Shallow Reverberation Prediction Methodology with SRME

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SUMMARY

It is well known that surface-related multiple elimination (SRME) breaks down when applied to shallow water datasets. The prediction is distorted at the reconstruction stage by the NMO stretch of the seabed, progressing to the loss of seabed information beyond the critical distance. Furthermore, the adaptive subtraction (multiple elimination) struggles when several orders of the predicted short period reverberation are present, within a given design window for minimization, as the predicted amplitude (and phase) between multiple orders from a single convolution of the data with itself are incorrect.

This abstract describes a novel seabed modelled SRME approach with regards to predicting simultaneously and non-iteratively both the amplitude and phase of simple and pegleg source and receiver-side sea layer reverberation correctly with minimal distortion for moderately undulating shallow seabeds.

Using a shallow water dataset from the Central North Sea, it is demonstrated that the 3D approach can replace more limited 1D τ-p shot-based deterministic multiple prediction techniques to form part of a multi-model multiple prediction strategy that includes iterative SRME where appropriate.

Introduction

Shallow water layer dereverberation remains one of the key challenges in seismic data processing. Particularly in areas where there are strong primary multiple generators in the overburden, the success of multiple elimination algorithms depends heavily upon their underlying assumptions and/or a priori information. A data-driven multiple prediction scheme, such as surface-related multiple elimination (SRME), makes no use of any a priori information about the subsurface geology, and is an established technique to remove complex multiples from the data. However, at the multiple prediction step, SRME assumes internal data consistency (Moore and Bisley, 2006), in that the surface multiple formed by combining any two events in the input dataset must also be present in that dataset. For shallow water datasets, this requirement is not met as the extrapolation of the very shallow recorded overburden, particularly the seabed primary, is distorted as the necessary wavefield reconstruction to zero offset is typically performed by a differential NMO operator. As offset approaches the critical distance, for which reflection occurs at the critical angle, any meaningful seabed information is finally lost.

A common solution to ensure internal consistency for SRME is to model the water layer, and adopting a novel implementation of this approach is described in more detail in the following section. Furthermore, it will be demonstrated that amplitude (and phase) between multiple (reverberation only) orders from a single convolution of the data with a suitable ray traced model can now be predicted correctly ensuring optimum minimization at the adaptive subtraction (multiple elimination) stage. In subsequent sections, synthetic results as proof of concept, followed by a field data example and some concluding remarks are presented.

Method

In the North Sea, the critical distance coincides with the differential NMO-based trace extrapolation to zero offset breaking down for the overburden just below the seabed (Figure 1). Modelling (ray tracing) the sea layer and convolving it with the recorded data is an effective approach for reverberation prediction as the source and receiver-side pegleg multiple contributions move closer to the original input source and receiver locations as the seabed gets shallower (Figure 2). Also bandwidth is not distorted, when the ray tracing is based on a spike, as the recorded input that it is convolved with still has the embedded wavelet information that forms part of the minimization at the elimination step. However, before this method is described further, a brief review of reverberation and current industry SRME solutions needs to be covered first.

Marine reverberation is generated just within the sea layer only (simple) or from a deeper primary (pegleg). The decay of the simple and pegleg reverberation series are not the same and, assuming a flattish earth, has led to the development of non-linear deterministic approaches over predictive deconvolution in the τ-p domain as both are present in the overburden. For the sake of brevity, only the pegleg reverberation that typically masks the target will be analysed further in this abstract although the method proposed extends to simple reverberation. A 1D pegleg reverberation series from deeper primaries is the result of all the possible combinations of source and receiver-side water layer pegleg multiples (Figure 3). Assuming internal data consistency is honoured, a single convolution of the data with itself will produce all the possible combinations of two recorded events leading to over prediction (Figure 4). If the seabed is modelled instead, the number of multiple contributing combinations is reduced (Figure 5), although not to the extent of the predicted pegleg reverberation decay being the same as the recorded input (Figure 6, second and last columns). Note that internal data consistency is still not achieved if the seabed primary is muted, to reduce extrapolation distortion, as key multiple contribution information is lost (Figure 6, eighth column).

The over prediction from a single convolution of the data with itself is due to only computing the first term of a series expansion of the feedback model for surface multiple generation. A theoretical solution for progressively incorporating the higher terms is to perform SRME iteratively (Berkhout and Verschuur, 1997). Consequently the iterative SRME approach has been adopted for variants of the water layer modelled approach described above by various workers (for example, Jin *et al.*, 2012) although there is an additional compute cost and the performance of the adaptive subtraction step for each iteration may be data dependent affecting the next one.

An alternative solution proposed in this abstract is to utilize and scale the over prediction, as the sea layer model is convolved with the input, with an operator so that the sum of multiple contributions for each reverberation has the correct overall amplitude. The operator is the 3D ray traced simple reverberation scaled appropriately for each order. For a flattish reverberation generating overburden, such as present in the Central North Sea, the operator does not need to extend beyond the first order ray traced reverberation. As the seabed becomes more irregular, the fidelity of the operator can be improved by including higher reverberation orders, although the trade-off is increasing model complexity. It is also important that the sea layer model and operator take the AVO of the seabed into account and do not extend beyond their respective critical distances. Both AVO and critical distance can be expressed in terms of the seabed reflectivity for the survey as a simple user parameter.

Synthetic and field examples

As proof of concept, a 1D shot synthetic produced from a central North Sea blocked well log, based on the reflectivity approach described by Kennett (1979), confirms the effectiveness of the proposed seabed modelled approach (Figure 7), particularly the surface-related pegleg reverberation prediction (SRMP) generated from the deeper overburden and Base Cretaceous Unconformity (BCU) primaries.

The field example is from an East Shetland Basin dual-sensor survey (maximum offset 6100m) acquired in 2012 using a conventional survey design with a dual source shot separation of 18.75m, with a seabed two-way time between 195ms and 207ms. The target is a tilted fault block mid-Jurassic play masked by pegleg reverberation from the BCU (Figure 8). Eliminating the first order BCU generated pegleg reverberation is notoriously difficult but, compared to the deterministic 1D reverberation prediction in τ-p space, the seabed modelled 3D SRME approach can adaptively subtract it almost completely based on the summation of both the source-side and receiver-side ray traced linkage traces before the convolution step.

Conclusions

A novel seabed modelled SRME proposed in this abstract can compute a correct reverberation model without the recourse to an iterative solution. The 3D SRMP technique can replace the more limited 1D deterministic shot-based reverberation approach in τ-p space to form part of an effective 3D multiple attenuation strategy for most shallow water datasets, including those surveys where the seabed is very shallow, as reconstructed distortion-free recorded data is only used in the convolution step.

References

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Moore, I. and Bisley, R. [2006] Multiple attenuation in shallow-water situations, *68th EAGE Annual International Conference and Exhibition,* Extended Abstract, F18.

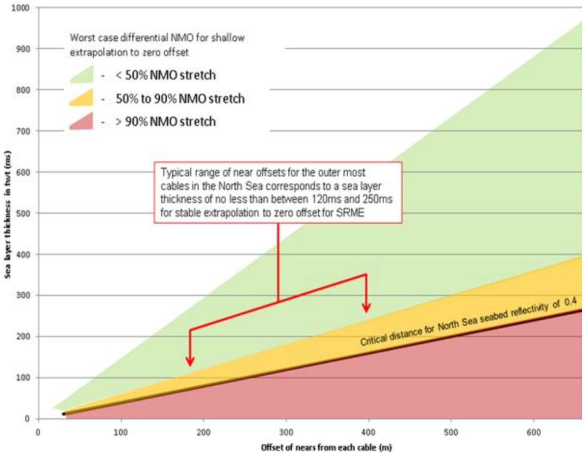


Figure 1 *In the North Sea, conventional SRME is still used where the seabed two-way time is greater than 120ms to 250ms depending on the acquisition geometry.*

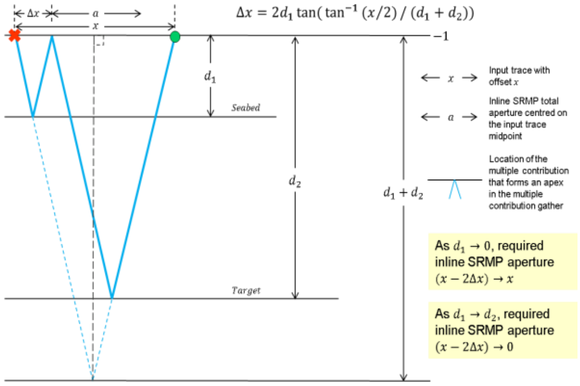


Figure 2 *Kinematics of a first order shot-side pegleg reverberation for a flat earth.*

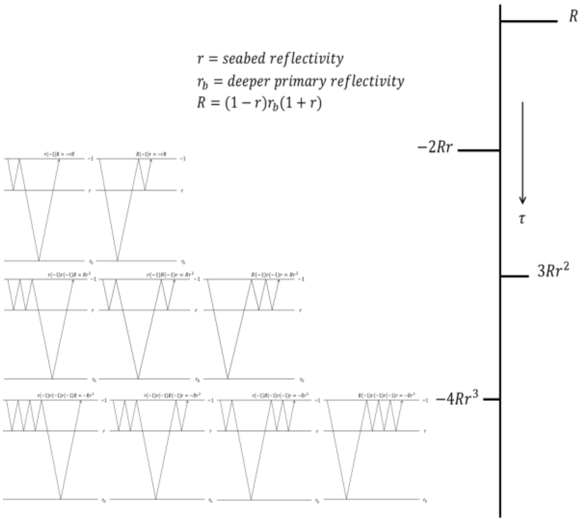


Figure 3 *Decay series of a 1D pegleg reverberation.*

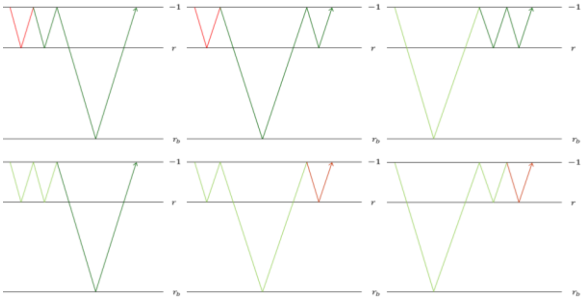


Figure 4 *Convolving the recorded input with its self for a flat earth for a 2^{nd} order pegleg reverberation (light red, source-side recorded seabed; light green, source-side input; dark red, receiver-side recorded seabed; dark green, receiver-side input).*

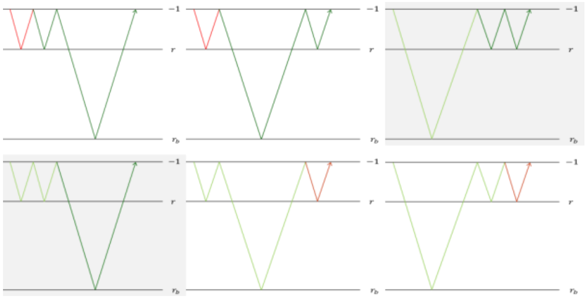
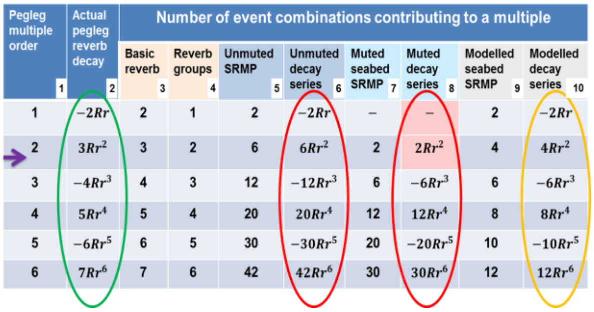


Figure 5 *Convolving the recorded input with a model of the seabed for a flat earth for a 2^{nd} order pegleg reverberation (light red, source-side modelled seabed; light green, source-side input; dark red, receiver-side modelled seabed; dark green, receiver-side input). The grey shaded combinations cannot now be computed.*



Pegleg multiple order 1	Actual pegleg reverb decay 2	Number of event combinations contributing to a multiple							
		Basic reverb 3	Reverb groups 4	Unmuted SRMP 5	Unmuted decay series 6	Muted seabed SRMP 7	Muted decay series 8	Modelled seabed SRMP 9	Modelled decay series 10
1	$-2Rr$	2	1	2	$-2Rr$	–	–	2	$-2Rr$
2	$3Rr^2$	3	2	6	$6Rr^2$	2	$2Rr^2$	4	$4Rr^2$
3	$-4Rr^3$	4	3	12	$-12Rr^3$	6	$-6Rr^3$	6	$-6Rr^3$
4	$5Rr^4$	5	4	20	$20Rr^4$	12	$12Rr^4$	8	$8Rr^4$
5	$-6Rr^5$	6	5	30	$-30Rr^5$	20	$-20Rr^5$	10	$-10Rr^5$
6	$7Rr^6$	7	6	42	$42Rr^6$	30	$30Rr^6$	12	$12Rr^6$

Figure 6 *The over prediction for the 2^{nd} order pegleg reverberation (purple arrow) in Figure 4 can be split into two groups of three contributions (columns 3 & 4) the product of which (column 5) produces the result for a single convolution of the data with itself (column 6). Muting the seabed causes significant loss of contributing information (columns 7 & 8) but modelling the seabed distorts the decay series (column 10) less when compared to the recorded input (column 2).*

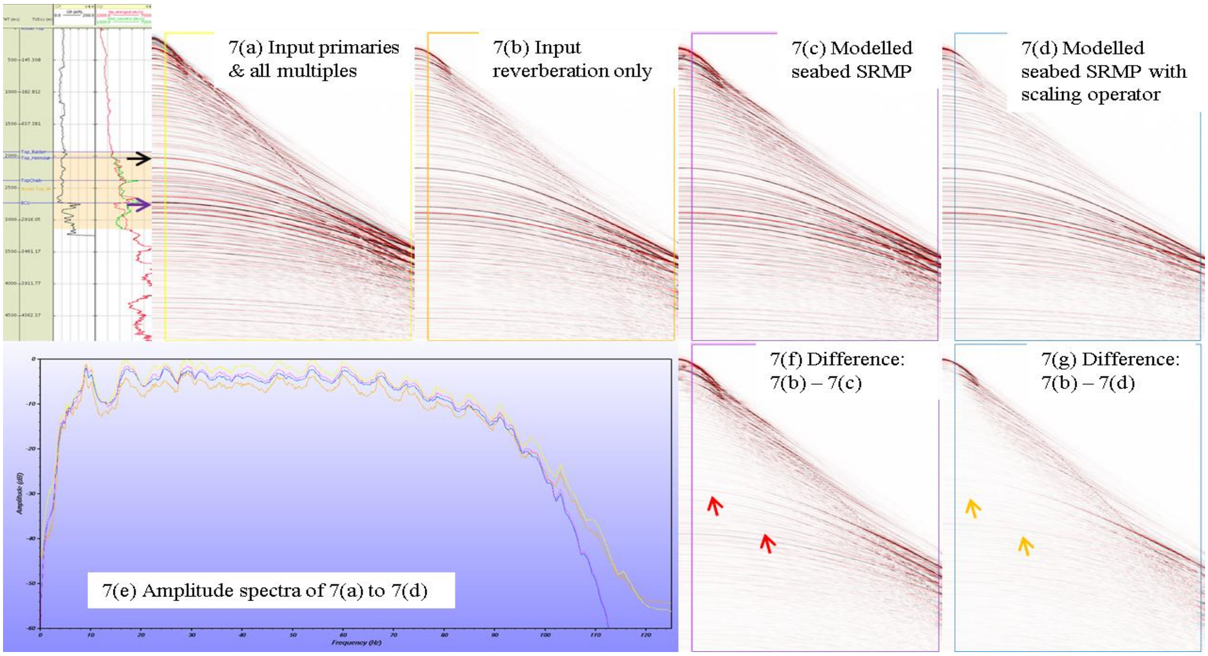


Figure 7 *(a) Synthetic shot (maximum offset 6km) based on a blocked central North Sea well log (top Heimdal and underlying BCU arrowed). (b) The reverberation contamination dominates. (c) 2D seabed modelled SRMP from convolving input (a) with the seabed model. (d) Modifying the seabed model in (c) with the proposed scaling operator. (e) Amplitude spectra corresponding to the displayed coloured analysis windows in TX space. (f) Difference between results (c) and (b) reveals residual reverberation from the top Heimdal onwards in time (red arrows). (g) Difference between (d) and (b) shows the computed prediction is now nearly the same as the theoretical result (orange arrows).*

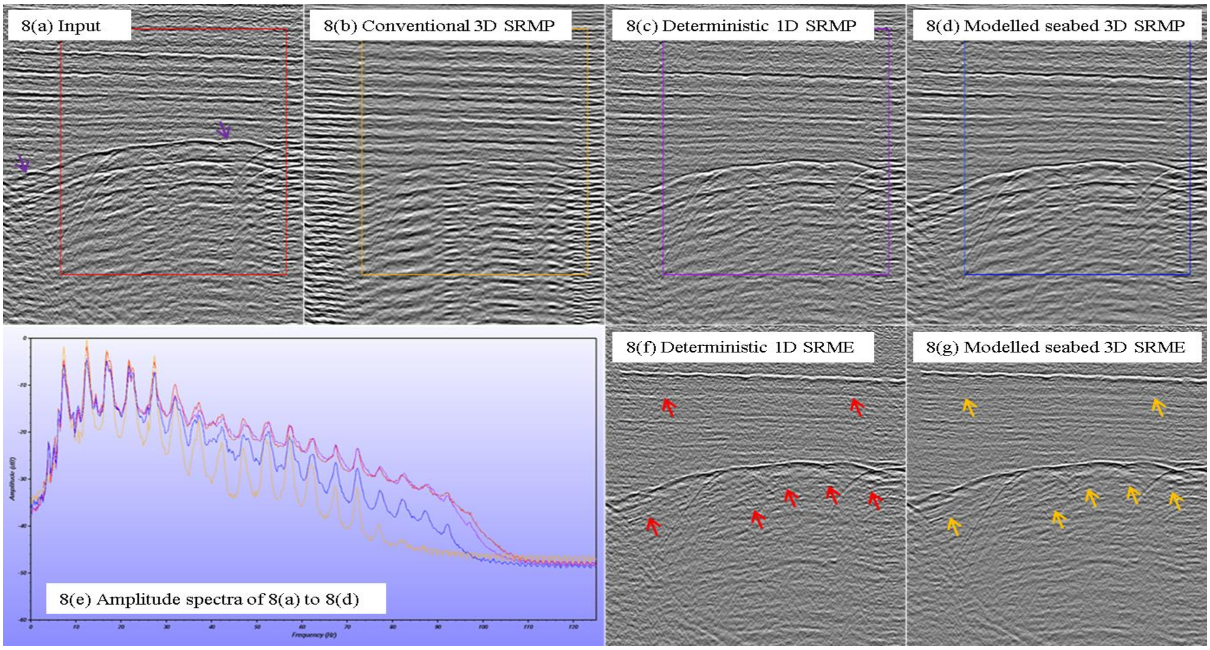


Figure 8 *(a) Input 2D NMO stack where the tilted fault blocks are masked by the pegleg reverberation below the BCU (purple arrows) between 2.5s and 2.8s two-way time. (b) After conventional 3D SRMP. (c) After 1D shot-based SRMP derived deterministically in τ-p space. (d) After seabed modelled SRMP with a scaling operator. (e) Amplitude spectra corresponding to the displayed coloured analysis windows in TX space. (f) After deterministic 1D SRME where the residual pegleg reverberation is still present (red arrows). (g) After seabed modelled SRME with a scaling operator where the reverberation has been eliminated (orange arrows).*