Non-linear slope tomography from common offset vector volumes as applied to Birba high density land WAZ survey from Oman

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Summary

A step change has been made in seismic imaging when moving from narrow-azimuth (NAZ) imaging to wide-azimuth (WAZ) imaging, mainly because of better illumination and higher fold. Likewise, a wider angular redundancy should help building more realistic depth velocity models as long as involved picking and tomography engines can handle correctly geometry of wide-azimuth surveys. For that purpose, the seismic dataset is split into common offset vector (COV) volumes gathering traces having a homogeneous offset and azimuth distribution and insuring minimum holes or fold variations due to acquisition irregularities (Vermeer, 2002). We present a non-linear slope tomography that has been extended to invert locally coherent events picked in prestack depth migrated (PreSDM) or prestack time migrated (PreSTM) COVs. We address picking and de-migration aspects as well as kinematic re-migration and velocity update processes. We illustrate our COV consistent model building workflow on a real high-density WAZ survey from Oman and show how velocity model and imaging have been improved when picking is done on gathers built from COVs rather than on gathers built from azimuth sectors.

Introduction

Migration velocity analysis (Liu, 1997) is the most common strategy for depth velocity model building. It usually involves an iterative process with several loops of PreSDM, structural dip and residual move-out (RMO) picking and linearized velocity update. The limitations of such a linear process have been pointed out and non-linear velocity updates have been proposed (Guillaume et al., 2001; Adler et al., 2008), that limit the number of iterative steps (PreSDM and picking) and predict RMO in the updated model. More recently, non-linear slope tomography has been introduced. It inverts locally coherent and planar events by using a more local inversion criterion for a higher resolution of the updated velocity model.

Figure 1: Slopes in un-migrated time domain are related to the measured dips in the migrated domain through kinematic de-migration. Left side represents a migrated locally coherent event and right side represents a de-migrated kinematic invariant.

In the WAZ context, the locally coherent events picked from migrated COVs are described by their position (X, Y, Z), their measured dips in X, Y spatial directions, and their local derivatives of the RMO surface in HX, HY offset vector directions. When
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Data are split into common azimuth subsets the local derivative of the RMO is only available in the direction of the azimuth, dip_H. Kinematic de-migration converts picked events, i.e. migrated facets, into locally coherent events in the un-migrated time domain. The associated parameters are model independent data, and are consequently called kinematic invariants (Guillaume et al., 2001). They are characterized by their central source and receiver positions, time and time slopes, slope_M and slope_H (Lambré, 2008) (Figure 1). In case of WAZ data we have access to vector slope_H with components corresponding to the H_x and H_y directions. In this paper, we extend the non-linear slope tomography method (Guillaume et al., 2008; Montel et al. 2009) to cope with kinematic invariants with a vector slope_H obtained from high density WAZ data sorted in COVs.

Method - Non-linear slope tomography from COVs

The input is in the form of locally coherent events picked in migrated or un-migrated COVs. When picked in the migrated domain, ray-based de-migration maps the events back to the un-migrated time domain.

A true WAZ kinematic invariant contains the source and receiver positions (midpoint M_X, M_Y, offsets H_X, H_Y), the travel-time T, and the slopes observed in the four directions M_X, M_Y, H_X and H_Y. Slopes slope_M and slope_H in the common offset cube are used as imaging conditions in kinematic migration. These two slopes are present in both NAZ and WAZ contexts. In NAZ case, a third slope slope_d in common midpoint (CMP) common azimuth gathers carries the velocity information. The WAZ context gives access to two slopes slope_H and slope_H, in a CMP super-gather, that both carry velocity information. As shown in Figure 2, vector kinematic invariants in un-migrated time domain are related to dips measured in the migrated domain through a formula given by Chauris et al. (2002) and involving ray-paths characteristics at surface and image positions.

The velocity model m to estimate can be gridded and/or layered. The velocity model parameters are typically defined by 3D cardinal cubic B-Spline functions that are adapted to ray tracing and to models with large spatial dimensions (due to compactness). The TTI (Tilted Transverse Isotropy) model includes velocity parameters, anisotropy parameters (δ, ε) and the axis of anisotropy symmetry.

The cost function to minimize is the sum of the square of the local derivatives of the RMO surface obtained for each kinematic invariant by a kinematic migration in the velocity model to be updated. For each kinematic invariant, the common offset kinematic migration fits shot and receiver positions and imaging information (travel-time and common offset slopes, slope_M and slope_H). In the NAZ case, the following C_{NAZ}(m) cost function is minimized:

$$C_{NAZ}(m) = \frac{1}{2} \sum_{d} \beta(dip_H(m, d))^2 + \text{regularization}(m),$$

where dip_H is the predicted local derivative in offset of RMO in the direction of the azimuth of the acquisition. Common midpoint slope slope_d is used to predict, in the model being updated, the local derivative in offset of RMO using the formula developed by Chauris et al. (2002) (Figure 2). In equation (1), β weight contains a quality factor assigned to each event to be inverted. Regularization term can carry a priori information on the model, for example constraints on first and second derivatives of the model parameters to estimate (Tikhonov regularisation).

In WAZ case, we have access to the measured local derivatives dip_H and dip_H of RMO in H_X and H_Y directions (Figures 1 and 2). The cost function becomes:
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\[ C_{WAZ}(m) = \frac{1}{2} \sum S \beta_s (dip_{Hx}(m,d))^2 + \beta_y (dip_{Hy}(m,d))^2 \] + regularization(m), \tag{2}

Through kinematic migration, we calculate the linear equations relating changes in modelled quantities dip\textsubscript{Hx} and dip\textsubscript{Hy} to changes in the velocity or anisotropy parameters, i.e. the Fréchet derivatives. In a local optimization scheme, Fréchet derivatives and computed residuals are used to build the linearized system to solve. The overall non-linear update of the velocity contains a multi-grid approach that allows to solve first for the long wavelengths of velocity and then progressively for shorter wavelengths, thus reducing the risk of getting trapped into a local minimum of the cost function. The denser the distribution of the kinematic invariants, the higher the expected resolution of the estimated velocity model.

Field data – Comparing picking and tomography in azimuth sectors manner with the proposed COVs method, using Birba WAZ survey as an example

We have applied this new workflow to Birba WAZ survey in South of Sultanate of Oman. In Birba high density seismic survey (Sambell et al., 2009) the spacing between shots lines is 100 m and 200 m between receivers lines. Maximum offset Hx is 5000m, maximum offset Hy is 4000m. 500 COVs have been built (reciprocity being applied). Processed area covers 780 km\textsuperscript{2}.

Figure 3: Left: velocity after inversion of RMO picked in azimuth sectors. Right: velocity after true WAZ inversion of RMO picked in COVs. Shallow “Natih” horizon is displayed in red and top salt surface is displayed in green/blue.

Figure 4: PreSDM image after inversion of RMO picked in azimuth sectors. Right: PreSDM image after inversion of RMO picked in COVs. The arrow show shallow Natih horizon (see Figure 3).
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Because of the high level of noise (Figures 4 and 5) in shallow subsurface in particular, COVs were filtered to improve S/N prior to dense volumetric picking of RMO and structural dip, here guided by a predefined skeleton. Tomographic inversions of RMO picked in both azimuth sectors and COVs have been carried out. Picking in azimuth sectors consisted in organizing the data in 5 different azimuth sectors (0, 45, 90, 135 and 180 degrees) so that RMO could be picked independently on five sets of 2D CIP gathers in a conventional manner. On the other hand, one pass RMO picking of COVs was performed on 3D CIP gathers along parabolic elliptical surfaces that account for azimuthal variations of RMO (Lecerf et al., 2009). Direct picking from COVs improved the turnaround dramatically. WAZ Tomography became easier to handle than multi-azimuth tomography as well since there is only one set of data to work with.

In figures 3, 4, 5 and 6, we compare new COVs consistent velocity model building workflow to the workflow based on azimuth sectors. The velocity model obtained after tomography from COVs is a bit simpler and more geological, especially below “Natih” horizon displayed in red colour in Figure 3. The velocity updates, in shallow part above Natih, are quite different, as shown in Figure 3: the PreSDM image (Figure 4) obtained after inversion of vector RMO slopes picked in COVs is a lot improved compared to the one obtained after inversion of RMO picked in azimuth sectors. Figure 5 shows flatter events at far offsets after tomography from COVs picks, as computed far offset traces stack contributions of traces with more homogeneous offset and azimuth distributions.

The PreSDM image computed after inversion of vector RMO slopes from COVs is also better in deeper part of the subsurface, where the continuity of top salt horizon has been clearly improved (Figure 6).

Conclusions

We presented a new depth velocity model building method making consistent use of common offset vector volumes (COVs) and based on non-linear slope tomography extended to vector slope H kinematic invariants. The combination of robust RMO picking on full COVs dataset and of true WAZ tomography from COVs has produced significant imaging improvement on high density Birba land WAZ survey. Moreover, the turnaround has been significantly reduced as traces have been ordered once, by COVs, prior to the velocity analysis, without need for reordering by azimuth sectors.

Acknowledgements

The authors wish to thank Petroleum Development Oman, the Ministry of Oil and Gas of the Sultanate of Oman for their permission to publish this paper.
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