The application of a self-adaptive generalized S-transform in seismic time-frequency analysis

Naihao Liu[1,2], Bo Zhang[2], Jinghuai Gao[1], Qian Wang[1], and Jie Qi[3]

[1]Xi'an Jiaotong University, China; [2]University of Alabama, United States; [3]University of Oklahoma, United States.

Summary

Choosing a proper time-frequency (TF) resolution for TF analysis is the key to obtain the reservoir properties from seismic data. The objective of this research is adaptively setting a proper TF resolution for the widely used generalized S transform (GST).

The self-adaptive generalized S-transform

The modified Gaussian window of the GST (Chen et al., 2009) is expressed as

$$g(t)=\frac{kf^{p}}{\sqrt{2\pi}}e^{-\frac{k^{2}f^{2p}t^{2}}{2}}, \qquad (1)$$

where k and p are adjustable parameters. The generalized S transform is then denoted as

$$GST(\tau,f)=\int_{-\infty}^{\infty}s(t)\frac{\left|kf^{p}\right|}{\sqrt{2\pi}}e^{-\frac{(t-\tau)^{2}(kf^{p})^{2}}{2}}e^{-i2\pi ft}dt, \qquad (2)$$

Using the Parseval's theorem, equation (2) is rewritten in frequency domain as

$$GST(\tau,f)=\int_{-\infty}^{\infty}S(\alpha+f)e^{-\frac{2\pi^{2}\alpha^{2}}{(kf^{p})^{2}}}e^{i2\pi\alpha\tau}d\alpha. \qquad (3)$$

Considering that the instantaneous frequency (IF) varies with the time-thickness of a wedge model, we propose the following workflow to adaptively set the TF resolution for the GST.

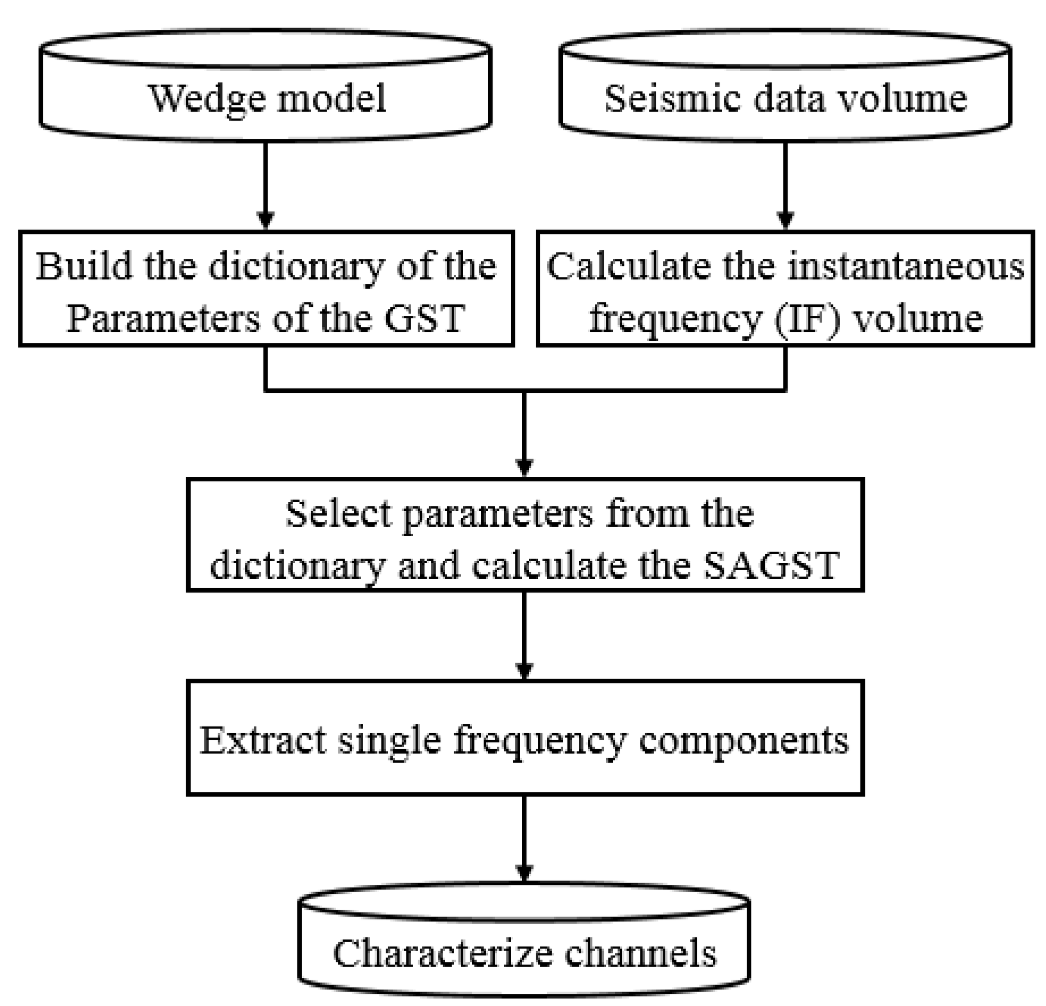

Figure 1: The workflow of the proposed SAGST.

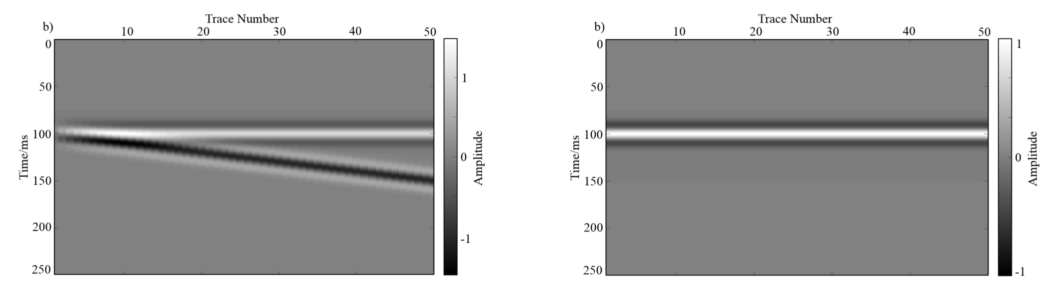

Figure 2: (a) The synthetic wedge model and (b) synthetic model with single reflection. The reflectivity pair of the wedge model has the same magnitude with opposite polarity.

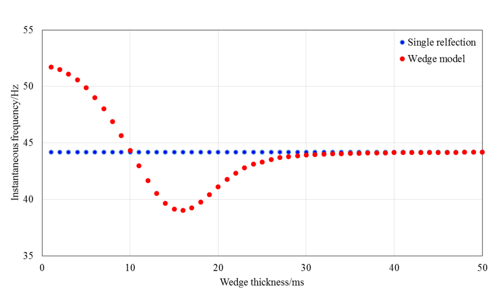

Figure 3: IF extracted from the single reflection (blue) and wedge model (red). The time location of the IF is at the first reflectivity location.

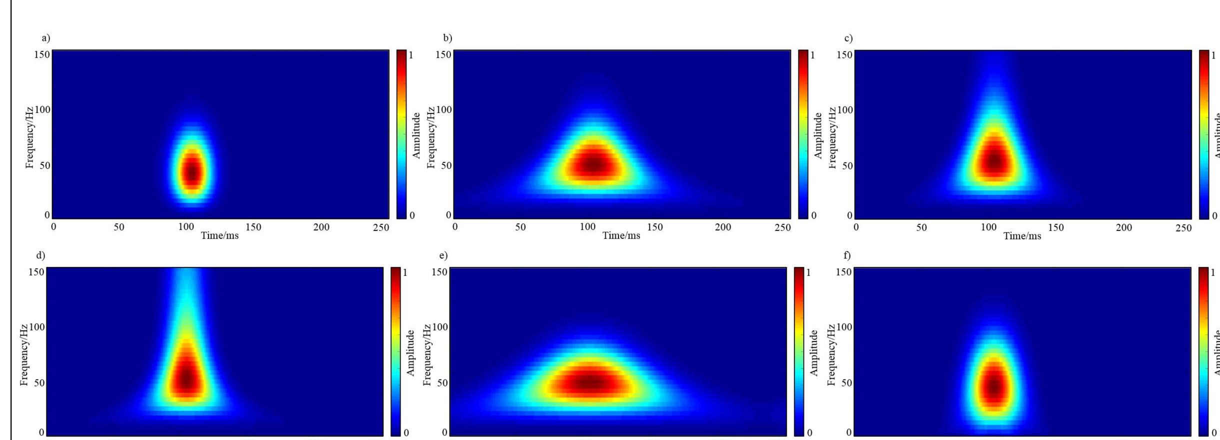

Figure 4: The normalized TF spectra of the 9th trace. (a) The theory TF spectrum, TF spectra calculated by the (b) standard ST, (c) MST (Li and Castagna, 2013) with (1.2,5), (d) GST with (1.2,1.2), (e) GST with (0.9,0.9), and (f) SAGST, respectively.

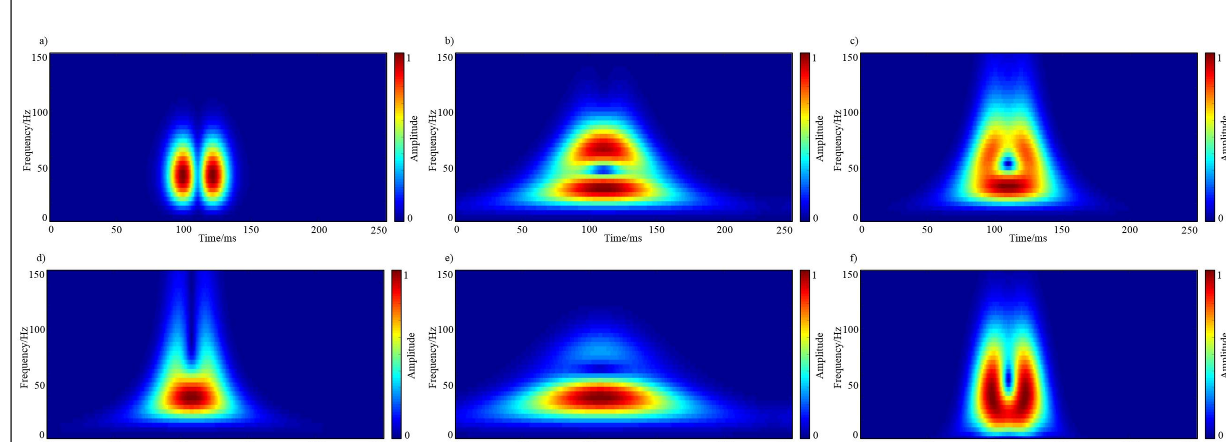

Figure 5: The normalized TF spectra of the 21st trace. (a) The theory TF spectrum, TF spectra calculated by the (b) standard ST, (c) MST with (1.2,5), (d) GST with (1.2,1.2), (e) GST with (0.9,0.9), and (f) SAGST.

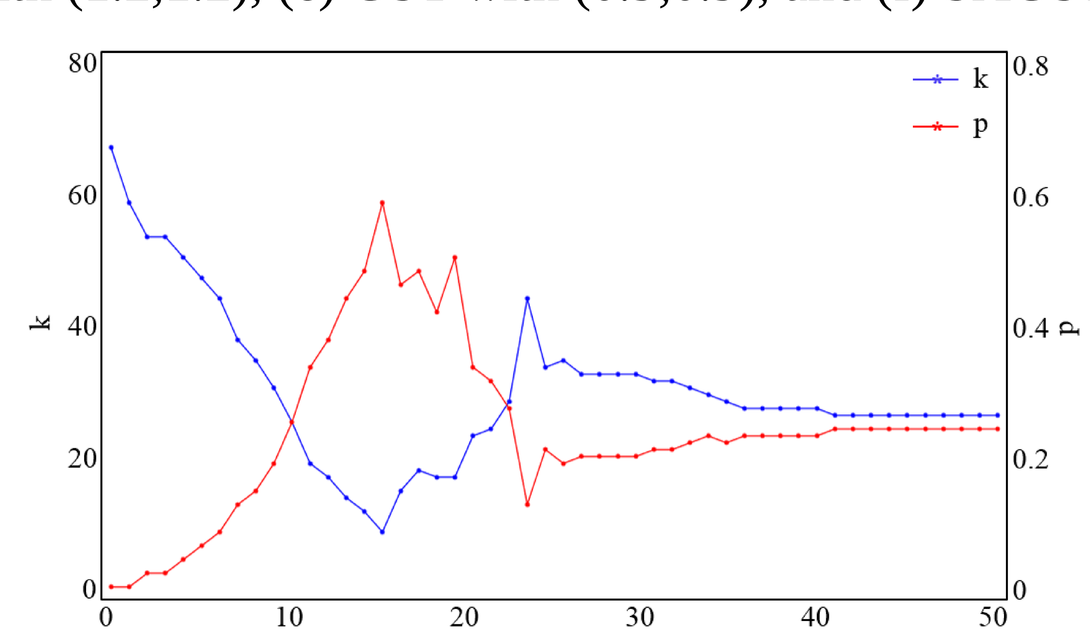

Figure 6: The optimized k (blue star line) and p (red star line) for different time thickness according to the IF parameters.

Synthetic data examples

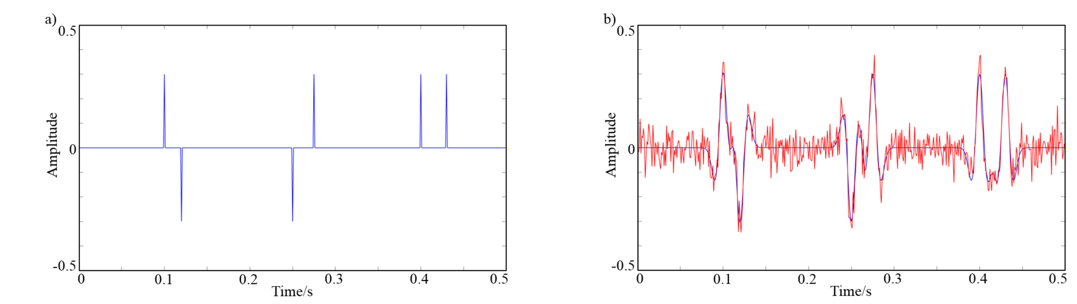

Figure 7: (a) Reflectivity, (b) noise-free trace (blue) and noisy trace (red) added with Gaussian white noise. The SNR is 5 dB. The first and second sets contain two reflectivity with opposite magnitude of 0.3. The third set contains two reflectivity with same magnitude of 0.3. The time thicknesses of the first, second, and third pairs are 20 ms, 25 ms, and 30 ms.

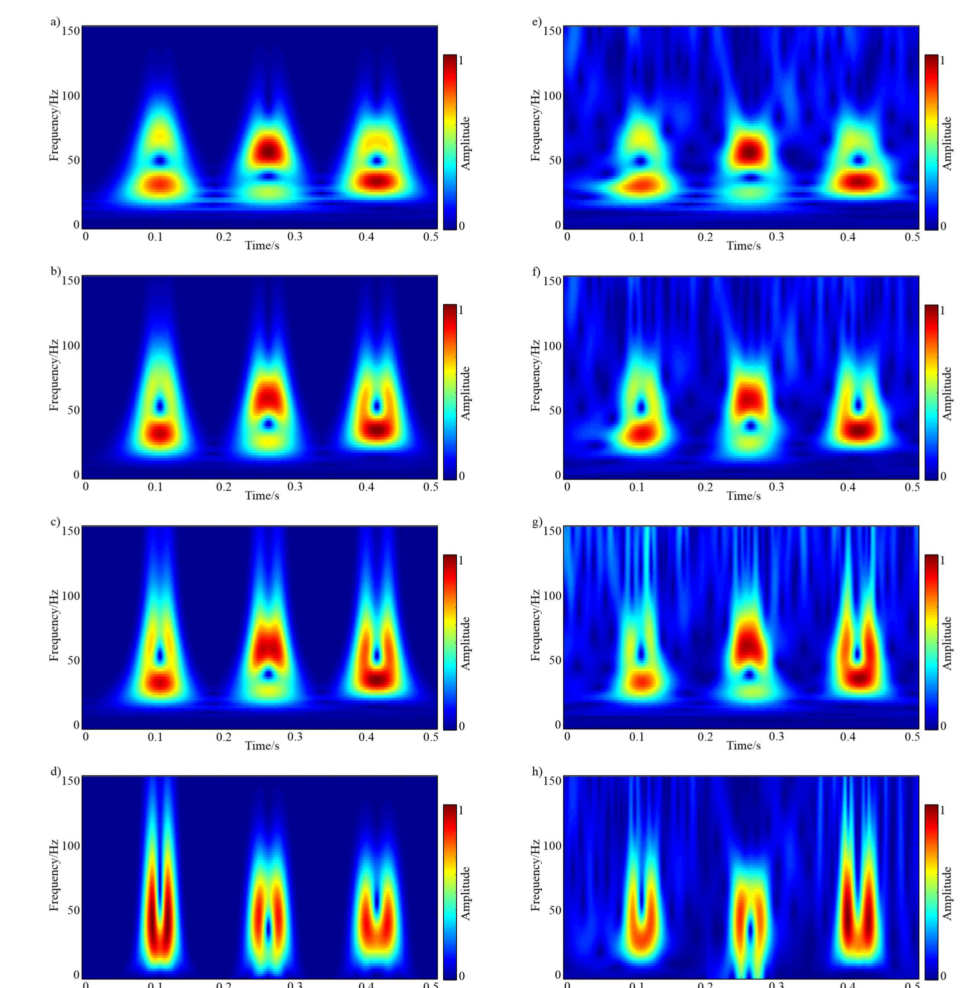

Figure 8: TF spectra of the noise-free and noisy seismic synthetic traces. Noise-free TF spectra calculated using the (a) standard ST, (b) MST with (1.2,5), (c) GST with (1.2,1.2), and (d) SAGST; noisy TF spectra calculated by the (e) standard ST, (f) MST, (g) GST, and (h) SAGST, respectively.

Field data

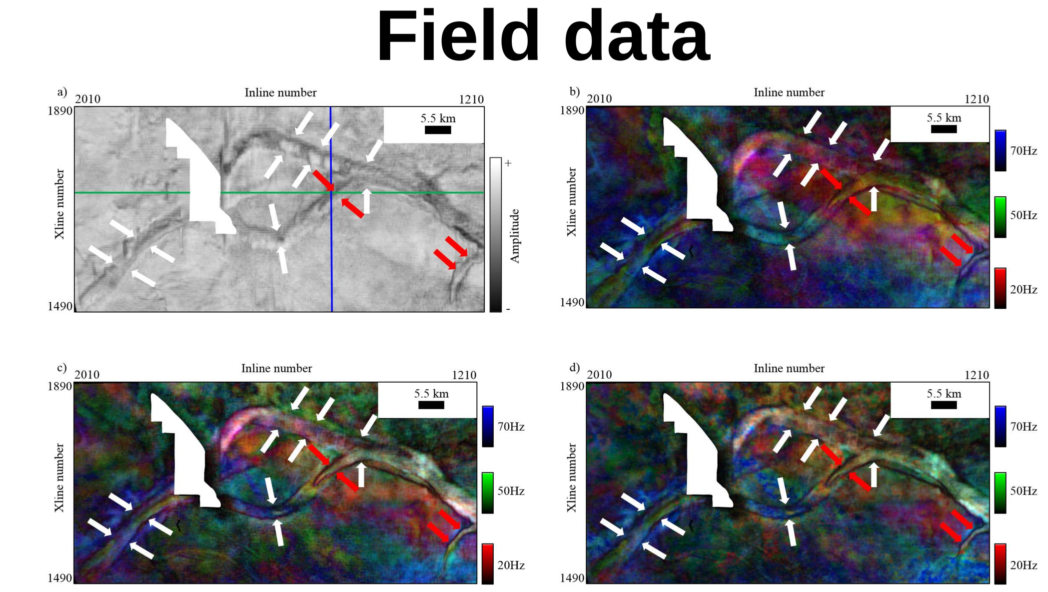

Figure 9: Field data. (a) The horizon slice of 3D seismic data, the green and blue lines denotes inline 1500 and crossline 1730; RGB blending images of the 20, 50, and 70 Hz slices calculated using the (b) ST, (c) GST with (1.2,1.2), and (d) SAGST. The white and red arrows denote channels with different thicknesses.

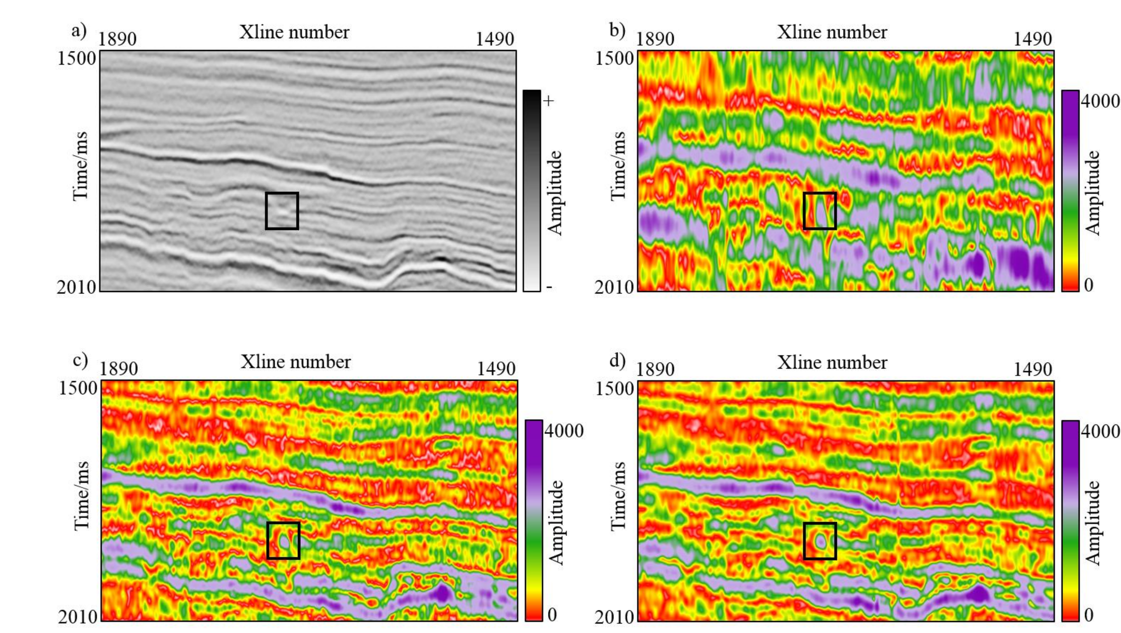

Figure 10: (a) An representative inline seismic section (blue line in Fig. 9(a)). The corresponding 50 Hz spectral components calculated using (b) ST, (c) GST, and (d) SAGST, respectively. The black and blue rectangles indicates the channels.

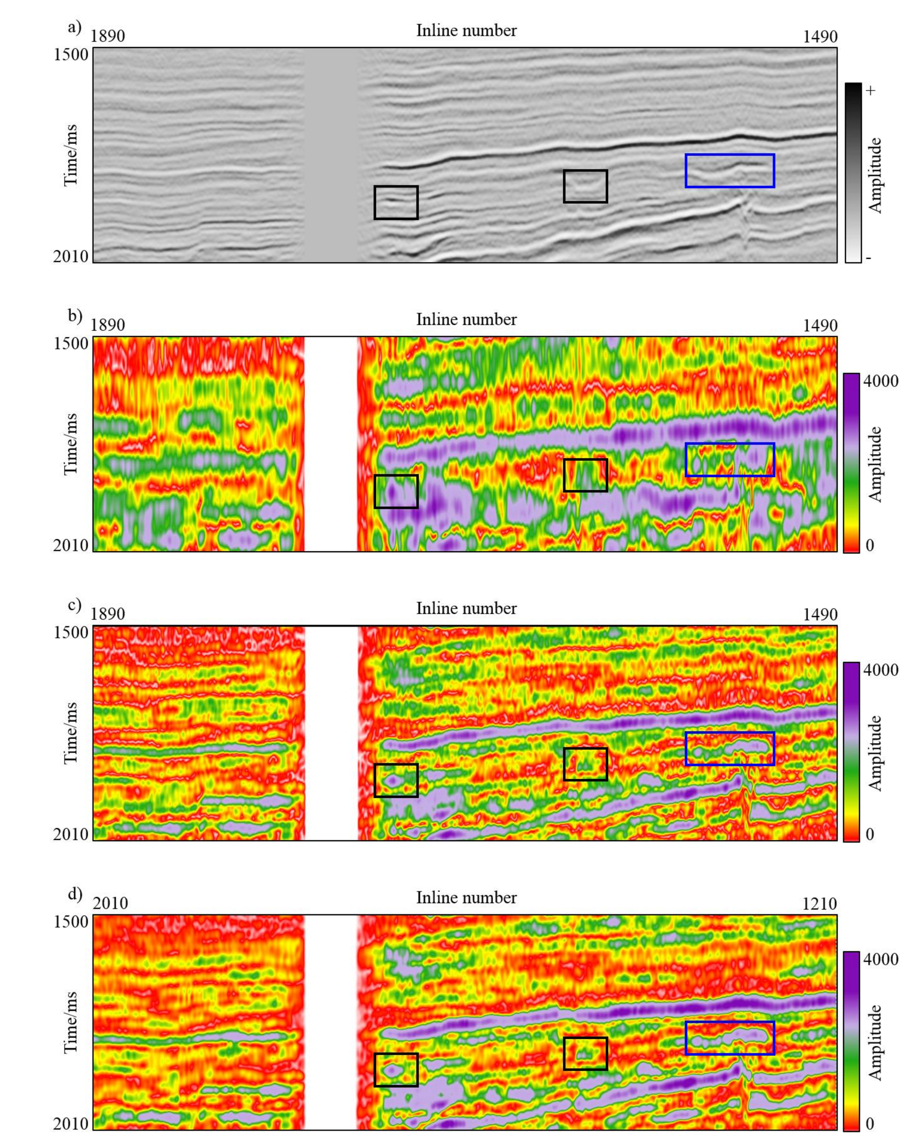

Figure 11: (a) An representative crossline seismic section (green line in Fig. 9(a)). The corresponding 50 Hz spectral components calculated using (b) ST, (c) GST, and (d) SAGST, respectively. The black and blue rectangles indicates the channels.

Conclusion

It is important to use an adaptive TF resolution to analyze seismic data. We propose a self-adaptive generalized S transform (SAGST) which employs the instantaneous frequency (IF) to optimize the TF resolution. Both synthetic data examples and field data demonstrate the validity and effectiveness of the proposed SAGST in distinguishing thin layers and detecting channels.