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Uncertainties interpretation in velocity models estimated through traveltime seismic tomography

Marcelo Cotta Rost (Petrobras), Luiz Alberto Santos (Petrobras/UFF), Marco Cetale (GISIS/UFF)

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Introduction

Estimating the velocity model through data inversion is an inherently ill-posed process that typically requires multiple iterative inversions to minimize discrepancies between calculated and observed data. The ambiguity in seismic velocity estimations can lead to uncertainties that must be quantitatively assessed to mitigate risks in subsurface imaging for oil exploration. Some seismic tomography studies focus on employing simulations informed by probability density functions, aiming to reconstruct models based on uncertainties from the covariance matrix, which facilitates the development of quantitative assessments for various geological scenarios. This study aims to identify and contextualize uncertainties in travel time tomography inversion across different scenarios, employing experimental investigations to explore relationships between uncertainties and inversion constraints, ultimately contributing to improved risk assessments in seismic exploration activities.

Method

Forward modeling in seismic tomography involves calculating the travel time for a ray to travel from a source (S) to a receiver (R) in a two (or three)-dimensional field, as described by the integral of the inverse of the velocity field along the ray path. Travel times are computed through finite-difference solutions of the eikonal equation for isotropic medium, which can model wavefront propagation. The study focuses on the iterative Gauss-Newton method for tomographic inversion, aimed at minimizing the objective function that combines data and model terms. Key to this process is the partial derivative matrix (G), which captures the relationship between travel time variations and model parameters. Regularization techniques are necessary to address the inherent indeterminacy in seismic tomography, allowing for a more robust estimation of model parameters. The study illustrates the interplay between forward modeling, tomographic inversion, and Bayesian inference in enhancing seismic imaging accuracy.

Results and Conclusions

Using a tomographic inversion algorithm, a series of experiments was conducted to estimate two-dimensional velocity models and analyze the associated uncertainties. The experiments aimed to estimate the velocity for three original models: a constant velocity of 2500 m/s and, a vertical gradient ranging from 1500 m/s to 4500 m/s and a more complex model featuring a salt diapir. Various regularization strategies were applied during the inversions, allowing for the evaluation of changes in the final model and associated uncertainties.

The results highlighted various distributions of standard deviations of the parameters derived from the posterior covariance matrices. The influence of regularization factors on the final results was significant, affecting the stability and independence of model parameters. Finally, the type of original model, the initial model used, and the experimental configurations were found to significantly impact uncertainty distributions, with simpler models showing greater uncertainty related to the data acquisition setup and inversion parameterization. The characterization of uncertainties was conducted based on the most coherent model solutions, emphasizing the importance of model initializations and regularization in achieving reliable results.