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Hybrid Tomography and Full Waveform Inversion Velocity Model Updating for Shallow Velocity Anomalies

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Summary

Geologically reasonable, data-driven velocity model building is a critical process for seismic imaging, particularly when the velocity is strongly heterogeneous within a layer or structure. When such features are prominent in the shallow, disruption of the signal may propagate through a significant portion of the image. A hybrid tomography-FWI workflow incorporating image-guided tomography and phase-only reflection full-waveform inversion is proposed as a method for generating robust and detailed model updates in these situations. Application to a narrow azimuth streamer survey demonstrates the effectiveness of the method in yielding detailed model updates and simplified geological structures in the final image.

Introduction

Geologically reasonable, data-driven velocity model building is a critical process for seismic imaging, particularly when the velocity is strongly heterogeneous within layers or structures. When such features are prominent in shallow imaging, the disruption of the signal due to an inaccurate velocity model may propagate down through a significant portion of the image.

We present a successful workflow for data with strong velocity and attenuation anomalies in otherwise orderly shallow sediment. Refraction and reflection-based full-waveform inversion (FWI) provide details of the high-resolution velocity contrasts, and alternating iterations of image-guided tomography resolve the larger scale velocity updates. Structure below the features is improved, with uplift more than 2 km deeper than the velocity anomalies.

Method and Theory

FWI produces high-resolution model updates based on comparisons of observed and modelled shot gathers. A multistage FWI job flow was created to avoid some of the inherent difficulties of this method (Mao et al., 2016). In the early steps of model building, the model may be significantly different from the true velocity. Cycle-skipping errors are mitigated by a dynamic-warping algorithm for diving wave FWI. As model building proceeds, higher-resolution updates are encouraged by the incorporation of reflection data, with updates conditioned by an image-guided smoothing scheme for phase-only reflection FWI (Figure 1).

Multistage FWI yields high-resolution features with realistic contrasts across structural interfaces. However, common-image gathers may still show residual moveout, suggesting that additional iterations of tomography should be considered. The tomographic suite for this project combines offset-dependent nonparameterized moveout picking with image-guided inversion to encourage data-driven high-resolution updates (Hilburn et al., 2014). Image-guided tomography enforces structural conformance in model updates. This is an ideal counterpart to the above FWI workflow because it can provide low frequency updates at early iterations, but also helps generate the necessary high-resolution velocity contrasts required to isolate strongly anomalous regions.

Examples

This workflow is applied to a 2017 narrow azimuth 3D survey off the western coast of Ireland, covering about 6500 km^2. The shallow region is contaminated by several anomalies characterized by significant sags in underlying layers due to compromised events in migrated gathers, suggesting sharp velocity contrasts. Image-guided tomography has been shown to be a robust model building method for these kinds of imaging issues, but early iteration reflection data around the anomaly is so poor that diving wave FWI is necessary to begin to construct the velocity contrasts needed.

Following our alternating FWI-tomography workflow, initial long wavelength model updates are provided by iteration 1 tomography. Iteration 2 consists of relatively low-resolution diving wave dynamic warping FWI updates. The tomographic update in iteration 3 improves overall gather flatness. Phase only reflection FWI in iteration 4 nearly finalizes the character of the model around the anomaly. Finally, iteration 5 is a tomographic update to correct any minute residual moveout errors around and below the anomaly, to begin the process of updating the deeper velocity model.

Imaging improvement (Figure 2) is driven by the ultraslow velocities generated within the upper section of the anomaly. Structure through and below the chalk layer is more geologically plausible, and event continuity is improved. The final pass of tomography has begun to resolve the deeper structure, a process which is only reliable due to the detailed model building in the shallow. The progression from low to high frequency updates, provided by alternating tomography and FWI application, brings events into better focus, with each model update providing an improved starting point for the subsequent steps. The final gathers are well-focused across the offset range.

Conclusions

The hybrid high-resolution FWI and tomographic model building workflow presented is applied to an offshore Ireland dataset which demonstrates strong velocity inhomogeneities in shallow sediments, disrupting the image around and beneath these anomalies. The combined update produces useful events from poorly imaged regions by improving continuity and focusing. The strong contrasts in the velocity model at the edges of the anomalies are necessary to successfully solve the complicated moveout observed in these events. Final imaging results are geologically simplified despite the high level of detail inserted into the model.

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References

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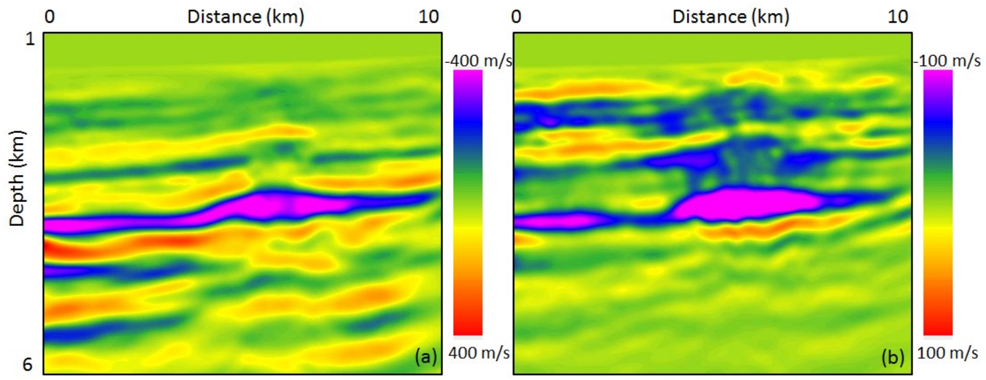

Figure 1 *Velocity update from (a) conventional reflection FWI (b) phase-only reflection FWI.*

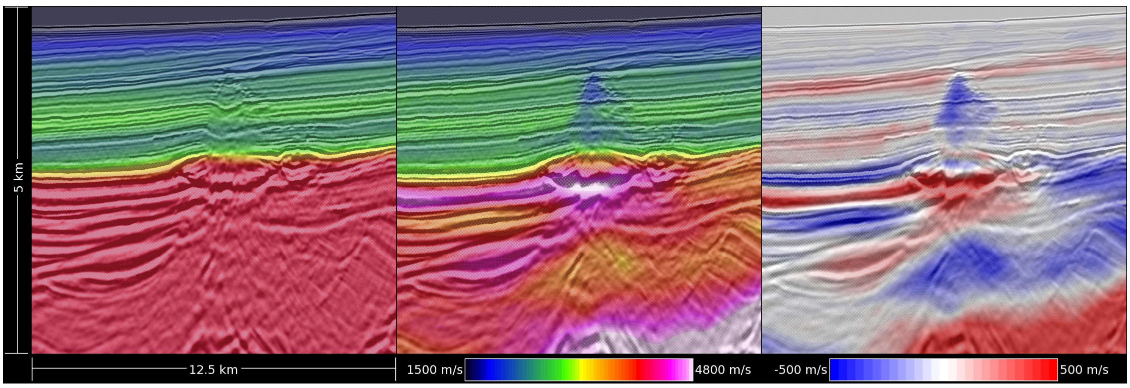

Figure 2 *Inline slices of: initial imaging and velocity (left), final imaging and velocity (center), and final imaging and total velocity update (right).*