Spectral Analysis of Lake Balaton seiches

Focusing on Transverse Seiches during the Yvette Cyclone

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Introduction & Objectives

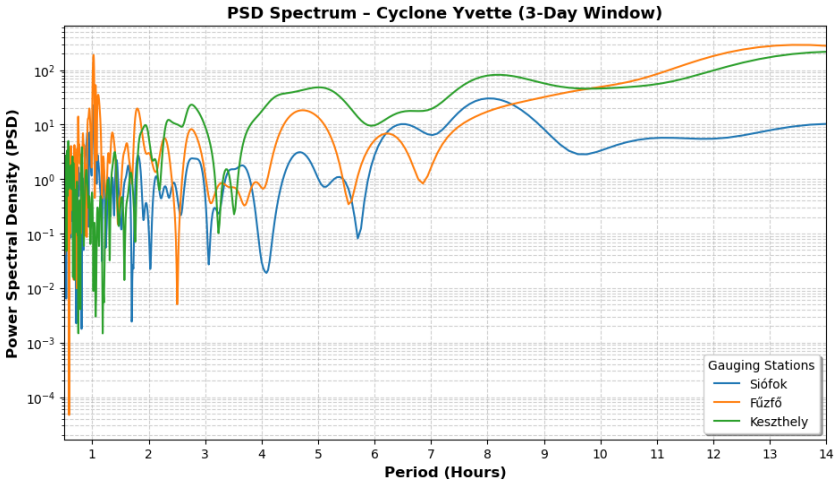
- **Focus:** Spectral analysis (PSD) of Lake Balaton's water level fluctuations (seiches).
- **Investigated Event:** Cyclone Yvette (14-16 May 2014).
- **Rationale:**
  - Extreme meteorological forcing with rapid onset.
  - Ideal conditions for analyzing high-frequency (short-period), local resonances rather than slow-building fronts.

Data & Methodology

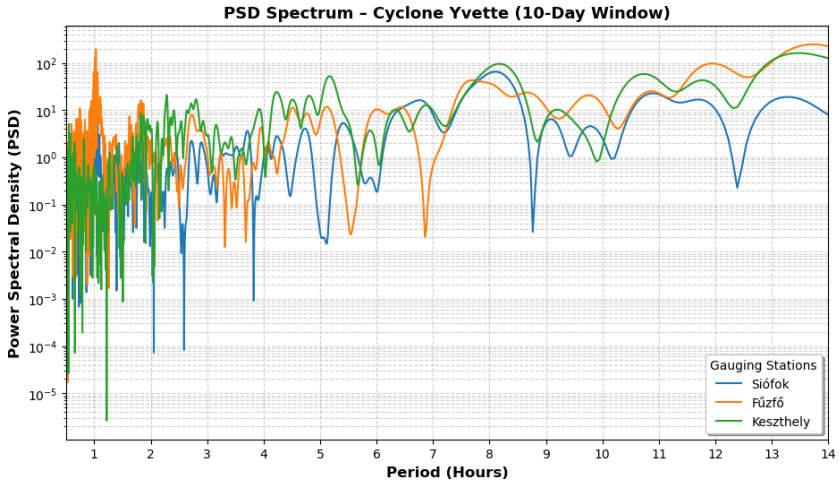
- **Data Sources:**
  - Water Level (5 min): Keszthely, Siófok, Fűzfő stations.
  - Wind (10 min): HungaroMet (speed and direction).
- **Processing & Method:**
  - **Detrending:** Raw water level data was filtered using a 7-day moving average to remove long-term mean water level changes.
  - **Spectral Analysis:** Fast Fourier Transform (FFT) applied to the detrended data to compute Power Spectral Density (PSD).
  - Dominant wind direction calculated using wind speed squared weighting (proportional to wind stress).
  - Theoretical eigenperiods estimated using the 1D Merian formula:

$$T = \frac{2L}{\sqrt{g \cdot h}}$$

Limitations of Longitudinal Seiche Analysis (7-8 h)



3-day window



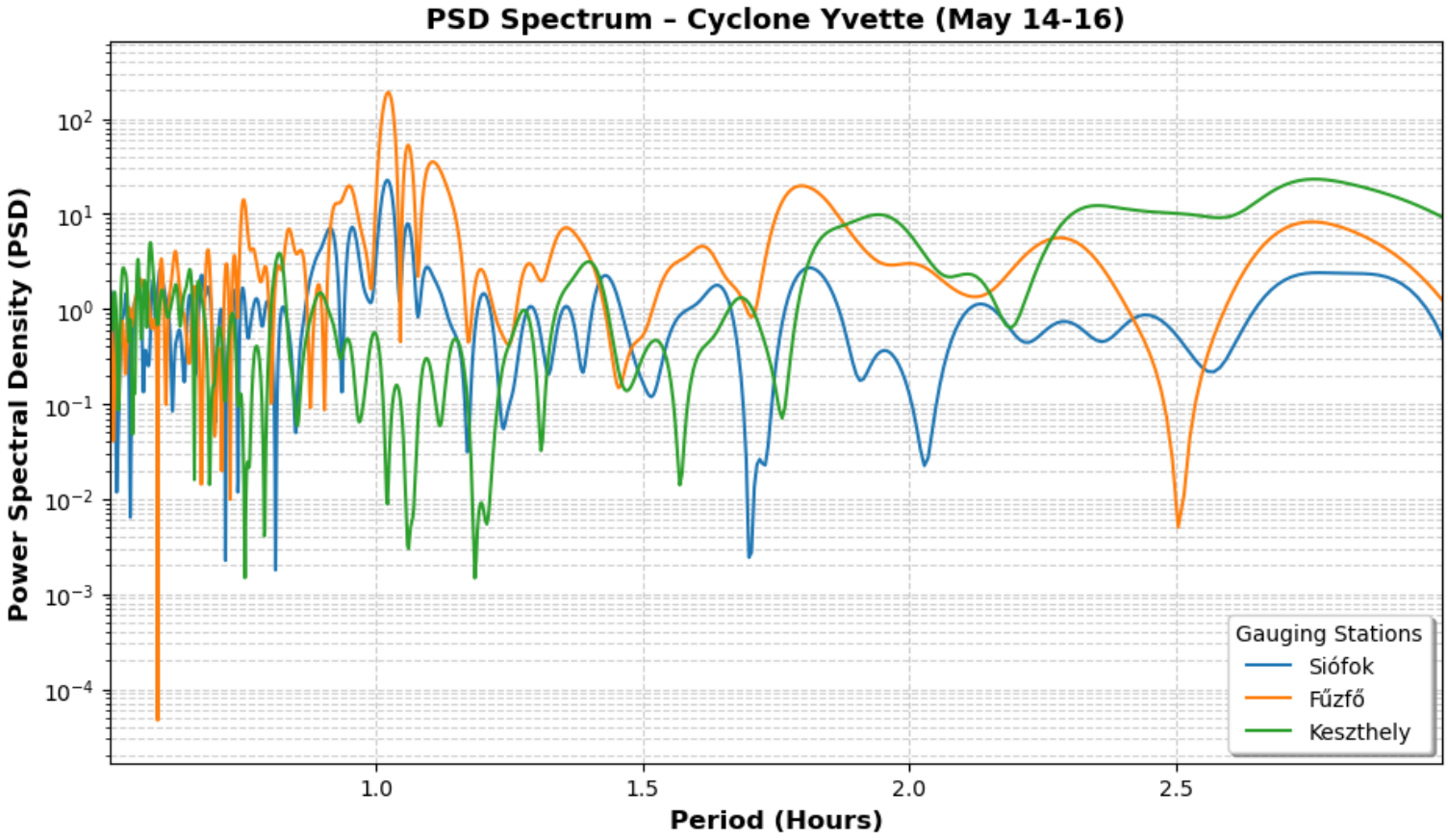
10-day window

- A 3-day window is mathematically too short to resolve 7-8h periods.
- Even in a 10-day window, no dominant 7-8h peak emerges.
- **Physical reason:** Purely Northern winds do not transfer energy to the East-West longitudinal axis.
- **Conclusion:** Analysis restricted to periods < 3 hours (transverse seiches).

PSD Results: Yvette Cyclone I.

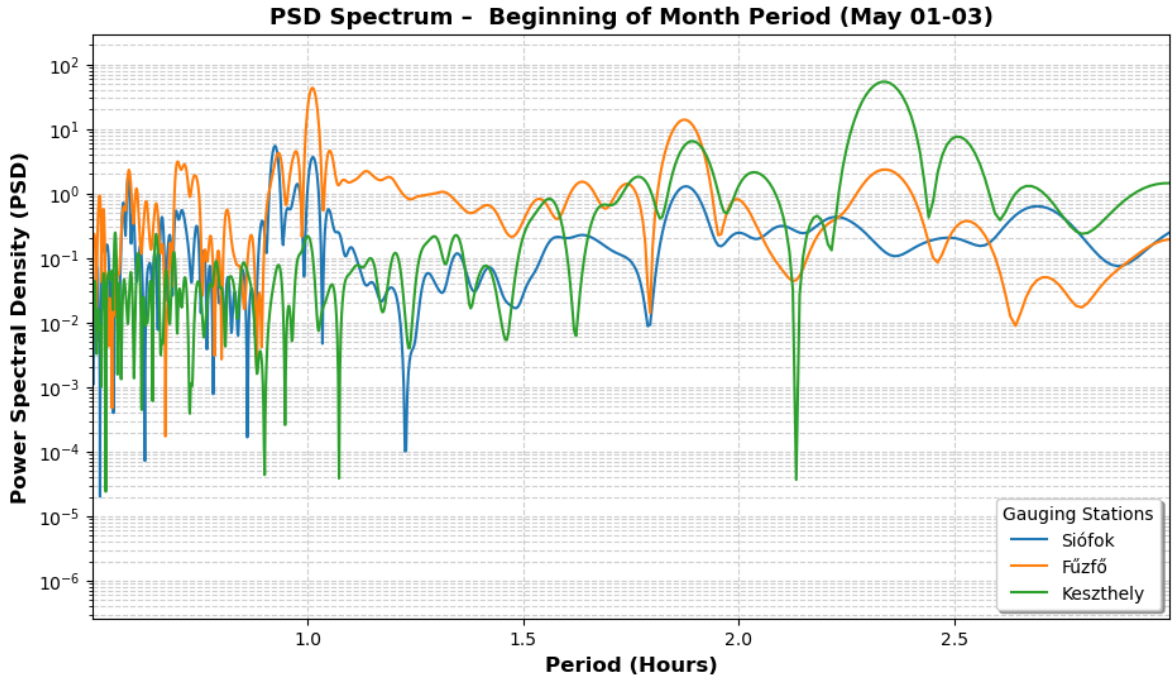
- **Dominant Wind Forcing:** 351.6° (N-NW).
- **Theoretical vs. Measured Peaks (0 – 1.5 h range):**
- **Keszthely:**
  - Estimated: ~ 0.62 h $\rightarrow$ Measured local peak: $\sim$ **0.6 h**.
- **Siófok:**
  - Estimated: ~ 1.36 h $\rightarrow$ Measured peak: $\sim$ **1.0 h**.
- **Fűzfő:**
  - Estimated: ~ 1.51 h $\rightarrow$ Measured sharp peak: $\sim$ **1.0 h**.
  - Overestimation due to complex basin geometry; the actual resonating water mass is shorter than the full cross-section.

PSD Results: Yvette Cyclone II.



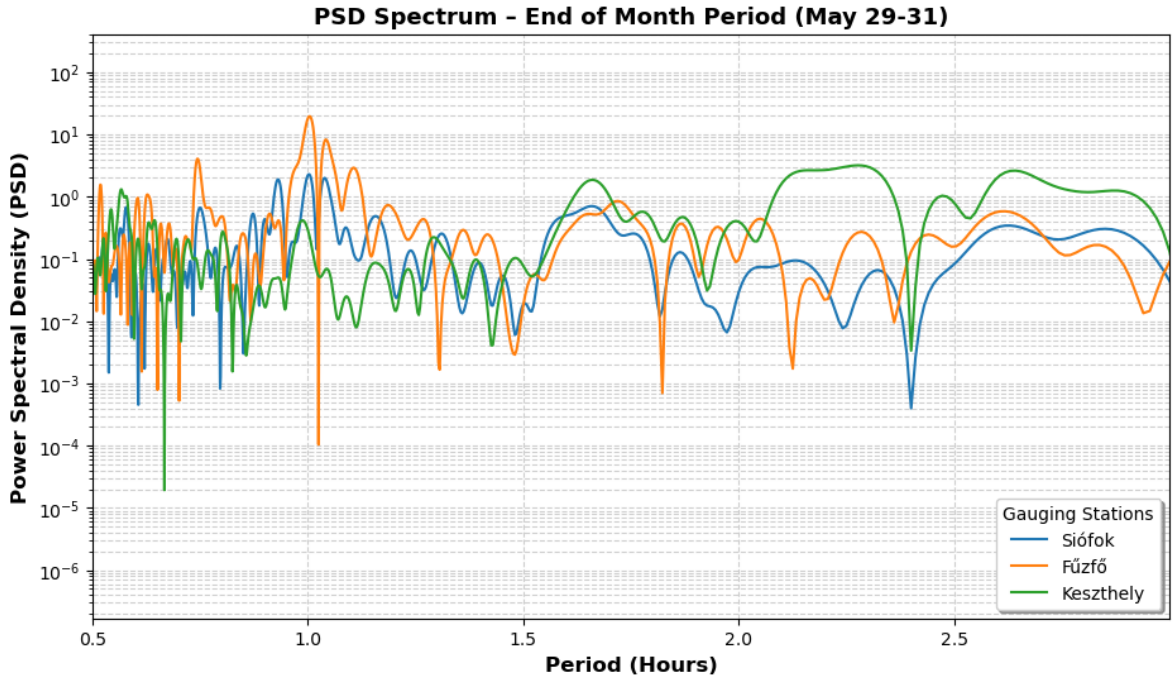
Transverse seiche peaks during extreme N-NW wind forcing.

Control Study: Calm Period (Early May)



- **Forcing:** Wind direction **1.7**° (North), but significantly lower energy.
- **Observation:** The ~ 1 h transverse peak at Fűzfő remains remarkably stable.
- **Conclusion:** Transverse resonance frequency is consistent and requires less wind stress to be maintained.

Sensitivity Analysis (End of May)



- **Forcing:** Wind direction shifted to **342**° (North-West).
- **Observation:** The energy of the transverse peaks dampens significantly compared to the purely Northern wind periods.
- **Conclusion:** The transverse seiche system is highly sensitive to wind direction.

Conclusions & Future Directions

Conclusions:

- Peaks in the < 1.5 h range are physical transverse seiches driven by Northern winds, validated by 1D Merian calculations and sensitivity analysis.

Future Directions:

- **Longitudinal Seiche (7-8 h):** Requires multi-month or seasonal continuous data windows combined with low-pass filtering to isolate low-frequency modes from noise.
- **Wavelet Analysis:** To observe the temporal evolution and energy dissipation of seiches over time.
- **Cross-Spectral Analysis:** To determine phase differences and coherence between stations (e.g., Keszthely and Fűzfő) confirming basin-wide oscillations.

AI usage

For this projeckt I used Google Gemini's 3.1 Pro version for:

- Coding: new data preparation, spectral analysis and plotting
- Source searching
- Creating the presentations' framework