Optimising Land Seismic Acquisition for Modern Noise Suppression in Processing

Graeme Eastwood
Land Seismic Noise Specialists
Perth
graeme@perseusconsulting.com

Christof Stork
Land Seismic Noise Specialists
Denver
cstork@landnoise.com

SUMMARY

Land seismic data is known to be far noisier than its' marine equivalent – the questions we want to begin to address are why and is there anything that can be done about it?

Noise issues with land data are often just explained by 'poor coupling', whatever that may mean. We believe that the main issue is not the connection between the source/receiver and the subsurface, but what happens to the energy in the top 10-100m during both the downgoing and upgoing phases.

Modern dense acquisition clearly helps, but does not solve the noise on its own, especially where micro-scattering noise is concerned. However, when this modern acquisition is coupled with new powerful noise removal processing technology, noise sparsity allows us to handle it more effectively. This is especially important for shallow scattering noise, which is difficult to sample unaliased in X & Y. The new algorithms use the same principals as compressive sensing, utilizing sparsity to handle aliased noise, so optimizing acquisition for these algorithms is, effectively, compressive sensing for the noise.

Key words: acquisition, processing, noise, scattering.

INTRODUCTION

Noise, as both unwanted energy and distortion of signal, is often the dominant problem with land seismic data, often being 10 to 100 times stronger than the signal (Stork, C., 2020[1]) and much redundancy of data and additional expense is incurred during acquisition to address noise issues. Seismic acquisition needs to sample the subsurface sufficiently well so that the noise can be effectively handled during processing, particularly when using new powerful noise removal algorithms that take advantage of the sparsity of the noise. This is especially important for near surface scattering noise, which is difficult to sample unaliased, so newly developed algorithms work with aliased noise by utilizing sparsity. These new noise removal algorithms use the same principals as compressive sensing, so optimizing acquisition for these algorithms is, effectively, compressive sensing for the noise.

Modern dense land acquisition methods can help with noise removal, but there are a number of factors which mean they are not the whole answer, including:

- The noise can have very short wavelengths
- Tight sampling does not solve signal distortion
- Some noise does not require ultra-dense sampling
- The gain in signal to noise ratio diminishes as we move to higher fold values.

However, this dense acquisition does provide much flexibility to modify and optimize seismic acquisition to aid processing.

In terms of handling noise issues inherent in seismic data, the success of any acquisition-processing combination is based on several factors - the amplitude of the noise relative to the signal, the types of noise within the data, the sampling of the noise in all dimensions, the ability of processing algorithms to address the noise and the seismic objective (frequency range, impedance inversion, AVO, subtle faults, complex structure).

Seismic noise and energy transmission vary dramatically by frequency. Data at the low and high frequency ends are often more than 10 times noisier than the data in the prime frequency range. Moreover, the noise at different frequencies can have vastly different characteristics. The low frequencies are often affected by trapped surface waves and macro-scattering while the middle and high frequencies are more affected by guided waves and micro-scattering distortion. We cannot eliminate these noise types in acquisition, but we can record the data sufficiently well to aid removing the noise in processing.

SCATTERING NOISE

Scattering noise is often the dominant noise in seismic data, especially at the high frequencies (Stork, C., 2020[2]). In some areas, such as mountainous foothills areas or karsted terrain, this scattering noise effects all frequencies. This noise can be up to 100 times stronger than the signal, but it is often very complex and poorly understood. It is often caused by strong heterogeneities in the top 10 meters of the earth where velocities can be as low as 100-200 m/sec. Micro-scattering noise is very difficult to remove because it is so strong, travels in all directions, often has short wavelengths of 1-5 meters, and appears as unorganized, complex noise (Stork, C., 2021).

Whereas macro-scattering (where the scatterer size is over about 30m) modelling and removal has some success, micro-scattering is very difficult to model and subtract because of its small scale. Tight inline spacing can remove the inline component of the noise, perhaps 50% of the total noise, but this may not be sufficient when the noise is so much stronger than the signal and we desire to remove over 90% of it. Relying on very high fold and aggressive statistical methods to remove the scattering would be both expensive and liable to artefacts.

Figure 1 shows how strong the effects of scattering noise can be. The two shots shown, one with little scattering noise and one with strong scattering, are only a few km apart but show vastly different S/N.

Although the micro-scattering produces complex, diffuse noise, it is not random. It is a physical phenomenon that is repeatable on the numerous shot gathers of a seismic reflection survey. The repeatability makes the patterns sparse. We measure the pattern of the scattering by performing a cross-correlation of each source and receiver with the neighbouring sources and receivers for the individual wave modes. A sample result for cross-correlation of 2 receivers for many shots in figure 2 shows a clear, repeatable pattern that is a measure of the scattering effect. Conventional theory expects wave modes between the neighboring source and receivers to have the same waveform but be time shifted, which would produce a compact cross-correlation pattern near t=0. However, we see that the actual pattern is complex with much energy far away from the central peak, showing that the scattering distortion effect is strong. This distortion shares some properties with surface consistent deconvolution, but is much more complex. We use the numerous correlations between neighboring sources and receivers to compute an inverse scattering operator to collapse the scattered energy back to primary energy (Stork, C., 2021).

An example of some data before and after this scattering correction is given in figure 3.

ANALYSIS OF LEGACY AND TEST DATA

Analysis of legacy data or acquisition of a small noise test can resolve a lot of questions about the nature of the noise, including:

- What type of shot generated noise is dominant, especially at the low and high frequencies, and what is the amplitude of this noise relative to the reflection signal?
- Are we correct in assuming that the low frequencies are affected by trapped surface waves and macro-scattering while the high frequencies are more affected by micro-scattering distortion?
- How effective are processing algorithms in removing the noise?
- What type of sampling is necessary to adequately remove the dominant type of noise in processing?
- How strong does the source need to be at the lower and upper frequency ranges for the reflection signal to not be harmed by background energy?

A field test of the noise can find and demonstrate an optimal acquisition-processing combination. This test will ideally be over-designed so that decimation tests and weaker source tests can show an optimal set of parameters with reasonable cost. A key challenge with analyzing test data is accurately measuring reflection signal with a test area that is likely too small for full azimuth pre-stack migration. Therefore, careful processing and analysis is needed to allow us to measure this signal level from pre-stack data.

Note that a 2D line is useful for quickly viewing raw signal levels with a basic stack, but it does not adequately test the effectiveness of processing algorithms in removing the noise from a 3D geometry. The multi-azimuth component of a 3D test is crucial for characterizing the noise and in aiding to remove the difficult scattering noise.

KEY ACQUISITION PARAMETERS TO OPTIMIZE

The noise and processing information can optimize the standard acquisition parameters of source count & spacings, receiver count & spacings, sweep types, number of vibrators, depth of explosives, and adjustments needed to allow for access constraints.

In addition, we propose optimizing more advanced parameters for irregular acquisition using surface noise prediction from soil penetrating remote sensing information:

- Identifying bad source/receiver locations that would benefit from moving locations by 10-50 meters in the crossline direction.
- Irregular source and receiver density to match surface noise intensity
- Adding crossline source and receiver locations in the noisiest areas
- Optimize regions where it is beneficial to switch source/receiver locations based on cost, noise, and access.

IRREGULAR ACQUISITION BASED ON NOISE PREDICTION

Regular acquisition is non-optimal when the noise is irregular. Irregular acquisition can help with irregular noise by moving source and receivers out of noisy areas, if possible. If the noisy areas are too large, irregular acquisition can increase the density of sources and receivers in those areas to create a more balanced "noise corrected CDP fold". Furthermore, the geometry of sources and receivers can be adapted to the noise character.

Figure 4 shows an example of a noise optimized irregular acquisition geometry.

A key enabling observation here is that seismic noise can be predicted from satellite and airborne remote sensing IR data, which can be used to show how different properties of the soil and shallow subsurface are distributed. These soil properties often have a heuristic correlation with seismic noise. The correlation can be confirmed with legacy data or a simple field test, enabling extrapolation over a wider area.

CONCLUSIONS

Much of the expense with land seismic acquisition (and processing) is focused on addressing noise within the data. The most challenging noise is often near surface back-scattering, which is difficult or impossible to record unaliased in X & Y. However, new noise removal algorithms in processing can address this scattering noise with some aliasing. Customizing the seismic acquisition to best sample the noise for these advanced processing methods has much potential for optimizing the end product.

ACKNOWLEDGMENTS

We would like to thank Land Seismic Noise Specialists for allowing us to present this data here.

REFERENCES

Stork, C., 2020[1], How does the thin near surface of the earth produce 10-100 times more noise on land seismic than on marine data: First Break, Vol 38 Issue 8, 67-75, doi 10.3997/1365-2397.fb2020062

Stork, C., 2020[2], Signal distortion is often the stronger noise with land seismic data rather than unwanted surface energy: 90th Meeting, SEG, Houston/Virtual, Extended Abstracts

Stork, C., 2021, A model for land seismic surface scattering noise has implications for acquisition and processing: 82nd EAGE Annual Meeting (planned), Amsterdam, Expanded Abstracts

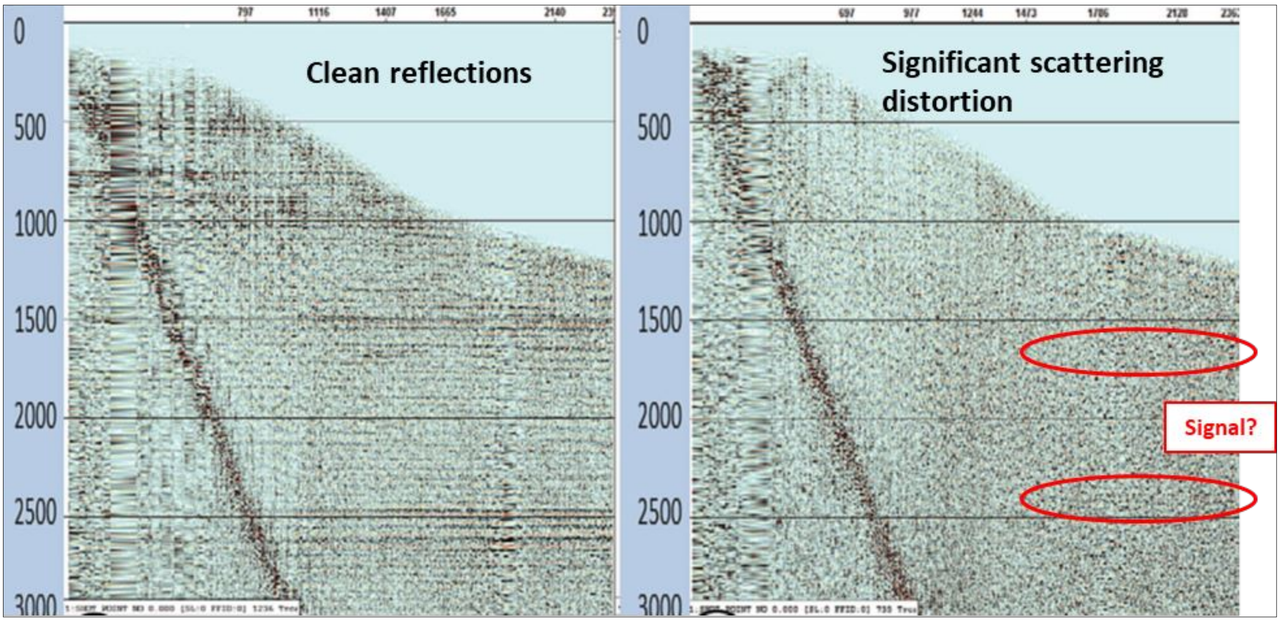

Figure 1. Real data example of the effect of surface scattering – shot gathers with NMO a few km apart (after Stork, C., 2020[1])

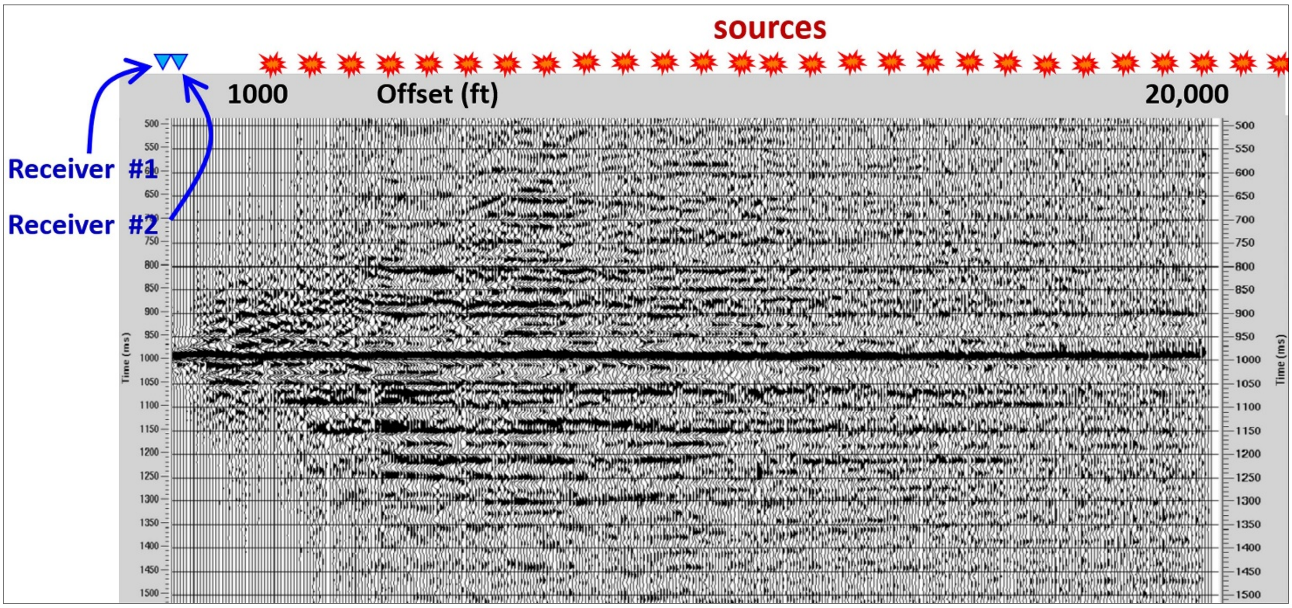

Figure 2. Cross-correlation of one wave mode between 2 receivers and many sources. Zero lag is at t = 1000ms. There is a clear pattern to the noise and the energy away from the central peak at zero lag indicates that the scattering effect is strong.

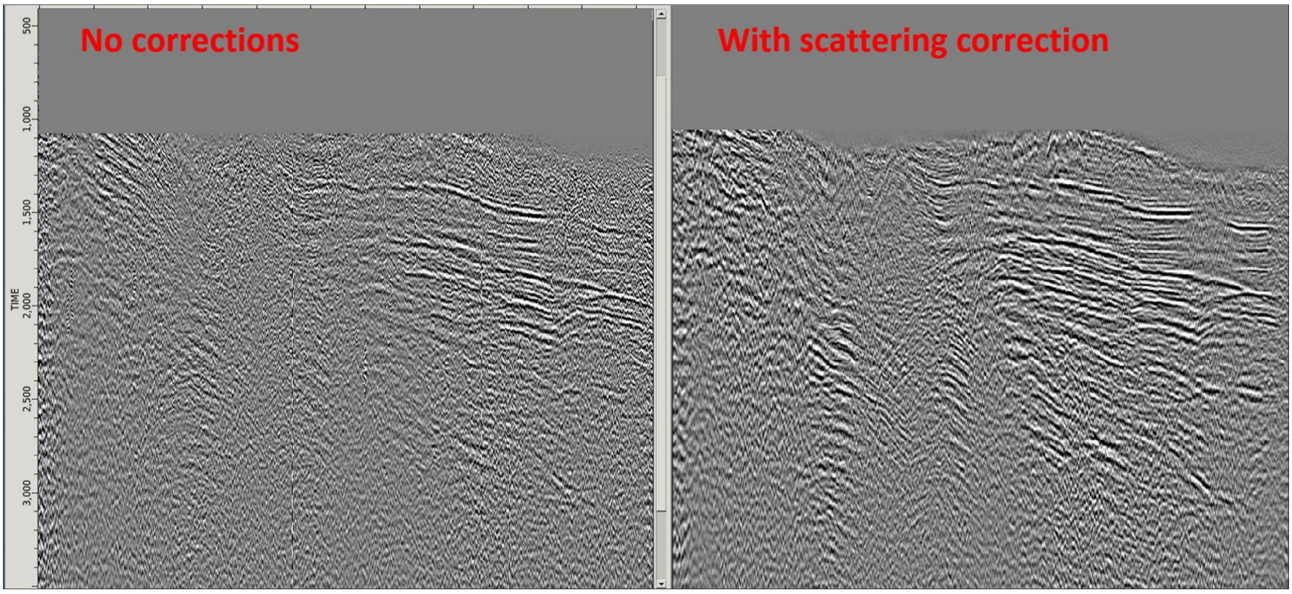

Figure 3. Example of stack data before (left) and after (right) correction for scattering effect.

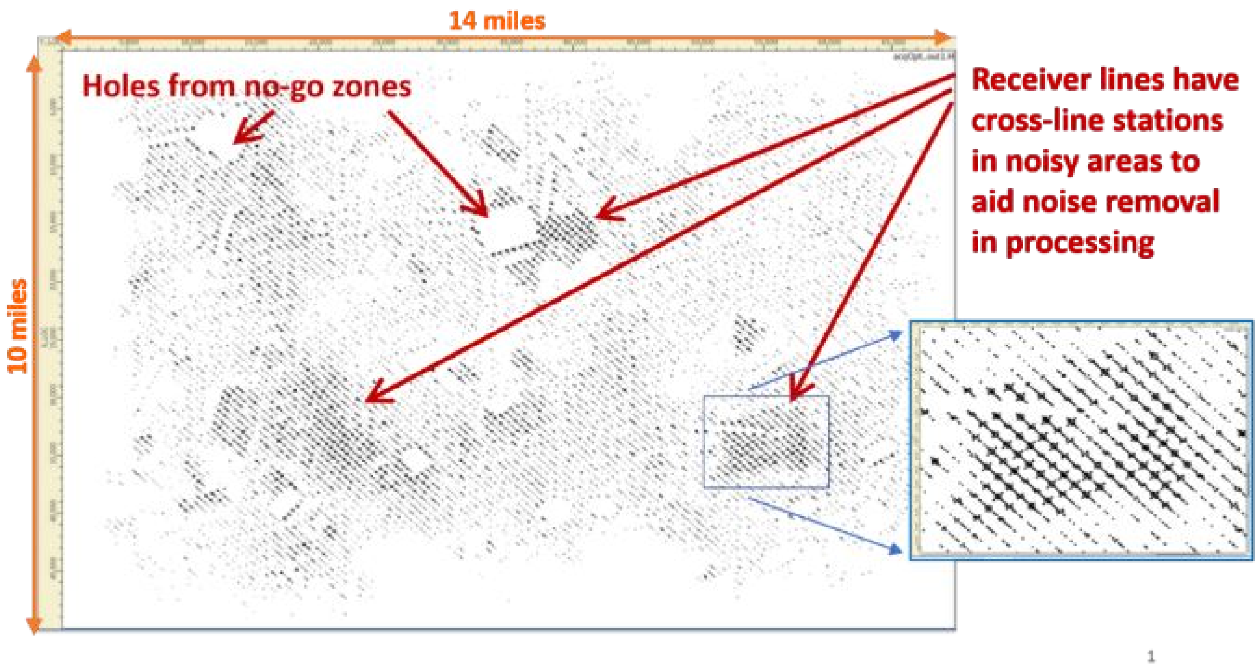

Figure 4. Example of a noise optimised irregular acquisition geometry utilising different types of receiver pattern. Similar layouts can be derived for source positions.