Multivariate Sensor Deployment at Power Substations – Incipient Failure Detection

Yarom Polsky, Kris Villez, Paul Groth, Bruce Warmack

Grid Modernization Laboratory Consortium

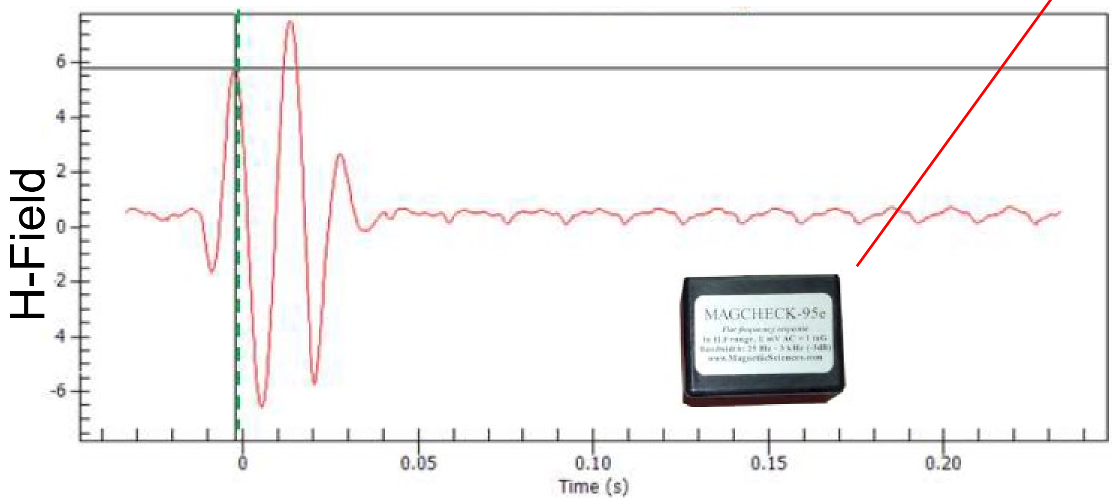
Goal: *Demonstrate multimodal sensing and analytics to detect and classify incipient failures of grid assets*

- Lawrence Livermore National Laboratory (**LLNL**) – Project lead – Develop and implement multimodal data fusion
- Oak Ridge National Laboratory (**ORNL**) – Project co-lead – Deploy and collect data from a variety of sensors and substations and perform analytics
- Sandia National Laboratories (**SNL**) – Machine learning methods (e.g., PMU, AMI) to assess static attributes of grid assets
- National Energy Technology Laboratory (**NETL**) – Develop and deploy novel fiber-optic chemical and physical sensors

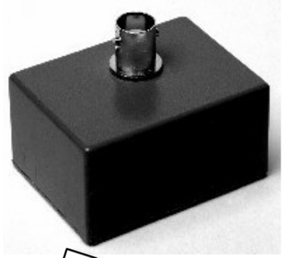
Sponsored by the Department of Energy Office of Electricity

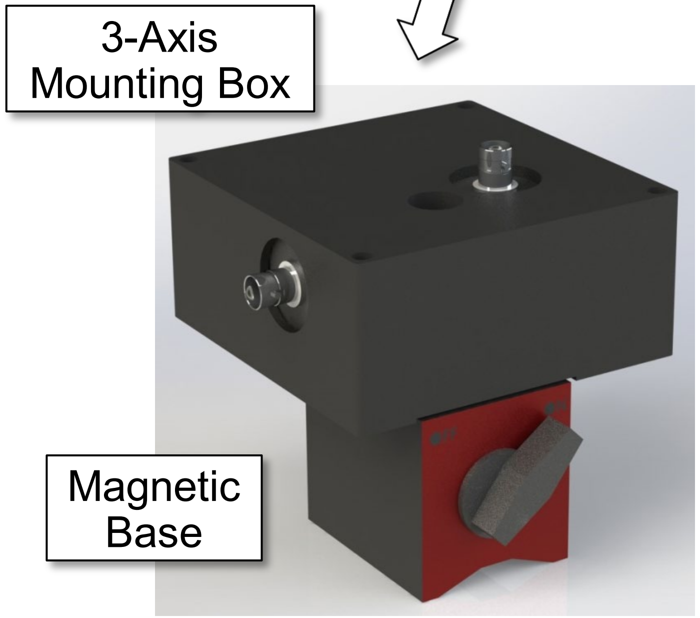
COTS Sensors: H-Field

- Magnetic field senses relative current fluctuations from nearby conductors, coils, and transformer core
- Placed near power lines, EPRI suggests this sensor for triggering PQ monitors on sporadic events
- We mount a 3-axis design magnetically on transformer cases



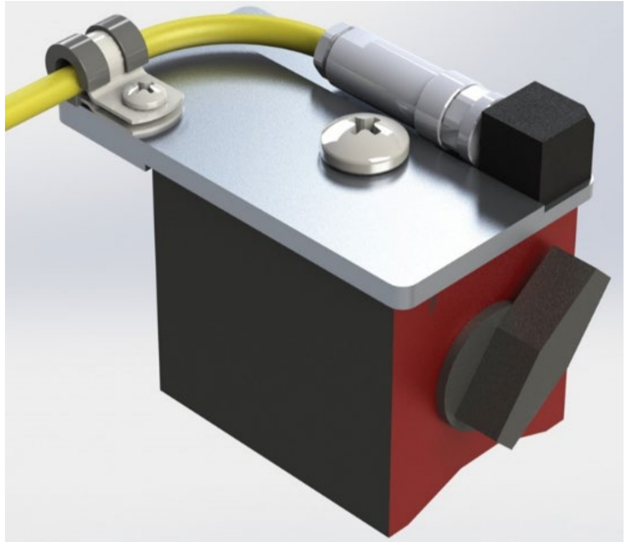
Magnetic Sciences [MC-95A](#)





Vibration, Temperature, Weather

- Vibration monitoring of the transformer senses relative load, tap-changer and gas-relay operations, pump, fans, and abnormal events to 4kHz
- Transformer condition and temperature monitored by IR camera
- Weather station: ambient T, RH, wind, solar, precipitation, lightning (EM)



3-axis Accelerometer
on magnetic base
(PCB Piezotronics 356A17)

Weather Station
WS800-UMB

IR Camera
AX8

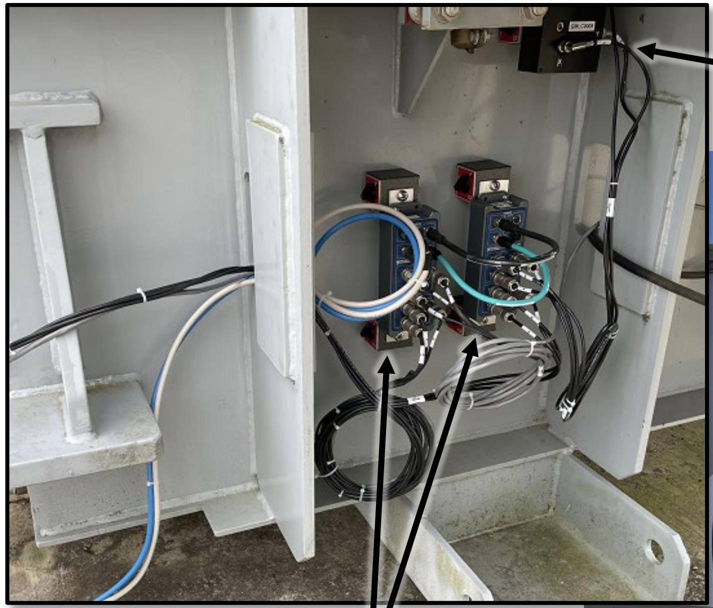
ORNL Substation

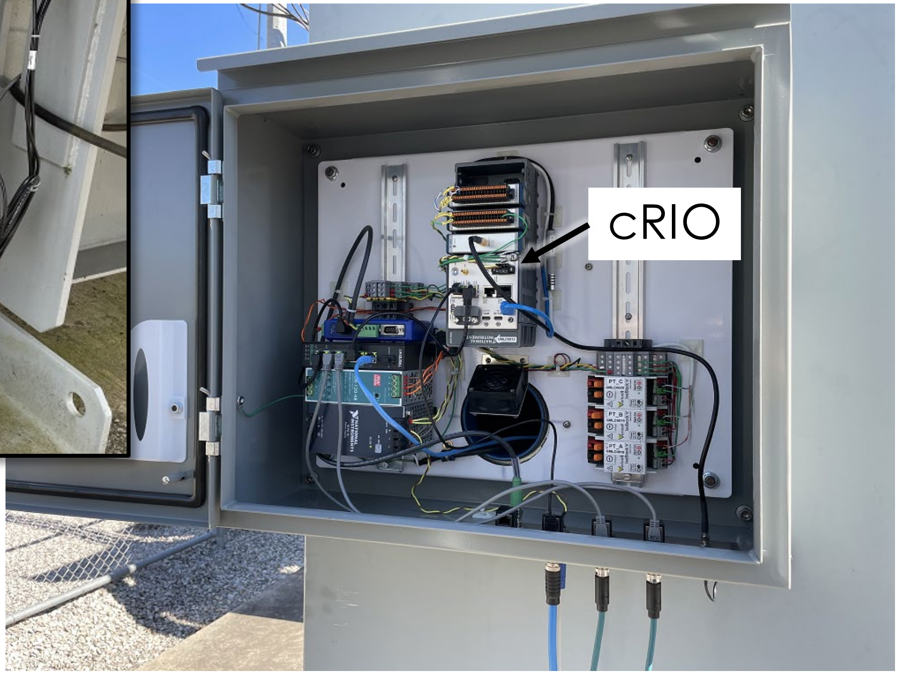
- Two 14 kV regulating transformers
- Monitor box provides convenient access

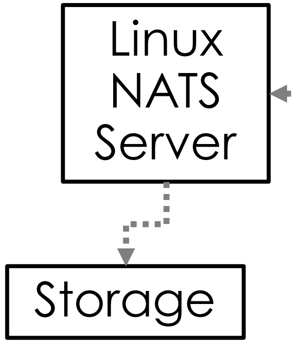
Oak Ridge National Laboratory

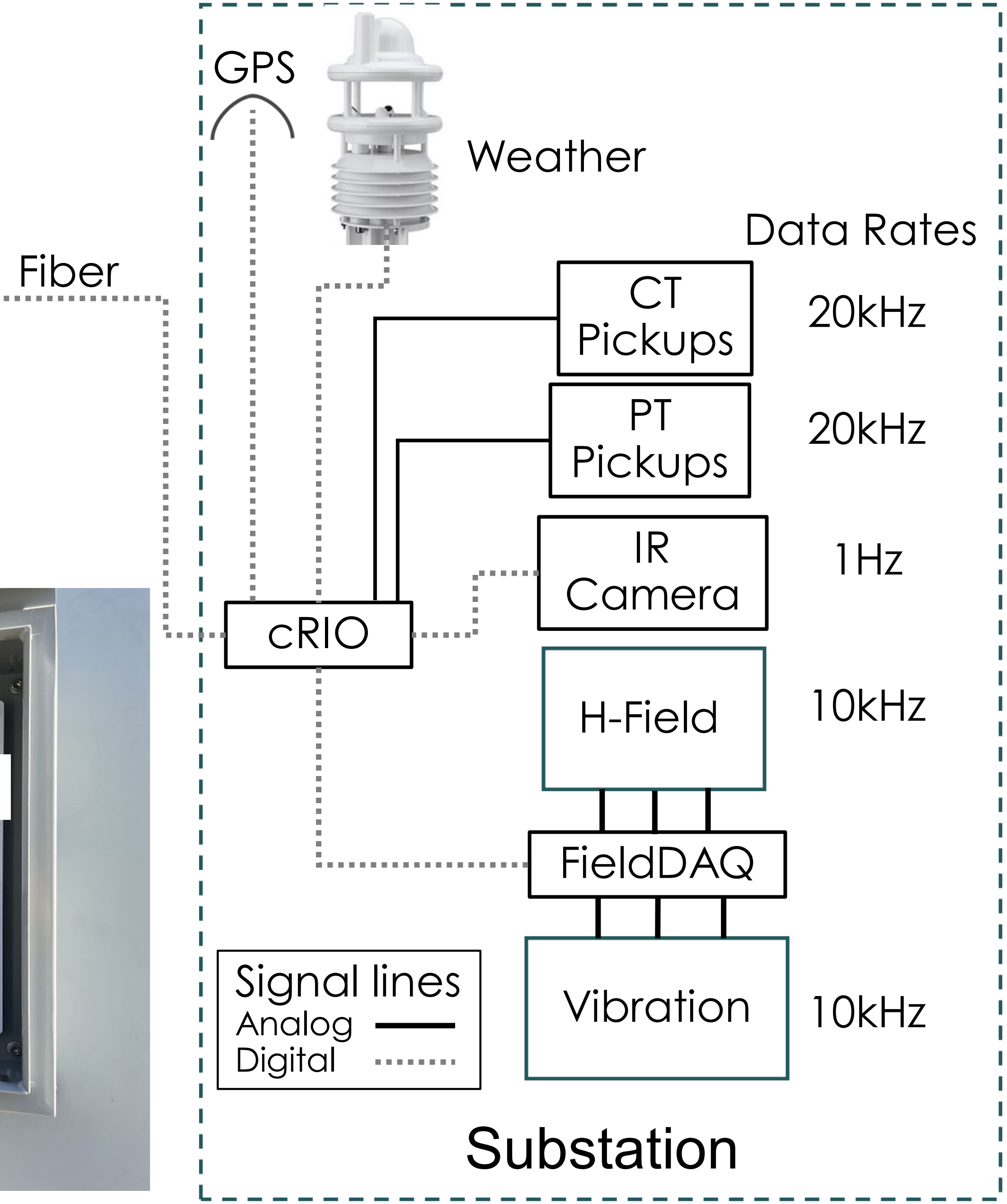
Field Sensors

- Each transformer has 2 vibration and 2 H-field sensors connected to 2 FieldDAQs to the cRIO that digitizes CTs/PTs and sends time-stamped messages to NATS









EPB Chattanooga Substations

- Substations chosen due to frequency of events

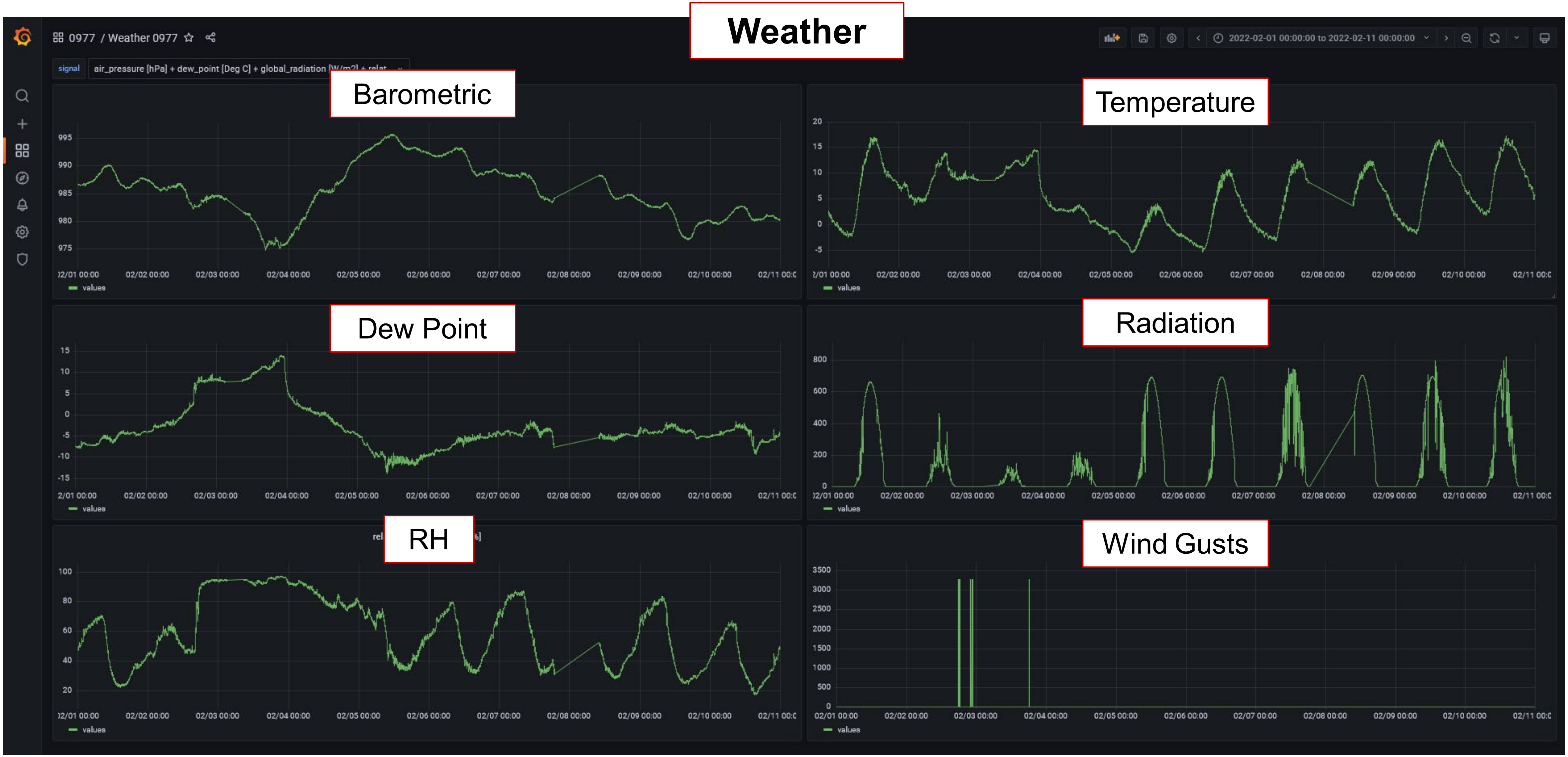
Big Ridge

Bakewell

Data collection and fiber connection In rack

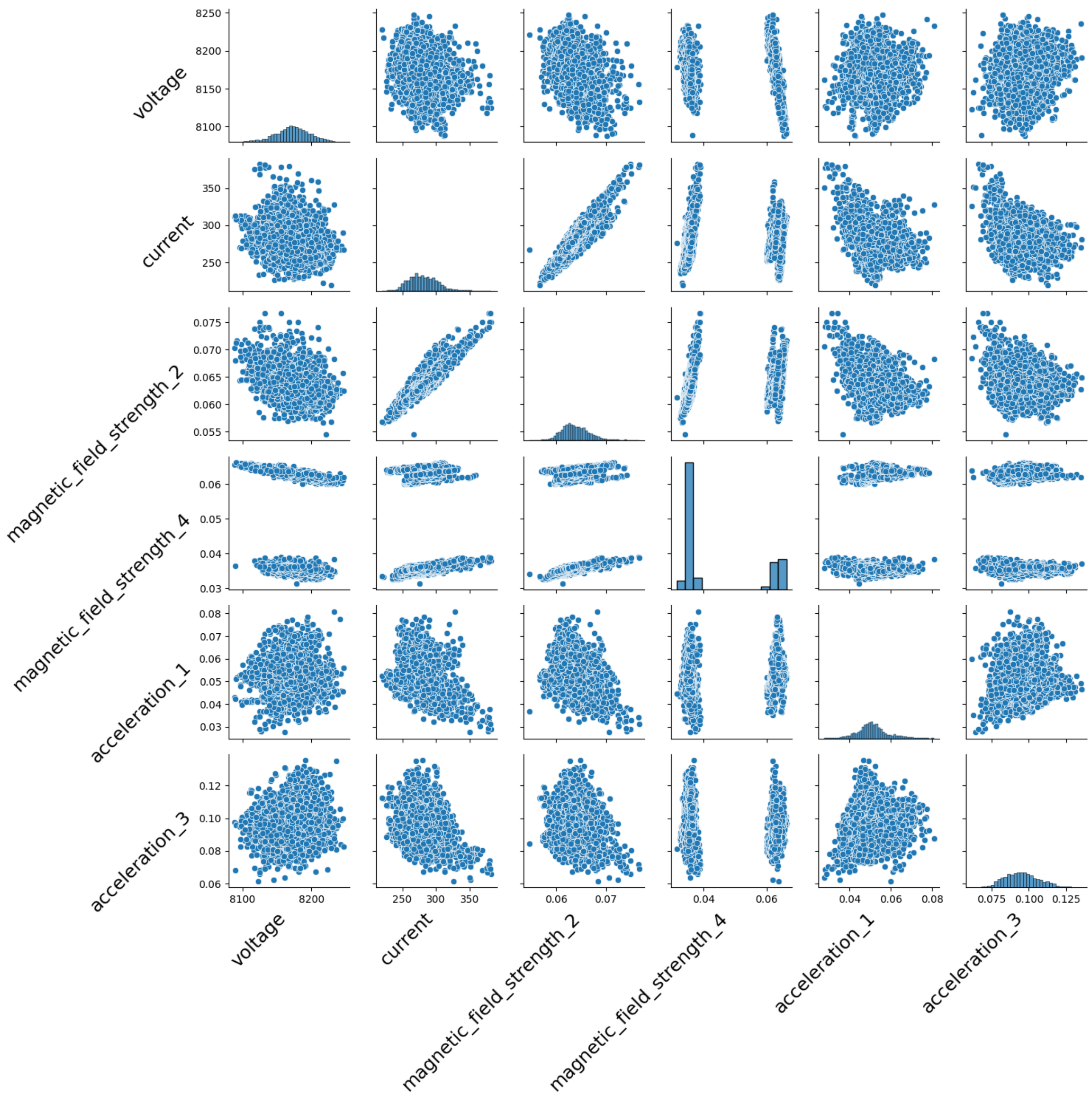
Each station equipped with three CTs, PT, two vibration, two H-field, IR camera, and weather sensors

Database dashboard



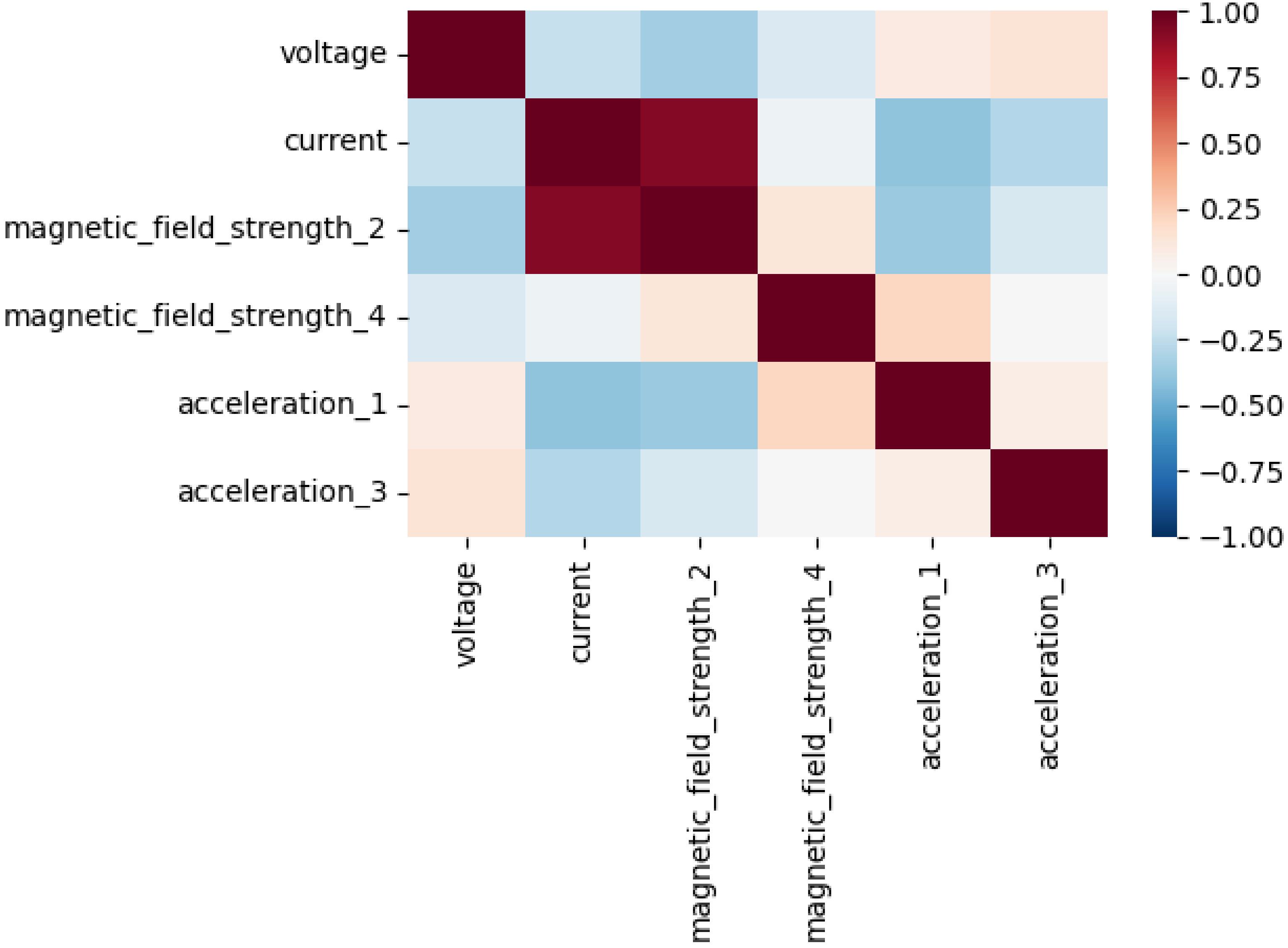
Oak Ridge National Laboratory

Correlation of RMS values: pair-plot (no-event data)



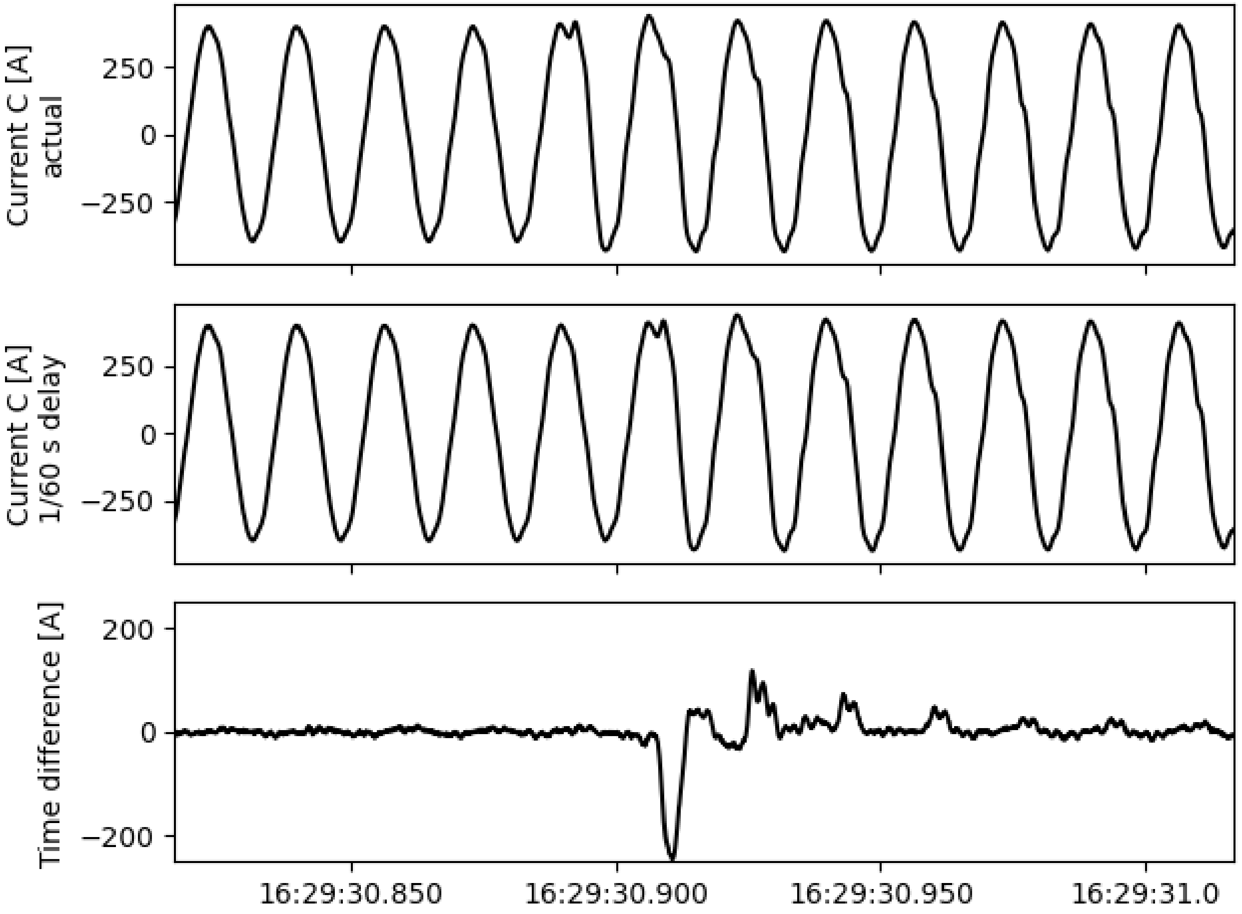
OAK RIDGE National Laboratory

RMS values – correlation heatmap (no-event data)

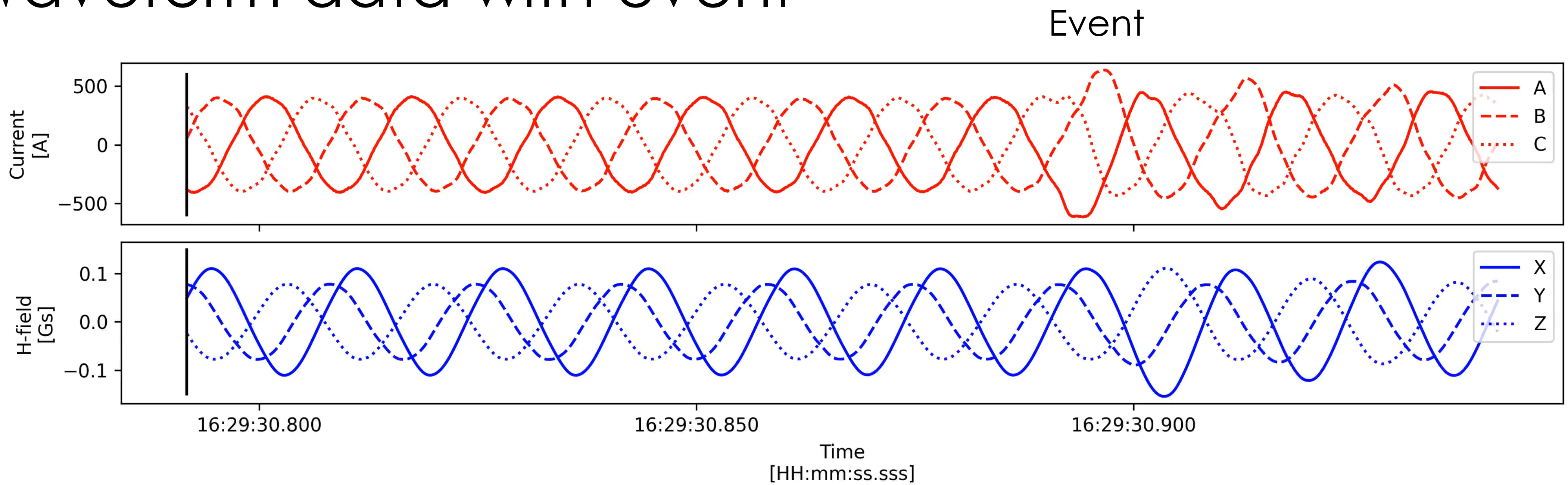


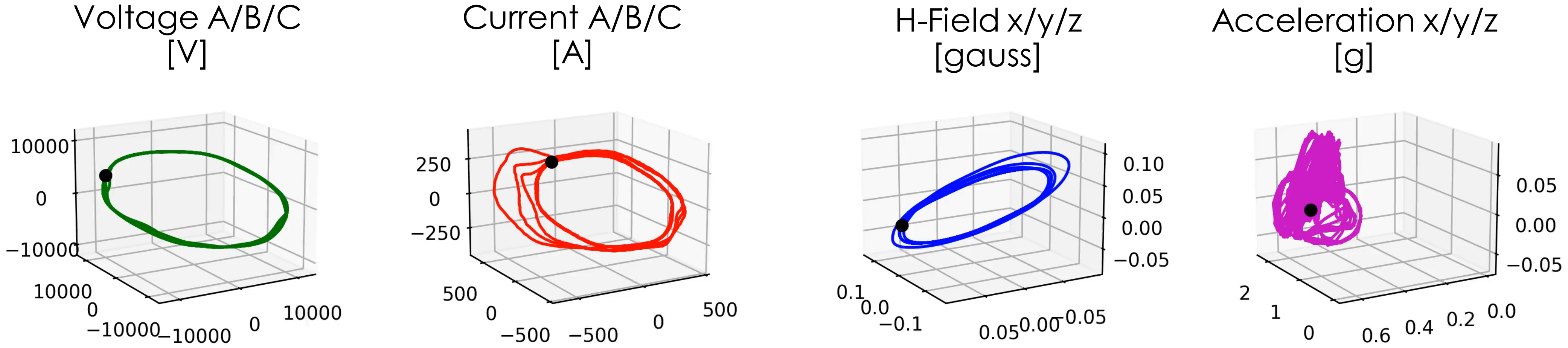
Edge Detection

- Simple real-time detection algorithm
  - Deployed at the source (edge computation)
  - CT and PT sensors (six channels)
  - Event based on cycle-to-cycle amplitude difference
  - Arbitrary threshold
  - 7000+ events detected (over 6 months)



Waveform data with event

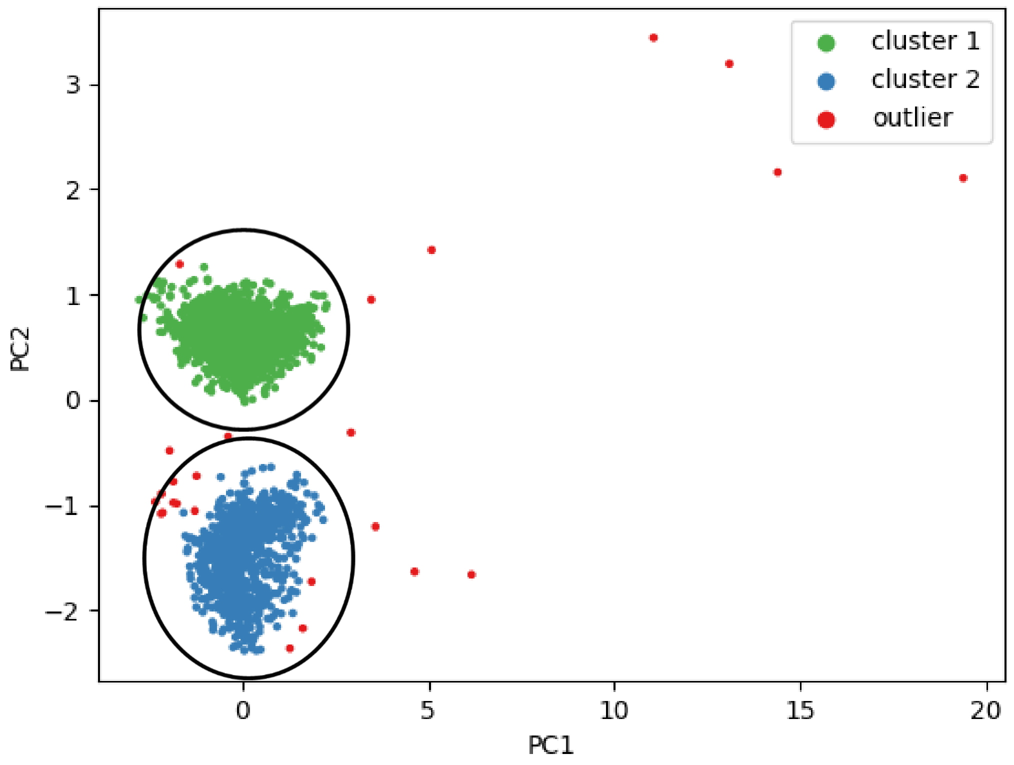


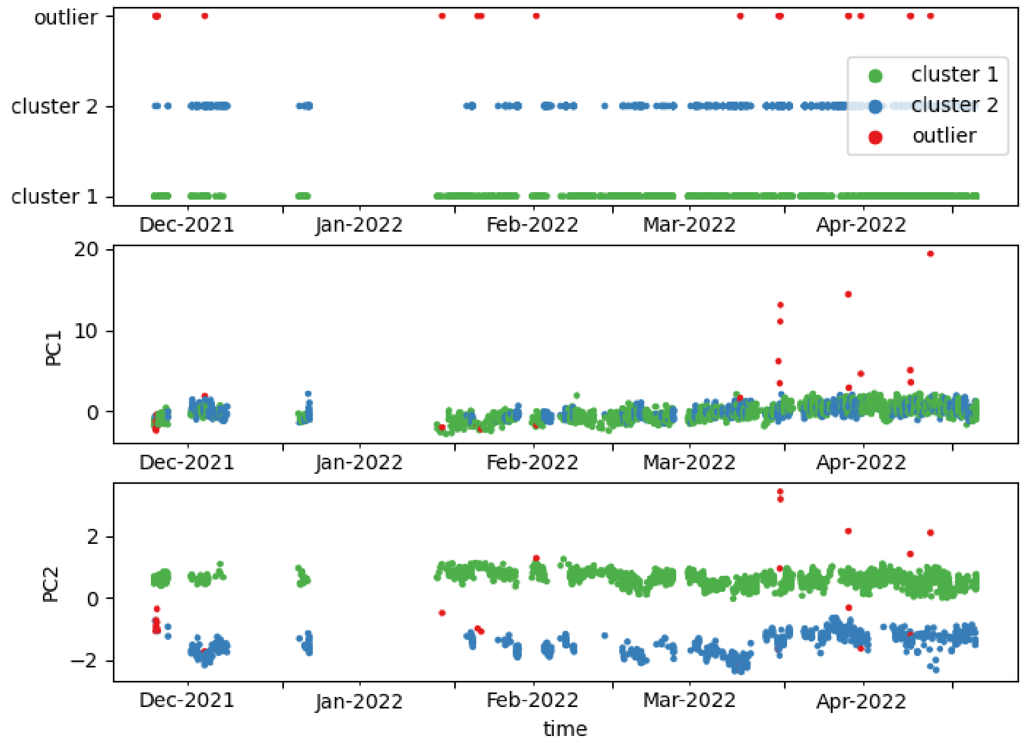


Event clustering

- For all sensor channels (18)
  - Compute time-differenced signal (1/20 seconds interval)
  - Compute RMS before, during, and after event
    - Of original signal -> 3 features per channel
    - Of time-differenced signal -> 3 features per channel
    - 18 channels x 6 features = 108 features per event
- Apply principal component analysis (PCA), reduce dimension to 2
- Apply clustering (DBSCAN)

Event clustering





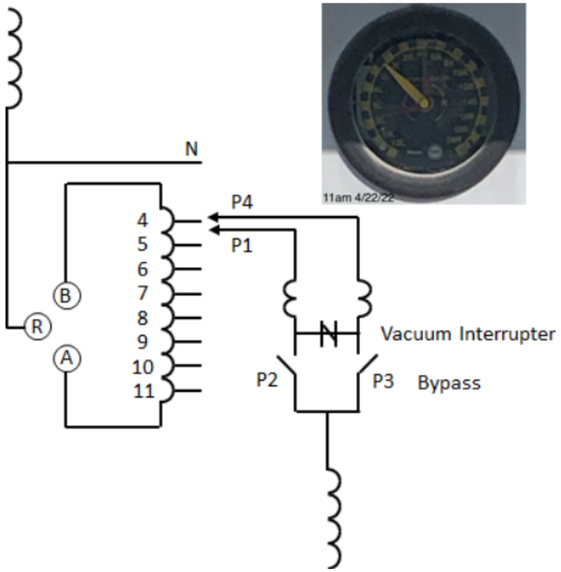
Two large clusters: Suspect mostly load changes

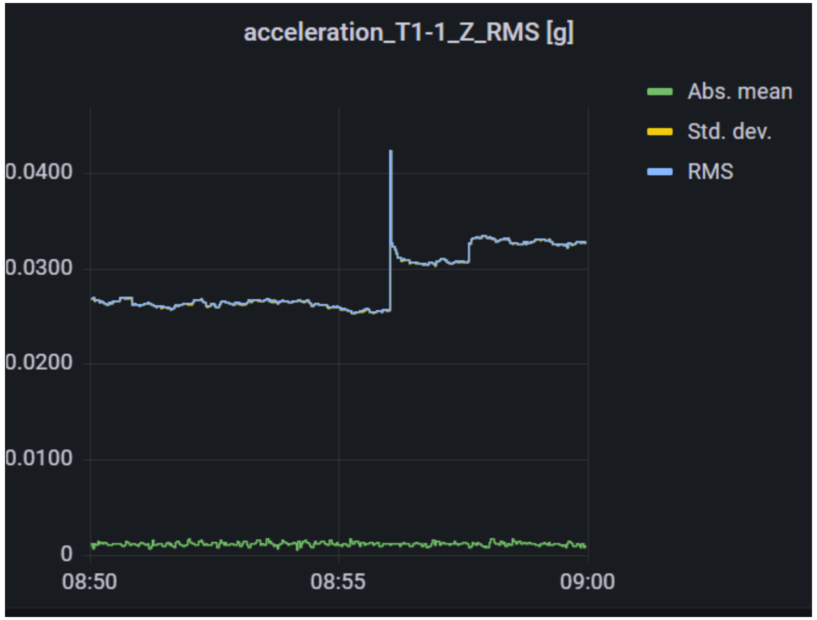
Small number of outliers: Events to inspect in detail

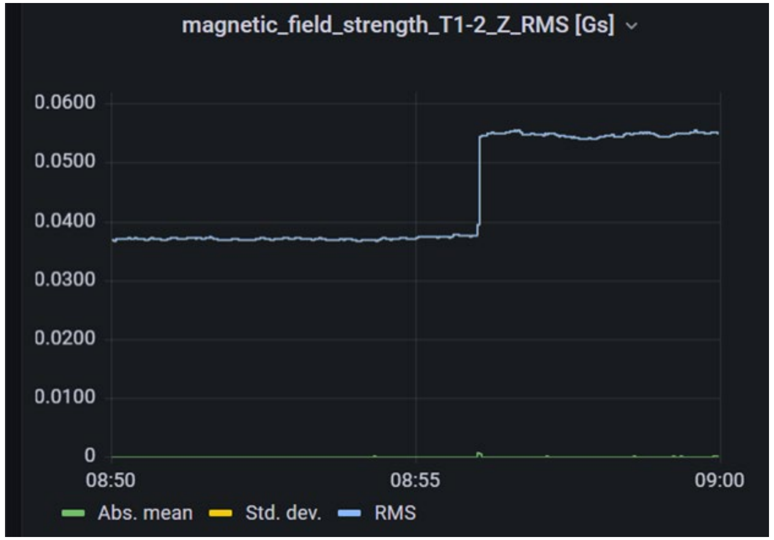
OAK RIDGE National Laboratory

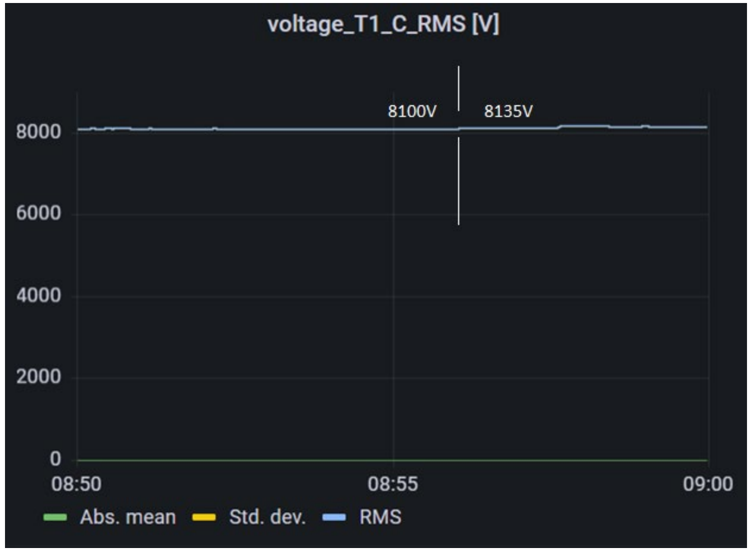
Tap Change

- Example shows a tap change on this auto-regulating transformer
- Vibrational shock, magnetic-field step and voltage change (0.6%)









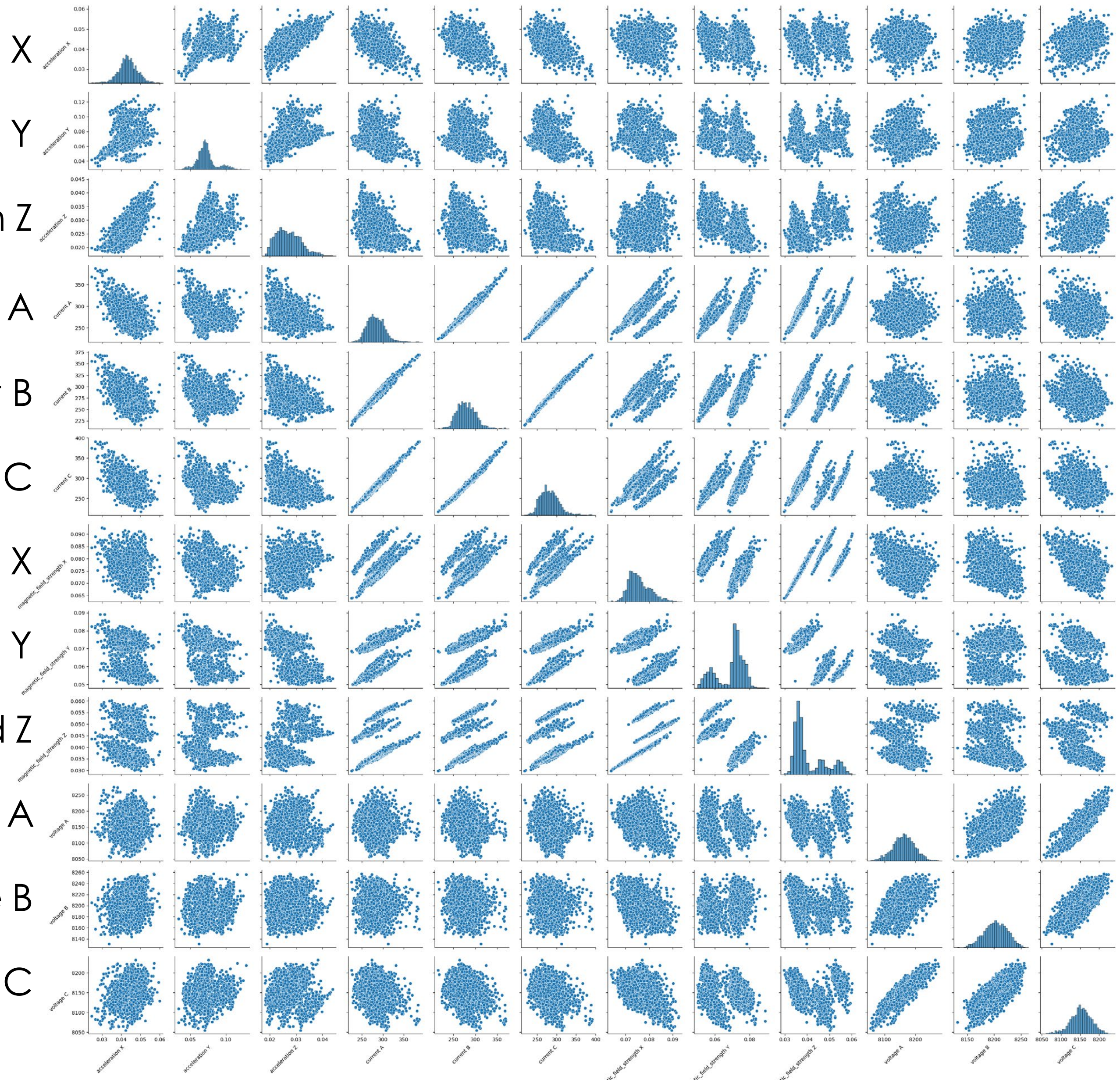
Summary

- Goal: Collect real-world data to analyze transients for possible indications of incipient failure
- Long-term data is essential due to sparseness of associated events
- Deployed high-speed waveform streaming of conventional CT/PT and unconventional (out-of-band or OOB) sensors at three substations
- Observed correlations between current and magnetic field and vibration
- Possible application of OOB sensors for verification of tap change or other operations
- Next steps:
  - Observe and annotate significant events
  - Perform multivariate analysis
  - Provide grid-health dashboard to inform utility operators

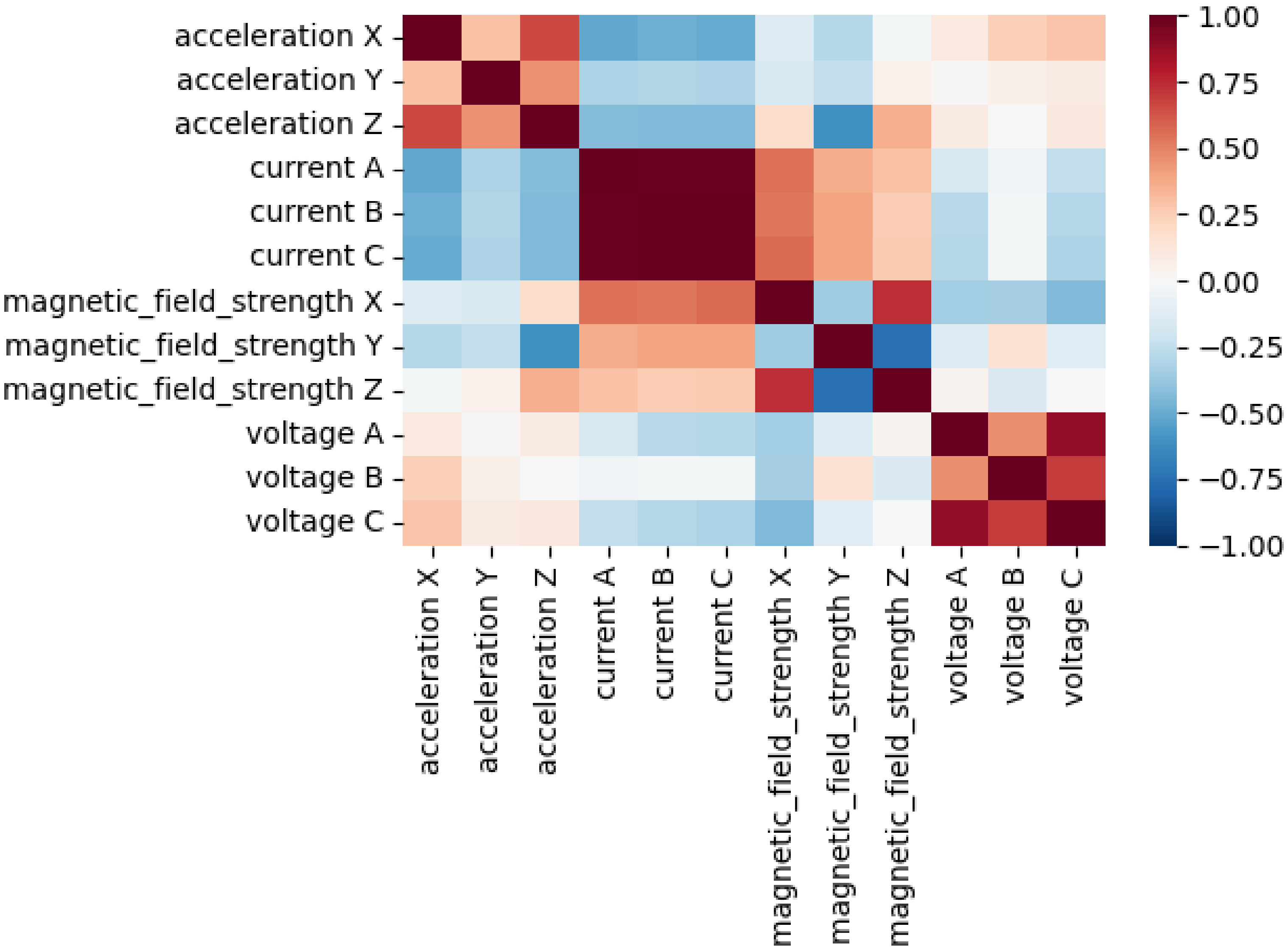
Extras

Correlation of RMS values: pair-plot (no-event data)

Acceleration X
Acceleration Y
Acceleration Z
Current A
Current B
Current C
H-Field X
H-Field Y
H-Field Z
Voltage A
Voltage B
Voltage C



RMS values – correlation heatmap (no-event data)



OAK RIDGE National Laboratory