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Multiparameter full-waveform impedance inversion – a step change in seismic imaging

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Introduction

Seismic imaging has long relied on migration-based methods such as Reverse Time Migration (RTM) and Least-Squares RTM (LSRTM) to produce subsurface images. However, these conventional approaches make strong assumptions about the wavefield and often struggle with challenges like illumination imbalance, migration crosstalk, and poor amplitude fidelity. As an alternative, full-waveform inversion (FWI) has emerged as a powerful method for directly recovering Earth properties by leveraging the full wavefield (Vigh et al., 2023, Cheng et al., 2025).

Traditionally, FWI has been employed in a monoparameter setting, focusing primarily on P-wave velocity (Vp) updates. However, this approach often encounters fundamental limitations, particularly due to parameter crosstalk, where density leakage in velocity updates leads to a suboptimal representation of the subsurface. To address these challenges, we propose a multiparameter FWI framework that jointly inverts for velocity and impedance (Vp, Ip), allowing for a more robust and physically meaningful parameterization. This approach not only improves kinematic updates but also enables the extraction of high-resolution FWI-derived reflectivity (FDR), a breakthrough that delivers superior structural and amplitude-consistent imaging (Cheng et al., 2024).

High-resolution FDR, computed directly from the inverted impedance model, represents a paradigm shift in seismic imaging. Unlike conventional migration, which relies on reflectivity assumptions and primary reflections, FDR leverages full-wave physics to reconstruct subsurface impedance contrasts with enhanced resolution, balanced illumination, and improved amplitude consistency. This work demonstrates how FDR, derived from multiparameter FWI, offers a transformative approach to seismic interpretation, outperforming traditional migration images.

Method and/or Theory

The key advancement presented in this work is the use of FWI-derived reflectivity (FDR) computed from a high-resolution impedance model obtained through multiparameter (Vp, Ip) inversion. Unlike conventional migration approaches that rely on primary reflections and kinematically optimized velocity models, our method leverages full-waveform physics to recover high-resolution impedance contrasts directly from seismic data. This approach enables more accurate structural interpretation and amplitude-consistent imaging, providing a major advantage over standard RTM or LSRTM methods.

Traditional monoparameter FWI primarily updates the velocity field, often suffering from parameter leakage and limited resolution. In contrast, our approach jointly inverts for Vp and Ip, ensuring that impedance variations are explicitly captured in the inversion process. The resulting high-resolution impedance model enables the direct extraction of reflectivity, producing FDR images with balanced illumination and improved resolution across all depth levels.

Figure 1a shows the Vp gradient in a conventional monoparameter FWI scheme. Instead of computing velocity updates in isolation, we adopt a multiparameter formulation where the FWI gradient is decomposed into separate Vp and Ip components (Figure 1b, 1c). This formulation allows for improved separation of velocity and density effects, reducing parameter crosstalk and enhancing the quality of the inverted models.

Examples

The effectiveness of high-resolution FDR is demonstrated through its application to a field dataset. Our results show that by incorporating impedance updates in the inversion process, FDR produces significantly sharper and more accurate subsurface images compared to conventional migration techniques.

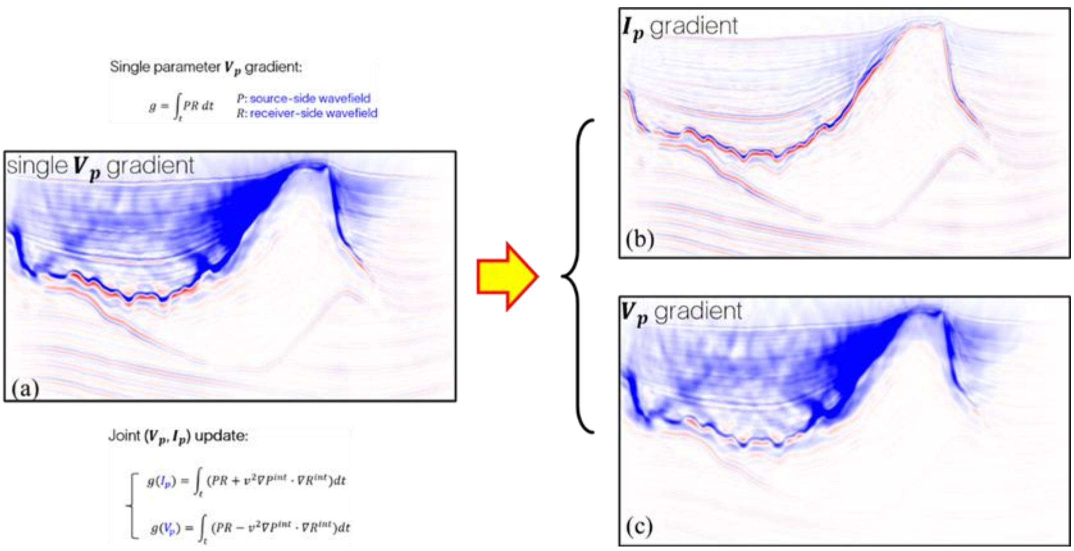

Figure 1: An example of a single Vp gradient from a monoparameter Vp update (a), and a Ip gradient (b) and a Vp gradient (c) from a multiparameter (Vp, Ip) update.

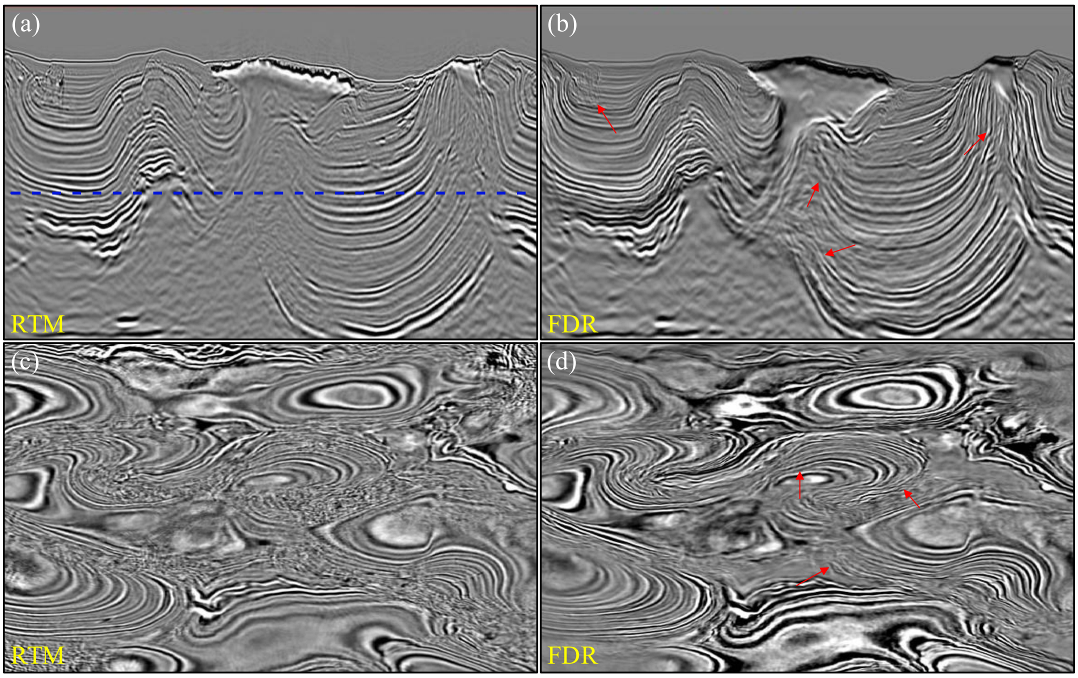

Figure 2: A real data example of comparisons between RTM and FDR in cross-section view (a), (b) and depth-slice view at 5 km depth as indicated by the blue dashed line (c), (d).

As shown in Figure 2, FDR outperforms RTM by delivering superior image clarity, particularly in areas with complex overburden structures. The balanced illumination and high-frequency content retained in FDR allow for better fault and steeply dipping event delineation and stratigraphic interpretation. Furthermore, the amplitude-preserving nature of FDR ensures that it is well-suited for reservoir characterization and quantitative seismic analysis.

Conclusions

The adoption of high-resolution FDR derived from multiparameter FWI (Vp, Ip) represents a major advancement in seismic imaging. By directly leveraging impedance updates, FDR overcomes the limitations of traditional migration-based methods, delivering improved resolution, balanced illumination, and amplitude consistency. This method not only enhances structural interpretation but also has the potential to provide reliable data for reservoir property estimation and AVO analysis.

Acknowledgments

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References

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