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Time Series Analysis : Early Detection of Crisis Signals in Financial Data, Cryptocurrencies, and Climate Data

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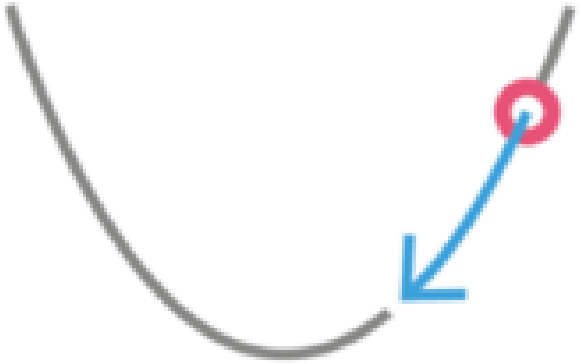
Table of Contents

Introduction

- Stability of complex systems is crucial.
- Critical transitions can disrupt this balance.
- Forecasting financial crises is paramount.
- Critical Slowing Down (CSD) theory offers promising tools.
- We explore its application to financial, meteorological, and Bitcoin market data.
- Our multidisciplinary approach assesses the relevance of early warning signals.

Critical Slowing Down Theory

- Common transitions in complex dynamic systems.
- Statistical physics theory to interpret these transitions.
- Critical slowdowns near critical points.
- Significant shift from one state to another.
- Slower recovery of the system after a disturbance.
- Detection of loss of stability in the system.



(a) Stable System

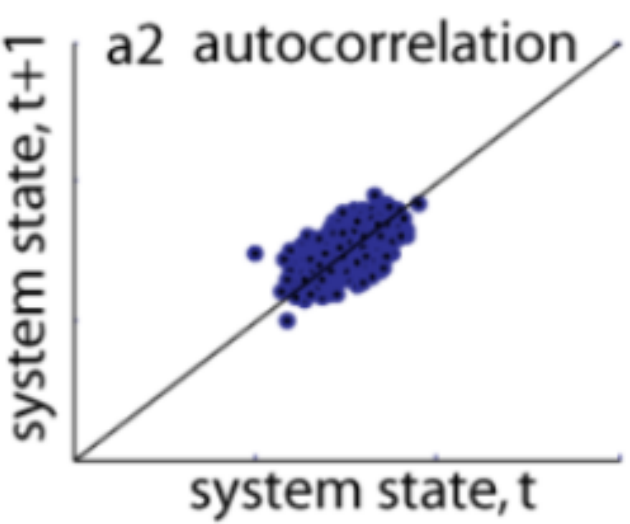
(b) System Close to Tilting

Early Warning Signals

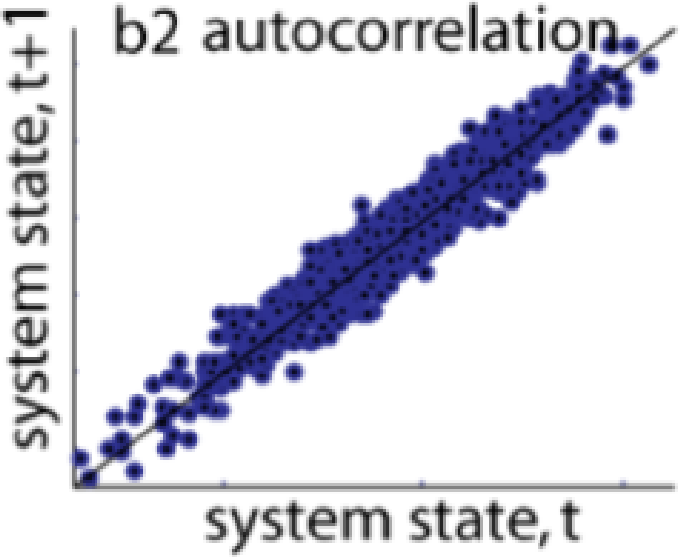
Early warning signals are indicators that exhibit distinctive changes before a critical transition. Some early warning signals may directly result from critical slowdown, similarity to its past, and increased variance:

- Slow recovery after disturbances:
  - As the system approaches a bifurcation, the recovery rate after small perturbations decreases.

Early Warning Signals: Autocorrelation

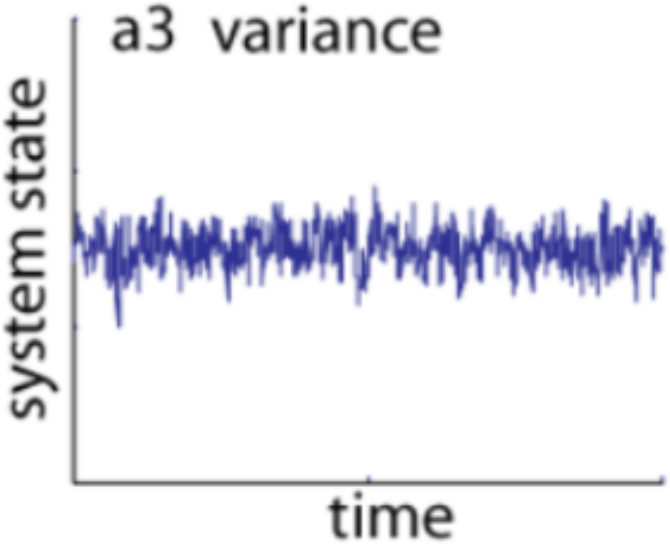


(a) Far from critical transition

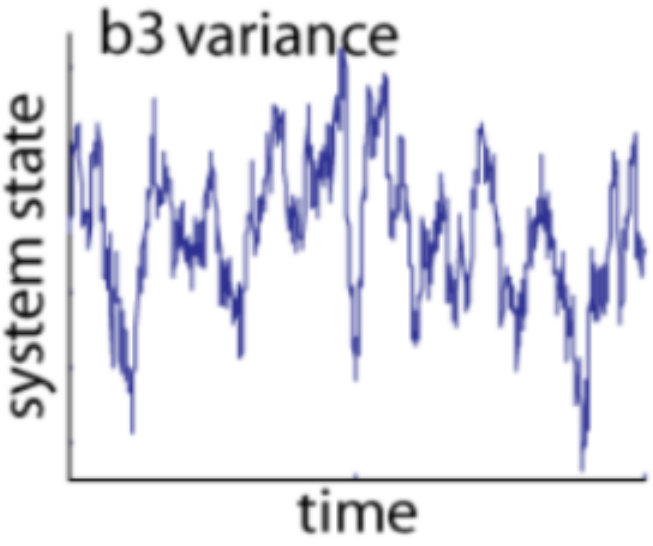


(b) Close to critical transition

Early Warning Signals: Variance

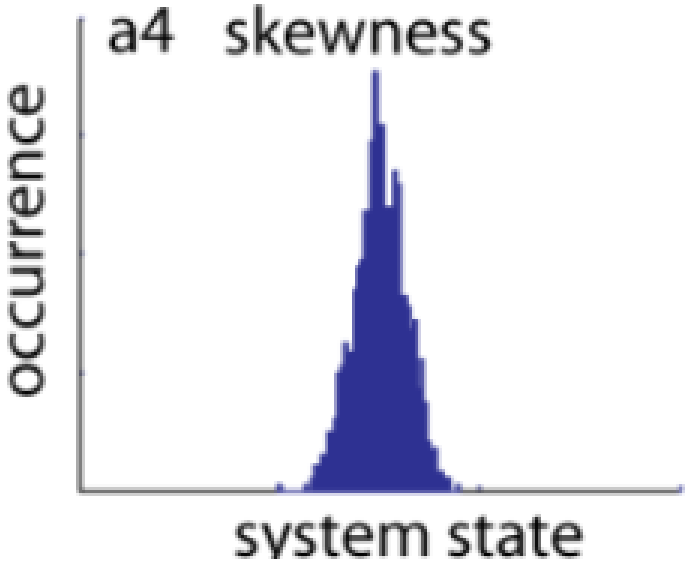


(a) Far from critical transition

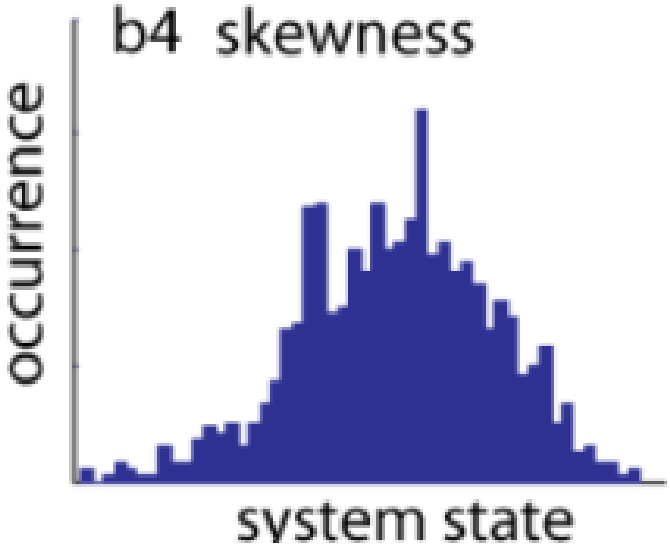


(b) Close to critical transition

Early Warning Signals: Skewness



(a) Far from critical transition



(b) Close to critical transition

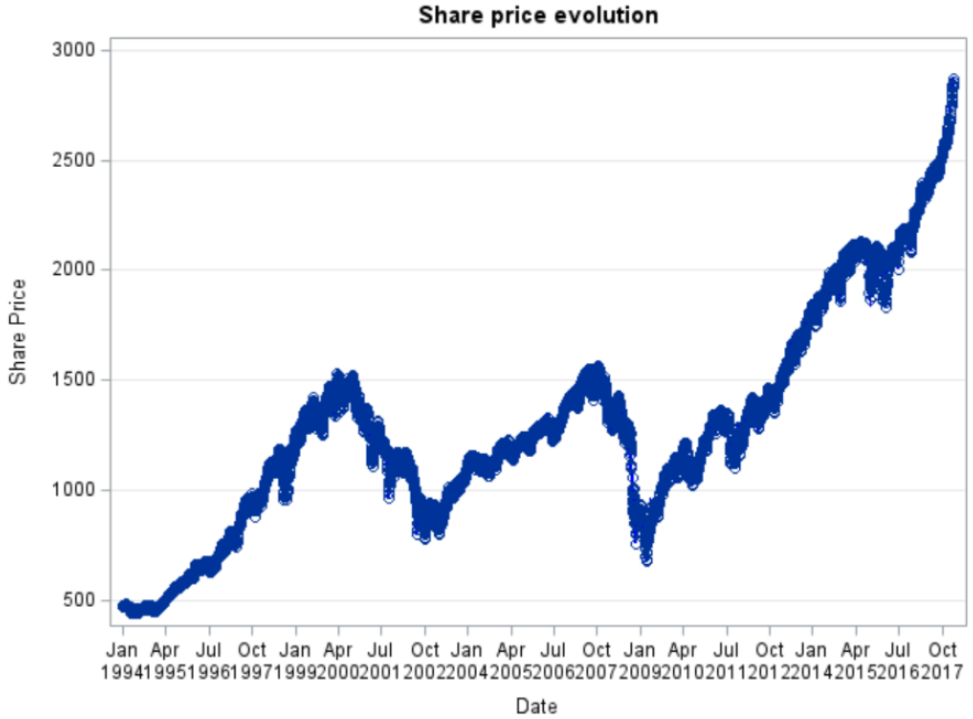
Data Exploitation

- Methods for detecting early signals of financial crises.
- Use of Critical Slowing Down (CSD) theory and leading indicators.
- Rigorous methodology to ensure validity and reliability of results.
- In-depth and multidimensional data analysis.

Data Exploitation

- Financial data: S&P 500 index between October 2007 and October 2009.
- Anticipation of the 2008 crisis.
- Origin of the crisis in the United States and its global impacts.
- Diverse causes: risky mortgages, securitization, etc.

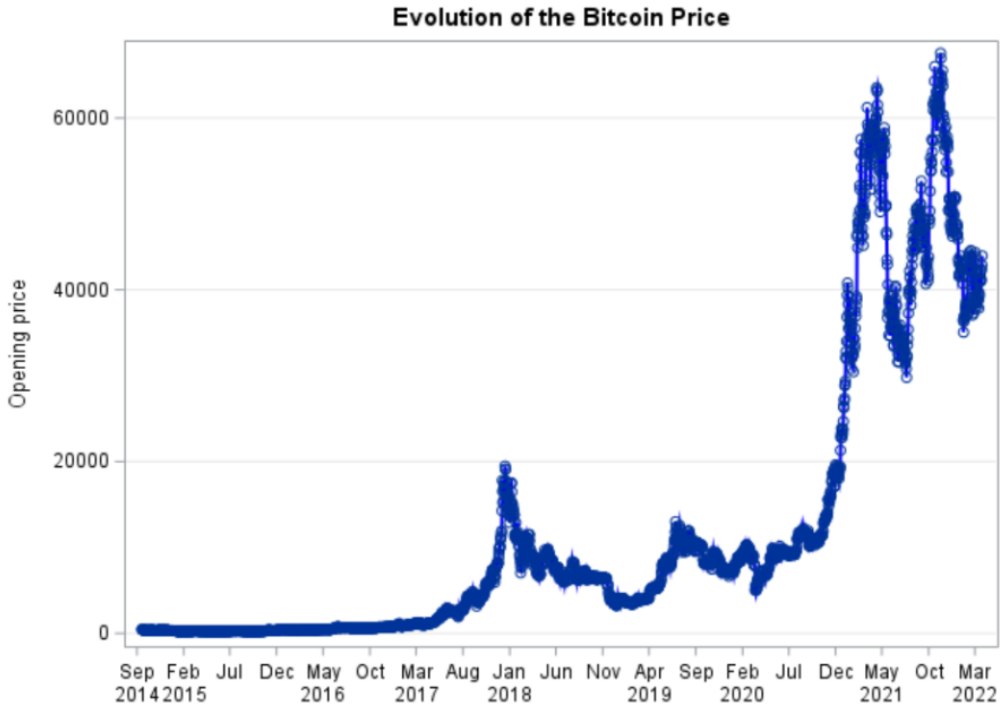
Data Exploitation: S&P 500



Data Exploitation

- Bitcoin data: March 2017 to December 2018.
- Identification of critical transitions.
- Rapid rise followed by sharp fall.
- Context conducive to applying CSD theory.

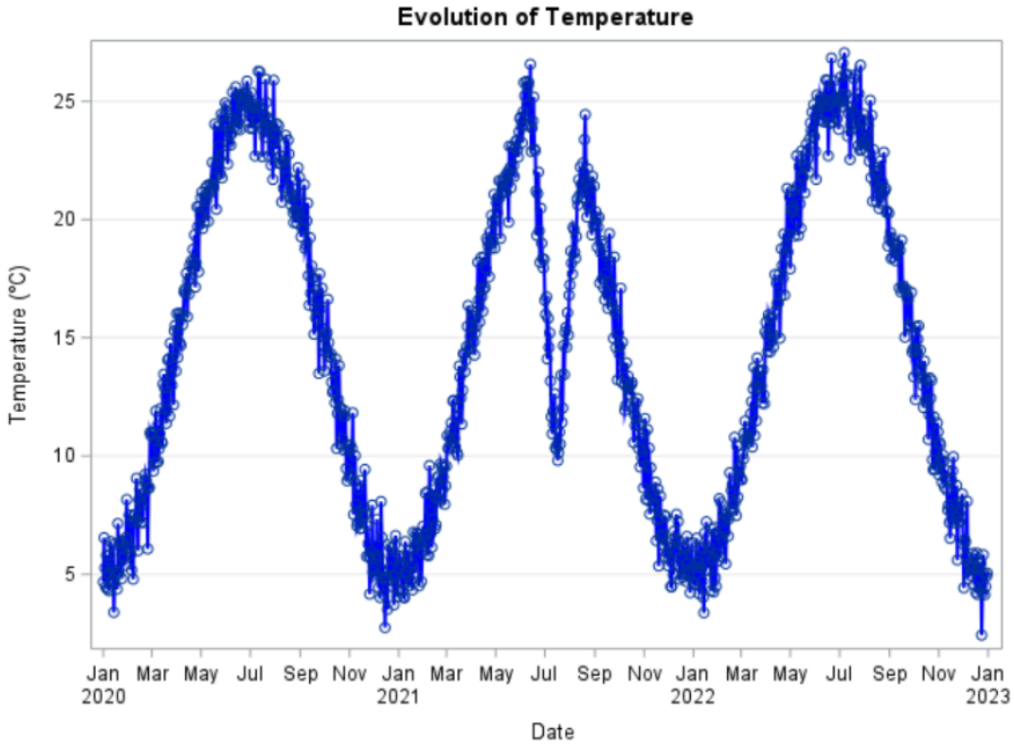
Data Exploitation: Bitcoin



Data Exploitation

- Crucial integration of meteorological data.
- Direct impact of weather conditions.
- Simulation of unusual meteorological events.

Data Exploitation: Weather



Trend Detrending Techniques

- In time series analysis, a crucial step is to remove long-term trends to focus on short-term fluctuations, a process called detrending.
- This step is essential as it reveals underlying dynamics and early signals of critical transitions in various complex systems, such as financial markets, cryptocurrencies, and climate data.
- By applying rigorous detrending methods, we can isolate significant variations that might otherwise be masked by long-term trends, thereby enhancing our ability to detect anomalies, predict potential crises, and understand the interactions between different phenomena.

Trend Detrending Techniques: Financial Data

- Financial data: S&P 500.
- Calculation of daily returns: data normalization.
- Removal of long-term trends (Detrending): application of a moving average smoothing method with a bandwidth of $= 15$.
- This transformation allows us to focus on significant short-term variations and identify early signals of potential financial crises.

Detrending Techniques: Bitcoin

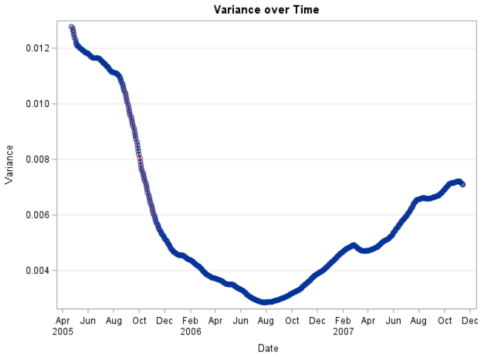
- Bitcoin data: calculation of daily returns, data normalization, and removal of long-term trends (Detrending) using a moving average smoothing method.
- This approach helps identify early signals of volatility and critical transitions in this relatively new and often volatile financial market.

Detrending Techniques: Meteorological Data

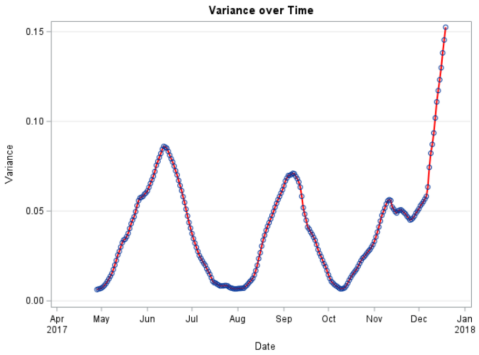
- Meteorological data: calculation of temperature anomalies, data normalization, and removal of long-term trends (Detrending) using a moving average smoothing method.
- This approach helps detect early signals of abrupt and potentially critical climate changes, with significant implications for ecological and financial systems.

Variance Analysis

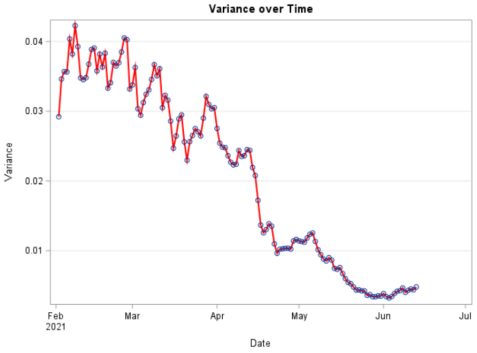
- Financial Data (S&P 500): Between April 2005 and December 2007, the variance shows a decreasing trend followed by a significant increase in December 2007, signaling increasing instability in the market.
- Bitcoin Data: From March 2017 to January 2018, the variance oscillates between 0 and 0.1, indicating relative price stability. However, a sharp increase in December 2017 signals an imminent change in the market.
- Meteorological Data: A decrease in variance is observed, initially suggesting stability but also possibly signaling increased sensitivity to disruptions and upcoming extreme weather events.



(a) Financial Data (S&P 500)



(b) Bitcoin Data

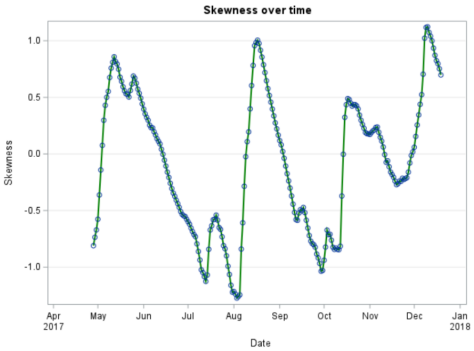


(c) Meteorological Data

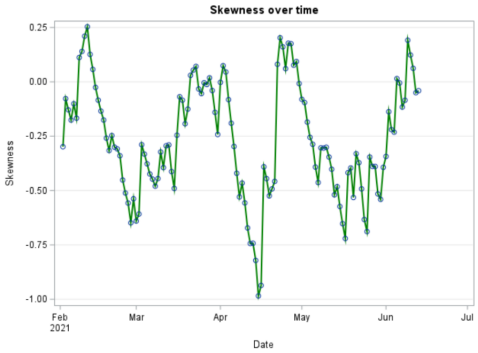
Skewness Analysis

- Financial Data (S&P 500): Between November 2002 and October 2007, skewness shows significant fluctuations, signaling increasing instability in the market.
- Bitcoin Data: From March 2017 to January 2018, skewness oscillates between positive and negative values, reflecting Bitcoin market fluctuations.
- Meteorological Data: Before a major event, temperature skewness fluctuates between positive and negative values, indicating increasing system vulnerability to shocks.

(a) Financial Data (S&P 500)



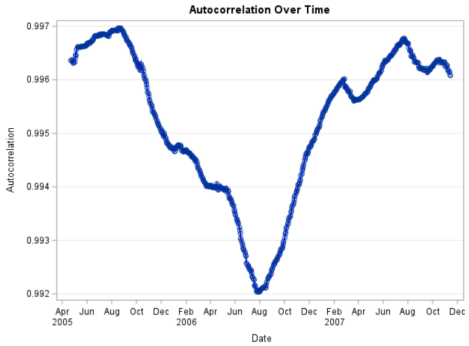
(b) Bitcoin Data



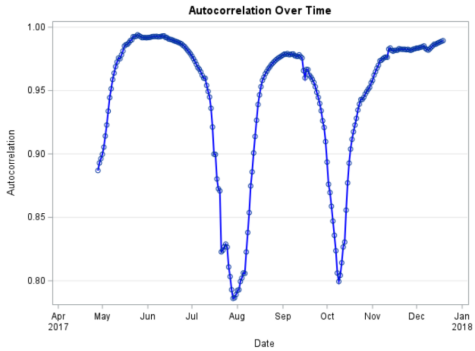
(c) Meteorological Data

First-Order Autocorrelation Analysis

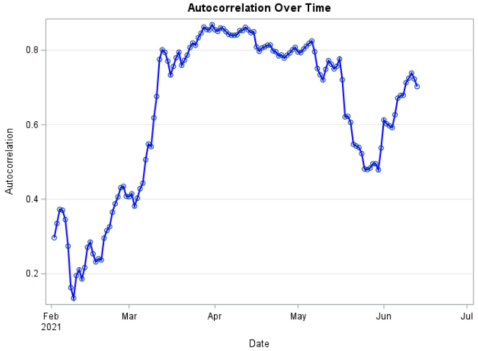
- Financial Data (S&P 500): The first-order autocorrelation of the S&P 500 index shows a downward trend between April 2005 and August 2006, followed by an increase towards December 2007, indicating a possible imminent critical transition.
- Bitcoin Data: The autocorrelation of Bitcoin price oscillates between approximately 0.78 and 1, with periods of growth and decay corresponding to Bitcoin price fluctuations.
- Meteorological Data: Autocorrelation of meteorological data reveals significant fluctuations, indicating dynamic complexity in climate trends.



(a) Financial Data (S&P 500)



(b) Bitcoin Data



(c) Meteorological Data

Conclusion

- Objective: Evaluate the effectiveness of indicators for predicting crises using Critical Slowing Down (CSD) theory.
- Indicators: Variance, skewness, and first-order autocorrelation (AR(1)).
- Results:
  - Variance: Good for financial markets, less for meteorological data.
  - Skewness: Useful but less stable than variance.
  - Autocorrelation: More reliable for predicting crises in meteorological data.
- Early warning signals offer valuable insights but do not always guarantee perfect anticipation of critical transitions.