Internal Multiple Attenuation and Wavelet Estimation

Paulo Marcos de Carvalho

PETROBRAS S/A, Rio de Janeiro, RJ, Brazil

ABSTRACT

In this work, the internal multiple attenuation method developed by Arthur Weglein and Fernanda Araujo Gasparotto (Araujo et al., 1994, Weglein et al., 1997) is applied, for evalluation purposes, to one synthetic and one real data sets. The wavelet estimation problem related to this method is considered and compared to its more well known role in the inverse scattering surface multiple attenuation method (Carvalho and Weglein, 1992, Weglein et al., 1997) and other simmilar methods.

INTRODUCTION

Multiple reflections and its attenuation methods are subjects that have always captured the attention of seismologists, because of their impacts on the interpretation of seismic data. Multiples may appear as false primaries, hide the primary reflections or just modify the amplitude of these events. There is a large number of multiple attenuation methods and they are extensively covered in the geophysical literature.

The method used in this work comes from the inverse series of scattering theory applied to seismic data and was developed by Arthur Weglein and Fernanda Araujo Gasparotto (Araujo et al., 1994, Weglein et al., 1997). Similarly to the surface multiple attenuation method derived from the same theory (Carvalho and Weglein, 1992, Weglein et al., 1997), this method requires the knowledge, or the estimation, of the wavelet for its successful application to real data.

In the following, I will give a brief description of the internal multiple attenuation method, compare the wavelet issue for both methods, show their differences and try to give an intuitive explanation for that. One synthetic data and one real data example of its application will be presented to illustrate the explanations.

GENERATING THE ESTIMATE OF THE INTERNAL MULTIPLE

The internal multiple attenuation method is implemented as a series. The first term, b_1, is just the input data, without the free surface multiples and the direct wave, and transformed by the following equations (Weglein et al., 1997):

$$b_1(k_g,k_s,z)=\int_{-\infty}^{+\infty}dk_z\ e^{-ik_z z}\ b_1(k_g,k_s,k_z)\quad ,$$

$$b_1(k_g,k_s,k_z)=-i2q_s e^{i(q_g e_g+q_s e_s)}\ D(k_g,k_s,q_g+q_s)\quad ,\qquad [1]$$

$$k_z=q_g+q_s=\sqrt{\left(\omega/c_0\right)^2-k_g^2}+\sqrt{\left(\omega/c_0\right)^2-k_s^2}\quad .$$

In these equations ω is the angular frequency k_g and k_s are the horizontal wave numbers for receiver and source coordinates, z is a pseudo-depth coordinate obtained from the change of variables shown above, c_0 is a constant reference velocity, and e_g and e_s are the depths of receivers and sources.

The second term of the inverse series is:

$$b_3(k_g,k_s,\omega)=\int_{-\infty}^{+\infty}dk_1\int_{-\infty}^{+\infty}dz_1\ e^{i(q_g+q_1)z_1}\ b_1(k_g,k_1,z_1)\int_{-\infty}^{+\infty}dk_2\int_{-\infty}^{z_1-\varepsilon}dz_2\ e^{-i(q_1+q_2)z_2}\ b_1(k_2,k_1,z_2)\times$$

$$\int_{z_2+\varepsilon}^{+\infty}dz_3\ e^{i(q_2+q_s)z_3}\ b_1(k_2,k_s,z_3)\quad ,\qquad [2]$$

where ε is a quantity related to the size of the wavelet.

This term gives a reasonable estimate of all internal multiples that may be present in the data. Higher order terms can be generated, but, normally, it is only necessary to use b_3 to attain multiple attenuation.

In the last step, the two terms, b_1 and b_3, are transformed back to data domain using the inverse of the transform represented in equation [1]. Then, terms are matched in a minimum energy basis and added to yield the multiple attenuated data.

THE ROLE OF THE WAVELET

Because the input data have a wavelet convolved with it, the b_3 term, that results from a third order interaction of b_1, has a wavelet impact of the third order. Its wavelet surplus is of the second order compared to the input data, and this must be corrected in order to have a good match between terms.

At this point, a comparison with the inverse scattering surface multiple attenuation method (Carvalho and Weglein, 1992, Weglein et al. 1997) or other similar methods (e.g., Verschuur et al., 1997) is useful to explain the difference of the wavelet estimation problem for the internal multiple case.

In the surface multiple case, each term is obtained from an operation of the input data with the predecessor term that includes a time convolution of them. Therefore, each term, beginning with the second, accumulates the convolution of an extra wavelet. For example, the third term has two extra wavelets convolved with it. In the frequency domain, the amplitude spectrum is multiplied by two extra amplitude spectra of the wavelet, and the phase spectrum has two extra phase spectra of the wavelet added to it.

For the internal multiple case, equation [2] shows that a more complex operation is performed to generate the multiple estimate. It is difficult to unravel the specific nature of this operation, but one interesting result can be observed directly from the application of the method to synthetic or real data as will be shown bellow. No matter what is the phase spectrum of the wavelet convolved with the input data, the wavelet in b_3 has this same phase spectrum. In terms of frequency domain, this means that, although the amplitude spectrum is multiplied by two extra amplitude spectra of the wavelet, the two extra phase spectra of the wavelet somehow cancelled each other in order to not affect the phase spectrum of b_3.

THE 1D CASE

The internal multiple attenuation method is highly simplified for a 1D medium. For the plane wave normal incidence case, equation [2] becomes:

$$b_3(z) = \int_{-\infty}^{z-\varepsilon} dz_1\, b_1(z_1) \int_{-\infty}^{z_1-\varepsilon} dz_2\, b_1(z_2)\; b_1(z - z_1 + z_2) \quad .$$

This equation does not involve any approximation. It is derived directly from equation [2] under the 1D plane wave assumption. Note that, in this case, after some manipulations, the left-hand term can be written in the z domain, there is one less z integral and the limits of the integrals have changed.

This simpler equation allows a better understating of the unusual operation performed by the method. Extending the upper limits of both integrals to infinity, the output term of the integrals would be considered as the result of the auto-correlation of b_1, followed by a convolution with b_1. This operation would cancel the two extra phase spectra of the wavelet that are involved in the process, leaving only the extra amplitude spectra. Although this is not exactly what happens in the generation of b_3, a similar process might occur in this case, as well as in the 2D case. This should be responsible for the cancellation of the influence of the phase of the wavelet in this internal multiple attenuation method.

DATA EXAMPLES

Two examples of the application of the method are presented here. The full 2D version of the algorithm was used in both cases.

Before being submitted to equation [2], b_1 was deconvolved by the amplitude spectrum of the corresponding wavelet. The resulting b_3 term was convolved with the amplitude spectrum of the wavelet. This procedure got rid of the two extra amplitude spectra that would be convolved with b_3. Nevertheless, nothing was done concerning the phase spectra of the wavelets.

The first example is from a simple 2D synthetic model with just two reflectors dipping approximately 5 degrees to opposite directions. A simulated seismic line was generated by ray tracing. Phase and amplitude characteristics of the data are correct within the limits of the ray tracing approximation. Only the two primaries and the first order internal multiple were modeled.

Figure 1a shows, from left to right, one shot gather obtained at the center of the model, the estimate of the internal multiple using the full 2D method, and the sum of them. The wavelet for these data is zero phase. The approximate 45 degrees phase rotation observed in the reflections is due to the 2D nature of the data. To match the two terms, only a single scale factor was used. The poorer attenuation at the far traces is due to wave number limitations in the generation of b_3 to speed-up computations. Figure 1b shows a detail of one trace from each seismogram at the level of the multiple. The polarity of the first trace was reversed to better show its match with the second trace.

Figures 2a and 2b show the same procedure as in the previous figures, but, in this case, the input data suffered a 40 ms time shift and a 90 degrees phase rotation prior to being submitted to the multiple attenuation scheme. This is equivalent to have the same data as before with a phase-modified wavelet. Again, just a single scale factor was used to match the data. This shows that the phase spectrum of the wavelet in the input data did not propagate cumulatively through the second term.

The second example is from a portion of a seismic line offshore the Brazilian coast. Figure 3a shows the stacked input data with an internal multiple at about 6500 ms generated by bounces between the sea floor and the strong reflector at 5500 ms. Figure 3b shows the output of the internal multiple attenuation process. The method was applied pre-stack, but due to strong noise in the multiple estimate term, probably caused by aliasing, both terms were stacked before the matching and summation steps. No phase treatment was applied to the input data.

Figure 4a. shows a detail of the multiple in the input data. The multiple is located between 6500 and 6600 ms. The estimate of the multiple is shown in Figure 4b. Figure 4c shows the estimate after matching with the input data. From the figures it can be seen that the raw estimate of the multiple already have a good match with the input data, no matter what phase spectrum the wavelet may have. The matching process did not change too much the phase of the multiple estimate.

CONCLUSION

The wavelet estimation problem for this internal multiple attenuation method is not sensible to the phase of the wavelet. This brings two positive impacts to its practical implementation. One is, obviously, the simpler match between the multiple and the attenuation term. The other is that being insensitive to time shifts, the method can be applied in a time focused way. Only data within the window that comprises the primaries that generated the multiple and the multiple itself, need to be processed.

AKNOWLEDGMENTS

Most of this work was done during a visiting period at ARCO Exploration and Production Technology in a joint research project between PETROBRAS and ARCO. The author thanks both companies for the oportunitty of doing and publishing this work. Special thanks to Lincoln Guardado, Jim O'Connell, Arthur Weglein, Vandemir Oliveira, Andre R. Rosa, David Campbell and Dennis Corrigan for making this research possible. Thanks also to Ken Matson and Chi Young for fruitful technical discussioons.

REFERENCES

Araujo, F.V., Weglein, A.B., Carvalho, P.M. and Stolt, R.H. 1994, Internal multiple attenuation: EAEG Abstracts.

Carvalho, P.M., Weglein, A.B. and Stolt, R.H. 1992, Nonlinear inverse scattering for mutiple attenuation: SEG Abstracts.

Verschuur, D.J., Berkhout, A.J. and Wapenaar, C.P.A., 1997, Adaptive surface-related multiple elimination, Geophysics 57, 1166-1177.

Weglein, A.B., Gasparotto, F.A., Carvalho, P.M. and Stolt, R.H. 1997, An inverse-scattering series for attenuating multiples in seismic reflection data: Geophysics, 62, 1975-1989.

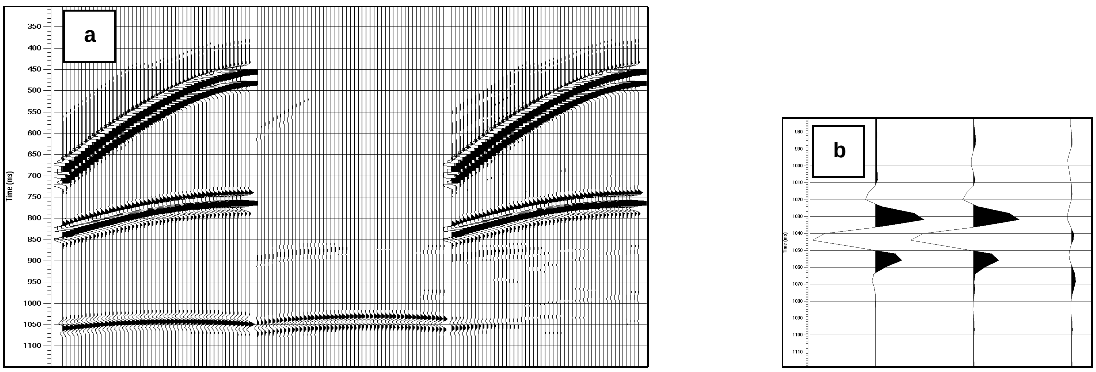

Figure 1: Synthetic data example with zero phase wavelet: a) from left to right: input data, estimate of the multiple and sum; b) detail of one trace of each seismogram at the multiple level (polarity of first trace is reversed).

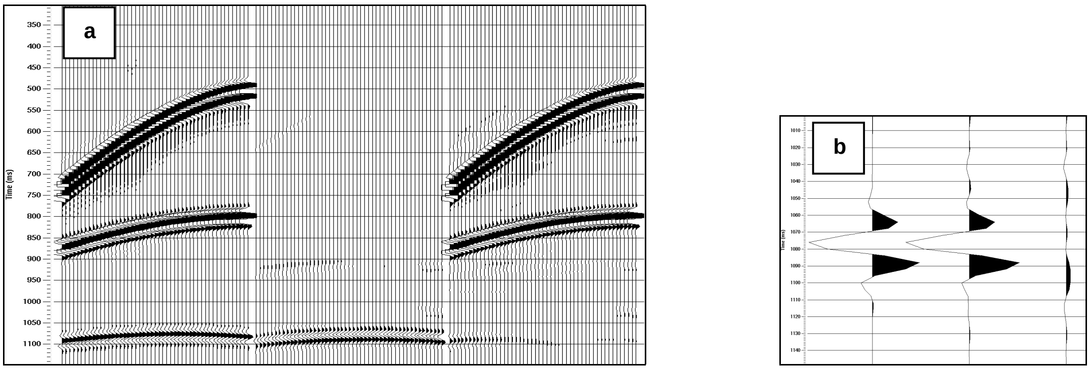

Figure 2: Same as in Figure 1, but with the phase-modified wavelet.

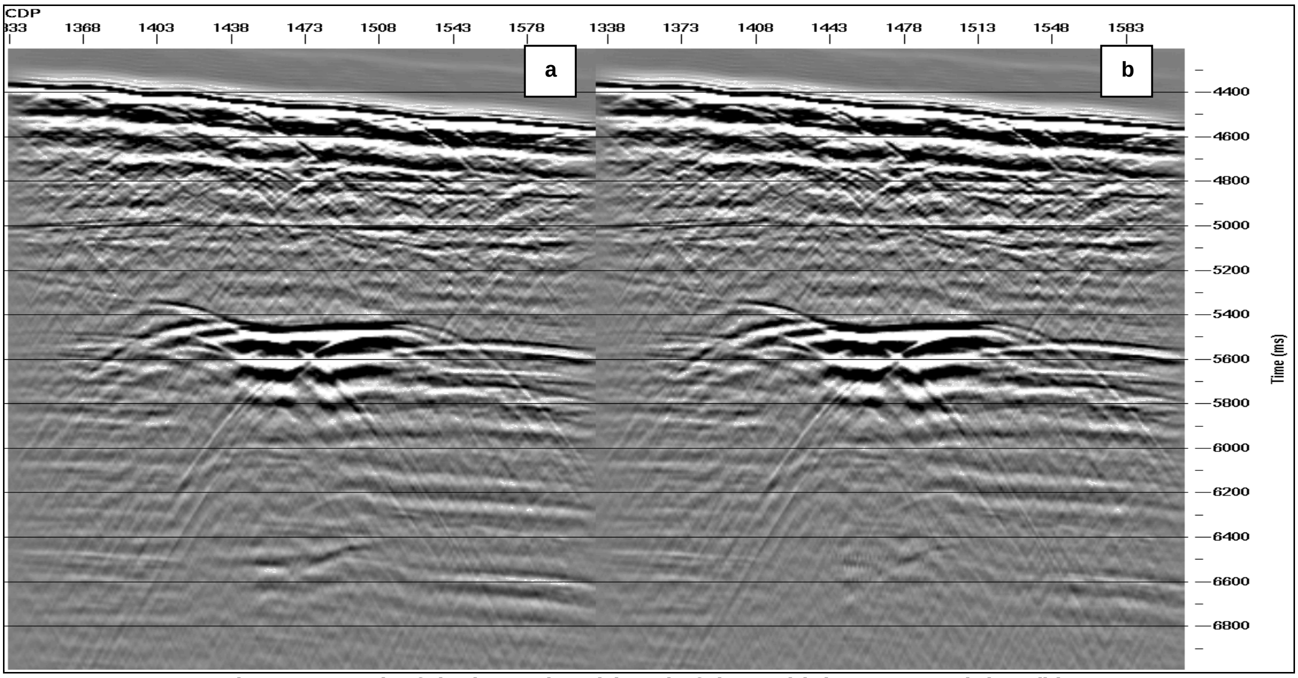

Figure 3: Stack of the input data (a) and of the multiple attenuated data (b).

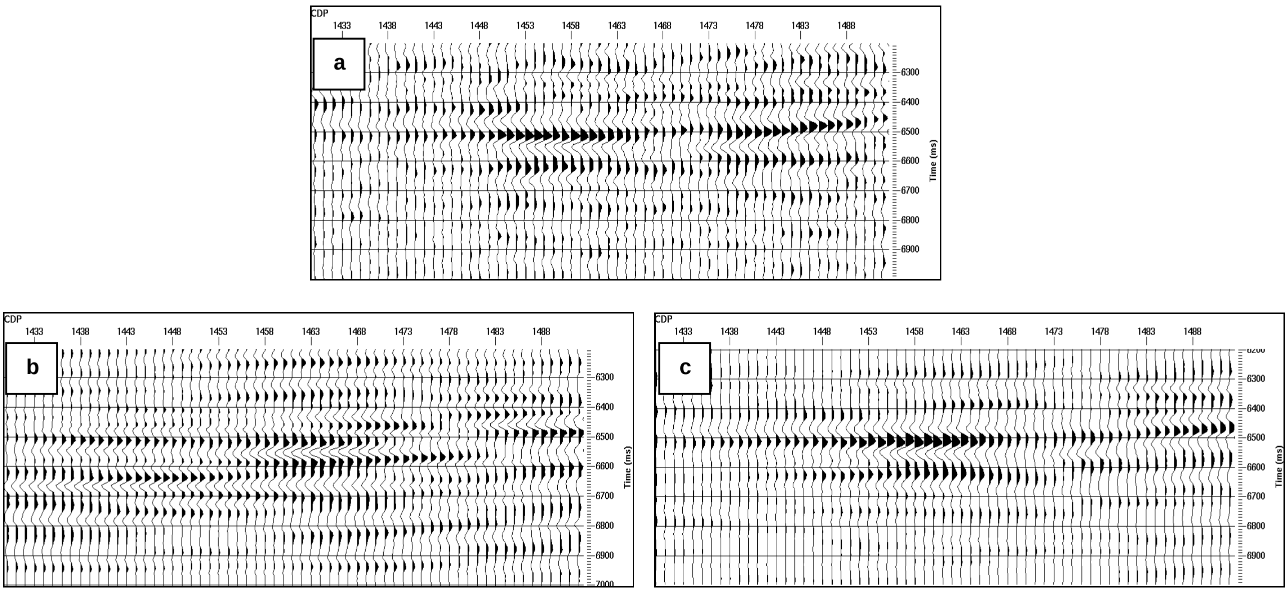

Figure 4: a) Detail of the multiple in Figure 3a; b) detail of the estimate of the multiple and c) the same after matching.