Summary

We have investigated how processing can improve repeatability between surface seismic and OBC (P/Z) data from the Statfjord Field, with application in seismic monitoring. We first tried post-stack matching of previously processed data sets. This proved sufficient for realistic mapping of production effects. Further improvements in repeatability were obtained by a proper 4D concurrent processing of OBC and surface seismic data.

Introduction

Seismic data acquired at the sea bottom will play a more important role in future reservoir monitoring. The potential benefits compared to conventional towed streamer data are: (i) improved imaging of the reservoir through the use of wide azimuths and more efficient multiple suppression techniques; (ii) better coverage beneath permanent field installations; (iii) improved repeatability and more frequent acquisitions through the use of permanent sensors (E-field); (iv) Added information through converted waves.

OBC data (pressure and vertical geophone component) can be combined with surface seismic for reservoir monitoring. One possibility is to monitor production effects between a baseline surface seismic and a repeat OBC. OBC can also be used as in-fill for surface seismic beneath permanent installations. In this paper we investigate how we can maximize repeatability between OBC and surface seismic through processing.

We use data from the Statfjord Field offshore Norway. The reservoir units consist of Jurassic sandstones (Brent Group, Dunlin Group and Statfjord Formation) at depths ranging from 2500-2800 meters. The towed streamer data sets were acquired in 1991 and 1997 using four and eight streamers, respectively. The OBC was acquired in 1997 in four swaths with two 5 km cables per swath, with 300 meters cable spacing. The shot point grid was 50x50 meters in in-line and cross-line directions. The shooting grid extended 3000 meters beyond the cable swath outlay in both in-line and cross-line directions.

First approach: Post-stack matching

The surface seismic data had been processed by Western Geophysical, while the P/Z OBC data had been processed by CGG. Both data sets had been processed to zero phase. We first took raw migrated differences between the P/Z data and each of the surface seismic data...
sets. The differences were large, also outside the reservoir. The noise in the differences masked any production-related 4D effects.

Next we tried trace-by-trace matching filters to match the PZ data to the 1997 surface seismic data. Two different design windows were tried: One shallow above the reservoir and one deeper including the reservoir. The shallow design window gave poor differences at reservoir level. The best differences were therefore obtained with the deep design window (Fig. 1). We attribute this to a non-consistent phase variation with time between the OBC and surface seismic data.

Difference attribute maps (Average Reflection Strength) between OBC and towed streamer data showed relatively small differences when comparing data acquired the same year (1997). The difference attribute maps between 1991 surface seismic and 1997 OBC data revealed production-related 4D effects similar to those obtained from surface seismic data (Fig. 2). This work has shown that simple post-stack matching applied to individually processed OBC and surface seismic data sets can be used as a fast assessment in time-lapse analysis.
Second approach: Pre-stack progressive convergence processing

Next we investigated how the 4D differences can be improved by applying 4D processing techniques concurrently to all data sets, starting from field data. The basic idea is to apply identical processing sequences and parameters to all data sets, with the objective to improve repeatability progressively throughout the processing sequence. For this test, the basic sequence that was applied to all data sets consisted of: band-pass filter, exponential and global gain correction, deterministic zero phasing using individual operators designed for each data set, static binning, 3D DMO stack and 3D random noise attenuation. At each critical step of the 4D processing, we checked the repeatability between the data sets using various QC tools. Before taking the final 4D differences, we applied global matching filters to match the OBC to the surface seismic data.

Due to different characteristics of the OBC and surface seismic data, the processing sequences were somewhat different. In addition to the basic sequence described above, the P and Z component of the OBC data were matched and summed in order to obtain the P-wave data. This P/Z summation was very efficient for attenuating the ghost and water layer peg-leg multiples. Furthermore, the receivers were re-datumed to the surface. For the surface seismic data, multiples were attenuated using long-gap tau-p predictive deconvolution. Inspection of the data showed more remaining multiple energy in the surface than the P/Z processed data. In order to improve repeatability further, additional multiple removal was applied to the surface seismic data: velocity filtering using a high-resolution Radon transform and a surface-consistent deconvolution in the T-X domain. These additional processes improved repeatability slightly.

The OBC data contains a much larger range of offsets and especially azimuths than the surface seismic data. In the static binning of the OBC data, we therefore selected the minimum azimuth in each bin and offset class in order to have azimuths similar to those of the surface data. Furthermore, the same mute function was applied to surface and OBC data in order to have similar offset distribution. For comparison, we also processed the OBC data with all azimuths. It was not clear if the processing with similar offset and azimuth distributions had a better repeatability, due to the increased noise level following from reduced fold. Fig. 3 shows typical data and differences after pre-stack progressive convergence processing.

It is clear that surface and OBC data exhibit different noise characteristics. In order to improve repeatability, we have applied a new technology developed by CGG. Based on geostatistical measurement in the frequency domain, the method extracts the common seismic cube between the surface seismic and the OBC data (Fig. 4). Taking advantage of the redundancy of the information, the resulting common seismic cube has a much higher S/N ratio and better resolution than each of the 4D data sets. It can be used for interpretation and reservoir characterization. The difference between each data set and the common seismic cube (partial differences) reveals parts of the 4D signature and also the noise that is specific to each data set. These partial differences have been processed for noise reduction, and the total 4D difference has been optimised by summing together the filtered partial differences.
Conclusions

Trace-by-trace post-stack matching and 4D differencing of existing OBC (P/Z) and surface seismic data may be sufficient for a first assessment of production effects.

Further improvements of repeatability can be obtained with pre-stack processing of all data sets, using similar processing sequences and parameters. The P/Z summation for OBC data is very efficient for multiple attenuation, however, special care must be taken to attenuate multiples on the surface seismic. Furthermore, the different noise characteristics of the OBC and surface seismic data merit special attention and different strategies for noise reduction. We have shown a promising new technique that allows for the extraction of a common part between OBC and surface seismic. By using this technique, we can generate new types of differences that can be used for 4D analysis and for processing to improve repeatability.

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