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OPTIMIZING RESOURCES

3D or not 3D, that is the question: raypath interferometry in 3D processing

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Summary

This investigation explores a way of extending the surface-correction technique, Raypath interferometry, from 2D to 3D. Problems discussed include dimensions for addressing a 3D data volume, creating a 3D surface function, and transforming 3D data to and from a raypath-parameter domain. Results are preliminary but promising.

Introduction

The technique called raypath interferometry was introduced several years ago as a way to correct seismic data for the distorting effects of an irregular surface layer, particularly in areas where the characteristics of this layer violate the assumptions enabling the estimation and application of 'static corrections', the conventional approach for correcting data (Henley, 2012a). Rather than abandon these simple assumptions, we have generalized them to make them applicable for most conceivable surface layers, including those for which the simple assumptions also work.

The most important of these assumptions is that of 'surface-consistency' in which all reflection energy leaving or arriving at a particular surface location is assumed to share the same near-vertical raypath segment. This assumption and the related constraint of 'stationarity' is what allows the estimation of a single time delay associated with a reflection arrival travelling through the surface layer at a particular location (by averaging over several raypaths sharing that surface location) and the correction of seismic data by applying a single time shift, equal to the estimated delay, to each seismic trace sharing that surface location. Surface-consistency requires that the average velocity of the surface layer be much less than the velocity of the underlying layer, in order for Snell's Law to ensure near-vertical raypaths in the surface layer. We generalize the concept of surface-consistency to 'raypath-consistency', in which the near-surface time delays for reflections are only equal for energy travelling along the same near-surface raypath segment at a common surface location. In this case, the raypath segments are no longer constrained to be near-vertical. This generalization requires transformation of the seismic data from the conventional X-T domain into a 'raypath' domain. This transformation simultaneously relaxes the stationarity constraint, since the length of each input X-T trace is distributed over many 'raypath parameters' in the new domain, and different corrections can be applied for each discrete raypath parameter (or trace segment).

The second, often unrecognized, assumption we make in order to justify 'static correction' is that the surface layer is homogeneous enough that each reflection is seen at the surface as a single discrete arrival. In this assumption, we ignore scattering, short-period multiples, and multi-path phenomena occurring in the surface layer, which can complicate a single reflection arrival with closely-associated secondary arrivals, giving it a waveform rather than the single spike that we normally assume. For raypath interferometry, we relax the single-arrival assumption to include scattering and multi-path arrivals, hence generalizing surface correction from a static trace shift to deconvolution of a waveform which we call the 'surface function'.

Many conventional static correction schemes use cross-correlations between raw seismic traces or between raw traces and 'pilot traces' to find the most likely inter-trace shifts by picking the correlation maxima. The inter-trace shift values then become the data in a matrix inversion, which relies on surface-consistency for its structure, to estimate the 'static shifts' which best satisfy the data. Raypath interferometry also uses cross-correlation of raw traces with pilot traces; but instead of using just the time delays of the correlation maxima, our technique uses each entire correlation function (conditioned) to generate an inverse filter which corrects the corresponding raw trace not only for the gross time shift, but also for any phase adjustments required by the reflection arrival 'waveform'. In this sense, our correction scheme is much like simple optical interferometry (Figure 1). Since the 'raw' traces to which we apply the interferometry are 'raypath domain' traces, transformed from the original X-T traces, we have 'raypath interferometry'.

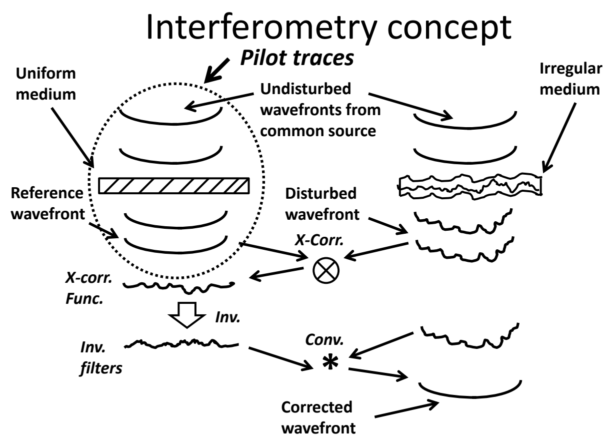

FIG. 1. Schematic illustrating simple optical interferometry concept

Details of the Method

Raypath interferometry was originally designed for application to 2D data sets (Henley, 2012a, 2012b), and has been demonstrated on difficult data sets which violated all normal assumptions for static corrections, as well as on very good data sets where conventional statics techniques work quite well (Henley, 2012b). One particularly important case involves the application of shear-wave statics to PS data, where the required statics may be non-stationary, as shown by Cova et al (2013a, 2013b, 2014a, 2014b, 2015a).

We initially used the radial trace (RT) transform to map raw X-T domain seismic data to a 'raypath domain', because of the simplicity and invertibility of the transform, but we have since shown that the related Snell-ray transform (Henley, 2015), as well as the Tau-P transform (Cova et al, 2015b) can also be used; although the latter can lose data resolution upon inversion without careful attention to bandwidth preservation.

We have achieved promising results on several varieties of 2D seismic data, but since much of the data acquired today are in the form of 3D surveys, it is important that we explore how to apply raypath interferometry in 3D. This report documents our early efforts to extend raypath interferometry to 3D.

The most straightforward way to move from 2D to 3D seemed to be to simply add another dimension to the 'surface function' that we estimate via cross-correlation in the 2D version of raypath interferometry. Since this 2D function already has dimensions of surface location and raypath parameter (or angle), making it compatible with 2D surface geometry, adding the new dimension of azimuth seemed the simplest way to expand the function to make it compatible with some form of 3D surface geometry (Figure 2). This new surface function then implies a particular binning scheme for 3D seismic traces in order to allow them to be used for best estimating the surface functions in each of the independent dimensions. Figure 3 shows the binning scheme constructed to best approximate the requirements. We decided to use the RT transform, initially, to map our input data from X-T to a raypath domain. Since the RT transform is a 2D planar mapping the source-receiver offset vectors of the X-T trace gathers input to the RT transform must be as nearly coplanar as possible. On the other hand, the trace population of any bin to be transformed must be large enough and uniform enough to yield useful RT transforms. These constraints are nearly mutually exclusive: narrow azimuth segments have sparse and irregular trace populations, even though the offsets are nearly coplanar; while wide azimuth segments have larger and more uniformly distributed trace populations, but at the expense of less well-aligned offset vectors. The binning scheme in Figure 3 is as close as we could come to satisfying both constraints simultaneously for the particular data set we chose to test, given the relative sparsity of many conventional 3D data sets.

Example

The most practical way to test ideas for 3D raypath interferometry was to use an actual data set. We determined that the 1995 Blackfoot 3C-3D data set (Lawton, 1996) would be suitable, since it is small enough (~10^6 traces per 3C component), has good data quality, and exhibits visible statics. Due to software shortcomings, we were only able to test raypath interferometry to the point of comparing 'corrected' X-T domain traces with raw traces, but not to final 3D stack comparisons.

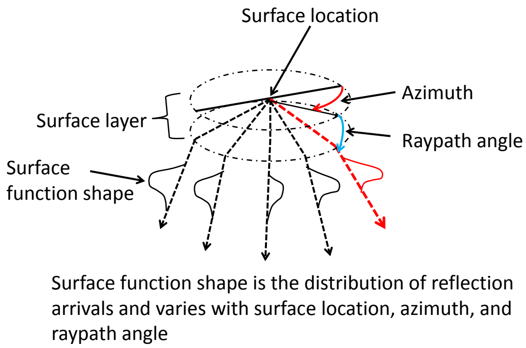

FIG. 2. 3D surface function concept

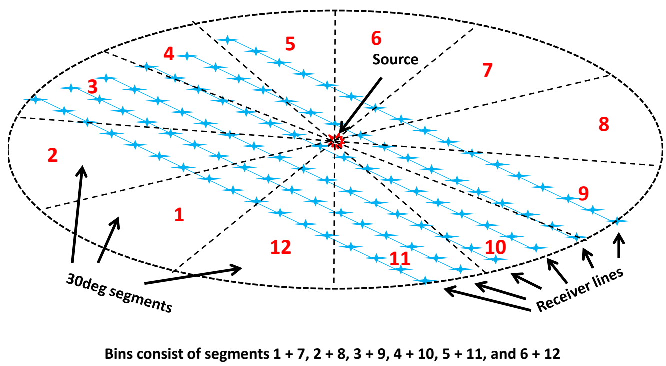

FIG. 3. 3D binning scheme for raypath interferometry

Figure 4 shows a single source gather from the Blackfoot survey (vertical component), sorted by receiver line and offset. When the traces are re-sorted according by azimuth and offset, with azimuth bins 10deg wide, the result is shown in Figure 5 (after removing NMO). Note the varying trace population in the azimuth bins, reflecting the fact that the source is not centered in the patch of receiver lines. In fact, more than half of the azimuth bins have too few traces to contribute to a meaningful RT transform. Note, as well, that the source-receiver offset, in the trace header plots, is not very linear, as required for our RT transform to be exactly invertible. If we triple the width of the azimuthal bins and combine azimuthal segments on opposite sides of the source point into propeller-shaped super-bins, as shown in Figure 3, we obtain the source gather shown in Figure 6, with only six azimuthal super-bins, each consisting of two segments aligned at 180deg. In this case, however, the bins each contain a reasonable population of traces, and combining opposite bin segments has made the offset distribution more linear in each super-bin.

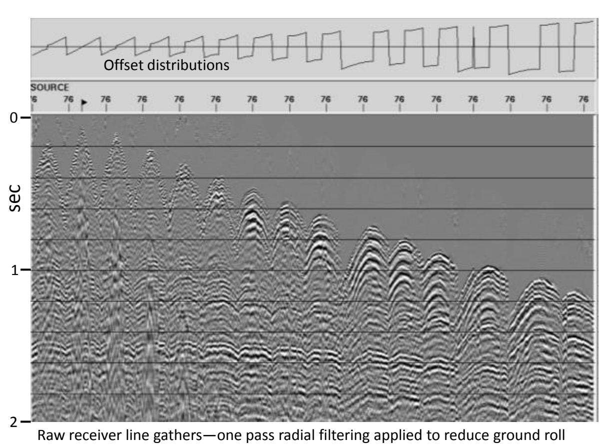

FIG. 4. source gather 76 from the Blackfoot survey

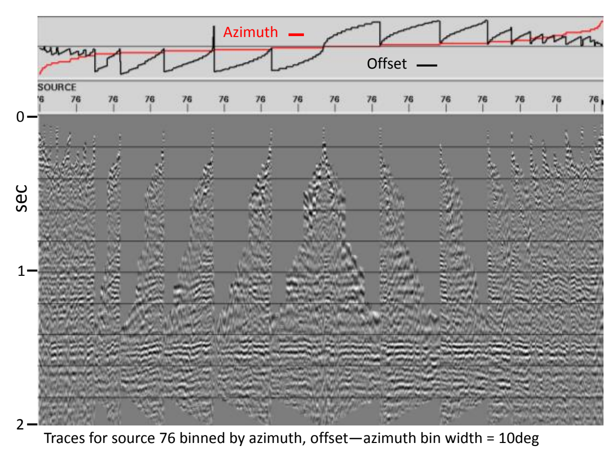

FIG. 5. Source gather 76 binned by azimuth in 10deg segments

The steps used to perform raypath interferometry on the data in Figure 6 are as follows:

- Apply the RT transform to the traces in each azimuth bin in Figure 6.
- Sort the resulting traces by raypath parameter, source, and azimuth—to form common-raypath gathers.
- Create the reference wavefield (pilot traces) for each common-raypath gather
    - Use trace mixing and SVD to apply one pass of smoothing
    - Re-sort the traces by raypath parameter, azimuth, and source
    - Use trace mixing and SVD to apply a second pass of smoothing to finish creation for a 3D reference wavefield
- Cross-correlate pilot traces with their corresponding raw 'raypath traces' and derive inverse filters from the conditioned cross-correlations.
- Apply inverse filters to their corresponding raypath traces.
- Re-sort corrected traces by source, azimuth, and raypath parameter.
- Apply inverse RT transform to the traces in each azimuth bin

The result of these operations is shown in Figure 7, which can be approximately compared to Figure 6. The comparison is made more difficult by the constrained offset linearity of our inverse RT transform. Nevertheless, it can be seen that the statics evident in Figure 6 have been significantly reduced in Figure 7. If we were to re-sort these corrected data to receiver, azimuth, and offset, and to repeat the raypath interferometry, these residual statics would likely vanish, as they do in 2D lines after passes of raypath interferometry in both source and receiver domains (Henley, 2014a, 2014b).

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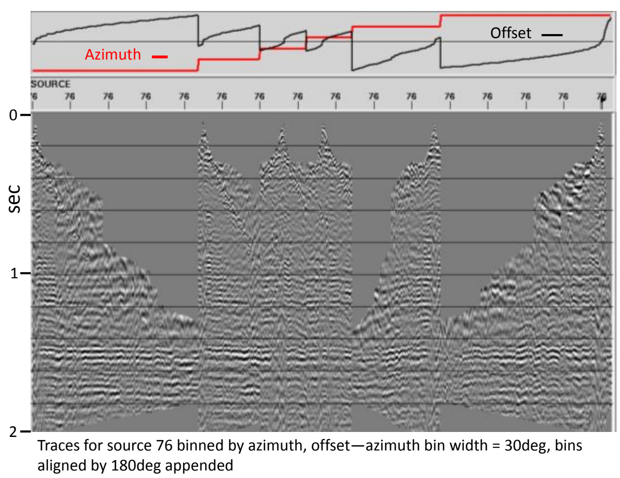

FIG. 6. Traces from source 76 binned for raypath transform

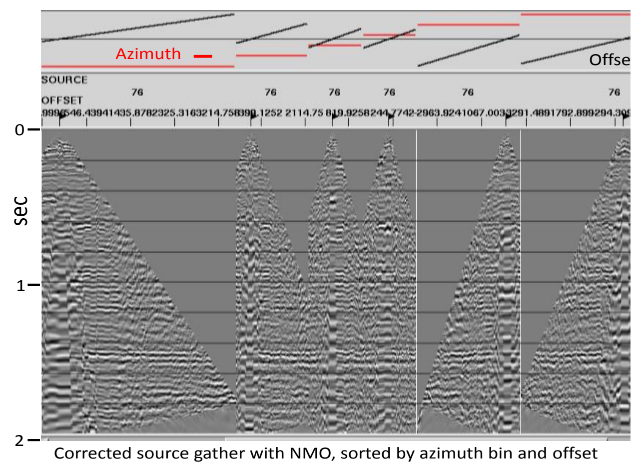

FIG. 7. Corrected traces from source 76 after approximate inverse raypath transform

Conclusions

The extension of raypath interferometry into 3D is in its early stages. We have followed what seems an obvious direction, and demonstrated reduction of obvious statics in a 3D data set, in spite of shortcomings in our existing software. We have not yet accomplished a full 2-pass application of the method, followed by 3D stacking, to fully verify the method. Likewise, we have not pursued the use of other transforms to go from the X-T domain to the raypath domain; nor have we examined the inline horizontal component of our Blackfoot data set, where this technique could be more important.

Acknowledgements

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