Reverse Time Migration of Multiples for OBS Data

Dongliang Zhang[*1] *1. King Abdullah University of Science and Technology (KAUST)*

SUMMARY

Reverse time migration of multiples (RTMM) is applied to OBS data with sparse receiver spacing. RTMM for OBS data unlike a marine streamer acquisition is implemented in the common receiver gathers (CRG) and provides a wider and denser illumination for each CRG than the conventional RTM of primaries. Hence, while the the conventional RTM image contains strong aliasing artifacts due to a sparser receiver interval, the RTMM image suffers from this artifacts less. This benefit of RTMM is demonstrated with numerical test on the Marmousi model for sparsely sampled OBS data.

INTRODUCTION

Acquisition of ocean bottom seismic data routinely employs hydrophones and three-component geophones or accelerometers embedded in a cable or individual nodes on the surface of ocean bottom, and the source distribution excited by the airgun is near the free surface. Therefore, OBS data provide a wide-azimuth geometry which is important for imaging complex structures such as salt bodies. Usually the receivers on the ocean bottom are very sparse to decrease the cost of the acquisition. However, conventional migration method suffer from the strong aliasing artifacts due to the sparse receiver interval. In the conventional method OBS data are separated into upgoing and down-going wavefields before migration (Barr and Sanders, 1989; Osen et al., 1999), and only the up-going wavefield is used to image the subsurface structure, which usually has a limited illumination. In fact, the ocean surface acts as a mirror to reflect the energy from the subsurface, so the receiver ghosts can be used for mirror imaging to enhance the illumination. Only the first-order down-going multiples are used in the mirror imaging method in VSP data (Zhang et al., 2005) and OBS data (Grion et al., 2007; Grion, 2012).

Unlike the the mirror imaging method which only uses the first-order multiple, reverse time migration of multiples (RTMM)(Liu et al., 2011; Zhang and Schuster, 2014) employs all orders of multiples. RTMM also has a wider and denser illumination of the reflector compared to the conventional RTM for each shot gather. When the numbers of shots and receivers are equal, the illumination area of conventional RTM will be about the same as RTMM, but the illumination density of RTMM will be much greater because each point on the surface acts as virtual source for any actual source point. When the number of shots are fewer than the receivers, the illumination of RTMM is superior to conventional RTM. For OBS data, I usually migrate the data in the common receiver gather (CRG) domain. In this case, the receiver can be considered as the shot by reciprocity, so the sparse receiver in OBS data can be considered as the sparse shot. Therefor, for OBS data RTMM should be superior to RTM.

In this paper, I will apply reverse time migration of multiples to the OBS data. A theory section provides the mathematical fundamentals. This is followed by the section for processing the OBS data, which will introduce the decomposition of up-going and down-going waves and the prediction of multiples. Then tests on the Marmousi model show that RTMM has a better illumination and fewer aliasing effects than conventional RTM, which demonstrates the key advantage of RTMM. Finally, a summary is presented at the end.

REVERSE TIME MIGRATION OF MULTIPLES

Liu et al. (2011) proposed reverse time seismic migration of multiples to enhance the illumination of the subsurface structure beneath a salt body. RTMM replaces the impulsive source wavelet with the recorded data that contain both primaries and multiples, and the input reflection data for back-propagating only consist of multiples predicted by SRME. Therefore, the image condition of RTMM is also the zero-lag cross-correlation of the forward and backward wavefields.

$$I(\mathbf{x}) = \sum_{\omega} [P_F(\mathbf{x},\omega) + M_F(\mathbf{x},\omega)] M_B(\mathbf{x},\omega), \qquad (1)$$

where $I(\mathbf{x})$ is the image on the location $\mathbf{x}$ and ω is the angular frequency. The forward wavefield consists of the forward-propagated primaries $P_F(\mathbf{x},\omega)$ and multiples $M_F(\mathbf{x},\omega)$, and the backward wavefield is the back-propagated multiples $M_B(\mathbf{x},\omega)$. Surface-related multiples are composed of various orders of multiples as follows

$$M(\mathbf{x},\omega) = \sum_{i=1}^{n} M^i(\mathbf{x},\omega), \qquad (2)$$

where $M^i(\mathbf{x},\omega)$ represents the ith-order multiple and n is the highest order of usable multiples.. If the primaries P_F is defined as the 0th-order multiple M_F^0, substituting equation 2 into equation 1 yields

$$\begin{aligned} I(\mathbf{x}) &= \sum_{\omega}\{[P_F(\mathbf{x},\omega) + \sum_{i=1}^{n} M_F^i(\mathbf{x},\omega)] \sum_{i=1}^{n} M_B^i(\mathbf{x},\omega)\} \\ &= \sum_{\omega}\{\sum_{i=0}^{n} M_F^i(\mathbf{x},\omega) \sum_{i=1}^{n} M_B^i(\mathbf{x},\omega)\}. \qquad (3) \end{aligned}$$

Expanding equation 3, the image condition can be expressed as

$$\begin{aligned} I(\mathbf{x}) &= \sum_{\omega}\{\sum_{i=0}^{n} M_F^i(\mathbf{x},\omega) M_B^{i+1}(\mathbf{x},\omega)\} \\ &+ \sum_{\omega}\{\sum_{i=0}^{n} M_F^i(\mathbf{x},\omega) \sum_{j=1,j\neq i+1}^{n} M_B^j(\mathbf{x},\omega)\}, \qquad (4) \end{aligned}$$

Where the first term represents the multiple imaging condition, which is the cross-correlation of the forward wavefield as the

DOI http://dx.doi.org/10.1190/segam2014-1074.1

forward-propagated ith-order multiple and the backward wavefield as the back-propagated $(i+1)$th-order multiple. Otherwise, cross-correlation generates cross-talk noise, which is indicated by the second term.

PROCESSING OF RTMM FOR OBS DATA

For the OBS data, the dense sources are excited on the surface and the sparse receives are located on the sea-bed. RTM for OBS data is usually implemented in the CRG domain, and before migration, converting the common shot gathers (CSG) into CRGs is necessary. Figure 1b shows the CRG converted from the CSG shown in Figure 1a. After convertion, the station or node can be treated as the virtual source and the sources on the surface can be treated as the virtual receivers. The virtual sources on the surface are used in the formula of RTMM, and applied in the CGR domain.

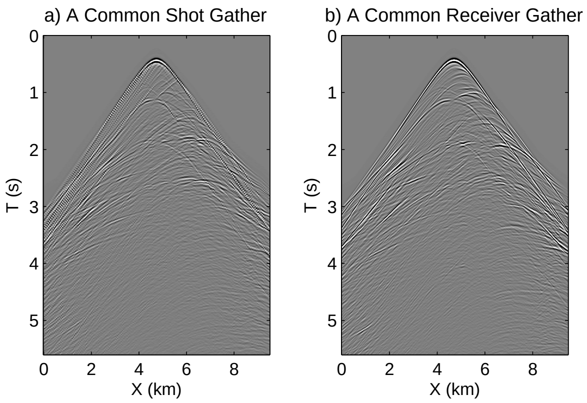

Figure 1: a) A common shot gather for the OBS data. b) A common receiver gather for the OBS data converted from the common shot gather.

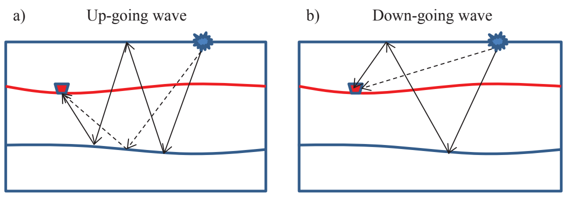

Figure 2: a) The up-going waves consist of primaries indicated by the dash line and multiples denoted by the solid line. b) The down-going waves is composed of the direct waves (dash line) and multiples (solid line).

According to the RTMM formula for OBS data, the CRG data are forward propagated, and the multiples in CRG are back propagated. To get the multiples, the $P-Z$ summation and the SRME will be used. By using the $P-Z$ summation of the pressure P recorded by hydrophones and the vertical particle velocity Z collected by geophones, the pressure wavefield P can be decomposed into up-gong U and down-going D components after proper scaling and wavelet processing. As shown in Figure 2a, the up-going wavefield contains primaries indicated by the dash lines and multiples indicated by the solid lines. The down-going wavefield shown in Figure 2b consists of multiples (solid line) and direct waves (dash line) that can be easily removed. For the up-going wavefield, Matson and Xia (2002) proposed a method that predicts and eliminates multiples followed by extrapolation of the wavefield to the seabed or surface. Pica et al. (2005) implemented SRME by using 3D wavefield modeling for surface-related multiple elimination (WFM SRME). In their method, the recorded data act as the virtual source to generate the multiples, which can be eliminated by the prediction-error filter. After up and down-going decomposition and SRME, the multiples can be generated through the summation of multiples in the up-gonging and down-going wavefields.

As shown in Figure 3a for the up-going waves, the migration image is constructed by cross-correlating the forward-propagating wavefield (blue solid line) of the primaries (blue dash line) and the back-propagating wavefield of the first-order multiples (red solid line). Here, the source field is the zero-th order multiple defined in equation 3 and the receiver field is the first-order multiple. This principle can be extended to the higher-order multiples. Figure 3b shows the RTMM for the down-going waves. It is similar to the case of up-going waves, except the direct waves are defined as the zero-th order multiple. Therefore, I can apply RTMM to both the up-going and down-going waves respectively, or combine them together. In this paper, I only show the results for the later case.

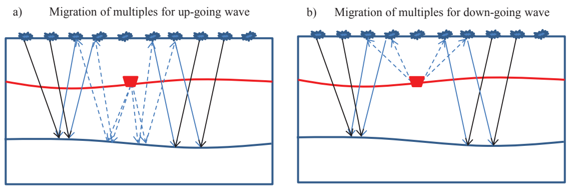

Figure 3: RTM of multiples for the a) up-going and b) down-going waves. Here, only the pair of the zeroth-first order multiple ray is shown. For the up-going waves, the migration image is constructed by cross-correlating the forward-propagated wavefield (blue solid line) of the primaries (blue dash line) as the virtual source and back-propagation of the first-order multiples (red solid line). For the downgoing waves, only the pair of the direct-first order multiple is shown. If the direct wave is defined as the zeroth-order multiple, it also satisfies the equation 3. The migration image is formed by cross-correlation of the forward-propated wavefield (blue solid line) of the direct waves (blue dash line) as the virtual source and back-propagation of the first-order multiples (red solid line). RTMM for both of the upgoing and downgoing waves can be extended to higher-order multiples.

EXAMPLE

The Marmousi model is discretized into a 350×950 grid with a gridpoint separation of 10 m. A fixed-spread acquisition ge-

DOI http://dx.doi.org/10.1190/segam2014-1074.1

ometry is used and there are 475 shots spaced at 20 m covering the entire surface. Migration images will be computed for four different receiver intervals with (50 m, 100 m, 200 m and 400 m) using conventional RTM of up-going primaries and RTM-M.

To simplify the test for RTMM with OBS data, the multiples are generated by a FD algorithm without using the general method discussed in the previous section. Using a mirror source above the free surface and an absorbing boundary condition on the top boundary, direct waves and primaries can be simulated and subtracted from the full data that contains both primaries and multiples to recover the pure multiples. Figure 4b shows a CRG with direct waves and primaries and Figure 4c shows the pure multiples obtained by subtracting Figure 4b from the full data (Figure 4a).

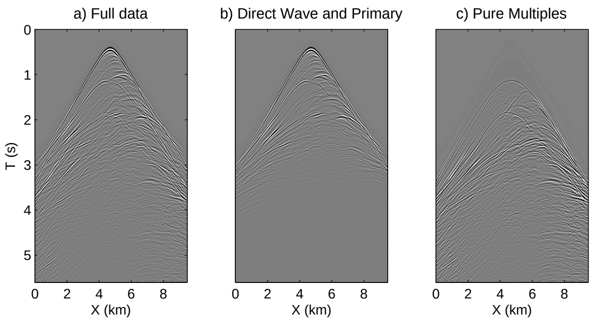

Figure 4: a) Full data containing direct waves, primaries and multiples. b) A CRG with direct waves and primaries. c) Multiples obtained by subtracting b) from a).

Figure 5 shows the migration images of primaries only and multiples only with different receiver spacings. The receiver intervals of Figure 5a-b, c-d, e-f and g-h are 50, 100, 200, and 400 m, respectively. Compared to conventional RTM image, the RTMM image has wider illumination. The aliasing around the receivers in the conventional RTM image become more serious with increasing receiver intervals, while the RTMM images do not suffer much from this problem. The RTMM image qualities are almost the same as that for the station spacings from 50 m to 400 m. Therefore, RTMM can be used rectify aliasing artifacts associated with OBS data recorded with a sparse receiver spacing. The reason for RTMM has a de-aliasing property is that the illumination area and the illumination density of image for each common receiver gather is wider than that of the primaries image.

CONCLUSIONS

I propose reverse time migration of multiples for OBS data to migrate the surface-related multiples. In this method the recorded CRGs are treated as an extended virtual source along the free surface and the back-propagated wavefield consists of back-propagated multiples predicted by the decomposition of up-going and down-going wavefields and SRME. Numerical tests on the Marmousi model suggest that RTMM of OBS data with sparse receivers can mitigate aliasing artifacts, because it has wider and denser illumination of each CRG than the conventional migration for up-going primaries. RTMM can generate the crosstalk so the next step is to use least-squares technique to suppress the crosstalk noise.

ACKNOWLEDGMENTS

I thank the KAUST Supercomputing Lab for the computer cycles they donated to this project. I are especially grateful for the use of the SHAHEEN supercomputer. I also acknowledge the support of the CSIM sponsors (http://csim.kaust.edu.sa).

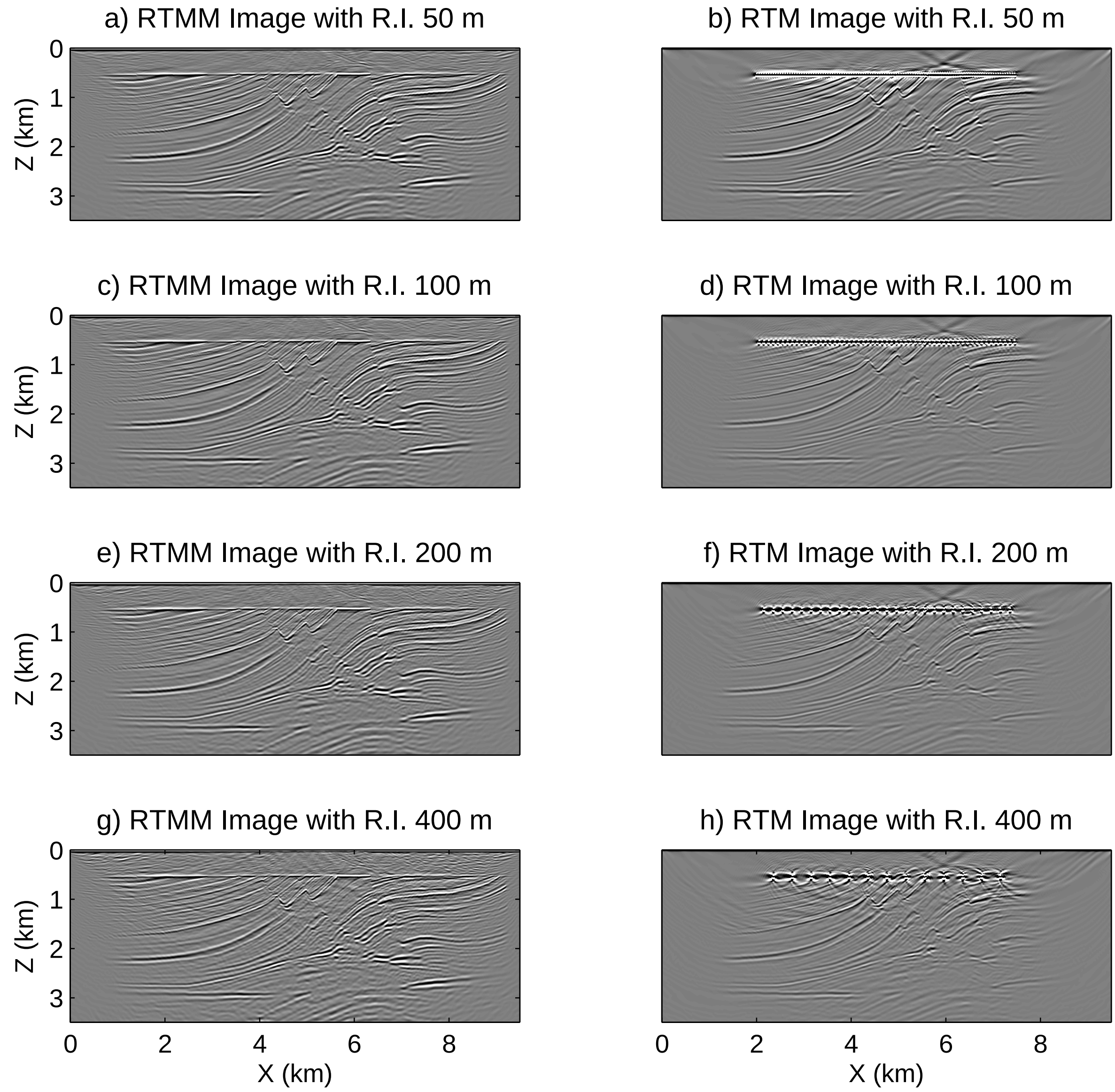

Figure 5: Migration images of primaries only with receiver intervals (R.I.) b) 50 m, d) 100 m, f) 200 m and h) 400 m. RTMM images with receiver intervals a) 50 m, c) 100 m, e) 200 m and g) 400 m.

DOI http://dx.doi.org/10.1190/segam2014-1074.1

http://dx.doi.org/10.1190/segam2014-1074.1

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2014 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Barr, F. J., and J. I. Sanders, 1989, Attenuation of water column reverberations using pressure and velocity detectors in a water bottom cable: 59th Annual International Meeting, SEG, Expanded Abstracts, **193**, 653–656.

Grion, S., 2012, OBS wavefield separation and its applications: Presented at the 9th Biennial International Conference & Exposition on Petroleum Geophysics.

Grion, S., R. Exley, M. Manin, X. Miao, A. Pica, Y. Wang, P. Granger, and S. Ronen, 2007, Mirror imaging of OBS data: First Break, **25**, 37–42.

Liu, Y., X. Chang, D. Jin, R. He, H. Sun, and Y. Zheng, 2011, Reverse-time migration of multiples for subsalt imaging: Geophysics, **76**, no. 5, WB209–WB216, http://dx.doi.org/10.1190/geo2010-0312.1.

Matson, K. H., and G. Xia, 2002, Combining freesurface multiple attenuation with wavefield continuation to attenuate 3D free-surface multiples on multicomponent ocean bottom seismic data: 72nd Annual International Meeting, SEG, Expanded Abstracts, **256**, 998–1001.

Osen, A., L. Amundsen, and A. Reitan, 1999, Removal of water layer multiples from multicomponent sea bottom data: Geophysics, **64**, 838–851, http://dx.doi.org/10.1190/1.1444594.

Pica, A., G. Poulain, B. David, M. Magesan, S. Baldock, T. Weisser, P. Hugonnet, and P. Herrmann, 2005, 3D surface related multiple modeling, principles and results: 75th Annual International Meeting, SEG, Expanded Abstracts, **530**, 2080–2083, http://dx.doi.org/10.1190/1.2148121.

Zhang, D., and G. Schuster, 2013, Least-squares reverse-time migration of multiples: Geophysics, **79**, no. 1, S11–S21, http://dx.doi.org/10.1190/geo2013-0156.1.