Automatic nonhyperbolic velocity analysis

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Summary

We present an automatic implementation of nonhyperbolic velocity analysis to invert for the moveout parameters: the moveout velocity and the effective anellipticity. These are required to perform all steps of time processing such as nonhyperbolic NMO corrections, compensation for geometrical spreading, dip-moveout, and time migration. The method is based on efficient parameterization and automatic event tracking to produce a zero-offset section and two attribute maps. The proposed approach avoids tedious manual picking which is impractical for dense parameter search required by nonhyperbolic velocity analysis. The methodology has been successfully applied to a long spread offshore dataset from the North Sea.

Method

Reflection moveouts are better described using high-order traveltime approximations accurate for long spreads and in anisotropic media (Alkhalifah and Tsvankin, 1995; Ursin and Stovas, 2006). For PP-waves, the fractional approximation provides the highest accuracy at different offset ranges (Alkhalifah and Tsvankin, 1995)

$$T(x)^2 = T(0)^2 + \frac{x^2}{V_{\mathrm{NMO}}^2} - \frac{2\bar{\eta}\,x^4}{V_{\mathrm{NMO}}^2\left[T(0)^2 V_{\mathrm{NMO}}^2 + (1+2\bar{\eta})x^2\right]} \qquad (1)$$

where x denotes the offset, V_{NMO} is the normal moveout velocity, and $\bar{\eta}$ is an effective anellipticity parameter. Nonhyperbolic velocity analysis is implemented by scanning for the optimal reflection parameters inside predefined corridors for the moveout velocity and the effective anellipticity. To search for the moveout parameters V_{NMO} and $\bar{\eta}$, one needs to implement this search in automatic way to avoid the manual interpretation of velocity spectra which is impractical for three-parameter search. Two parameterizations are commonly used to perform the parameter scan. The requirement for a given parameterization is to ensure a regular moveout and anellipticity sampling. We propose here a new sampling method that overcomes the shortcomings of the commonly used parameterization and a workflow to implement automatically the nonhyperbolic search to seismic data.

Parameterization

To account for the drawbacks of previous parameterizations (Alkhalifah 1997; Siliqi and Bousquié, 2000), we define alternatively two variables q_1 and q_2 to sample the moveout parameters according to the simple relations

$$q_1 = \frac{1}{V_{\mathrm{NMO}}^2} \quad \text{and} \quad q_2 = \frac{2\bar{\eta}}{V_{\mathrm{NMO}}^2} = 2\bar{\eta}\, q_1 \qquad (2)$$

Both variables are in units of slowness squared. The variable q_1 is responsible for the sampling of the moveout velocity and q_2 is governing the sampling of the effective anellipticity given a tentative moveout velocity. The processing parameters are deduced from the optimal $q_1 - q_2$ couple through simple relations too

$$V_{\mathrm{NMO}} = \frac{1}{\sqrt{q_1}} \quad \text{and} \quad \bar{\eta} = \frac{q_2}{2q_1} \qquad (3)$$

In this new parameterization, the traveltime approximation in equation 1 can be compactly written as

$$T(x)^2 = T(0)^2 + q_1 x^2\left[1 - \frac{q_2 x^2}{T(0)^2 + (q_1+q_2)x^2}\right] \qquad (4)$$

Compared to popular parameterizations, the proposed search domain $q_1 - q_2$ handles both the moveout and the anellipticity sampling properly. Figures 1a, b, and c show the sampling of the moveout velocity and anellipticity for a velocity parameter scanned for in the range [1500-2500 m/s] and an anellipticity parameter in the range [0-0.4]. The result for the $V_{\mathrm{NMO}} - V_{\mathrm{H}}$ parameterization (Alkhalifah, 1997) is shown in Figure 1a. It offers a good sampling of the anellipticity coefficient, but large moveouts corresponding to low velocities are undersampled (Figure 1d). The sampling for the $dT_n - \tau_0$ parameterization (Siliqi and Bousquié, 2000) is shown Figure 1b. This domain samples regularly the moveout range (Figure 1e), but the anellipticity parameter is badly handled. The results of the proposed $q_1 - q_2$ parameterization are shown in Figure 1c. The velocity sampling for this domain is quite similar to that allowed by the $dT_n - \tau_0$ domain. This almost regular moveout sampling (Figure 1f) treats the moveout velocities in an optimal way. Thus, low velocities are densely sampled due to their large curvatures, while high velocities which correspond to small curvatures are coarsely sampled. The anellipticity sampling is almost regular and looks similar to the one offered by the $V_{\mathrm{NMO}} - V_{\mathrm{H}}$ domain.

Bootstrapped differential semblance

We propose a new coherency estimator to discriminate the moveout parameters in a reasonable computing time comparable to that of summation methods. We define bootstrapping in the seismic context as a random reordering of seismic traces so that the traces initially arranged in increased offset order will be reorganized in an unpredictable manner using random number generation algorithms. Bootstrapping is applied here to the differential semblance (Brandsberg-Dahl *et al.*, 2003) to form what we define as bootstrapped differential semblance (called BDS for brevity). This allows for a better discrimination of the reflection parameters. For discrete seismic data in space and time, the BDS coefficient is defined as

$$BDS = 1 - \frac{N \sum_{i=2}^{N} \sum_{t=t_0-\lambda/2}^{t_0+\lambda/2} \left[d\left(t,\overline{x}_i\right) - d\left(t,\overline{x}_{i\text{-}1}\right) \right]^2}{2\left(N-1\right) \sum_{i=1}^{N} \sum_{t=t_0-\lambda/2}^{t_0+\lambda/2} d\left(t,\overline{x}_i\right)^2} \quad (4)$$

where $\overline{x}_i \{i=1, N\}$ is the bootstrapped series of the offset array $x_i \{i=1, N\}$ obtained by random sorting of the traces inside the window. N is the total number of traces inside the window after applying the aperture mute, and λ is the width of the time window. Figure 2 illustrates the notion of bootstrapping with a time window containing an event with a good guess of the moveout parameters (Figure 2a) and the window after bootstrapping is applied (Figure2b) where wavelet time-shifts are more apparent.

Event detection and centering

The BDS curve is computed for time slices at increasing zero-offset times. The resulting curve of maximum semblance at each CMP position is used to identify reflections which naturally correspond to high BDS values. We used a derivative-based strategy to detect the peaks corresponding to events on the BDS curve. A threshold is specified to reject low amplitude peaks and a smoothness factor is used to ignore high-frequency spikes related to noise. This detection process shows efficiency on both synthetic data corrupted with noise and on marine data as well. The picked moveout parameters are updated to reduce inaccuracies on $T(0)$ which propagate on both V_{NMO} and $\overline{\eta}$. This is achieved via an iterative approach aiming at removing the time error while picking an event. This is performed by computing a pilot trace of the window containing the event and evaluating the time shift of its maximum peak with respect to the window center time to update the zero-offset time value. Later, a time slice is constructed to find the optimal moveout parameters $V_{\text{NMO}}, \overline{\eta}$ at the newly estimated $T(0)$-value using a two-dimensional parameter search via the proposed parameterization. A new time window is built with the updated parameters $\left(T(0), V_{\text{NMO}}, \overline{\eta}\right)$ and the procedure is iterated until the maximum peak of the pilot trace coincides with the window center or when a given number of iterations is achieved.

North Sea data example

The described algorithm was applied to a long spread marine dataset from the North Sea. Both hyperbolic and nonhyperbolic velocity analyses were applied to the data. We used an aperture limit (offset-to-depth ratio) equal to 0.9 to track the moveout velocity for the hyperbolic search, and an aperture value equal to 1.9 to estimate the moveout velocity and the effective anellipticity for the nonhyperbolic search based on equation 1. We used a time-varying corridor to scan for the velocity parameters using the picked parameters from the previously processed CMP gather. The anellipticity is scanned in the time-invariant range [0-0.4]. The velocity law obtained at a given CMP location is used to apply the truncation at the next CMP location to enhance accuracy on the estimated parameters. To accelerate computations, the nonhyperbolic search is implemented in a two-pass routine. In the first pass, a hyperbolic search with an aperture value equal to 0.9 is applied to identify the events in the gathers. Later, the nonhyperbolic search is limited only on the identified events on a larger aperture (1.9) using dense parameter sampling in the proposed parameterization (equations 2 and 3). Figure 3 shows a given CMP gather before (3a) and after aperture truncation (3b) using the value 1.9. The computed BDS curve and its derivative are shown in Figure 3c and 3d respectively. Most of the events in the gather can be identified on the BDS curve. The derivative is used to pick the maxima which correspond to zero-crossings. The result of applying NMO corrections from hyperbolic and nonhyperbolic searches are illustrated on Figures 3e and 3f respectively. Note in particular the good flattening of the strong event at far offsets from nonhyperbolic NMO corrections, while noticeable residual moveouts are observed for the hyperbolic NMO corrections. Figure 4a shows the identified picks from running the algorithm on the whole seismic line. Spatial correlation between the picks can be seen and contains the fingerprints of the main reflectors in the stacked sections from the hyperbolic (Figure 4d) and the nonhyperbolic (4e) searches. The BDS map (Figure 4b) contains also the features of the key reflectors. The BDS derivative map shows a similar behavior except that event positions are located at zero-crossings with a time shift that is equal to half the time window length (Figure 4c). The stack resulted from the nonhyperbolic search shows better event continuity and energy than the hyperbolic search. This is due to the fact that nonhyperbolic moveout corrections put in phase more traces in the gather leading to a better stack quality. To access the vertical velocity required for depth imaging, additional information in the form of converted PS data is required.

Conclusions

We proposed a workflow for the automatic implementation of nonhyperbolic velocity analysis which combines efficient sampling and automatic event detection. The bootstrapped differential semblance (BDS) estimator allows for efficient event detection and more accurate parameter tracking. The bootstrapping detects slight wavelets shifts and allows the discrimination between the parameters giving a good fit to the reflection moveout. The proposed parameterization allows for an optimal moveout sampling leading a better estimation of the moveout parameters. The computed attributes, the BDS map and its derivative, contain the fingerprints of the key reflectors in the area, and can be used in horizon picking for structural interpretation, for instance. The approach showed efficiency on a real long-spread marine dataset from the

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North Sea. The obtained velocity and anellipticity fields can be used to invert for apparent interval parameters through generalized Dix equations. Both heterogeneous isotropic layers and homogeneous VTI layers will give the same effective moveout parameters (Ursin and Stovas, 2005; Stovas and Ursin, 2007). When the interval anellipticity is zero, the layer is VTI with elliptic anisotropy or isotropic. In all cases, PS reflection data is needed to estimate all layer parameters.

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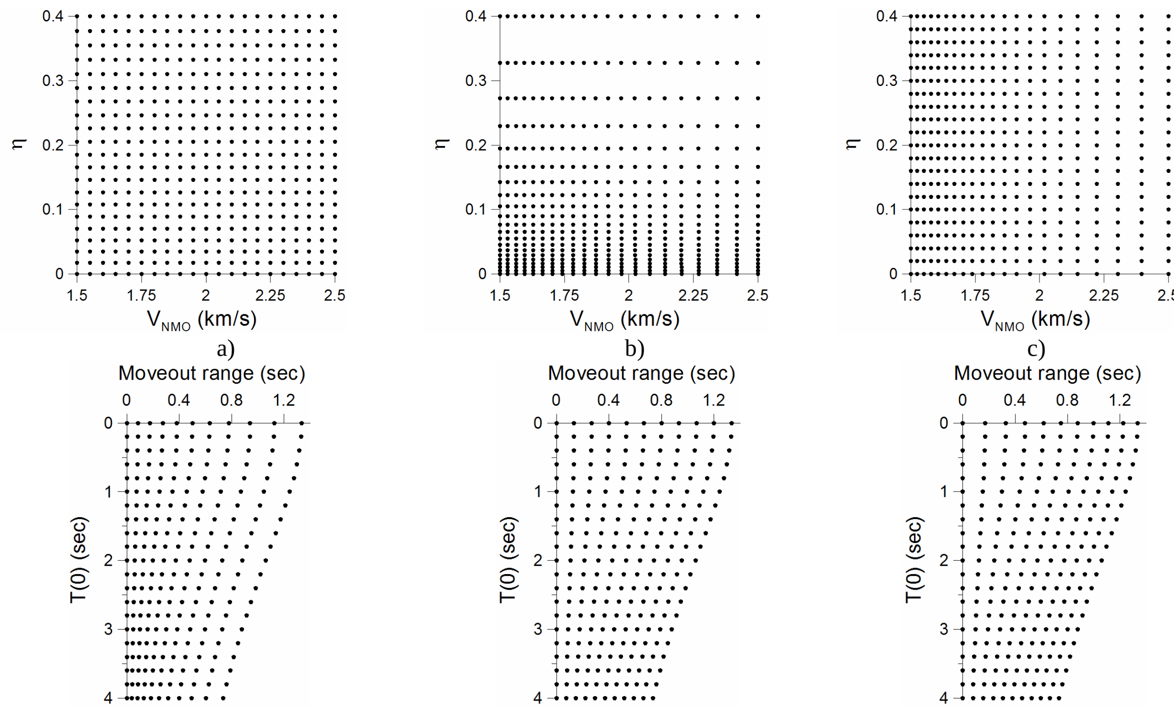

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Figure 1. Sampling of the moveout parameters for the different parameterizations.

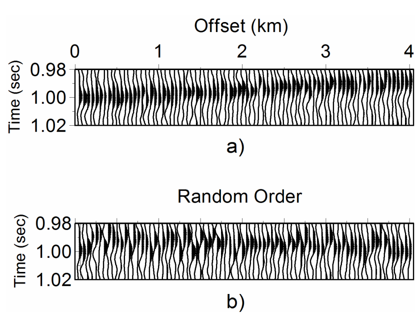

Figure 2. Result of application of bootstrapping on a time gate.

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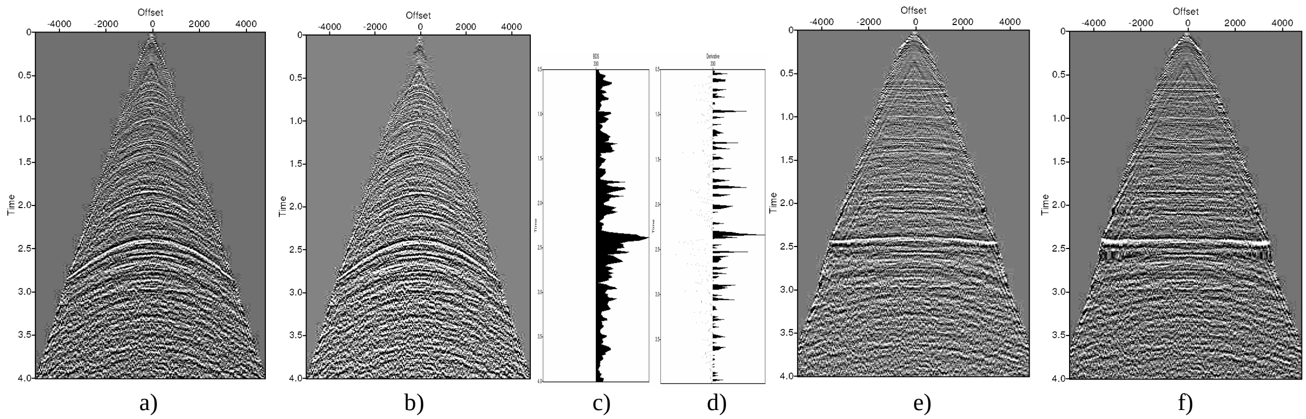

Figure 3. Velocity analysis on a CMP gather from North Sea.

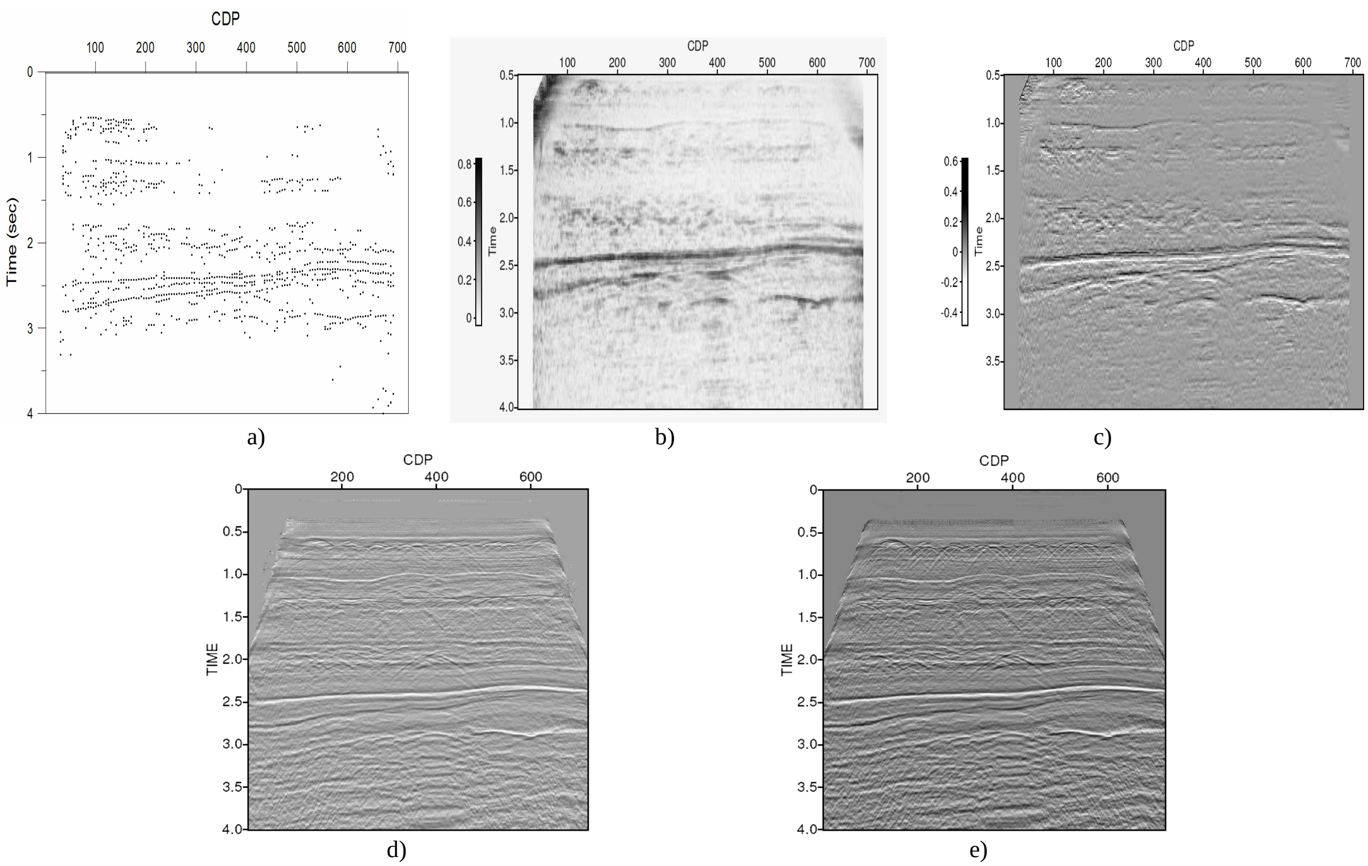

Figure 4. Attribute maps and stacked sections from hyperbolic and nonhyperbolic velocity analyses.

EDITED REFERENCES

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