3D Symmetric Sampling on Land of Sparse Acquisition Geometries

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Introduction

For successful AVO analysis the quality and reliability of the prestack data has to be ensured by a combination of high-quality acquisition and powerful processing. Therefore, it is appropriate to consider some ingredients of data acquisition that are necessary to achieve reliable reflection amplitudes. Based on two earlier papers (Vermeer, 2010a; 2010b), this paper discusses various ways to improve prestack data quality. I start with a review of the symmetric sampling technique which is in my view the best way of selecting acquisition parameters, followed by a discussion of various aspects of parameter choice that influence final prestack land data quality.

Review of 3D symmetric sampling

The most common 3D acquisition geometries are parallel geometry, orthogonal geometry and areal geometry (Vermeer, 2002). Parallel and orthogonal geometry are line geometries in which sources and receivers are sampled densely along the respective acquisition lines, whereas the line intervals correspond to the sparsely sampled coordinates. There are two types of areal geometry; in type 1 the sources are densely sampled and the receivers are coarsely sampled in *x* and *y*; in type 2 it is the other way around.

Each geometry is (partially) characterized by its basic subset. In the line geometries the basic subset consists of the combination of all data corresponding to one shot line and one receiver line; i.e., in parallel geometry the basic subset is a midpoint line, whereas in orthogonal geometry the basic subset is the cross-spread. In areal geometry type 1 the basic subset is the 3D receiver gather, whereas in areal geometry type 2 it is the 3D shot gather.

A common feature of these basic subsets is that two of the spatial coordinates are fixed, whereas the other two are densely sampled. Therefore, a common factor in defining 3D symmetric sampling for the three types of geometries is the requirement of proper sampling of the basic subsets of the geometries. In array-based acquisition geometries proper sampling of the desired signal rather than the total wavefield is also considered acceptable in 3D symmetric sampling. Proper sampling of the basic subsets implies proper sampling of two of the four spatial coordinates. The other two coordinates will be sampled sparsely, in general.

For each one of the three main acquisition geometries the sampling requirements of the basic subsets have to be supplemented with additional requirements for complete 3D symmetric sampling. In parallel geometry the additional requirement is to achieve square bins; this boils down to a distance between the midpoint lines (= crossline binsize) that is equal to one half of the shot and receiver station intervals.

Orthogonal geometry can be characterized by three pairs of parameters: shot and receiver station intervals, shot and receiver line intervals, and maximum inline and crossline offsets. These pairs determine binsize, unit cell and midpoint area of cross-spread, each pair having its own aspect ratio. 3D symmetric sampling of orthogonal geometry requires that all three aspect ratios of the geometry are equal to 1, because in that way inline and crossline direction are treated in entirely the same way. 3D symmetric sampling also requires the geometry to be regular; that means that all cross-spreads of the geometry have same-size midpoint areas with center-spread acquisition for shots and for receivers. An impressive example of this kind of acquisition (enabled by large channel capacity) is described in Girard *et al*. (2007). They used 25-m station intervals, 200-m line intervals and 3000-m maximum offsets.

Areal geometry may be sampled in a similar way as orthogonal geometry. For instance for type 1 areal geometry, the shot station interval can be small in *x* and *y*, the receiver grid interval would be large in both *x* and *y*, and the maximum offsets may be the same in *x* and *y*. This would again lead to three aspect ratios (station interval, grid interval and midpoint range of 3D receiver).

Main benefits of 3D symmetric sampling are noise removal in basic subsets, prestack imaging of single-fold gathers (OVT gathers, see below), and better AVO analysis.

Ways to improve data quality

Higher maximum frequency. The maximum frequency that can be acquired in a given survey area is usually taken for granted. It may often be in the order of 70 Hz. Baeten and van der Heijden (2008) did not take maximum frequency for granted. They carried out an elaborate experiment in the Oman desert and achieved maximum frequencies of 150 Hz for layers as deep as 2000 m. This remarkable achievement required considerable effort; the vibroseis sweep consisted of two parts, one for the lower frequencies up to 80 Hz and a number of repeated non-linear sweeps for frequencies from 80 to 150 Hz. They also found that single-sensor recording with very accurate positioning was essential to preserve the high frequencies. The kind of effort they spent is not easily adopted in production-oriented data acquisition; nevertheless, this experiment proved that higher frequencies are achievable, and it is likely that further developments in technology will allow the acquisition of higher maximum frequencies, also in a production environment. If maximum frequency could only be raised to 110 Hz, this would already provide enormous benefits.

Smaller station spacing. Ideally, the station intervals should be equal to the basic sampling interval Δx, defined as $\Delta x = V_{min} / (2f_{max})$, where V_{min} is minimum apparent velocity of any coherent events in the wavefield and f_{max} is maximum frequency. A somewhat less strict requirement is to use the adequate sampling interval defined in Baeten *et al*. (2000). Even less strict is to use the basic *signal* sampling interval that depends on the minimum apparent velocity of the desired signal rather than that of the total wavefield. In this case it may be necessary to compensate coarse sampling of the noise by the use of field arrays.

Often, larger intervals than the basic signal sampling interval are used; it is quite common to select an event-oriented sampling interval that samples reflection events without aliasing in the zero-offset section. In that case part of the signal wavefield is still aliased, in particular the diffractions and shallow events with smaller apparent velocities and higher frequencies. For maximum frequencies in the order of 70 Hz, it is usually sufficient to use sampling intervals in the order of 20 or 25 m; yet in current practice, it is quite common to use station intervals of 50 m, 220 feet (67 m) or more. Of course, higher maximum frequencies call for even smaller station intervals.

In case the desired wavefield is properly sampled, it is not necessary to prevent migration-operator aliasing (Biondi 2001) by high-cut filtering; instead, the data can be and should be interpolated to half the basic signal sampling interval, thus preserving precious high frequencies. Interesting examples of the benefit of small station intervals are shown in Lansley (2004) for land data and in Calvert *et al*. (2003) for marine data.

Single-point acquisition versus array-based acquisition. In Vermeer (2010b) I argue that array-based acquisition is often just as good as single-point acquisition, provided the station interval is not larger than the basic signal sampling interval. The combination of adjacent arrays and prestack processing may be just as successful for linear noise suppression as prestack processing of single-point data. Also, reflection amplitudes are hardly affected for such station intervals. An exception is the existence of large intra-array statics; these may suppress the higher frequencies in the data. Large variability of statics occurs for serious elevation variations and also in arctic conditions (Strobbia *et al*. 2009).

Intra-array statics become easily relatively large for higher frequencies. This is illustrated in Figure 1, which shows that the standard deviation of intra-array statics causing 6 and 12 dB suppression by the array is inversely proportional with frequency. (Figure 1 is based on formula given in Baeten and van der Heijden 2008.) A standard deviation of only 2 ms produces already 6 dB attenuation at 92 Hz. Therefore, arrays quickly become unacceptable for high-frequency requirements. At the same time, high frequencies also require the use of small station intervals, so that arrays are no longer required to compensate for coarse sampling of the ground roll. A balanced overview of single-sensor acquisition versus array-based acquisition is given by Mougenot *et al*. (2011).

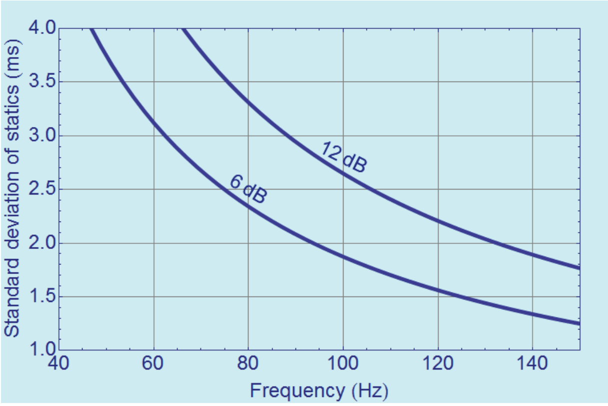

Figure 1 *Standard deviation in intra-array statics leading to 6 or 12 dB suppression as a function of frequency.*

Smaller line intervals. The line intervals in orthogonal geometry determine its sparsity. The line intervals also determine the size of the offset-vector tiles (OVTs) that may be used to construct OVT gathers or pseudo-COV gathers (common offset-vector gathers). In the ideal COV gather all shot receiver pairs have the same offset vector (same absolute offset and same shot/receiver azimuth). The smaller the OVTs the closer the pseudo-COV gathers look like true COV gathers. For small OVTs single-fold prestack imaging of the pseudo-COV gathers leads to minimal migration artifacts, whereas for larger OVTs (larger line intervals) reciprocal OVT gathers may be used to mitigate the effect of the spatial discontinuities between the tiles in a pseudo-COV gather (Vermeer, 2007). Similar reasoning applies to areal geometry, but then for the grid interval of the sparsely sampled unit.

Figure 2a and b illustrate the effect of using reciprocal OVT gathers of areal geometry to suppress migration noise of single-fold OVT gathers with 400 × 400 m tiles, whereas Figure 2c shows the significant improvement in data quality with smaller grid interval of 200 × 200 m.

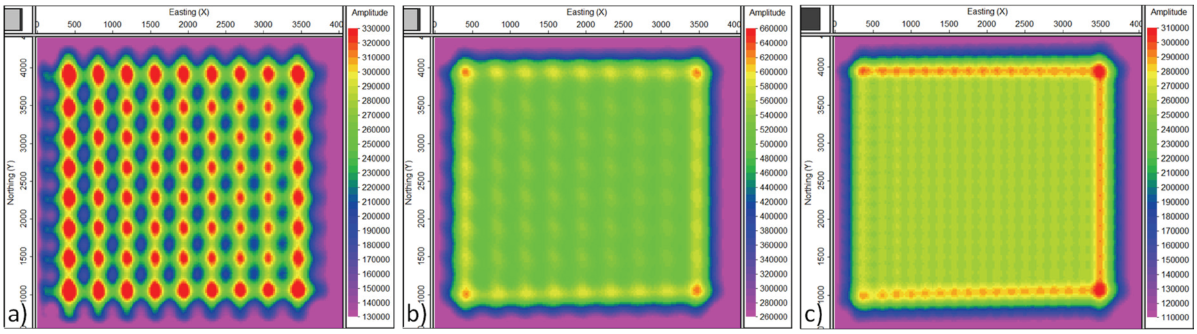

Figure 2 *Imaging of a reflector with 15° dip by OVT gathers in areal geometry. a) Horizon slice for 400 × 400 m OVTs from upper right corner of 3D shot, b) 400 × 400 m reciprocal OVTs from upper right and lower left combined, c) 200 × 200 m OVTs from upper right corner of 3D shot.*

Increase fold. Reducing line intervals also leads to an increase in fold assuming the same maximum inline and maximum crossline offsets. An increase in fold should lead to an increase in S/N, also for the higher frequencies, thus also improving the resolution of the data. This was illustrated vividly by Anderson *et al*. (2006), who used a 3D survey with 200-m line intervals to simulate surveys with larger line intervals of 800 and 400 m. The maximum useful frequency was approximately 40, 50, 57, and 72 Hz for surveys with 24, 48, 144 and 300+-fold. Other authors also report considerable data quality improvements with increased fold.

Longer offsets. In the early days of AVO-analysis simplified formulas were used for reflection coefficients that were valid up to about 30°. Nowadays more accurate formulas are used that describe reflection coefficients for all angles of incidence. This means that for AVO-analysis angles beyond 40° may be useful. The correspondingly long offsets may also be used for more accurate velocity analysis, but may reduce resolution if also used for imaging. In case azimuthal anisotropy does not play a role in AVO analysis, a good strategy may be to select the maximum inline offset according to AVO-requirements, whereas the maximum crossline offset can be chosen smaller, just to satisfy imaging requirements. This is one example where an asymmetric geometry may be chosen as a compromise between survey objective and survey cost. (Another example is an asymmetric geometry for optimal *C*-wave acquisition.)

Discussion

Very powerful interpolation techniques are available these days to improve the sampling of the seismic data. In my view these techniques can be used with great effect to regularize irregular data. Regularization is an essential step toward optimal final results. It is nearly always necessary, because there are hardly any surveys in which the acquisition geometry can be acquired according to the nominal design. On the other hand, regularity is essential to minimize artifacts caused by variations in fold, and spatial discontinuities such as caused by gaps in the acquired data. If the line intervals become small enough (how small is the big question), full 3D with four properly sampled spatial coordinates can be reconstructed with enormous scope for all kinds of detailed analysis.

Conclusions

Technology developments continue to offer opportunities for better data quality. Virtually all seismic surveys use sparse acquisition geometries. Reducing the sparsity by reducing line intervals will often lead to better data quality, but also increasing sampling density of the densely sampled coordinates will often be beneficial. There is still a wealth of improvement to be realized by using higher maximum frequencies.

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