Getting something for nothing: noise attenuation in an aliased world

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G e o C o n v e n t i o n   2 0 1 2 : V i s i o n

Summary

One of the most effective ways to deal with source-generated coherent noise, which often contaminates seismic reflection records, is to record the data in the field using spatial sampling small enough to avoid aliasing the highest frequency components of the lowest-velocity surface wave energy. The offending noise can then be effectively estimated and removed by application of various processing techniques.

Even when the noise wavefronts are visibly aliased on the seismic trace gathers, however, there are some simple techniques which can enhance the effectiveness of noise attenuation methods. While none of them are as effective as decreasing the spatial sample interval during data acquisition, the improvements are significant.

We demonstrate three methods, using seismic data created by the CREWES physical modeling system.

Introduction

As seismic acquisition techniques and systems continue to evolve towards ever-increasing numbers of sensors on the ground, more data are being acquired using single sensors rather than the hard-wired geophone groups commonly deployed over much of the history of seismic exploration. When single-sensor data are acquired, the sensor spacing should be decreased to allow the acquisition geometry to spatially sample the outgoing source-generated surface waves and refractions with minimal aliasing. Various processing algorithms can then be used to effectively attenuate the surface wave and refraction 'noise', usually more effectively than the equivalent hard-wired geophone groups (Henley et al 2007, 2009).

Often, however, the receiver or source spacing required for the most effective sampling and attenuation of linear coherent noise is too small (typically1-2m) to be considered practical for a particular prospect. There are, nevertheless, some simple processing operations which can enhance the attenuation of coherent noise by radial trace filtering (Henley, 2003). None of them are as effective as reducing the source or receiver spacing by a factor of 2 during acquisition, but each is significantly better than simply applying radial trace filtering alone to the original aliased data.

The methods are demonstrated below on a seismic trace gather generated in the CREWES physical modeling facility. The original gather was acquired with spatial sampling sufficiently fine to properly sample the very strong surface wave which dominates the gather, preventing a clear view of the underlying reflections (Figure 1). When the data are properly sampled, the surface wave and its repeats can be effectively estimated and subtracted using standard radial trace filtering techniques (Figure 2).

An under-sampled gather was created from that shown in Figure 1 by simply discarding every other trace, thus doubling the receiver spacing; and on this gather, the same radial trace filter sequence is not nearly as effective (Figure 3). Hence, we show three simple methods for improving this result.
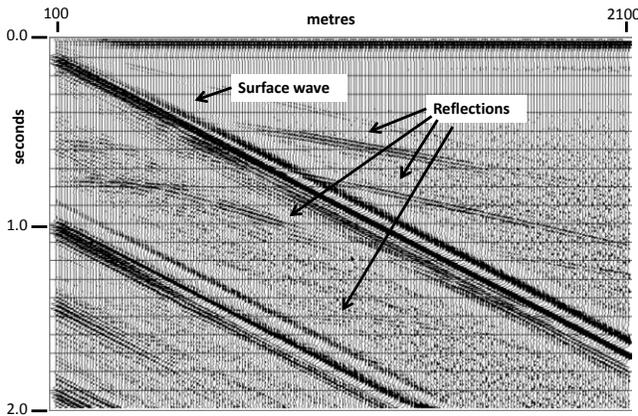

Figure 1. Trace gather from physical model with proper spatial sampling: coherent noise is not significantly aliased.
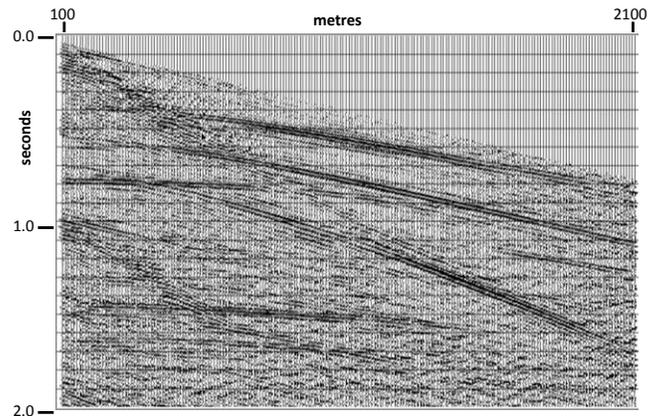

Figure 2. Application of radial trace filtering has attenuated most of the coherent noise on this gather, revealing many reflections.

Methods

We demonstrate here three different methods for reducing the effects of aliasing due to spatial under-sampling on a seismic trace gather, two of them linear, one non-linear. Not surprisingly, the non-linear method is the most effective, but the inevitable tradeoff is that it destroys AVO relationships.

The simplest method for improving coherent noise attenuation of a single aliased noise is de-aliasing by application of constant-velocity linear moveout (LMO) prior to estimating the noise. The LMO operation realigns neighboring waveforms in coherent noise wavefronts, thus removing the aliasing. The LMO simultaneously misaligns the reflection events of the trace gather, but this aliasing doesn't matter, since reflections are eliminated with a low-pass filter as a part of the coherent noise estimation. Once the noise is estimated, LMO is removed and the noise estimate is subtracted from the original gather. Figure 4 shows the effectiveness of this operation, compared to the aliased result in Figure 3.
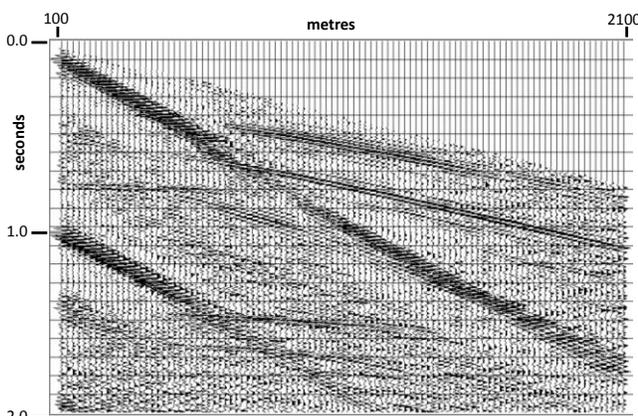

Figure 3. When receiver spacing is doubled during acquisition, coherent noise is aliased, making attenuation much less effective.
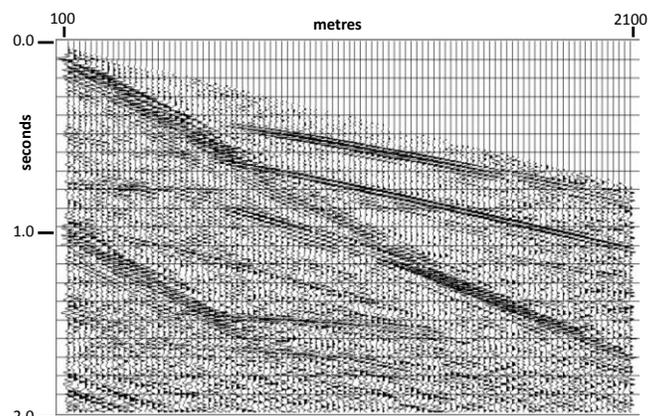

Figure 4. If LMO is applied to the trace gather to reduce coherent noise aliasing, attenuation is significantly more effective.

Another similar method uses a higher-velocity LMO to partially de-alias the noise on a gather without aliasing the reflections. Following the LMO step, however, the entire gather is interpolated to half the receiver interval, using a simple two-trace linear interpolator. When the LMO is reversed, the result is a gather whose events, both reflections and noise, have been interpolated to the denser spatial sampling. Estimation and subtraction of the linear noise on this gather (Figure 5) is more effective than on the original aliased gather (Figure 3), but still not as good as on the original gather, properly sampled during acquisition.
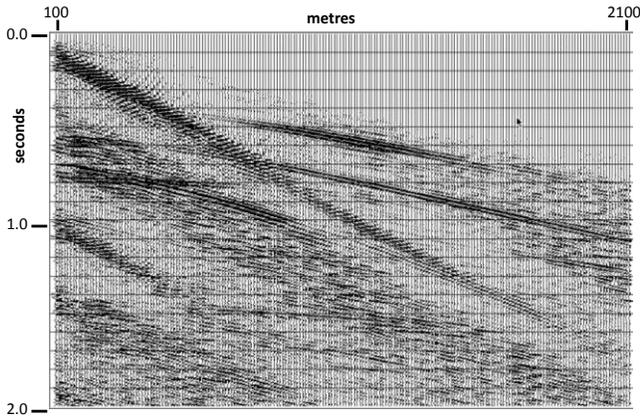

Figure 5. When the noise is de-aliased and the gather linearly interpolated, attenuation becomes even more effective.
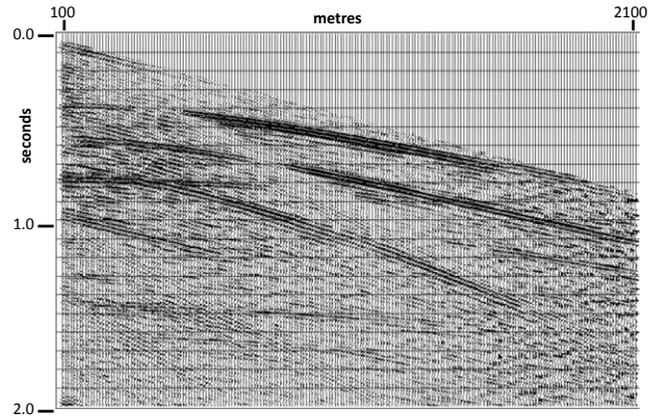

Figure 6. The application of AGC in the radial trace domain before linearly interpolating the trace gather leads to the greatest coherent noise attenuation, but at the cost of AVO relationships.

One way to take advantage of the large amplitude contrast between a coherent noise wavefront and underlying reflections is to transform the trace gather to the radial trace domain using a narrow velocity range whose dip is parallel to the apparent velocity of the coherent noise. Application of short-window AGC in this domain dramatically reduces the amplitude of the coherent noise, which is captured by a relatively small group of radial traces (see Appendix). When the radial trace transform is inverted, the gather can be linearly interpolated to half the receiver spacing and subjected to conventional radial trace filtering, which results in the gather shown in Figure 6. Comparing this with Figure 2, we see that the coherent noise attenuation has been very effective, and that there is less random noise, as well, due to the interpolation. Reflections are visible at all levels in Figure 6, but deeper ones are not as strong as in Figure 2. This method is easily the most effective for attenuating coherent noises in a single narrow velocity range, but it must be remembered that applying AGC in the radial trace domain effectively destroys AVO amplitude relationships, since the AGC operator is effectively applied laterally across many traces in the X-T domain (Appendix).

Conclusions

It is always best to acquire seismic reflection data using spatial sampling that allows recording the source-generated noise without significant aliasing. If this is not possible, however, there are some simple processing tricks that can extend the coherent noise attenuation capabilities of methods like radial trace filtering, especially on single-velocity events. For methods that preserve linearity, the improvement is significant but modest. The most effective method demonstrated here uses a nonlinear operator, but destroys AVO relationships in the original data. No method shown is as effective as proper sampling during acquisition, however.

Also, the methods demonstrated work well on single noise events with a discrete apparent velocity. A gather exhibiting a range of coherent events with different velocities, as is typical of much seismic field data, would likely require one complete application of the chosen method for each aliased noise.

Acknowledgements

References

Henley, David C. 2003, Coherent noise attenuation in the radial trace domain, Geophysics, **68**. No. 4, pp1408-1416.

Henley, David C., Hall, Kevin, Bland, Henry, Gallant, Eric, and Margrave, Gary, 2007, "High-effort" seismic acquisition: improving image detail, 2007 CSPG CSEG Convention, Expanded Abstracts.

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Appendix

To help visualize why radial trace domain AGC is so effective, we show in Figure A1 the raw trace gather from Figure 1, transformed to the radial trace dip domain using a narrow velocity range centered on the velocity of the very strong surface wave. In that domain, traces are parallel to the coherent noise wavefronts, so the noise maps to near-DC traces whose overall amplitudes are basically those of the coherent noise wavefronts. All that is required to attenuate the noise, over its entire bandwidth, is to apply trace amplitude normalization to the traces of the radial trace transform. Experience has shown that a short window AGC is more effective than whole-trace normalization, and Figure A2 shows the result of applying such an operator to the traces of Figure A1. It is obvious that simply leveling the relative trace amplitudes of the radial trace transform has greatly attenuated the very strong surface wave and its repeat. Comparing the relative amplitudes of various portions of the prominent reflections between Figures A1 and A2 (whose overall normalization is the same) confirms that the radial trace domain AGC dramatically alters the AVO relationships in the original gather.
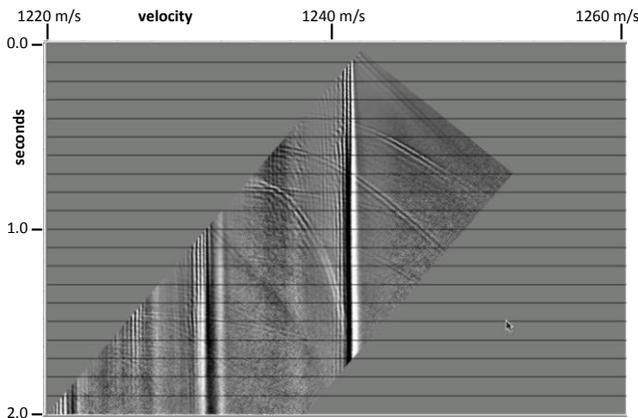
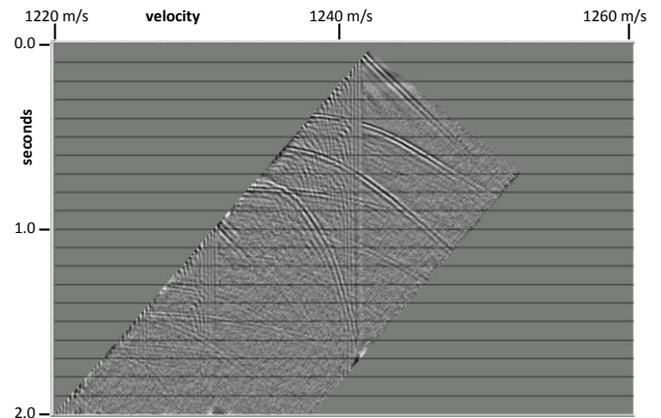Figure A1. Radial trace dip transform of trace gather in Figure 1

Figure A2. Radial trace dip transform of trace gather in Figure 1 after AGC. Noise amplitudes are dramatically reduced relative to reflections.