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Simultaneous-source Acquisition and Environmental Noise - Good or Bad?

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SUMMARY

The promise of simultaneous-source acquisition in improving acquisition efficiency and/or sampling has been studied by a number of authors, especially over the last few years. However, most of these studies focussed on processing the signal associated with the known shots, rather than on the impact of environmental noise. The presence of environmental noise will clearly degrade the processed product from a simultaneous-source dataset, much as it does a conventional (sequential) dataset. In addition, the impact of the noise on the separation process is a concern for simultaneous-source data. The story is not all bad, however. Simultaneous-source acquisition generally involves increased source effort compared to an equivalent sequential data set, and, therefore, the signal-to-noise ratio of the acquired data is improved. This observation raises the possibility that simultaneous-source data could be acquired in higher-noise environments than the equivalent sequential data. We study this possibility using real simultaneous-source data acquired with varying environmental noise levels. Comparisons between simulated sequential and simultaneous-source products with varying noise levels indicate that simultaneous-source acquisition can indeed produce equivalent results in a significantly noisier environment.
Introduction

Simultaneous-source acquisition has been routine for land data for a number of years now, largely because the increased acquisition efficiency it provides allows for significant increases in fold, which in turn, provides significant improvements in sampling and noise attenuation. More recently, simultaneous-source acquisition for marine data has been shown to be commercially viable (Moore et al., 2012), especially if the desire is to improve sampling. Most marine studies involving simultaneous-source data have, however, not considered the effect of environmental noise to any significant extent.

For our purposes, we define environmental (or ambient) noise to be recorded energy that is not generated by known shots. Specifically, environmental noise includes weather-related noise, e.g., swell noise, towing-related noise, and noise from external sources such as infrastructure or third-party seismic acquisition.

Simultaneous-source data processing typically requires separation of the recorded data into contributions from individual shots, often associated with two or more distinct source arrays. Environmental noise is, by definition, not associated with any shot, and, therefore, a correct separation should ideally allocate such noise to a residual of unseparated data. In practice, separation is never perfect, and it is to be expected that the quality of the separation of the signal will degrade as the environmental noise level is increased. In addition, some, or even the majority, of the environmental noise will be allocated to the separated shots rather than the residual. This suggests that environmental noise might be more of a problem for simultaneous-source data than for sequential data.

However, the situation with respect to environmental noise is much more complex than simply assessing its impact on the separation. A key observation is that the underlying signal-to-ambient noise ratio (SANR) of simultaneous-source data is generally higher than that of sequential data, because the signal level is increased whilst the noise level remains the same (Beasley et al., 2012). This effect offsets the detrimental effect of the noise on the separation, and may mean that the overall impact of environmental noise on simultaneous-source data is less severe than that on sequential data. In turn, that would mean that the noise specs for a simultaneous-source data set could be made less restrictive, and weather downtime would be reduced.

In this abstract, we investigate the relative effects of environmental noise on sequential and simultaneous-source data using simulations based on a commercially acquired simultaneous-source survey (Moore et al., 2012). The acquisition objectives for this survey were associated with sampling and not with this investigation, and, therefore, the acquired data are not ideal for our purposes. However, they do naturally contain lines acquired in a variety of sea states, including lines that were sufficiently noisy that they were rejected and reacquired based on conventional noise specifications.

Method

Simplistically, our method of investigation is to,
1. obtain a noise-free simultaneous-source data set and an equivalent noise-free sequential data set,
2. obtain noise models corresponding to realistic environmental noise at various levels,
3. add the noise models to the noise-free data sets and process them to some product of interest,
4. measure the quality of the product of interest as a function of noise level, and
5. determine equivalent noise levels for both types of data for a given, fixed quality.

There are, however, a number of difficulties with this methodology in practice.
A. Whilst we acquired some relatively noise-free simultaneous-source data, we did not acquire any corresponding sequential data. The sequential data must, therefore, be derived from the simultaneous-source data. This must be done in a way that avoids biasing the conclusions through starting with a relatively poor sequential data set.
B. We only recorded noise-only data for very short sequences. Generating realistic noise models at various levels for entire lines, therefore, requires extraction of the ambient noise component from the recorded data.

C. Due to limitations on available resources, the product of interest was limited to a product that could be produced through 2D processing.

**Figure 1** Flow charts for generating the noise-free data sets (left) and the noise model (right).

The flowchart for deriving the noise-free data sets is shown in Figure 1. In our case, the acquisition used a conventional, NAZ, flip-flop geometry except that the two sources were fired nearly simultaneously (dithered). The sequential data set was derived by separating a noise-attenuated version of a quiet line and selecting the data corresponding to one source (S1). To mitigate problem A, the corresponding simultaneous-source data set was not simply the noise-attenuated line, but is simulated from the separated data using a new set of dithers. This means that imperfections in the separation process affect both data sets equally. Note also that the separation process generates an unseparated residual. This was very small and was rejected.

The flowchart for deriving the noise models is also shown in Figure 1. Extracting realistic noise from recorded data is remarkably difficult. Simply applying a conventional noise attenuation algorithm and scaling the extracted noise only generates the component of the noise that can be easily removed, even after scaling. The flow presented in the figure was determined (somewhat empirically) to generate a noise model that had appropriate statistics in terms of variability of its strength with channel and shot number, etc., whilst also being realistically difficult to remove and having a realistic effect on the product of interest.

Our study involved processing five types of data set:
A. Simultaneous-source data separated using the production method to get S1. The residual was added back, so that signal loss is minimized.
B. As A, but without the residual add-back.
C. Sequential data generated at the simultaneous-source shot spacing. It would not have been practical to acquire this data set, but it is included as a benchmark.
D. Sequential data with alternate shots dropped and then reinterpolated. This represents the sequential equivalent to A or B at the same fold.
E. As D, but with the interpolated shots dropped for imaging (halving the fold).

For our purposes, the products of interest were prestack time migration angle stacks. The qualities of these products were measured by assessing the noise levels as a function of angle and time. Because the steep-dip content of the product is dominated by noise, the noise level was measured simply by measuring the amplitude of this component.
**Results**

The results are shown in Figure 2, which compares the qualities of the far-angle stacks in the target time zone as a function of the noise level. Key observations are:

1. A is slightly quieter than C at low noise levels. This is because the separation process allocates some of the noise to S2, which is lost relative to C.
2. Beyond about 30 $\mu$bar, A becomes noisier than C because the separation process is degraded by the strong noise.
3. A is significantly quieter than D and E, except at very high noise levels. This indicates that products from simultaneous-source acquisition are significantly quieter than those from the equivalent sequential data set.
4. C is quieter than D and E, indicating the benefit of double-fold (single-source) acquisition for sequential data, i.e., that interpolation is not an alternative to acquisition.
5. D and E are similar, indicating that the comparisons are not particularly biased by the imaged fold.
6. At low noise levels, B is quietest. Whilst this is largely due to the allocation of ambient noise to the residual during separation (a good thing), it should also be recognised that some signal, especially complex, steeply dipping signal, can also be allocated to the residual. Not adding back the residual, therefore, carries risk of signal loss.

**Figure 2** Comparison of product quality as a function of noise level for the different data types. The left panel is a zoom of that on the right. The definitions of the data sets, A-E, are given in the text.

Figure 3 shows a comparison of products with equivalent quality for data types A and E, which represent the most realistic options for simultaneous-source and sequential acquisition, respectively. The background noise level for E was fixed at 10 $\mu$bar (in spec) and the corresponding product quality was matched to that for data of type A. The corresponding noise level for the type A data set was 30 $\mu$bar, indicating that, at these noise levels, simultaneous-source data can stand substantially more environmental noise than sequential data based on the equivalence of this product.
Conclusions

Whilst there are clearly uncertainties in our analysis method, there are also strong indications that the fundamental increase in SANR associated with simultaneous-source acquisition leads to an overall benefit in terms of the rejection of environmental noise, at least at realistic noise levels. At higher noise levels where the separation process breaks down, even sequential data would be considered too noisy to be acceptable. We believe, therefore, that the potential to relax weather-related acquisition specifications for simultaneous-source data is strong. Further study, ideally using data acquired specifically to assess this issue, is required to mitigate the risk.

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References


![Figure 3](image_url) Comparison of equivalent final products for simultaneous-source data set A (left) and sequential data set E (right). The upper and lower panels show the processed data and the steeply dipping noise component of those data, respectively. The original noise level of the simultaneous-source data was three times that of the sequential data. Both have final dipping noise levels of about 80 (see Figure 2).