3D finite-offset depth tomography model building: Green Canyon, Gulf of Mexico

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Summary

A more detailed velocity analysis is required for successful pre-stack depth migration model building and tomographic methods offer a potential solution. However, migration velocity analysis is often an underdetermined problem. We present a new finite-offset depth tomography scheme that overcomes the problems of non-linearity and allows us to perform automatic dense velocity analysis in structurally complex areas were classical linear methods fail. We demonstrate the advantage of the new tomography scheme on a deep offshore Gulf of Mexico dataset from the Green Canyon area.

Introduction

There is a clear need in the seismic industry to produce high quality pre-stack depth migration (PreSDM) images in a short time to meet exploration deadlines. To achieve this goal, the velocity model building phase which accounts for about 50% of the PreSDM project lifetime has to be sped up significantly. Unfortunately it has become widely accepted that simple but fast vertical velocity update techniques such as the one proposed by Deregowski (1990) fail in the presence of complex geological structures. The use of more accurate but a more computation intensive tomographic inversion schemes offers a solution (Guillaume et al. 2001, Sexton et al. 2001).

In order to achieve both, fast turnaround and high accuracy in complex geological settings we have implemented a model building methodology which uses a very flexible explicit smooth and/or blocky, anisotropic explicit model description. Each layer is described as transversely isotropic with a vertical axis of symmetry (VTI), and the P-wave phase velocity has the form:

\[ V(x, y, z) = (V_0(x, y) + K(x, y) \cdot z + DV(x, y, z)) \cdot A(\epsilon, \delta, \theta_{\text{phase}}) \]

where the terms \((V_0(x, y) + K(x, y) \cdot z)\) and/or \(DV(x, y, z)\) describes the phase velocity and the term \(A\) implements the weak anisotropy approximation of the phase velocity, as a function of the Thomsen parameters \(\epsilon\) and \(\delta\). The \(V_0(x,y)\) (and respectively \(DV\)) term is parameterized by 2D/3D cardinal cubic Bspline functions.

Explicit velocity model description

To ensure that the velocity model representation is flexible enough to accommodate a wide range of possible velocity models we have selected a smooth and/or blocky, anisotropic explicit model description. Each layer is described as transversely isotropic with a vertical axis of symmetry (VTI), and the P-wave phase velocity has the form:

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3D finite offset depth tomography

To compute and pick RMO curves common image point (CIP) gathers are generated from a single dense PreSDM run through an initial velocity model which will have classically been created from a dense RMS velocity field through simple Dix conversion. RMO curves are picked automatically along predefined events by performing a number of curvature scans over a user defined scan range using a parabolic approximation of the residual move-out curve. Semblance is computed along each parabola and the best fit is selected as the one with the highest semblance value. The scanning process results in two attribute maps, a near-offset depth map of the selected reflector and a map of 2nd order residual curvatures (Figure 1).

Figure 1: RMO picking results for a selection of CIP gathers for a single event. Blue on the curvature map represents a negative move-out (velocity too fast) and red a positive move-out (velocity too slow).

The variations of the event position in depth with offset (or reflection angle), measured on the CIP-gathers as shown in figure 1, constitute the original observed data that will feed the inversion process. But the image position observed on each CIP-gather are directly linked to the chosen velocity model used for the migration. To eliminate this velocity...
model dependency of the depth-domain observations, the observed image-point facets are back-projected to the acquisition surface (de-migrated), to produce pseudo model-independent data. These are (for each individual offset or azimuth trace): a source position, a receiver position, the travelt ime and the travelt ime slope. All these so-called invariants are computed from ray tracing as shown in Figure 2. These new de-migrated observations are in the de-migrated time domain and are similar in nature to the input data for time-slope tomographic inversion. A ray-based event migration, preserving travel time, time-slope and of course source and receiver locations, allows to compute new image positions in the current version of the velocity model at any stage of the updating process (Fig. 2). A least squares criterion, which measures the misalignment of the re-migrated image point facets, feeds an iterative inversion scheme implementing a multi-grid like approach.

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The advantage of the inversion scheme presented here (Figure 3) is that the original migration model doesn’t need to be the initial inversion model and the velocity model description and parameterization can indeed change completely between the migration model and the parameterized models used in the inversion.

Since de-migrated observations can be kinematically re-migrated in the new updated model our inversion scheme is able to predict the remaining residual move-out corresponding to this updated model. This provides us with a very powerful QC tool, which makes it possible to validate the picked RMO data without having to run a new PreSDM through the updated velocity model.

Note that during each inversion step the re-migration sequence is performed (non-linear part) followed by the velocity update using a linear solver. This iterative scheme allows us to solve the non-linearity problem of the overall global tomographic velocity update. Figure 3 illustrates the non-linear inversion loop inside the 3D finite offset tomography.

Figure 2: Event de-migration and re-migration procedure in 3D finite offset tomography

Figure 4a shows a smooth model synthetic data example of a high velocity anomaly. Horizontal lines represent locations on which CIP gather information was provided for the tomographic update. The right hand side of figure 4a shows the initial migration model together with the B spline grid that was chosen for the internal model representation.

Figure 4b shows the inversion results for the same synthetic smooth model. On the left hand side the result of the non-linear inversion is shown whereas on the right hand side the standard linear inversion result is displayed. The benefit of the non-linear inversion scheme is evident from the results in Figure 4b.

![Flow chart of non-linear inversion loop](image)

![Figure 4a: Left hand side: Vertical section through true (smooth) velocity model, with overlaid horizons selected for RMO picking. Right hand side: Initial velocity model (constant velocity 2000 m/s) with overlaid nodes of B spline grid.](image)

![Figure 4b: Left hand side: Vertical section through final model after non-linear inversion. The maximal velocity error is $\Delta v_{\text{max}} = +/\ 150 \text{m/s}. \ Right \ hand \ side: \ Final \ model \ after \ linear \ inversion. \ The \ maximal \ velocity \ error \ is \ $\Delta v_{\text{max}} = 750 \text{m/s.}$](image)
Green Canyon Gulf of Mexico example

We illustrate the advantages of 3D depth tomography over routinely used 1D velocity updates by applying our 3D inversion methodology to the sedimentary basin in the Green Canyon area in the Gulf of Mexico. The high quality seismic input data volume was acquired in 2001 as part of a non-exclusive survey program and comprised an input area of about 171.5 OCS (approximately 4000 km²) and an output area of 86 OCS (approx. 2000 km²) with a nominal fold of 54. The 3D inversion test was conducted on a 400 km² sub-volume.

19 individual seismic events were picked on a dense PostSDM dataset in two large basin areas to serve as a guide for the subsequent automatic RMO picking (figure 5). Residual moveout was computed on a 200 x 200 meter grid and together with estimates of the local structural dip presented to the 3D depth tomography for inversion. The inversion model was parameterized using 1700 meters spacing between 3D Bsplines nodes in X and Y and 2000 meters in Z. Convergence was reached after 8 iterations in less than 3 hours on a standard Linux PC.

Figure 6a shows the initial 1D inversion model used for the tomographic update. White crosses on the figure indicate the location of move-out information used in the inversion. Figure 6b displays the RMO map associated with the initial model for a single event at about 3000 meters depth. The residual moveout is expressed as a depth delay between the zero-offset trace and maximum offset used for the inversion. The result after 3D depth tomography is displayed in figures 6c and 6d. As expected for the Gulf of Mexico the velocity variations are still very smooth and do not follow the stratigraphic trend. Figure 6d also demonstrated that the picked event has been successfully flattened by the tomography as the average depth delay associated with the RMO curve has been reduced from 80 meters to less than 5 meters.

Finally figure 7 shows a comparison of 2D sections through the final PreSDM image computed with (a) the initial velocity model, (b) a 1D updated model and (c) the model after 3D finite-offset tomography. This comparison clearly demonstrates the improvements achieved with the 3D update in particular in areas of significant structural dip highlighted by circles (maximum dip in the section was 30 degrees).

Conclusion

We have introduced a new 3D finite-offset depth tomography scheme that can be used both in a blocky and/or smooth model context. To overcome the problem of non-linearity and under-determination of the velocity analysis the new inversion scheme uses an iterative (multi-grid) inversion where new observations are automatically produced after each inversion step by means of internal kinematic de- and re-migration.

The successful application of our 3D tomography on a real Gulf of Mexico dataset in the Green Canyon area demonstrates the advantage of our 3D inversion scheme over classical linear approaches in particular in areas of greater structural complexity.

References


Figure 6: a) Initial 1D inversion model used for tomographic update with associated residual move-out map (b) for one of the 19 events picked. RMO is expressed as depth delay between the zero-offset trace and the largest offset used in the inversion. c) 2D section of final velocity model after 8 iterations with corresponding RMO map. Average residual has been reduced to +/- 5 meters after tomographic update.

Figure 7: a) 2D PreSDM section using the initial migration model computed by simple Dix conversion of final RMS velocity field of PreSTM project, b) same 2D section as before but migrated through a 1D updated velocity model and c) results for the velocity model after 3D depth tomography. Circles indicate areas of significant improvements in the final image after tomographic update.