Autoregressive Extrapolation Applied to Tomography in the Cross-Borehole Geometry

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Summary

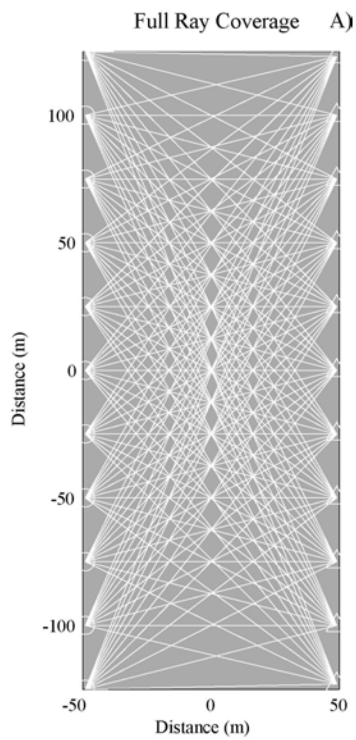
Autoregressive (AR) extrapolation is tested using a synthetic tomography example with a cross-borehole geometry. Previous work by Menke (1984) showed that cross-borehole tomography has a limited resolution in the cross hole direction. We first apply AR extrapolation to partial data and then compare tomographic inversions using the full data and the extrapolation data. Both the overall pattern of the extended data and the tomographic reconstruction with the extended data show that AR extrapolation can effectively extend the synthetic cross-borehole tomographic data to a broader coverage and can improve the cross-hole resolution of the reconstruction.

Introduction

The ray coverage in cross-borehole tomography problems is inherently incomplete, since there is not completely surrounding coverage by sources and receivers (Menke, 1984). The tomographic reconstruction is limited by this experimental geometry. To improve the resolution of the reconstruction, we use two-stage autoregressive extrapolation (AR) techniques to extend the existing ray coverage to a broader range. Two-stage AR extrapolation algorithm is implemented based on the work of Claerbout (1992; 1998a; 1998b; 2002) and Fomel and Claerbout (2003). Li and Nowack (2004) have applied AR extrapolation methods to synthetic and real data for laboratory rock samples and have shown that AR extrapolation techniques are an effective way to do data extrapolation for seismic tomography experiments. A two-stage AR extrapolation method is applied to synthetic data for seismic tomography using a cross-borehole geometry. Tomographic reconstructions using full, partial and extrapolated datasets are then performed and compared.

Cross-Borehole Geometry and Ray Coverage

We investigate seismic tomography using a cross-borehole geometry and ray coverage. The size of the synthetic cross-borehole model is 100 m in width and 250 m in depth. There are a total of 51 shots and 51 receivers that are deployed along two separate boreholes. The spacing in the borehole is 2.5 m for both shots and receivers. For each shot, rays are traced to every receiver and the travel-times are computed. Figure 1(a) shows the homogeneous starting model with a velocity of 2.0 km/s and a ray diagram showing every fifth shot and receiver point. The circles show the shot positions and the triangles show the receiver positions. The partial ray coverage is shown in figure 1(b) where 10 shots and 10 receivers from each end of the model have been removed. For both the full data and partial data, the ray coverage is denser at the center, and become sparser at the edges of the model. The true model for this experiment is shown in figure 1(c) where the square at the center of the model is a high velocity heterogeneity with a velocity of 2.1 km/s.



AR Data Extrapolation for the Cross-Borehole Geometry

Rays were traced for all possible shot-receiver combinations for the synthetic true model using the code of Cerveny et al. (1988). Travel-time differences are then calculated between the true model and starting model. Since the two-stage AR extrapolation performs better for flattened features, the travel-time data are plotted for source-receiver half offset vs. source-receiver midpoint coordinates. Figure 2(a) shows the plot of the full dataset in the outer rectangle.

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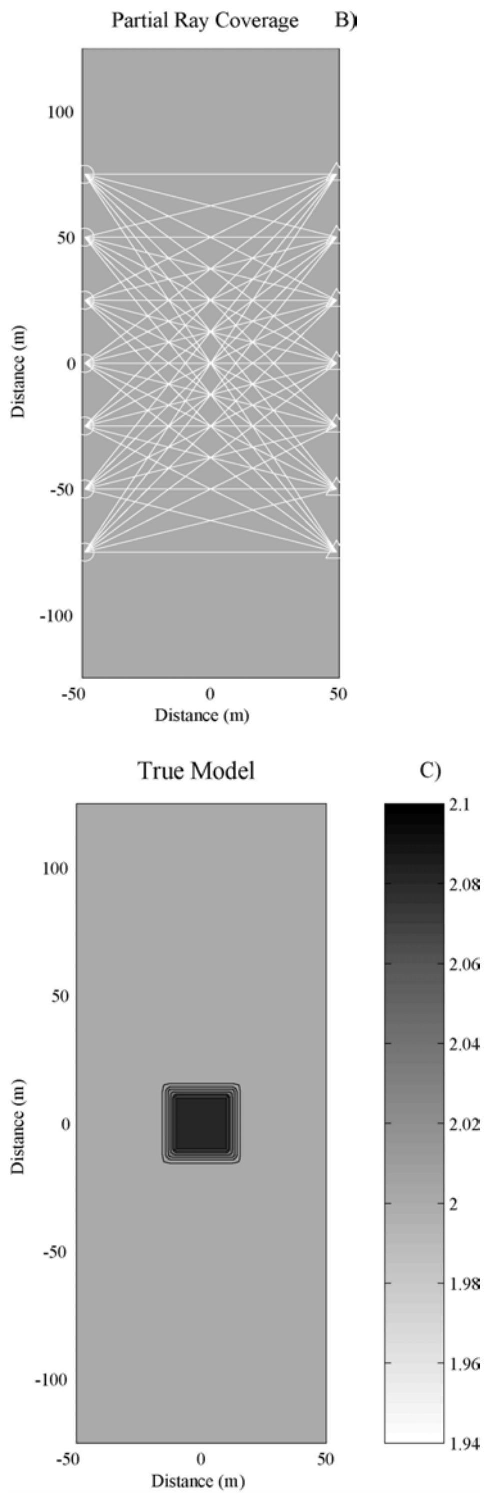
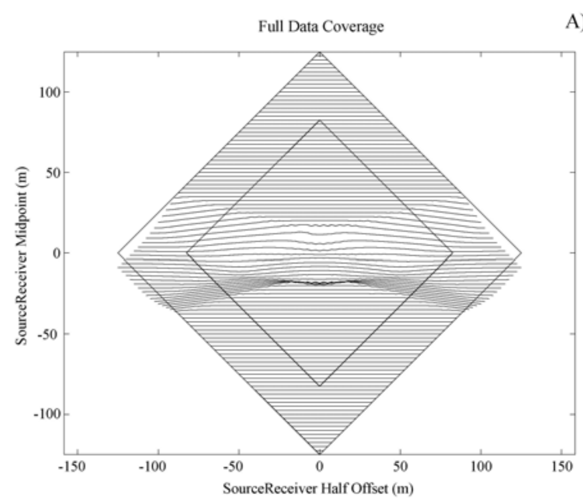


Figure 1 (a) Homogeneous starting model and ray diagram for every five shot points and every five receivers. Circles show shot positions, and triangles are receiver positions. (b) Ray diagram after removing 10 shots and 10 receivers from the top and bottom of the boreholes. (c) True model. The square at the center shows a high velocity heterogeneity.

The data within the inner rectangle show the partial dataset after removing 10 shots and 10 receivers from each end of the model. A two-stage AR extrapolation is applied to the partial data within the inner diamond, and the extended dataset is shown in figure 2(b). Comparing the full dataset in figure 2(a) and the extended dataset in figure 2(b), the overall pattern is very similar. This shows that the two-stage AR extrapolation technique can work for this synthetic cross-borehole geometry. Li and Nowack (2004) showed for laboratory geometries of rock samples that the AR extrapolation works very well in the presence of noise and this also holds true for field experiment using a cross-borehole geometry.



Tomographic Inversions using Full, Partial, and Extended Data

The full dataset shown in figure 2(a), partial dataset within the inner diamond in figure 2(a), and the extended dataset shown in figure 2(b) are all used for regularized seismic tomography inversions (Tarantola, 1987; Wang, 1993). The reconstructions are performed on a regular 41 by 101 model grid.

Figures 3(a), (b) and (c) demonstrate the reconstructions for full, partial and extended datasets, respectively. Comparing

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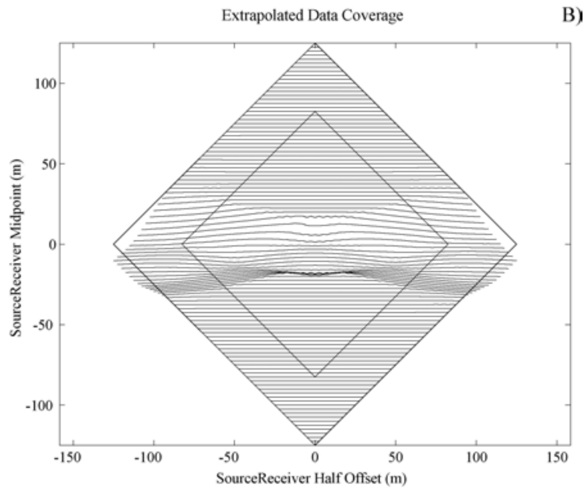
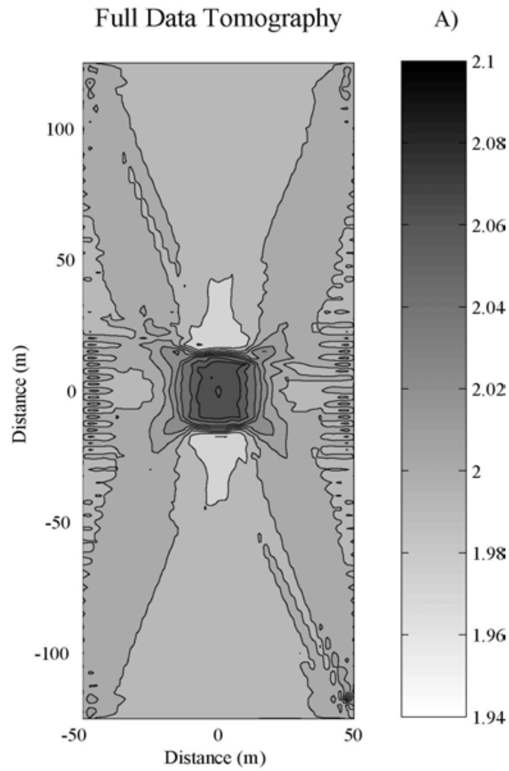


Figure 2 (a) Plot of the full data set. The data within the inner rectangle show the partial dataset after removing 10 shots and 10 receivers from the top and bottom of the boreholes. (b) Plot of the extrapolated dataset.

these tomographic inversions, we see that all three of them have similar vertical resolutions. However, figure 3(a) and (c) have much better horizontal resolutions than figure 3(b) which has larger side lobes, The better horizontal resolution for figure 3(a) results from more oblique rays for the full dataset (figure 2(a)) that can constrain the position of the sides of the high velocity heterogeneity (Menke, 1984). The inversion result with the extended data shown in figure 3(c) is very close to the inversion using the full dataset in figure 3(a), and it greatly improves the horizontal resolution from the partial data reconstruction (figure 3(b)). This shows that the two-stage AR extrapolation method can efficiently extrapolate the partial data to a broader range for a cross-borehole tomography geometry, and it could be an effective way to overcome the limitation of ray coverage for real cross-borehole tomographic experiments.

Conclusions

The horizontal resolution for cross-borehole tomography experiments is limited because of the experimental geometry and partial ray coverage. Our two-stage AR extrapolation technique has been shown to be an effective way to perform data extrapolation for seismic tomography problems (Li and Nowack, 2004). To test whether our two-stage AR extrapolation algorithm can improve the resolution of cross-borehole tomography, a test on synthetic data was performed. Both the extrapolated data and tomographic reconstruction with the extrapolated data show



that AR extrapolation can effectively extend the synthetic cross-borehole tomographic data to a broader coverage and can improve the resolution of the tomographic reconstruction using cross-borehole geometries.

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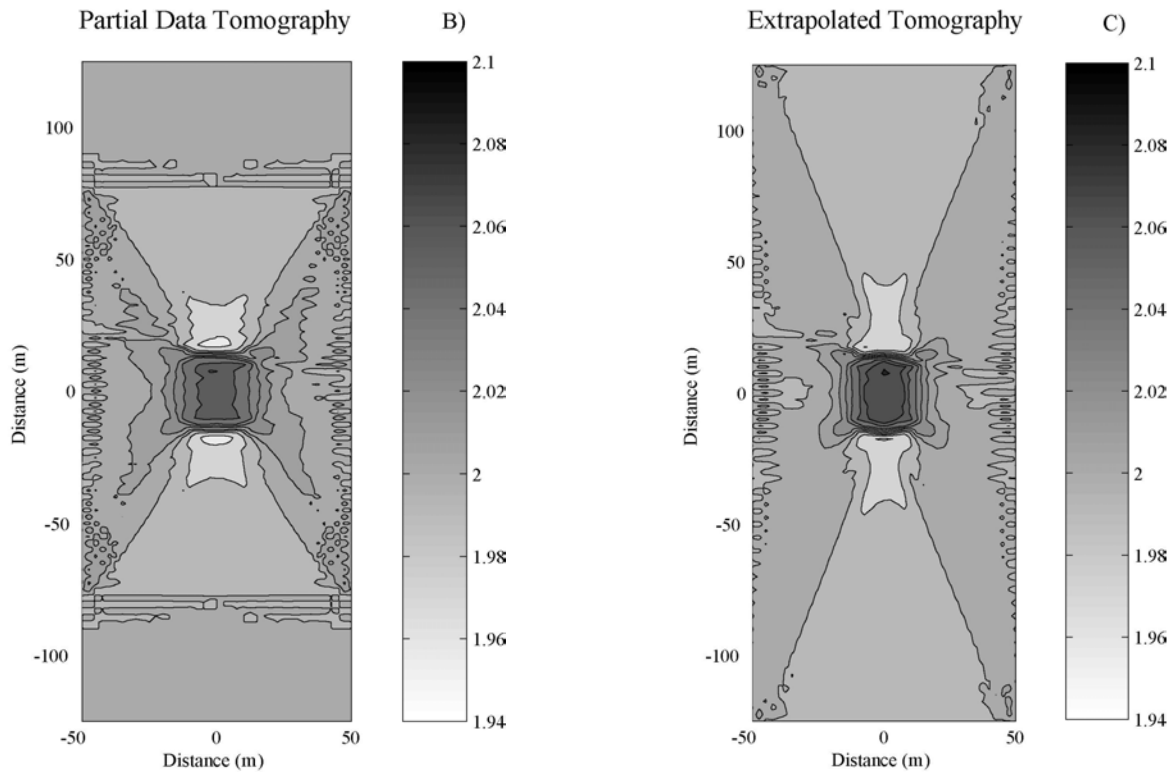

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Figure 3 (a) Inversion result with the full dataset (data within the outer diamond in figure 2(a)). (b) Inversion result with the partial dataset (data within the inner diamond in figure 2(a)). (c) Inversion result with the extended dataset (data within the outer diamond in figure 2(b))

EDITED REFERENCES

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