Correcting PS receiver statics using hybrid raypath interferometry

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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 is used to show 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 resurgence 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 time positions of the cross-correlation maxima have been used in statics computations. We, however, use complete cross-correlation functions to derive inverse filters, which then remove 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. Because of the limited offset aperture and lower S/N of the PS traces, however, it proved 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 reflections). 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 typically share only one correlated event (a reflection on the PP trace and a conversion on the PS trace from the same geological horizon), and which contain other *unrelated* reflected or converted events. The correlated event chosen is usually stronger than neighboring events, on both traces, so the global cross-correlation maximum will occur at 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. Also, the cross-correlation function will exhibit smaller peaks, 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 show 'spurious' peaks due to alignment of non-correlated events, the global maximum of the correlation will be much larger *relative to the spurious peaks*, since *all events* align at one shift to contribute to the global maximum correlation value. Our concern is that significant spurious cross-correlation peaks will lead to inverse filters which not only correct PS traces for receiver statics but also contaminate them with spurious event artifacts.

In order to evaluate the importance 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. For every 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, as shown in Figure 2, and that using the 'raypath-consistent' approach provided more robust results than the 'surface-consistent' approach.

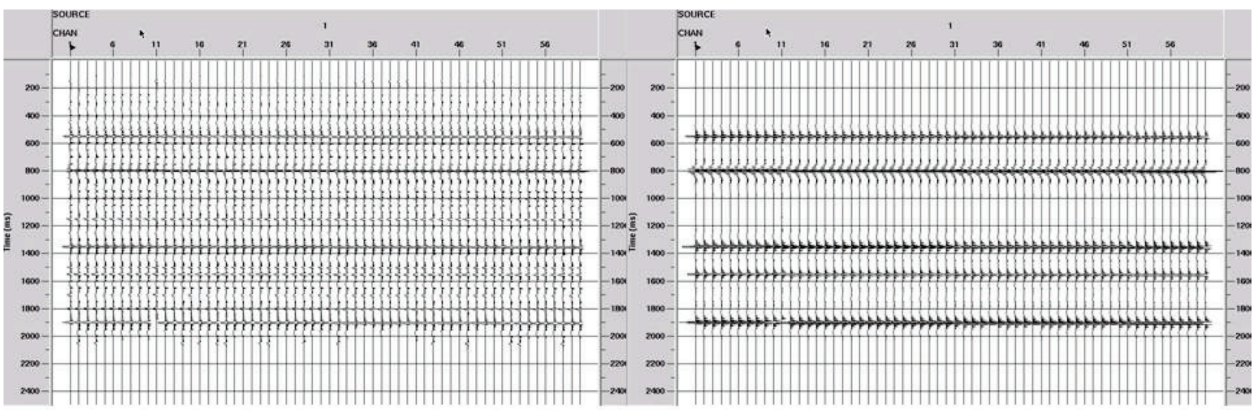

Figure 1: Synthetic PS shot gather with five legitimate events exhibiting 'spurious event' artifacts after hybrid interferometry based on raw cross-correlations (left) vs. the same PS shot gather after hybrid interferometry with 'conditioned' cross-correlations (right).

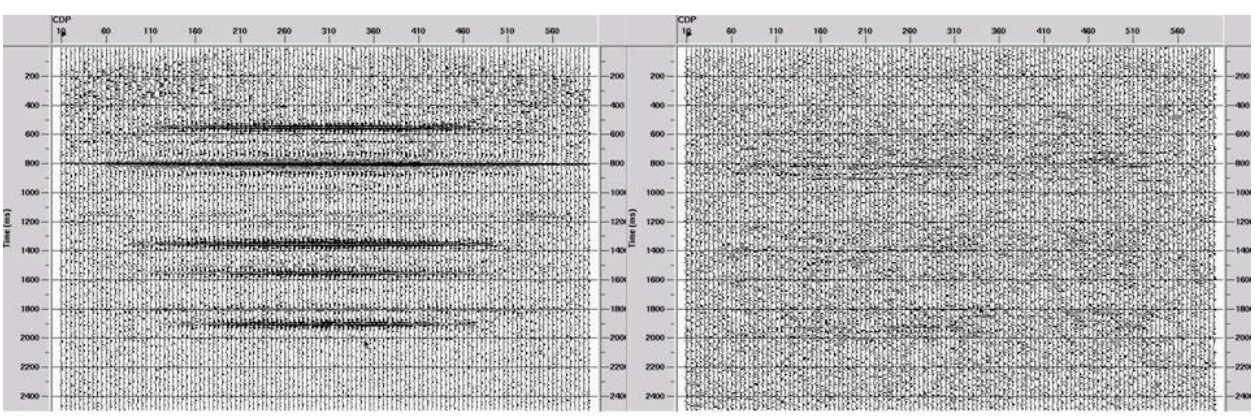

Figure 2: CDP stack of synthetic PS data after application of hybrid raypath interferometry to correct PS receiver statics (left) vs. CDP stack of uncorrected synthetic PS data (right).

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 multicomponent 2D survey, conducted 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. 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.

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.

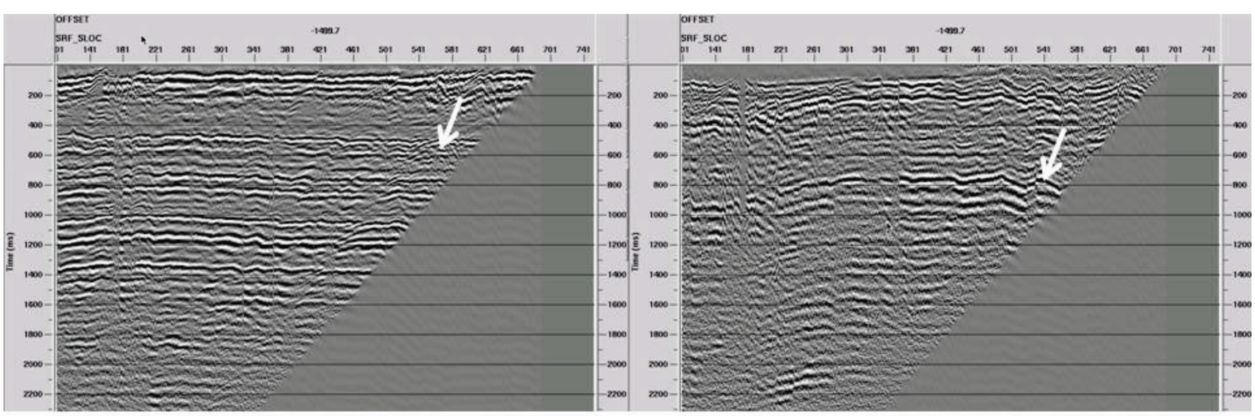

Figure 3: Comparison of PP common angle gather (left) with its corresponding PS common angle gather (right) for the apparent velocity of -1499 m/s. The arrow indicates the chosen event

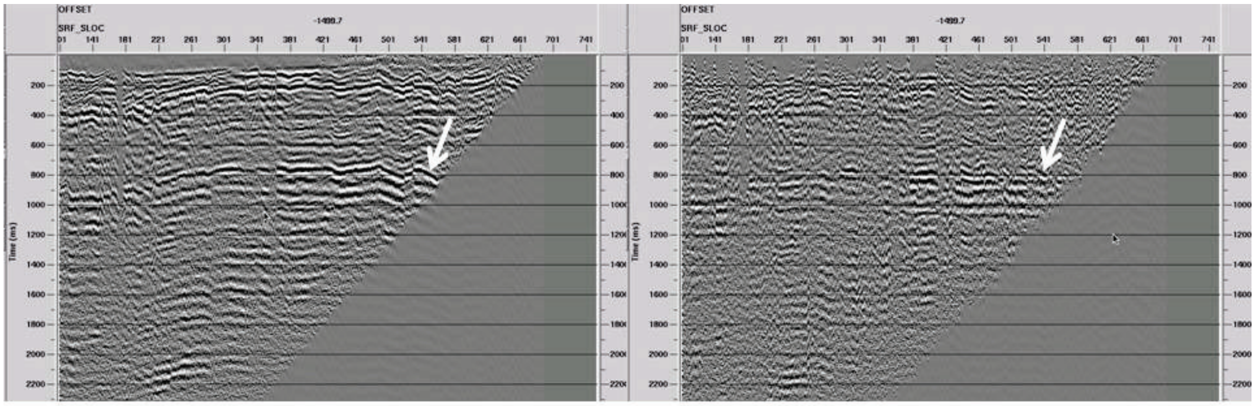

Figure 4: PS common angle gather before (left) and after (right) correction by interferometry.

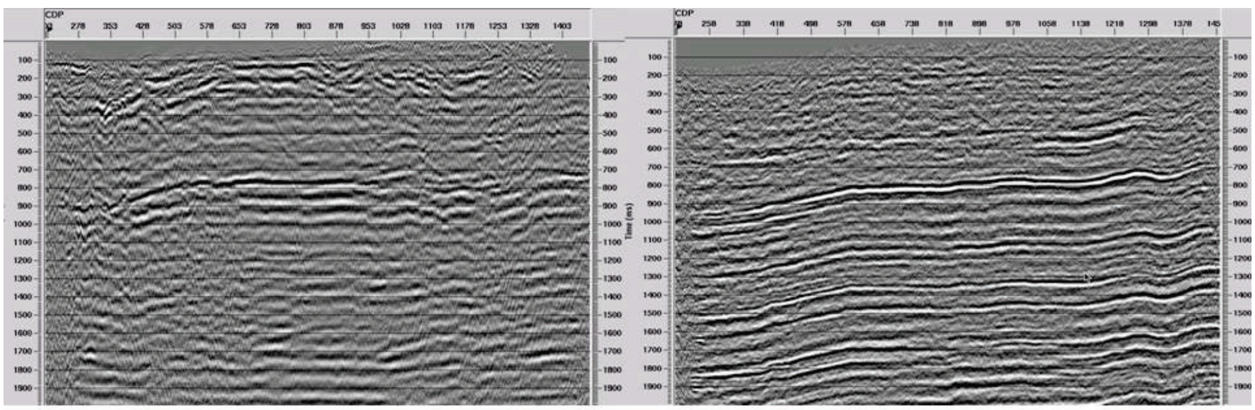

Figure 5: CCP stack of uncorrected PS data (left) vs. CCP stack of PS data after hybrid raypath interferometry (right)

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