Submission code: LMNVJ75PM7

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1D Acoustic Full-Waveform Inversion Using Bayesian Analysis with Markov Chain Monte Carlo

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Introduction

In full-waveform inversion (FWI), accurate initial models are critical to prevent cycle-skipping, a phenomenon where the inversion gets trapped in very incorrect solutions due to large phase errors between observed and modeled data. Poor initial models often cause the algorithm to converge to non-informative local minima, compromising the final image quality. This study proposes a new approach to estimate P-wave velocity using one-dimensional FWI combined with Bayesian analysis. Our goal is to produce kinetically accurate velocity model to serve as reliable initial subsurface models for subsequent 3D FWI problems. Accurate initial models are crucial to reducing cycle skipping during 3D FWI.

Methodology

We present in this work a gradient-free, 1D Bayesian inversion method designed to circumvent non-informative local minima inherent in deterministic approaches. Our proposal integrates prior geological knowledge with observed seismic data, quantifying uncertainties in the estimated P-wave velocity models through probabilistic inference. By leveraging Markov Chain Monte Carlo (MCMC) sampling, we explore the posterior parameter distributions, ensuring robust characterization of uncertainties and inter-parameter correlations. This approach not only provides point estimates (e.g., maximum a posteriori, MAP) but also delivers credible intervals for the estimated P-wave velocity models. By adopting this Bayesian paradigm, we move beyond single ”best-fit” solutions, instead quantifying how uncertainties propagate from data noise, model simplifications, and prior assumptions. The method is particularly valuable in scenarios where non-uniqueness plagues traditional inversions, such as in FWI problems. We generate synthetic seismic data by simulating wave propagation using the 3D acoustic wave equation to validate our proposal under realistic conditions, while intentionally simplifying the inversion to a 1D model space.

Results and Conclusions

Our results demonstrate that the 1D Bayesian FWI accurately recovers velocity profiles with well-defined uncertainty bounds. These profiles can effectively serve as initial models for subsequent seismic inversion workflows. This improvement significantly reduces the risk of cycle skipping in 3D FWI, facilitating better convergence and producing more reliable seismic images. Overall, the method provides a powerful and computationally efficient tool to generate enhanced initial models, ultimately increasing the robustness of full-waveform seismic inversion workflows.