

Applicability of TTI RTM to Structured Land Datasets

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Summary

Structured land plays demand treatment of topography, anisotropy, and multipathing. Kirchhoff prestack depth migration delivers on the first two of these requirements, but can fail to image adequately at depth because it is unsuitable for multipath imaging. TTI RTM is gaining acceptance in marine applications because of its ability to image complex structures, and here we demonstrate its ability to unlock intractable land structures as well.

A complex land dataset with topography has been successfully imaged up to high frequencies required for land processing in this region (90 Hz). Comparison with analogous Kirchhoff results show improvement at depth, and the ability to image structures with greater resolution than in Kirchhoff imaging. The Kirchhoff image is benefitted in the near surface where the ability to carry out post-migration muting is key in removing noise and enhancing structure.

Kirchhoff and RTM imaging were also carried out on a dataset formed by regularization and interpolation in the receiver domain. This comparison shows that such data preparation reduces noise and yield clearer images, both shallow and deep. For deep images the RTM image is again superior to Kirchhoff, while the shallow images for this case are of similar quality.

Introduction

Improving the interpretability of structured land plays is a significant challenge for imaging technologies. Topography, anisotropy, and illumination at depth are all factors that must be dealt with in the search for a solution. The first two of these are well-addressed by the most sophisticated land imaging in common use, namely TTI (tilted transverse isotropy) Kirchhoff prestack depth migration. Multipathing issues however place limits on the ability of Kirchhoff migration to address illumination at depth, and there is increasing interest in the application of wavefield techniques, such as RTM (reverse-time migration), to decrease interpretative risk.

The theory of RTM has existed for some time (Baysal et al., 1983; Whitmore, 1983) but has had to wait on developments in computing technology to become useful to the seismic industry. Even now its straightforward application would be impractical, particularly in anisotropic media, but additional research has expedited the application of TTI RTM to marine data sets, particularly in the Gulf of Mexico (Huang et al., 2009). It is naturally of interest to see whether this experience can now be extended to the topography and high frequencies inherent in some land imaging.

In the present study we will apply TTI RTM to 3D field data from Southeastern Oklahoma. Our purpose is to address three questions: 1) Can TTI RTM be applied with topography and high frequencies? 2) How do TTI RTM images compare with those of TTI Kirchhoff? 3) Is data preparation (specifically, interpolation) of value in improving RTM images? The answers to these questions will assist us in seeing the best way forward at this point in seismic land exploration.

Method

In RTM, migration is performed on one shot gather at a time, and the results for all shots are stacked to yield the final image. The RTM migration of a single shot gather begins by forward

modeling the shot wavefield, allowing it to propagate forward in time throughout the velocity model. This essentially creates a “movie” of the seismic wavefield emanating from the given shot. To start the actual imaging, this “movie” is run backwards in time, returning back toward the source. Simultaneously with this, the receiver wavefield recorded at the surface is also propagated backwards in time, toward the reflectors. As it moves down through the velocity model, it will overlap at certain times with the source wavefield moving back up. The correlation between the two wavefields is noted at each propagation timestep, and when summed over all times gives a representation of subsurface reflectors.

The primary strength of RTM is that it is based on wavefields propagating as dictated by the wave equation. Other methods involve approximations to the wave equation, such as ray tracing or directional propagation, and thus may fail to image some events and structure inherent in the data, such as prismatic reflections and steep dips. RTM is valued because of its facility in migrating features such as these. However in its simplest form it also produces a variety of artifacts, which can obscure the information of primary interest. Coping with this “information overdose” has been the focus of much recent research in RTM (Zhang and Sun, 2009; Zhang et al., 2009).

The number of potential RTM artifacts is increased even further in TTI media. However, in highly tilted geology TTI models are essential to good imaging. TTI anisotropy accounts for the fact that seismic velocities are faster parallel to bedding than perpendicular to bedding. When bedding planes are horizontal this can be accounted for with simpler VTI (vertical transverse isotropy) models, but when tectonic forces have caused folding of bedding planes away from horizontal, then TTI models are a more natural representation of the subsurface. Thus the ability to deal with RTM artifacts becomes critical in highly structured media.

The present calculations have been carried out using a finite-difference implementation of RTM (Zhang and Zhang, 2008). The TTI velocities, which in principle require a multicomponent treatment, are obtained from an approximation due to Alkhalifah (1998) which allows modeling to be restricted to P-wave modes.

Application

The following example allows us to test the value of TTI RTM relative to TTI Kirchhoff PSDM in structured land data.

Description of dataset

Our dataset is a subset of an Atoka / South Ammo merged dataset of the CGGVeritas Houston data library. The field from which this data is obtained is located in the Arkoma basin in southeast Oklahoma. The merged dataset covers approximately 360 km², while the subset we consider, shown in Figure 1a, is approximately half that size. The receiver spacing is 220 ft x 880 ft, and the nominal bin spacing is 110 ft x 110 ft.

A new dataset was created from this by means of regularization and interpolation, using the proprietary 5D technique described in Trad (2007). These operations were performed only in the receiver domain, yielding receiver spacing of 220 ft x 220 ft. Shot locations remained unchanged. Considerable care is required to do this in the presence of topography. Figure 1b shows a closeup of a portion of Figure 1a, and Figure 1c shows the same region but with receiver locations obtained through regularization and interpolation.

The blue line in Figure 1a indicates the location of the crossline displayed in Figure 2.

Details of the migrations

An anisotropic velocity model was developed using Residual Curvature Analysis (RCA) and Interactive Tomography (IT3D) in combination with other techniques, using a top-down, layer-

by-layer approach, and was optimized for Kirchhoff migration. The same velocity model was then used for RTM.

A half-aperture of 16000 ft is employed for both methods. The data contain a broad spectrum of frequencies, dropping down 20 dB at about 80 Hz. For consistency, both migrations used an Ormsby migration wavelet defined by $(f_1, f_2, f_3, f_4)=(4, 6, 80, 90)$ Hz.

For the Kirchhoff migration, typical post-migration muting was applied prior to stack. No post-migration muting was carried out for RTM.

Comparison of Kirchhoff and reverse-time migrations

Figures 2a and 2c compare a central crossline as rendered by the two migration methods. RTM does not differ from Kirchhoff in some parts of the section, which is to be expected where the model is simple. However in other places, such as inlines 750 to 800, where a potential geological target could be found, RTM has imaged with greater resolution, yielding a more interpretable image. Such results are typical of comparisons between Kirchhoff and wavefield techniques in TTI media (Ursenbach and Bale, 2009).

Effect of interpolation on RTM imaging

Figures 2b and 2d show the result of imaging with interpolated data. The interpolation procedure appears to decrease the noise level of both the shallow and deep images and to define the structure more clearly. Of particular interest, the shallow RTM image is competitive with the near-surface Kirchhoff, despite the absence of post-migration muting in the former.

Conclusions

The results of this study demonstrate that RTM can be performed to high frequency (80-100 Hz) on structured 3D land datasets with surface topography. This makes a new tool available to processors attempting to extract clearer information of the deep subsurface, where multipathing can be significant. Further clarity in both shallow and deeper parts of the image can be obtained by regularizing and interpolating data in the receiver domain, and, for the present dataset, this erases advantages of Kirchhoff migration in the shallow image.

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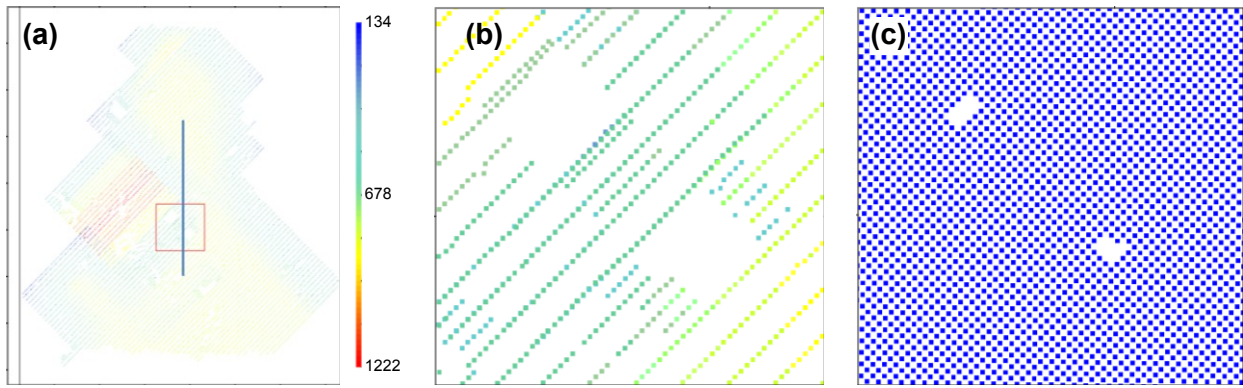


Figure 1: **(a)** Initial distribution and fold of receivers for dataset used in RTM. Blue line indicates location of crossline displayed in Figure 2. **(b)** Detail of region in red box of (a). **(c)** Detail of same region as in (b) after regularization and interpolation.

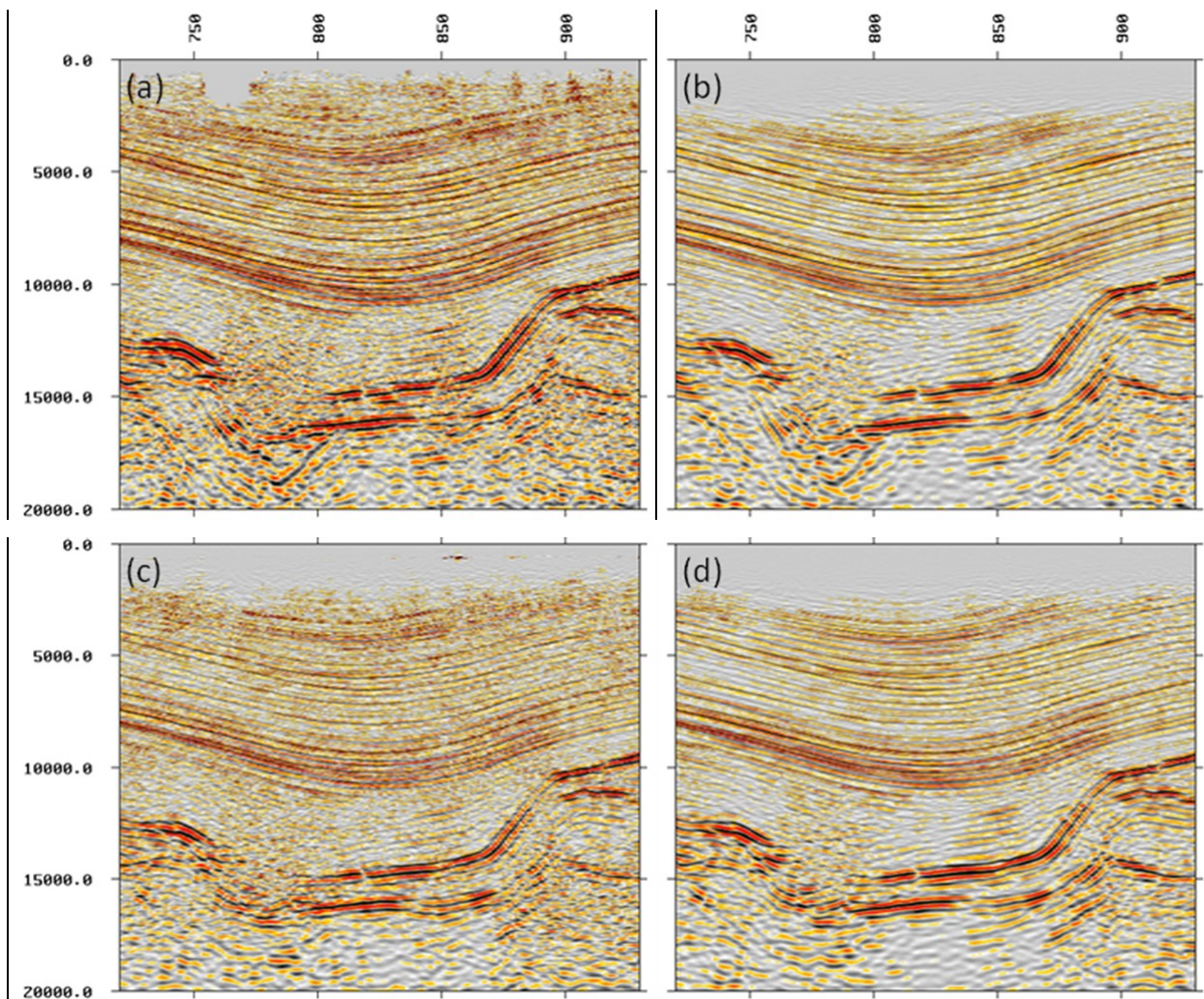


Figure 2: Depth images of crossline 586 indicated by blue line in Figure 1a, as obtained using three different methods. **(a)** TTI Kirchhoff PSDM. **(b)** Kirchhoff following regularization and interpolation. **(c)** RTM. **(d)** RTM following regularization and interpolation. All images have had a 6000 m AGC applied. The vertical axis is in feet and the horizontal axis is in inlines, with 110 ft/inline.