Interferometric Approach to Complete Refraction Statics Solution

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Summary

Variations in the thickness and low velocity in the weathered layer affect dramatically the quality of the imaging of the deeper reflectors of land seismic data. Therefore the goal is to obtain an accurate near surface model from refraction data and to replace variable low velocity with the velocity below weathering to improve resolution of the seismic data.

A data driven statistical interferometric approach is used to eliminate one of the most time consuming steps, namely first break picking from the land seismic data processing sequence and to minimize the possibility of human error. The reliability of the proposed static solution is achieved by utilizing the first arrival signal instead of the scalar first break pick times.

Introduction

The variety of the various refraction solutions, such as reciprocal methods, tomography and so on, commonly used in land seismic data processing to derive a near surface model, utilize first break picks to obtain the weathering model (Cox, 1999). The quality of the solution relies substantially not only on the method itself, but on the quality of the refracted first arrivals and hence the ease of first break picking.

Meanwhile new methods of refraction imaging which do not require first break picking, such as the refraction convolution section and refraction velocity analysis, have been developed (Palmer, 2001, 2009; de Franco, 2005, 2011).

Utilizing these new methods we will show how to create an initial multi-layered shallow model. A new proprietary technique is then proposed to update and correct this model and compute refraction statics corrections.

Theory and Method

The first critical assumption for this method is that the seismic survey is acquired along straight lines. The second assumption is that shot positions coincide with at least some receiver positions. We will discuss later how we can compensate for the possible errors, due to the fact that real 2D and 3D geometry does not completely satisfy these assumptions.

To build the initial near surface model we generate a 2-dimensional common receiver time image of several shallow seismic refractors and a time image of the spatial variations of seismic refraction velocity for the same refractors (Palmer, 2001, 2009; de Franco, 2005, 2011).

First, we generate the refraction convolution stack to obtain delay times at each receiver position (Figure 1), by convolving trace S1-R1 with S2-R1 and cross-correlating the result with the trace S1-S2, assuming that there is a receiver at the position of the shot S2.

Convolution of the time series is equivalent to the addition of the signal times and cross-correlation is equivalent to subtraction. Hence, the resulting trace will have an amplitude peak corresponding to the delay time at the receiver R1, where delay time t_d is given by:

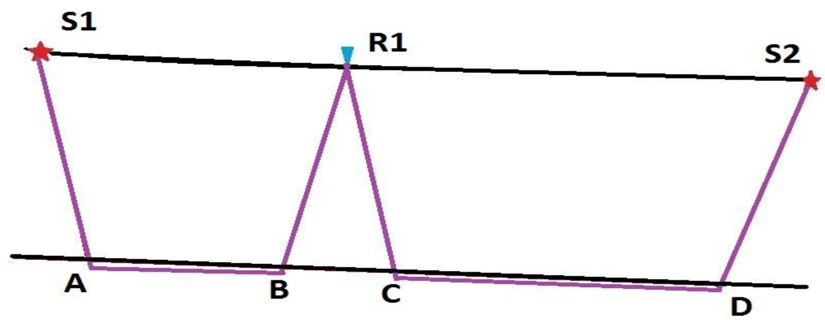
$$t_d = t_{B-R1} + t_{C-R1} - t_{C-B}$$

Next, the resulting traces are stacked over all available shot combinations which fire into the receiver R1 to produce one trace of the refraction convolution stack (RCS):

$$T = \sum (S1\ A\ B\ R1) * (S2\ D\ C\ R1) \otimes (S1\ A\ D\ S2)$$

Note, that this stacking procedure will increase the signal to noise ratio, making it much easier to pick delay times. At the same time, the low amplitude signal and high noise will indicate areas with possible geometry problems or low quality first arrivals, providing us with an excellent QC tool.

Figure 1: Generation of Refraction Convolution Stack.



Next, the interferometric approach is used to obtain the shallow refraction velocity (Figure 2). Traces from the same shot and for a fixed receiver distance (R1-R2) are cross-correlated. The resulting traces are stacked over all available shots for each receiver pair – first shots on one side of the receiver pair are stacked (i.e. all shots like S1), then shots on the other side (i.e. shots like S2).

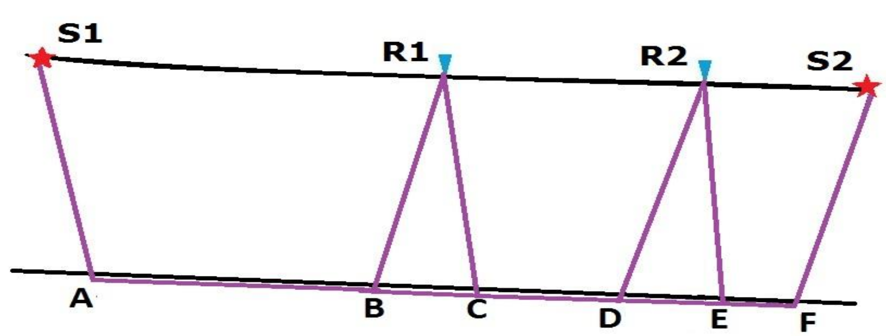
To compensate for possible layer thickness changes we then convolve the two summed results (from opposite sides) to produce one trace of the refraction velocity stack (RVS):

$$T = \sum ((S1\ A\ B\ R1) \otimes (S1\ A\ D\ R2)) * \sum (S2\ F\ E\ R2) \otimes (S2\ F\ C\ R1))$$

These calculations effectively remove the paths from the shot to the closest receiver. The resulting trace will have an amplitude peak corresponding to the time t_v equal to the double defined receiver distance, divided by the refraction velocity:

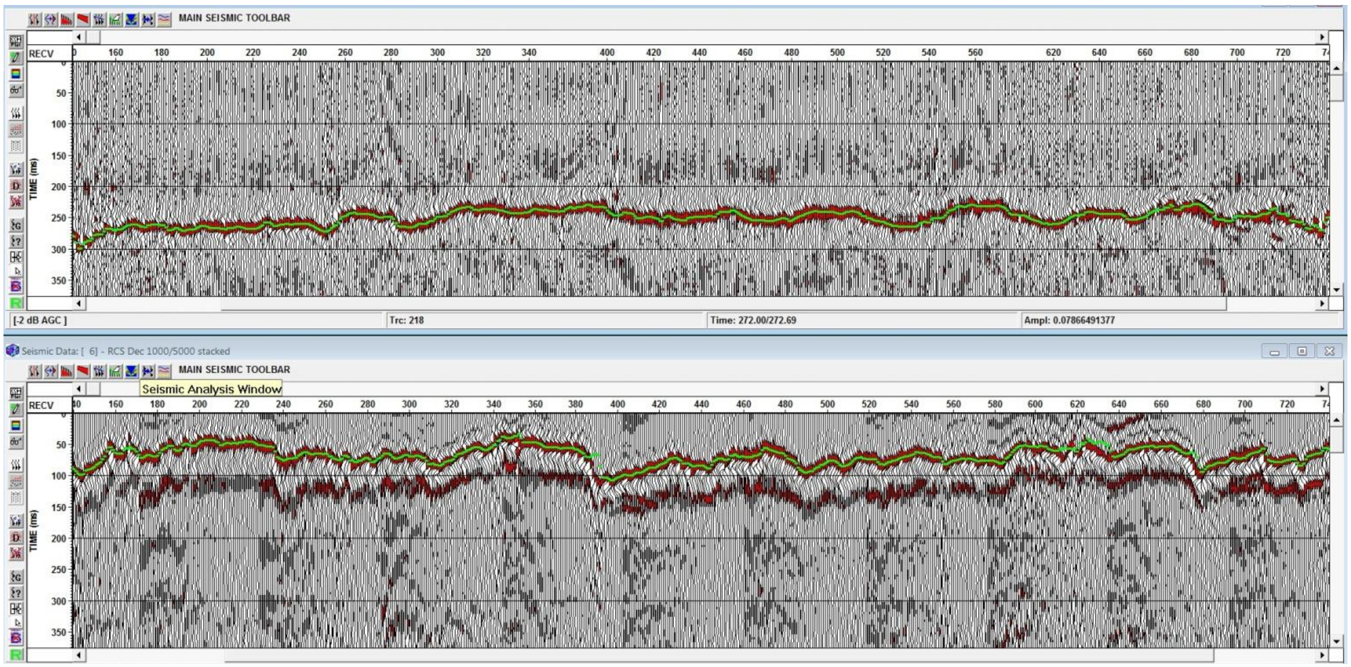
$$t_v = 2 * X_{R1-R2}/V_{C-D}$$

Figure 2: Generation of Refraction Velocity Stack.



Offset discrimination is used to generate separate sections for refractors at different depths, i.e. we use shorter offset ranges for shallow refractors and longer offsets for deeper refractors. Note there is no need to "pick" a so-called "branch point", since the act of stacking many times will emphasize the desired refractor. Figure 3 represents an example of the refraction convolution stack (RCS) and refraction velocity stack (RVS) generated for one of the refractors. The green picks show the result of applying an automatic picking algorithm to the "events".

Figure 3: Refraction Convolution Stack and Refraction Velocity Stack.



After picking the events automatically in a manner similar to horizon picking, the near surface depth model is obtained, using Snell's law. Initial static corrections to replace weathering velocity $\boldsymbol{V_w}$ with replacement velocity $\boldsymbol{V_r}$, are also computed at this step. We show below an example of the replacement statics computation for a one layer model, which is easily expandable to a multi-layer model, expressed using the delay time described earlier:

$$t_{stat=}\frac{t_d}{2}\sqrt{\frac{V_r - V_w}{V_r + V_w}}$$

This solution of the near surface depth and velocity model has thus been accomplished solely by data processing (forming receiver stacks of trace convolutions and correlations) with a final step of automatic picking.

We now propose a new additional statistical approach to perform model quality control, update the depth model and derive more accurate static corrections.

After obtaining the depth model, we can compute theoretical refracted first arrivals for all refractors – by ray-tracing the refracted arrival for every shot-receiver pair through the model.

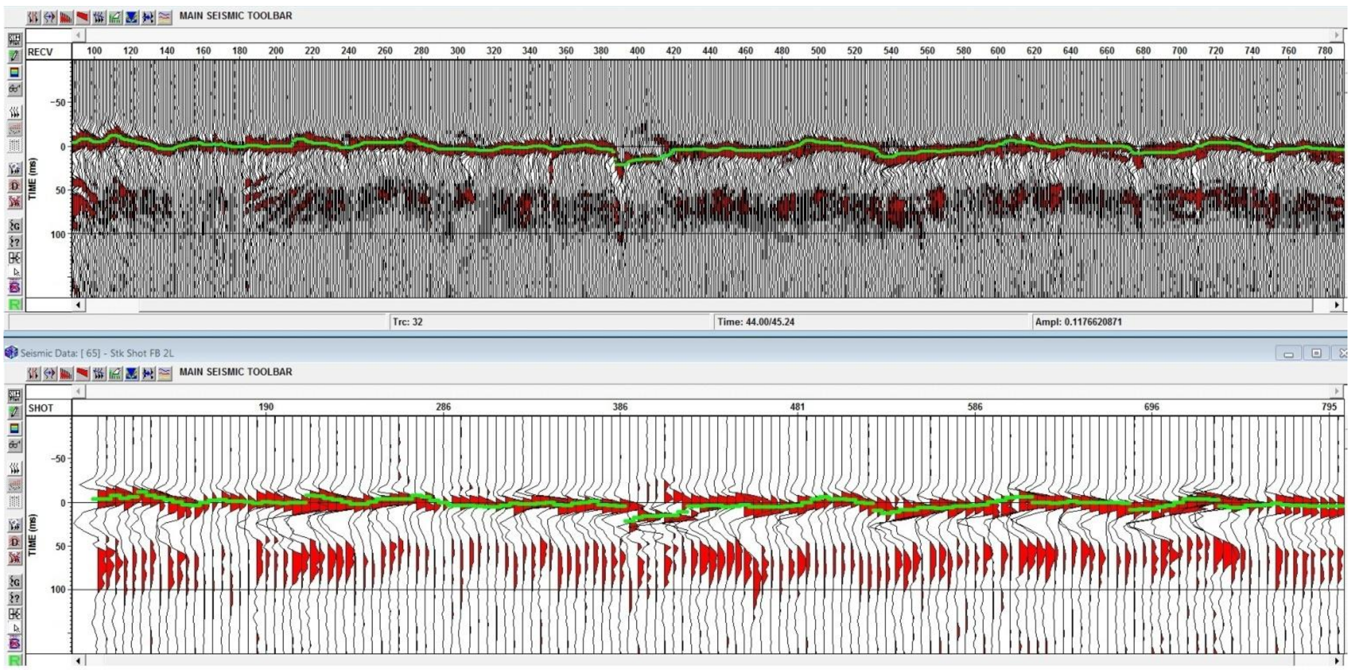
These model first breaks ("mfb") are then applied as static time shifts and the data are then stacked in the common receiver and common shot domains for the same offset ranges as for the initial model calculation. Essentially we are performing LMO (linear move-out) for each refractor – followed by stacking the LMO'd traces belonging to common receivers and common shots.

If the model correctly describes the subsurface, then flattening to the model first breaks and stacking will create a flat horizon at time zero. Any deviation from time zero represents the average difference between the model and the real slant times in the shot or receiver domain.

Two scenarios are possible. If the behavior of the horizons on the common receiver and common shot stacks resemble each other (as in Figure 4), the average deviation of the model delay times depends only on the spatial position (i.e. both shot and receiver stacks agree on the residual static at each surface position).

Figure 4 shows the mfb stack, first by common receiver (above) and then common shot (below). The green line on the common shot stack shows the same horizon, picked on common receiver stack. Horizons do coincide at the same spatial positions.

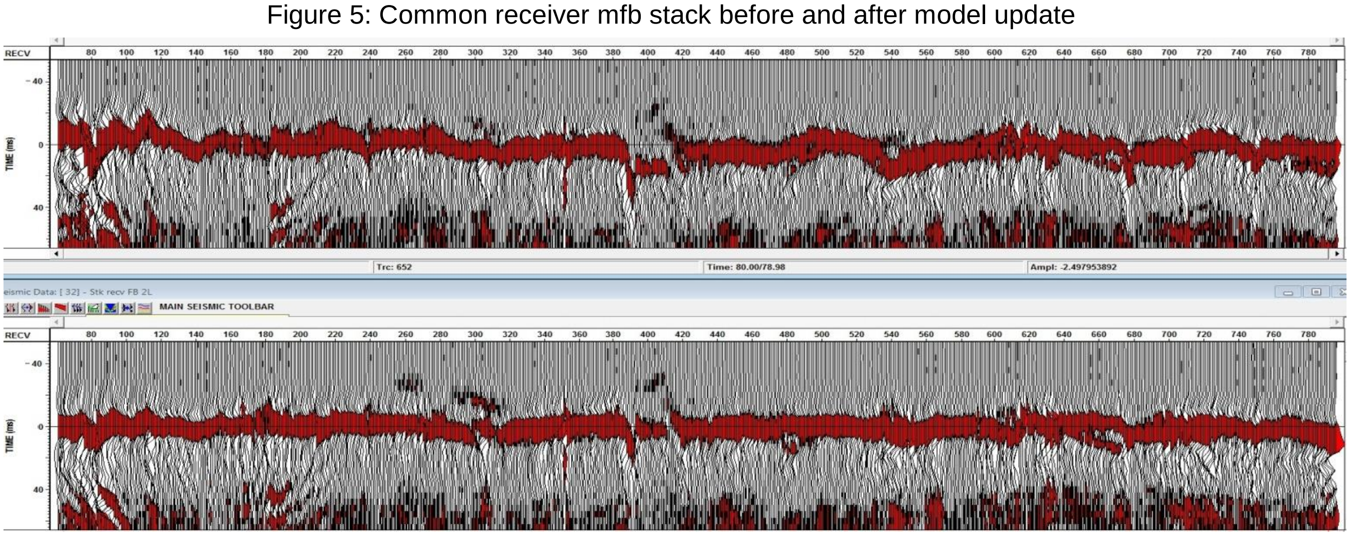
Figure 4: Common receiver and common shot mfb stack, initial model.



Any deviation from the horizontal line is then applied (added) to the delay times obtained from the RCS to update the depth model and compute new statics corrections.

Figure 5 shows the common receiver stack (zoomed in time) obtained with the initial model (above) and the updated model (below).

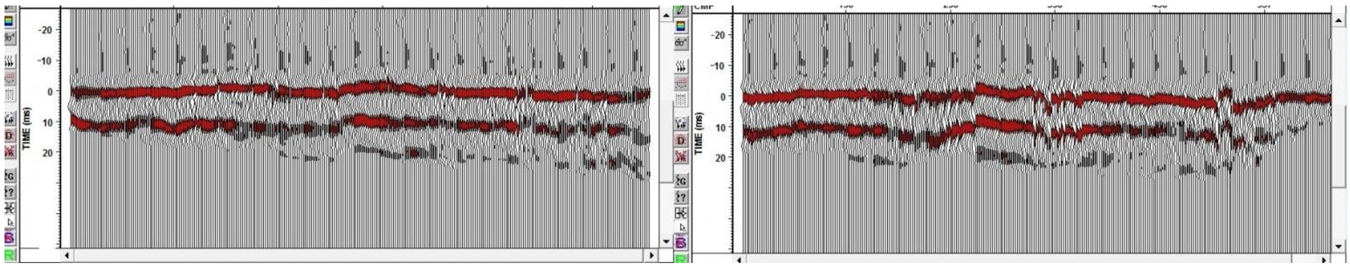
Figure 5: Common receiver mfb stack before and after model update



The second scenario, however, arises in the case of crooked lines, buried shots or geometry errors, where horizons on the common receiver and common shot stacks can behave differently. That means that the depth model cannot be updated and separate shot and receiver consistent time corrections should be applied on the pre-stack data in addition to the interferometric refraction statics corrections.

Figure 6 shows common receiver and common shot stacks obtained with the initial model. Clearly, horizons do not coincide at the same spatial positions.

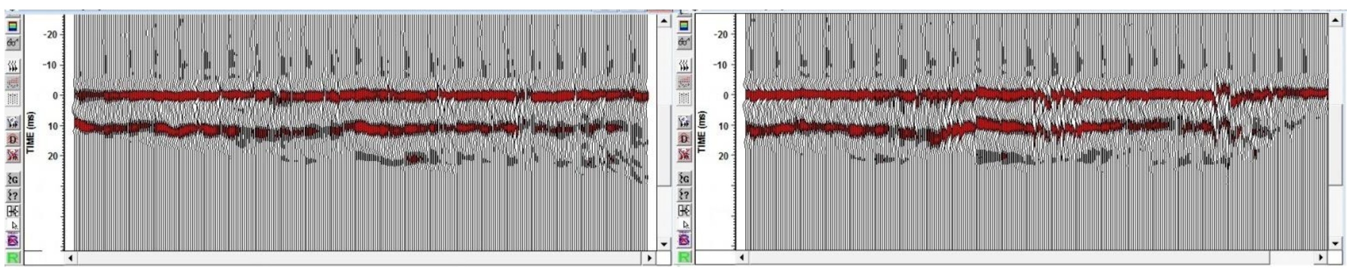
Figure 6: Common receiver and common shot mfb stack, initial model.



Surface consistent mfb corrections, derived from the deviation from the horizontal lines on common receiver and common shot stacks are applied on each pre-stack trace.

Figure 7 shows common receiver and common shot stacks obtained after application.

Figure 7: Common receiver and common shot mfb stack after corrections



New model first breaks can be calculated and the procedure can be repeated in an iterative manner until a satisfactory “flatness” of the horizons at time zero on the common receiver and common shot stacks is achieved.

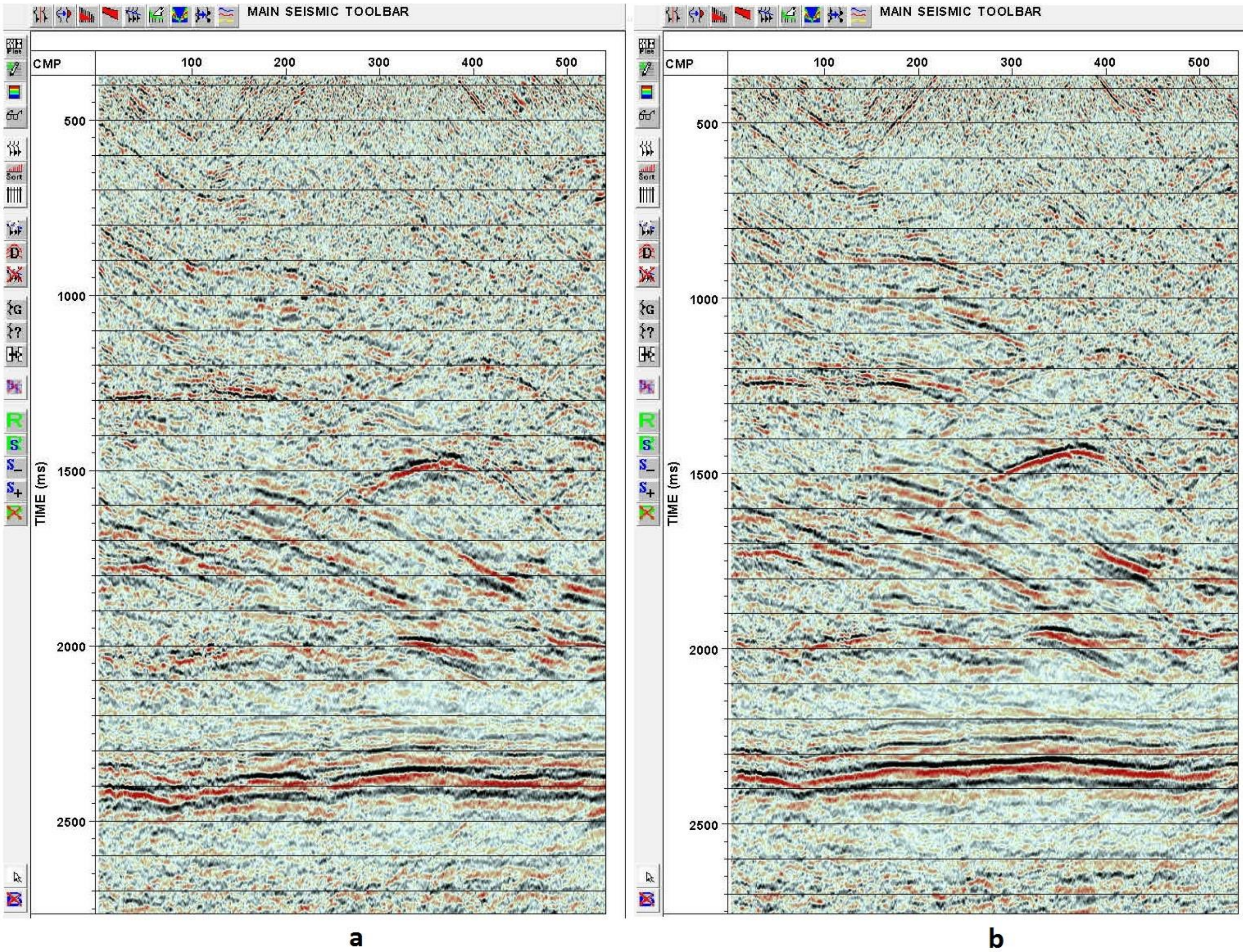
Note that computed model first breaks can also be used as an effective guide to perform real first break picking with very high accuracy, if necessary.

Examples

The first real data example (data courtesy of Husky Oil and Talisman Energy) shows the result of the application of interferometric refraction statics corrections. A two layer near surface model has been built to compute refraction statics.

Figure 8 shows the brute stack (CMP) before (a) and after (b) interferometric refraction statics corrections. Elevation static corrections were applied in both cases.

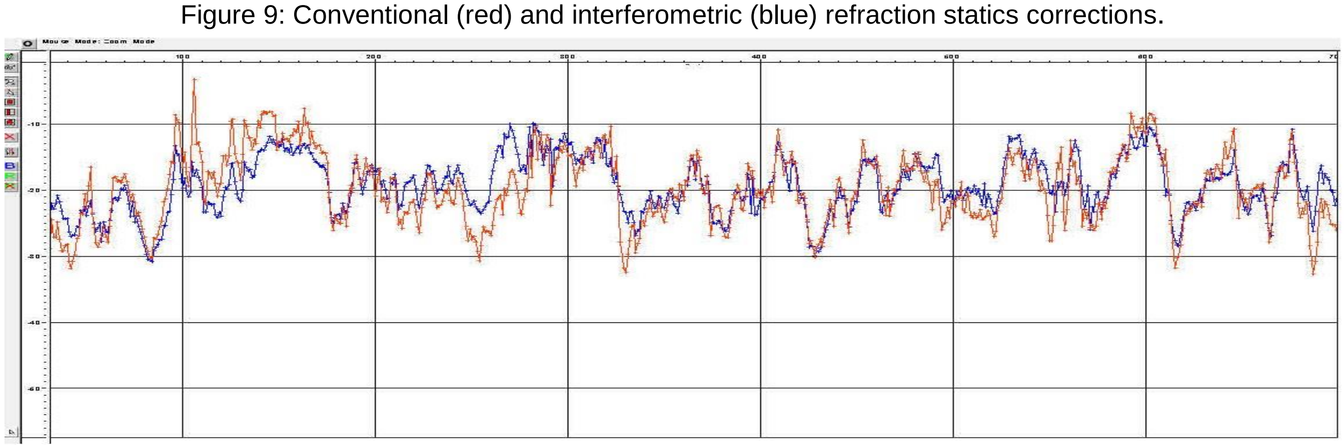
Figure 8: Brute stack before (a) and after (b) interferometric refraction statics corrections



It is useful to compare the interferometric static solution with the static solution obtained using a conventional method of interpreting picked first arrivals.

Figure 9 shows interferometric refraction statics corrections in blue and a sum of conventionally derived long and short wave statics in red. Note, that the proposed interferometric method allows us to derive long and short wave statics accurately and simultaneously.

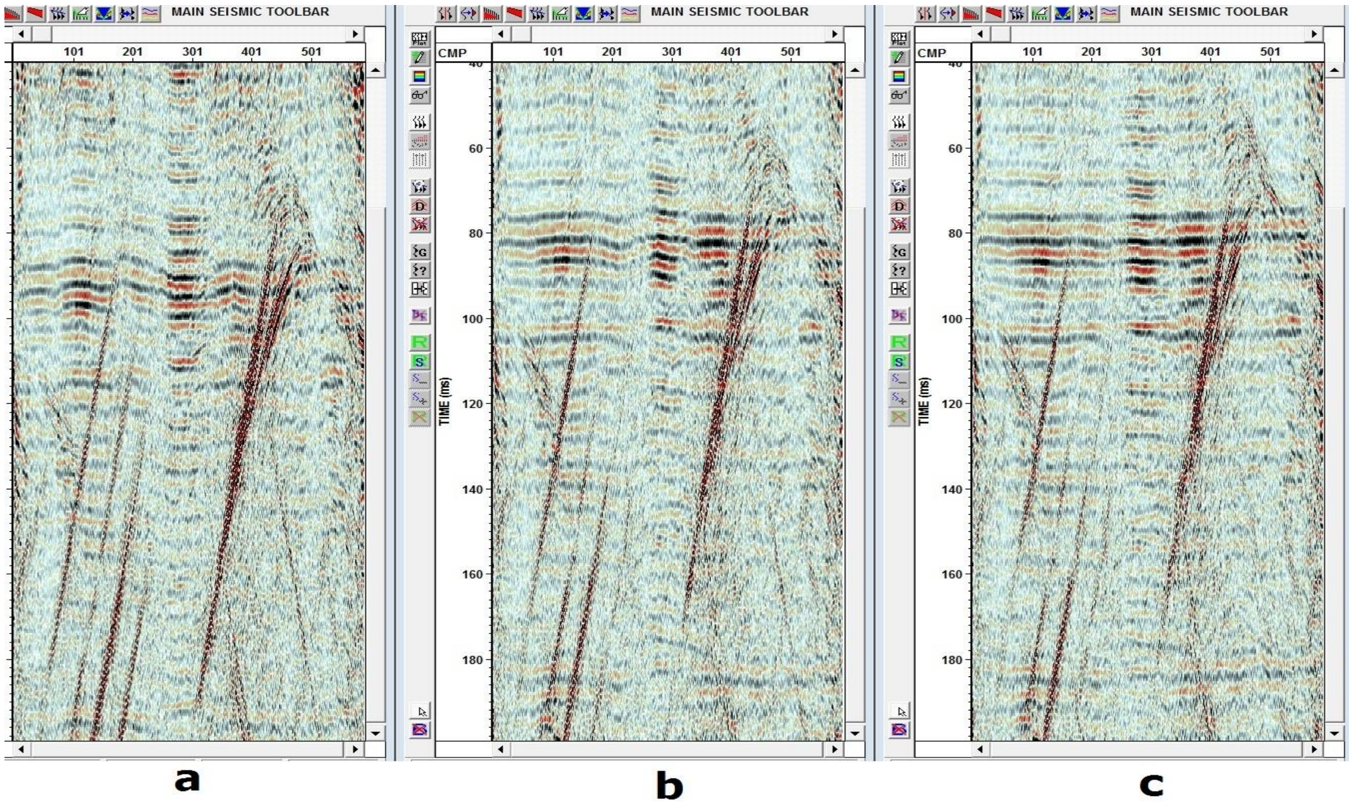
Figure 9: Conventional (red) and interferometric (blue) refraction statics corrections.



The second real data example shows data with short maximum offsets. Figure 10 represents the brute stack (CMP) before (a) and after (b) interferometric refraction statics corrections. On the right (c) interferometric refraction statics corrections and surface consistent mfb corrections are applied.

Note, that the raw data has been CMP stacked with no noise suppression or residual statics applied.

Figure 10: Brute stack before (a), after (b) interferometric refraction statics corrections and after mfb corrections(c)



Conclusions

We have developed a complete new interactive refraction technology to create a multi-layered shallow model of depths and velocities, update that model, and compute long and short wave refraction statics simultaneously, as well as accurately predict first arrival times.

Although the method still relies on the refraction first arrival signal, the statics solution is obtained by simple data processing techniques and automatic horizon picking without the need to pick first breaks.

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