LOCALIZATION OF DIFFRACTED SEISMIC NOISE SOURCES
USING AN ARRAY OF SEISMIC SENSORS

Necati Gulunay

CGGVeritas R&D, Cairo

ABSTRACT

Seismic receiver arrays that are used in modern 3D marine surveys can also be used as 2D sensor arrays in the localization of the diffracted noise sources and hence allow attenuation of such noise from the seismic records.

1. INTRODUCTION

Modern seismic prospecting uses recorded 3D seismic data in determination of oil or gas bearing strata. A typical survey area could be as large as 4000 km^2. Surveys can be done in land and marine environments. Due to cost considerations shots are fired at certain space intervals (at the surface of the earth) and echoes are taken by sensitive receivers which are either geophones or hydrophones, again at certain lateral intervals. In marine 3D most surveys are made as narrow azimuth (NAZ) surveys. That is, in NAZ surveys, receivers are distributed along a line (or a few lines) behind a shot as shown in Figure 1.
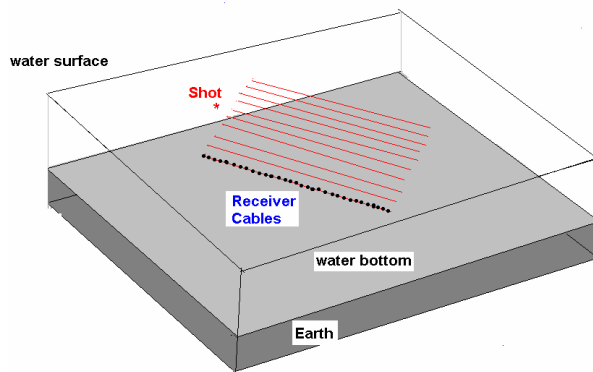

Figure 1 Schematic view of a 3D Marine recording geometry. Shot and receivers are almost at the water surface (at about 8m depth to be more precise).

Recently we are seeing wide azimuth (WAZ) surveys where receivers sample a wider area in perpendicular direction to acquisition. NAZ marine surveys are made of individual shots (an acoustic explosion). Shots are fired and recording is done on what geophysicists call "sail lines", the straight lines that the boat travels on while pulling the source (air guns) and the receiver cables. In such a survey the shots very near the boat and are typically 25 meters apart along the sail line and the boat pulls (currently) up to 12 streamers that are about 100 m apart. On each streamer there are about 720 receivers, that are 12.5 meters apart. The sail lines are typically 300m-500m apart, as to give 50 percent overlap between the streamers. Approximately 4000-8000 receivers are used for each shot of a typical modern NAZ marine seismic survey. That is these few thousand receivers are positioned over a rectangular area of roughly 1km by 9 km with roughly 12.5m inline and 100m crossline separation (and at approximately the water surface). In WAZ surveys we are seeing this rectangular area aiming to reach a square (for example 7km by 9km in WAZ vs. 1 km by 9 km in NAZ). As such, these receivers form a sampling array for the seismic waveform in a similar way that electromagnetic and astronomical antenna arrays do, but perhaps with much more elements.

In seismic surveys, the aim is to send seismic signals downward into the earth and to receive their response. However, seismic energy radiated from the source can travel sideways, get scattered, and get received back by the same receivers, contaminating the weak earth signal they aim to receive. 3D marine surveys occasionally suffer from such scattering of source energy from sharp discontinuities at, or around, the sea bottom. Nearby rigs, wellheads, shipwrecks, and, boulders at the sea bottom add to the problem. As the reflected energy from deep strata is weak and such scattered noise is much stronger than reflections, since it has traveled only in water, the position of these energy sources must be detected and the noise energy recorded on the seismic recordings (also called "traces") made with such sources must be attenuated. Such strong energy interferes with many seismic processing algorithms that expect vertical propagation (reflections from earth's layers) and hence need to be attenuated.

This problem had been recognized by Manin et al [6] and a solution was suggested. Assuming that the coordinates of the noise source can be obtained they suggested flattening the data with time shifts corresponding to the travel times and suppressing the

noise with multi-channel filters. Recently, Fookes et al[1] suggested picking arrival times of the noise, and then calculating the position of the noise source from the travel times and the coordinates of the source and receivers. Once the noise source is calculated the corresponding noise energy is attenuated as in the method proposed by Manin et al [6].   More recently, a method called "Diffraction imaging" is used by Khaidukov et al [4] with 2D surveys for separately imaging weak point diffractors and thereby helping interpretation of faults in migrated seismic sections. Shtivelman et al [7] uses multi-velocity imaging of subsurface inhomogeneities. Recently, Gulunay et al [3] described a method that used such 3D marine records (multi-streamers) and the best estimate of wave propagation velocity in water to detect and suppress noise originating from shallow diffractors using the 3D marine shot records.

2. DIFFRACTOR LOCATION SCAN METHOD

As there can be hundreds of diffractors in cases where the water bottom contains outcrop and escarpments, it is very labor intensive to apply processes like the one described by Fookes et al [1]. We aim to perform this automatically as will be described in the following paragraphs.

The energy of the diffracted noise travels from the source and hits the diffractor. The diffractor then scatters energy back, via Huygens Principle, and the energy arrives at the receivers at time

$$T = T_s + T_r \qquad \text{(Eq 1)}$$

where T_s is the time from source to diffractor

$$T_s = \frac{1}{V}\sqrt{(x_s - x_d)^2 + (y_s - y_d)^2 + z_d^2}$$

and T_r is the time from diffractor to receiver

$$T_r = \frac{1}{V}\sqrt{(x_r - x_d)^2 + (y_r - y_d)^2 + z_d^2} \quad .$$

Given (assuming) a diffractor point D=(x_d, y_d, z_d) amplitudes of data at times T given in Eq 1 from all traces (i.,e. source S=(x_s , y_s,) and receiver R=(x_r , y_r) pairs) can be summed as in the depth migration process. Seismic depth migration is a process that carries energy to their correct location in space and depth. Our algorithm, similar to depth migration, carries the energy received at a receiver to its correct position D, assuming velocity we use is correct. Indeed double square root equation (Eq 1) is the exact equation that the migration process uses. In our algorithm stack amplitudes, or stack power, could be used to estimate how strong this diffractor is. One can use other coherency measures as well for this purpose. Semblance is known to be the most efficient and practical coherency measure. Semblance, aside form a scale factor,

is the ratio of square of the summed signed amplitudes to the sum of the squared amplitudes. When the number in the sum are of the same sign and about the magnitude the semblance approaches one, and if they are random in magnitude and in sign semblance tends to go to zero. For every such assumed diffractor position, D, we can obtain a semblance value, indicating how coherent energy from this diffractor is when some or ALL of the traces in the survey that get contaminated from this diffractor are considered. This idea, i.e. trying systematically various diffractor positions to see what semblance values they produce   is   the   essence
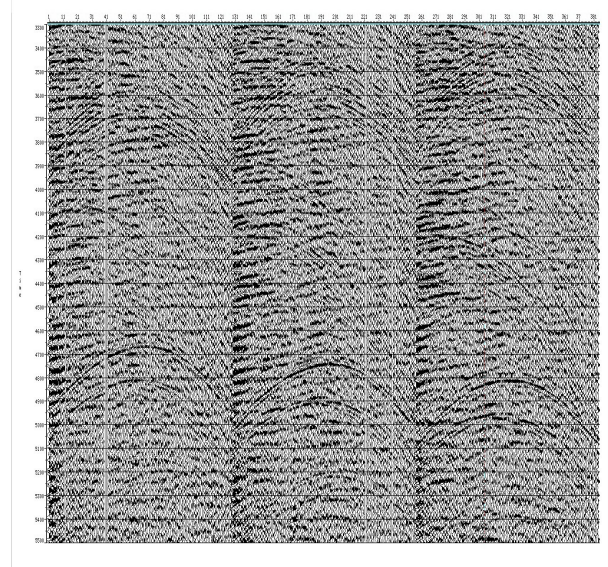

Figure 2: A shot with three cables contaminated with diffracted noise

of our method that we call "diffractor scanning", or simply, DSCAN, similar to the well accepted term VSCAN that is used for stacking velocity scanning. (In seismic industry, stacking velocity scan is done for a common mid point (CMP) data. Velocity is used to do Normal Moveout (NMO) correction which is a process that eliminates time differences between different travel paths for the traces of that CMP so that they can be stacked correctly). In fact, VSCAN was also used for migration velocity analysis by Gonzales et al [2]. Landa et al. [5] used semblance scans to find diffractors buried in 3D half space in land seismic surveys.   We use the best estimate of the water velocity in Eq. (1) and generally assume z_d=0 for shallow water cases. Note that given the finite record length (typically from 5 to 14 seconds) and for a given shot record there is a finite zone that one needs to scan to find the diffractor locations that are affecting that shot. That is, we only need to scan an area limited around our shot (source and receivers) controlled by water velocity, V, and recording time, T_L:

3. FIELD TEST

We have tested this method on a sail line from a shallow water (about 60 ms) data set that was provided by Noble energy. Shots have 3 cables, each with 128 traces. The record length is 6 seconds and the sample interval is 2ms. A typical noisy shot is shown in Figure 2. Close inspection of the shot record suggests that there are ten or so diffractors but it is not easy to determine which event belongs to which diffractor.
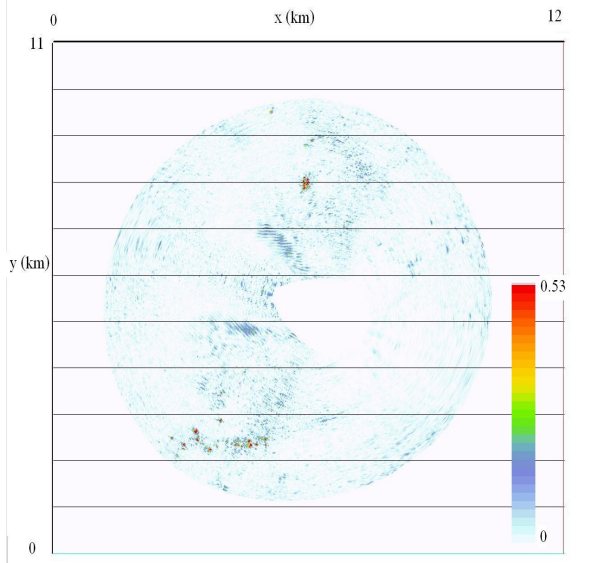

Figure 3. Diffractor semblance scan for the shot in Figure 1. Scan covers an area of 11km by 12 km.
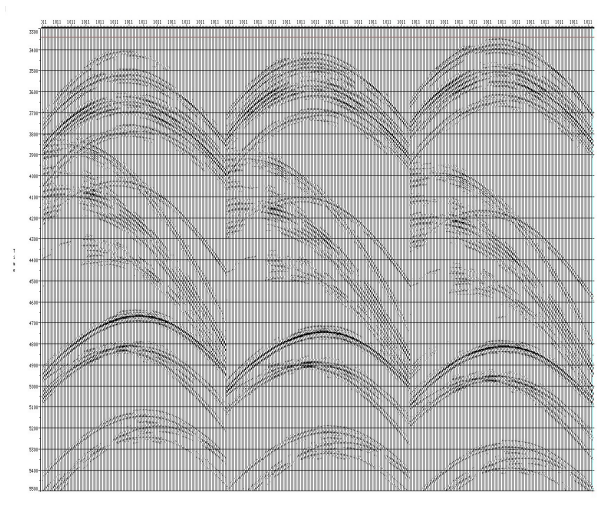

Figure 4: Diffraction model produced from most coherent diffractors

The semblance scan of this shot using $z_d=0$ and an area of 11km by 12 km for (x_d, y_d) gives the distribution shown in Figure 3. We used V=1538 m/s in the scans. The scan distance increment was 10m both in inline and crossline directions. Experience, however, shows that one does not have to be this precise. A coarser surface grid can be used but then the length of the time window used in semblance calculations has to be increased. Note that there is one semblance value for every (x_d, y_d) point on the grid. An example of 10m by 10m grid semblance scan is shown in Figure 3. The hole in the middle of the semblance distribution shown in Figure 3 is due to the fact that first second of data was not included in the diffractor scan. Diffractor selection is now made using local maxima criteria with thresholding. The highest semblance value found in the search was 0.53. If the top 50 percent of the semblance values are used then 3 diffractors are detected, with the top 60 percent 6 diffractors and with the top 85 percent, 22 diffractors are detected.
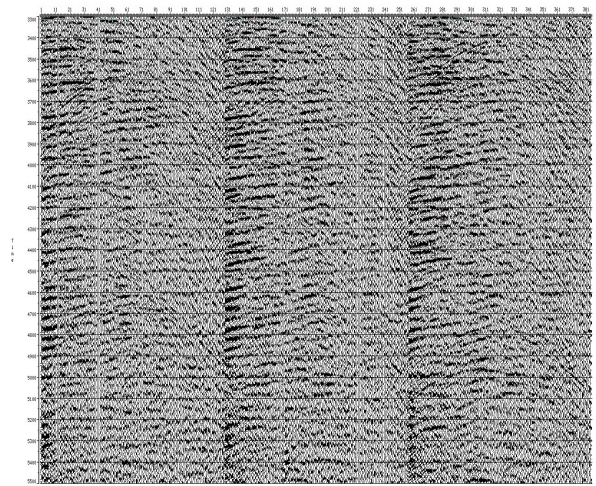

Figure 5. Shot after subtracting the model in Figure 4 from the record in Figure 2.

4. NOISE MODEL BUILDING

For each of the diffractors selected from the semblance distribution travel times to the trace at hand can be calculated and the diffracted energy around that time picked to model the diffracted noise.

Figure 4 shows the result of this process for 22 diffractors picked from the semblance scan. By subtracting this model from the input (straight subtraction) we obtain a record that represents the signal only (Figure 5). Comparison of this result with the input record suggests that method is successful in detecting and attenuation shallow water diffractions.

One may wonder what the quantitative metric of the DSCAN method is. If the right model is built (Figure 4)

and subtracted from the input record (Figure 2) then the semblance plots that will be made from them (Figure 5) should not have the peaks shown in Figure 3 any more. For that reason one may state the metric as minimizing the energy in the semblance plot by bringing maximum of the semblance plot for each shot under a threshold level defined by the user. This level is indeed the same level over which an event is defined as a diffractor in the above paragraphs.

5. ANOTHER FIELD DATA SET

Second data set is a 3D marine data obtained with 2816 receivers (i.e. 8 streamers, each with 352 receivers). The seismic stack section from this data, Figure 6, exhibits shallow water bottom with abrupt changes. These locations are the cause of steeply dipping high frequency diffractions seen in the later portions of the same section (Figure 7). The deeper portions of this data also exhibit events which are difficult to distinguish from reflections as they are lower in frequency content than the diffractions traveling with water velocity. Study of these events in the common shot records, (see Figure 8 around 4800 ms), however, suggests that they may be broadside events, most likely with a higher velocity than water velocity.
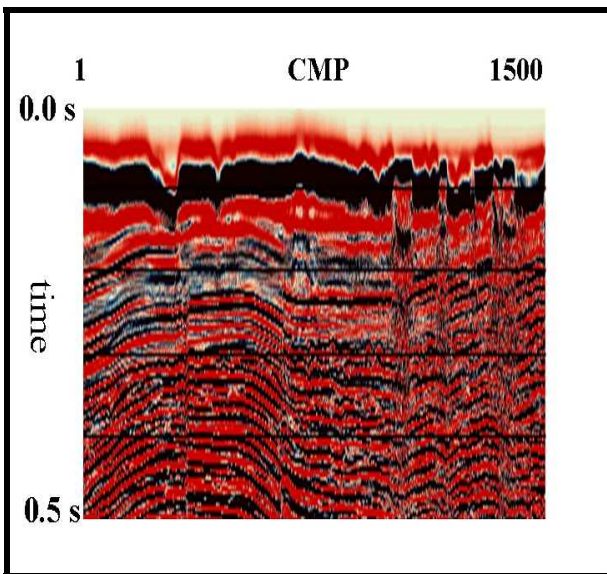

Figure 6. A surface line from a shallow 3D marine survey.

Figure 8 has indeed steep linear diffracted energy patterns which seem to originate from nearly inline anomalies (with respect to this particular subsurface line) in the water bottom and are traveling with water velocity. Initially, we attempted processing this data with velocity of 1550 m/s which only handled this steeply dipping noise but not the broadside diffractors around 4800 ms. Steeply

dipping linear events could, indeed, be suppressed by Radon or F-K type filters after some dealiasing process and there is no need to apply this type of scan process for such noise. After realizing that we were not attenuating these broadside diffractions we decided to run a velocity analysis. We tried velocities between 1500 m/s and 1800 m/s with an increment of 50 m/s.
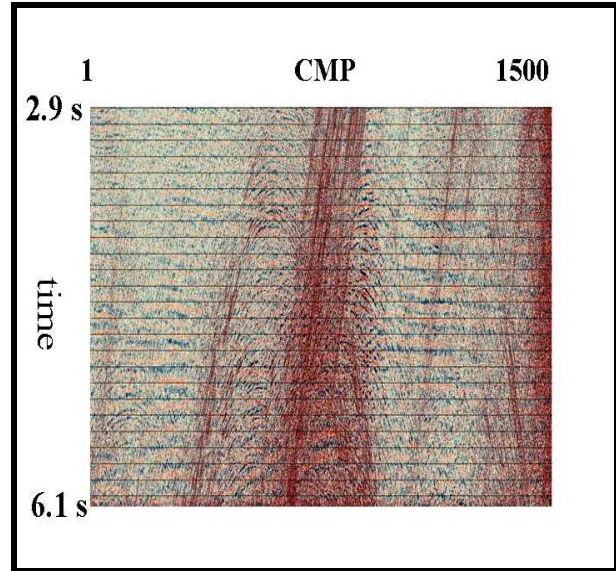

Figure 7. Deeper portions of the same subsurface line in Figure 6. Note the broadside as well as linear diffractions.

Close inspection of such analysis suggested that the strongest diffractor was indeed almost broadside and its velocity was around 1650 m/s.
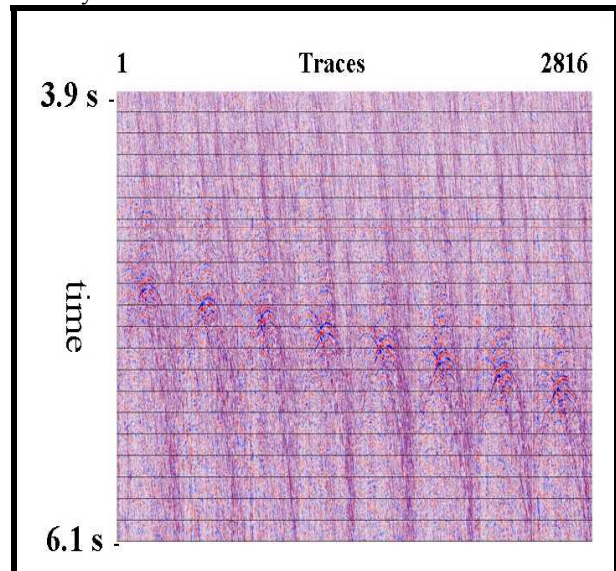

Figure 8. A 3D shot with 8 cables. Note the broadside as well as steep linear diffractions.

Figure 9 shows the diffraction noise model for a few strong diffractors picked using this diffractor velocity, 1650 m/s. Figure 10 is the result after straight subtraction of the noise model from the input record shown in Figure 8. It is clear that broadside diffractions are now well attenuated.
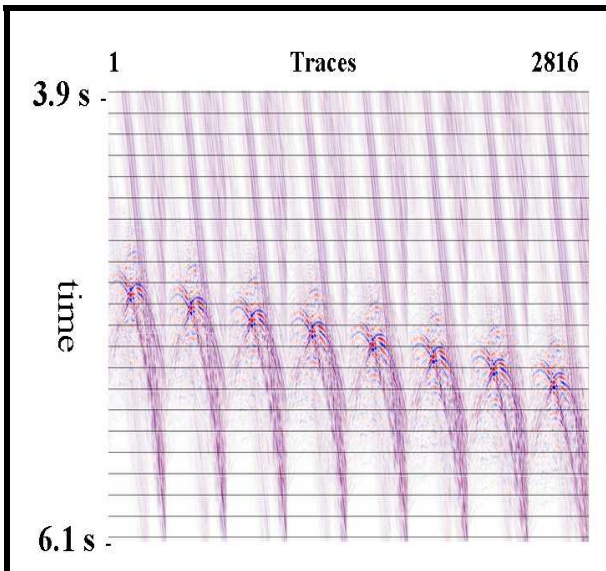

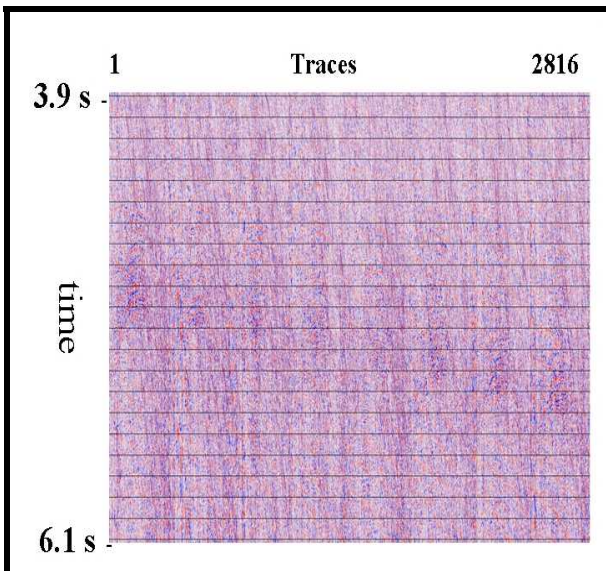**Figure 9. Noise model with v=1650 m/s for 8 cables for the record shown in Figure 8**.

Figure 10. Same record in Figure 8 after subtracting the diffractions in Figure 9.

5. CONCLUSIONS

We have presented an automated method for attenuating diffracted energy that originates from shallow water bottom anomalies. The method uses the seismic sensor array itself (which contains thousands of receivers) in locating the position of the noise sources. Once such locations are determined then signal processing techniques can be used to time align and mute out the noise energy from seismic records.

6. ACKNOWLEDGMENT

7. REFERENCES

[1] G. Fookes, G., Warner, C., and, Borselen, R. V., 2003, "Practical interference noise elimination in modern marine data processing", 73rd Ann. Internat,. Mtg., Soc. Expl. Geophys., Expanded Abstracts.

[2] A. Gonzales-Serrano and , Chon, Y.T, 1984, "Migration velocity analysis", 54th Ann. Internat,. Mtg., Soc. Expl. Geophys., Expanded Abstracts.

[3] N. Gulunay, S. Depagne, and M. Magesan, 2006,. "Fast Broadside Diffractors: A case history." , 76thAnnual International Meeting of the Society of Exploration Geophysicists, Expanded Abstracts

[4] V. Khaidukov, V., Landa, E., and, Moser, T. J.,2004, "Diffraction imaging by focusing-defocusing: An outlook on seismic resolution", Geophysics, **69**, 6, 1478-1490.

[5] E. Landa,, Shtivelman, V, and, Gelchinsky, B., 1987, "A method for detection of diffracted waves on common-offset sections"., Geophy. Pros., **35**, 359-373.

[6] M. Manin, and , Bonnot, J. N, 1993, "Industrial and seismic noise removal in marine processing", 55th Conference of Eur. Assn. Geosci. Eng.

[7] V. Shtivelman, and , Keydar, S., 2004, "Imaging shallow subsurface inhomogeneities by 3D multipath diffraction summation", First Break, **23**, 39-42.