High-Resolution 4D Acquisition

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Summary

Tidal effects and changes in water layer properties during acquisition of base and monitor surveys may have a dominating and detrimental effect on the quality of the 4D data set. They can be measured accurately and compensated for in the processing. Weather-related noise can be avoided with solid streamer technology, while high frequency noise is handled by a dense hydrophone spacing. Onboard seismic processing allows for a pseudo-real-time quality control of the match between base and monitor seismic data. With pre-survey modeling a relation can be built between the quality of the 4D survey and source and receiver position errors, from which the acquisition specifications can be derived.

NRMS as 4D quality measure

In areas without changes in pore fluids the recorded seismic data in the base and in the monitor survey should be equal. Hence, subtraction of the base and monitor data set will theoretically yield an empty data set. Differences are typically caused by inaccurate duplication of the source and streamer positions and due to noise in both data sets.

The difference between base and monitor is expressed by the Normalised Root Mean Square NRMS of the amplitudes in the difference cube. With the normalisation the NRMS will be between 0 for data sets which are identical and up to 2 for data sets which are increasingly unequal and out of phase.

Figure-1 shows the NRMS as function of the accuracy of the duplication of the source and receiver positions. The NRMS values are expected to increase with increasing errors in the duplication of these positions. This analysis does not show this relation. In figure-1A the high NRMS values in blue and red are caused by time shifts They must first be handled properly before this relation can be seen. In figure-1B the high NRMS values in orange relate to low S/N-ratios. Hence, the noise must first be reduced.

Handling of the time shifts

Tidal effects appear in the seismic measurements as small time shifts. Hence, the base and the monitor data set cannot be subtracted properly, leaving signal energy in the difference cube. High-accuracy GPS measurements can be used to derive tidal statics for application during the seismic processing.

Temperature and salinity change the acoustic properties of the water layer. This can also be corrected for by statics or more advanced techniques.

Handling of the noise

While shallow streamers record more high frequency reflections, they also record more noise, caused by the wave action at the sea surface. This noise mainly

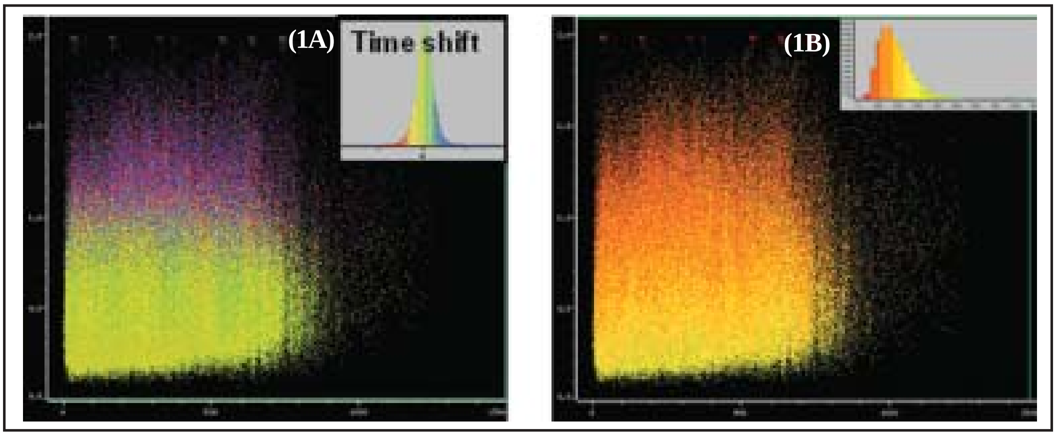


Fig. 1: NRMS versus position error, showing the influence of time shifts (1A) and lS/N-ratio (1B) on NRMS.

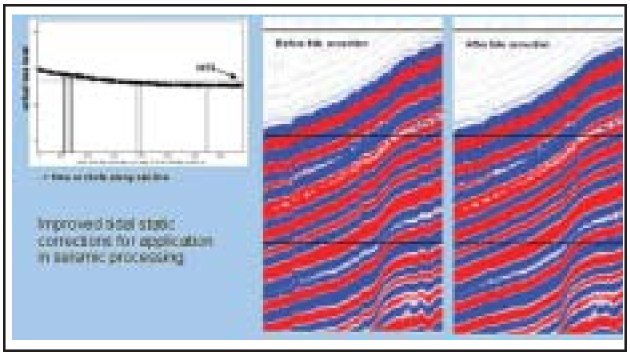


Fig. 2: GPS-based tidal corrections and its application as seen in a cross-line seismic section.

travels inside the liquid-filled streamers. Hence it is not equally present in solid streamers. Figure-3 shows a hybrid streamer with solid sections at short offsets (top of the graph) and liquid sections at longer offsets (bottom of the graph). The red colours indicate weather-related noise bursts. Hence, instead of the application of noise filters, the noise can just be avoided by implementing solid streamer technology.

Broad-band and high-frequency noise is normally spatially uncorrelated. Hence, the best noise filter is the summation of many hydrophones. The noise attenuation is proportional to the square root of the number of hydrophones. Most liquid streamers have typically 0.78 m hydrophone spacing yielding 16 hydrophones for a 12.5 m group length. Sercel's solid streamers have a larger hydrophone spacing yielding 8 hydrophones for a 12.5 m group length. Figure-4 shows two shot records with solid sections on the left and liquid sections on the right and confirms the similarity in signal-to-noise ratio despite the different hydrophone spacing. However, when the number of hydrophones in the solid sections is reduced from 8 to 4 for a 12.5 m group, as shown in figure-4A and indicated by the red bar, the S/N ratio visibly decreases. Obviously, the reduction from 16 to 4 hydrophones in the liquid sections will yield double this deterioration (not shown here).

4D Seismic Acquisition QC

Onboard seismic processing of the monitor data allows for a preview of its similarity with the seismic data

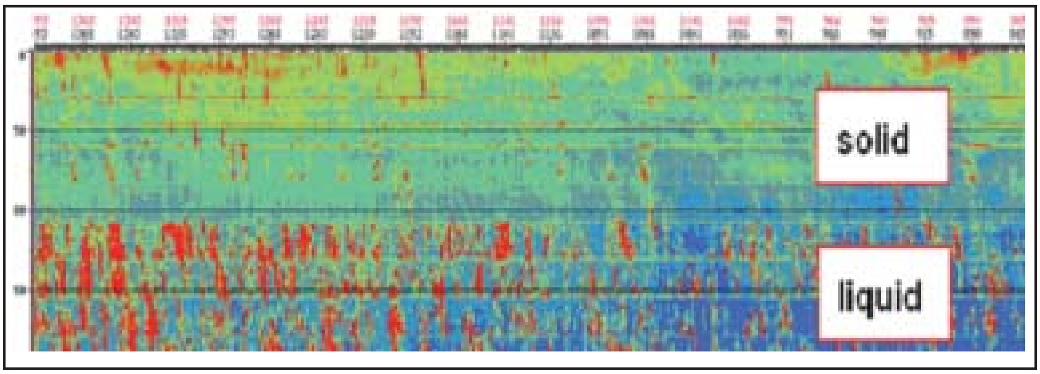


Fig. 3: Weather-related noise in solid and liquid streamer sections. The offsets increase downwards with solid sections at near offsets and liquid sections at larger offsets; shotpoints increase along the horizontal axis.

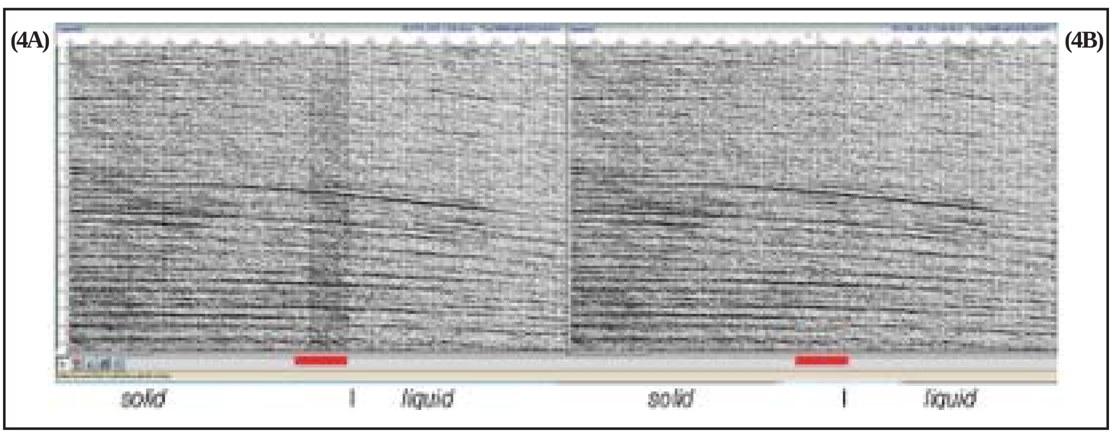


Fig. 4: Two hybrid shot records, each with solid sections at left and liquid sections at right side. See text for explanation.

of the base survey. Figure-5 shows this similarity as good in blue and poor in red. In the black areas no acquisition of monitor data has yet taken place.

4D Survey planning

With pre-survey modelling synthetic seismic data can be generated for the base and the planned monitor data set. From the difference of these data sets a synthetic NRMS map can be produced. If this modelling is done with increasing errors in the duplication of the source and receiver positions for the monitor data set, a relation can be built between position errors and NRMS. This relation can be used in combination with the expected strength of the 4D signal to define the maximum acceptable NRMS level in order to be able to see this 4D signal.

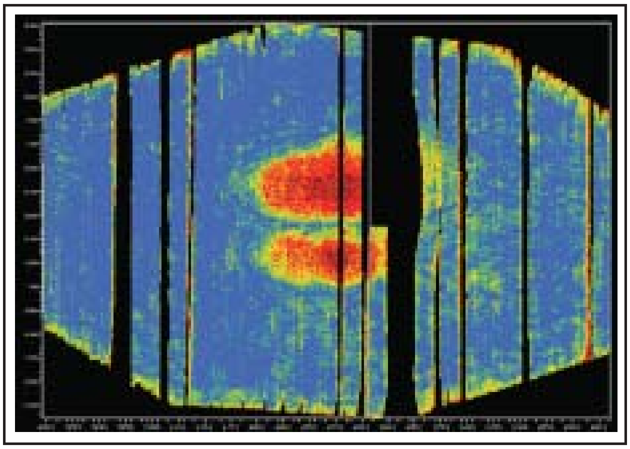
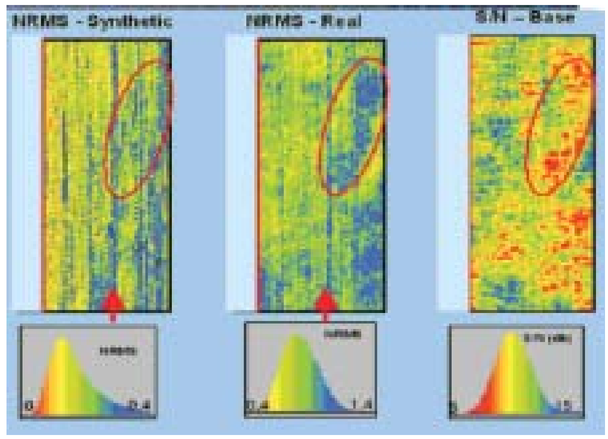


Fig. 5: Onboard 4D Seismic Acquisition QC showing the similarity between the base seismic data and the monitor seismic data, currently being acquired.

Figure-6B shows the real NRMS map of the real base and monitor surveys. For the synthetic NRMS map in 6A the P1/90 navigation of base and monitor was used. The arrow in both maps indicates a line with high NRMS in blue with apparently inaccurate duplication of source and receiver positions. Areas with low S/N-ratio in Figure-6C explain why some areas in the real map have higher NRMS than the corresponding areas in the synthetic map.



(6A) (6B) (6C)

Fig. 6: Similarity between synthetic and real NRMS maps and differences explained by the S/N-ratio map.

Conclusions

Various tools and techniques are available for 4D pre-survey analysis, onboard 4D acquisition QC and 4D processing to ensure that the survey objectives are met.