Deblending RTM in the receiver domain

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Summary

In some acquisition geometries, such as ocean bottom node surveys (OBN), there are many more sources than receivers. Therefore, we need to develop processing and inversion techniques that work efficiently in the receiver domain. Using the reciprocity principle, we can exchange source and receiver locations. Therefore, we can migrate the data using receiver domain Reverse Time Migration (RTM), which saves computation time compared with the conventional shot domain RTM. This problem is also important for blended source acquisitions. Many deblending techniques use the incoherency of blending interferences in the receiver domain. This incoherency results from the random time delays of the sources. In this abstract, we investigate receiver domain RTM for both migration of regular surveys and its possible use for the deblending of simultaneous sources.

Methodology

Reciprocity and receiver domain RTM

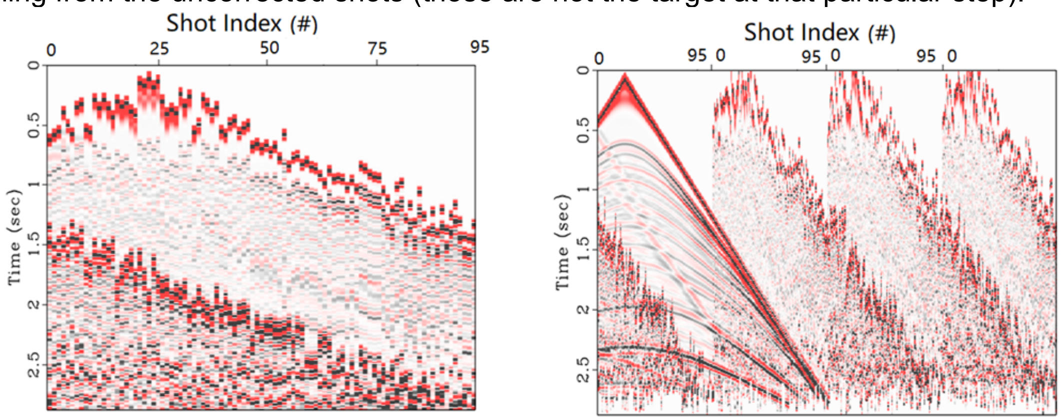
The principle of reciprocity states that exchanging the location of the sources and receivers produces the same observed waveform (Claerbout, 1985). From a kinematic point of view, seismic traces remain unchanged after exchanging the source and receiver locations. Conventionally, we use RTM in the shot domain, and its computation time increases linearly with the number of shots. This because each shot requires its own forward/backward modeling and imaging condition. In some seismic acquisition geometries, such as ocean bottom node surveys (OBN), the number of sources is much larger than the number of receivers. For these cases, it is significantly more efficient to migrate the data in the receiver domain, which is possible by utilizing the reciprocity principle. In principle, we can exchange the locations of shots and receivers, and the calculation time becomes proportional to the number of receivers

Deblending by random time delays during RTM

In a conventional acquisition, we record seismic reflections from only one source at a time. On the other hand, blending acquisition fires multiple sources simultaneously (Garottu, 1983; Beasley et al., 1998; Berkhout, 2008). We can call these blended shots “supershots”. Compared with the traditional acquisition method, blending acquisitions have the advantage of saving time and/or increasing shot density. On the other hand, seismic processing usually requires unblended shot records, so we have to deblend before seismic processing and imaging. There are several proposed methods for deblending (Berkhout, 2008; Mahdad et al., 2011; Akerberg et al., 2008; Beasley, 2008; Abma and Yan, 2009).

In the blended acquisition, we fire the shots with some random time delay between them. This randomization makes the interferences have an incoherent structure in the receiver domain (Berkhout et al., 2009; Mahdad et al., 2011). The existence of several shot locations for each trace implies that each trace has multiple sets of offsets, azimuths, shot statics, and time delays.

For shots with time delays, it is possible to separate blended shots by converting from shot domain to other domains where gathers have a space dimension with different shots. Unless the time delays are removed, seismic events are incoherent across traces that contain different shots (and therefore different time delays).
The shot domain RTM for blended data is quite simple to implement. The backward wavefield is created as usual by injecting the blended data, but the forward wavefield is created by simultaneous injection of multiple sources with their respective time delays. The cross-correlation of forward and backward wavefields is done for each supershot, and by summing them together, we get a reflectivity image.
In blended receiver domain RTM with pseudo-deblending, time delays are removed for a particular target shot at each step. In the common receiver gather in Figure 1, the time delay set for the first shot is applied for all the shot slices. The energy coming from this target shot appears coherent in receiver gathers. Since the data wavefield is formed by different shots (instead of different receivers as for conventional RTM), energy from unwanted shots propagates backward in time with an incoherent time signature. The RTM imaging condition that correlates forward and backward wavefields act as a filter that eliminates incoherent energy coming from the uncorrected shots (those are not the target at that particular step).



a) Common receiver gather/CRG of blended data
b) CRG of blended data after pseudo-deblending (extend size nblend times and apply time shifting)

Figure 1 Common receiver gather of blended data before and after pseudo-deblending

Dithering in receiver domain RTM

In deblending by migration/demigration (Trad, 2018), Green functions can act as basis functions onto which we can decompose the seismic data (Ibrahim et al.,2018), independently of whether data are blended or not. In previous work, this has been done with Stolt operators (Trad et al., 2012; Ibrahim and Sacchi, 2015), but in those cases, the basis functions were more akin to apex shifted hyperbolas that true scatter responses. Since RTM can handle simultaneous shots in a natural way, we can use it to perform deblending. Using migration operators, we map the blended data first to the reflectivity image and then use this image to predict the shots to their location in a new regular survey. The key challenge is to eliminate crosstalk by the cross-correlation imaging condition. Although, in principle, the imaging condition is not enough, and some crosstalk remains, that can be taken care of by using least-squares RTM (LSRTM). The blended energy is mapped to the correct reflector model, which can be used to predict the data to any arbitrary geometry as it has also been done for regularization (Trad, 2015).

There are different possible implementations to implement receiver domain RTM. The size of data in the receiver domain increases along the shot dimension as many times as shots are blended, as a consequence of removing the dithering one shot at a time. However, by running the migration one receiver gathers at a time, there isn't any computing penalty since the number of traces for the backward field does not affect computing time.

Results

For unblended acquisition, the results of shot domain RTM and receiver domain RTM are the same, as we show in Figure 2 by migrating data generated in a simple three-layer model. Here we just use an OBN type of geometry with more shots than receivers (97 sources and 5 receivers) evenly distributed on the top of the surface.

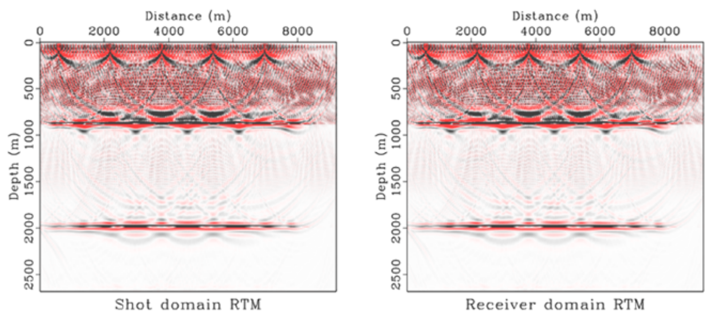


Figure 2 Unblended results for two-layered model

For blended data and dithering, it is not easy to deduce by pure logic if results should be identical, in particular for RTM. We use an experimental approach by testing with data generated with the Marmousi velocity model. Simultaneous sources are simulated with 4 shots per supershot. We use five receivers on the surface. If the number of shots in time remains the same as the previous case, the number of shots increases four times. As a result, the new shot interval is one-fourth of the non-blended case. To simulate an OBN survey, we modify the Marmousi model by adding a water layer on top (Figure 3). We generate data with 4th order finite differences and migrate with RTM in both the shot and receiver domains. To simulate OBN acquisition, we locate 95 x 4 blended supershots on the surface and 5 receivers on the water bottom. The results of shot and receiver domain RTM are shown in Figure 4. Results for the shot and receiver domain RTM are nearly the same, except for some difference in the shot footprint.

Conclusions

Most acquisitions have more shots than receivers except for the important case of OBN. Shot domain RTM is efficient and natural for the first case, but for OBN, it is more efficient to apply a receiver domain RTM. For the case of blended marine acquisition, where several shots can be firing independently of each other at the same time. Since the source boats do not carry streamers, they can maneuver freely without interference, producing a very efficient type of acquisition. We use the reciprocity principle for PP data, but not yet considered the PS case. When using simultaneous sources acquisition with time dithering, there are a few different approaches that can be taken. We have only considered one of them. Blended acquisition saves acquisition time and cost. RTM attenuates incoherent shots, and dithering in blended receiver domain RTM is effective in deblending.

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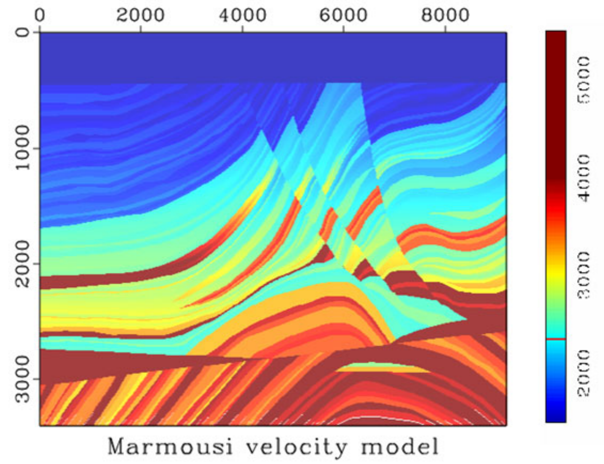

Figure 3 Modified Marmousi model

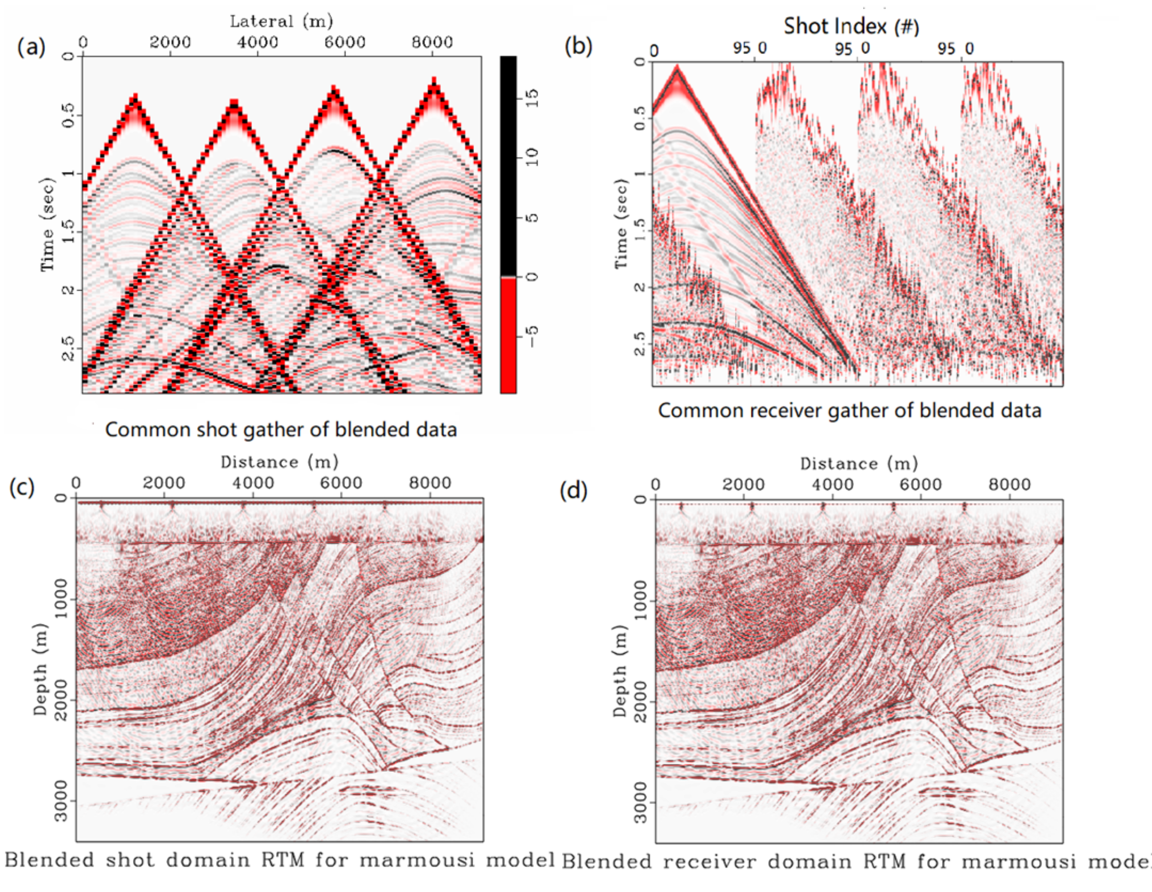

Figure 4 a) The shot domain data, b) receiver domain data. c) shot domain RTM and d) receiver domain RTM