FULL WAVEFORM INVERSION USING FO CRS TOMOGRAPHY INITIAL MODEL: A CASE STUDY IN THE TACUTU BASIN

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Abstract

This article focuses on improving subsurface velocity model estimation, which is crucial for accurate seismic imaging. It highlights the use of Finite Offset Common Reflection Surface (FO CRS) tomography, a method that efficiently utilizes reflection data and generates initial subsurface models from time-migrated sections. Despite its advantages, FO CRS often lacks the resolution necessary for detailed analysis. To overcome this limitation, we propose a hybrid methodology that combines FO CRS tomography with Full Waveform Inversion (FWI), leveraging the efficiency of the former and the high-resolution capabilities of the latter. We provide a theoretical overview of both techniques and apply them to field data from the Tacutu sedimentary basin, demonstrating their effectiveness in enhancing subsurface model accuracy. The results from applying Least-Squares Reverse Time Migration (LSRTM) on pre-stack seismic data demonstrate that the combination of FO CRS and FWI significantly enhances fault delineation and accuracy in identifying igneous intrusion events, aligning with geological interpretations while improving resolution.

Introduction

In recent years, FO CRS tomography has emerged as a powerful tool for generating initial subsurface models due to its efficiency in utilizing reflection data (Mesquita et al., 2019). This method uniquely begins its process with a time-migrated section, resulting in a subsurface model that incorporates prestack data information. By utilizing coherence information, the FO CRS maximizes the reflection conditions and clearly delineates the interfaces of the proposed model.

However, while FO CRS provides a strong starting point, it often lacks the resolution necessary for detailed geological interpretation. To overcome this limitation, we propose a hybrid methodology that integrates the efficiency of FO CRS tomography with the high-resolution capabilities of FWI. This approach aims to improve the accuracy of the subsurface model, enabling a deeper understanding of geological formations and their characteristics.

We provide a brief theoretical overview of FO CRS and FWI inversion tomography strategies, which serves as the foundation for the subsequent application of these techniques. Utilizing field data from the Tacutu sedimentary basin, we demonstrate the effectiveness and potential implications of our proposed solution.

FO CRS tomography

The FO CRS tomography deal with the model parameters: horizontal distance (X), depth (Z), number of layers (n), and interface node points (m). Layer velocities may be constant or vary laterally, often represented by spline functions if interfaces are curved. The inversion estimates the vertical node positions and velocities, defined as, represented as **n'** = (**Z**, **V**), with adjustments made for varying node points per layer (Landa et al., 1988).

To construct a depth-velocity macromodel, reflection times are converted to depth using time migrated section and image ray tracing (Hubral, 1977). Splines interpolate the interface geometry. Traveltimes in CMP configuration are computed using the FO CRS approximation (Garabito et al., 2011):

$$T_{CMP}^2 = \left[t_0 + \left(\frac{1}{v_0}\right)(a_2\Delta h)\right]^2 - \left(\frac{t_0}{v_0}\right)[a_4 - a_5]\Delta h^2. \tag{1}$$

Where, $a_2 = sin\beta_G - sin\beta_S,\ \ a_4 = K_2cos^2\beta_S$ and $a_5 = K_3cos^2\beta_G,\ K = 4K_1 - 3K_3$. The function t_0 represents the reflection traveltime taken by the central ray. β_S and β_G are the initial and emergence angles of the central ray at the source *S* and receiver *G* positions, respectively. These positions are denoted by x_S and x_G. The term Δh = $h - h_0$ corresponds to the half-offset displacements, where h_0 = $(x_G - x_S)/2$ is the half-offset of the central ray. The velocities $v_S$and v_G correspond to the velocity at source S and receiver G, respectively. The wavefront curvatures (K_1 , K_2, and K_3) are calculated at the respective emergence points of the central ray (Zhang et al., 2001 and Mesquita et al. ,2019).

We use a depth-velocity model to apply a time-to-depth converter for parameters m_{CRS} ={**V**, **Z, W**} and to identify reflection events. Coherence is optimized in prestack gathers via semblance measurement using FO CRS traveltime approach, with the inversion strategy maximizing coherence along CMP trajectories based on mean semblance values that is applied layer by layer (Niedell and Taner, 1971).

Full waveform inversion

Based on Tarantola (1984), the FWI aims to iteratively refine a subsurface model by minimizing the misfit between the full wavefield observed (d_{obs}) and modeled data (d_{mod}). A key computational challenge is evaluating the Fréchet derivative matrix **J**. To address this, the adjoint-state method (Tarantola, 1984) provides a way to compute the gradient of the objective function ∇*E*(**m**) implicitly.

The inversion process typically involves minimizing the least-squares misfit:

$$E(m) = \frac{1}{2}\delta d^T \delta d = \frac{1}{2}\sum_{i=1}^{N} \delta d_i^2. \tag{2}$$

Where $\delta d = d_{obs} - d_{mod}$. The model is updated using the steepest descent method:

$$m_{K+1} = m_K - \alpha \nabla E(m). \tag{3}$$

Here, α is the step length, chosen to ensure convergence. The gradient in the adjoint formulation quantifies the sensitivity of the pressure field to perturbations in the model parameters (Tarantola, 1984).

Results

This paper introduces a strategy that integrates FO CRS tomography and FWI to enhance subsurface velocity modeling. FO CRS tomography provides an initial model, aiding in FWI optimization. The data is from a seismic survey in the Tacutu Basin, Brazil. Figure 1(a) illustrates the 50-RL-90 seismic line, measuring 44200 meters, acquired with a symmetric split-spread setup. Figure 1(b) shows the area inverted by FO CRS tomography, covering CMP gathers 1000 to 1420, with a total offset of 10,500 meters.

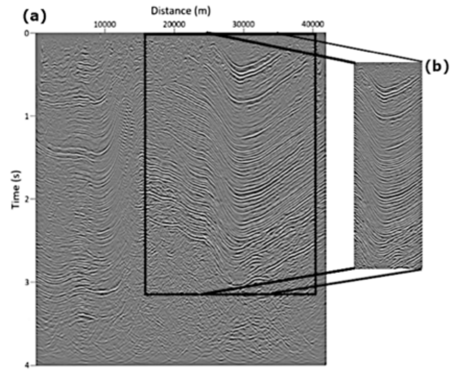

Figure 1: (a) Time migrated seismic section of the 50-RL-90 seismic line from the Tacutu dataset, where the black rectangle delimits the area that was inverted by the FO-CRS tomography. b) 15 shots were selected in the extracted area to carry out the inversion process by FWI. (modified from Eiras and Kinoshita (1990)).

The FO CRS model is shown in Figure 2(a) and the FO CRS + FWI model is depicted in Figure 2(b). Figures 2(c) and 2(d) show the results obtained by the LSRTM migration in-depth applied to the FO CRS model and FO CRS + FWI model, respectively. Twenty-seven shots were used in this migration process within the studied area. The result showed that FO CRS tomography combined with FWI can achieve greater details than FO CRS toography alone, since the faults become more visible after application. It is also possible to note that in Figure 2(c) the reflectors are visible, but their inclination is not captured in detail, while in Figure 2(d), the inclusion of FWI in the process allowed a substantial improvement in the definition and inclination of the reflectors.

Conclusions

Our research demonstrates the effectiveness of combining FWI method with FO CRS tomography for seismic velocity inversion in the Tacutu Basin. This integrated approach overcomes the limitations of FO CRS, particularly in complex subsurface scenarios, by refining velocity models and improving image resolution, especially at greater depths. Our findings align with previous interpretations of the area's geological formations (Eiras and Kinoshita, 1990; Garabito et al., 2005), confirming the presence of an anticlinal fault fold and enhancing the understanding of the stratigraphic units within the region.

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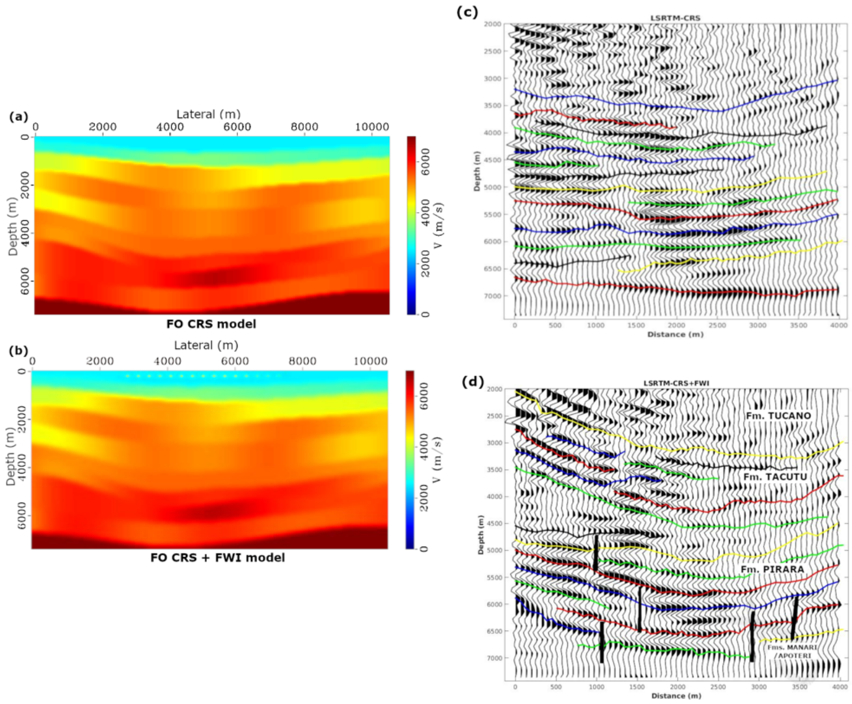

Figure 2: (a) The FO CRS model obtained from FO CRS tomography. This is a smoothing of the model obtained in the work of Mesquita et al. (2019). (b) The FO CRS + FWI model obtained from the FWI method. (c) Depth migrated section by the LSRTM method using the FO CRS model (Figure 2(a)). (d) Depth migrated section by the LSRTM method using the FO CRS + FWI model (Figure 2(b)).

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