Processing overcomes repeatability issues

The use of legacy 3-D seismic data in 4-D studies has the potential to add valuable baselines in the description of the life of a reservoir.

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Time-lapse (4-D) seismic surveys have been in use for many years and have steadily gained popularity and credibility with oil companies. Many if not all reservoirs could benefit from 4-D seismic studies to map changes due to production and to guide future development. Lack of suitable data has been the most often quoted reason for not performing such a study, conventional wisdom dictating that a useful 4-D result requires repeatable acquisition geometries and processing sequences between vintages.

With the development of dedicated 4-D processing tools and workflows, the need for absolute consistency is significantly reduced. With the judicious application of modern processing techniques, robust solutions can be derived from surveys with significantly different acquisition geometries. While it is true that dedicated 4-D surveys with repeatable acquisition will deliver the best results, the application of appropriate processing techniques can allow the use of legacy 3-D datasets. Typically, this legacy dataset will be all that is available to provide a pre-production 4-D baseline. The question is whether these data are sufficiently “4-D-friendly” to provide accurate and dependable 4-D results.

The case study used here is from the Foinaven field, which is part of three BP-operated fields from West of Shetlands. There were three vintages of survey at the time of the study. The baseline for the field is derived from a 1993 survey. A second survey was acquired in 2002; this was not acquired as a dedicated time-lapse project but was nevertheless used to generate time-lapse results. In early 2004, a carefully planned survey was acquired to match the 1993 vintage and provide a high-quality 4-D signal. It used a dense, overlapping acquisition to provide repeatable source and receiver positions with the original vintage.

The 1993 and 2002 vintages had been previously processed using a dip moveout (DMO) style processing flow, and while BP had used these products to extract significant value from these data, further benefits were anticipated using the more advanced techniques developed since the original dedicated 4-D processing flow had been implemented. All vintages were therefore completely reprocessed with an updated dedicated 4-D parallel processing sequence using Kirchhoff prestack time imaging (PSTM) and also improved noise suppression technology.

The aim of time-lapse processing is to provide data free of noise and multiples in a consistent manner for each vintage to obtain a reliable 4-D signal. There are several key components all aimed at progressively “equalizing” the different vintages. First, deterministic processes are used whenever possible, e.g., for zero phasing and for tidal statics. Second, progressive cross-equalization is enforced by using repeatability metrics such as normalized root mean square (NRMS) or predictability to drive the processing. Finally, the use of simultaneous processes such as 4-D binning and co-filtering techniques means that the repeatability of the vintages is progressively enhanced.

In this case study the reprocessing used a significantly more evolved time-lapse sequence which included water layer statics, bin centering regularization, simultaneous 4-D binning, Kirchhoff PSTM, geostatistical footprint removal and co-filtering techniques. All of these processes incrementally “equalize” the two vintages to deliver a superior 4-D...
signal when compared to the original processing.

Four-D binning is one of the new generation of time lapse-specific processes which makes simultaneous use of the two data vintages of the 4-D dataset. It is a process by which pairs of traces between two vintages are compared for each bin on a common grid with respect to navigation attributes and/or seismic repeatability. We might, for example, want to select traces which have the highest cross-correlation or the smallest change in source-receiver geometry.

Whatever criterion is chosen (and in general we will make use of several), we simultaneously populate a specific bin in both surveys using traces that exhibit the greatest similarity, immediately taking a significant step in reducing acquisition differences where possible.

One of the most often-used 4-D metrics is the NRMS value which we have already mentioned. NRMS is sensitive to noise, statics, phase and amplitude differences between surveys. The lower the NRMS value, the better the repeatability between the vintages.

During any 3-D or 4-D processing sequence, we expect that every process applied will progressively improve the quality of the data and the overall similarity of the vintages, hence reducing the NRMS value. Figure 1a illustrates the behavior of the extracted average NRMS attribute as seen between the 1993 and 2002 surveys compared to that seen from the 1993 and 2004 surveys during processing. The comparisons are made on two horizons, one of which is a window around the reservoir. It is clear that each processing step results in a reduction in the NRMS value; i.e., the overall differences between the datasets are decreasing. It is interesting to note that the same trend is seen between both pairs of data — remember that only the 1993-2004 dataset pair is considered as "4-D-friendly" acquisition.

Figure 2 shows NRMS maps at the reservoir level from the start and end of the processing for each of the 4-D dataset pairs. One thing that is very apparent from these map displays is that there are significant acquisition-related differences between the 1993 and 2002 data (the blue linear pattern seen in Figure 2a). These differences are reduced, not surprisingly, between the 1993 and 2004 surveys (Figure 2b) thanks to the planned 4-D-friendly acquisition.

The NRMS maps for the final processed data are shown in Figures 2c and 2d. As expected, the quality of this attribute is generally better for the dedicated 4-D dataset pair. However, what is of more interest is that the data derived from the non-dedicated 4-D survey is not far behind. It is instructive to examine the processed data shown in Figure 1b. Here we show the global average NRMS for each 4-D result. The three points on this schematic indicate the NRMS for the original 1993-2002 DMO processing, the 1993-2002 data reprocessed with the updated parallel sequence and the parallel processed 1993-2004 4-D-friendly datasets. In real terms we see an improvement of approximately 25% in the NRMS when using dedicated acquisition. We can see, however, that the improvement from using the updated 4-D processing sequence is even greater.

The impact of the general improvements in processing technology from the original DMO sequence to the new PSTM-based sequence is shown in Figure 3. Unsurprisingly, there is a great improvement in the image quality in terms of signal content and resolution. Roughly speaking, the improvement that can be observed here in the signal quality equates to the improvement in the NRMS value due to processing seen in Figure 1b, although the impact of the simultaneous 4-D-specific processing steps will not be obvious until we examine the 4-D signal.

While it is obvious that dedicated 4-D acquisition will always provide the best
results, it is important to realize that advances in dedicated 4-D processing sequences can have a very significant impact, as illustrated by this case study. There are several conclusions which can be drawn from this.

First, dedicated 4-D parallel processing will maximize the value of 4-D data. Although this will involve the expense of reprocessing original vintages in tandem with the latest survey, operators will always benefit from the latest developments in time-lapse processing.

Second, repeatable 4-D acquisition is desirable but not mandatory if time or resources are limited or if acquisition obstacles are present.

This leads us to a possible third conclusion regarding the use of legacy data for time-lapse studies. It is likely that the pre-production seismic data available for the reservoir may fall short of current 4-D-friendly acquisition criteria. Perhaps at last we are at the stage where 4-D processing has evolved sufficiently for many of these legacy datasets to play a valuable role in time-lapse studies.