Regularizing land acquisitions using Shot Continuation Operators: effects on amplitudes

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Abstract

Interpolation of pre-stack data is a key processing tool for the reduction of acquisition costs and it is generally needed when the wavefield sampling needs to be densified along shot and/or receivers. Irregular and sparse sampling of the wavefield in 3D surveys generates spatial aliasing. Wavefield interpolation by 3D shot continuation operator (3D SCO) can yield densely sampled data by interpolating common shot gathers (e.g., from irregular shot/receiver sampling into a regular acquisition). The tests shown here have been carried out on synthetics (the SEG/EAGE Overthrust Model), and on field data. Synthetic 3D data simulate land and OBC acquisitions; field data is part of a 3D land acquisition. For regularly sampled wavefield (e.g., Overthrust model dataset) the interpolation accuracy of 3D SCO is comparable with other methods (e.g., predictive techniques). When the sampling geometry is not regular such as for 3D land data, the 3D SCO interpolates the needed common shot gathers from the neigbouring ones. The comparison of post-stack data shows that the number of the shot points can be halved since the decimated shot gathers yield an interpolated stack-section with interesting quality.

Introduction

Interpolation of seismic data can be a useful method to reduce costs of seismic acquisitions, while improving the performances of those processing algorithms that cannot cope with coarsely sampled or aliased data. Nowadays, 3D seismic surveys usually yield irregularly sampled data that need regularization. Besides, different approaches must be used to plan cost-effective acquisitions in different environments (e.g., land surveys or Ocean Bottom Cable acquisitions).

The 3D shot continuation operator (3D SCO)

The 3D SCO is a pre-stack operator developed to estimate a common shot gather (CSG) from neighboring CSGs for 3D acquisition geometries; the estimation is performed according to a specified velocity model. 3D SCO can be specialized in any domain (e.g., offset and azimuth) and it can be viewed as a generalization of the well-known DMO (or continuation to zero offset). The 3D shot continuation operator can be basically described as the chain of two steps: the migration of one common shot gather, say S_1, and then the demigration to a displaced common shot gather S_2. It is important to stress that the Kirchhoff-type integral implementation permits to handle irregular sampling, usually encountered in real data (Spagnolini, 1996; Bagaini, 1996). The 3D SCO is space and time varying. However, its aperture is smaller than calculating explicitly the two steps of migration and demigration: 3D SCO is computationally cheaper.

Similarly to DMO, the kinematics of 3D SCO can be (logically and practically) divided into two parts:

1. NMO correction of the Common Shot Gathers with a known velocity model;
2. Structural shot continuation (also referred to as SMO – Shot Moveout), that depends on geometrical parameters only and it is <u>independent on velocity</u>.

The 3D SMO is space-variant but <u>time-invariant</u> operator, this latter property greatly reduces the computational cost of the operator when applied to large dataset. In addition, the equivalence 3D SCO = NMO + 3D SMO allows to handle variable velocity model similarly to standard DMO processing.

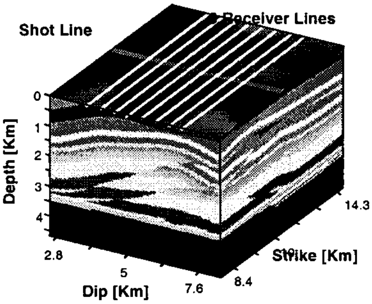
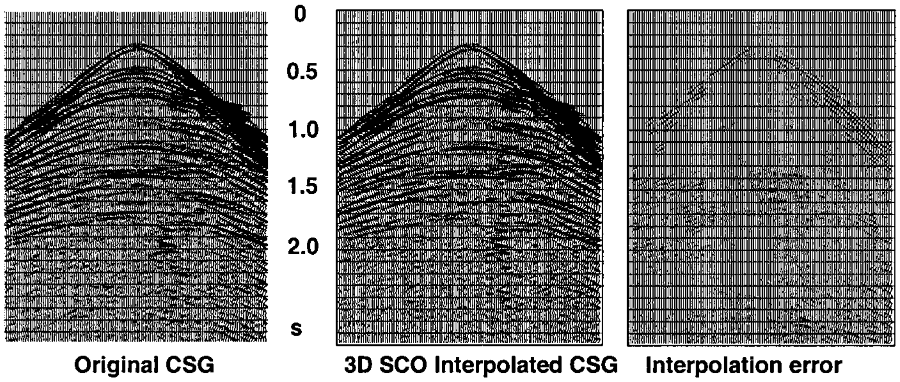


Figure 1. SEG/EAGE Overthrust model (selected area).



Original CSG **3D SCO Interpolated CSG** **Interpolation error**

Figure 2. The CSG (S_{DIP}=4800 m) is shown. **Left:** the original CSG (missing in the decimated dataset). **Middle:** the interpolated CSG by using 3D SCO. **Right:** the interpolation error (residual).

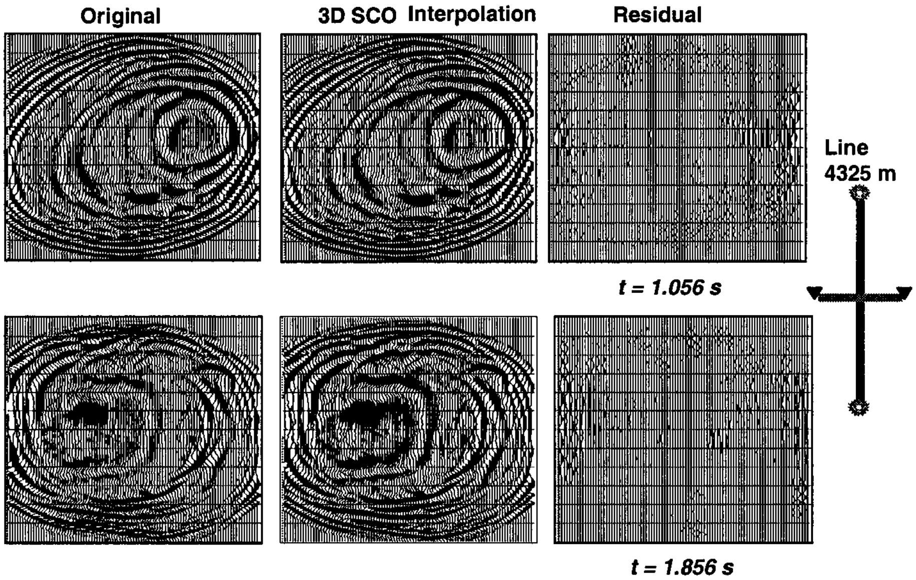


Figure 3. Time slices of one cross-spread SEG/EAGE Overthrust model (t=1.856s: deep events under the faults).

Overthrust 3d model: A4 “Patch” acquisition

The SEG-EAGE Overthrust 3D Model represents a useful benchmarking tool for 3D processing algorithms. The selected dataset, called “A-4 Patch”, simulates a 3D acquisition, with a single line of shooting laid down over the faults (called "Dip line"). The shot spacing is 50 m. 8 receiver lines (line spacing: 300 m) are orthogonal to the shot line; the receivers distance is 50 m (Figure 1). The choice of this 3D dataset allows the validation of the 3D SCO algorithm with 3D data that show a complete azimuthal range, and the comparison of interpolation results obtained with a completely different approach. Examples reported next are selected from the faulted zone (detailed view of the velocity model is in Figure 1) of the Overthrust Model. The presence of strong dipping events (i.e., aliased data) and complex tectonics propose this model as a severe task for interpolation techniques when the aim is that of preserving amplitudes.

Example 1 (3D Overthrust Model): shot densification for land survey

3D SCO will be first used to double the shot density. Shot spacing of the original dataset is 50 m: every other shot has been taken out (1:2 shot decimation), then the removed shots have been interpolated. Severe aliasing problems can be shown from a crossline view of one cross-spread of the decimated dataset and/or its *f-k* spectrum. Therefore, the interpolation will have to de-alias the dataset. 3D SCO processing is shot oriented; here we have chosen to estimate each missing common shot gather starting from the two nearest common shot gathers, as this choice leads to a lower sensitivity to the velocity model

(Spagnolini, 1995). 3D SCO interpolation can be hardly distinguished from the original reference: the best way to understand 3D SCO potentialities is to show (displayed with the same amplitude scale), the interpolated result along with interpolation error (Original CGS minus Interpolated CSG). The low amplitudes of the residual (figure 2) illustrate how the interpolation task has been correctly achieved (result is almost correct both kinematically and dynamically). The position of the selected shot (4800 m) is directly over the most complex faulted zone of the model with strong dipping events (figure 1). Another way to appreciate the quality of 3D SCO interpolation is to show time slices for the same cross-spread at different times: the residuals (negligibly small for practical purposes with both methods) demonstrate how wavefield reconstruction is almost correct both for shallow and deeper times (figure 3).

Interpolation of shots (from $\Delta S=100$ m to $\Delta S=50$ m) has been compared in Mazzucchelli et al. (1998) with a completely different technique that exploits the spatial predictability of the wavefield as parameterized by one (or more) plane events (Spitz, 1991). In fact, the algorithm based on prediction error filtering (PEF) is model independent and it has a simple form only when traces are located on a regular grid (in this case, interpolation problem can be solved without any attempt of explicitly calculating true dips of seismic events). Comparisons between the two methods show that energy of the error is lower for 3D SCO interpolation than for PEF interpolation even if the two different techniques have a similar computational cost ($\mathrm{CPU_{SCO}} \sim 3\mathrm{CPU_{PEF}}$) [see Mazzucchelli et al. (1998) for more details].

Example 2 (3D Overthrust Model): receiver line densification for OBC acquisition

The same A4 "Patch" dataset can be interpreted as part of an Ocean Bottom Cable (OBC) marine acquisition. In an OBC-type survey, the reduction of costs requires the reduction (and then the interpolation) of receiver lines (which are laid down in deep water). Therefore, we performed the interpolation of A4 dataset receiver lines, halving their original space (from 300 m to 150 m). Due to large intervals between receiver lines, these data show a severe aliasing. No direct comparison with original data can be made for this example: the best way to evaluate the quality of the interpolation is to show time slices (figure 4) selected from three near cross-spreads (e.g. the interpolated one, and the two neighboring ones at a distance of 150 m). Visual inspection assures the correctness of 3D SCO interpolation for this example: results are encouraging even in presence of complex tectonics and of aliased events.

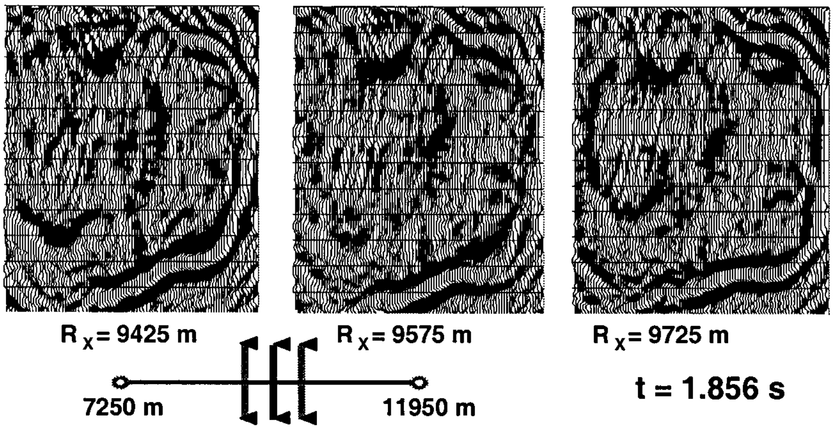
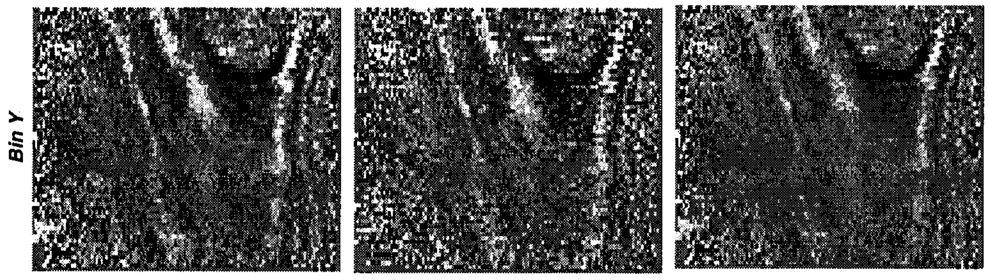


Figure 4. Three time slices from near receiver lines cross-spreads (time 1.856 s).

Example 3 (land data): shot interpolation/regularization

Shots of 3D land data have been decimated 1:2 similarly to Overthrust dataset (Example 1) in order to evaluate the feasibility to reduce the cost of 3D land acquisition. The purpose is to evaluate the quality of the post-stack imaging obtained by using the full survey or the survey that contains half the number of shot points (similarly to Example 1 the decimated shot gathers have been interpolated by using 3D SCO). For such an irregularly spaced sources/receivers a suitable pre-processing has been optimized in order to reduce the sensitivity of 3D SCO to velocity model and statics. Figure 5 shows the time slice (t=1.6s) of stack section obtained from the original data (360 shot points), from 1:2 shot decimated data (180 shot points), and from the decimated data after interpolation. Finally figure 6 shows the stack amplitudes before and after the decimation/interpolation. We can conclude that stack section degradation is negligible when the number of shot points is halved and the missing shot gathers are interpolated by using the 3D SCO. Better results could be obtained by optimizing shot decimation strategy (here simply one every other shot has been removed from the dataset).



original data **1:2 shot decimated data** **1:2 shot decimation + 3D SCO interpolation**

Figure 5. Stack section of 3D land data (time slice t=1.6s, bin size 40×40m) from the overall survey (left, max. coverage 90), from 1:2 shot decimated data (center, max coverage 53), from 3D SCO interpolation of 1:2 shot decimated data (right).

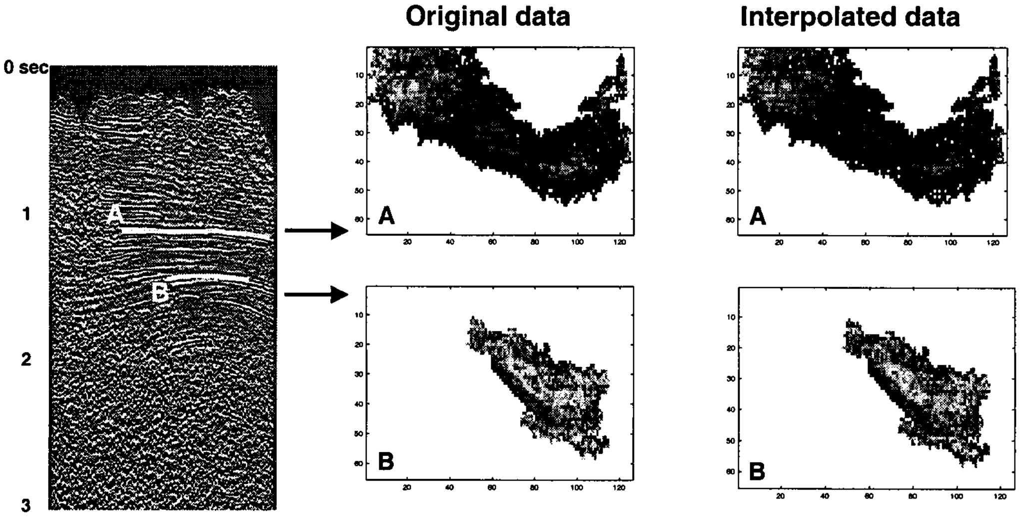


Figure 6. Amplitude variations from original data and from interpolated data (target events labelled as A and B are indicated on stack section).

Conclusions

The examples shown here demonstrate the potentialities of 3D SCO as an interpolation technique: residuals show little energy, even if data are coarse sampled and show aliasing problems. Our testing demonstrated that 3D SCO interpolation is reasonable (i.e., interpolation error is below 10%) even if the errors in the velocity model is approx. 5%-10%. For land acquisition the 3D SCO allows the reduction of the number of shot points thus leaving the same quality of stack sections. 3D SCO is feasible even for OBC-like geometries without any data re-ordering (3D SCO always operates in Common Shot domain). Thus, because of its ability to handle irregularly sampled data, 3D SCO demonstrates to be a very interesting tool to interpolate 3D seismic data. Similarly to any wave-equation based processing, a careful pre-processing can improve interpolation results as coherent noise and statics can degrade their performances.

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