

Land Seismic Full-Waveform Inversion for Simultaneous Velocity and Reflectivity Estimation: A Case Study from the Bengal Basin, India

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Summary

This case study deals with a land FWI project executed by ONGC in collaboration with S-Cube in the Bengal Basin, India, in which Time Space Lag FWI (TSLFWI) is applied directly to shot records from the topography. The inversion updates velocities to more than 10 km depth on a 440 square km survey area, recovering clearly resolved channel-like features of potential interest in the Tertiary interval that was poorly defined in a conventional tomography-driven velocity model. The same workflow simultaneously produces a high-frequency reflectivity image as a by-product of the impedance update, removing the necessity for a separate migration. The results demonstrate that the FWI workflow that has been validated on deep-marine data cleanly transfers to onshore basins with minimal data pre-processing, bringing out the desired output.

Introduction and context

Of late, the Bengal Basin is emerging as a promising hydrocarbon province in India. However, seismic imaging in the region remains challenging due to strong cultural noise, rapidly varying near-surface conditions associated with alluvium, weathered layers, paleo-channels, and locally indurated horizons. Imaging complexity is further compounded by rapid Tertiary sedimentation, a structurally complex hinge zone, and laterally varying Eocene limestone, exhibiting a strong velocity contrast with clastic. Conventional workflows based on statics, time-processing, and ray-based velocity model building often struggle to handle, resulting in limited resolution, subjective interpretations and processing artifacts.

In this study, we apply Full Waveform Inversion (FWI) with joint velocity and impedance inversion to address these challenges in a unified, physics-driven framework. The methodology directly minimises the misfit between observed and modelled wavefields, enabling trace-by-trace data fitting while naturally accounting for complex geology and associated wave phenomena. The adaptive-waveform strategy helps mitigate cycle skipping and enables stable convergence from a smooth starting model, while the joint parameterisation simultaneously delivers both a high-resolution velocity model and a reflectivity image without a separate migration step. Building on earlier success in a deep-water offshore case study (Ghosh et al., 2025), the present work demonstrates the applicability of the approach to a challenging land seismic data, where surface-wave dominance, topographic variations, and the need for accurate geometry handling make the inversion problem significantly more demanding.

Data and methodology

The dataset consists of 18,854 dynamite shots having nominal bin size 20 m $\times$ 20 m and max offsets 6100 m. Prior to inversion, careful pre-conditioning was performed that include 1) automated geometry and topography corrections 2) 50 Hz industrial noise was removed, 3) surface-consistent amplitude scaling and deconvolution, 4) minimal signal conditioning in the offset-frequency band used for inversion. These steps preserve the transmitted and reflected energy that FWI exploits while removing features that would otherwise influence the misfit.

FWI is being run with multi-scale frequency-band continuation starting from a smooth initial model that already captures the broad-scale geological layering. An integrated inversion workflow was applied, combining time-space-lag FWI (TSLFWI) and reflection waveform inversion (RWI). An acoustic anisotropic inversion was performed, starting from 4 Hz to 11.5 Hz in a staggered manner. TSLFWI inverted the early arrival at long offsets & diving waves that build a kinematically accurate shallow velocity. RWI then updates the deeper macro model using reflections. The inversion refines the velocity over approximately 22 $\times$ 20 $\times$ 11 km and provides stable and geologically consistent velocity field.

Once the kinematics of the velocity model is fixed, the impedance is inverted to reduce the amplitude misfits, generating a high-frequency reflectivity image. This reflectivity captures the “true” subsurface reflectivity unperturbed by the conventional noise attenuation imprints. The convergence of all the inversions is monitored

through the quantitative data-domain objective function and through qualitative inspection of the evolution of the velocity field and the reflectivity image at successive iterations.

Results

Figure 1 compares the smooth initial velocity model (a) with the FWI velocity. The FWI update sharpens a clear low-velocity, channel body indicated by black arrow in fig 1.b absent in the starting model. The velocity contrast between the carbonates and clastic is also clearly delineated (yellow arrows) in the final velocity model (fig 1.b). The reflectivity image (c) shows continuous, high-frequency reflectors throughout depth range, including the coherent, laterally continuous Cretaceous reflector along with adequate delineation of hinge-zone (yellow arrow fig 1.d) confirming that the model update is geologically consistent. Importantly, the reflectivity is recovered as a by-product of the same FWI pass, with no separate migration step. The inversion results are proving significant insight of the underlying key features and will help for image enhancement, reduce uncertainties in interpretation and enhance clarity in decision-making.

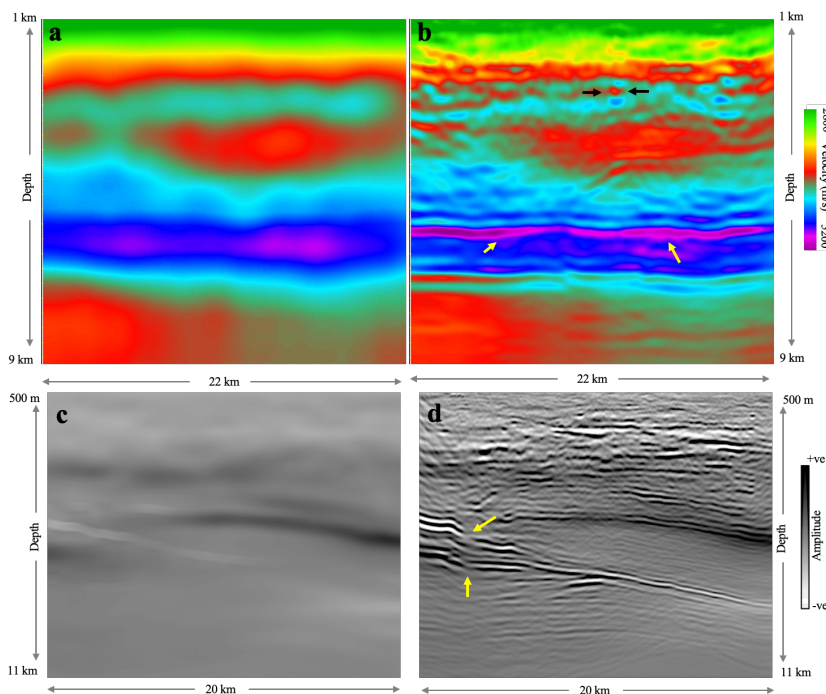


Figure 1. A representative xline from (a) the starting model (b) final model. FWI reflectivity on a representative inline from the (c) initial iteration and (d) final updated model.

Conclusions and significance

The results show a high-resolution, geologically validated velocity model, rendered through the simultaneous inversion of the velocity field and the reflectivity, along with a reflectivity derived image of the subsurface without any migration. The case study provides an insight into an innovative workflow that reveals the intricacies of the subsurface by directly analysing the acquired nascent wavefield with minimal manual interventions and reduce the turn-around time for prospect generations. The proposed methodology is an extension of the FWI workflow earlier performed on the deep waters of Mahanadi basin, with minimal pre-processing to make it amenable to solve the land data challenges. This generalized workflow of waveform inversion is directly applicable to other onshore datasets across the country.

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Reference:

Ghosh, S., Jain, D., Saxena, P., Shah, N., Warner M. (2025). High-Resolution Velocity Model Building Using Full Waveform Inversion: A Case Study from Deep-Water Block Mahanadi Basin, India, SPG 2025, Jaipur.