A new twist on spiral shooting

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Summary

Data acquisition using variable density has become increasingly common in recent years, often driven by the need for dense sampling over an area of interest and sparser sampling over a much larger "halo" required for velocity model building using full waveform inversion (FWI). These designs can readily be accomplished on the receiver side using nodes, but variable density shots have historically been less easy to implement. We propose a spiral data acquisition geometry that offers benefits in certain applications.

Introduction

The required sample density to achieve an image of a particular resolution is well understood based on Nyquist's theorem. For OBN acquisition, receivers are typically more expensive than shots, so sparse receiver nodes are employed, with dense shots delivering the required sample density. Dense shot carpets of 50m x 50m or even 25m x 25m are common. With the growing use of full waveform inversion, very large acquisition haloes are required, often equal to 3 times the burial depth of the target. Thus, for an imaged area of 100 km^2 and a burial depth of 6km the total acquisition area is 2,116 km^2. The shot density in the halo is the primary determinant of the cost of an OBN survey. In this halo area the required acquisition density is reduced as a function of the distance from area of interest because of the reduced high frequency content present at longer offset and increasingly remote data. In the present work, we consider the pros and cons of a traditional, linear approach and a novel variable density spiral approach.

The conventional approach : straight lines

With traditional survey designs based on straight lines the options to reduce shot density are quite limited. The dense shot carpet over the area of interest is acquired with one or more dual or triple source vessels acquiring adjacent vessel passes at a spacing equal to the shot spacing multiplied by the number of sources. The only way to reduce the shot density is to truncate some subset of lines : perhaps every 2nd, 3rd or 4th line would be extended to the edge of the halo, with the rest removed.

Figure 1 illustrates a typical approach to achieving variable density shots using a conventional linear grid. In this example, the dense shot carpet (50m x 50m) is extended to 2 km beyond the area of interest. Then every 3rd vessel pass is extended to the

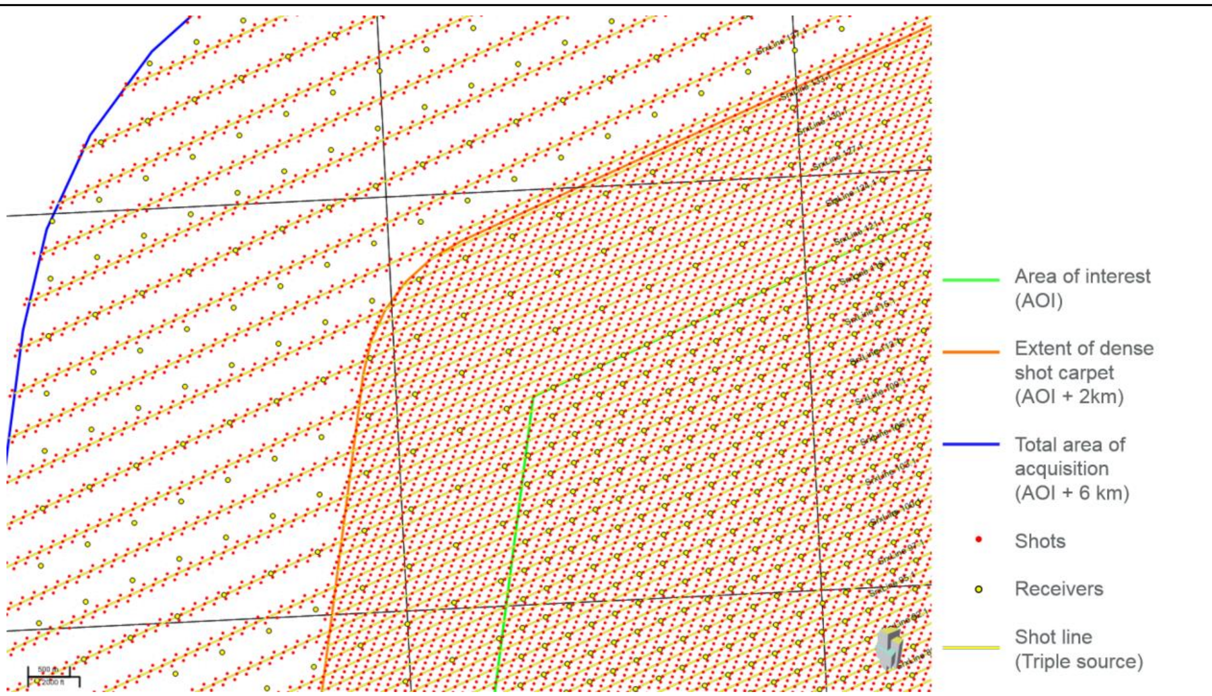

Figure 1 : Variable density shots using a conventional grid of lines with every 3rd line extended.

acquisition boundary. Note that since each triple source vessel pass is 150 m apart, the maximum crossline source separation in the halo is 350m. The inherent discontinuity in the density of the shot carpet could be reduced by going to every 2nd line, and then to every 4th line.

What's wrong with straight lines ?

The straight-line approach has delivered many highly successful projects. However, there are two areas of inefficiency built into this geometry.

The first is obvious. At the end of each line the vessel must transit to the next line. Line change time is not always completely wasted. It allows for source maintenance and gives the observers an occasional peaceful break! Recently, some contractors have started to shoot on turns generating additional data, but these data are often erratic in their distribution due to the small radius of the turn. Figure 2 illustrates the line change pattern on a typical project. Line changes on this project represent 23% of the time to shoot the survey.

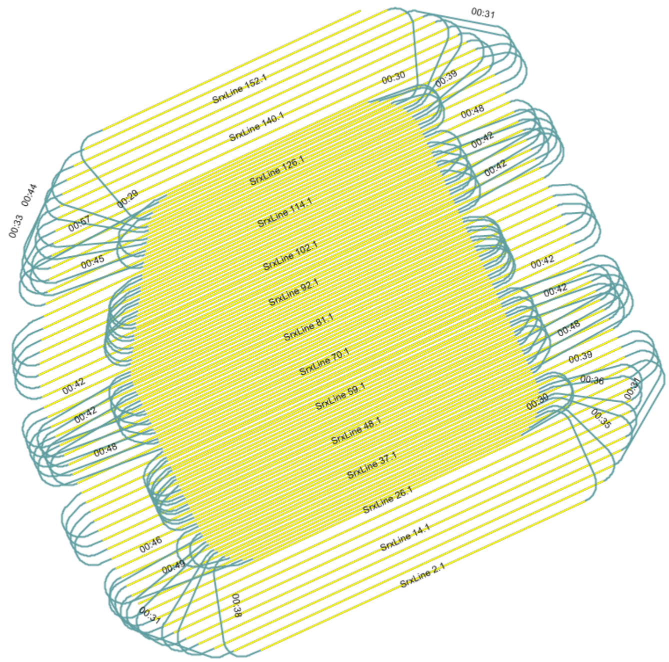

Figure 2 : Vessel lines : Shooting (yellow) Line Change (grey)

The second issue is more subtle. It relates to the discontinuity in surface shot spacing. Anytime there is a discontinuity in sampling, there is some risk of introducing an acquisition footprint. With modern processing technology, particularly FWI, this be a manageable risk, but a more insidious problem remains. By definition at the point where the density changes it is almost certain that we are oversampling the wavefield on the denser side of the transition. As we are often forced to cut corners in order to reduce cost, it is often the case that lines are truncated too early, and on the sparse side of the transition, the wavefield is not adequately sampled, as shown in Figure 3. For these reasons, we decided to explore an alternative shooting geometry.

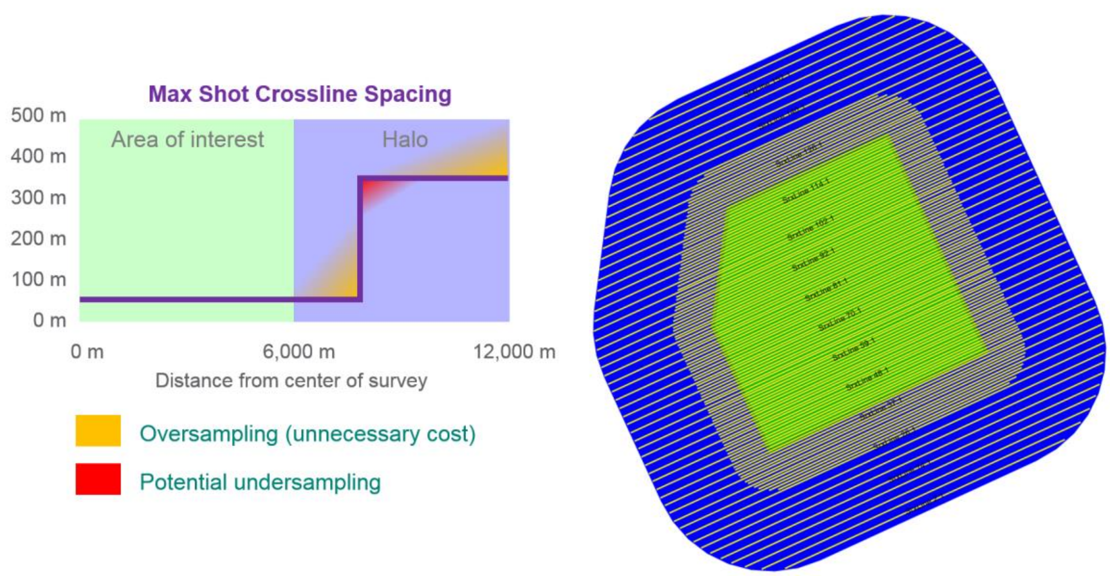

Figure 3 : Sampling density (Conventional linear shooting)

A variable density spiral shooting pattern

In the mid 1980's, Bill French[1] recognized the potential of circle shooting to increase efficiency by eliminating line changes. Nick Moldoveanu[2] and Lasse Amundsen[3] further developed the art of streamer shooting in circles. Pacal[4] investigated the potential to use spiral acquisition for a combined VSP and ocean bottom node project on the landmark Atlantis 4C OBN survey. All of these works pursued the goal of uniform sampling. We propose to use the natural properties of spirals to enable gradually varying sampling of the wavefield as shown in Figure 4.

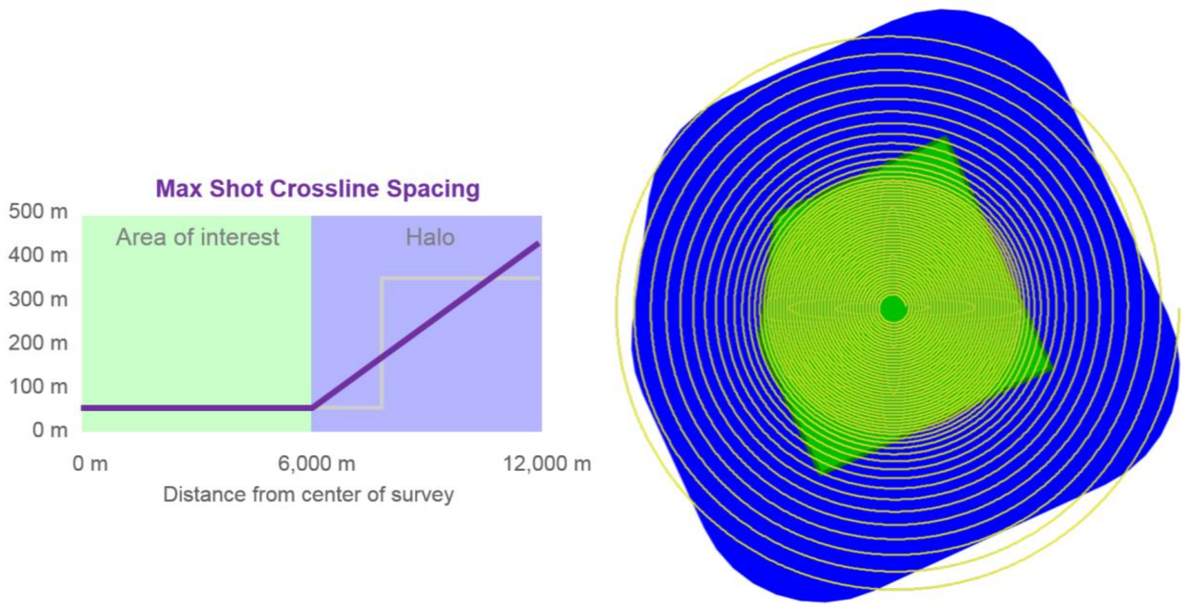

Figure 4 : Sampling density (Spiral shooting)

A spiral survey is normally acquired from the outside to in. This allows the helmsman to start with a familiar, gentle curve. As the crew grows in confidence and master the required skills, (and in the absence of long streamers) they can typically get within a few hundred meters of the center of the circle. The center of the circle can then be filled in with a small straight line central survey. In the example shown in Figure 4, the vessel line spacing at the outer edge of the survey starts at 500m, and reduces steadily until it reaches 150m around the edge of the area of interest. The line spacing is then fixed at 150m over the area of interest.

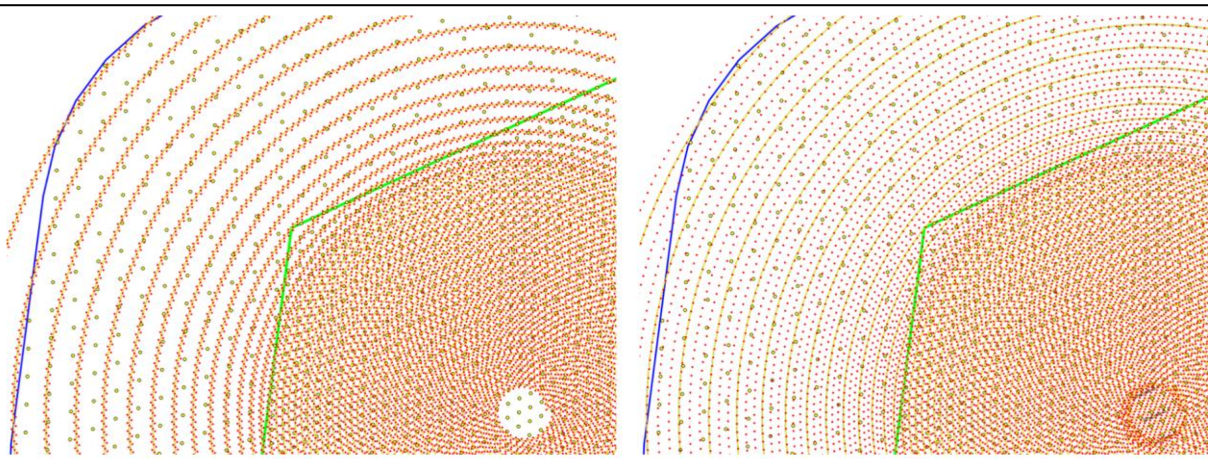

Figure 5 (left) Variable density spiral with constant source separation (right) Variable density spiral with regularized source spacing and central linear survey

Further cost savings can be achieved by using a larger in-line shot interval, enabling faster shooting, on the outer circles. It would also be possible to vary the in-line shot spacing to enable compressive sensing, as suggested by Monk et al. (2012)[5]. Several contractors now have the capability to employ steerable wide towed sources which could be used to regularize the surface source spacing as shown in Figure 5 (right).

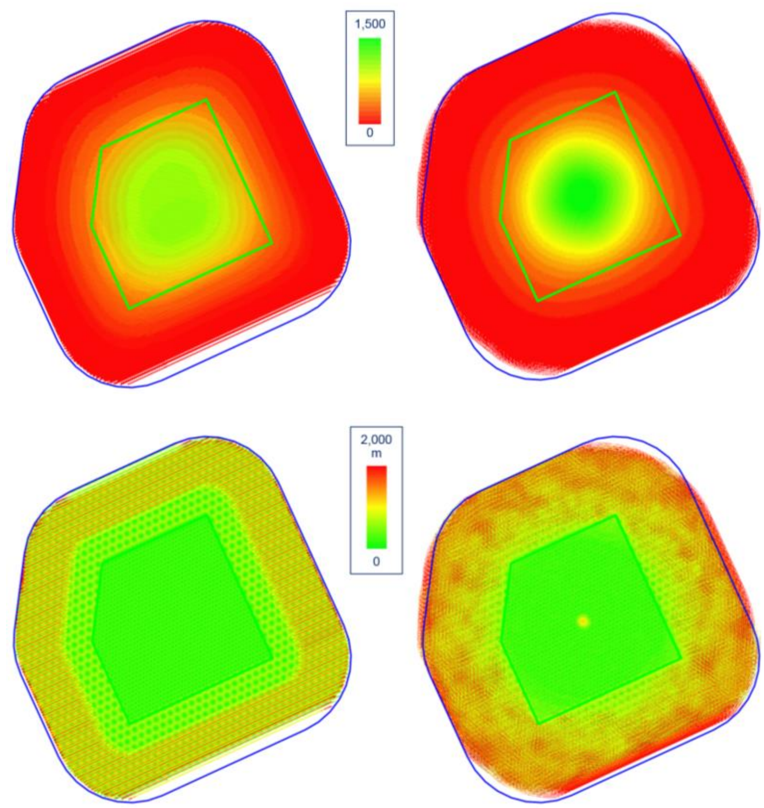

Figure 6 : (left) conventional survey (right) variable density spiral without central linear survey (upper) fold (lower) minimum offset

Survey Design	Shots per day
Straight Line	**3,490**
Spiral	4,440
Spiral + Straight line "Hole"	**4,297**

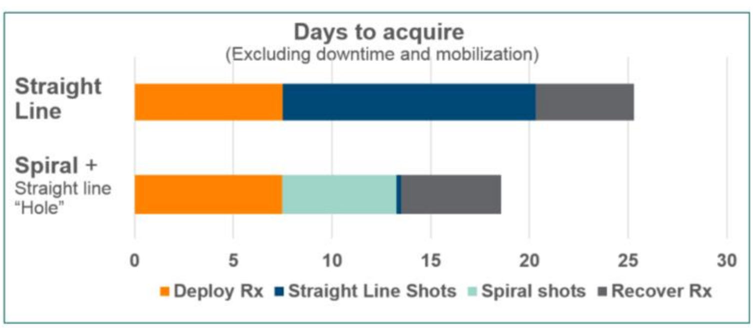

Figure 7 : Operational statistics : Conventional vs linear : downtime excluded

The spirals shown in Figure 5 deliver fold with offset and azimuth distributions (Figure 6) similar to what would be achieved in the conventional design in Figure 1, but with significantly reduced cost.

What's wrong with spirals ?

Spirals are not appropriate for every project. They work well for small, OBN or VSP reservoir development projects that can be accomplished with a single receiver deployment, but they are less efficient for large exploration surveys where receivers must be rolled. Cycloids could have merit in these applications, but the benefits are significantly reduced.

Operational and HSE issues including crew stress and situational awareness associated with continuous turning and continuous shooting are largely irrelevant with modern navigation software.

Perhaps the biggest concern with spirals is that they do not fit well with adjacent surveys, so any future extension of a spiral survey may not be efficient.

Summary and Conclusions

Spiral shooting is not new, but in certain applications the potential cost savings with a variable density spiral are significant. On the small survey considered here, shooting time was reduced by 54% through the elimination of oversampling and line changes. (Figure 7)