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Broadband Processing of West of Shetland Data

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SUMMARY

We present broadband processing results for a dataset acquired north-west of Shetland. Attenuation of multiples was challenging because of the presence of a hard, variable depth water bottom and complex geology. Streamers were towed deep (20m to 30m) during acquisition, with a mild slant of 1m per km of offset, and with a maximum offset of 10km. This acquisition configuration allowed the use of multiple attenuation methods designed for conventional data, while at the same time allowing broadband post-migration de-ghosting with an overall processing turnaround time comparable to that for conventional processing projects.

Introduction

This paper describes the broadband processing of deep-tow 2D marine survey data obtained as part of a broadband regional Faroes/West of Shetland well-tie Survey. A central feature of the processing was the ability to obtain a final broadband product using what is essentially a conventional pre-migration processing sequence. The only addition to the sequence is a step for receiver-side ghost removal after imaging. The use of standard de-multiple and pre-stack time migration algorithms contrasts with the configuration-specific processing algorithms (Sablon et al. 2012) or pre-imaging de-ghosting that are necessary when broadband acquisition utilizes a strongly curved or slanted cable. A series of example images are provided to illustrate key steps in the processing sequence.

Data acquisition

Fifteen 2D lines totalling 2134km were acquired in the Shetland-Faroe basin in May 2013 by MV Artemis Atlantic. The source was an airgun array towed at 8m depth, with total volume $0.071m^3$ (4330 cubic inches) and pressure 141bar (2000psi). The shot interval was 25m. The receiver cable was towed deep with a very gentle slant of 1m per km to facilitate rigging and minimize tug noise. Cable depth was 20m at the near end and 30m at the far end. The cable comprised 800 hydrophone channels, the first at offset 150m and with channel spacing of 12.5m, so 10km length in total. The filters used were 2Hz-18dB/octave and 214Hz-574dB/octave. The example line shown in this paper was 194km in length, acquired across the basin sailing in a north-westerly direction.

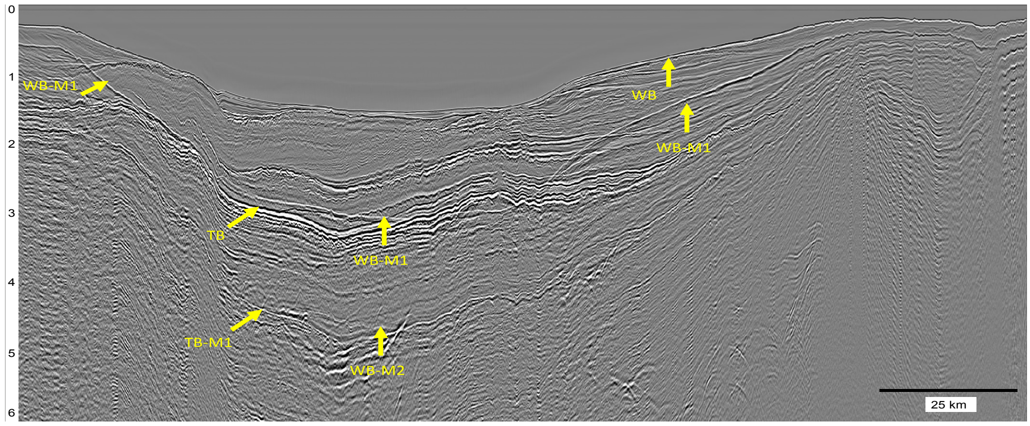
Processing sequence

The processing sequence in outline is outlined in Table 1. The most prominent multiples observed in the dataset were water-layer multiples originating from the high impedance contrast primary reflectors. These were the water bottom and of the top of the basalt layer. These key primaries are marked in Figure 1 as WB and TB respectively together with examples of their respective order of multiples, marked with suffix M1 and M2.

1. Re-datum to mean sea-level
2. Source de-signature
3. Anti-alias filter and resample to 4 ms
4. Swell and linear noise attenuation
5. Multiple attenuation
6. Anti-alias and alternate channel drop
7. Hi-resolution Radon de-multiple
8. Offset regularization
9. F-X deconvolution
10. 2D Kirchoff pre-stack time migration
11. Hi-resolution de-multiple
12. De-ghosting
13. Post-stack deconvolution and scaling

Table 1 *Processing sequence.*

After datum correction to mean sea-level, attenuation of multiples was carried out using a standard implementation of 2D SRME. Figure 1b shows the result for our example line and it can be seen that SRME worked very well in the majority of areas; the water column being in the range 120m to 1150m. However, in the shallower regions of the survey, e.g. the yellow box in Figure 1b, it can be seen that there is some residual energy that needs attention. Here, the accuracy of the SRME model is confounded by an incomplete record of the seabed reflection at the near offsets, and by multiples that are very high in amplitude compared to the primaries (due to the hard seabed). We therefore investigated additional multiple models (Figure 2). The first was produced using a wave-field extrapolation algorithm, which complemented the SRME result for the multiples associated with the deeper horizons and the second was generated using an algorithm designed specifically for shallow-water multiple attenuation. This latter approach derives an operator from the data that represents the (missing) water-bottom reflection and subsequently convolves this with the original data to generate a multiple model. See for example Hargreaves (2006) for a discussion on this type of algorithm.



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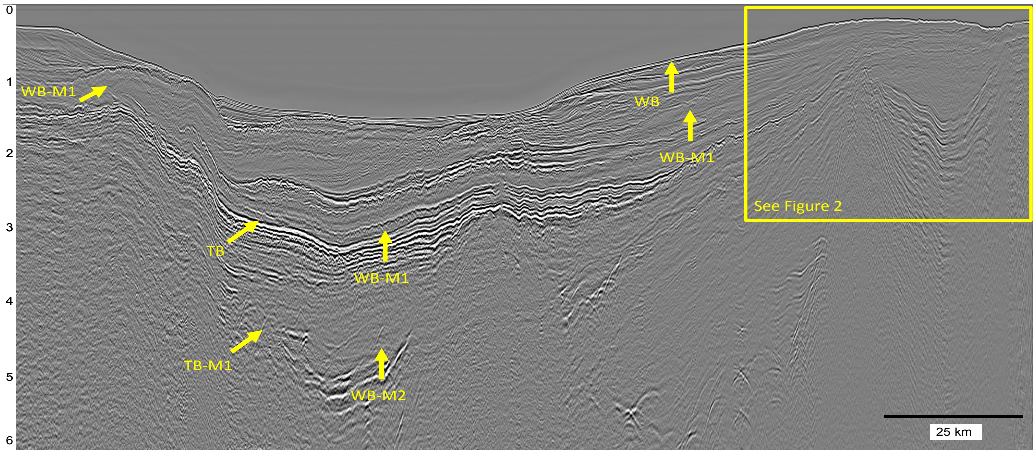


b

Figure 1 *Stacked section before and after application of 2D SRME which shows generally very effective attenuation of multiple energy. WB = water-bottom, TB = top of basalt, M#=multiple, nth order. However, note there is residual surface multiple energy corresponding to the TB horizon at the right-hand-side of the section, outlined with the yellow box.*

In all cases, the multiple model is adaptively subtracted from the original data with careful attention paid to preserving primary signal while maximizing multiple removal. In the shallow region, a much improved result over SRME alone was found after a second stage of subtraction using the multiple model derived from wave-field extrapolation, Figure 2c. However, it was found possible to obtain comparable attenuation using the shallow water algorithm alone, Figure 2d. This approach was also found to be more effective at removing the first and second order multiples from the water-bottom and beneath the central belt of basalt. The simpler methodology and improved result favour this choice of algorithm for the dataset. After velocity picking, further attenuation of multiple energy was carried out using hi-resolution parabolic Radon transforms with a mute to discriminate primary from multiple based on residual move-out. After de-multiple, alternate channels were dropped, the offsets were regularized, treated again for noise, and the binned offsets migrated using a 2-D Kirchhoff pre-stack time migration algorithm with 6km aperture and 50degree dip limit. The migrated stack with zero-phase wavelet is provided in Figure 3a.

After a final round of residual noise and multiple removal, the migrated pre-stack dataset was de-ghosted. The high signal to noise ratio that is key to successful ghost removal was achieved by towing streamers deep in order to reduce the effects of swell noise. The receiver and source ghost notches induced by sea-surface reflections were compensated for by a post-imaging 2D de-ghosting process, applied using a 1D operator. The de-ghosting process was time-space variant, and de-ghosting operators were derived using a combination of adaptive estimation and a-priori information on cable depth, water velocity and sea-surface reflection coefficient. The process also included statistical corrections for the minimization of any residual ghost energy. The final de-ghosted time-migrated stack is shown in Figure 3b.

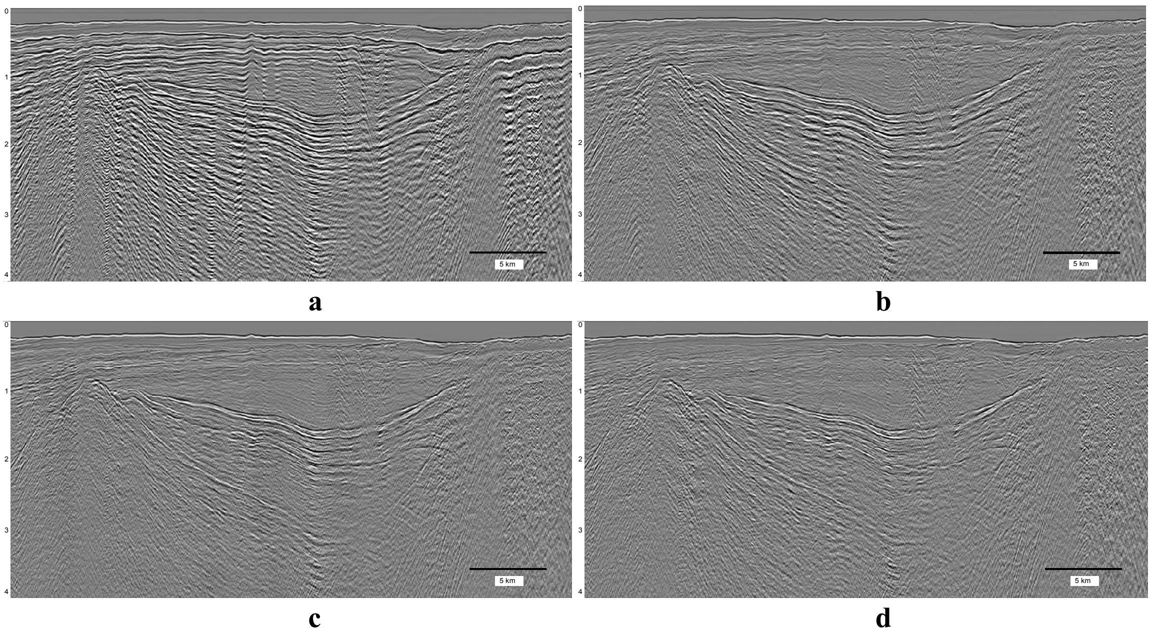
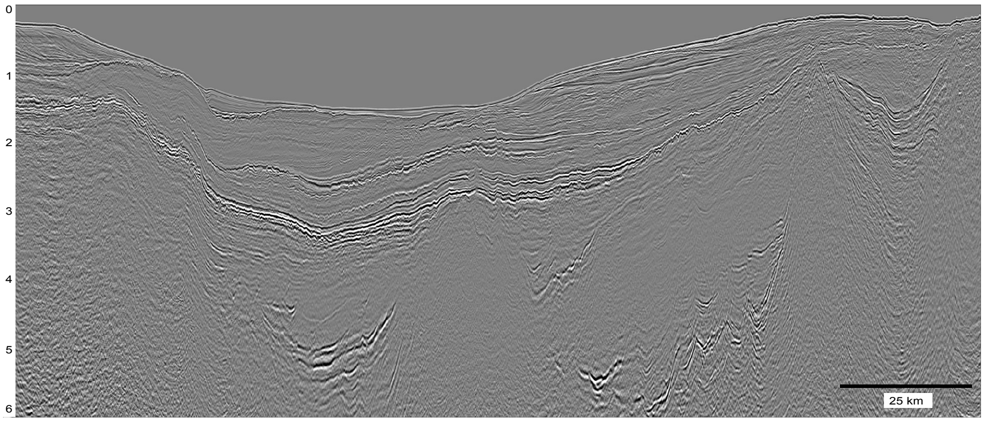


Figure 2 *Stacked section for 0-4 seconds, showing zoomed and additionally gained section after figure 1.* ***a*** *is input before multiple attenuation* ***b*** *is after 2D SRME* ***c*** *is after SRME and use of the wave-field extrapolation de-multiple model, finally* ***c*** *is the shallow water de-multiple algorithm applied to input for comparison.*

Discussion

The success of broadband processing requires the removal of ghost events from seismic data. These cause frequency-dependent constructive and destructive interference, with a consequent attenuation of signal in specific frequency bands (notches). Variable depth acquisitions with either a curved or pronounced linear slant provide notch diversity for stacking purposes. However, they induce a strong variability in ghost response with respect to offset, therefore breaking down the stationary wavelet assumption that many processing algorithms require (e.g. Semblance velocity analysis, SRME). A more complex, time consuming processing sequence is therefore required (Sablon et al., 2012), or pre-imaging de-ghosting may be needed in order to keep the processing sequence simple. On the other hand, when the cable depth is kept constant the processing sequence prior to de-ghosting does not require modification, and processing turnaround time is not affected. Additionally, in the case of constant cable depth acquisitions, de-ghosting does not rely on notch diversity but on signal to noise ratio (SNR), as discussed in Williams and Pollatos (2011). The cable is towed deep for all offsets, therefore guaranteeing a high SNR even at the near offsets, in contrast with slanted or curved acquisitions where these offsets are shallower. Grion et al. (2013) compared broadband images over adjacent lines acquired in calm and rough seas, thus confirming that deep tows provide isolation from weather effects for structural imaging purposes. De-ghosting is then performed before stacking migrated offsets. For operational reasons, the cable may be towed with a slight slant (e.g. 1m per km of offset), which still allows for a conventional pre-de-ghosting processing sequence.



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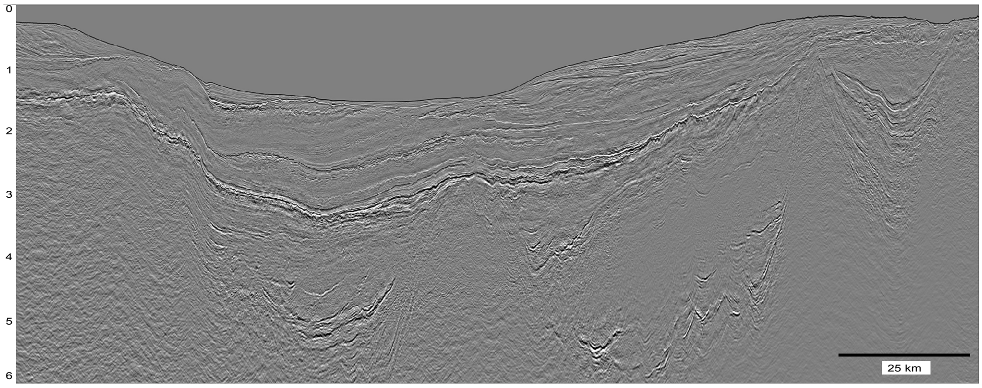

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Figure 3 *Time-migrated images **a** before and **b** after de-ghosting.*

Conclusions

Inspection of migrated images and NMO stacks has demonstrated that successful multiple removal can be achieved for a challenging broadband West of Shetland dataset. Algorithms designed for conventional seismic data are therefore confirmed to be suitable for broadband processing, when acquisition is performed using a constant depth deep tow, or with a mild slant. For the dataset here presented, a slant of 1m per km of offset was used, for operational reasons only.

Acknowledgements

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References

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