# 4D Using Non-repeated OBS Acquisition Systems on the Njord Field

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## SUMMARY

Seismic monitoring has been challenging on the Njord field. The rather weak 4D responses related to production have been difficult to detect due to the noise level in the streamer 4D seismic data and due to dominant overpressure effect after injection. The streamer seismic data was replaced by Ocean Bottom Seismic (OBS) in 2010 and the first repeat was performed in 2014. The 4D noise level is expected to improve using Ocean Bottom Seismic (OBS) due to repeated receiver positions and better coverage closer to installations. However the sensor technologies and the seismic source were not repeated and we show how we accommodated for this. In addition, we will show how the lack of shallow overburden illumination through the OBS acquisition was compensated for using streamer seismic data and imaging with multiples.

## Introduction

The Njord field, discovered in 1985, is situated in the southern part of the Haltenbanken area in the Norwegian Sea. Hydrocarbon-bearing formations are of Middle Jurassic Ile formation at the top, Lower Jurassic Tilje formation in the middle and Lower Jurassic Åre formation at the bottom. Seismic monitoring, using streamer seismic, has been challenging due to overpressure effect shadowing rather weak production 4D responses and the noise level in the streamer 4D seismic data (Østmo *et al.*, 2013). The expected 4D effects (2010-2014) are impedance changes due to fluid movement and gas out of solution effects.

OBS are expected to give higher quality 4D due to repeated receiver positions and better coverage closer to installations (Eriksrud, M., 2014, Watts *et al.*, 2011). A study by Wei (2014) concluded that different sensor technologies (geophones vs MEMS accelerometer) performs equally well and that other factors, like coupling and stability are more important. The base 4D time-lapse OBS was acquired in 2010 using ION's Vectorseis system. It records the acceleration of the ground displacement rather than its velocity and the derivative of the pressure signal using an analogue front-end circuit. The monitor survey in 2014 was acquired with Fairfield Nodal using standard geophones (measuring velocity) and hydrophones (measuring pressure).

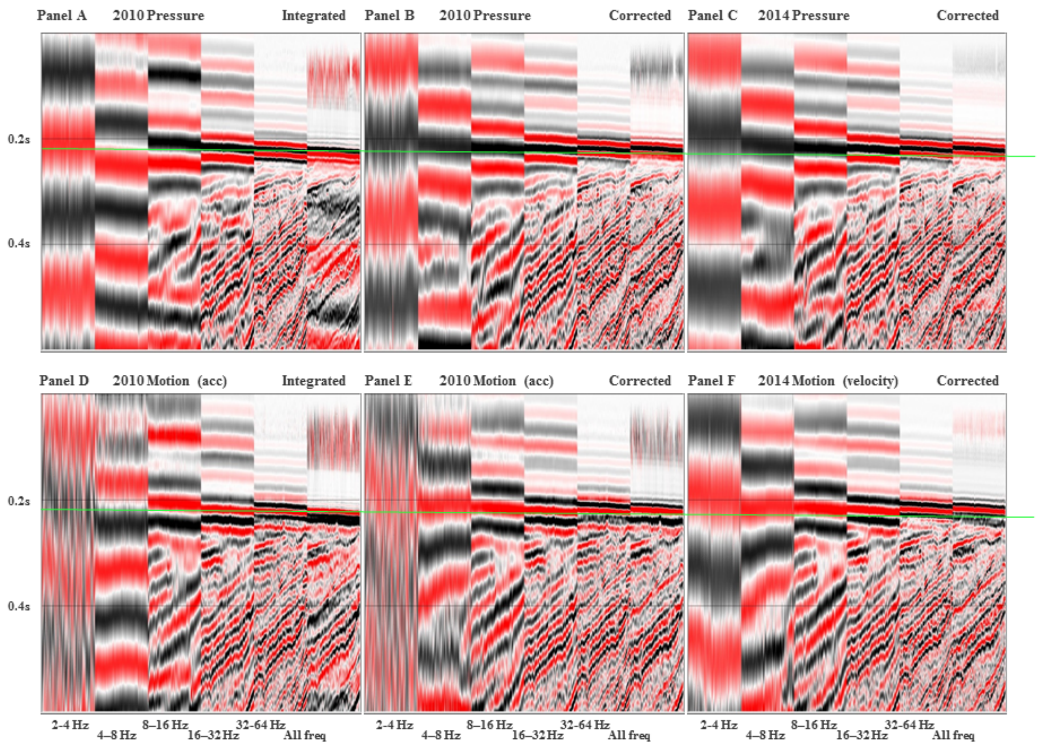


***Figure 1** Comparisons of the 2010 and 2014 sensors. Receiver stacks in frequency panel using near-offsets. Panel A and D are before designature, calibration and 4D matching (integration only applied). Panel B, C, E and F are after calibration, 4D matching and designature (corrected).*

Conventional OBS processing consists of extracting the upgoing wavefield using a summation (PZ summation) of co-located pressure sensors and calibrated motion sensors (Soubaras, 1996). The calibration includes removing differences between measuring pressure/ motion and local coupling effects. The strategy for the calibration in the Njord processing was to combine calibration and 4D matching. In this processes we needed to pair receivers based on distance. For each paired receiver we performed 4D navigation binning, which equalized the shot coverage.

With the sensors at the seabed the shallow subsurface is not properly sampled and the overburden will not be properly imaged using primary only data. Pre-migration de-multiple consisted of adaptive subtraction of 3D wave equation multiple models. A shallow image is needed for this method to predict multiples from the shallow subsurface. In addition we need shallow full-angle gathers for velocity model building. In the Njord case we utilized a streamer dataset for the reflectivity model and velocity model building in the main processing and tested imaging with multiples for future possible overburden imaging.

**Source corrections**

Source signatures, with its bubble tails, usually appear stronger on OBS compared to streamer and limit the data-windows that can be used for the subsequent calibration (Kristiansen *et al.*, 2015). We used near offset data and separated the wavefield in up- and down-going components and extracted the source signature from the de-ghosted version of the down-going wavefield, above the seabed. This simple approach worked well, aided by the water-depth of ~300m and variability in the near-surface geology. Figure 1 shows the application of de-signature (panel A/B and panel D/E), with the most visible effect on the pressure sensor on all frequency panels.

**Instrument corrections and calibration**

The calibration was done in three steps; deterministic corrections, coupling corrections and corrections to remove receiver ghost and receiver side multiples. The deterministic corrections were based on lab-measured responses and were designed to output flat spectrum and constant phase. Figure 1 shows the comparisons in frequency bands, with good match for the pressure sensor (panel B/C). The motion sensor direct arrival is not perfectly match (panel E/F), but a zoom focused on the primary event (Figure 2) shows good match above 4Hz.

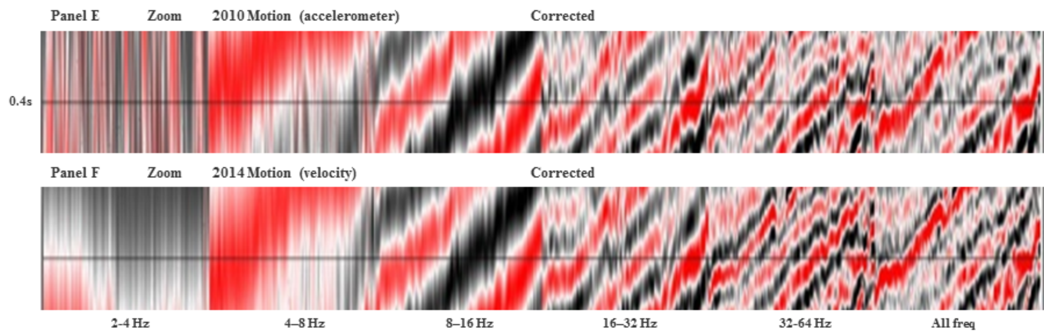


***Figure 2*** *Zoom of figure 1 highlighting the match of primary reflectors on the motion sensors.*

The coupling variability was removed using surface consistent amplitude correction (SCAC) of the 2010 and 2014 pressure sensor. Some frequency dependant coupling effects were observed on the accelerometer (2010) compared to the velocity (2014) sensors. Semi-global 4D matching operators were designed for the accelerometer motion sensor (compared to velocity motion sensor), with receiver line to receiver lines variation.

After careful testing of different demultiple techniques and combinations, we found that the most effective demultiple route was to remove all receiver side multiples in the PZ summation. To achieve this we calculated calibration scalars based on the pressure/velocity RMS ratio of the near-trace direct arrival and applied correction to the motion sensor. In practise this means that each motion sensor was scaled up with individual scalars before PZ summation. The near-trace direct arrival for the 2010 survey had in areas over-saturation problems. As an alternative to calibration to the hydrophone, the calibration scalars were extracted using the RMS ratio between the 2010/2014 motion sensors. In this process the coupling variability was removed as the pressure sensors were already corrected using SCAC. After this correction, the receiver ghost and receiver multiple energy in the pressure and motion sensor were comparable for near-angle data (we have assumed vertical incident at the seabed) and most important they were comparable in 4D sense.

## Result

In our case we relied on one of the surveys having a clean recording of the direct arrival for narrow offset. This is necessary in order to extract the farfield signature and accurately removing the bubble energy. When the farfield is extracted on one survey, other surveys can be 4D matched using other parts of the data. Leaving non-repeated bubble energy in the data is commonly seen as horizontal stripes in the final 4D difference. These horizontal stripes, when coinciding with the real 4D response, can severally damage the quality. When non-repeated source and instrument effects are removed from the datasets, the subsequent calibration is straight forward as long as the receiver locations are well repeated. The calibration steps, done for each receiver individually, are locally data-dependant. We assumed that paired receivers are co-located and that the shallow geology and local coupling are the same. The distance between 4D paired receivers was on average ~10m, but at extreme ~25m (mostly in x-line direction). We experienced that in areas with poorer repeatability and varying shallow conditions manual editing/corrections were required.

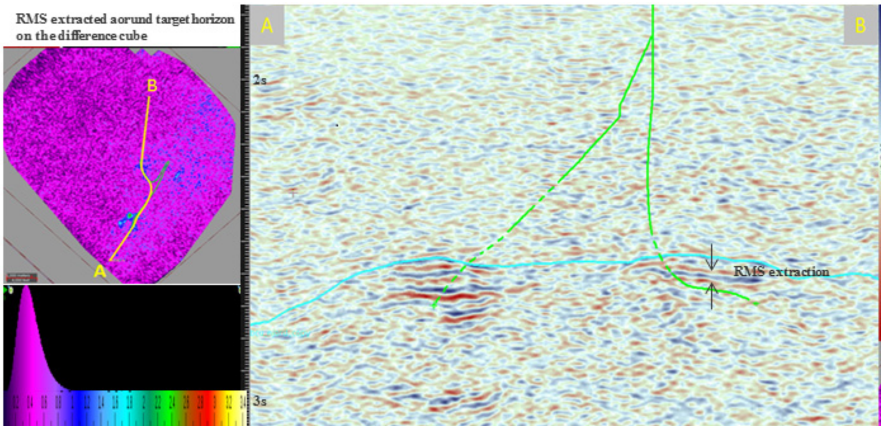

***Figure 3*** *Example line through two main 4D responses (below BCU marked in cyan) corresponding to production effects.*

The observed 4D responses (see figure 3) have relative low noise level and are consistent with expectable modelled 4D effects presented in (Østmo *et al*., 2013). The largest observed 4D response agrees with the production history of a compartmentalised segment in the south-west area of the field. The best 3D image was achieved using a multi-azimuth offset-class Kirchhoff depth migration. No significant reduction in 4D noise was observed by performing further 4D binning in offset-classes or azimuth selection prior to migration. We believe that we have achieved good 4D response in the frequency range 4-64Hz, removing the effects of the non-repeated acquisition.

To improve the areal coverage and to produce full angular gathers, a depth imaging solution exploiting multiples was tested (Lu *et al*., 2015). The method uses all orders of multiples in the data to extend the illumination in the shallow overburden and eliminate the footprint typically observed in OBS acquisitions. The data used is direct PZ-summation data which is only pre-conditioned with appropriate de-noise. Figure 4 shows a promising result in the overburden, with no expected 4D difference.

## Conclusion

The processing sequence was tailored to remove difference in sensor technologies and survey layout. We found that the velocity and accelerometer sensors had good 4D repeatability above 4Hz. The critical factors were getting the lab-measured instrument responses and removing the source imprint. Repeating the receiver positions were critical for stable results and reducing the need for manual work. Nonetheless fast turnaround is challenging to achieve due to the 4D processing being done at the very early stages of processing. For repeated acquisition system, with good near-trace direct arrival recording, the need for co-processing at the early stage would be reduced. In situations where streamer data is not available the shallow image (missing from OBS) can be retained from exploiting the multiples for imaging. The 4D result confirms that careful 4D processing, focusing on 4D matching, 4D binning, demultiple, designature and noise removal enables the extraction of valuable and successful 4D response from a non-repeated acquisition system.

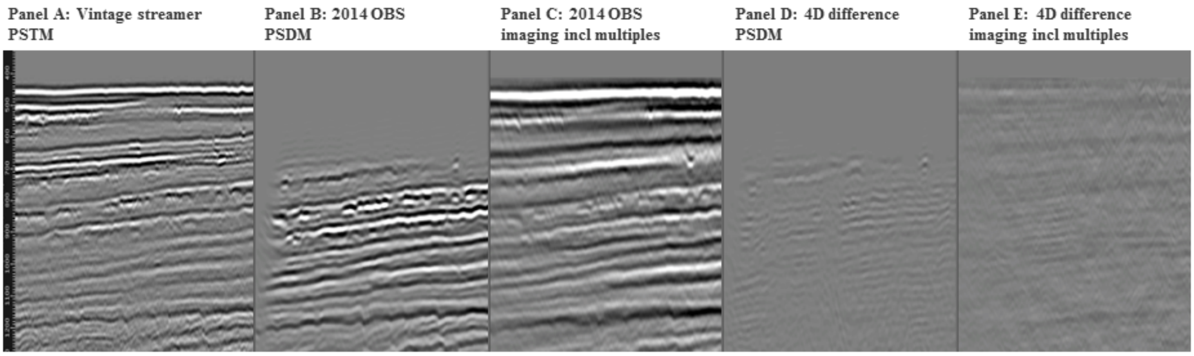


***Figure 4*** *Shallow image and 4D difference using different datasets and imaging techniques. Panel A: Vintage streamer data, Panel B: 2014 OBS production PSDM, Panel C: 2014 OBS Imaging including multiples and Panel D-E 4D differences. All images displayed in time.*

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**References**

S.Østmo & P.J. McFadzean [2013]. Reliable 4D Seismic Interpretation at the Njord Field - the Importance of the Petro-elastic Model *75$^{th}$ EAGE Conference and Exhibition,* Expanded Abstracts.

J. Wei [2013]. Comparing the MEMS accelerometer and the analog geophone. *The Leading Edge,* **32**(10), 1206-1210.

M. Eriksrud [2014]. Seabed permanent reservoir monitoring (PRM) – A valid 4D seismic technology for fields in the North Sea. *First Break,* **32**(5), 67-73.

R. Soubaras [1996]. Ocean-bottom hydrophone and geophone processing. *66th Ann. Internat. Mtg., Soc. Expl. Geophys*., 24-27.

S. Lu, A.A. Valenciano N. Chemingui & D.B. Lecerf [2015]. Separated Wavefield Imaging of Ocean Bottom Seismic (OBS) Data *77th EAGE Conference & Exhibition 201.5*

P. Kristiansen, D. Dangle, E.P. Andren & N. Cockrell [2015]. Deepwater OBN and Source Designature – Using the Information in the Data and Improving the processing. *77th EAGE Conference & Exhibition 2015.*

G.F.T. Watts & G. Beaudoin [2011]. Cables and Nodes - Evaluating Today's Seabed Seismic Aquisition Toolkit" *EAGE Workshop on Permanent Reservoir Monitoring (PRM)-Using Seismic Data 2011*, Trondheim, Norway.