Simulations of Seismic Acquisition Footprint

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Summary

Seismic acquisition footprint generally consists of modulations in recorded amplitudes that are spatially correlated to the surface locations of sources and receivers used in a survey. These amplitude variations obscure the true reflection response of the subsurface. In this study, synthetic seismic data were produced using numerical modelling code written in MATLAB. An "exhaustive" dataset was created using a survey design incorporating dense grids of sources and receivers, chosen to guarantee fully unaliased sampling of the seismic reflections. A more commonly used survey design, involving sparser spatial sampling and resulting in forms of spatial aliasing, was created by selecting specific traces from the exhaustive survey. Both datasets were subjected to two distinct processing flows: one including stacking and poststack migration, and the other involving prestack migration. Final processed images from the exhaustive dataset were compared to those from the decimated dataset. Algorithm-dependent footprint, including edge artefacts and aperture imprints, was observed in both the exhaustive and decimated datasets. Footprint consisting of periodic amplitude variations in the interior of the surveys, similar to that observed in field data and likely produced by poor sampling, was observed in the decimated dataset. This type of footprint was also observed to vary in strength between images produced with different processing algorithms.

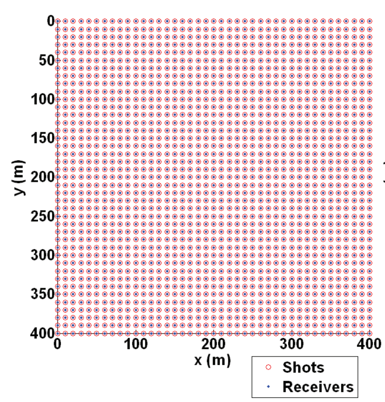
Introduction

With the purpose of increasing the understanding of the causes of acquisition footprint as well as developing strategies for reducing its effect, a seismic forward modelling study was initiated to simulate footprint artefacts observed in field data. Spatial sampling of the seismic wavefield is likely to have a central role in acquisition footprint; therefore, an effective strategy to investigate footprint is to compare seismic images produced with "exhaustive" spatial sampling to those produced with more typical source and receiver geometries. Exhaustive sampling involves very dense source and receiver lattices with source and receiver intervals small enough to adequately sample all seismic events without aliasing, while typical geometries generally involve sparser and more irregular source and receiver sampling.

Method

The simulations were generated by the process of numerical seismic forward modelling. A Rayleigh-Sommerfeld method was used in 3D (Margrave and Cooper, 2008). The method produces a shot record by initiating a source with a given spectrum and downward continuing the wavefield to the reflector by phase-shifting. Then, the wavefield is multiplied by a reflection coefficient which is a function of x and y. Finally the wavefield is propagated back to the surface. The method includes spreading loss but not multiples, direct arrivals, or noise. The speed of Rayleigh-Sommerfeld modelling compared to Kirchhoff modelling in 3D prompted its use in this study. The interaction between the survey geometry and different imaging algorithms were examined by comparing results produced using “conventional” seismic processing (normal moveout correction, stack, and poststack migration) with those obtained using prestack migration algorithms. These investigations produced some preliminary conclusions, while providing groundwork for further modelling work in the examination of acquisition footprint in seismic data.

The “exhaustive” dataset was produced using shot, receiver, shot line, and receiver line spacings of 10 m. Figure 1a) shows the geometry. The survey involves 1681 shots, with 1681 receivers live per shot, which required three days to model, using a Matlab code on a single cpu.. The spectrum of the wavelet used in the modelling and the velocities of the layers in the model are described by Margrave and Cooper (2008). In order to produce datasets simulating more typical field acquisition geometries, several decimations of the exhaustive dataset were produced. One of these decimated datasets will be discussed here. As shown in Figure 1b), the decimated survey geometry is an orthogonal survey design typical of many land 3D surveys. The source lines run parallel to the y-axis and the receiver lines run parallel to the x-axis. The source line and receiver line spacings are 80 m, though the source and receiver spacings within lines remain equal to the exhaustive sampling interval, 10 m.



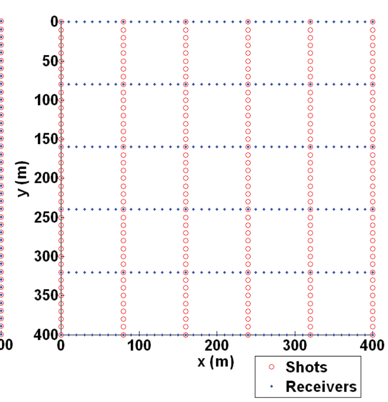


Figure1: Geometry of a) the exhaustive survey and b) the decimated survey.

Results

Both the exhaustive and decimated datasets were subjected to several processing techniques, in order to examine the interaction between sampling and various imaging algorithms. In all cases, exact model velocities were used and deconvolution was not applied. Processing at the University of Calgary was performed in MATLAB, producing a CMP stack, a Kirchhoff poststack migration of that stack, and a Kirchhoff prestack migration. Two additional prestack migration algorithms were applied to the data by industrial partners in this study. Table 1 summarizes the five different flows.

Method	Description
UofC Stack	Deterministic gain, NMO correction, mute, stacking
UofC Poststack Migration	Kirchhoff poststack migration of UofC Stack, using Bleistein (2001) weights for zero offset
UofC Prestack Migration	Kirchhoff shot record migration using Bleistein (2001) shot weights, mute, stacking of migrated shots
Prestack Migration A	Formation of common-offset-vector volumes, Kirchhoff migration, stacking of migrated COV volumes
Prestack Migration B	Formation of common-offset volumes, weighting by offset-range limited fold, Kirchhoff migration, stacking of migrated CO volumes

Table 1: Summary of processing methods applied to the model data.

Figures 2 and 3 show time and depth slices from processed volumes produced by applying the five processing methods. Each figure contains the slices corresponding to the appropriate time or depth of two reflectors in the model (one at 100m, corresponding to a reflector with a constant reflection coefficient, and one at 200m, corresponding to a reflector with a channel feature) from both the exhaustive and decimated datasets. All slices are scaled individually to their maximum and minimum amplitudes and are plotted using a linear colour scale.

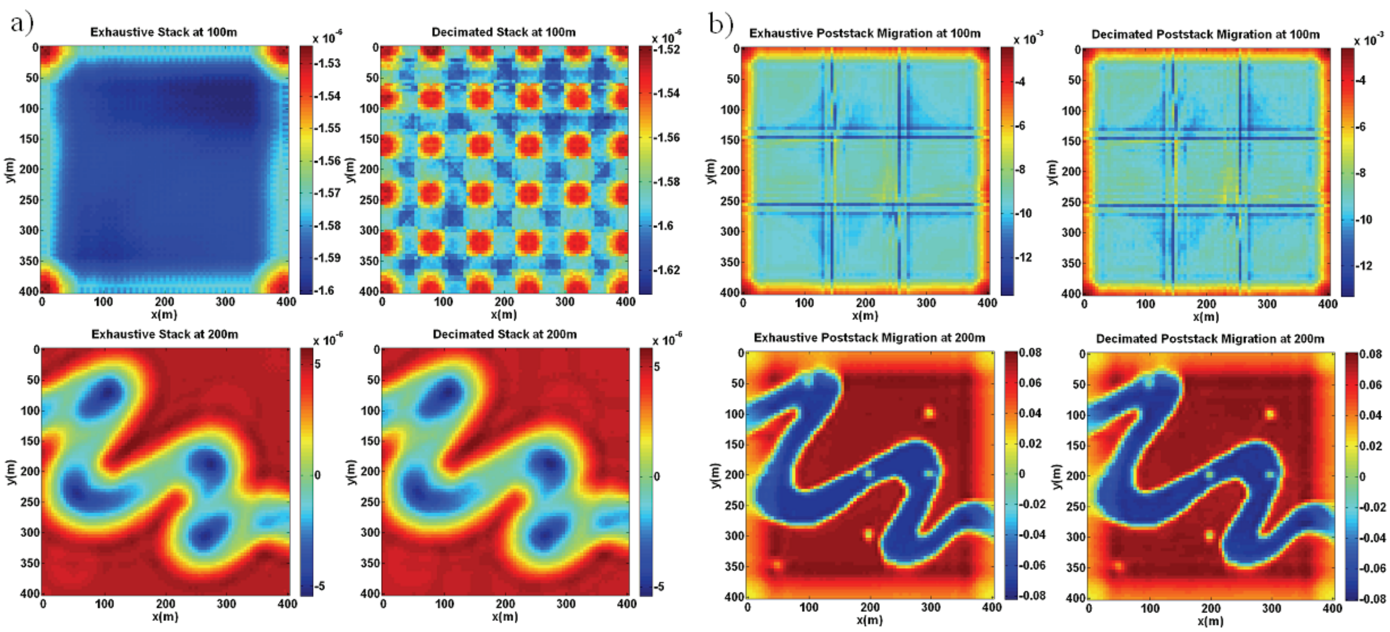


Figure2: Slices from a) stacks and b) poststack migrations for the exhaustive and decimated datasets.

Conclusions

The objective of this project was to perform numerical simulations in order to investigate the causes of commonly observed artefacts in seismic field data, known as acquisition footprint. By defining footprint as any features observed on an image of a featureless reflector, we consider two broad classes of footprint produced in this study. The first consists of amplitude variations related to the edges of the survey, including edge artefacts and aperture effects; this type of footprint was observed in both the exhaustive and decimated datasets, and was observed to vary between processing algorithms. The second class of footprint consists of amplitude variations in the interior of the survey, which are more prevalent in the decimated dataset. Observations of footprint in the decimated datasets are generally consistent with typical field data. In our simulations, observed footprint was (1) most organized in the unmigrated stack, (2) somewhat randomized after poststack migration, and (3) most severe after prestack migration, though highly variable using different prestack migration algorithms, suggesting that migration weighting schemes in prestack migration are key to minimizing the effects of footprint.

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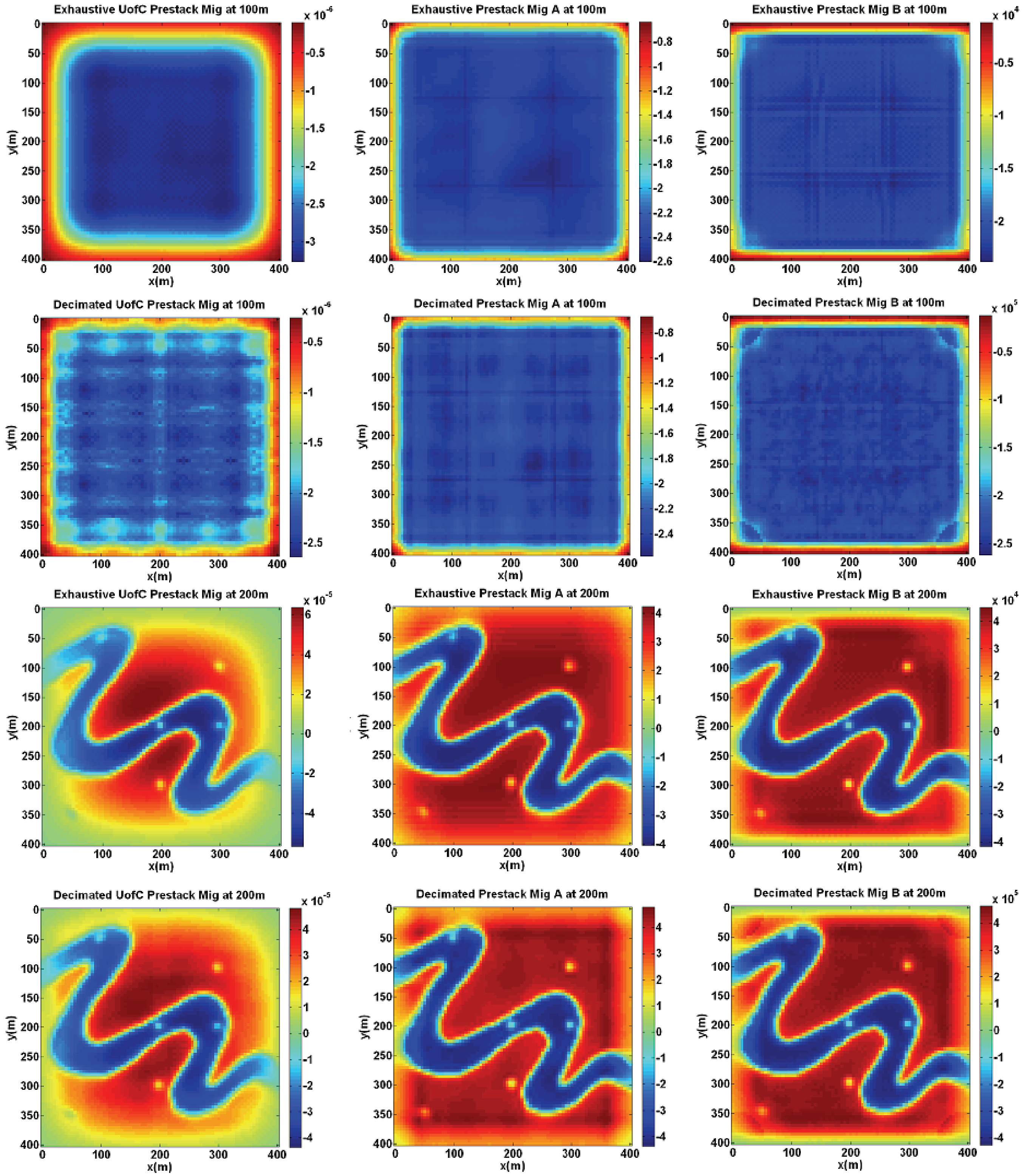

Figure3: Slices from prestack migrations for the exhaustive and decimated datasets. Leftmost column: UofC; middle column: industrial algorithm A; rightmost column: industrial algorithm B.