Spatial sampling, coherent noise, and subsurface resolution: conclusions from field experiments
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Summary

A recent trend in seismic data acquisition is the deployment of receivers and/or sources at increasingly smaller surface station intervals. Two coupled objectives for this decreased spatial sampling are more effective coherent noise attenuation, and higher image resolution, both lateral and vertical. We demonstrate, using field experiment results.

Introduction

Much recent system development effort in seismic acquisition has been aimed at increasing the number of recording channels, and hence the number of independent seismic sensors that can be recorded simultaneously. Concurrently, improvements in sensor design have increased the uniformity of their responses over a broader band of frequencies. Both of these trends have made it easier to design field experiments with the potential for both improved noise attenuation and increased subsurface image resolution.

Conventional wisdom on designing seismic reflection acquisition geometry dictates that the source and receiver spacing be chosen to prevent aliasing, within the image bandwidth, of subsurface structural details. Other, more stringent constraints on spacing, such as preventing the aliasing of coherent noise, have often been ignored to minimize costs, or have been addressed by using hard-wired sensor arrays. Such arrays attenuate noise components travelling parallel to them by summing the waveforms out of phase. The attenuation achieved is often modest, however, due to limited array length and to unavoidable variations in sensor spacing, soil coupling, and soil conditions between sensors (Hoffe et al., 2002). As we show below, better results can be obtained by recording each sensor individually and applying multi-channel noise attenuation during processing.

It is often assumed that the vertical resolution of seismic data is determined by source and receiver characteristics, the earth response, and the time sampling of the seismic data; and that lateral resolution is determined primarily by the spatial sampling of the surface by sources and receivers. The two aspects of resolution are sometimes explicitly linked only during migration or other wavefield processing.

We maintain, however, that vertical and lateral resolution are fundamentally coupled aspects of data acquisition, and that the presence in most land seismic surveys of coherent noise (generated by the source and propagated along or parallel to the surface of the earth) degrades resolution in both dimensions, since the frequency spectrum of coherent noise significantly overlaps that of the desired reflection signal, and impairs our ability to recover the full spectrum of the reflections. Thus, spatial sampling (source/receiver spacing), because of its influence on the effectiveness of coherent noise attenuation, can have a strong effect on both vertical and lateral seismic resolution.

A unique opportunity

In 2006, the Geoscience Department at the University of Calgary acquired a new seismic acquisition system (ARAM ARIES), as well as an IVI Envirovibe source. As a result, CREWES gained the unique opportunity to experiment with acquisition parameters and procedures independent of the financial or logistical support of a sponsor company. This gave us a great deal of freedom in the choice of experiments to perform. One of the first ideas we chose to test was that of spacing geophones on the ground at such a close interval that virtually all coherent noise could be sampled without significant aliasing. A field experiment was performed in August of 2006 along a public road southwest of Calgary, near Longview, and the subsequent processing of the data demonstrated the significant resolution benefits of single-phone finely-spaced acquisition compared with more conventional geometry (Henley et al., 2007). We discuss these results below.

More opportunity

In addition to the use of a modern acquisition system, CREWES also obtained access to a section of University-owned rural land near Priddis, where seismic experiments can be performed almost at will. Since we had achieved encouraging results with the earlier 2006 experiment, we conducted two further tests at the Priddis site, one in 2008, the other in 2009. In 2008, the objective was to determine what receiver spacing would de-alias virtually all coherent noise, thus allowing the optimum image resolution (Henley et al., 2009); while in 2009, a major objective was to determine whether reciprocity could be used, in some circumstances, to substitute fine source spacing for fine receiver spacing. The results of these two experiments are also summarized below.

The three experiments

The 2006 ‘Longview’ experiment:
Spatial sampling and coherent noise

The experiment consisted of 376 vertical component geophones spaced 2.5m apart, comprising a 2D line of about 937m in length, oriented on strike with the very mild subsurface structure of the region. The source spectrum was 10-200Hz, and the source was applied at 5m intervals from one end of the spread to the other. The resulting data constituted our primary data set, but four other sets were created from this primary set by summing groups of adjacent geophones as if they were wired into arrays, then decimating the original receiver spacing appropriately. Thus we had data sets corresponding to 2.5, 5, 10, 20, and 40m receiver spacing. All of these were processed with exactly the same processing flows, except for the first stage—coherent noise attenuation. For that stage, we used the reasonable criterion that filters would be applied only to those noise modes that were actually visible on the source gathers. Since much of the coherent noise is hopelessly aliased by receiver spacing greater than 2.5m, we were unable to detect various noise modes on the more coarsely sampled data, and could not design filters for them.

Figure 1 shows a raw shot gather from this experiment, while Figure 2 shows the gather from the same source position for a 10m simulated receiver spacing. It is evident that, due to aliasing, several of the coherent noise modes evident on the gather in Figure 1 are not unambiguously visible on the gather in Figure 2. This does not mean that the simulated arrays have properly attenuated them, just that they are visually ambiguous.

Figure 3 shows the gather from Figure 1 after multiple passes of radial trace coherent noise attenuation (Henley 2003), as well as Gabor deconvolution (Margrave et al., 2011), and Figure 4 shows the gather from Figure 2 after the same processing except for noise attenuation. While the surviving coherent events on both Figures 3 and...
Spatial sampling and coherent noise

4 appear flat at this scale, due to the aspect ratio, if the figures were compressed laterally, these events would be seen to have the hyperbolic moveout characterizing reflections. Figures 5 and 6, respectively, show identical near-surface portions of the migrated CMP stack sections resulting from identical processing of the 2.5m and 10m data sets. The differences in image resolution, both lateral and vertical, are striking and obvious. Phase coherence spectra for these sections (not shown here) confirm the increased bandwidth and lateral resolution and stability of the 2.5m section. Much of the difference is due to the fact that we could detect and subtract more coherent noise on the 2.5m data set, revealing more of the underlying reflection signal.

The 2008 Priddis experiment

Encouraged by our results with the Longview experiment, we decided to conduct a new experiment early in 2008 at the University’s Priddis site southwest of Calgary. This experiment consisted of deploying a short spread of 200 3C geophones at 1m intervals, and shooting through the spread with our mini-vibrator. In this survey, the 400m source line was offset 5m parallel to the receiver line and centred on it, with source positions every 10m along the line. Figure 7 shows a source gather from this line before coherent noise attenuation, and Figure 8 shows the same gather after noise attenuation and deconvolution. Figures 9 and 10 show the CMP stacks for the unfiltered data and the filtered data, respectively. As in the 2006 experiment, our conclusion is that the very fine receiver spacing enables maximally effective noise removal, thereby revealing the inherent resolution of the resulting stack image. This experiment also convinced us that 1m receiver spacing is probably finer than necessary to sample coherent noise adequately in most cases, except possibly for higher frequency components of air blast.
Spatial sampling and coherent noise

The 2009 Priddis experiment

In 2009, we once again had the opportunity to conduct a high-resolution survey at the Priddis site, but at a slightly different location than the 2008 effort. We required this 3C survey to be about 1km in length; so our supply of 3C phones, the frozen ground, and available survey time dictated that receiver spacing could be no finer than 4m. This gave us the opportunity to test reciprocity by replacing fine receiver spacing with fine source spacing. Hence, the vibrator points on this line were spaced at 2m, making receiver gathers the proper domain for coherent noise analysis and attenuation on this line.

As can be seen in Figure 11, coherent noise displayed on a receiver gather shows good coherence and little aliasing, making it amenable to noise attenuation. The frozen ground in this case likely worked in our favor to improve the apparent reciprocity. Figure 12 confirms the effectiveness of our noise removal on these gathers.

Conclusions

Our field results suggest that one fruitful way to utilize newer acquisition systems, with their large number of channels and reduced cabling, is to deploy single sensors, as closely spaced as 2m, so that all possible source-generated coherent noise modes are recorded with minimal aliasing. This maximizes the effectiveness of coherent noise removal, hence leading to the greatest resolution of the final seismic image, both laterally and vertically.

Our results also suggest that reducing the source spacing (relatively easy with a vibrator or other surface source) can, through reciprocity, provide an acceptable alternative for close receiver spacing, under favorable circumstances (laterally uniform source coupling).

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