Simultaneous sources: The inaugural full-field, marine seismic case history from Australia

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SUMMARY

Simultaneous (blended) sources have attracted a great deal of attention recently because of their potential to increase significantly the rate at which seismic data can be acquired. The viability of the method was previously demonstrated through the use of small-scale tests on synthetic and field data. In this paper, we present a case history from Australia of the first field-development-scale use of this technology in the world.

Concept studies involving simulations of simultaneous-source data from conventional data indicated that the proposed survey design would yield data that were separable into components for each source. The resultant data set contains twice as many traces as its conventional equivalent, and provides improved sampling for important processing steps such as coherent noise attenuation.

Simultaneous-source acquisition requires quality control methods that are specific to the technique to ensure that the data are acquired as planned. New QC methods were developed specifically for this project, and showed that no problems related to the simultaneous-source technique were encountered.

Data processing involved source separation at an early stage, after which a conventional processing sequence could be used on the resultant, densely-sampled data set. Separation was performed using a sparse inversion technique, which proved very effective. Very little signal leakage was observed, and the interference was almost completely suppressed.

Through this case history, we demonstrate the viability of simultaneous sources as an effective marine seismic acquisition method.

Key words: simultaneous, blended, separation, sampling

INTRODUCTION

Simultaneous-source acquisition is an established technology for land data, and has a proven record of providing enormous increases in acquisition efficiency. A plethora of associated acronyms bear witness to the rapid development of the technology over recent years. Notable methods are slip-sweep (Rozemond, 1996), HFVS (Allen *et al.*, 1998), DSSS (Bouska, 2010), ISS (Howe *et al.*, 2008) and DSS (Bagaini and Ji, 2010). A useful summary was provided by Bagaini (2010). All of these methods provide efficiency gains through firing two or more sources sufficiently close together in time that the recorded energy interferes. The interference is then handled in processing.

The corresponding techniques for marine acquisition have seen somewhat slower development, despite being introduced over a decade ago (Beasley *et al.*, 1998). The main reasons for this are consequences of the extra constraints marine acquisition places on its sources. Specifically, marine sources typically lack the ability to shape the source wavelet as can be done for land vibrators. Moreover, each source must move continuously at constant speed, and introducing extra source boats to achieve significant distance separation between sources is expensive.

Initially, most marine, simultaneous-source studies involved wide-azimuth (WAZ) data (Stefani *et al.*, 2007; Fromyr *et al.*, 2008; Dragoset *et al.*, 2009). WAZ acquisition typically involves multiple source vessels, and may require several passes for each line. Simultaneous sources can be used to reduce the shot interval for each pass, thereby reducing aliasing effects or improving efficiency by reducing the number of passes that are required.

In this study, we consider the application of simultaneous source (SimSource*) technology to a conventional, narrow-azimuth (NAZ) survey. Data from the region have previously been acquired using a standard "flip-flop" technique, in which the sources fire alternately every 18.75 m, leading to a 37.5-m shot interval for each source line. The use of simultaneous sources, such that both sources are fired every 18.75 m, halves the shot interval for each source line, thereby providing better-sampled data for coherent noise attenuation and imaging. No extra vessels are required, and the overall acquisition time is unaffected.

In principle, the SimSource methodology is very simple. The sources are dithered relative to one-another to enable separation using a sparse inversion technique (Moore *et al.*, 2008; Akerberg *et al.*, 2008). Once separated, the data can be processed conventionally, and will benefit naturally from the improved sampling. The key to success is, therefore, the quality of the source separation. To mitigate the risk associated with the separation process, concept studies were performed on similar data sets. These studies indicated that source separation was possible at the proposed shot interval.

The SimSource separation process depends on the dithers, and does not require that the sources be physically separated by a significant distance. In fact, the close proximity of the two sources for this survey ensured that the relative signal strengths were comparable, avoiding problems that can occur if the signal from one source dominates the record.

Only minor software modifications to the Q-Marine* acquisition system were required to acquire data in SimSource mode. However, some of the standard quality control processes were no longer applicable because of the interference between sources, and additional processes were required to check that the firing times and navigational data were correct. In practice, these processes worked well, and no specific problems were encountered.

Processing is ongoing, but source separation results so far, both for prestack data and for stacks of imaged data, indicate that the separation step performs well, as expected from the concept studies.

CONCEPT STUDIES

Concept studies were performed to assess the viability of the method for the proposed survey. In the primary study, a line was acquired in both conventional and SimSource modes. The conventional data had a 12.5-m shot interval, and were used to simulate SimSource data with 12.5-m, 18.75-m and 25-m shot intervals (using shot interpolation where necessary) by adding shot gathers to dithered versions of themselves. The separated data can then be compared to the original data to assess the quality of the separation process. It should be noted, however, that we cannot expect to separate ambient noise because it is not source-generated. The results indicated that separability was reasonably good, but decreased, as expected, with increasing shot interval.

Real SimSource data were shot with 12.5-m and 18.75-m shot intervals, allowing separation tests to be run at the same shot intervals as for the simulated data. The results validated the conclusions from the simulated data tests, and it was decided that SimSource acquisition with an 18.75-m shot interval was viable for the upcoming survey.

As a final test, separation tests were run on a simulated SimSource line from the proposed survey area to have water depths and noise levels that were representative of the proposed survey. The separation results (Figure 1) were also considered satisfactory.

DATA ACQUISITION

The acquisition geometry, apart from the use of SimSource, was a conventional NAZ geometry using 10 x 6000-m Q-Marine cables with 75-m separation. The two sources were fired simultaneously (apart from the dithers) every 18.75 m. One source was considered to be the "master" and shot on position. The "dithered" source fired with prescribed time differences (dithers) relative to the master source. The dithers were essentially randomly distributed over a small time window.

Conventional QC products were used whenever they were appropriate. In addition, QC products were designed specifically to check that the firing times were in agreement with the planned dithers. Two main methods were used to do this:

1. Passively separated data were inspected in the common channel domain for both sources (Figure 2). Passive separation simply involves aligning the data in time such that time zero corresponds to the firing time for the chosen source. The energy associated with that source becomes coherent, and any observed lack of coherency is an indication of a potential problem with the associated dither.
2. Autocorrelations were computed and the secondary peaks, which are related to the timing dithers, were auto-picked and compared with the planned dithers to provide an automated QC. Any discrepancies were then investigated manually.

In practice, the SimSource aspects of the acquisition proceeded without any problems. Some lines were reshot due to weather, and there was a small amount of infill.

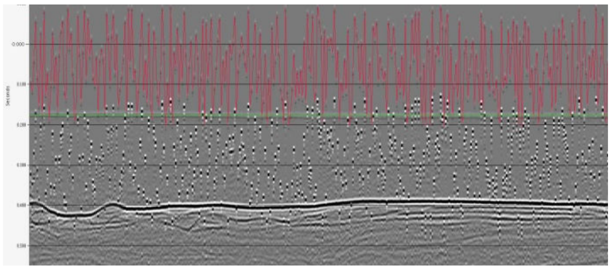

Figure 2. Part of a common channel section after passive separation for the dithered source, as used for onboard QC. The coherency of the water bottom reflection and the direct arrival (green graph) indicate that the data were acquired using the planned dithers. The red graph shows the predicted direct arrival times for the master source, taking the dithers into account. The close agreement between this graph and the observed direct arrivals also indicates that the data were acquired correctly.

METHOD AND RESULTS

Recorded SimSource data differ from conventional data in that each trace has two shot locations associated with it, as well as a dither time. At this stage, the data volume is the same as for the equivalent conventional survey. Any processes applied before separation must preserve the signal from both sources. The separation process cannot, of course, separate noise that is not source generated, and it is, therefore, desirable to remove this noise component prior to separation. Noise attenuation of this kind must generally be run in the common shot domain where the signal from both sources is coherent. In other domains, the signal from one source will not be coherent and the noise attenuation process is likely to attenuate that signal.

Active separation was performed using a sparse inversion method (Moore *et al.*, 2008) applied to common channels. Sparseness is promoted using a time-domain, linear Radon transform that effectively separates each trace into estimated components for each source, together with a (small) residual of unseparated energy. Figure 3 shows an example that demonstrates the effectiveness of the separation process. The residual contains both ambient noise and signal that has not been modelled, typically because it is weak or complex. To avoid attenuating this signal, the residual was added back to the separated data for both sources. After separation, the data volume is doubled and each trace is associated with only a single source. Conventional processing can be used from this point onwards.

CONCLUSIONS

Although data processing is not yet complete, a preliminary conclusion is that the SimSource acquisition technique was successful. No issues were encountered during the data acquisition phase, indicating that the method is sufficiently robust to be used on full-scale 3D surveys. The critical source-separation step in the processing sequence performed well. There was very little signal leakage between sources, and results so far have been in accordance with expectations based on the concept studies.

Whilst it is often difficult to make a quantitative evaluation of the benefits associated with the application of such new technology, in this case, a conventional survey was acquired within three months of the SimSource survey with significant overlap in the imaged areas. The line orientations were not the same and the processing was performed separately, but expectations based on previous experience are that the SimSource acquisition will yield better attenuation of the coherent noise, and that doubling the fold will lead to an improved signal-to-noise ratio in the image.

This project involved the use of advanced technology in a new area, and minimizing the associated risks was extremely important. The preliminary concept tests were very valuable in providing confidence that the method would work, and in assisting with the survey design.

Although the motivation for this project was to acquire well-sampled data to improve our ability to attenuate coherent noise, SimSource technology also has potential advantages with respect to ambient noise. The acquired data have higher signal-to-noise ratio than the equivalent conventional data because the signal content of each trace is increased. There exists, therefore, the potential to shoot SimSource data in more adverse weather conditions than would be used for conventional data, although it is, of course, important that the presence of the ambient noise does not affect signal separability too much. This will be the subject of further study.

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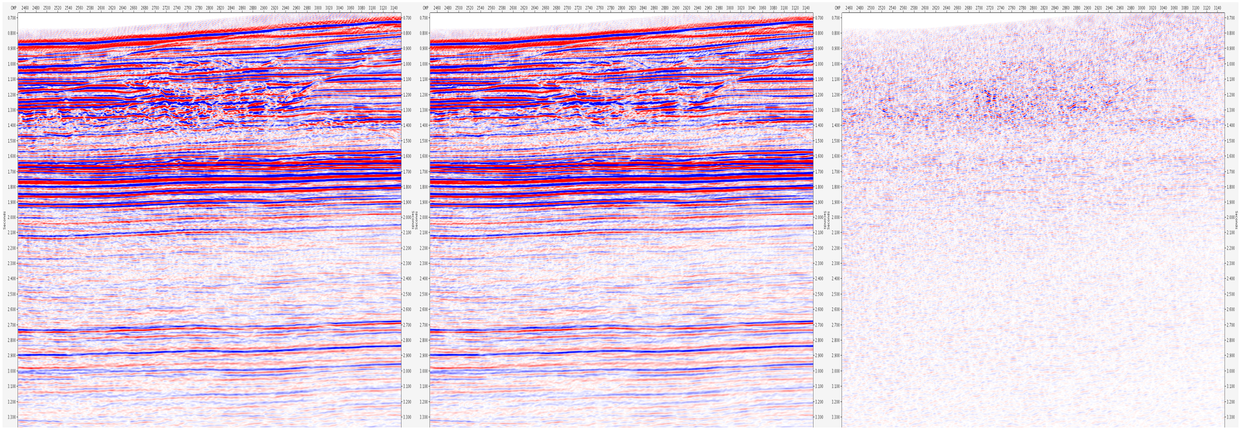

Figure 1. **Conventional (left) and simulated SimSource (centre) images from the concept study. The difference (right) indicates that signal loss is minor, and some of this signal loss is due to imperfections in the interpolation used to create the conventional data set.**

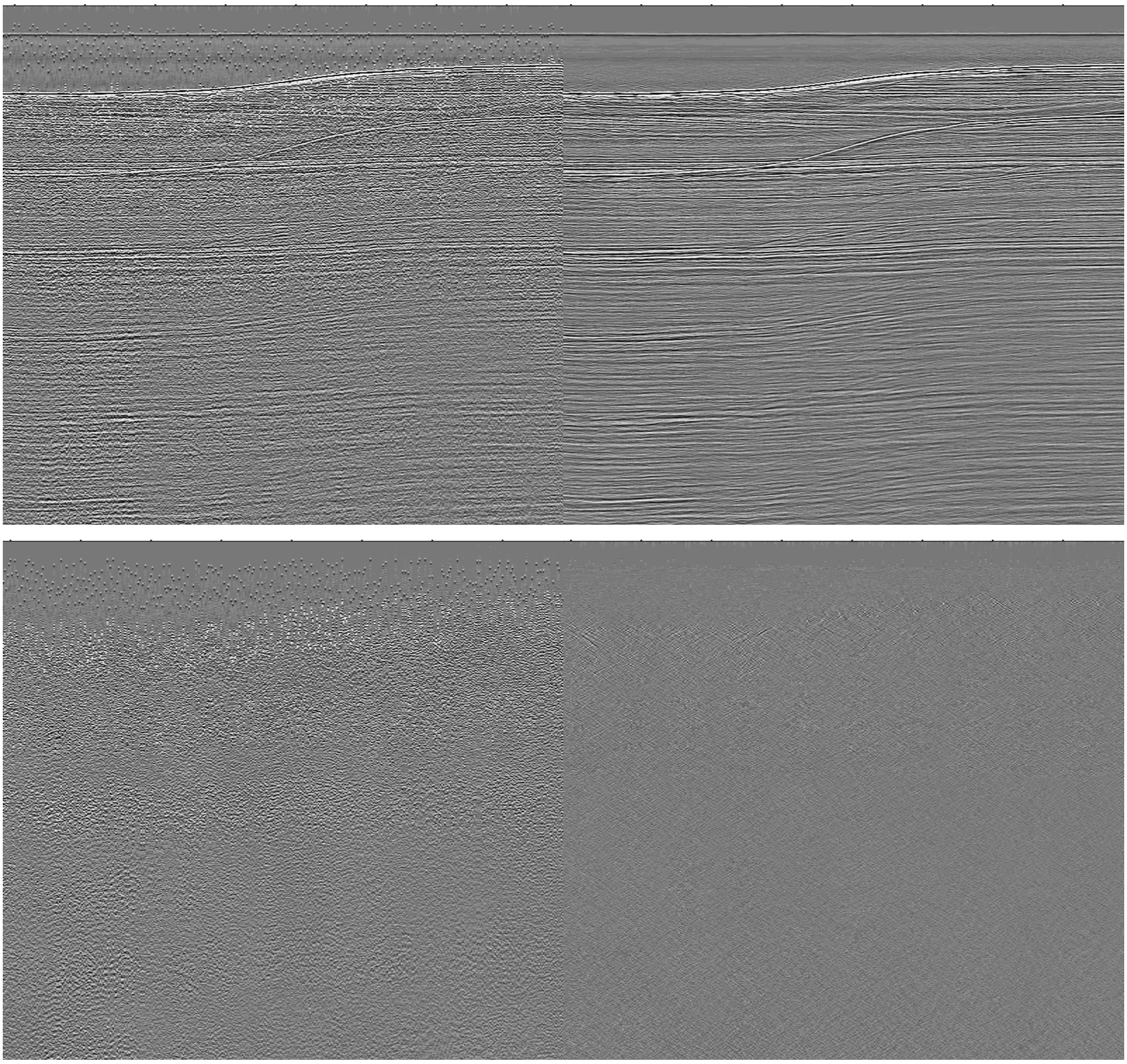

Figure 3. Separation of part of a common offset plane. The input data (top left) are separated into S1 (top right) and S2 (bottom left) components, plus a residual (bottom right) of unseparated energy. The residual is small and contains mainly noise. The S2 data are shown in S1-time and the lack of coherent energy in this section indicates a low level of leakage. In S2-time, the separated S2 data look much like the separated S1 data due to the close proximity of the sources. About 3 s of data are shown, and the lateral extent is about 7.5 km.