Can we reduce significantly the number of OBN by using Full Wavefield Migration?

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Abstract

This paper analyses the ability of Full Wavefield Migration (FWM) algorithms for providing an extended illumination for imaging without the OBN positioning constrain. Using deep-water OBN datasets, we investigate the effect of minimal sensor distributions on the resolution of the seismic image. Unusual OBN acquisition parametrization such as very limited aperture, extensive separation distance and innovative "donut" layout designs are investigated and discussed. The results demonstrate that the Full Wavefield Migration algorithm allows the reduction of OBN density, enabling a large distance between receivers and providing more geometry flexibility without compromising the image quality. An innovative OBN acquisition with a "donut" design is proposed for combining velocity modeling using refracted and diving waves (FWI) and imaging with Full Wavefield Migration. Reducing the number of nodes deployed for the same final image quality can positively influence the economics of an OBN acquisition survey.

Introduction

Reservoir imaging and monitoring using marine seismic data has always been a challenge when production infrastructures are installed in the vicinity of the field. Ocean Bottom Node (OBN) acquisition takes advantage of decoupling seismic sources and recording sensors for offering dense shooting, wide azimuthal illumination and long offsets in congested marine environments. Because the nodal recording systems are laying on the seafloor, the OBN deployment requires complex and expensive operations, especially in a deep-water environment. Production installations set on seafloor (anchors, flow line, wellhead, etc.) add further operational challenges and extra costs in order to provide the desired regular OBN layout geometry.

Reducing the number of nodes deployed can directly impact the economics of an OBN deployment. In the other hand, a critical number of sensors are essential in order to guarantee a sufficient fold of seismic reflections. Optimum receiver spacing requirements for seabed acquisition have been documented in the literature. Typically, a modern sparse OBN geometry may have a receiver distance separation between 200m and 300 m when the up-going wavefield is used for imaging (primary reflections). In a deep-water environment, the usage is to exploit the down-going wavefield with mirror imaging, which allows the recording grid to be sparser. Nevertheless, 500 m separation seems to be an established maximum for getting a decent signal-to-noise ratio and preserving the imaging resolution.

The parametrisation of the OBN grid is not the only criteria analysed for providing a good reservoir image. The sensor location relative to the target and the extension of the receiver patch should be assessed during the feasibility study using seismic modeling tools. The surface covered by the sensors is then defined to ensure correct illumination of the targeted reservoirs.

This study analyses the potential of using Full Wavefield Migration (FWM) algorithm for breaking the constraint of density, geometry and location of the seabed OBN layout. Using real dataset of a deep-water West Africa OBN survey, we simulate and investigate the impact of various alternative sensor geometries on the resolution of the seismic image. Radical OBN acquisition parametrization such as very limited aperture, extensive separation distance and original “donut” layout designs have been tested.

Full Wavefield Migration for OBS dataset

Previous studies, using Ocean Bottom Sensor (OBS) datasets from a Permanent Reservoir Monitoring (PRM) pilot project in the Brazilian deep waters, have demonstrated the illumination benefit of including all the recorded sea-surface multiples in a 3D and 4D imaging process (Lecerf et al., 2015, Lu et al. , 2015). The methodology, named Separated Wavefield IMaging (SWIM), was initially developed for streamer data and was later adapted to OBS datasets. The concept has been extended in order to include the primary reflections in an integrated process (Lu & al., 2018). As both primaries and multiples are combined simultaneously, the method is defined as Full Wavefield Migration (FWM). To summarize the multi-wavefields imaging principle, the source wavefield composed from all recorded data is forward extrapolated, the receiver wavefield composed from the same recorded data is backward extrapolated and an image is constructed by applying a deconvolution imaging condition of the two wavefields.

FWM imaging makes use of primaries and every order of sea-surface multiples available in the data. The illumination, retrieved from a single source-receiver pair, contains numerous hit points at the target level. In fact, applied to OBN data, the methodology transforms every shot pair into a virtual sea-surface source-receiver system. Consequently, the illuminated area is essentially defined by the location of the seismic sources and the maximum order of multiples recorded. Some receiver decimation studies have been published demonstrating the potential of such imaging techniques for Ocean Bottom Cable (OBC) acquisitions in shallow water context (Van der Burg et al., 2018).

Framework of the deep-water OBN imaging study

In deep offshore West Africa, an OBN survey has been acquired using 1200 receivers with a water depth around 1500 m. The geometry and the density of the OBN layout has been optimized for imaging the reservoir using the down-going wavefield with a Kirchhoff mirror migration algorithm. Two node grids density have been defined; on the top of the reservoir, the seabed receivers are distributed over a hexagonal grid of 300 m x 346 m (noted the “core”), while a “ring” with sparser receiver grid of 600 m x 346 m was deployed around the “core”. The external sparse ring was necessary to preserve enough aperture and to insure satisfactory illumination on the edge of the reservoir. For computing practicability, our imaging illumination study involves a subset of the initial dataset, choosing 350 OBNs. The selected OBNs simulate the original design with both density distributions, a “dense core” and a “sparse external ring”. The pilot area represents approximately a third of the initial OBN area (Figure1).

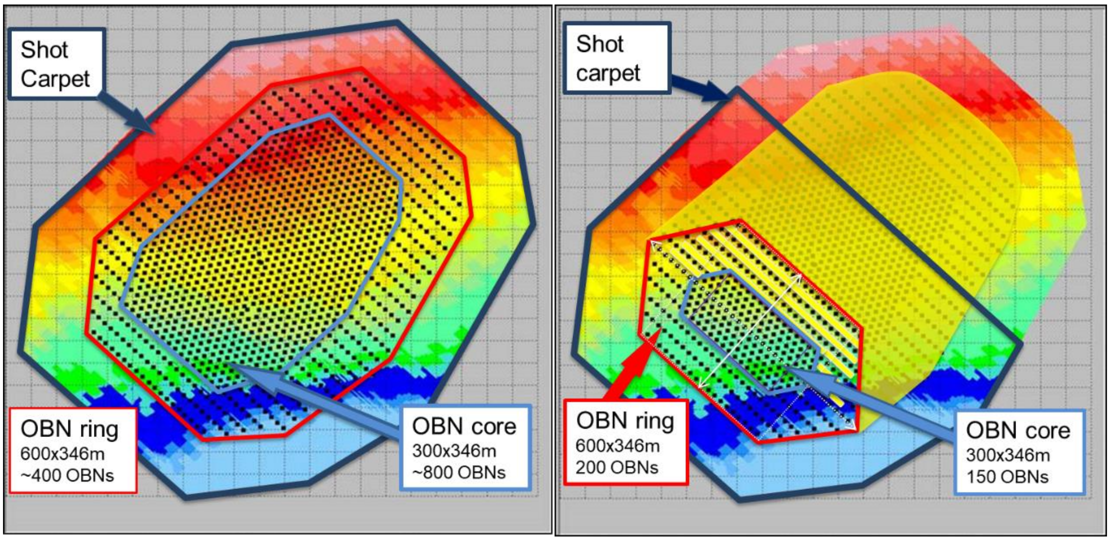

Figure 1: *Left, full survey design. Right, selection of 350 OBNs simulating the same design.*

One of the objectives for this study is to demonstrate the ability of the Full Wavefield Migration technique to extend the image aperture despite a minimal node layout. To do so, we analyse, in the pilot area, the illumination impact on the reservoir image independently for the core and the ring.

OBN aperture reduction

The first illumination analysis consists of eliminating OBNs and preserving only the 150 receivers included in the core area. We run in parallel a conventional one-way wave-equation migration (WEM) using the down-going wavefield (mirror imaging) with the same selected subset of OBN data.

Four images are generated corresponding to the two migration algorithms, WEM and FWM, with both OBN layouts (Figure 2). The top row displays the depth slice images using all OBN in the pilot area, including the core and the ring (350 OBNs), produced by WEM mirror imaging (left) and by FWM imaging (right) respectively. The bottom row represents the depth slice images created with sensors included in the core only (150 OBNs). The red hexagon symbolises the layout area of the selected OBNs participating to the image. The analysis of the depth slices shows that FWM images have a significant illumination extension compared to conventional WEM mirror imaging, especially when the core OBNs are utilized.

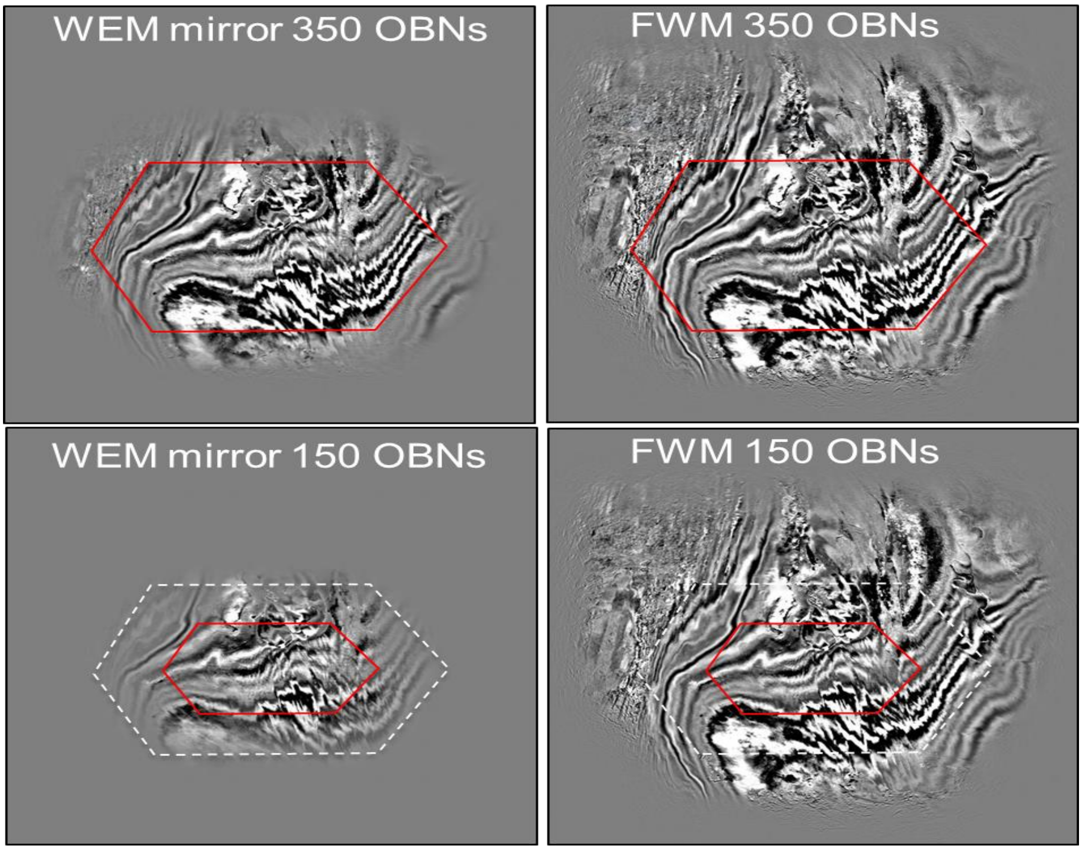

Figure 2*: Depth slice images: Top left, WEM mirror 350 OBNs. Top right, FWM 350 OBNs. Bottom left, WEM mirror 150 OBNs. Bottom right FWM 150 OBNs. The OBN used for imaging are located inside the red hexagon. The dashed white line is for comparison only.*

The area illuminated by FWM is essentially defined by the surface distribution of the source shooting. Because of the multiplicity of the reflections preserved in the data, the density of "hit point" at the target can be largely enhanced. The illumination gain is proportional of the number of multiple present in the record length regardless the water depth. Unlike conventional imaging, the location of the seabed sensor is not essential for considering fold attributes. Figure 3 shows the Inline section of the seismic image for respectively the WEM mirror and the FWM algorithm. The extension of the image reveals some geological features on the edge of the OBN location.

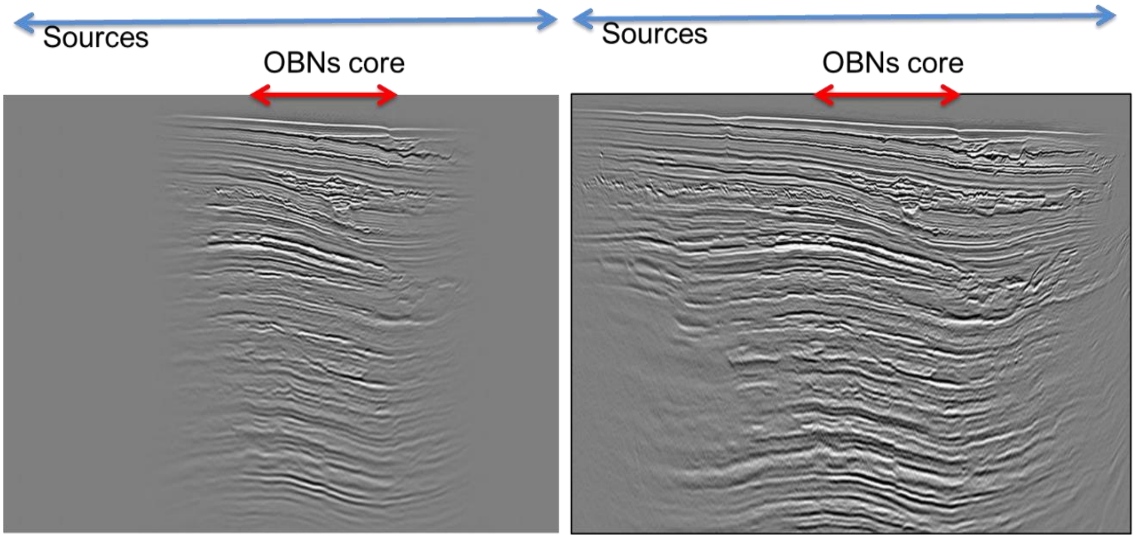

Figure 3*: Image sections: Left, WEM mirror 150 OBNs. Right, FWM 150 OBNs*

The first test demonstrates that the sparse OBN ring is not necessary for illuminating the edge of the reservoir if FWM is used. We can mention additional benefits such as the number of receiver which has been considerably reduced (by factor 2) without compromising the image resolution.

Donut design for FWM Imaging and FWI velocity modeling

An innovative geometry has been investigated in order to simulate an optimum acquisition for imaging with FWM and Full Waveform Inversion (FWI). For FWI, a nominal long offset is necessary for penetrating to a given depth using transmission. By creating a receiver donut design laying on the seabed, the required offset is preserved for illuminating the centre of the survey with refracted and/or diving waves. We simulate the donut design by selecting the 200 OBNs belonging to the external sparse ring. The central receiver hole is 2400 m wide and 6500 m long. The missing receivers in the centre will have a dramatic consequence for imaging with primary reflections. It can be noticed that the FWM is able to fill the central part by taking advantage of the sea-surface multiples (Figure 4).

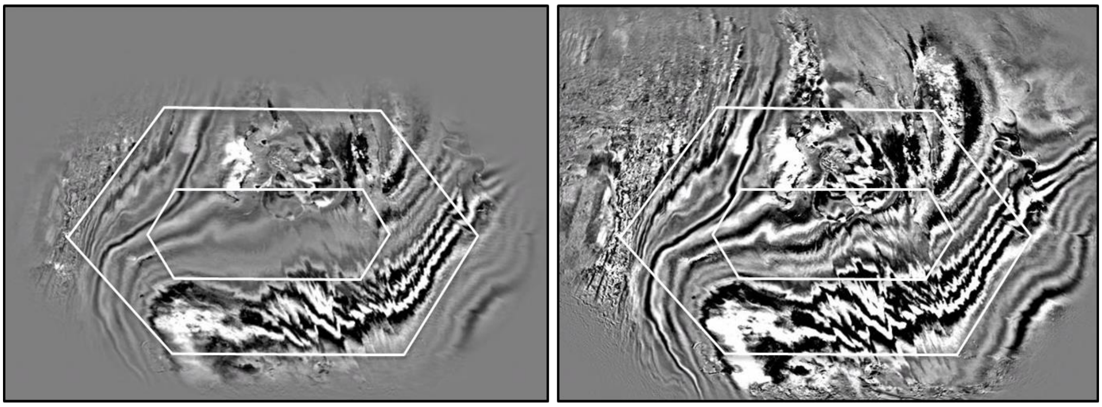

Figure 4*: OBN Donut design: The 200 OBNs are located between the two white hexagons, excluding the "core". The central hole, with missing OBN, is 2400 m wide and 6500 m long. Depth slice images for WEM mirror (left) and FWM (right).*

Conclusion

We demonstrate the potential of using a Full Wavefield Migration (FWM) algorithm to radically reduce the OBN density, enabling a large distance between receivers and providing more geometry flexibility. Various alternative sensor geometries have been investigated and analysed. An innovative OBN acquisition with a "donut" design is proposed for combining velocity model building using refracted/diving waves (FWI) and imaging with Full Wavefield Migration.

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