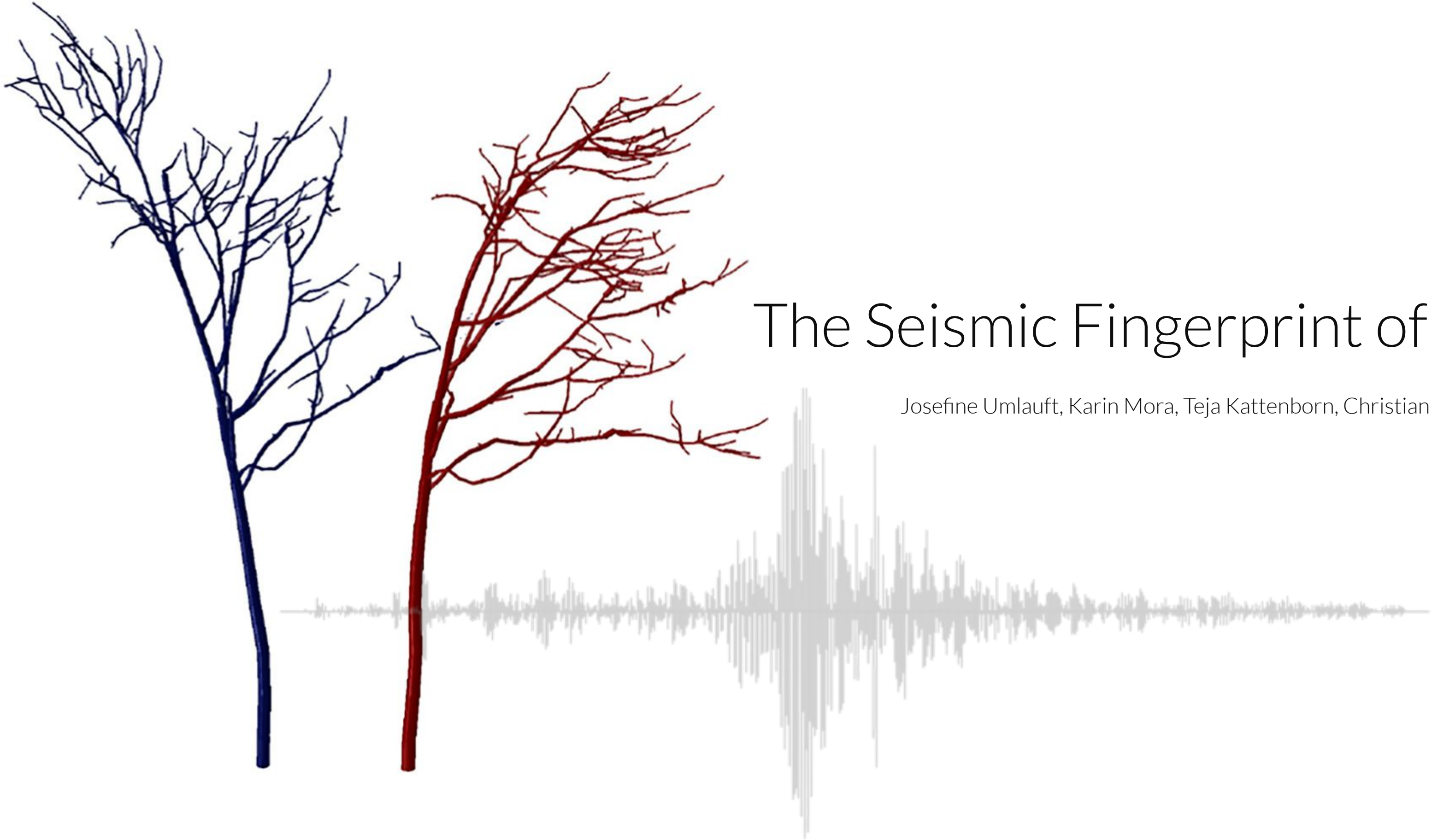
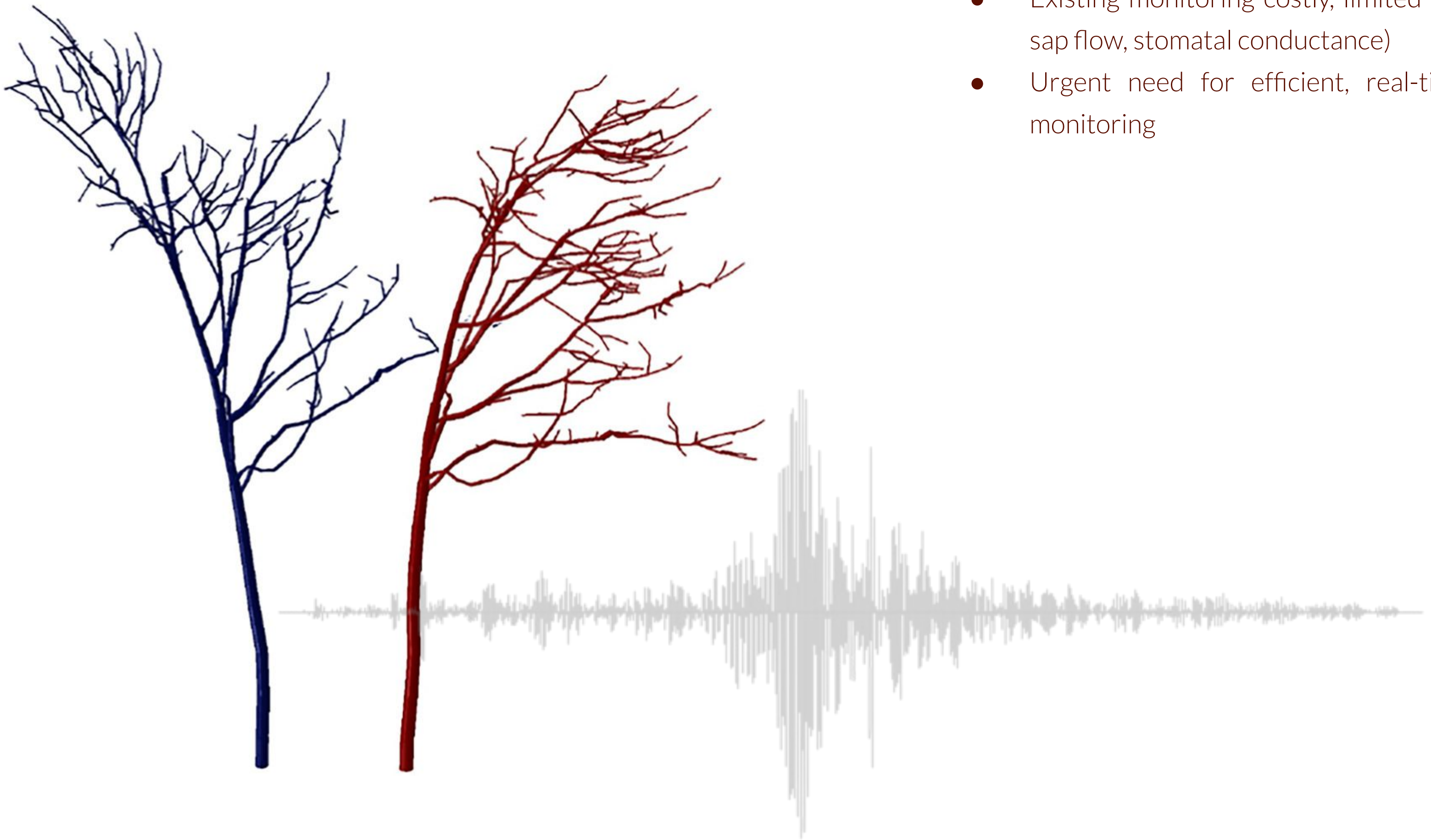
The Seismic Fingerprint of Tree Sway

Josefine Umlauft, Karin Mora, Teja Kattenborn, Christian Wirth, Christiane Werner



Motivation



- Forests are stressed by climate change (heatwaves, droughts)
- Existing monitoring costly, limited scale/resolution (e.g. sap flow, stomatal conductance)
- Urgent need for efficient, real-time, large-scale tree monitoring

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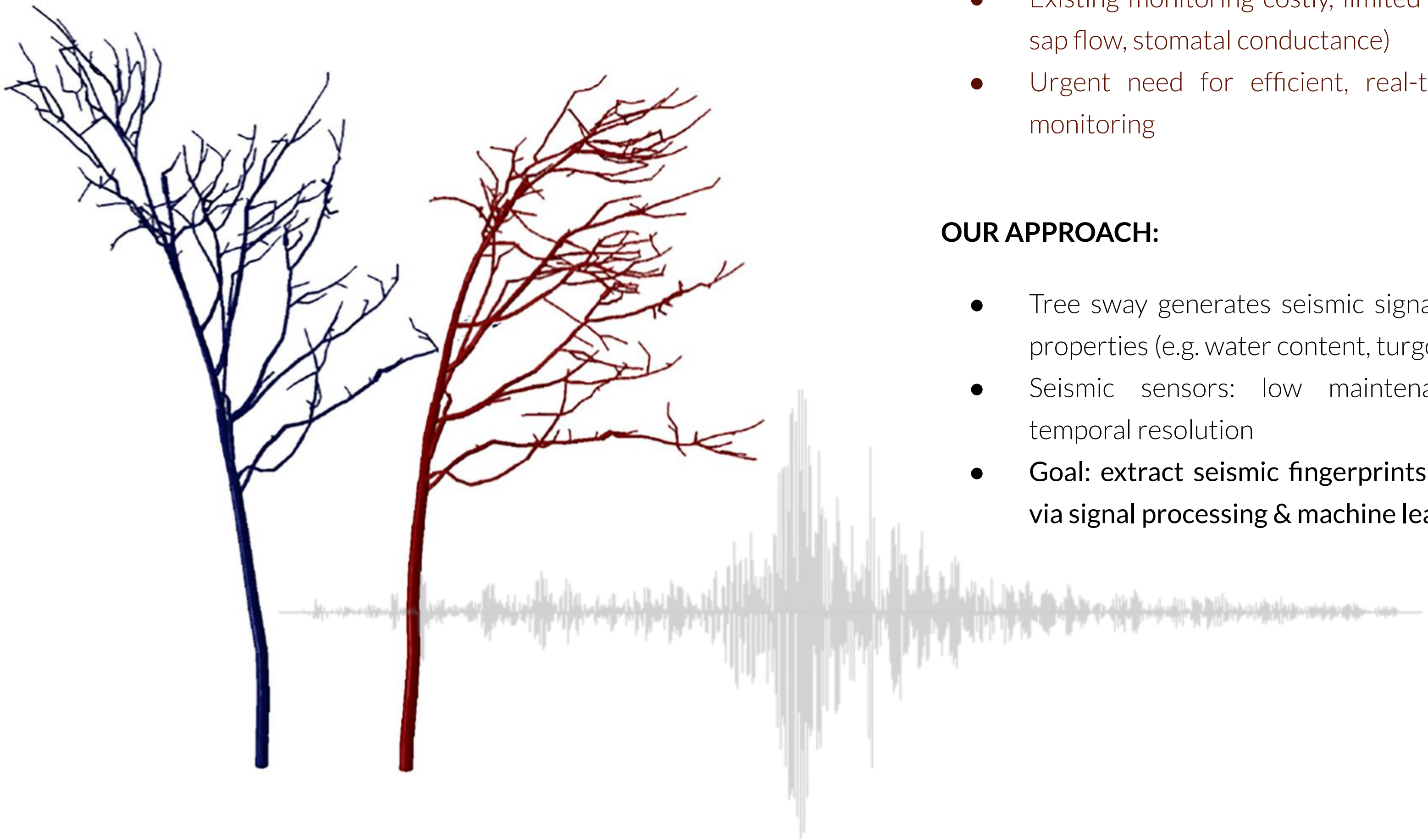

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OUR APPROACH:

- Tree sway generates seismic signals reflecting material properties (e.g. water content, turgor pressure)
- Seismic sensors: low maintenance, scalable, high temporal resolution
- **Goal: extract seismic fingerprints as stress indicators via signal processing & machine learning**

Site & Instrumentation

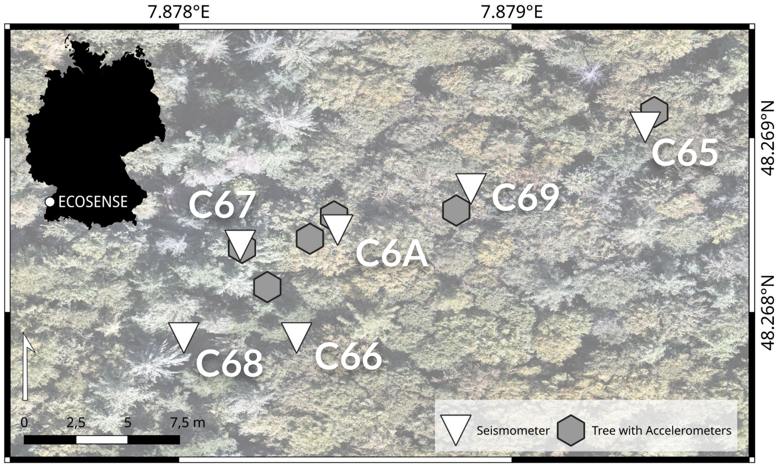
ECOSENSE
DFG Collaborative Research Center (Freiburg University)

Multi-scale quantification and modelling of spatio-temporal dynamics of ecosystem processes by smart autonomous sensor networks

6 buried seismometers

6 trees with 3 accelerometers each

- 3 component velocity/acceleration time series
- sampling frequency = 100 Hz
- continuous records since July 2024



Site & Instrumentation

SEISMOMETER
(Trillium Compact 120 - Nanometrics)

ACCELEROMETER
(Episensor - Kinematrics)

Approach

I. DETERMINING THE FINGERPRINT

accelerometer measurements on the trunk serve as direct ground truth for determining the seismic tree sway fingerprint at ground level

II. FROM FINGERPRINT TO FEATURES

we derive, compare and integrate tree sway fingerprints across the site using a seismometer array

III. FINGERPRINT FEATURES PREDICT WIND VELOCITIES

we predict wind velocities as a function of time based on the extracted features

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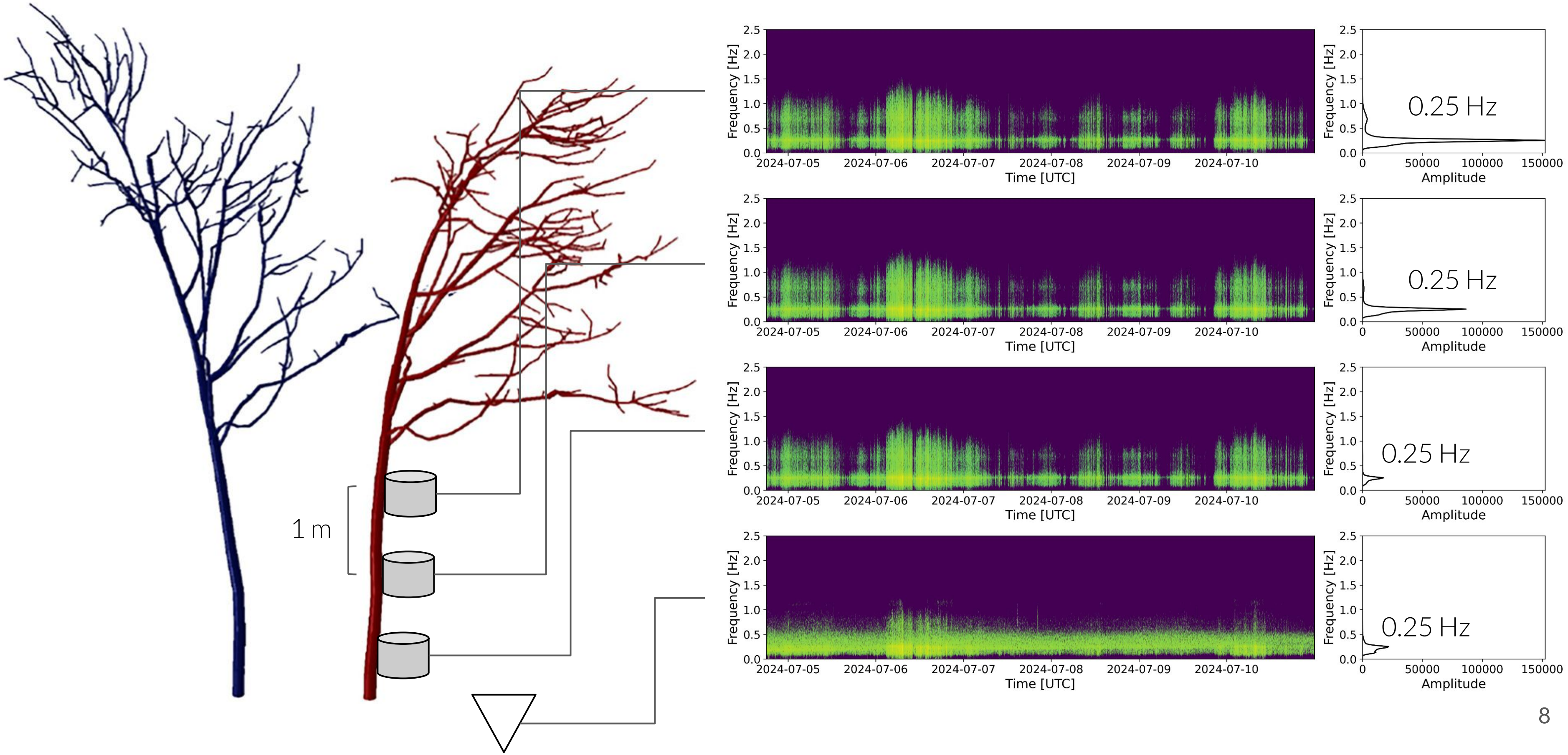

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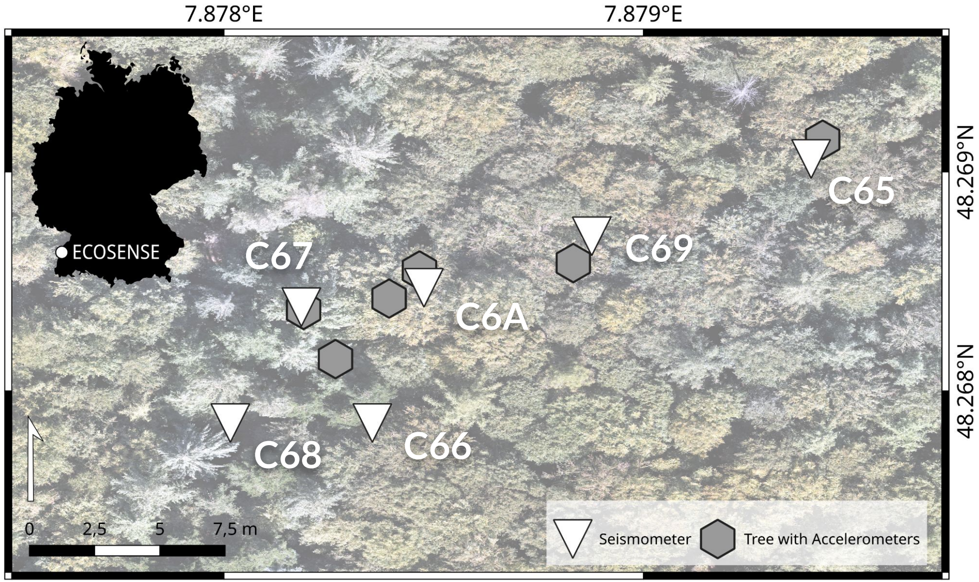
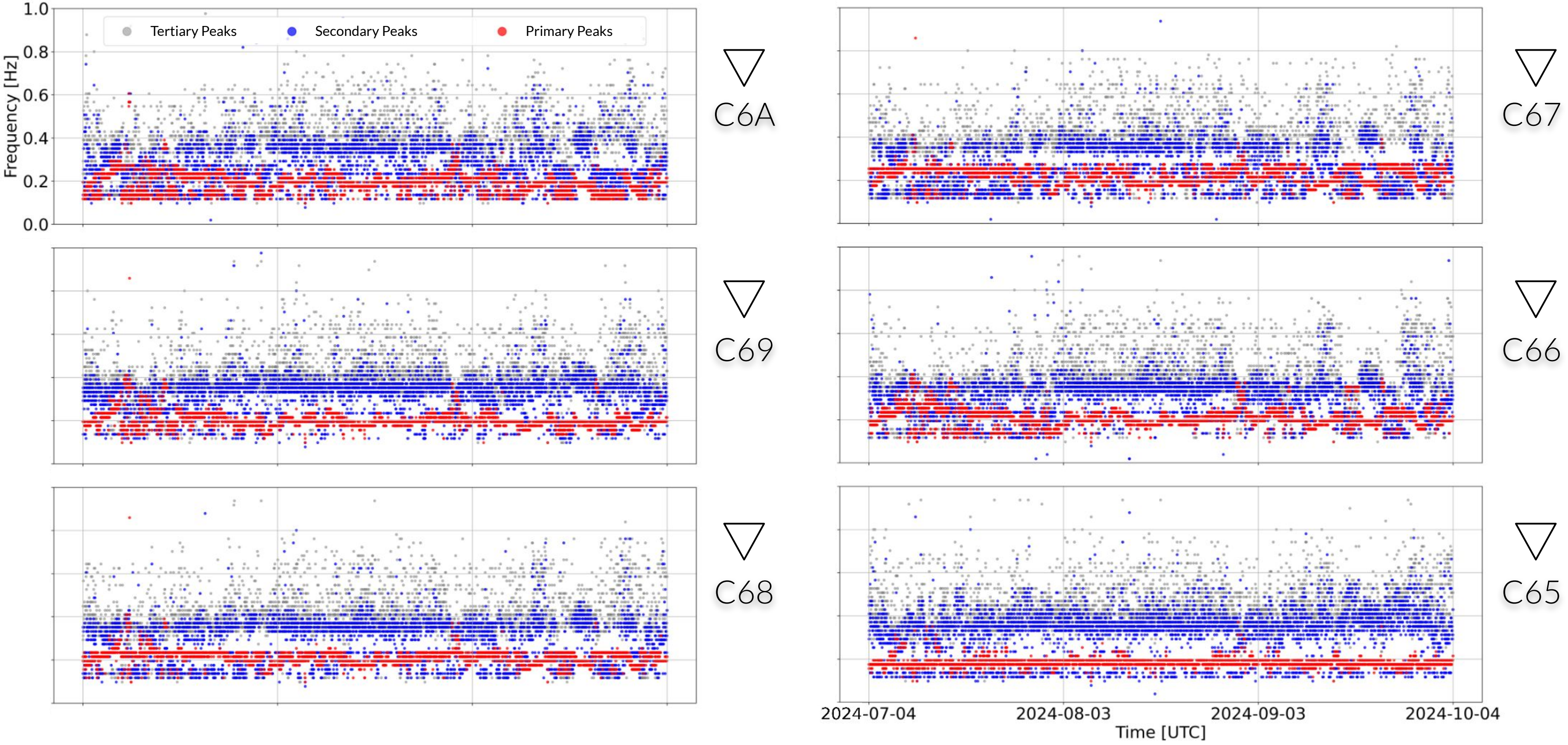


a. Spectral Analysis

b. Eigenvector Analysis

II. From Fingerprint to Features

a. Spectral Analysis



II. From Fingerprint to Features

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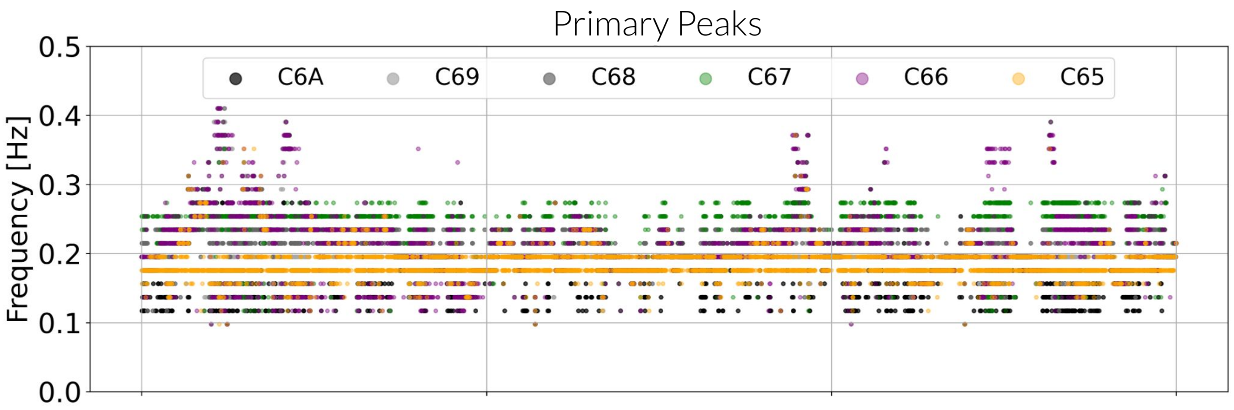

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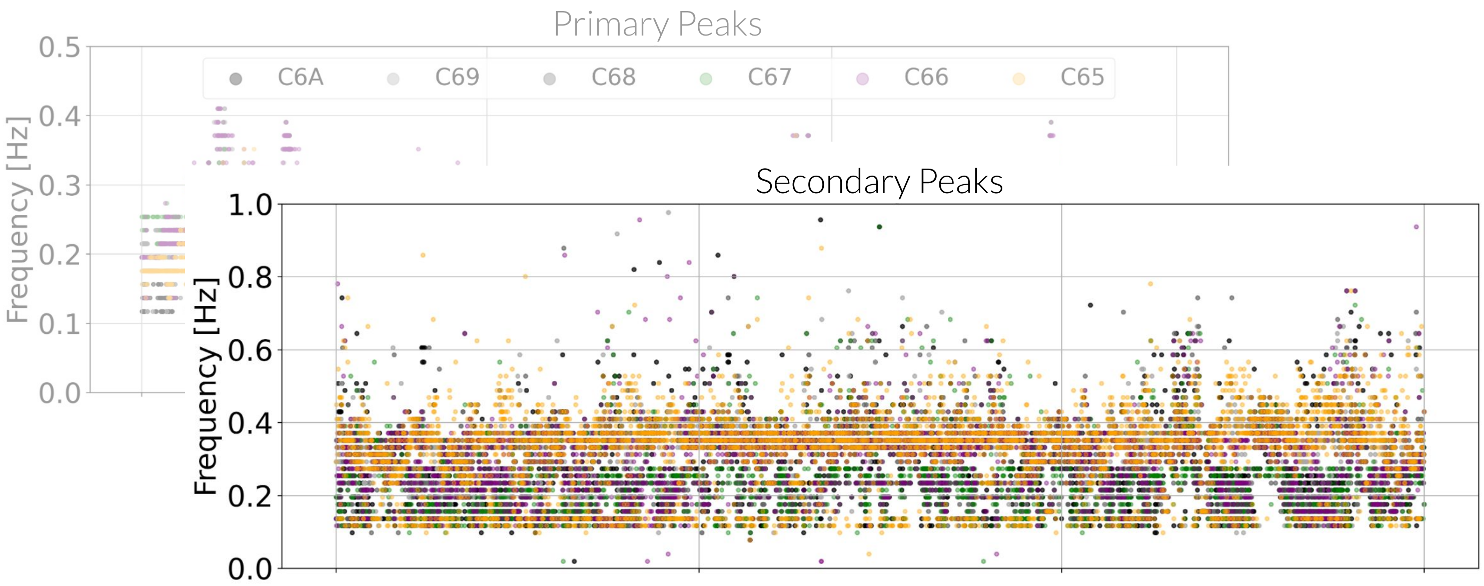

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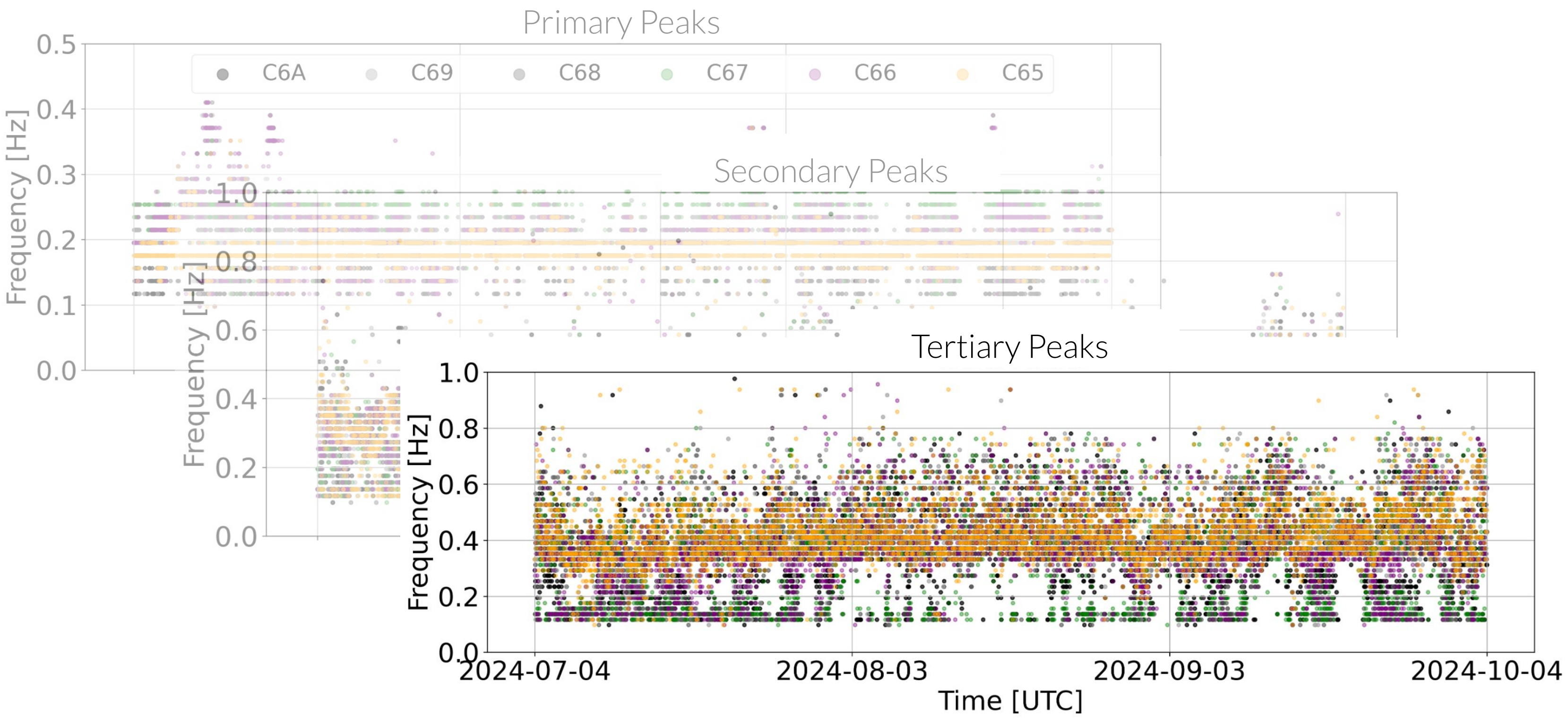

II. From Fingerprint to Features

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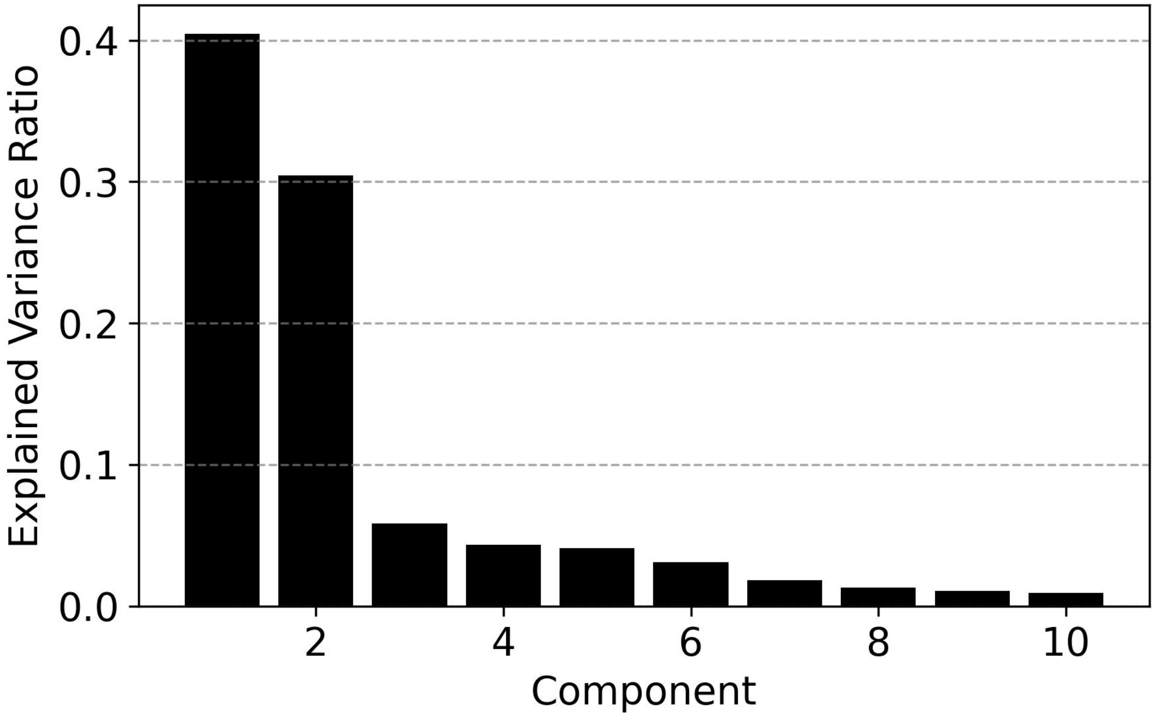
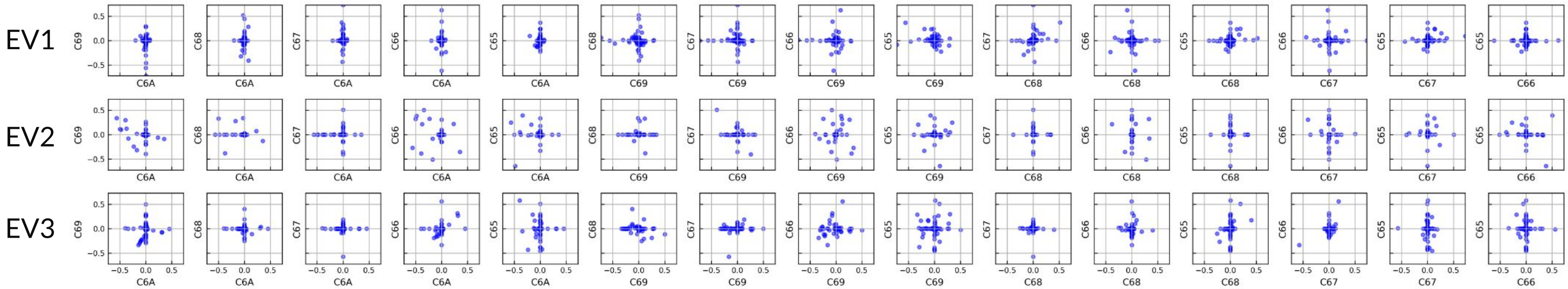


II. From Fingerprint to Features

b. Eigenvector Analysis

Spatial Eigenvector Amplitudes



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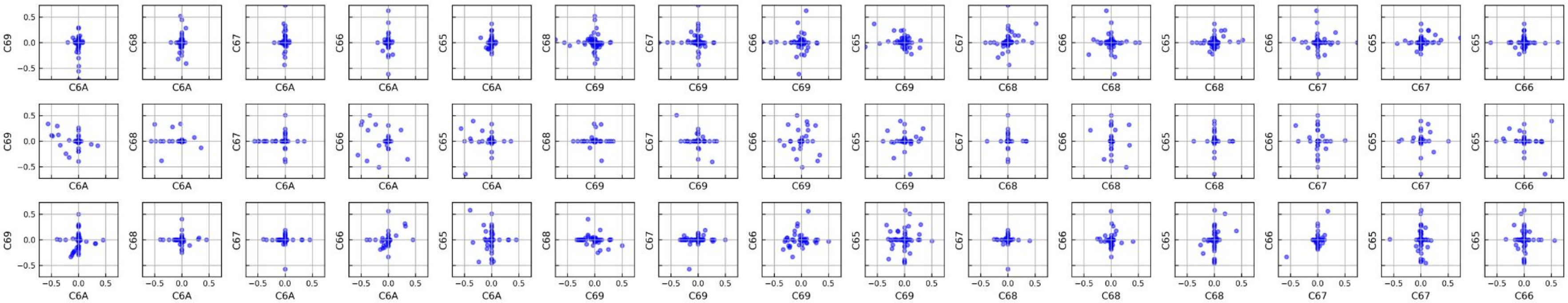
Spatial Eigenvector Amplitudes

EV1

EV2

EV3

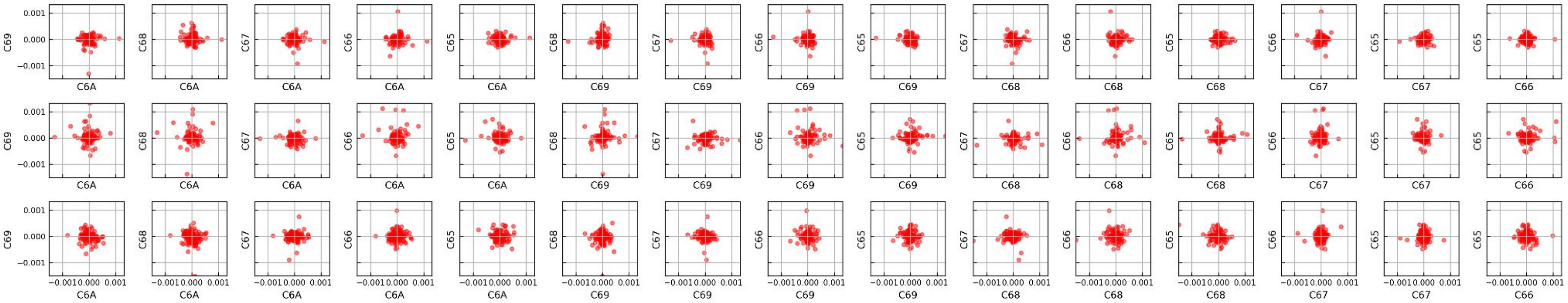


Temporal Eigenvector Amplitudes

EV1

EV2

EV3



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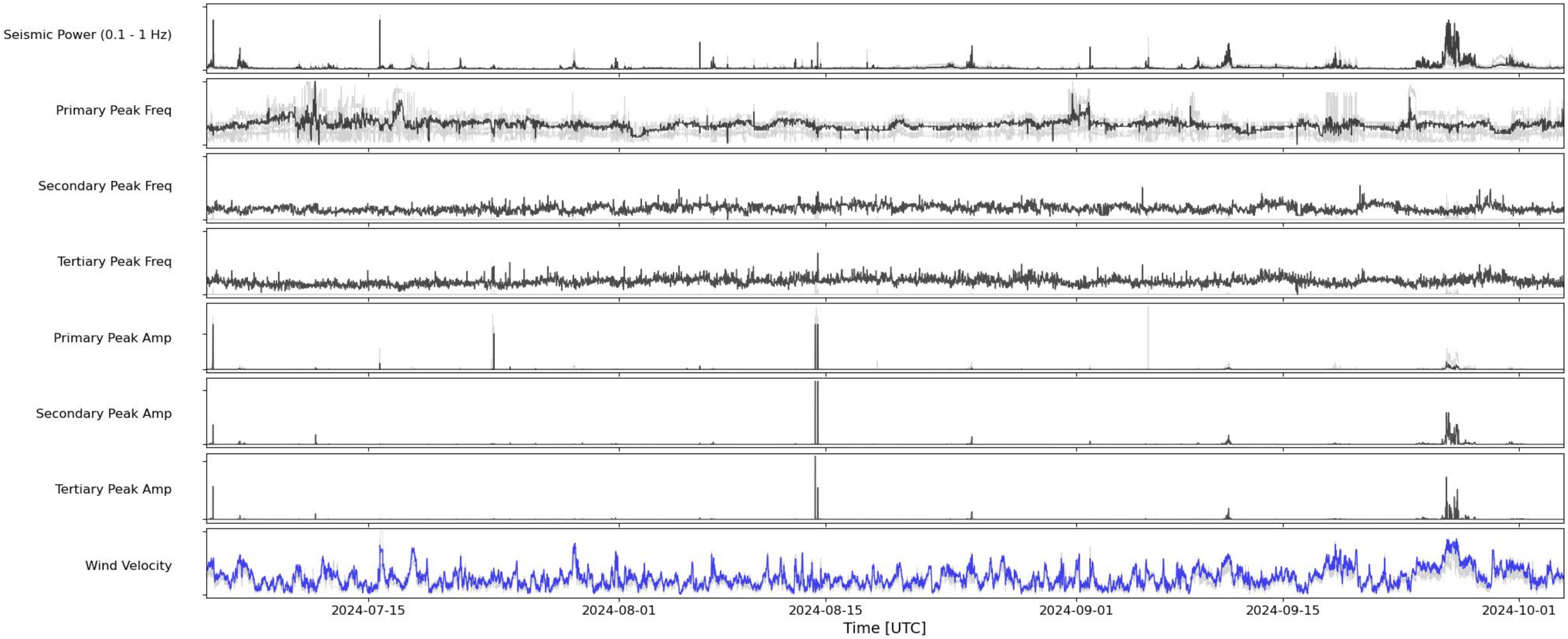
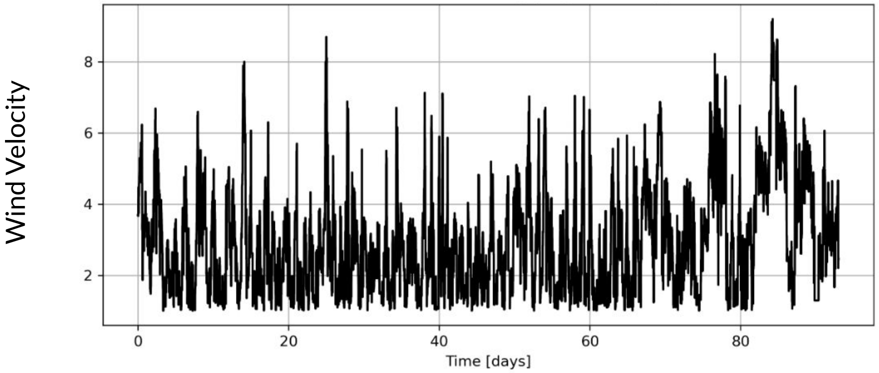
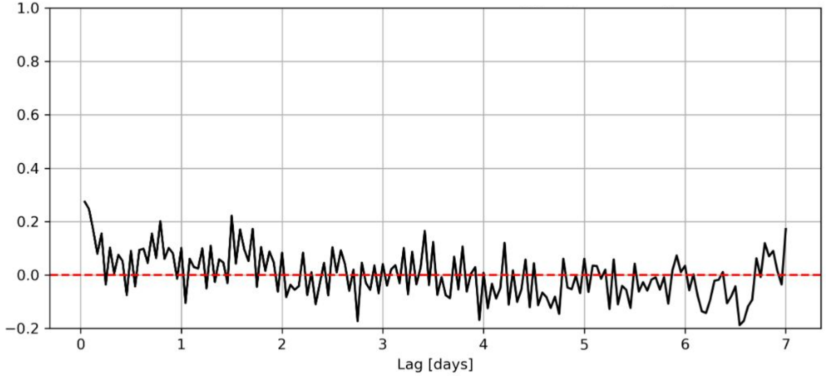


III. Fingerprint Features predict Wind Velocities

Time Series



Temporal Autocorrelation



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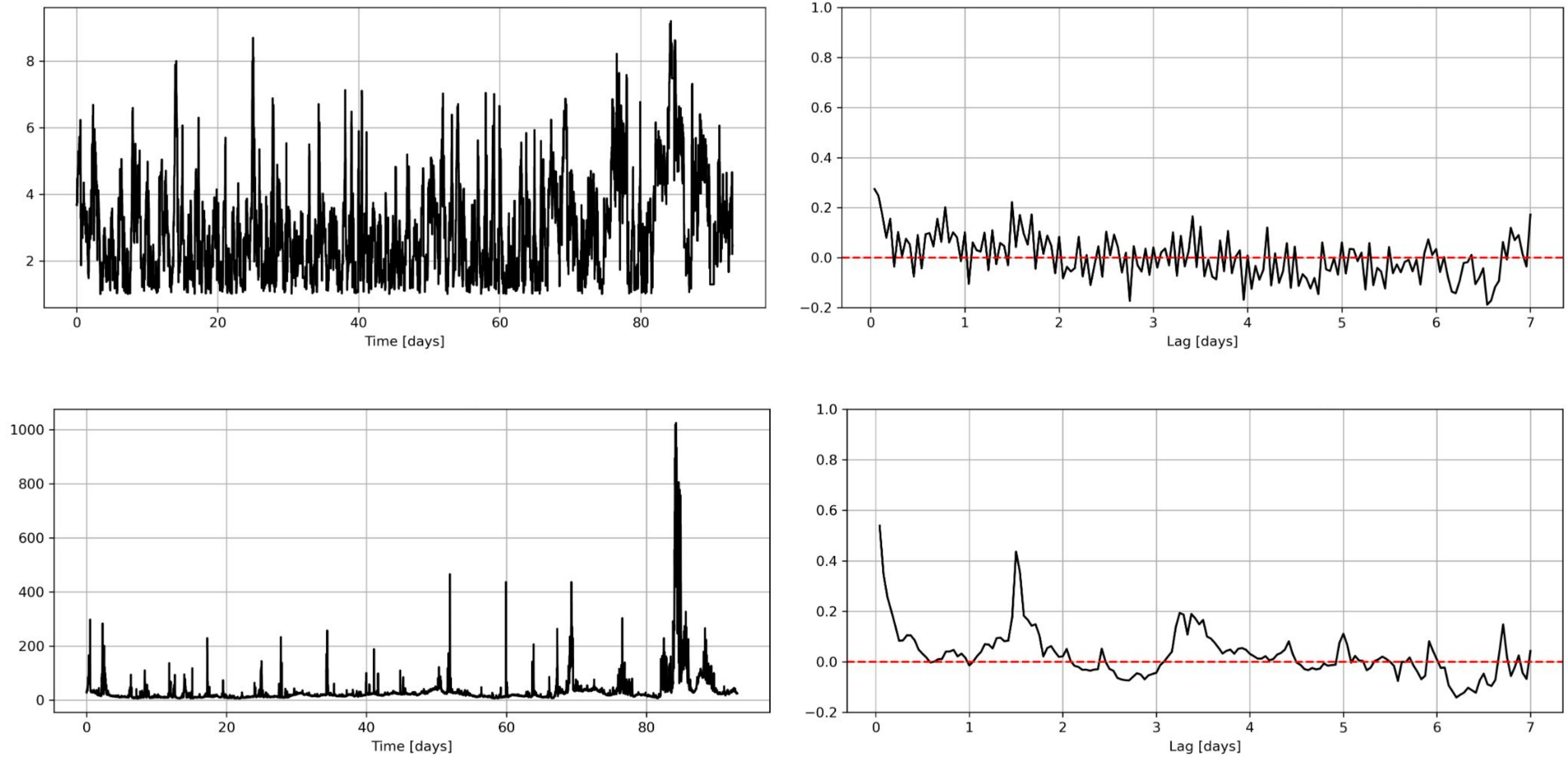
Time Series

Temporal Autocorrelation

Wind Velocity

Seismic Power (0.1- 1 Hz)



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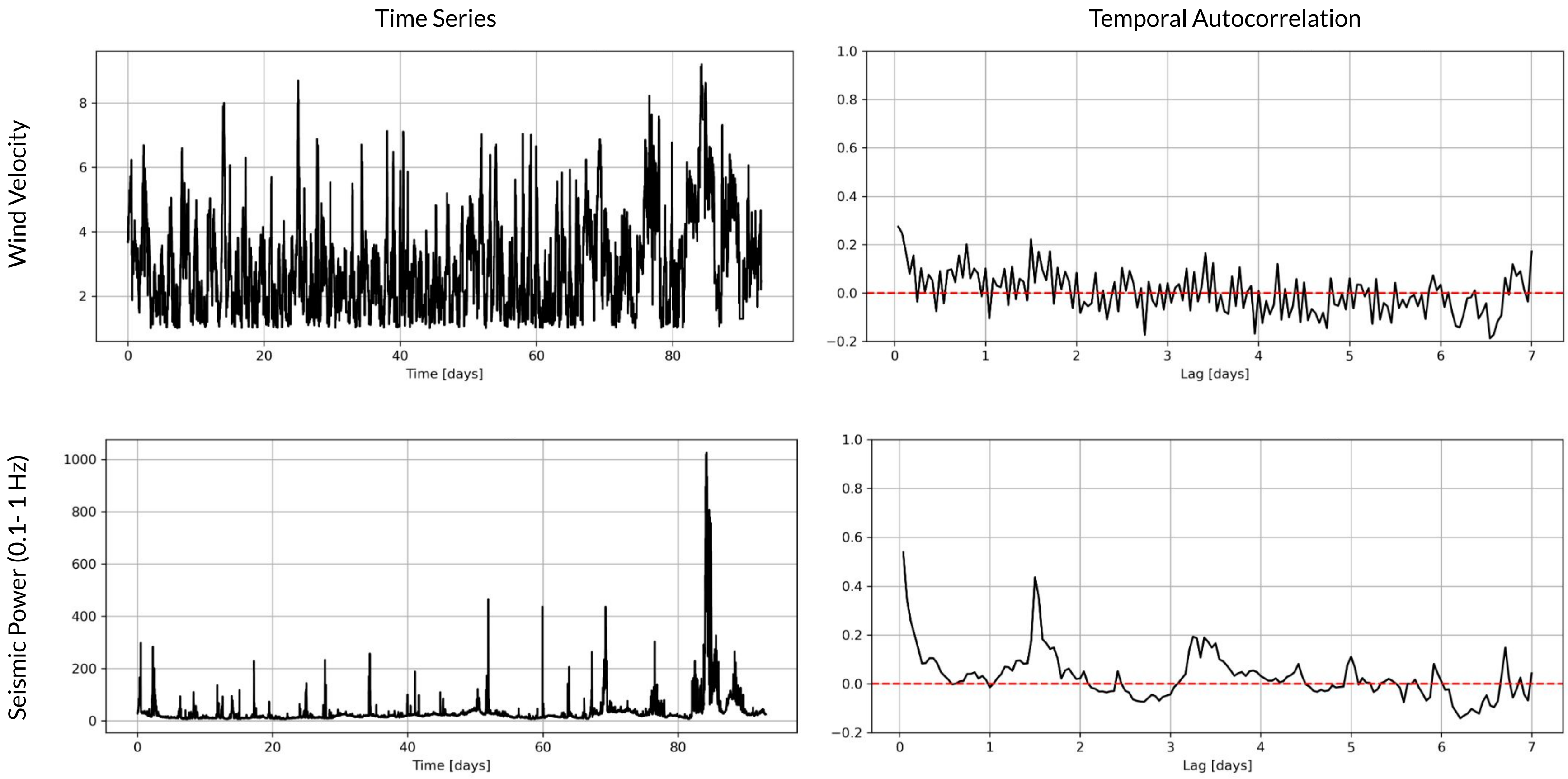

may be autocorrelated

good to go

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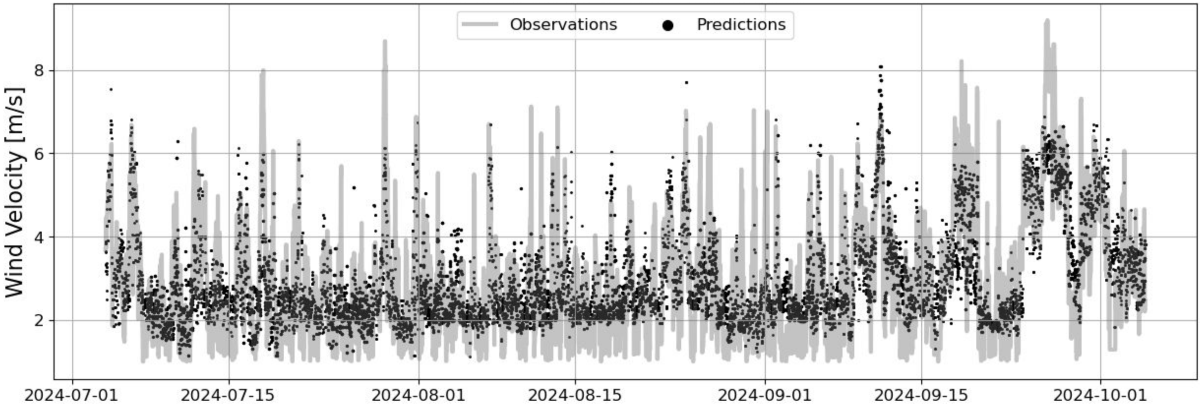

XGBoost Model with 5-fold cross-validation and 96 hrs block split

CC train: 0.75
CC test = 0.71

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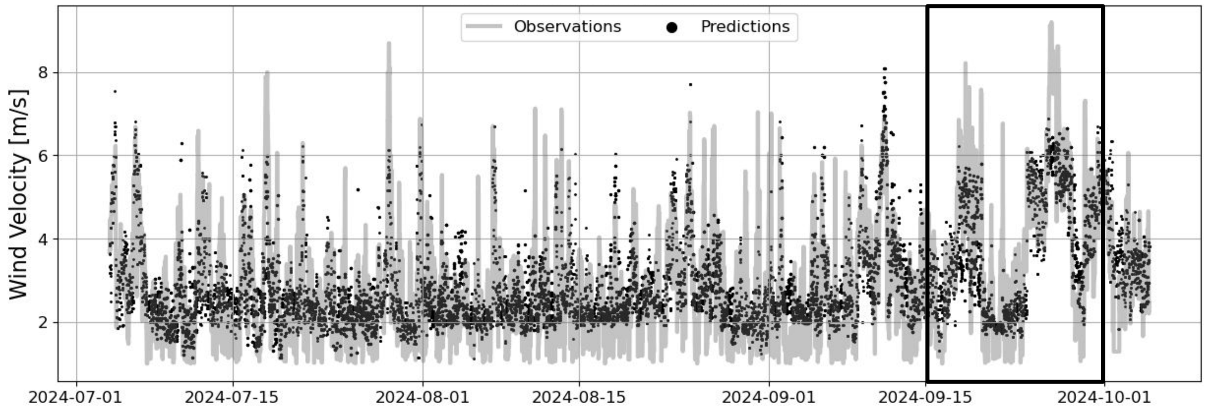

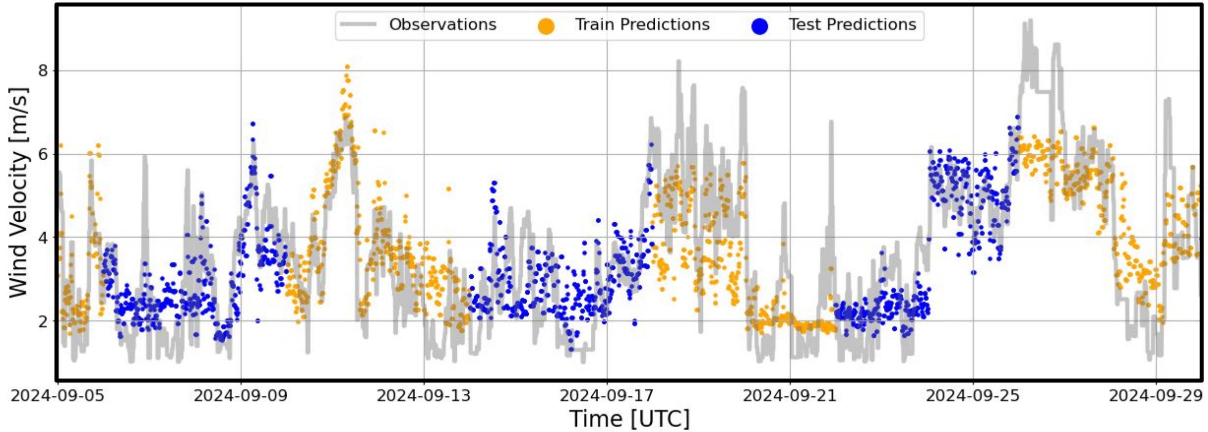

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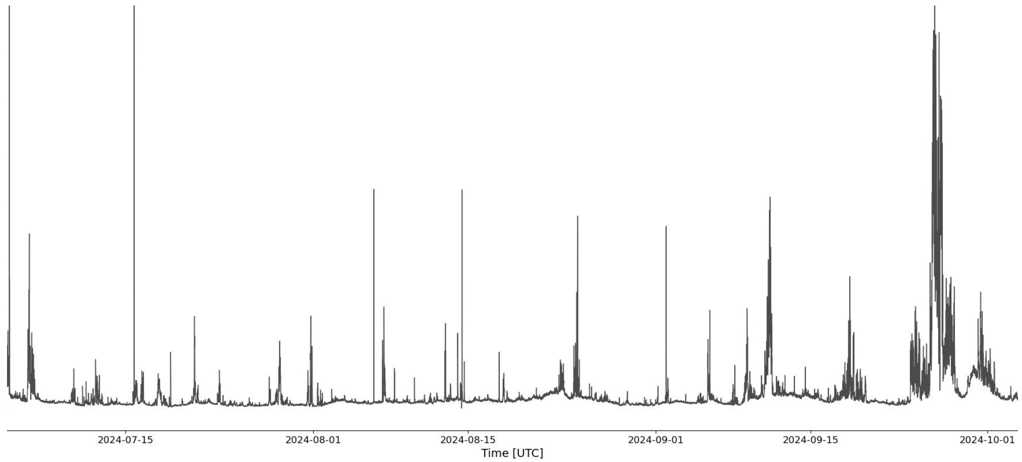

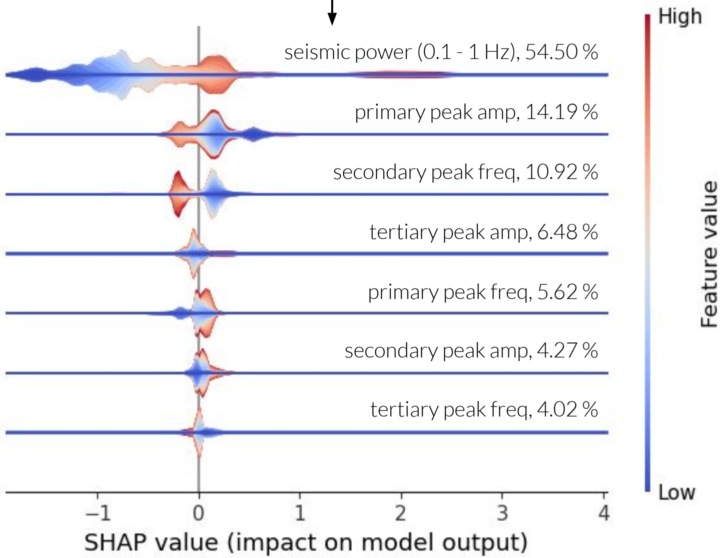

Conclusions

- Spectral Analysis
  - consistent **main peaks between 0.1-0.4 Hz, with a dominant band around 0.25 Hz**
  - secondary and tertiary peaks between 01.-1 Hz
  - internal temporal variations

- Eigenvector Analysis
  - coherent energy across the array, modes are correlated

- Model Predictions
  - CC > 70 %
  - most important feature: seismic power (0.1 - 1 Hz)
  - fails to predict low and high values

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  - **ML Model:** further testing and tuning
  - **Keep measuring:** longer time series provide insights into seasonal dependencies
  - **Modeling:** bending modes, source function …
  - **Interaction/Coupling:** other seismic sources (microseism?), tree vitality parameters

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THANK YOU!