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Migrating passive seismic data

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ABSTRACT

It is possible to migrate raw passive seismic data with a modified shot-profile migration algorithm to produce a subsurface image. This skips time-intensive and space-consuming pre-processing steps as has heretofore been assumed necessary. Further, output sections are better focused and more accurately imaged using less computer time.

INTRODUCTION

Claerbout (1968) provides a one-dimensional proof that sparked the idea of imaging the subsurface without a source. By auto-correlating time series collected on the surface of the earth, he shows that one can produce the equivalent to a zero-offset time section. Zhang (1989) extends the one-dimensional proof of that conjecture, through plane-wave decomposition, to full space. Importantly, he also shows that by cross-correlating each receiver with every other, one constructs pseudo shot gathers as a function of offset. These gathers are identical to conventional shot gathers and can be treated as such throughout further processing steps.

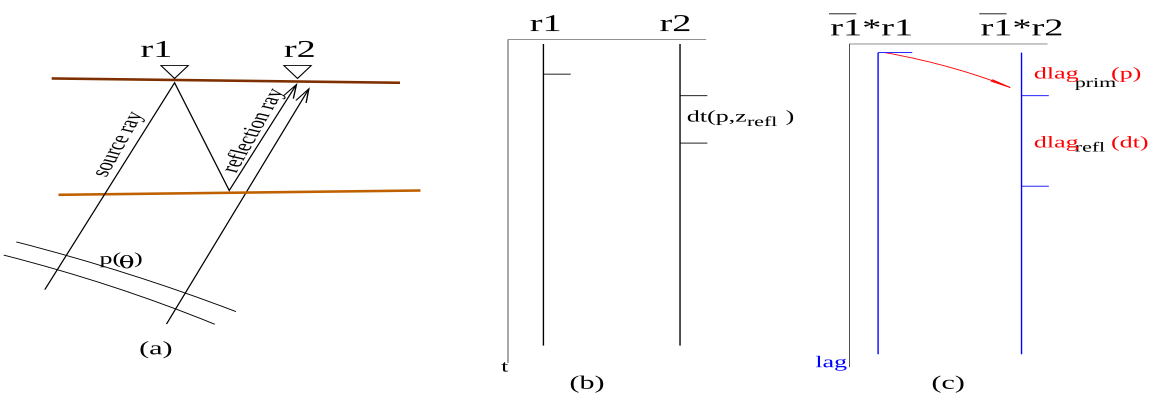

Figure 1: (a) Cartoon showing the incident plane-wave energy reflecting from the free surface and then again from a buried reflector. (b) Time-series built from arrivals depicted in left panel. (c) Correlations of signals from receivers $r1$ and $r2$. brad1-noise [NR]

The cartoon in Figure 1 shows schematically how an upcoming wave-train, $P(\theta)$, will reflect from the surface and act as a source at receiver r1 for the subsurface reflection recorded

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at r2. An intuitive understanding of this experiment and the manufacture of pseudo shot gathers can be developed by progressing through the panels of Figure 1 from the earth model in panel (a) through the raw data recording in panel (b) to the correlated records in panel (c) where the fast-axis is now in units of correlation lag.

The correlation step has two important functions when applied to raw passive data. First, it collapses to an impulse the long source functions of the ambient sound energy recorded at each station. Second, it develops hyperbolic move-out of these impulses as a single input trace is correlated with data from stations at increasing offset. Figure 2 shows a representative gather from a synthetic passive dataset over a two-layer earth-model.

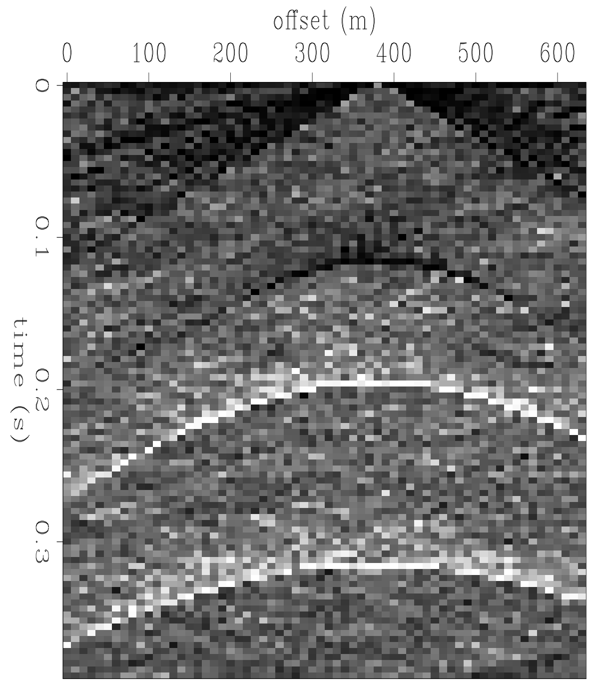

Figure 2: Representative pseudo shot gather from data cube generated by cross-correlating all traces from a modeled passive seismic dataset. The raw data trace that has been correlated with all the others serves as the source location for the gather. Notice the "virtual multiple" at 0.11 seconds. This arises due to the partial correlation of the two reflectors between themselves. The greater the velocity contrast, the less visible this event. Its zero-offset time is equal to the difference in time between the two events. brad1-shot [CR]

After the pseudo shot gathers are constructed through correlation, a conventional five-dimensional data volume is ready for any common processing flow such as sorting and migration. However, I show that it is possible to migrate the raw data directly with a shot-profile migration algorithm that has been modified to use an areal source rather than a conventional impulse or wavelet. I present comparisons of both methods performed on modeled data and comment on some of their characteristics and costs.

METHODOLOGY

The imaging condition for shot-profile migration (Claerbout, 1971) is

$$I(\mathbf{x},z) = \sum_{\omega} P^{g}(\mathbf{x},z,\omega)\overline{P^{s}(\mathbf{x},z,\omega)}, \qquad (1)$$

where the image, I, is a function of surface location, $\mathbf{x}$, and depth, z, and geophone and source wavefields, $P^{g,s}$, are functions of location, depth and frequency, ω. I hypothesized that the correlation in the imaging condition would satisfy that in the passive seismic conjecture and make calculating the correlations prior to processing unnecessary. Further, we could rely on the dispersion relation to handle the unknown phase characteristics of the ambient noise-field rather than hoping that the correlations will collapse these wave-trains into a well-behaved wavelet.

Therefore, without making the intermediate processing step of correlating all traces with each other, we can downward continue the receiver wavefield, P^g, from every location back into the earth. This means we are migrating the entire dataset as one large shot gather. Remembering the cartoon in Figure 1, we can comfortably accept the same wavefield for P^s since the source wavefield is recorded by each receiver as it reflects from the free surface. Setting $P^g = P^s$, I then migrate the data with a modified shot-profile algorithm similar to that presented in Guitton (2002).

DISCUSSION

Figure 3 shows the result of migrating the gathers manufactured through correlation in panel (a) and migrating the raw data directly in panel (b). The raw passive data was modeled over a two layer earth-model and looks like random noise.

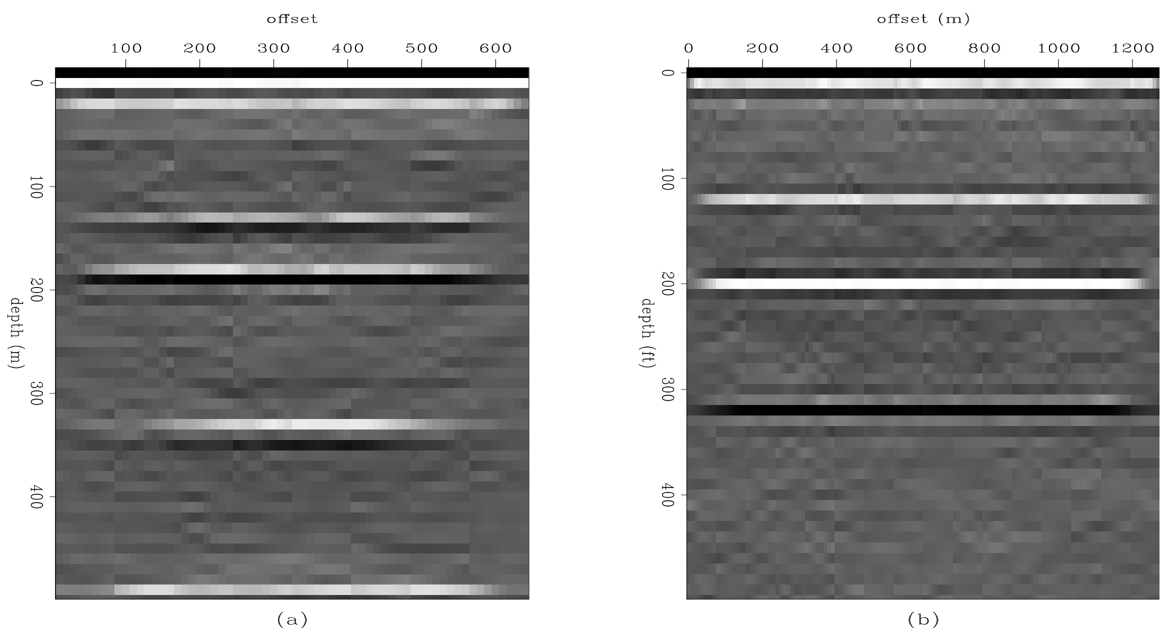

Figure 3: Left panel is result of migrating manufactured shot gathers. Right panel is the result of migrating the raw data directly. Notice the virtual multiple at 120 meters and the ramping of amplitudes of the two events from the edges to the center. The phase differences between the two panels is a result of the incorrect wavelet introduced in the migrations of the correlations. brad1-comp [CR]

In the migrated sections, we see again the presence of the virtual multiple mentioned in the caption of Figure 2. This event is imaged at 120 meters depth which is the same as the separation between the two events in the model. This event exists because the two reflectors correlate with each other as well as the free surface. Real data may not be prone to this problem due to the saving grace of intra-bed multiples. Such an arrival would have opposite polarity from the virtual multiple and thus be destructed. Because of overly simplistic modeling code, such intra-bed multiples are not part of this test data.

Another feature of the section that deserves note is the ramping of amplitude of the reflectors from the edges to the middle of the model. This phenomenon is due to the experiment enjoying a linear, monotonic fold increase from one at the edges to half of the number of receivers at the center.

The size and cost differences for the two starting points described above for processing are significant. Making the correlation cube from the raw data squares the size of the data. However, after correlation, it is no longer necessary to maintain the extraordinarily long time series of the original data. We are free to discard all of the correlation lags computed after longest time the survey is actually interested in and only need migrate that many frequencies. By thus doing so, we shrink the data back down to about its original size. Therefore, the size of the data sets input to migration are roughly equivalent whether we consider the raw data or the correlated shot gathers. The large difference in processing time comes largely in sorting and write statements. By migrating all of the raw data as one shot gather, we enjoy operating on one entirely populated model space with only loops over depth and frequency. In contrast, the correlated data has the number of receivers equal to the number of shots to loop through, each of which populates only a small segment of the model space.

Comparisons of the time taken to migrate the two sections shown in Figure 3 show the correlated sections taking a bit more than twice as to compute with the same program. This does not include the time needed to produce the correlation volume from the raw data to use as input which makes the comparison even worse. Further, the raw data migrated section shown here was computed with a new parallel migration program that runs on our multi-node computer cluster. This architecture is well suited to the structure of real passive seismic datasets where we can expect a reasonably small model space and need to loop through a huge number of frequencies due to the multiple hours of recording.

Lastly, due to the source wavefield being completely full instead of incredibly sparse, as in conventional shot-profile migration, there is an opportunity to investigate better imaging conditions as discussed in Valenciano and Biondi (2002). This type of advanced imaging condition would also address the existence of the virtual multiples if the intra-bed multiples are of insufficient strength to cancel the multiple in real data considerations.

CONCLUSION

Migrating raw passive seismic data directly produces a cleaner, more crisp image than first correlating the input traces before migration. This new method is faster and requires less overhead, and is very efficient.

Several passive seismic datasets have been collected or acquired from various sources in the last few months. Now that a fully-parallel 3D code has been completed, I will begin processing real data examples that include shallow investigations, ocean bottom cable data, and conventional exploration geometries.

To continue to advance this effort, I am in great need of quality data acquired with as many receivers as possible. It would be very easy to collect such data by simply recording passively from receivers left in the field on a 3D acquisition overnight or during any sort of lengthy down-time. In order to best test the validity of this experiment, simple geology that provides excellent quality conventional data such as the flat limestone of west Texas would be preferred.

ACKNOWLEDGMENTS

Antoine Guitton's paper in the previous report congealed a vague hypothesis into a testable theory with his presentation of migration with an areal source. Development of the 3D parallel code used the WEI libraries of Bob Clapp and Paul Sava. Their considerable infrastructure and willingness to explain it made this product obtainable in a much shorter amount of time than could otherwise be hoped.

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