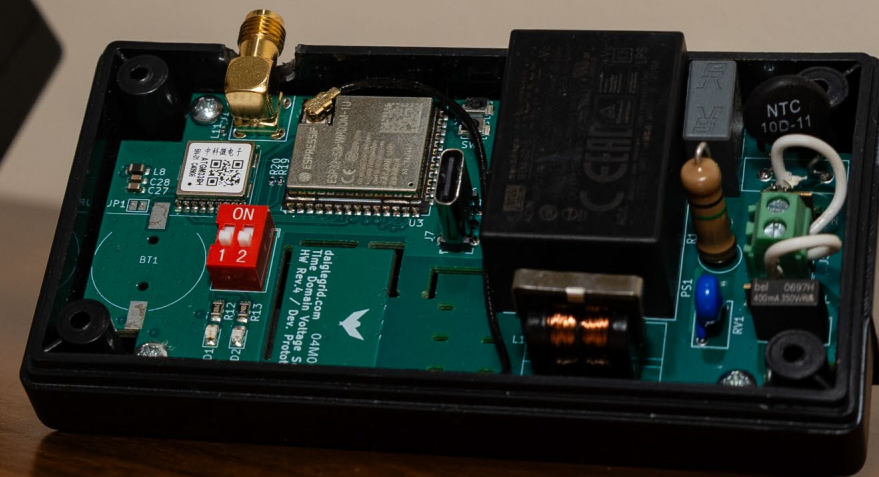


# KGRID: Crowd Sourced Voltage Waveform Monitoring

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# Overview

- KGRID and what it aims to achieve
  - System Architecture
  - Accessing the waveform data
- Applications of waveform measurements
- Recent disturbances captured by KGRID
- Next steps for this system

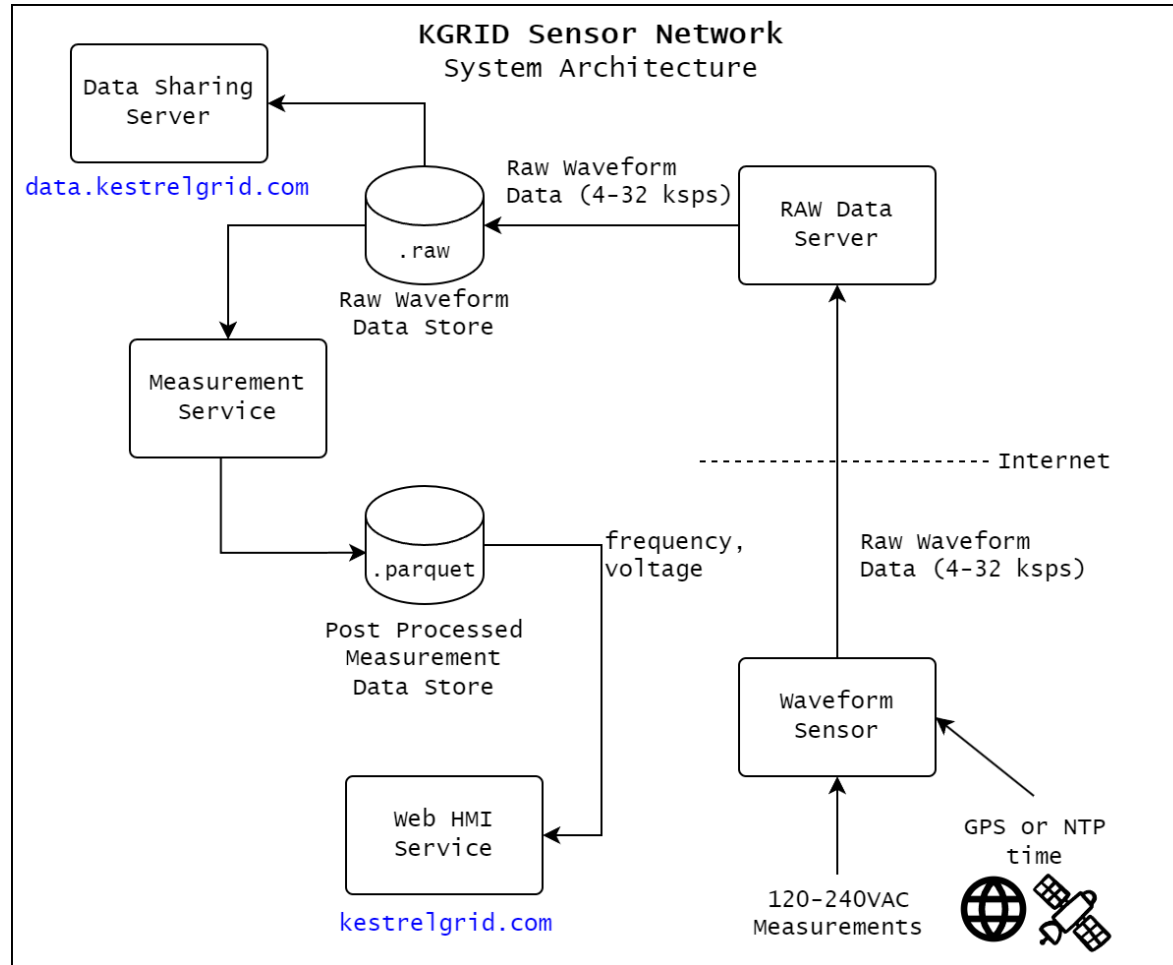


# KGRID Objectives (aka kestrelgrid)

## End-to-end voltage waveform monitoring for R&D

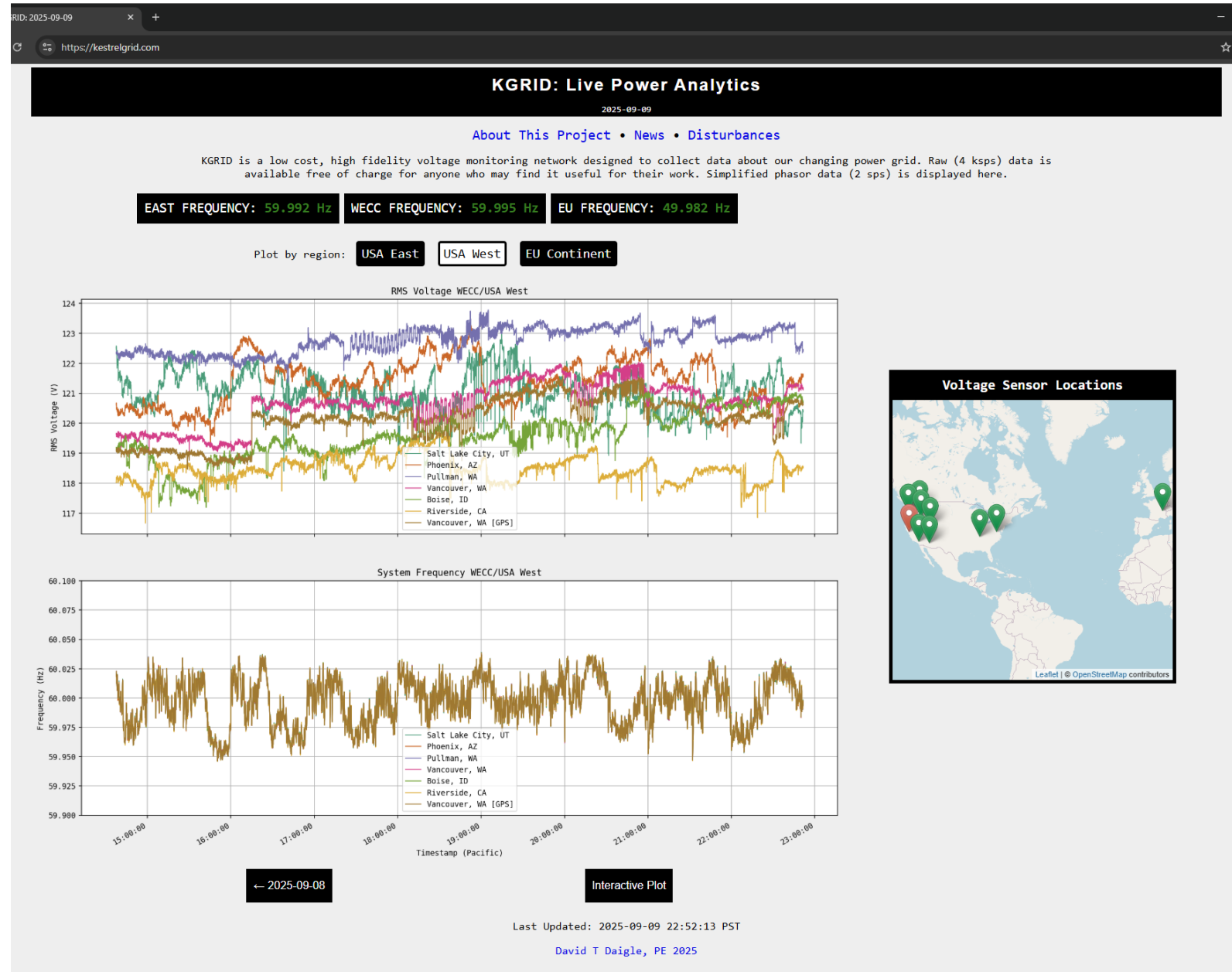
- **High Fidelity** – 4-32 ksps @ 16-24 bit
- **Low Cost** – <\$150/unit at scale
- More Accurate Time with **GPS**
- **Low Complexity** – Configure Wi-Fi with smartphone, optionally connect GPS antenna
- **Open data sharing for the community**

# System Architecture



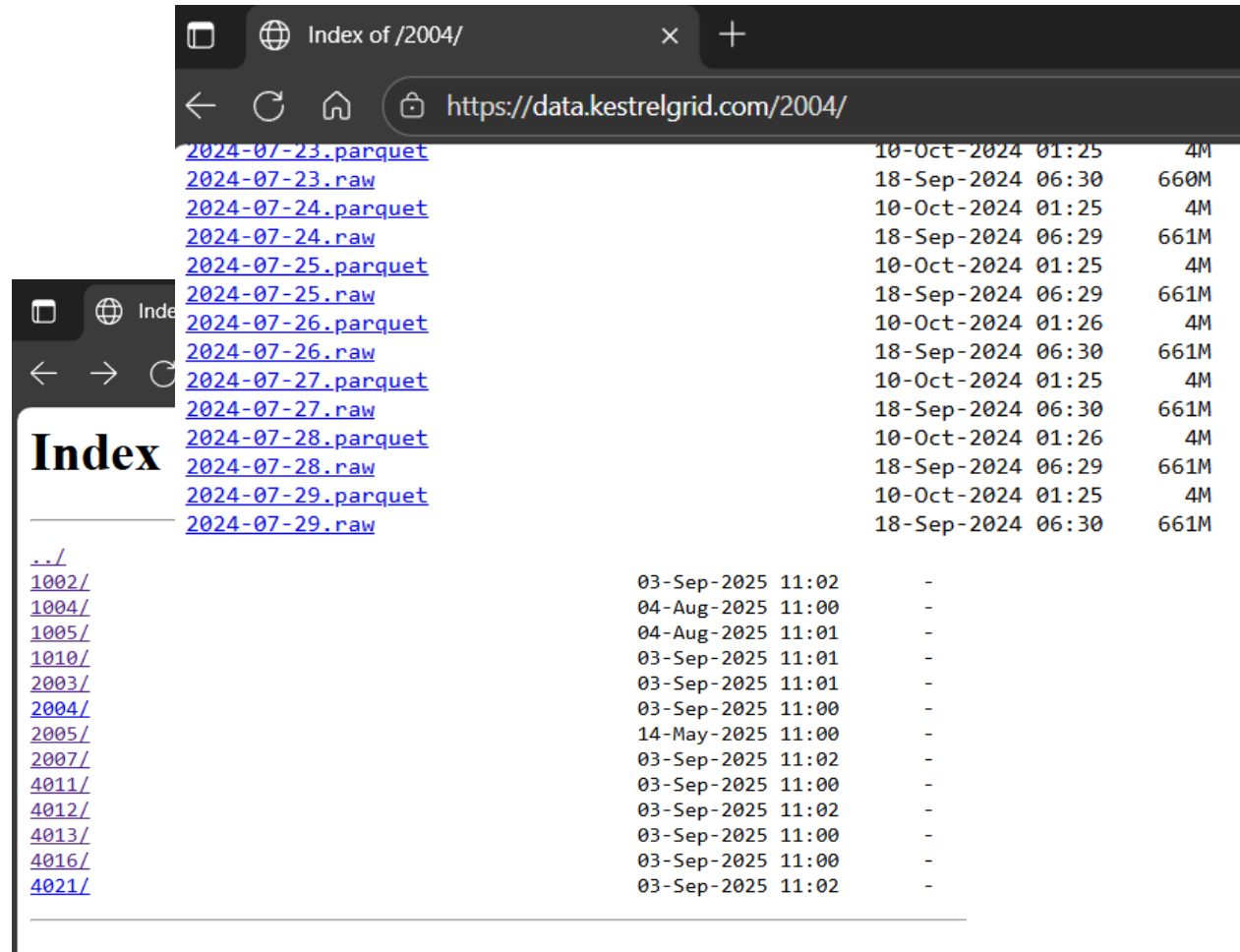
# Live Data

- View phasor data on web display here:  
<https://kestrelgrid.com/>
- 12 sensor deployments since March 2024
  - 8 in WECC
  - 2 in EI
  - 1 in EU
- 2.2 TB of waveform data and counting....





# Data Sharing



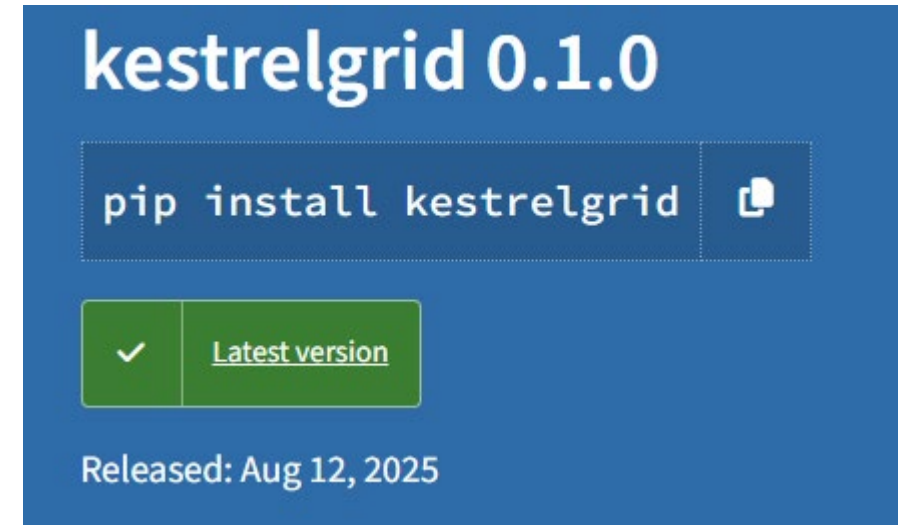
<a href="#">2024-07-23.parquet</a>	10-Oct-2024	01:25	4M
<a href="#">2024-07-23.raw</a>	18-Sep-2024	06:30	660M
<a href="#">2024-07-24.parquet</a>	10-Oct-2024	01:25	4M
<a href="#">2024-07-24.raw</a>	18-Sep-2024	06:29	661M
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<a href="#">2024-07-29.raw</a>	18-Sep-2024	06:30	661M

<a href="#">../</a>			
<a href="#">1002/</a>	03-Sep-2025	11:02	-
<a href="#">1004/</a>	04-Aug-2025	11:00	-
<a href="#">1005/</a>	04-Aug-2025	11:01	-
<a href="#">1010/</a>	03-Sep-2025	11:01	-
<a href="#">2003/</a>	03-Sep-2025	11:01	-
<a href="#">2004/</a>	03-Sep-2025	11:00	-
<a href="#">2005/</a>	14-May-2025	11:00	-
<a href="#">2007/</a>	03-Sep-2025	11:02	-
<a href="#">4011/</a>	03-Sep-2025	11:00	-
<a href="#">4012/</a>	03-Sep-2025	11:02	-
<a href="#">4013/</a>	03-Sep-2025	11:00	-
<a href="#">4016/</a>	03-Sep-2025	11:00	-
<a href="#">4021/</a>	03-Sep-2025	11:02	-

Continuous raw point on wave data downloadable over the internet

<https://pypi.org/project/kestrelgrid/>



“kestrelgrid” Python package available  
for install to read raw data

Send me an email if you'd like access to  
the data sharing server

# Sensor Deployment

- GPS or NTP time
- **Standard (Wi-Fi)** -> stream data to kestrelgrid.com
- **Cellular** -> stream data to kestrelgrid.com via cellular modem, bypasses need to configure network
- **Archiver** -> stream to local server, no network needed
  - GPS required
  - Archive up to 1.5 TB
  - Can optionally still configure modem or Wi-Fi to access data
  - Good for higher fidelity (32 kbps) and/or limited bandwidth



32 ksps “Archiver” deployment with GPS and 1.5 TB of storage on Raspberry Pi Zero 2W

# Waveform Measurement Applications

- High-resolution instantaneous measured quantities are preferred for identifying oscillations through field measurements (>10x sample rate preferred) [1]
- Waveform measurements are useful for EMT model waveform playback and model validation
- Waveform measurements unify other measurement types, (e.g. power quality, DFR, synchrophasor)

The presence or absence of frequency characteristics can be used to narrow down failure modes

Characteristics		Causality/Failure Modes														
		Sub/super Synchronous Oscillations				Voltage Control–Induced Oscillations			Angle (Transient) Stability–Induced Oscillations			Frequency or Active Power Control–Induced Oscillations			Harmonic Oscillations	
		Traditional SSR	Control interaction with network (SSCI)	Torsional interaction with IBRs (SSTI)	Ferro-resonance with nonlinear elements	Voltage control mistuning	Voltage control malperformance	PSS and torque-related mistuning	Incipient voltage collapse	Large signal transfer limit	FIDVR or other load/DER failure	PFC/ governor mistuning	Inter-regional power oscillations	Market services miscoordination	Within plant	Between plants and/or network elements
Frequency	Very low < 0.1 Hz											0.2<w<2	0.01<w<.2	0.01>w		
	Low 0.1 < F < 3															
	Subsynchron 3 < F < 60(F0)															
	Supersynchron F0 < F < ~500 Hz															
	> 3rd harmonic or >2 kHz															

Strong positive indicator
  Weak positive indicator
  Neutral indicator
  Weak contraindicator
  Contraindicator



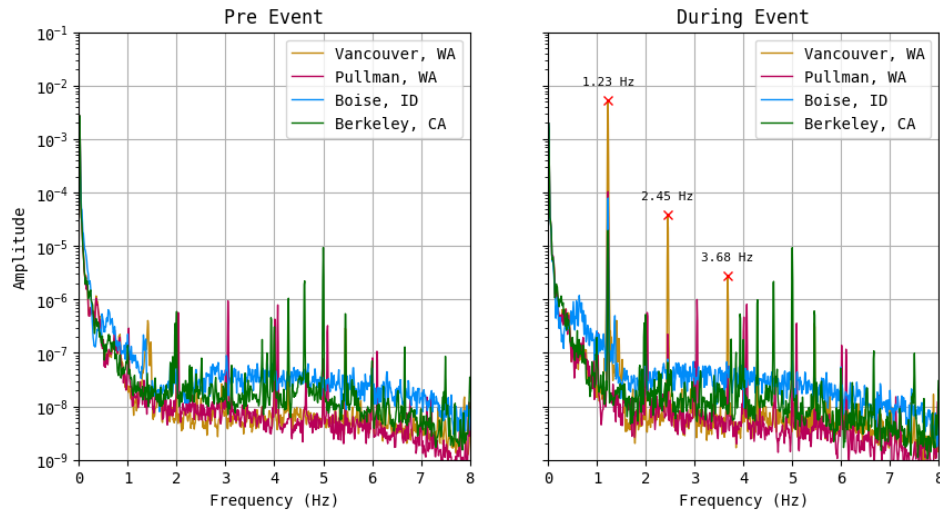
# Point on Wave Captures of Recent Events

Description	Time	Location
Pacific Northwest Hydro Event	November 30 2024 18:31-18:43 PPT	WECC – Pacific Northwest
WECC Event	March 11, 2025 11:50-11:52 PPT	WECC
Iberian Blackout	April 28, 2025 12:00-13:00 CET	Europe – Iberian Peninsula

**All measurements in subsequent slides are derived from KGRID waveform data.**

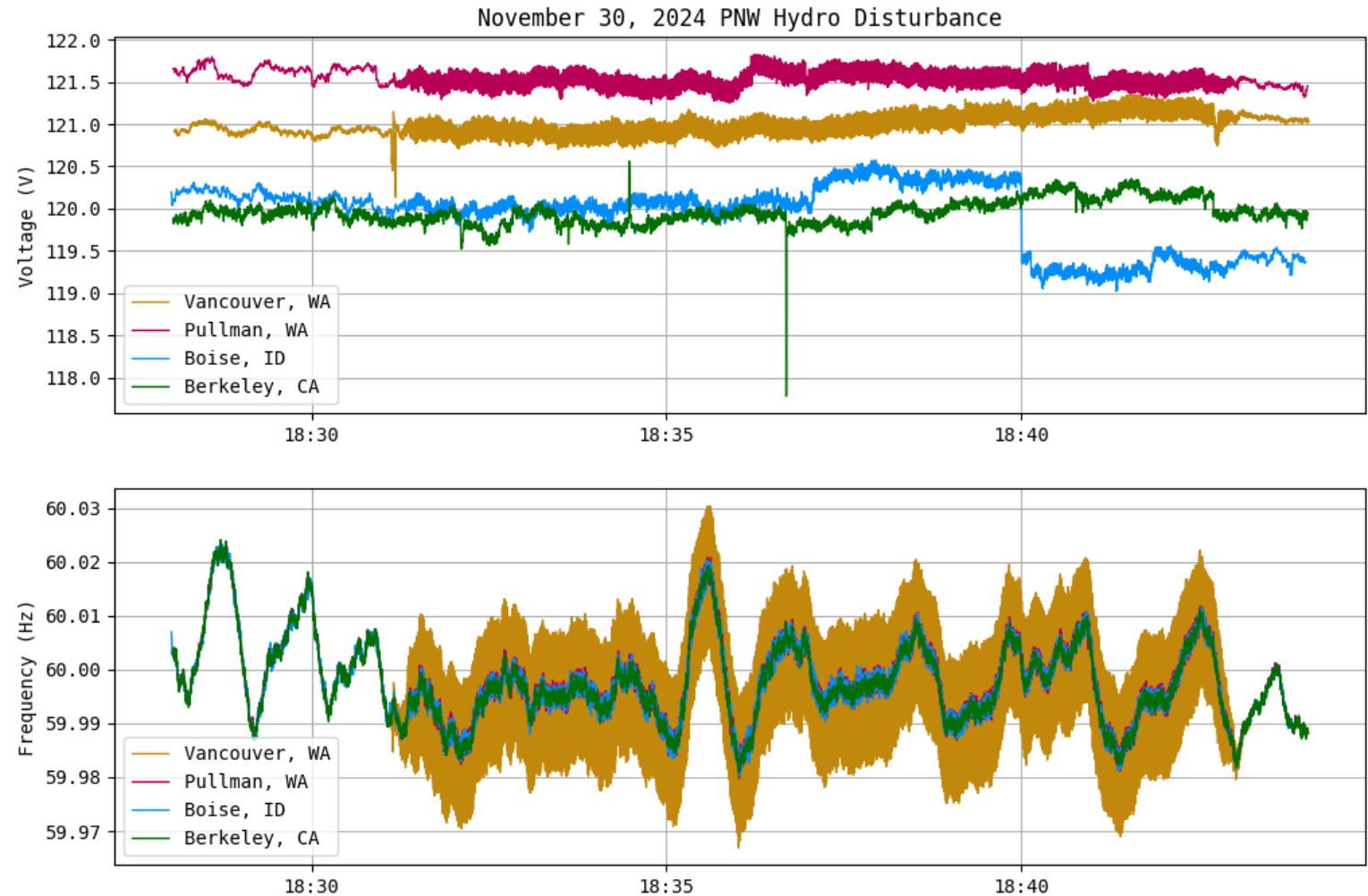
# Pacific Northwest Hydro Event

November 30, 2025 18:31-18:43 PPT



## Quick Summary

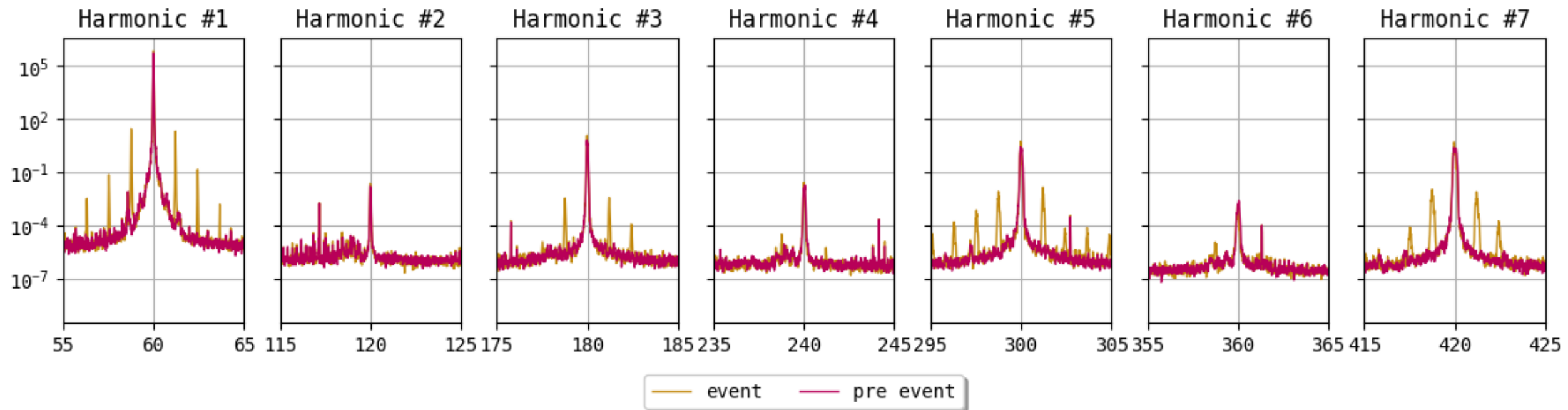
- Line trip followed by hydro unit trip
- ~12 minutes of 1.23 Hz oscillations + harmonics until two hydro units tripped by operator



Additional Event Information: [https://www.naspi.org/sites/default/files/2025-04/01\\_01\\_01\\_Daigle\\_CAISO\\_20250415.pdf](https://www.naspi.org/sites/default/files/2025-04/01_01_01_Daigle_CAISO_20250415.pdf)

# Pacific Northwest Hydro Event

- What else can we see in raw waveform data?
  - Modulated frequency appears clearly as sidelobes in fundamental and odd harmonics, but not even.

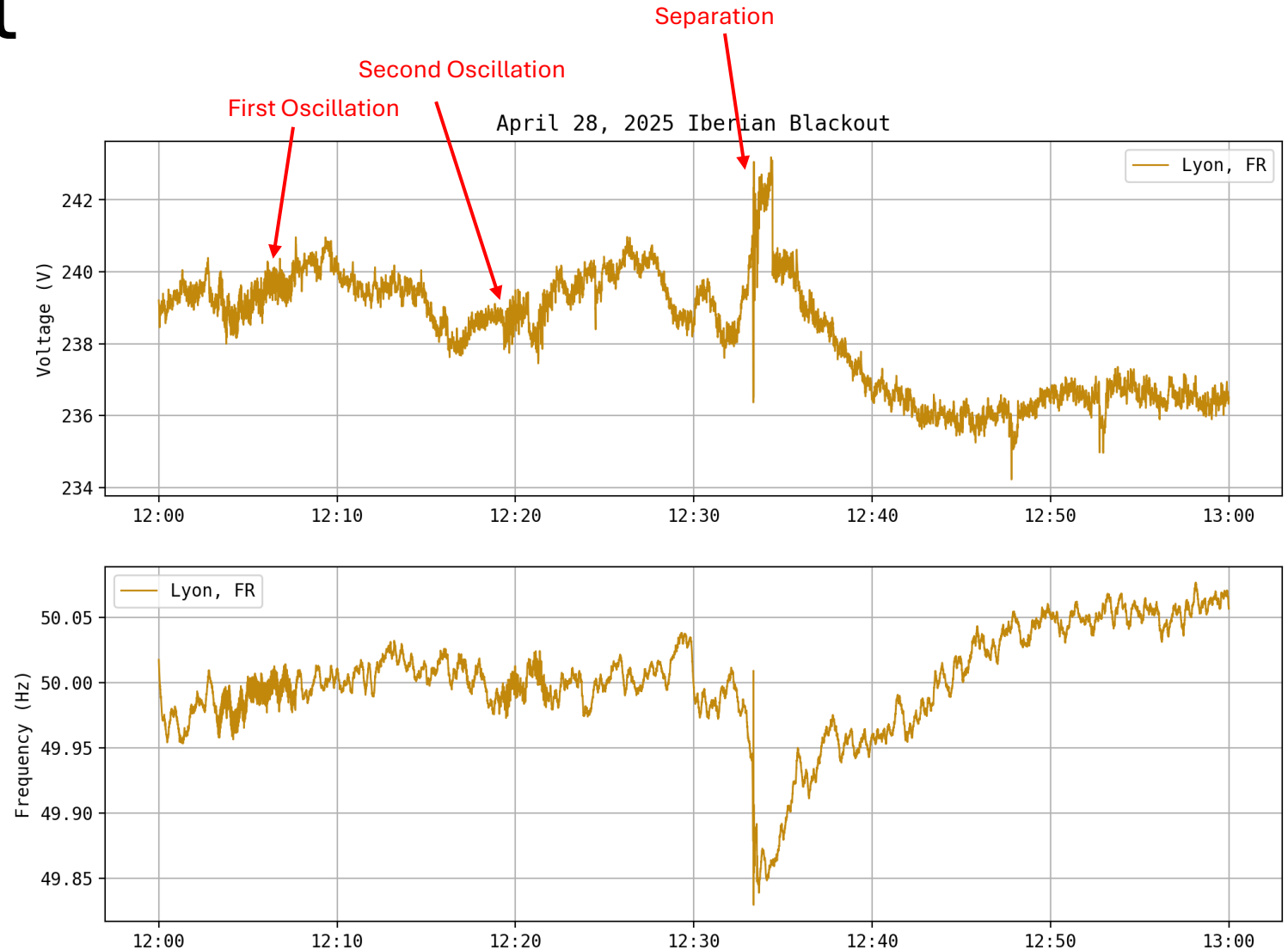


# Iberian Blackout

April 28, 2025 12:00-13:00 CEST

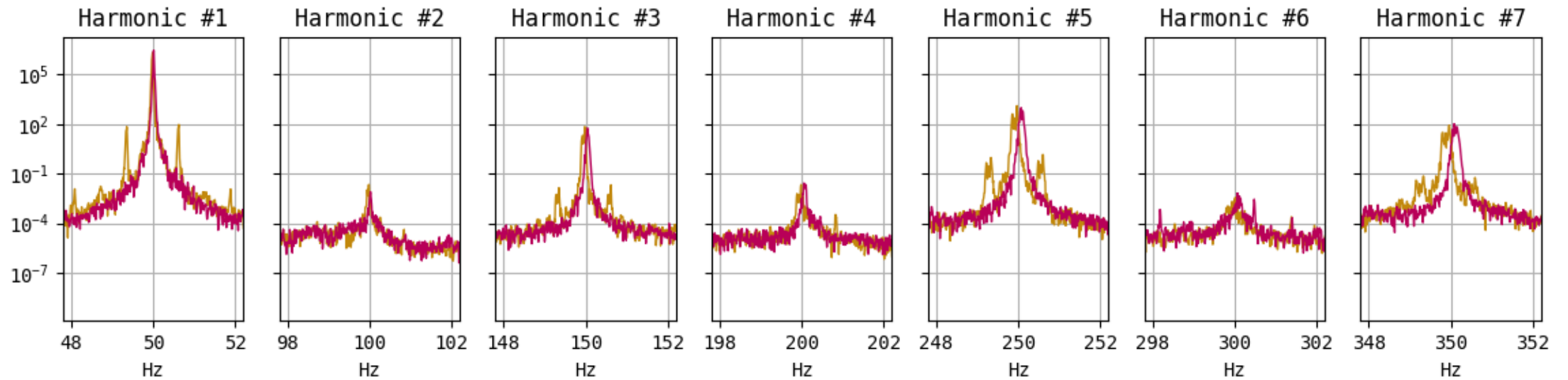
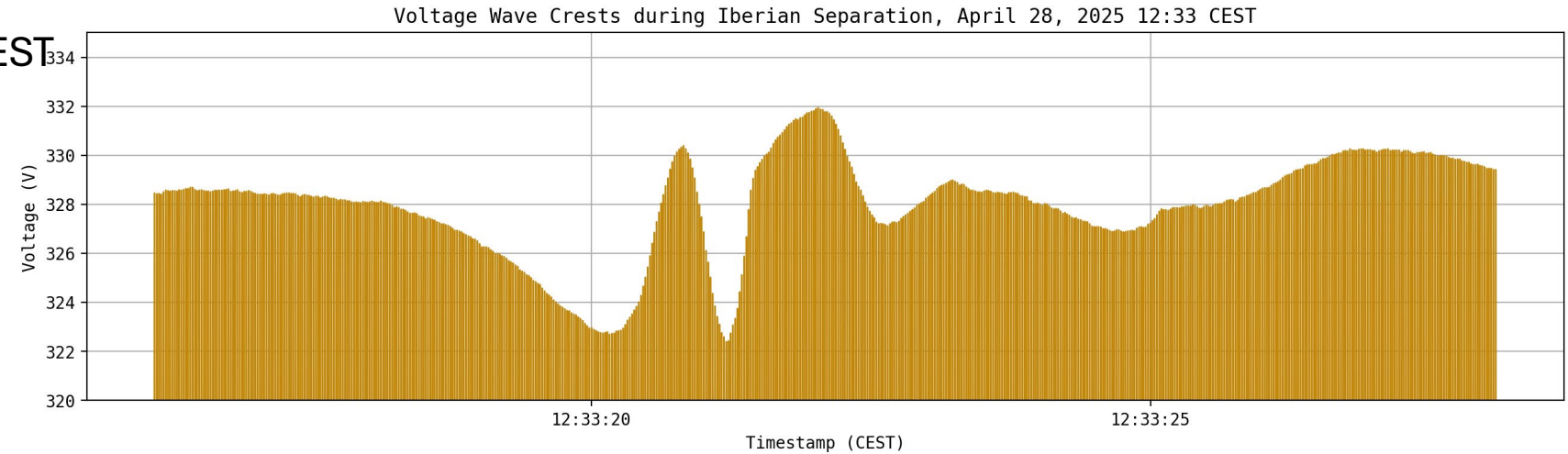
## Event Summary

- 12:03-12:07: 0.64 Hz forced oscillation
- 12:19-12:22: 0.21 Hz forced oscillation
- 12:33: Separation of the Iberian peninsula



# Iberian Blackout

April 28, 2025 12:00-13:00 CEST



0.64 Hz side lobes during first oscillation

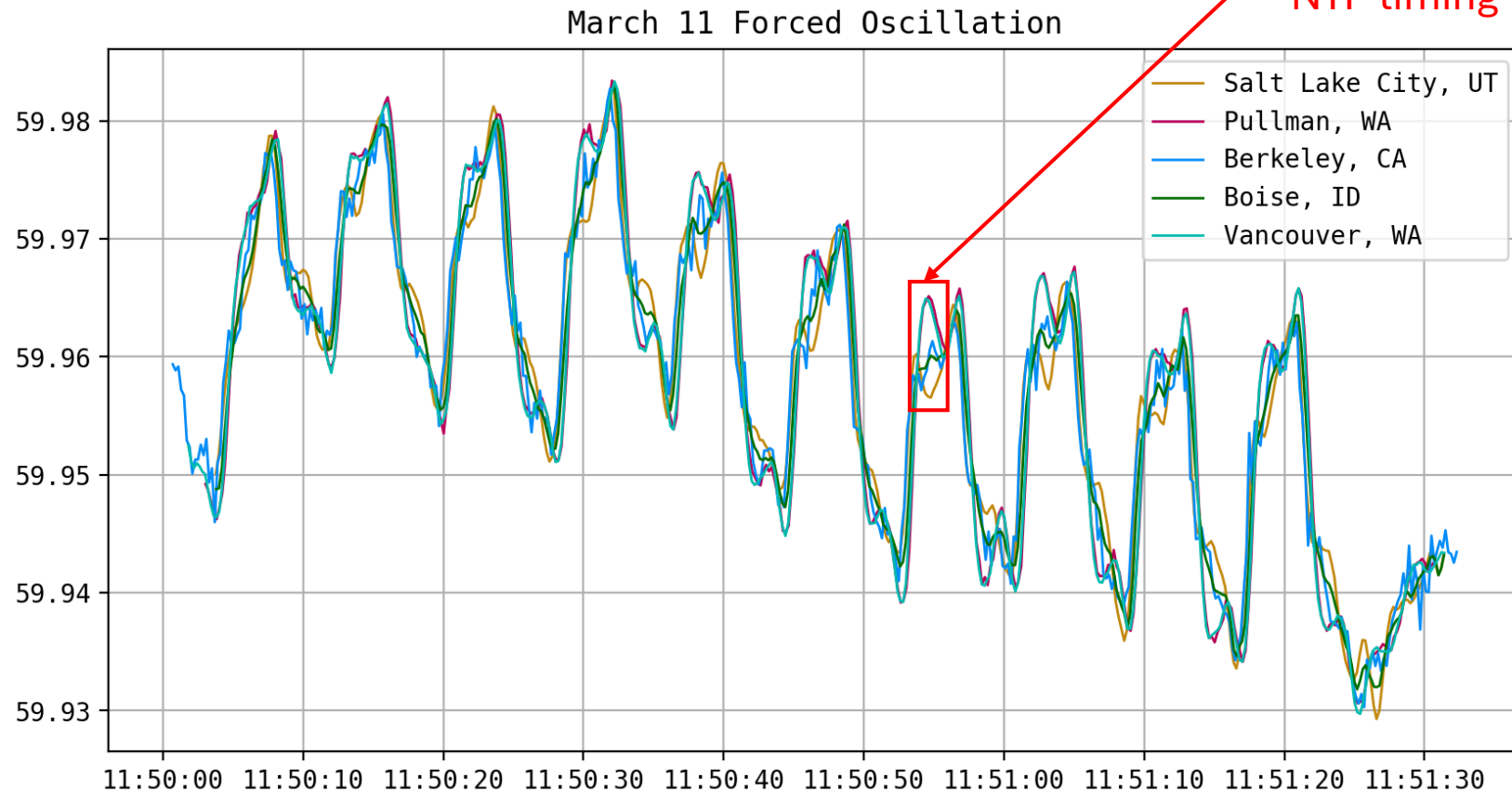




# WECC Forced Oscillation

March 11, 2025 11:50-11:52 PPT

Mode Shapes Visible  
(UT vs PNW) despite  
most sensors using  
NTP timing



# Possible Future Steps

- Need volunteers to help deploy in key locations, more interconnects, areas with high IBR, HVDC, or Large Load penetration
  - Recently, 14.7 Hz oscillations observed from data center in Dominion [1]
  - 550 Hz, 1270 Hz, 700 Hz, and 1.8 kHz oscillations from HVDC projects in China [2]
- Data validation/benchmarking
- Improvement of time domain analysis and detection techniques

[1] Mishra et al. “Understanding the inception of 14.7 Hz oscillations emerging from a data center”, Sustainable Energy, Grids and Networks, 2025

[2] Rui Zhu, “Analysis of high frequency oscillations based on MMC-HVDC system” , 2023 5th International Conference on Energy, Power and Grid (ICEPG 2023), 2023

# Questions?

Please email me at [ddaigle@daiglegrid.com](mailto:ddaigle@daiglegrid.com) if you would like access to the waveform data server or would like to host a sensor.

Thanks!

