Minimizing noise with corrected seismic

Rough seas introduce unwanted noise in 4-D surveys. New techniques help keep things quiet.

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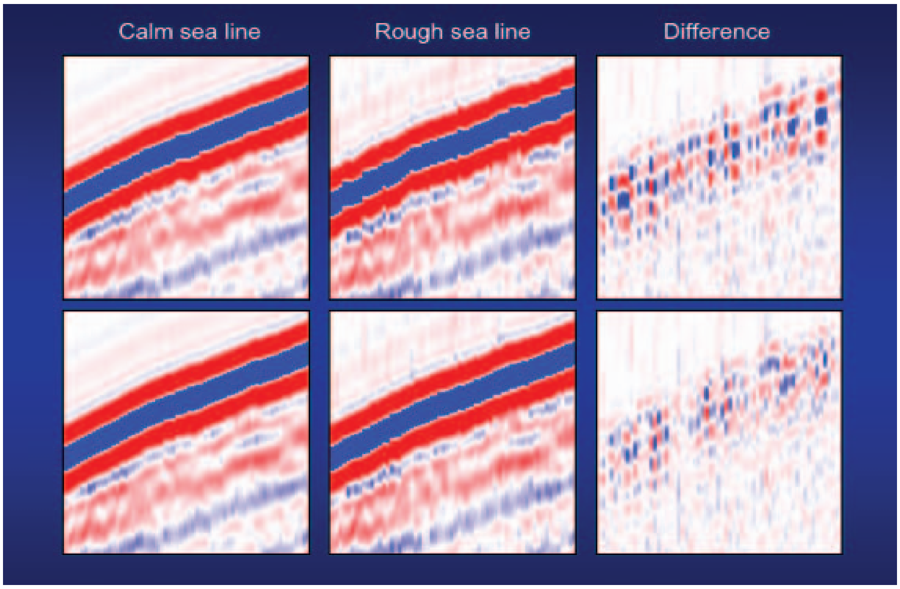

Figure 1. Single sensor common-offset displays over a waterbottom are from a baseline acquired in a calm sea (left) and a repeat line acquired in a rough sea (middle). Their difference is shown on the right. The top row shows the data before wave height corrections, and the bottom row shows the data after the corrections at the source and receivers. The wave height corrections have improved the repeatability of the data from 20.5% to 15.2% NRMS. The remnant noise in the bottom difference display is largely due to the uncorrected 18-ft (5.6-m) average difference between the common midpoint positions of the two lines and the differences in residual swell noise. (Images courtesy of WesternGeco)

Ten years ago time-lapse seismic was used by only a handful of oil and gas companies. Repeating acquisition geometries was problematic, as was determining whether changes in the surveys were reflecting anything significant that was occurring in the reservoir. However, over the past few years, notable results have been documented by operators who have used successive overlapping 3-D surveys to map changes in reservoir properties as a result of production.

Studying changes that have occurred during the time between surveys has given insight to better understand preferential permeability, reservoir drainage patterns, and waterflood effectiveness. In fact, time-lapse seismic, called 4-D with the fourth dimension representing time, can be used for measuring geomechanical changes above, to the sides of, and even under the reservoir. Consequently, 4-D has become an important part of reservoir management and is beginning to be used routinely by many major oil companies all over the world to increase the total recovery factor of their reservoirs.

Problem-solving

Even so, 4-D surveys present many challenges. For example, during the acquisition process, both source and receiver vintage positions must be accurately repeated as even very small changes in the earth's response may indicate a change in hydrocarbon production. In 2007, WesternGeco brought Dynamic Spread Control (DSC) to the market. DSC is an automated vessel, streamer, and source steering technique for repeatability in 4-D studies and increased accuracy for Q-enabled over/under and rich- and wide-azimuth surveys in complex imaging areas. Recently, utilizing the full suite of DSC evidenced a repeatability achievement of better than 20-ft (6-m) crossline at 2-sigma level.

Through the development of DSC, other sources of perturbation in the dataset have become evident as sources of time-lapse noise. Among these is the impact of the differing sea surface between data vintages. Deterministic correction for this effect will enable the quantitative study of more subtle or shorter period time-lapse effects.

In an ideal world towed marine seismic data would always be acquired in flat-calm seas. Unfortunately, this is not often the case, and the rough sea surface introduces perturbations in the recorded seismic data from both the source and the receiver side. Correction for these distortions effectively flattens the sea surface, resulting in data equivalent to that acquired in a calm sea. Source elevations are corrected, and the time-variant receiver ghost is corrected through novel sub-Hz data recordings that image the instantaneous sea surface profile. For the best results, wave height corrections should be applied to all vintages of the 4-D seismic records utilizing the latest seismic acquisition equipment, highly accurate GPS results, and advanced processing techniques.

A corrected understanding

When conducting a seismic survey,

streamers remain nearly horizontal and do not rise and fall with the waves when towed through water. This is due to the tension and depth controllers and results in seismic energy being reflected from the subsurface and arriving at the streamer in a coherent front. As the sea surface topography is always changing due to the wave movement, the reflected ghost energy also continuously changes. Consequently, time- and space-variant perturbations are introduced into the receiver ghost amplitude and phase (the ghost is energy that travels upwards from a shot and is then reflected downwards by the surface, thereby joining with and confusing the returning seismic wave). This leads to a change in ghost timing while the ghost data is mixed with scattered noise from the sea surface.

Variations in wave heights are detected by all of the hydrophones in each streamer as ultra low-frequency pressure changes. To record the measurements, an ultra low-frequency response must be accurately calibrated and single-sensor technology applied without any additional digital low-cut field filter. The acquisition system must be designed to record continuously rather than just during the shot listening time to effectively sample the ultra low frequencies. These ultra low-frequency pressure changes, which are actually recorded separately from the seismic data, are inverted to wave heights and used to derive local compact 2-D correction filters.

Source and streamer corrections

As sources are tied to the sea surface by chains and ropes between the guns and their floats, they behave very differently than streamers. As the floats go up and down with the wave movement, the gun depth is approximately constant. Therefore, the ghost periods are also nearly constant. The main perturbation on the source due to the wave heights is a shot-to-shot source static.

RTK GPS is used to accurately measure the *x-y-z-t* positions and wave heights at the source array floats. Together with the ultra low-frequency measurements on the receivers, these two independent types of measurement are used prestack to correct shot-to-shot elevation statics and for receiver-ghost perturbations correction to improve repeatability for 4-D seismic reservoir monitoring.

Additionally, once the receiver ghosts are stabilized, spectral broadening using deterministic 2-D deghosting filters may be applied if desired.

Usage in the Gulf of Mexico

Wave-height corrections were applied in the Gulf of Mexico in 2007 using airgun arrays and single-sensor towed streamers. Figure 1 presents examples of common-offset sections showing the water bottom reflection of a repeated seismic line. The first pass was acquired in quiet weather, the second pass in rough weather. After applying the wave height corrections (source and receiver), the normalized root mean square (NRMS) of the difference, i.e., the time-lapse noise that needs to be minimized, has decreased from 20.5% to 15.2%. This is a relative improvement of 26%.

Figure 2 shows the effectiveness, on stacked images, of applying wave height corrections (source and receiver). Again, the first pass shows calm conditions, the second rough conditions. NRMS is reduced from 12.7% to 10.9%, showing a relative improvement of 14.2%.

The future of 4-D

The latest acquisition techniques and data processing technologies enable the inversion of pressure measurements and the application of wave-height corrections. This results in improved reflector continuity, improved wavelet stability, and, most significantly, improved repeatability between 4-D surveys. Advancements in 4-D technology enable monitoring with greater accuracy than before and allow operators to view changes not only in the reservoir but above, around, and under it, resulting in more meaningful and successful intervention.

In fact, there are five main events that will benefit from this reduction in time-lapse noise floor and the consequent improved reservoir definition 4-D data:

1. The need to react to unexpected well or injection program failure;
2. The need to search for bypassed zones and for a better well placement;
3. The need to develop reservoir production plans and validate the dynamic model;
4. The need to monitor fluid migration, injection paths, and well placement; and
5. The question of whether to abandon the field or not.

Through continuous technological advancements, data repeatability will continue to improve, leading to even greater use of time-lapse monitoring surveys throughout the world with oil and gas companies reaping the benefits. E&P

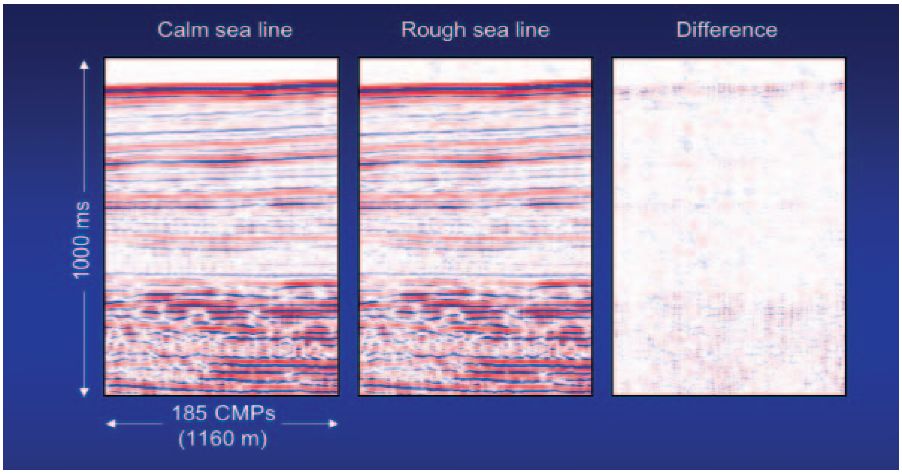

Figure 2. Stacks of the calm and rough sea line after wave height corrections have been applied. The post-stack % NRMS has changed from 12.7 to 10.9%. As in Figure 1, the slight mispositioning of the two 2-D lines and the differences in their levels of swell noise has resulted in remnant 4-D noise in the difference plot.