High resolution imaging on OBN data: A case study from Santos Basin

Abstract Summary

Ocean Bottom Node (OBN) seismic acquisition offers rich azimuthal coverage and long offsets, which are valuable for velocity model building. Despite the better sampling of the wavefield, OBN can still be challenged by variations in illumination in complex geological settings, which can lead to non-optimal amplitude response and spectral deficiencies. In these cases, techniques like image-domain Least Squares Migration (LSM) can be highly effective, enhancing both image quality and subsurface illumination.

In this case study from the Santos Basin, we demonstrate the integration of Dynamic Matching Full Waveform Inversion (DM-FWI) for velocity model building with image-domain LSM applied to both Kirchhoff and Reverse Time Migration (RTM). Our results show that this approach, not only delivers higher resolution and better illumination through deblurring and illumination correction but also yields a significantly more robust Amplitude Versus Angle (AVA) response in RTM compared to Kirchhoff migration. These improvements highlight the critical role of advanced migration techniques in maximizing the value of OBN data for seismic interpretation and reservoir characterization.

Introduction

The primary objective of seismic imaging is to generate a high-fidelity, high-resolution representation of the Earth's subsurface. The accuracy of reflector positioning is predominantly governed by the earth model, while resolution and amplitude fidelity depend on the choice of migration algorithm which directly impacts resolution and amplitude accuracy, acquisition parameters including source-receiver geometry and frequency content that influences illumination and noise levels, and overburden properties like velocity variations, illumination angles, and attenuation effects within the overlying strata, which can distort wavefield propagation and degrade image quality.

In this case study from the Santos Basin, offshore Brazil, we present an advanced seismic imaging workflow that combines Ocean Bottom Node acquisition, Full Waveform Inversion (FWI) for velocity model building, and Least-Squares Migration, including Least-Squares Kirchhoff Pre-Stack Depth Migration (LS-KPSDM) and Least-Squares Reverse Time Migration (LS-RTM) at 45Hz, both applied in the image domain.

Our results highlight how FWI leverages long-offset OBN data to resolve complex velocity structures, while least-squares migration enhances illumination, spatial resolution, and amplitude fidelity. Furthermore, we show that LSM effectively calibrates the Amplitude Versus Angle response across different migration algorithms, providing more reliable seismic interpretations for reservoir characterization. This integrated approach underscores the importance of combining advanced velocity modeling and migration techniques to maximize the value of OBN data in challenging geological environments.

Full Waveform Inversion

The inherent benefits such as ultra-long offset, full azimuth (FAZ) illumination and low-frequency content, make the OBN data a perfect candidate for Full Waveform Inversion process. We applied Dynamic Matching FWI (DM FWI) algorithm to this data, which is a technique that uses an objective function to maximize the normalized local cross correlation. This local window dynamic matching scheme mitigates the amplitude impact on FWI by downplaying the large amplitude events and amplifying the contribution from weaker events, which is critical to allow the signal rather than the noise to win in the misfit computation. The detailed implementation is summarized in Mao et al. (2020).

Least Squares

Least-squares migration seeks to minimize inadequacies in the acquisition data sampling and their effects on the migration algorithm. Compared to conventional migrations, the output from LSM process is a more accurate and higher resolution subsurface image. LSM addresses the imaging step as an inversion process, rather than a migration (Nemeth et al., 1999) and can be implemented in either the image or data domains.

In this case instance, LSM was used in the image-domain to deconvolve the depth migrated gathers based on point-spread functions (PSF). The PSFs are computed using modeling and migration operators consistent with the images being input to the inversion process, i.e. LS-KPSDM uses Kirchhoff operators while LS-RTM uses an RTM operator. The inversion process can also be extended to pre-stack domain, by expanding the dimensionalities to angle or offset domain (Valenciano et al, 2019).

Results

The complex overburden in the area and pre-salt targets present significant challenges for velocity model building. Using Dynamic Matching Full-Waveform Inversion (DM FWI) on an Ocean Bottom Node (OBN) dataset, which provides long offsets and good low-frequency content significantly improved the velocity model. This enhancement led to better imaging and flattened gathers, as demonstrated in Figure 1.

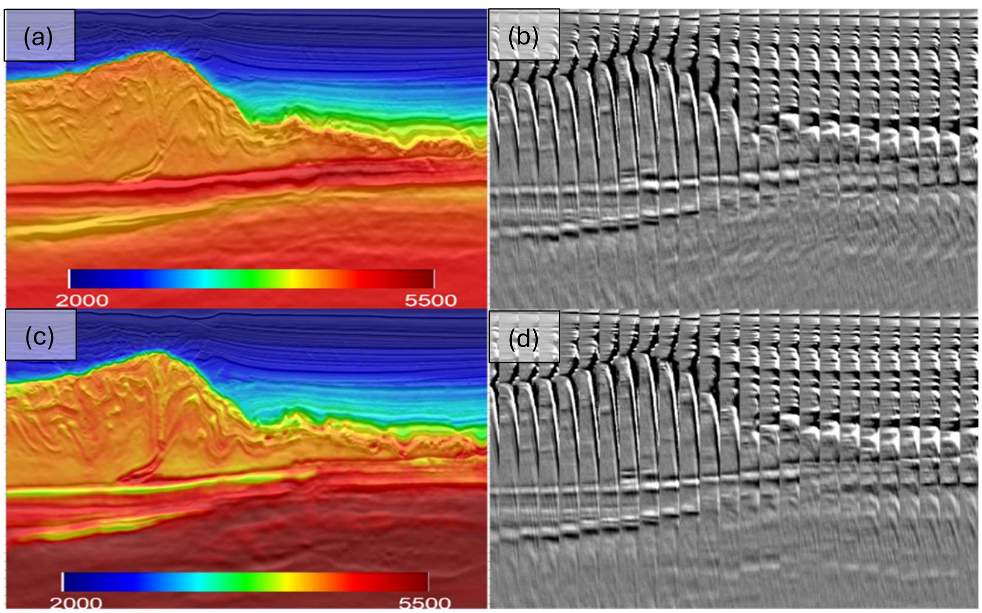

Figure 1: The seismic image with the velocity model overlaid in (a) shows the legacy data, and (b) shows the gathers. On (c) and (d) we have the equivalent for the full integrity processing, using DM FWI.

Figure 2 compares KPSDM with LS-KPSDM, displaying stacked sections and angle gathers. The LS-KPSDM result shows enhanced resolution and better-balanced amplitudes while preserving the original Amplitude Versus Angle (AVA) response.

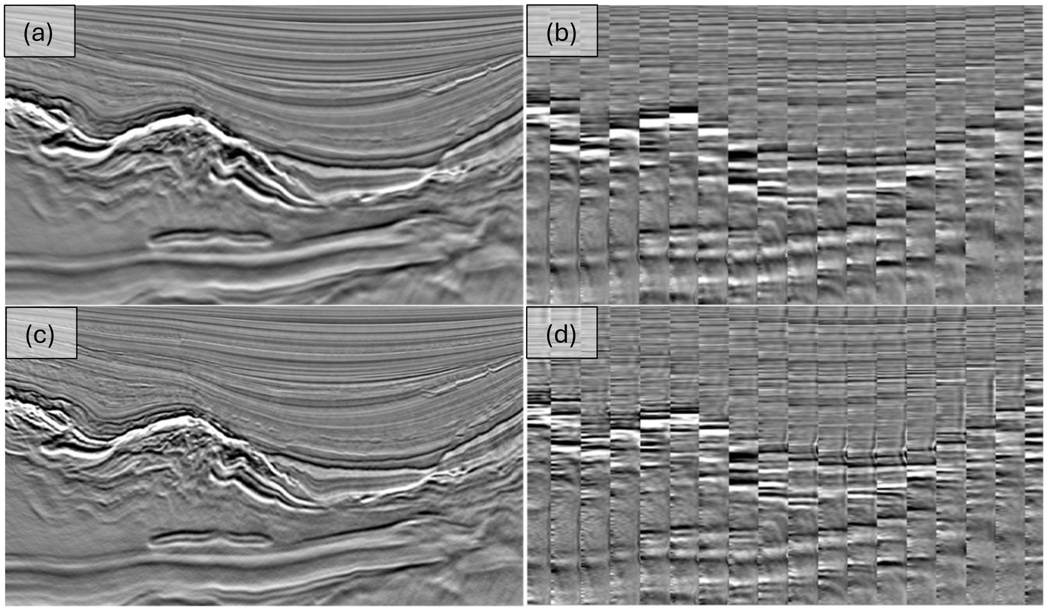

Figure 2: Kirchhoff pre-stack depth migration (KPSDM) results showing the stacked section (a) and angle gathers (b), alongside the least-squares KPSDM (LS-KPSDM) stacked section (c) and angle gathers (d).

Figure 3 presents a comparison between conventional RTM (45Hz) and LS-RTM (45Hz), showcasing gathers and stacked sections. Beyond improved resolution and amplitude balancing, LS-RTM effectively corrects for Amplitude Versus Angle distortions, leading to more reliable AVA analysis.

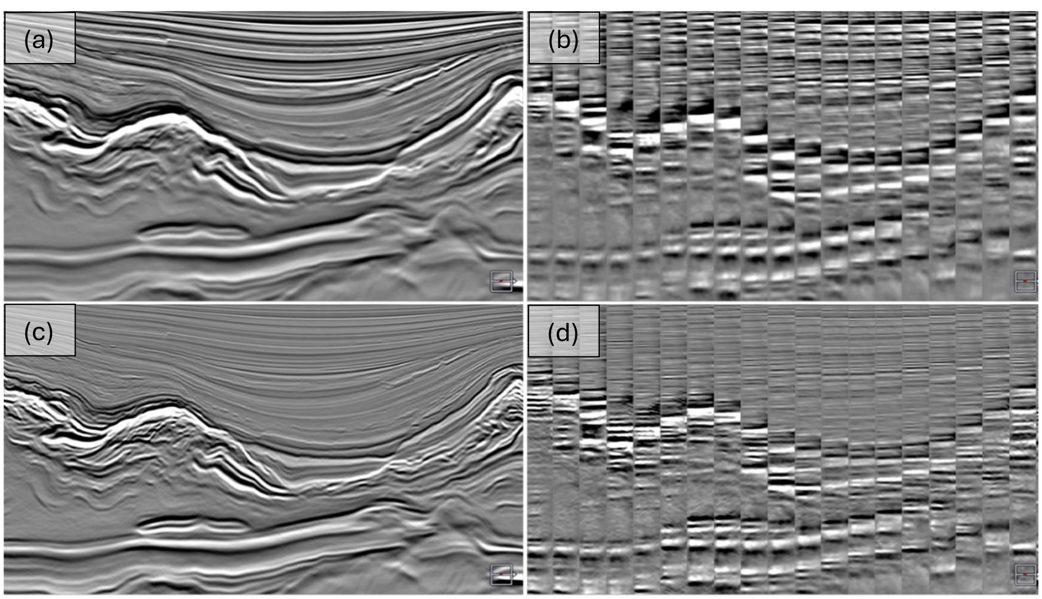

Figure 3: 45 Hz reverse time migration (RTM) results showing the stacked section (a) and angle gathers (b), alongside the 45 Hz least-squares RTM (LS-RTM) stacked section (c) and angle gathers (d).

Conclusions

This study demonstrates the critical importance of integrating high-quality OBN acquisition data with advanced inversion and imaging techniques to overcome challenges in complex geological environments.

Dynamic Matching FWI (DM-FWI) successfully improved the velocity model, resulting in sharper imaging, better structural focusing, and flatter gathers. Furthermore, image-domain Least-Squares Migration enhanced seismic resolution for both Kirchhoff and RTM migrations while correcting illumination-based amplitude distortions through multi-dimensional deconvolution. These improvements provide a more reliable AVA response, enabling more accurate quantitative interpretation, particularly in pre-salt reservoirs where seismic fidelity is crucial.

By combining long-offset OBN data, DM-FWI, and LSM, this workflow delivers superior subsurface imaging and reservoir characterization, setting a robust foundation for exploration and development in challenging settings.

Acknowledgments

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