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Measuring Wavelet Phase through the Seismic Processing Sequence

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Summary

We apply a new method of simultaneously estimating surface-consistent statics and phase variations to a land 3C/3D dataset from central Alberta in order to monitor how the phase of the seismic wavelet changes in the land seismic processing flow. We use this method to measure in a quantitative manner the degree to which a typical AVO-compliant processing flow succeeds in producing an image with an embedded wavelet with consistent phase. We also insert this tool at various stages of the flow in order to measure the effect of important processing steps on wavelet phase.

Introduction

The goal of AVO-compliant processing is to attenuate noise as much as possible while at the same time preserve the character of the signal in order to produce a clean, high-resolution final seismic image with an embedded seismic wavelet that is consistent in terms of amplitude, frequency bandwidth and phase. This is a requirement since the interpreter needs to know that any changes in the subtle character of reflectors are caused by geology, and not by some flaw in the processing.

It is straightforward to measure, or at least estimate, the changes in the total amplitude spectrum and bandwidth of the seismic signal at various stages of the seismic processing flow, so we often look at averaged amplitude spectra of seismic trace at various processing steps in order to quality-control our processing.

However, measuring how the phase of the signal changes at various stages in the processing flow is something that is rarely, if ever, done because the processor lacks the means to do it. Typically, determination of the phase of the seismic wavelet is done by the interpreter after processing is complete by matching the seismic image to synthetic seismograms at well locations. How much the wavelet phase is changing during the processing flow, and whether the phase turns out being spatially consistent, is something that we have always wanted to measure, but we have been unable to do so.

Cary and Nagarajappa (2014) introduced a method of measuring and correcting for surface-consistent wavelet phase variations. This method is typically applied once, late in the flow, after noise attenuation, velocity analysis and statics are well determined, but it can also be applied at various stages to monitor how phase is changing, so this is how we use this method in this paper. The method is a straightforward extension of the stack-power maximization algorithm of Ronen and Claerbout (1984) to resolve both statics and phase simulataneously. Although the method is incapable of reliably estimating long-wavelength changes in phase for the same reason that residual statics methods are incapable of estimating long-wavelength statics variations, the method provides highly valuable and accurate results of short and medium wavelength variations.

We measure simultaneous statics and phase variations before and after surface-consistent deconvolution, and before and after surface-consistent residual statics. We are also able to assess the impact on phase of a second pass of surface-consistent deconvolution and measure whether the phase variations are reduced by this extra pass of deconvolution. We attempt to use the method to measure an approximation to the average phase of surface-consistent deconvolution operators in order to assess whether various changes in deconvolution parameters do a better or worse job of removing phase variations in the data.

Example

To illustrate the analysis of phase through the processing sequence, we use the 65 km2 Washout Creek 3C/3D seismic survey from the Arcis Seismic Solutions data library, acquired in 2014. The survey is located in the West Pembina area of Alberta and was designed to assist in the evaluation and development of several plays including the Cretaceous (Cardium, Mannville) and the Devonian (Duvernay). This orthogonal survey used a total of 5340 dynamite shots (0.5kg @ 9m depth) and 7304 three-component accelerometers.

Figure 1 shows a portion of a typical dynamite shot gather before and after application of surface-consistent deconvolution (100ms operator length; 0.01% prewhitening). Before deconvolution, ground roll attenuation was applied, and steps were taken to protect against contamination by high-amplitude traces. Figure 1 clearly shows that deconvolution has broadened the bandwidth of signal and noise. The amount of whitening of the amplitude spectra is shown quantitatively in Figure 2. A lot of noise as well as signal has been whitened by this process, so it is typical to look at stacked data before and after deconvolution to get a clearer indication of the action of deconvolution on the amplitude spectrum of the signal.

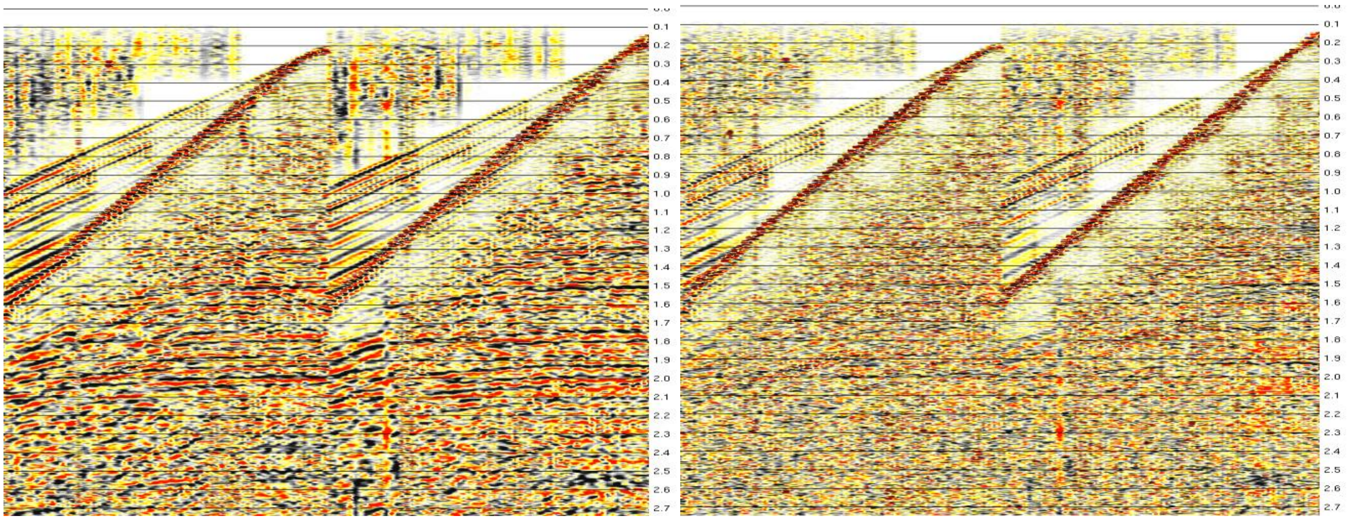

Figure 1: Two receiver lines from a dynamite shot gather before (left) and after (right) surface-consistent deconvolution.

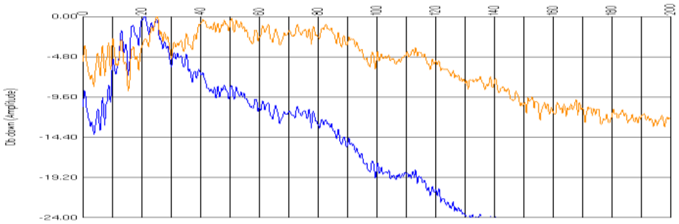

Figure 2: Average amplitude spectra of traces in Fig.1 before (blue) and after (orange) surface-consistent deconvolution.

Surface-consistent deconvolution has two basic purposes: to broaden the amplitude spectrum of the embedded wavelet and to convert the phase spectrum of the embedded wavelet from minimum phase to zero phase. Figures 1 and 2 illustrate the effect of deconvolution on the amplitude spectra, but we would like to measure what is happening to the phase spectra as well. Obtaining absolute zero phase data is often not the real goal of processing since well ties can overcome a bulk phase rotation that often remains after processing. However, it is the goal of processing to remove lateral variations in wavelet phase.

Although consistency of phase has always been the goal of processing, it has always been difficult to measure quantitatively what is happening to phase. The method of Cary and Nagarajappa (2014) enables the measurement of surface-consistent phase variations. The method is sensitive to noise and NMO velocities, so in this analysis final velocities were always used and basic noise attenuation measures such as AGC and frequency filtering (6/12-60/80Hz) were always applied in the phase analysis flows in order to try to increase accuracy. Despite these measures, it is likely that phase measurements early in the processing sequence are more influenced by noise than those later in the flow.

Figure 3 shows maps of the source phase before and after surface-consistent deconvolution as measured by the new method.

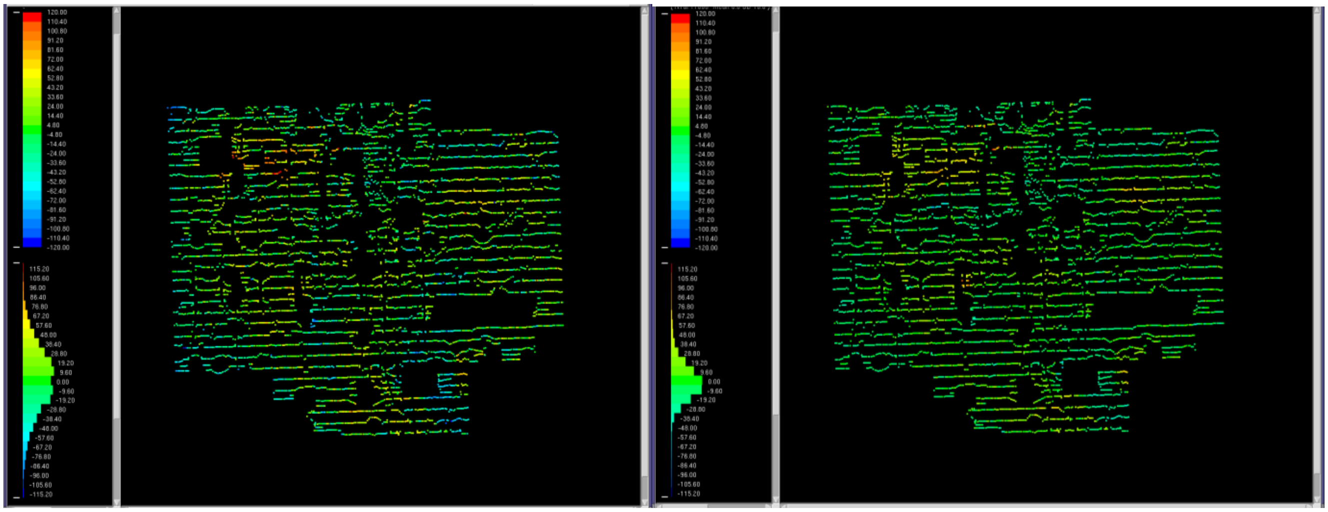

Figure 3: Source phase variations before (left) and after (right) surface-consistent deconvolution. The colour scales are both from -120° (blue) to +120° (red). The standard deviation of phase has been reduced from 26° to 15° by deconvolution.

The source phase maps in Figure 3 indicate that spatial variations in phase have been reduced from a range of roughly ±75° before deconvolution to ±35° after deconvolution, and the standard deviation has been reduced from 26° to 15°. Receiver phase variations show similar reductions from about ±75° before deconvolution to ±35° after deconvolution.

After more noise attenuation and statics were applied to the data, a second pass of surface-consistent deconvolution was applied. The seismic bandwidth was thereby improved, and as Figure 4 shows, the phase variations of both sources and receivers have been further reduced as well. The standard deviations of phase are reduced to about ±10°.

Figure 5 shows a summary of phase variations through the seismic processing sequence in terms of the histograms of source and receiver phase variations before deconvolution, after surface-consistent deconvolution 1, and after surface-consistent deconvolution 2. Surface-consistent deconvolution has a measureable beneficial effect on phase consistency after each pass.

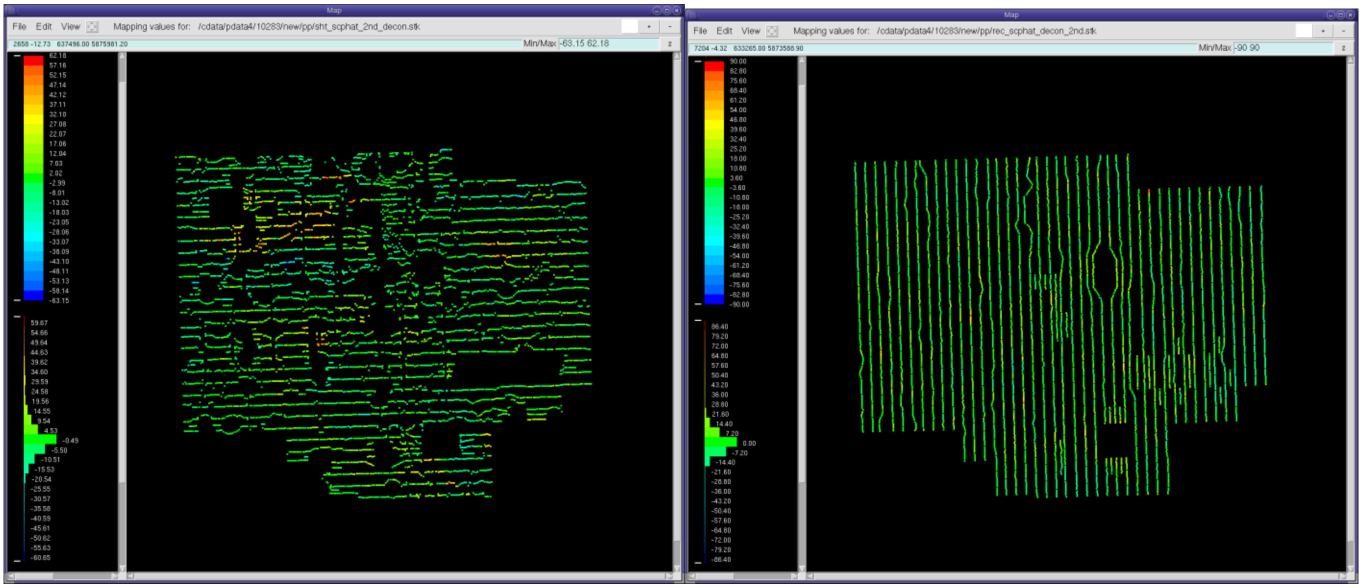

Figure 4: Source phase variations (left) and receiver phase variations (right) after two passes of surface-consistent deconvolution. The colour scales are both from -120° (blue) to +120° (red).

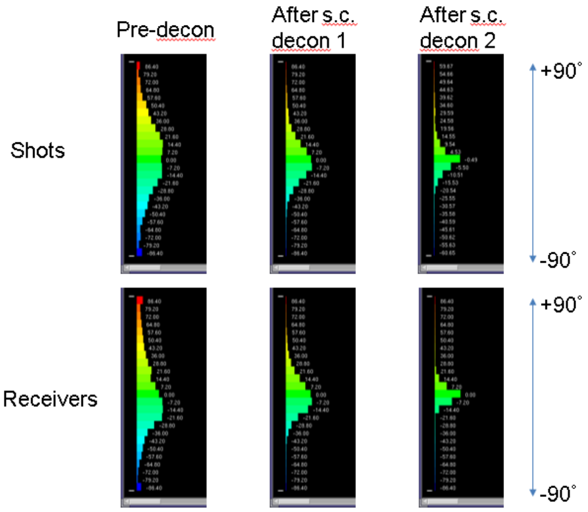

Figure 5: Histograms of source (top) and receiver (bottom) phase variations through the seismic processing sequence.

Conclusions

The surface-consistent phase measurements shown here are results which are for the first time giving information about the action of deconvolution which can be used to improve the control of phase during controlled-amplitude and phase processing. For example, there is evidence that phase variations that remain after one pass of deconvolution can be reduced with a second pass of deconvolution.

Acknowledgements

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References

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Ronen, J. and Claerbout, J.F., 1984, Surface-consistent residual statics by stack optimization, SEG Technical Program Expanded Abstracts, 420-422.