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'It's all acquisition's fault'

Advanced time-lapse seismic acquisition improves quality and delivers results more quickly.

Paddy Smith, WesternGeco

Imagine a world where time-lapse seismic surveys were acquired identically from year to year, and the acquisition environment did not change. The time-lapse seismic data processor's job would be easy – design a simple and robust processing flow that images the seismic data consistently from one survey to the next.

Unfortunately, the processor's job is anything but simple. Many things, notably the environment, change from survey to survey. These changes introduce data perturbations that must be compensated for. Compensation processes often rely on measurements made from the seismic data themselves, and it can be a delicate and time-consuming business to do this without modifying the changes related to hydrocarbon production to resolve.

So, in a sense, the long delay that frequently occurs between end of acquisition and start of interpretation is due to acquisition rather than processing.

Control what you can, measure what you cannot

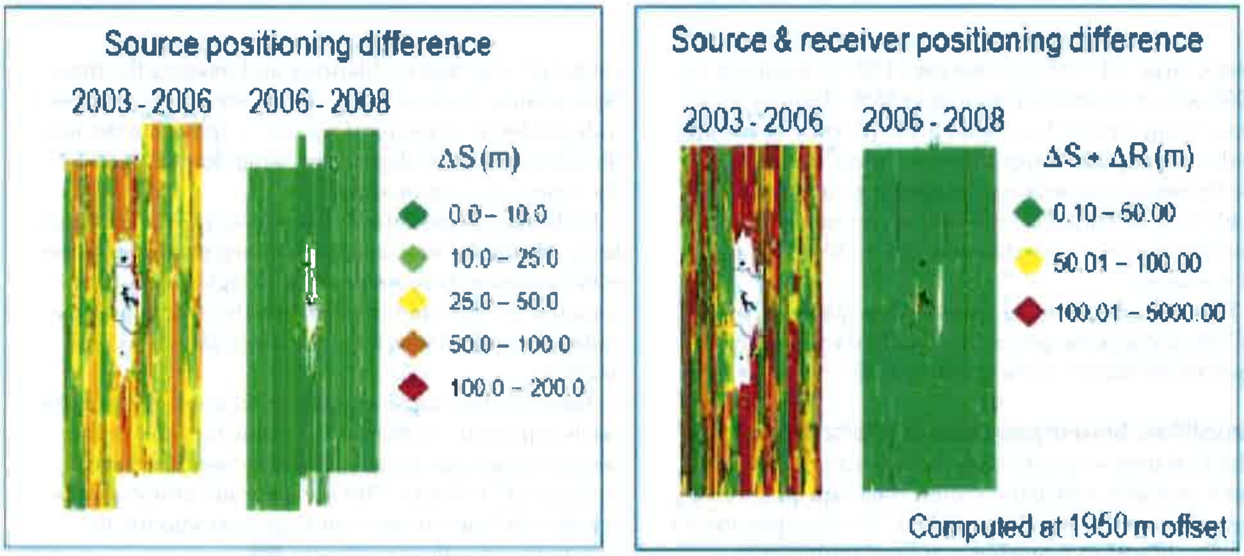
One approach to resolving this problem is to control the variability of the acquisition. For example, one might place a permanent seismic monitoring system over a producing field so the locations and characteristics of the receivers and instruments are fixed. This can be a good solution, but in many cases the flexibility and cost-effectiveness of marine streamer acquisition make it a preferred technology.

WesternGeco has developed a technology to control the variability of marine streamer acquisition, first by introducing a steerable streamer that records the output of individually calibrated hydrophones and then by deploying a fully integrated system called Dynamic Spread Control (DSC). This system monitors the environment and automatically steers the vessel, sources, and streamers to acquire the desired shot and receiver locations. The first generation of DSC could steer the streamers up to about three degrees against prevailing currents, controlling cross-flow noise using digital noise suppression algorithms applied to the point receiver data. A new generation of steering devices, which can achieve a feather differential up to six degrees, was introduced in 2010.

Survey-averaged CMS signatures are shown for a pair of time-lapse surveys acquired using identical source configurations and parameters. The middle panel to the right shows the 4-D difference that results when the zero-phasing operator computed for the first survey is applied to both datasets. Low-frequency residual energy is marked by arrows. (Images courtesy of WesternGeco; data courtesy of Statoil)

However, seismic acquisition companies cannot control the waves. The acquisition environment changes during and between surveys. The WesternGeco approach is to measure these changes to enable deterministic compensation rather than derive corrections from the seismic data themselves. The result is more accurate and is unaffected by survey-to-survey changes caused by hydrocarbon production.

A wide range of information is measured. For every shot, the Calibrated Marine Source (CMS) system measures the output of each airgun in the source array. These are combined to create an individual farfield sig-



The left panel compares source positioning differences for surveys acquired in 2003, 2006, and 2008 with identical acquisition configurations. DSC reduces the source and receiver positioning errors to well below 164 ft (50 m) for most of the survey. (Data courtesy of ConocoPhillips)

nature for each shot, enabling compensation of shot-to-shot and survey-to-survey variations in source output. GPS-based measurements of actual tide heights are made and can be significantly more accurate than those predicted from tide tables. In addition, the 4-D CALM system measures the effect of sea-surface waves on seismic data. The seismic sources, being suspended from floats, tend to move up and down with the waves. This movement is measured by GPS and enables compensation of the effects of wave motion on the source datum. The streamers, on the other hand, tend to stay at the same level within the water column, and the waves move up and down above them as the seismic shot is recorded. This causes the streamer ghost component of the seismic wavelet to vary with acquisition record time and offset along the streamer. The Q-Marine point-receiver marine seismic system digitally records the output of each individually calibrated hydrophone as a continuous full-bandwidth stream of data, enabling the very low-frequency pressure information associated with the wave motion to be captured and inverted for wave heights. These are used to compute time- and offset-variant filters that remove the effects of wave motion on the streamer ghost.

Another technique acquires velocity information in the water column. The system continuously records a depth- and space-variant water column seismic velocity profile as each line is being acquired. This enables deterministic compensation of the effects of line-to-line and survey-to-survey changes in water column velocity. This is the most recently introduced component and represents the last piece in the time-lapse seismic acquisition puzzle. All corrections that are routinely applied in time-lapse seismic processing now are handled by the acquisition system.

In 2006 and 2008, survey-averaged CMS signatures for a pair of time-lapse surveys were acquired using identical source configurations and parameters. These wavelets are the desired output of the shot-by-shot CMS signature deconvolution procedure. The averaged signatures are used to compute combined zero-phasing and debubbling operators that are applied to the seismic data.

A 4-D difference resulted when the zero-phasing operator computed for the 2006 survey was applied to both the 2006 and 2008 datasets, as would be the case when processing conventional 4-D seismic data. Low-frequency residual energy can be seen on the survey. If each survey is zero-phased using an operator derived from the appropriate signature for that survey, the low-frequency energy is no longer present. The minor differences in residual bubble train between the two signatures are genuine. At first glance, this could appear to be a minor issue, but it can significantly hamper 4-D seismic inversion.

Source positioning differences were compared for surveys acquired in 2003, 2006, and 2008 with identical acquisition configurations. The 2006 survey did not attempt to duplicate the 2003 source and receiver locations, and the source positioning differences are, as a result, large. The 2008 survey used DSC to duplicate the 2006 source locations, resulting in 95% of source locations being repeated to within 8.2 ft (2.5 m). The source and receiver positioning difference maps can be seen for the same comparisons, computed at an offset of 6,400 ft (1,950 m). DSC reduced source and receiver positioning errors to well below 164 ft (50 m) for most of the survey.

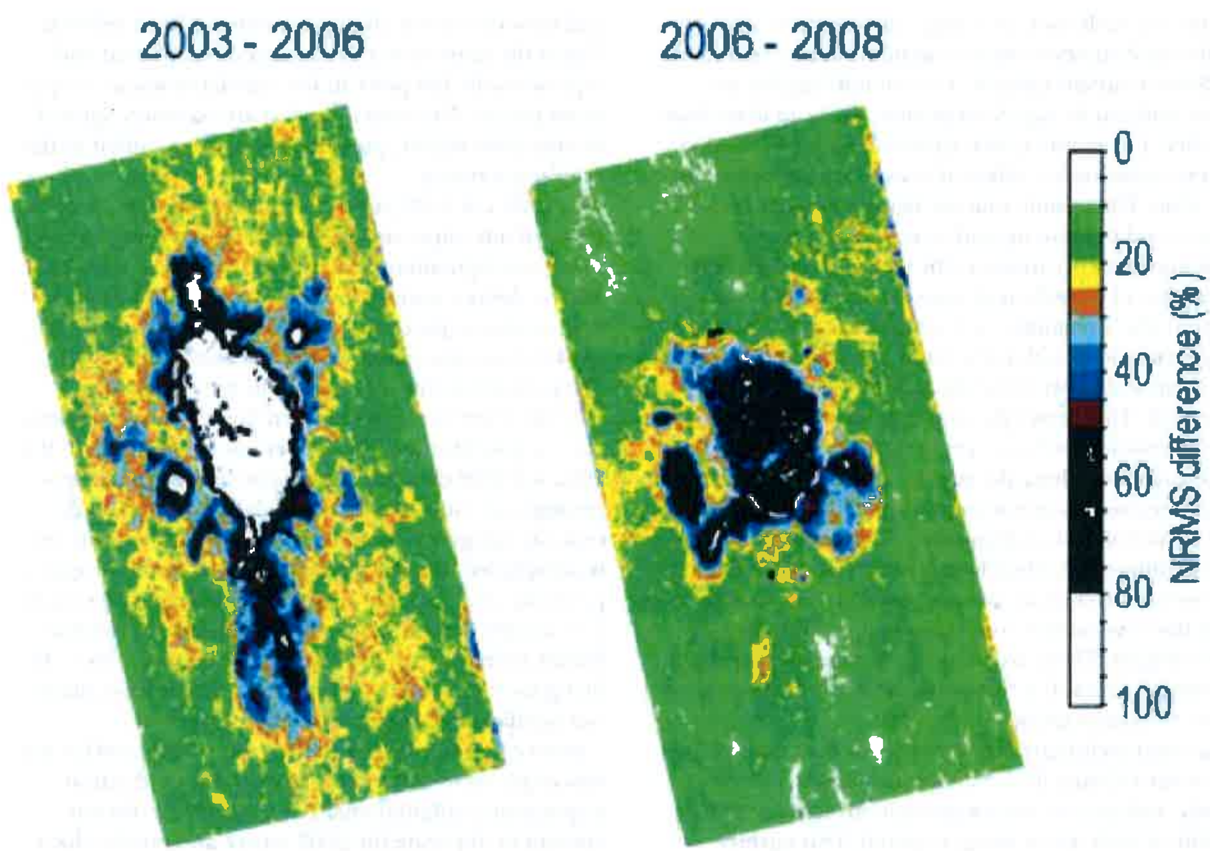
This has a direct impact on 4-D data quality. The use of DSC reduces the general normalized root-mean squared difference levels to 8% to 12%.

Simplified time-lapse seismic data processing

The Q-Marine acquisition system now can deliver accurately repeated time-lapse seismic data with all necessary environmental corrections applied. The data processor's job is confined to removing noise and multiples in a robust manner and regularizing and imaging the time-lapse seismic datasets. Each new survey can be processed independently of the previous one, minimizing the likelihood that the time-lapse processing flow will modify the time-lapse seismic signal.

In the past, WesternGeco has routinely delivered time-lapse seismic datasets using predefined processing flows with turnarounds between one and eight weeks. Turnarounds are expected to reduce further when multiple vintages acquired with all of the components become available.

Advanced time-lapse acquisition technology can accurately represent changes in the subsurface and deliver results within time frames previously associated with "quick-look" volumes. This accuracy and efficient delivery directly benefits reservoir engineers who use the data to monitor their reservoirs. EP



The use of DSC reduces the general normalized root-mean squared difference levels to 8% to 12%. (Data courtesy of ConocoPhillips)