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Analysis of some aspects of locating sources with passive seismic data: synthetic examples

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ABSTRACT

Locating sources of seismic energy by computing the semblance along moveout trajectories requires knowledge of the velocity structure. Since our knowledge of the medium velocities is always imperfect, there will be errors in the location of sources. Using an incorrect average velocity results in a vertical shift of the semblance maximum as compared with the actual source location. The presence of random travel time fluctuations causes a decrease in the maximum semblance value without changing its location.
Sources can be located even if the data are aliased. Synthetic tests show that while some artifacts are introduced by the aliasing, meaningful results can still be obtained, especially when the source signal is broadband. For any proposed experiment, such synthetic tests should be run to see how well one can expect to locate sources given the proposed array geometry.

INTRODUCTION

During my stay at SEP, I participated in the processing of several "passive" datasets, with the goal of locating seismic sources, either primary (endogenous sources of microseismic background noise) or secondary (scatterers). (Vanyan & Cole, 1990). In addition, similar source location techniques are being applied to novel source datasets, including pump noise (Cole & Vanyan, 1990) and drill-bit (Cole, 1991) sources.

To locate seismic sources an algorithm based on computing the so-called semblance coefficient for points in a 3-D grid (Nikolaev & Troitskiy,1987) is used:

$$Sem(x,y,z) = \frac{\sum_t \left(\sum_i S_i(t+t_i)\right)^2}{M \sum_t \sum_i S_i^2(t+t_i)}. \tag{1}$$

Here x, y, and z are the coordinates of a point in the medium, t_i is the travel time from that point to geophone i, and M is the number of channels.

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The idea is that if there is a source at some point in the medium, then semblance computed at this point will have a large value. The possibility of locating sources depends on different conditions: correspondence of the chosen model to reality, knowledge of velocity structure, configuration of the seismic array, presence of obstacles, etc. The impact of some of these aspects on the quality of the results can be considered using synthetic data. Such analysis can reveal how well, for a given array geometry, we can hope to locate sources. Such computations can also aid in interpreting semblance results obtained for real data.

In this paper I consider the effects on the source location method of (1) velocity variations and (2) spatial aliasing. The synthetic datasets were obtained for two different seismic array geometries. The first is a sparse 24 channel array used for registering microseismic background noise in Iceland (Cole & Vanyan, 1990). This array is shown in Figure **??**.

The second one is the 240 channel seismic array used in the SEP drill-bit source experiment (Cole, 1991). This array is shown in Figure **??**. Actually the array used in these studies differs slightly from the one used in the field. In the field experiment the layout of geophones is not quite so regular. But the dimensions and spacing are as shown here. Geometry of the Iceland array. Geometry of the drill-bit array.

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Figure 1:

VELOCITY VARIATIONS

The equation (1) contains time delays which are computed using a velocity model. Usually this velocity model is rather simple (e.g., average velocity as a function of

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Figure 2:

depth). The velocity structure in the medium can be much more complex and naturally the difference between the model and reality decreases the quality of the result. The errors in velocity model can be divided into two basic groups: (1) errors in average velocities, and (2) small scale velocity fluctuations which manifest themselves as small traveltime fluctuations.

Errors in average velocities

To demonstrate effect of using a velocity model differing from the actual medium velocity I constructed a synthetic dataset that is representative of the drill-bit problem: 240 channels, one source at a depth of 1000 feet, and a velocity 9000 feet/sec. Random noise was added to seismic traces; the power of the noise equals the power of the signal. The data were filtered with a 70-100 Hz bandpass filter. The semblance coefficient was computed for two velocity models: (1) a velocity 9000 feet/sec (corresponding to the "true" velocity), and (2) a velocity of 10000 feet/sec. Figure **??** and **??** show the maximum value of semblance as a function of depth for these two cases. It can be seen that using wrong velocity, we still are able to locate the source, though the depth of maximum is shifted and the maximum value of the semblance has been decreased. Semblance as function of depth using the true velocity model.
$V_{true} = V_{model} = 9000 feet/sec$. Semblance as function of depth using an incorrect

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Figure 3: v9000

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Figure 4: v10000

velocity model.
$V_{true} = 9000 feet/sec$
$V_{model} = 10000 feet/sec$

Small scale velocity fluctuations

The presence of such fluctuations can be modeled by adding small random perturbations to the travel times. These random shifts decrease the semblance values, especially for high-frequency signals. The particular results will depend on different circumstances (shape of the seismic array, frequency content of the signal, etc.), so here I show the effect of adding random velocity fluctuations to the data described above by adding time shifts to each trace. Figure **??** shows the decrease of semblance that accompanies an increase in the standard deviation of the time perturbations. Such time shifts can sometimes be caused by the uppermost layer of the medium. In this (favorable) case, they can be treated as a function of geophone location and hopefully can be compensated for (static corrections). Also, some kind of static corrections can be made using crosscorrelations. Steve Cole created an iterative algorithm for applying such corrections to passive seismic data. Effect on semblance computation

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Figure 5: vran

of small random velocity fluctuations. The horizontal axis is the standard deviation of travel times divided by the period of the signal.

SPATIALLY ALIASED DATA

The datasets we have processed were spatially aliased (at least in part). The traditional conclusion is that for the aliased high frequencies we cannot obtain useful information about source locations, and we should filter the traces accordingly before any multichannel processing. Contrary to this traditional view, we obtained some interesting and promising results using high-frequency data that were supposedly aliased. The question is, how reliable are these results?

All pictures below show the semblance patterns for horizontal slices taken at depths where the source was actually located. These pictures were obtained for different parameters (spectrum, depth) of the source, so we can get an idea how the picture changes for different situations.

For the Iceland array, the distance between channels was 200 meters and the near-surface velocity about 2000 m/s. This means that for steep dips the data are aliased for frequencies greater than 5 Hz (in other words, nearly all frequencies). Figures **??**, **??**, and **??** show semblance patterns for frequencies 10, 20, and 50 Hz (here I used monochromatic sources); the depth was 100 meters. For all these frequencies (well above aliasing) the location of the source is unambiguously determined.

The same patterns for sources at a depth of 1000 meters are shown in Figures **??**, **??**, and **??**. These patterns are clearly contaminated with "sidelobes", and locating of sources for frequencies higher than roughly 10-15 Hz becomes much less reliable.

For an intermediate depth of 500 meters (Figure **??**) the picture is not much worse than for 100 meters even for as high a frequency as 50 Hz.

Figures **??** and **??** were obtained using a broad band (60-100 Hz) signal for depths of 100 and 1000 meters, respectively. The results have improved considerably. Apparently, this improvement is due to destructive interference of the sidelobes of different frequencies.

The drill-bit array is much more dense than the Iceland array. Assuming a velocity of about 10000 feet/s the data is aliased for frequencies higher than roughly 50 Hz.

Semblance patterns for this array were obtained for two source depths – 900 and 450 meters – and frequencies 100 and 200 Hz (Figure **??**, **??**, and **??**). The results show that for very high frequencies and shallow depths sidelobes can be present, but their amplitudes are significantly smaller than that of the main peak. Figure **??** shows the result for a broadband signal for the depth of 450 meters. The picture again is much better than the monochromatic case. Semblance for depth 100 meters, frequency 10 Hz. Iceland array. Semblance for depth 100 meters, frequency 20 Hz. Iceland array. Semblance for depth 100 meters, frequency 50 Hz. Iceland array. Semblance for depth 1000 meters, frequency 10 Hz. Iceland array. Semblance for depth 1000 meters, frequency 20 Hz. Iceland array. Semblance for depth 1000 meters, frequency 50 Hz. Iceland array. Semblance for depth 500 meters, frequency 50 Hz. Iceland array. Semblance for depth 100 meters, broadband signal 60-100 Hz. Iceland

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Figure 6: al10s.100

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Figure 7: al20s.100

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Figure 8: al50s.100

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Figure 9: al10s

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Figure 10: al20s

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Figure 11: al50s

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Figure 12: al50s.500

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Figure 13: b60100.100

array. Semblance for depth 1000 meters, broadband signal 60-100 Hz. Iceland array.

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Figure 14: b60100.1000

Semblance for depth 900 meters, frequency 100 Hz. Drill-bit array. Semblance for depth 900 meters, frequency 200 Hz. Drill-bit array. Semblance for depth 450 meters, frequency 200 Hz. Drill-bit array. Semblance for depth 450 meters, broadband signal 150-200 Hz. Drill-bit array.

CONCLUSIONS

Considering the above cases leads to the following conclusions:

- Before performing an experiment where array data will be used to locate sources in the way described here, some simple computations should be performed. This "array calibration" tells us, given the array geometry, how accurately we can expect to locate sources.

- When we use incorrect velocities in determining the moveout trajectory used for computing semblance, we can still locate the energy source. However, in the result, the source location will be shifted from its true position (mostly in the vertical direction) and the signal to noise ratio decreases. Here I considered the

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Figure 15: tun100s

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Figure 16: tun200

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Figure 17: tun200.1500

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Figure 18: tun150200

case of a 10% velocity error and found that the magnitude of the semblance maximum decreased approximately by a factor of three.

- Computations have been performed for spatially aliased data for two different seismic arrays. The results show that even with aliased data we can still do a good job of locating sources. Pictures of better quality were obtained using broadband signals. Using narrowband high-frequency signals can result in serious artifacts (sidelobes).

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