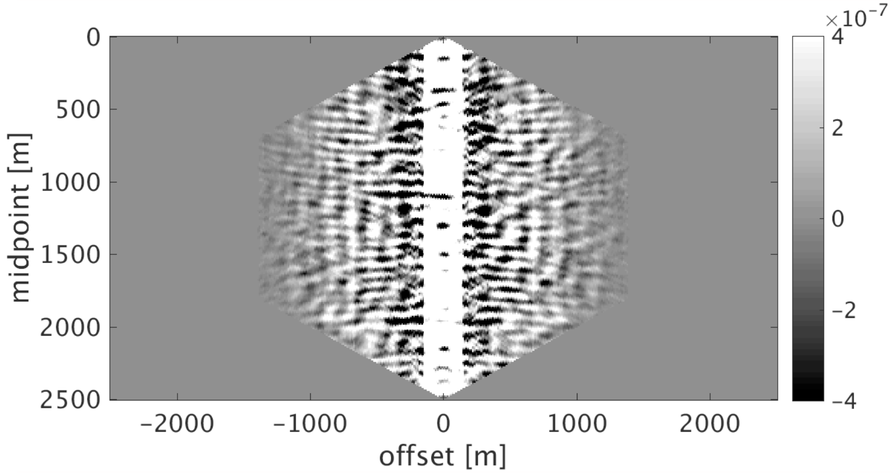


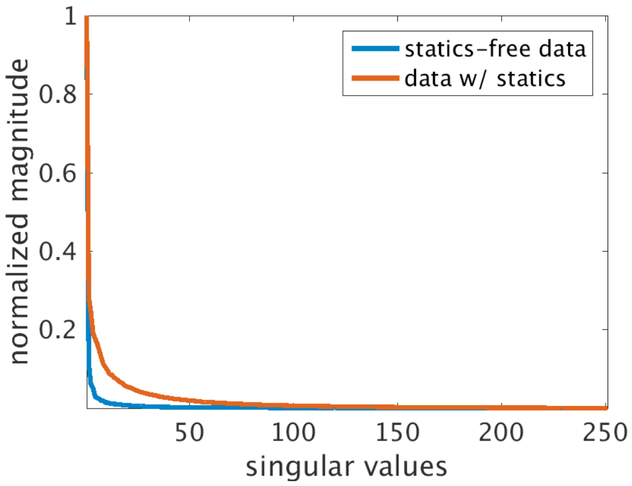




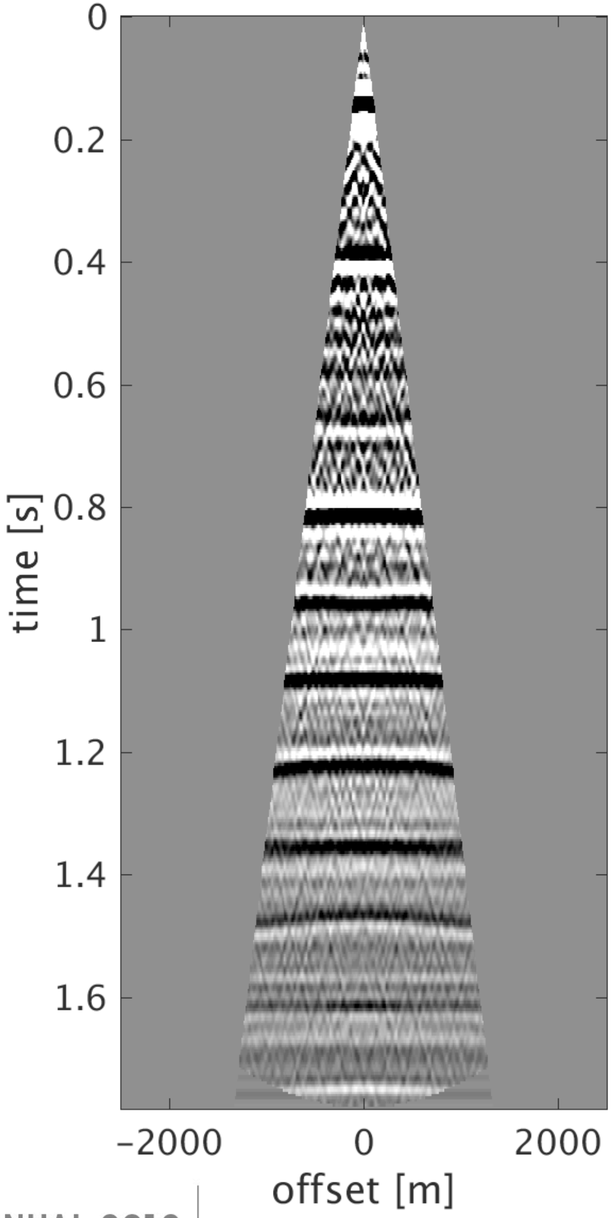
Example (ii): NMO

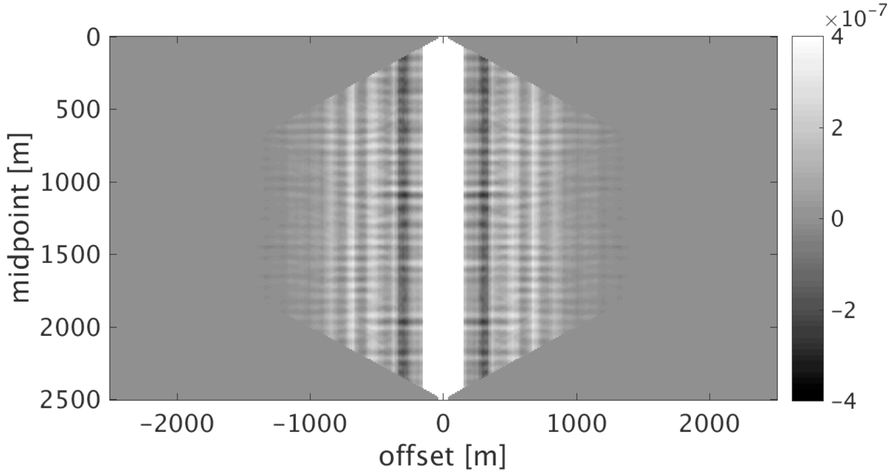




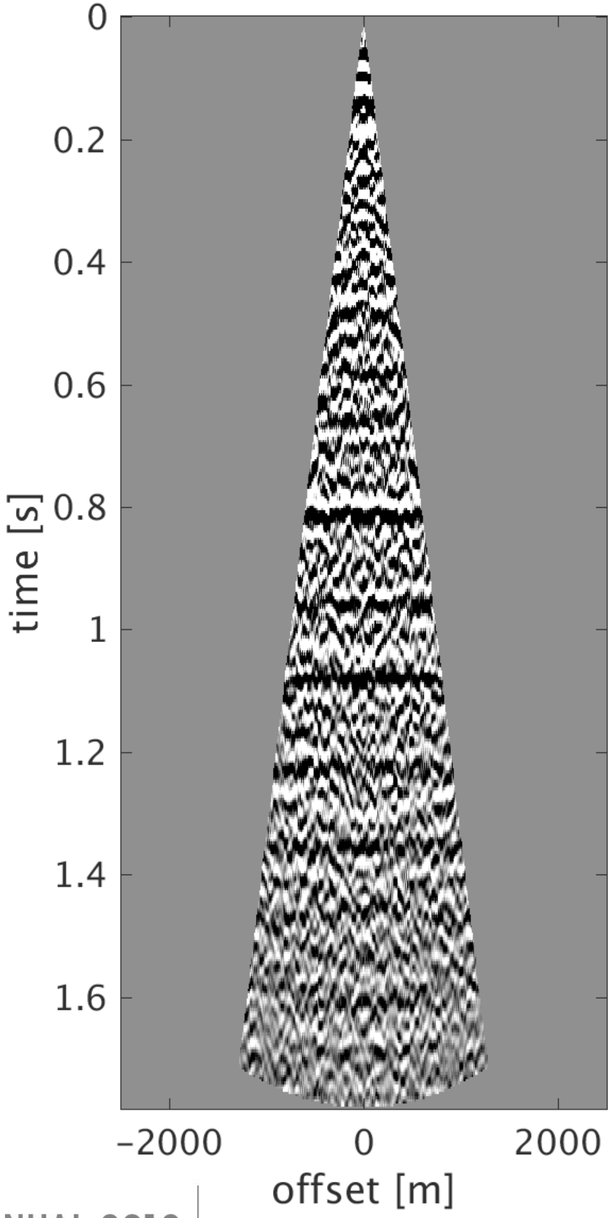


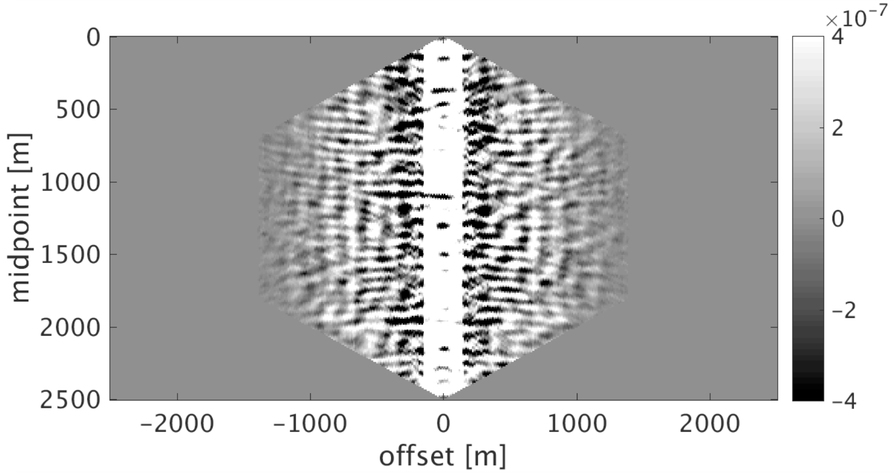
Example (ii): Statics correction



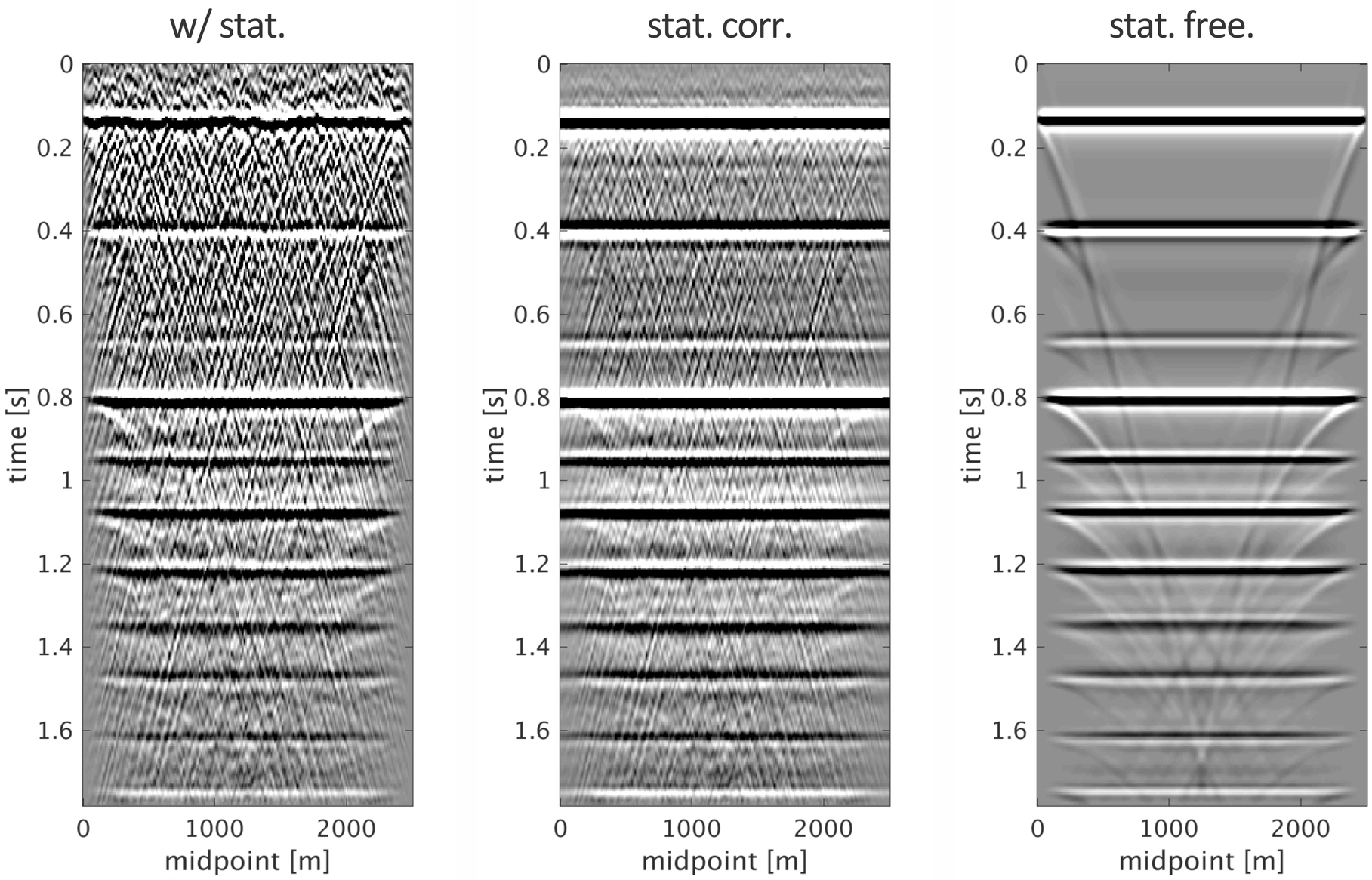


Example (ii): NMO

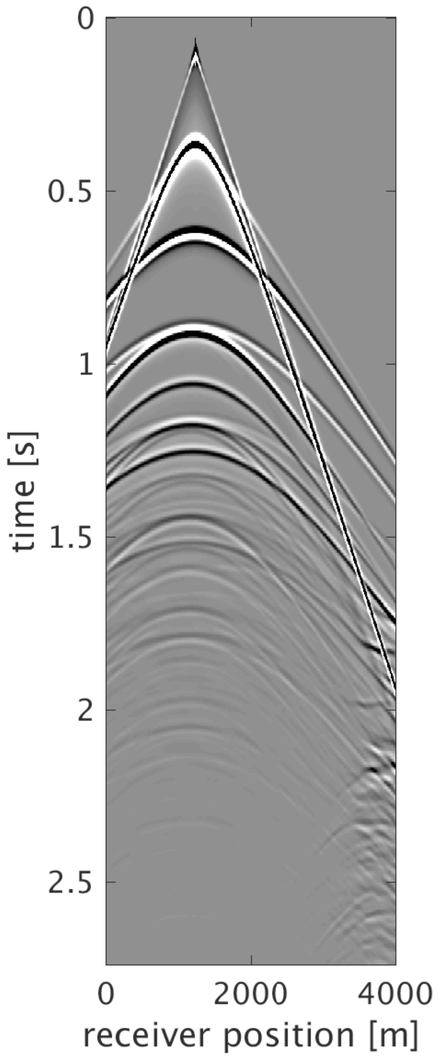


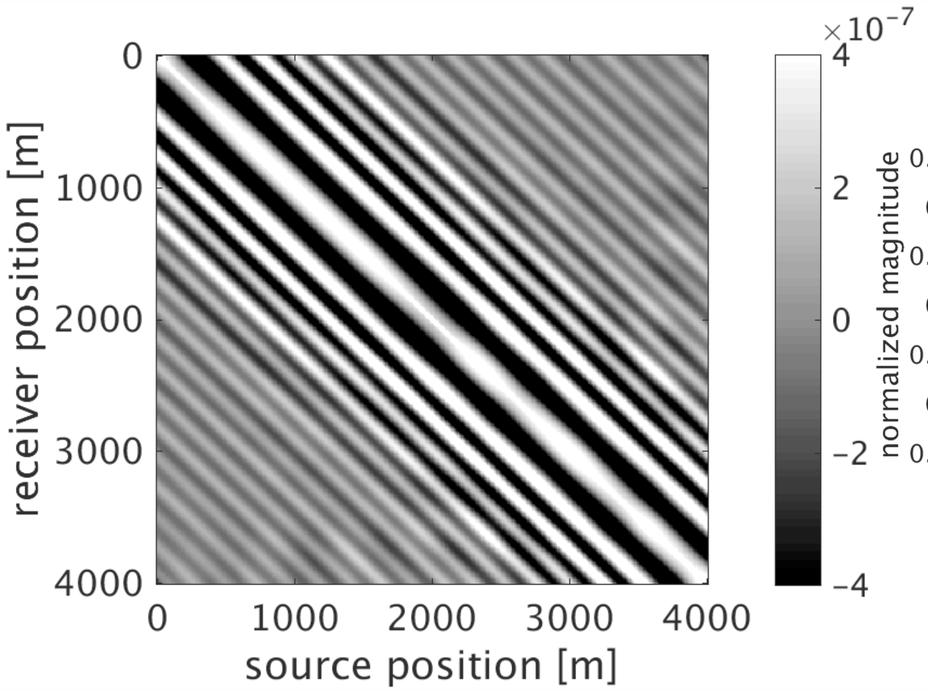


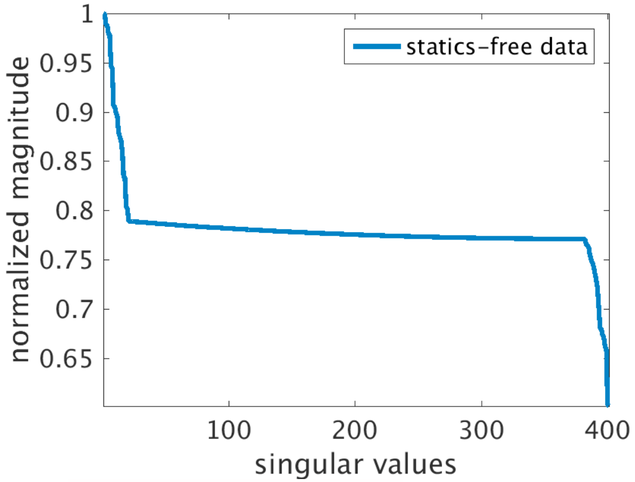
Example (ii): Stack



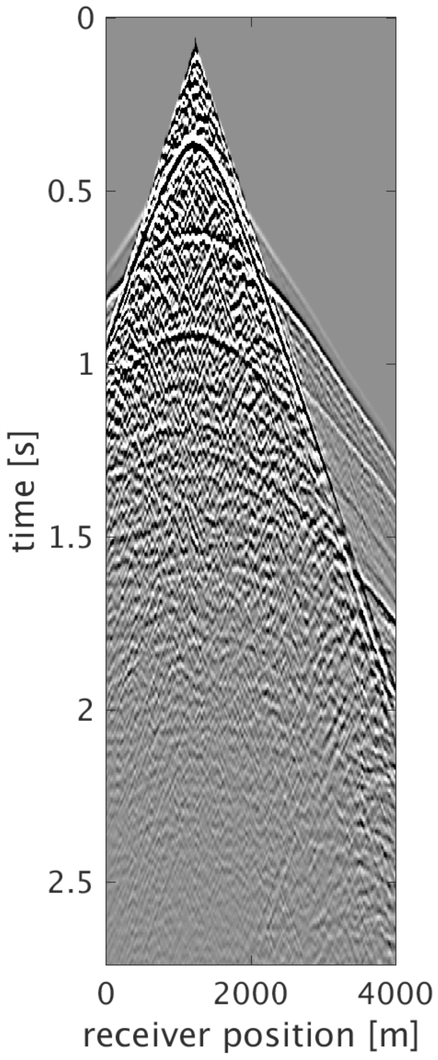
Example (iii): statics-free data

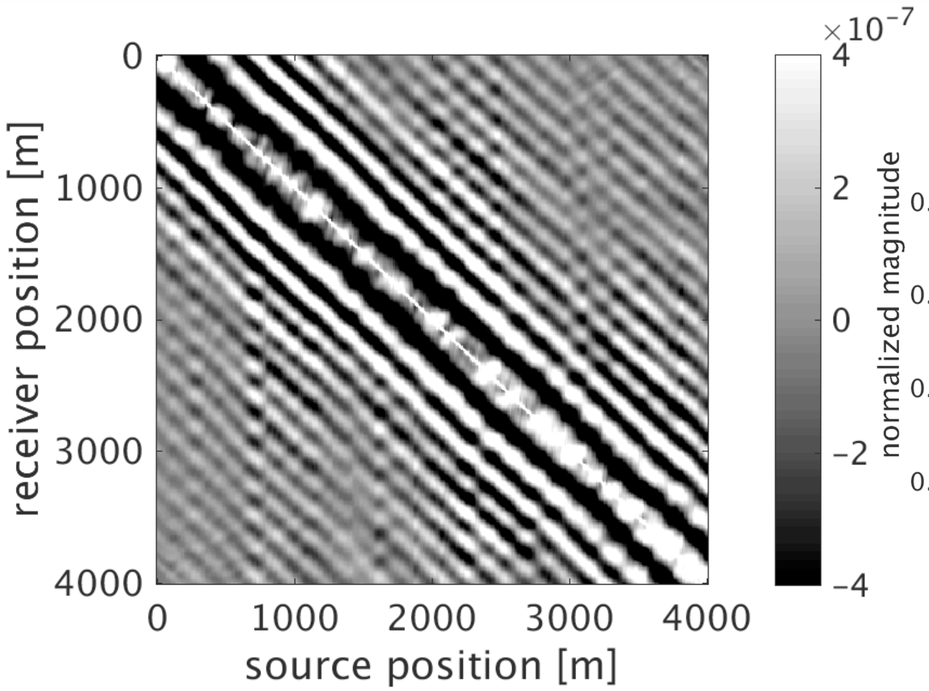


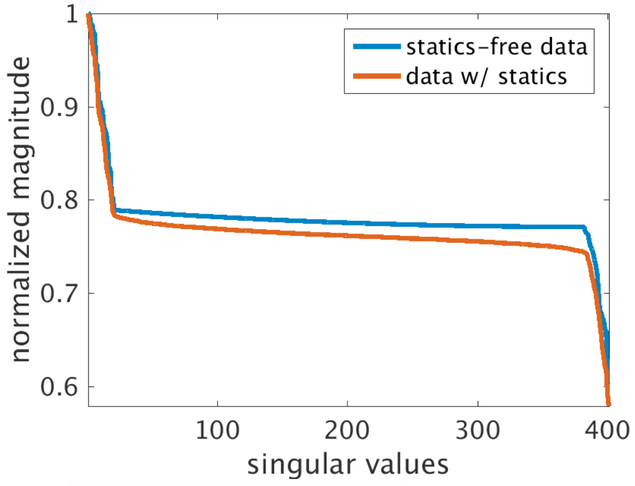




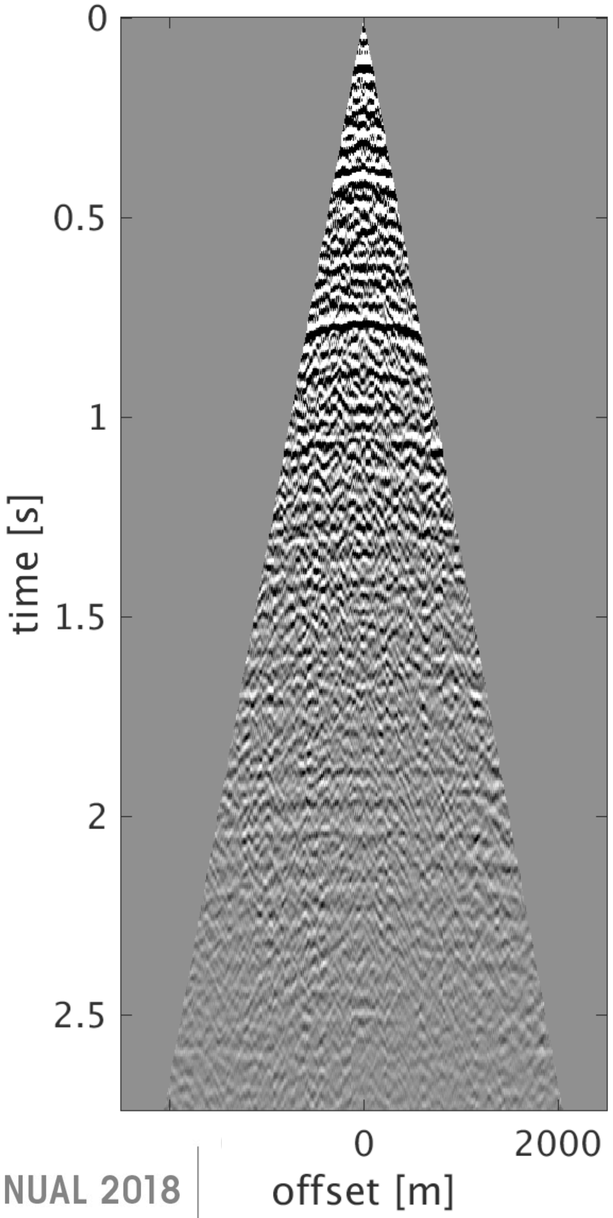
Example (iii): data w/ statics

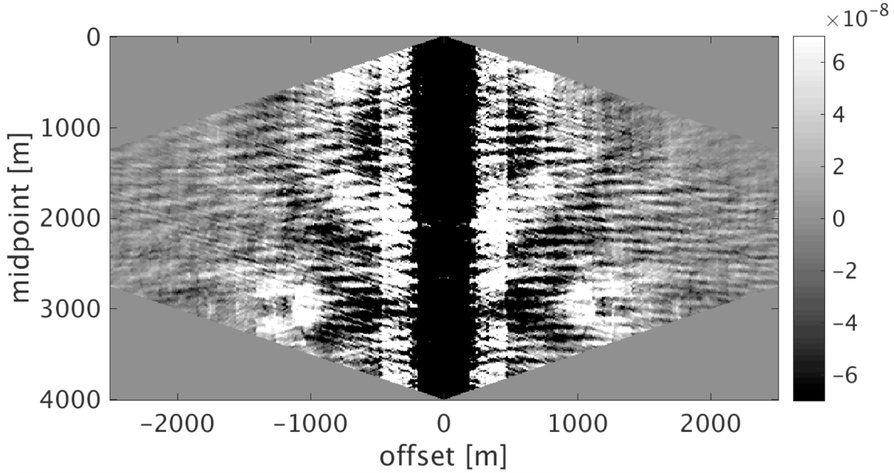


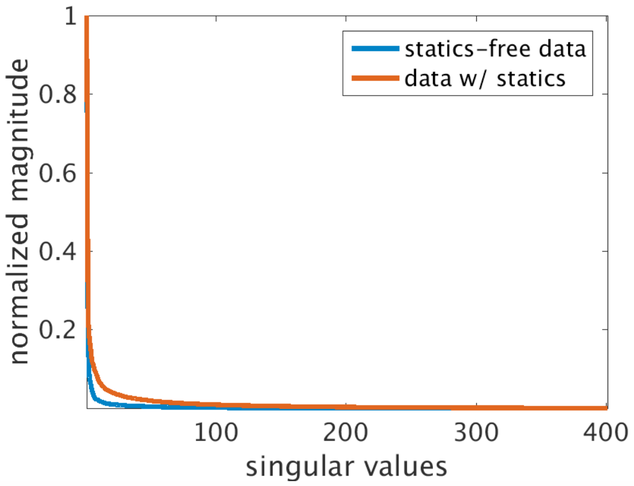




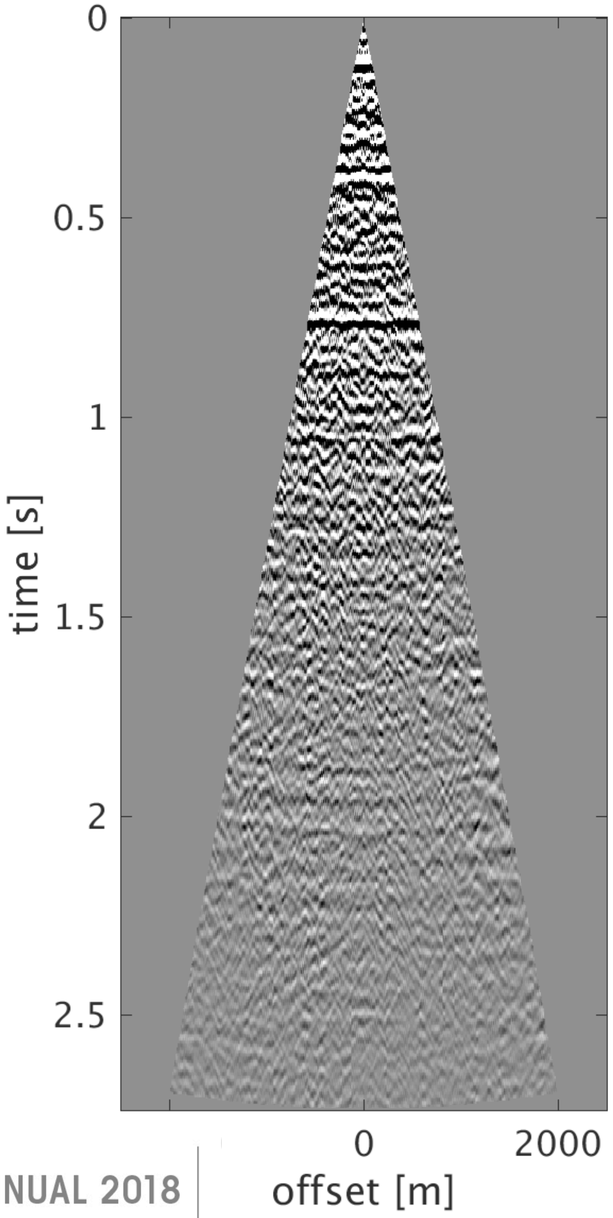
Example (iii): m-h domain

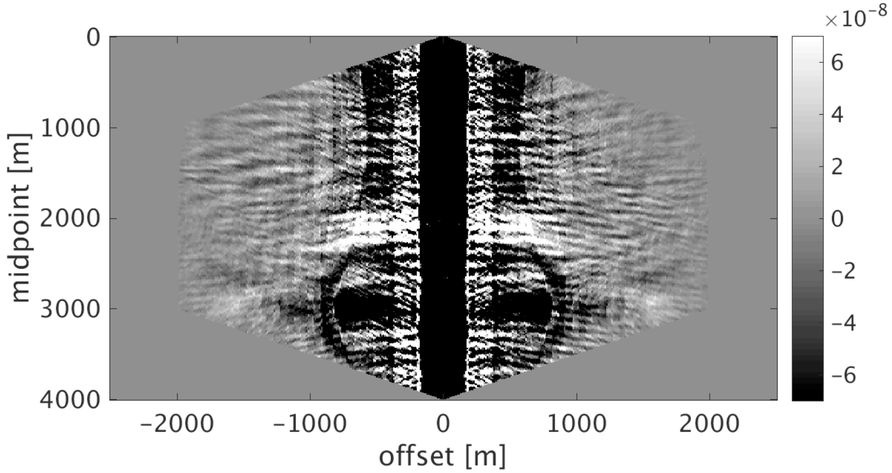


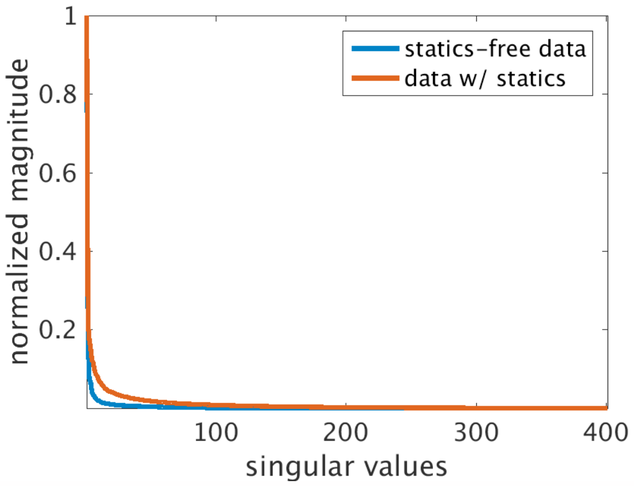




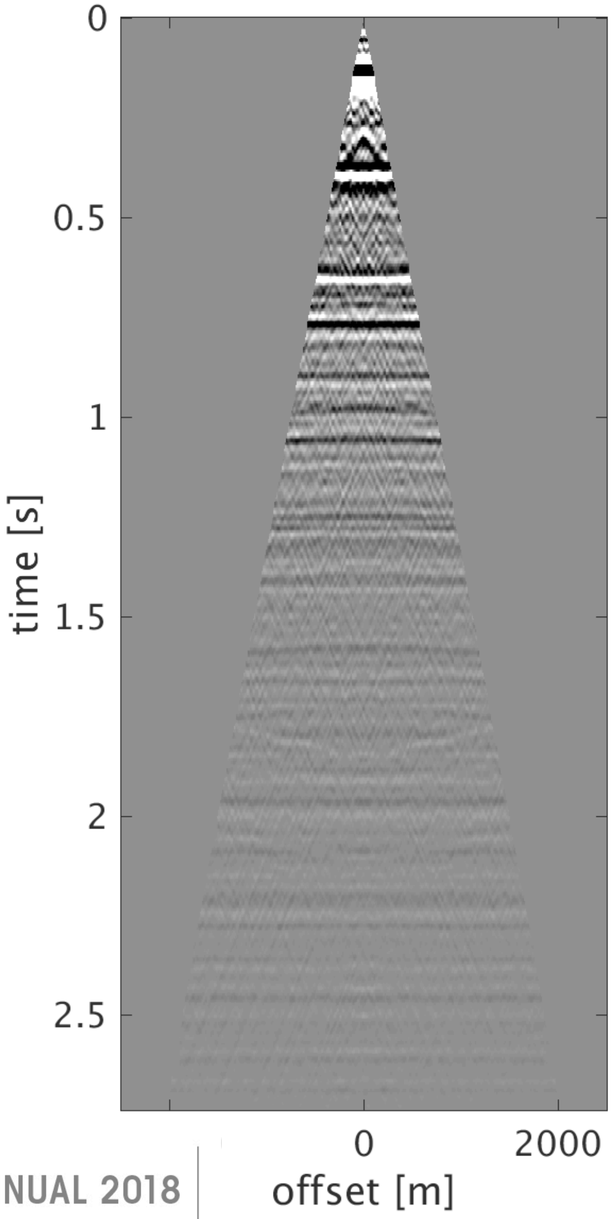
Example (iii): NMO

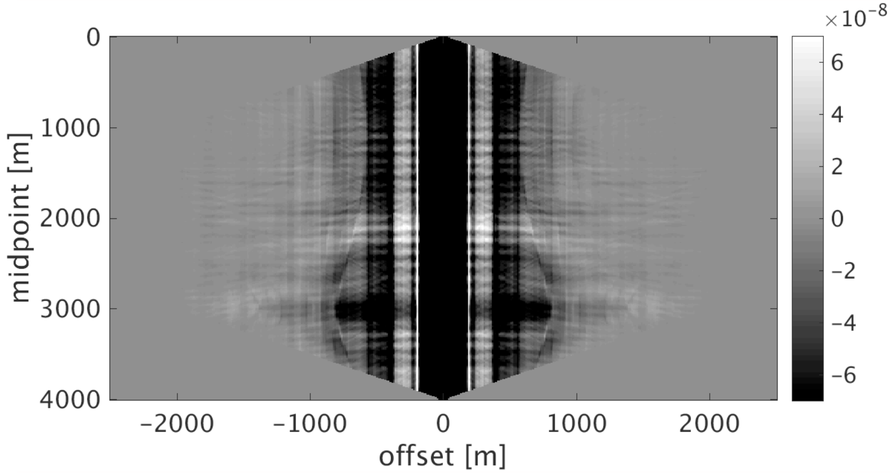




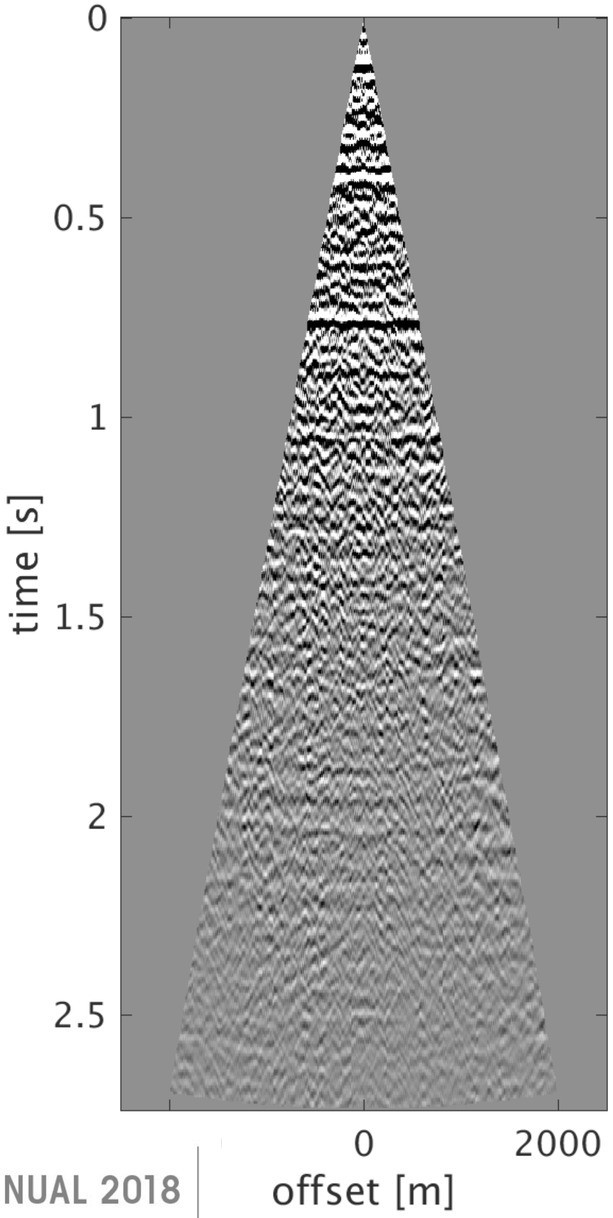


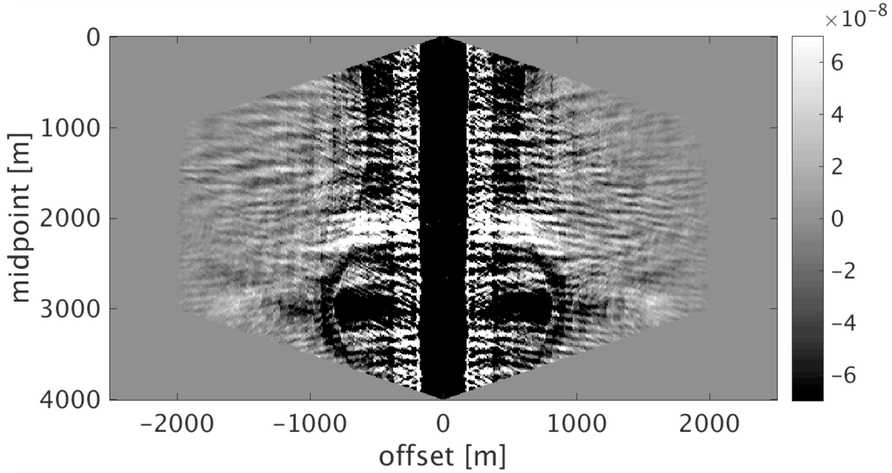
Example (iii): Statics correction



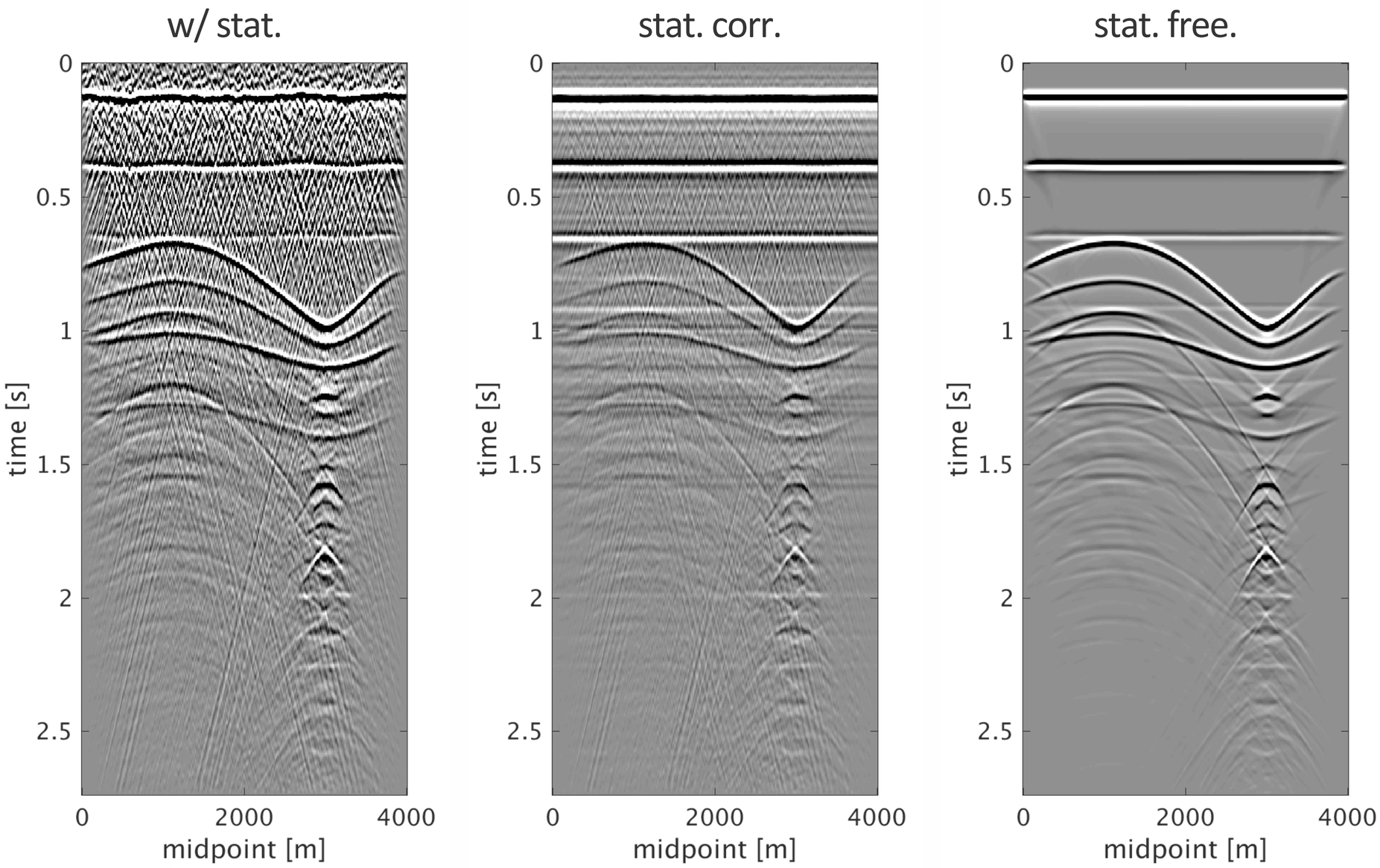


Example (iii): NMO





Example (iii): Stack



Numerical examples
Real data

U.S. Geological Survey: https://www.usgs.gov

Alaska 2D land line 31-81

src: 55

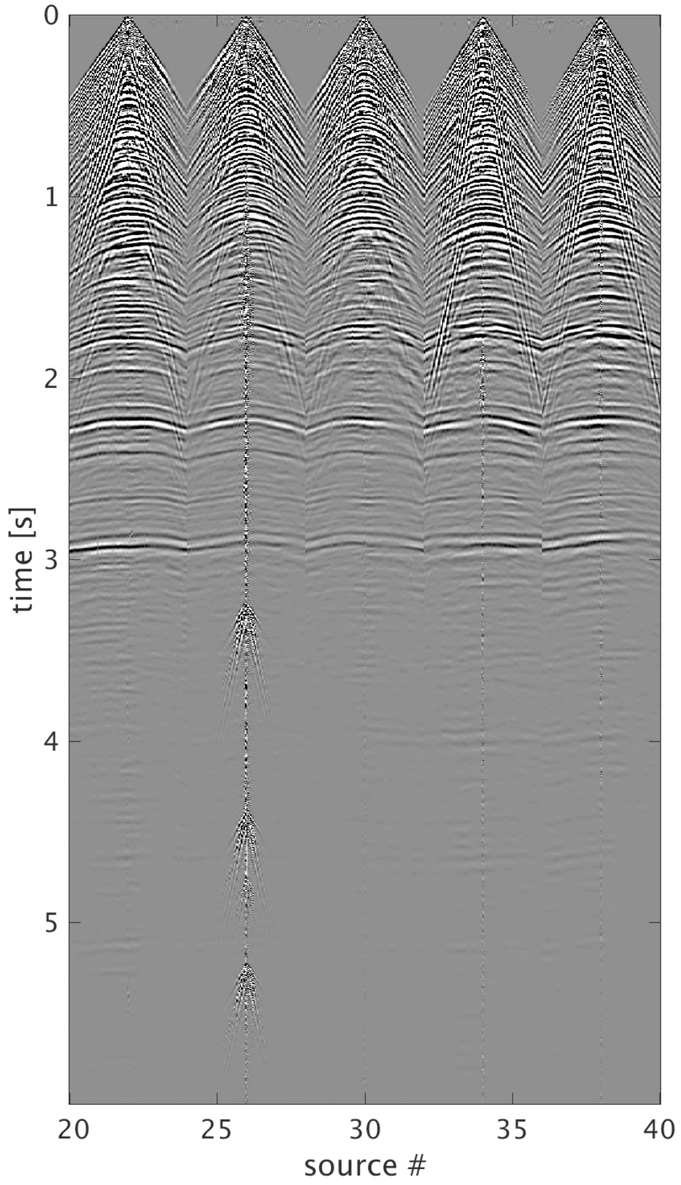
rec: 96

src interval: $440\ \mathrm{ft}$

rec interval: $110\ \mathrm{ft}$

fold: 12

Not much long wavelength statics

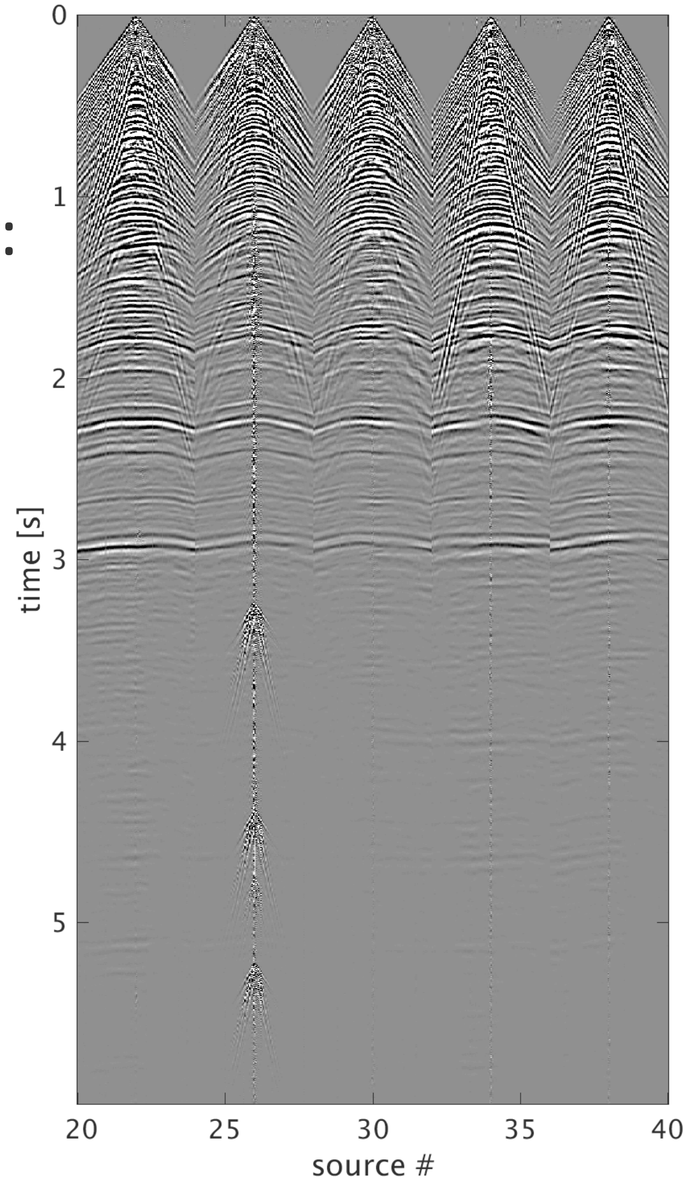


Schleicher, K. and John, A. [2012] Open Data/Open Source: Seismic Unix scripts to process a 2D land line. Tech. rep., Citeseer.

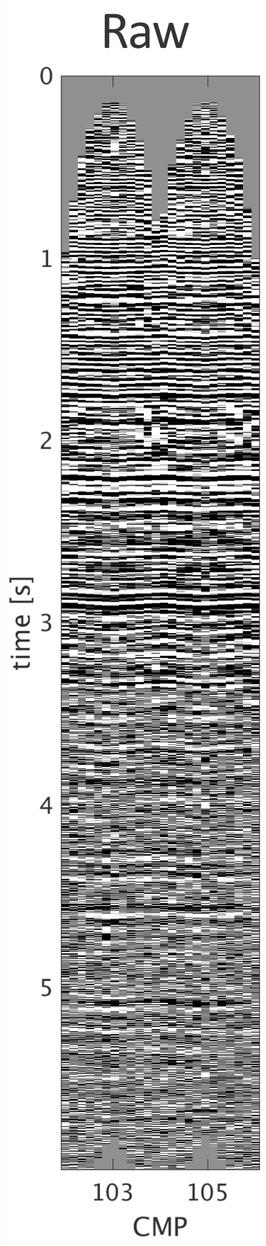
Alaska 2D land line 31-81

Conventional seismic processing workflow:

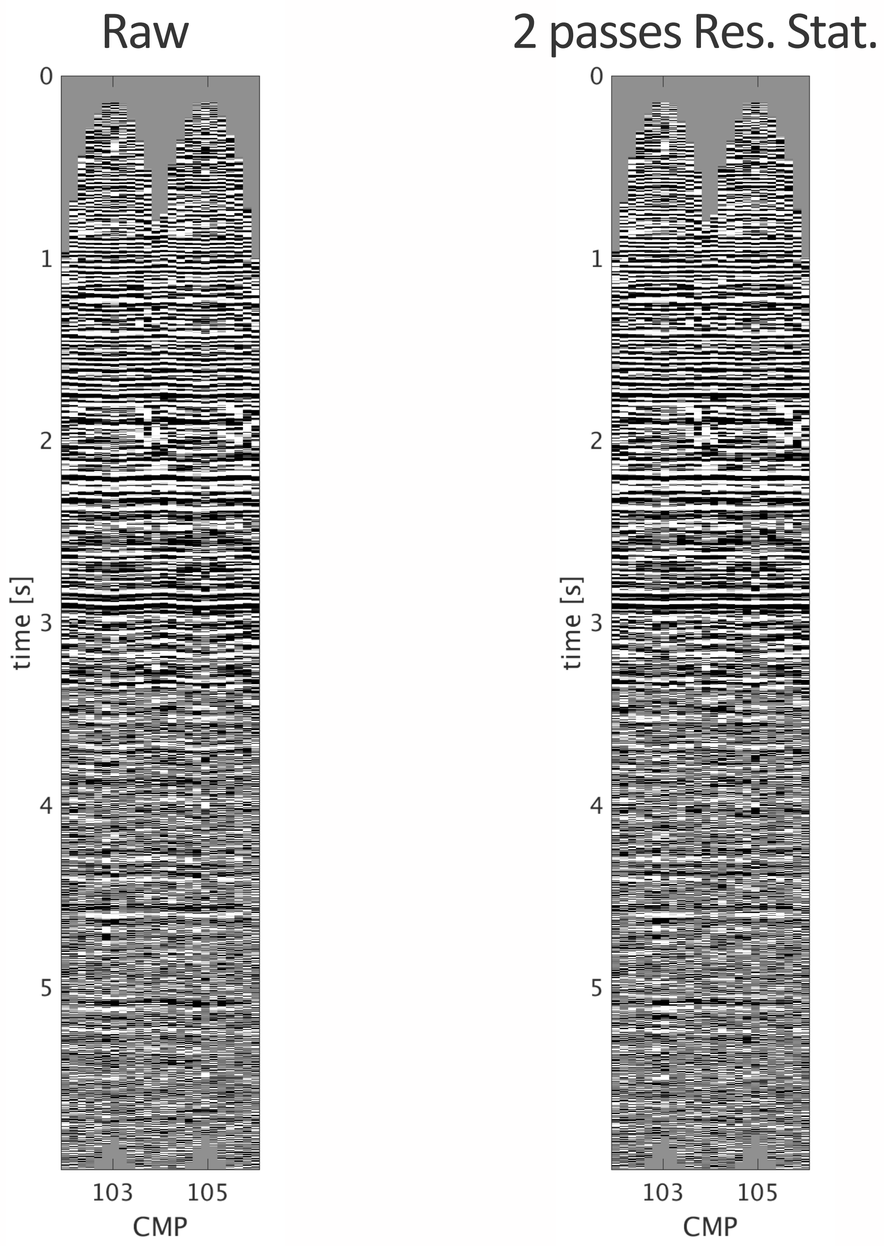
- Geometric spread correction
- Ground roll attenuation
- Datum statics correction
- NMO Correction



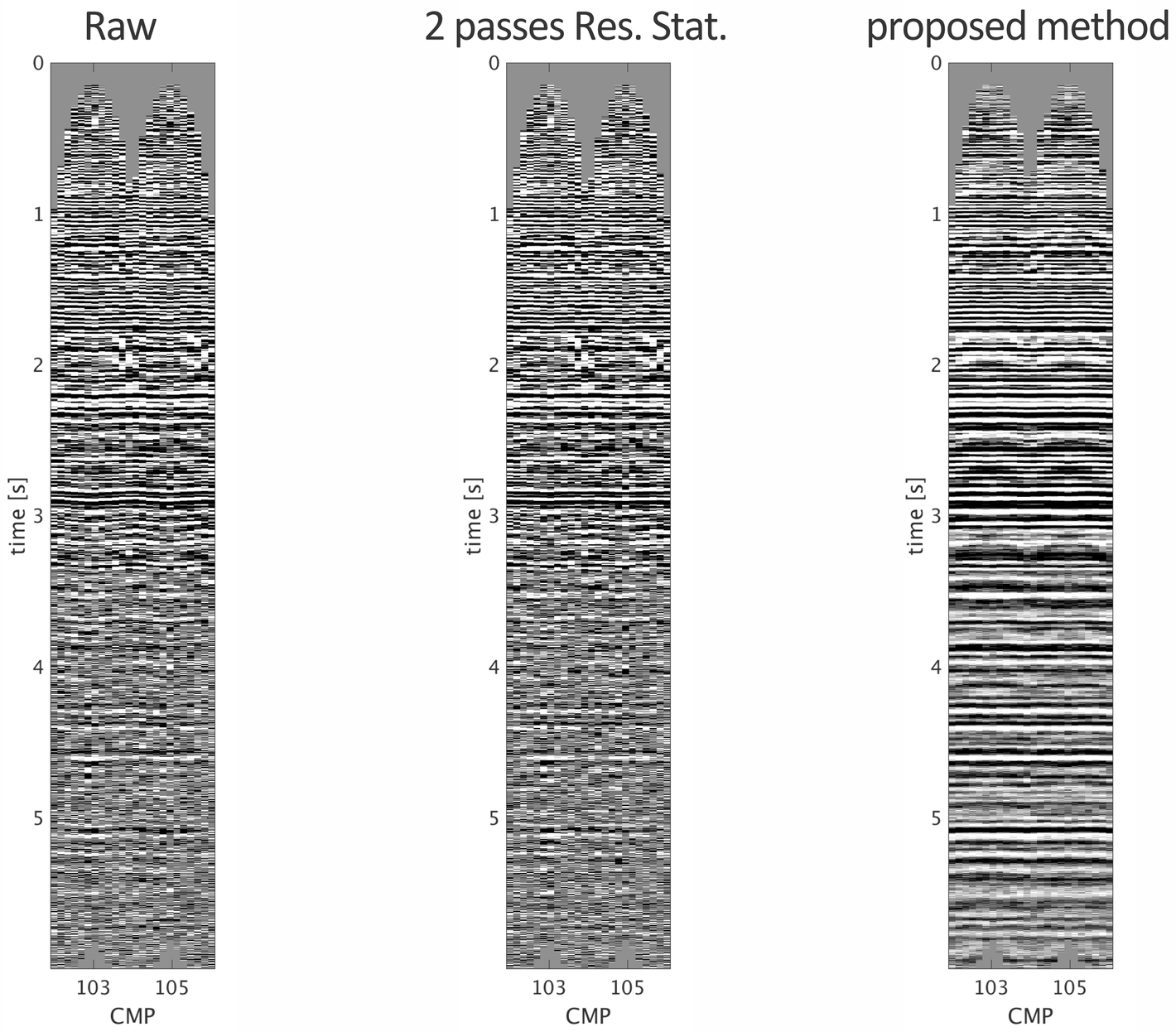
NMO-corrected CMPS



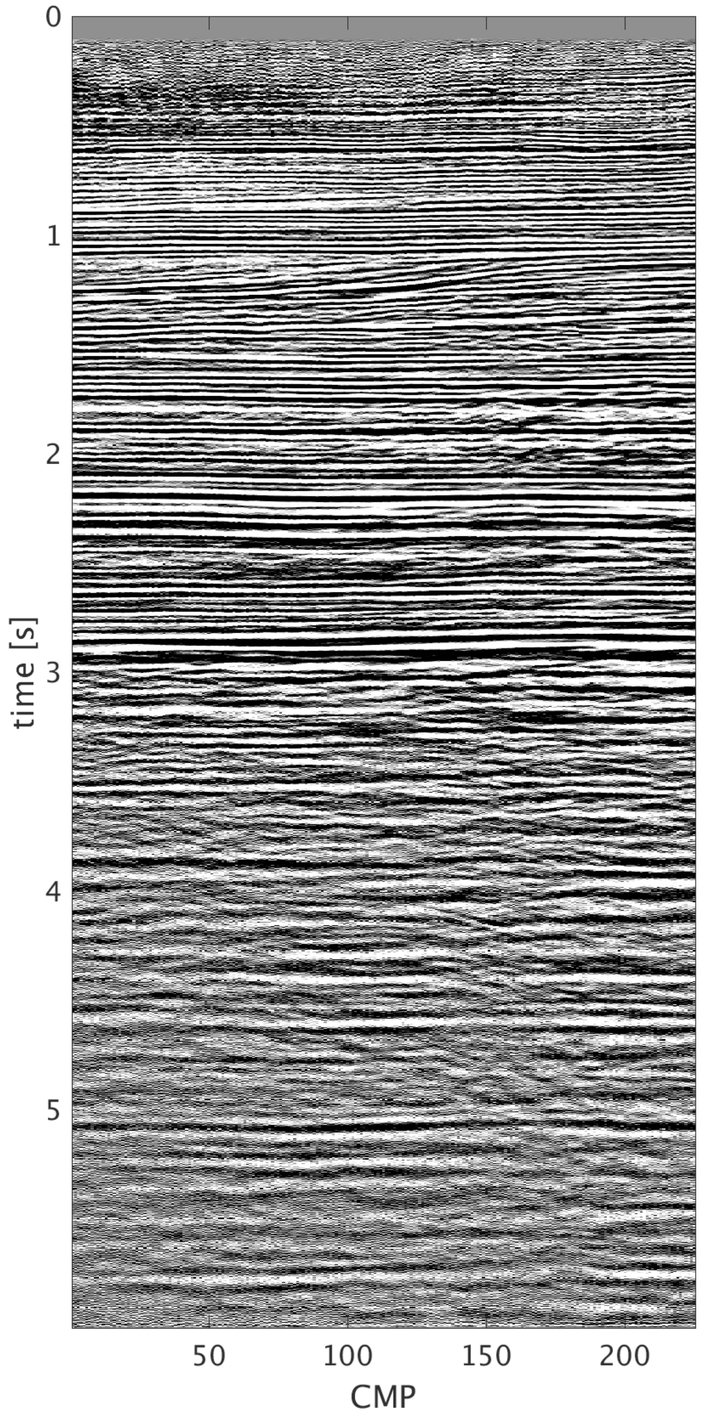
NMO-corrected CMPS



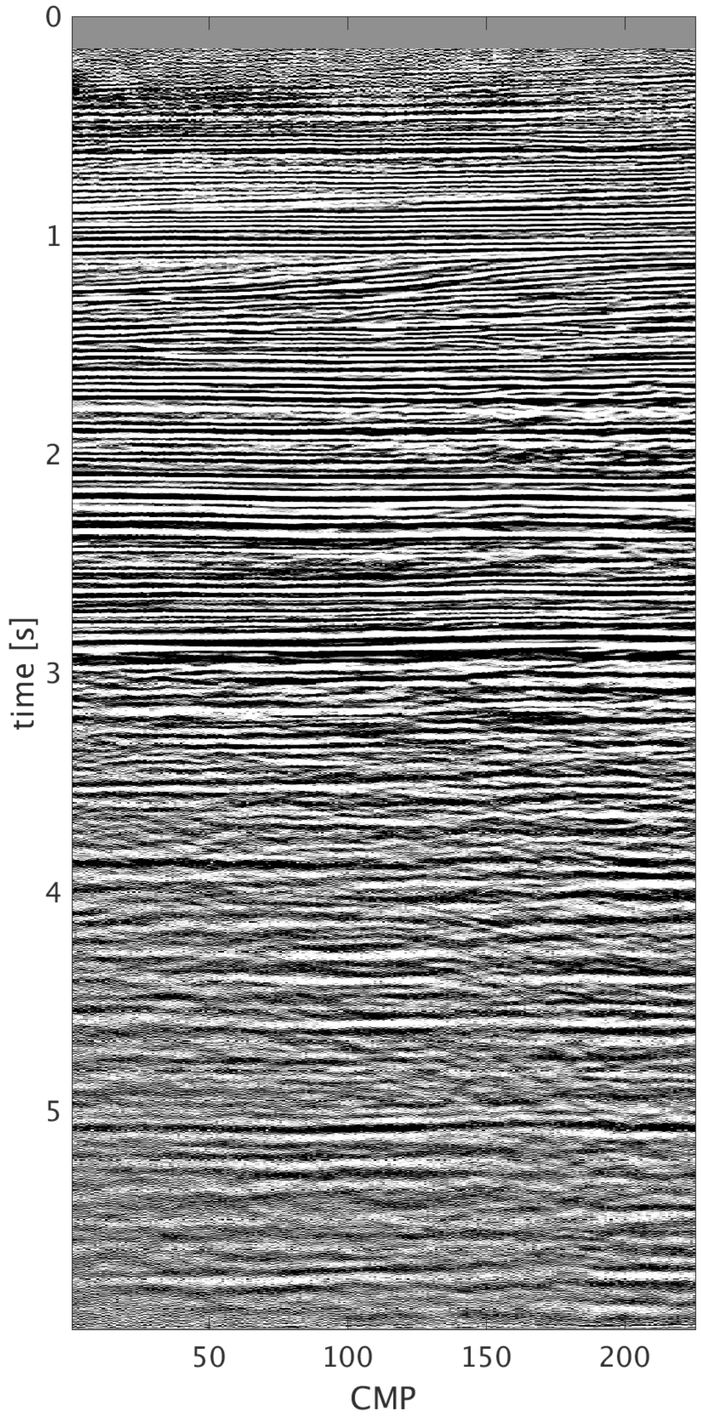
NMO-corrected CMPS



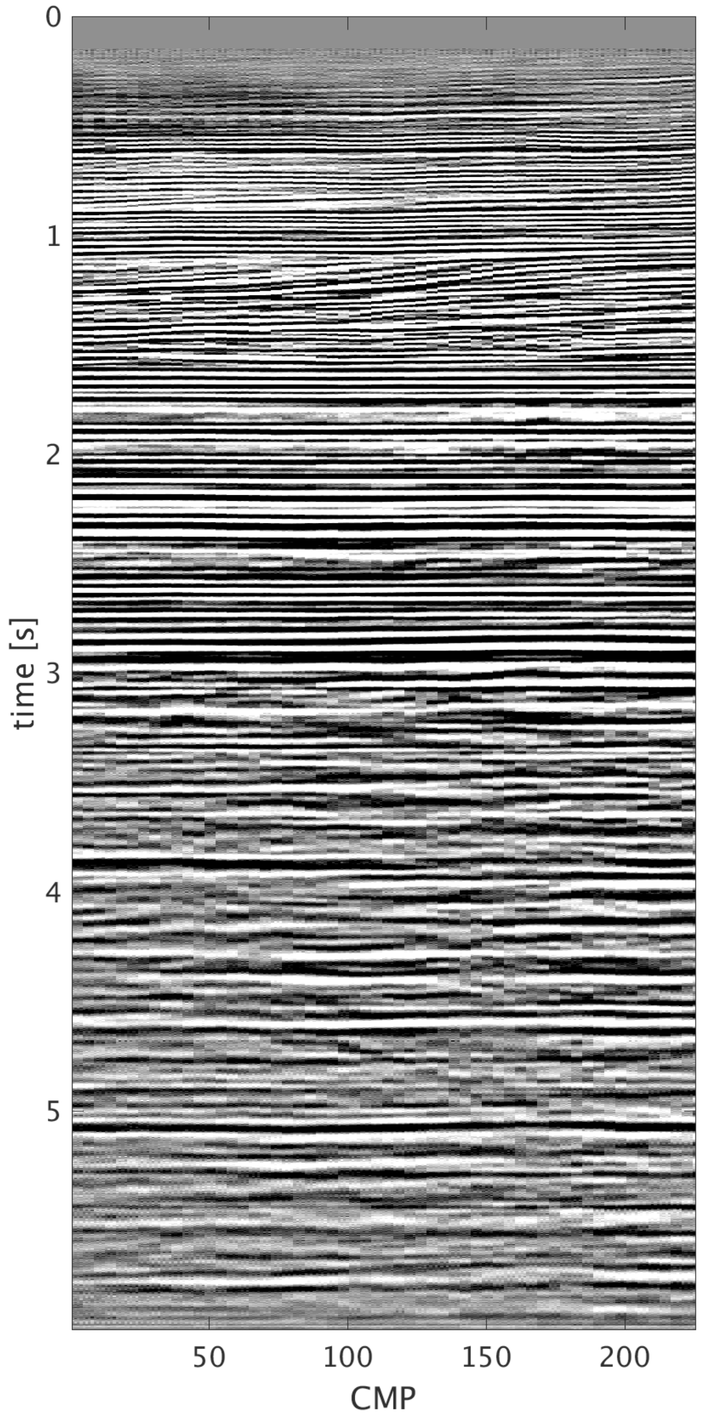
Stack



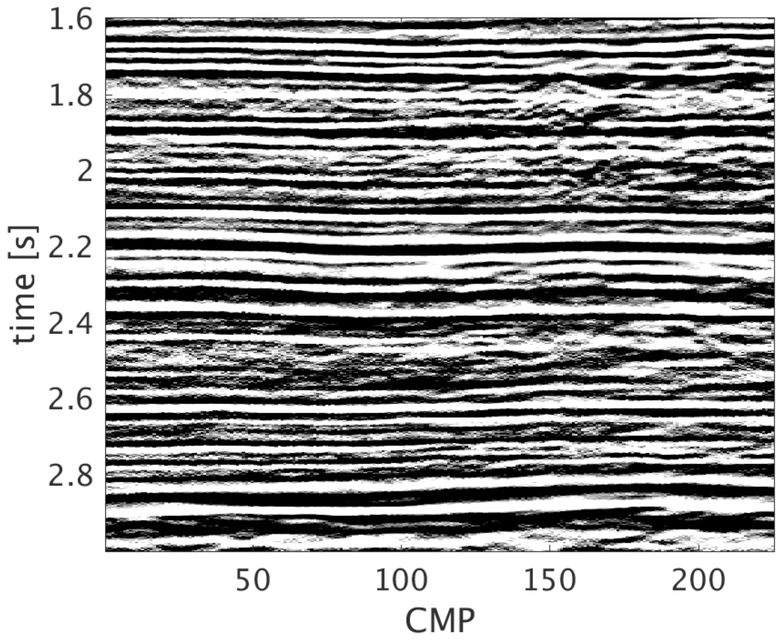
Stack W/ res. stat.

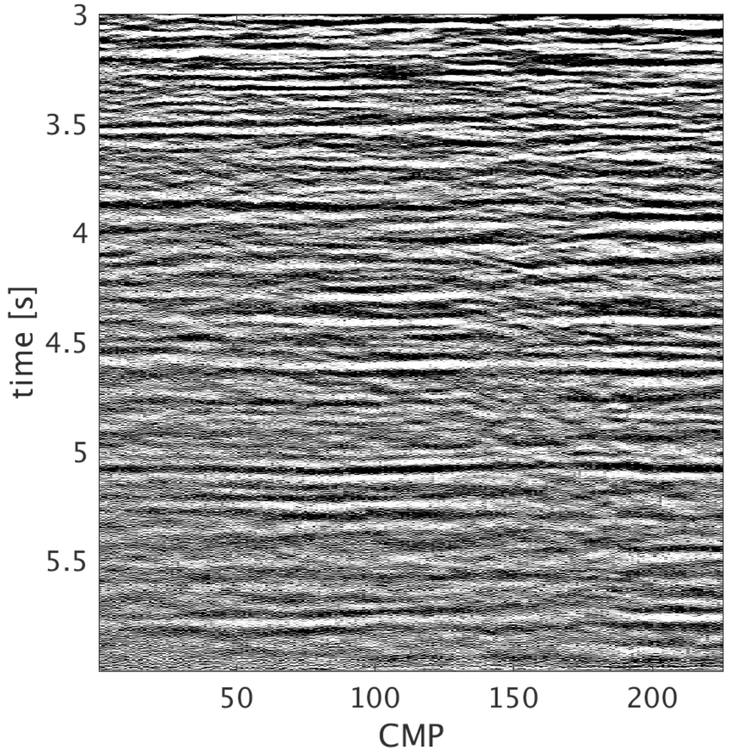


Stack W/ proposed method

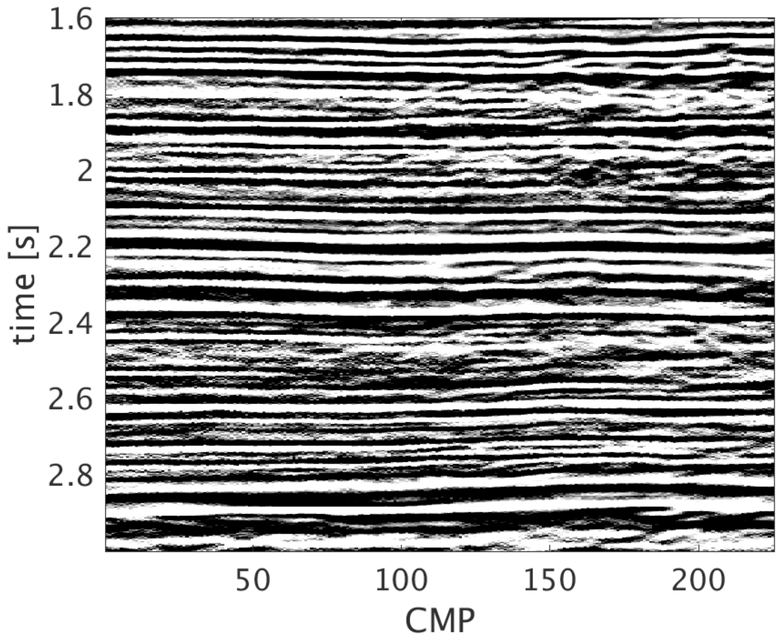


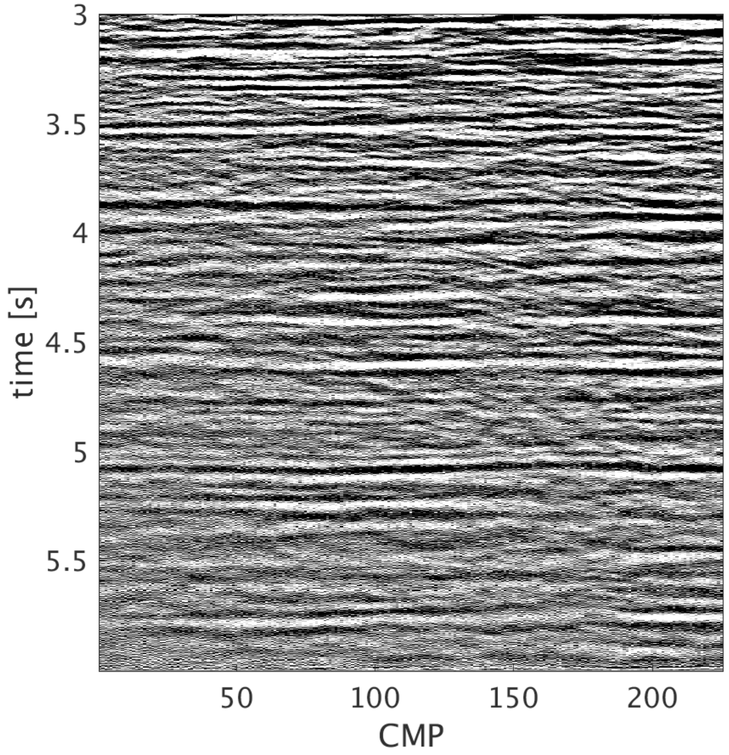
Stack


1.6
1.8
2
2.2
2.4
2.6
2.8
time [s]
50
100
150
200
CMP

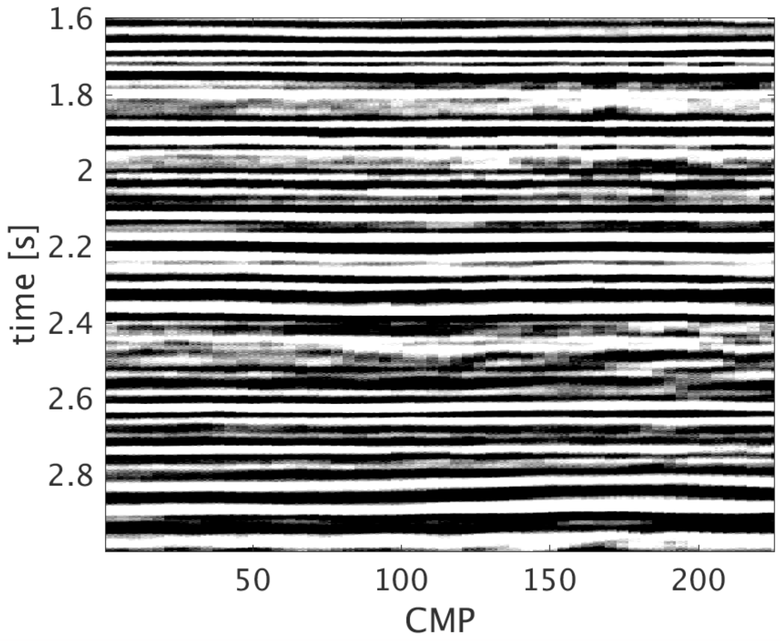

3
3.5
4
4.5
5
5.5
time [s]
50
100
150
200
CMP

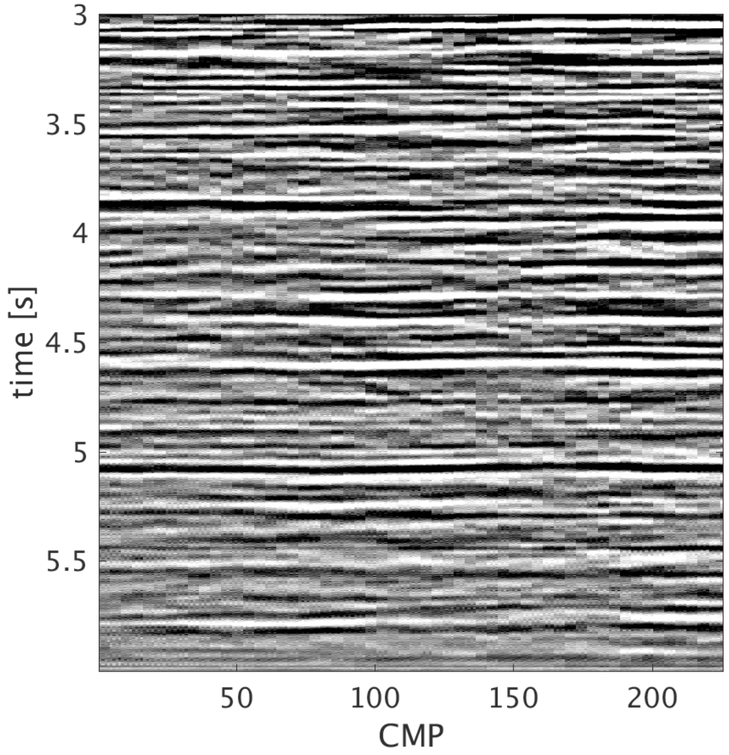
Stack w/ residual statics



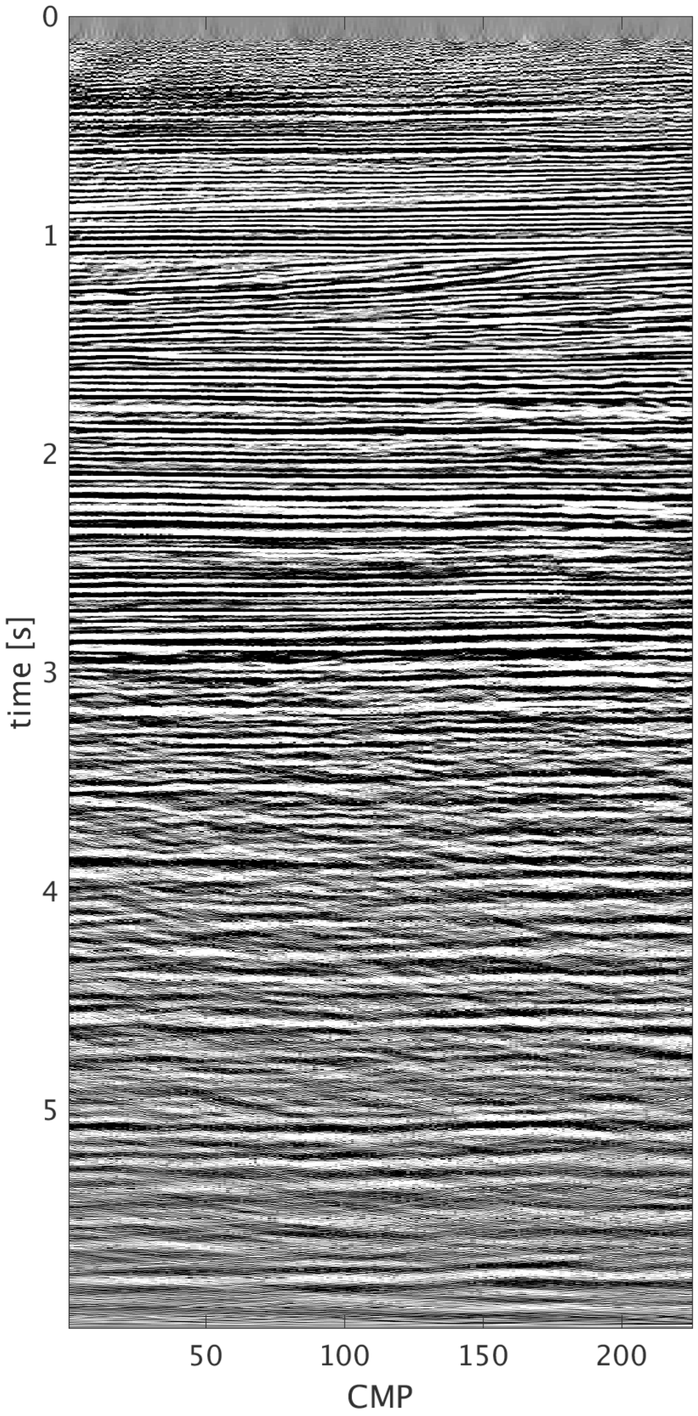


Stack w/ proposed method

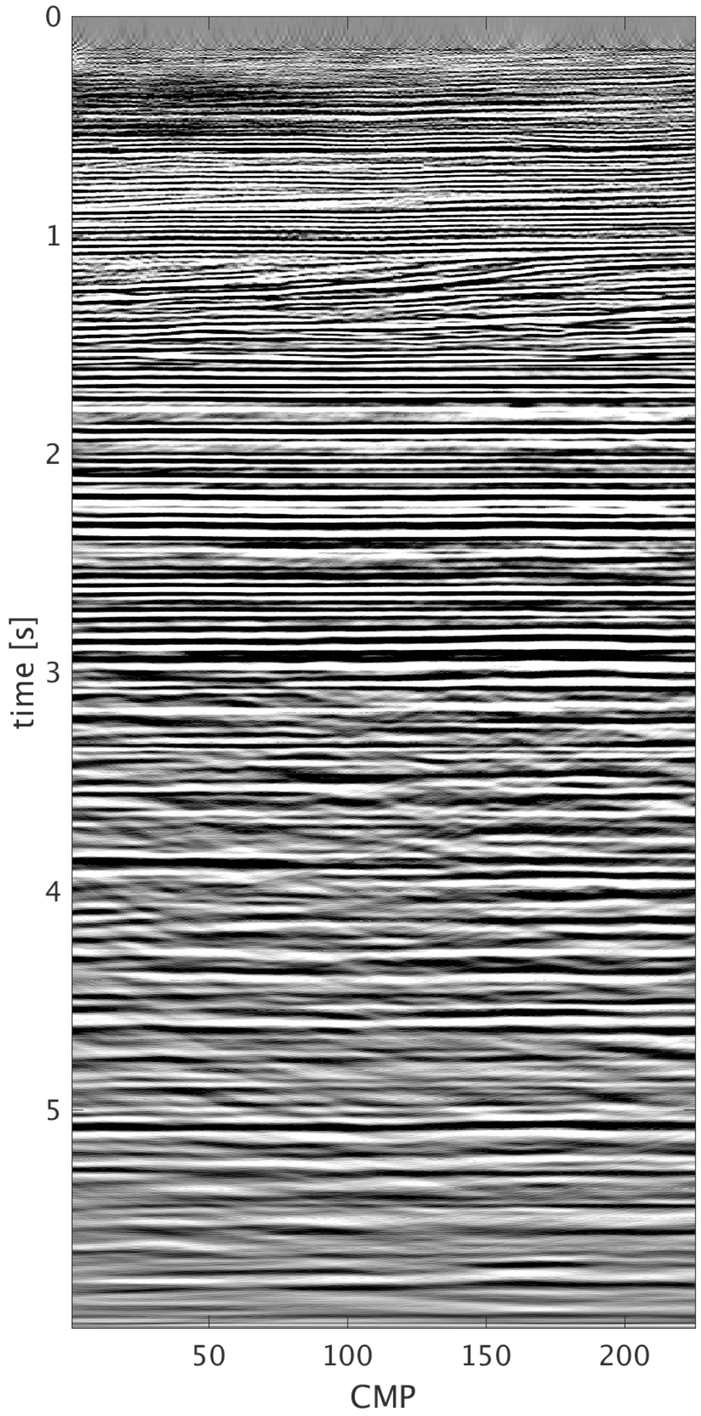




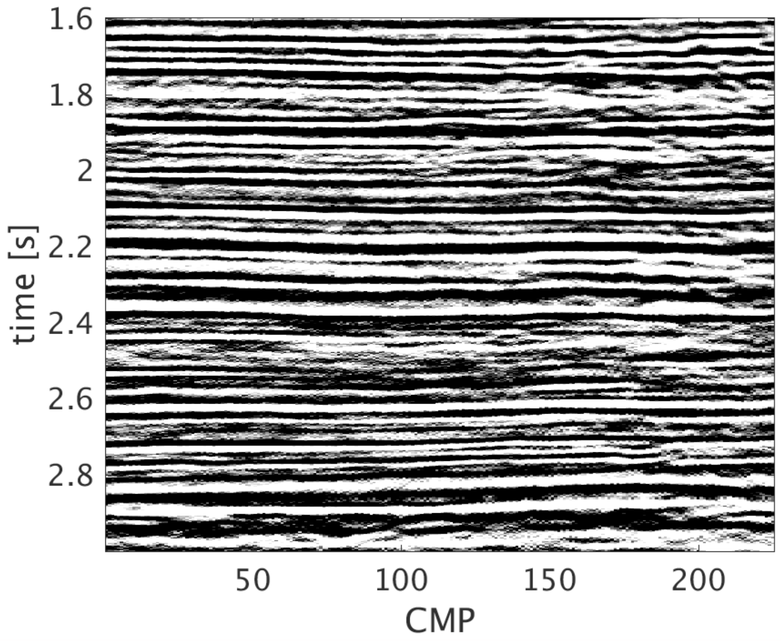
PSTM w/ res. stat.

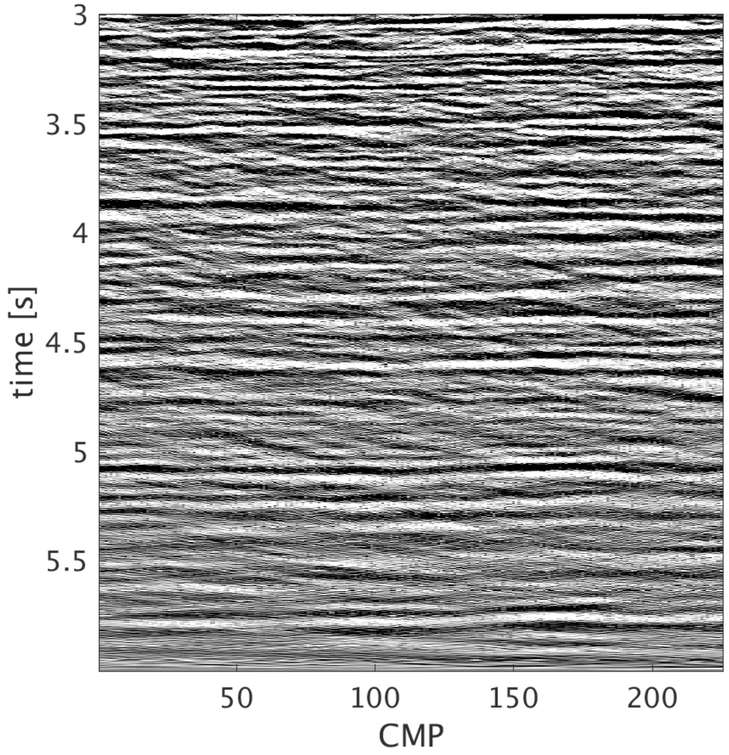


PSTM w/ prop. meth.

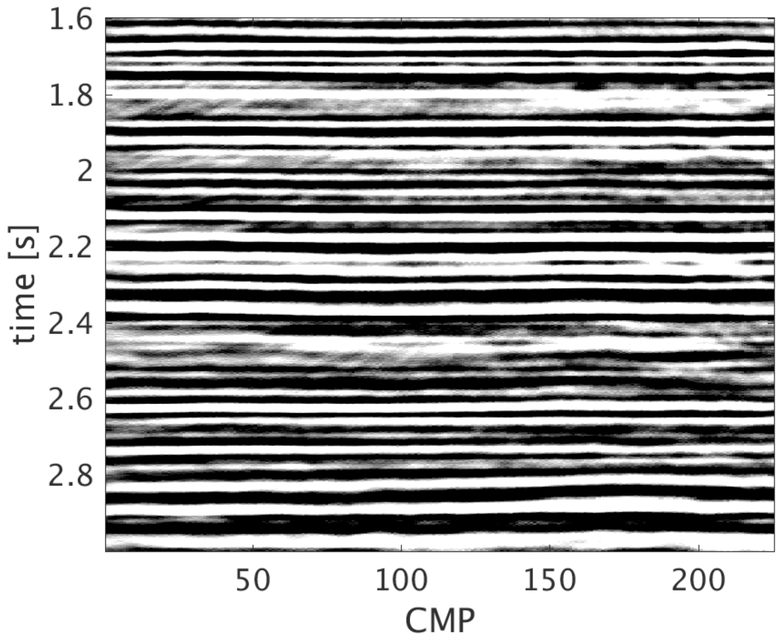


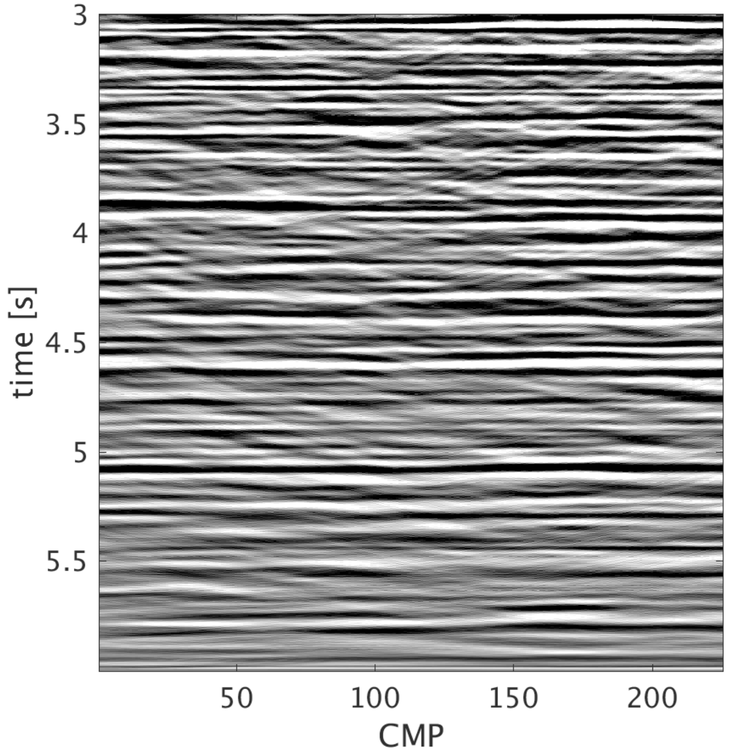
PSTM w/ res. stat.





PSTM w/ prop. meth.





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Thank you for your attention!