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Statics or Statistics?—The Near-Surface Revisited

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Abstract

In spite of a seeming myriad of procedures for compensating seismic data for the effects of the highly variable near-surface weathered layer, usually classified as "statics" methods, there remain many data sets, which are inadequately served by existing techniques. In most of these cases, the data simply do not conform to the assumptions of the "statics" model of near-surface correction. By taking a statistical approach, we re-examine not only the simple statics model, but also the concept of surface-consistency, and the notion of "picking" of event times. We replace the notion of a single picked event time with that of a "distribution function" of times and show that this concept not only relaxes the constraints of the "statics" model, but also suggests a technique for data correction—deconvolution of the distribution function. We demonstrate some early attempts to implement a "statics deconvolution" method on real data and discuss the key problems encountered in the technique.

Introduction

It is a well-known fact in geophysics that the highly variable near-surface layer of the earth often causes significant difficulties for imaging seismic reflection data. In addition to supporting a variety of source-generated coherent noises, which often mask reflections, this layer, through its irregular thickness and/or velocity structure also causes timing and phase differences between reflection events recorded at neighboring surface stations. Frequently, the near-surface layer is significantly lower in velocity than its underlying layers. When this is the case, the argument is usually made that corrections for the near surface layer need only be relative time shifts of the seismic traces to account for transit time differences through the layer…the "static shift approximation". What allows this approximation to succeed in a majority of cases is the fact that seismic travel paths through the near-surface layer are near vertical and therefore nearly coincident for all travel paths originating or ending at a particular surface location. Hence, any time delays due to transit through the near-surface layer are the same for all travel paths associated with a single surface location—surface consistent, in other words. Figure 1 is a schematic that is used to justify this approach, while Figure 2 shows some reasons why it does not work in some cases. Surface-consistency fails as soon as the near-surface layer has a significantly higher velocity than the underlying layers, since near-surface travel path segments are no longer nearly vertical and coincident. Furthermore, when an array of receivers (or sources) is used at each station, a wavefront arriving from a deep reflector may not arrive simultaneously at all the sensors (or from all the sources), leading to a closely spaced series of wavefront arrivals on the recording channel. In addition, there may be more than one travel path along which significant seismic energy can travel from source to receiver, leading to "multi-path" arrivals. Included with the latter would be such phenomena as short-period peg leg multiples. Since the pattern of these arrivals can change from trace to trace, it is obvious that simply applying relative time shifts to seismic traces cannot deal with the underlying phenomena, except in an approximate way. We need a way of compensating for all the significant arrival delays embedded in each seismic trace.

From elementary signal processing theory, we know that a time-shifted time series can be considered the convolution of the zero-shift time series with a time-shifted unit copy spike, and that the shift can be removed from the time series (or seismic trace) by deconvolving the copy spike. This suggests an obvious approach for removing a "distribution" of static shifts from a seismic trace: find a deconvolution operator for the "distribution function" and apply it to the seismic trace. Figure 3 demonstrates this principle with a simple model. In the model, a sequence of five closely spaced spikes of different amplitudes represents five possible arrivals of different amplitude for a single reflection wavefront as observed at the seismic recorder. Given an estimate of the distribution function (in this case, a bandlimited version of the actual function), a match filter can be derived, which will remove the effects of the distribution function (static shifts) from the input trace.

Practice

The notion of a statics distribution function is not new—Rothman (1984, 1986) introduced the concept with respect to the uncertainty in picking events on seismic traces, and further used the idea to motivate the simulated annealing method for static corrections. In that approach, however, it was still assumed that a single time shift was the most appropriate correction to apply to a seismic trace, and that the distribution function simply expressed the statistical uncertainty associated with finding that time shift for each trace. The simulated annealing technique ultimately aimed at finding the "optimum" single shift for each trace.

In our approach, however, we propose that it is not necessary to find an "optimum" time shift from the distribution function, and instead, we deconvolve the entire distribution function from each trace. In this method, the deconvolution process itself can be done in several ways; using a match filter, or using one of several types of inverse filters; but key to the success is estimating the distribution function for each trace in the first place. As a starting point, we begin by using the cross-correlation between each raw trace of a data set and a "pilot" trace obtained from some smoothed version of the data. Various ad hoc manipulations performed on the cross-correlation can make its appearance more like our expected "distribution function"—with non-negative sample values whose sum is unity; and a deconvolution operator can be derived from this modified correlation function.

Example

Figure 4 shows a plot of statics distribution functions estimated for the vertical component of the Hansen Harbour experimental 2D 3C seismic line in the Canadian arctic. Note that several of these functions (Figure 4a.) have more than one peak, possibly indicating some multi-path phenomenon. When the distribution functions are deconvolved from their respective traces, the result is the stack in Figure 5. Shown for comparison in Figure 6 is the brute stack with no statics applied. Some modest improvement gives us the incentive to further develop the method.

Conclusions

We have identified a promising technique for removing near-surface effects from seismic traces, which relaxes the usual static correction assumptions. Because it is a deconvolution technique, the method could be made time varying. The key to its success is a robust method for determining the statics distribution functions embedded in the raw seismic traces—encouraging preliminary results have so far been obtained using a modified cross-correlation function.

Acknowledgements

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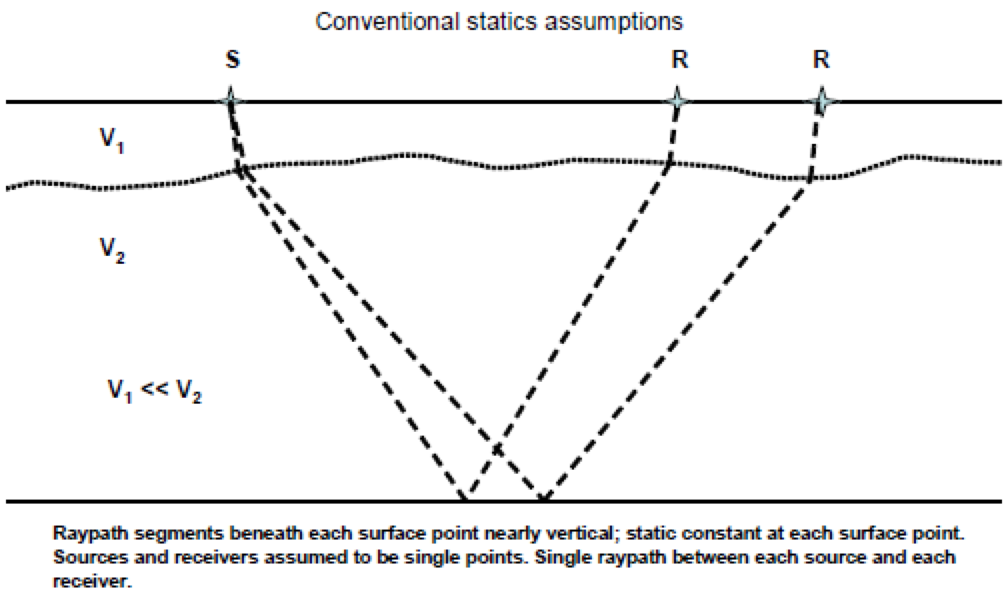


Figure 1. Simplifying assumptions for surface-consistent statics.

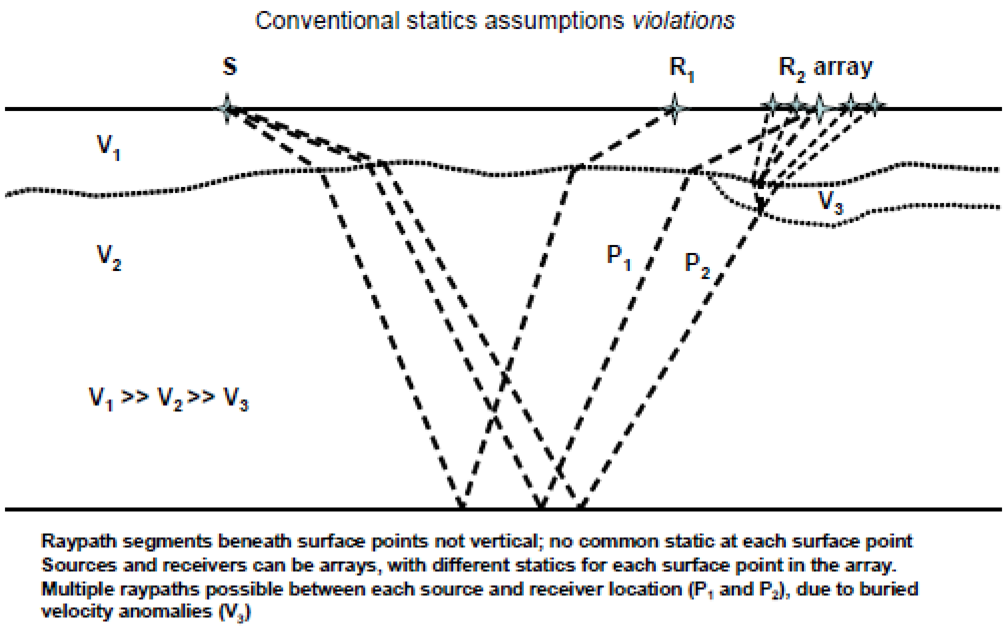
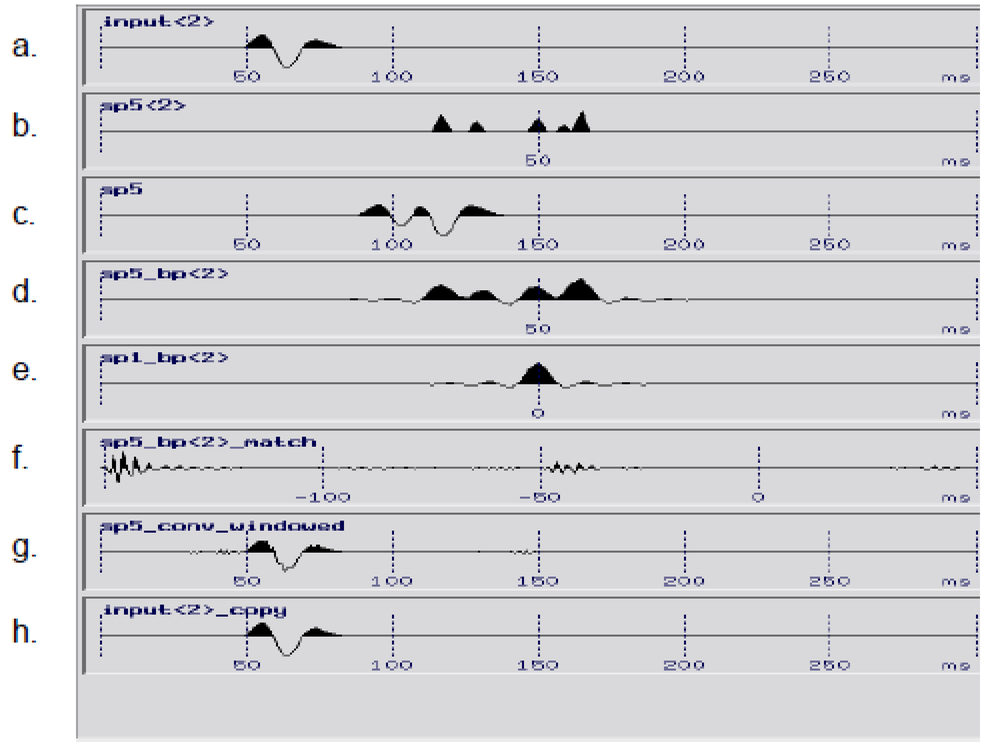
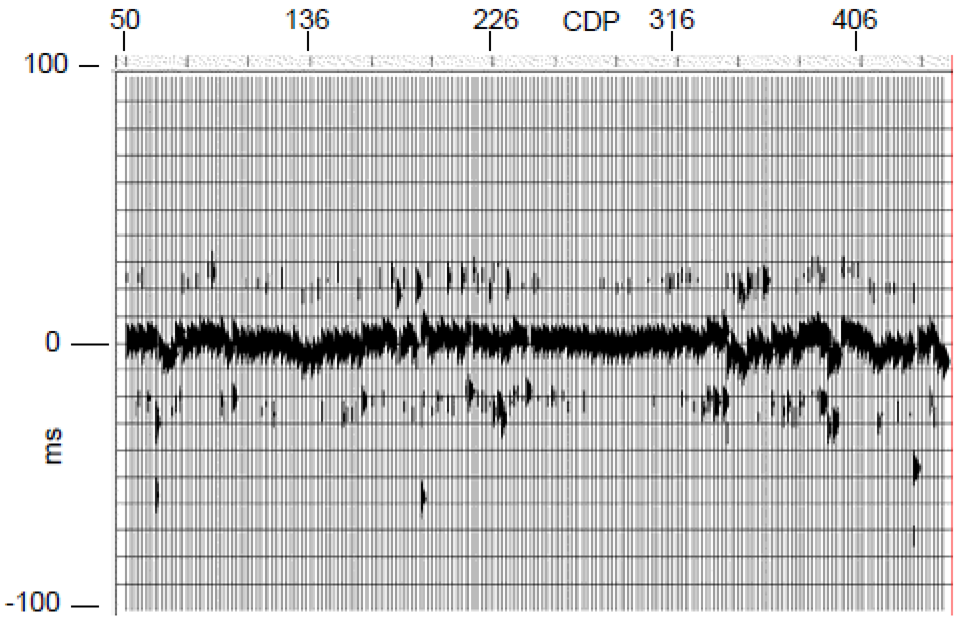


Figure 2. Surface-consistency violated in several ways.

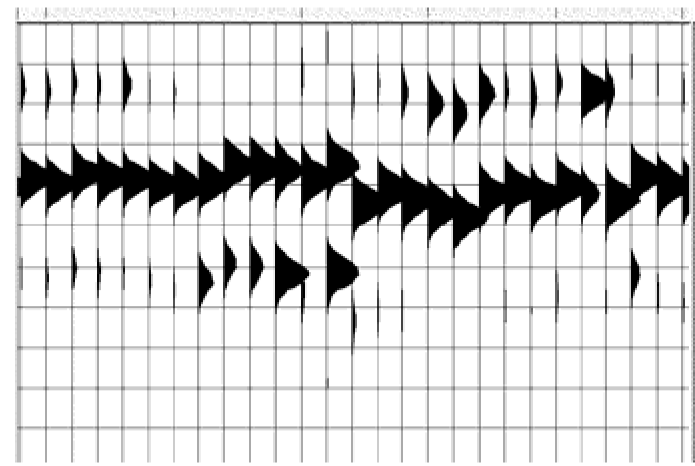


The static deconvolution principle

Figure 3. Deconvolving statics: a.) input seismic trace; b.) spikes representing five different wavefront arrivals; c.) trace a. convolved with spikes b; d.) bandlimited estimate of spike sequence b; e.) bandlimited, zero-shift unit spike; f.) match filter between spike estimate d. and zero-shift spike e; g.) match filter applied to trace c; h.) original input seismic trace for comparison. Note that the effects of the spikes are almost perfectly removed from the trace, even though only bandlimited versions of the spike sequence and zero shift spike were used to derive the match filter. This gives us some hope that even imperfectly estimated statics distribution functions can be used to deconvolve statics.

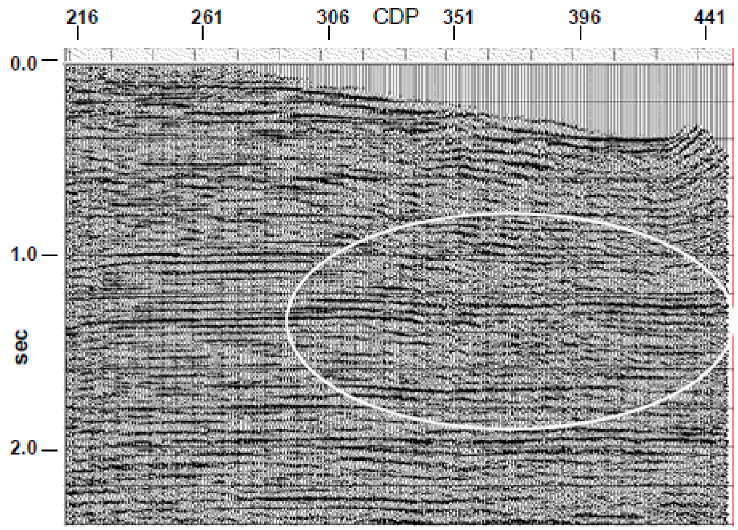


Shot static distribution functions between brute stack pilot traces and raw input shot gathers



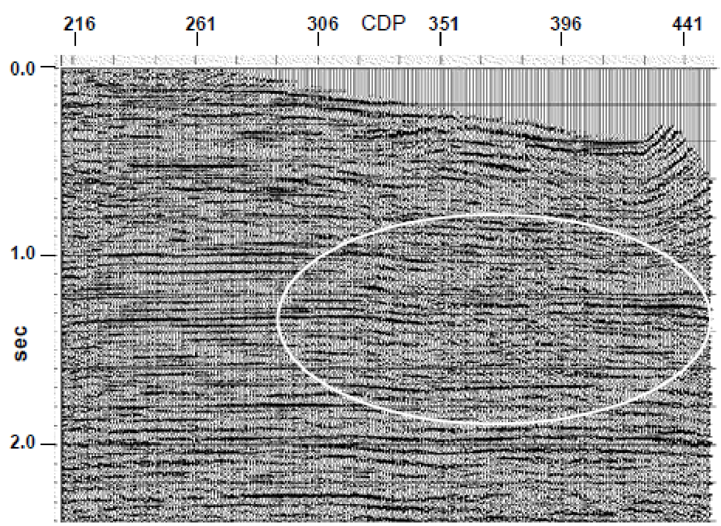
Static distribution functions showing some bimodal distributions—evidence for multi-path?

Figure 4. The distribution functions estimated for Hansen Harbour line. Figure 4a (right) Detail of static distribution functions.



Hansen Harbour stack—pilot trace statics applied by match filter between distribution function and single spike

Figure 5. Hansen Harbour stack with deconvolution statics applied.



Hansen Harbour brute stack—no statics applied

Figure 6. Hansen Harbour brute stack—no statics.