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Accurate and Automatic Computation of Refraction Statics in Large 3D Seismic Datasets

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Summary

Analysis of first-break travel-time data was improved by 1) using reciprocal travel-time analysis to control the accuracy of the picks and identify errors in geometry; 2) τ-p parameterization of the travel times, from which the initial statics depth model is obtained without any inversion, and 3) using accurate multi-layer ray-tracing and iterative inversion for a 3D depth model. Model resolution analysis and data statistics were measured in order to determine the optimal model inversion parameters. By using this method, surface-consistent statics were calculated and applied to a real 3D seismic dataset from southern Saskatchewan.

Introduction

Inversion for refraction statics is a key part of three-dimensional (3D) reflection seismic processing. Refraction statics corrections aim to remove the effects of shallow subsurface by using first-arrival travel times. However, careful analysis of first-arrival data is required prior to inversion for the statics. Any errors in the geometry or first-arrival travel times caused during acquisition or processing would propagate into the resulting model and may harm the final image. We attempt to make use of the redundancy of first-arrival travel-time data in 3D seismic dataset to help analysing and improving the quality of the travel-time data early in the processing sequence and before any inversion.

Our goal is creating a complete environment for refraction-data analysis which would allow extensive analysis of all stages of the solution. Although inspired by the GLI3D program (Hampson and Russell, 1984), our statics inversion scheme is different from it in several key aspects. First, travel-times are treated as surfaces, and extensive travel-time quality control (QC) is performed by using statistical methods and interactive, 3D visualization. Second, a layered, variable-depth velocity model is used in the inversion, with explicit interpolation in two horizontal dimensions. This results in deriving a good starting model by using the numerical Herglotz-Weichert transform of (τ,p)-parameterized travel times. Third, several ray-tracing schemes are tested and compared. Along with data QC, we also perform a number of model QC checks during the inversion. Model resolution analysis (perturbation- and checkerboard tests) is performed to obtain the optimum grid size and measure the resolution limits. Finally, the procedure is integrated in a processing system with extensive capabilities for waveform and travel-time data analysis. Surface-consistent statics are calculated from the final model and can be seamlessly applied to the data.

The above environment represents a fairly large software project, and some details of the travel-time parameterization, visualization, and inversion for the initial model were given in Morozov and Jhajhria (2008, 2009). Here, we focus on the inversion, model resolution analysis, and application of the results to a 3D dataset from southern Saskatchewan (Figure 1). The approach was designed as a research prototype, with most code implemented in Matlab. Further details of this approach can be found in Jhajhria (2009).

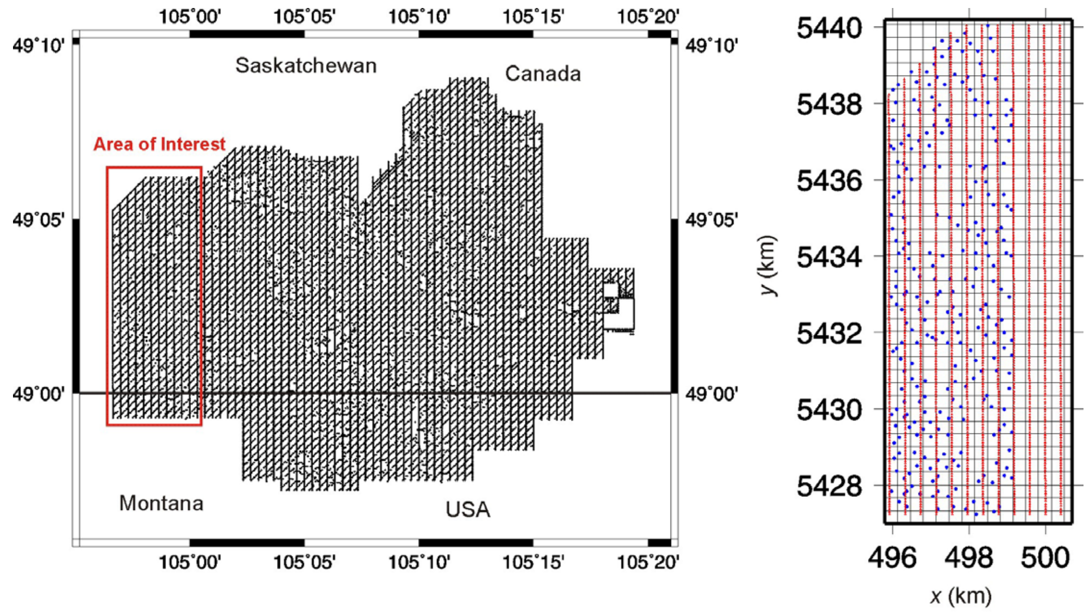

Figure 1: Left: source-receiver layout of the Beaver Ranch 3D dataset. Right: Area selected for this study. Seismic sources are shown in blue, receivers in red, and the inversion grid in black.

Model resolution analysis

By examining the first-arrival travel-times in the Beaver Ranch dataset (Figure 1), we found that a three-segment model was sufficient for approximating all the travel-time curves in the τ-p form. Consequently, we inverted for a three-layer depth model, with velocities of 0.667 km/sec, 1.5 km/sec, and 2.0 km/sec, overlain over a 3.0-km/sec half-space. These velocities were fixed, and only the depths of the three refracting interfaces were varied during the inversion.

Before applying the inversion to real data, it is important to examine the ability of the algorithm to invert for the various types of detail of the model. Such testing is known as model resolution analysis (Menke, 1984) and is the basis for selecting the optimal inversion grid size for the given ray coverage. Model resolution analysis is commonly performed by two approaches. In the first of these methods, an individual node of the model is performed, and synthetic travel times are calculated and inverted in order to see how the perturbed node is resolved by the

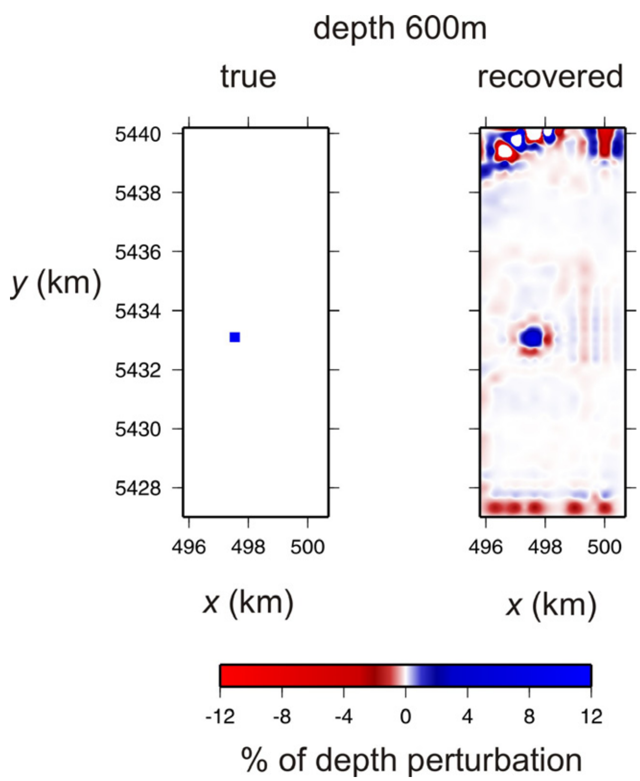

Figure 2: Perturbed model depth in a 1-layer model (left) and inverted from it (right) using a 335-m inversion grid. Note the side-lobes in the recovered model.

inversion (Figure 2). This method shows the details of parameter trade-offs within the model (Figure 2), and results in a "resolution matrix" when applied to all nodes within the model.

Another type of resolution analysis often employed in tomography (Humphreys and Clayton, 1988) is the so-called "checkerboard" test. In this method, a regular alternating spatial pattern is generated in the model, and the inversion is tested for its ability to recover this pattern by using the actual source-receiver distribution. The advantage of this approach is in its ability to examine the entire model at once, although with less detail of the trade-off between the different model nodes.

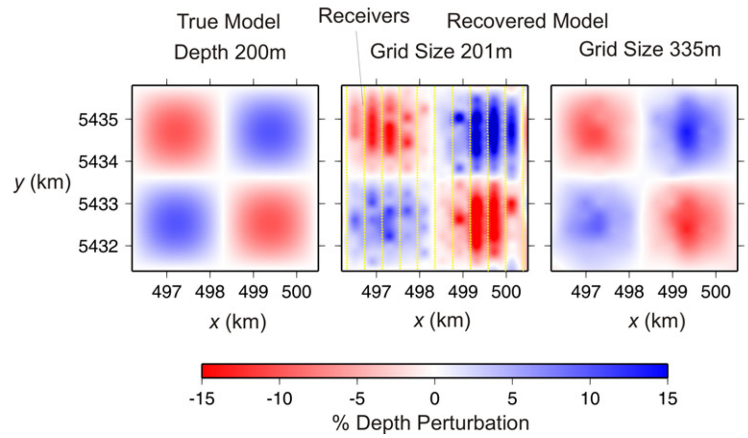

Figure 3: close-up view of the checkerboard test using grid sizes of 201 m and 335 m. Note the linear features (acquisition footprint) appearing in the model recovered by using grid size of 201 m.

Checkerboard testing is an effective way to measure resolution, and its results are immediately interpretable. Examples of such testing for our case are shown in Figure 3, and also in Morozov and Jhajhria (2009). Note the spurious pattern in the inversion caused by the acquisition footprint when using smaller model grid sizes (Figure 3). From this test, we decided to use 335 m as the grid size for inverting the real data.

Application to real data

Because the initial model was derived from the travel-time data, it already predicted the travel times relatively closely. This model was further improved using multi-layer accurate ray tracing technique and non-linear SIRT- (Simultaneous Iterative Reconstruction Technique-) based inversion scheme. Several ray-tracing approaches were examined and compared for their accuracy and efficiency (Jhajhria, 2009).

The result of inversion for the selected part of Beaver Ranch dataset (Figure 1) is shown in Figure 4. As one can see, there is a significant variation in the depths of the three refracting interfaces. Near the edges of the model, data coverage is reduced, leading to strong edge effects in the resolution tests (Figure 2), and these areas were smoothed in the model (Figure 4).

After the depth model was obtained, we derived surface-consistent statics by tracing vertically-propagating rays through the layered velocity structure. In the well-covered part of the area, the resulting statics were sufficient for aligning the reflections in the (Figure 5).

Conclusions

Using decomposition of refraction travel-times in 3D, the quality of first breaks was improved and errors in geometry were identified. The starting model was obtained from the first-break times and was improved

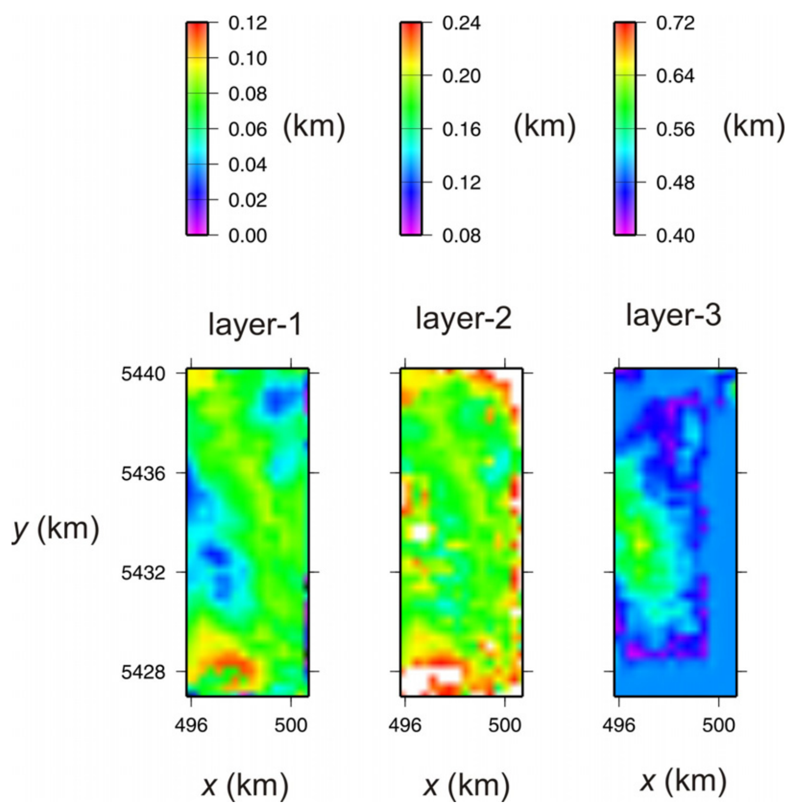

Figure 4: Depth to three model interfaces obtained from the inversion

further by using accurate ray-tracing and refined inversion techniques. Resolution analysis was performed to check for selecting inversion parameters and for assessing the limits of attainable resolution. Near-surface refraction model was further created, statics calculated, and applied to a real dataset.

The statics solution presented here can be described as “long-wavelength” (model-based), and additional static terms (such as surface-consistent and non-surface consistent source, receiver, and *ad hoc* midpoint) can be derived by the software in which the present approach is embedded (Morozov and Jhajhria, 2008, 2009).

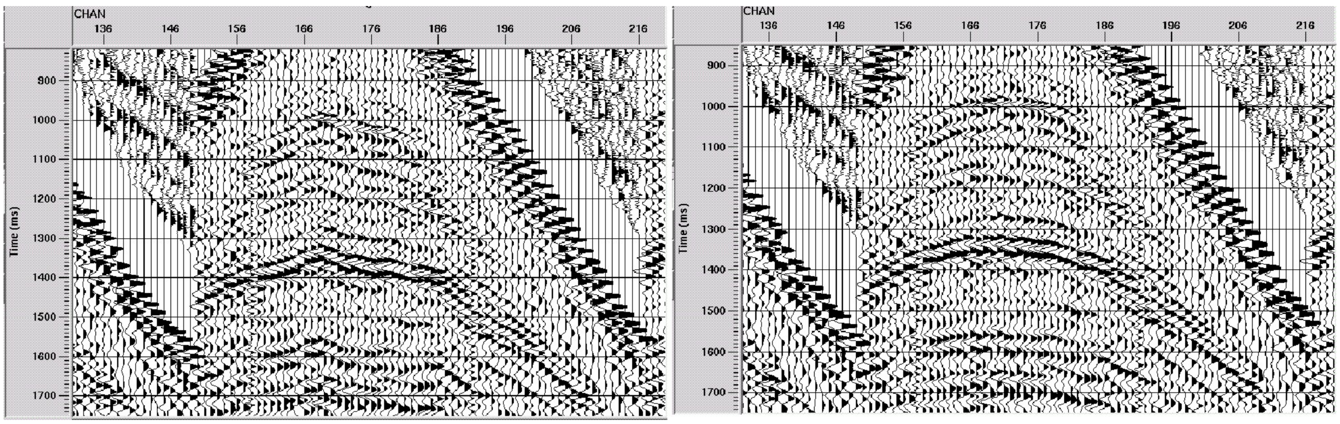

Figure 5: A fragment of a shot section before (left) and after (right) application of model-based refraction statics.

Acknowledgements

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References

Hampson, D., and Russell, B., 1984, First-break interpretation using generalized inversion, J. Can. Soc. Explor. Geophys., 20, 40-54.

Humphreys, E. and Clayton, R.W. (1988) Adaptation of back-projection tomography of seismic travel time problems. J. Geophys. Res., 93, 1073-85.

Jhajhria, A., 2009, Accurate and Automatic Refraction Statics in Large 3D Seismic Datasets, M.Sc. thesis, University of Saskatchewan, Saskatoon, SK

Menke, W., 1984, Geophysical data analysis: Discrete inverse theory, Academic Press.

Morozov, I. B., and A. Jhajhria, 2008. 3D Refraction Statics Integrated with Surface-Consistent First-Break Picking, Iterative Inversion, and 3D Visualization, 2008 CSPG/CSEG/CWLS Convention

Morozov, I. B., and A. Jhajhria, 2009. Integrated Analysis and Inversion of 3D Refraction Travel Times, 2009 CSPG/CSEG/CWLS Convention