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4D Ocean Bottom Node Decimation Study over the North Sea Golden Eagle Field

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Summary

Ocean Bottom Node (OBN) surveys provide full azimuth coverage with long offsets and rich bandwidth. These attributes improve the resolution, stability, and steep-dip fidelity of seismic images derived from the data, which are desirable for 4D monitoring of a producing oilfield. However, acquisition of OBN data is expensive, and it is important to understand the impact of receiver density (which directly affects the acquisition cost) on the resultant seismic image. Here, using a dense North Sea 4D dataset, we demonstrate the impact of node density on both the 3D and 4D seismic image by migrating progressively sparser node configurations (including 50x300 m and 300x300 m cases) and comparing the results. It is shown that 4D image quality is more sensitive to changes in node density than is the 3D image. Furthermore, an acceptable sparse survey for 3D imaging may be inadequate for 4D applications. Attempts to mitigate the effects of reduced node density with processing methods show partial success for 4D imaging, but serve to highlight the importance of suitable node density in 4D survey design for North Sea OBN data. Our tests suggest a minimum node density of 100x300 m is necessary for this 4D example.

Introduction

Ocean Bottom Node (OBN) surveys provide full azimuth coverage with long offsets and rich bandwidth. These attributes improve the resolution, stability, and steep-dip fidelity of seismic images derived from the data, which are desirable for 4D monitoring of a producing oilfield. These have been the key drivers for OBN take-up in the North Sea. In order to cover a sufficient area whilst keeping costs down, OBN data are often acquired with sparse receiver geometries. Typical receiver spacing can range from 50m (dense) to 300-400m (sparse). With recent improvements in node inventories, smaller node sizes, and more efficient deployment via node-on-rope acquisitions, it is now feasible to efficiently deploy nodes at higher densities. With reduced acquisition effort and costs, OBN acquisition is now a viable option for many assets. Bunting & Moses (2016) provide an overview of recent trends in OBN acquisition as well as the benefits when compared to towed streamer surveys.

However, although decreasing, the cost of an OBN acquisition is still high and it is therefore important to understand the impact of receiver density (which affects the acquisition cost) on the resultant 3D and 4D seismic quality. Shot geometries typically use a 25 or 50m regular or staggered grid, but it is the receiver density that has the largest impact upon the processing and final image quality as seabed receivers generally contain significant levels of receiver-specific noise and are usually less well sampled. A suitable receiver density is required for optimal imaging whilst keeping costs down and allowing the receiver spread to cover the spatial extent required.

Here, using a dense North Sea 4D dataset over the Golden Eagle field, we demonstrate the impact of OBN density on both the 3D and 4D seismic image by migrating progressively sparser node configurations (including 50x300m and 300x300m cases) and comparing the results. During the course of processing, a strong denoise process is used to improve the 4D result. This is applied to the various decimation tests in order to assess its effectiveness on sparser node density datasets and determine whether it might mitigate some of the effects of reduced node sampling.

Through these tests it is shown that the stacked 4D image quality is more sensitive to changes in node density than is the 3D image, and that an acceptable sparse survey for 3D imaging may be inadequate for 4D applications. Attempts to mitigate the effects of reduced node density with processing methods show partial success for 4D imaging, but serve to highlight the importance of suitable node density in 4D survey design for North Sea OBN data.

Method

The Golden Eagle field is located 90km North of Aberdeen in water depths of 100m. The field has two target reservoir sands – the Lower Cretaceous Punt sands and the Upper Jurassic Burns sands. Multiples originating from the water bottom and a rugose shallow lignite layer combine with strong Vz noise (i.e. receiver-specific noise present on the Z geophone but not the hydrophone, a component of which is Scholte waves) to form the main processing challenges within the datasets. The expected 4D fluid production signal at target comprises a small impedance change, although it is clearly identifiable in the 4D seismic difference created with the dense 50x300 m receiver array which agrees with the modelled 4D signal. Baseline and monitor surveys were acquired in 2015 and 2018 with receivers spaced 50m along and 300m between lines, covering a total area of 74km^2. Shots were acquired on a staggered 25m grid. Both acquisitions had the same overall shot and receiver geometry. Figure 1 shows the receiver layout as well as the associated Common Offset Vector fold distribution.

The Golden Eagle survey therefore allowed for the impact of node density on the seismic image to be assessed in both 3D and 4D through progressive reduction of the receiver density. Higher densities are expected to give an improved image through stronger, more continuous imaging with less footprint, a better cancellation of receiver domain sources of noise (residual Vz noise and multiple energy), and higher signal to noise ratios. A previous study on the baseline dataset had demonstrated this for 3D imaging (Wilson & Dutton, 2019).

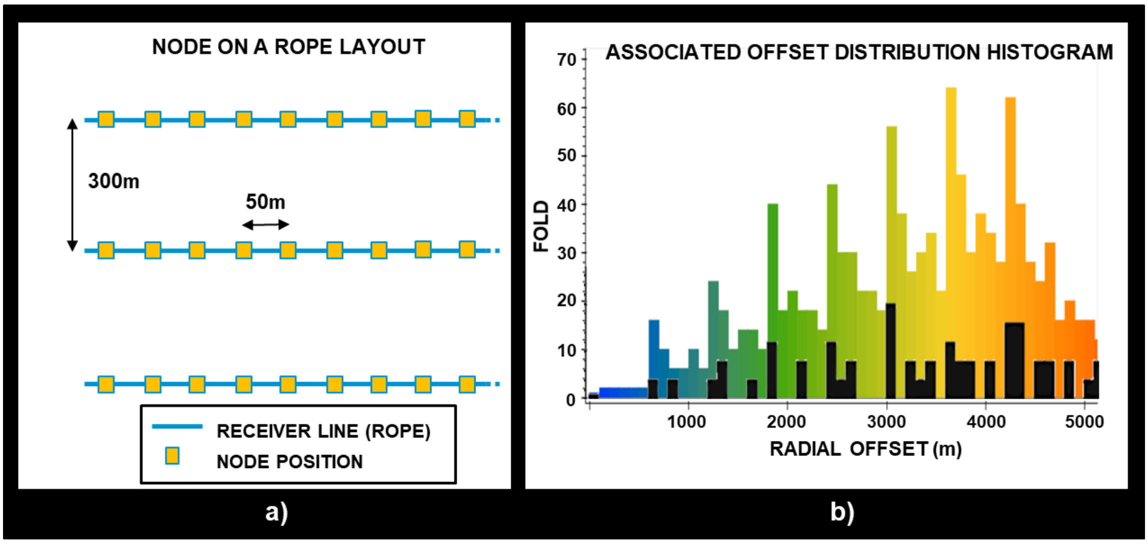

Figure 1 *a) Golden Eagle receiver layout. b) Resultant 100m offset class distribution based on 100x600m offset vector tiles. Shown for reference in black is the offset distribution for a decimated 300x300m node acquisition (the sparsest decimation tested, offset vector tiles of 600x600m). The clear jumps in fold are caused by the 300m spacing of the receiver-lines, and the denser acquisition clearly fills the near offset fold distribution much better than the sparse geometry.*

A test area consisting of 10 receiver lines was chosen over an identifiable 4D signal. The data up to migration had been processed through a standard North Sea OBN processing sequence including initialisation (shot & receiver repositioning, tidal, water column and clock drift corrections, residual rotation), regularisation, denoise, wavefield separation, and demultiple. Care had been taken at all stages to ensure that the 4D signal was unharmed. The processing is largely carried out in the receiver domain, node by node, and therefore the impact of node density to this point has little discernible impact upon the result. Higher densities along the receiver line do however open up the potential for shot domain processing which is a powerful method of attenuation of receiver specific noise such as Scholte waves. Sparser acquisitions prohibit this and are traditionally denoised in the receiver domain. The data is then Kirchhoff migrated in the Common Offset Vector domain at the acquired node density (50x300m offset vector tiles) and at progressively reduced node densities, with the sparsest being 300x300m migrated on 600x600m tiles. The migrated datasets were finally converted back to the time domain and stacked. The results are shown in Figure 2 and Figure 3.

Processing methods are available which aim to reduce the 4D noise levels and remove artifacts associated with a sparser acquisition: a strong curvelet domain denoise (Peng & Huang, 2014), guided by the stack, was applied pre stack to the migrated datasets in an attempt to recover the underlying 4D signal and mitigate some of the effects of the sparser densities.

Results

In 3D (Figure 2) the structure at target is similar regardless of the receiver decimation, although there is clearly additional noise and a slight degradation of the continuity of signal events as the node density decreases. For structural interpretation purposes, the sparser results are poorer but sufficient. However, the 4D image is significantly degraded by the sparser configurations; going from the densest to the intermediate node densities, the noise levels increase, although the 4D signal is still recognisable. Increasing the node spacing further to 300m along-line spacing results in a 4D signal that cannot be reliably interpreted and is difficult to reconcile with the 4D result seen at higher densities. NRMS mean values calculated between the decimated datasets and the 300x50m dataset equivalent give an indication of the signal degradation/higher noise levels associated with the decimation, these are all significantly larger for the 4D difference than for the 3D comparisons (Figure 2). The 4D NRMS levels at target reflect these observations with globally higher values and a noisier appearance for sparser receiver geometries (Figure 3).

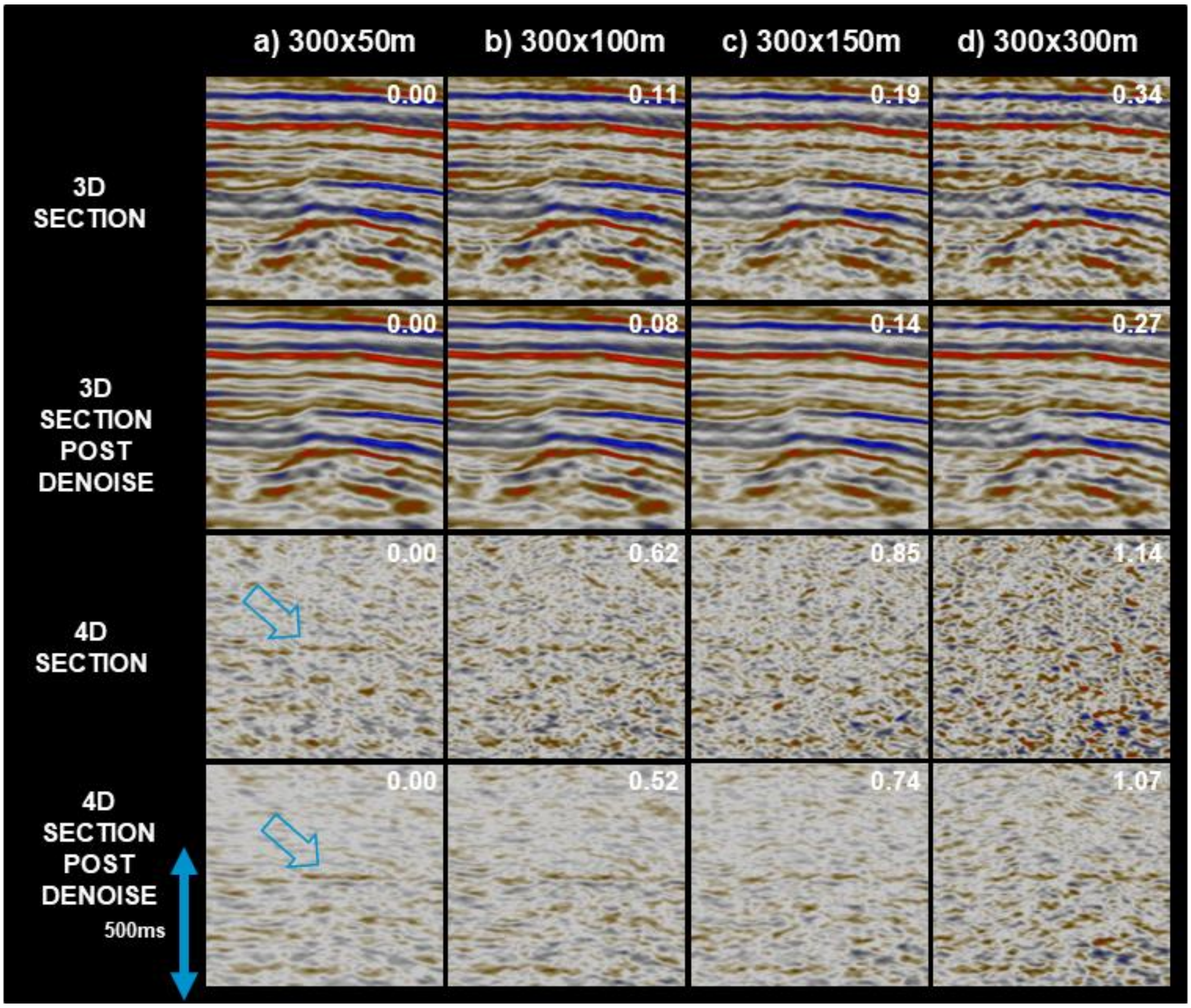

Figure 2 *Images showing the 3D Section (upper) and the 4D section (lower) with and without Curvelet Domain Guided Denoise for: a) 300x50m node density, b) 300x100m node density, c) 300x150m node density, d) 300x300m node density. Numbers provide the mean NRMS level between the dataset and the 300x50m dataset equivalent over a 100ms window at target. 4D fluid production signal is identified by the blue arrows in the 300x50m images.*

On the 50x300m node spacing dataset, the curvelet domain guided denoise successfully cleans up the 4D signal with a significant reduction in 4D noise and no appreciable harm to the 4D signal visible in the data. A similar impact is seen at other node densities, including the sparsest. The 4D time slice of the 300x300m node spacing dataset is, after denoise, recognisable as the same event seen at 50x300m node spacing, although it is clearly noisier and interpretable with lower levels of confidence than is achieved with the higher node density. These denoise tests are encouraging for application in situations where the underlying 4D signal is unclear or has a low signal-to-noise ratio.

The results in Figures 2 and 3 illustrate the effect of variable receiver fold for imaging with a given velocity model. Changes in node density would also impact the velocity model building process, however, as reflection tomography benefits from closer node spacing and therefore a finer sampling of offsets for residual moveout characterisation. Greater node density also helps to suppress acquisition footprint in applications of full waveform inversion. It is not clear from these results what impact the change in node density would have on the velocity model in this survey area.

Conclusions

A set of decimation tests were run on the North Sea Golden Eagle dataset, the results of which demonstrate why node density is critical for a good quality 4D result that can be confidently interpreted. Processing can help mitigate against some of the effects of a sparse node density but is unlikely to reach the quality achieved with a higher acquisition density. Based on these results, 300x100m node spacing provides a good compromise between spatial receiver coverage and 4D image quality. This density also allows for processing to be applied in the common-shot domain to further leverage receiver-to-receiver differences in noise. This is particularly important in the North Sea where the shallow water-bottom creates datasets swamped by multiple energy and highly contaminated with Vz noise.

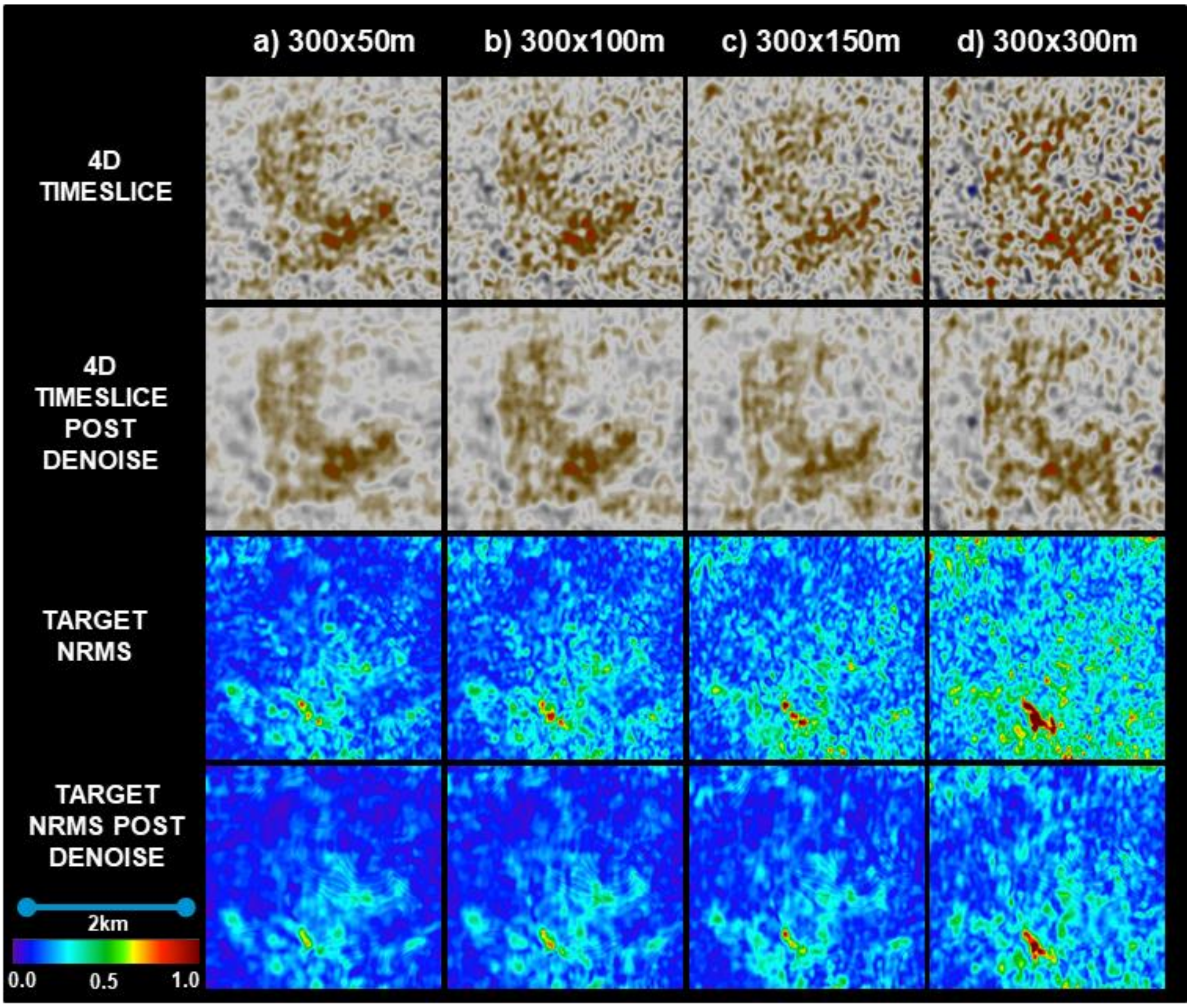

Figure 3 *A time-slice through the 4D Difference (upper) and the 4D NRMS in a 100ms window at target (lower) with and without curvelet domain guided denoise for a) 300x50m node density, b) 300x100m node density, c) 300x150m node density, d) 300x300m node density*

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