Improved shallow water demultiple with 3D multi-model subtraction

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Summary

Shallow water environments are dominated by short period reverberation contamination. Surface-related multiple elimination (SRME) can be successfully applied but distortion at the multiple prediction stage must be minimized so that the adaptive subtraction (multiple elimination) step does not struggle when several multiple orders of the reverberation are present, within a given design window, for minimization.

This abstract quantitatively reviews the issue of SRME over-prediction for both convolutional and wavefield extrapolation seabed-based approaches using synthetic and field examples. An optimal demultiple approach is proposed using only 3D non-linear multiple prediction operators with regards to predicting simultaneously and non-iteratively both the amplitude and timing of simple and pegleg source and receiver-side sea layer reverberation correctly with minimal distortion for moderately undulating shallow seabed.

Introduction

One of the key challenges of SRME is in shallow water environments. 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 key assumption is maintaining internal data consistency (Moore and Bisley, 2006), where the surface multiple formed by combining any two events in the input dataset must also be present in that dataset. A solution, for shallow datasets, is to model the water layer in order to drive a suitable non-linear 3D operator to correctly predict both the decay of the simple (water layer only) and pegleg (from a deeper primary) reverberation series thus ensuring optimum minimization at the adaptive subtraction (multiple elimination) stage.

At target, the adaptive subtraction based on one reverberation model (even when generated properly as described above), is sometimes not enough. But applying one demultiple step after another to eliminate the same family of multiples can be flawed, as the first demultiple process may overdrive the second, producing processing artefacts. Instead, an alternative robust dereverberation strategy is to simultaneously adaptively subtract similar multiple prediction models (Mei and Zou, 2010) that fully honor internal data consistency. Two completely different reverberation prediction techniques, relying on the two-way time horizon of the seabed, are described and evaluated: convolutional 3D SRME and wavefield extrapolation 3D SRME.

Comparison of reverberation prediction methods

The shallow water convolutional 3D SRME convolves the recorded data, suitably reconstructed, with the 3D ray traced seabed. The ray tracing honours the AVO (based on Wang, 1999) and local 3D dip of the seabed where the user only has to provide the seabed two-way time at zero offset (for example, from picking the first order multiple of the seabed from its autocorrelation), the corresponding reflectivity for the survey and the velocity of the water column. As only a single convolution is carried out, the amplitudes of the computed reverberation are still too high. However, this over prediction can be scaled down overall, assuming a flattish seabed, by also including in the convolution at least the modelling of the first order simple seabed reverberation (Barnes *et al*, 2014).

With wavefield extrapolation 3D SRME, a surface-related multiple model is generated by adding an additional round trip of the recorded data through the earth. The user provides two auxiliary datasets: a cube that represents the earth's reflectivity and a corresponding 3D velocity field (Brittan *et al*, 2011). For shallow water reverberation prediction, the reflectivity cube can simply be the seabed two-way time at zero offset (map migrated if steep dips are present), and the velocity field set invariantly to the velocity of the water layer. In this case, the result is kinematically the same as the seabed modelled only convolutional reverberation prediction described above. An analytical review of the two reverberation prediction methods is shown in Table 1. Note that for both techniques, shallow primaries below the seabed can be added to predict surface-related multiples other than reverberation, although extending the reflectivity cube for the wavefield extrapolation is more data driven and progressively removes the amplitude distortion.

Synthetic and field data studies

As proof of concept, an input 1D earth shot synthetic was produced with a maximum offset of 4500m, based on the reflectivity approach described by Kennett (1979). A central North Sea well log was blocked, for a seabed two-way time of 160ms, to generate 75 primaries and up to 15 orders of surface-related multiples (both reverberation and longer period) and internal multiples. Both seabed-based convolutional and wavefield extrapolation 3D reverberation prediction approaches are compared to the reverberation only modelled result (Figure 1) and confirm the mild

DOI http://dx.doi.org/10.1190/segam2015-5856770.1

amplitude distortion tabulated in Table 1. For the simple reverberation prediction decay series in the shallow overburden (orange arrows), local scaling performed as part of the adaptive subtraction step would be effective. At target, the amplitude distortion with pegleg multiple order affects the fading tail end of the decay train. Overall, the bandwidth of the reverberation is honoured for both multiple prediction approaches.

The field example is a dual-sensor survey from the Norwegian sector of the North Sea acquired in 2013 using a conventional survey design: dual shot (separation 18.75m), 12 streamers (7050m long, 75m apart) with a near inline offset of 100m. The main target is a classical tilted fault block mid-Jurassic play masked by pegleg reverberation from the Base Cretaceous Unconformity (BCU) where the seabed two-way time gradually varies between 170ms to 400ms with an overall dip of around 0.4º and locally up to over 4º.

Input is heavily contaminated by surface-related multiples, particularly reverberation (Figure 2). Decomposing the prediction of the reverberation into source-side and receiver-side multiples (Figure 3) reveals that, for this dataset, the moveout of some of the source-side multiple contamination is the same as the primary moveout and must, in particular, be removed. The dereverberation is further improved by performing a simultaneous adaptive subtraction when including the wavefield extrapolation multiple models (Figures 4 and 5). A suitable muted 3D SRME can then be applied afterwards to predict and attenuate the longer period surface related multiples which are evident, particularly below the BCU.

Conclusions

A shallow water demultiple strategy is proposed from a quantitative analysis of reverberation decay series and a successful application to a field dataset. The approach involves generating complementary multiple models using suitable non-linear 3D dereverberation operators and then performing the multiple elimination step via simultaneous adaptive subtraction.

Acknowledgments

The authors would like to thank Statoil Petroleum AS and their partners, Petoro AS, Centrica Resources (Norge) AS, Total E&P Norge AS and A/S Norske Shell for allowing us to present this work. Also thanks to the Petroleum Geo-Services Imaging team in Norway including Konstantin Koch, Tobias Jokisch and Julien Oukili. Also thanks to Euan Anderson from Petroleum Geo-Services MultiClient Reservoir for preparing the well log.

Multiple order	Simple reverb decay	Pegleg reverb decay	Standard single convolutional SRME		Seabed only-based convolutional & wavefield extrapolation SRME	
1	2	3	4 Simple	5 Pegleg	6 Simple	7 Pegleg
1	$-r^2$	$-2Rr$	$-r^2$	$-2Rr$	$-2r^2$	$-2Rr$
2	r^3	$3Rr^2$	$2r^3$	$6Rr^2$	$2r^3$	$4Rr^2$
3	$-r^4$	$-4Rr^3$	$-3r^4$	$-12Rr^3$	$-2r^4$	$-6Rr^3$
4	r^5	$5Rr^4$	$4r^5$	$20Rr^4$	$2r^5$	$8Rr^4$
5	$-r^6$	$-6Rr^5$	$-5r^6$	$-30Rr^5$	$-2r^6$	$-10Rr^5$
6	r^7	$7Rr^6$	$6r^7$	$42Rr^6$	$2r^7$	$12Rr^6$

$R = (1-r)r_b(1+r)$ where r = seabed reflectivity, r_b = deeper primary reflectivity

Table 1: Reverberation decay analysis. Simple and pegleg reverberation have different decay trains (columns 2 and 3). Standard convolutional SRME is too distorted for shallow water adaptive subtraction (columns 4 and 5). However, seabed-only based convolutional and wavefield extrapolation reverberation prediction locally maintain the relative amplitudes of the simple reverberation decay train (column 6) or are only affected by a mild over prediction for the pegleg reverberation series (column 7). The seabed modelled convolutional reverberation model can be further modified to scale down the over prediction so that the result is similar to columns 1 and 2 for a flattish overburden.

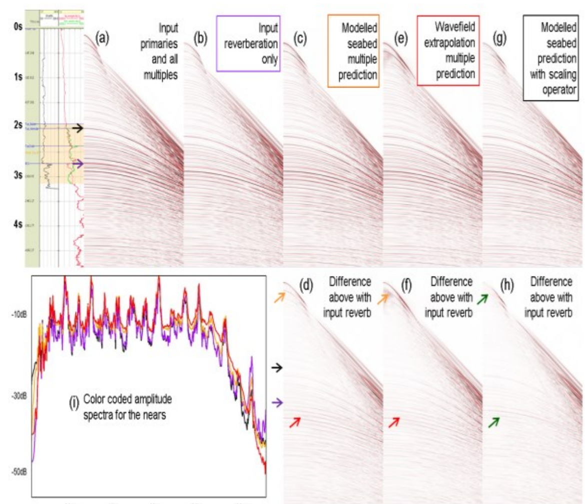

Figure 1: (a) Synthetic input shot based on a blocked central North Sea well log (top Heimdal and underlying Base Cretaceous Unconformity arrowed). (b) The actual reverberation only contamination dominates. (c) and (e) The convolutional and wavefield extrapolation seabed-based 3D reverberation prediction are the same when the former only ray traces the seabed. (d) and (f) Corresponding differences below with the input reverberation reveal that the simple multiple decay series (orange arrows) are computed correctly but have twice the absolute amplitudes, whereas the second order pegleg multiples and above (red arrows) are mildly but progressively over predicted as shown in Table 1. (g) and (h) The convolutional 3D reverberation prediction can be further enhanced by extending the seabed ray tracing to scale down the over prediction so that the amplitudes are now the same as the actual reverberation contamination (green arrows). (i) The corresponding color coded amplitude spectra are very similar.

DOI http://dx.doi.org/10.1190/segam2015-5856770.1

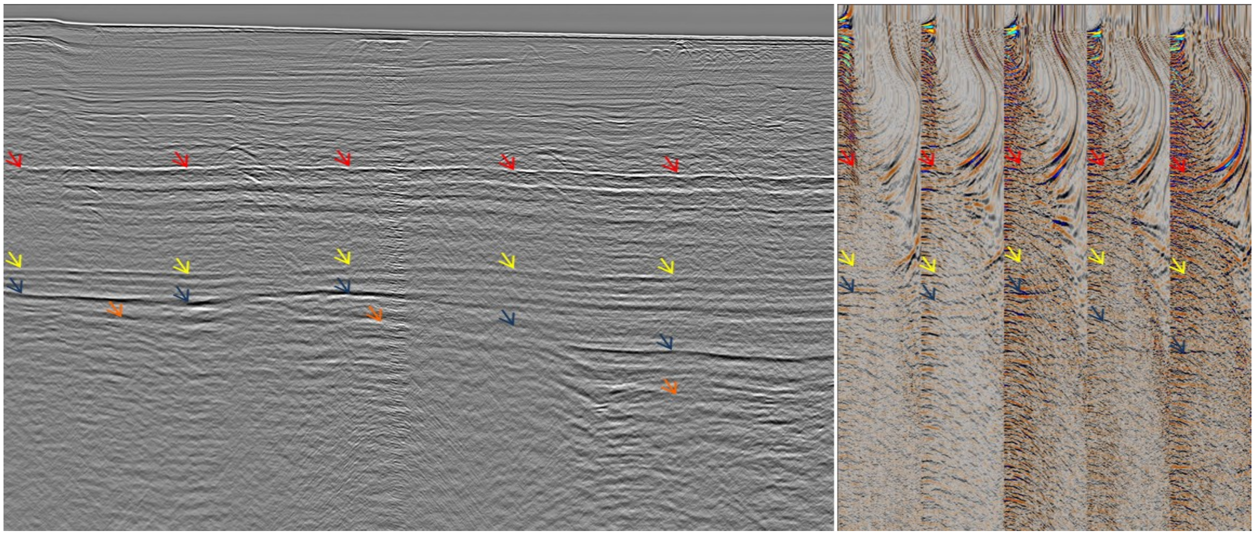

Figure 2: Input 2D full offset NMO stack and selected CMP gathers where the tilted fault blocks are masked by the pegleg reverberation (first order: orange arrows) below the BCU (blue arrows). Top Balder and top Svarte formations (red and yellow arrows respectively) are also highlighted. Two-way time up to 6s displayed.

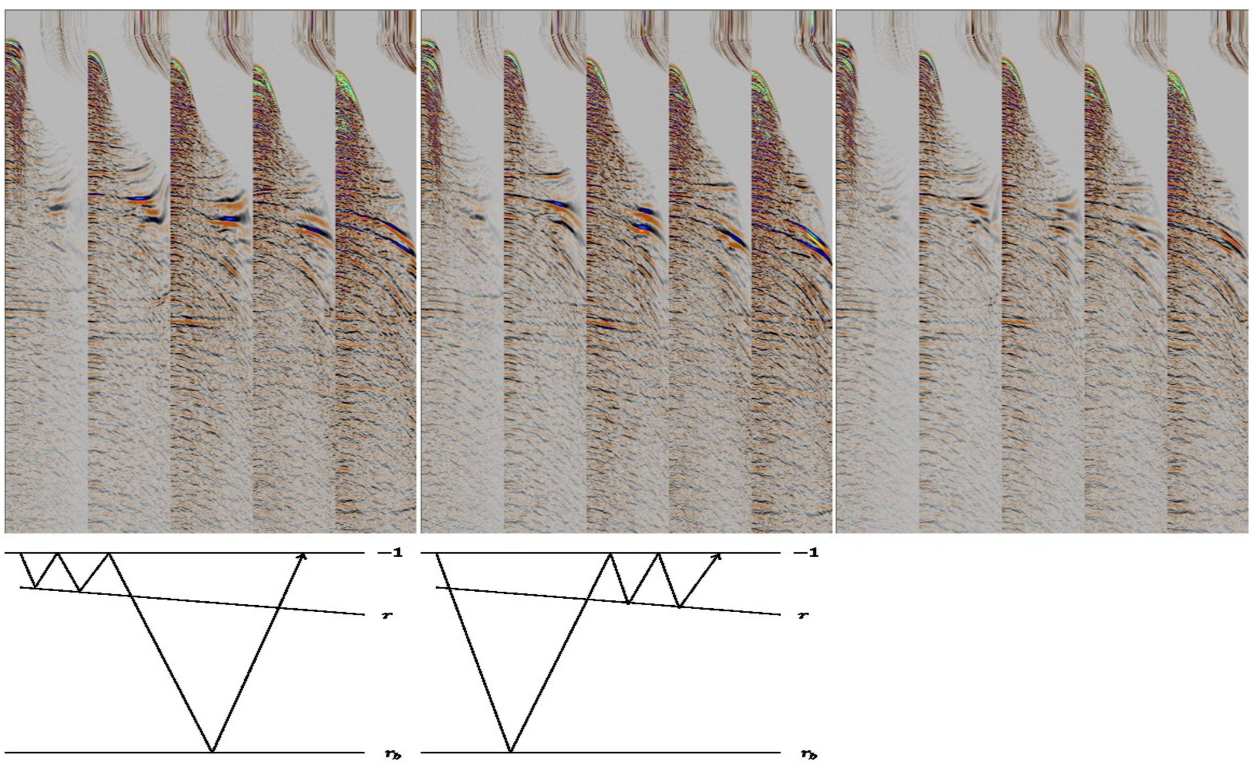

Figure 3: NMO CMP gathers of convolutional seabed modelled 3D reverberation prediction. The moveout of the source-side (left) and receiver-side (middle) multiple models correspond to whether the corresponding multiple contributions are located up dip or down dip. Summing the models is shown on the right.

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Figure 4: NMO CMP gathers showing the difference between input and convolutional seabed modelled 3D SRME (left), the difference between the input and simultaneous adaptive subtraction that also includes wavefield extrapolation prediction (middle), and the summed convolutional multiple model for comparison (right) as in Figure 2. Example improvement is highlighted.

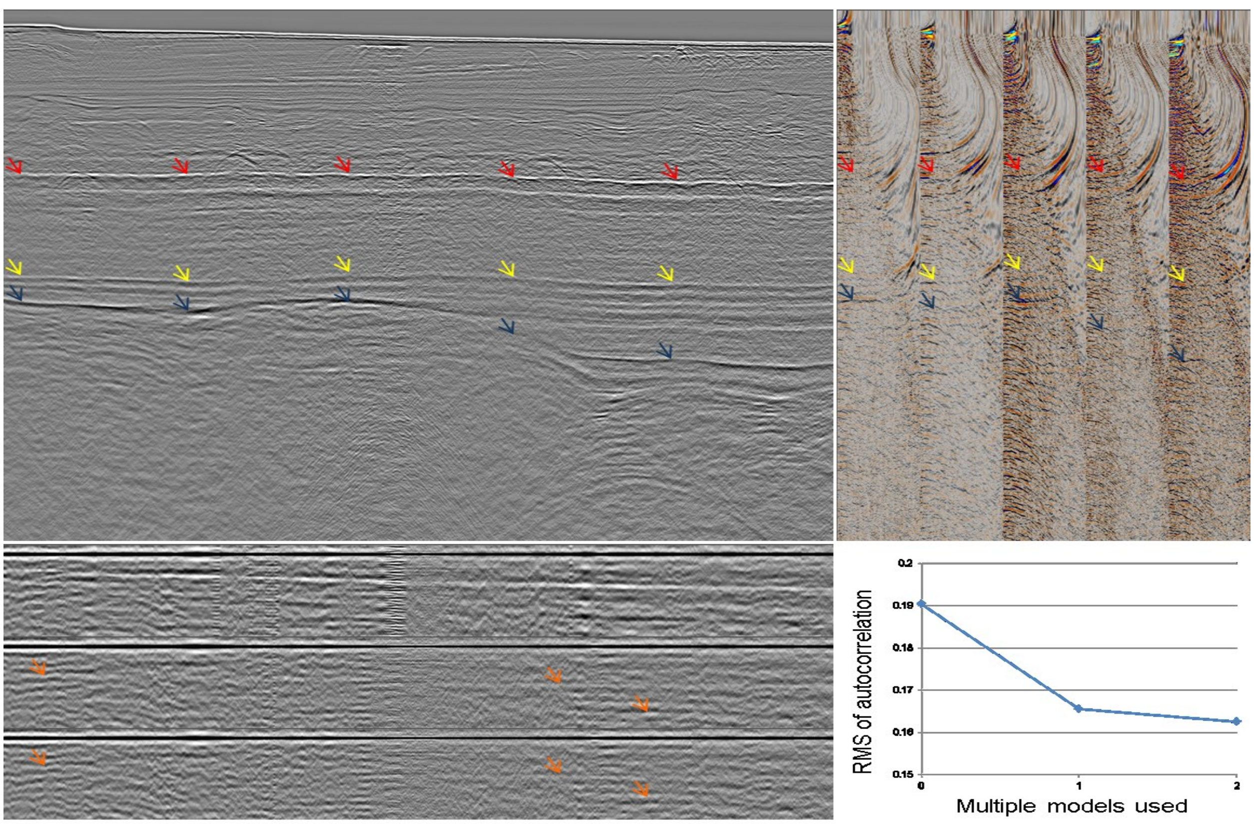

Figure 5: NMO stack and selected CMP gathers (top row) after simultaneous adaptive subtraction of convolutional & wavefield extrapolation reverberation models. Autocorrelograms (design gate from top Svarte) of the input (top), after convolutional SRME (middle) and combined convolutional and wavefield extrapolation SRME (bottom), with a plot of the average autocorrelation RMS (right), showing the improvement.

DOI http://dx.doi.org/10.1190/segam2015-5856770.1

EDITED REFERENCES

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