Report 6

Point Scatterer Migration Responses for Regular, Uniform and Quasi-Monte Carlo Distributions of Sources and Geophones

Jing Chen

ABSTRACT

Previous work with field data showed that quasi-Monte Carlo distributions of traces produce migrated images with fewer artifacts than do the regular and uniform distributions of traces. To understand the nature of this result we compute the point scatterer migration responses of regular, uniform and quasi-Monte Carlo distributions of seismic sources and geophones. Results show that for a spatially aliased trace distribution, the quasi-Monte Carlo images contain noticeably fewer migration artifacts than the regular and uniform images. The uniform migration image contains the most artifacts because the grating lobes of the migration operators reinforce one another. For a fixed number of traces, the quasi-Monte Carlo geometry has the least spatial aliasing, the regular geometry is moderately spatial aliased and the uniform geometry has the most spatial aliasing. Migration tests with West Texas field data support these conclusions.

INTRODUCTION

The 3-D surface survey geometry has a great impact on the quality of subsurface imaging. Different surface geometries produce migration images of differing qualities,
as determined by the number of migration artifacts. Fine distributions of sources and geophones produce high quality images but are expensive. On the other hand, coarse trace distributions can generate many artifacts. It is important to identify the key factors that govern the tradeoff between survey resolution and survey expense.

This report classifies 3-D surface survey geometries into three categories: regular, uniform and quasi-Monte Carlo distributions of surface sources and geophones. A regular distribution has source and geophone lines, which are orthogonal. Sources and geophones are closely spaced along the lines while the lines are coarsely spaced. The uniform distribution has both sources and geophones spaced equally along two orthogonal directions. In the quasi-Monte Carlo (QM) distribution, the sources and geophones are randomly distributed.

Our goal is to find which distribution produces the fewest migration artifacts for a given number of traces.

First we compute the point scatterer responses of the regular, the uniform and the QM geometries for dense trace distributions. For dense trace distributions, the aperture size and the number of traces are similar to that of a West Texas survey geometry which we will examine. Then we evaluate the migration responses for coarse trace distributions. Coarser trace distributions are obtained by subsampling the data to 1/4 or 1/8 of its number of traces.

**METHODOLOGY**

The point scatterer migration responses will be computed for the regular, the uniform and the quasi-Monte Carlo distributions of sources and receivers.

The source wavelet is proportional to the derivative of a Gaussian distribution and has a time extent of 20 ms, similar to that for the W. Texas field data traces. This wavelet is shown in Figure 6.1. The corresponding wavelength is about 300 ft in a homogeneous medium with a model velocity of 15,000 ft/s.

The model shown in Figure 6.2 consists of 3 point scatterers buried at 9,000 ft in a homogeneous medium. Table 1 lists the coordinates of the point scatterers. For this model, the synthetic seismograms are calculated and then migrated to give migration images for each kind of surface source and geophone distribution. Three image slices are obtained. Two are vertical slices, while the third is a horizontal slice. Each slice contains two of the three point scatterers. The migrated images are compared for their artifacts to evaluate the performance of each kind of source - receiver geometry.

Table 1. Point scatterer coordinates.

<table>
<thead>
<tr>
<th>Pt. Scatterer</th>
<th>$x_p$ (ft)</th>
<th>$y_p$ (ft)</th>
<th>$z_p$ (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>9,000</td>
</tr>
<tr>
<td>2</td>
<td>-1,500</td>
<td>0</td>
<td>9,000</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>-1,500</td>
<td>9,000</td>
</tr>
</tbody>
</table>
Figure 6.1: The source wavelet used for forward modeling is a derivative of a Gaussian distribution with a width of 20 ms.
Model Configuration For Point Scatterer Tests

Figure 6.2: Model configuration for point scatterer tests. The shot and receiver aperture areas are $L_{xs} \times L_{ys}$ and $L_{xr} \times L_{yr}$. Here $L_{xs} = 23,760$ ft, $L_{ys} = 10,560$ ft, $L_{xr} = 23,760$ ft, and $L_{yr} = 23,760$ ft, and the depth of the point scatterers is 9,000 ft. The surface survey geometry may have regular, uniform or quasi-Monte Carlo distributions of shots and geophones. Two vertical (XZ, YZ) image slices and one horizontal (XY) image slice are computed for each survey geometry pattern.
NUMERICAL EXPERIMENTS

Migrating densely distributed traces

Table 2 lists the spatial sampling intervals ($\Delta x_s$, $\Delta y_s$, $\Delta x_r$ and $\Delta y_r$) and trace numbers for each survey geometry. The regular distribution of shots and geophones is designed to simulate the W. Texas field data geometry. The uniform trace and quasi-Monte Carlo trace distributions are stipulated to have the same number of traces as the regular distribution. The number of traces for the regular distribution is 1,298,517, which is about four times that of the actual number of the traces for the W. Texas survey. The reason for this is that in the regular geometry all geophones are turned on for each shot while in the W. Texas survey only a portion of the geophones are turned on for each shot.

The regular distribution has a fine sampling in each direction. Compared with the seismic wavelength (300 ft), this geometry is not spatially aliased in either direction, while the uniform distribution is spatially aliased.

<table>
<thead>
<tr>
<th>Geometry</th>
<th>$\Delta x_s$ (ft)</th>
<th>$\Delta y_s$ (ft)</th>
<th>$\Delta x_r$ (ft)</th>
<th>$\Delta y_r$ (ft)</th>
<th>Number of Traces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>1,320</td>
<td>330</td>
<td>220</td>
<td>1,320</td>
<td>1,298,517</td>
</tr>
<tr>
<td>Uniform</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>1,309,499</td>
</tr>
<tr>
<td>QM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,298,517</td>
</tr>
</tbody>
</table>

The regular distribution of shots and geophones is shown in Figure 6.3, while the uniform and the quasi-Monte Carlo distributions are shown in Figures 6.4 and 6.5, respectively. These distributions have about the same number of traces as the regular distribution but have different shot and geophone distributions.

Synthetic data were generated for the point scatterer model in Figure 6.2 and the three kinds of trace distributions in Figures 6.3 through 6.5. These data were migrated to give the nine image slices shown in Figures 6.6 through 6.8.

To best visualize the migration artifacts, different scales were used in plotting these figures. The vertical slices (XZ and YZ) are plotted to 0.025 of the peak amplitude, while the horizontal slices (XY) are plotted to 0.1 of their peak amplitudes.

Figure 6.6 shows the XZ slices of the regular, the uniform and the quasi-Monte Carlo (QM) images. There are almost no noticeable migration artifacts in the XZ slices of the regular migration image (RM) and the quasi-Monte Carlo migration image (QM), because the geometries are not spatially aliased. In contrast, there are apparent migration artifacts in the XZ slice of the uniform migration image (UM), because the spatial sampling interval in the X direction for the uniform grid is 580 ft, which is greater than the 300 ft wavelength of the seismic wavelet.

Figure 6.7 displays the YZ slices of the RM, UM and QM images, respectively. There are still almost no noticeable migration artifacts in the YZ slice of the QM image but there are some migration artifacts in the YZ slice of the RM image, although the
Figure 6.3: Regular shot and geophone distributions simulating that of the West Texas shooting geometry. Crosses represent shot positions and dots represent geophone positions. There are 1,298,517 traces associated with the above geometry which is roughly 4 times the number of traces recorded in the W. Texas field experiment. The spatial sampling intervals are $\Delta x_s = 1,320$ ft, $\Delta y_s = 330$ ft, $\Delta x_r = 220$ ft, and $\Delta y_r = 1,320$ ft. Unlike the actual W. Texas survey geometry, all geophones are turned on for each shot point.
Figure 6.4: Uniform distribution of shots and geophones. Crosses represent shot positions and dots represent geophone positions. There are 1,309,499 traces which is roughly the same number of traces as in Figure 6.3. The aperture area of the survey is the same as in Figure 6.3. The shots and the geophones have an uniform spatial sampling interval $\Delta x_s = \Delta y_s = \Delta x_r = \Delta y_r = 580$ ft. Unlike the actual W. Texas survey geometry, all geophones are turned on for each shot point.
Figure 6.5: The quasi-Monte Carlo distributions of shots and geophones. There are 1,309,499 traces, which is the same as in Figure 6.3. Only 8,000 points are displayed here and the aperture area of the survey is the same as in Figure 6.3. Each source shoots into a different distribution of geophones.
Figure 6.6: XZ slices of the images obtained by migrating the regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.7: YZ slices of the images obtained by migrating the regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
artifacts are weaker than those in the YZ slice of the UM image. The regular geometry is slightly aliased in the Y direction because its 330 ft spatial sampling interval in the Y direction is slightly greater than the 300 ft wavelength. The YZ slice of the migrated uniform image has the most severe migration artifacts among the three slices, apparently due to its coarse 580 ft sampling interval.

Figure 6.8 shows the horizontal (XY) migration slices for each distribution. The UM slice has strong migration artifacts. The RM slice has some artifacts but their magnitudes are smaller than those for the UM slice. The artifacts in the RM slice have a Y directional trend because the sampling in the X direction was finer than the sampling in the Y direction. The small artifacts in the QM slice have no preferred trend because of the random spatial sampling. Artifact strength on average appears to be about the same as in the RM image, but with less coherence.

Migrating the 1/4 subsampled data

The last section shows that for a dense trace distribution, the regular and the quasi-Monte Carlo distributions produce images with almost the same quality. Now consider the case where the number of traces are reduced to just 1/4 of the original number. Table 3 shows the spatial sampling intervals and the number of traces for the regular, the uniform and the quasi-Monte Carlo trace distributions at 1/4 subsampling. The regularly spaced 1/4 subsampled data are obtained by quadrupling the geophone sampling interval in the X direction while keeping the other three sampling intervals unchanged. The uniformly spaced data were sampled at an interval of 830 ft to get the 1/4 subsampling. In this case the regular geometry is spatially aliased in the X direction but still finely sampled in the Y direction. The uniform geometry is spatially aliased in both the X and the Y directions.

<table>
<thead>
<tr>
<th>Geometry</th>
<th>$\Delta x_s$ (ft)</th>
<th>$\Delta y_s$ (ft)</th>
<th>$\Delta x_r$ (ft)</th>
<th>$\Delta y_r$ (ft)</th>
<th>Trace Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>1,320</td>
<td>330</td>
<td>880</td>
<td>1,320</td>
<td>333,564</td>
</tr>
<tr>
<td>Uniform</td>
<td>830</td>
<td>830</td>
<td>830</td>
<td>830</td>
<td>317,057</td>
</tr>
<tr>
<td>QM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>333,564</td>
</tr>
</tbody>
</table>

The regular trace distribution for the 1/4 subsampled data is shown in Figure 6.9, and the uniform and the quasi-Monte Carlo distributions are shown in Figures 6.10 and 6.11, respectively. These distributions have about the same number of traces but different shot and geophone distributions.

Figures 6.12, 6.13 and 6.14 show the XZ, YZ and XY migration slices for the regular, uniform and quasi-Monte Carlo distributions of the 1/4 subsampled data.

Both the XZ and the YZ slices of the 1/4 RM image have noticeable migration artifacts. The XZ slice of the 1/4 RM image has stronger artifacts than those derived using the entire regular data set in Figure 6.6. These artifacts are even stronger
Figure 6.8: XY slices of the images obtained by migrating the regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.9: Shot and geophone distributions simulating 1/4 regular subsampling of the West Texas survey geometry. Crosses represent shot positions and dots represent geophone positions. There are 333,564 traces which is roughly 1/4 the number of traces in Figure 6.3. This geometry is obtained by quadrupling the geophone sampling interval in the X direction. The spatial sampling intervals are $\Delta x_s = 1,320$ ft, $\Delta y_s = 330$ ft, $\Delta x_r = 880$ ft, $\Delta y_r = 1,320$ ft. All geophones are turned on for each shot point.
Figure 6.10: Uniform distribution of shots and geophones simulating 1/4 subsampling. Crosses represent shot positions and dots represent geophone positions. There are 317,057 traces, which are roughly 1/4 the number of traces in Figure 6.3. The aperture area of the survey is the same as in Figure 6.3. The shots and the geophones have an uniform spatial sampling interval \( \Delta x_s = \Delta y_s = \Delta x_r = \Delta y_r = 830 \text{ ft} \). Note that all geophones are turned on for each shot point.
Figure 6.11: The quasi-Monte Carlo distribution of shots and geophones simulating 1/4 subsampling. Crosses represent shot positions and dots represent geophone positions. There are 333,564 traces which is roughly 1/4 the number of traces in Figure 6.3. Only 2,000 traces are displayed here. The aperture area of the survey is the same as in Figure 6.3.
than those in the YZ slice of the 1/4 RM image in Figure 6.13, because the sampling interval in the X direction ($\Delta x_r = 880 \text{ ft}$) is larger than the sampling interval in the Y direction ($\Delta y_s = 330 \text{ ft}$). The two vertical slices of the 1/4 QM image (Figures 6.12 and 6.13) have fewer artifacts than the corresponding vertical slices of the 1/4 RM image. This results from the random distribution of shots and geophones. The vertical slices of the 1/4 UM image have the most artifacts because the spatial sampling in either direction is more severely aliased than in the other sampling schemes. There are stronger migration artifacts in the horizontal slices than in the vertical slices. The XY slice of the 1/4 RM image shows the artifacts trend in the X direction; this is because the X direction is more coarsely sampled. The artifacts in the 1/4 UM image have no distinct trend because the sampling intervals are the same in both X and Y directions. The XY slice of the 1/4 QM image has smaller but more randomly distributed artifacts than that of the 1/4 RM image.

### Migrating the 1/8 subsampled data

The survey parameters for the coarsest distributions are shown in Table 4, where the data are subsampled to 1/8 of the total number of traces. At the 1/8 subsampling, the geophone sampling interval in the X direction for the regular geometry is 1,760 ft but in the Y direction is still 330 ft, which is slightly higher than the seismic wavelength. The uniform geometry has a sampling interval of 980 ft.

<table>
<thead>
<tr>
<th>Geometry</th>
<th>$\Delta x_s$ (ft)</th>
<th>$\Delta y_s$ (ft)</th>
<th>$\Delta x_r$ (ft)</th>
<th>$\Delta y_r$ (ft)</th>
<th>Trace No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>1,320</td>
<td>330</td>
<td>1,760</td>
<td>1,320</td>
<td>178,695</td>
</tr>
<tr>
<td>Uniform</td>
<td>980</td>
<td>980</td>
<td>980</td>
<td>980</td>
<td>178,750</td>
</tr>
<tr>
<td>QM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>178,695</td>
</tr>
</tbody>
</table>

The shot and geophone distributions for the regular, the uniform and the quasi-Monte Carlo geometries at 1/8 subsampling are shown in Figures 6.15, 6.16 and 6.17. Figures 6.18, 6.19 and 6.20 show the XZ, YZ and XY migration slices for the regular, uniform and quasi-Monte Carlo distributions of the 1/8 subsampled data.

At the 1/8 subsampling, both the RM and UM images have strong artifacts in the vertical slices. The artifacts in the vertical slices of the 1/8 RM and UM images are much stronger than those in the original images. However, artifacts in the vertical slices of the 1/8 QM image are relatively weak. These images have almost the same quality as the vertical image slices of the entire quasi-Monte Carlo data. This shows that the quasi-Monte Carlo distribution of traces can reduce migration artifacts even when the data has a coarse trace distribution. The cancellation of artifacts come from the irregular and random distribution of back projected seismic energy.

There are stronger migration artifacts in the horizontal slices than in the vertical slices. But the horizontal slice of the 1/8 QM image seems to have the least artifacts of the three horizontal images.
Figure 6.12: XZ slices of the images obtained by migrating the 1/4 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.13: YZ slices of the images obtained by migrating the 1/4 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.14: XY slices of the images obtained by migrating the 1/4 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.15: Shot and geophone distributions simulating the 1/8 regular subsampling. Crosses represent shot positions and dots represent geophone positions. There are 178,695 traces which is roughly 1/8 the number of traces in Figure 6.3. This geometry is obtained by enlarging the geophone sampling interval by a factor of 8 in the X direction. The spatial sampling intervals are $\Delta x_s = 1,320\, ft$, $\Delta y_s = 330\, ft$, $\Delta x_r = 1,760\, ft$, and $\Delta y_r = 1,320\, ft$. All geophones are turned on for each shot point.
Figure 6.16: The uniform distributions of shots and geophones simulating 1/8 uniform subsampling. Crosses represent shot positions and dots represent geophone positions. There are 178,750 traces which is roughly 1/8 number of traces in Figure 6.3. The aperture area of the survey is the same as in Figure 6.3. The shots and the geophones have an uniform spatial sampling interval $\Delta x_s = \Delta y_s = \Delta x_r = \Delta y_r = 980$ ft. All geophones are turned on for each shot point.
Figure 6.17: The quasi-Monte Carlo distributions of shots and geophones simulating 1/8 subsampling. Crosses represent shot positions and dots represent geophone positions. There are 178,695 traces which is roughly 1/8 the number of traces in Figure 6.3. Only 1,000 traces are displayed here. The aperture area of the survey is the same as in Figure 6.3.
Figure 6.18: XZ slices of the images obtained by migrating the 1/8 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.19: YZ slices of the images obtained by migrating the 1/8 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Figure 6.20: XY slices of the images obtained by migrating the 1/8 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions.
Migrating the data with an incorrect migration velocity

Spatial aliasing in the surface survey geometry is not the only cause of migration artifacts. One important cause is an incorrect migration velocity. The following tests show that if an incorrect velocity model is used, the images defocus and result in strong migration artifacts.

As an example, the 1/8 subsampled data for different geometries are migrated with an incorrect velocity. The velocities used in the migrations are shown in Table 5. The velocity error is about 3% with respect to the true velocity used in the forward modeling.

<table>
<thead>
<tr>
<th>Model Velocity</th>
<th>Migration Velocity</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000 ft/s</td>
<td>15,500 ft/s</td>
<td>3.33%</td>
</tr>
</tbody>
</table>

Figures 6.21, 6.22 and 6.23 show, respectively, the XZ, YZ and XY migration slices of the 1/8 RM, 1/8 UM and 1/8 QM images with an incorrect migration velocity. These figures show that the use of an incorrect migration velocity results in much stronger migration artifacts than those in the images migrated with the correct velocity. The combination of incorrect velocity and spatial aliasing makes the image more severely polluted by the artifacts and therefore badly reduces the S/N ratio of the image. The point scatterers are not identified as clearly as in the images obtained with the correct velocity.

In the XZ slices (Figure 6.21), the artifacts associated with the quasi-Monte Carlo data are significantly weaker than those for the regular or the uniform data.

These figures show that even for the images obtained with an incorrect velocity, the QM distribution produces fewer artifacts than the regular and the uniform distributions.

FIELD DATA TEST

To test the performance of the regular, the uniform and the quasi-Monte Carlo migration algorithms, the West Texas field data traces were interpolated to a regular grid, a uniform grid and a quasi-Monte Carlo grid and were then migrated. The number of the interpolated traces for each kind of grid is roughly 1/8 of the total number of traces in the W. Texas data. The migrated images for the 1/8 regular, 1/8 uniform and 1/8 quasi-Monte Carlo data are shown in Figures 6.24, 6.25 and 6.26. They indicate that the QM image has fewer artifacts than the RM image and the UM image has the most severe artifacts. These results are consistent with the point scatterer tests. However, we cannot be sure how much the interpolation inferred the final images.
Figure 6.21: XZ slices of the images obtained by migrating the 1/8 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions with an incorrect migration velocity.
Figure 6.22: YZ slices of the images obtained by migrating the 1/8 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions with an incorrect migration velocity.
Figure 6.23: XY slices of the images obtained by migrating the 1/8 regular (top), uniform (middle) and quasi-Monte Carlo (bottom) trace distributions with an incorrect migration velocity.
Figure 6.24: Migrated image of the 1/8 regularly interpolated traces.
Figure 6.25: Migrated image of the 1/8 uniformly interpolated traces.
Figure 6.26: Migrated image of the 1/8 QM traces.
DISCUSSION

Point scatterer migration responses have been computed for different 3-D surface survey geometries. As long as the survey geometries are spatially aliased, the migration of a quasi-Monte Carlo distribution of traces typically generated fewer and weaker artifacts than the regular and the uniform distributions of traces. The UM images yielded the worst migration artifacts. An incorrect migration velocity causes severe migration artifacts, but again the QM images were, typically, of noticeably better quality than the RM and UM images. These results are consistent with field data tests (Chen, 1997) and suggest that a greater regularity in trace spacing tends to amplify the grating lobes in the migration operator.

Why did the UM images have the strongest artifacts? The explanation is that the grating lobes of the migration operators are reinforced when the spatial sampling interval is the same for both the X and Y directions. This can be seen by recalling the formula for 3-D prestack migration (Chen, 1996):

\[
m(\mathbf{r}_i, \omega) = \frac{\sin((2N_{sz} + 1)kL_{sx}x_i/N_{sx}r_p)}{\sin(kL_{sx}x_i/N_{sx}r_p)} \times \frac{\sin((2N_{sy} + 1)kL_{sy}y_i/N_{sy}r_p)}{\sin(kL_{sy}y_i/N_{sy}r_p)} \times \frac{\sin((2N_{gx} + 1)kL_{gz}x_i/N_{gx}r_p)}{\sin(kL_{gz}x_i/N_{gx}r_p)} \times \frac{\sin((2N_{gy} + 1)kL_{gy}y_i/N_{gy}r_p)}{\sin(kL_{gy}y_i/N_{gy}r_p)},
\]

(6.1)

where \(m(\mathbf{r}_i, \omega)\) is the point scatterer response of 3-D prestack migration; \(k\) is the wavenumber; and \(r_p\) is the depth of the point scatterer. Here we assume a shot and geophone array of areas \(L_{sx} \times L_{sy}\) and \(L_{gz} \times L_{gy}\), respectively; and \(2N_{sz} + 1\), \(2N_{sy} + 1\) are the number of source sampling points in the X and Y directions, respectively. There are a total of \((2N_{gz} + 1) \times (2N_{gy} + 1)\) geophones.

Equation 6.1 can be rewritten in terms of spatial sampling intervals as

\[
m(\mathbf{r}_i, \omega) = \frac{\sin(k2L_{sx}x_i/r_p)}{\sin(kd_{sx}x_i/r_p)} \times \frac{\sin(k2L_{sy}y_i/r_p)}{\sin(kd_{sy}y_i/r_p)} \times \frac{\sin(k2L_{gz}x_i/r_p)}{\sin(kd_{gz}x_i/r_p)} \times \frac{\sin(k2L_{gy}y_i/r_p)}{\sin(kd_{gy}y_i/r_p)},
\]

(6.2)

where \(d_{sx}, d_{sy}, d_{gz}, d_{gy}\) are the spatial sampling intervals for sources and receivers in the X and Y directions. Equation 6.2 shows that for the uniform distribution where \(d_{sx} = d_{sy} = d_{gz} = d_{gy}\), the grating lobe positions are spatially coincident for all four sinc functions. Thus, the grating lobe amplitudes are amplified. Compare this to the regular trace distribution where \(d_{sx}, d_{sy}, d_{gz}\) and \(d_{gy}\) are different. In this case,
the grating lobes of each sinc function often occupy different locations so that the product of the sinc functions typically attenuate the grating lobe amplitudes.

The regular-grid geometries we designed here are similar, but not exactly equal to those of the W. Texas field geometry. The difference is that here all geophones record each shot, but in the W. Texas data just a portion of the geophones record a shot.

The point scatterer migration responses obtained here have a rather high signal to noise (S/N) ratio compared to the actual W. Texas field data and the synthetic data are noise free. In the field data images the artifacts are much stronger than those in the point scatterer tests and they have almost the same amplitude as the images. This is because the point scatterer model was used in the synthetic tests where all traces record the wavefield from the point scatterers, while in the field data migration only a portion of the traces record an individual reflector point. In fact, there are some constraints in the field data migration which also remarkably reduce the number of traces contributed to one image point.

**CONCLUSION**

The following conclusions can be drawn from the point scatterer tests and the field data tests:

1. If the spatial sampling intervals are smaller than the seismic wavelength, then the data is not aliased. Both regular, uniform and QM geometries produce few migration artifacts, provided a proper velocity is used for migration.

2. For spatially aliased data, migration artifacts tend to occur in the direction which is aliased.

3. Given the same number of traces, the uniform distribution is most likely to be aliased, while the QM distribution is least likely to be aliased. Therefore the QM distribution produces migration images with fewer artifacts.

4. An incorrect migration velocity defocuses the migrated image and causes severe artifacts.

5. For a given number of traces, an optimal 3-D survey design should distribute the traces such that there is no spatial aliasing in each direction.

**ACKNOWLEDGEMENTS**

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**REFERENCES**
