Wrinkles in time: removing surface effects from 3D source ensembles

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Summary

Raypath interferometry can be used to apply near-surface corrections to 3D data, but the required computer resources can be a challenge. We propose a new approach to using this method in 3D, in which we first interferometrically correct individual single-fold source ensembles for effects at the receiver locations. The second stage of this approach would then consist of removing surface effects at the source positions. While not as robust as a full 3D multi-fold scheme, this approach would accommodate significantly larger 3D data sets.

Theory / Method

Correcting seismic data for the effects of an irregular and inhomogeneous near-surface layer remains one of the more challenging processing steps in the imaging of these data. Fortunately, in most cases, simplifying assumptions can be made which allow data to be corrected through the application of time shifts to the raw traces of the data set. However, in exploration areas where high near-surface velocities compromise the usual surface-consistency assumption, or where non-stationary (time-varying) corrections are required, such as with S-wave or converted wave data (Cova,et al, 2015, 2017), a more general approach must be taken. The raypath interferometry method was developed to accommodate these more problematic data sets (Henley, 2012). The key assumptions upon which this technique is based are the following: 1). seismic events traversing the same raypath segment through the near-surface layer will share a common correction; and 2). seismic events recorded at the surface may consist of more than one discrete arrival (an arrival distribution), due to scattering processes in the near-surface. The raypath consistency assumption requires seismic data to be transformed from the X-T domain to a ray-parameter domain for processing, while the arrival distribution assumption leads to the estimation and removal of 'surface functions' using interferometric techniques. However, when near-surface velocities are low, raypath-consistency reduces to surface-consistency, since near-surface raypath segments are nearly vertical and coincident; and when the near-surface layer is relatively homogeneous, the surface functions reduce to single spikes, hence justifying the conventional 'statics' approach of correction by simple time-shifting, rather than deconvolution.

Raypath interferometry has been successfully applied to several 2D seismic data sets, both for P-waves and for PS (converted) waves (Henley, 2012, 2014, Cova et al, 2015, 2017). In every case, raypath interferometry provided results that were equal or superior to results obtained by conventional statics correction, particularly for converted wave data (Cova et al, 2015).

More recently, raypath interferometry methods were extended to the 3D domain, where encouraging results were obtained on a relatively small 3D 3C data set (Henley, 2016, 2017). The difficulties encountered in the extension of the technique were two-fold. The first obstacle was reconciling the polar coordinates (surface location, raypath angle, source-receiver azimuth) of the desired 'surface functions' with the Cartesian acquisition coordinates of the raw data. For a multi-fold 3D data set, the geometric trace attributes which seemed to offer the best possibilities for constructing subset ensembles of traces relatively compatible with surface function coordinate space were: source location index, source-receiver offset, and source-receiver azimuth. We were able to construct reasonably distributed trace ensembles with coordinates of azimuth, offset, and source location in which the seismic events were coherent enough to address the next step in processing: transformation to the ray-parameter domain (Henley, 2016).

The second issue encountered in 3D raypath interferometry was how to transform to the ray-parameter domain using a 2D transform. First, we assume that the raw seismic traces can be binned by azimuth, offset, and source location to *approximately* lie in a 2D vertical plane, where trace population and distribution within these bins controls the choice of bin dimensions. Our preferred transform was the radial trace (RT) transform, because of its high-fidelity inversion and relatively compact storage requirements, but the version available worked properly only for data whose X-T geometry was *strictly* 2D. Hence, we chose the Tau-P transform, which correctly handles geometry, even for data which are *not* strictly 2D. Unfortunately, in order to be able to sufficiently preserve input data resolution, the storage requirements for the forward transform, in the existing implementation, are as much as two orders of magnitude greater than those for the input ensemble (Henley, 2017).

Ultimately, we successfully applied raypath interferometry to our small 3D 3C data set (a million traces), but were forced to conclude that the method was impractically tedious, unless our data compellingly require non-stationary corrections, (e.g. converted wave data).

More recently, we considered whether it would be possible to modify our techniques for application to a much larger 3D data set. We began to explore how we could modify or simplify our approach from the ‘full raypath interferometry’ to some simpler version. An obvious direction was to process a large 3D data set in ‘patches’ to be merged later; and a logical starting point was to process each individual source gather in the survey as if it were a stand-alone single-fold 3D survey. If we could remove the ‘time wrinkles’ in coherent events due to near-surface conditions at receivers within each source gather, then the corrected source ensembles could be used in some undetermined fashion to derive inter-source corrections to complete the process.

While this second step has not yet been determined or implemented, we have explored the first step by attempting the receiver-side correction of individual 3D source gathers. Here, we demonstrate doing the corrections in three different ways: in 2D, using X-T domain interferometry on 2D sub-ensembles; in 3D, using X-T interferometry on 3D trace ensembles; and in 3D using raypath interferometry on 3D ray-parameter trace ensembles.

The data and its processing

The data set on which we tested our new approach was a single 3D source gather consisting of 32 receiver lines, with over 6700 traces of difficult data, acquired by Devon Energy. Our goal was to apply each of the three different interferometry approaches, and to compare the output for improved event continuity and coherence with the original raw data. Since, in the context of a 3D source gather, the receiver line ensemble is the best spatially sampled sub-group of traces, we chose to compare each of our approaches in the receiver line domain, even when the actual ensemble in which the data were processed was typically an azimuth/offset gather.

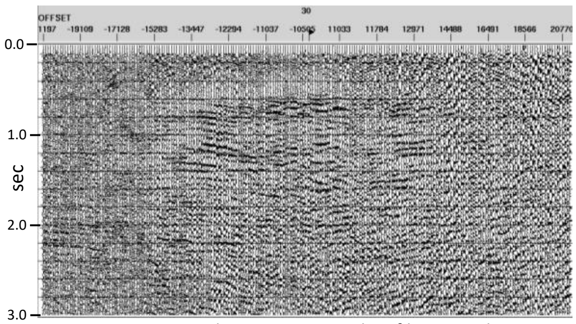
Because of significant coherent surface wave noise on this source ensemble, a radial trace fan filter was applied to the entire source ensemble before any further processing (Henley, 2003).

The three ‘time-wrinkle’ reduction processes:

- 2D—interferometry on flattened receiver line ensembles—1D wavefield estimation.
- 3D—interferometry on flattened azimuth/offset ensembles—2D wavefield estimation.
- 3D—raypath interferometry on flattened azimuth/Tau-P ensembles—2D wavefield estimation.

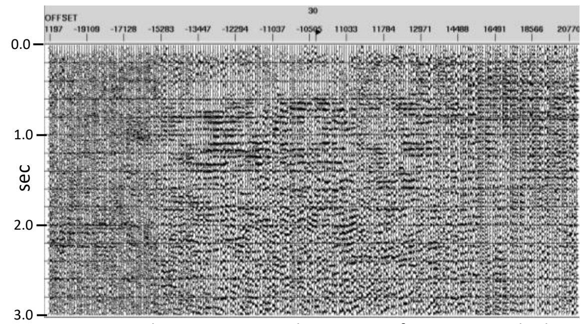
Results

We show here the results for receiver line 30 of our test source ensemble, for which the source position offset is relatively large. Figure 1 shows this receiver line after coherent noise attenuation, and removal of linear moveout to flatten coherent events. After 2D interferometry, the ensemble appears as in Figure 2, with significantly improved event and coherence.



Receiver line 30—LMO and RT filtering only

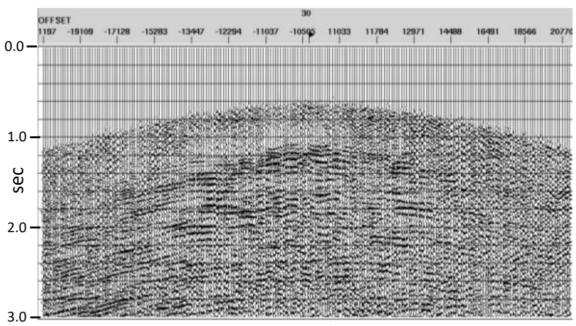
FIG. 1. Raw ensemble, receiver line 30, LMO



Receiver line 30—LMO and AGC—interferometry applied

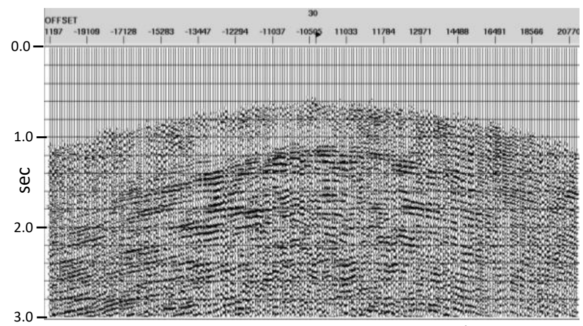
FIG. 2. 2D interferometry applied.

When we sort the source ensemble into azimuth/offset bins and apply 3D interferometry, we see the following: Figure 3 shows the raw receiver line ensemble 30, but with no LMO, while Figure 4 shows this receiver line ensemble after 3D interferometry.



Receiver line 30—RT filtered only

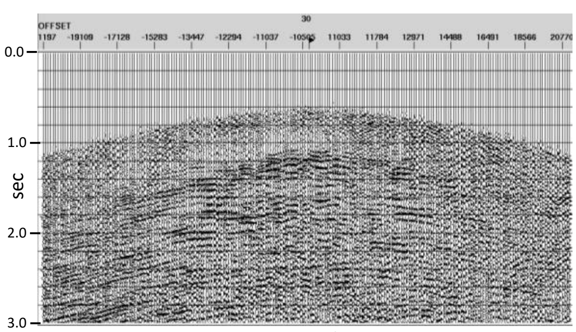
FIG. 3. Raw receiver line ensemble 30, no LMO



Receiver line 30—3D interferometry in the azimuth/R-line domain

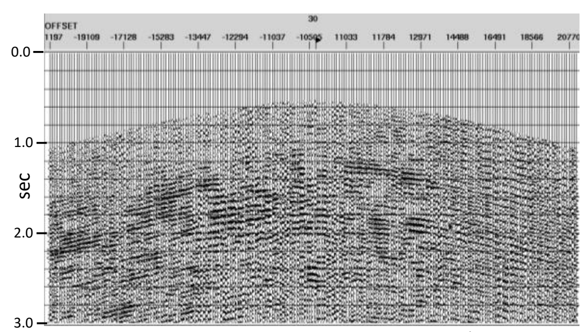
FIG. 4. 3D interferometry in azimuth/offset

We further transform the azimuth/offset ensembles to the Tau-P ray-parameter domain prior to applying interferometry, the raypath approach. Figure 5 shows the raw receiver line ensemble 30, while Figure 6 is the same ensemble after 3D raypath interferometry applied in the azimuth/offset domain.



Receiver line 30—RT filtered only

FIG. 5. Raw receiver line ensemble 30, no LMO



Receiver line 30—3D interferometry in the Tau-P azimuth/offset domain

FIG. 6. 3D raypath interferometry in azimuth/offset

Discussion

Each of the three interferometric processes demonstrated above exhibits improvement in event coherence. The 2D result, however, leaves the corrections uncorrelated between receiver lines, while the

3D results do not. In 3D, it is difficult to decide which result is best, since the corrections are applied in vertical time in the first case and along raypaths in the second. For these P-wave data, however, it is unlikely that the raypath approach is needed. Coherent event disturbances, or ‘wrinkles in time’, are reduced in all cases, but a 3D approach is likely the best to apply before finding and applying corrections between source gathers in the next step of the surface correction process.

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