Static corrections via raypath interferometry: recent field experience

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Summary

Raypath interferometry is a processing technique developed to address problems encountered with conventional static corrections methods in areas where basic assumptions used by these methods are violated. It introduces the 'raypath-consistency' concept to generalize the usual 'surface-consistency' constraint used in conventional statics methods; and it uses interferometry concepts to accommodate uncertain or non-discrete reflection arrivals by replacing event picking and time shifting with cross-correlation and deconvolution.

Raypath interferometry was first successfully applied to a high-resolution seismic line in the MacKenzie Delta, for which surface-consistency was violated by the high-velocity permafrost surface layer, and which manifested instances of multipath arrivals, which contaminate the primary reflection arrivals.

Although developed primarily to handle problem lines like the MacKenzie Delta line, raypath interferometry is a generally applicable technique which works equally well on data for which conventional statics methods are also successful. We demonstrate this using a recent 3C seismic survey from the Hussar, Alberta area. Furthermore, we demonstrate raypath interferometry on the radial component (PS) of these data, where the large shear-wave statics appear to be non-stationary.

Introduction

Raypath interferometry was developed to apply near-surface corrections to reflection seismic data sets for which conventional statics corrections are unsatisfactory (Henley, 2012, 2010, 2008). Statics fail for some data because one or more basic statics correction assumptions are violated by the particular near-surface conditions. We show how two of the assumptions can be generalized in order to accommodate these conditions.

The conventional assumption that a simple weathered layer causes only a pure time delay for a discrete reflection arrival can be replaced by a model in which a 'surface function', characterizing a more complex weathered layer, is convolved with a discrete reflection arrival to capture not only the simple transit time delay of the reflection event, but any multi-path and scattered arrivals associated with the particular surface location. Adoption of the surface function replaces the usual near-surface correction procedure of time shifting traces to deconvolution, where the surface function for each source/receiver position is estimated and removed from the data traces by inverse filtering.

Next, the surface-consistency constraint common to most conventional statics methods can be extended to the concept of 'raypath consistency'. Raypath consistency is introduced by re-defining the surface function to include variation with the near-surface raypath angle, as well as the surface location. Use of the angle-dependent surface function hence requires that raw seismic data be mapped into some domain in which a near-surface raypath-angle parameter is a coordinate. In our raypath interferometry procedure, the radial trace (RT) transform is used to map raw seismic data to an approximate raypath-angle domain, a simple interferometric method is used to deconvolve surface functions in this domain, and the corrected data are re-mapped to the original XT domain for CMP stack imaging.

Details of the method

The starting point for raypath interferometry, as for many conventional statics correction methods, is a set of NMO-corrected source or receiver gathers. Each gather is transformed to the radial trace (RT) domain, resulting in a set of RT source (or receiver) gathers. Since the principle coordinate for these gathers, the 'raypath parameter' has the dimensions of velocity, the RT traces are then sorted by velocity and surface location to form 'common-raypath-parameter' gathers (comparable to common-offset gathers in the XT domain). We then find and apply near-surface corrections to these gathers.

To accomplish this interferometrically, a 'reference wavefield', or pilot trace panel is created for each common-raypath-parameter gather. One way of doing this is by applying 'guided' trace mixing (conforming to visible structure) across each common-raypath-parameter panel, with the mixing window approximately the same as the length of a receiver spread. Each trace from the original common-raypath-parameter gather is cross-correlated with its corresponding trace in the pilot trace gather. The individual cross-correlation functions (or 'surface functions') are then used to derive broadband inverse filters, each of which is applied to its corresponding input trace. This cross-correlation/inverse filtering operation constitutes the interferometric correction. The corrected common-raypath-parameter gathers are re-sorted to RT source (receiver) gathers, which are inverse RT-transformed to source (receiver) gathers for CMP stack imaging. By sorting the corrected source (receiver) gathers to receiver (source) gathers, the whole raypath interferometry procedure may be repeated to improve the solution, although for surface sources and receivers, the improvements are relatively minor.

Examples

To illustrate the capabilities of raypath interferometry, we first display the MacKenzie Delta line for which the method was developed. The data on this line are generally of high quality, except where the line crosses zones of melted permafrost and ice-covered river channels. These surface conditions lead to large, non-stationary statics and to multi-path arrivals near river channel edges. Source-generated coherent noise was also a serious issue, but was addressed separately. Figure 1 compares the CMP stack of this line, with no static corrections applied, to the CMP stack after raypath interferometry. A satisfactory conventional statics solution was never obtained for this line.

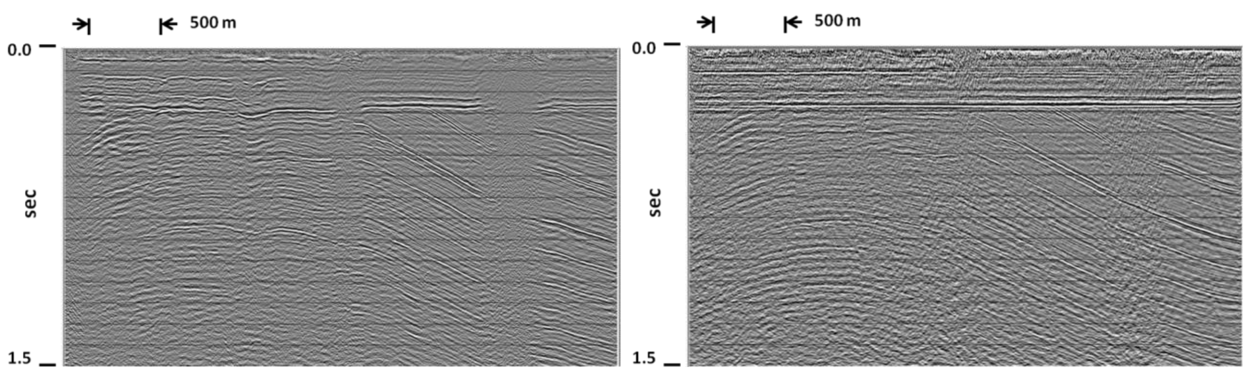

FIG. 1. MacKenzie Delta high-resolution line with visible statics on the brute CMP stack (left). The CMP stack on the right, after raypath interferometry, shows much more near-surface detail, as well as event continuity in the deep structure.

Next, we show the vertical component (PP) data from our Hussar seismic line, which ***does not violate*** the surface-consistency constraint, and hence can be satisfactorily corrected with conventional residual statics techniques. Since surface-consistency is just a special case of raypath-consistency, which applies whenever the near-surface layer is much lower in velocity than deeper layers, we expect raypath interferometry to provide statics correction at least as good as conventional. Figure 2 shows the brute stacks for the Hussar vertical (PP) component and the radial (PS) component with no statics applied in either case. The PP section is a CMP stack, and the PS section is a CCP stack.

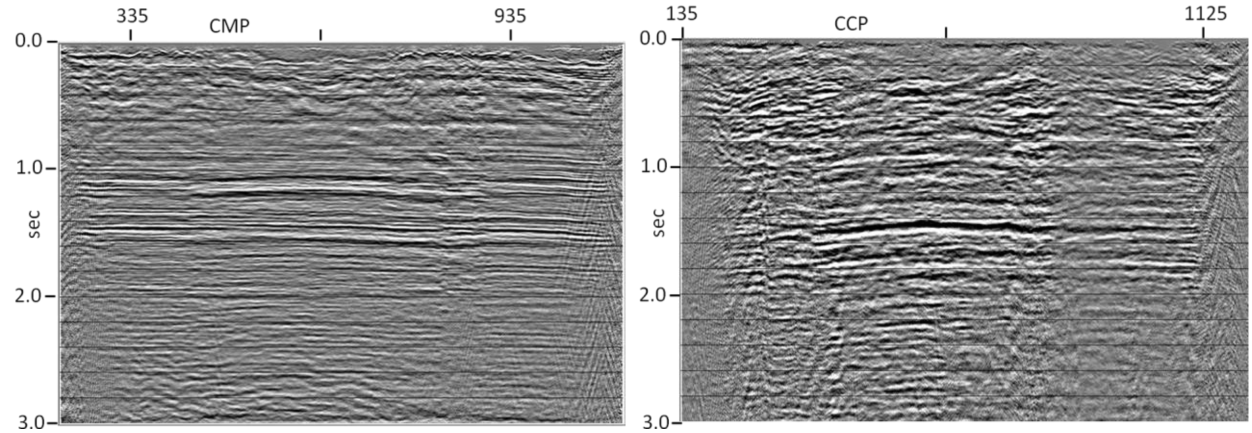

FIG. 2. Brute stacks of Hussar 3C survey, no statics applied. CMP stack of PP data on the left, CCP stack of PS data on the right.

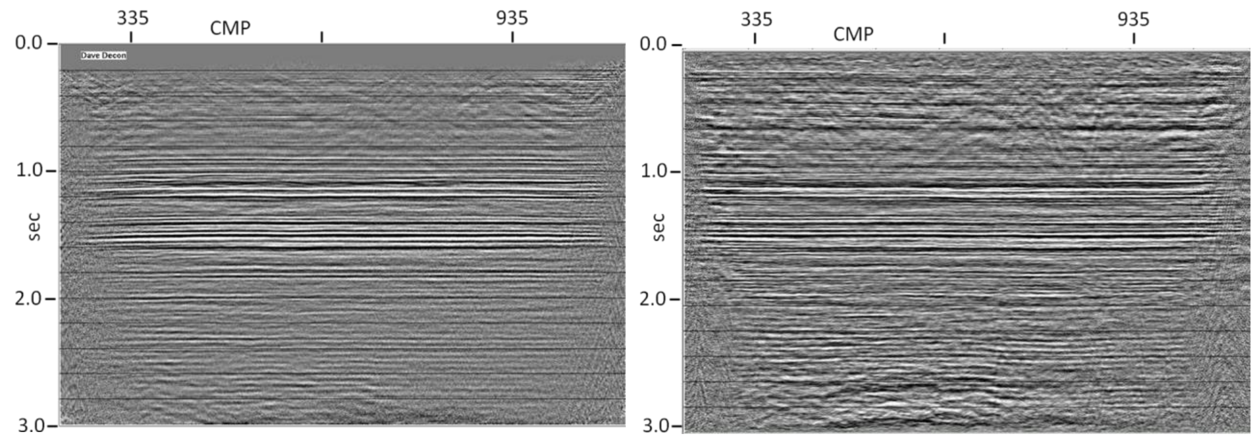

FIG. 3. Comparison of CMP stacks of Hussar PP data after conventional statics and NMO analysis (left) and after raypath interferometry with a single NMO function (right).

As the comparison in Figure 3 shows, the raypath interferometry process provides residual statics correction that is at least as good as the conventional results. Because it is also a whitening process, there may actually be slightly more detail visible in the prominent layer at about 1.2sec.

For converted-wave data, a good case can be made that the required shear-wave receiver corrections are non-stationary. If surface-consistent statics are derived, the non-stationarity will likely force compensating variations into the NMO velocities, while raypath interferometry can apply receiver corrections independently of NMO. Figure 4 shows the comparison between conventional PS statics coupled with NMO analysis on the one hand and raypath interferometry using a single NMO function on the other. Figure 5 compares a common-receiver stack for the Hussar PS data, with no applied statics, to the common-receiver stack after raypath interferometry. On the brute receiver stack (left) very large statics can be seen in several places; and the statics appear to be larger for shallow events than for deeper ones at the same receiver location, strongly suggesting that these statics are non-stationary. The application of raypath interferometry provides corrections that remove the statics as well as the apparent non-stationarity.

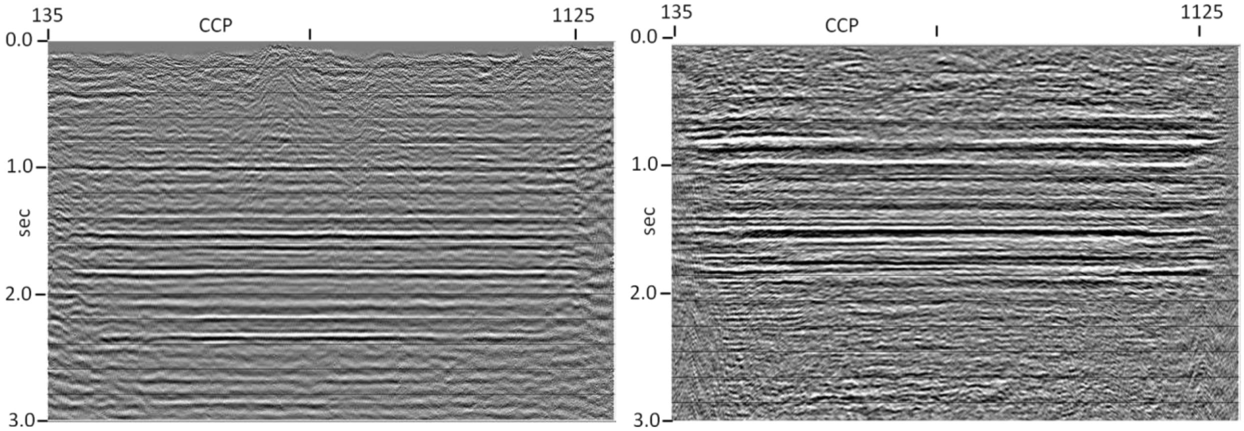

FIG. 4. Comparison of CCP stacks of Hussar PS data after conventional statics and NMO analysis (left), and after raypath interferometry with a single NMO function (right).

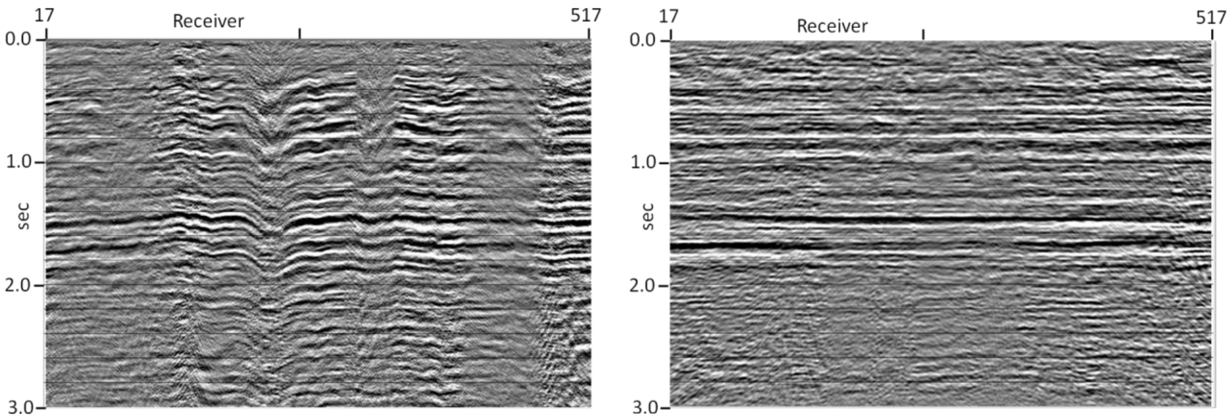

FIG. 5. Common-receiver stack of uncorrected Hussar PS data (left) strongly suggests non-stationary shear statics are required to correct the data. The common-receiver stack on the right shows the result of applying raypath interferometry, which applies non-stationary corrections without altering NMO velocities.

Conclusions

Raypath interferometry is a technique for applying corrections to seismic data to compensate for the effects of a complex near-surface layer where the normal assumptions used in conventional static corrections are violated. Since the method is based on generalizing surface-consistency to raypath-consistency, it works just as well on data which do not violate surface-consistency. Since it uses interferometric principles, it can also compensate for surface-related multipath or scattered reflection arrivals, which are not always apparent on raw data.

Acknowledgements

The author acknowledges CREWES and NSERC for financial support, various CREWES sponsors for use of the Hussar data, and Shell for continuing use of the MacKenzie Delta data. Thanks to Helen Isaac for conventional processing on the Hussar data.

References

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