Internal multiple attenuation on Encana data

Qiang Fu and Arthur B. Weglein, M-OSRP, University of Houston

SUMMARY

The attenuation of internal multiple energy on land data is still one of the most challenging tasks in seismic data preprocessing. Low data quality and lack of velocity information of complicated structure (especially in near surface) on land data often result in poor predictions in many cases. Inverse Scattering Series (ISS) internal multiple attenuation is a very promising algorithm to attenuate internal multiple energy on land seismic exploration data. The key characteristic of this ISS-based methods is that they do not require any information about the subsurface, i.e., they are fully data driven. Internal multiples from all possible generators are predicted simultaneously from the input data. In this paper we apply Inverse Scattering Series (ISS) internal multiple attenuation algorithms on a land seismic data from Canada.

INTRODUCTION

Inverse Scattering Series (ISS) internal multiple attenuation is a data-driven internal multiple attenuation algorithm (Araújo et al., 1994; Weglein et al., 1997). The lack of any need for information about the medium through which the seismic wave propagates or the reflectors from which the internal multiples generate makes the algorithm feasible in areas with complicated geological structure. The algorithm predicts internal multiples for all horizons at once with no manual intervention required in the whole procedure. Weglein et al. (2003) provided a very comprehensive and detailed review on inverse scattering series applied on seismic exploration.

This ISS internal multiple-attenuation scheme is basically the first term in a subseries of the ISS that predicts the exact time and amplitude of all internal multiples without subsurface information. The ISS attenuation algorithm predicts the correct traveltimes and approximate amplitudes of all the internal multiples in the data, including converted-wave internal multiples (Coates and Weglein, 1996). Carvalho (1992) pioneered the free-surface ISS method and applied it to field data. Matson et al. (1999) were the first to apply the ISS internal multiple algorithm to marine towed-streamer field data. Matson (1997) and Weglein et al. (1997) extended the ISS methods for removing free-surface and internal multiples from ocean-bottom and land data. Fu et al. (2010) presented the first land field data example of ISS internal multiple algorithm. Terenghi (2011) showed a result of pre-stack field data internal multiple attenuation on Encana on-shore data.

THEORY

The ISS internal multiple attenuation algorithm in 2D starts with the input data, $D(k_g, k_s, \omega)$, that is deghosted and has all free-surface multiples eliminated. The parameters, k_g, k_s, and ω represent the Fourier conjugates to receiver, source and time, respectively. The ISS internal multiple attenuation algorithm for first order internal multiple prediction in a 2D earth is given by Araújo et al. (1994); Weglein et al. (1997):

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

The quantity $b_1(k_g,k_s,z)$ corresponds to an un-collapsed migration (Weglein et al., 1997) of an effective incident plane-wave data which is given by $-2iq_sD(k_g,k_s,\omega)$ The vertical wavenumbers for receiver, q_g, and source q_s, are given by $q_i = sqn(\omega)\sqrt{\frac{\omega^2}{c_0^2}-k_i^2}$ for $i=(q,s)$; c_0 is the constant reference velocity; z_s and z_g are source and receiver depths; and z_i $(i=1,2,3)$ represents pseudodepth.

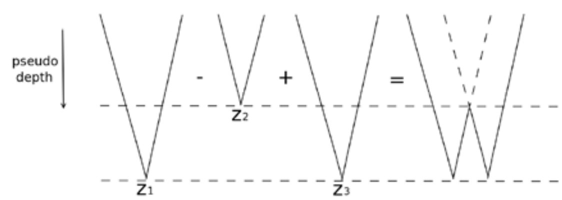

Figure 1: The sub-events of an internal multiple event. The internal multiple events(rightmost one) is constructed by three sub-events (left three) that satisfy the lower-higher-lower relationship in pseudodepth z_i $(i=1,2,3)$.

The construction of a first order internal multiple is illustrated in Figure 1. The first order internal multiple is composed of three sub-events that satisfy $z_1 > z_2$ and $z_3 > z_2$. The traveltime of the internal multiple is the sum of the traveltimes of the two deeper sub-events minus the traveltime of the shallower one. The parameter ε introduced in equation 1 to preclude $z_1 = z_2$ and $z_2 = z_3$ in the integrals. For band limited data, ε is related to the width of the wavelet. The output of equation 1, b_3, is divided by the obliquity factor and transformed back to the space-time domain. When we subtract the predicted internal multiples from the original input data (by adaptive subtraction), all first order internal multiples are attenuated and higher order internal multiples are altered.

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DATA AND METHOD CHOSEN TO ACCOMMODATE THE DATA

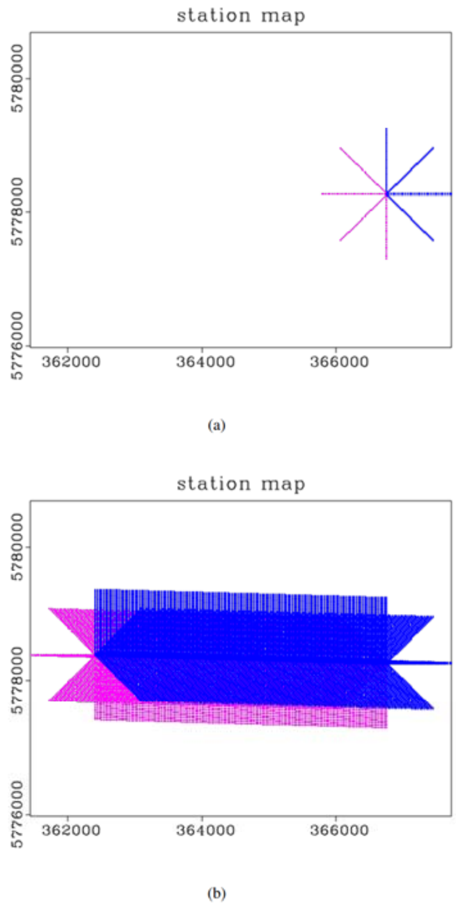

Figure 2: (a) Acquisition geometry map of the the first CMP gather of the data. (b) Acquisition geometry map of the whole Encana data. Red dots represent the source locations and the blue dots represent the receiver locations.

The Encana data is from the Western Canadian Sedimentary Basin, and it is situated over a restricted Devonian shelf basin. This shallow basin was initially connected to open marine waters. Pinnacle reefs grew in this marine environment and later filled with oil, making them a prime exploration target. The connection to the open marine later became restricted, causing the basin to fill with evaporates, which consist primarily of anhydrite today. The anhydrite acts as a lateral seal and cap rock for the porous reef reservoirs.

These reefs should be very easy to find in the seismic data. The basinal anhydrite produces a very strong peak reflection, but the response is almost reversed when there is a reef present, as the reef porosity has much lower acoustic impedance than the anhydrite. This is the case with the western part of this basin, where the reefs have all been found. On the East side of the basin, the situation is quite different. There, a Lower Cretaceous coal, which reaches 15 meters in thickness, produces severe multiple interference that obscures the entire Paleozoic section. Many reefs have been found there, but there have been many more dry holes drilled than successes, due to this interference. Most commercial multiple attenuation algorithms fail to remove this interference. Our goal here is to make the reefs clearly visible in seismic data in the East side of the basin as it does in the West side.

As mentioned in the previous section, Fu et al. (2010) tested the ISS internal multiple attenuation algorithm on the Arabian Peninsula land field data. Although Arabian Peninsula land field data in Fu et al. (2010) has better data quality, it also has much more complicated geological features. So it is hard to pick a single clear target to judge the internal multiple attenuation result. This Encana data is inferior in data quality (lower S/N ratio) and acquisition geometry (limited fold and offset range) comparing with the Arabian Peninsula data, but there is a very simple target or criterion - the disappeared target layer (the reef). The Encana data has four different azimuths, but this does not provide much help for the internal multiple attenuation task. Terenghi (2011) tested the same method on another Canadian field data, however, that data has large offset coverage.

The Encana data we use here is a multi-azimuth 2D survey line. Figure 2(b) shows the acquisition geometry of the data. And the geometry of the first CMP gather of this data is shown in Figure 2(a). All CMP stations of the data compose a straight line on the map, so this is a 2D survey line even though there are multiple azimuths in the data. The data is a relative old data (from mid 1990s), so it has a very low fold for each CMP gather (32 traces). The 2D ISS internal multiple predication algorithm requires a full coverage input (each shot gather has all receivers on the exact same stations, and we have a shot gather for each station. e.g. there is a trace between every stations pair.). If we want to perform the 2D ISS internal multiple predication, we would need to carry out a large amount of extrapolation to make a full 2D coverage data from the low fold data we have. That would not only be expensive for computation cost but also not reliable to ”make” so much data by extrapolation. Given the structures of the whole survey line is fairly flat, the 1.5D pre-stack method would be a suitable choice for the internal multiple attenuation task on this data. In equation 1 we have shown 2D ISS internal multiple attenuation algorithm. The 1.5D ISS internal multiple attenuation algorithm is a straight forward extension of 2D algorithm, which can be described as below

$$
\begin{aligned}
b_3^{1.5D}(k_x;\omega) = {} & \frac{1}{(2\pi)^4} e^{-iq(z_g-z_s)} e^{iq(z_g-z_s)} \\
& \times \int_{-\infty}^{+\infty} dz_1 b_1(k_x,z_1) e^{2iqz_1} \\
& \times \int_{-\infty}^{z_1-\varepsilon} dz_2 b_1(k_x,z_2) e^{-2iqz_2} \\
& \times \int_{z_2+\varepsilon}^{+\infty} dz_3 b_1(k_x,z_3) e^{2iqz_3}. \qquad (2)
\end{aligned}
$$

The notation in equation 2 are the same as the one in equation 1. If we compare it with the 2D version, the only difference is that in 1.5D formula the output has only one horizontal spatial wavenumber index k_x rather than two (k_g and k_s). This is obvious since under the 1.5D assumption (flat-layer medium), all horizontal incident wavenumber should be equal to the re-

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flected wavenumber ($k_g = k_1 = k_2 = k_s = k_x$). Hence there is only one horizontal spatial wavenumber k_x in equation 2.

RESULTS

Figure 3 and 4 show the input data in pre-stack and post-stack domains, respectively. As required by the ISS internal multiple attenuation algorithm, the data is first deghosted and has all free-surface multiples eliminated. In this case, the major multiple generator is the coal layer. We can see the reflector clearly in Figure 4 (in the vicinity of 1s) and the target layer (the reef) should be around 1.15s can not be seen in Figure 4.

Figure 5 and 6 show the internal multiple attenuation result in pre-stack and post-stack domains, respectively. The reference velocity c_0 used is the shallowest layer NMO velocity (averaged horizontally). After internal multiple attenuation, we can see that a significant amount of internal multiple energy is removed in the vicinity of 1.15s. However, we can still barely find the reef clearly. The result shows that there is marginal improvement of the target event after ISS internal multiple attenuation with this limited offset data.

Figure 7 and 8 are the predicted internal multiples in pre-stack and post-stack domains, respectively. Although the method knows nothing about the generator, the predicted internal multiples only appear below the main generator. Figure 7 shows the predicted internal multiples has primarily far offset component (with some near offset still visible). The near offset component is critical to obtain an effective internal multiple attenuation result. Therefore, the lack of near offset internal multiple prediction is an important reason we do not obtain very satisfactory result in this case. That is due to the fact that there is very limited offset coverage of the input data.

The data acquisition geometry consists of 4 different azimuths. We also tried to use the data of each azimuth separately and the results are not significantly different comparing the result by using data of all azimuths together. To use all azimuth data results a little better quality in the post-stack section and has 4 times higher fold comparing single azimuth data, which is increasing the S/N ratio.

CONCLUSIONS

We applied 1.5D pre-stack ISS internal multiple attenuation on Encana land seismic data and got marginal improvement of the target event. The result is not as satisfactory as the same ISS internal attenuation algorithm on the Arabian Peninsula data (Fu et al., 2010). This is due to the ISS internal multiple attenuation algorithm requiring a Fourier transform to be performed along the offset axis. That requires a reasonable offset range in the input data to avoid truncated effects. Considering the data acquisition geometry (32 traces per CMP gather and maximum offset 2000m), this is a positive and encouraging result. The ISS algorithm for the surface and internal multiple attenuation require reasonable data collection in terms of sampling and offset to be effective and to deliver its promise.

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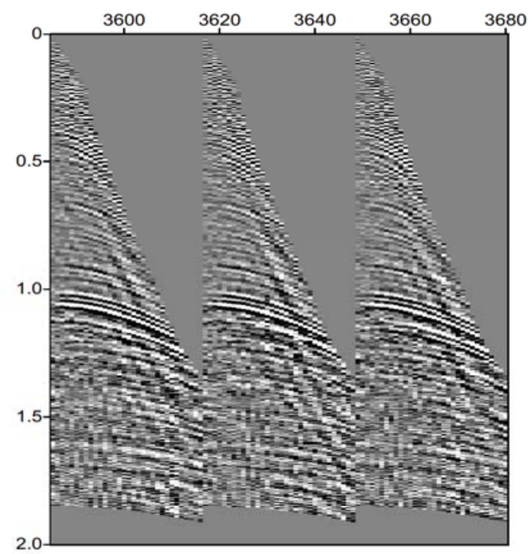

Figure 3: Three pre-stack gathers of of input data.

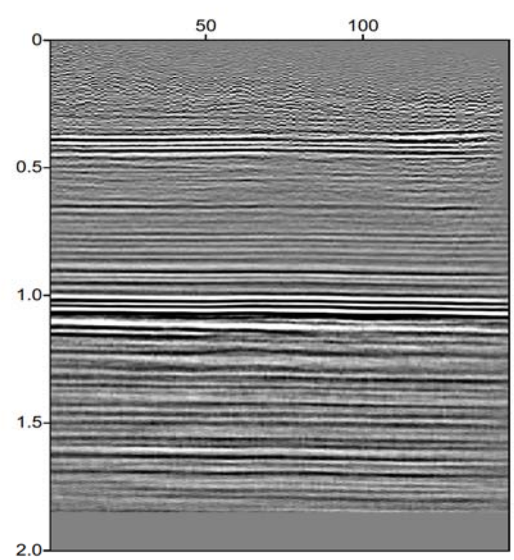

Figure 4: Stack section of input data.

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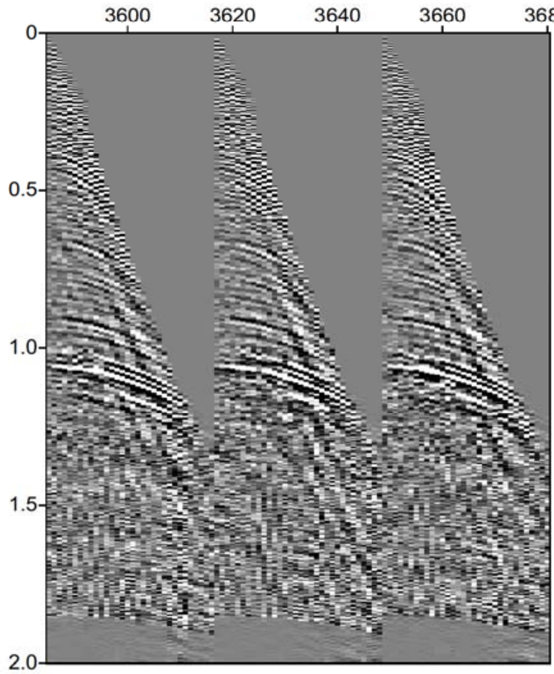

Figure 5: Three pre-stack gathers of internal multiple attenuation result.

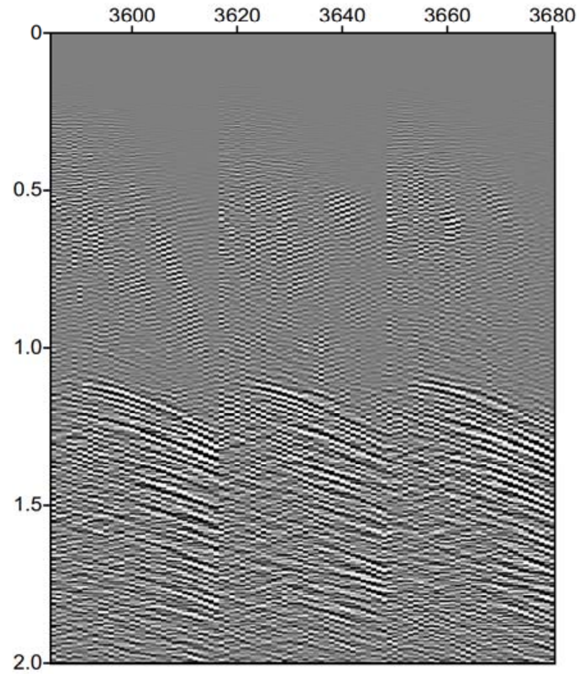

Figure 7: Three pre-stack gathers of internal multiple prediction.

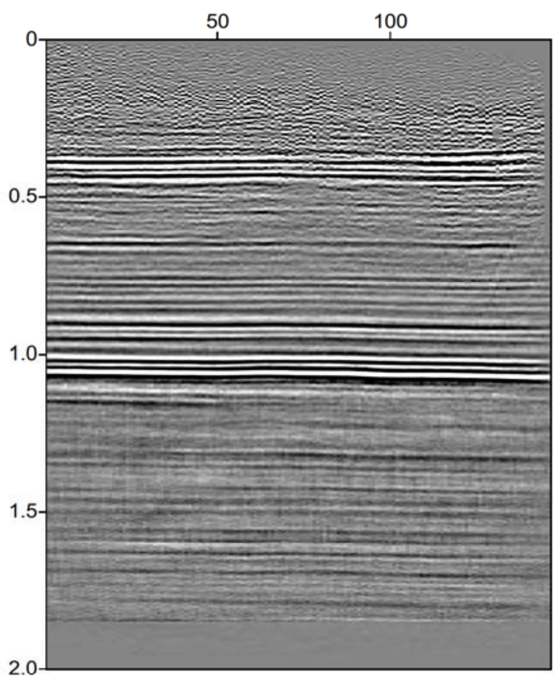

Figure 6: Stack section of internal multiple attenuation result.

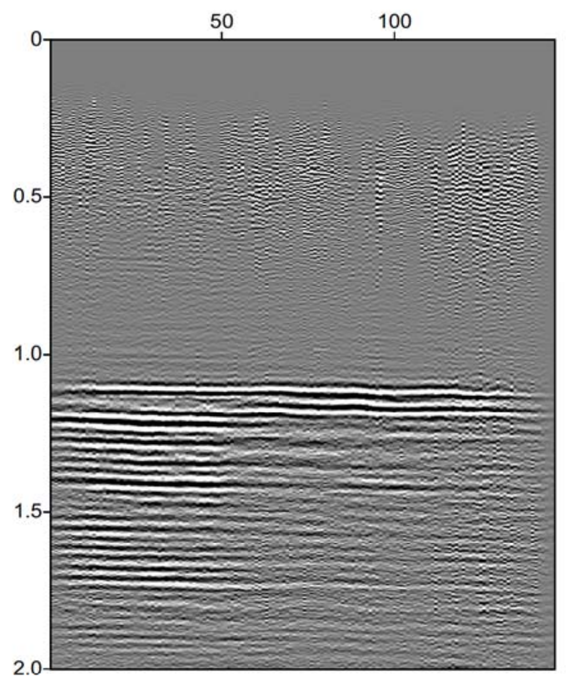

Figure 8: Stack section of internal multiple prediction.

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