Ocean Bottom Node processing in deep offshore environment for reservoir monitoring

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Abstract

To complement a 3D High Resolution streamer survey, Total E&P operated in 2008-2009 a large 3D Ocean Bottom Node (OBN) acquisition to monitor a hydrocarbon reservoir in deep offshore Angola (Ceragioli et al, 2010). Mirror node imaging has already proved to be more appropriate for 4D imaging and reconciliation with streamer data. However positioning and timing issues as well as azimuthal coherent stacking of data need to be precisely tackled for better preserving their high frequency content. In this paper we show the importance of estimating accurate time statics for nodes deployed in a deep offshore environment. Secondly we demonstrate that the concept of Offset Vector Binning using hexagonal tiles is applicable to this node data acquisition. Mirrored data migration in Common Offset Vector domain provides Common Image Gathers with preserved offset and azimuthal information, which enables azimuthal residual velocity analysis for a better stacking of information at all offsets and azimuths.

Introduction

Deep water hotspots like Angola are becoming increasingly congested with production infrastructures (like FPSO). Operators wishing to monitor production at these sites are faced with operational difficulties to perform time lapse surveys using the conventional surface streamer method. Undershooting strategy with independent source and streamer vessels navigating around obstacles may be chosen for compensating the lack of coverage, but acquisition repeatability is difficult to achieve as undershooting often provides missing short offset illuminations and inconsistent azimuth distribution. Moreover the HSE issue cannot be neglected as streamer vessel comes close to production facilities. Ocean Bottom Seismic technologies offer an attractive solution for acquiring infill time lapse seismic data as a complement to streamer acquisition to enable a full coverage of the target zone (Boelle et al., 2005).

To complement a 3D High Resolution streamer survey, Total E&P operated in 2008-2009 a large 3D Ocean Bottom Node (OBN) acquisition to monitor a hydrocarbon reservoir in deep offshore Angola. In a previous paper Lecerf et al. (2010) showed that imaging the down-going wavefield (mirror imaging) offers a better framework for reconciliation with streamer data as it provides an image of sea-floor and shallow levels, which enables an efficient calibration. In addition the down-going wavefield presents less ray path difference with streamer than the more standard up-going wavefield.

After imaging the whole up-going wavefield, comparison with HR streamer data showed a loss in the high frequency content of node data. After investigation it appeared that the root cause of the loss of high frequencies was unsolved timing issues, which have a detrimental impact on the final result. In this paper we propose new techniques to improve all processing steps which may affect the quality of stacking, namely: water layer variations, node synchronization, clock drift, node and sources positioning and azimuthal stacking velocity variations.

Seismic data description

In 1300 meters of water depth, 480 multi-component autonomous nodes were deployed with Remotely Operated Vehicles (ROV) along a 230m hexagonal grid in two distinct patches called D1 and D2. Shot sail lines were navigated on top of nodes in a dual source flip-flop sequence, in such a way that each receiver recorded data from a dense full azimuth 37.5m by 37.5m grid of shot points with a maximum offset of 2.5km. In order to analyze repeatability issues, a small size pilot zone was covered with 29 pairs of collocated nodes (average distance ≈ 5m) and two surveys were shot on top of them.

Positioning and timing issues

As this acquisition was planned within the framework of a 4D project where the very first base campaign was a High Resolution surface streamer survey, positioning and timing issues would have a strong impact on the final result.

In this deep offshore context the positioning of nodes is performed using Remotely Operated Vehicles, so that accuracy is constrained by the inherent limits of ROVs acoustic instruments. Using first break time picks enable this limitation to be overcome and has ensured a high accuracy positioning. On the other hand the source positioning does not take advantage of the redundancy which is usually obtained with surface streamer acquisitions.

As nodes are fully autonomous, timing issues are not only driven by the water column (tides and water velocity variations), but synchronization and clock drift need to be also taken into account, and last but not least, swell might also be at the origin of some time delays. We have then developed a technique which provides an estimate of these delays in one step. Figure 1 highlights, for one node gather, the time striping effect due to tides and to possible long period water velocity variation or clock drift. Associated time statics can be estimated in a shot consistent manner. Figure 2 displays these statics for two sail-lines: long periods are mainly related to tides, intermediate periods could be due to inaccuracy in source coordinates when the sail-line trajectory is not fully rectilinear, and the shortest periods are due either to swell or to noise. As displayed on Figure 3, our method also provides time delays for each node; a QC based on an estimate of velocity enables to check the validity of these delays and also to point out some nodes with abnormal behavior. Figure 4 shows the gain in coherency between receiver stacks after applying these time delays. As the whole acquisition was performed with two distinct patches, time reconciliation between the two was ensured thanks to a precise estimate of average velocity in the water column (respectively 1493.5 m/s and 1492 m/s for patches D1 and D2).

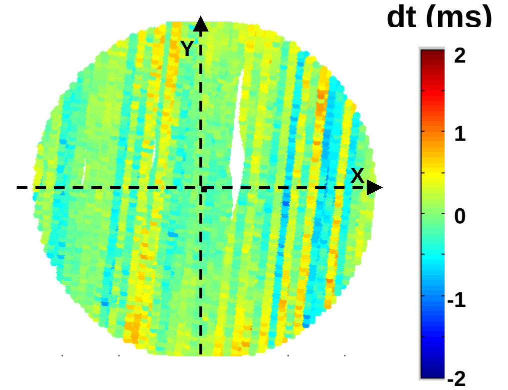

Figure 1: Time striping observed on one node collection.

Depending on their origin, statics are applied in a well adapted manner taking into account the nature of wavefield which is processed:

- tidal statics are multiplied by three for the down-going wavefield,
- for velocity related statics, also known as cold water statics, data from patch D2 are NMO corrected with their own velocity, then time shifted and inverse NMO is applied with D1 velocity,
- time delays between nodes are applied once for both up-going and down-going wavefields,
- time variations related to inaccuracies in source location should be compensated after computing new source coordinates from corrected transit times, similarly to what was done to relocate nodes.

Figure 5 shows the improvement in coherency on Asymptotic Common Reflection Point gathers when all these corrections are applied.

As this method estimates all timing information at first, it is no longer necessary to image the data with the standard common receiver gathering. With this conventional approach, time issues which are node consistent are often postponed after migration. Such a sequence does not enable to use the Common Offset Vector sorting, as this technique requires to migrate simultaneously data originating from different nodes.

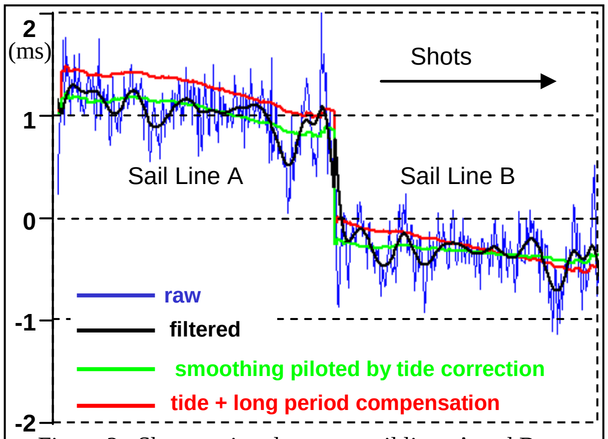

Figure 2: Shots statics along two sail lines A and B

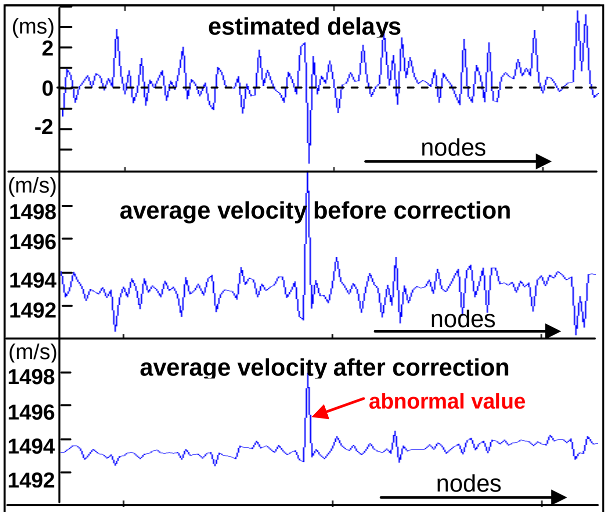

Figure 3: Synchronization delays between node records. An independent QC based on velocity estimate shows the beneficial impact.

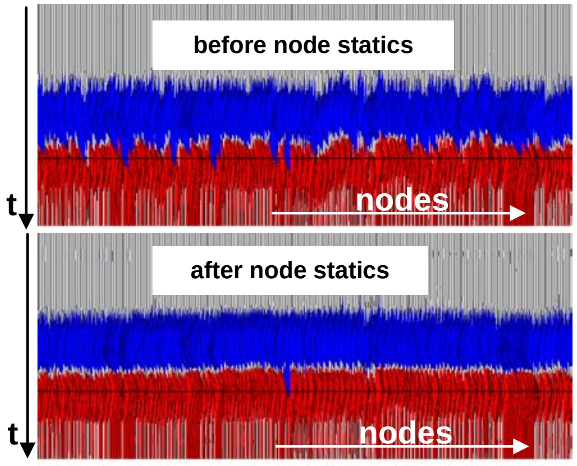

Figure 4: Common receiver near offset stack after Linear-Moved-Out : $t - V^{-1}\sqrt{X_R^2 + Z_R^2}$

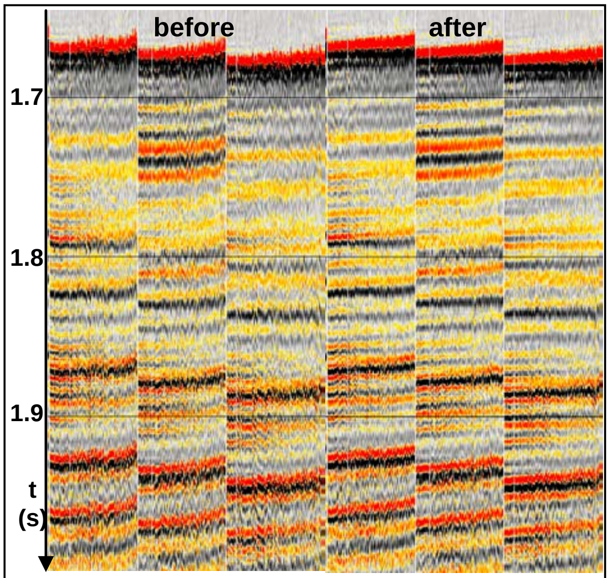

Figure 5: Mirror Asymptotic Common Reflection Point gathers before and after applying shot, receiver and cold water statics.

Azimuthal processing: Hexagonal Offset Vector Tiling

Inspired by dense WAZ land data processing in Offset Vector Tile (OVT), we have defined hexagonal tiles adapted to the nodes acquisition geometry. The OVT processing has the advantage of preserving the offset and azimuthal information even after migration, this enables to optimize the stack after applying an azimuthally variant residual velocity correction (Lecerf et al., 2009).

Figure 6 reminds the way D. Lecerf et al. (2010) have defined hexagonal tiles for a given shot stripe and an OBN receiver line. In this sketch, binning has been performed following the usual mid-point rule. A more rigorous approach will lead to a depth varying binning. For the down-going wavefield the correct Γ value is 1/3 at sea-floor, with Γ defined as $(x_D-x_S)/(x_R-x_S)$, where x_S, x_R and x_D are respectively the abscises of source, receiver and reflection point. In our study the reservoir depth is close to the water thickness, consequently the correct Γ value at target is close to 0.4. We assume that the slight over fold due to approximate binning might be compensated by the correct weighting in the migration scheme.

All single bin traces defined in a hexagonal tile are associated with a nominal offset and azimuth which are preserved through the migration according to offset vector coordinates. Each COV volume is migrated independently, after migration Common Image Gathers (CIG) collect traces at the imaged point from all migrated COV cubes. Snail organization highlights kinematic azimuthal variations which can be compensated for by azimuthally variant residual velocity analysis, yielding then an optimal stacking of data.

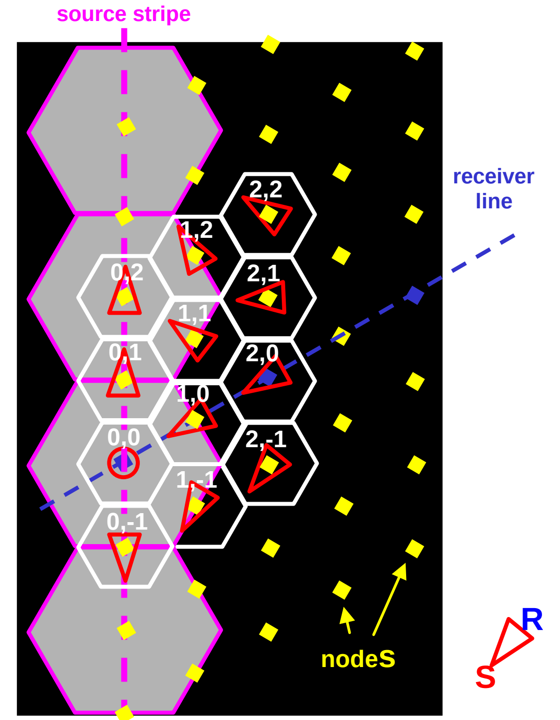

Figure 6: Hexagonal tile definition based on CMP binning. Red arrows define the source-receiver directions.

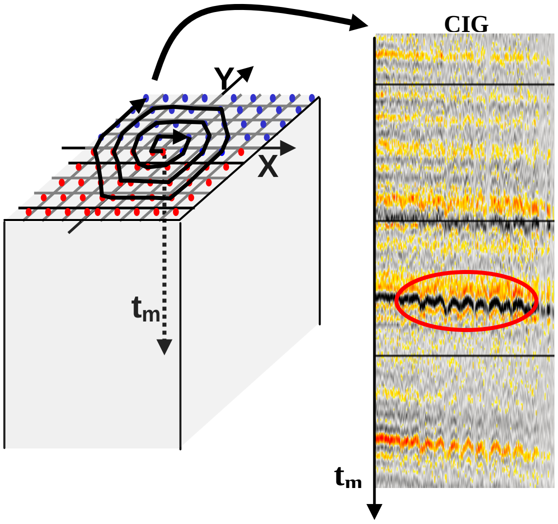

Figure 7: Common Image Gather in snail organization: in each radial offset class, traces are sorted according to increasing azimuth. Evidence of kinematic variations versus azimuth can be seen.

The 4D issue

In previous sections we have shown that it is possible to apply corrections to compensate positioning, timing and velocity inaccuracies, which are fundamental issues for 4D studies. As mentioned earlier this node survey was performed in order to complement a 4D High Resolution streamer monitor survey, consequently the node image can:

- either be considered as part of this monitor and will have to be compared with base streamer data,
- or be considered as a base for future node acquisitions.

These two scenarios lead to address very different questions.

In the first case Lecerf et al. (2010) identified the down-going node wavefield as being more appropriate for reconciliation with streamer dataset. Firstly, the overburden mirror image is very valuable for computing calibration operators, because no production effect is expected in this time window; secondly the down-going node wavefield has less ray path difference with streamer data than the up-going wavefield. In order to improve the similarity between the down-going node and the streamer data we proposed to transform both datasets into the angle-domain to get equivalent stretch.

In the second case first node data will be compared with a new node dataset, once again we think that the down-going wavefield is more appropriate for 4D studies as it provides an image of shallow layers which can be used for calibration. One might think that node repeatability would then be an issue for 4D studies as nodes are retrievable devices; but thanks to the repeatability test which has been previously described, a rough comparison was possible between four possible node surveys (R1S1-R1S2-R2S1-R2S2). Figure 8 shows that, except for a low frequency noise, the node repeatability is better than source repeatability, hence demonstrating the suitability of nodes for repeated time-lapse surveys.

Conclusions

In the context of deep offshore development, node technology seems to be a valuable solution when large infrastructures obstruct the reservoir illumination from the sea surface. The imaging of down-going wavefield has a high potential for 4D studies as soon as positioning, timing and velocity issues are correctly addressed. A data driven technique has been developed and successfully tested to handle shot, receiver and cold water statics. The concept of Offset Vector Binning using hexagonal tiles is applicable to this node data acquisition, and enables to correctly stack contributions coming from all offsets and azimuths. Finally it has been shown that receiver repeatability, often seen as a potential weakness of retrievable devices, reaches a very acceptable level in such deep offshore environment.

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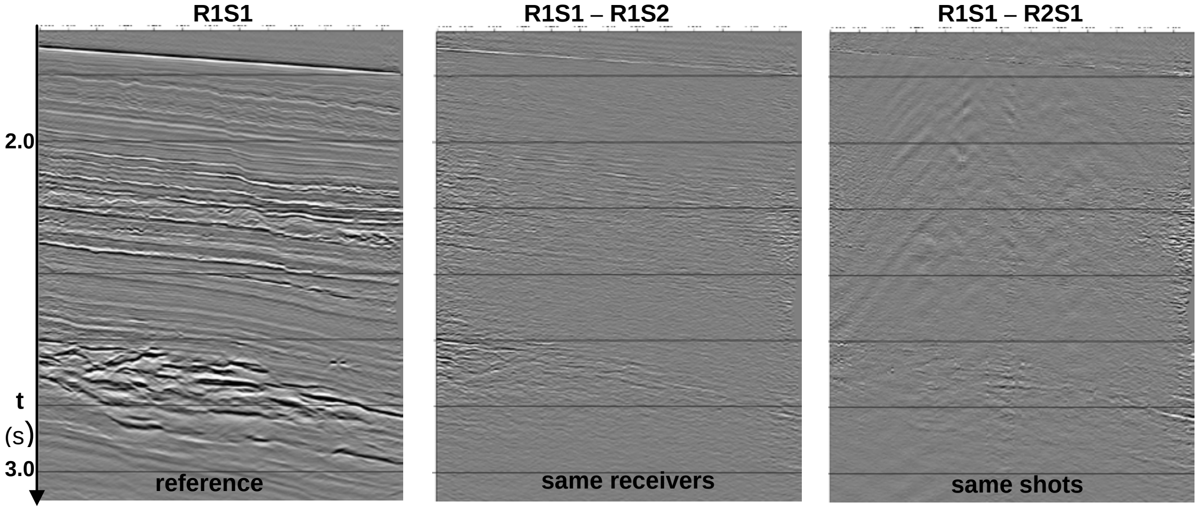

Figure 8: The pilot repeatability test. Two surveys S1 and S2 were shot on top of collocated pairs of nodes (R1 and R2). Four images were built after imaging the down-going wavefield. It enables to compare node vs. source repeatability.