Migration and demigration deblending in receiver domain

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ABSTRACT

In some important cases, for example, ocean bottom node surveys(OBN), seismic acquisitions have more sources than receivers. This brings the need to develop processing and inversion techniques that work more efficiently in the receiver domain. After exchanging source and receiver location, receiver domain Reverse Time Migration (RTM) can save significant computation time compared with shot domain RTM. This problem is also interesting because some deblending techniques exploit incoherence in the receiver domain created by time delays in the shot domain to separate simultaneous sources. In this report, we investigate receiver domain RTM for both migration of regular surveys and its possible use for the deblending of simultaneous sources.

INTRODUCTION: NODE ACQUISITION AND RECEIVER DOMAIN RTM

Land surveys normally have more receivers than shots because shots are more expensive. Sometimes when needed, if converted waves are of no interest, processors assume reciprocity and create shots from the receivers. Similarly, marine streamer surveys tend to have more receivers than shots since adding more receivers to the streamer has a very small additional cost. Techniques like RTM are a good fit for these cases because of two reasons: first, each shot is a different physical experiment and can be handled naturally by the non-homogeneous wave equation; second, the computational cost is linearly proportional to the number of shots, imaging more receivers is practically free. But for some types of surveys like ocean bottom node acquisition (Zhang et al., 2013), the situation is completely reverse. Nodes are significantly more expensive than shots and are therefore located far from each other, as shown in Figure 1.

This brings many different issues for processing and migration. First of all, the coarse sampling in the receiver domain is far larger than the coarse sampling of shots in other surveys. Nodes can be located a few hundred meters from each other, and illumination in the shallow layers under the ocean are barely illuminated. It is in this scenario that the reciprocity principle becomes very important.

Several variants of node processing have been suggested over the years. For example, often the first multiple of the data (receiver ghost) is processed and migrated instead of the primaries. Interpolation of nodes has often being attempted although with mild success only. This is particularly difficult because of time-variant midpoints because of different elevations. This problem is often addressed by some sort of datuming, which has its own difficulties due again to sampling. For PS waves, which are often the main goal of OBN surveys, the migration of multiples is not possible (S waves do not travel in water). A large list of challenges for OBN surveys awaits to be solved.

In this report, we start investigating this list of interest for OBN surveys with two different problems. First, we address RTM in the receiver domain with the sole purpose of saving computation time. We are aware this is probably often done in industrial settings

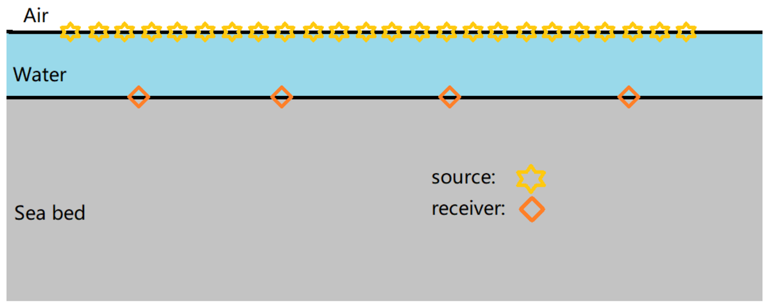

FIG. 1. Ocean bottom node acquisition has more shots than receivers

but nonetheless, we need to start somewhere. Second, we investigate how to deblend shots from the receiver gathers using migration/demigration techniques. Since nodes are fixed, the cost of OBN can be substantially reduced if many ships can fire simultaneously, creating dense shot carpets. We do not assume that migration/demigration techniques are the best option to deblend OBN surveys but we believe it is an interesting option since the complexity of OBN data may be naturally handled by Green functions as opposed to parametric transforms like Fourier or Radon transforms.

METHOD

Linearization assumption of subsurface

The Earth's response can generally be approximated as linear and any response to any complex force can be calculated as a sum of the displacement of constituent body forces. In the same way, the response to many multiple seismic sources can be considered as a sum of responses to each independent source.

Reciprocity of seismogram

The principle of reciprocity illustrates that the location of the source and receiver can be exchanged and the same waveform will be observed(Claerbout, 1985). That was based on the reciprocity of the ray trace. As a result, the travel time is constant before and after exchanging the source and receiver. The validity for reciprocity of based on the assumption that all waves are scalar phenomena with scalar sources and scalar receivers. For instance, acoustic pressure wave generated by the explosive source and pressure-sensitive receivers fulfills the scalar requirements, which is common in marine surveys like airgun and hydrophone. Things turn quite complicated when directional sources and receivers are involved. So for ocean bottom node acquisition, only PP wave can be easily proved to fit the reciprocity. Because only P wave source is valid in the marine acquisition and pressure-sensitive receivers that can only detect P wave is available for reciprocity.

Dithering in blended shots

Conventional acquisitions record energy come from only one source at a time. Blending acquisitions fire multiple sources simultaneously, as shown in Figure 2 (Zhang et al.,

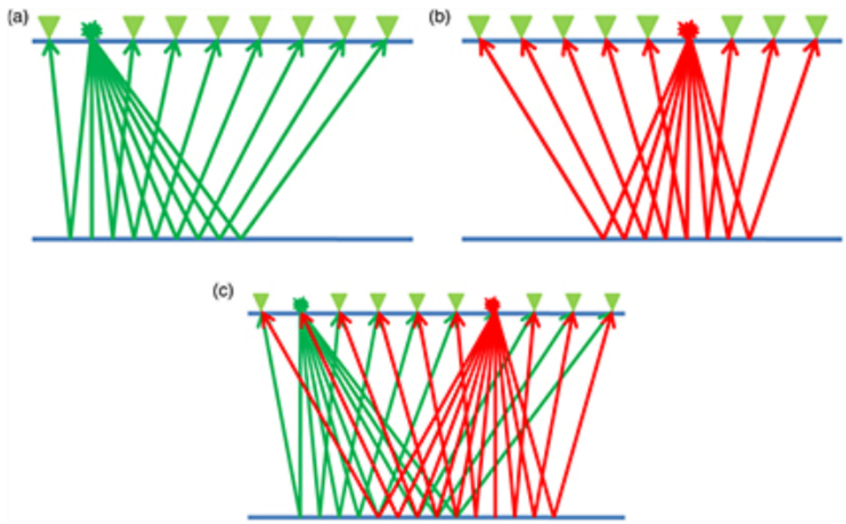

FIG. 2. (a) and (b) are illustrations of conventional acquisition and (c) is simultaneous sources acquisition

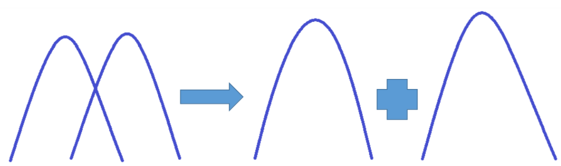

FIG. 3. Deblending separates blended shots

2015)(Garottu, 1983). We call the shot record of blended acquisition "supershot". Compared with the traditional acquisition method, blending acquisitions have the advantage of saving time and/or achieving denser shot density. On the other hand, seismic processing normally requires unblended shot records, so deblending is introduced to separate the supershots into shots, as shown in Figure 3. Even if we can migrate with multiple source gathers, a separation is needed for denoising, static corrections, velocity analysis and gathering other required information. To facilitate deblending, often shots are fired with some random time delay between them (known)(Berkhout, 2008). The existence of several shot locations for each trace implies that each trace has multiple sets of offsets, azimuths, shot statics and time delays, as shown in Figure 4. The challenging part for deblending is that each shot gather may have multiple events and it is hard to determine which event belongs to which shot gather, as shown in Figure 5.

For shots with time delays, it is possible to separate blended shots by converting from shot domain to other domains. Unless the time delays are removed, seismic events are incoherent in between traces that contain different shots (and therefore time delays). This happens for example in the midpoint, receiver, common offset and azimuth vectors, offset domains, as shown in Figure 6. Utilizing time delay from Figure 4, we could remove time delay based on each shot inside each "supershot". The target shot that sets the delay time is the shot we want to separate and all the other shots are unwanted noise. In that way, we dither each shot record in the shot domain and add zero paddings for the blank. After dithering, the target shot turns coherent while all the other shots remain incoherent in the

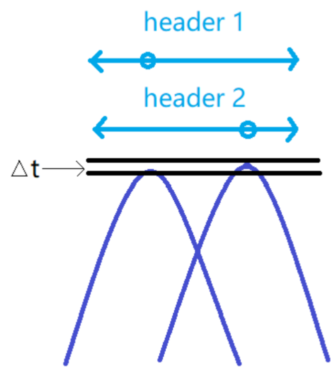

FIG. 4. Information for deblending includes multiple sets of headers and time delay between sources

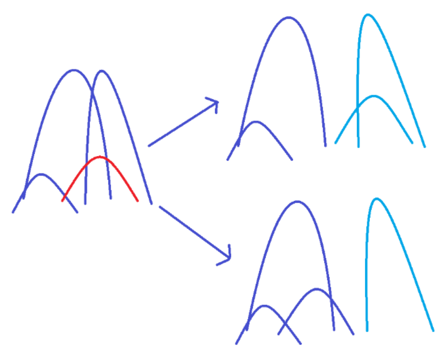

FIG. 5. Challenging in deblending is which event belongs to which shot gather

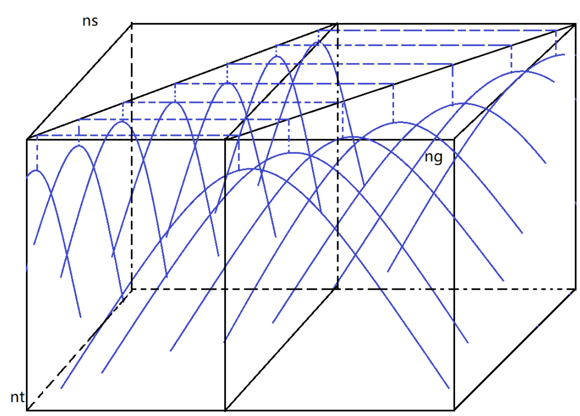

FIG. 6. Blended acquisition in shot and receiver domain

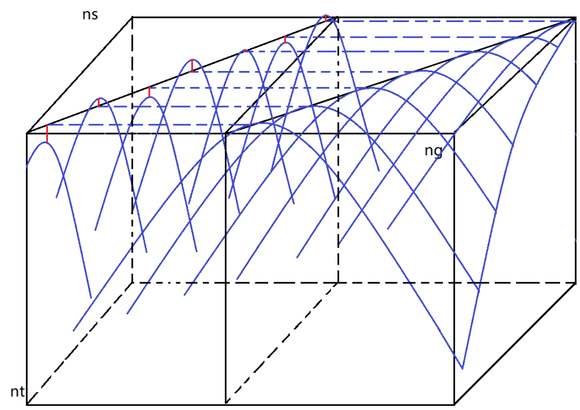

FIG. 7. Dithered data from blended acquisition. The shot on the right is target shot and the red lines is the random delay time from dithering of target shot

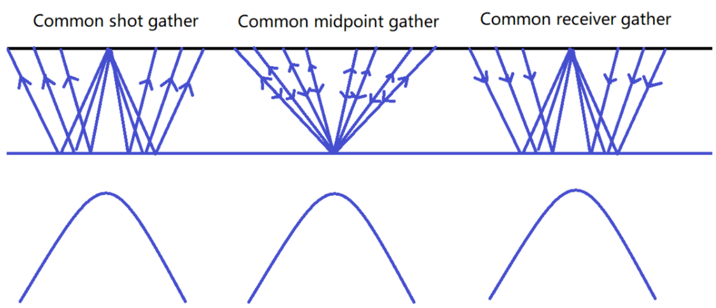

FIG. 8. Unblended acquisition in shot domain, midpoint domain and receiver domain

receiver domain because delay time only fits with the target shot, as shown in Figure 7. For unblended acquisition, shot record shares similar shape in shot domain, midpoint domain and receiver domain, as shown in Figure 8. But in dithered blended data, target shots turns coherent in midpoint domain and receiver domain, as shown in Figure 9. For each target shot in one supershot, there's a set of dithering time delay. Consequently, the size of the data increases by n_{blend} times, where n_{blend} is the number of sources simultaneously.

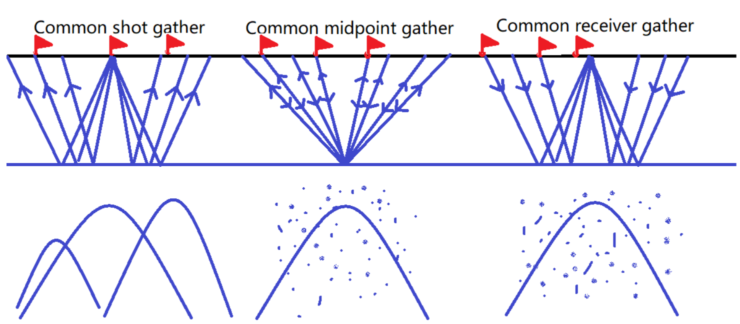

FIG. 9. Blended acquisition in the shot domain, midpoint domain, and receiver domain. The red flags are the source locations

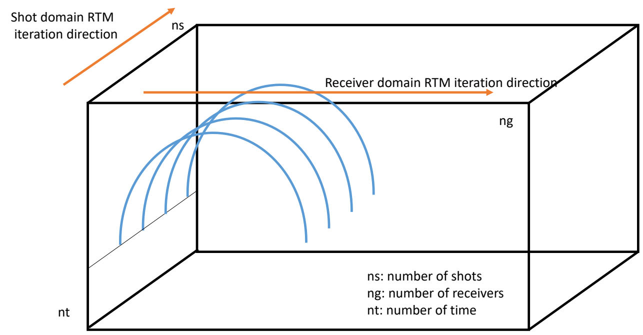

FIG. 10. Number of iteration for shot domain RTM and receiver domain RTM

RTM in the receiver domain

For node acquisition, the number of iteration can be quite large in shot domain RTM. So receiver domain RTM is needed. In shot domain Rtm, the data from all receivers are inserted into the wavefield backward propagation for each shot. Utilizing reciprocity of seismogram from the previous chapter, the location of shots and receivers can be exchanged, and the number of shots after reciprocity is the previous number of receivers, which decreases the number of iterations significantly, as shown in Figure 10. Adding that dithered blended data also needs to be operated in the receiver domain.

Dithering and deblending in receiver domain RTM

Deblending can be achieved by migration blended data onto a model, and then demigration. After the demigration the model becomes unblended data. The blended data after dithering are processed by receiver domain RTM.

The shot domain RTM for blended data is quite simple to get. Firstly, inject data reversely in backward wave propagation and set multiple sources with time delay in forward wavefield for each supershot. Then calculate cross-correlation of forward wavefield and backward wavefield in each supershot. Finally, sum all the cross-correlations together. But receiver domain RTM for blended data is more tricky than that in the shot domain. The size of data in the receiver domain is $n_{blended}$ times larger than the original data. So the number of iteration in blended receiver domain RTM is the number of receivers times the number of blended. For example, the unshifted data in Figure 6 has two sets of random time delays(known) for each of the shots inside the supershot. Figure 7 shows data that was shifted based on the time delays of the second shot.

The application of dithering for blended data in receiver domain RTM can be tricky. In forward modeling, the random time delay(known) in shot causes different apex location of each shot inside the supershot. After dithering based on the time delays of the target shot, the start time of the target shot should be zero in all locations. So in the forward wavefield of source propagation, there's no time delay for source wavelet injection in receiver domain RTM, which the opposite of shot domain RTM. For the backward wavefield, the dithered data is injected. For dithering data, only the target shot is coherent while all other shots

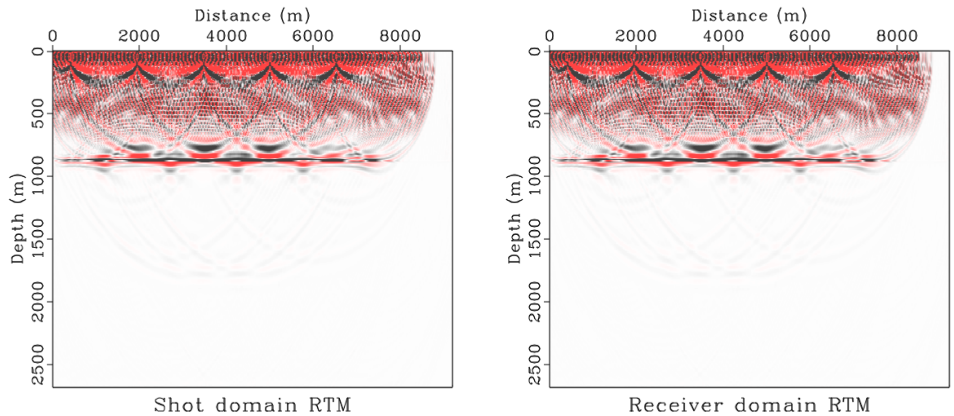

FIG. 11. Results of shot domain RTM and receiver domain RTM for a two-layer model

are incoherent. So the corresponding shot wavefield only fits with the target shot and the stacking of their cross-correlations strengthens the result. In contrast, all other incoherent data do not fit with the forward wave propagation and cross-correlations get weak after summation.

RESULTS AND DISCUSSION

Unblended acquisition in two-layer model

For unblended acquisition, the difference between shot domain RTM and receiver domain RTM is the way data injected into the backward propagation. The results of the two RTM methods shall be similar. A two-layered velocity model is utilized to test two RTM methods. 97 sources and 5 receivers are evenly distributed on the top of the surface. Wave propagation employed the 4th-order finite-difference method. Two results are shown in Figure 11. It can be seen that two results are exactly alike, as they should be. After subtraction of the two results, the only slight difference appears in the shot footprint. There are 97 sources and 5 receivers in the acquisition, as a result, the shot domain RTM needs 97 times of wave correlation while the receiver domain only needs 5 times of iteration. The iteration wavefield shares the same size as the velocity model in both two RTM methods. Consequently, the computation quantity for shot domain RTM is nearly 20 times larger than the receiver domain RTM.

Blended acquisition in two-layer model

With the same velocity model as before, simultaneous sources acquisition is employed for blended data. The number of blending is 4, that is to say, 4 sources are shot simultaneously. So one super shot contains 4 shots. Five receivers are placed on the top of the velocity model. If the number of shots in time remains the same as the previous one, the number of shots increases four times. As a result, the new shot interval is one-forth of that before. Compared with unblended results in Figure 11, the noise is strong in blended result, as shown in Figure 12 and 13. The reason for that is all shots are considered as noise in one supershot apart from the target shot. Another reason for noise in Figure 13 is the dithering. After dithering all shots are incoherent except target shot. The source forward wavefield in

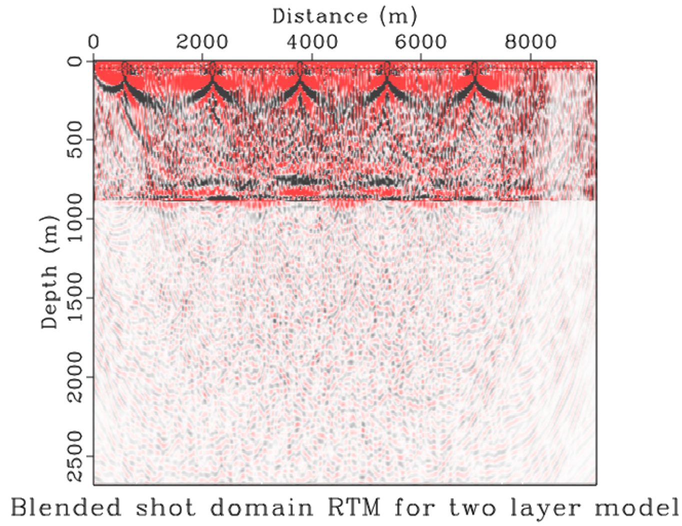

FIG. 12. Shot domain RTM from blended data

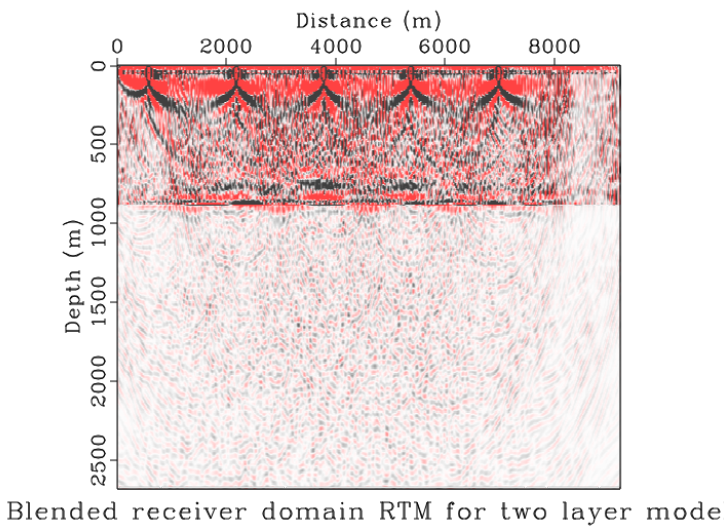

FIG. 13. Receiver domain RTM from blended data

RTM only fits with the backward wavefield of the target shot and all other incoherent shots are noise. It can be concluded from Figure12 and 13 that the results of shot and receiver domain RTM are nearly exactly alike. The only difference is the shot footprint on the top of the image. But receiver domain RTM needs less calculation. In shot domain RTM, the cross-correlation of forward and backward wavefields need to be computed 95 times, which is the number of shots on time array. While on the receiver domain the cross-correlation only executes 20 times, which is the multiplication of receivers number and simultaneous source number. For blended data, the computation of shot domain RTM is 5 times larger than that in receiver domain RTM and image qualities remain the same.

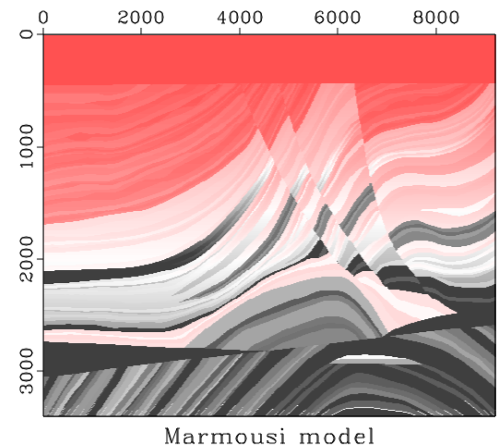

FIG. 14. Marmousi model with water layer on the top

Blended acquisition in marmousi model

Marmousi model with water layer on the top is utilized for RTM in two domains, as shown in Figure 14. Similar to the acquisition system in two-layered model, 95×4 shots and 5 receivers are distributed evenly on the water surface. The results of shot and receiver domain RTM is shown in Figure 15. The Laplace function and depth gain control are involved in the processing to increase the quality of images. So only reflectors are displayed. It can be observed that the results of the shot and receiver domain RTM are nearly the same. Similar to the results of the two-layered model, the only difference is the shot footprint. For complicated velocity models like marmousi, shot and receiver domain RTM can still migrate the blended data well. Still the computation of shot domain RTM is 5 times larger than that in receiver domain RTM and image qualities remain the same.

CONCLUSIONS

Most acquisitions have more shots than receivers. And shot domain RTM is a powerful migration tool for inversion. Node mode sea bed acquisition has more shots than receivers, for which shot domain RTM consumes much computation. Based on the reciprocity of the ray trace, the reciprocity algorithm of wave propagation is derived, and it can be utilized in the exchange of source and receiver locations and transformation of data in receiver domain RTM. After reciprocity of data, receiver domain RTM costs less computation time compared with shot domain RTM, and the results of the shot and receiver domain are the same. Simultaneous sources acquisition produces blended data. With the help of dithering in blended data, receiver domain RTM works for blended data migration.

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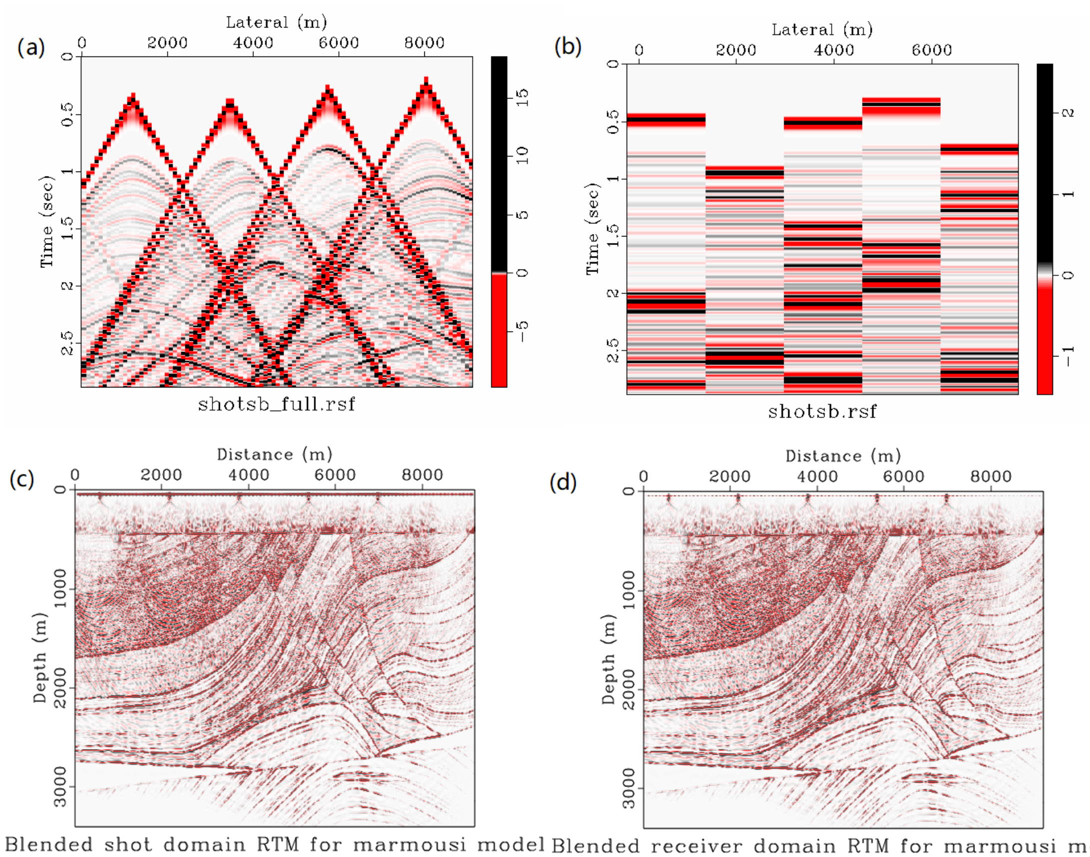

FIG. 15. (a) is the blended shot in a shot domain, (b) is the blended shot record in a receiver domain, (c) is the result of shot domain RTM from blended data and (d) is the result of receiver domain RTM from blended data

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