Joint turning-ray and reflection tomography for velocity model building in foothill areas

Junru Jiao and Xianhuai Zhu, Forland Geophysical Service, USA

Summary

Due to low oil price, land seismic exploration has become more active recently while it is more challenge to estimate velocity model for land imaging than marine seismic imaging because of complex near surface structures and rugose topography. We propose a joint turning-ray and reflection tomographic method to handle the challenge. First, turning-ray tomography is used to derive near the surface model. Then, we combine the near surface model with the initial subsurface model. Taking the combined model as starting model, we go through post-migration tomographic process to build the model for imaging. The proposed method has been successfully applied to a 2D complex synthetic example. The results demonstrate that the proposed method derives a very decent model even there are no reflection information available in a few hundred meters underneath surface.

Introduction

Reflection tomography based on post-migration has dominated the velocity model building in seismic image, especially for marine seismic exploration where the near surface model is not problematic. In other hand, the reflection tomography encounters challenge to derive near surface model with high quality because there are only very limited valid traces, even no valid traces, in near surface up to a few hundred meters in depth from the surface. An alternative method is desirable to obtain near surface model. Here, we propose joint turning-ray tomography and reflection tomography to build velocity model for foothill exploration. First, we pick first break for input to turning-ray tomography derive near surface depth model. An initial subsurface depth model is obtained by converting RMS velocities into interval velocities in depth domain. Then, we merge the near surface model with the initial model which is used as the starting model for reflection tomography. We test the proposed method on a complex 2D synthetic data example.

Principle of joint tomography

Turning-ray tomography has been conventionally used to calculate static which was referred as tomo-statics (Zhu, et al., 1992). In turning-ray tomography, the medium to be imaged is generalized into a continuous medium, such that the first arrivals recorded at the surface need not be associated with refractors having strong velocity contrasts. Turning-ray tomography inverts for velocity model by minimizing misfits between observed first-break times and calculated travel times from turning-rays. Since a continuous medium is assumed, the inversion results in grid-based model. Usually, generation of robust results requires that the recording aperture (signed offsets) be at least four times larger than the desired imaging depth. Therefore, we can use this model as a good estimation of near surface model combined with reflection tomography. However, in practical, we need to select maximum depths of reliable velocities according to ray density for every location.

Reflection tomography based on post migration utilizes depth residuals among traces within a common image gather generated from prestack depth migration (Stork, C., 1992; Jiao, et al., 2010). The residuals are distributed along reflection rays. By minimizing the residuals, reflection tomography inverts for velocity perturbation and then updates velocity model according to the previous model. Reflection tomography is an iterative process of prestack depth migration and tomographic inversion until the residuals are flattened since linearization is applied.

Since we combine near surface model from turning-ray tomography and normally this model is more accurate and has higher resolution than reflection tomography, we keep this model unchanged during early stages of iterations. To combine both models streamless, we allow reflection tomography to also update the shallow party in later stage of iterations.

Synthetic data example

We have applied the proposed method and workflow to a 2D synthetic data sets which simulates Canadian Foothills (Boonyasiriwat,et al. 2009), has the length of 20 km in crossline and the depth of 6.5 km, and has rogues topography with elevation difference up to as 700 meters and complex subsurface geological structures. The very specific feature of the model is that there are no reflection layers within 600 meters underneath the surface, which makes it very difficult to derive near surface model by reflection tomography. We first picked the first-breaks from common shot gathers, then performed turning-ray tomography. Figure 1 and 2 show the ray density and inverted near surface velocity model respectively. According to the distribution of ray density in Figure 1, we picked a horizon as the maximum depths for reliable velocities. The maximum thickness of inverted model is up to 1200 meters. To have an initial model for prestack depth migration, we heavily smooth the true model in both horizontal and vertical directions, scale velocity by 0.95

and then combined it with near surface model above the horizon and with tapering in adjacent zone of horizon. This combined model is presented in Figure 3.

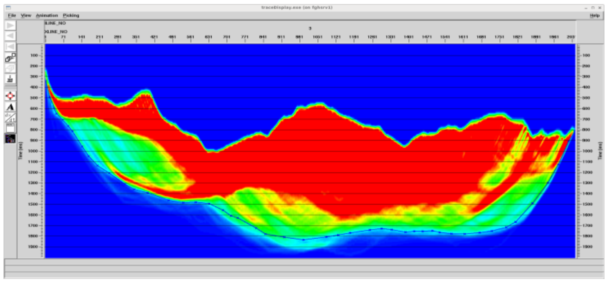

Figure 1. Ray density from turning-ray tomography. The dot line in the deeper part is the horizon for maximum depth of reliable velocities.

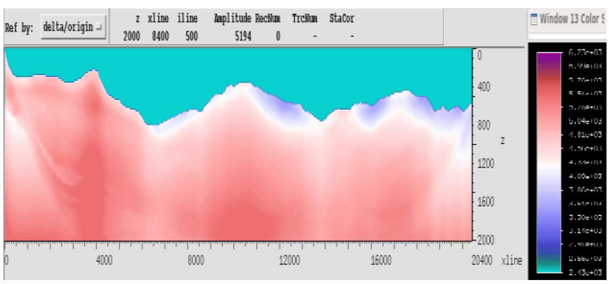

Figure 2. Inverted near surface model from turning-ray tomography.

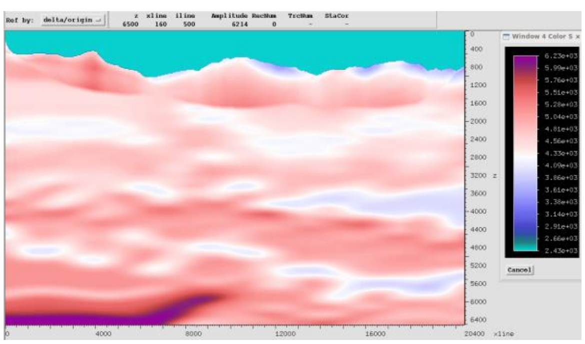

Figure 3. The combined initial model for reflection tomography. Inverted near surface model from turning-ray tomography.

Beginning with the initial combined model, we perform migration and reflection tomography iterations. We use Kirchhoff prestack depth migration to generate common image gathers in the offset-depth domain. The offsets of gather are from 100 meter to 7900 meters with increment of 200 meters and the depth is to 6500 meters with interval of 5 meters. Figure 4 shows the common image gathers for every 1000 meters in crossline from 2500 to 18500 meters. Most events are curved up since velocities are scaled by 0.95. The stacked migration from the initial model is given in Figure 5.

During first three tomographic iterations, we keep the near surface party unchanged by applying masking function in inversion. Late on, we allow reflection tomography update both near surface and subsurface parties. We find that reflection tomography adds more details into near surface model slightly. After several iterations, flatness of CIG improves significantly and more details are revealed for velocity model. Figure 6 and 7 show the common image gathers and stack from the final inverted model in Figure 8. For comparison, we also present the true velocity model and corresponding stacked migration and common image gathers in Figure 9, 10, and 11 respectively. Although the inverted model is quite smooth, it shows the major features of true model. The proposed joint tomography derives the overthrust structure in the middle part of the model.

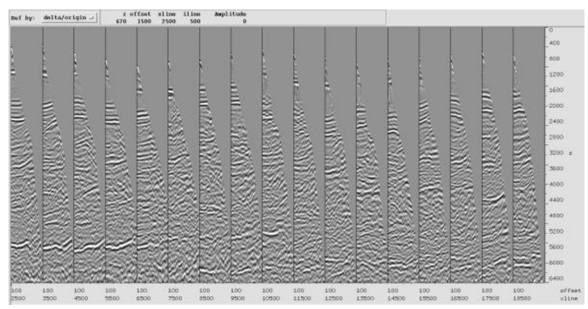

Figure 4. Common image gathers from the combined initial model. The gathers are in depth-offset domain. The offset is from 100 to 7900 meters with 200 meter increment.

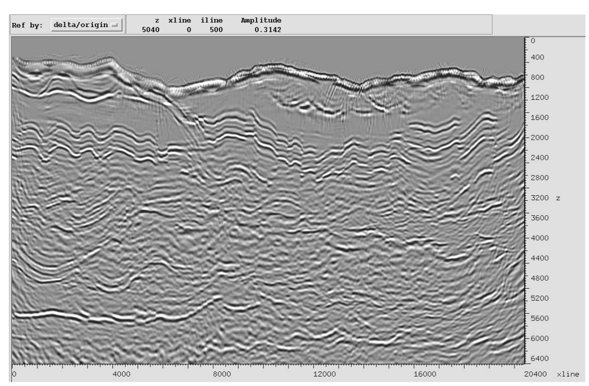

Figure 5. Stacked migration from the initial velocity model.

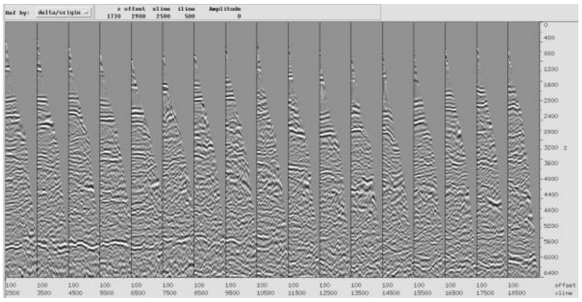

Figure 6. The common image gathers for every 100 xline using the updated velocity model from the proposed joint tomography after several iterations.

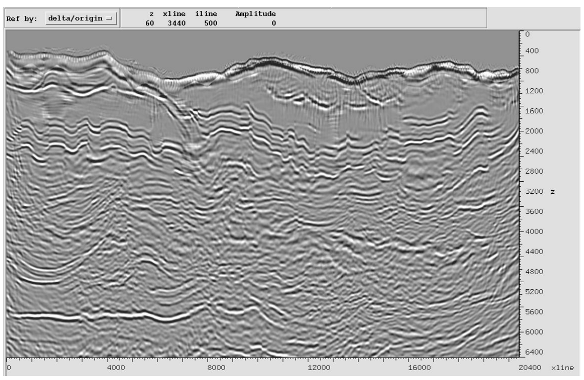

Figure 7. The stacked migration using the updated velocity model from the proposed joint tomography after several iterations.

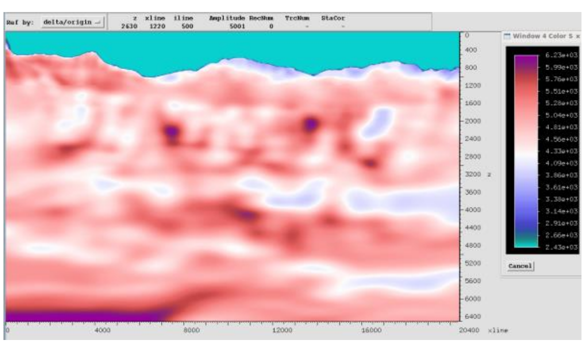

Figure 8. The updated velocity model from the proposed joint tomography after several iterations.

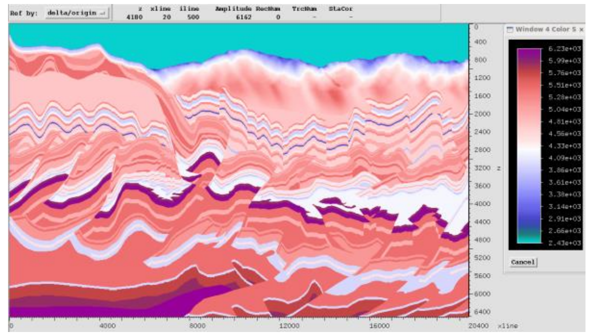

Figure 9. The true velocity model derived from Canadian Foothill. This model is used to generate synthetic seismic shots for this study.

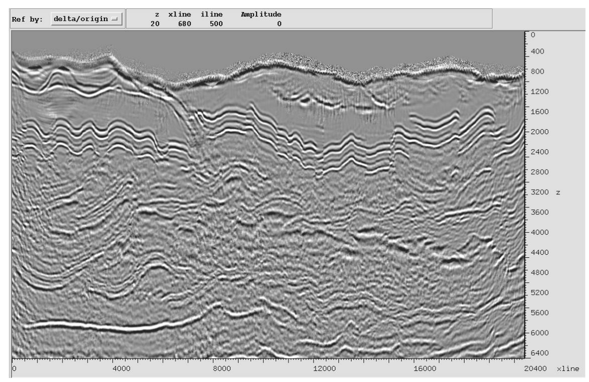

Figure 10. The stacked migration using the true velocity model.

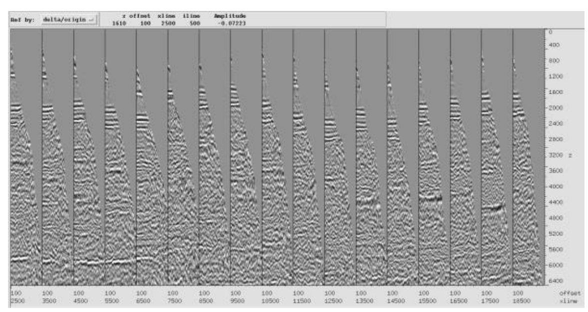

Figure 11. Common image gathers from the true velocity model.

Conclusions and future work

We have proposed a method of joint turning-ray and reflection tomography to build velocity. The proposed method handles with difficulty of estimation for near surface model in land seismic imaging. We first use turning-ray tomography to derive near surface model according to first arrivals without requiring for reflections. Then, post-migration reflection tomography is applied to invert for the subsurface model with near surface model masked. We have applied the proposed method to the complex 2D synthetic data sets successfully.

For future work, we will apply the proposed method to 3D field examples and extend to anisotropic media.

Acknowledgements

We thank Forland Geophysical Services for permission to publish this work. We also thanks our colleges Pan Deng, Grace Yan, Lei Fu, and Bin Yang for meaningful discussions.

References

Boonyasiriwat, C., Valasek, P., Routh, P., and Zhu, X, 2009, Application of multiscale waveform tomography for high-resolution velocity estimation in complex geologic environments: Canadian Foothills synthetic data example: The Leading Edge, April 2009, 454-456.

Jiao, J., Zhou, C., D., Lin, S., Van der Burg, D., and Brandsberg-Dahl, S. (2010), Velocity model building strategy for multi-azimuth surveys, 80th SEG Annual Meeting.

Stork, C., 1992, Reflection tomography in the postmigrated domain: Geophysics, Soc. of Expl. Geophys., 57, 680-692.

Zhu, X., Sixta, D.P., and Angstman, B.G., 1992, Tomostatics: Turning-ray tomography + static corrections: The Leading Edge, 12, 15-23.