PRE-MIGRATION RESIDUAL MULTIPLE SUBTRACTION USING POST-MIGRATION MATCHING FOR NORTH SEA OBN DATA

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Summary

In the North Sea, water bottom related surface multiples offer one of the largest challenges to a seismic processing project with a careful balance between multiple attenuation and primary preservation required when using a model and subtract approach. For Ocean Bottom Node (OBN) data Up/down deconvolution can be used to output the reflectivity where multiple and source signature will be removed, eliminating the need for an adaptive subtraction as part of the principle de-multiple process. Residual multiple can however still be present where the assumptions within the up/down deconvolution method do not adequately describe the reality of the data. Often, these residuals are only noticeable once migrated, particularly where a diffracted component is prevalent. In this paper, a method using the coherency of residual multiple evaluated on migrated and stacked data is used to drive pre-migration residual multiple attenuation through the use of a matched-subtraction.

Pre-migration residual multiple subtraction using post-migration matching for North Sea OBN data

Introduction

In the North Sea, water bottom related surface multiples offer one of the largest challenges to a seismic processing project, with a careful balance between multiple attenuation and primary preservation required when using a model and subtract approach. Alternatively, up/down deconvolution (Wang et al. 2010) can be used for Ocean Bottom Node (OBN) data, for which adaptive subtractions are not necessary if forming an image from the output reflectivity. Residual multiple can however still be present where the assumptions within the up/down deconvolution method do not adequately describe the reality of the data. These assumptions relate not only to the equivalence of source-side and receiver-side wavenumber, but also to accuracy of the deconvolution operator (the downgoing wavefield) in terms of seismic noise and fidelity of the water wave and other early arrivals (Haacke et al., 2019). Errors in the process can lead to residual multiple that interferes with interpretation. Often, these residuals are only noticeable once migrated, particularly where a diffracted component is prevalent. In this paper, a method using the coherency of residual multiple evaluated on migrated and stacked data is used to drive pre-migration residual multiple attenuation through the use of a matched-subtraction .

Method

The dataset used for the matched-subtraction method is from the Central North Sea, over the Dunbar field. Production from Dunbar is controlled by small scale faulting within larger scale fault blocks, which occur throughout the field. Due to the subtle fault features forming the main target in Jurassic rocks, which are deep and notoriously challenging to image, a robust de-multiple process was required that would reduce the need for significant post migration de-multiple effort.

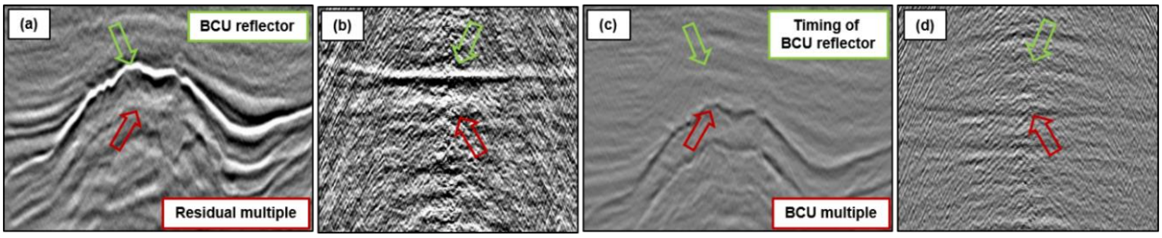

***Figure 1** (a) RTM stack of up/down deconvolution reflectivity; (b) Receiver gather with NMO after up/down deconvolution; (c) RTM stack of the up/down deconvolution multiple model; (d) Receiver gather with NMO of multiple model. RTM stacks are depth migrated and stretched time.*

Up/down deconvolution was used as the primary de-multiple tool for the Dunbar OBN dataset. The up/down deconvolution process produces a reflectivity which should be free of surface multiple, and with the source signature removed (Amundsen, 2001, Wang et. al. 2010). In addition to the reflectivity, a multiple model is produced by convolving the Green’s function of the water column with the reflectivity and the input data (Lokshtanov, 2000). In this example both reflectivity and model were output from the process and used in the matched-subtraction method. The reflectivity and multiple model are shown in Figure 1, with a Reverse Time Migration (RTM) depth-migrated stack (stretched to time) of the reflectivity shown in Figure 1a. Some residual multiples are observable on the section, indicated by a red arrow. At the location shown, the Base Cretaceous Unconformity (BCU) reaches a structural high and narrow faulting acting as baffles within the reservoir is prevalent with few strong reflectors present. This leaves the area below the BCU relatively sparse in terms of primary energy, which means that residual multiple stands out once migrated. Elsewhere in the survey, the residual multiple was less clear due to the presence of strong primary reflectors.

Though the residual multiple is obvious post migration, it is challenging to identify on pre-migration receiver gathers (Figure 1b). The multiple model produced by up/down deconvolution is shown in Figures 1c and 1d. We can see that the BCU multiple in the model ties well visually with the residual multiple once migrated. However, the presence of noise, proximity of primary reflectors, and similarity of moveout between the multiple and primary events inhibit the use of an adaption technique to remove the residual multiple directly from the pre-migration gathers.

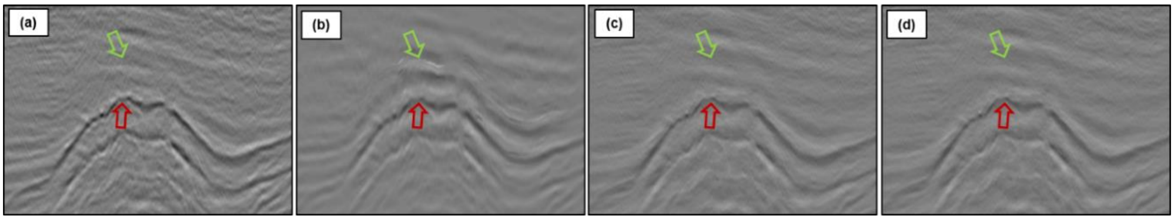

Figure 2 *(a) Raw migrated multiple model; (b) Migrated multiple model after post-migration adaption; (c) Multiple model after application of matching filter applied post-migration; (d) Multiple model after application of matching filter applied pre-migration.*

Analysis of the residual multiple in the migrated reflectivity section indicated that the multiple was strongest at mid frequencies (8 to 32 Hz) with no clear residual at low frequencies (2 to 8 Hz). This observation led to a bandwidth limited least squares adaption between the raw migrated multiple model and the migrated reflectivity. The least squares adaption used an L1 norm to reduce the adaption to primary energy, and adaption windows were small to ensure an aggressive subtraction result was achieved. The raw multiple model is shown in Figure 2a and the resultant model from the adaption can be seen in Figure 2b. The adapted model shows some cross-talk from locations where multiple in the model has adapted to the BCU primary event, indicated by the green arrow.

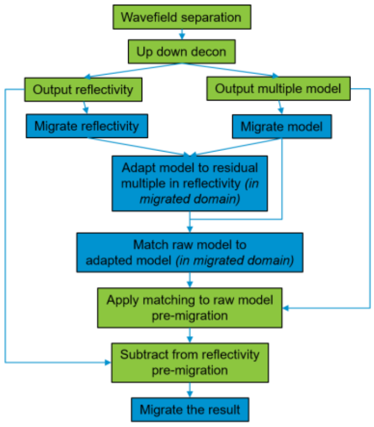

Figure 3 *Flowchart detailing the matched subtraction flow*

Following this adaption, the raw migrated multiple model was spectrally matched (amplitude and phase) to the adapted model. This was done by isolating the most significant multiple in both the adapted and raw migrated model with a mute based on the predicted BCU multiple time. To aid matching, the models (raw and adapted) were limited to locations where the multiple did not intersect with any significant primary. This was done with an RMS amplitude extraction from a migrated volume in time, using a window centred on the predicted BCU multiple. Where amplitudes were found to be anomalously high it was observed that primary cut across the residual multiple. This RMS was used as a mask to reject areas where primaries could contaminate the matching. For the matching, each receiver line was migrated using RTM and matching was completed using a single volume to derive a global operator. Once matching was complete, the extracted operator was then applied to the raw, migrated multiple model and a direct subtraction completed. The residual BCU multiple was attenuated with similar efficiency to the post-migration adaptive subtraction approach. Figure 2c shows that an additional benefit of the post-migration matching is a significant reduction in the cross talk between primary and multiple as the adaptive filtering was now applied globally, as opposed to a locally windowed approach. Clear primary damage at the BCU can be observed in Figure 2b, which is not present in Figure 2c.

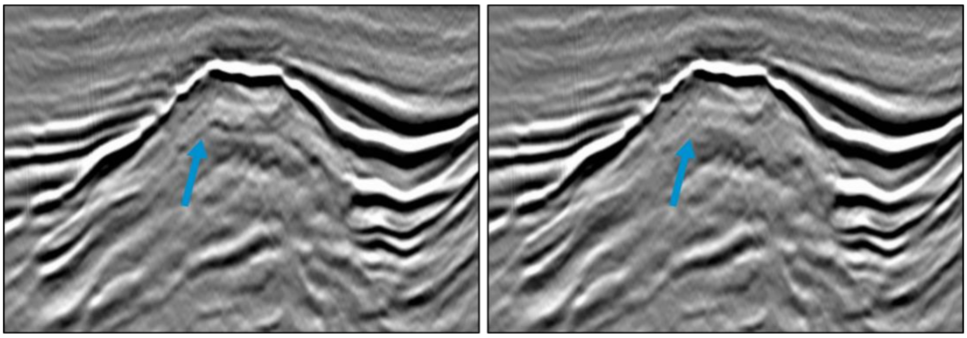

Figure 4 *OBN sections from Up down deconvolution (left) and Up/down deconvolution with residual subtraction (right). Residual multiple under the BCU after up/down deconvolution is successfully attenuated by the residual subtraction application, revealing primary seismic reflectors and faulting structures beneath.*

The match filter was then applied pre-migration to emulate the effect of the post-migration adaption without windowing and on the pre-migration data. Here, the same operators derived on the migration data (stretched to time) were applied to the pre-migration multiple model and a direct subtraction performed, also pre-migration. Once complete, the subtraction result and matched multiple model were migrated.

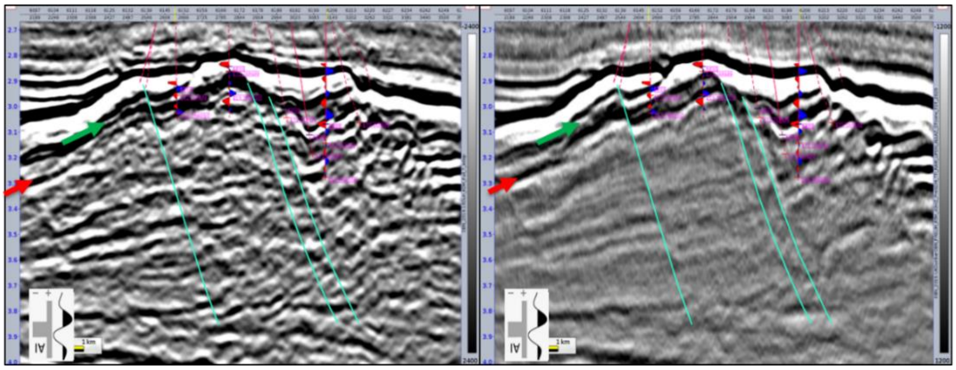

Figure 5 *Seismic section from legacy streamer data (left) and OBN data (right) showing significant improvement to clarity and lateral coherency of main reservoir reflectors including key reservoir markers such as Dunlin (Green arrow, white reflector) and Triassic (red arrow, black reflector). Additionally, sections highlight significant improvement in clarity of both large and small scale faulting across the reservoir.*

The post-migration match filter derivation and pre-migration application workflow is summarised in Figure 3.

Results

Application of matching in the pre-migration domain provides a result that is visibly similar to matching in the post-migration domain, Figure 2d. Figure 4 shows the result of the pre-migration matched-subtraction in comparison to the reflectivity migrated with no residual multiple attenuation. The residual multiple, which is clearly present in the reflectivity output from up/down deconvolution, is attenuated by the pre-migration match-filtered multiple subtraction, revealing important primary reflectors below the BCU.Overall, the matched subtraction solution was found to reduce residual multiple across the survey and provide a clearer OBN image with less ambiguous structure below the BCU. A seismic section and a seismic coherency extraction comparison with legacy processed towed streamer image (Figures 5 and 6) show that key reservoir reflectors are now better defined, and large and small scale faulting below the BCU is significantly clearer in the OBN data after pre-migration residual multiple subtraction using image domain matching.

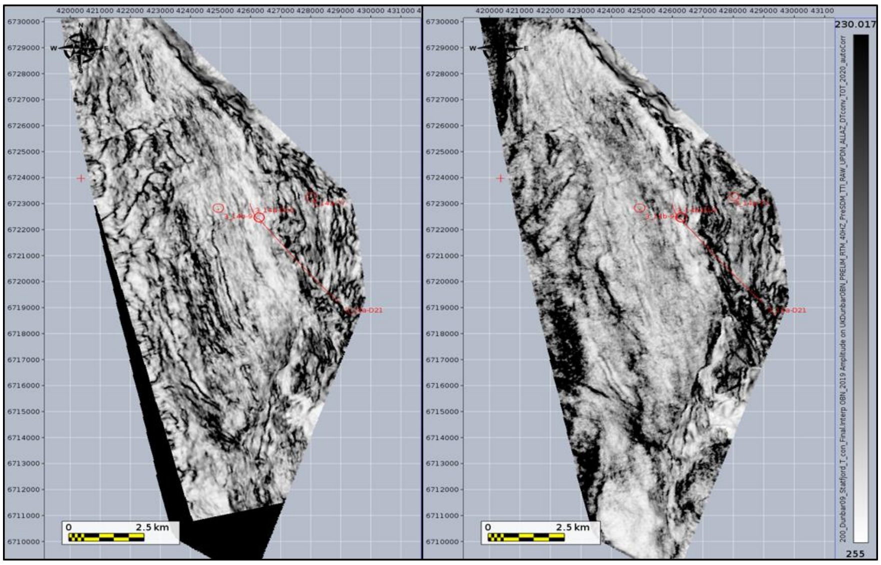

Figure 6 *Coherency slices at Statfjord level for legacy streamer data (left) and OBN data (right) showing significant improvement in clarity of fault determination from OBN data*

Conclusions

Data in the migrated domain can help simplify the problem of differentiating multiple from primary. In this example, depth migrated seismic data has been used to match a modelled multiple to residual multiple in the data. The post-migration local adaption has been replaced with a global filtering applied to the pre-migration multiple model and shown to produce similar levels of residual multiple attenuation after migration. This approach has proved robust on the Dunbar OBN dataset, successfully removing multiple below BCU while reducing the risk of primary damage. Results show improved clarity and interpretability of faulting below BCU, which are important features in this reservoir. The filtering approach may prove useful in settings where windowed adaptive subtraction proves difficult on pre-migrated data, and where removal of remnant multiple post-imaging is undesirable.

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