Tu E103 12

Robust Surface-consistent Phase Estimation

P.W. Cary* (Arcis Seismic Solutions, TGS) & N. Nagarajappa (Arcis Seismic Solutions, TGS)

SUMMARY

We have developed a robust method of estimating surface-consistent residual wavelet phase that is based on the simultaneous maximization of stack-power as a function of both statics and phase. 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 the algorithm comes up with statics and phase corrections that are strongly anti-correlated. We explain the observed anti-correlation by the fact that previous residual statics steps 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. These observations lead us to believe that the phase errors that are estimated with this method are real and are being robustly estimated.

Introduction

Variable source and receiver types, coupling variations, and variable near-surface conditions are the main reasons why 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 surface-consistent processes from ever working perfectly, especially if the noise is surface-consistent as well as the signal. For example, we expect that surface-consistent noise will 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.

We have developed a robust method of estimating surface-consistent residual wavelet phase that is based on the simultaneous maximization of stack-power as a function of both statics and phase. 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 the algorithm comes up with statics and phase corrections that are strongly anti-correlated. We explain the observed anti-correlation by the fact that previous residual statics steps 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. These observations lead us to believe that the phase errors that are estimated with this method are real and are being robustly estimated.

Method

A considerable amount of previous work on surface-consistent phase estimation has been done by Taner et al. (1974, 1980, 1981), Sword (1983), Downie (1988), Ronen and Claerbout (1985), Cambois and Stoffa (1993), Guo and Zhou (2001). Despite all of this previous work, surface-consistent phase estimation is generally never included in standard processing flows. This is presumably due to doubts about the reliability of the phase estimates.

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 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.

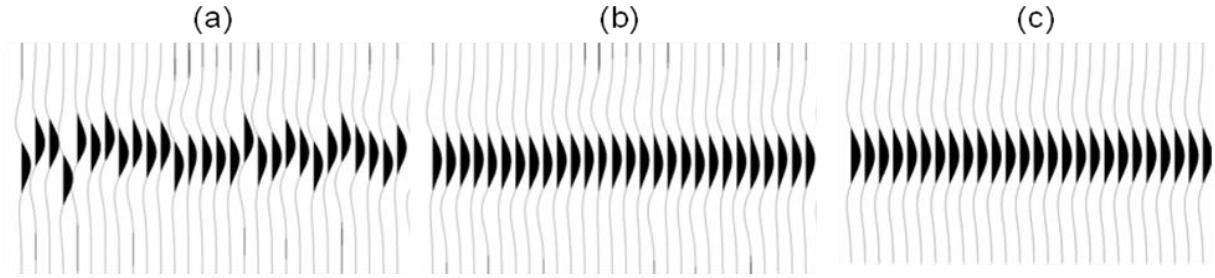

Figure 1 *A simple synthetic example showing (a) a gather with surface-consistent statics and phase variations, (b) the same gather after surface-consistent residual statics correction, and (c) the same gather after simultaneous surface-consistent statics and phase correction.*

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

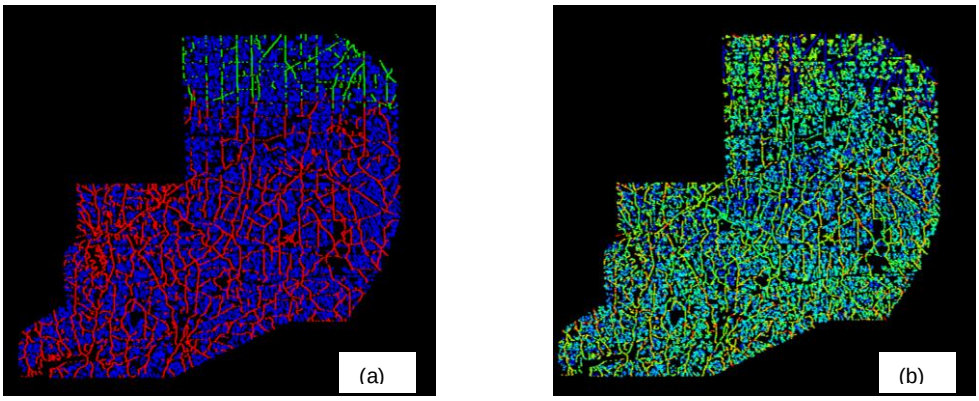

Figure 2*(a): Shot map of the Firestone 3D: Green: Vibroseis with nonlinear sweep, Red: Vibroseis with linear sweep, Blue: dynamite. Figure 2(b): Source phase variations as determined by simultaneous static and phase estimation. An obvious correlation of phase with source type can be observed.*

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.

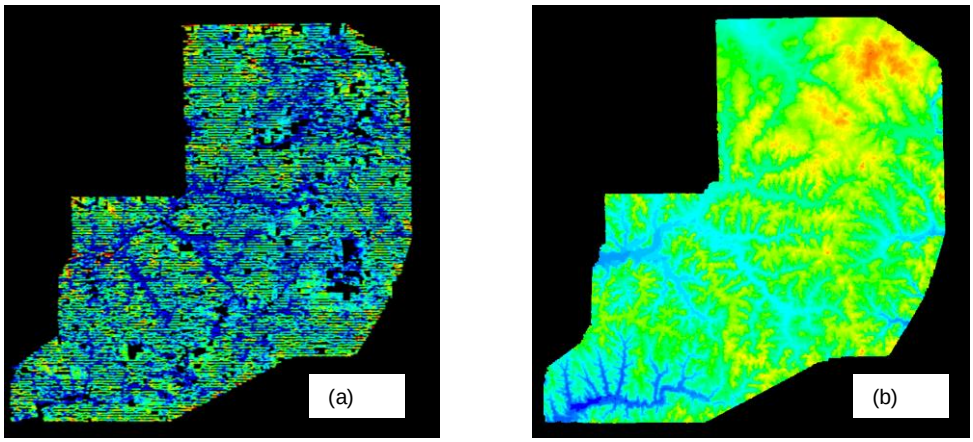

Figure 3*(a): Receiver phase variations as determined by simultaneous statics and phase estimation. The colour scale is blue: -30°, green: 0°, red: 30°. Figure 3(b) CDP elevations: 950ft (blue) to 1350ft (red). There is a clear correlation of receiver phase and drainage features in the surface topography.*

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 shows an example of an inline 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 be become more consistent with the corrections applied (e.g. the red horizon between 800 and 850ms).

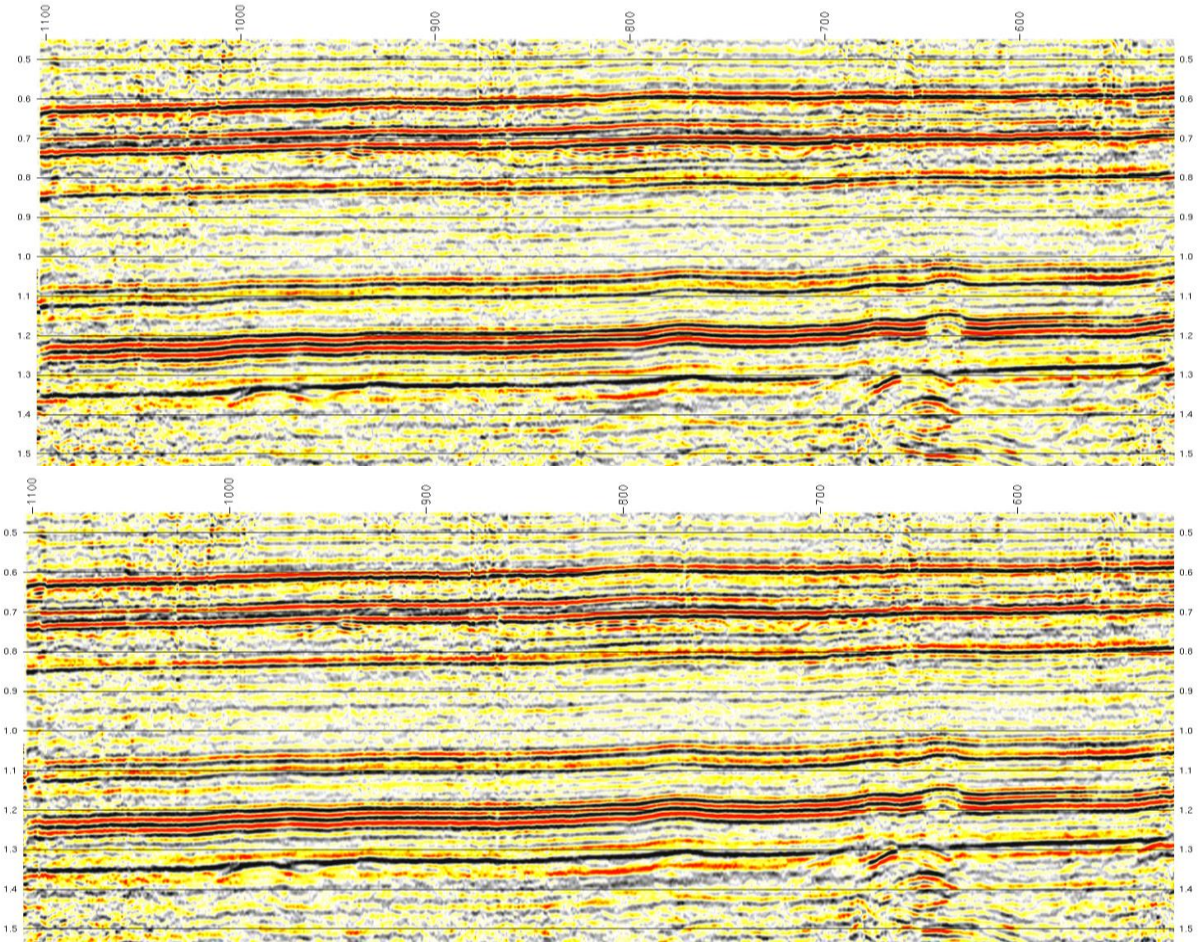

Figure 4*(a)(top): Example of an inline before statics and phase correction, and. Figure 4(b)(bottom): with phase and statics corrections applied.*

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 anti-correlated.

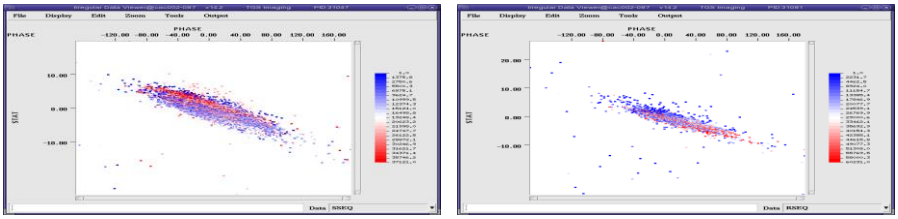

Figure 5 *Cross-plots of statics versus phase for all sources (left) and receivers (right) in the Firestone 3D survey.*

We believe that this anti-correlation 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. Regardless of the original location of the green dot, the statics and phase will lie somewhere along the red line, as observed in Figure 5.

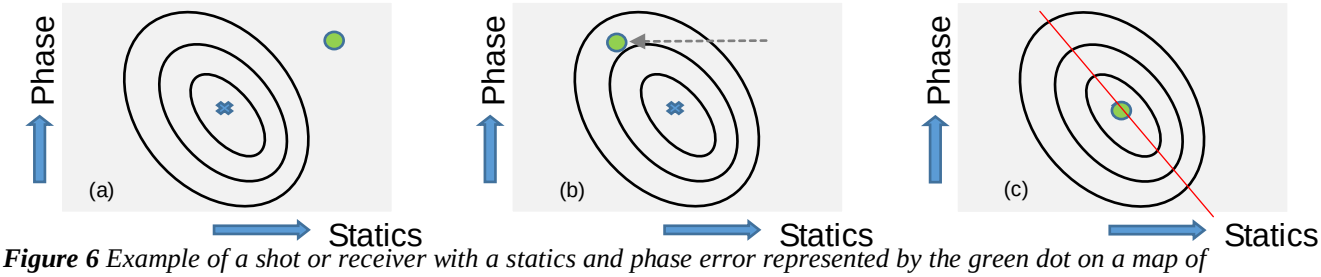

Figure 6 *Example of a shot or receiver with a statics and phase error represented by the green dot on a map of contoured stack-power (a) after deconvolution, (b) after residual statics, and (c) after simultaneous statics and phase correction.*

Conclusions

We have presented the basic methodology of a method for simultaneously estimating surface-consistent phase and statics errors. Not only is the method robust, but the phase errors that it estimates appear to be reliable because the stack-power is improved, the phase maps make physical sense in relation to surface features, correlation with source type, and the observed anti-correlation of statics and phase estimates. We expect this method to be capable of resolving short to medium wavelength phase errors, but as with all surface-consistent methods, long wavelength variations in phase will be virtually impossible to resolve.

Acknowledgements

We thank TGS for permission to publish this paper. The data example is the Firestone 3D (Ohio) from the TGS multi-client data library.

References

Cambois. G. and Stoffa, P. [1993] Surface-consistent phase decomposition in the log/Fourier domain, *Geophysics*, 58, 1099-1111.
Downie, A. L. [1988] Near-surface corrections, 58th SEG Annual International Meeting, Extended Abstracts, 780-782.
Guo, J. and Zhou, X. [2001], Surface-consistent phase corrections, 71st SEG Annual International Meeting, Extended Abstracts.
Ronen, J. and Claerbout, J.F. [1985] Surface-consistent residual statics estimation by stack-power optimization, *Geophysics*, 50, 2759-2767.
Sword, C. [1983] The generalized frequency-dependent surface-consistent statics problem: Stanford Expl. Proj. Rep. 35, 19-41.
Taner, M.T. and Coburn, K.W. [1980] Surface-consistent estimation of source-and-receiver response functions, 50th SEG Annual International Meeting, Extended Abstracts.
Taner, M.T. and Koehler, F., 1981, Surface-consistent corrections, *Geophysics*, 46, 17-22.
Taner, M.T. Koehler, F. and Alhilali, K.A. [1974], Estimation and corrections of near-surface time anomalies, *Geophysics*, 39, 441-463.