# Hybrid raypath interferometry: correcting converted wave receiver statics

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**Summary**

A technique termed 'hybrid raypath interferometry', for removing near-surface effects from seismic data, is used to remove converted wave receiver statics. A model study shows that artifacts caused by the 'hybrid' aspect of the method are minimized by a 'conditioning' step. The method is applied with encouraging results to the Spring Coulee multicomponent data set.

**Introduction**

In the most general sense, seismic interferometry includes acquisition and processing techniques which use cross-correlations of raw traces to help image the data, or to remove various effects from the traces before imaging. A surge of interest in this broad field has led to a number of new techniques for passive seismic imaging (Draganov et al., 2009), migration (Zhou et al., 2006), and removal of near-surface effects, including statics (Bakulin and Calvert, 2006), (Henley, 2008), for example.

Cross-correlations of raw seismic traces have been central to statics correction techniques for many years, typically being used to detect the relative time shift between two raw traces or between a raw trace and a 'pilot' trace. Until recently, however, only the lag times of the cross-correlation maxima have been used in statics computations. We, however, use modified cross-correlation functions to derive inverse filters, which then deconvolve the static shifts and other phase differences from the raw traces, hence 'statics deconvolution' (Henley, 2006).

Initially applied in the common-shot or common-receiver domain, statics deconvolution was later extended to the 'common-raypath' domain, which removed the constraints of surface-consistency and time-stationarity. This enabled the technique to solve difficult statics problems, like those encountered in the Arctic, with its irregular high-velocity surface permafrost layer. The first successful demonstration of 'raypath interferometry', in fact, was on a MacKenzie Delta seismic line with very large non-surface-consistent statics associated with river channels.

The most successful variant of raypath interferometry utilized pilot traces created from raw seismic traces summed along structural horizons. Hence, the initial attempt to apply interferometry to converted wave data followed the same approach. The limited offset aperture and lower S/N of the PS traces, however, made it difficult to create useable pilot traces. DeMeersman and Roizman (2009), however, showed how to use cross-correlations of PP and PS direct arrival events to find receiver statics, using both vertical and radial seismic components, and we subsequently modified the raypath interferometry method to use PP events as pilot traces for PS events—hence '*hybrid* raypath interferometry'.

**Theoretical concerns**

Conventionally, interferometry involves cross-correlations of similar traces containing directly corresponding events (like reflection sequences). When these events are aligned by the proper shift between traces, they all contribute to the correlation maximum. In hybrid interferometry, however, we compare traces which may share only one common event (a reflection on the PP trace and a conversion on the PS trace from the same geological horizon), and which contain other *non-corresponding* events. The common event chosen is usually stronger than neighboring events, on both traces, so the global cross-correlation maximum will usually indicate the relative shift between the reflection on the PP trace and the corresponding converted event on the PS trace. However, the other events on the two traces *do not align* at this shift and don't contribute to the maximum correlation value. They *do*, however, contribute to smaller side lobes, at various time shifts, corresponding to the chance alignment of non-related events on the two input traces. While the cross-correlation of *similar* traces (two PP or two PS traces) will also exhibit side lobes due to alignment of non-correlated events, the *global maximum* of this correlation will be much larger *relative to the spurious side lobes* since *all corresponding events* align at a single shift to contribute to its value. Our concern here is that the significantly *larger spurious side lobes* of the hybrid cross-correlation function may lead to inverse filters which not only correct PS traces for receiver statics but also *contaminate* them with spurious event artifacts during the statics deconvolution.

In order to evaluate the significance of these artifacts on our proposed 'hybrid interferometry' method, we created several synthetic seismic models with simulated PP and PS trace gathers, in which the traces contained various discrete reflected or converted events, and in which the PS traces contained large random receiver statics (+/- 150 ms max.). For each model, we cross-correlated the PP traces with their corresponding PS traces and derived inverse filters, with which we corrected the PS traces for statics. We found that by properly 'conditioning' the cross-correlation functions before deriving the inverse filters, the 'spurious event' artifacts could be greatly diminished (Figure 1). We further verified, using a complete synthetic 2D multicomponent survey, that we could correct PS receiver statics in the presence of significant bandlimited random noise, (Figure 2) and that using the 'raypath-consistent' approach provided more robust results than the 'surface-consistent' approach (not shown here).

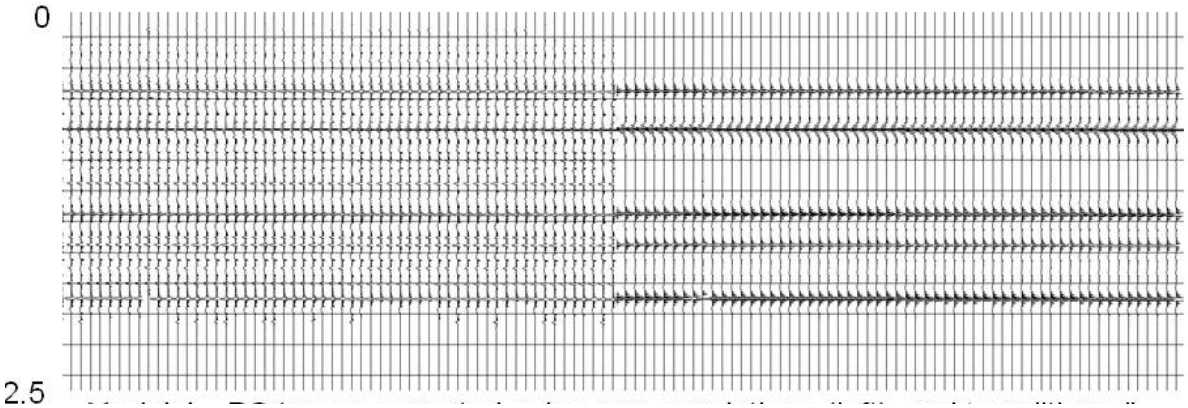


Fig. 1. Synthetic traces on left have been corrected for statics using inverse filters derived from 'raw' cross-correlation functions, while those on the right have been corrected using 'conditioned' cross-correlations. Spurious events are quite evident on the left panel between the five legitimate events, but are much diminished on the right panel (whose display amplitude is greater).

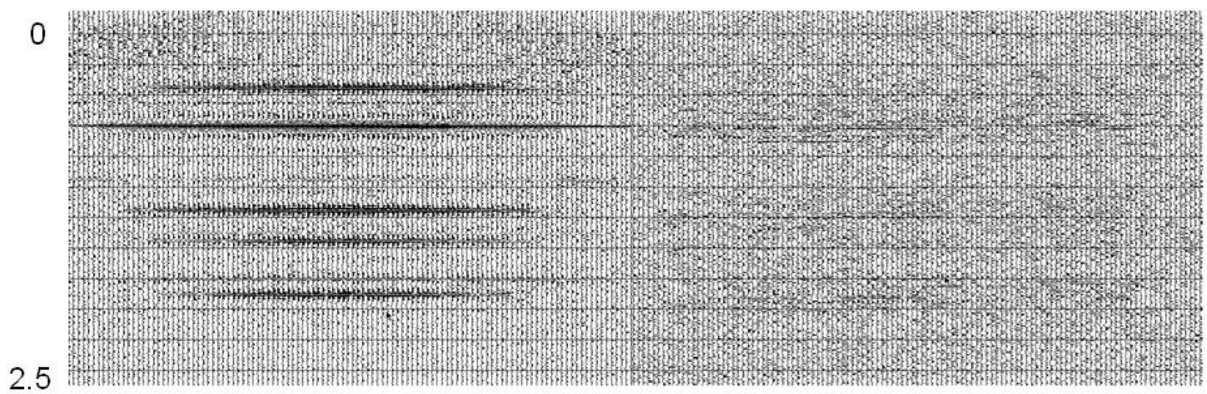


Fig. 2. CCP stack (left) of synthetic converted wave shot gathers corrected for receiver statics using 'hybrid' raypath interferometry, in which PP traces acted as pilot traces for PS traces. Right panel is CCP stack of the uncorrected gathers. Statics are so large (+/- 150 ms, uniformly distributed) that they destroy event coherence unless corrections are made. Little evidence of spurious events can be seen on the left panel.

**Details of the method**

The first step in applying hybrid raypath interferometry is to apply all known statics and the best available NMO correction to the PP (vertical component) data, and to sort the traces to receiver gathers. Only PP shot statics are applied to the PS (radial component) data, however, as well as the best available NMO correction, before sorting these traces, as well, to receiver gathers.

The receiver gathers for both components are transformed to the radial trace (RT) domain, using identical parameters, and the resulting RT receiver gathers are sorted by apparent velocity (raypath angle) and receiver location to form common-angle gathers (analogous to common-offset gathers in the XT domain). Each PP common-angle gather is matched to the PS common-angle gather with the same apparent velocity, and the PS common-angle gathers are shifted up in time to approximately match the chosen converted wave event with its corresponding reflected event on the PP common-angle gathers.

For each pair of PP and PS common-angle gathers, PP and PS traces having common receiver locations are cross-correlated over a window which includes the matched reflected and converted events, the cross-correlations are ‘conditioned’ (samples raised to an odd power and Hanning weighted), and an inverse filter is derived for each function. Each inverse filter is convolved with its corresponding PS trace in the common-angle gather to correct the trace.

To finish the procedure, the corrected PS common-angle gathers are re-sorted to their original RT receiver gathers, and each gather inverse transformed back to an XT domain receiver gather. The corrected receiver gathers can then be CCP stacked.

**Field Example**

Our field example is the Spring Coulee 3C 2D survey, conducted in southern Alberta early in 2008. We show, in Figure 3, a pair of common-angle gathers for this survey, for the apparent velocity -1499 m/s. This figure shows the reflected event on the PP (vertical component) data, as well as its corresponding converted wave event on the PS (radial component) data. The relative shift between these events is about 300 ms. Figure 4 shows the uncorrected PS gather from Figure 3 compared with its corrected version. All the common angle gathers for this line (600 for this survey) are corrected in a similar manner, then re-sorted and converted back to the XT domain for CCP stacking. Figure 5 compares the CCP stack of the PS data with no receiver statics to the CCP stack of the same data after our hybrid raypath interferometry. The improvement is obvious.

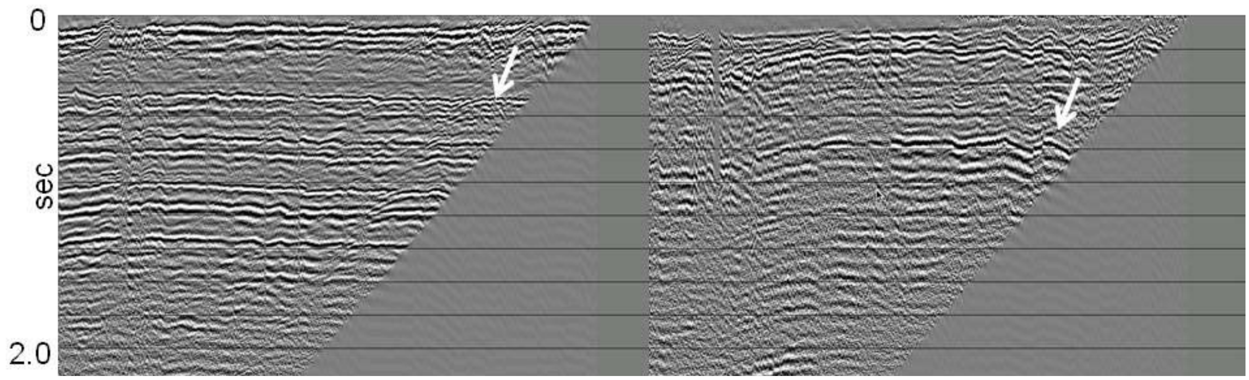


Fig. 3. Common-angle gather for apparent velocity -1499 m/s for vertical component (left), and corresponding common-angle gather for apparent velocity of -1499 m/s for radial component (right). Arrows indicate the corresponding PP reflection and PS conversion events.

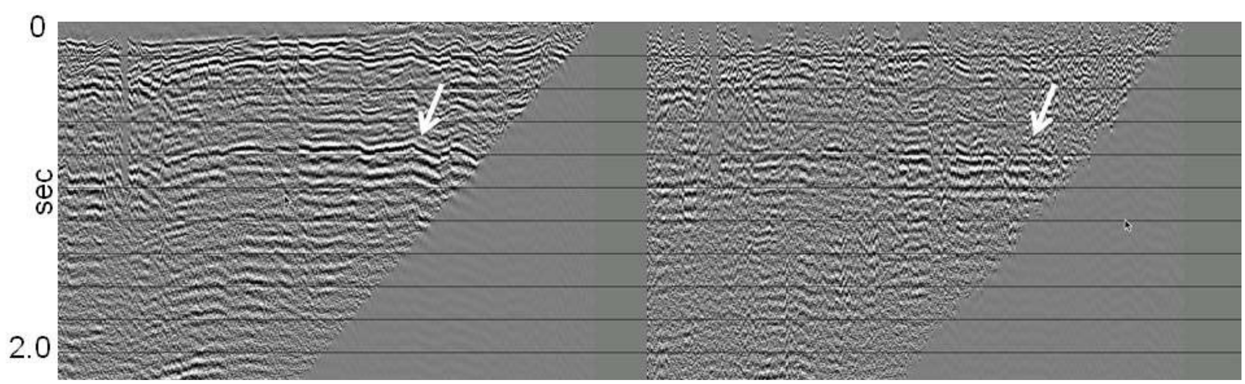


Fig. 4. Common-angle gather for apparent velocity -1499 m/s for PS converted wave events before correction (left), and after correction using raypath interferometry (right). Arrows indicate area of obvious improvement. Note the loss of structural relief, however, after correction.

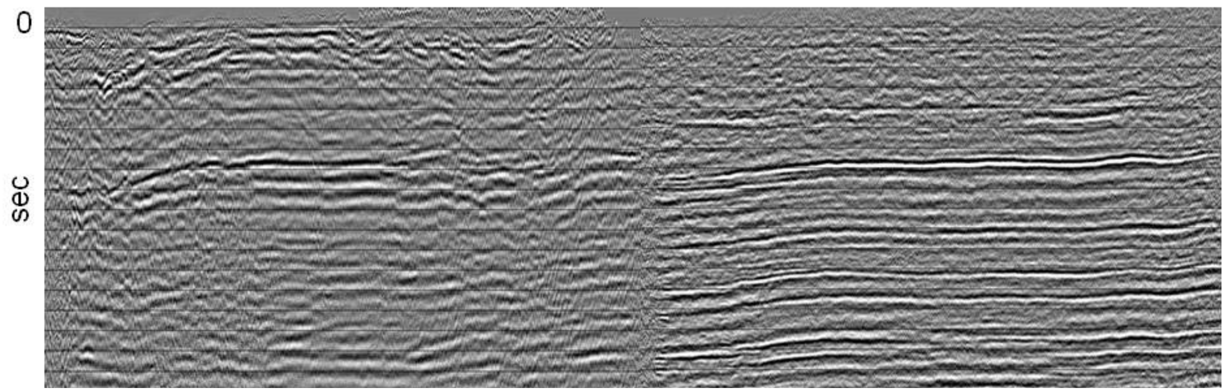


Fig. 5. CCP stack of uncorrected PS data (left) vs. CCP stack of PS data corrected using hybrid raypath interferometry (right). Because the method uses PP reflections as the pilot, the geological structure of the result is that of the PP data and needs to be further corrected to properly show the PS structure.

## Conclusions

Extending raypath interferometry into a 'hybrid' application, cross-correlating PP reflection events with PS converted wave events appears to be a promising new approach for removing receiver statics from converted wave data. One problem yet to be solved is properly preserving structure, since our hybrid technique corrects for the *differences* between the PP and PS events, hence removing PP structure from the PS section.

An extension of the hybrid approach, which we have already tested with some success, is to use the common-angle gathers corrected by the hybrid method to form new pilot trace gathers to be used in a second pass of raypath interferometry. Even if these pilot traces have some residual spurious event noise, their correlation with the raw PS traces should be much less affected by spurious side lobes than the actual 'hybrid' first pass.

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