Application of Inverse Scattering Series Method for Internal Multiple Attenuation – a case study

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SUMMARY

Internal multiples due to a series of subsurface impedance contrasts are commonly observed in seismic data acquired in various places such as the Gippsland Basin of Australia and the Santos Basin of Brazil. The origin of these impedance contrasts can be due to coal seams as in the case of the Gippsland Basin or geological unconformities as in the Santos Basin. Regardless of how they are generated, internal multiple reflections often pose problems to the interpretation of geological structures. They are not easily handled by conventional de-multiple methods such as Radon Transform because internal multiples often have little difference in moveout than their corresponding primary events, or predictive deconvolution because the multiple generators, and hence the multiple period, are often not known.

In this paper, we present a case study of applying inverse scattering series (ISS) based method for attenuating internal multiples. The ISS method is a data-driven approach that can predict all internal multiples of a given order without any priori knowledge of the multiple generators. Moreover, it does not require any information about the subsurface velocity field. We discuss the application of this method for handling internal multiples in Santos Basin data, and present results on both the synthetic and field data from the Tupi oilfield. The results show that the internal multiples are well predicted and, with a suitably constrained subtraction technique, the migration artifacts caused by these multiples are greatly suppressed resulting in much clearer migration image for interpretation.

Key words: Internal multiple, Inverse scattering

INTRODUCTION

Internal multiples are the multiply reflected events in the measured wavefield that have experienced downward reflections below the free surface. The order of an internal multiple is defined by the total number of downward reflections it has experienced. Generally, internal multiples have relative weak amplitude compared with primary events and surface related multiples. That is why internal multiple attenuation is normally not a routine process included in most of the data processing workflow. Nevertheless, the presence of these multiples can pose problems to reservoir characterization due to associated migration artifacts in seismic images. This has been observed in seismic data acquired in places such as the Gippsland Basin of Australia where coal seams are the source of the internal multiple generators and the Santos Basin of Brazil where geological unconformities are the source for downward reflections. With the increasing demand for high quality seismic data processing to meet the exploration challenges, such internal multiples cannot be neglected since they degrade seismic images and hence hinder interpretation.

Removal of this kind of multiples is not easily handled by conventional de-multiple methods such as Radon Transform because internal multiples often do not exhibit sufficient moveout, or predictive deconvolution due to the fact that multiple period is seldom known. Various methods have been developed over the years to address this issue, e.g. Weglein *et al.* (1997), Verschuur and Berkhout (1997), Jakubowicz (1998), Pica and Delmas (2008). The convolution-correction based method (Verschuur and Berkhout, 1997 and Jakubowicz, 1998) is a sophisticated data-driven approach which can be used to attenuate all internal multiples generated by a specific horizon that causes the downward reflections. This method has been successfully used in the field survey to improve the image quality (Hemdb *et al.*, 2010). Many iterations of modeling are required, however, when there are multiple generators. Model based method (Pica and Delmas, 2008) has also been suggested for handling internal multiples. It has an advantage of modeling all the possible internal multiples from a migrated seismic image but the image needs to be free of multiples in the first place. The methodology based on inverse scattering series (ISS) (Weglein *et al.* 1997) is claimed to be able to predict internal multiples of certain order from all possible generators without the need of interpretative intervention. The downside of the method is that it is computational intensive. But with the increasing usage of graphics processing unit (GPU) for seismic data processing, it becomes apparent that ISS can be a viable solution for internal multiple suppression.

In this paper, ISS based method (2D case) is implemented and applied for attenuating internal multiple in seismic data that was acquired from the Santos Basin. Both the synthetic and field data tests show encouraging results. With constrained adaptive subtraction technique, the internal multiples in both cases are greatly attenuated.

METHOD

ISS based method is derived from the scattering theory, and can be understood by considering the relationship between forward and inverse scattering. Four tasks - surface multiple removal, internal multiple removal, imaging and inversion - can be derived from scattering series by matching task-specific subseries to their corresponding tasks (Weglein *et al.*, 1997). For internal multiple suppression, the input data is assumed to be free of coherent noise such as source and/or receiver ghost events, direct waves and surface related multiples. In the process, ISS requires the knowledge of source signature as well as extrapolated near offset traces for multiple modeling.

ISS based method can predict all order of internal multiples D_{IM} through infinite subseries as shown in Equation (1) (Weglein *et al.*, 1997):

$$D_{IM}\left(k_g, k_s, \omega\right) = \left(-2iq_s\right)^{-1} \sum_{n=1}^{\infty} b_{2n+1}\left(k_g, k_s, q_g + q_s\right) \quad (1)$$

where k represents horizontal wavenumber and q is vertical wavenumber. They satisfy the relationship of $k^2+q^2=(\omega/c_0)^2$, where ω is angular temporal frequency, and c_0 represents reference velocity (water velocity for marine surveys). Subscripts g and s stand for geophone/hydrophone and source respectively. More attenuators, denoted by b_{2n+1}, are included in Equation (1) for more accurate prediction of the multiple. The first attenuator b_3 is used for mainly attenuating the first order internal multiple. It is shown in the following equation:

$$\begin{aligned} & b_3\left(k_g, k_s, q_g + q_s\right) \\ & = \frac{1}{(2\pi)^2}\int_{-\infty}^{\infty} e^{-iq_1\left(z_g - z_s\right)} dk_1 \int_{-\infty}^{\infty} e^{iq_2\left(z_g - z_s\right)} dk_2 \\ & \times \int_{-\infty}^{\infty} e^{i\left(q_g + q_1\right)z_1} b_1\left(k_g, k_1, z_1\right) dz_1 \\ & \times \int_{-\infty}^{z_1+\varepsilon} e^{-i\left(q_1 + q_2\right)z_2} b_1\left(k_1, k_2, z_2\right) dz_2 \\ & \times \int_{z_2+\varepsilon}^{\infty} e^{i\left(q_2 + q_s\right)z_3} b_1\left(k_2, k_s, z_3\right) dz_3 \end{aligned} \quad (2)$$

where $b_1(k_g, k_s, z)$ is the pseudo migrated data using the reference velocity from $b_1(k_g, k_s, q_s+q_g)$, which is defined in terms of data D through Equation (3):

$$b_1\left(k_g, k_s, q_g + q_s\right) = -2iq_s D\left(k_g, k_s, \omega\right) \quad (3)$$

where D is the input data in frequency domain without the effect of the source wavelet, A (i.e. it has been deconvolved with A). z is the pseudo depth. z_s and z_g are source and receiver depth respectively. ε is a positive quantity to ensure that z_1 and z_3 are always greater than z_2. In practice, ε is slightly longer than source wavelet length. Higher order attenuators $b_{n=5,7\ \ldots\infty}$, can be formulated in the similar way that satisfy the "low-high-low" relationship for internal multiple modelling (Weglein *et al.*, 1997).

The first attenuator b_3 can predict the first order internal multiple with correct travel-time but the amplitude component is always less than the true value. The closed form of b_3 has been presented by Ramírez and Weglein (2008) to improve the amplitude prediction of internal multiples. But its effectiveness is highly dependent on the accuracy of source wavelet deconvolution. Including higher order attenuators in the modelling can enhance amplitude accuracy but at the expense of longer computational time. Therefore, our strategy is to use only the first attenuator b_3 in the modelling and then adaptive subtraction for handling the amplitude difference between the input and the model.

SYNTHETIC AND FIELD DATA EXAMPLES

The ISS based approach was applied on a 2D synthetic and field data from Santos Basin, offshore Brazil, where significant internal multiples are evident. Figure 1(a) shows the field data from a line close to the Tupi discovery. A series of impedance contrasts above pre-salt can be observed such as the water bottom (WB), top of salt (TOS) and the layered salt structures. All these reflectors are the generators of the internal multiples. A synthetic data, shown in Figure 1(b), was generated by acoustic modelling using the corresponding velocity from the field data. The density model was iteratively updated until the events in the synthetic data look close to those in the field data. The internal multiples, however, are amplified in the synthetic data so that they can be easily identified. The synthetic data in this case is used to illustrate and examine the effectiveness of the ISS method.

All internal multiples are predicted simultaneously and they are then adaptively subtracted from input data. The stack sections of input, subtraction result and their difference are depicted in Figure 2. The multiples around pre-salt, which mainly related to water bottom generator, are greatly attenuated. Some diffraction tails were not predicted correctly though due to aliasing. Those internal multiples generated from the top of salt and layered evaporites are also modelled. They are relatively weaker than the primaries, but still can be observed and attenuated from the synthetic data. The effectiveness of ISS method can further be illustrated by investigating the magnified near offset section (250m) shown in Figure 4. The corresponding results from the field data are displayed in Figure 3 and 5. It can be seen that most of the internal multiples have been modelled and attenuated although they are not as obvious as in the case of synthetic data because the multiples are much weaker in the field data. Moreover, the noise in the input field data degrades the performance of prediction and subtraction. Extending ISS to an 3D operation can improve the accuracy of multiple modelling.

To observe the effect of internal multiples on migration results, Kirchhoff time migration was performed on the synthetic and field data. Migration stacks before and after internal multiples suppression are show in Figure 6 for synthetic data, and Figure 7 for field data. Migration swings are greatly attenuated in the synthetic data. For the field data, internal multiple attenuation also helps in improving the quality of the image.

CONCLUSIONS

We have discussed the application of ISS based method for attenuating internal multiple in the data acquired from the Santos Basin. ISS method can predict internal multiples generated from all possible generators simultaneously, without requirement of any subsurface information. Both the synthetic and field data show that ISS is effective in suppressing the internal multiples. Further improvement such as anti-aliasing and input data precondition (e.g. denoise, statics removal and accurate source signature deconvolution) may enhance the effectiveness of modelling. Adaptive subtraction is still needed for compensating the inaccuracy in the source signature deconvolution process.

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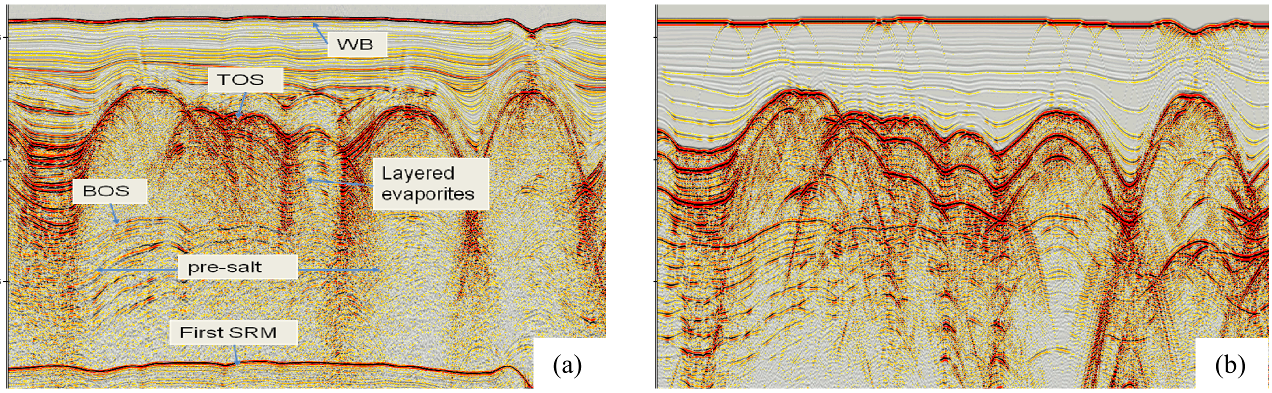

Figure 1. Near offset data of one line near the Tupi discovery which show strong internal multiples, (a) field data, and (b) synthetic data (Noted: WB is water bottom, TOS is top of salt, BOS is bottom of salt and SRM is surface reflection multiple.)

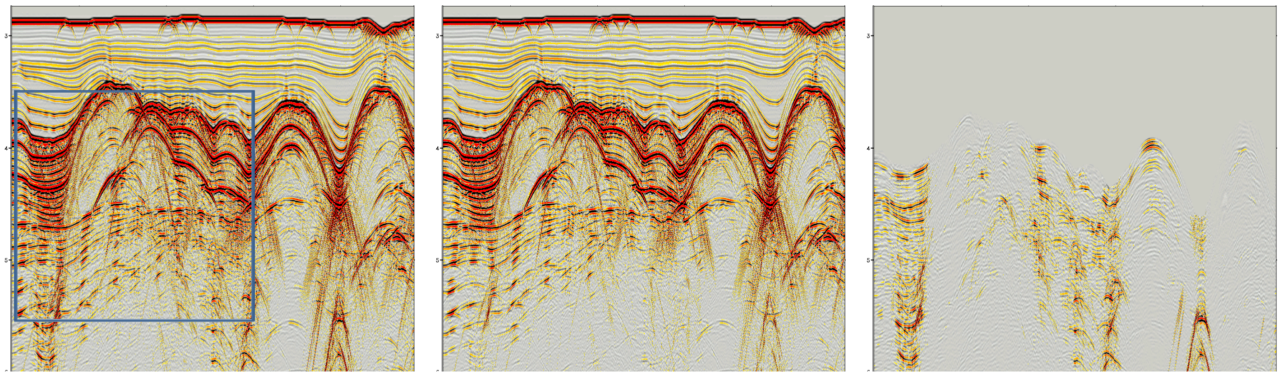

Figure 2. Brute stack of the synthetic data, (left) input, (mid) after internal multiple attenuation and (right) difference

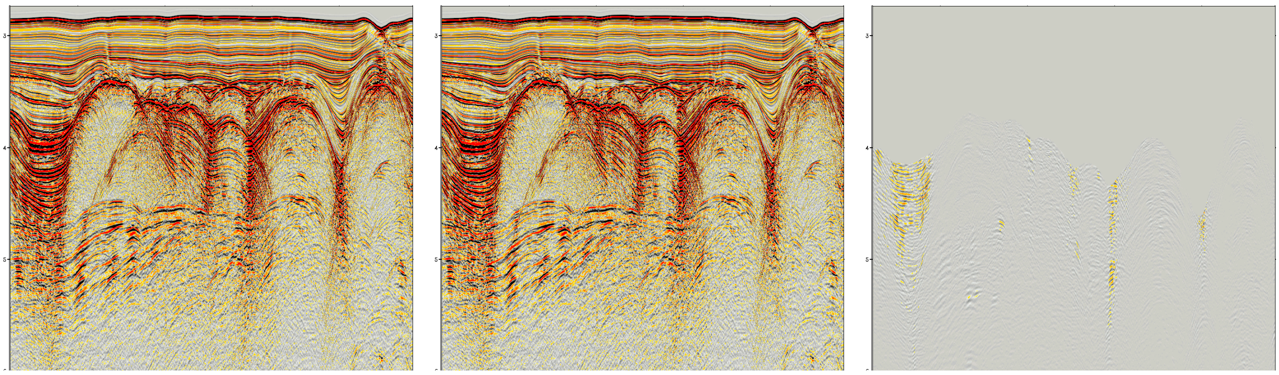

Figure 3. Brute stack of the field data, (left) input, (mid) after internal multiple attenuation and (right) difference

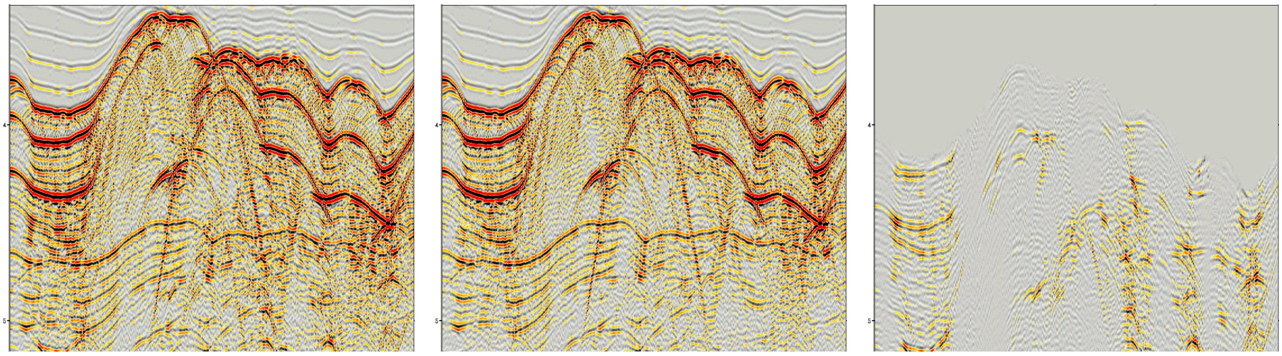

Figure 4. Near offset of the synthetic data, (left) input, (mid) after internal multiple attenuation and (right) difference

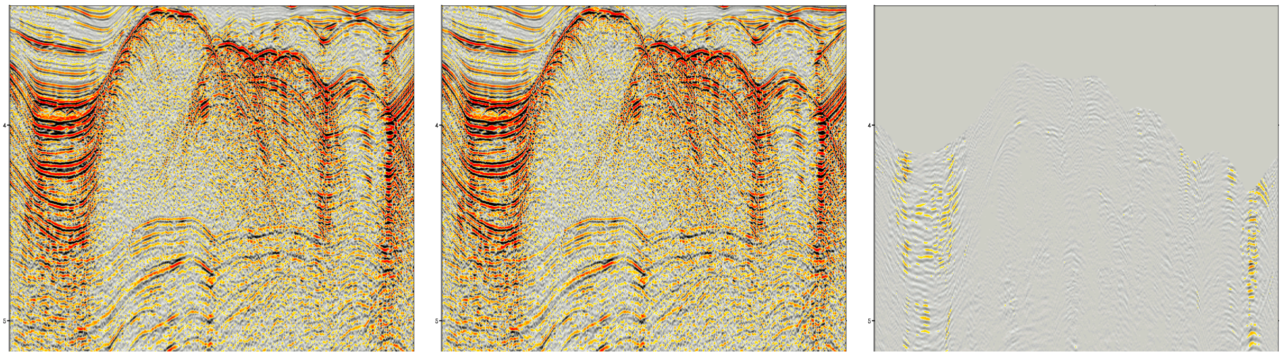

Figure 5. Near offset of the field data, (left) input, (mid) after internal multiple attenuation and (right) difference

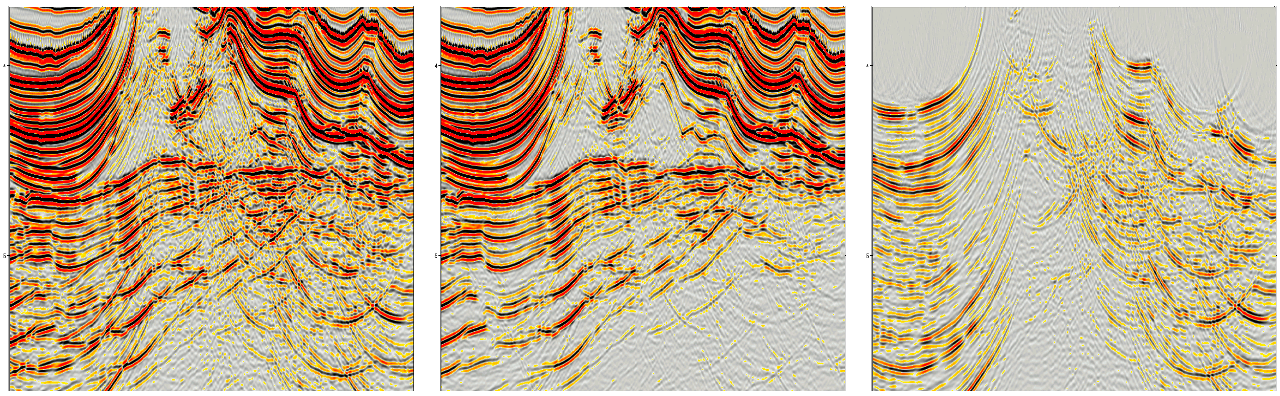

Figure 6. Migration stack of the synthetic data, (left) input, (mid) after internal multiple attenuation and (right) difference

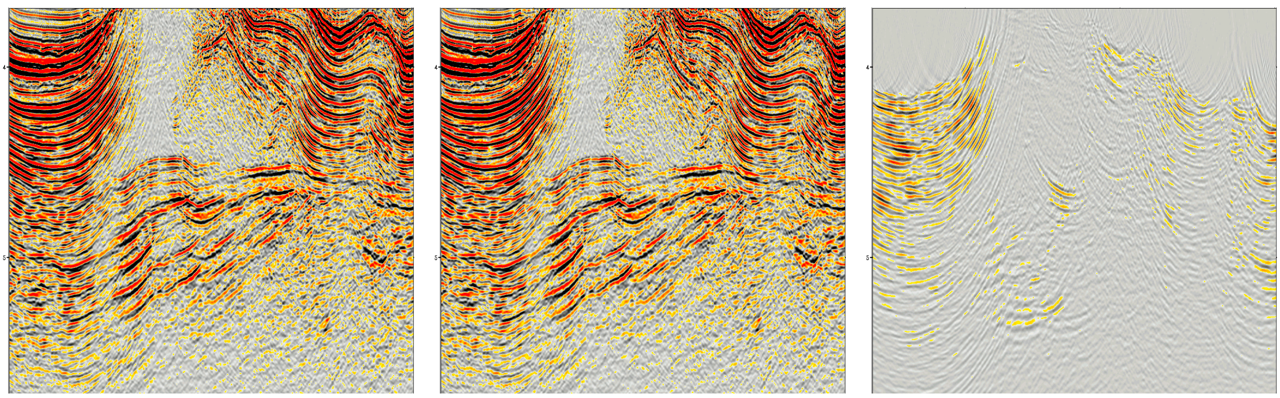

Figure 7. Migration stack of the field data, (left) input, (mid) after internal multiple attenuation and (right) difference (with 6 dB gain)