2374. Wavepath Tomography for Subsalt Velocity Model Building

M.M. Fliedner* (3DGeo Inc.), W. Curry (Stanford University), M.P. Brown (3DGeo Inc.) & D. Bevc (3DGeo Inc.)

Summary

In complex velocity models, such as below rugose salt bodies, wavefield continuation migration is usually superior to Kirchhoff methods because of multi-pathing, sharp velocity contrasts and the bandlimited nature of seismic wave propagation. Wavepath tomography offers a way to build the velocity model in a way that is consistent with the migration operator: instead of tracing rays to backproject residual velocities, a "wavepath" is constructed using the actual wavefield continuation operator to represent the wave propagation between surface source/receiver pairs and subsurface reflection points by cross-correlation of impulse responses downgoing from the surface location and upgoing from the reflection point. The size of the inversion matrix is kept to a manageable size by restricting the correlated wavefield to the first Fresnel zone. The considerable expense of computing a single wavepath kernel can be partially offset in comparison to ray tomography, by the smaller number of backprojections necessary to sample the velocity model adequately. In synthetic tests, wavepath tomography yields velocity updates comparable to ray tomography while being better conditioned.

Introduction

In regions of structural complexity such as below rugose salt bodies, raytracing based tomographic velocity model updating suffers from similar problems as Kirchhoff migration: it may not be possible to trace rays through certain parts of the model and multipathing is not easy to take into account. Wavefield continuation imaging methods, such as common azimuth or shot profile migration overcome these shortcomings naturally. It is therefore desirable to base the velocity model building on the same methods. Wavepath tomography replaces backprojection of velocity errors along rays with backprojection along wavepaths that are generated with the same propagation operator as the seismic image. In this paper we describe the method of wavepath tomography with a synthetic 2D example, the subsalt region of the Sigsbee model. The process, however, is formulated and implemented in 3D.

Methodology: wavepaths

Wavepath tomography is based on an idea by Woodward (1989): instead of tracing rays to backproject residual velocities, a “wavepath” is constructed using the actual wavefield continuation operator to represent the wave propagation between surface source/receiver pairs and subsurface reflection points. In this way multi-pathing, sharp velocity contrasts, and the bandlimited nature of seismic wave propagation can be modeled more naturally than with geometric rays.

To create a wavepath for a given velocity model, the impulse responses of the wavefield propagator are calculated for a source at the desired surface location (downgoing wavefield) and at the reflection point (upgoing wavefield) for one frequency. The two wavefields are then cross-correlated and the imaginary part of the product is retained (3D examples in Figs. 1 and 2).

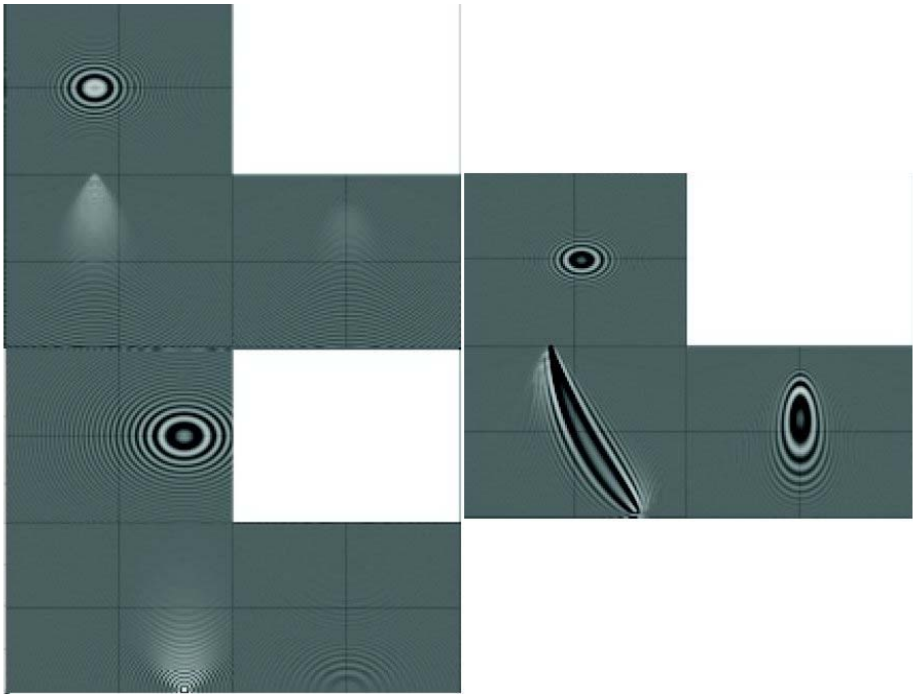

Figure 1: v(z) single frequency wavepath example. Top left: downgoing wavefield, bottom left: upgoing wavefield, right: correlated wavefield (wavepath kernel).

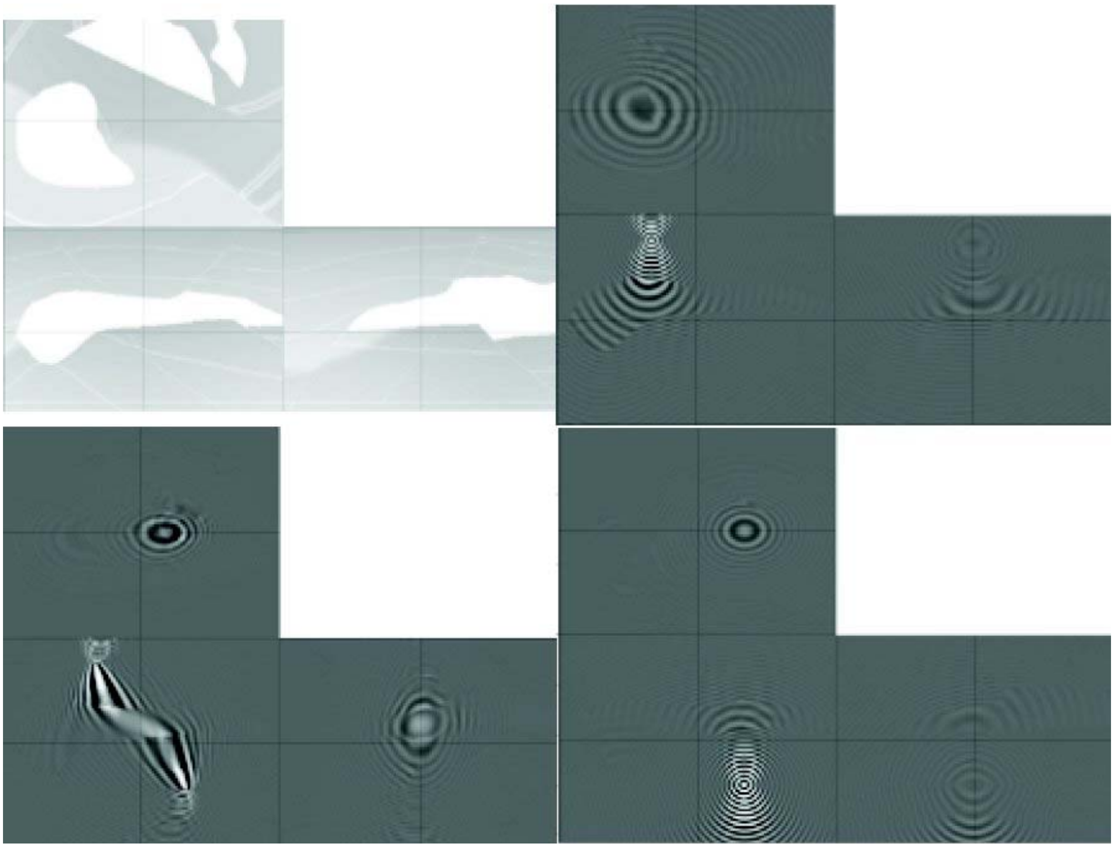

Figure 2: SEG-EAGE C3 velocity model (top left), single frequency wavepath example. Top right: downgoing wavefield, bottom right: upgoing wavefield, bottom left: correlated wavefield (wavepath kernel).

By adding kernels for several frequencies, the bandwidth of the seismic image can be faithfully represented, but for velocity model building, a single central frequency is sufficient.

In order to achieve a compact wavepath and thereby minimize the size of the inversion problem, the kernel outside a volume like the first Fresnel zone is zeroed. This can be achieved simply by thresholding the wavepath amplitude, tracking the central zero crossing, or employing a pseudo-eikonal event tracker (Brown et al., 2006) by treating the kernel as a pseudo-velocity field. The latter method works especially well in 3D.

Methodology: Backprojection

The proper inversion weights for the tomographic velocity update can be easily understood by considering the ray analogy:

In the ray approximation, the inversion weights a_{ij} of the inversion matrix A

$$A\Delta s = \Delta \tau$$

represent the length of raypath segments for each slowness cell traversed by a ray, the row sum is therefore equal to the ray length l. For a wavepath of unit amplitude everywhere over its support, the row sum equals its volume V. Consequently, the average weight is $a_{ij}=l/V$. Without changing the row sum, each individual weight can be modified according to the actual amplitude of the wavepath kernel.

Example: Sigsbee subsalt velocity update

As an example, we show a single tomographic update of the subsalt region in the Sigsbee velocity model. The starting migration velocity is correct down to base salt and constant below. A fairly small number of backprojection points is selected (Fig 3.) based on reflection and semblance strengths, and reflector coherency (Bevc et al, 2006). Examples of normal incidence wavepaths are shown in Fig. 4 (offset wavepaths, where source and receiver surface location are separate, were not used for this example). In contrast to infinitely narrow raypaths, the width of the wavepaths provides a natural regularization of the inversion. The updated velocity model (Fig. 5) is smoothed to compensate for the considerable gaps in backprojection point coverage. The result is comparable with what can be achieved with ray tomography using the same residual data, but with 20 times the number of rays (normal and oblique incidence).

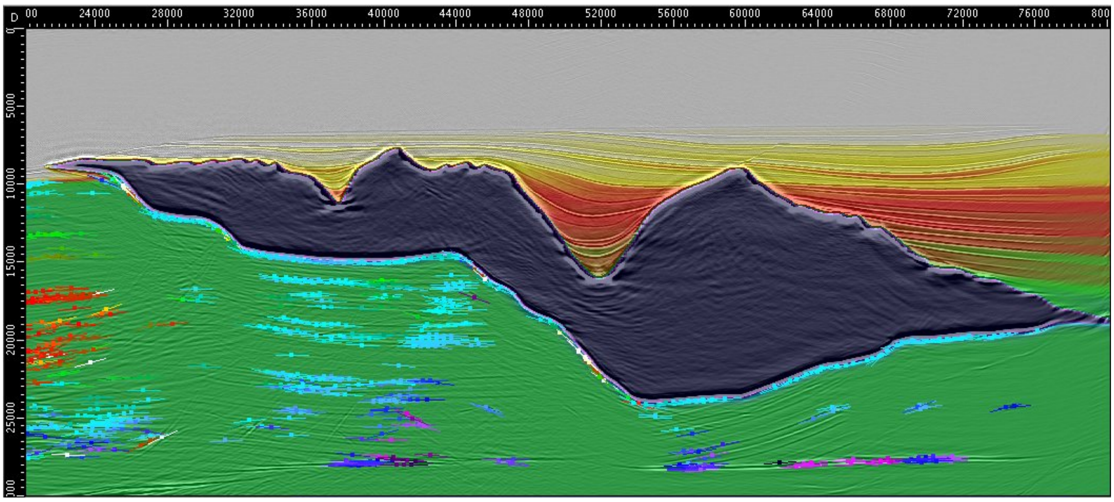

Figure 3: Sigsbee synthetic model; starting velocity model (constant below salt) and backprojection points (colour indicates velocity residual) overlaid on seismic image.

Conclusions

In areas of complex velocity that are challenging for raytracing based velocity inversion methods, wavepath tomography offers a naturally regularized alternative that is consistent with the wavefield continuation migration method used to produce the seismic image.

The considerable expense of computing a single wavepath kernel is partially offset, in comparison to ray tomography, by the smaller number of backprojections necessary to sample the velocity model adequately.

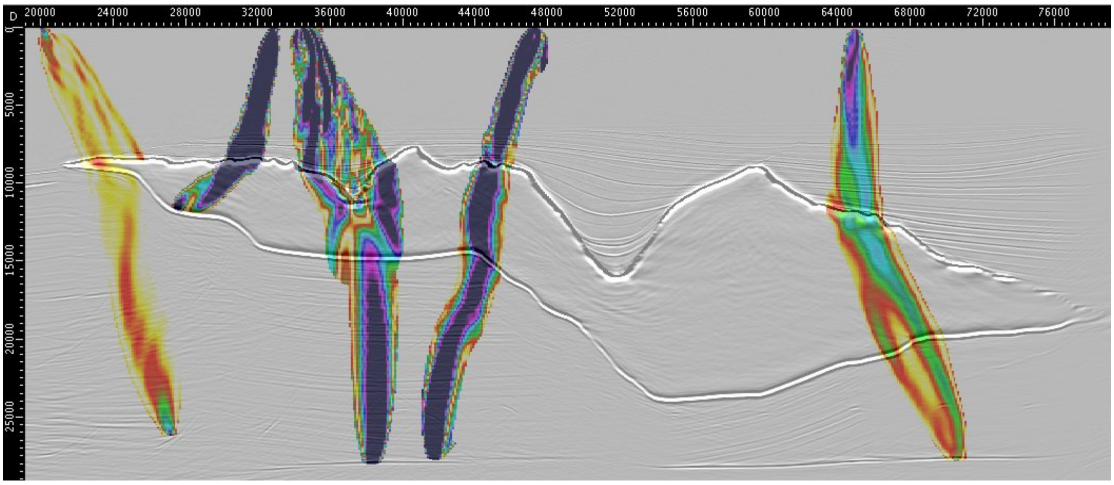

Figure 4: selected normal incidence wavepaths through Sigsbee starting model (Fig. 3).

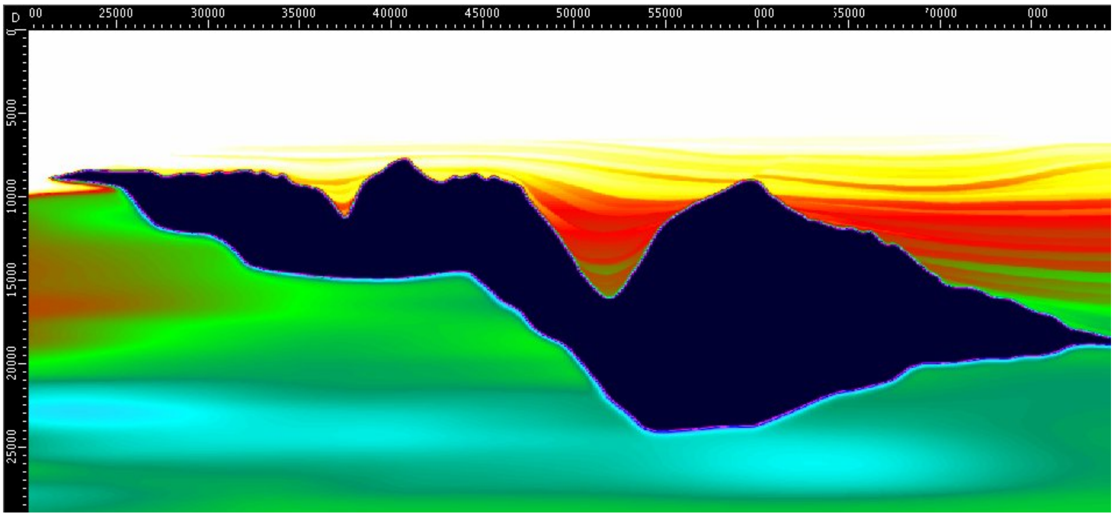

Figure 5: single iteration wavepath tomographic update of Sigsbee starting velocity model (Fig. 3).

References

Bevc, D., Fliedner, M., and VanderKwaak, J., 2006, 3-D tomographic updating with automatic volume-based picking: SEG Expanded Abstracts, 3330-3334.

Biondi, B. and Tisserant, T., 2004, 3D angle domain common-image gathers for migration velocity analysis: Geophysical Prospecting **52**, 575-591.

Brown, M.P., Morton, S.A., and Whittle, G., 2006, Seismic event tracking by global path optimization: SEG Expanded Abstracts, 1063-1067.

Ji, J., 1995, Sequential Seismic Inversion Using Plane-Wave Synthesis: PhD Thesis, Stanford, CA, 115 p.

Woodward, M.J. , 1989, Wave-Equation Tomography: PhD Thesis, Stanford, CA, 73 p.