DYNAMIC MATCHING FWI USING DENSE LONG OFFSET OBN DATA IN THE NORWEGIAN NORTH SEA

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Summary

We outline the evolution of a velocity model building workflow incorporating Dynamic Matching Full Waveform Inversion and multi-azimuth tomography for dense, long offset Ocean Bottom Node data in the Norwegian North Sea and evaluate the improvements this high-resolution velocity model brings to the final migrated image. Event positioning, reflector continuity and image resolution are all enhanced when compared to legacy processing and the model itself can now be considered an interpretable final product as we push towards higher frequencies.

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Introduction

The Utsira Ocean Bottom Node (OBN) survey was the first large scale, densely sampled, long offset node survey acquired on the Norwegian Continental Shelf. Dense node acquisition allows for improved imaging resolution due to higher fold and the ability to derive interpretable high resolution velocity models using Full Waveform Inversion (FWI). Data were acquired over two seasons in 2018 and 2019 using a triple-source configuration and a 25x50 m shot carpet. Receiver nodes were placed with a 50 m inline and 300 m crossline spacing. The survey area can be seen in figure 1, which also shows the recently acquired NOAKA OBN survey. This was acquired with a similar acquisition configuration, albeit by a single vessel and is currently being processed.

The geology of both the Utsira and NOAKA survey areas is complex, most notably the shallow channels, sand injectites / v-brights and gas anomalies, all of which represent significant variations in velocity. FWI can be used to successfully model this complex overburden and in turn, improve the imaging of deeper events.

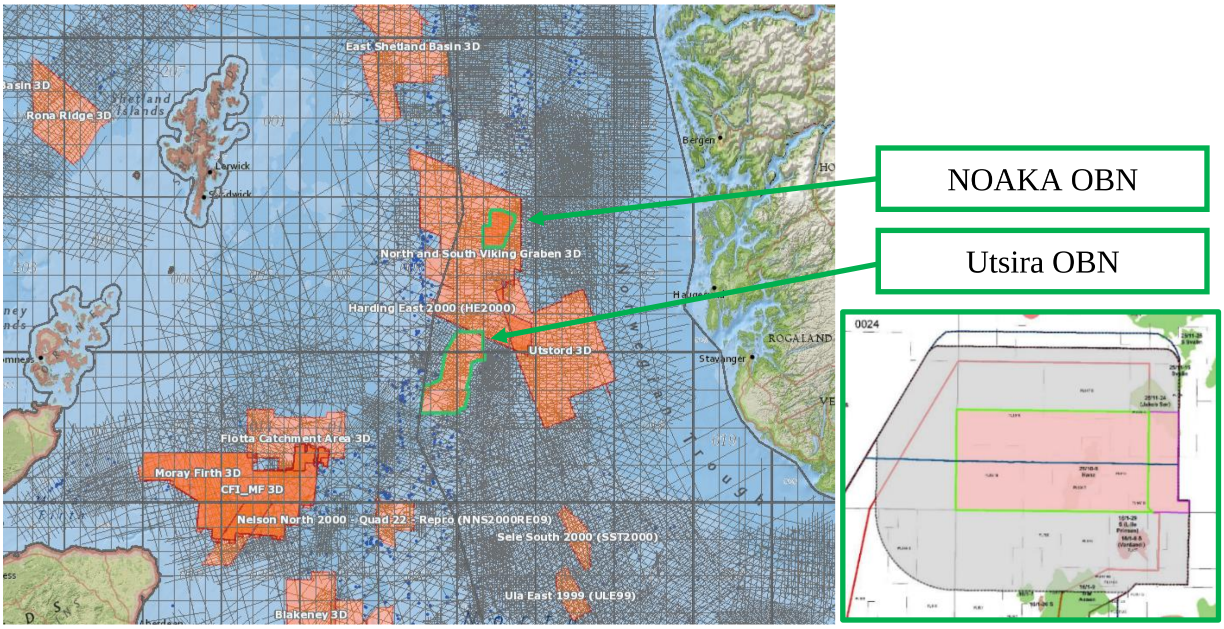

Figure 1 *Location map of Utsira and NOAKA OBN surveys*

Regional processing was initially undertaken in 2019 and 2020 where model building was limited to early arrival energy, near offsets (6.7 km) and lower frequencies (5 Hz). Due to the limited offsets used, the FWI update was not able to reach the depth of the injectites (1.2–2 km). The deeper model was updated with a conventional tomographic approach, which accounted for the low-resolution background velocity trend. The final image obtained via this approach showed good positioning of the shallow events and improved the continuity of events beneath this complex overburden, though it was thought that resolution could still be improved.

To take better advantage of this dense, long offset dataset, further model building tests were carried out on a subset of data, this time utilising up to 17 km of offset and updating up to 8 Hz with FWI (Ramirez et al. 2020). This resulted in an improved image from the higher resolution velocity model, which was successfully able to update further through the complex overburden.

Due to further recent advances in FWI technology, velocity model building was carried out again in 2020-2021 using Dynamic Matching FWI, which was able not only to take advantage of the long offsets (17 km), but also use the entire wavefield and push to higher frequencies (12 Hz), allowing for even greater model detail from reflection events down to approximately 5 km and in turn deliver an interpretable model. This phase of model building used both the deblended hydrophone dataset as well as the upgoing wavefield data after Up-Down Deconvolution (UDD). This was carried out on a subset of the main data volume, which can be seen on the inset of figure 1.

Method and Theory

Dynamic Matching FWI (Mao et al. 2020, Sheng et al. 2021) uses a local correlation objective function to minimise the mismatch between the observed input data and synthetic gathers derived from finite difference modelling. The robustness of this process is improved with the addition of temporal and spatial windowing, which enhances the lateral coherency of the signal and thus minimises the effect of any coherent noise or noise bursts. The window size varies depending on the frequency of the update. This windowed local cross-correlation approach minimises the effects of amplitude uncertainty and allows the FWI to focus on kinematic differences. With these constraints, Dynamic Matching FWI is less prone to cycle-skipping than a conventional least squares FWI. It is also able to take advantage of the full wavefield, including diving wave and reflection events.

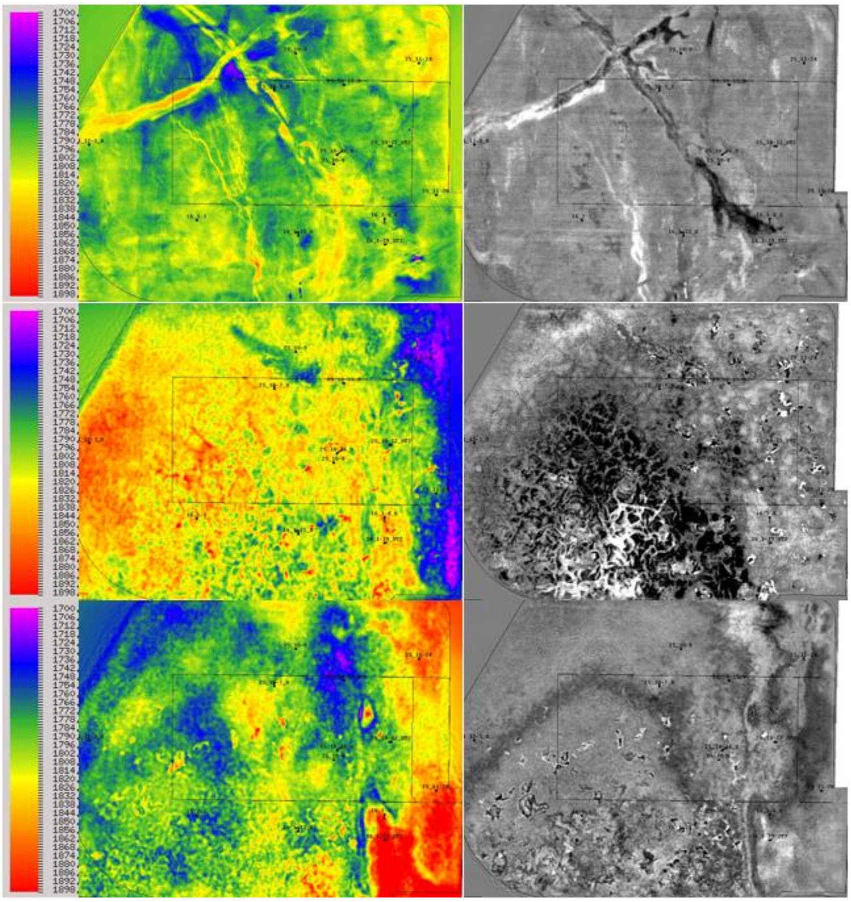

***Figure 2** Final velocity model depth slices (left) show a good correlation with the seismic image (right)*

The initial velocity model was derived from the underlying Jormungandr 2D^{cubed} PSTM velocity field. This model was heavily smoothed and converted to depth interval velocity. A water velocity function was then inserted based on recorded temperature and salinity (TS dip) data. This model was then calibrated to the 13 wells located within the survey area for this subset of data.

After calibration, an initial anisotropy model was derived at the well locations using Focussing Analysis (FAN). This model was constrained to single values of delta and epsilon within the main geological layers present in the survey area, water bottom – Top Skade – Top Balder – Top Shetland – basement. The first pass of DMFWI targeted refraction and shallow reflection energy from the hydrophone dataset. An initial wavelet was extracted from the near 1000 m offset and two passes of wavelet matching were carried out to refine the wavelet ahead of model building. DMFWI was then run over 63 iterations with an increasing maximum offset, up to 17 km. This was limited to 4 Hz for the initial pass of model building but was still able to successfully model the shallow overburden. Following this initial pass of FWI, the anisotropy model was updated based on mistie information at well locations.

The second pass of DMFWI focussed on deeper reflection energy from the upgoing wavefield dataset after up/down deconvolution. Ahead of model building, another round of wavelet matching was undertaken for this new input dataset. Offset was limited to 6.7 km for this dataset and 33 iterations were run with an increasing frequency range, up to 12 Hz. The anisotropy model was updated once again after this step. The resulting model from this second pass of DMFWI can be seen in figure 2.

Data were then regularised into six azimuth sectors using 4D Anti-Leakage Fourier Transform (ALFT) regularisation and model building was continued using multi-azimuth tomography ahead of final migration.

Results

The final velocity model derived from this updated workflow accurately represents the complex overburden present in the area, this can be seen in the depth slices in figure 2 and in section in figure 3b overlaid on the final migrated seismic image. The additional detail incorporated into this model reduces deflections in the events beneath, which results in more continuous reflections and a simplified geology, as can be seen in the comparison of legacy and final images (figures 3c & 3d).

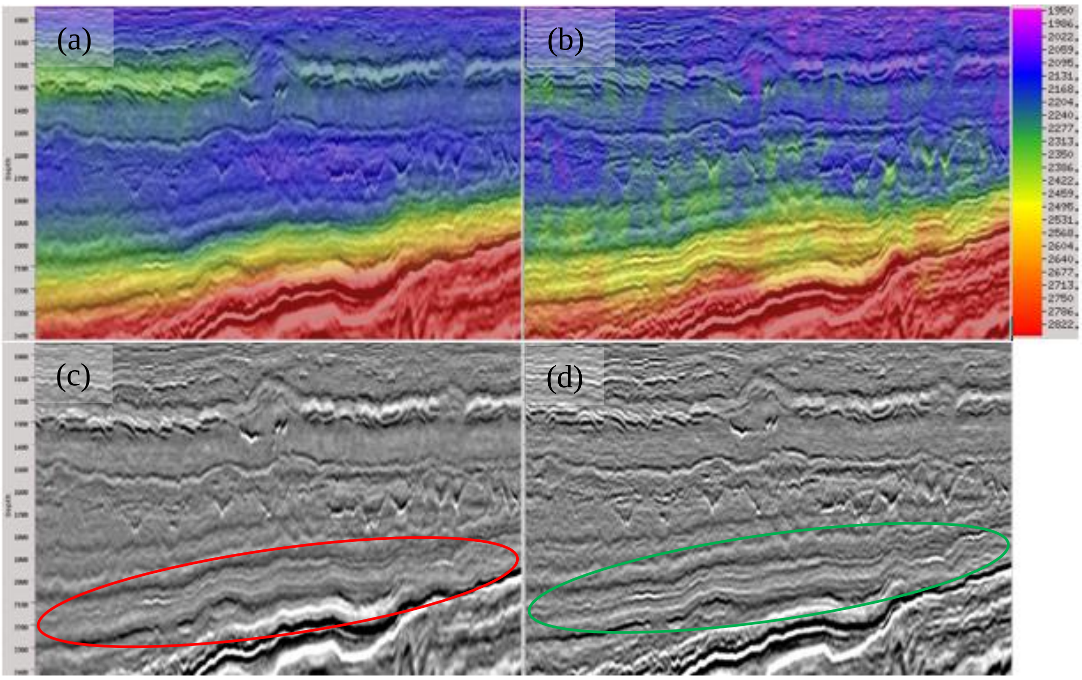

Figure 3 *Comparison between a) legacy and b) final model after DMFWI and multi-azimuth tomography. Improved resolution and event continuity can be seen between c) legacy and d) final image*

FWI images were generated using the derivative of the modelled velocity fields and these showed that the main geological features were picked up in the model, but the resolution at 12 Hz was relatively low when compared with the seismic image. As such, a test was run where the FWI was increased up to 16 Hz, which gave a significant improvement in resolution to the FWI reflectivity image generated, this comparison can be seen in figure 4 Although imaging improvements become less obvious as FWI models are pushed to higher frequencies, the interpretability of these models is significantly enhanced. Based on this initial test phase of FWI imaging we’re now looking at running FWI to even higher frequencies, which is quickly becoming a new standard in the industry.

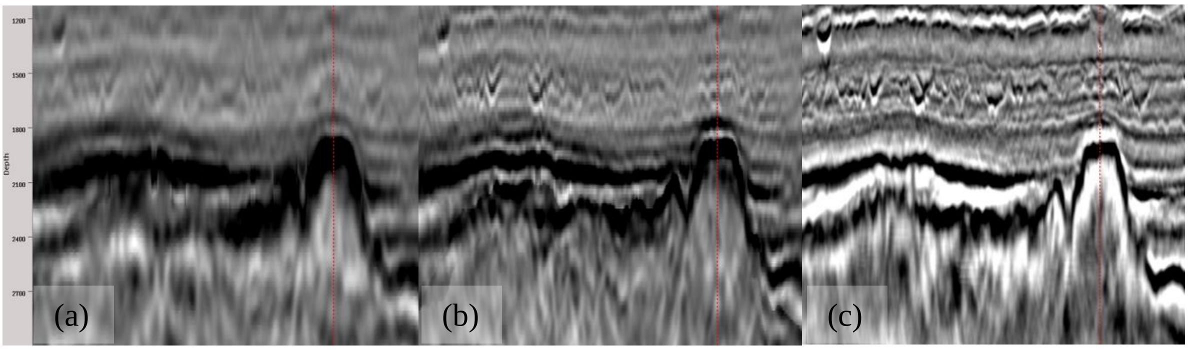

Figure 4 *FWI reflectivity images with a) 12 Hz and b) 16 Hz FWI velocity models, compared to c) migrated seismic image*

Jansen et al (2021) independently derived a velocity model for the area, incorporating well information with a machine-learning workflow, which generally agrees with the DMFWI model, albeit at a different resolution. Both models showed that the prospective hydrocarbon filled injectites have a lower overall velocity than the non-prospective brine filled injectites. This helps to demonstrate the value in generating realistic, high-resolution velocity models such as this for interpretation purposes.

Conclusions

Through various iterations of model building, improvements from Dynamic Matching FWI and multi-azimuth tomography we have been able to generate an interpretable high-resolution velocity model to describe the complex overburden geology of the Utsira High region of the Norwegian North Sea. Utilising offsets up to 17 km has also helped with the modelling of deeper geological targets.

This improved model, in conjunction with the dense node acquisition has in turn introduced significant improvements to the resolution and positioning of the final image, where reflectivity continuity beneath the complex shallow overburden anomalies has been improved. These structures, as well as complex faulting and deeper geological features have all benefited from this high-resolution model building approach using a dense, long offset OBN dataset.

The model building workflow developed here is being utilised and further refined in the recent NOAKA node acquisition survey, located to the north of Utsira, which can be seen in figure 1.

Acknowledgements

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