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Efficient Multiparameter Elastic RTM Angle Gather

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Abstract

We propose a multiparameter elastic reverse time migration (RTM) angle gather method that uses an elastic imaging condition to efficiently extract angle-dependent reflectivity. Compared to conventional angle gather techniques, our approach is computationally faster and consistent with the elastic radiation patterns, albeit with lower angle resolution. The resolution can be enhanced using higher-order, beyond-elastic imaging conditions. Numerical examples show that multiparameter elastic RTM angle gather capture key AVA behaviors and offer a rapid, practical alternative to more complex anlge gather methods—making it a useful counterpart to multiparameter elastic full-waveform inversion (FWI).

Introduction

Multiparameter elastic FWI inverts for multiple elastic properties simultaneously, offering detailed subsurface information. However, a corresponding RTM-based method that complements this multiparameter elastic framework remains underexplored. Conventional RTM angle gathers often rely on complex, non-elastic methods to capture angle-dependent reflectivity, which can make them less consistent with multiparameter elastic FWI.

In this work, we propose using multiparameter elastic RTM angle gathers based on an elastic imaging condition (Feng et al., 2025a, 2025b) that is consistent with the adjoint of the elastic wave equation. This approach enables fast and physically consistent angle gathers aligned with multiparameter elastic FWI. While the elastic imaging condition corresponds to a second-order Fourier series and offers lower angle resolution, its efficiency makes it attractive—and resolution can be further enhanced using beyond-elastic imaging conditions.

Theory

Fourier series imaging condition introduces the Fourier series terms I_n (Feng et al., 2025a, 2025b):

$$I_n = \int (V_p \nabla)^{(n)} P^{(n)} : (V_p \nabla)^{(n)} R^{(n)} dt, \tag{1}$$

where V_p is the P-wave velocity, and n is the order. Here, $P^{(n)}$ indicates that P is time-integrated n times, and $(V_p \nabla)^{(n)}$ applies the spatial gradient ∇ followed by V_p scaling, repeated n times. The Frobenius inner product $(:)$ sums component-wise tensor products.

We formulate the generation of angle gathers $I(\theta)$ from Fourier series terms as an inverse problem, with an objective function $\mathcal{L}$ to minimize:

$$\mathcal{L}[I(\theta)] = \sum_n \left\| \int_\theta \cos^n\theta I(\theta) d\theta - I_n \right\|_2^2 + \text{regularization}, \tag{2}$$

where θ is the scattering angle ranges from 0° to 360°, consistent with the FWI community's convention. The reflection angle is given by either $\theta/2$ or $(360° - \theta)\ /2$, whichever is smaller.

The zero order Fourier series term I_0 corresponds to the regular RTM image. Including up to second-order terms ($n \leq 2$) yields the elastic imaging condition, which captures angle-dependent reflectivity of three elastic parameters with radiation patterns $1, \cos\theta$ and $\cos^2\theta$. We refer to this as the multiparameter elastic RTM angle gather. Incorporating higher-order terms I_n $(n > 2)$ with radiation pattern $\cos^n\theta$ further enhances angle resolution, offering a beyond-elastic imaging condition.

Results

2.5D synthetic example with different AVO classes

We applied our multiparameter elastic RTM angle gather to a 2.5D elastic synthetic model with six embedded anomalies to mimic amplitude variation with angle (AVA) classes 1, 2, and 3 in both sediment and subsalt regions (Figures 1a–1c). We simulated pressure wavefields through 3D elastic modeling, and then RTM was performed using multiparameter elastic RTM angle gather with elastic imaging condition. For comparison, we also provide the angle gather obtained by direction-vector-based methods (Yoon and Marfurt, 2003; Vyas et al., 2011).

Figure 1d shows the regular RTM image ($n = 0$), while Figure 2a presents multiparameter elastic RTM angle gather covering reflection angles $\theta/2$ up to 60°. The sediment anomalies in the red, blue, green solid boxes in Figure 2a align with the true AVA behavior: increasing negative amplitude with angle, decreasing positive amplitude with angle, and polarity reversal, respectively. In the subsalt region (dashed boxes), limited illumination degrades AVA clarity, which could be improved by multiparamter elastic FWI. Compared to direction-vector-based angle gather in Figure 2b, our method captures similar features with lower angle resolution but higher efficiency.

Gulf of Mexico field data example

The field data was acquired from the Gulf of Mexico and features a large, connected salt structure. A P-wave velocity model, generated through FWI using low-frequency, ultra-long-offset ocean-bottom node (OBN) data, serves as input for RTM with acoustic tilted transversely isotropic (TTI) propagator. This RTM leverages downgoing from OBNs with dense node spacing (600 m) and a maximum frequency content of 18 Hz.

Figure 3a shows an RTM angle gather using a beyond-elastic imaging condition (third order), while Figure 3b shows the angle gather from a direction-vector-based method. In the sediment region (green boxes), both approaches highlight strong amplitudes at mid angles ($\theta/2 \approx 20° \text{ to } 50°$), consistent with full-azimuth OBN coverage. In the subsalt region (red box), the beyond-elastic RTM angle gather shows stronger small-angle amplitude and broader illumination but with lower resolution—likely due to interpolation into the elastic radiation pattern, resembling the FDR angle gather from multiparameter elastic FWI.

Conclusions

We proposed and demonstrated a multiparameter elastic RTM angle gather approach using anelastic imaging condition. This enables low-cost RTM angle gathers that capture multiparameter elastic sensitivity and remain consistent with the adjoint of the elastic wave equation. Angle resolution was improved using higher-order beyond-elastic imaging conditions. Compared to direction-vector-based methods, our approach offers similar AVA characteristics, making it a practical and efficient tool as counterpart to multiparamter elastic FWI.

Acknowledgments

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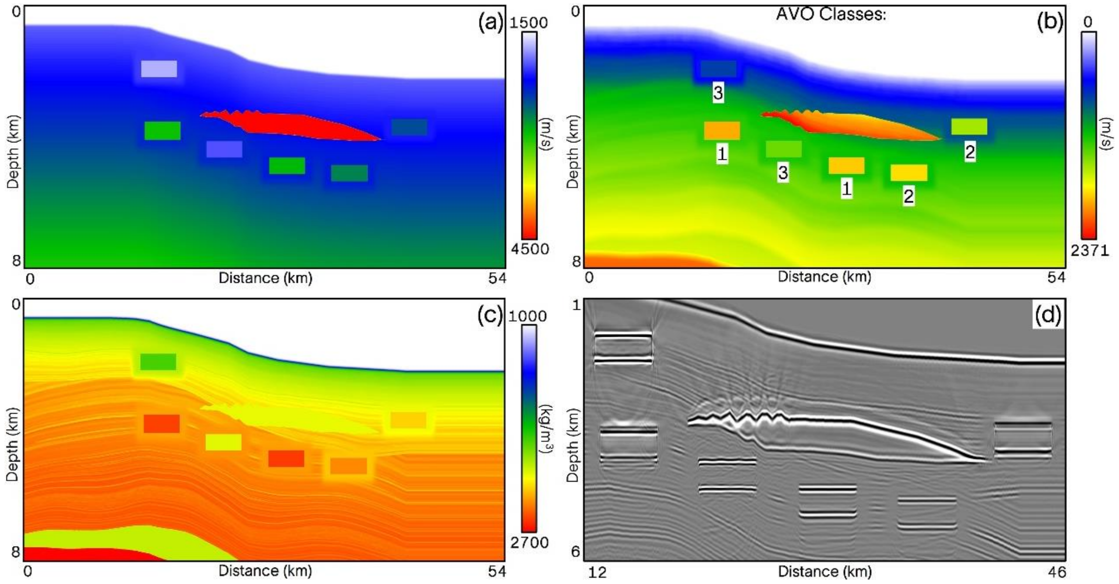

Figure 1: A synthetic example: True (a) P-wave velocity, (b) S-wave velocity, and (c) density models. (d) Zero-order Fourier series term I_0 (regular RTM image).

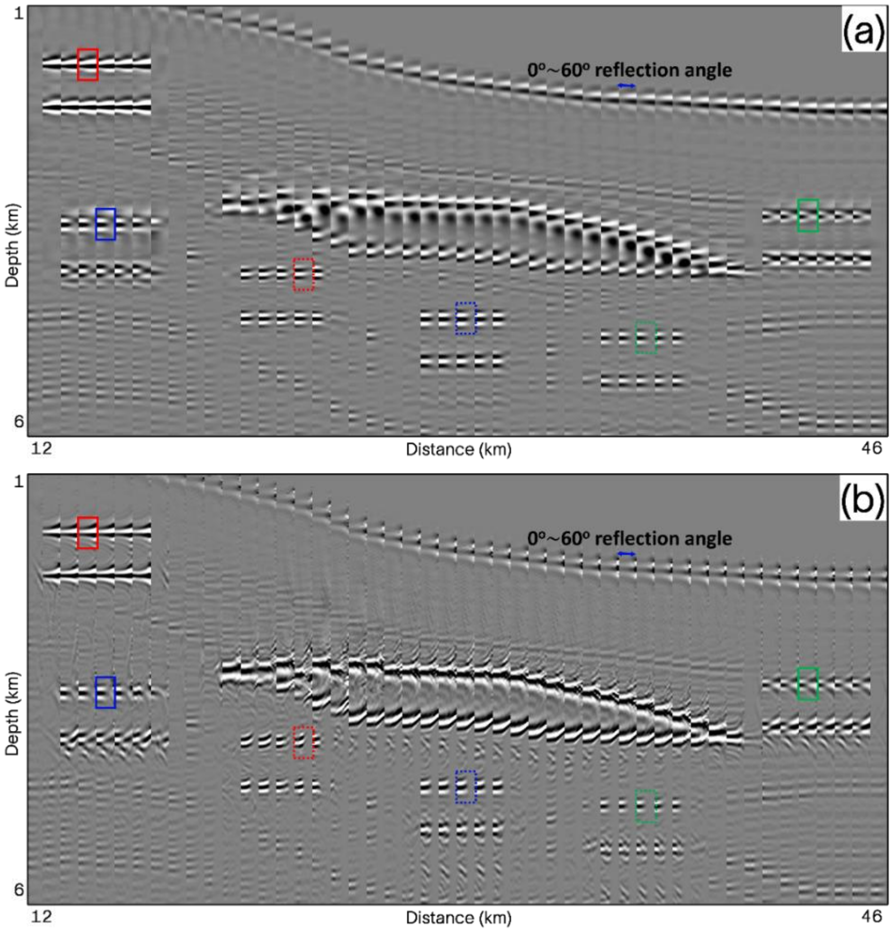

Figure 2: A synthetic example: (a) multiparamter elastic RTM angle gather, (b) angle gather by direction-vector-based methods.

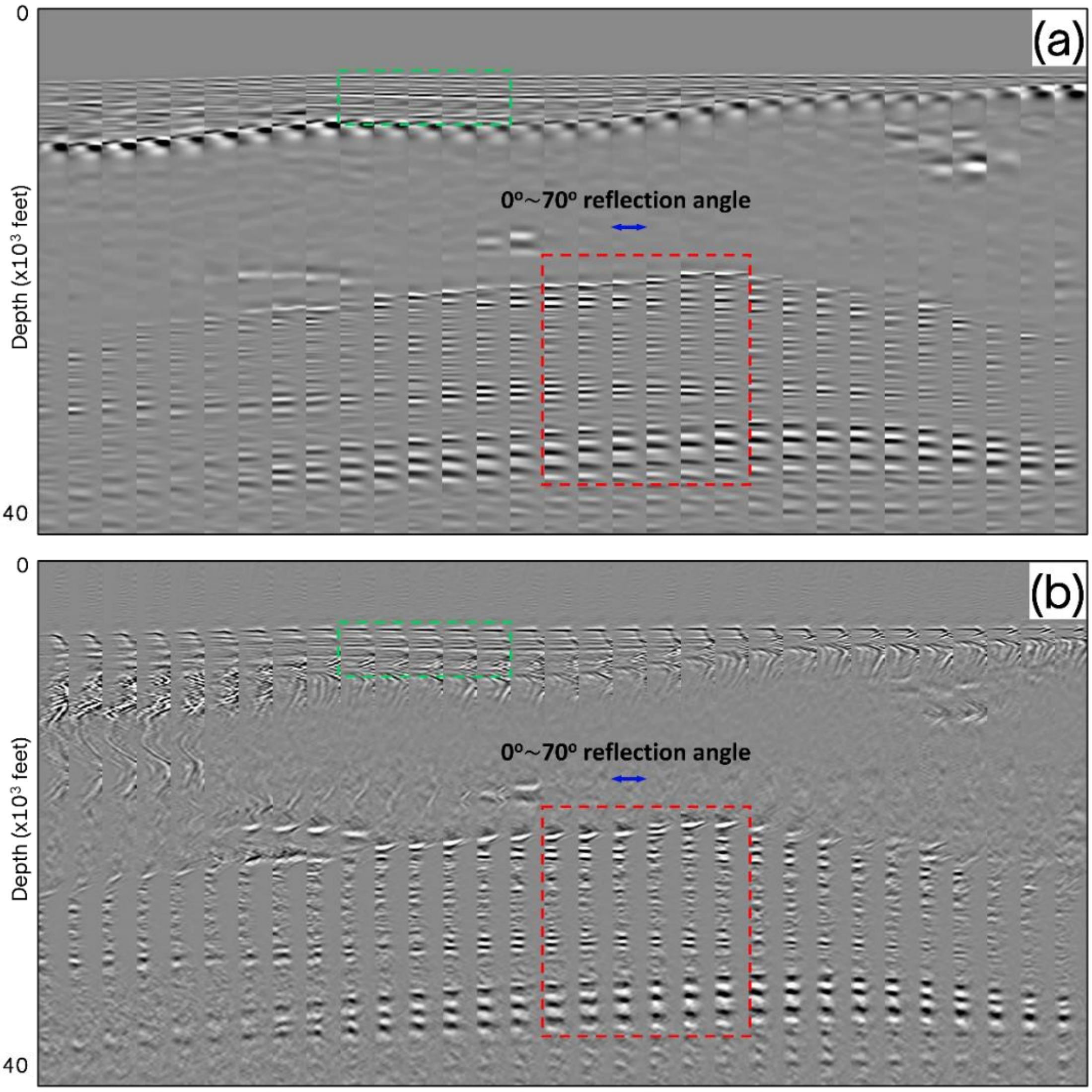

Figure 3: Gulf of Mexico example: (a) multiparamter elastic RTM angle gather, (b) angle gather by direction-vector-based methods.

References

Feng, Z., X. Chen, and D. Vigh, 2025a, Fourier series imaging condition for RTM and FWI angle gathers – elastic and beyond: 84th Conference and Exhibition, EAGE, Extended Abstracts

Feng, Z., X. Chen, and D. Vigh, 2025b, Fourier series imaging condition: RTM angle gathers with elastic and beyond-elastic imaging conditions, and prospect of beyond-elastic FWI: SEG Technical Program Expanded Abstracts

Vyas M., Nichols D., and Mobley E., 2011, Efficient RTM angle gathers using source directions, SEG Technical Program Expanded Abstracts 2011.

Yoon, K., and K. Marfurt, 2006, Reverse-time migration using the Poynting vector: Exploration Geophysics, 37, 102–107.