GeoConvention
Calgary • Canada • March 7-11 2016
OPTIMIZING RESOURCES

Using corrected phase to localize geological features in seismic data

Heather K. Hardeman, Michael P. Lamoureux
CREWES, University of Calgary

Summary

We consider the time-frequency analysis method, basis pursuit. We look specifically at the phase attribute produced from the results of running basis pursuit on various data sets. We explore the numerical results of derivative of the corrected phase attribute proposed in (Han et al.,2015). We consider the phase attribute provided by other spectral decomposition methods, continuous wavelet transform and synchro-squeezing transform, and apply the derivative of the corrected phase process to these attributes. We end with a comparison of the results for basis pursuit to those of continuous wavelet transform and synchro-squeezing transform.

Introduction

Time frequency analysis, or spectral decomposition, characterizes seismic signals with respect to frequency and time. From this information, we can derive seismic attributes for the purposes of localizing geological features in seismic data. Popular time-frequency analysis methods include the continuous wavelet transform (CWT) and the short-time Fourier transform (STFT) as well as other spectral decomposition methods include the synchro-squeezing transform (SST) and basis pursuit.

In (Han et al.,2015), the authors apply all four of these methods to seismic data and compare the results experimentally. They found that basis pursuit provided the most promising results. Specifically, they discussed the amplitude and phase attributes. They also proposed a derivative of corrected phase attribute which we will discuss in the next section. We will focus on the time-frequency analysis method, basis pursuit, and consider applications of the derivative of the corrected phase attribute. We will also compare these results to the results provided by other time-frequency methods when considering the derivative of the corrected phase method.

Basis Pursuit and the Derivative of Corrected Phase Method

The spectral decomposition method basis pursuit decomposes the signal from seismic data into individual atoms of a predefined dictionary. In time-frequency analysis, atoms are elementary waveforms which are discrete and populate a given dictionary (Tary et al., 2014). Specifically, the signal can be represented in series or matrix notation.

Basis pursuit involves the following two steps: (1) a minimization term used to reduce the number of retrieved atoms as well as their magnitude, and (2) simultaneously identifying all the atoms by applying a single inversion problem.

In particular, the method we used involved basis pursuit denoising. The object was to minimize the cost function:

$$J = ||\boldsymbol{s} + D\boldsymbol{a}||_2^2 + \lambda||\boldsymbol{a}||_1$$

where the first term is the least-squares difference between the observed data and the predicted data, and the second term is the regularization term where lambda controls the relative strength between the data misfit and the number of non-zero coefficients of the vector **a**.

This algorithm is guaranteed to converge eventually to a local optimum. The success of basis pursuit depends heavily on the predefined dictionary; however, while a larger wavelet dictionary provides better results, it also causes a longer computation time of the algorithm.

In (Han et al.,2015), the authors noted arbitrary horizontal lines which did not provide any information when considering the phase attribute produced by time-frequency analysis methods. As such, the derivative of the corrected phase method attempts to eliminate these coherent lines. To correct the phase, it takes the time-dependent curve from the phase attribute produced by a spectral decomposition method and unwraps the curve before fitting it to a quadratic equation. After which, the quadratic is subtracted from the original curve. Taking the derivative of these residuals highlights the change in phase. Theoretically, it highlights the boundary of the geological structures.

Examples

We apply basis pursuit to following post-stack data set which is known as the CREWES Blackfoot data set; however, we will refer to it as the valley data set based on the geological feature we are interested in identifying. While we could consider several different seismic attributes with these results, we focus on the phase attribute.

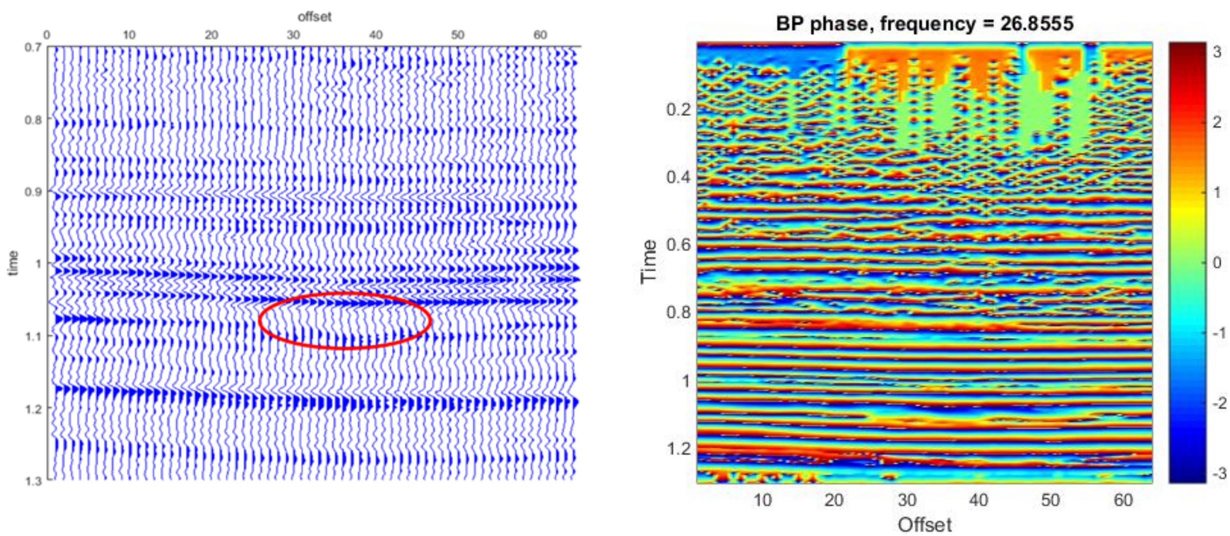

Fig. 1: The post-stack data of CREWES Blackfoot data set (left). The phase attribute produced by basis pursuit for the CREWES Blackfoot data set at approximately 26 Hz (right).

At approximately 26 Hz, the valley is relatively easy to localize using the phase attribute produced by basis pursuit. The arbitrary horizontal lines distract from locating the valley. Thus, applying the derivative of the corrected phase method, we find that these coherent lines are smoothed to some degree and pinpointing the valley becomes much clearer. Consulting Fig. 2, we see that the boundary of the valley is evident when considering the derivative of the corrected phase attribute.

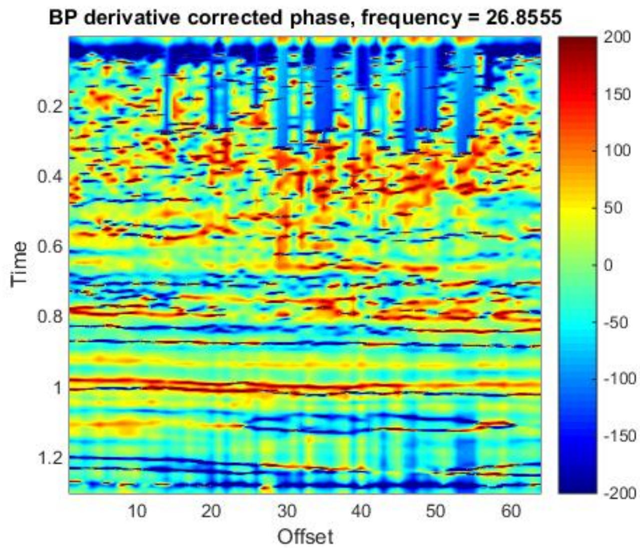

Fig. 2: Derivative of the corrected phase method for the CREWES Blackfoot data set at approximately 26 Hz using basis pursuit.

Now, we compare these results to those of the continuous wavelet transform (CWT) and the synchro-squeezing transform (SST).

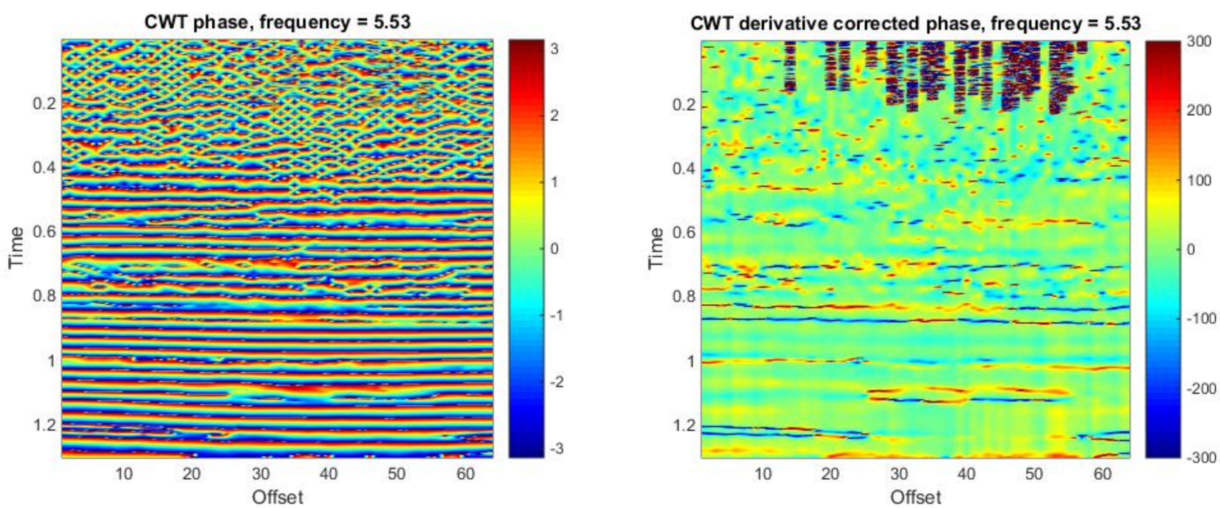

Fig. 3: Phase attribute for the CREWES Blackfoot data set at approximately 6 Hz using CWT (left). Derivative of the corrected phase method for the CREWES Blackfoot data set at approximately 6 Hz using the CWT (right).

For CWT, the valley can be localized at approximately 6 Hz when considering the phase attribute; however, the valley is not as clear as it is for basis pursuit. Similarly, the derivative of the corrected phase method highlights the boundary of the valley when using the results from the phase attribute produced by CWT. As with the phase attribute, note that the boundary of the valley is not as bold using the results of CWT as it is for the results of basis pursuit.

For SST, the valley is impossible to identify when using the phase attribute. In Fig. 4 (left), the phase attribute is plotted at approximately 18 Hz. On the right in Fig. 4, the derivative of the corrected phase method is applied to the phase attribute and again, the valley is impossible to locate.

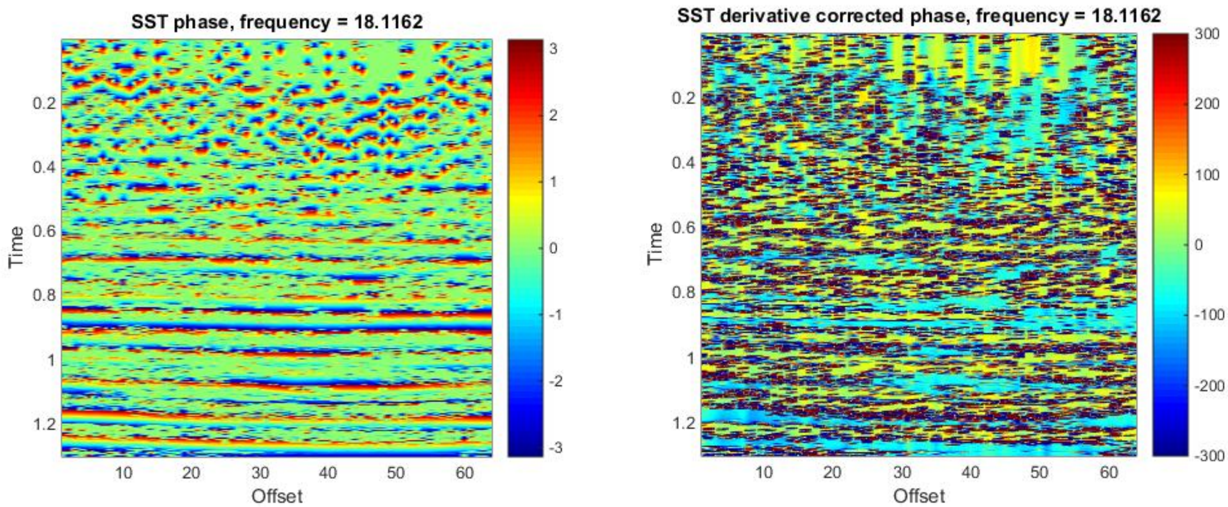

Fig. 4: D Phase attribute for the CREWES Blackfoot data set at approximately 18 Hz using SST (left). Derivative of the corrected phase method for the CREWES Blackfoot data set at approximately 18 Hz using the SST (right).

The inability to localize the valley in the phase attribute thus appears to affect the ability to locate the valley when the derivative of the corrected phase method is applied to the data set.

It should be noted that these data sets were considered over a range of frequencies. Making a “movie” of the data where each frame corresponded to a frequency in this range, the geological features were much clearer. Also, it was possible to see the structure form over the range of frequencies.

Conclusions

We demonstrated the effectiveness of basis pursuit in identifying geological features when consulting the phase attribute. We also exhibited the extended capabilities of locating geological structures in seismic data once the phase is corrected and we considered the derivative of the corrected phase. We observed that to some degree the success of the derivative of the corrected phase method is dependent on how clearly the phase attribute localizes the geological feature. This result is evident with all time-frequency analysis methods we considered. As in (Han et al.,2015), basis pursuit performed the best with respect to the phase attribute as well as the derivative of the corrected phase method. The continuous wavelet transform performed adequately for the data set and both methods whereas the synchro-squeezing transform struggled to identify the valley.

Acknowledgements

The authors gratefully acknowledge the financial support of the industrial sponsors of the CREWES project at the University of Calgary. This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13 and the second author's Discovery grant. CGG and the CREWES consortium of Calgary, Alberta graciously provided both data and software tools for the project.

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