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Robust Interbed Multiple Modelling and Attenuation for Variable-Density Surveys Onshore Oman

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Summary

Pre-stack multiple modelling and attenuation remains a significant challenge for processing and imaging of onshore seismic surveys. Due mainly to noise in the data, as well as irregular and incomplete spatial sampling, pre-stack applications seem to lag behind the relatively complete theories available to model internal multiples. In practice, generation of inaccurate multiple models that are subsequently adapted to the data can easily cause signal damage where dip discrimination between primaries and multiples is low. This is often diagnosed by appreciable distortion of the multiple model during adaption. Using data from onshore Oman, pre-stack multiple modelling and attenuation performed with variations of the predictive deconvolution and correlation-convolution methods produce accurate multiple models that undergo little distortion during adaption. The methods appear robust for pre-stack use, with the eventual aim of both structural and AVO analysis of the data. Results were achieved with careful attention to the mechanics of the data-driven predictions, and by limiting the freedom of the methods to react to noise in the gathers. Improvements to the stability of AVO analysis were due particularly to increased fidelity of near-angle data.

Introduction

Methods relating to internal multiple modelling and attenuation are relatively well developed in concept (Berkhout and Verschuur, 1997; Weglein, 1999). However, practical application to noisy and irregular land data remains a significant challenge for seismic processing and imaging onshore. This is particularly so for pre-stack applications in which subsequent analysis of Amplitude Variation with Offset (AVO) is a key objective. In this paper we discuss the problem of modelling and attenuating internal multiples in a set of merged surveys with different acquisition parameters onshore Oman (Figure 1). The final images are produced from five constituent surveys, comprised of approximately 22 billion traces, with variable density and array-formed properties that affect their relative noise levels. The handling of noise is key to accurate pre-stack multiple attenuation.

The survey area has a near-horizontally layered structure in the overburden with dipping reflectors at the reservoir. Time-varying autocorrelations (Figure 2) show a strong short-period reverberation throughout the data. Since this period develops early in the seismic record, it is thought to arise from a generator in the near surface. Predictive Deconvolution After Stack, DAS, (Taner, 1980) works well with this reverberation (Figure 3), but has minimal impact when applied pre-stack. Attempts with Internal Scattering Series, ISS, methods (Weglein et al., 1997), land-SRME (Wang and Wang, 2013), and surface-consistent deconvolution were also ineffective pre-stack, potentially due to noise in the gathers. Finally, application of post-stack deconvolution operators to pre-stack data (Gulunay and Benjamin, 2008) was difficult to control in respect to its AVO behaviour and response to noise. In the following paragraphs we describe a simple but robust solution to the multiple attenuation problem.

Method

The first process is referred to as “deconstructed deconvolution”, and seeks to emulate the success of DAS but with pre-stack application. It is similar to the method of Gulunay and Benjamin (2008), but with tightly controlled deconvolution filtering. The method requires characterisation of the short-period reverberation across the survey area. Autocorrelation analysis of stacks from each survey produced a set of reverberation time-periods and autocorrelation amplitudes for each image location. These time-periods and amplitude scalars were sense-checked using a controlled deconvolution with the full stack (Figure 3). This process simply shifts the stack by the spatially-variable autocorrelation time-periods, and scales the result by the autocorrelation amplitude prior to adaptive subtraction. Results show first that the raw model does not undergo significant kinematic distortion or modification of amplitudes during adaption to the input stack data, and second that the performance is similar to the DAS result produced with a 60 ms gap and 140 ms active operator length.

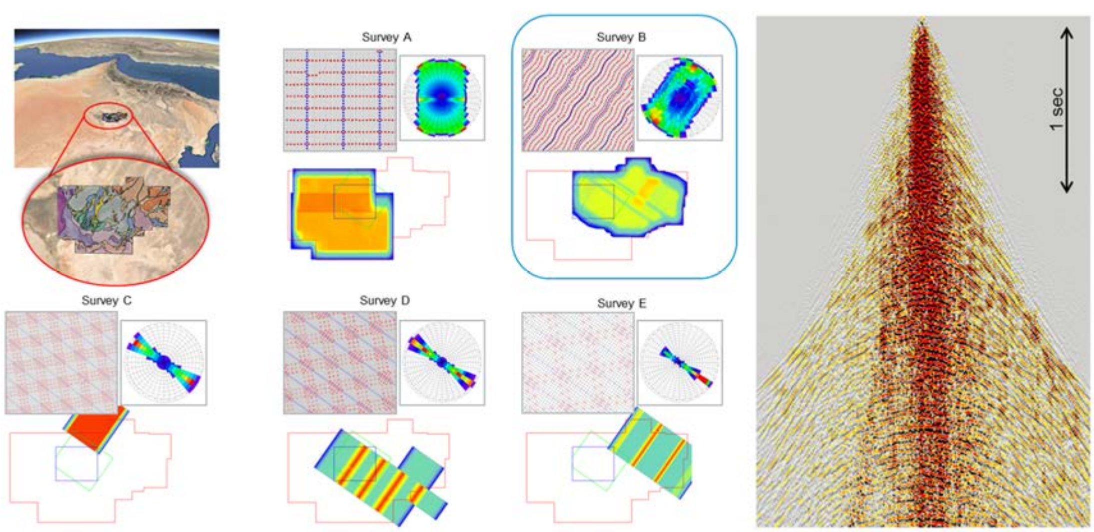

Figure 1 *(Left) Survey location in Oman with representations of acquisition geometry in the five constituent surveys. (Right) Example shot gather from the array-formed Survey B.*

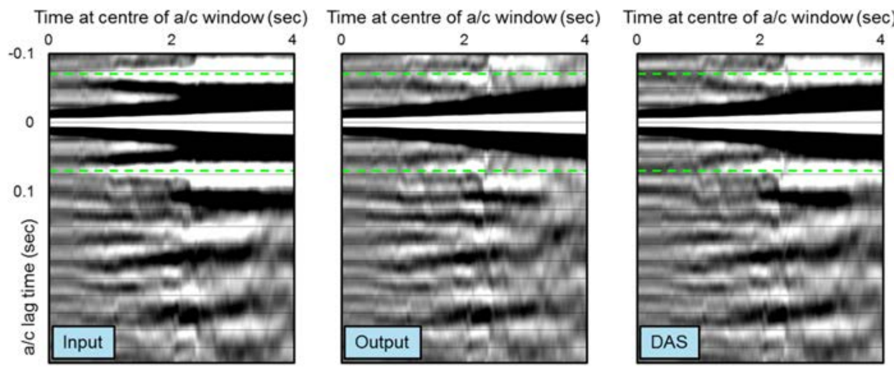

Figure 2 *Time-variant autocorrelation (a/c) analysis using 0.5 sec sliding windows in the full stack before (input) and after (output) multiple attenuation with the deconstructed deconvolution method, and predictive deconvolution after stack (DAS). Dashed green lines mark 70 ms.*

To emulate these encouraging results pre-stack, the autocorrelation analysis was repeated on near, mid, and far angle stacks, with resulting time-periods and amplitude scalars interpolated to a finer set of angles sufficient to describe the pre-stack data. This produced a deconstructed-deconvolution operator with natural spatial and angle variation. Use of partial-angle stacks helped mitigate the effects of noise, and enabled the target reverberation to be characterised in the same way for data recorded with different acquisition geometries. Gathers were then regularised to a geometry suitable for 3D f-kx-ky transform and sparsified to reduce noise levels. The sparse data were phase shifted by $e^{ik_z\Delta}$ where $i^2 = -1$, $k_z = \left(\frac{\omega^2}{v^2} - {k_x}^2 - {k_y}^2\right)^{1/2}$ is the vertical wavenumber for angular frequency ω, and $\Delta = \tau v$ where τ is the picked autocorrelation reverberation period at the centre of the gather and v is a constant near surface velocity estimate consistent with results of first-break refraction tomography. Tests using the value of τ from other locations around the gather showed only small changes, as the τ function is slowly varying in space. The phase-shifted data were scaled by the picked autocorrelation amplitudes according to their mid-point coordinate and estimated reflection angle, and underwent a 2-stage adaption process. First the sparse phase-shifted and scaled data were adapted to the sparse version of the input data using medium-length filters and 2 second adaption windows to prevent over-adaption of the model. Second the result was mapped back to the coordinates of the input gather then adapted to the raw data with short filters and 1 second adaption windows designed to minimise local distortion. Results (Figure 4) show comparable performance to the simpler post-stack application, and to the DAS, albeit with a cleaner multiple model than was obtained with those post-stack methods. Conversely, Deconvolution Before Stack (DBS) again performed poorly by comparison, with the output stack showing little net difference to the input.

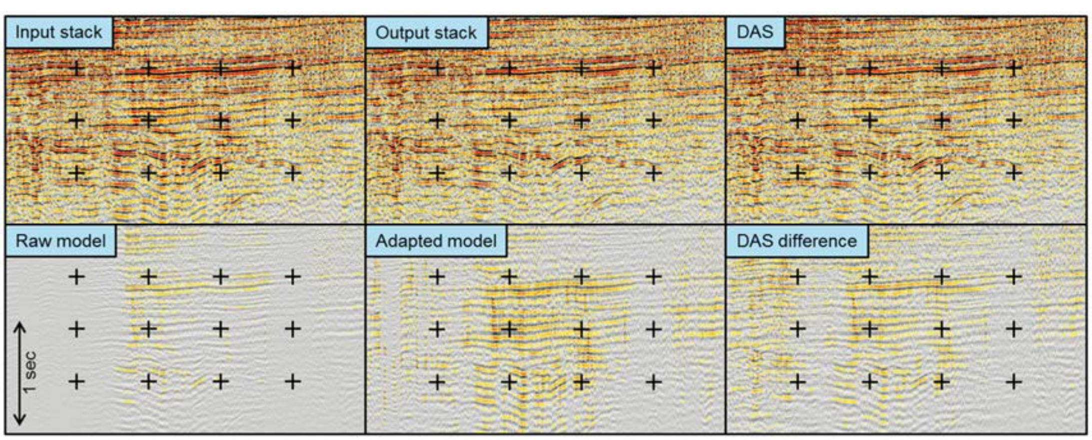

Figure 3 *Full stack without multiple attenuation (input), then after post-stack predictive deconvolution (DAS) and after post-stack deconstructed deconvolution (output). The deconstructed deconvolution multiple model does not change significantly during adaption.*

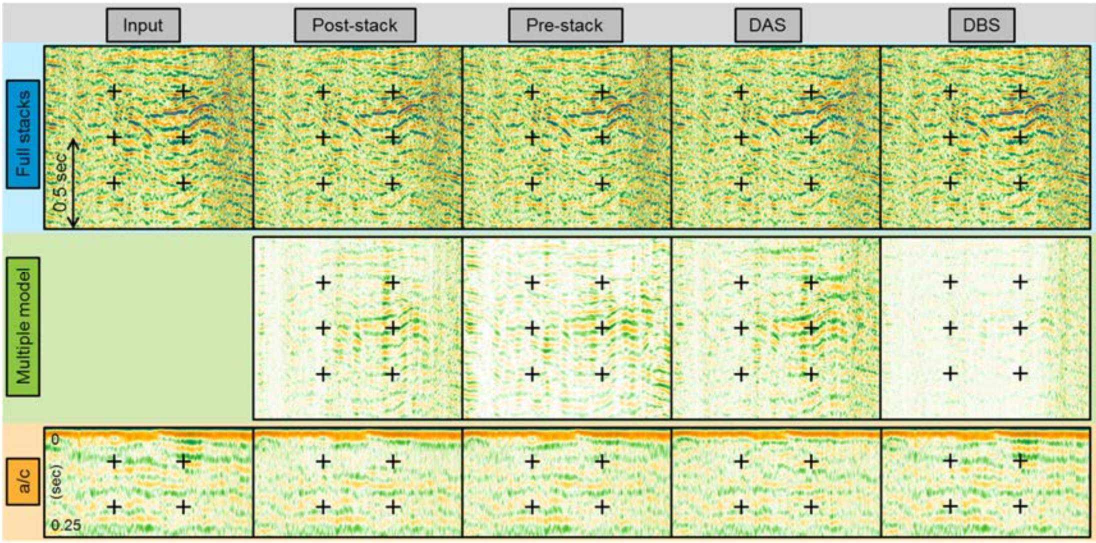

Figure 4 *Stacks before and after multiple modelling and subtraction using the deconstructed deconvolution method (post- and pre-stack), with comparison to predictive deconvolution post (DAS) and pre (DBS) stack. a/c denotes autocorrelation functions.*

Having attenuated the strong short-period reverberation, residual multiples were then visible from carbonate layers located above the reservoir. This time, an attempt with 1.5D ISS was more successful (Figure 5), but still produced a noisy model which altered significantly during adaption. This is attributed to pre-stack noise levels accumulating through the large number of multiple generator combinations incorporated in ISS. Furthermore, it is not clear to what extent the free-surface multiples had been removed, as required for ISS. The intra-carbonate multiples were thus handled in common-offset classes using a modified form of the correlation-convolution method (Jakubowicz, 1998). Using trace-by-trace correlations, a multiple prediction filter was produced from windows of data around the suspected upgoing and downgoing generators, which was then convolved with the data to produce a multiple model. The accuracy of the model was seen to improve when the multiple prediction filter was warped to the autocorrelation of the reverberations visible at target depths. The warping step alters the kinematics of the events in the prediction filter to fit more closely with the observed reverberations in the data. The warped prediction filter is then convolved with the data to produce a multiple model which is stable, in that its kinematics are not much altered in subsequent adaption (Figure 5). Application in common-offset classes captured the pre-stack variability of the data.

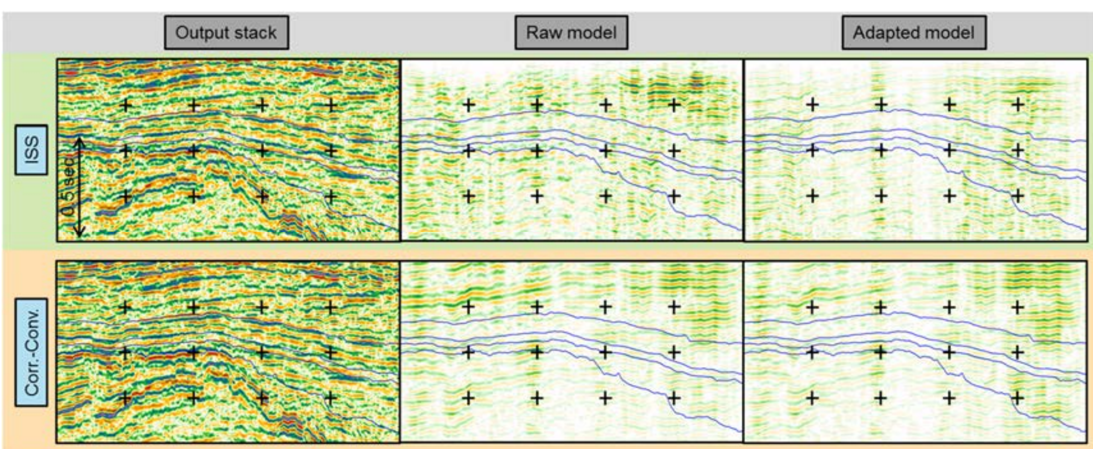

Figure 5 *Comparison of results from a 1.5 dimensional pre-stack application of ISS and the modified correlation-convolution method. Note the low levels of distortion of the correlation-convolution multiple model during adaption. The ISS model undergoes more distortion.*

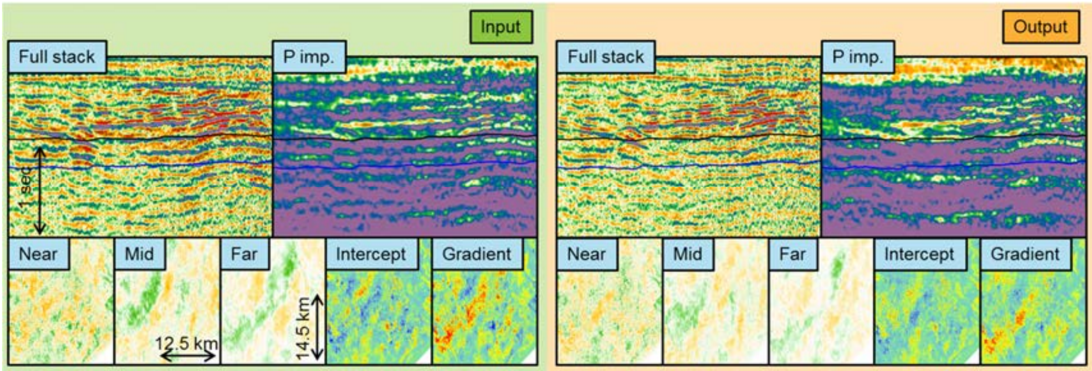

Figure 6 *Full stack results and P impedance (from AVO inversion of partial-angle stacks) before and after multiple attenuation. The AVO intercept and gradient maps from the top reservoir horizon respond well to multiple attenuation, mainly due to improvement of the near stack.*

Results

The combined effect of both the pre-stack deconstructed deconvolution and the modified correlation-convolution methods is a dataset with significantly attenuated multiple suitable for AVO analysis (Figure 6). Improvements to the data, particularly the near stack, lead to improved impedance volumes from AVO inversion as well as increased spatial stability to the AVO intercept and gradient.

Conclusions

Noise in onshore data makes the application of elegant pre-stack multiple modelling and attenuation methods difficult. This is compounded by variability in acquisition configurations that can alter noise characteristics and signal sampling between surveys in the same area. Application of a pre-stack deconstructed deconvolution technique, with careful treatment of the modelling and adaption steps in data onshore Oman, performed robustly on gathers with results comparable to post-stack predictive deconvolution. Subsequent processing with a modified form of the correlation-convolution technique further removed multiples interfering with reservoir-depth arrivals, producing a net result of pre-stack multiple attenuation that is good for both structural interpretation and AVO analysis.

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References

Berkhout, A.J. and Verschuur, D.J. [1997] Estimation of multiple scattering by iterative inversion, Part 1: theoretical considerations. *Geophysics*, **62**, 1586-1595.

Gulunay, N. and Benjamin, N. [2008] Poststack driven prestack deconvolution (PPDEC) for noisy land data and radial trace mixing for signal enhancement. *SEG Technical Program*, 2507-2511.

Jakubowicz, H. [1998] Wave equation prediction and removal of interbed multiples. *SEG Technical Program*, 1527-1530.

Taner, M.T. [1980] Long period sea-floor multiples and their suppression. *Geophysical Prospecting*, **28**, 30-48.

Weglein, A.B. [1999] Multiple attenuation: an overview of recent advances and the road ahead. *The Leading Edge*, **18**, 40-44.

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

Wang, J., and Wang. S. [2013] Practical strategies for data-driven land multiple attenuation. *SEG Technical Program*, 4101-4105.