Attenuation of multiple diffractions using a cascaded noise removal sequence

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Introduction

Multiple diffractions are a significant noise problem on seismic data from many of the world's most important hydrocarbon-rich provinces. These noises are most prevalent in the case of deep water and a complex near-surface reflection sequence. In such regimes the multiples of diffracted energy by the near surface geology are often coincident in time with primary reflections within the subsurface. The energy composing the primary reflections will have a considerably reduced amplitude and frequency content due to the long travel-paths through the Earth; in contrast the multiples from the near-surface reflectors have travelled most of their propagation path through the very weakly absorbing sea-layer. Thus the deeper parts of the seismic section are dominated, particularly at high frequencies, by the incoherent, high amplitude diffracted multiple arrivals. Due to their aliased, non-hyperbolic nature these arrivals are difficult to suppress using standard demultiple methods e.g. 2-D SRME, parabolic Radon demultiple.

It has been shown that the use of high-fold, multi-azimuth data acquisition can considerably increase the effectiveness of CMP stacking in removing diffracted multiple energy (Widmaier *et al.*, 2002); however, for standard marine acquisition, a rigorous noise attenuation methodology must be adopted. Indeed, while techniques such as 3-D SRME hold great promise for multiple diffraction attenuation (van Borselen *et al.*, 2004), in this paper we discuss how for typical field data a cascaded sequence of (up to) four different processes can be used to attenuate the problem events (Figure 1).

The process of noise removal using a 3-D weighted slant stack (NS3D) is documented in Martinez *et al.* (2000) and Martinez (2003). In brief, a sub-volume of a given dataset is transformed using a 3-D weighted slant stack (where the weights are, in general, smoothed inverse power of trace amplitudes) and then inverse transformed to an output trace at the centre of the volume. This process results in the suppression of steeply dipping coherent, incoherent and impulsive noise. In the examples that follow the input dataset to the NS3D process is a volume with shot on one horizontal axis and channel on the other. The NS3D process is used to remove the incoherent, steeply dipping diffracted multiple energy while preserving the coherent primary events (Figure 2).

Multiple Diffaction Attenuation

Multiple diffraction attenuation (MDA) is an innovative processing technique designed to attenuate high-energy reverberations of near-surface diffractions. The method utilises a pattern recognition technique to separate the high-amplitude diffracted multiple arrivals from the underlying primary energy. The separation is based on the different frequency, amplitude and phase characteristics of the two types of events. By utilising all these characteristics, the process may be finely tuned to the particular nature of the diffracted multiple energy in any given geological regime.

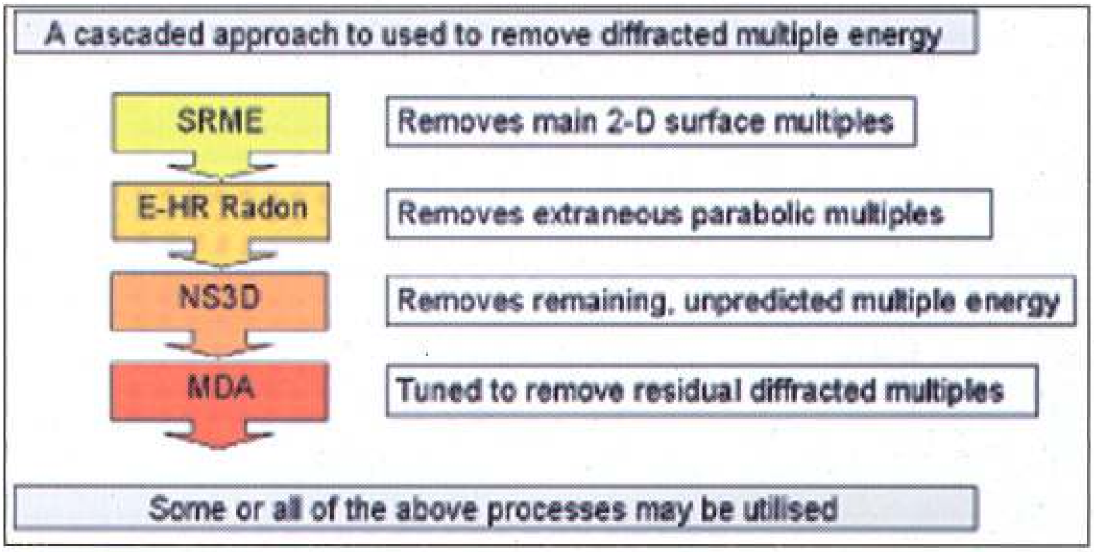

Figure 1. Summary of the cascaded approach to diffracted multiple attenuation.**3-D weighted slant-stack**

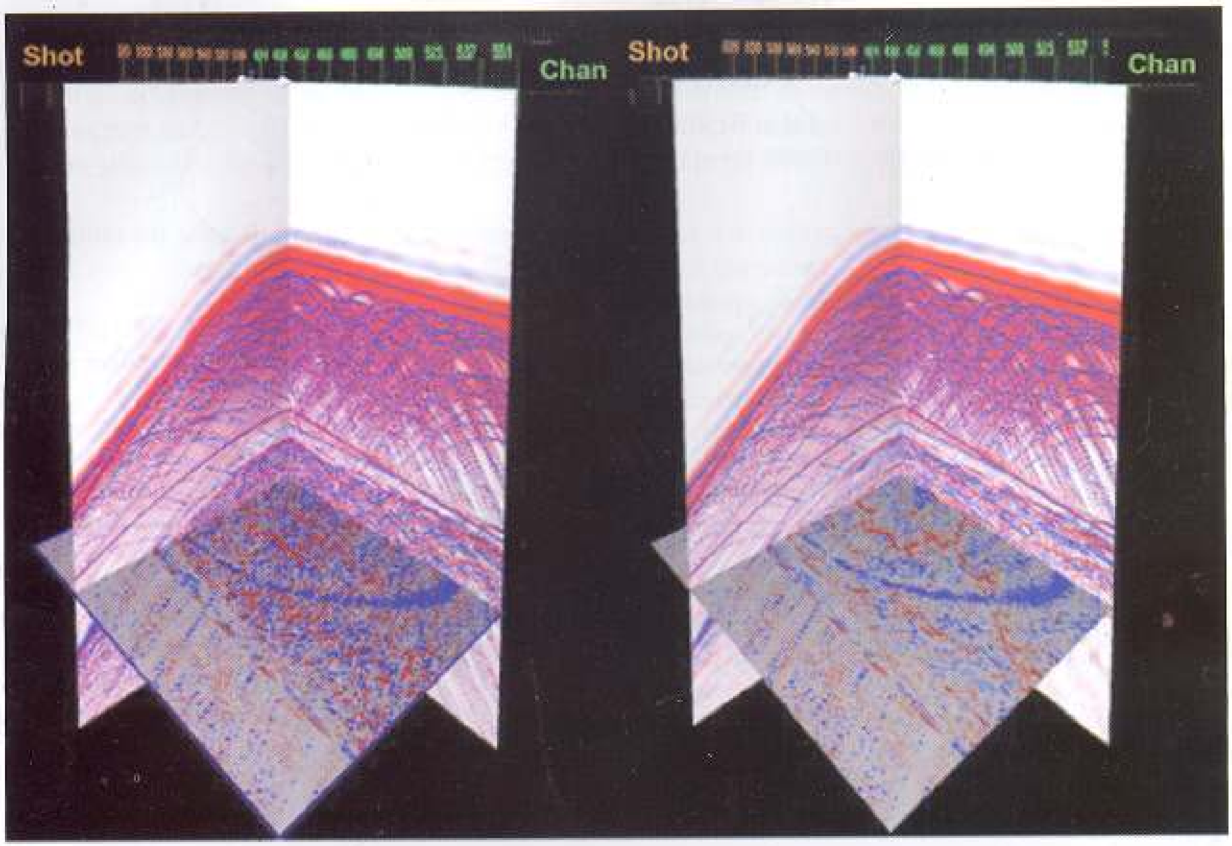

Figure2: (a) Shot/channel volume from a synthetic seismic dataset after the application of 2-D SRME; (b): The same volume after the application of 2-D SRME and NS3D. Note the reduction in the diffracted multiple energy due to the 3-D weighted slant stack.

Synthetic example

The synthetic dataset was generated using 3-D ray tracing over a model containing five smooth, flat or gently dipping reflectors. The model also contained one hundred and forty point diffractors that were pseudo-randomly distributed in the second layer of the model situated 150 m below the seabed. An NMO stack of the input dataset is shown in Figure 3. The first process applied to the synthetic dataset was a 2-D Surface Related Multiple Elimination (Verschuur and Berkhout, 1997; King *et al.*, 2000). While the 2-D SRME process appeared to predict well the strong water bottom multiple, it was evident that the complex diffracted multiples were not well predicted (in either phase or amplitude). The poor prediction of the out-of-plane diffracted multiples is not a surprise; indeed, this is a general phenomenon of the method that has been noted in the literature (e.g., Kabir and Abma, 2003). The ideal solution for this problem would be a 3-D SRME type approach, however for many acquisition scenarios (especially reprocessing work) the coarseness and limited aperture of the crossline sampling may still mean that the diffracted multiples are not well predicted.

The application of enhanced high-resolution Radon based methods to these data suggested that, while some effect can be seen on the pre-stack data, the improvement on the stacked data was less marked. This may be explained by the observation that due to the aliased and non-hyperbolic nature of the multiple arrivals, the residuals and artefacts left by Radon processes tend to be high amplitude samples at near offsets. The application of both a non-standard parameterisation of parabolic Radon demultiple and a shifted-apex Radon demultiple algorithm (Hargreaves *et al.*, 2003) on this dataset showed improvements over the standard high-resolution Radon demultiple result, however, while improving the multiple attenuation both processes also increased the level of primary attenuation. It was therefore decided to only apply 2-D SRME and NS3D. The result (Figure 4) shows that the majority of the multiple energy has been removed and the underlying K72 primary is now clearly interpretable.

As a result of the nature of the synthetic datasets, the amplitude behaviour with offset of the primary events is a known quantity. It is therefore possible to use this attribute to quantify the primary preservation of our chosen demultiple processing. This process was undertaken by measuring the RMS amplitude in a 50 ms window about the K72 primary event (Figure 4). This event was chosen as it is overlain by both the coherent water-bottom multiple and the incoherent diffracted multiples. The result of the analysis suggests that the SRME and NS3D processing flow preserves the relative amplitudes of the primary events (Figure 5).

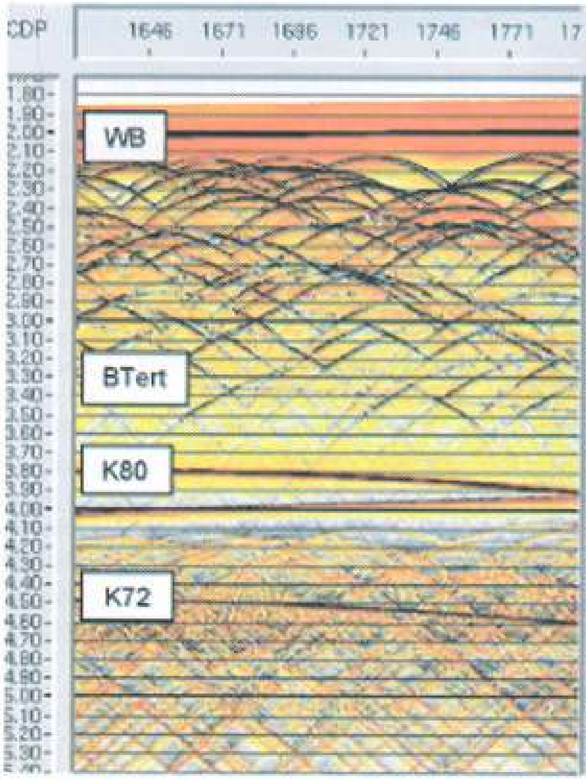

Figure 3. NMO stack of raw synthetic dataset

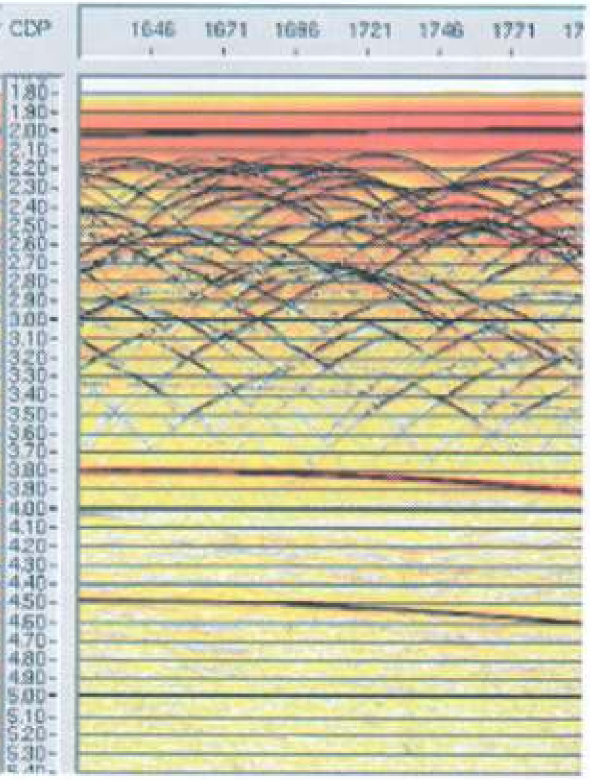

Figure 4. Synthetic data set after the application of 2-D SRME and NS3D.

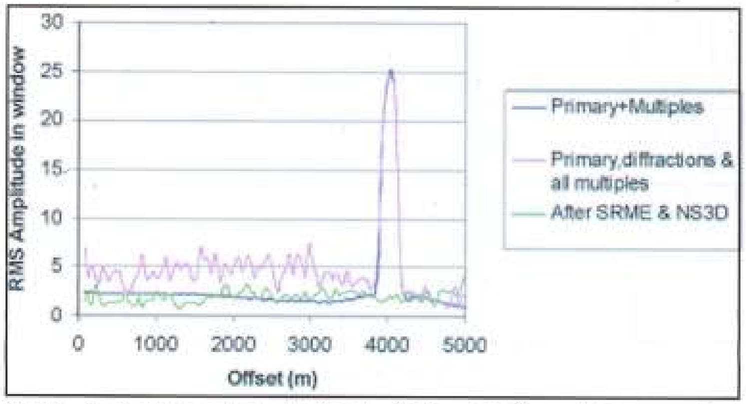

Figure 5. Typical amplitude plot for the K72 event before and after processing. The amplitudes were measured in a 50ms window about the event on a typical shot record from the synthetic dataset. The magenta line shows the event amplitude before demultiple. The dark blue line shows the true amplitude behaviour of the event when there are no multiple diffractions in the dataset. The jitter on the magenta line is due to the interference of the diffracted multiple arrivals whilst the large peak in the plot at approximately 4000m offset is the water bottom multiple crossing the primary event. An ideal (primary-preserving) demultiple process would result in an amplitude plot that closely follows the dark blue line (except at the crossing of the water bottom multiple). The green line shows the amplitude behaviour after the 2-D SRME and NS3D processing flow and appears to indicate good preservation of relative primary amplitudes.

Field examples

The processing sequence was tested on a number of field datasets. A section of the NMO stack of one of the field datasets is depicted in Figure 6. All the field datasets exhibited a strong water bottom and sub-water bottom multiple sequence and Figure 6 clearly illustrates the diffracted multiple energy that contaminates the deeper parts of the section. The testing suggested that a sequence of 2-D SRME followed by enhanced high-resolution (E-HR) Radon demultiple, NS3D and MDA gives the optimum level of multiple energy attenuation on the field datasets (Figure 7). In contrast to the preferred processing applied to the synthetic dataset, a comparison of the pre-stack gathers with and without the intermediate Radon demultiple shows that at pre-stack level the Radon process significantly reduces the remnant multiple energy level. This difference may be a result of the field datasets containing more in-line multiple diffraction generators than the synthetic data. In addition, the synthetic data did not contain any internal multiples.

In general, it may be observed that on all field datasets a multi-stage demultiple approach is required to adequately suppress the diffracted multiple energy. Utilising NS3D and MDA within such a multi-stage demultiple significantly reduces the remnant multiple on both the pre-stack and post-stack datasets. The reduction in remnant pre-stack multiple may well be crucial for any pre-stack data analysis (such as velocity picking, AVO and even pre-stack time migration).

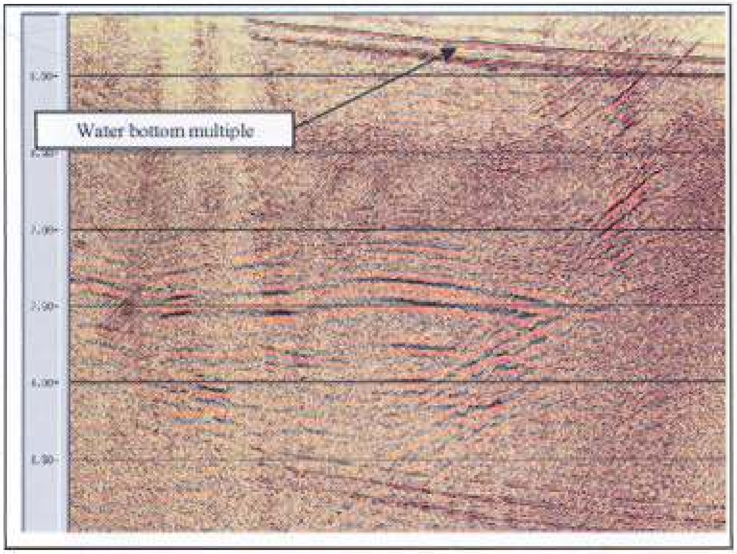

Figure 6. Section of the raw NMO stack from one of the field datasets. discontinuous, dipping diffracted multiple energy can be seen across the section.

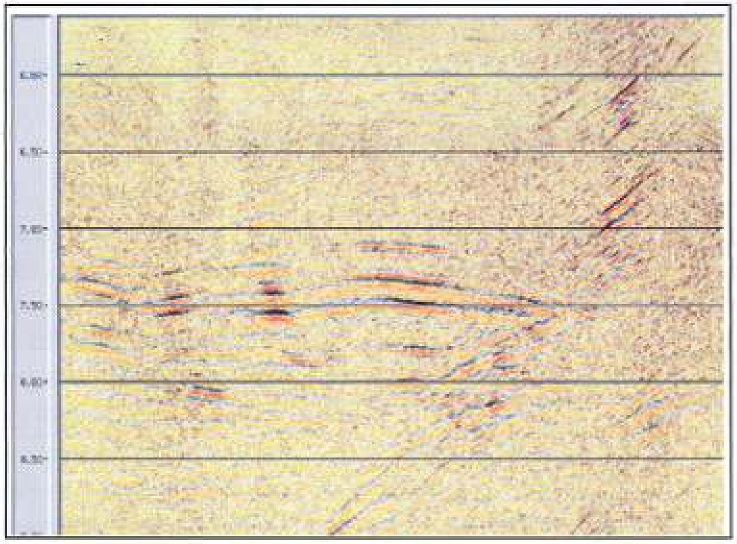

Figure 7. Section of the NMO stack of one of the field datasets after the application of 2-D SRME, E-HR parabolic Radon demultiple, NS3D and MDA. This stack should be compared with the input data in Figure 4.

Conclusions

This paper illustrates that the use of both a 3-D weighted slant stack noise attenuation procedure and a pattern-recognition based process can have significant benefits when attempting to suppress diffracted multiple energy. These processes appear to be most beneficial when applied in a cascaded demultiple sequence containing 2-D SRME and (optionally) high resolution parabolic Radon demultiple. Studies employing synthetic data have shown that primary amplitudes are well preserved by the process.

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