Effectively Handling Different Types of Data in Facility Areas for Improved 4D Imaging

D. Chu* (ExxonMobil Exploration Company), G. Mohler (ExxonMobil Exploration Company), G. Chen (ExxonMobil Exploration Company), J.J. Bishop (ExxonMobil Exploration Company), V. Gudipati (ExxonMobil Exploration Company), M. Helgerud (ExxonMobil Exploration Company), D. Johnston (ExoonMobil Production Company), S. Reevell (Petroleum Geo-Services) & F. Robin (Petroleum Geo-Services)

SUMMARY

A workflow has been designed to process different types of streamer acquisition for a single 4D survey. Undershoot data has been processed together with prime lines, but special attention has been made to ensure the undershoot data are consistent with prime lines after water column statics correction. A trapezoid filter has been used to optimally reject bad trace pairs by finding the compromise between DSDR and NRMS. Single boat data of different azimuths has been processed separately and merged post-migration. The processing workflow has been adjusted to accommodate two boat reverse push lines. The final 4D results have shown the effectiveness of the workflow.

Introduction

The 4D program described in this presentation is over a major deep water field offshore West Africa. The baseline survey was acquired in 2002 as a part of the exploration program. The nominal line orientation was 077°/257°. Production facilities put in place in 2003 introduced obstructions for acquisition of the subsequent monitor surveys in 2006, 2008 and 2012. The facilities include an FPSO and CALM buoy, which are about 2 km apart and are located above one of the main reservoirs – presenting a challenge to our effort to acquire continuous coverage in a repeatable manner.

Monitor prime line acquisition followed the same nominal line orientation of the baseline in order to maximize repeatability. However the facilities obstructions generate two acquisition holes in the prime coverage. To fill in these holes, three additional types of seismic coverage were acquired:

1) Two sets of single-vessel acquisition, with orientation roughly perpendicular to prime azimuth provided coverage over elongated portions of the prime acquisition holes associated with the facilities. This acquisition type is referred to as 'box-in'.

2) Dual-vessel undershoot data acquired along the prime line azimuths provided coverage beneath the facilities.

3) Dual-vessel reverse-push acquisition acquired to mimic prior-vintage prime and undershoot sail lines when ocean currents generated a streamer feather that was opposite to that of the prior vintage. This technique proved useful in close passes. Many lines likely would not have been possible otherwise.

Although coverage holes have been mostly filled for the monitor surveys, processing all the data together has proven to be a challenge and the quality of the 4D image near the facilities has been relatively poor in previous processing.

For the 2012 monitor processing described in this paper, special care has been taken to the data in the vicinity of facility area. The goal is to make different types of data be as consistent with each other as possible to reduce the 4D noise and the potential migration swings.

4D processing workflow

Careful '4D-QC', an essential part of 4D processing, is conducted at every key step to ensure that each process is '4D-friendly' – either improving, or not affecting, the similarity of the 4D seismic vintages (Miller and Helgerud, 2009). Large volumes of data and their extracted attributes are reviewed in various domains. The differences between vintages are measured over specific QC horizons or fixed time windows. For this project, the primary 4D attributes examined are (i) Normalized RMS Difference (NRMS), (ii) time shift, and (iii) RMS amplitude ratio. In addition, a 10°-40° angle stack difference (4DQC stack) is tracked throughout the processing flow to allow QC of incremental changes in the 4D response over the full seismic volume.

The major processing steps are signal processing and noise attenuation, Radon demultiple, water column statics, binning, regularization and pre-stack time migration. The most significant improvements in the consistency between the surveys were a result of a new workflow for water column statics (WCS), a revised 4D binning strategy for non-prime data, and a smart merging of the different data types.

The WCS solution was derived in two steps: water layer replacement, followed by traditional cross-line gradient water column statics. The water layer replacement is designed to remove the sail line-to-sail line variations of the water velocity field caused by changes of temperature and salinity with location, water depth and acquisition period. The water-bottom arrival time is controlled by replacing the actual average water velocity to a given reference velocity. The choice of smooth reference velocity field enables a correction for timing mismatch mainly visible between adjacent sail lines. Furthermore, using the same reference velocity field between vintages enables alignment of the water-bottom reflection times between surveys. The correction consists of the application of a differential NMO correction with a static time shift at zero offset, where the estimated water velocity is removed and the reference water velocity is applied at each CMP location. The time correction at zero offset depends on the ratio of the model velocity to the observed velocity and water bottom depth. For traditional cross-line gradient cold-water statics shifts, the model is created based on baseline data using a near-offset class. For prime lines and box-in lines, zero-offset statics are derived using an offset of 500m.

Time varying time-shifts between two survey vintages are used to measure how well the data are registered relative to each other. If two surveys are well-registered, then statistically there should be no time shifts at any given depth. A subset of time-varying time shifts between two monitor surveys after WCS, derived through cross correlation, are shown in Figure 1. The figure shows that the new approach improves the time registration between surveys.

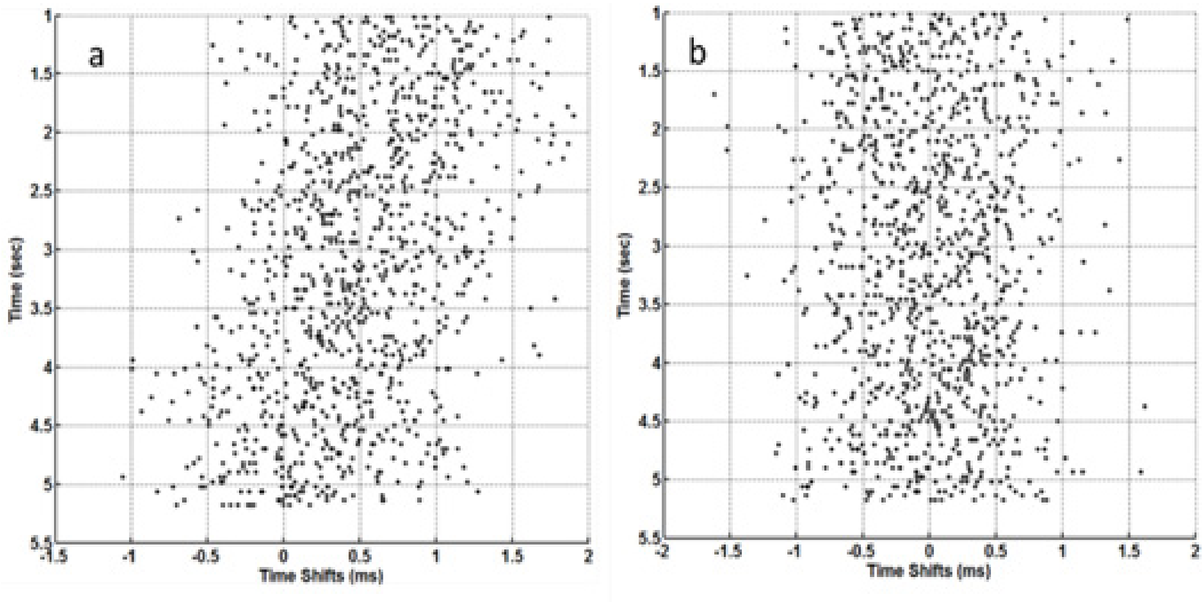

Figure 1 *Time-varying time shifts between two monitor surveys after water column statics. a) Applying traditional cross-line gradient water column statics only; b) Applying water replacement first, then cross-line gradient water column statics.*

The box-in and undershoot data types were handled in distinct manners – the goal being to register all non-prime data with prime data in order to minimize migration artifacts. The following is a description of the strategy adopted for handling each of the data types present in the facilities area.

Undershoot data: Three issues associated with the undershoot data are a challenge to compatibility with prime data: 1) Lack of near-offset data reduces the fold of full- and near-angle stacks; 2) Lack of near offset data presents a challenge in attaining a high-quality water column statics solution; and 3) geometric nonrepeatability (DSDR) is generally higher than in prime lines, leading to inferior seismic repeatability. While there is nothing we can do about the fold at near offsets, processing steps can be carefully designed to minimize the impact of the last two issues.

For undershoot lines, the nearest available offset that provides enough coverage to generate a WCS solution varies from sail line to sail line. Extensive tests were conducted to assess the best way to determine which offset should be used as reference and how to make undershoot data be consistent with the prime data. In the end, we use the first available offset independently for each undershoot sail line. We performed a partial NMO correction to 500 m and derived static shifts with respect to the baseline model at 500 m. The near-offset classes used for WCS ranged from 650 m to 1900 m.

Tiwari et al (2013) have shown that rejecting trace pairs with large DSDR can improve 4D seismic imaging. This is especially important for the undershoot data, where a large percentage of the trace pairs have a large DSDR. However, if trace rejection is based upon DSDR only, a high percentage of trace pairs is rejected and the 4D image is adversely impacted. Therefore, we have designed a trapezoid filter based on DSDR *and* seismic repeatability (NRMS) to achieve a balance (Figure 2): the rejection rate is reduced while the net effect of rejection is to improve the 4D image. The filter changes for different offsets.

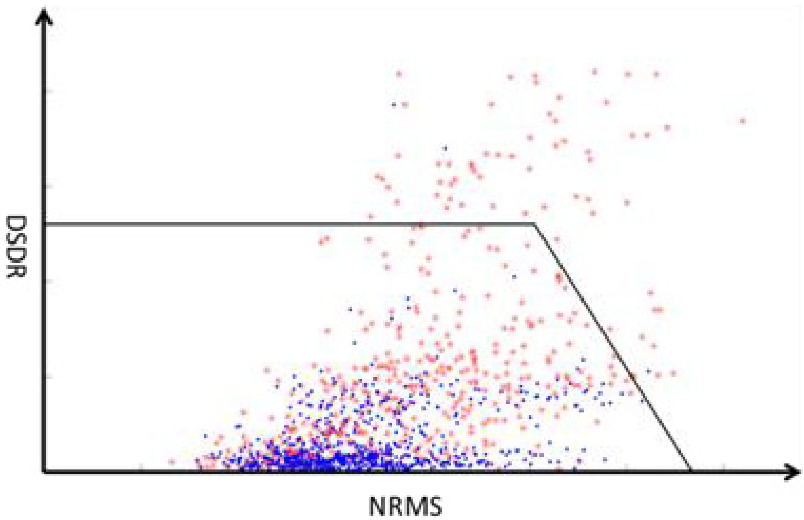

Figure 2 *Schematic plot for trapezoid filter in seismic repeatability (NRMS) and geometric repeatability (DSDR) domain. Trace pairs are plotted in the cross plot are for undershoot (red stars) and prime lines (blue dots). Trace pairs outside the trapezoid are rejected.*

Box-in data: Box-in data are single-vessel acquisition with an azimuth roughly perpendicular to the prime data. Consequently the associated ray paths are significantly different from the prime data. Both the seismic image and the travel times will be different because of different illumination. The differences between box-in and prime data vary with different offsets and different depths, dependent on the heterogeneity of the subsurface. Chu et al. (2013) have demonstrated the advantage of post-migration merging of data acquired in different azimuths. This approach is similar to the methodology used by Hatchell et al. (2012) for processing node data. For each seismic bin, the method corrects the travel time difference by applying time alignment after migration. Then, the RMS energy of the different azimuth data is compared. If RMS values are similar, the seismic data are stacked with each other. If the energy is significantly different, only the stronger of the seismic data are used. For example, in the prime data hole, the energy for the prime line seismic will be significantly lower than the box-in data. Box-in data will be chosen without contribution from the prime lines. Another scenario for which one data type is chosen over the other is when there is preferential illumination because of near-surface effects (i.e. shallow gas) (Chu, 2013).

Therefore, we chose to independently process the box-in data from the prime and undershoot data. Box-in and prime/undershoot data are merged post migration.

Two boat reverse push data: When the current is opposite to the baseline survey and the current is going toward the facility. We had to use two boast reverse push to simulate feather in the baseline survey. Similar to the undershoot data, but less severe, near offsets are missing. Water column statics has to be carefully worked to make sure they are register well with prime lines. To accommodate the reverse push lines, receiver motion correction has to be done early in the workflow, before the water column statics. Instead of correcting the receivers toward source, receivers were corrected away from the source for reverse push lines. This correction affects the arrival time up to 8 ms for the far offsets.

Results

NRMS extracted from an interval above the reservoir for the full-stack data show a mean seismic non-repeatability value of about 0.1. The repeatability in the undershoot area is on par with the prime area. The mean NRMS value is further improved to about 0.07 where there is overlap between box-in and prime/undershoot. This is the result of increased fold.

The 4D quadrature difference sections between the 2008 and 2006 monitor surveys obtained from previous processing and current processing will be compared at presentation. For the previous processing, the undershoot, box-in and prime were combined pre-migration during binning. Each selected trace pair consisted of only one data type; 'mixed' data-type trace pairs were not allowed. Migration swings are apparent near the facility areas. The data are too noisy to make reliable 4D interpretations. With current processing of the same set of data, swing noises have been greatly reduced. The 4D data now show impedance decreases in both upper and lower reservoirs, likely the result of gas coming out of solution due to pressure draw-down below the bubble point. The new processed data enable the interpreters to define reservoir fluid movement and identify future opportunities near the facility area with more confidence.

Conclusions

A 4D processing workflow has been designed to optimally handle different acquisition data types, which has resulted in improved repeatability underneath facilities. Undershoot data are more consistent with prime lines after a series of improvements in water column statics. Treating box-in and prime/undershoot separately all the way through migration enables us to better compensate for the effects of differing ray paths for different data types, consequently reducing migration-swing artifacts. The use of a combined filter of DSDR and NRMS to reject bad trace pairs optimizes the seismic coverage and seismic repeatability. Merging different azimuthal 4D data has yielded improved repeatability because of increased fold where data overlap.

References

Chu, D, G. Chen, M. Helgerud, D. Chang, Irina Gorysheva, E. Sze and A. Hohrath, Utilizing Dual Azimuth Seismic Data to meet the 3D and 4D interpretation challenges at Kizomba C [2013] *IPTC*.

A.C. Miller and M.B., Helgerud,[2009] 4D seismic repeatability: Lessons from Hoover-Madison-Marshall. *SEG Technical Program Expanded Abstracts*, 3884-3888.

P.J. Hatchell, M. Tatanova and A.C. Evans, [2012] Suppressing 4D-noise by Weighted Stacking of Up-going and Down-going Wave-fields. *74th EAGE Conference & Exhibition.*

U.K. Tiwari, M.B. Helgerud, G. Chen, C.E. Trantham, E.E. Assiak, A.O. Ejayeriese, R.E. Lory, N.C. Nwogbo, F.O. Obere, E. Kaszycka, P. Hayes and R. Schouten [2013] A Tale of Two Fields - Impact of Acquisition and Geology on 4D Seimic Data Quality. *75th EAGE Conference & Exhibition.*