



Prestack Rank-Reduction-Based Noise Suppression: Practise

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Summary

Prestack random-noise suppression is a difficult problem in land seismic processing. A companion paper in this conference describes the theory behind a family of rank-reduction methods applied in the constant-frequency domain. These methods, which include eigenimage, Cadzow, and hybrid filters, have properties which appear ideal for performing prestack noise suppression. Here we show how to apply these methods in practise to improve signal-to-noise and prepare data for AVO analysis.

Introduction

Prestack random-noise suppression is a difficult problem in land seismic processing. Some reasons for attempting it are to:

- Reveal signal in noisy areas.
- Improve AVO and azimuthal analysis.
- Improve multiple attenuation, velocity analysis, and statics correction.

Complicating this are residual statics, imperfect normal-moveout (NMO) correction, non-uniformly spaced traces, the need to preserve multiples (so that multiple removal is not hampered later) and subtle amplitude anomalies (of critical importance to AVO and azimuthal analysis).

A companion paper (Trickett and Burroughs, 2009) describes a family of rank-reduction-based filters, including eigenimage, Cadzow and hybrid eigenimage-Cadzow, all applied on constant-frequency slices in multiple dimensions. Each has strengths and weaknesses:

<i>Property</i>	<i>Eigenimage</i>	<i>Hybrid</i>	<i>Cadzow</i>
Exact when rank \geq number of dips	Yes	Yes	Yes
Allows non-uniform spacing	Yes	Some dimensions	No
Allows surface-consistent statics & filters	Yes	Some dimensions	No
Maximum strength	Mild	Moderate	Strong
Number of spatial dimensions	2	Any	Any

This paper demonstrates how these filters are used in practise to perform prestack random-noise suppression. In particular, we show that they are powerful tools for revealing signal in very noisy areas, and we show how they allow AVO analysis when excessive random noise would otherwise prevent it.

Filtering is not applied to the entire data set at once, but rather to overlapping tiles – typically with a spatial dimension of 21 traces and a time window of 400 ms – which are merged together afterwards. The filter strength is determined by the rank – the number of decomposed images that are summed together to create the noise-suppressed image. The smaller the rank, the harsher the filter. The exactness property says that we can expect signal loss when the number of conflicting dips exceeds the rank, hence the maximum number of distinct dips in a tile is a lower bound for the rank. NMO correction is recommended prior to filtering - by flattening the data, we decrease the number of distinct dips, permitting signal preservation at a lower rank than is achievable without NMO.

Source-Receiver Domain

A powerful way to perform prestack noise suppression is f-xy filtering with the x dimension representing source and the y dimension representing receiver (Grimm et al, 2003). In other words, we lay out unstacked 2D traces as if they were on a surface diagram (Figure 1).

For land data, receivers are typically uniformly spaced but sources are not. This suggests using eigenimage-Cadzw (EC) filtering, where the sources are eigenimage and the receivers are Cadzw. This filter is of moderate strength, and can handle source-consistent (but not receiver-consistent) statics. For a stronger filter we can use a pure f-xy Cadzw (C^2) filter. If sources are not uniformly spaced, however, we will be smearing structure for the sake of better signal-to-noise, so this is not recommended for dipping data.

For 3D surveys we can separate the data into cross-spreads - that is, we filter together all traces associated with a single source and receiver line. Again we can apply an EC filter, or a C^2 filter if sources are regularly spaced (Figure 3 a,b,c).

Another option for 3D data is to work with multi-cross-spreads. In this scheme we group together traces from a single source line and multiple receiver lines. There are three dimensions – the source position, the receiver line, and the receiver position within the line. Typically an EC^2 hybrid filter is used, with eigenimage in the source dimension and Cadzw in the other two dimensions (Figure 3 a,d,e). This filter is very strong, and is appropriate for those noisy data sets where we are “desperately seeking signal”.

CMP – Offset Domain

In the CMP–offset domain, the uniform spacing and density of the CMP grid is ideal for Cadzw filtering. The principal problem is that offsets are erratically spaced in each gather. Two solutions are to (1) bin the offsets to create common-offset stacks beforehand, or (2) perform prestack migration beforehand. Creating common-offset stacks beforehand is a good solution if your only goal is to produce a clean stack, perhaps one to be used as a statics model. The second option – performing noise suppression after prestack migration – is the more useful.

For 2D data, one can apply either a pure Cadzw C^2 , or a hybrid EC filter where the offset dimension is treated as eigenimage. The latter is safest if the offset bins are not equally spaced.

For 3D data one can apply a EC^2 or C^3 filter. Since Cadzw filtering becomes about 4 times stronger (that is, increases the signal-to-noise ratio by 4) with each added dimension, the C^3 filter is extraordinarily powerful at revealing signal in very noisy areas (Figures 4 and 5).

Preserving Amplitude Anomalies

The rank-reduction-based filters preserve AVO, demonstrated by the following experiment. Artificial 3D gathers with amplitude anomalies were created (Figure 5). Noise was then added. The hybrid filter EC^2 was applied to the gathers using Cadzw in the two CMP dimensions and eigenimage in the offset dimension. The filter does a remarkable job of separating true amplitude changes from noise. This filter is so powerful that it might allow AVO analysis in areas that were previously too noisy.

Final Remarks

We have described a powerful and versatile family of random-noise suppression filters, and demonstrated many ways that they can be applied to prestack data. The three-spatial-dimension versions of these filters are so strong that they have the potential to reveal previously hidden signal – perhaps opening up areas that were once unexplorable - and allow AVO analysis in areas that were previously too noisy.

Acknowledgements

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References

- Burroughs, L., and Trickett, S., 2009, Prestack Rank-Reduction-Based Noise Suppression: Theory: This conference.
 Grimm, J., Aleksic, V., McVee, D., and Trickett, S., 2003, Prestack F-xy Eigenimage Noise Suppression, CSEG Convention Abstracts.

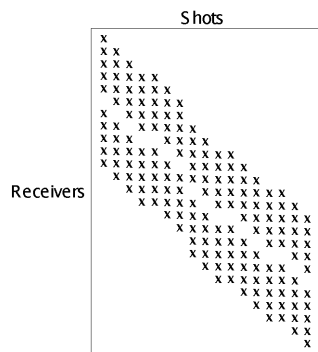


Figure 1: A surface diagram where traces are organized by source and receiver position.

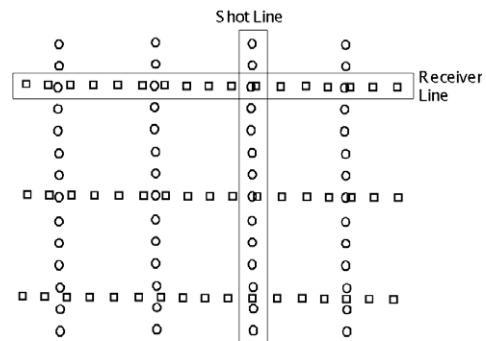


Figure 2: For 3D volumes, every combination of shot and receiver line can be filtered separately as if it were a 2-D line.

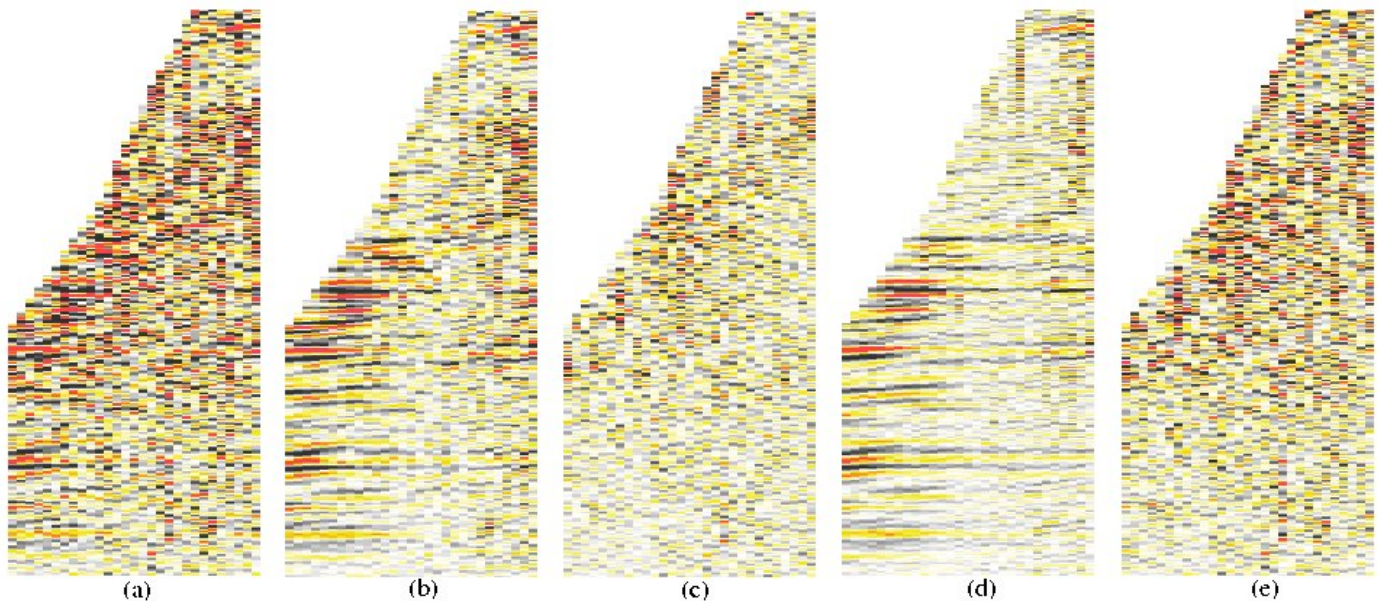


Figure 3: (a) Raw shot. (b) Shot after **EC** filtering in the cross-spread domain. (c) Difference between a and b, (d) Shot after **EC²** filtering in the multi-cross-spread domain. (e) Difference between a and d. Note the preservation of offset-dependent effects and under-corrected events.

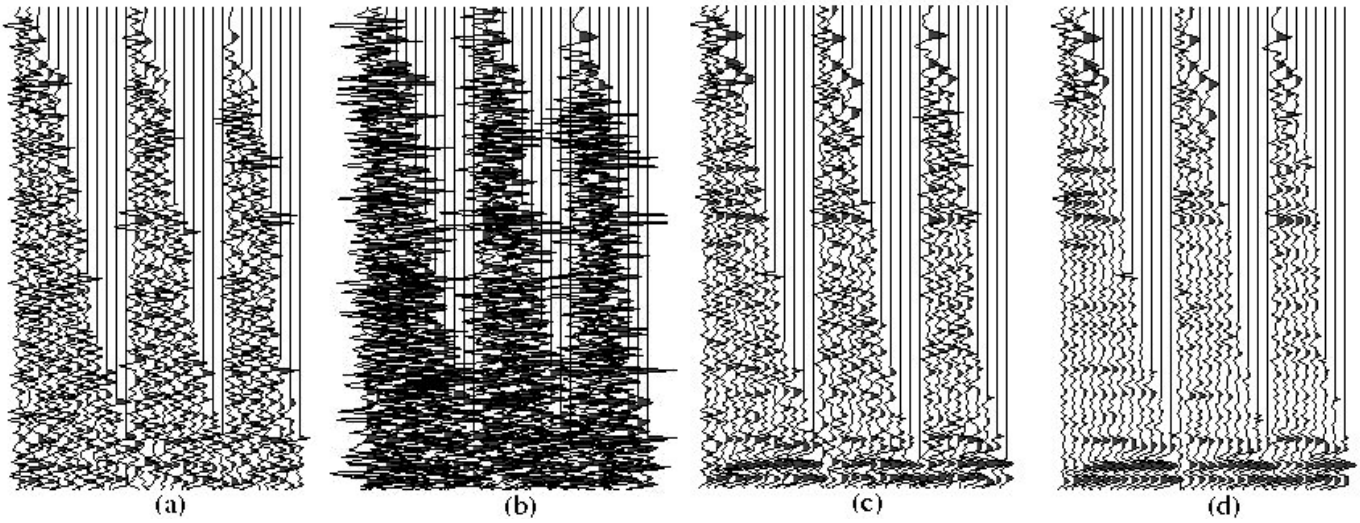


Figure 4: (a) Raw 3D CDP gathers. (b) Scaled by 3. (c) Gathers in b after \mathbf{EC}^2 noise suppression. (d) Gather in b after \mathbf{C}^3 noise suppression.

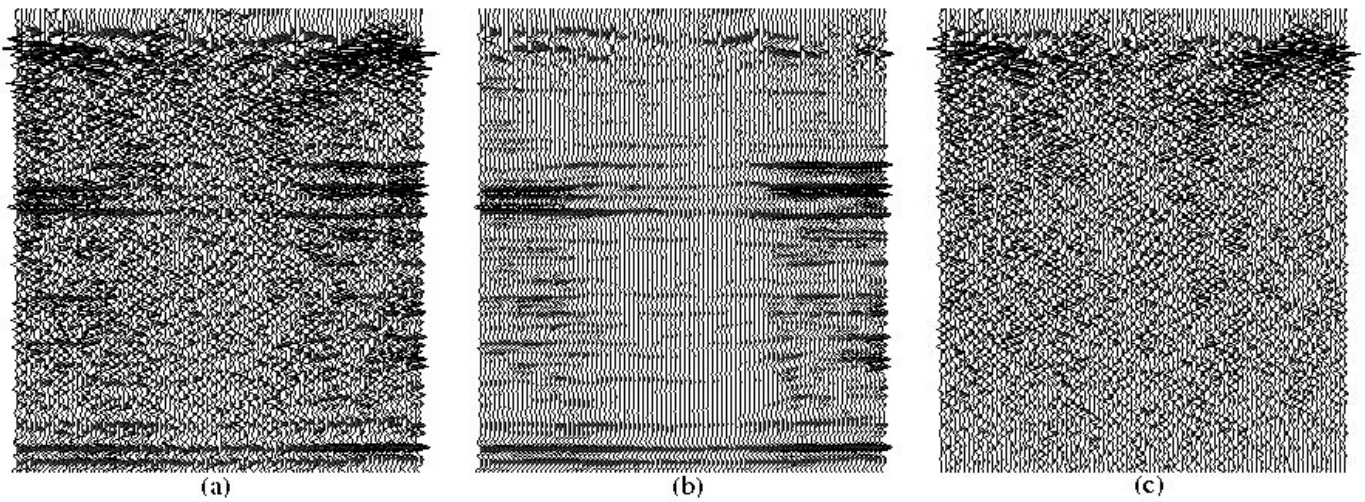


Figure 5: (a) Raw stack of Figure 4 gathers. (b) Stack after \mathbf{EC}^2 noise suppression. (c) Difference between stacks a and b.

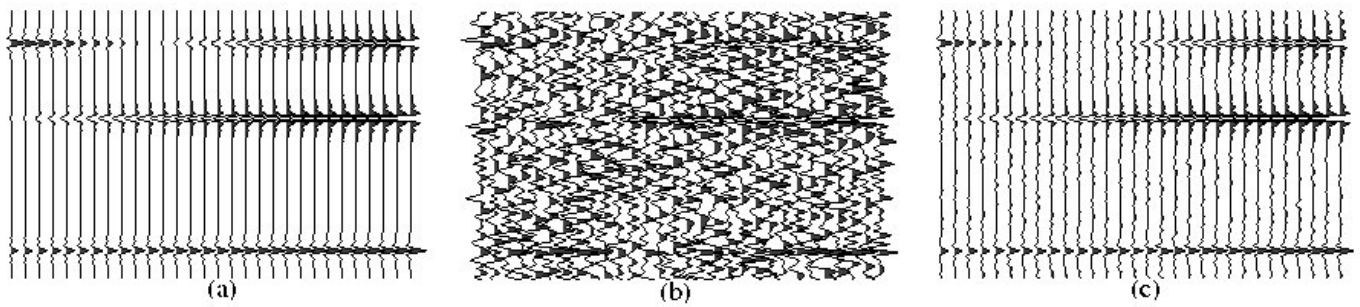


Figure 6: (a) Artificial gather with AVO effects from a 3D data set. (b) After adding random noise. (c) Noisy gather after \mathbf{EC}^2 noise suppression.