Multiple Attenuation by the WHLP-CRS Method

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Abstract

Multiple attenuation is a classical problem in processing and interpretation of seismic reflection sections. A special number of SEG´s The Leading EDGE (1999) is dedicated to the subject of multiple identification and attenuation, where is noticeable the non existence of a technique to provide both identification and attenuation that can be applied to all possible cases, due to the diversity of the geology responsible for the generation of multiples.

This paper presents part of the theory that combines the CRS stack and Wiener-Hopf-Levinson prediction (WHLP) operators to perform multiple attenuation for 2D curved reflectors. The strategy uses the wave front attributes to calculate space-time shift windows to introduce the necessary "periodicity" between the primary and its multiple for calculating the WHLP operator. The operation was applied in common-source time sections, where there are no periodicity between the primary and its multiple. The operator is calculated with the true amplitude of the signal, what is expected to give it more efficiency. The combination of these two theories to obtain the multiple attenuation operator is here denominated WHLP-CRS.

Introduction

The geological motivation of the present work is the presence of diabase sills in the sedimentary basins of the Amazon region, since they generate strong multiples that can obscure primary information, and consequently make difficult the processing, the interpretation and the imaging of time sections aiming at petroleum exploration.

In multiple attenuation in zero-offset (ZO) configuration using the classical WHL technique, the prediction operator is calculated after the ZO section has been obtained. In this procedure, the section may contain undesirable effects from processing, as stack pulse stretch and deformation, that is transferred to the operator's resolution. In this sense, searching for a more robust operator, the tendency is to calculate an operator for the survey configuration using the actual amplitudes of the signal, expecting a better resolution in multiple attenuation. As a consequence of this analysis, we encircle the inconvenience of the processed data to obtain a ZO section, and propose multiple attenuation by restructuring the WHLP theory for using both concepts of shifting windows and wavefront attributes (CRS-stack operator output) to design the WHLP-CRS operator to apply in the survey configuration, where the WHLP operator is calculated with the real amplitude of the signal. (Garabito et al, 2001; Jägger et. al, 2001; Mann, 2002).

Method

The CRS-stack output products are 1 ZO section, and 3 sections of cinematic wave front attributes (emergency angle β_0, and curvatures K_{NIP} and K_N) measured with respect to the reference point (t_0, X_0).

The CRS-stack is attractive for not presenting a strong restriction with respect to interface curvatures, and for being relatively independent of the velocity model. In CRS stack, the wave front attributes are estimated directly from the multiple coverage data. (Hoecht, 1998).

The transit time of primary reflections in the neighborhood of the normal central ray is given by:

$$t^2(x_m,h) = \left(t_0 + \frac{2\sin\beta_0}{v_0}(x_m - x_0)\right)^2 + \frac{2\,t_0\cos^2\beta_0}{v_0}\left(\frac{(x_m - x_0)^2}{R_N} + \frac{h^2}{R_{NIP}}\right)$$

where t_0 is the double travel-time along the normal ray, and v_0 is a velocity close to the surface, and around the point X_0. The relations between coordinate systems are:

$$x_m = \frac{(x_G + x_S)}{2} \quad \text{and} \quad h = \frac{(x_G - x_S)}{2}.$$

x_m is the mid-point, h the half offset, x_S and x_G are, respectively, the source and geophone coordinates.

One first problem in the simulation of ZO section consists on the determination of the trio of attributes β_0, R_{NIP} and R_N for each image point of the ZO. The determination of the trio (β_0, R_{NIP} and R_N) is formulated as a parameter maximization (or minimization) problem, having for object function the semblance cube (*NxMxP*). The trio´s extreme values as: $-\pi/2 < \beta_0 < +\pi/2$ and $-\infty < R_{NIP}, R_N < +\infty$.

The parameter optimization requires a high computer effort, since the parameter search is done for every point (t_0,X_0) of the ZO section. In the present work, the search of the trio (β_0, R_{NIP} and R_N) was realized with the computer program of Garabito (2001), for which the block diagram is shown in Figure 1.

The WHL filter coefficients (h_i) are obtained by the minimization of the variance of the deviations between the functions z_k (desired output) and y_k (real output). The object function is written as:

$$e(h_i) = E\{(z_k - y_k)^2\}.$$

The stochastic processes y_k and z_k are considered as stationary. The real output of the filter, y_k, is given by the linear convolution of the input, g_k, with the coefficients of the filter in the form:

$$y_k = \sum_{i=0}^{N-1} h_i \, g_{k-i} \ ,$$

where *N* is the number of filter coefficients, *P* is the number of points in the observed trace. The input g_k is represented by the simple convolution model:

$$g_k = s_k + v_k = \sum_{i=0}^{M-1} w_i \, r_{k-i} + v_k \ ,$$

where w_i is the source-pulse, r_i the distribution of reflection coefficients, v_k is the additive noise (noise component of the signal), and s_k is the message (non noise component of the signal).

Minimization of the object function results in the so-called WHL normal equation (Peacock and Treitel, 1969):

$$\sum_{i=0}^{N-1} h_i \phi_{gg}(j-i) = \phi_{zg}(j) \ .$$

The solution of this linear system of equations results in the coefficients h_i. $\phi_{gg}(.)$ represents the hypothetical bilateral stochastic autocorrelation of the input, and $\phi_{zg}(.)$ the hypothetical unilateral stochastic crosscorrelation between the desired and the observed signals.

Several deconvolution operators can be organized from the general solution. For comparison, we present the following operators. The smoothing operator is defined by setting: (a) the input as $g_k = s_k + v_k$, where s_k is the message and v_k the additive noise; (b) the desired output is $z_k = s_k$; (c) the correlations are as: $\phi_{gg}(j) = \phi_{ss}(j) + \phi_{vv}(j)$, $\phi_{zg}(j) = \phi_{ss}(j)$ and $\phi_{vv}(j) = \sigma_v^2 \, \delta(j)$. The parametric normal equation has the form:

$$\sum_{i=0}^{N-1} h_i \, [\, \phi_{ss}(j-i) + \sigma_v^2 \, \delta(j-i) \,] = \phi_{ss}(j) \ .$$

A second problem is the impulse operator defined by setting: (a) the input as $g_k = s_k + v_k$, where s_k is a convolution and v_k is the additive noise; (b) the desired output is $z_k = r_k$; (c) the correlations are as $\phi_{gg}(j) = \sigma_r^2 \phi_{ww}(j) + \phi_{vv}(j)$, $\phi_{zg}(j) = \sigma_r^2 w_{-j}$ (with $w_{-j} = w_0$ for $j = 0$, and $w_{-j} = 0$ for $j > 0$) and $\phi_{vv}(j) = \sigma_v^2 \, \delta(j)$. The parametric normal equation has the form:

$$\sum_{i=0}^{N-1} h_i \, [\, \sigma_r^2 \phi_{ww}(j-i) + \sigma_v^2 \, \delta(j-i) \,] = \sigma_r^2 w_{-j} \ .$$

A third operator is the prediction defined by setting: (a) the input as $g_k = s_k + v_k$, where s_k is the message and v_k the additive noise; (b) the desired output is $z_k = s_{k+T}$, where T is the prediction distance; (c) the correlations are as: $\phi_{gg}(j) = \phi_{ss}(j) + \phi_{vv}(j)$, $\phi_{zg}(j) = \phi_{ss}(j+T)$ and $\phi_{vv}(j) = \sigma_v^2 \, \delta(j)$. The parametric normal equation has the form:

$$\sum_{i=0}^{N-1} h_i \, [\, \phi_{gg}(j-i) + \sigma_v^2 \, \delta(j-i) \,] = \phi_{ss}(j+T) \ .$$

In all these basic formulations, the stochastic crosscorrelations are considered as null; i. e., $\phi_{sn}(j) = \phi_{ns}(j) = 0$. Additive noise is considered as white series; i. e. : $\phi_{vv}(0) = \sigma_v^2$, $\phi_{vv}(j) = 0$, $j \neq 0$.

In the present work we consider only the prediction problem. In the present strategy, the normal equation is organized such that the prediction operator is calculated with the information windowed by a lower limit as $W_1(x_m, h; T_{hyp})$, and by an upper limit as $W_2(x_m, h; T_{hyp})$. This window shifts and changes in time and space based on the double travel time expressed as:

$$T_{hyp} = T_{hyp}(x_m, h; T_0, K_n, K_{nip}, \beta_0, V_0) \ .$$

This function is then responsible for introducing the periodicity between the primary and its multiple of first order.

The normal equation is modified to the CMP configuration, and is expressed as:

$$\sum_{k=0}^{N-1} h_k \phi_{gg}(l-k; x_m, h, T_{hyp}) = \phi_{gg}(l+T; x_m, h, T_{hyp}) \ ,$$

where $W_1 \le l \le W_2$. The operator is calculated trace-to-trace, and applied in its own time-space window. The periodicity between the primary and its multiple is defined by the relation:

$$W_2(x_m, h; T_{hyp}) - W_1(x_m, h; T_{hyp}) = 2T + 2Cp \ ,$$

where *T* is the periodicity, and λ is the pulse length. The application of the WHLP-CRS filter is explained with the help of the block diagram given in Figure 2. (Alves, 2003).

Results

In order to evaluate the WHLP-CRS operator, we processed several synthetic models, and selected relevant results for presentations. The case is of internal multiples relative to a high velocity layer with curved interfaces, simulating typical geological situations as modeled for the Amazon sedimentary basin.

We use here with the theory, a simple model formed by a layer over a half-space, where we process a multiple in common-source. Other examples more meaningful, with respect to high velocity layers and curved interfaces, are presented in Leite et al. (2003) for this Eighth Congress of SBGf.

Figure 3 shows the common-source section and the upper and lower limits of the shifting windows.

Figure 4 shows the autocorrelation, the crosscorrelation, the prediction-error operator, the input and the output of the WHLP-CRS operator. We can observe from input “b” and output “c” that the operator is efficient.

Figure 5 shows the CRS stack operator, and the attribute sections for the wave front parameters.

Figure 6 shows the zero-offset simulated by the CRS stack, before and after the application of the WHLP-CRS operator.

Conclusions

An important observation is that the concept of time-space shifting windows on the autocorrelation allows the extension of the theory of the WHLP operator for multiple attenuation in time domain, to configurations where there is no periodicity between primary and its multiple, as is the case of CS and CMP configurations. This makes possible to treat models with dipping-plane and curve interfaces with good and consistent results.

In a parallel work (Leite et al, 2003), present details of the algorithm and results for the theory here discussed, and demonstrate numerically that the model is coherent and produce good results.

The extension of the conventional WHLP method to admit the CRS-stack is very attractive, what makes the WHLP-CRS a basically data-driven method. Among the difficulties that we face, are the ones related to conflict (crossing) between primaries and non related multiples, to the small separations between primaries and its multiples, and to the eternal dipping problem. Another difficulty, here not analyzed in details, has to do with the interpretation of the autocorrelation function.

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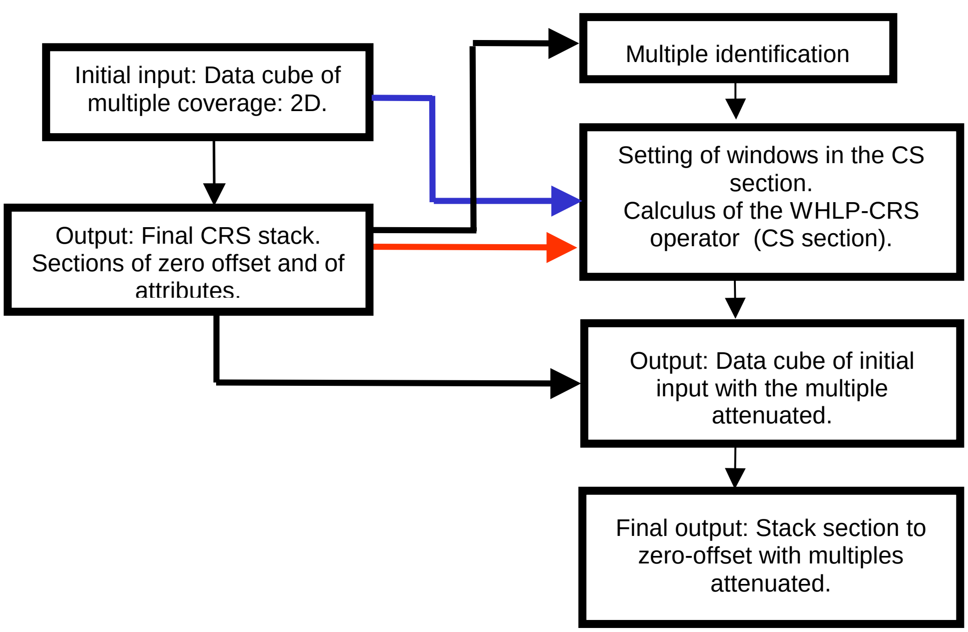

Figure 2. Simple block diagram for the process of multiple attenuation with the WHLP-CRS method.

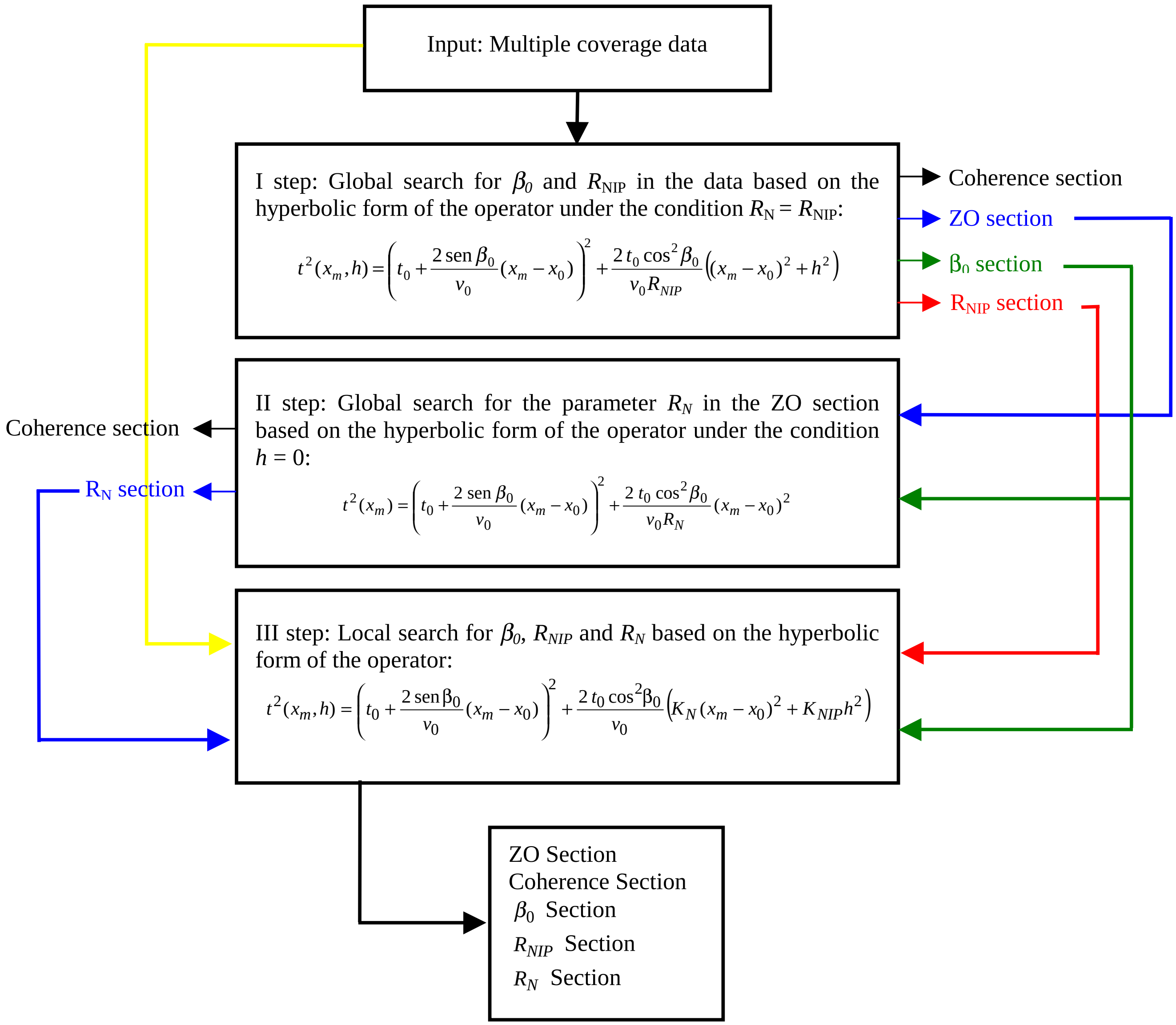

Figure 1. Block diagram for the CRS stack. The final results are: 1 ZO section, 1 semblance section, and 1 section for each one of the 3 parameters β_0, R_{NIP} and R_N. Total of 5 section presentations.

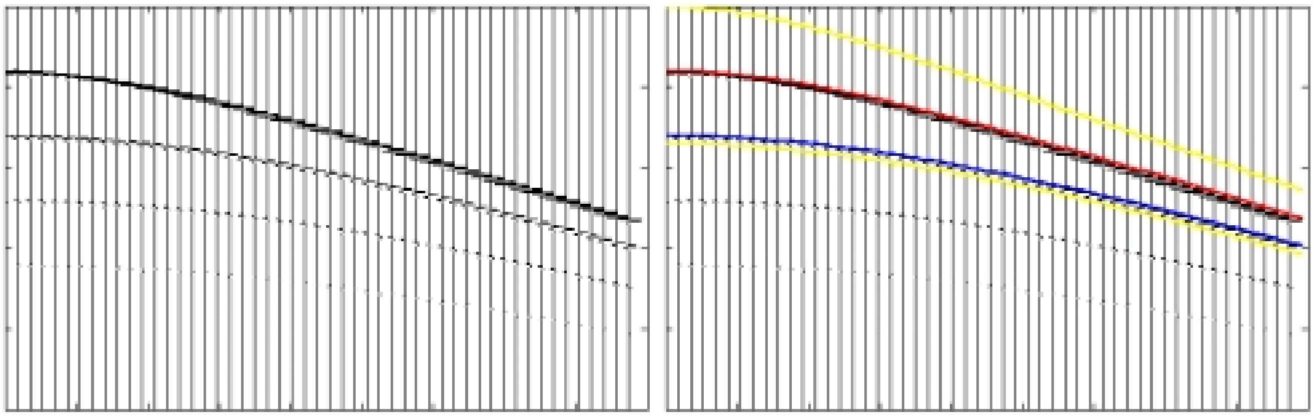

Figure 3. Left: Common-source section of a model formed by a layer over a half-space, where are also presented the multiples of first, second and third orders. Right: Common-source section with the upper and lower limits of the shifting windows (yellow lines). The red and blue lines are travel times of, respectively, primary and first order multiple.

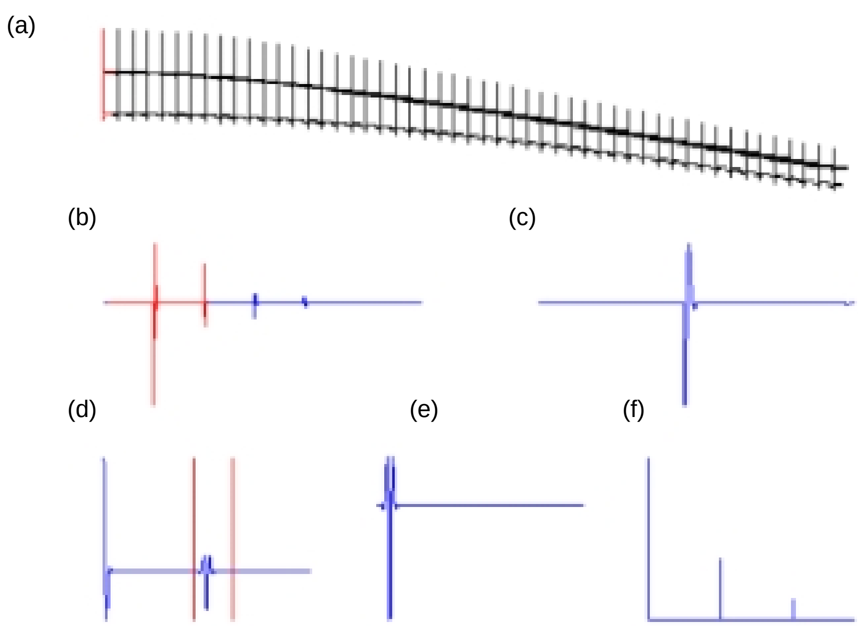

Figure 4. (a) Windowed segment of the common-source section. (b) First trace of the common-source section, and display of the windowed segment in red. (c) Windowed segment (shown in 'b') after application of the WHLP-CRS operator. (d) Autocorrelation of the windowed segment in 'a' together with a selection window for the multiple event. (e) Crosscorrelation between real and desired outputs. (f) Calculated operator, with the autocorrelation in 'd' and the crosscorrelation of item 'e', responsible for the efficient attenuation of the multiple.

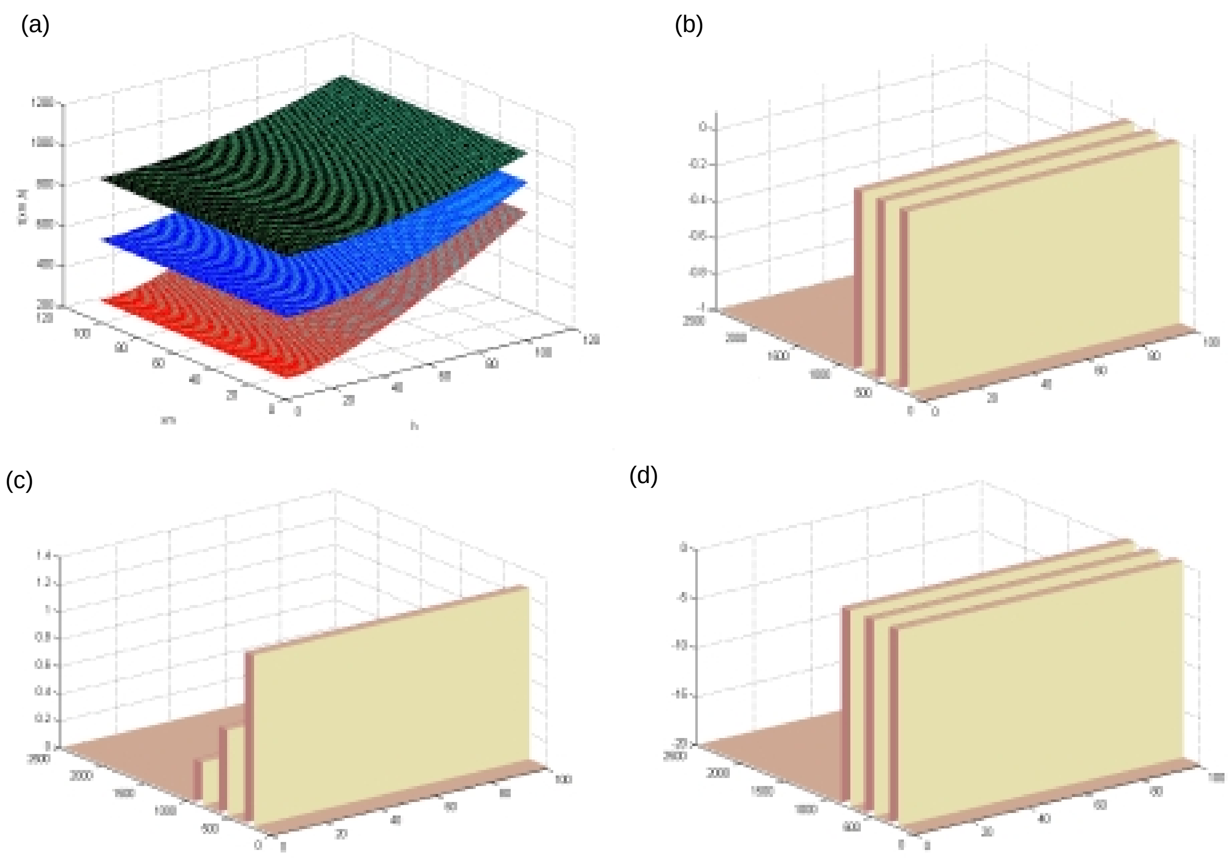

Figure 5. (a) Transit time impulse response. The red surface represents the primary, and the blue and green the multiples of first and second order, respectively. *h* represents the half-offset source-receptor, and x_m the mid-point. $v_1 = 2000\ m/s$, $v_2 = 4500\ m/s$, $e_1 = 800\ m$, $\Delta x = 50\ m$, $\Delta t = 2\ ms$. Parameters for simulating the ZO stacked section of Figure 1: (b) K_n (in km). (c) K_{nip} (in km). (d) β_0 (in degrees).

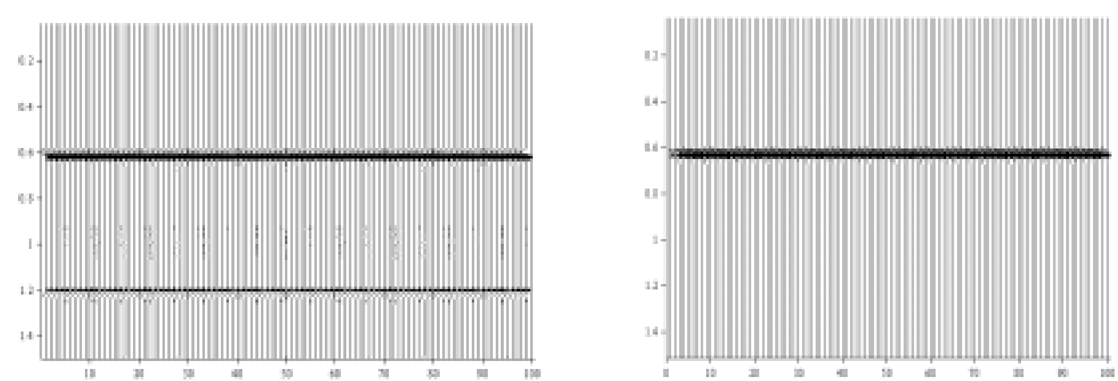

Figure 6. (a) ZO section simulated with the CRS operator, having for input the sections not treated with the prediction filter. (b) ZO section simulated with the CRS operator, having for input the sections treated with the prediction filter.