

# **MWD for Shallow Water Demultiple: A Hibernia Case Study\***

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## **Abstract**

Model-based Water-layer Demultiple (MWD) is a recently-developed method aimed at tackling the challenge of multiple attenuation in shallow water. MWD works by modeling the Green's function of the water-bottom primary reflections based on a user-supplied water-layer model, then convolving it with the recorded data to predict water-layer-related multiples. In this paper, MWD is applied to Hibernia field data which has a water depth of around 70-90 meters. The results show that while SRME by itself has limited success, MWD is effective in attacking water-layer-related multiples. The effectiveness is attributed to the fact that MWD predicts the multiple models with correct relative amplitude and a spectrum similar to the input data's. SRME, on the other hand, suffers in shallow-water situations, primarily due to cross-talk between multiples. Once the water-layer-related multiples are removed by MWD, SRME can then be applied to predict and eliminate other types of surface-related multiples which tend to have longer periodicity and less cross-talk. The combination of MWD and SRME is demonstrated as an effective demultiple package for shallow-water data and results in fewer residual multiples and better-preserved primaries over tau-p gapped deconvolution. This, in turn, contributes to a more realistic velocity model and, finally, higher quality images.

## **Introduction**

Hibernia oil field, discovered in 1979, is located approximately 315 kilometers east-southeast of St. John's, Newfoundland and Labrador, Canada. Water depth around Hibernia is approximately 70-90 meters, and seismic data from the area are typically plagued by strong surface-related multiples (SRMs) that pose a tough challenge to seismic imaging. Oftentimes high order multiples are recorded with significant amplitude. The presence of multiples can generate artefacts in the final image and also adds another degree of difficulty in velocity model building. Therefore, multiple attenuation is critical to generating an accurate image in the reservoir zone.

Predictive deconvolution (Aláí et al., 2002) in the x-t or tau-p domain has routinely been used for attenuating short-period multiples in shallow water. However, predictive deconvolution by nature attenuates periodic events, without differentiating between primaries and multiples. Surface-Related Multiple Elimination (SRME) (Verschuur, 2006), though an effective method in deep water demultiple, usually

shows limited success in shallow water situations. To tackle the challenge of multiple attenuation in shallow water, Model-based Water-layer Demultiple (MWD) was recently developed (Wang et al., 2011).

In the following sections, we briefly summarize the MWD methodology and its application to Hibernia data. We demonstrate that MWD effectively attenuates water-layer-related multiples (WLRMs) while preserving primary events. Subsequent SRME can further attenuate non-water-layer-related SRMs. In this study we observe that cross-talk between multiples significantly limits the effectiveness of SRME in shallow water. When MWD removes the water-layer-related multiples first, SRME can generate more accurate predictions of the SRMs. We demonstrate that MWD followed by SRME, as an integrated demultiple tool, has a significant edge over predictive deconvolution methods.

## Methodology

To briefly explain the methodology developed by Wang et al. in 2011, MWD first models the Green's function of water-layer primary reflections,  $G$ , based on a user-supplied water-layer model. A model for the WLRMs,  $M$ , can then be obtained by convolving the recorded data,  $D$ , with the modelled Green's function,  $G$ :

$$M = D \otimes G \quad (1)$$

The WLRMs are then attenuated by adaptive subtraction of the model from the input data in a way similar to SRME.

## Examples

We tested both 3D SRME (Lin et al., 2005) and 3D MWD (Wang et al., 2011) on the same dataset. The results are shown in [Figure 1](#) as a 2D post-stack time migration. Identical parameters are used in the adaptive subtraction step for a fair comparison except that for SRME, a matching filter equivalent to the inverse of the source wavelet is applied to correct the spectrum mismatch. [Figure 1a](#) is the image before multiple attenuation, whereas [Figure 1b](#) and [Figure 1c](#) are images after SRME and MWD, respectively. The multiple models predicted by SRME ([Figure 1d](#)) and MWD ([Figure 1e](#)) are also given. Short vertical lines illustrate the interval of WLRMs with the following: a) corresponding to the primaries on the top and the first-order WLRMs on the bottom, or b) corresponding to first-order WLRMs on the top and second-order WLRMs on the bottom. While SRME ([Figure 1b](#)) works reasonably well in the shallower section, it leaves a significant amount of residual peg-leg multiples in the deeper section. MWD ([Figure 1c](#)), however, effectively removes WLRMs from top to bottom, while at the same time no noticeable primary damage is observed. The inset of [Figure 1](#) shows the amplitude spectra of the input data, the SRME model and the MWD model. Notice that the MWD model has a spectrum similar to the input data while the spectrum of the SRME model is distorted, requiring a matching filter to correct the mismatch.

The failure of SRME in shallow water has previously been attributed to the absence of near-offset data (Verschuur, 2006; Hargreaves, 2006; Hung et al., 2010). However, from our study, we believe that the cross-talk between multiples (Verschuur, 2006) is primarily responsible for the failure of SRME in shallow water, where many orders of multiples are present with significant amplitudes. This conclusion is based on

several observations. First, SRME works reasonably well in the shallower sections in a way similar to MWD, where cross-talk is not an issue ([Figure 1b](#) and [Figure 1c](#)). For deeper sections, peg-leg multiples are still predicted by SRME, but they are shadowed by higher-order multiples of shallower events, whose amplitudes are significantly over-predicted (Hugonnet, 2002) due to cross-talk ([Figure 1d](#)). MWD eliminates the cross-talk problem (Wang et al., 2011) by convolving the recorded data (primaries & multiples) with the Green's function of water bottom primary reflections such that primaries are used to predict first-order WLRMs. In turn, the first-order WLRMs are used to predict second-order WLRMs, and so on. MWD's improvement over SRME is significant due to this removal of the cross-talk issue. An additional indicator of the negative influence of cross-talk in SRME is shown in [Figure 1f](#), which shows the SRME model predicted by using MWD output as its input. Here the input to SRME is the original data without WLRMs, thus the cross-talk issue has largely been mitigated for SRME. From [Figure 1f](#) we can see that first-order peg-leg multiples in the deeper sections can also be well-predicted, even though the near offset data are still missing; this confirms that SRME fails to predict a model with correct relative amplitude in the first run ([Figure 1d](#)), mainly due to the cross-talk between multiples. To summarize, the effectiveness of MWD is attributed to the intrinsic ability of MWD to predict WLRMs with correct relative amplitude (note the overall similarity between [Figure 1a](#) and [Figure 1e](#)) and a spectrum similar to the input data's (inset of [Figure 1](#)).

Next we demonstrate that the combination of MWD and SRME is a powerful demultiple tool. On one hand, MWD only models and attacks WLRMs, a subset of SRMs. Thus, SRME is still necessary to attack non-water-layer-related SRMs. Furthermore, MWD actually helps SRME make better predictions of SRMs by first removing most WLRMs. In addition, since the MWD model has a spectrum and relative amplitude similar to the input data, mild matching filters are usually sufficient for adaptive subtraction. As a result, the internal consistency of the wave-field is well-preserved, which is important for the subsequent SRME to work properly. [Figure 2](#) shows images of 3D post-stack time migration of the section: (a) before multiple removal, (b) after tau-p gapped deconvolution, and (c) after MWD+SRME. Again, vertical lines overlay with primaries on the top-end and first-order multiple on the bottom-end. Compared to MWD+SRME, the tau-p gapped deconvolution method leaves more residual multiples. In addition, tau-p gapped deconvolution also creates false events, as outlined by the three red arrows. We note that the artefact is located in a position that mirrors the top event (pointed to by the upper blue arrows) by the second event in the middle (indicated by dot-dashed lines). Artefacts similar to this are not unusual for gapped deconvolution methods and are a consequence of their predictive deconvolution nature.

[Figure 3](#) shows two images from 3D pre-stack depth migration using: (a) the input dataset after tau-p gapped deconvolution and velocity derived from it (the legacy processing) and (b) the input dataset after MWD+SRME and velocity derived from it (the current reprocessing). The legacy image shown on the left contains artefacts (yellow arrow) and is heavily contaminated by residual multiples (some of which are marked by red arrows). With the help of MWD+SRME, a cleaner image is achieved, as shown on the right. More importantly, the current reprocessing of the Hibernia field data significantly improved fault imaging (green arrows). The improvement over the legacy image is partially attributed to the fact that a velocity model can be built on top of a more trustworthy dataset with fewer residual multiples and better-preserved primaries.

## **Discussions and Conclusions**

We have demonstrated that MWD can effectively attenuate WLRMs in data near the Hibernia oil field, Canada. The effectiveness of MWD on shallow water demultiple is attributed to its ability to predict multiple models with correct relative amplitude and correct spectrum. These advantages of MWD result in better multiple removal and better preserved primaries. In contrast, SRME by itself leaves large amounts of residual peg-leg multiples, mainly due to cross-talk between multiples.

In addition, we propose that an integrated package, MWD+SRME, be used for shallow water demultiple in particular. MWD ensures that subsequent SRME has significantly less cross-talk influence by removing the bulk of WLRMs beforehand. SRME can help attenuate longer-period SRMs. In comparison, tau-p gapped deconvolution leaves more residual multiples and creates artefacts. Due to move-out similarity between primaries and their corresponding peg-leg multiples in shallow water situations, residual multiples will be difficult to remove using successive demultiple steps based on move-out discrimination (e.g. radon demultiple). With the help of MWD+SRME, a more realistic velocity model can be built and better final images can be expected.

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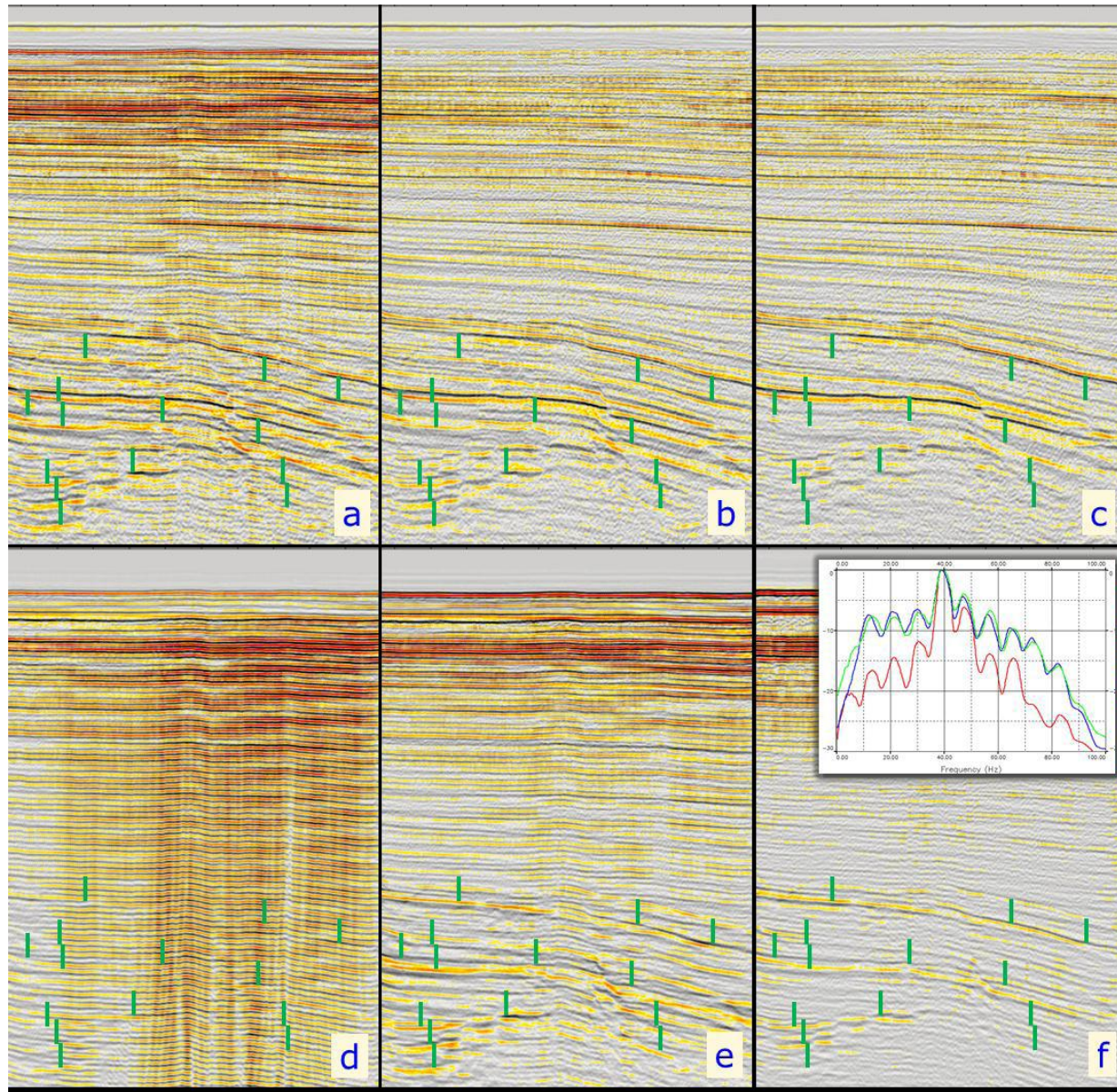


Figure 1. 2D post-stack time migration of (a) before multiple removal, (b) after SRME, (c) after MWD, (d) SRME multiple model, (e) MWD model, and (f) SRME model after MWD. Inset: Amplitude spectra measured on input data (blue), SRME model (red), and MWD model (green).

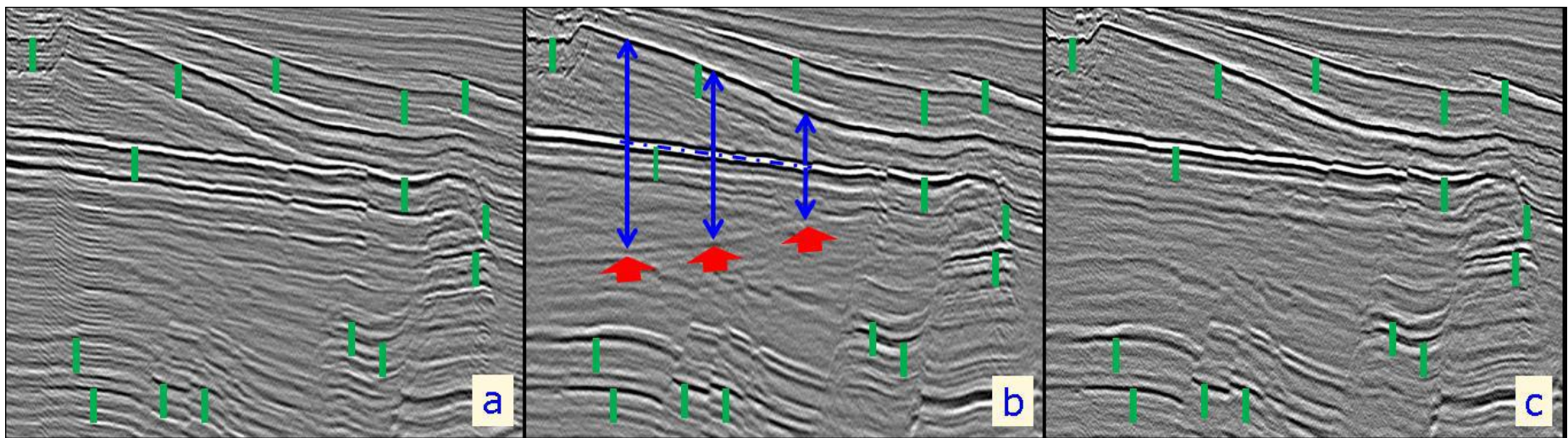


Figure 2. 3D post-stack time migration of (a) before multiple removal, (b) after tau-p gapped deconvolution, and (c) after MWD+SRME.



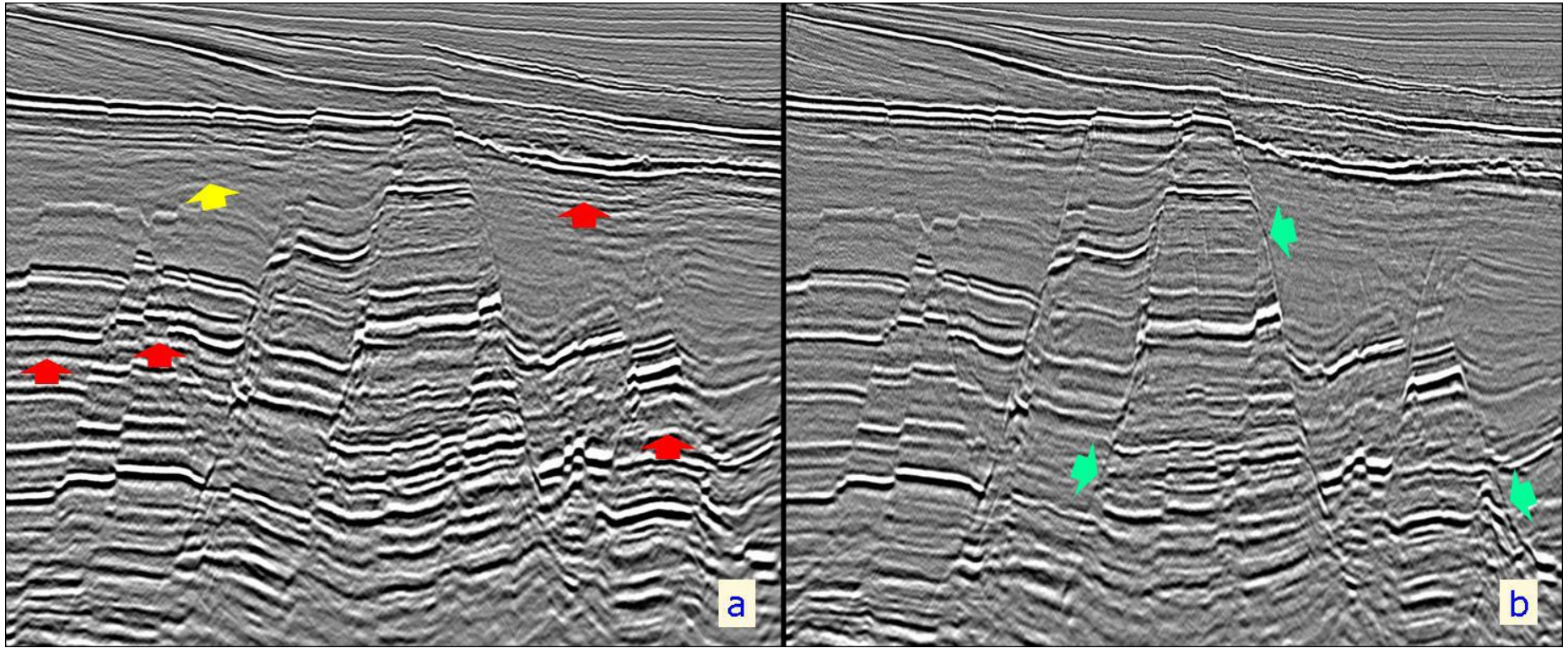


Figure 3. 3D pre-stack depth migration using (a) dataset after tau-p gapped deconvolution and velocity derived from it and (b) dataset after MWD+SRME and velocity derived from it.