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On the use of a source-independent formulation in acoustic and elastic FWI

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Introduction

Advances in high-performance computing have encouraged many studies on Elastic Full-Waveform Inversion (EFWI) for its potential to estimate multiple parameters and generate higher-resolution velocity models. Despite these advantages, acoustic FWI remains the industry standard due to its lower computational cost and more straightforward formulation.

Both acoustic and elastic FWI require a reliable initial P-wave velocity model for convergence. Elastic FWI adds complexity by also needing initial estimates of S-wave velocity and density. The VP/VS ratio is rarely known, and density estimation is even more uncertain. Empirical relations are often used but must be applied carefully to match the geological setting.

However, one of the main challenges and persistent limitations in waveform inversion is that wave propagation physics is never fully captured, leading to inaccuracies in phase and, more critically, in amplitude. Acoustic simulations are particularly limited in this regard, and even elastic modeling may fail to reproduce all amplitude-related effects. In this study, we explore this issue by investigating a robust, source-independent objective function for both acoustic and elastic cases, aiming to reduce sensitivity to source uncertainty and amplitude mismatch. We apply both approaches to benchmark synthetic datasets to assess their effectiveness in velocity model building, especially when starting from poor initial models. Additionally, we compare the computational cost and practical challenges associated with elastic and acoustic inversions, emphasizing the importance of using robust objective functions in both contexts.

Theory and Method

Traditional least-squares misfit functions are highly sensitive to amplitude discrepancies and prone to cycle-skipping, especially when the source is uncertain or the initial model is poor. Several alternative approaches have been proposed to address these issues, including objective functions based on optimal transport and matching filters. In this study, we focus on the class of source-independent objective functions as a strategy to compare the robustness of both acoustic and elastic FWI. These functionals often involve the convolution of observed and modeled wavefields with a common reference trace, removing explicit dependence on the source wavelet and enabling a multiscale inversion framework through the appropriate choice of the reference trace, and the use of normalized cross-correlation between convolved traces to enhance phase alignment while reducing amplitude sensitivity.

Results and Conclusions

This study aimed to compare the effectiveness of acoustic and elastic FWI when using source-independent objective functions to mitigate source-related uncertainties and amplitude discrepancies. Tests on synthetic benchmark datasets focused on velocity model reconstruction from poor initial conditions. Preliminary results suggest that robust source-independent objective functions can reduce sensitivity to source uncertainty and amplitude mismatch, contributing to more stable and accurate inversions. These findings are expected to provide valuable insights into the comparative robustness, convergence behavior, and computational cost of each formulation, supporting more informed choices in practical FWI applications. Based on these analyses, a hybrid workflow combining acoustic and elastic modeling strategies may offer a balanced trade-off between physical realism and computational efficiency.