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Teager Kaiser energy attribute and its applications

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Summary

We present a detailed description and evaluation of the Teager–Kaiser (TK) energy attribute and demonstrate its application to seismic interpretation using a 3D seismic dataset from the Lower Magdalena Valley (LMV) Basin in onshore northwest Colombia. Although widely used in signal processing and biomedical applications, TK energy remains relatively uncommon in seismic analysis. The study shows that TK energy is particularly effective in delineating gas-related seismic anomalies, producing more localized and distinct responses than conventional energy-based attributes.

Introduction

Our work begins by revisiting the concept of seismic trace energy, which is fundamental to geophysical interpretation. Seismic energy serves as a quantitative measure of signal strength and is commonly used to distinguish meaningful reflections from noise and to identify amplitude anomalies associated with changes in lithology or fluid content. Traditional approaches estimate seismic energy by summing the squared amplitudes of seismic traces over a moving time window, yielding attributes such as instantaneous energy or RMS amplitude. While effective, these measures depend solely on amplitude and may smear anomalies spatially.

To provide a physical basis for TK energy, the authors relate seismic wave propagation to simple harmonic motion (SHM). In this framework, rock particles oscillate as energy alternates between kinetic and potential forms, similar to a mass–spring system. Seismic instruments measure particle motion, which is primarily associated with kinetic energy, but this motion originates from strain energy carried by the wave. This analogy motivates the use of TK energy, which estimates instantaneous signal energy by incorporating both amplitude and frequency.

The theoretical foundation of TK energy is reviewed following Kaiser's formulation, which shows that the energy of a harmonic oscillator is proportional to the square of its amplitude and the square of its frequency. Unlike conventional energy attributes, TK energy responds to rapid changes in both amplitude and frequency, making it sensitive to subtle signal variations. The study discusses the challenges associated with applying TK energy to multifrequency signals, such as seismic data, where discrete implementations can suffer from cross-term interference. Previous work demonstrated that this issue can be mitigated by computing TK energy on narrowband components derived through continuous wavelet transform (CWT) decomposition.

Building on this framework, the authors implement TK energy using noise-robust differential operators to compute first and second derivatives, following established methods that suppress high-frequency noise. TK energy is computed on the analytic (complex) seismic trace, further improving stability. Because TK energy is inherently non-negative and involves nonlinear filtering, it exhibits a lower apparent frequency content than the original seismic data, a characteristic discussed through spectral analysis.

Applications

The practical value of the TK energy attribute is demonstrated using a merged 3D seismic dataset acquired over the LMV Basin. The geological setting is described in detail, focusing on the Late Oligocene–Early Miocene Ciénaga de Oro Formation, which hosts known gas-bearing reservoirs. The seismic data were preconditioned using structure-oriented principal component filtering to enhance signal-to-noise ratio while preserving geological features, ensuring reliable attribute extraction.

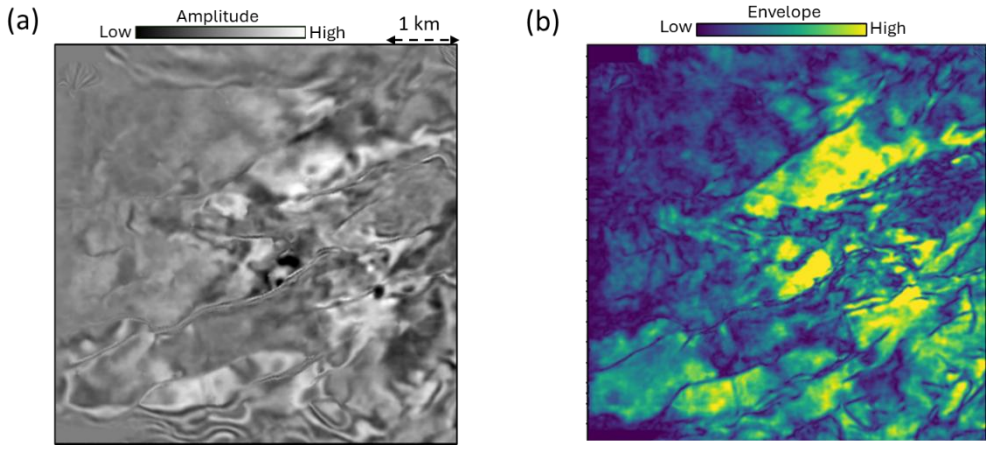
Comparisons between conventional attributes, such as instantaneous amplitude (envelope) and envelope energy, and TK energy show that while all attributes highlight high-amplitude anomalies, *TK energy produces sharper, more compact, and more interpretable responses*. Gas-related anomalies that appear smeared or ambiguous in envelope-based attributes are rendered as discrete and localized features in TK energy displays, both on vertical sections and stratal slices.

The analysis is extended by applying TK energy to spectral voice components derived from CWT-based spectral decomposition. Spectral magnitude slices at dominant frequencies (20–45 Hz) reveal frequency-dependent amplitude anomalies, some associated with hydrocarbons. When TK energy is computed on these narrowband components, the resulting attributes further enhance anomaly localization and reduce amplitude halos, outperforming spectral magnitude alone.

Finally, the study evaluates the contribution of TK energy to unsupervised seismic facies classification using self-organizing maps (SOM). Two SOM runs are compared: one using a conventional attribute set and another that includes TK energy. The *inclusion of TK energy significantly improves the clarity and focus of the SOM results, reducing clutter and allowing gas-related anomalies to stand out more clearly*. Although quantitative validation is limited by the availability of well control, qualitative comparisons strongly support the added value of TK energy.

Conclusions

We conclude that *TK energy is a powerful and underutilized seismic attribute with strong potential for identifying gas-related anomalies, especially when combined with spectral decomposition and machine learning workflows*. Its sensitivity to both amplitude and frequency enables more localized and distinct imaging of subtle features, making it a valuable addition to modern seismic interpretation and attribute analysis.



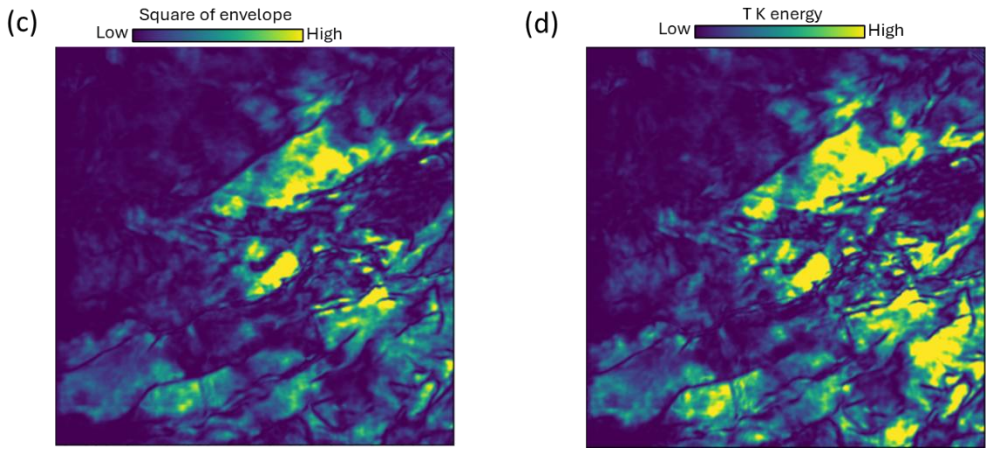


Figure 1: Stratal slices 30 ms below a marker and extracted from the (a) the input seismic volume with structure-oriented filtering (SOF), (b) instantaneous amplitude (envelope) computed on the input seismic volume with SOF, (c) square of instantaneous amplitude (envelope) computed on the input seismic volume with SOF, and (c) Teager Kaiser energy of input complex trace. Notice how the high amplitude anomalies are seen clearly on the Teager Kaiser energy display, which is better than the equivalent envelope display in (b) where many of these anomalies are seen bleeding at the edges, or in (c) where many of the anomalies are not defined well.

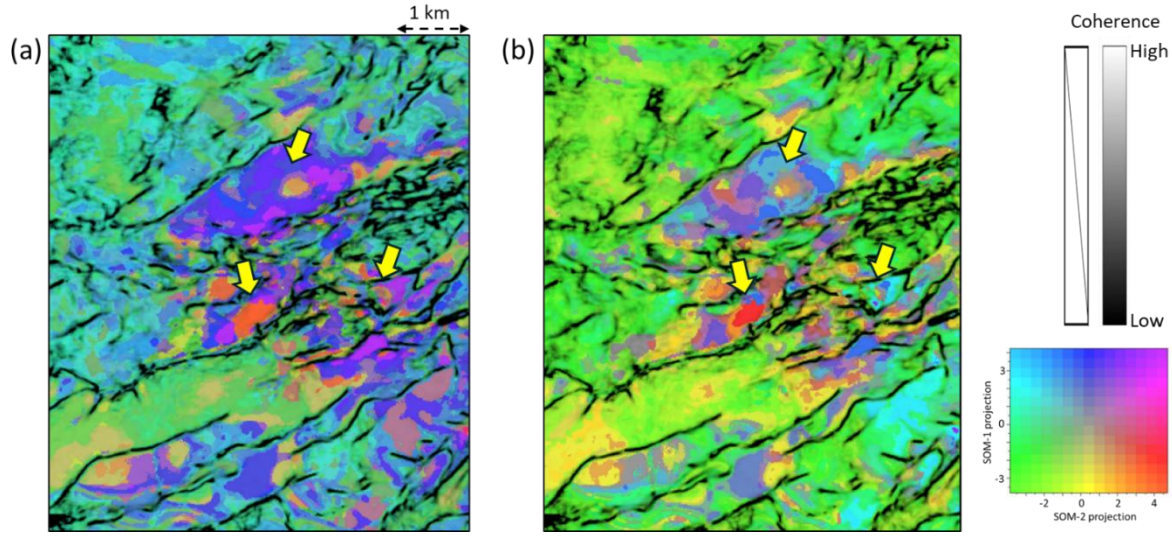


Figure 2: Stratal slices 30 ms below a marker and extracted from the SOM-1 versus SOM-2 crossplot volume generated by using (a) relative acoustic impedance, sweetness, GLCM homogeneity, spectral magnitude at 20 Hz, 30 Hz and 40 Hz attributes, and (b) Teager Kaiser energy attribute added to the attributes mentioned in (a). Both displays are corendered with multispectral coherence in black. We notice that the display in (a) looks busy, and the anomalies marked with yellow block arrows which are associated with hydrocarbons are not clearly discernable from the other events. The display in (b) shows the anomalies marked with yellow block arrows to be clearly defined and stand out from the background.

Acknowledgements

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