Wavelet-Induced Mode Extraction Procedure: Application to ENSO

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Abstract

WIME (**W**avelet-**I**nduced **M**ode **E**xtraction): This algorithm draws inspiration from Empirical Mode Decomposition and is tailored to decompose signals into their oscillatory components through Continuous Wavelet Transform. This method has yielded intriguing results in climatology [1], [2].
This improved version applied to the ONI signal (ENSO index) yields impressive results, boasting a **correlation of 0.96** for detecting El niño and La niña events.

1. WIME methodology

WIME method:

- Matrix with energy values.
- Spectrum generation.
- Detection of average maxima considering energy, concavity, and noise.
- Evolution over time (ridge), in frequency and amplitude.
- Extraction and Subtraction of the component.

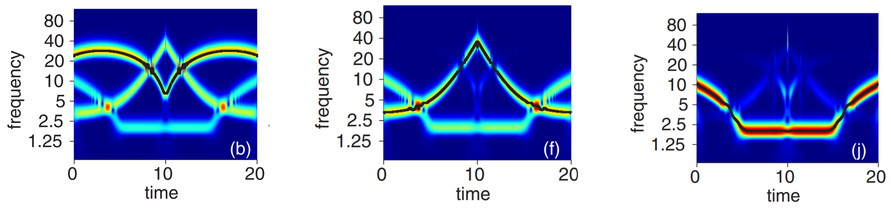

Figure 1: Time-frequency representation of the function f and ridge detected by WIME (black curve) [3].

2. Spectrum (and average maximum detection)

ONI (**O**ceanic **N**iño **I**ndex): based on Sea Surface Temperature

The spectrum allows us to identify the first 8 oscillatory components.

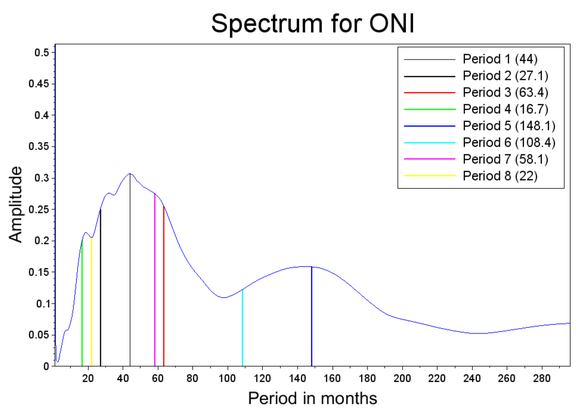

Figure 2: Spectrum generated by WIME, from ONI signal (1951-2023 [4]). Vertical lines show the first periods.

3. Extraction of oscillatory components

First six oscillatory components included

Correlation: 0.94
RMSE: 0.29°C

The presence of an El Niño phase (respectively a la Niña phase) is signaled by an $ONI \geq 0.5$ (respectively $ONI \leq -0.5$), shown by red dotted lines, for at least 5 consecutive months.

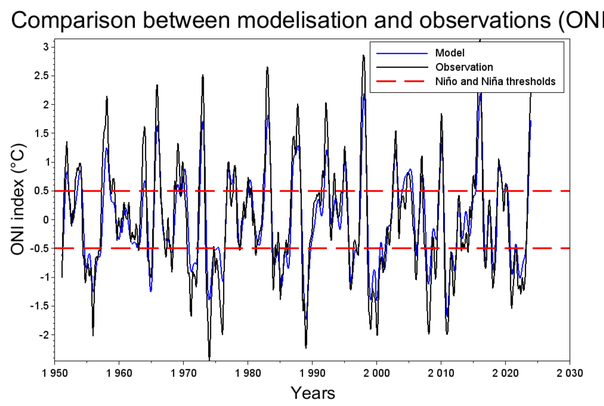

Figure 3: Comparison between ONI model (blue line) and ONI observed (black line) for 1951-2023 [4].

4. Quality (correlations)

Increasing modelling quality as we add oscillatory components. Higher detection of extrems events (but underestimation of them).

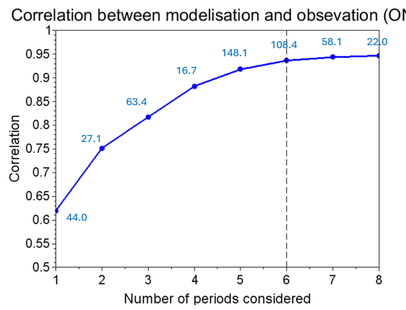

Figure 4: Correlation between modelisation and observations for ONI index, for different number of oscillatory components included [4]. Labels indicate the periods (in months). Black dotted line show the start of the plateau.

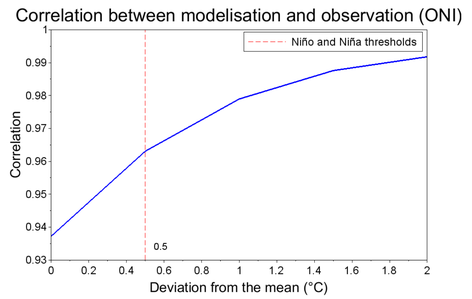

Figure 5: Correlation between modelisation and observation for ONI index (first 6 periods considered), for different definitions of "extreme event" [4].

5. Perspectives

- Application on various climatic indices (SOI, QBO, NAO ...) and variable (temperatures...)
- Applications on geological signals (such as Milankovich cycles)
- Applications on magnetic signals
- **Extrapolation for predicting ENSO**, and other climatic data.
- Understanding the role of natural variability vs global warming (for example, to explain recent observed extreme events like Ice sheet melting or drought in Europe).
- **Improving GCM** by adding ENSO period and their evolutions.

References

[1] S. Nicolay et al. "30 and 43 months period cycles found in air temperature time series using the Morlet wavelet". In: *Climate Dynamics* (2009).

[2] S. Nicolay et al. "A statistical validation for the cycles found in air temperature data using a Morlet wavelet-based method". In: *Nonlinear Processes in Geophysics* (2010).

[3] A. Deliège and S. Nicolay. "Extracting oscillating components from nonstationary time series: A wavelet-induced method". In: *Phys. Rev. E* 96 (3 2017), p. 033307.

[4] E. Faulx. *Frequency analysis of temperature and ENSO data: modal extraction.* In progress.