W002

Building Detailed Structurally Conformable Velocity Models with High Definition Tomography

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SUMMARY

Velocity model building remains a crucial step in seismic depth imaging. A general drawback of conventional tomographic approaches is that the estimated velocity models do not conform enough to structures. We present several applications of an innovative high resolution tomography that inverts densely picked residual move-out data to reveal detailed structurally conformable velocities. The application to the synthetic 2D Marmousi II dataset offers the possibility to carefully assess the method. It demonstrates the ability to produce structurally conformable velocity models with a level of detail that promotes velocity attributes as an aid to geological interpretation. As such it can offer an alternative to full waveform inversion for the interpretation of reflected waves. Finally we show an application to a 3D land dataset where the obtained higher resolution velocity model results in improved focusing of migrated images and improved match to well velocities.
Introduction

Successive step changes in tomography-based migration velocity analysis have resulted in much improved seismic imaging. As for any inversion-based method, these step changes fall in two categories: a first one concerns the data to invert and a second family relates to the model-space representation and the inversion algorithms.

On the data side, recent high density rich azimuth acquisition geometries have greatly increased the angular redundancy / diversity of wave-paths that constitutes the main velocity discriminator. De-noising and signal enhancement techniques have also significantly contributed to improve reliability of dense automated picking tools (Siliqi et al., 2009). On the model-space representation and tomographic inversion algorithm side, we have been able to solve bigger and bigger regularized linear systems and we can now QC enormous amount of data. First tomography approaches involved iterative processes with several iterations of prestack depth migrations (preSDM), residual move-out (RMO) picking and linear update of velocity (Liu, 1997). Non-linear tomography (Guillaume et al., 2001) and more recently non-linear slope tomography (Billette et al., 2003; Lambaré, 2008; Guillaume et al., 2008) use a local focusing criterion with no assumptions about the shape of the reflectors or of the RMO curves. Moreover, the physics of wave propagation is more accurately taken into account with tilted transverse isotropy (TTI) velocity models.

Despite these advances, velocity models updated with such approaches remain smooth and poorly conform to structures (Figure 1 right); this aspect appears as a serious drawback considering velocity structures revealed by full waveform inversion (Plessix et al., 2010). This opinion appears well stated but could be mitigated when looking at the RMO field picked by a dense automated picking (Figure 1 middle). Such field exhibits nice detailed features corresponding to geological structures. The rapid changes in RMO in the gently dipping thin beds and in the structured area do not translate into detailed velocities after conventional tomography. Can we do better?

Guillaume et al. (2011) recently proposed an innovative high definition (HD) tomography that can estimate detailed structurally conformable velocity models. In the present paper we present several applications of the approach. The capability of the method to reveal detailed spatial variations of velocity and to improve seismic imaging is first illustrated using the Marmousi II synthetic example. We then apply the high definition tomography to a land field dataset.

High definition tomography

High definition tomography has to be applied starting from an accurate velocity model obtained by conventional tomography. We can have a multi-layer velocity model representation in which layer boundaries describing strong velocity contrasts can be introduced. Inside the layers the size of the velocity grid mesh is chosen according to the density of data and to the expected spatial wavelengths of velocity variations.

Figure 1: Limits of conventional tomography. Detailed RMO maps (middle) picked on PreSDM results (left) do not translate into detailed velocities (right).

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High definition tomography inverts densely picked RMO and dip data. RMO picking is performed in a continuous manner, thus gathering huge amounts of detailed RMO information obtained either tracking local coherency in multi-dimension (Traonnmilin et al., 2009) or scanning parametric curves along common image point (CIP) gathers (Siliqi et al., 2009). The multi-dimensional tracking approach is more accurate when the signal to noise ratio is sufficiently high, while the curve/surface picking methods can be preferred when signal to noise ratio is low.

Because tomography from surface seismics experiments tries to solve a quite ill-posed inversion problem in some kind of least squares sense, it is important to make it as well-conditioned as possible and to reject outliers in RMO picks as much as possible. The high definition tomography proposed by Guillaume et al. (2011) accurately translates the validated small spatial variations of RMO (as shown in figure 1) into localized perturbations of velocity.

**Synthetic Marmousi II dataset**

We consider an acoustic version of the well known Marmousi II synthetic model (Martin et al., 2006) with a water column of 460m. This model is interesting because it exhibits velocity discontinuities that we can expect to recover with our high definition tomography. Seismic data are computed by an acoustic wave equation finite differences scheme for a marine type acquisition with a maximum offset of 3 km.

![Figure 2: Marmousi velocities and RMO picks. 2a) conventional tomo velocity; 2b) Second order term of RMO picks; 2c) HD tomo velocity; 2d) Exact velocity (slightly smoothed).](image)

First we perform conventional velocity model building, producing a relatively smooth velocity model (Fig. 2a). A PreSDM is done for this velocity model producing CIP gathers on which we pick RMO. Figure 2b shows the distribution of the second order approximation of the picked RMO curves. We then perform a high definition tomography (Fig. 2c) and finally compare to a slightly smoothed version of the exact model (Fig. 2d). In Figure 3 the velocity models are all superimposed with the corresponding depth migrated image.

The conventional tomographic approach has computed a smooth model that produces a depth migrated image characterized by good focusing and positioning. However, the computed velocity model is poorly correlated to the detailed geology; for example, the thin “red” layer has not been found and structures are distorted in some places.

The high definition tomography computes a very detailed velocity model that conforms to the structural image and that matches quite well the exact velocity model. In particular, the thin “red” layer has been detected and its shape is correct. Similarly the shallower “blue-purple” low velocity zone in the top left part of the model shows detailed layered velocity variations that follow almost perfectly the thin beds present in the exact models. Figure 3d shows the exact vertical velocity profile (in black, smoothed in order to fit with the high definition tomographic result) together with the conventional tomography (red) and high definition tomography (yellow) velocity profiles at four
The variations of velocity are nicely detected and quantified, even the small ones in the shallow part. The amplitude of the estimated variations is a bit high in the deeper part.

**Figure 3:** 3a) conventional tomo velocity and Kirchhoff preSDM; 3b) HD tomo and re-migrated image; 3c) Exact velocity and image; 3d) vertical velocity profiles at positions A, B, C & D.

**Field land dataset**

High definition tomography is applied to a cross-spread land acquisition in an area of salt tectonics. The fold is only 15 and maximum offset is 3 km. A conventional velocity model building (Guillaume et al., 2008) was first done allowing to image the complex structures and to fit to the wells thank to the introduction of TTI isotropy. We then performed a HD tomography using dense dip and RMO picks. Figure 4 shows in-line and cross-line sections of the high definition velocity model superimposed with the depth migrated images. We can see again that the HD velocity model exhibits a nice conformity with the geological structures.

**Figure 4:** Comparison of conventional tomography and preSDM (left) and HD tomography and preSDM (right), showing cross-line section (top) and in-line section (bottom) at location of Well A.

A close-up in Figure 5 of preSDM stack images obtained for the conventional and HD velocity models also shows that salt wings imaging is improved by HD tomography. Figure 5 also shows a comparison of the velocity profiles at two wells (Well B is nearby shown vertical sections). We notice that the conventional velocity model already fits the well velocity reasonably well, but the HD velocity model recovers some higher resolution features that match the well even better.
Conclusion

We have presented two applications of an innovative high resolution tomography that inverts densely picked residual move-out data for revealing detailed structurally conformable velocities. The application to the synthetic 2D Marmousi II dataset demonstrates the ability to produce structurally conformable velocity models with a level of detail that promotes velocity attributes as an aid to geological interpretation. As such it can offer an alternative to full waveform inversion for the interpretation of reflected waves. The application to a 3D land dataset demonstrates the capability of the method with a noisy dataset. The obtained higher resolution velocity model results in improved focusing and improved match to well velocities.

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