Nonlinear Interpolation of Geometrically Constructed End-ons GPR gathers

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Abstract

This work presents a feasible methodology in which we assemble a limited number of collinear fixed-offset profiles into sparse end-on gathers followed by trace interpolation. We use here an adaptive prediction-error filtering and a regularized non-stationary regression to interpolate data gaps on sparse end-on gathers. The interpolation methodology is first tested on a decimated, otherwise alias-free end-on gather. We next use the same technique on heavily aliased end-on gathers assembled from 7 collinear fixed-offset profiles. . We also show that different interpolated gathers obtained through that procedure remain independent of each other.

Introduction

The RES (radio-echo sounding) and the GPR (ground penetrating radar) have been extensively used for surface-based cryospheric studies for several decades (Walford, 1964). Applications have included ice mass thickness, basal conditions, liquid water content, and ice internal structure. Apart from the basement or other odd causes such as lakes, reflections are usually confined to within the firn layer, an irregularly stratified, inhomogeneous and anisotropic material, a metamorphic product of snowfall.

As important as ice stratigraphy is the knowledge of medium velocity variations in a given area. This is usually done with a limited number of CMP gathers yielding 1-D velocity models, providing an estimate of the RMS velocity above a given reflector, which can be inverted to produce the interval velocities, i.e., the velocity between reflectors, (Yilmaz, 2001). Of course it is much better to have a 2-D or even a 3-D velocity model, a practical challenge even when resorting to a multichannel equipment, in practice restricted to a few channels. With a single-channel GPR that task may prove to be impractical in most situations.

Many workers have been using increasingly sophisticated acquisition and processing techniques borrowed from seismics to the GPR (e.g. Fisher et al., 1992; Pipan et al., 1999, 2005; Grasmueck et al., 2005). In the most successful cases GPR data is acquired using the multi-offset (MOff) with a result of improving spatial resolution over a subsurface with complex reflectivity. The main issue here is that data should be acquired according to full-resolution criterion (Grasmueck et al., 2005) to mitigate spatial aliasing. With the current GPR technology that criterion is very difficult to meet in practice. Although image quality is greatly improved by application of MOff it remains open to dispute whether improvement justifies the greatly increased acquisition effort.

This work presents a feasible way to assemble a limited number of colinear fixed-offset profiles into sparse end-on gathers followed by trace interpolation. This is a mandatory step due to the unavoidable heavily aliased characteristics of the assembled multioffset data. In this manner fieldwork and processing are intertwined in the present methodology. The objective is to maximize the accuracy of the measured velocity distribution and thus of the final GPR image with the resources of pre-stack processing.

Fieldwork

Our dataset was acquired in the interior of offset and multi-offset strategies. For most fixed-offset profiles we have used an acquisition train made out of four sledges, two for the antennae, one for the rover GPS and one for the console and batteries, was dragged by a man assuring a spatial sampling less than one decimeter, as seen in Figure 1.

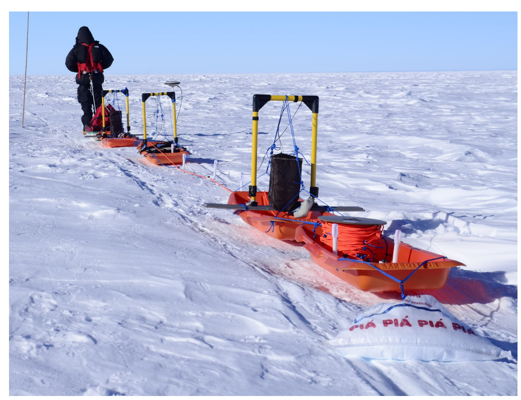

*Figure 1.*A view of the acquisition train

The antennae were mounted on individual sledges of the acquisition train. The GPR transmitting and receiving antennae were mounted on the second and fourth sledges, respectively. The GPS antenna was mounted on the third sledge, next to and at a fixed distance from the GPR transmitting antenna. The GPR console was kept on the first sledge while the GPS console was mounted on the third sledge, together with its antenna. The fiber optics were kept clear from ground by several small plastic catamarans, completing the man-hauled acquisition train.

Location was obtained by post-processed differential GPS with a local base. The local base in turn was referenced by another base set on a rocky outcrop by our colleagues at Union Glacier, some 500 km due North of our camp.

In this paper we are going to concentrate on two types of end-on (EO) data along a single 500m profile; one is a dense spread while the other is a lot sparser, geometrically constructed from assembling seven collinear fixed-offset profiles. The dense spread (dEO) has two orders of magnitude more traces than the sparse spreads (sEO).

The data processing flow consisted of extensive and laborious trace edition and geometry, time-zero correction, bandpass-filter, gain stages, interpolation and velocity estimation via CMP semblance analysis. We focus here only in the last two processing stages. The sEO is a result of assembling 7 distinct and colinear fixed-offset profiles. That is a known field strategy to efficiently obtain a variable offset profile from many independent fixed-offset profiles (Bradford et alli, 2009, Baradello et al, 2005). We kindly suggest the reader to resort to the literature for details of that field strategy.

Results

We use interpolation to fill gaps in our sEO profiles. Here we employ an approach that deals with the spectrum of the recorded data estimated by antialiasing prediction-error filters (PEFs) of low-frequency data. Those PEFs can interpolate the high frequencies beyond aliasing. As we assume stationarity for the real data dividing it into sufficient small patches. The PEFs are implemented in t-x (time-space) domain, less likely to create spurious events in the presence of noise, (Abma and Kabir, 2005).

PEF coefficients are estimated via a least-squares problem that reduces to a linear inversion. Therefore data interpolation can be performed as an inverse problem so a PEF can be used to fill in missing data in a two-step approach. Firstly a PEF is estimated by minimizing the output of a convolution of the known data with an unknown PEF. Secondly the missing data are estimated by minimizing the convolution of the recently calculated PEF with the unknown model, constrained by the known data. Details of that methodology are beyond the reach of this paper, the reader can find them in (Fomel, 2009) and references therein

We cut a centrally located 100m long dEO to 31m to reduce the total number of traces from 1062 to 292. In this manner the maximum offset to agree with the one of the sEOs we discuss below. We then produce a heavily aliased EO gather by muting 80% of its traces, the artificial gaps becoming more frequent and wider with increasing offset. We use the use existing traces to directly estimate adaptive PEF coefficients simultaneously in time-space in a RNA approach to interpolate the muted data. Figure 2 shows that the adaptive PEFs interpolation retrieved 80% of the decimated traces, removing spatial aliasing with minimal noise, mostly restricted to the larger offsets.

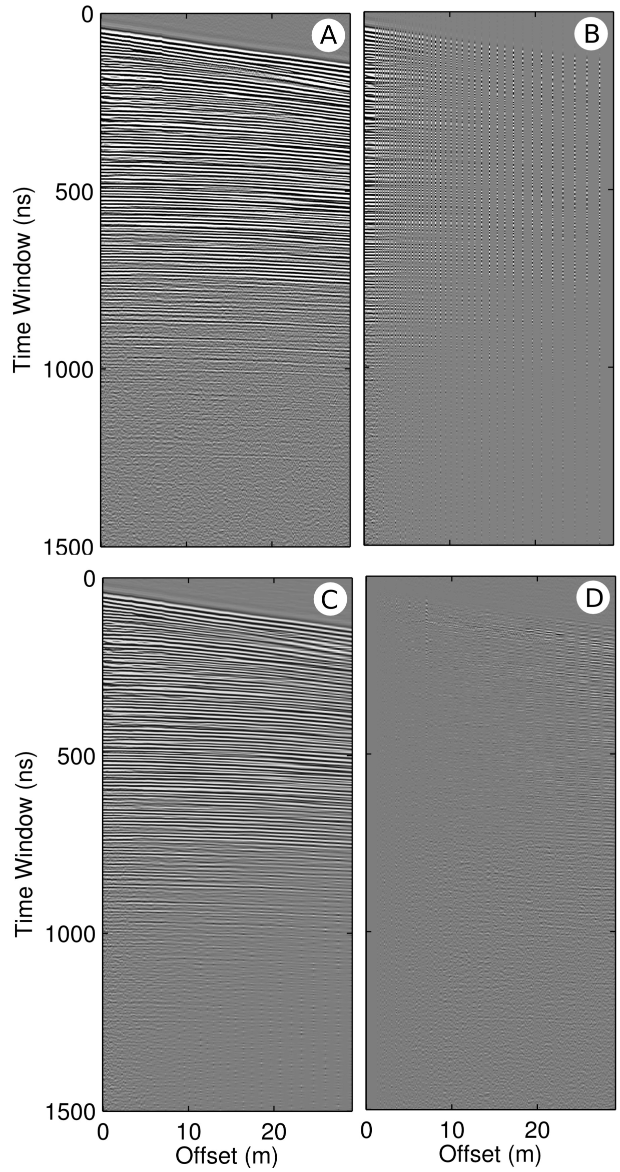

Figure 2. Panel A shows the original dEO without alias with 292 traces. Panel B shows the aliased gather with 80% of its traces muted with highly non-uniform spatial spacing between groups of remaining traces. Panel C gives the trace interpolation of the aliased data. Panel D gives the difference between Panels A and C.

We move on to interpolate the heavily aliased sEOs described above, interpolating traces, paving the way to further steps in pre-stack data processing. We pick a particular sEO with a source point close to the corresponding one of the dEO. That aliased gather is just 7 fold with offsets within the interval 1.9, …,31m. We use the PEF produced by our dEO as a first estimate for the sEO PEF in the process of interpolating traces. For that we firstly fill in the gaps of the sEO with null traces up to end up with the same 292 traces of the dEO and then we input the latter final PEF. Figure 3 shows the interpolation succeeded in the sense that the interpolated section looks compatible with the dEO shown in Figure 2 with some imperfections. One is that useful data stops short of 10^3ns followed by conspicuous numerical artifacts at the original trace positions.

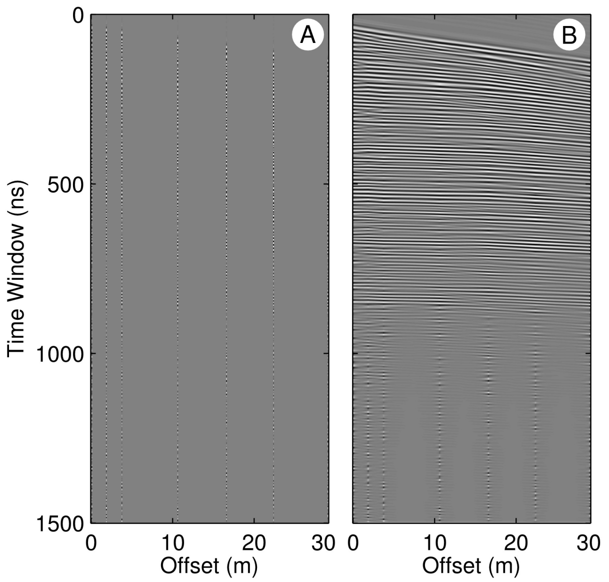

Figure 3. The result of trace interpolation on a sparse common source gather. Panel A shows the interpolation on the gaps between the 7 traces of the original sEO. The position of the original traces is numbered at the bottom of Panel A. Panel B shows the difference between the interpolated sEO and the dEO with its original 292 traces.

Figure 4 compares the semblance spectra and the velocity models of the dEO and the sEO. We estimate the two velocity models using the semblance spectra with automatic velocity picking. The two interpolated sEOs are not only dissimilar but also produce conspicuously distinct velocity models. We see that notwithstanding the use of a common first guess for the sEO and the dEO gathers, the interpolation results sections retain a high degree of independence between them.

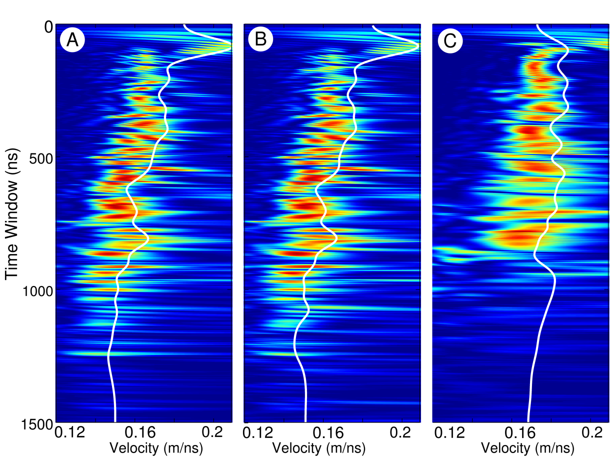

Figure 4. Semblance analysis and picked velocity models for the full and interpolated dEO (panels A and B) and the interpolated sEO (panel C).

Conclusions

This work shows the interpolation done on a dataset obtained in the interior of Antarctica using geometrically constructed EO from assembled collinear fixed-offset GPR profiles. We have successfully reconstructed each sparse and heavily aliased EO gather with minimal noise, mostly restricted to larger offsets. We have dealt with the sparsity of our assembled gathers by imposing the PEF from an alias-free dense end-on as a first estimate in the process of filling in the gaps with interpolated traces allowing to reach beyond alias.

Acknowledgments

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