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Acquiring and Imaging Ultra High Density Land Seismic Data - Practical Challenges and the Impact of Spatial Sampling

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SUMMARY

Ultra high density Full-Azimuth land acquisition has become possible in recent years thanks to significant advancements in recording systems, the introduction of simultaneous sourcing acquisition techniques (Rozemond, 1996 - Bouska, 2008; Howe et al., 2008) and the move towards point source, point sensor configurations. While the benefits of high density acquisition are not in doubt the costs are still significant. Hence there is a strong requirement to understand the effort / benefit relationship when moving to high density acquisition. Such data can also bring challenges and opportunities for seismic processing and imaging (Ellis, 2013). In this presentation we take an ultra-high fold test dataset and decimate to simulate 20 different acquisition sub-sets. By carefully designing a processing sequence to process the data consistently between the datasets, it is possible to understand how shot and receiver sampling for each configuration affects processes such as noise attenuation, surface consistent processing, velocities, the final imaging and attributes.
Introduction

In this paper we take an ultra-high density test dataset and decimate to simulate 20 different acquisition sub-sets. By carefully designing a processing sequence to process the data consistently between the datasets, it is possible to understand how shot and receiver sampling for each configuration affects processes such as noise attenuation, surface consistent processing, velocities, the final imaging and attributes. The area chosen for the test was part of a larger survey (Figure 1) of 5000 km², originally acquired in the Risha area of Jordan in 2010-11, using a Distance-Separated Simultaneous Shooting method (DSSS). The test survey was a 64 km² acquired using Independent Simultaneous Shooting (ISS®) method.

Data Acquisition

Between June 17th, 2011 and July 2nd, 2011, a high density Independent Simultaneous Shooting survey was acquired on a flat gravel surface to the east of the Risha concession (a 7,200 km² area in Eastern Jordan bordering Iraq, Saudi Arabia and Syria). This field trial was designed and carried out by BP: it was acquired immediately following the completion of the Risha 3D Distance Separated Simultaneous Sweeping survey and overlapped an area of about 64 km² to the east of the concession. The ISS® field trial geometry is a 25x25m shot grid shooting onto a 50x50m receiver grid to produce an extremely well sampled survey in both offsets and azimuths. This was achieved using a 8x4km rolling receiver spread which was shot through twice in opposite directions to sample all the azimuths in the centre of the survey (Figure 2).

A total of 230,400 vibrator positions (VPs) were acquired during the field trial giving a nominal fold of 8000, reduced later to 6400 after limiting the offset to 4 km. This very dense shooting generated a dataset of about 3 billion traces - after combing and correlating - and gave the "small" 64 km² field trial the equivalent size of a 15,500 km² of standard marine 3D survey. ISS® with 24 hour operations allowed very high levels of production: at its peak, the field trial operations were achieving 24,475 VPs per day (Figure 3).

Prior to going into this decimation study the dataset was combed and correlated, and the interference noise was removed.

Test Geometries

The dataset was decimated to simulate 20 different types of acquisition. A 50x50m carpet of shots was first extracted from the 25x25m shot dataset to produce two sets of shot
configurations. For each of these, a further set of 10 receiver configurations were chosen to represent both grid and linear style acquisitions (Figure 4). Grid (or nodal) style geometries have equal spacing of receivers in both directions whereas linear (or cable style) acquisitions have denser spacing in one direction. The 25m shot datasets give a bin spacing of 12.5x12.5m and the 50m shot datasets a bin spacing of 25x25m but for individual bins the fold and azimuth/offset distribution is almost identical (Figure 5).

**Figure 4** - Grid (nodal) and linear style acquisitions. **Figure 5** - Fold and azimuth/offset distribution

### Processing Sequence

The design of the processing sequence was a key part of this work as it had to deliver an extensive list of final deliverables (final stacks, AVO & azimuthal attributes) that could be used to compare decimations in a data analysis stage. With this in mind, it was important to deliver all datasets through a processing sequence that had minimal difference in the parameters while at the same time ensuring that the pre-stack migrated data for all the tests were good enough to use surface fitting methods to extract azimuthal velocity and amplitude attributes.

Other considerations were: (i) to choose a processing flow that represented the true data sampling challenges for each decimation, (ii) not to over-process the highest fold datasets, (iii) to address poor signal-to-noise ratios that are inherent in point source/receiver acquisitions, and (iv) to use the latest software developments to take advantage of the improved sampling of signal and noise. With these aims in mind a sequence was first tested in Phase 1 of the project on the densest and least dense datasets to ensure that the final products fulfilled expectations (Figure 6).

The carpet sampling of shots allowed a significant proportion of the de-noise steps to be performed in the receiver domain using two parallel flows for the 25x25m and 50x50m shot decimations. The receiver decimations took place later at the offset vector tile (OVT) binning stage. The use of OVTs (pseudo minimal fold classes) was fundamental to the work flow as it ensured decimations would stay as close to their original geometry and retain azimuth information post migration for the attribute analysis stage. Several conditions were introduced to simplify the flow and reduce the number of variables for the comparison. These included applying a single velocity field and a single set of surface consistent parameters per shot decimation. Tests showed that these conditions did have a small impact on the results but were far outweighed by other data sampling factors in the flow.

**Figure 6** – Test flow for phase 1
Practical Challenges

Coping with increased data volumes is the first and most important challenge with ultra-high density full-azimuth acquisition. Hardware and software developments made it possible to cope with the 15 Tb of data produced for each processing step without compromising turnaround. This included the ability to easily view complete receiver gathers of more than 100,000 traces. Recent developments on simultaneous joint inversion for surface consistent amplitude and deconvolution (Garcern & Le Meur, 2012), and Monte Carlo residual statics algorithms (Poulain & Le Meur, 2012) were also used to process up to 2 billion traces on the densest datasets without the need for decimation or sub-stacking the input data. Noisy pre-stack data caused by the surface conditions, absence of field arrays (point source/receiver) and blended sources acquisition made it difficult to see any signal on pre-stack gathers during the early stages of processing. This had consequences for quality control (QC) during the processing steps as only full fold stacks could initially be used to see the effects of parameters on signal (ideally this QC should also include migration). It was important to take advantage of the increased data sampling to apply efficient signal enhancement methods to improve the signal-to-noise ratio of the data. This was employed initially as a parallel flow to pre-condition data to compute signal driven deconvolution operators later applied onto original data and also used as part of the preparation for post migration attribute extraction. The use of parallel noise flows ensured that the phase and amplitude of the original traces were not compromised by array forming too early in the sequence.

Impact of Spatial Sampling

Images from the final stack of all 20 decimations are shown in Figure 7. While it is possible to make early judgments on the impact of geometry on the final image, these tests have also highlighted key areas in the sequence where shot and receiver sampling have significant effects. The impact of shot geometry sampling is first seen at the linear noise attenuation stage where it is evident that 25m shot sampling enables a better removal of the scattered aliased ground roll compared to that of the 50m shot data. The benefits of good noise removal early in the sequence can be observed at every stage of the receiver processing. The greater shot density on the 25m shot dataset can also be used to derive a more optimal solution for the surface consistent attributes by improving the signal-to-noise ratio in the parallel de-noise flows. The benefit was an improvement of the vertical resolution with better amplitude and phase stability along the horizons. The impact of receiver geometry is seen more clearly at the OVT de-noise and post migration processing stages. The denser receiver sampling increases the effectiveness of noise attenuation here, thereby increasing the difference between the lowest and highest decimation datasets. The comparison between linear and grid geometries can also be assessed, although other factors such as using reciprocity for OVT binning can have an influence on the results. The handling of noise had been the dominant concern in the processing but the impact of spatial sampling on signal is equally important. Spatial sampling should be more critical in more structurally complex areas than Risha which require un-aliased sampling of steep reflections and diffractions. However, it is still possible to compare the final results on the densest datasets and see improving resolution on the final image with increasing trace density. At these higher densities the differences are small so it is only by going to detailed attribute analysis at the reservoir levels that these differences can be properly assessed. The results of this analysis will go further towards understanding the cost benefit relationship for ultra-high density full-azimuth acquisition.

Conclusions

The benefits of increased spatial sampling are clearly shown in the improved resolution and better signal-to-noise content of the final image. This work has also shown how increased sampling can benefit other areas of processing such as velocities, statics and de-multiple. The problems of processing vast quantities of, initially, very noisy records have been overcome due to improved
workflows and developing de-noise solutions that ensure entire signal preservation. It is also shown that adequate noise sampling is often the key to getting good results. These results form part of an ongoing analysis and we anticipate that more detailed conclusions will be possible once the full data analysis work is completed.

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