Nonstationary phase estimation: A tool for seismic interpretation?

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Summary

Phase mismatches sometimes occur between final processed seismic sections and zero-phase synthetics based on well logs – despite best efforts for controlled-phase acquisition and processing. Statistical estimation of the phase of a seismic wavelet is feasible using kurtosis maximization by constant phase rotation, even if the phase is nonstationary. After estimation, we achieve space-and-time-varying zero-phasing by phase rotation. We demonstrate how a statistical analysis provides pertinent information about the data that can be used for zero-phasing, as a quality control to check deterministic phase corrections, or even as an interpretational tool for highlighting areas of potential interest or areas of potential wavelet instability.

Introduction

Controlled-phase acquisition and processing plays an important role in current acquisition and processing strategies (Trantham, 1994). Despite best efforts to control the phase of the wavelet during the entire acquisition and processing sequence, phase mismatches regularly occur between final processed data based on deterministic zero-phase shaping and zero-phase synthetics created from well logs. Existing well logs act here as ground truth, and a further phase correction is applied to the data such that they match the zero-phase synthetics. Unfortunately, well logs are not always available, nor are they always accurate; moreover, different wells can predict different phase corrections, or the phase mismatch can vary with time. Statistical wavelet-estimation methods do not require well logs and analyze the seismic data directly.

Theory and/or Method

We employ the statistical method of Van der Baan (2008) and Van der Baan and Fomel (2009) to estimate the nonstationary amplitude spectrum and phase of a seismic wavelet. This method applies a series of phase rotations to the data. The angle where the resulting output is maximally non-Gaussian corresponds to the desired zero-phase trace. This method is made robust by casting the problem into the framework of local attributes (Fomel, 2007), leading to a regularized least-squares optimization across the entire seismic section (Fomel et al., 2007). This allows for the use of smaller analysis windows such that the resulting technique cannot only be used for zero-phasing seismic data, but also as an analysis tool for detecting subtle stratigraphic features in the local geology or for detecting temporal and/or spatial variations in the embedded seismic wavelet.

Case History

In this presentation we focus on a dataset from the Western Canadian Sedimentary Basin also analyzed in Perz (2001). The dataset is known to display unusually large variations in both local frequency content and local phase, particularly below a sequence of coal layers. Both the nonstationary frequency content and phase variations are attributed to stratigraphic filtering due to the highly fluctuating velocity and density variations within the coal sequence, leading to frequency-dependent transmissivity (Figure 1). Variations in thin-layering can also lead to phase changes. An isolated thin bed such as a high-velocity chalk marker leads to a well-known seismic response with approximately a 90-degrees phase shift; by contrast, an irregular sequence of thin beds of varying thicknesses is unlikely to display the same characteristic response. Local phase analysis can thus help to detect subtle variations in thin-layering and also to highlight areas in which the embedded wavelet exhibits phase instability (Figure 2).

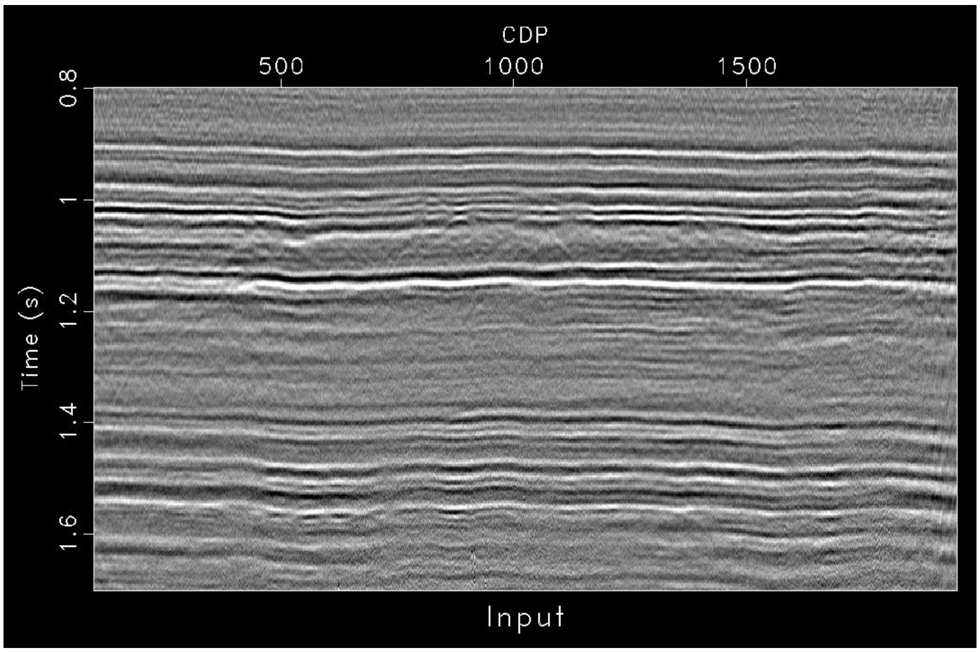

Figure 1: *Stacked section displaying large variations in local frequency content. The coals are at t=1.05s. Variations in peak frequency can for instance be seen by comparing the section on the left and right of CMP 450 between 1.4 and 1.6 s. These variations result from frequency-dependent stratigraphic filtering through the overburden.*

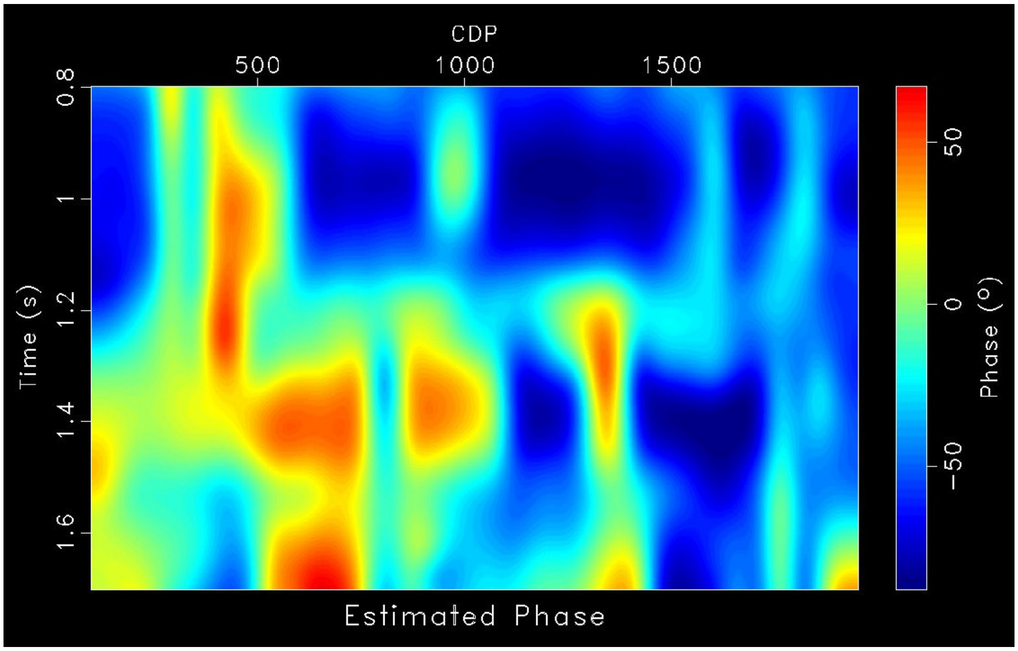

Figure 2: *Estimated phase. Large variations in phase occur throughout the seismic section highlighting potential areas of interest. This happens for instance around CMP 450 between t=1.4 and 1.6 s but also below the pinch out at CMP 1300 at t=1.17s.*

Conclusions

Kurtosis maximization by constant phase rotation is a useful tool for nonstationary phase estimation. Statistical phase analysis can not only be used to extract nonstationary seismic wavelets suitable for deconvolution, as a quality control to check deterministic phase corrections resulting from seismic-to-well ties but also as an interpretional tool either to highlight areas of subtle stratigraphic variations in the local geology (including pinch outs, and variations in turbidite and coal sequences, meandering channels and carbonate reefs) or to red-flag spatial variations in wavelet character.

Acknowledgements

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