3D local tomography - residual interval velocity analysis on a depth solid model

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SUMMARY

An interactive method for the determination of interval velocities and interface depths in 3D complex areas is presented. Starting with an initial velocity depth model, the tomographic principle is used to relate pertubations in layer slowness and interface depths to traveltime changes along CRP rays (Kosloff et al, 1996). The additional constraint of preserving zero offset traveltimes along normal incidence rays enables us to relate interface depth changes to slowness changes and thus reduce the problem to a single parameter problem. By separating the traveltime error function into two parts, contribution of slowness from the overburden and contribution of slowness from the current location, the global tomography is converted to a simple interval velocity analysis problem.

The first step in the proposed method is a special 3D reflector prestack depth migration (Koren et al, 1988). The migration is performed on a coarse output grid, where the output consists of CRP gathers in windows centered around the reflecting horizons (CRP migrated panels) and the corresponding CRP ray paths for the relevant output offsets and azimuths. The second step is velocity-depth model updating. For a given layer, a semblance profile of varying residual interval velocities is calculated along the migration grid. The criteria for picking the residual interval velocities is the flatness of the migrated panels at each location. A map of slowness perturbation is then built. Next, depth perturbations are found for the entire model according to the condition that zero-offset traveltimes remain constant. The velocity-depth model is rebuilt only after the errors at all locations and all layers have been picked. The method handles general complex structures and not only layer-cake type structures. For subsurface representation, we use a solid model that consists of triangulated surfaces surrounding closed volumes. The solid model is designed for handling non-layer cake structures such as salt bodies, lenses, or truncated formations. The method is demonstrated on a 2D synthetic example and on a 3D field dataset from the Gulf of Mexico.

METHOD

The local tomography analyzes velocities (slowness) and interface depths of a subsurface model. It is presented as velocity analysis for a given layer at a given CRP location. We assume that the velocity errors and the corresponding depth changes have already been picked and calculated for a part of the structure. These pertubations are accounted for while analysing the current location.

The method relies on the tomographic principle presented in Farra et al (1989), and Kosloff et al, (1996). Consider a CRP ray pair emanating from an interface at a CRP. When the slowness and interface depths of the model are perturbed, the first order approximation of the corresponding traveltime change is given by:

$$\delta t = \int_{ray} \delta S_L \, dl + \sum_{intersections} \Delta P_z^i \delta z_i \qquad (1)$$

(Farra et al, 1989). δS_L is the perturbation in layer slowness, δz_i is the change in interface depth at an intersection point with the ray, and ΔP_z^i is the change in the vertical slowness directly above and below the interface at the intersection point of the ray. The integration in (1) is along the original unperturbed ray paths.

Our goal now is to relate slowness change in a layer to the corresponding change in depth of the layer interfaces, in order to convert the coupled velocity depth parameter problem into a single parameter velocity analysis problem. For this objective we make the assumption that the zero offset times from all the interfaces remain constant. The zero offset times are calculated using normal incidence ray tracing. Separating the right hand side of (1) into two parts, one part containing contributions from layers for which updates have previously been calculated, and the second part containing contributions from the layer currently being analyzed, the problem can be reformulated as a local velocity analysis problem:

$$\delta t = \int_p \delta S_L dl + \sum_p \Delta P_z^i \delta z_i + \int_c \delta S_L dl + \Delta P_z^c \delta z_c \qquad (2)$$

where a subscript or superscript p stands for previously updated layers, and a subscript or superscript c stands for layer currently being updated. According to the previously stated assumption, $\delta t = 0$ for the zero offset ray. Using (2), this allows to express δz_c in terms of errors in the overburden previously analyzed and the errors in slowness for the current layer to be locally analyzed;

$$\delta z_c = -\frac{1}{\Delta p_z^{oc}}\left[\int_p \delta S_L dl + \sum_p \Delta P_z^{0i} \delta z_i + \int_c \delta S_L dl^0\right] \qquad (3)$$

where the superscript *0* is used to denote the zero offset ray.

Equations (2) and (3) are used for a velocity scan where different values of δS_L^c are tested. Time scaled depth migrated gathers (CRP panels) are analyzed within a window centered around the reflection. Given a test value δS_L^c, δz_c can be calculated from (3). Both variables can then be substituted into (2) to give the time shift δt. The corresponding trace within the gate is then shifted by this value. After all traces are shifted, semblance is calculated. The selected slowness error value corresponds to the highest semblance which corresponds the flattest gather. To improve the performance of the method in the presence of noise we have found that it is preferable to use correlated gathers instead of the original gathers. After δS_L^c has been evaluated at a number of CRP locations, the values are linearly interpolated to create a slowness update map for the whole layer.

After determining a slowness error map for a layer, the depth changes at each migrated location are determined by a variant of (3):

$$\delta z = -\frac{1}{\Delta p_z^{o}}\left[\int_p \delta S_L dl^0 + \sum_p \Delta P_z^{0i} \delta z_i\right] \qquad (4)$$

Equation (4) is applied from the top down in the order in which the interfaces appear at the given trace.

EXAMPLES

The local tomography is demonstrated here on a 2D synthetic data using the layout illustrated in Figure 1. The initial depth model is shown in the section panel by the thin solid lines. This model was built by ray migrating time horizons into depth using the velocity field indicated in the vertical velocity panel (no lateral velocity changes). We describe here the updating procedure for the fourth layer where the velocity errors for the first three layers have already been determined. CRP ray paths for all offsets at the selected location are shown. The initial velocity along the layer currently being analyzed and the picked residual interval velocities overlaid on the semblance profile are shown in the horizon velocity panel.

The CRP migrated panel, shifted according to the picked residual velocity, is shown in the QC depth gate. The movement of the horizons as a result of the picked residual velocities is indicated by the thick lines in the section panel. Note that the initial velocity at the fourth layer is 3750 m/s, where the true velocity within this layer varies from 3500 m/s to 4500 m/s. Our procedure succeeded in resolving the true lateral velocity profile.

In our presentation, we will show this procedure applied to a 3D dataset from the Gulf of Mexico.

CONCLUSIONS

We have presented an interactive method for updating interface depths and interval velocities of a subsurface model. The method uses prestack depth migrated gathers as input in windows centered around the reflecting interfaces. The two parameter problem of determining layer velocities and interface depths is reduced to a one parameter problem by imposing the preservation of zero offset times. For each location within a given layer, the velocity error is first determined. The corresponding interface depths for all layers are then calculated using the preservation of zero offset times. The analysis is performed at selected CRP locations and is carried out one layer at a time.

The theoretical foundation of the method is the tomographic principle, which is a linear approximation relating slowness and interface depth perturbations to traveltime changes along ray paths. For each tested slowness perturbation, the tomographic principle is used to calculate the corresponding time changes along CRP ray paths. These time shifts are applied to the time scaled migrated panel which is then tested for flatness. The selected velocity is the one which best flattens the CRP panel. Since the analysis is based on ray tracing, there is no use of hyperbolic assumptions.

This velocity analysis method does not require building new subsurface horizons during the analysis. The original horizons and the original depth migrated panels are used in analysing all layers. This feature is especially important in 3D where prestack migration and model building procedures can be cumbersome and very slow.

The new velocity updating procedure should be considered a complementary method to global tomography. The method can be used for a visual evaluation of a depth-velocity model by inspecting the flatness of migrated CRP gathers at different locations. Local tomography can be used for calculating gross changes in the model while leaving the resolution of the finer details to the global methods. Finally, a novel use of local tomography is for picking non hyperbolic traveltime errors on the depth migrated gathers. This is possible since the errors in velocity and depth correspond to errors in traveltimes along the ray paths, which are not necessarily hyperbolic. In fact, this is exactly the kind of input that is required for the global tomography inversion (Kosloff et al, 1996).

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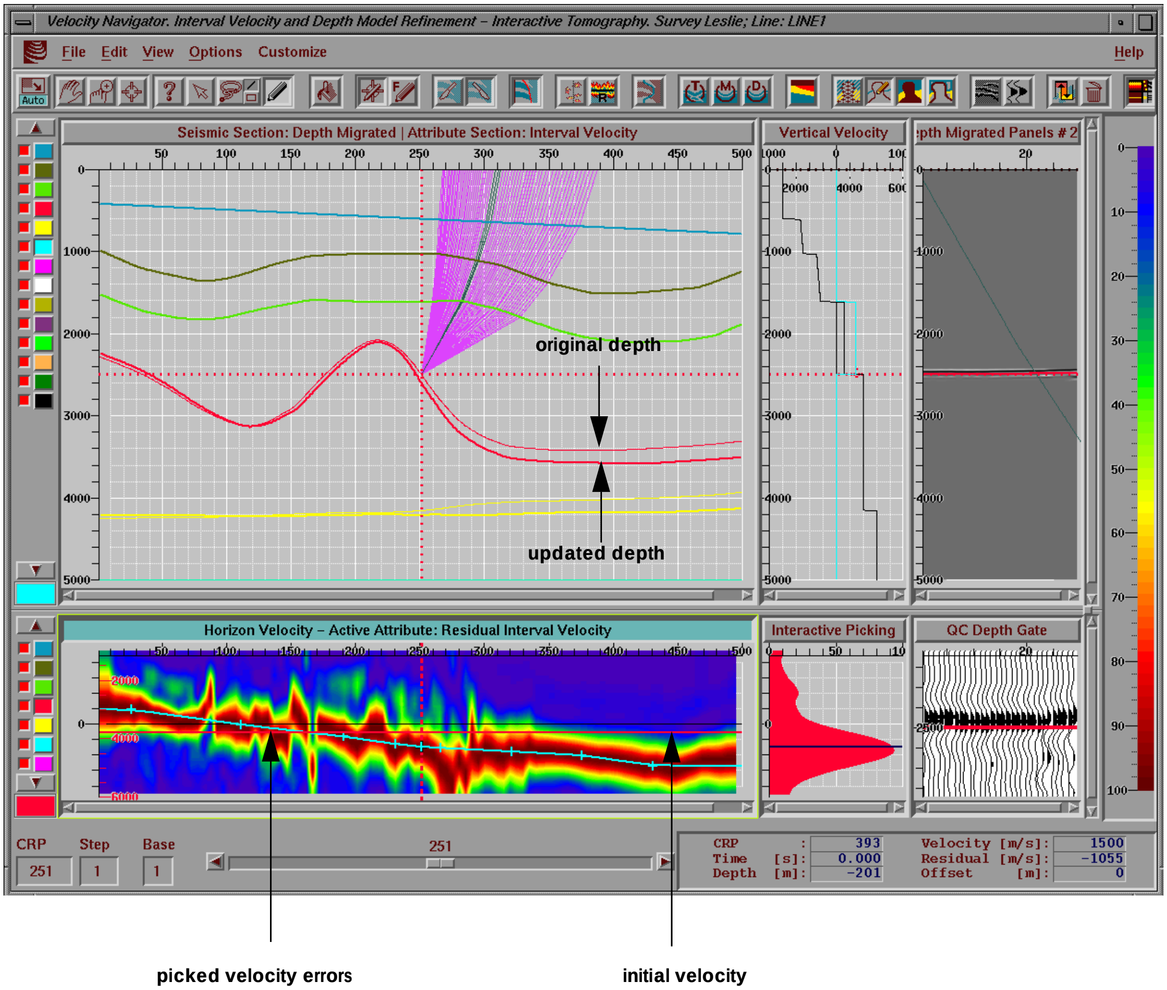
Velocity Navigator. Interval Velocity and Depth Model Refinement – Interactive Tomography. Survey Leslie; Line: LINE1
File Edit View Options Customize Help
Seismic Section: Depth Migrated | Attribute Section: Interval Velocity
Vertical Velocity
original depth
updated depth
Horizon Velocity – Active Attribute: Residual Interval Velocity
Interactive Picking
QC Depth Gate
CRP Step Base
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picked velocity errors
initial velocity

Figure 1