Denoising high-amplitude cross-flow noise using curvelet-based stable principle component pursuit

Rajiv Kumar[1], Nick Moldoveanu[2] and Felix J. Herrmann[1]
1 SLIM, University of British Columbia, Vancouver, Canada
2 WesternGeco, Houston, USA

PARIS 2017

Introduction

- Towed-streamer acquisition is often contaminated with swell noise
- Weak and/or strong reflections are hidden under the noise; degrade quality of processing steps such as SRME, imaging and inversion
- Swell noise is high-amplitude, low- and/or high-frequency noise (Moldoveanu et. Al., 2011); 0-12 Hz of frequency spectrum is infected
- We propose curvelet based stable principle component pursuit (Candès et. al., 2000, Herrmann et al., 2013)
- Curvelet are multiscale, multidirectional, localized little plane wave with oscillatory and smooth characteristics in different directions (Figure 1); Differentiate different signal components on the basis of locations, dip and frequency content.
- Swell noise and seismic signal maps to different scales and different locations (Figure 2); swell noise is predominantly vertically oriented suggest an underlying low-rank structure; seismic events are localized along the filament structures that have curvature
- We use SPCP approach (Aravkin et al., 2014) due to its ability to separate sparse and low-rank component.

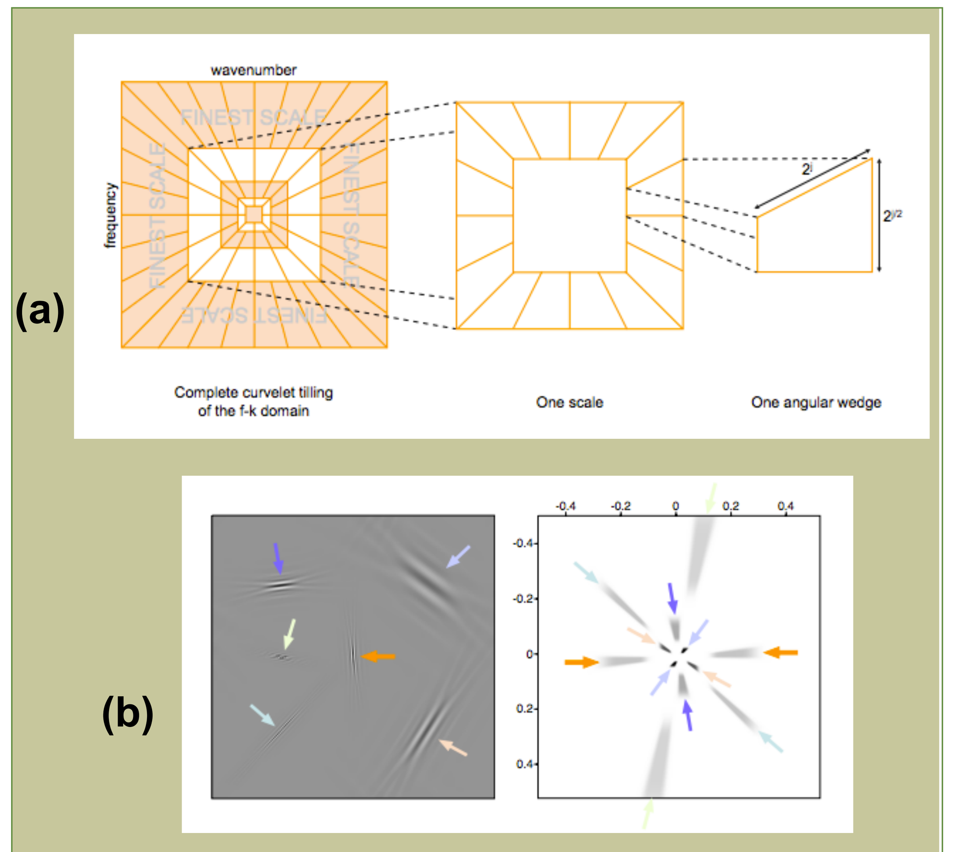

Figure 1: Properties of the curvelet transform. (Source: Herrmann and Hennenfent (2008)). (a) Curvelet tiling and (b) Curvelet in physical and Fourier domain.

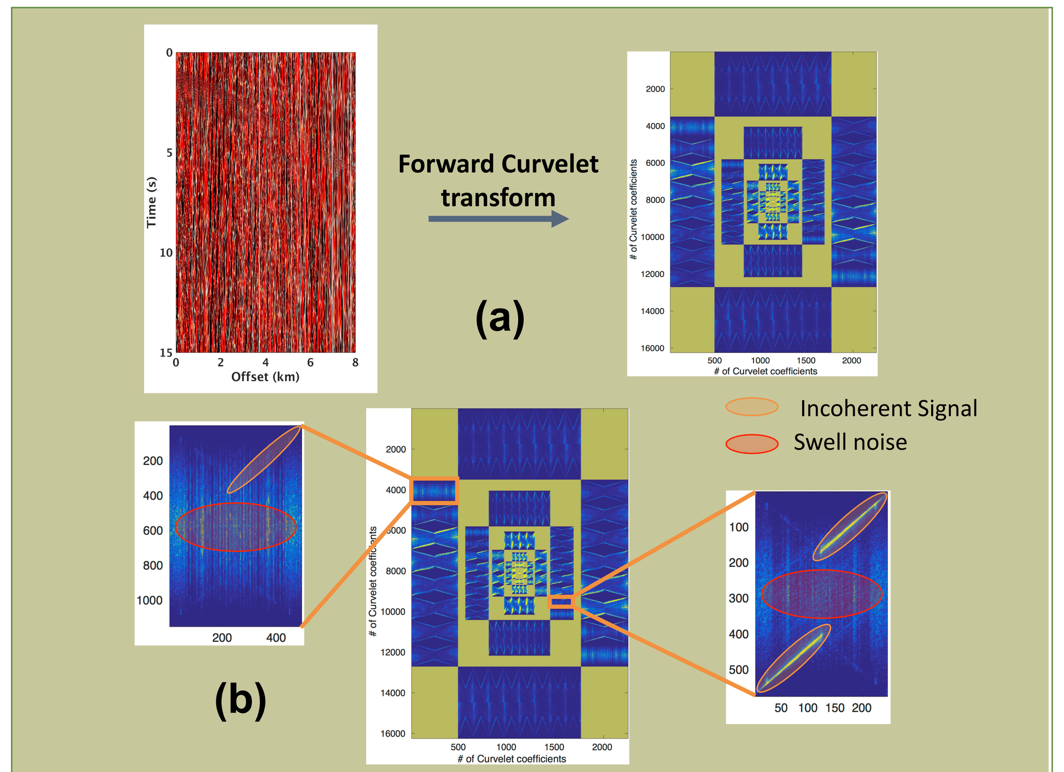

Figure 2: (a) Forward curvelet transform of noisy input data. (b) Noisy absolute value of the curvelet coefficients extracted from a parabolic angular wedge corresponding to the different frequencies and wavenumbers at coarser and finer scales. We can clearly see that cross-flow noise (red region) and signal (orange region) are mapped to distinct dip locations.

Methodology

Given the noisy curvelet coefficients (in each angular wedge corresponding to a subset of frequencies and wavenumbers at different scales) organized as matrices $\mathbf{Y}$, we decompose the low-rank cross-flow noise components $\mathbf{L}$, and a sparse components $\mathbf{S}$ via solving the following convex optimization program:

$$\text{(1)} \quad \text{minimize}_{\mathbf{L},\mathbf{S}} \quad \max(\|\mathbf{L}\|_*, \lambda_{max}\|\mathbf{S}\|_1) \quad \text{subject to} \quad \|\mathbf{L}+\mathbf{S}-\mathbf{Y}\|_F \le \epsilon,$$

where $\|.\|_1$, $\|.\|_*$, and $\|.\|_F$ are given by $\|\mathbf{S}\|_1 = \sum_{i,j}|s_{i,j}|$, $\|\mathbf{L}\|_* = \sum_i \sigma_i(\mathbf{L})$, and $\|\mathbf{B}\|_F = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m} b_{i,j}^2}$.

Here, λ_{max} controls the relative importance of the low-rank component $\mathbf{L}$ vs. the sparse component $\mathbf{S}$ and ϵ is the ℓ_2 norm of the error in the residual not explained by the superposition of $\mathbf{L}$ and $\mathbf{S}$.

Curvelet-based SPCP Framework

- perform the forward curvelet transform on each shot gather; extract the noisy curvelet coefficients along parabolic angular wedges at each scale and organize these coefficients into a matrix $\mathbf{Y}$;
- solve SPCP (equation 1) on each of these matrices independently to separate the low-rank flow noise $\mathbf{L}$ from the sparse diving waves and reflected component $\mathbf{S}$;
- insert the separated curvelet coefficients for each scale back into the corresponding parabolic angular wedges;
- perform the inverse curvelet transform to get estimates for shot records for the separated components.

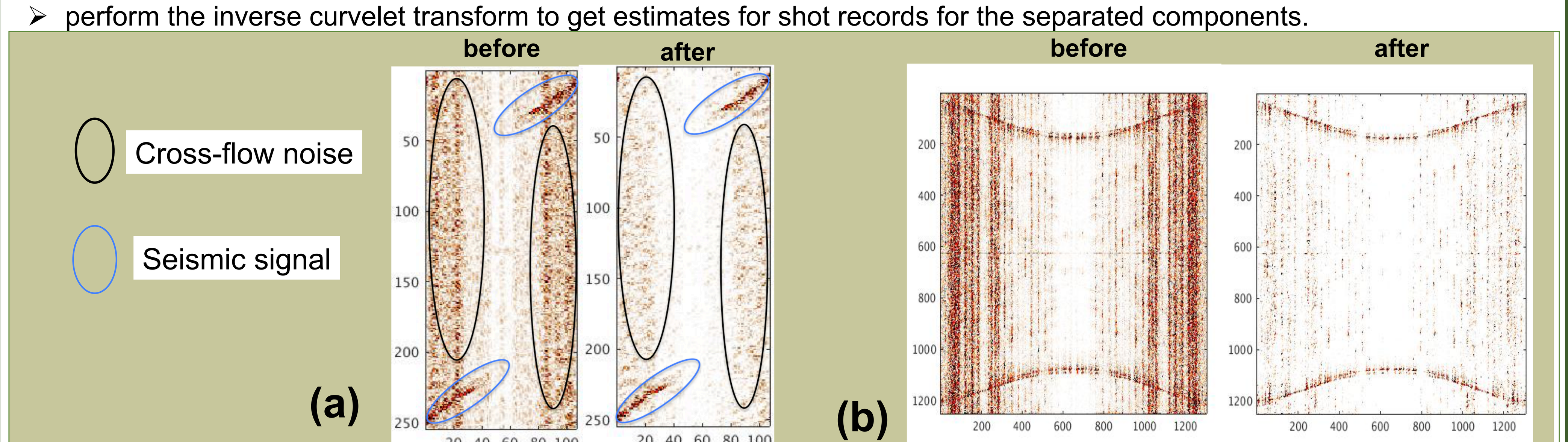

Figure 3: Denoised results of parabolic angular wedge corresponding to the low-frequencies and high-wavenumbers at (a) coarser and (b) finer scale. Curvelet-based SPCP formulation can attenuate the low-rank cross-flow noise without damaging curvelet coefficients associated to the seismic signal.

Results

Towed-streamer acquisition

The coil survey used in this study was acquired with an acquisition system that has single sensors (hydrophones) spaced at 3.125 m and without a low-cut acquisition filter applied.

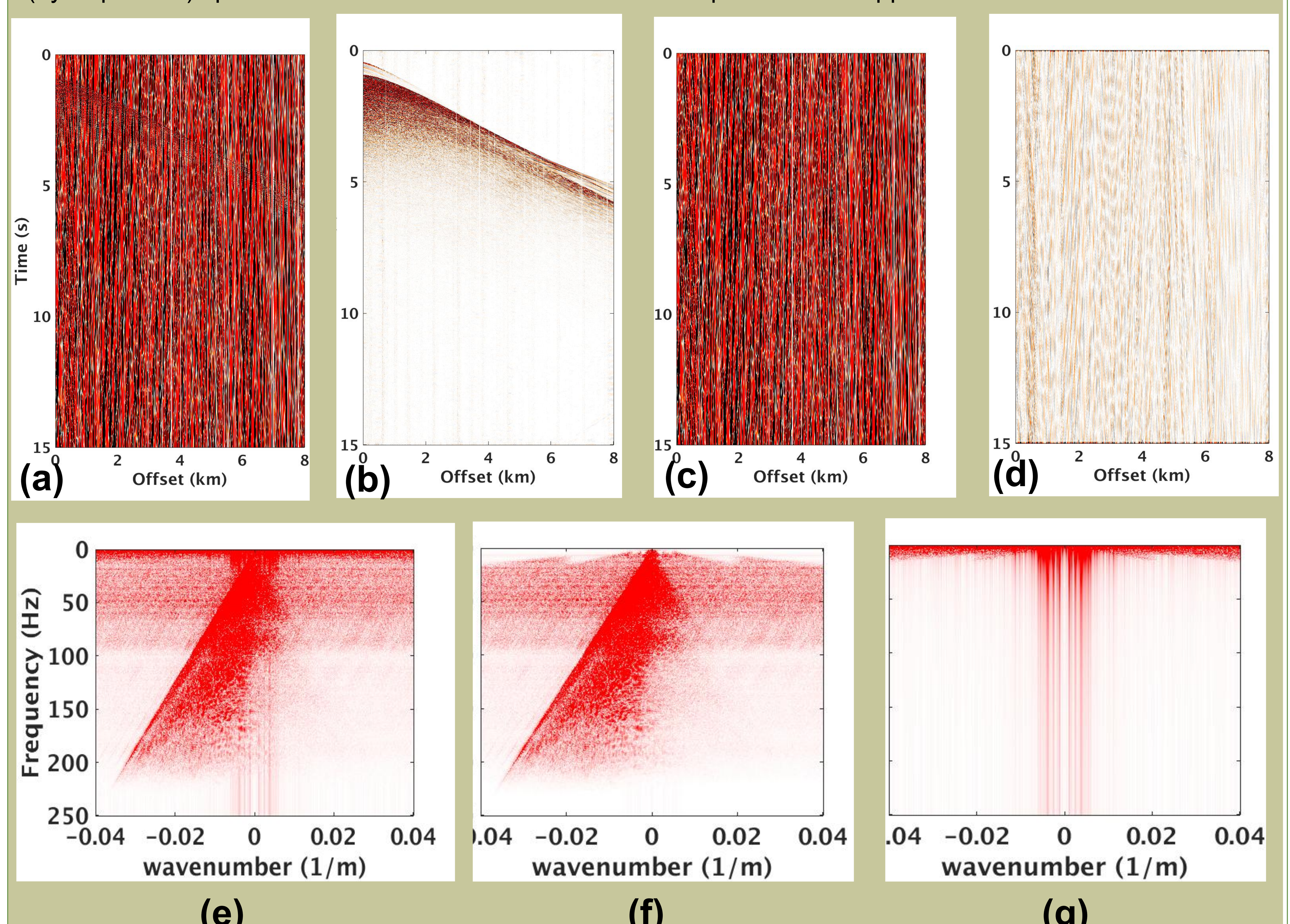

Figure 4: (a) Towed-streamer data contaminated with swell noise, (b) Denoising using curvelet-based SPCP formulation, (c) Residual (low-rank cross-flow noise). To evaluate the efficacy of the denoising framework, we apply a low-cut 4 Hz filter on the low-rank cross-flow noise (b). We observe that we are not loosing coherent seismic signals in the residual (d). (e, f, g) corresponding frequency-wavenumber spectrum.

Conclusions

- Curvelet transform maps noise and signal to different scales and angles
- Successfully separate morphologically distinct components into low-rank noise and sparse seismic signal
- Require single forward and inverse curvelet transform
- Only perform denoising on selected scales and wedges in curvelet domain
- Proposed framework is also suitable for Ground Roll

Acknowledgements

This research was carried out as part of the SINBAD II project with the support of the member organizations of the SINBAD Consortium. We would like to thanks Stephen Becker and Aleksandr Aravkin for the MATLAB codes used in this work to solve the SPCP formulation.

Reference

Aravkin, A., Becker, S., Cevher, V. and Olsen, P. [2014] A variational approach to stable principal component pursuit. Conference on Uncertainty in Artificial Intelligence (UAI).

Candes, E.J. and Donoho, D.L. [2000] Curvelets: A surprisingly effective nonadaptive representation for objects with edges. Tech. rep., DTIC Document.

Herrmann, F.J. and Hennenfent, G. [2008] Non-parametric seismic data recovery with curvelet frames. Geophysical Journal International, 173, 233–248.

Martin, J., Ozbek, A., Combee, L., Lunde, N., Bittleston, S. and Kragh, E. [2000] Acquisition of marine point receiver seismic data with a towed streamer. In: Annual Meeting Abstracts, Society of Exploration Geophysicists.

Moldoveanu, N. [2011] Attenuation of high energy marine towed-streamer noise. In: 2011 SEG Annual Meeting. Society of Exploration Geophysicists.

Neelamani, R., Baumstein, A.I., Gillard, D.G., Hadidi, M.T. and Soroka, W.L. [2008] Coherent and random noise attenuation using the curvelet transform. The Leading Edge, 27(2), 240–248.

Contact Information

Email id: rakumar@eoas.ubc.ca, fherrmann@eoas.ubc.ca