Signal processing enhancements of GPR data in a carbonate environment

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ABSTRACT

The University of Calgary has been conducting geophysical research at the Maya site of Maax Na in Belize, Central America for several years. The 2002-2004 field seasons have resulted in the acquisition of a number of 2-D and 3-D ground-penetrating radar (GPR) surveys using the 250 MHz Noggin Smart-Cart. Results employing an improved processing flow and new ways of approaching and presenting the GPR data will be discussed.

The ground-penetrating radar (GPR) processing was accomplished using the Reflexw software package and involved several steps including the application of gain, filtering, and a Q-filter deconvolution algorithm. The correct application of gain is critical in presenting a real geologic representation of the near-surface. Interpolation issues relating to a lack of regularly sampled data have been addressed. An initial attempt at interpolation of the coarsely gridded GPR data using 3-D Kirchoff time migration techniques has produced some promising results.

INTRODUCTION

Geophysical techniques are not new to the geotechnical, forensic or archaeological worlds, in fact, methods such as ground-penetrating radar (GPR) have been used in the exploration of a number of shallow sites since the late seventies. Near-surface explorers in the past used information garnered from the interactively acquired raw GPR images to outline areas of interest (Annan, 2003). Due to mixed success, these techniques were often abandoned.

Most geophysicists conversely have been trained to look at these raw images, namely the unprocessed and unfiltered records, as an initial product to be further manipulated. Our intention is to continually improve subsurface information with the use of processing algorithms, and to present information in unique and creative ways. With a multidisciplinary approach to archaeological site research which is becoming more the norm, it is a logical progression that more detailed representations of the subsurface will allow for a more defined picture of human history.

The University of Calgary has been involved in geophysical research at the Maax Na archaeological site in Belize for the last four years. This report will focus on the results from the GPR survey work at the plaza and the introduction of new ways of approaching and presenting the data.

Maax Na is a Maya archaeological ceremonial site situated in the Rio Bravo Conservation area of the Programme for Belize. Hundreds of intact structures within and around the site centre including temples, pyramids, stelae and caves have been excavated and mapped (King, 2004). Early excavations at the plaza have revealed layers of buried stonework each of which served as a pavement surface at a different stage of the settlement's history (Perkins, 2005).

Geologically Ma ax Na consists of a thick sequence of marine carbonates, primarily limestone (Aitken and Stewart, 2003). The composition of the near surface consists mainly of soil, humus, and limestone detritus above the thick limestone bedrock.

GPR SURVEY

GPR involves the transmission and reflection of electromagnetic energy in the earth's sub-surface. The GPR record represents a series of reflections indicating changes in the impedance of one or more electrical/magnetic properties namely, dielectric permittivity, magnetic susceptibility and electrical conductivity. The recorded signal is generally measured in nanoseconds. The signal penetration and success of GPR surveying is directly tied to the composition of the near-surface and the frequency of the GPR antenna.

Dielectric permittivity is inversely proportional to radar velocity and appears to be the most sensitive property to the saturation of the near surface. Velocity information that was collected over the four field seasons varied dramatically due to climatic conditions. Velocity values in 2002 and 2004 ranged from 0.072 - 0.106 m/ns. These velocities appear to be consistent with a more saturated near-surface environment. Rainfall was present in the area weeks before and during the field work. Conversely, velocities of 0.122 – 0.140 m/ns were acquired in the parched spring of 2003 when drought like conditions prevailed.

Figure 1 outlines a number of 2-D GPR lines that were reshot in 2004 and extended in length, and a small 3-D grid (5m x 5m) surveyed over a ceremonial pit. Deviations in the survey were due to the presence of tree roots, rocks, and surficial depressions.

The GPR equipment consisted of a Noggin® 250 and Smart Cart® system manufactured by Sensors and Software Ltd. The antenna frequency was 250 MHz. Velocities were measured by fitting hyperbolic curves to point diffractors. A trace interval of 5 cm was set for all the GPR lines with a sample rate of 0.4 ns. The 3-D surveys were acquired in a forward reverse set-up in which every second line was shot in an alternate direction for expediency. Lines were located at 50 cm intervals.

PROCESSING

Processing was achieved using the Reflexw software specifically modified for application to ground-penetrating radar (Sandmaier, 1997). The most successful processing flow to date consists of a static time shift, setting equidistant traces, application of a dewow filter, and running average spatial filter, followed by a diffraction stack migration and a bandpass filter. Figure 2 represents the before and after processing display of Line X7. A velocity value of 0.072 m/ns, measured interactively in the field by curve fitting, was used in migration.

The application of a gain function is especially critical to GPR data due to the rapid attenuation of the electromagnetic energy with depth. This is due in part to heat conversion and the fact that the unconsolidated near-surface absorbs higher frequency energy than the underlying compact rocks (Jain, 1986). Several gain functions were studied including AGC, a y-gain function in which gain values (db) are manually entered in the time(y)-direction as shown in Figure 3, and an energy decay function. The manual y-gain proved to be the most erratic as it caused a definite processing artifact at 50 ns as shown in Figure 4. To recognize the presence of "processing artifacts" from real world geology necessitates not just an understanding of the near-surface, but how these processes work. Figure 5 represents a display of Line 6 processed using an energy decay curve which proved to be the best for preserving amplitude information at depth.

Wavelet dispersion caused by frequency-dependent attenuation is prevalent in GPR data and often identified by the blurriness of the events with depth. In order to improve the deeper data, a deconvolution algorithm was implemented using an inverse-Q filter developed by (Irving and Knight, 2003). It essentially calculates the subsurface Q from the reflection GPR data. The attenuation is assumed to be of the constant Q type, where it generally varies linearly with frequency over the signal bandwidth. As shown in Figure 6, a series of Q values were tested on the data and it was determined that a Q value of 20 to 30 resulted in improved data at 100 ns and deeper. The resultant section, as featured in Figure 7, is processed with the Reflexw flow and includes a spatial averaging 2-D filter which serves to smooth the image and improve the continuity at depth.

Another avenue of research the University of Calgary is pursuing involves the problem of interpolation of the GPR grid and is best illustrated in Figure 8. A 3-D GPR survey does not represent a true 3-D in a seismic acquisition sense, but a series of 2-D lines more representative of a swath. Typically, the GPR lines are finely sampled along a particular line at 5 cm, but because every other line is shot 50 cm apart, there are huge gaps (10:1) in information between lines. Interpolation essentially attempts to fill in the spaces or holes but often a simple algorithm such as averaging is used.

We believe we can improve on this by using 3-D Kirchoff time migration. This would entail mapping all the existing data points to their correct position in space along a hyperboloid. Figure 9 outlines how this is accomplished through a series of steps or migration passes. In 3-D space, a point reflector produces a hyperbolic type of reflection surface called a hyperboloid. Kirchoff time migration simply weighs and sums all the samples that lie on the hyperboloid to produce the output sample (Bancroft, 2004). By imposing a series of migration passes that slice the entire volume vertically in one direction, followed by the orthogonal direction, the results are a true representative position of migrated energy. This methodology uses all data points and does not attempt to synthesize or average the existing information.

A comparison of the results of the initial migration in the x-direction is shown in Figures 10 and 11. The resulting energy profile from the corner of the grid is almost identical to the grid centre. It essentially represents the reconstruction of energy including noise, aliasing problems and sideswipe energy from out of plane as evidenced by the "smiles". This display serves to illustrate the problem rather than the solution however the results look intriguing and may improve with varying the aperture and offset parameters.

The idea of collecting information from “holes” in space is not confined to GPR data. Seismic companies shooting 2-D or 3-D data in land and marine environments are also besieged with the problem. Any advancements in solving the GPR problem may have important applications in the seismic world.

CONCLUSIONS

Application of gain functions to visually improve data at depth must be applied carefully.The use of a refined processing flow combined with a Q-filter improves the data dramatically at depth. We found a Q factor of 25 to be appropriate in this case.

Interpolation continues to be an important issue and warrants further work. Application of a 3-D Kirchoff migration appears to be a promising interpolation technique.Continued research will focus on acquisition parameter selection and the importance of survey direction.

FUTURE EFFORTS

The University of Calgary recently shot a small survey on a property east of Fish Creek Park over a septic field to help answer some of our questions regarding interpolation. In this particular survey, line separation was reduced to 20 cm (compared to 50 cm at Ma ax Na), with trace interval set at 5 cm. Line separation is controlled to some extent by the width of the instrument itself. The Noggin Smart-Cart is approximately 25 cm in width from wheel to wheel which makes acquiring smaller intervals cumbersome. Questions pertaining to line separation distance and spatial resolution, suitable trace intervals, and the importance of acquisition direction will be addressed. Interpolation using the full dataset and subsets of the dataset will bring to light best practices in terms of parameter selection. This research will be used to improve our acquisition parameters and how we acquire the data when we return to Belize in 2006.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the members of the CREWES Project, the dedicated team of archaeologists engaged with the Maax Na Archaeological Project namely Drs. Eleanor King of Howard University, Washington, D.C., and Leslie Shaw, and Claire Allum formerly of Bowdoin College, Brunswick, Maine, and the permit holder for the overall Programme for Belize Archaeology Project, Dr. Fred Valdez Jr., and the Belizean Institute of Archaeology.

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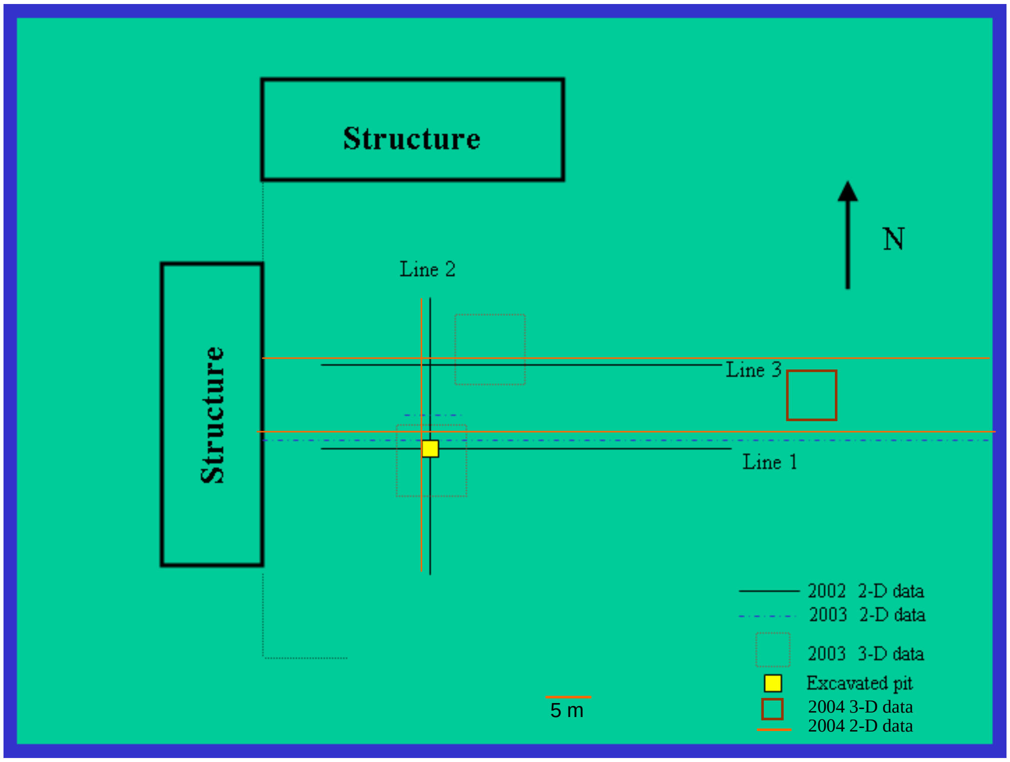

FIG. 1. Acquisition layout over the three last field seasons (2002-2004).

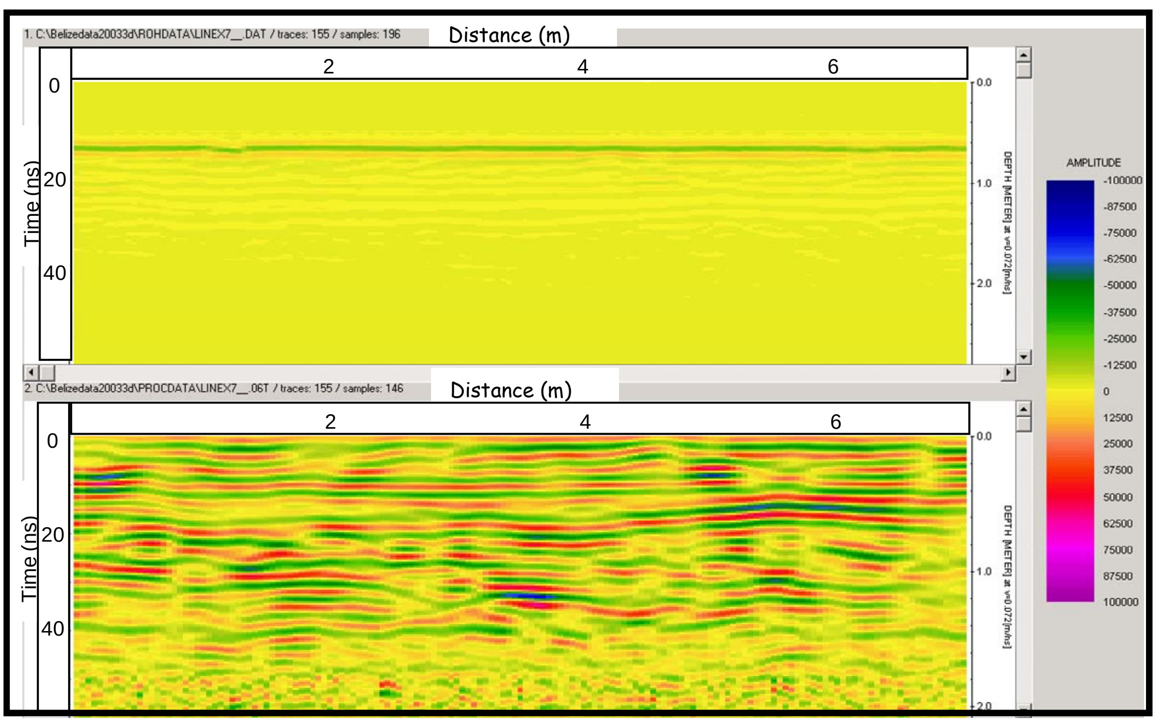

FIG. 2. Before and after image of Line X7 extracted from 3-D data using Reflexw.

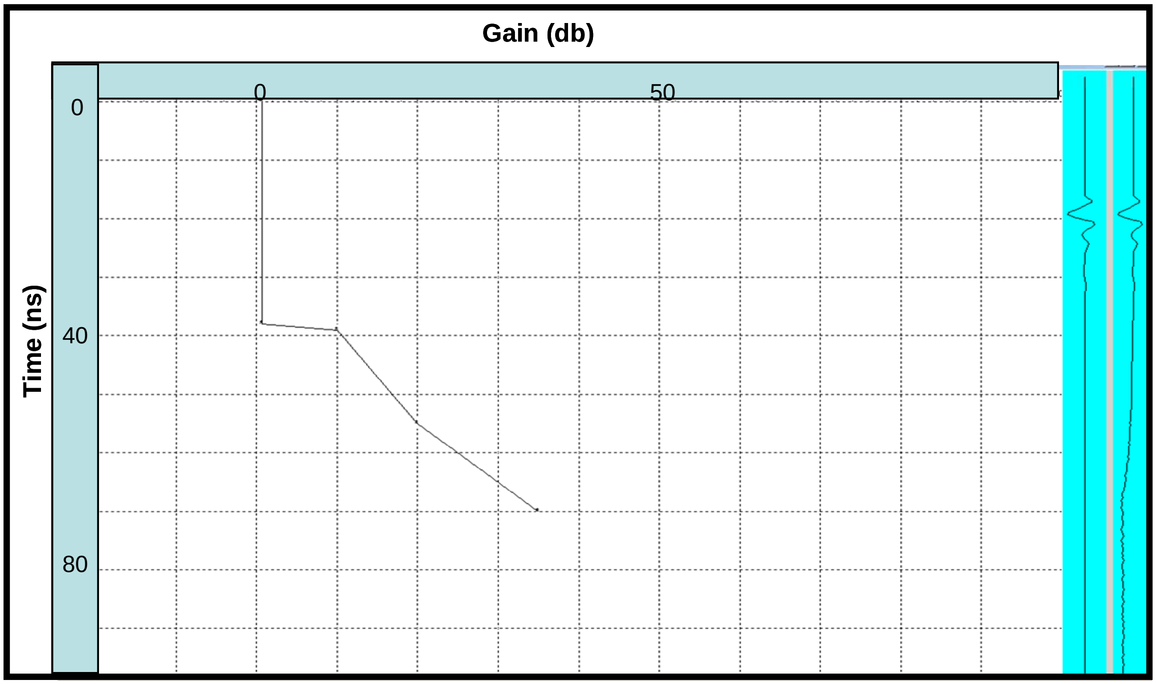

FIG. 3. Manual y-gain function applied to GPR data showing an increase with depth.

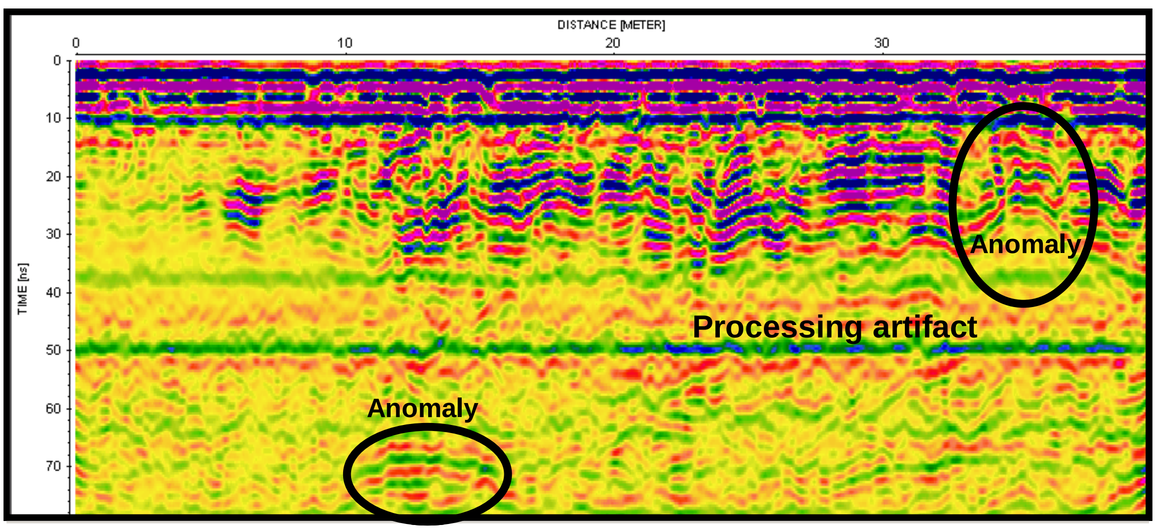

FIG. 4. 2004 GPR 2-D data (0 - 40 m of Line 6) processed using a manual gain function and showing an anomalous linear event at 50 ns.

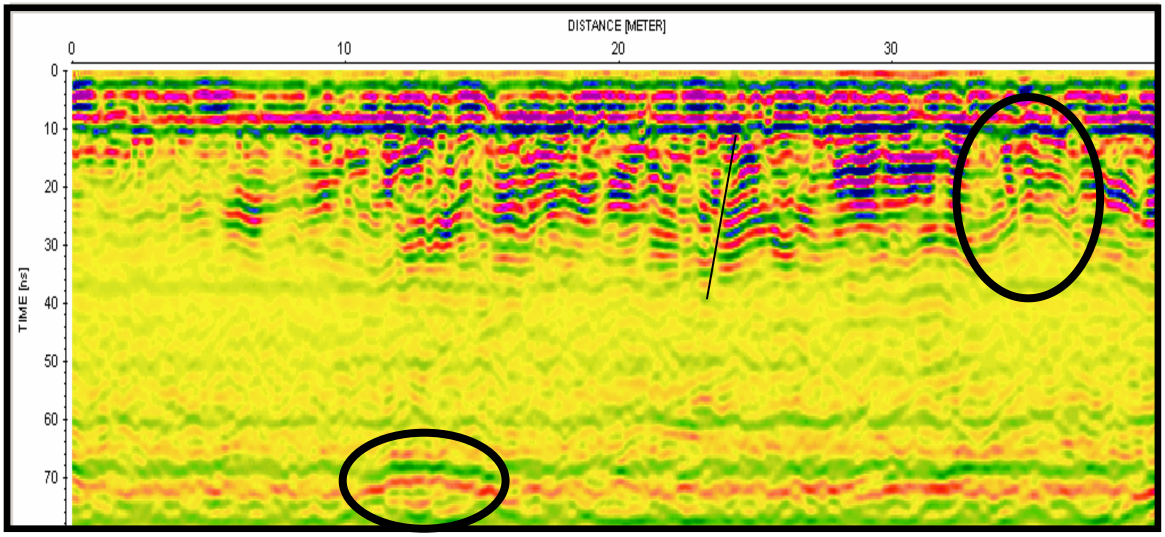

FIG. 5. 2004 GPR 2-D (0 - 40 m of Line 6) data processed correctly using an energy decay curve which does not introduce the processing artifact at 50 ns.

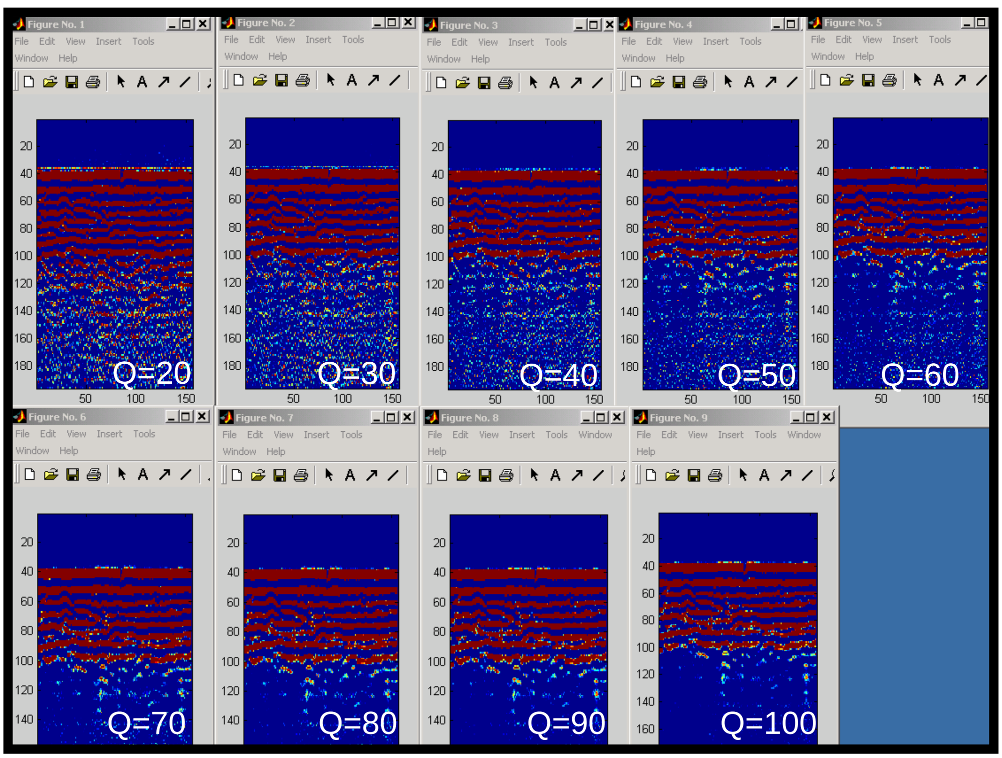

FIG. 6. The testing of various Q filters to improve data resolution at depth.

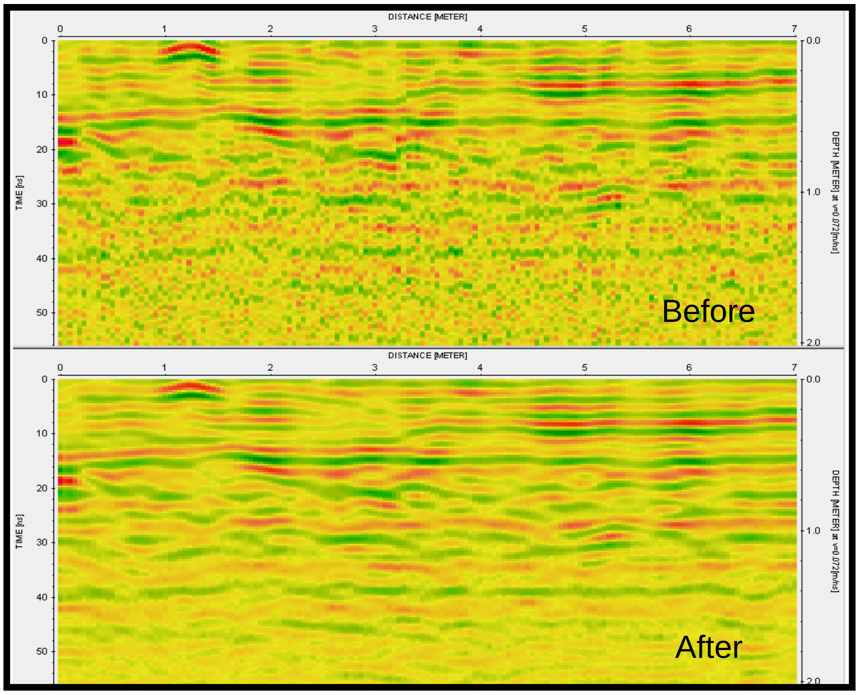

FIG. 7. Improvement in LineX0 after the application of a Q filter and a spatial filter.

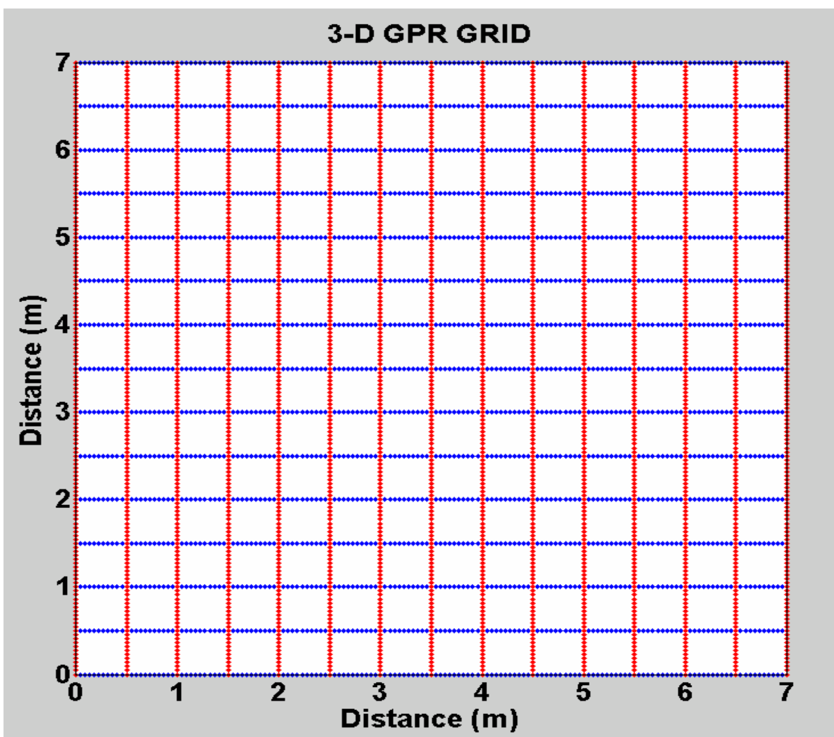

FIG. 8. Interpolation challenge due to the finely/coarsely sampled data.

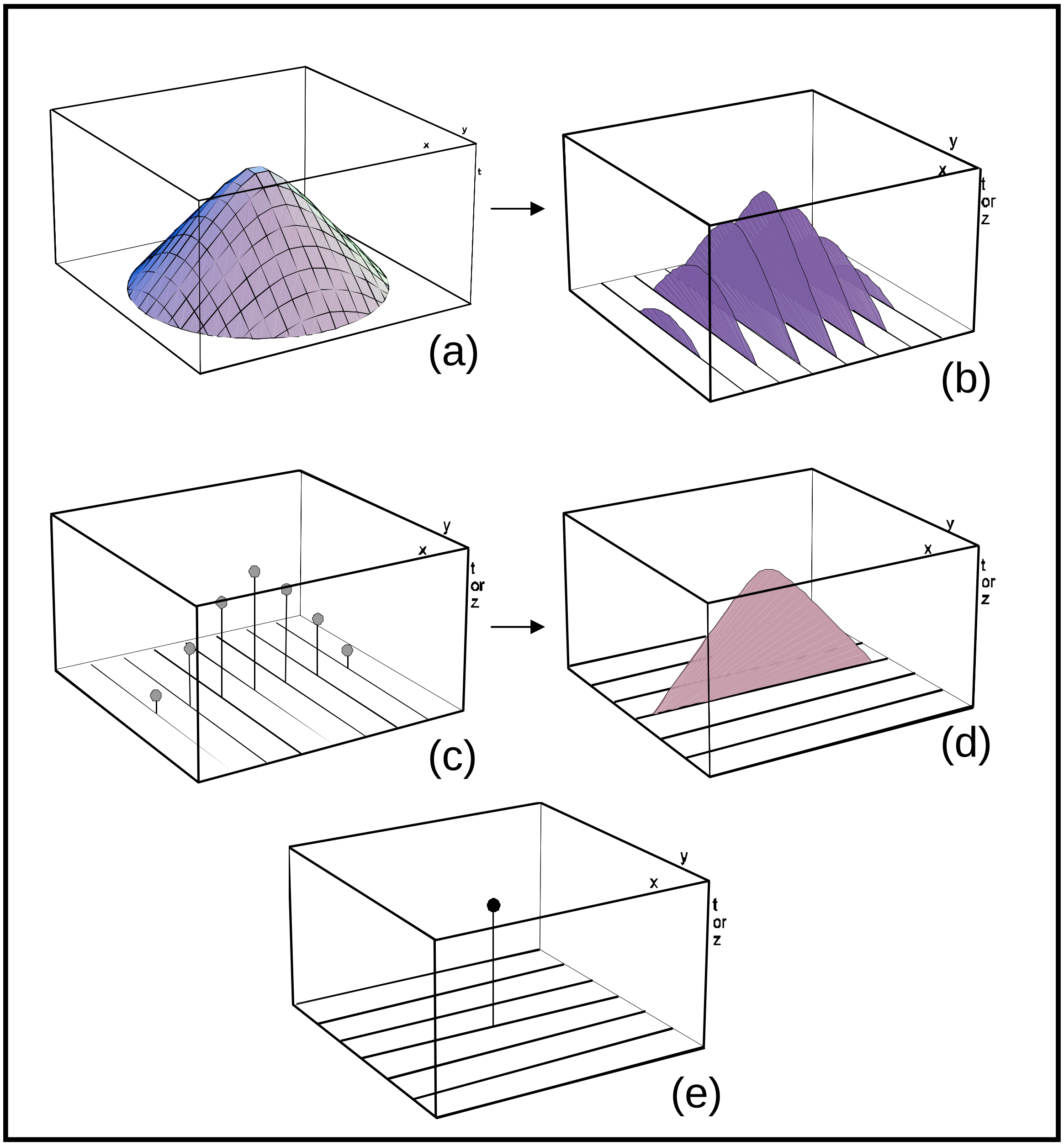

FIG. 9. Kirchoff 3-D migration interpolation: (a) A point scatterer produces a hyperboloid in 3-D space; (b) and (c) are the results of a first pass migration in one direction; a second migration pass in the orthogonal direction results in a hyperbola (d) and the final migrated point (e).

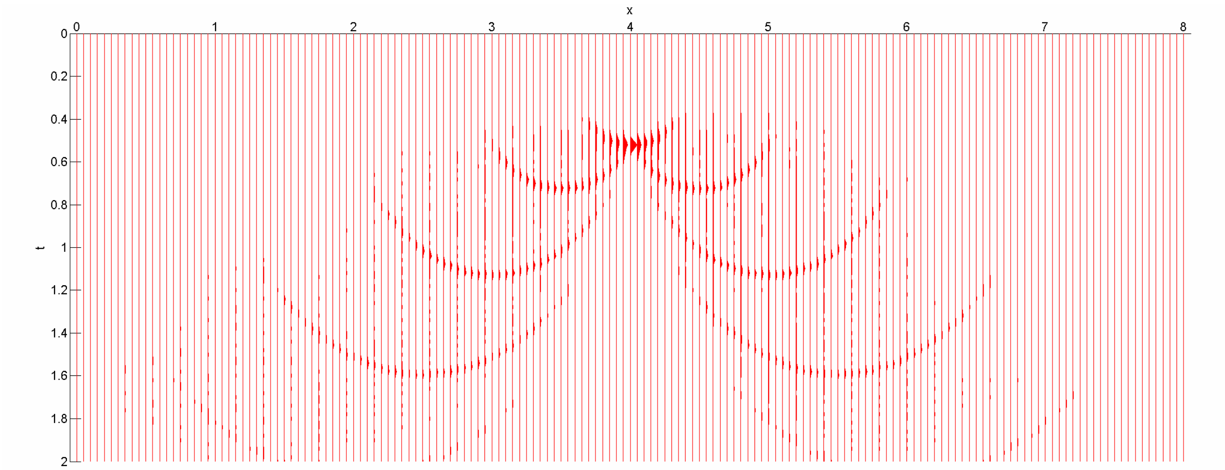

FIG. 10. Migration results from corner of grid or square.

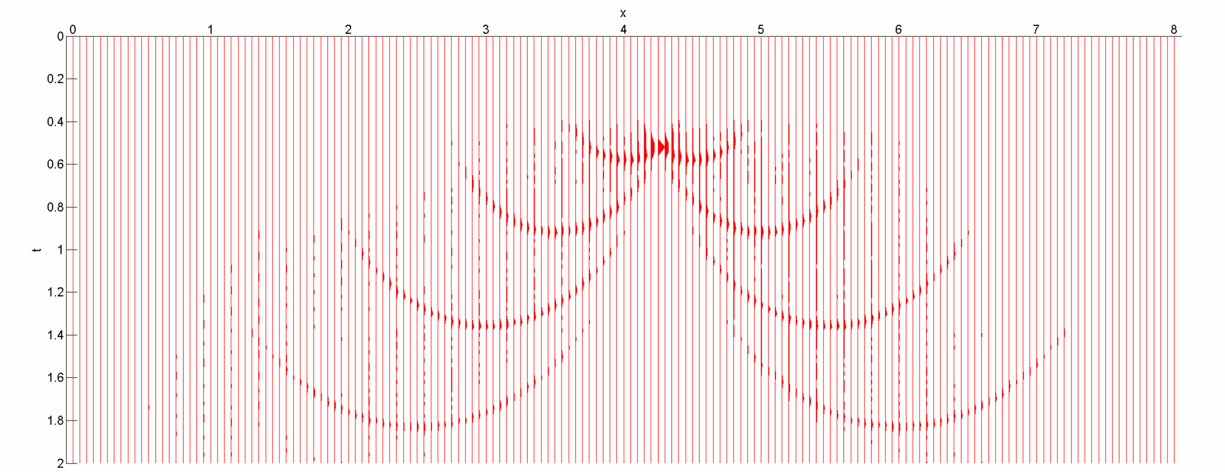

FIG. 11. Migration results from centre of grid or square.