Azimuthal residual velocity analysis in offset vector for WAZ imaging

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Summary

This paper presents an original method for azimuthal residual velocity analysis in a context of wide azimuth acquisition geometry. The 3D analysis is performed on individual Common Image Gather and takes full advantage of the offset vector binning concept which preserves the offset and azimuth information in a consistent manner. The proposed azimuthal residual velocity analysis is based on semblance optimisation by scanning isotropic and anisotropic components of a parabolic elliptical model. The significant imaging improvement that we are seeing with our land data case demonstrates the accuracy of the extracted azimuthal parameters. The azimuthal residual moveout allows seismic events to be stacked constructively when strong azimuthal variations occur.
Introduction

Wide azimuth acquisitions provide a full azimuthal illumination of the structures for a more accurate image. Additionally, analysing azimuthal variations of the seismic response may offer information on fractures orientation. To meet both objectives, it is essential that the wide azimuth character of the data is preserved throughout the processing sequences in order to get full benefit of true 3D algorithms. In this perspective, the use of the offset vector binning concept, introduced by Cary (1999) and Vermeer (2002) on dense wide azimuth datasets is advantageous as it preserves offset and azimuth information even after migration.

Grechka and Tsvankin (1998) have shown that the azimuthal variations of the measured NMO velocity can be approximated with an elliptical model. Different approaches are currently proposed in the industry in order to evaluate azimuthal velocity variations, such as independent 2D NMO velocity analysis in azimuthal sectors or 3D surface fitting of azimuthal NMO travel-time picks (Jenner et al., 2001). Alternatively, semblance or stack response analysis using trial values of azimuthal anisotropy parameter has been confirmed to be a reliable approach for dataset with a poor signal to noise ratio (Sun et al., 2008).

Because the presence of noise in the data makes the travel-time picking process difficult, our azimuthal residual velocity analysis is based on semblance optimisation, taking advantage of the offset vector traces distribution in a Common Image Gather (CIG). We propose to scan parameters corresponding to the isotropic and anisotropic components of the parabolic elliptical model, instead of conventional azimuthal parameters Vfast, Vslow and (Vfast) azimuth.

Offset Vector classes

Preserving the recorded traces offset and azimuthal information throughout the processing sequence is essential for the effectiveness of any 3D algorithm. Because shots and receivers are distributed with regular intervals in a cartesian grid, the definition of offset X and offset Y classes naturally provides a single fold volume for each Common Offset Vector (COV) cube. This defines the so called “pseudo-minimal data sets” (Vermeer, 2002). The offset X and offset Y ranges define a surface called “tile” which includes several single fold bins, where the bin dimension is chosen according to the shot and receiver sampling interval. The tile dimension is determined from shot lines and receiver lines distance intervals such that no gap or overlap appears in the COV volume. As an example, figure 1a represents two adjacent tiles corresponding to an offset X of 400 m and an offset Y of 400m, such that traces included in both tiles have same offset and azimuth reference. Figure 1b shows the distribution of the reference azimuth for each tile belonging to the same cross-spread. The offset and azimuthal tile information defined in such way can be used in a post-migration azimuthal processing.

In summary, the offset vector binning uses the same cartesian system than the acquisition geometry and hence ensures an optimum distribution of seismic traces in each COV volume: one trace per bin. Conventional sectoring approach using polar coordinate system provides cubes with holes and over folds, which requires an offset and azimuth interpolation process with careful fold compensation.

Azimuthal residual velocity analysis in Offset Vector domain

Pre-stack migration is achieved independently for each COV volume. Offset and azimuth information of migrated traces is preserved through the offset vector coordinates of the class centre. The resulting CIG is composed of traces regularly distributed in offset X and offset Y.

The proposed azimuthal residual velocity analysis method is based on semblance optimisation computed within the 3D CIGs. Starting from the NMO elliptical model defined by Grechka and Tsvankin (1998), the residual parabolic NMO correction is derived in a cartesian coordinate system. Rearranging the expression, we define three variables Q, R and S which describe the residual travel-time function. The isotropic part is represented by Q (no azimuthal variation) and anisotropic components are represented by R and S:
\[ t = \tau + Q_y x^2 + y^2 - R x^2 - y^2 + S 2xy \]

where

\[ Q = \frac{Q_y + Q_y'}{2}, R = \frac{Q_y - Q_y'}{2} \cos(2\alpha), S = \frac{Q_y - Q_y'}{2} \sin(2\alpha) \]

\( x \) and \( y \) correspond respectively to the offset X and offset Y coordinate in the CIG. \( Q_y \) and \( Q_y' \) define the ellipse axes of the parabolic residual move-out. \( \alpha \) represents the orientation of the ellipse long axis with respect to the X coordinate axis and \( \tau \) is the time at zero offset.

For each \( \tau \), a semblance is computed under trial values of these three defined parameters. Optimum azimuthal parameters are then extracted using the semblance maximum.

**Real dataset application**

A wide azimuth land dataset has been chosen to validate the methodology. The wide azimuth survey consists in a dense acquisition with 200 m shot line spacing and 200 m receiver line spacing (orthogonal shot receiver lines acquisition, 25 m receiver interval, 25 m shot interval. Bin 12.5 x 12.5 m). An isotropic PreSTM has been run on individual COV volume. The resulting offset vector CIGs contain 225 traces each: 15 offset X classes and 15 offset Y classes with 400 m interval distance. This makes up a relatively homogeneous distribution of azimuth (0-360°) and offset (0-4200 m) for a given CIG. Given the limited incidence angles, we have used the parabolic RMO approximation for the elliptical model.

*Figure 2* shows the representation of a seismic event in a CIG gather before and after azimuthal residual move-out correction. When traces are sorted in “snail gather”, that is increasing azimuth within each offset range, any seismic event may exhibit a wavy behaviour as a consequence of azimuthal kinematic variations. After the azimuthal residual move-out application using the optimum elliptical parameters \( Q, R \) and \( S \), the event is flattened and can be stacked successfully.

If such azimuthal kinematic variations are not corrected, it is interesting to see how a single seismic event may be duplicated when all azimuths are stacked together (especially for the far stack). *Figure 3* illustrates the seismic event duplication in the far offset stack. Because tops and bottoms of the sinusoid corresponding to the main ellipse axis orientation (Vfast and Vslow) are stacked constructively, two superimposed events may be observed when strong azimuthal variation occur. The seismic event discontinuity can provide consequently an erroneous interpretation.

For comparison, the proposed azimuthal residual velocity analysis has been performed in parallel with a conventional 2D velocity analysis in 6 azimuthal sectors, using the same CIGs. *Figure 4* shows time slice results for far offset stacks. Significant resolution improvement of the stack can be observed with a conventional 2D velocity analysis in 6 azimuthal sectors.重大 offset data. Secondly, the 2D residual NMO cannot correct for azimuthal time-shift variation within a sector, especially at large offset where the fan is widely open.

**Discussion**

We have shown that an azimuthal residual move-out, based on a parabolic elliptical model, is able to effectively compensate azimuthal kinematic variations that have not been handled with an isotropic PSTM scheme. However, distinguishing between intrinsic azimuthal anisotropy and apparent anisotropy effect due to dipping structures in the overburden is delicate. Jenner, 2007, has shown with synthetic modelling how to create structural azimuthal anisotropy with an isotropic velocity model. *Figure 5* shows the correlation that we observe between azimuthal corrections and structural dip and spatial RMS velocity variations. It suggests that the apparent anisotropy would be predominant in the
azimuthal kinematic effect. A potential azimuthal AVO analysis may be able to characterise the intrinsic azimuthal anisotropy distinctively.

Conclusion

With the emergence of modern dense wide azimuth acquisitions, offset vector binning appears as a natural and efficient approach to preserve recorded data azimuthal information without excessive use of regularisation or interpolation schemes. The PSTM in common offset vector domain provides well sampled CIGs with regular trace distribution in a cartesian coordinate system optimal for post-migration azimuthal processing.

Through our land data case study, we demonstrate that a velocity analysis algorithm that simultaneously takes into account all azimuths is less sensitive to the noise than independent 2D analysis within azimuthal sectors. Because picking individual travel time for surface fitting is delicate in the presence of noise, the proposed azimuthal residual velocity analysis is based on semblance optimisation by scanning isotropic and anisotropic components of a parabolic elliptical model.

The spectacular imaging improvement we are seeing after azimuthal residual move-out validates the accuracy of the extracted azimuthal parameters. Whatever the causes, structural or intrinsic anisotropy, the correct azimuthal travel-times compensation is an essential prerequisite for a better structural image and/or for any azimuthal amplitude analysis such as fracture characterization studies.

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References

Grechka, V. and Tsvankin, I., [1998], 3-D description of normal moveout in anisotropic inhomogeneous media, Geophysics, 63, 1079-1072.
Jenner E., Williams M., Davis T., [2001]. A new method for azimuthal velocity analysis and application to a 3D survey, Weyburn filed, Saskatchewan, Canada. 71th SEG annual meeting, 20, 102-105, Expanded Abstract

Figure 1: a) Offset vector definition within cross-spread domain. 2 cross-spreads are represented with the tile offset X 400 m and offset Y 400 m.
b) One cross-spread: Azimuth distribution on different tiles with offset vector binning.
Figure 2: CIG with increasing azimuth within each offset range (500 ms time window)
a) Before azimuthal residual move out.
b) After azimuthal residual move-out using parabolic elliptical model.

Figure 3: Example of azimuthal variation effect on the far offset stack (full azimuths):
a) Before correction, seismic events appear discontinue due to the duplication.
b) After correction, seismic events come out continue.

Figure 4: Time slices of the far offset stack (full azimuths)
a) Before azimuthal residual move out.
b) After azimuthal residual move out with 6 sectors independent velocity analysis.
c) After azimuthal residual move out with true 3D velocity analysis using Q, R and S scans.

Figure 5: Time slice of azimuthal velocity attributes represented with segment:
Segment orientation: azimuth $V_{fast}$, segment length: magnitude $V_{fast}$-$V_{slow}$
a) Azimuthal velocity attributes overlaid with time migration RMS velocity field.
b) Azimuthal velocity attributes overlaid with seismic.