ADAPTION-FREE OBN DEMULTIPLE USING UP-DOWN DECONVOLUTION AND WAVE-EQUATION DECONVOLUTION

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Summary

Up-down deconvolution remains a powerful tool for the processing of ocean-bottom node data through its ability to efficiently attenuate free-surface multiples along with the source ghost and signature. Practical receiver-domain implementations in the frequency-wavenumber domain, however, assume layer-cake geology and can leave residual multiples from dipping multiple generators. Using synthetic and real data examples, we examine the layer-cake limitations of receiver-domain up-down deconvolution and propose the use of a wave-equation deconvolution residual demultiple approach. In contrast to many multiple attenuation approaches, the proposed flow does not require any adaptive subtraction for either the up-down deconvolution or the wave-equation deconvolution demultiple steps.

Adaption-free OBN demultiple using up-down deconvolution and wave-equation deconvolution

Introduction

For ocean-bottom surveys (OBS), recording of both hydrophone and geophone data allows estimation of up-going and down-going wavefields. The availability of these wavefields facilitates the use of up-down deconvolution methods to directly estimate the Earth's reflectivity (Amundsen, 2001). The reflectivity should be free of the source wavelet, source ghost, and all free-surface multiples. Ideally, to correctly handle the 3D subsurface, multi-dimensional implementations should be used (Amundsen et al., 2001). This is seldom possible due to the insufficient sampling density of ocean-bottom receivers and, in practice, implementations in the common-receiver domain are used. Even though these implementations assume a layer-cake Earth, they are highly effective in many geological environments.

Most conventional demultiple methods predict surface-related multiples using a convolution between data and primaries (Surface-Related Multiple Elimination (SRME); Berkhout and Verschuur, 1997). While SRME does not suffer from the layer-cake assumption, it is not suitable for OBS-only datasets as it requires sources and receivers to be close to the free-surface. In shallow water areas we may use an estimate of surface-datum primaries either based on knowledge of the water-depth (e.g., Wang et al., 2011) or from deconvolution-based methods (Biersteker, 2001 or Poole, 2019). Deconvolution-based approaches result in a multiple model at the correct amplitude and are not reliant on adaptive subtraction.

In this paper we will examine the limits of up-down deconvolution using synthetic and real data. We will then show how the demultiple and source designature/deghost benefits of up-down deconvolution may be complemented by a wave-equation deconvolution (WEdecon; Poole, 2019) residual demultiple approach. Neither method is dependent on adaptive subtraction.

Theory and synthetic analysis

Synthetic data were generated using Born modelling based on a 1D velocity function (Figure 1a) and reflectors corresponding to a flat waterbottom at 108 m with an angular channel (Figure 1b). Shotpoints were generated every 12.5 m with receivers on a 25 m spacing. Receivers were placed within the water-column to avoid the strong acquisition footprint that would result from the OBS receivers being positioned on the seabed. Up-going and down-going data were modelled with the free-surface to simulate data after up-down separation. RTM imaging of the up-going data is given in Figure 1c, where a series of multiples can be seen following the shallow primaries.

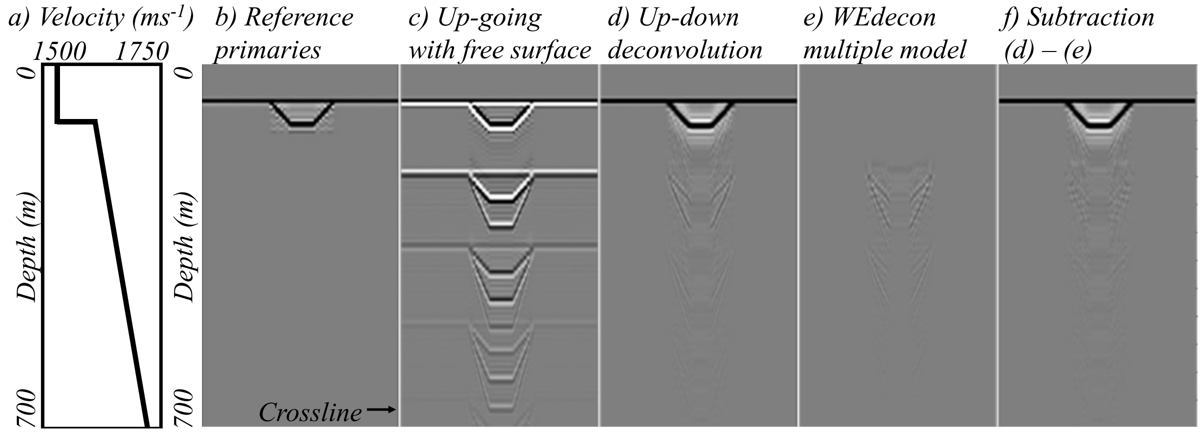

Figure 1 *a) Velocity profile used for the modelling, b) RTM image of the reference primaries, c) RTM image of the up-going wavefield modelled with the free-surface, d) RTM image after up-down deconvolution, e) Residual multiples estimated by WEdecon, and f) Up-down deconvolution result after subtraction of the residual multiples estimated using WEdecon.*

Up-down deconvolution was applied in the frequency-wavenumber domain using up-going and down-going receiver gathers, following which the data was imaged with RTM for QC (Figure 1d). Compared to the image of the up-going wavefield generated with the free-surface (Figure 1c), we see that the up-down deconvolution result has effectively removed the source ghost, along with the majority of free-surface multiples. Some residual multiples can still be observed in the image, primarily relating to the sloping part of the channel feature, where the layer-cake assumption of the up-down deconvolution process broke down. It should be noted that these multiples were still significantly attenuated compared to the up-going wavefield with the free-surface (Figure 1c).

To attenuate the residual multiples, WEdecon demultiple (Poole, 2019) was applied after up-down deconvolution. WEdecon demultiple consists of two parts: WEdecon imaging, followed by multiple prediction and subtraction. WEdecon imaging requires the derivation of an optimal shallow reflectivity image responsible for changing a downward propagating wavefield into the following order of reflection in an upward propagating wavefield. A downward propagating primary will come back as an upward propagating first-order multiple, a downward propagating first-order multiple will return as an upward propagating second-order multiple, and so on. In practice, the shallow reflectivity is estimated from the primaries and the multiples using an iterative least-squares migration process as described by Poole (2019). The process has similarities to gapped-deconvolution, where the deconvolution operator is expressed in the image domain instead of the time domain. In the proposed processing flow, data after up-down deconvolution are used as input to the WEdecon imaging step, and a minimum image depth, similar to the purpose of a gap in gapped-deconvolution, is used to avoid the trivial solution of a spike at depth zero. In the second step, the WEdecon image was used for multiple prediction using the method of Pica et al. (2005).

Figure 2a shows the WEdecon image using up-going data as input. The image captures the full periodicity of the multiples and bears a close resemblance to the reference primaries shown in Figure 1b. Figure 2b shows the WEdecon image using up-down deconvolution data as input. This image is much weaker than Figure 2a as most of the multiples have already been removed by the up-down deconvolution process. The residual multiples image is strongest on the dipping parts of the channels, which is consistent with the majority of residual multiples left in the data after up-down deconvolution (refer to Figure 1d). Figure 2c shows the difference between Figure 2a and Figure 2b, which highlights the mainly horizontal multiple generators addressed by the up-down deconvolution process. Figure 1e shows an RTM image of residual multiples predicted using the reflectivity of Figure 2b with the method of Pica et al. (2005). Figure 1f shows a straight subtraction of these residual multiples, after which very little residual multiple remains.

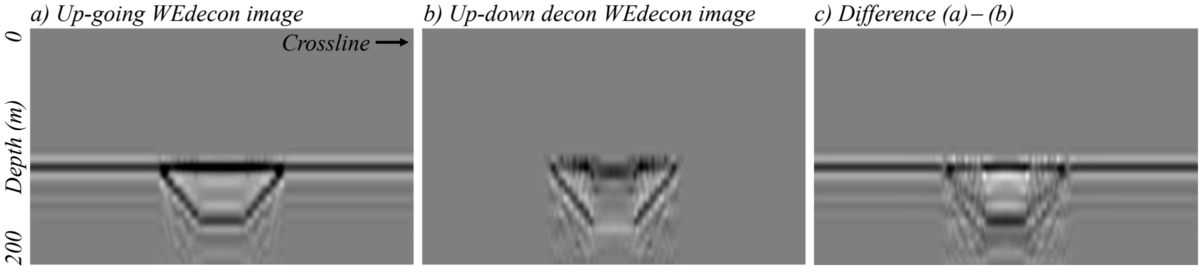

Figure 2 *Wave-equation deconvolution images using as input: a) Up-going data, b) Up-down deconvolution data, and c) Difference (a) – (b).*

Real data example

The real data example comes from an ocean-bottom node (OBN) dataset acquired in the Central North Sea in 2020. Hydrophone and vertical geophone recordings were denoised and calibrated, following which the acquired 50 m × 50 m shot grid was regularised and de-aliased to a 12.5 m × 12.5 m sampling. These processed hydrophone and vertical geophone data were summed and subtracted to calculate up-going and down-going wavefields, respectively. As shown in Figure 3a, the up-going wavefield was heavily contaminated by reverberating multiples, masking the primary reflections. Figure 3b shows the results of receiver-domain up-down deconvolution, applied in the frequency-wavenumber domain. Compared to the up-going image, we can see attenuation of the source ghost as well as heavy attenuation of free-surface multiples. Some first-order waterbottom peg-leg multiples still remain in the result along with more complex multiples not handled by the receiver-domain up-down deconvolution implementation due to the layer-cake assumption.

Figure 4a shows one-way wave-equation imaging of the up-going dataset in the shallow section. This up-going image exhibits poor spatial continuity due to a lack of primary illumination at small reflection angles, making it unsuitable for multiple prediction with the approach of Pica et al. (2005). Figure 4b shows a WEdecon image derived using the hydrophone data. This image captures the strong short-period multiple periodicities in the hydrophone data. Some waterbottom cross-talk can be seen, highlighted by the yellow arrow, which is analogous to the Backus term (Backus, 1959) and corrects the relative amplitude of higher-order multiple arrivals. Figure 4c shows a WEdecon image generated using the up-down deconvolution data. As observed on the synthetic example, the WEdecon image after up-down deconvolution was much weaker than the WEdecon image derived using the hydrophone data as most of the multiples were removed by the up-down deconvolution process. As well as a slight residual waterbottom multiple, residual multiple from small gas features and shallow channels are visible (see yellow arrows in Figure 4c); these were not attenuated by the up-down deconvolution process. As the WEdecon method is amplitude consistent, both Figures 4b and 4c are displayed at the same display gain. Figure 4d shows the difference between Figures 4b and 4c, highlighting the multiple generators handled by up-down deconvolution. This difference is dominated by flat reflectors, as expected.

Figure 3d shows RTM imaging of residual multiples predicted using the image from Figure 4c as input to the multiple modelling approach of Pica et al. (2005). A straight-subtraction of these multiples from the up-down deconvolution result is given in Figure 3c. Compared to the up-down deconvolution image (Figure 4b), we can see a nice attenuation of residual free-surface multiples. Attenuation of residual multiples using conventional multiple modelling approaches (e.g., Wang et al., 2011) typically involve an adaptive subtraction and can be prone to attenuating strong primary energy as well as the weak residual multiples. Note that neither the up-down deconvolution nor the WEdecon processes required any adaptive subtraction.

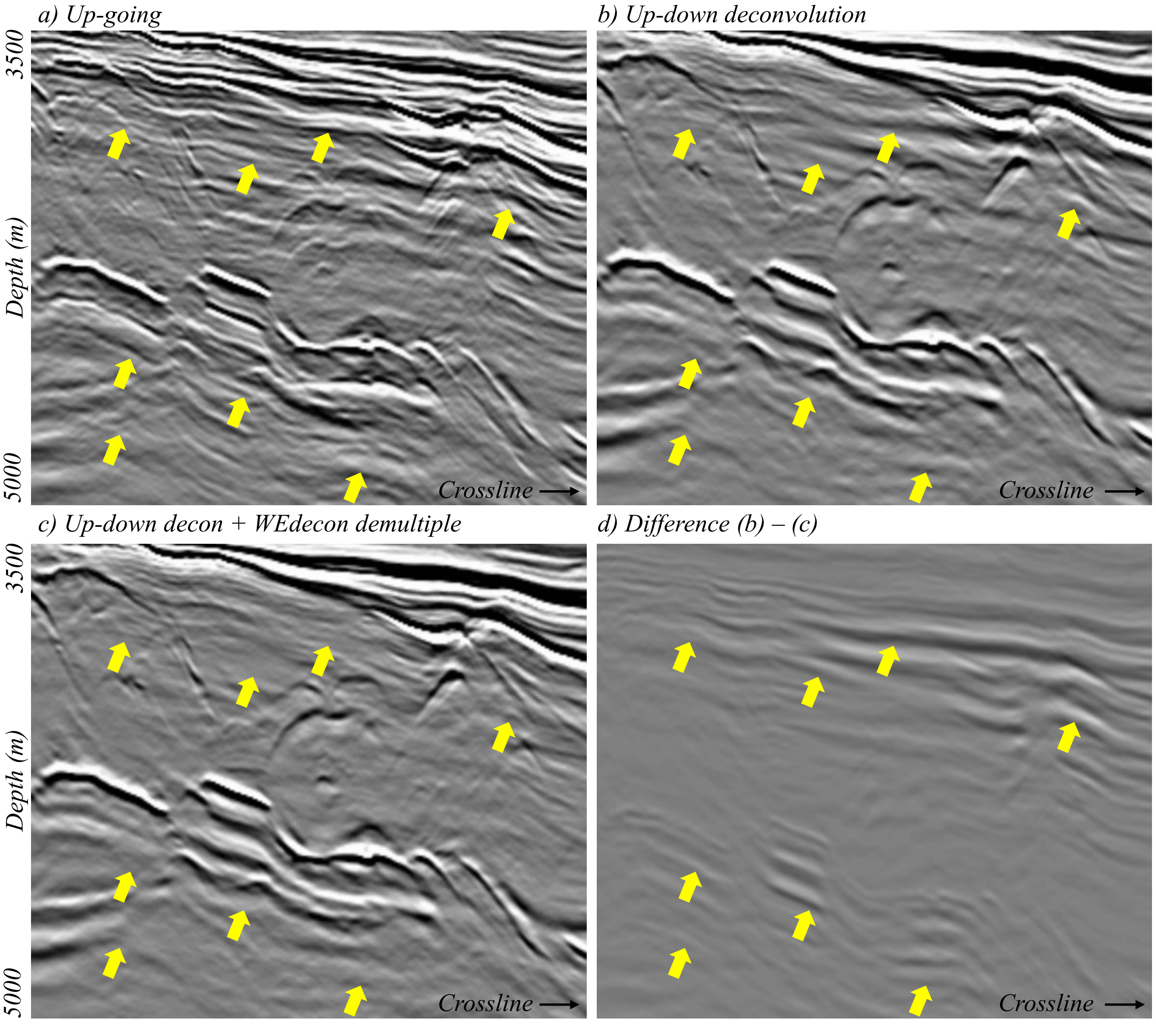

Figure 3 *RTM images of: a) Up-going data, b) Data after up-down deconvolution, c) Data after up-down deconvolution followed by WEdecon-driven demultiple, and d) Difference (b) – (c).*

Conclusions

Using synthetic and real data examples, we have examined the layer-cake limitations of up-down deconvolution in the receiver domain. We have proposed the use of wave-equation deconvolution as an approach to attenuate residual multiples left by up-down deconvolution. Synthetic and real data examples have highlighted the effectiveness of this combination, which did not involve any adaptive subtraction.

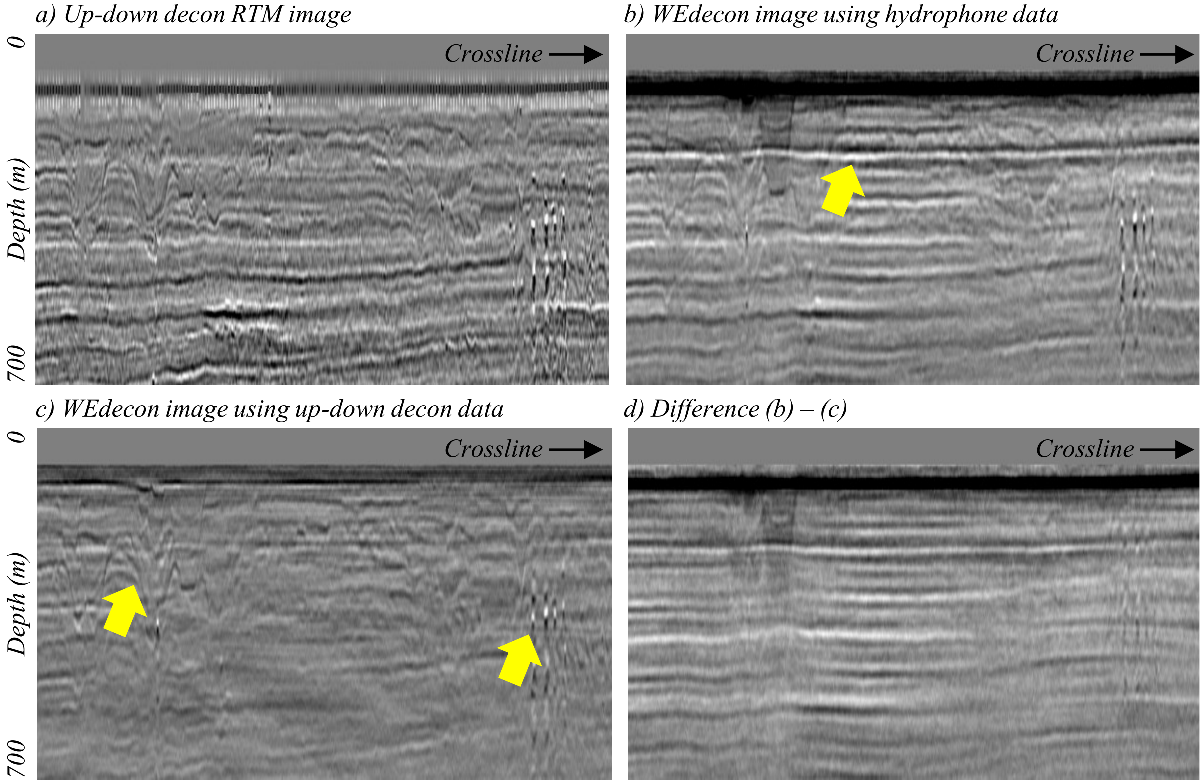

Figure 4 *a) Up-down deconvolution RTM image, b) WEdecon image using hydrophone data as input, c) WEdecon image using up-down deconvolution data as input, and d) Difference (b) – (c).*

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