P186 Time processing of field data with a non-hyperbolic model-based traveltime equation

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Introduction

Non-hyperbolic approximations of time-offset curves usually have at least three terms. This complicates velocity analysis and time processing of seismic data.

Causse and Hokstad (2000) and Causse (2004) have shown how to construct traveltime series that require fewer terms to reach a certain level of accuracy. Their idea is to use available information on velocity-depth trends and on acquisition geometry (offset range) to constrain the construction of the traveltime approximations: the obtained series is optimal for accurately describing synthetic traveltime curves modeled in velocity models that respect the expected velocity-depth trend.

Here, we show that an equation of this type with only two terms (but still non-hyperbolic) is sufficient for time processing (velocity analysis, moveout correction, stacking and prestack time migration) of seismic data with offsets as large as 5.8 km.

Method

The approximation we use is

$$t^2(x) = c_1 f_1(x) + c_2 f_2(x)\,. \qquad (1)$$

The basis functions $f_1(x)$ and $f_2(x)$ are easily calculated by singular value decomposition of the modeled traveltime curves (Causse, 2004). To construct these modeled traveltime curves we must know the velocity-depth trend, e.g. via a sparse intitial velocity analysis.

Equation (1) can be used for moveout correction. The values of coefficients c_1 and c_2 can be chosen to optimally flatten primary reflections, as for usual velocity analysis. A linear relation can be established between c_1 and c_2, and the two-way vertical time and RMS velocity (Causse, 2004). Therefore, velocity analysis with the equation (1) can still be done on velocity spectra represented in the usual (t_0, V_{RMS}) plane (Causse and Arntsen, 2003). As soon as the velocity analysis is performed, the traveltime of any reflected events is given by equation (1), and tables of one-way traveltimes for prestack migration can also easily be constructed. Hence, any time processing method based on equation (1) (called Optaprox) can be used.

Results

We apply our model-based non-hyperbolic traveltime approximation to a 42 km long 2D seismic line, where offsets up to 5.8 km are available. An initial hyperbolic velocity analysis was done, using only small offsets in the data (25% stretch mute) to provide information on the velocity-depth variations. This information was used to construct the basis functions. Hyperbolic velocity analysis and Optaprox velocity analysis were then carried out for every 50th CMP (i.e. with intervals of 614 m), keeping larger offsets (50% stretch mute). Figures 1 and 2 show velocity spectra obtained with the conventional approach and with Optaprox. Optaprox provides sharper semblance peaks for the primary reflections. Stacking velocities estimated by hyperbolic velocity analysis are higher than with Optaprox. The theory indicates that stacking velocities are higher than the correct RMS velocities (Al-Chalabi, 1974), and that the velocities estimated with Optaprox are closer to the RMS values (Causse, 2004, Causse and Arntsen, 2003). These results seem to confirm this, and suggest that Optaprox gives a more correct estimation of velocities.

Figure 3 shows moveout corrected gathers. Hyperbolic correction cannot flatten all primary events on the large range of offsets used here: we observe residual moveout with the usual “hockey stick” shape. A much better moveout correction is obtained with Optaprox. This is confirmed by the CIGs (Figure 4), and supports the idea that the kinematics of wave propagation is better represented by Optaprox. In area D, the CIGs and the moveout corrected gathers are quite different, and the Optaprox CIGs are not so flat. In this area, the velocities would probably need to be iteratively updated to obtain a better flattening of the CIGs.

Figure 4 shows stacked sections obtained after prestack time migration in three different offset ranges. The Optaprox stacked sections are clearer at large offsets, and there is a better consistency between the imaged reflectors and structures at small and larger offsets with Optaprox. Event B, which is not a primary, is visible on the hyperbolic middle-offset stack, but strongly attenuated on the Optaprox middle-offset stack.

Conclusion

We have used a non-hyperbolic time equation, obtained by singular value decomposition of modeled traveltime curves, for time processing of seismic data with large offsets (up to 5.8 km): Velocity analysis, moveout correction, stacking and prestack time migration based on this approximation have been applied and compared to hyperbolic time processing.

Even if the traveltime equation used had only two terms, like a hyperbola, it has proven its ability to perform an efficient non-hyperbolic processing, with clear improvements at large offsets compared to hyperbolic processing: the primary reflections are more properly flattened and the stacked sections are clearer. The velocities estimated during Optaprox velocity analysis are lower than the hyperbolic stacking velocities, and certainly closer to the correct RMS velocities. Here a single “iteration” was done. The velocities could certainly be improved further by iterative updates providing flatter CIGs and enhanced stacked sections.

Compared to usual approaches to non-hyperbolic processing, our method avoids the extra work and computations required by three-term equations. Only small extra computations related to the construction of the basis functions f_1 and f_2 are required: traveltime modeling and SVD. Non hyperbolic traveltimes are often taken for an indication of anisotropy, and effective anisotropic parameters are introduced to flatten the gathers. Our Optaprox approximation assumed isotropic models (although it could take anisotropy into account), and the non-hyperbolicity of traveltimes results here from ray bending only. Since the gathers are properly flattened, ray bending is probably the main cause of non-hyperbolicity for this data.

Acknowledgments

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References

Al-Chalabi, M., 1974, An analysis of stacking, RMS, average and interval velocities over a horizontally layered ground, Geophysical Prospecting 22, 458-475.

Causse, E., 2004, Approximations of reflection traveltimes with high accuracy at all offsets, Journal of Geophysics and Engineering, 1, pp 28-45.

Causse, E., and Arntsen, B., 2003, Velocity analysis with a two-term non-hyperbolic traveltime approximation, 65th EAGE conference, P-001.

Causse, E., and Hokstad, K., 2000, Seismisk prosessering med generelle ikke-hyperbolske gangtidsapproksimasjoner, Norwegian Patent Application, nr. 20003643.

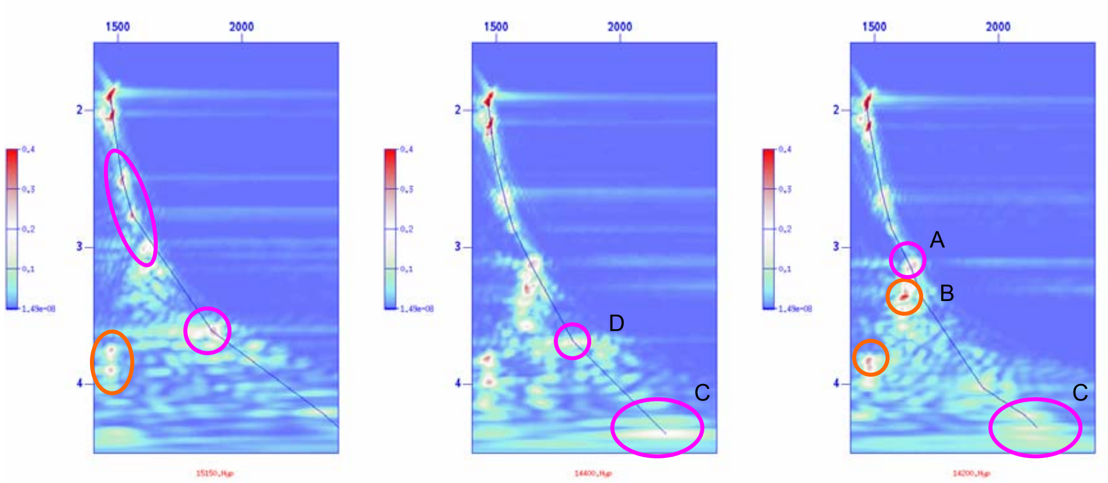

Figure 1: Hyperbolic velocity analysis, at 18, 27.3 and 29.7 km along the seismic line, from left to right. Pink ellipses show some primary reflections and orange ellipses other types of reflections (e.g. multiples). The thin blue line shows the trend picked during hyperbolic velocity analysis.

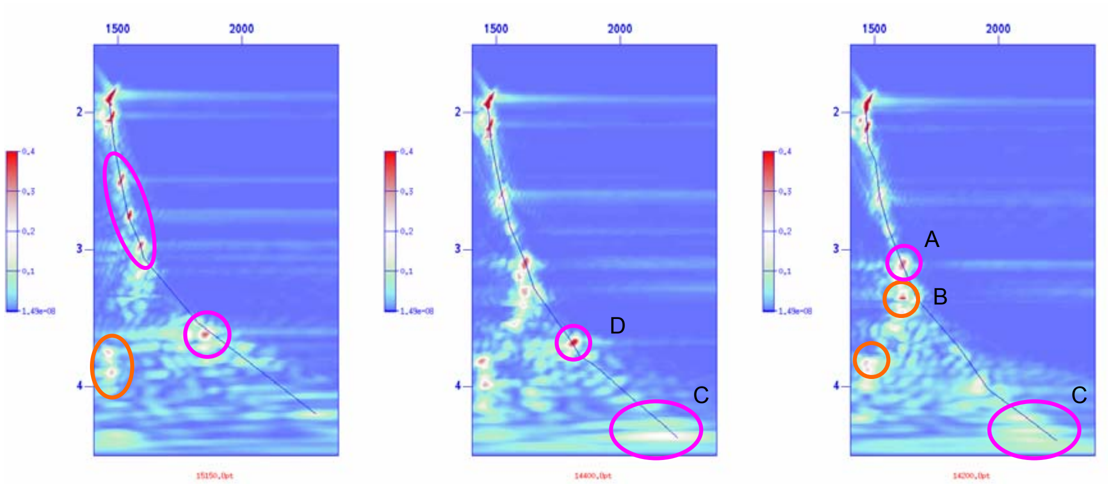

Figure 2: Optaprox velocity analysis, at 18, 27.3 and 29.7 km along the seismic line, from left to right. The ellipses are at exactly the same location as in Figure 1 for easier comparison. The thin blue line shows the trend picked during Optaprox velocity analysis.

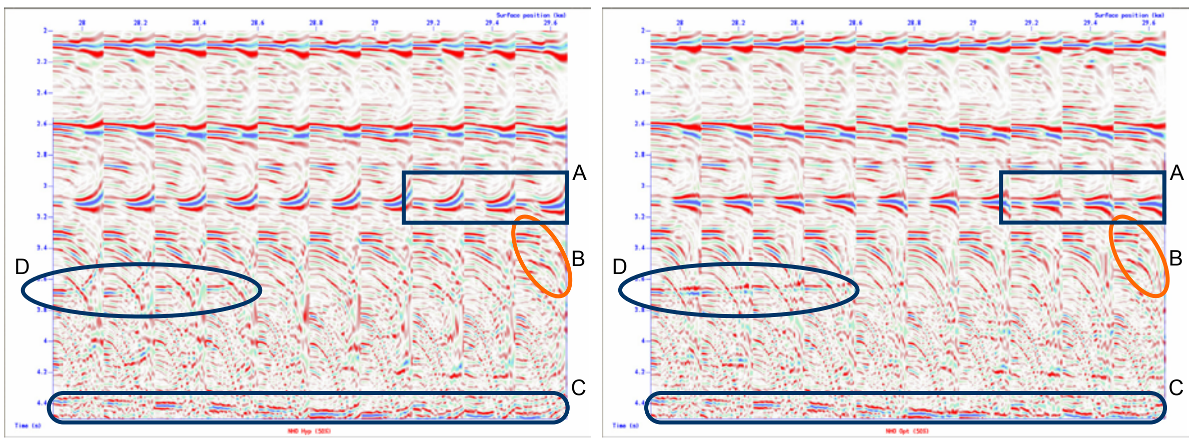

Figure 3: Selected CMP gathers, between 28 km and 30 km along the line, after hyperbolic moveout correction (left) and Optaprox moveout correction (right), using the trends picked on velocity spectra such as the ones in Figures 1 and 2. The letters refer to events identified on the velocity spectra. Event B is not a primary reflection.

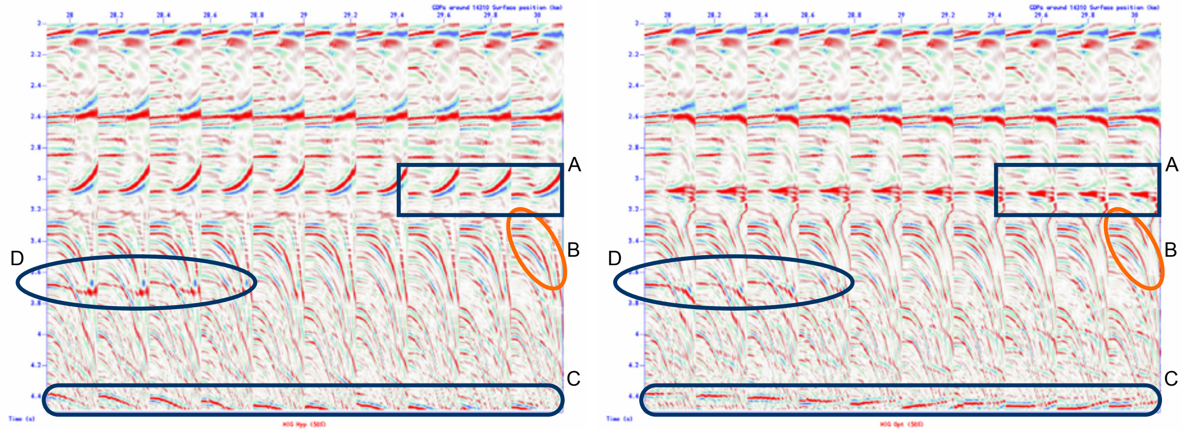

Figure 4: Common Image Gathers (CIGs) obtained after time migration with hyperbolic traveltimes (left) and Optaprox traveltimes (right), shown in the same range of offsets as the moveout corrected gathers in Figure3.

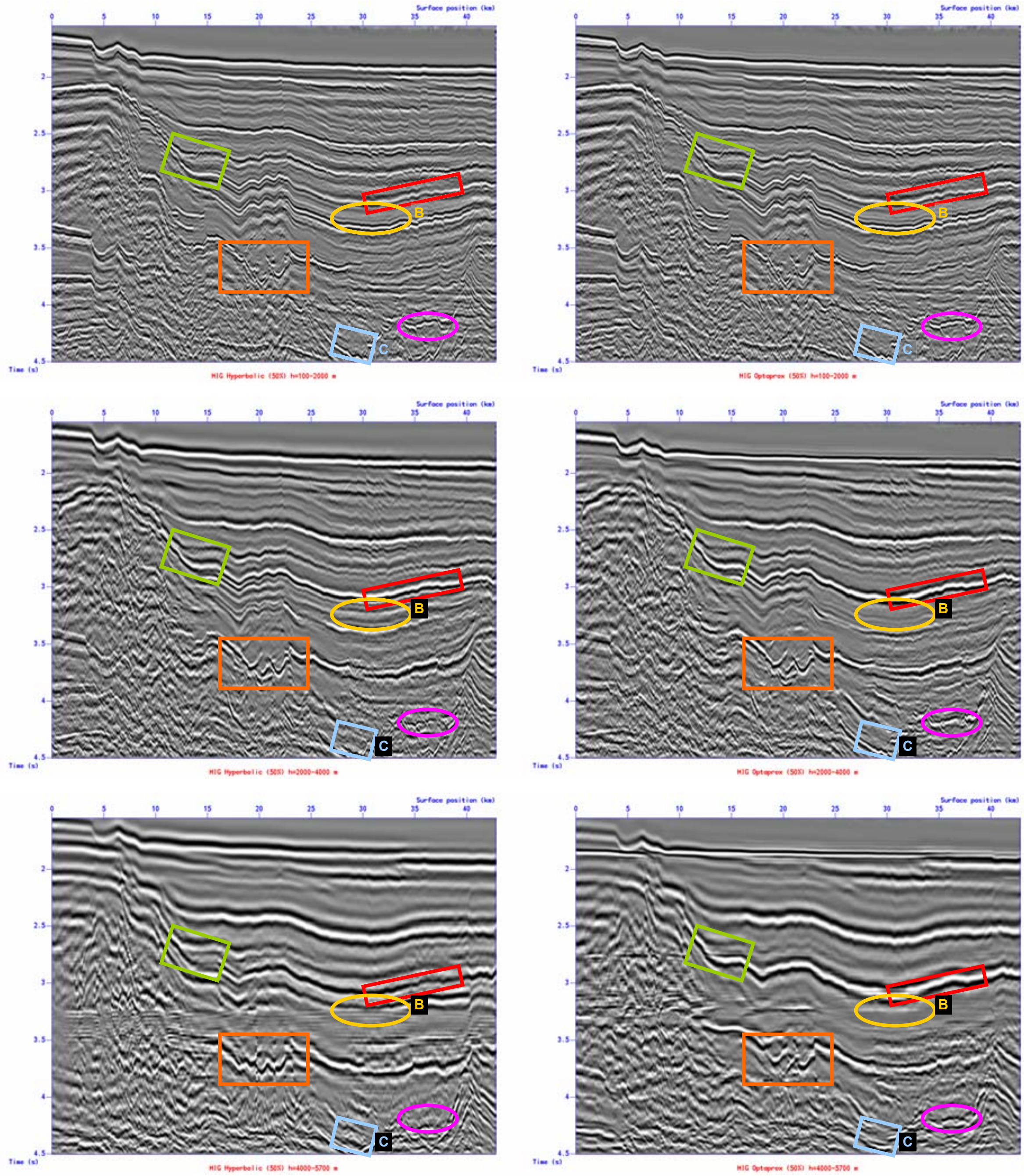

Figure 5: Stacked sections obtained after hyperbolic (left) and Optaprox migration (right), for offset ranges 0.1 to 2 km (upper sections), 2 to 4 km (middle sections) and 4 to 5.8 km (lower sections).