

Anisotropy Estimation and Image Remapping Using Model Based Moveout

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SUMMARY

Typically model parameter estimation is achieved through multiple iterations of linearized tomography and depth migration. In this paper we discuss a method to reduce the migration effort by applying local approximations to the imaging and modelling operators using a 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 imaging and linearized tomography or generalized iterative inversion can be applied. The model based moveout and tomography is demonstrated for anisotropic inversion in the case of known subsurface control, where the vertical velocity is known and the task is to estimate the anisotropic Thomsen parameters for VTI media. The method requires an iterative joint inversion of these parameters by projecting residual depth errors onto model updates.

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 linearized tomography and depth migration. In this paper we discuss a method to reduce the remigration effort by applying local approximations to the imaging and modelling operators using a 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 imaging and linearized tomography or generalized iterative inversion can be applied. The model based moveout uses travel time and ray parameter information for remapping and can be used as an event demigration-remigration and can also do specular re-mapping of the image.

Unfortunately, it is typically not possible to resolve all of the model parameters (velocity, anisotropy) using surface data alone. We require a priori information to reduce the null space of the inversion. This prior information can be in the form of educated guessing or interpretation or information coming from subsurface control such as well logs, check shot surveys, and vertical or offset VSP's. In this paper we show an example comparing a model based moveout of the image in a starting and updated model to actual Kirchhoff depth migration of the updated model. We also discuss anisotropic inversion in the case of known subsurface control, where the vertical velocity is known and the task is to estimate the anisotropic Thomsen parameters for VTI media. The method requires an iterative joint inversion of these parameters by projecting residual depth errors onto model updates.

Because the model based moveout is relatively fast relative to remigration, a large number of models can be tested and thus tomographic updates can be achieved efficiently at control locations (e.g. well locations). Updated models away from control locations can then be approximated by interpolation or extrapolation, followed by a full 3D tomographic inversion.

Method – Model Based Moveout

Migration operators map surface time data onto subsurface images and can produce offset (or angle) dependent gathers 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:

$$\beta(\mathbf{x}, \mathbf{m}) = \int d^2\xi A(\mathbf{x}, \xi) \frac{\partial}{\partial t} U(\mathbf{x}_g, \mathbf{x}_s, t_m(\mathbf{x}, \mathbf{x}_g) + t_m(\mathbf{x}_s, \mathbf{x})) \quad (1)$$

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

At a specific specular point \mathbf{y}_m two ray paths connect this point with the surface locations. After the migration of the data with a new velocity model, then this specular reflection point \mathbf{y}_m would move to a new point \mathbf{y}_{m+1} with new ray paths connecting surface locations as shown in Figure 1.

If the subsurface dip and opening angle is known (as in angle gathers) or are computed (as in offset gathers), then an approximation to the remigration of the data can be achieved by the following processing:

1. Kinematic “demigration” (remapping): for model \mathbf{m} and image point \mathbf{y}_m , compute travel times and emergent ray parameters $\{t_m(\mathbf{x}_s, \mathbf{y}), \mathbf{p}(\mathbf{x}_s, \mathbf{y})\}$ and $\{t_m(\mathbf{x}_g, \mathbf{y}), \mathbf{p}(\mathbf{x}_g, \mathbf{y})\}$ and extract data $\beta(\mathbf{y}_m, \mathbf{m})$,
2. Kinematic “remigration” (remapping): for model $\mathbf{m}+1$ from surface points \mathbf{x}_s and \mathbf{x}_g compute new specular point at \mathbf{y}_{m+1} remap the data $\beta(\mathbf{y}_m, \mathbf{m})$ to $\beta(\mathbf{y}_{m+1}, \mathbf{m}+1)$

We define the mapping $M : \beta(y_m, \mathbf{m}) \rightarrow \beta(y_{m+1}, \mathbf{m} + 1)$ as model based moveout (MMO). Ideally, we would want to map all subsurface points for model \mathbf{m} , to new subsurface points for model $\mathbf{m}+1$. However, in practice to perform tomographic inversion it is sufficient to only map selected subsurface positions (again note Figure 1.) In some cases, (e.g. small subsurface dip) the MMO is simply implemented as a ray-traced based reverse and forward moveout procedure, where offset (or angle gathers) are mapped from depth gathers to time gathers for model \mathbf{m} and then remapped to depth gathers for model $\mathbf{m}+1$. The basic workflow is shown in see Figure 2.

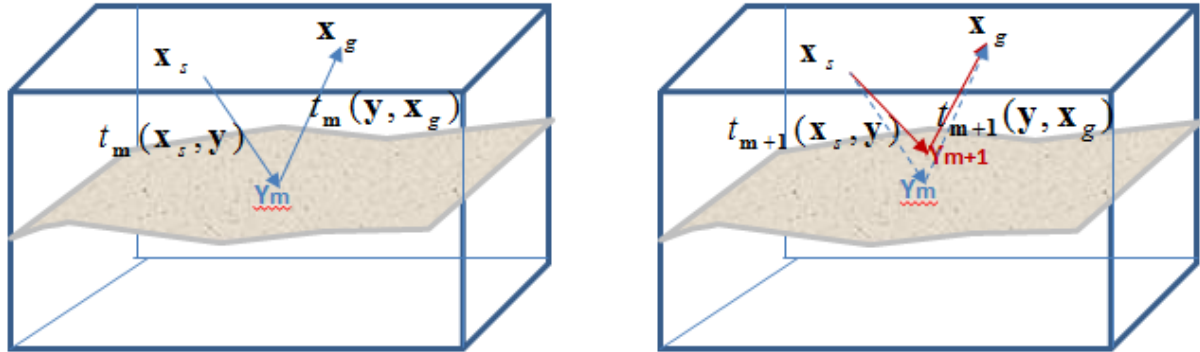


Figure 1 The left shows the specular point from a migration for a given model. The right shows the repositioning of the specular point in a new model compared with the old model. This repositioning can be achieved by remigration of the data or by approximated by local demigration – remigration.

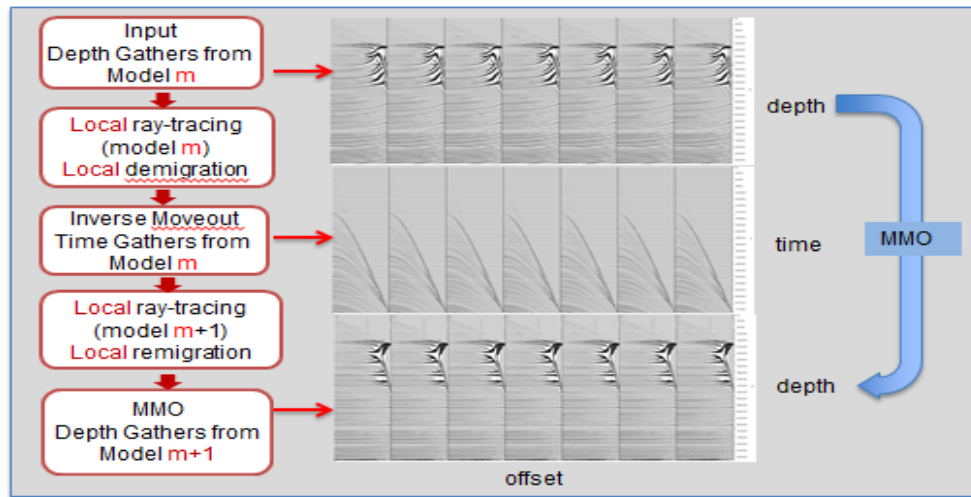
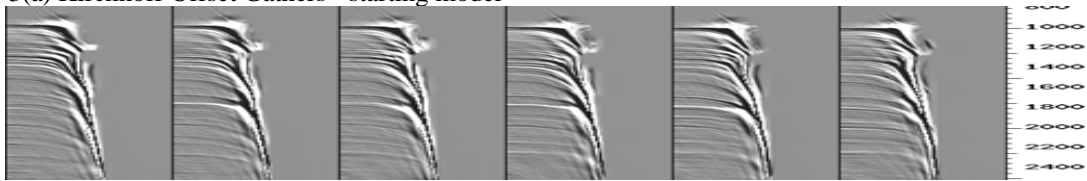


Figure 2 Model based moveout data mapping of gathers: Depth gathers from the first migration are mapped from (offset,depth) to (offset,time) using a local specular demigration of model \mathbf{m} , then mapped from (offset,time) to (offset,depth) using a local specular re-migration using model $\mathbf{m}+1$.

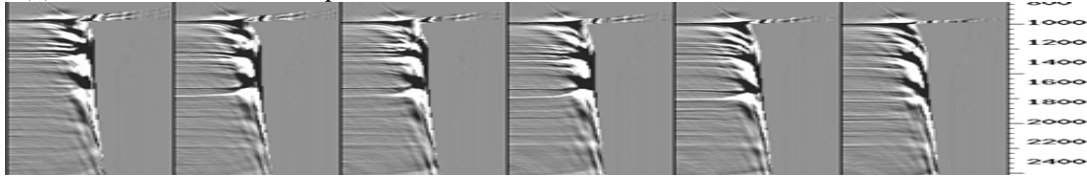
Example 1 – Comparison of Model Based Moveout and New Migration of Data

A comparison between remigration of data and model based a local MMO is shown in Figure 3. The top set of gathers (Figure 3a) is a set of Kirchhoff based common offset gathers for an initial model for data in 1 km water depths. The model was then updated and then tested by using MMO to the data – remapping the imaged data from the old model to the new model as shown in Figure 3b. The data was also fully migrated with the Kirchhoff depth migration for the new model so that it could be directly compared to the MMO gathers, as shown in Figure 3c. As can be seen the MMO and Kirchhoff second migration are the same, which is key for using the MMO as an approximation to migration using a new model.

3(a) Kirchhoff Offset Gathers - starting model



3(b) MMO Offset Gathers - updated model



3(c) Kirchhoff Offset Gathers - updated model

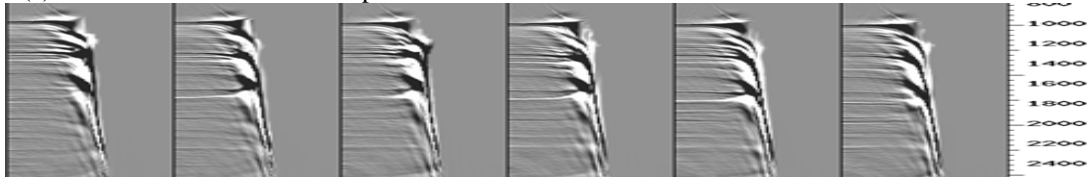


Figure 3 Comparison of model based moveout to a full depth migration (3a) shows an initial Kirchhoff depth migration.; (3b) is the model based moveout (MMO) for an updated model; (3c) is the Kirchhoff migration of the same updated model. Note the MMO and the full remigration gathers are very similar – and thus MMO approximates a new migration with much less computational effort.

Example 2 – Tomographic updating for VTI anisotropic estimation near a well.

Whether implemented globally in 3D via a ray-traced migration or locally via a locally ray-traced imaging procedure, MMO provides a very efficient means of testing, and consequently, updating velocity models without the cost of a full remigration. It should also be noted that the MMO process can be used in local model updating by applying the demigration-remigration below datums above which the velocity model has been determined.

One application of MMO is to estimate anisotropy parameters in a vicinity of a well. To demonstrate this we apply this 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 (Zhu, et al. 2011). The process involves the following steps:

1. A full prestack depth migration to image the data with a starting model (in this case the starting model was anisotropic with $\delta = .005$ and $\varepsilon = .01$ below the water bottom)
2. Pick residual depth errors, compute rays and travel times, map the residual depth errors onto travel time errors and solve a linearized joint tomography system to simultaneously update δ and ε to obtain an updated model.
3. Use MMO to remap all of the picked events from the old model to the new model, giving new residuals for the new model. (Note that no repicking of the data residuals is necessary.) Using these newly mapped residuals, repeat the joint tomography process and create new updates for δ and ε .
4. Repeat step 3 until the residual errors have been reduced to a minimum (or an acceptable level).
5. Apply the full data MMO or a full remigration and then return to step 2 if necessary.

The model data from BP was a full TTI 2D data, where we selected a location that was in the VTI portion of the model. To simulate an idealized well situation, the vertical velocity was assumed to be known. The data was migrated with a Kirchhoff depth migration using an initial model with $\delta = .05$ and $\varepsilon = .01$ below the water bottom. The gathers were automatically picked and a set of tomography iterations were performed. Both the depth gathers 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 gather and the three iterations of the MMO are shown in the left hand part of Figure 4. The anisotropy parameters for the true model (red) and the third iteration estimate (blue) are shown in the center. The third iteration MMO gather and the true Kirchhoff depth migration gathers 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.

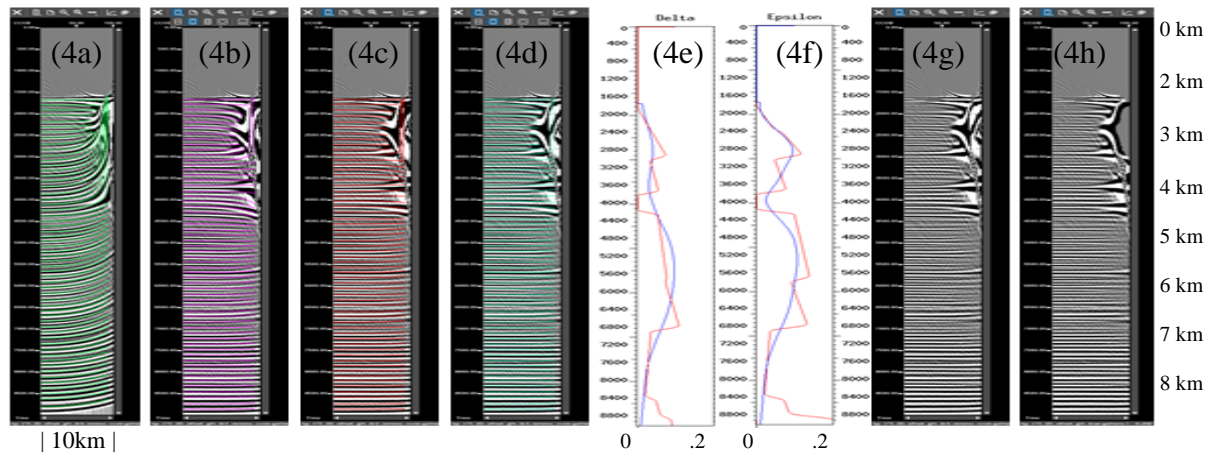


Figure 4 Anisotropic parameter estimation with vertical velocities given from “well” control. Gathers and event picks for a starting model are in (4a). Shown in (4b) – (4d) are model based moveout (MMO) gathers and remapped residual error picks for three joint tomography model updates. The final estimates (blue) and true (red) values of delta and epsilon are shown in (4e) and (4f) respectively. The final MMO gathers and Kirchhoff migration for the true model are shown in (4g) and (4h) respectively.

Conclusions

A model based moveout (MMO) procedure is defined as remapping of the specular reflections of imaged data to new positions in a new model as an approximation to a full migration of the data. In some cases, the full data as well as events picks can be remapped, allowing for an automated re-imaging and tomographic updating process, which does not require full remigration at each iteration, nor does it require new residuals to be picked for each iteration. Only ray tracing, equation setup and inversion are required per iteration. A useful application of this technology is in the estimation of anisotropy in the vicinity of well control. The remapping of the residuals in the MMO is locally equivalent to map demigration-remigration for use in 3D tomography.

Acknowledgements

We thank PGS for giving permission to give this presentation and BP for the synthetic model data.

References

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