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Internal Multiple Attenuation on Radial Gathers With Inverse-Scattering Series Prediction

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Summary

We present a novel workflow for pre-stack prediction and attenuation of internal multiples, applicable to data acquired with orthogonal survey geometries with mild structural variations. First, we interpolate the data pre-stack (5D) data to common midpoint (CMP) gathers with regular sampling in offset and azimuth. Such CMP gathers are suitable for noise attenuation as shown in previously published case studies. Next, we predict internal multiples in radial gathers (common midpoint and common azimuth gathers). We use the leading term of the inverse scattering series to perform the algorithm called inverse-scattering series internal multiple prediction (ISIMP) and obtain a pre-stack model of internal multiples without input of subsurface information. We follow the prediction of internal multiples with multidimensional adaptive subtraction and apply this workflow to data from the Cooper basin, Australia. We note that the transformation to the radial domain has been a key enabler for this workflow.

Introduction

The case study area is located in the Cooper basin in the northeastern part of South Australia, where a broadband, full-azimuth, orthogonal land survey was acquired using point-source and point-receiver acquisition technology designed to deliver dense spatial sampling (Bilsby et al., 2014). Figure 1 shows a comparison of the standard processing of legacy conventional data with the latest processing of the point-source point-receiver data.

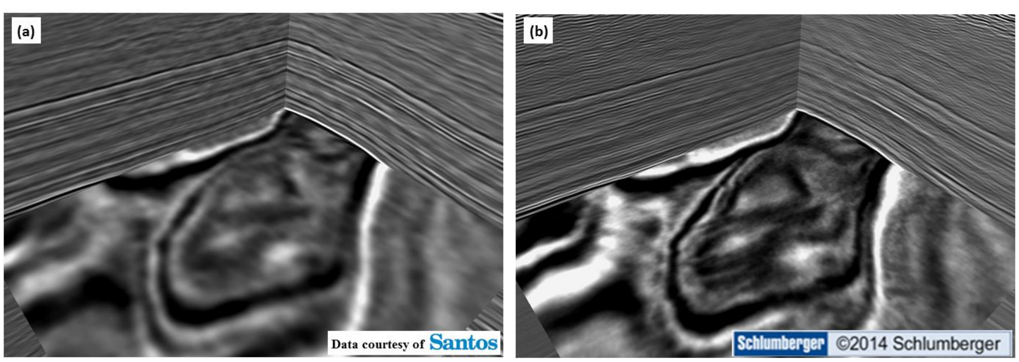

Figure 1. Inline, crossline and timeslice from final migrated cube after: (a) standard processing of legacy data, (b) latest processing of the point-source and point-receiver acquisition data (Bilsby et al., 2014).

The integration of the point-source, point-receiver acquisition design and data processing technology is a fundamental component of the overall data enhancement strategy. It enables the development of specialized coherent and random noise attenuation workflows combined with new geometry interpolation and regularization techniques, which in turn are important to develop an effective multiple attenuation workflow. The new interpolation and regularization scheme allows the application of processing techniques that require regular distribution of offsets over a single gather, a difficult requirement to meet for orthogonal land geometries.

Processing seismic data contaminated with internal multiples is challenging for every onshore survey. High and low impedance contrasts over formations are known to generate internal multiple events that will interfere with the primary reflection information from the seismic data, making interpretation and reservoir characterization ambiguous over the target zone. This particular phenomenon is quite common in the Middle East and North Africa (El-Emam et al., 2001), but is observed in any number of onshore surveys with layered formations. Velocity-based attenuation methods fail to attenuate internal multiples due to lack of velocity discrimination between the underlying primaries and multiples. Data-driven prediction algorithms followed by adaptive subtraction have been proven to be more effective (Wu et al., 2011).

ISIMP on Radial domain gathers

The inverse scattering series internal multiple prediction (ISIMP) algorithm is a completely data-driven method: it does not require a priori information about the subsurface, such as major interfaces generating the internal multiples or the velocity field (Fu et al., 2010). Given a downward multiple generation zone, the algorithm predicts all the internal multiples originating from this interval at once. This internal multiple-attenuation scheme is basically the leading term in a sub-series of the inverse scattering series that predicts the exact time and approximate amplitude of all internal multiples, including converted-waves internal multiples (Coates and Weglein, 1996).

Let $D(k_x,\omega)$ be the input data free of system wavelet variations and free-surface multiples. k_x and ω represent the Fourier conjugates to offset and time, respectively. Assuming a dataset with relatively flat structure geology, the ISIMP algorithm for a given common midpoint location and a 1D Earth (1.5D mode) can be written below

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

This method is a straightforward extension of the 2D algorithm devised by Weglein et al. (1997) for a flat-layer medium (Pan et al., 2014). The quantity $b_1(k_x,z)$ corresponds to an uncollapsed migration of an effective incident plane-wave given by $-2iqD(k_x,\omega)$, and the vertical wavenumber $q = sqn(\omega)\sqrt{\frac{\omega^2}{c_0^2} - k_x^2}$; c_0 is the constant reference velocity; and $z_i(i = 1,2,3)$ represents the pseudodpath. The user parameter ε is used to preclude $z_1 = z_2$ and $z_2 = z_3$ in the integrals, and relates with the width of the wavelet for band-limited data. The main advantage of the 1.5D mode over the normal incidence (1D mode) is the ability to correctly predict internal multiples at different offsets, without the need of prior prediction with a zero-offset correction (Xavier de Melo et al., 2014). The 1.5D algorithm is gather based (shot or common midpoint) and requires regular offset spacing on the input gather. The acquisition geometry needed to produce this spatial sampling is, for all practical purposes, not achievable in the field.

Regular sampling in offset can be achieved by applying a 5D interpolation workflow based on the approach presented by Gamal Eldin et al. (2014). Input data originally acquired from the orthogonal survey are interpolated so that the azimuth and offset are regularly sampled for all midpoint locations. This so-called radial domain interpolation (Figure 2) is crucial for 1.5D ISIMP algorithm since it provides uniform offset sampling at each azimuth. After interpolation the prediction is done for each common midpoint and common azimuth gather.

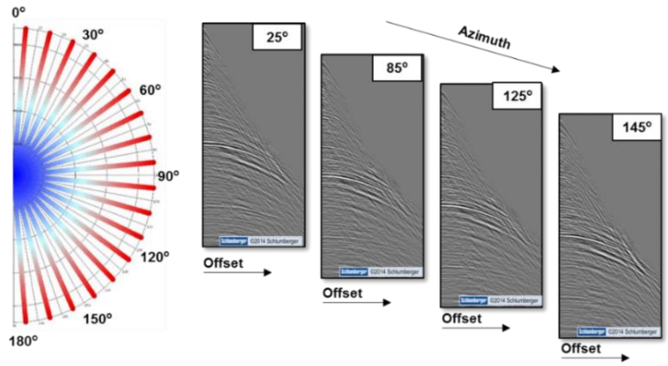

Figure 2. Radial domain gather over a given midpoint. The diagram on the left shows a top-view of trace locations. A selection of common azimuth gathers is displayed on the right. Internal multiples are predicted on each gather independently with the ISIMP algorithm.

A multidimensional adaptive subtraction framework is applied, with windows and matching filter computation based on azimuth, offset, midpoint and time domains, providing a better matching constraint from models predicted in different radial gathers. The multidimensional adaptive subtraction also addresses the variation of internal multiples across azimuths, since ISIMP predictions are computed on each azimuth sector separately.

Examples

The survey was recently reprocessed so that the distortion of the signal and internal multiples is minimized, better preparing the data for 5D interpolation and ISIMP. Borehole information suggests that all formations between the near-surface (~0.2 s two-way traveltime – TWT) until Hutton Sandstone (~1.7 s TWT) may contribute to generate internal multiples between 1.2 s and 2.2 s TWT, a trend of potential multiple generators.

Application of ISIMP prediction is done in the radial domain after time imaging. Migrated gathers had inverse moveout applied to the gathers prior prediction and grouped as common-image-point and common-azimuth gathers. The 1D layered Earth assumption is a reasonable approximation due to the relatively simple structure with little overburden dip present across the data. The multidimensional adaptive subtraction matches the predicted model with the internal multiples present in the field data taking into account the azimuth, offset, midpoint and time for data/model windowing and filter computation. Adaptive subtraction is parameterized in such a way as to minimize signal distortion, while maximizing the removal of the internal multiples.

Common image point (CIP) gathers and semblance plots in Figure 3 show the attenuation of the internal multiple energy present in the data, leaving most of the strong primaries untouched and revealing weak ones, previously hidden by internal multiples. Semblance plots also show that the overall velocity trend after ISIMP internal multiple attenuation is better defined, making easier to define the correct primary velocity field, especially on events below 2.1 s.

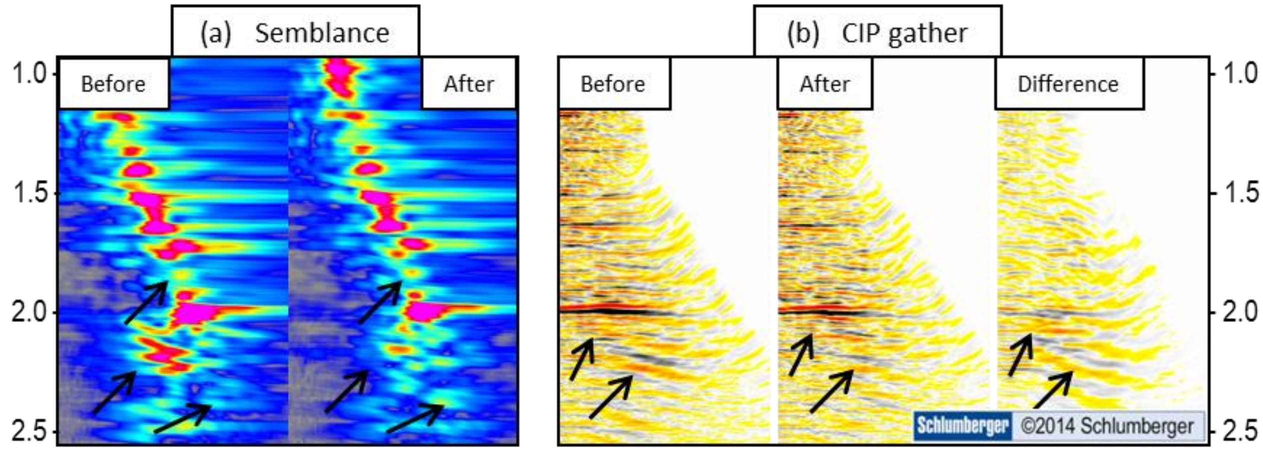

Figure 3 a) Semblance panels and (b) CIP gathers before and after multiple attenuation. Arrows indicate where strong multiples are removed. Semblance shows major improvement after 2.1 seconds.

Figure 4 shows an inline image sections before and after the ISIMP internal multiple attenuation. The mild multidimensional subtraction shows a general improvement in continuity and resolution of weak reflections, indicating that the interfering multiple events are being attenuated across the whole section.

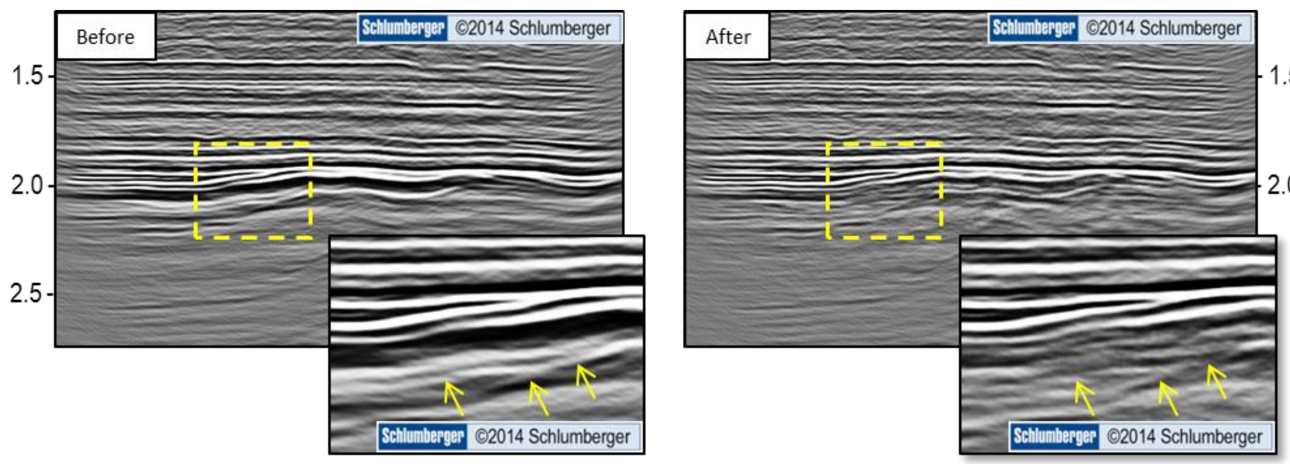

Figure 4 Stack section before (left) and after (right) multiple attenuation. Arrows show places where the major multiple interferences are attenuated. See also the corresponding time interval around 2 seconds on the semblance plot results shown on Figure 3.

Conclusions

Broadband point-source point-receiver land acquisition combined with advanced processing made possible the usage of the ISIMP algorithm for internal multiple prediction. The 5D radial interpolation is a crucial part of the processing workflow as it allows us to make use of the 1.5D ISIMP. Adaptive subtraction results show a clear improvement on semblance and stack when compared with the data before multiple attenuation, revealing events that could not be previously seen due interference of internal multiples

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