Surface-consistent phase corrections by stack-power maximization

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Summary

In land AVO processing, near-surface heterogeneity issues are resolved through the use of surface-consistent processing. In particular, it is assumed that variable source and receiver wavelet and coupling effects are corrected by surface-consistent deconvolution. Statics solutions are then resolved assuming that surface-consistent phase variations no longer exist. However, surface-consistent wavelet phase errors may still exist in the data after deconvolution due to factors such as surface-consistent noise. If this is true, the phase errors would be difficult to observe because surface-consistent statics would attempt to "resolve" the wavelet misalignments caused by phase variations with statics corrections. We have developed a robust surface-consistent method that simultaneously resolves residual statics and phase rotations by maximizing the stack power. In our solutions we observe that statics and phase estimates are strongly anticorrelated, which is what one would expect if statics were being used to correct phase errors earlier in the processing flow. In addition, phase errors estimated by the method often correlate with features of surface topography and with different source types, which adds to the evidence that residual phase errors are being correctly resolved.

Introduction

Variable source and receiver types, coupling variations, and variable near-surface conditions are the main reasons that surface-consistent processing techniques (deconvolution, statics, scaling) are standardly applied to land seismic data. However, since surface-consistent methods are statistical, factors such as noise prevent them from ever working perfectly, especially if the noise is surface-consistent as well as the signal.

For example, Cary and Nagarajappa (2013) show that surface-consistent noise introduces a bias in the surface-consistent scalars that are derived using the standard surface-consistent amplitude decomposition. This biased surface-consistent scaling solution produces signal amplitudes that are too dim in noisy parts of the stack, whereas the unbiased solution produces more balanced signal amplitudes on the stack.

It has long been known that wavelet-phase estimation is most sensitive to the low-frequency end of the spectrum, which is the most difficult part of the spectrum to reliably measure for land data that is contaminated with source-generated noise (White, 1987). It is reasonable to assume that both signal and noise vary surface-consistently. For example, in a noisy part of the data the signal-to-noise ratio goes down because both signal and noise change: the signal level goes down and the noise level goes up. This will produce surface-consistent errors in low-frequency spectral estimates. So we expect that surface-consistent low-frequency noise could generate surface-consistent errors in wavelet phase after surface-consistent deconvolution. However, wavelet phase can be difficult to estimate reliably in the presence of noise, so methods that try to estimate phase typically suffer from a lack of robustness.

A considerable amount of previous work on surface-consistent phase estimation has been done by Taner et al. (1974, 1981, 1991), Sword (1983), Downie (1988), Ronen and Claerbout (1985), Cambois and Stoffa (1993), Guo and Zhou (2001) and Calvert and Perkins (2001). We have chosen to use aspects from this previous work which we believe provide the most stable, robust solution. Our method of estimating residual wavelet phase is based on the simultaneous maximization of stack-power as a function of both statics and phase, which appears to be very similar to method used by Downie (1988). We have put more effort into examining the character of the solutions than previous workers in order to determine whether our solutions are robust and reliable.

Method

We have chosen to use the following techniques and assumptions in order to obtain a robust method of surface-consistent phase estimation:

- A constant (frequency-independent) phase rotation is assumed for each source and receiver.
- Relative (not absolute) surface-consistent phase variations are estimated.
- Phase and statics corrections are simultaneously estimated.
- The method of stack-power maximization (Ronen and Claerbout, 1985) is used because of its robustness in the presence of noise.

Figure 1 shows a simple synthetic example that illustrates what we believe could be happening to the seismic wavelet during a typical land processing flow: after surface-consistent deconvolution, both residual statics and phase errors may exist as in Figure 1(a). Surface-consistent residual statics is designed to improve the coherence of events, so it does this by aligning peaks with peaks and troughs with troughs as best it can, despite the phase variations, as shown in Figure 1(b). On real data, it would be difficult to know that phase errors remain in the data because the coherence of the events appears good. Our method

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simultaneously estimates both statics and phase corrections, and therefore finds the optimum solution in Figure 1(c). The difference between the coherence of the wavelets in Figure 1(b) and 1(c) may not appear to be large, but this amount of difference could easily be significant when analysing the data for subtle stratigraphic features, AVO variations or reservoir attributes.

Real Data Example

We use a 3D dataset from Ohio (Firestone 3D) to illustrate the phase estimation method. This dataset was acquired with three different source types as shown in Figure 2(a). Vibroseis with a nonlinear sweep was used on the roads in the north part of the survey, Vibroseis with a linear sweep

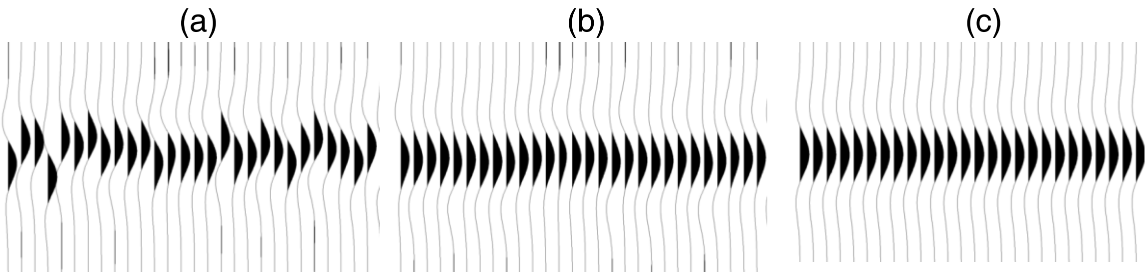

Figure 1*: A simple synthetic example showing (a) a gather with surface-consistent statics and phase variations, (b) the same gather after surface-consistent residual statics correction, and (c) the same gather after simultaneous surface-consistent statics and phase correction.*

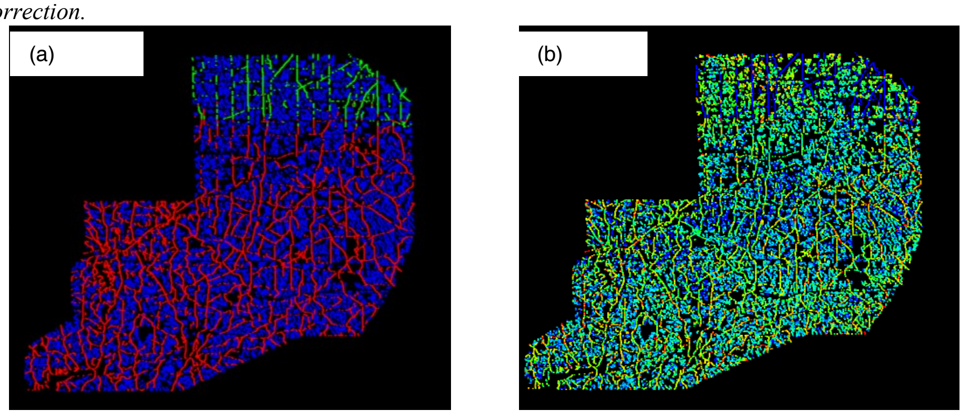

Figure 2*(a): Shot map of the Firestone 3D: Green: Vibroseis with nonlinear sweep, Red: Vibroseis with linear sweep, Blue: dynamite. Figure 2(b): Source phase variations as determined by simultaneous static and phase estimation. An obvious correlation of phase with source type can be observed. : dynamite: -25^0+/-18^0, nonlinear Vib: -104^0+/-16^0, linear Vib:17^0+/-18^0*

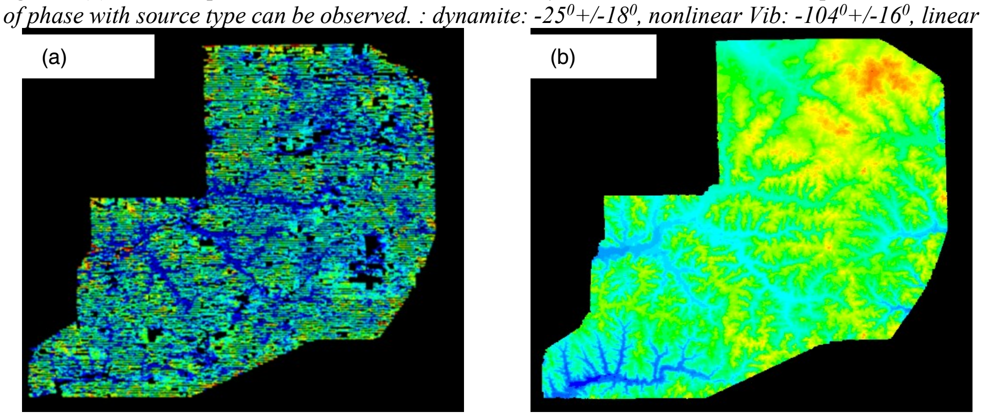

Figure 3*(a): Receiver phase variations as determined by simultaneous statics and phase estimation. The colour scale is blue: -30°, green: 0°, red: 30°. Figure 3(b) CDP elevations: 950ft (blue) to 1350ft (red). There is a clear correlation of receiver phase and drainage features in the surface topography.*

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was used on the roads elsewhere in the survey, and dynamite was used between the roads.

Figure 2(b) shows the source solution from our simultaneous phase and statics estimation method. There is an obvious correlation of phase with source type. The mean and standard deviation of the phase as a function of source type was found to be: dynamite: -25±18°; nonlinear Vibroseis: -104±16°; linear Vibroseis: 17±18°. These phase estimates were confirmed by a separate analysis of phase differences between stacked traces formed with each different source type. In addition, subtle spatial variations possibly due to near-surface source effects are captured in Figure 2(b).

Figure 3(a) shows the spatial variations in receiver phase that were determined by the simultaneous statics and phase estimation. These receiver phase variations show an obvious correlation with features in the surface topography shown in Figure 3(b).

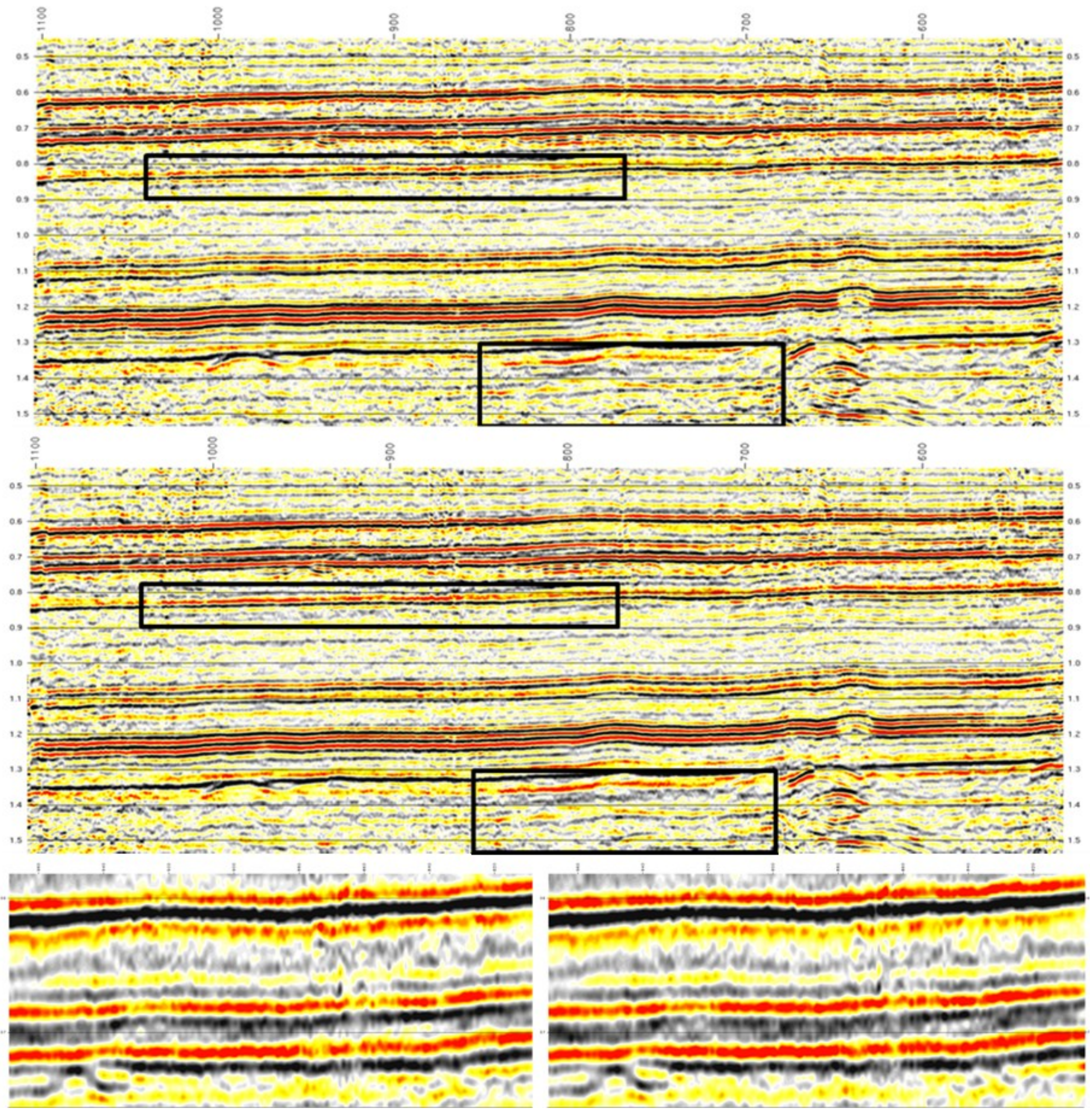

Figure 4*(a)(top): Example of an inline before statics and phase correction, and Figure 4(b)(middle): with phase and statics corrections applied. Expanded view of a part of 4(a) and 4(b) are shown in Figure 4(c) (bottom left): before statics and phase correction and Figure 4(d)(bottom right): after phase and statics corrections applied. Areas of improved wavelet consistency have been highlighted within the boxes. In the expanded view, a few key events are shown.*

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Figure 4 shows CDP stack examples from the northern part of the survey with and without the phase and statics corrections applied. The input to the simultaneous statics and phase estimation was the prestack data that went into the stack in Figure 4(a), which has two previous passes of residual statics applied. When comparing the stacks with and without surface-consistent phase corrections, we note that the phase character of the horizons appears to become more consistent with the corrections applied.

Figure 5 shows cross-plots of the surface-consistent statics and phase for all sources (left) and receivers (right) in the 3D survey. We see that the algorithm has estimated statics and phase errors that are strongly anticorrelated.

We believe that this anticorrelation of statics and phase is due to the fact that previous applications of residual statics in the processing flow have tried to produce coherent events by using statics to correct for phase errors. For example, if the contours in Figure 6 represent the stack-power of a shot or receiver as a function of statics and phase, and the green dot in Figure 6(a) represents the phase and statics error after deconvolution, then residual statics will move the green dot along a line of constant phase to the location in Figure 6(b) in order to maximize the stack power. The subsequent simultaneous statics and phase correction will move the green dot along the red line to the true stack-power maximum, which explains the anticorrelation of statics and phase in Figure 5.

Conclusions

Real data examples show that stack-power and image quality are improved in a robust fashion with the simultaneous estimation of statics and phase corrections. We typically apply the process after residual statics are applied, and we observe that statics and phase corrections are strongly anticorrelated. We explain the observed anticorrelation by the fact that previous residual statics applications in the processing flow were improperly trying to correct residual phase errors with statics corrections. Maps of phase errors often show good correlation with features of the surface topography. In addition, phase differences between different source types are reliably estimated with the new algorithm when compared with a standard method of phase estimation at overlapping CDP stack locations.

In addition to providing more reliable reservoir characterization, we expect this method to be useful in the merging of land 3D surveys and in land time-lapse processing. The method is capable of resolving short to medium wavelength phase errors, but as with all surface-consistent methods, long wavelength variations in phase will be difficult to resolve.

Acknowledgements

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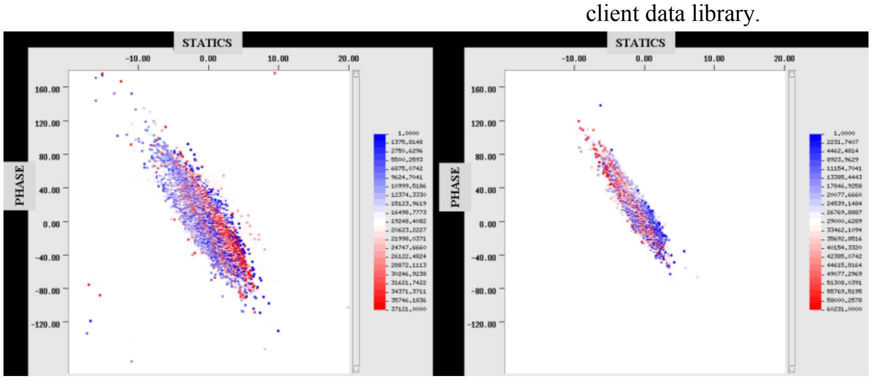

Figure 5: *Cross-plots of statics versus phase for all sources (left) and receivers (right) in the Firestone 3D survey.*

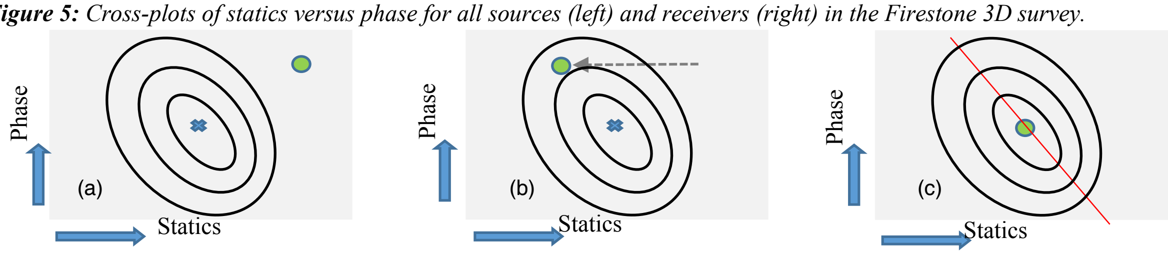

Figure 6: *Example of a shot or receiver with a statics and phase error represented by the green dot on a map of contoured stack-power (a) after deconvolution, (b) after residual statics, and (c) after simultaneous statics and phase correction.*

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EDITED REFERENCES

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