Geological Velocity and Anisotropy Fields from Seismic Data

David Le Meur, Todd Mojesky *CGG Canada Services Ltd.*
Risto Siliqi *CGG, Paris France*

2004 CSEG National Convention

Summary

High-density parameters to improve the focusing process are now a standard for time processing. Typically, two parameters are required to flatten gathers: an effective velocity *(V)* and anellipticity (η). Picking *V* and η using the classical two-pass techniques based on a residual moveout approach cannot be a long-term solution. The resultant stacking fields are only somewhat tied to the inherent geology. We propose in this paper an original process to pick and filter simultaneously *V* and η: firstly two "orthogonal" parameters are obtained using an original parameterization of the non-hyperbolic moveout, and secondly thanks to the parameter decomposition geostatistical techniques are used to fill and filter these two fields. Indeed with these decoupled parameters the effects of the anisotropy are effectively separated from the velocity estimation and the resulting fields make more geological sense (RMS velocity – effective anellipticity). Furthermore, the gathers are almost perfectly flat which makes AVO analysis possible at any offset.

Introduction

Dense automatic velocity picking of V and η is now a standard to improve the focusing process. This work has been achieved with the use of the shifted hyperbola concept proposed by Castle (1984) and extended to anellipticity by Siliqi and Bousquie (2000). Two different approaches are historically developed: The first approach is based on the parabolic approximation of the residual moveout which allow us to compute the velocity field in a first pass (Adler and Brandwood, 1999), and an η field in a second pass (Le Meur et al. 2001). The second approach uses the full moveout equation to compute the velocity function (De Bazelaire and Viallix, 1994) and is extended here to the non- hyperbolic moveout equation to compute in one pass the (V, η) pairs.

In the first, residual moveout case, two passes are cascaded to estimate two dense fields of effective parameters *V* and η. The first pass uses the near-offset part of the gather to fix an effective velocity and the second pass uses the far-offset part to compute the η function. However in practice, this technique has some weaknesses: iterative dense *V* and η picking are required, but more importantly, the estimation of *V* and η are very sensitive to the mute function separating near to far offsets. In this case, *V* is really a stacking velocity, not an RMS velocity, and η is rather far from the effective anellipticity defined by Alkhalifah (1997). In conclusion, although two-pass parameter picking can provide excellent stacking functions, their "geological" meaning would be questionable.

In the second, full moveout case, Siliqi (2001) proposed a practical way to perform (V, η) scans for sparse manual picking using the anelliptic shifted hyperbolic moveout. Thanks to a new parameterization, the moveout corrections can be transformed to static shifts. The substitution of a dynamic moveout correction by a static one is fundamental for automatic dense picking because it reduces the time taken for the analyses and improves the quality of the spectra by avoiding the stretch at far offsets. This new double-scan is called the *"simultaneous picking of V and* η*"*.

However, mis-picks interference and various artifacts can still contaminate the two-parameter fields provided by this new bispectral picking. Geostatistical techniques are usually employed to both fill and filter dense fields (Le Meur and Herrmann, 2002). The daily practice of two-parameter processing shows how critical it is to properly fill and filter *V* and η to preserved the moveout quality at far offsets. Based on the uncorrelated statistical properties, the two new time parameters are separately filled and filtered. Once this work is done, the effects of anisotropy are effectively separated from the velocity estimation, and the recombined *V*, η fields make more geological sense and optimize the stack. This new methodology of filling and filtering is called the *"simultaneous filtering of V and* η*".*

Simultaneous picking of V and η

The effects of *V* and η on the moveout are not uniformly distributed along the offsets. If the velocity affects all the offsets, the effect of the η is concentrated on far offsets only. Let us describe the shifted hyperbola moveout on the local coordinates, where the reflection curve appears to be a hyperbola. Two features can constrain the hyperbolic shape of the reflection curve for these coordinates: the residual moveout at the largest offset *(dtn)* and the zero-offset traveltime (τ_0) (figure 1). If *dtn* is independent of the fact that the moveout is hyperbolic or not, τ_0 differs from t_0 only when the reflection curve has a non-hyperbolic shape.

The bispectral analysis proposed by Siliqi (2001), which represents a double-scan of *V* and V_{an} (proportional to η) is shown in figure 2b. This picture illustrates the correlation between the two parameters: all plausible *V*-η solutions are located through the skewed red pattern. On the other hand, the *dtn*-τ_0 panel demonstrates the non-correlation of these new internal moveout parameters (figure 2a). The best (dtn, τ_0) pair seems to be much better constrained. The *dtn* resolution is striking and the variation of τ_0 is restricted to a small area around the maximum of the semblance. In spite of the stretched pattern the η resolution remains acceptable. It is enough to compare the gap between the zero and the estimated η on both panels (figure 2a).

Now, compare the statistical behavior of several independent local pickings done on (V, V_{an}) and (dtn, τ_0) scan respectively. After having centered and normalized all the parameters, the computation of cross-plots show the predictability from one parameter to the other. In the case of the (V, V_{an}) double scan the two linear regression functions are close, inducing a correlation between the two parameters. On the other hand, with the (*dtn*, τ_0) double scan the two regression functions are almost perpendicular, showing that the two attributes are statistically uncorrelated and that any action on one does not affect the other. Thanks to this orthogonality, *dtn* and τ_0 are good candidates for the filling and filtering processing before to be back-projected in *V* and η via simple algebra.

Simultaneous geostatistical filling and filtering of V and η

We propose an appropriate process to perform a simultaneous filling and filtering of *V* and η based on a separate processing of *dtn* and τ_0.

The first step is a simultaneous filling of the *V* and η empty areas, where the automatic picking failed or various QCs based on lateral coherencies and/or Dix-inversion abilities removed outlier values (picture 4a). Using their uncorrelated properties, a separated filling of *dtn* and τ_0 is firstly performed with a 3D ordinary kriging following by a back-projection to obtain the filled *V* and η. The time slice of the *V* field shows the benefits of this approach (picture 4b). Thanks to an adequate a-priori variogram-modeling the gaps are correctly filled while respecting the geological content of the original picks.

The goal of the filtering step is the removal of the non-geological features, which corrupt the *dtn* and τ_0 fields (picture 4b). More advanced techniques, such as 3D factorial kriging, seem to be appropriate for this task. Separate modeling of the *dtn* and τ_0 3D experimental variograms allows filtering of outlier patterns and directional artifacts without harming the small-scale variations of these fields. The optimal filtering of the uncorrelated parameters *dtn* and τ_0 corresponds to the requested simultaneous filtering of *V* and η. The time slice of *V* field shows the benefits of this approach: various artifacts are removed and high-frequency geological content is preserved (figures 4c and 4d).

After performing this appropriate methodology to obtain the final *V* and η field, a non-hyperbolic moveout correction is applied on long streamer data (figure 5). Note that the use of such dense filtered *V* and η fields succeeds in flattening events for the full far-offset (7 km) without any use of mute functions, which optimizes the stack and makes AVO analysis possible. An overlay of the filtered velocity and η field on the stack section is shown on figures 7a and 7b. Two typical behaviors can be observed: the anellipticity follows the structures, whereas the velocity contour lines are parallel to the water bottom, something generally expected for VRMS velocities. The observation demonstrates the decoupling of the derived velocity from the anellipticity (ray bending and/or anisotropy).

Conclusions

The focusing of the large offset data requires the handling of accurate parameters *V* and η. We propose in this paper an original automatic dense bispectral routine able to pick simultaneously in an uncorrelated way both the RMS velocity and the effective η. The simultaneous geostatistical interpolation and filtering of these fields achieve the objective: performing the most accurate moveout through the use of lithologically meaningful *V* and η parameters.

References

Adler, F., and Brandwood, S., 1999, robust estimation of dense 3D stacking velocities from automated picking: 69th Ann. Internat. Mtg., SEG Expanded Abstracts.

Alkhalifah, T., 1997, Velocity analysis using nonhyperbolic moveout in transversely isotropic media: Geophysics, 62, 1839-1854.
Castle, R. J., 1994, A theory of normal moveout: Geophysics, 59, 983-999

de Bazelaire, E. and Viallix, J. R., 1994, Normal moveout in focus: Geophys. Prosp., Eur. Assn. Geosci. Eng., 42, 477-499.

Le Meur, D., Siliqi, R. and Adler, F., 2001. Reliable Parameter Fields for Non-Hyperbolic Normal Moveout, 63rd EAGE Annual Meeting.

Le Meur, D. and Herrmann, F., 2002. Pre-conditioning of the densely sampled stacking velocity field. 64th EAGE Annual Meeting.

Siliqi, R., and Bousquié, N., 2000, Anelliptic time processing based on a shifted hyperbola approach: 70th Ann. Internat. Mtg., SEG Expanded Abstracts.

Siliqi, R, 2001, Technological leap in time processing focuses the data throughout anisotropic media: First Break, 19, No. 11.

Siliqi, R. and Bousquié, N., 2000, Anelliptic time processing based on a shifted hyperbola approach, 70th Ann. Internat. Mtg: Soc. of Expl. Geophys., 2245-2248.

Siliqi, R., 2001, Technological leap in time processing focuses the data throughout anisotropic media: First Break, 19, no. 11, 612-618

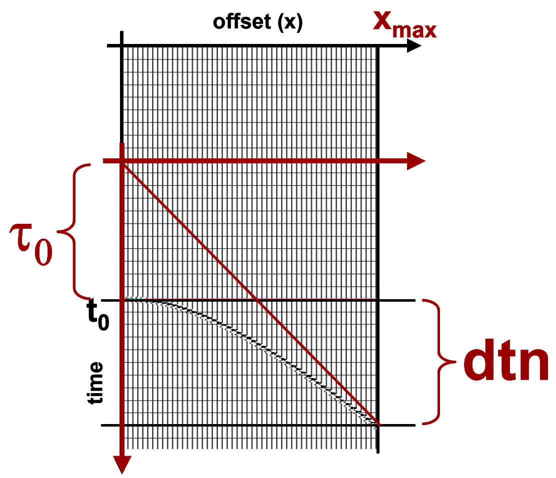


Figure 1 : New parameterization of the shifted hyperbola moveout.

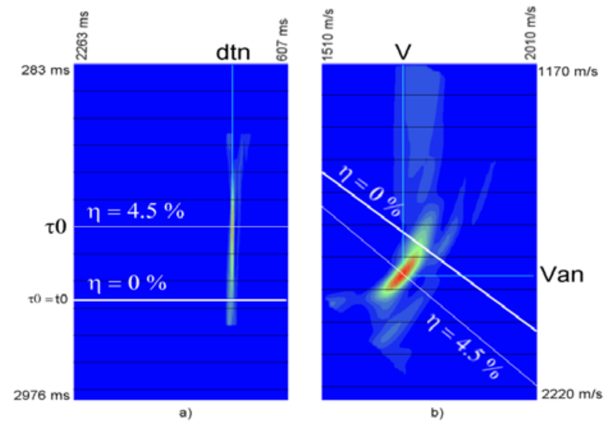
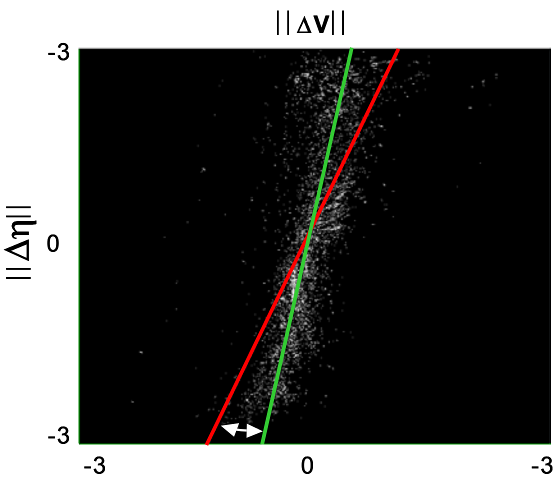


Figure 2: Bispectral panels allowing the picking of V and η. The scanned parameters cover the same range of V and η.

a) new approach $(dtn,\ \tau_0)$ - time axes.

b) current approach $(V,\ V_{an})$ - velocity axes.



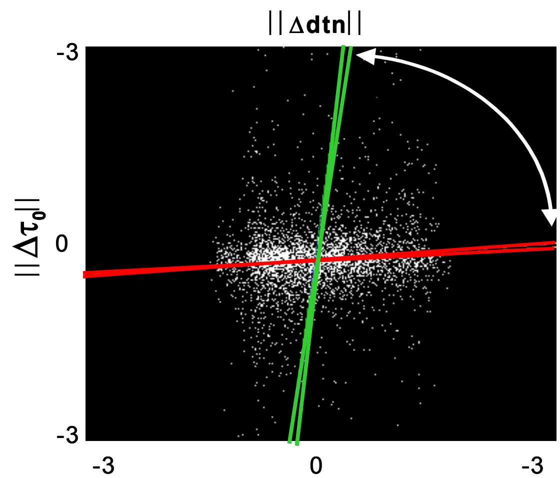


Fig3: Statistical properties of centered and normalized bispectral parameters. The two linear regression functions are shown in color.

Fig3a: Current approach (V,η). Close axes (correlation)

Fig3b: New approach (den, τ_0). Quasi-perpendicular axes (no correlation)

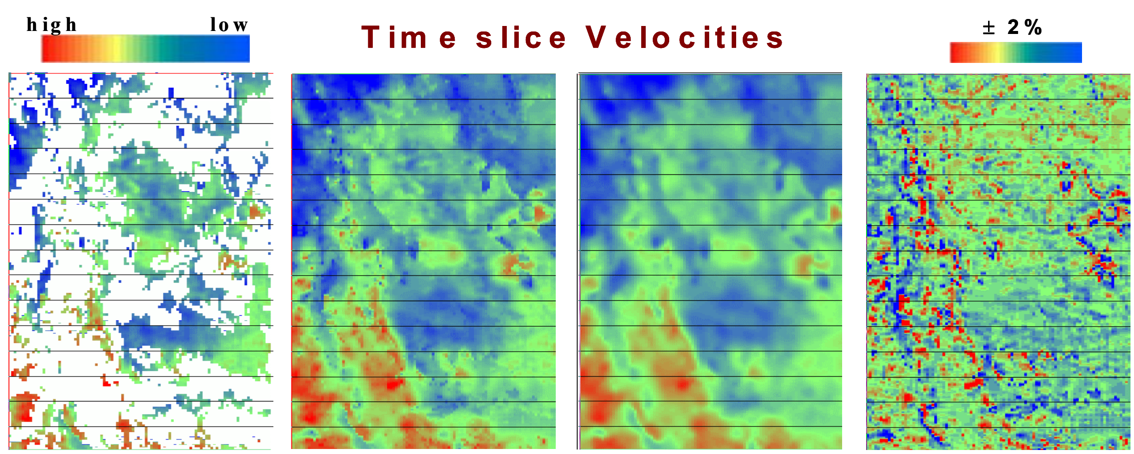


Fig 4a: raw picks, Blank values are empty space

Fig4b: filled field. The gap is correctly filled and respect the geological content

Fig4c: filtered field. Localized and organized outliers are removed without harming the small scale velocity variation.

Fig4d: rejected part containing the localized and organized noise and non-geological feature.

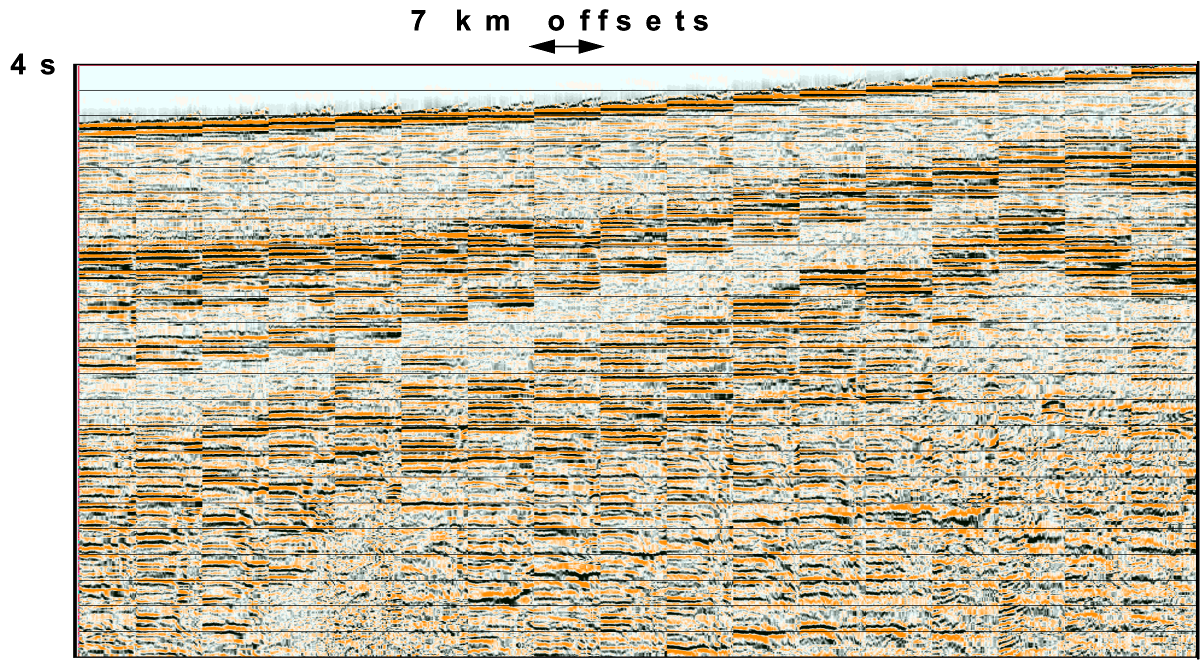


Figure 5: Corrected deep offshore bin gathers V and η dense fields obtained by the simultaneous picking and filtering process.

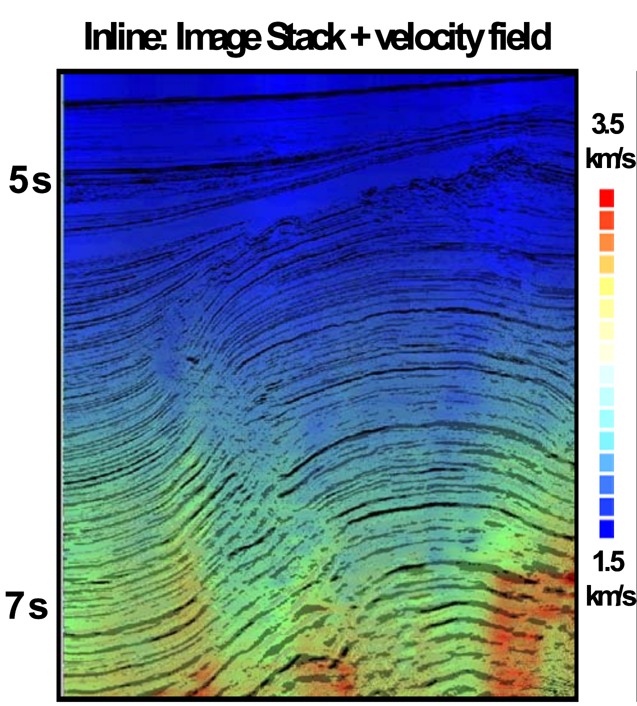


Fig6a: Velocity field is super-imposed on the stack section The velocity field cuts across the layering and roughly follows the water bottom. .

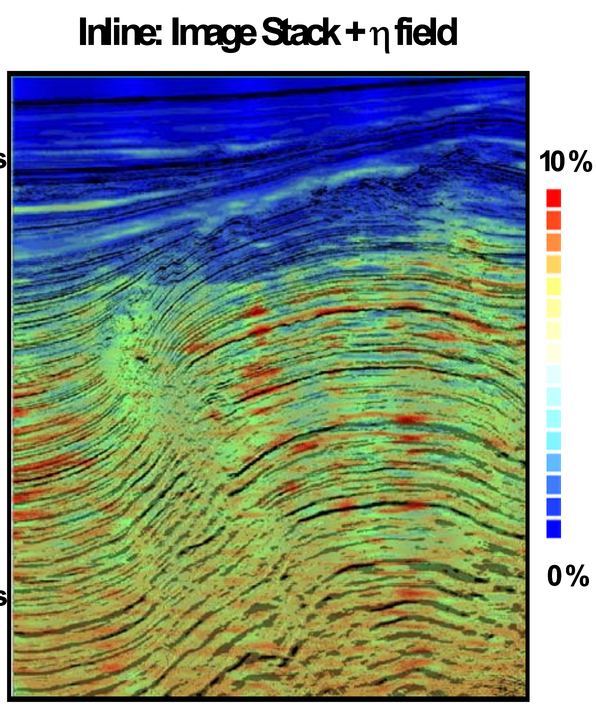


Fig6b: η field is super-imposed on the stack section. The eta follows the geological structure.