Using multiples to extend the imaged area of OBN data from the Santos basin

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Abstract

Ocean-bottom node (OBN) seismic acquisition provides the ability to substantially improve the image quality of pre-salt reservoirs compared to that obtained from narrow-azimuth (NAZ) streamer acquisition. The still substantially larger expense of OBN acquisition, however, often limits the spatial area for which data is acquired. When using the surface-related multiples in the imaging process, the resulting spatial extent of the imaged area can be improved beyond the spatial extent of the image obtained using primaries only. This means that with the same data a larger area can be imaged. We show an example of a reverse-time migration with multiples for the imaging of a field in the Santos basin offshore Brazil.

Introduction

Marine seismic acquisition records the energy reflected back from the earth as well as their echoes from the water surface. These echoes are usually referred to as surface-related multiples. Historically seismic imaging algorithms are based on waves reflecting in the earth only once and cannot handle waves that reflect down at the water surface as well. In seismic data processing, therefore, we try to remove such waves prior to imaging using surface-related multiple elimination (SRME, e.g. Verschuur *et al*., 1992). As such, these multiples are treated as noise. However, there is valuable information hidden in these surface-related multiples, as they bounce inside the earth multiple times at different locations. For this reason reverse time migration (RTM) was recently extended to allow the use of these multiples as signal in the imaging procedure (e.g. Yang *et al*. 2015). In this method (at least for the streamer case) the data are forward propagated from the receiver and correlated with the backward propagated multiple injected at another receiver. We refer to this method as RTM with multiples (RTMM).

OBN seismic acquisition provides both full-azimuth coverage as well as the ability to record very long offset data. Therefore, when compared to narrow-azimuth (NAZ) streamer data OBN data usually results in a much improved seismic image. This is particularly true for reservoirs that are buried underneath a complex overburden such as in the pre-salt offshore Brazil (e.g. Marques *et al*., 2016). Putting receivers on the ocean-floor is an expensive procedure. Therefore an attempt is made to make the receiver spacing as large as possible to minimize the cost, while at the same time maintaining a good enough image at the target depth. The down-side of the resulting sparse receiver grid is a poor illumination of the shallow subsurface. After the wavefield has been decomposed into its up- and down-going components, this problem can be partially addressed using mirror imaging of the down-going primary wavefield (e.g., Grion *et al*. 2007). This down-going wavefield provides additional illumination of the subsurface because the reflection point in the subsurface is different than that from the up-going wavefield.

Even though the down-going primary wavefield can be viewed as a multiple (also referred to as a ghost), it is different from surface-related multiples which bounce inside the earth multiple times instead of only once. Therefore, surface-related multiples offer the opportunity to further improve the illumination beyond the improvement obtained from using both the up- and down-going primary reflections (e.g., Yang *et al*., 2015).

Here we show the application of RTMM to image OBN data obtained from a field in the Santos basin offshore Brazil. We show that using the multiples in the imaging, the lateral extent of the area for which an image is obtained is extended beyond the area of the image obtained when using only the primary reflections. Knowing how the image quality of RTMM can be deteriorated due to the presence of cross-talk, we show how a particular type of cross-talk present in this data, can be attenuated when streamer data is available for the same area.

RTMM using OBN data

Ocean bottom nodes record seismic energy using both a hydrophone and a three-component geophone. The pressure recorded by the hydrophone and the vertical velocity recorded by vertical component of the geophone, can be combined to decompose the wavefield at the receiver location into its up-going and down-going components (e.g. Barr and Sanders, 1989). In the 1990s, only the up-going wavefield was used to image the subsurface (see Figure 1a) while the down-going wavefield was discarded. However, the down-going wavefield contains valuable subsurface information as well. It can be imaged without modifying existing imaging algorithms by simply moving the receiver location used during imaging, to its mirror location above the sea surface (e.g., Clarke *et al.*, 2006 and Grion *et al*., 2007) [see Figure 1b]. This is usually referred to as mirror imaging.

When comparing the reflection point for the down-going wave with the up-going wave (cf. Figure 1a and 1b) for the same source-receiver pair, it is clear that the reflection point for the down-going wave is further away from the

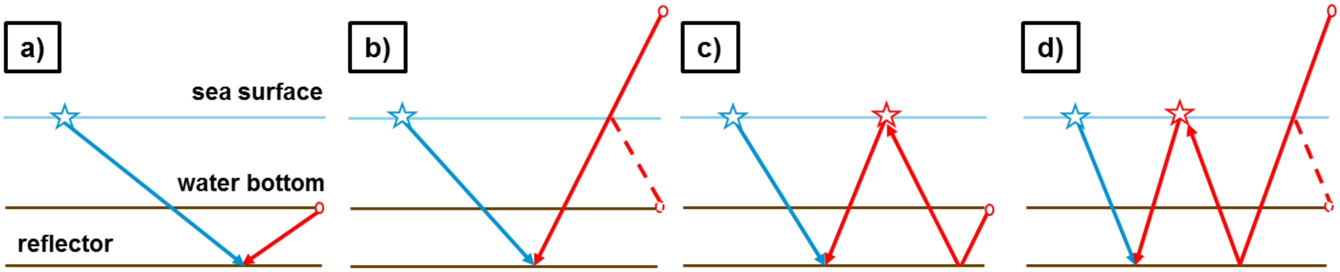

Figure 1 - Schematic diagrams showing the imaging principle for (a) up-going primaries, (b) down-going primaries, (c) up-going multiples, and (d) down-going multiples.

receiver laterally than for the up-going wave. This difference is most pronounced for the shallow reflectors. Therefore imaging using the down-going wavefield in particular benefits the image of the shallow subsurface. The success of mirror imaging allowed a refocusing of the acquisition effort from the receiver side to the shot side, making the acquisition of OBN data more cost-efficient.

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Mirror imaging uses the down-going wave that has reflected at the water-surface only once. The remaining wavefields such as the up-going wavefield that reflected once or more times at the water surface, as well as the down-going wavefield that has reflected twice or more at the water surface, contain valuable information as well (Lecerf *et al*. 2015, and Yang *et al*. 2015,); they contain reflections that have reflected inside the earth at different locations. RTMM takes advantage of the extra illumination to produce better or complementary images.

Figures 1c and 1d show the principle of imaging using the up-going wavefield that has reflected once at the sea-surface and the down-going wavefield that has reflected twice at the surface, respectively. We mention that for OBN acquisition (using reciprocity) the wavefields that are recorded at the receiver location, are backward and forward propagated from the source locations. This is different for streamer acquisition, where the data are backward and forward propagated from the receiver locations (e.g. Yang *et al*. 2015).

When comparing Figures 1a, 1b, 1c and 1d, we can see that for a horizontal reflection the reflection point that is imaged at the intersection of the blue and red lines for a fixed offset, is moving further and further away laterally from the receiver location. This shows how for OBN data the multiples can be used to extend the imaged area substantially beyond the extent of the area imaged using primary energy only.

Cross-talk in RTMM

It is known that the possibility of creating artefacts due to cross-talk is a major drawback of the method described to image multiples. This method suffers from two different types of cross-talk noise: cross-order and cross-event cross-talk (Yang *et al*. 2015). Cross-order cross-talk occurs when multiples that differ by more than one order create imaging artefacts. For example, a multiple of order 1 can create an imaging artefact due to cross-talk with a multiple of order 3. An accurate image is formed only by multiples that differ by just one order. Therefore the natural way to remove this cross-talk is to separate the different orders of multiples, and image only pairs of multiples that have the correct order. Such cross-talk can be easily handled in deep water, but is more difficult to attenuate in shallow water. Another strategy is to model and subtract cross-order cross-talk (Lu *et al*. 2016).

The field of study is situated in an area of deep water that in places exceeds 2km of depth. The large thickness of the water-column causes sequential orders of multiples to be separated in time by almost 3 seconds. This helps with the separation of different orders of multiples to avoid

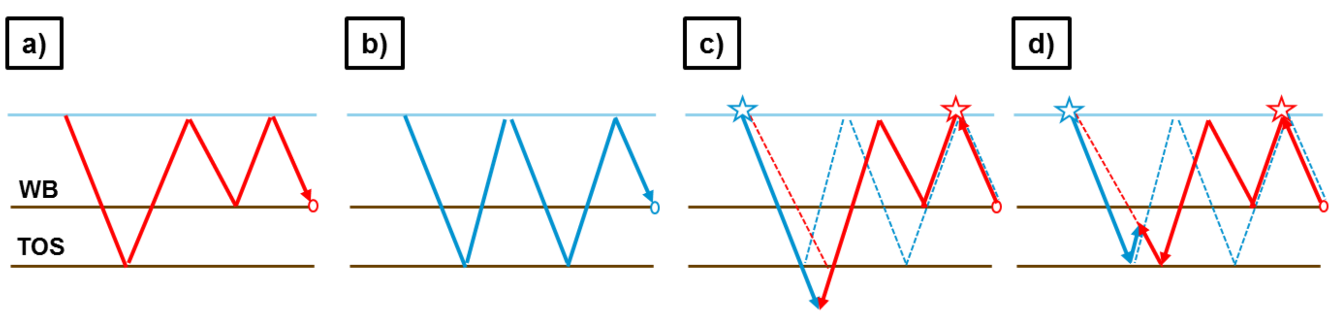

Figure 2 - Schematic diagrams showing 2 examples of cross-event cross-talk (c and d) between down-going multiples related to reflections from different events (a and b).

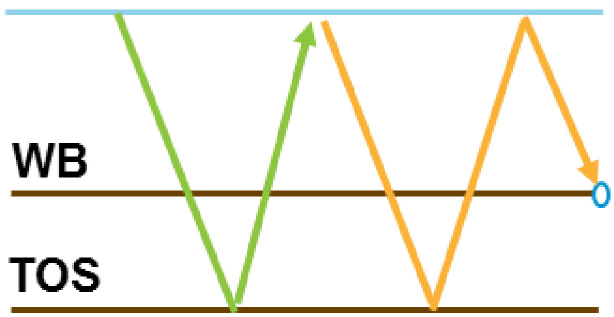

Figure 3 - Schematic diagram showing how the event from Figure 3B can be predicted using convolution of streamer data (green) with down-going OBN data.

cross-order cross-talk. However, due to the large time-differences between different sequential orders of multiples, such cross-talk would occur either below the target area or above the sea-floor. This makes the need to separate different orders of multiples prior to RTMM less important.

The second type of cross-talk is cross-event cross-talk. Such cross-talk can occur in migration with multiples, because the forward propagated wavefield contains many reflections, as opposed to a single pulse when migrating only primaries. Therefore reflected events that are not related to the same reflector can create false reflectors in the image. Such cross-talk is most likely to happen for events that have high amplitudes, such as between the water-bottom (WB) and the top of salt (TOS) reflections.

Figure 2a shows a schematic ray-path of down-going multiple energy from a combination of a TOS and WB reflection, while Figure 2b shows the same for a combination of two TOS reflections. Since both reflections have strong amplitudes, they can create artefacts in the image when using RTMM. This is illustrated in Figures 2c and 2d. The artefacts will occur at the crossing of the red and blue lines, and thus create artefacts both below and above the salt.

It turns out that we can predict this particular cross-talk. First, if we take the WB recording at the receiver, we can, using reciprocity, forward propagate this from the red source location in Figure 2c, to model the event indicated by the thick red arrow in Figure 2c. Next we would need to have the blue event from Figure 2b and backward propagate it from the blue source location in Figure 2c. The interaction of both waves then models the artefacts and can subsequently be adaptively subtracted from the RTMM result.

The blue event from Figure 2b can be modeled using OBN data, if streamer data from the same area is also available (Ikelle 1999), as shown in Figure 3. The green part of the event can be obtained from streamer data if the WB event is muted, while the orange part of the event can be obtained from down-going OBN data with again the WB event muted. As in surface-related multiple attenuation (SRME), both data can then be convolved with each other to obtain the blue event from Figure 2b.

Imaging using RTMM

Figure 4a shows an image above the base of salt (BOS) obtained from OBN data from one field in Santos basin using RTMM. The blue arrows indicate the locations where the cross-event cross-talk between the WB and TOS can be observed. Because in this area we also had streamer data available, we were able to predict this cross-event cross-talk using the method just described. Figure 4b shows the same image except after the cross-event cross-talk has been removed. It can be seen that both above and below the TOS, the cross-talk has been attenuated well resulting in improved continuity of the imaged events.

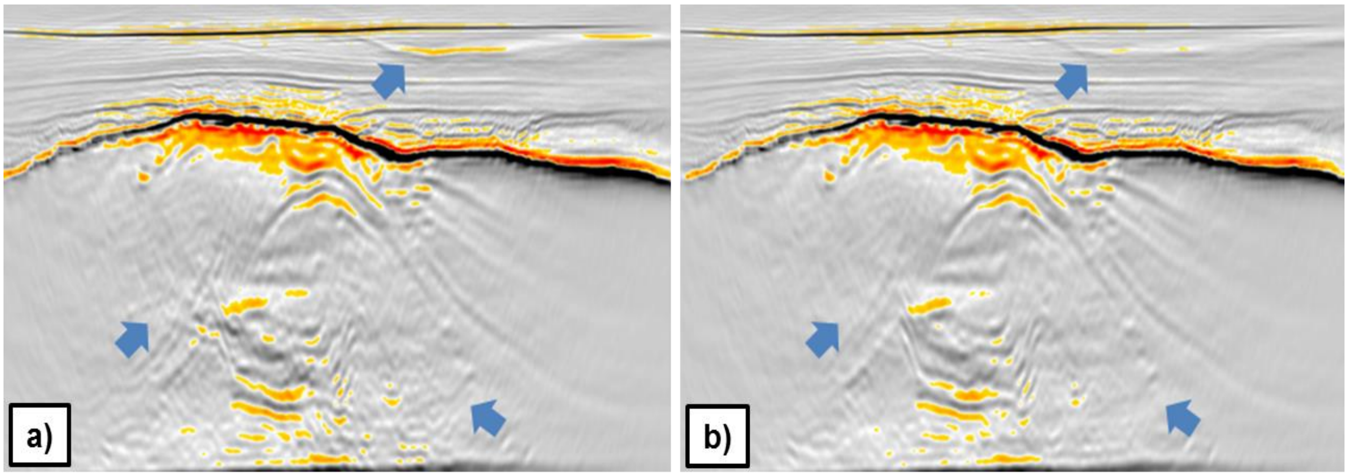

Figure 4 – RTMM in-line image (a) before cross-talk attenuation and (b) after cross-talk attenuation. After cross-talk attenuation the cross-event artefacts is successfully attenuated.

Figures 5 and 6 show the result of imaging using RTMM for an image including the area below the BOS. Figure 5 shows an in-line image while Figure 6 shows a depth slice at about 500m below the WB. Figures 5a and 6a show the image obtained when using only up-going primary energy. The node positions are clearly visible at the sea-floor, and the poor resulting shallow image is clearly observed. The spatial extent of the image hardly goes beyond the area covered by the nodes. When using the down-going wavefield (i.e. the first order multiple), the quality of the shallow image is substantially improved, as expected (Figures 5b and 6b). At the same time the

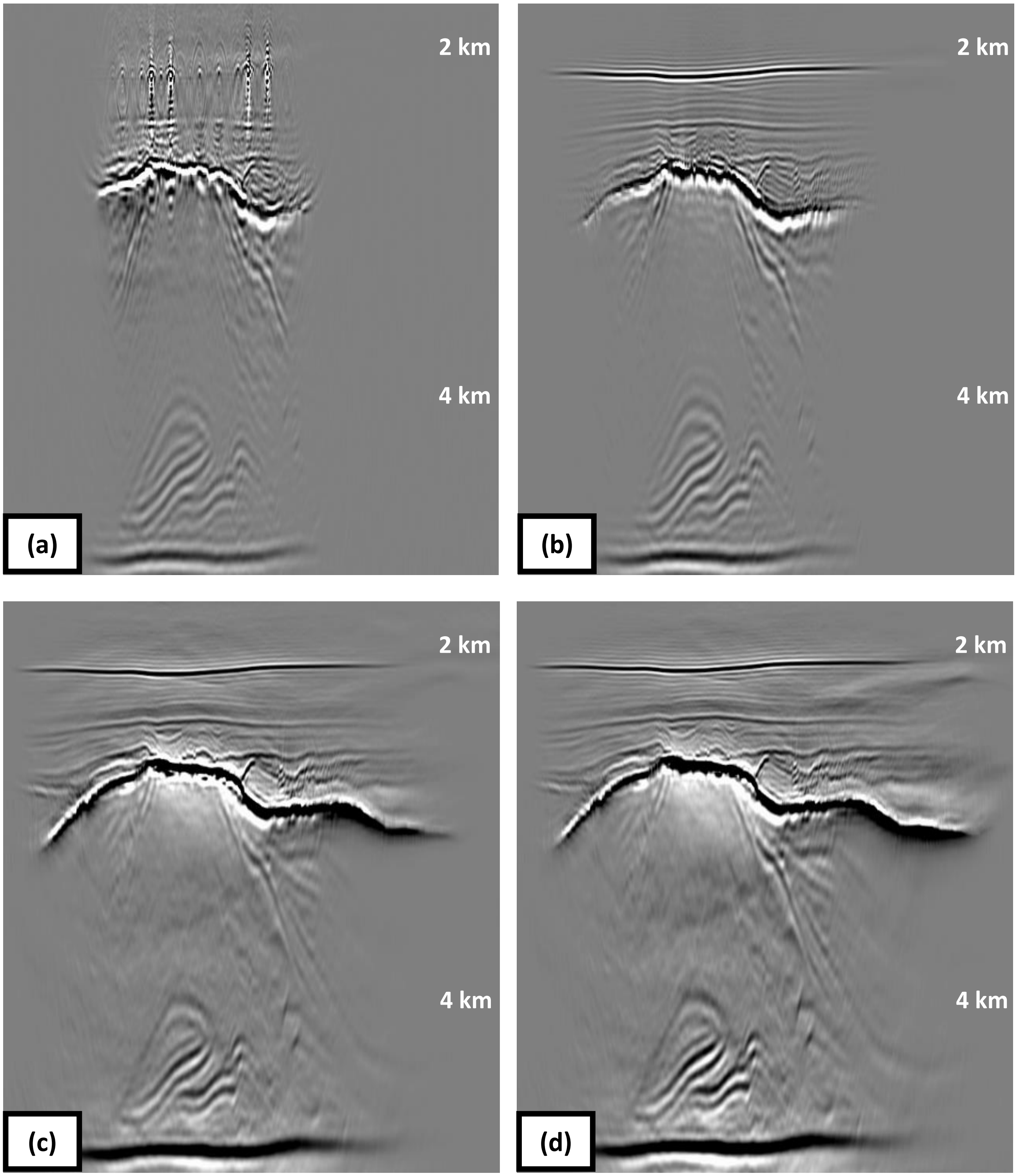

Figure 5 – In-line images of (a) up-going primaries, (b) down-going primaries, (c) up-going multiples and (d) down-going multiples. As we include multiples in the imaging, the imaged area is well extended beyond the spatial extend of the nodes due to the extra illumination provided by the multiples.

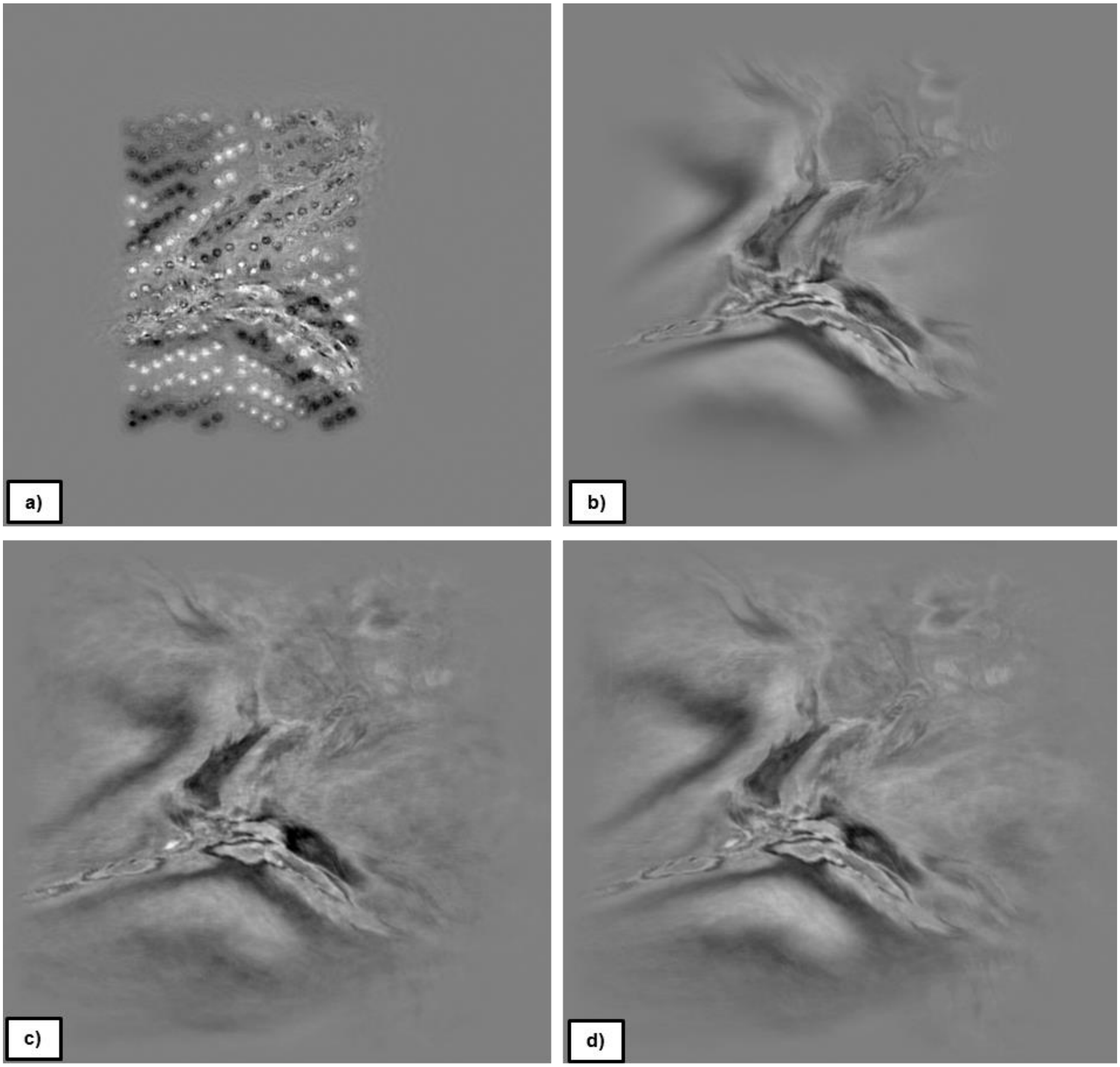

Figure 6 - Depth slices at about 500m below the water-bottom of (a) up-going primary, (b) down-going primary, (c) up-going multiple and (d) down-going multiple image.

spatial extent of the imaged area is enlarged. When using the multiples in RTMM (Figures 5c, 5d, 6c and 6d), we can see that the spatial extent of the imaged area has increased even further. For the deeper pre-salt area, the imaged area is also extended somewhat (cf. Figures 5b and 5d). At the same time, the image quality of the RTMM image at the pre-salt level is comparable to that obtained using up- and down-going primaries only in RTM.

We emphasize that the increase in the spatial extent of the image is obtained by using the multiples already present in the data. When using primary energy only during imaging, a comparable spatial extent of the image could have only been obtained if a larger area of the ocean floor would have been covered with nodes. This would require an increase in acquisition costs. When using the multiples as signal in the imaging procedure, however, no further increase in acquisition costs is necessary.

Conclusions

Using RTMM to image, we were able to improve the image quality of the shallow beyond the image quality obtained using the down-going primaries. Furthermore, the spatial extent of the image of the pre-salt area was extended as well. At the same time, at the pre-salt depth level, the quality of the image obtained using RTMM was comparable to that obtained using up- or down-going primaries in RTM. Therefore, using the multiples, a larger area was imaged without any additional acquisition costs.

Due to the large water depths at our field of interest, the attenuation of cross-order cross-talk between multiples was less important. The cross-event cross-talk between WB and TOS reflections was predicted using an SRME-like process for OBN data, using the OBN data as well as the streamer data that was available for the same area. Attenuation of this cross-talk further improved the image.

Acknowledgments

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References

BARR, F. J., AND SANDERS, J. I., 1989, *Attenuation of water column reverberations using pressure and velocity detectors in a water-bottom cable*, SEG Technical Program Expanded Abstracts, pp. 653-656.

CLARKE, R., XIA, G., KABIR, N., SIRGUE, L., MICHELL, S., 2006, *Case study: A large 3D wide azimuth ocean bottom node survey in deep water GOM*, SEG Technical Program Expanded Abstracts 2006: 1128-1132.

GRION, S., EXLEY, R., MANIN, M., MIAO, X., PICA, A., WANG, Y., GRANGER, P., AND RONEN, S., 2007, *Mirror imaging of OBS data*, First Break

IKELLE, L. T., 1999, *Combining two seismic experiments to attenuate free-surface multiples in OBC data*: Geophysical Prospecting, 47, 179–193,

LECERF, D., HODGES, E., LU S., VALENCIANO, A., CHEMINGUI, N., JOHANN, P., THEDY, E., 2015, *Imaging primaries and high-order multiples for permanent reservoir monitoring: Application to Jubarte field*, Leading Edge

LU, S., WHITMORE, N.D., VALENCIANO, A.A., CHEMINGUI, N., RONHOLT, G., 2016, *A practical crosstalk attenuation method for separated wavefield imaging*, 86th Annual International Meeting, SEG, Expanded Abstracts, 4235-4239

MARQUEZ, V., ARTUR GROVER, A., FERREIRA, D., YU, Z., KNELLER, E., CAROTTI, D., DOUMA, H., WALKER, C., BRAGA L., VELASQUEZ, M., URASAKI, E., TRIQUES, A., DE LIMA, G., SANTIAGO, T., DA CRUZ, N., VERAS, I., 2017, *Improving pre-salt imaging in the Santos Basin through OBN acquisition,* 15th Congresso da Sociedade Brasileira de Geofisica

VERSCHUUR, D. J., BERKHOUT, A. J. AND WAPENAAR, C. P. A., 1992, *Adaptive surface-related multiple elimination, Geophysics*, 57, 1166-1177

YANG, Z., HEMBD, J., CHEN, H., YANG, J., 2015, *Reverse Time Migration of Multiples: Applications and Challenges*, The Leading Edge