A fast VTI model building method using model based moveout

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Summary

Typically VTI model parameter estimation is achieved through multiple iterations of depth migration, residual moveout estimation, and linearized tomography. In this paper we discuss a method to reduce the effort of migration and residual moveout estimation by applying local approximations to the imaging and modeling operators using model based moveout, which is a mapping between imaged specular reflections in initial and updated models. This allows for very efficient imaging and model testing, so that multiple iterations of linearized tomography or generalized iterative inversion can be applied. In this paper, model based moveout is combined with joint tomography to build an efficient workflow suitable for estimating Thomsen parameters and for early depth velocity model building. The method is demonstrated for a synthetic well and for a dual-sensor data set from the Gulf of Mexico.

Introduction

Imaging in anisotropic media brings not only the challenge of more advanced imaging algorithms, but also the burden of estimating the model parameters required for the imaging process. Typically model parameter estimation is achieved through multiple iterations of pre-stack depth migration, residual moveout estimation (RMO) and linearized tomography. In this paper we discuss a method to reduce the remigration effort by applying approximations to the imaging and modelling operators using a model based moveout (MMO) (Liu, et. al., 2014), which is a mapping between imaged specular reflections in initial and updated models. The MMO uses travel time and ray parameter information for remapping and can be used as an event demigration-remigration operator.

The method combines MMO with joint tomography (Zhou, et al. 2011) for fast VTI model building. Instead of running RMO and migration multiple times, this method starts with one pass of RMO, then efficiently maps residual and common image gathers (CIG) by MMO during model updating. This new method is demonstrated on both synthetic and field examples. For the synthetic example, we discuss anisotropic inversion in the case of known subsurface control at a well location, where the vertical velocity is known and the task is to estimate the anisotropic Thomsen parameters for VTI media. In field example we show a case study of applying MMO with sonic well log input for VTI model building in the Gulf of Mexico. Both synthetic and field examples show that that MMO is an accurate approximation to pre-stack depth migration when subsurface dips are reasonably small. This demonstrates that MMO can provide a fast alternative to full migration during each tomographic VTI model iteration.

Model Based Moveout (MMO)

Migration operators map surface time data onto subsurface images and can produce offset or angle domain CIGs by decomposition of the data into separate input or output subsets. For example, in Kirchhoff migration, the output image is computed by a surface integral of the input data of the form:

$$\beta(\boldsymbol{x},\boldsymbol{m}) = \int d^2\boldsymbol{\xi} A(\boldsymbol{x},\boldsymbol{\xi}) \frac{\partial}{\partial t} U\left(\boldsymbol{x_g},\boldsymbol{x_s},t_m(\boldsymbol{x},\boldsymbol{x_g}) + t_m(\boldsymbol{x_s},\boldsymbol{x})\right) \quad (1)$$

where $t_m(\boldsymbol{x},\boldsymbol{x_g})$ and $t_m(\boldsymbol{x_s},\boldsymbol{x})$ are the travel times from the source to image point and the image point to the receiver for a model **m.** This integral defines an amplitude and phase mapping from the surface data for source and receiver locations $\boldsymbol{x_s}$ and $\boldsymbol{x_g}$ to all specular reflection points.

At a specific specular point $\boldsymbol{y_m}$ two ray paths connect this point with the surface locations. After the migration of the data with a new velocity model, this specular reflection point $\boldsymbol{y_m}$ would move to a new point $\boldsymbol{y_{m+1}}$ with new ray paths connecting surface locations. If the subsurface dip and opening angle is known (as in angle CIGs) or are computed (as in offset CIGs), then an approximation to the remigration of the data can be achieved by the following processing:

1. Kinematic "demigration" (remapping): for model **m** and image point $\boldsymbol{y_m}$, compute travel times and emergent ray parameters $\{t_m(\boldsymbol{x_s},\boldsymbol{y}), p(\boldsymbol{x_s},\boldsymbol{y})\}$, $\{t_m(\boldsymbol{x_g},\boldsymbol{y}), p(\boldsymbol{x_g},\boldsymbol{y})\}$ and extract data $\beta(\boldsymbol{y_m},\boldsymbol{m})$,
2. Kinematic "remigration" (remapping): for model **m**+1 from surface points $\boldsymbol{x_s}$ and $\boldsymbol{x_g}$ compute new specular point at $\boldsymbol{y_{m+1}}$ remap the data $\beta(\boldsymbol{y_m},\boldsymbol{m})$ to $\beta(\boldsymbol{y_{m+1}},\boldsymbol{m+1})$.

In some cases, (e.g. small subsurface dip) the mapping $M : \beta(\boldsymbol{y_m},\boldsymbol{m}) \rightarrow \beta(\boldsymbol{y_{m+1}},\boldsymbol{m+1})$ can be approximated as a ray-traced based reverse and forward moveout procedure, which we call model based moveout (MMO). Offset (or angle CIGs) are mapped from depth CIGs to time CIGs for model **m** and then remapped to depth CIGs for model **m+1.** MMO can be applied to the entire gathers or to RMO picks themselves, removing the need to re-pick residual moveout between tomographic iterations. The basic workflow is shown by Figure 1**.**

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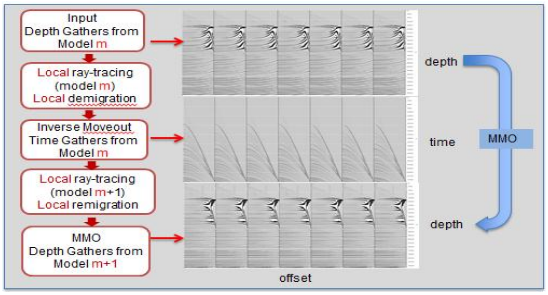


Figure 1. Model based moveout data mapping of CIGs: Depth CIGs from the first migration are mapped from (offset,depth) to (offset,time) using a local specular demigration of model **m**, then mapped from (offset,time) to (offset,depth) using a local specular re-migration using model **m**+1.

Fast VTI Model Building Method

Conventional VTI model building requires multiple iterations of depth migrations and RMO (Figure 2A). The fast MMO-driven workflow is shown in Figure 2B. The workflow involves the following steps:

Step1 : Prestack depth migration to create CIGs from a starting model;

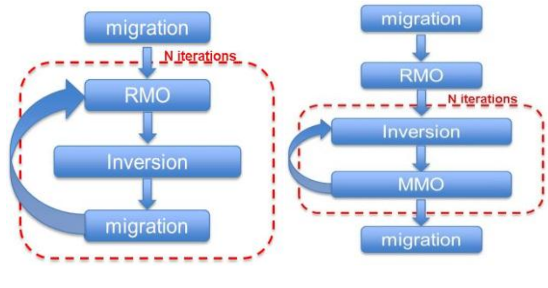
Step 2: Pick residual depth errors;

Step 3: Joint tomographic inversion for updates to Thomsen parameters and/or velocity;

Step 4: Use MMO to remap all of the picked residuals from the old model to the new model (Note that no re-picking of the data residuals is necessary.). Use these newly mapped residual picks to repeat Step 3 until the residual errors been been sufficiently reduced;

Step 5: Apply the full migration or MMO with the updated model to finalize the workflow.

Compared with conventional workflow (Figure 2A), the new MMO based VTI model building method avoids multiple passes of pre-stack depth migration and RMO and is much more efficient.



A **B**

Figure 2. Comparison between conventional VTI model building workflow (A) and the new one by using MMO (B), in which RMO is needed for only one round and multiple migration effort is avoided.

Synthetic Example

One possible application of applying the MMO based fast VTI model building method is to estimate anisotropy parameters in the vicinity of a well. To demonstrate this we apply the method to a synthetic dataset (supplied by BP) where we assume a known vertical velocity and estimate the Thomsen parameters δ and ε using joint tomographic inversion. A Kirchhoff depth migration was performed using an initial model with $\delta = 0.05$ and $\epsilon = 0.1$ below the water bottom. The CIGs were automatically picked and a set of tomography iterations were performed. Both the depth CIGs and the residual error picks were automatically remapped using the MMO for each iteration (no re-picking was required). The depth error picks were used as input to each joint tomography iteration.

The starting offset CIGs and three iterations of the MMO are shown in the left hand part of Figure 3. The anisotropy parameters for the true model (red) and the third iteration estimate (blue) are shown in the center. The third iteration MMO CIG and the true Kirchhoff depth migration CIGs are displayed on the right hand side. After three iterations the regularized tomography produces a good estimate of the anisotropy parameters to a depth of 8 km. The accuracy of the picking and the availability of reasonably long offsets (10 km) assisted in obtaining accurate δ and ε estimates.

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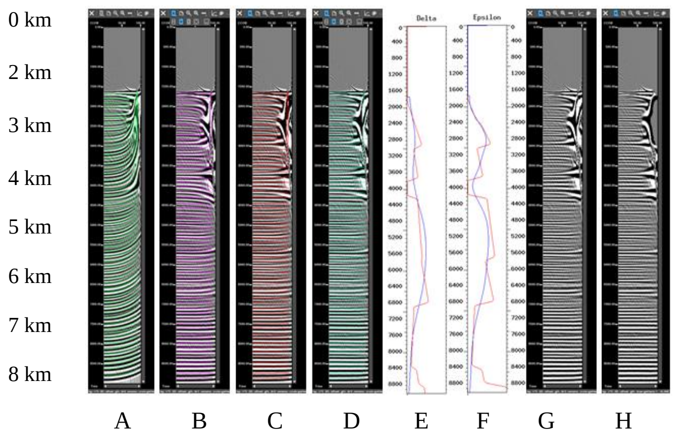

Figure 3. Anisotropic parameter estimation with vertical velocities given from "well" control. CIGs and event picks for a starting model are in (A). Shown in (B) – (D) are model based moveout (MMO) CIGs and remapped residual error picks for three joint tomography model updates. The final estimates (blue) and true (red) values of delta and epsilon are shown in (E) and (F) respectively. The final MMO CIGs and Kirchhoff migration for the true model are shown in (G) and (H) respectively.

Field Example

The MMO based fast VTI model building method is tested on field data from a Gulf of Mexico survey acquired by dual sensor acquisition technology. The starting isotropic model (Figure 4) was built from a single sonic log by applying structural based extrapolation (Zhou et. al. 2014). The starting VTI model is constructed with $\delta = 0.04$ and $\epsilon = 0.08$ below the water bottom. Figure 5A shows the initial offset CIGs derived by Kirchhoff depth migration.

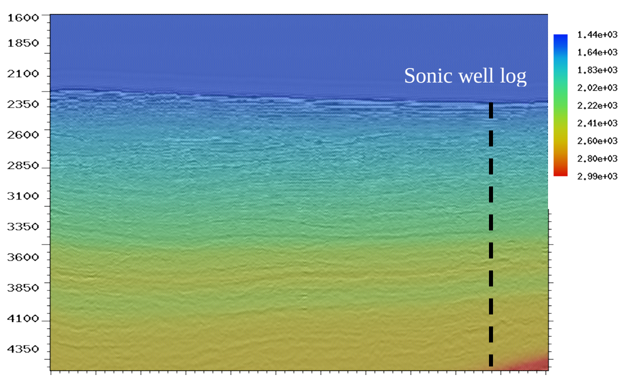

Figure 4. Starting isotropic model overlays on initial migrated stack. The initial isotropic model is built from a single check shot using structural based extrapolation.

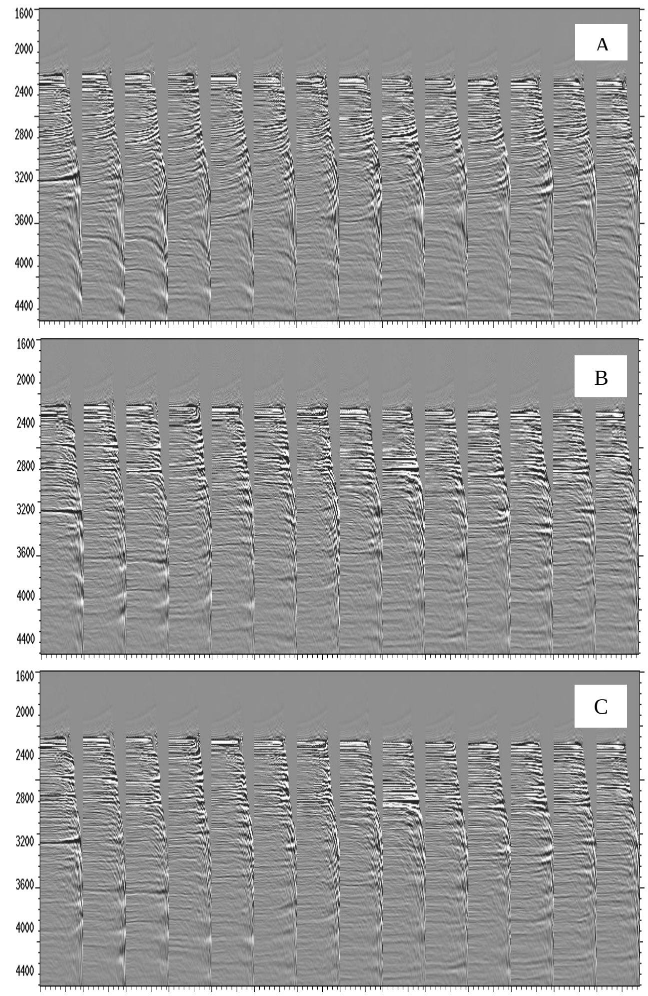

Figure 5: Comparison between MMO and Kirchhoff depth migration. Migrated offset CIGs for starting model are in (A). By using MMO based VTI model building workflow (Figure 3B), the updated MMO offset CIGs are shown in (B); (C) shows the updated offset CIGs derived by Kirchhoff depth migration.

Figure 5B shows the resulting CIGs after one pass of residual moveout estimation and several iterations of joint tomography and MMO. Most of the reflectors within sediment have been flattened. Figure 6 shows the updated ε and δ distribution, which follow the geological structure in consistent manner.

Figure 5C shows offset CIGs derived by a Kirchhoff depth migration using the updated VTI model. By comparing Figures 5B and 5C, note that MMO provides an accurate approximation to Kirchhoff depth migration, while MMO runs ~90 times faster than Kirchhoff depth migration on the same computation platform. Figure 7 demonstrates that

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MMO is capable of accurately remapping picked residuals during VTI model updating, removing the need for iterative RMO estimation.

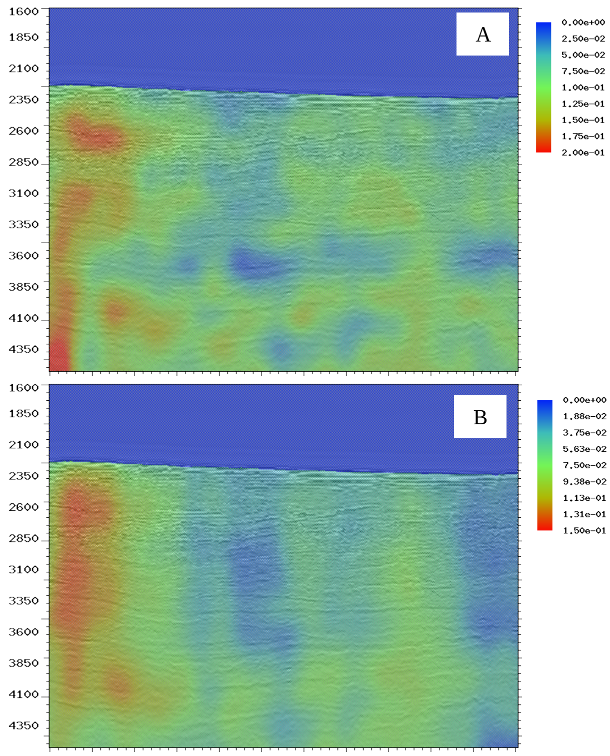

Figure 6: Stack overlays with (A) updated ε field and (B) updated δ field.

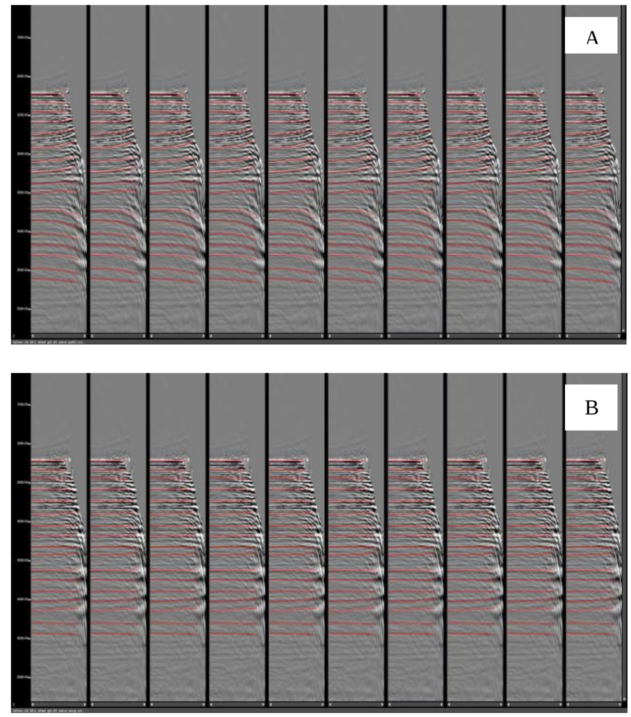

Figure 7. (A) RMO picked residuals (red curves) overlaid on offset CIGs from starting migration; (B) After model updating, both picked residuals and CIGs are remapped without re-running migration and RMO.

Conclusions

A model based moveout (MMO) procedure is defined as a vertical remapping of the specular reflections of imaged data to new positions in a new model as an approximation to a full remigration of the data. MMO can be applied to both full gathers and picked residuals, allowing for an automated re-imaging and tomographic updating process. Applying MMO to picked residuals increases the efficiency as it removes the need to re-pick residual between tomographic iterations. Based on MMO, we developed an efficient new VTI model building workflow which is suitable for gentle dips or early depth model building. The method has been demonstrated for both synthetic and field data examples. The results show that the MMO based VTI model building workflow is stable, suitably accurate, and efficient.

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EDITED REFERENCES

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