Validating Model-Based Analysis of the British Columbia Modes using Measurements

September 12, 2025

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U.S. DEPARTMENT OF ENERGY BATTELLE

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PNNL-SA-215423

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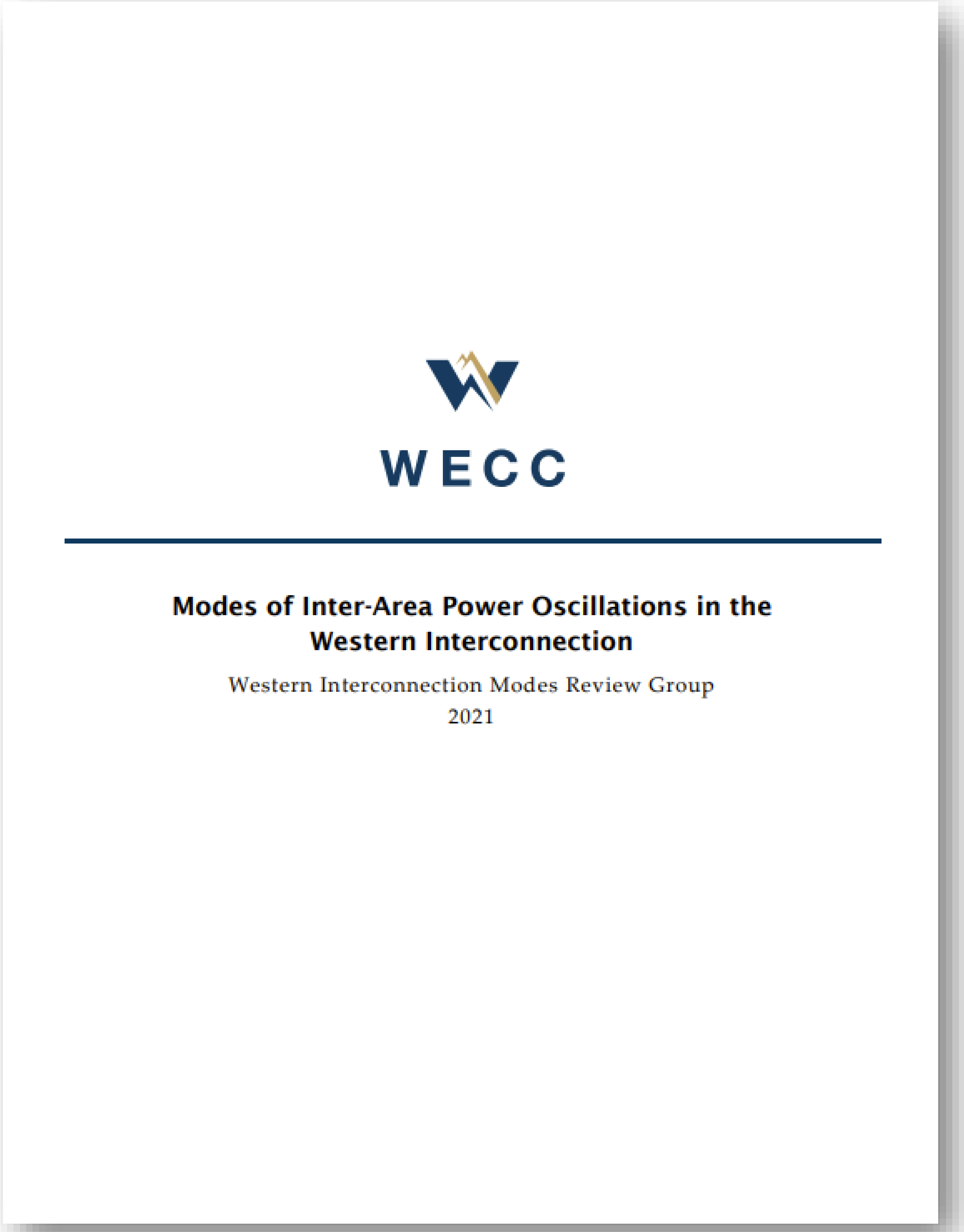
Background

- The Western Interconnection Modes Review Group (WIMRG) was formed to evaluate and document the power system’s inter-area electromechanical modes of oscillation
- The study was based on:
  - Two WECC transient stability base cases
  - Synchrophasor measurements from 11 days spanning 2016-2019
    - ✓ Only 1 day had data from the Minette substation near the Kemano power plant


WECC

Modes of Inter-Area Power Oscillations in the Western Interconnection

Western Interconnection Modes Review Group

2021

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Findings and Recommendations

Future work recommendations include:

1. Continued monitoring of all the modes from PMU measurements and field tests. This includes major switching events, system faults, major generation losses (with and without faults), and probing tests conducted using the Pacific DC Intertie (PDCI) and the Chief Joseph braking resistor.
2. Collection of high-quality synchrophasor data at Kemano/Minette for field tests designed to better excite the BC modes. Compare those measurements with data recorded at Shrum, Revelstoke, Cranbrook, and the surrounding Pacific Northwest. Large ambient datasets and event datasets are both desired.
3. Development and analysis of several simulation datasets designed to excite and investigate the BC area modes.
4. Assessment of cases in which Alberta is weakly connected to the rest of the system.

...ases that reflect the operating conditions of interest.
...ystem data in which those conditions were observed.
...on base cases with initial power flow conditions coincident
...sed datasets.
...ted via simulation. Sensitivity analysis is needed for single-
...ree-phase faults. Sensitivity is also desired for normal
... times. This is expected to become more important with
...ed resources.
...ollability, and interaction paths of the modes with more
...itial analysis is presented in this report, but more work is
...ions.
...ction-grade mode meter settings for the EWA and MT

... retirement of Colstrip units on the characteristics of the MT

... the effect of future grid configurations and resource dispatch
...s study should consider the addition of new inverter-based

Summary of mode properties.

Mode	Freq. (Hz)	Shape	Interaction Path(s)	Controllability	Grade	Comments
NSA	0.20–0.30	Alberta vs. System	Alberta–BC (Path 1) Northwest–CA (Path 3)	Alberta	Well understood	Well understood from 2014 report. Analysis for 2021 report confirms 2014 conclusions. An Alberta disconnect causes this mode to disappear.
NSB	0.35–0.45	Alberta vs. (BC + N. U.S.) vs. S. U.S.	COI (Path 66)	Widespread, incl. PDCI	Well understood	The most widespread mode in the system. An Alberta disconnect causes mode frequency and damping to decrease.
EWA	0.35–0.45	(Colorado + E. Wyo.) vs. System	Wyoming–ID (Path 19) Colorado–UT (Path 30) Colorado–NM (Path 31)	Colorado area	Marginally understood	Close in frequency to the NSB mode. Extensive new knowledge in 2021 report.
BCA	0.50–0.72	BC vs. N. U.S. vs. S. U.S.	Unknown	Unknown	Not understood	Model studies hypothesize two BC modes. Need improved PMU coverage in western BC (e.g., Kemano).
BCB	0.60–0.72	W. edge vs. System vs. E. edge	Unknown	Unknown	Not understood	(See above.)
MT	0.70–0.90	Montana vs. System	Montana–NW (Path 8)	Montana, incl. Colstrip	Well understood	Sometimes confused with one of the BC modes. Extensive new knowledge in 2021 report.

Model-Based Hypothesis: Two BC Modes

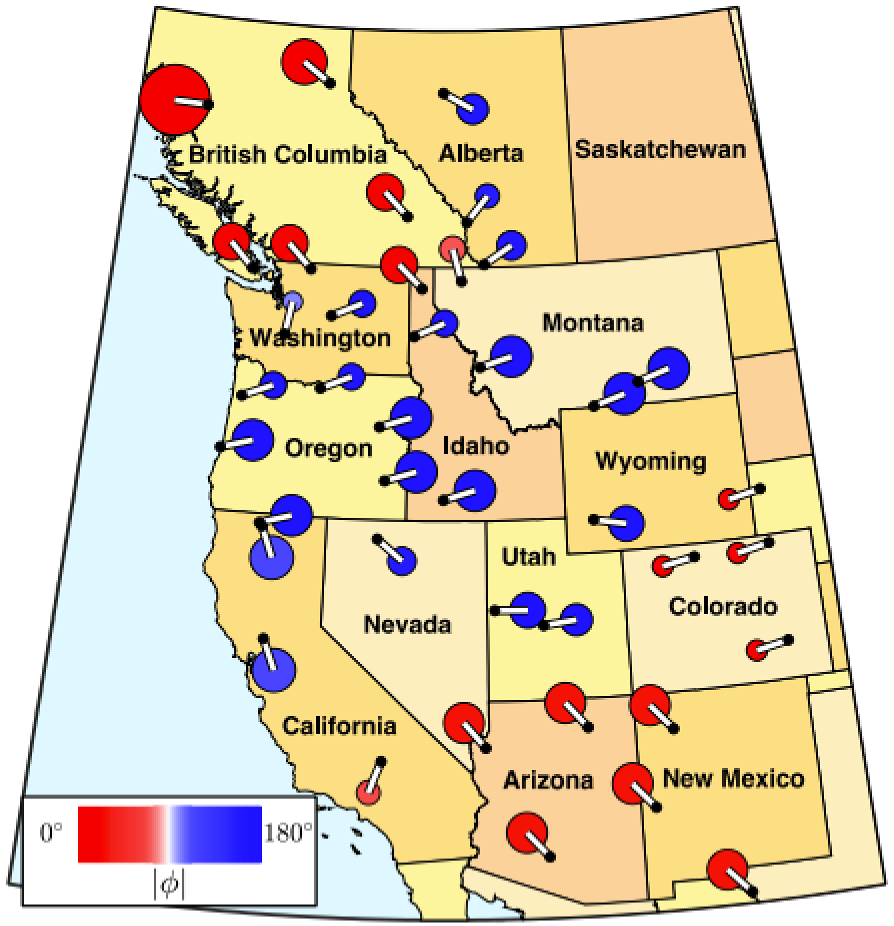


Figure 52: BCA mode shape, 0.71 Hz, 10.0%, 2020 Light Spring.

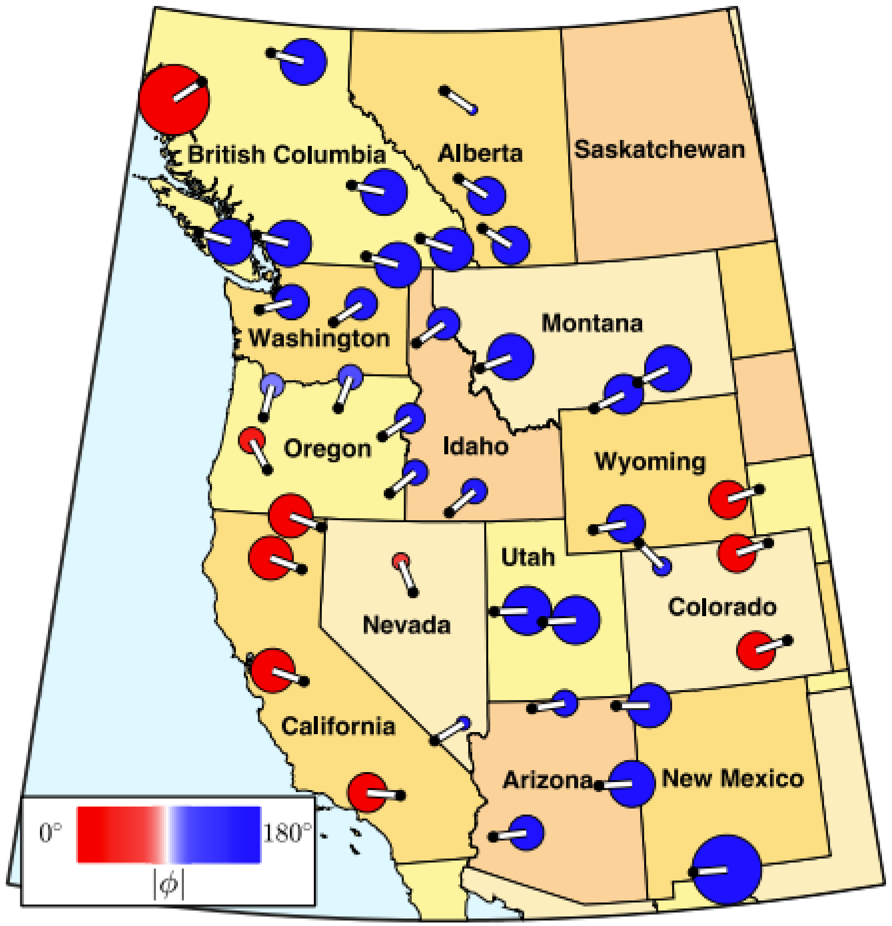


Figure 56: BCB mode shape, 0.72 Hz 12.5%, 2020 Light Spring.

Objectives of 2025 Measurement-Based Study

- Determine if the two-mode hypothesis can be validated
- Improve understanding of the BC modes
- Determine if continuous monitoring is possible

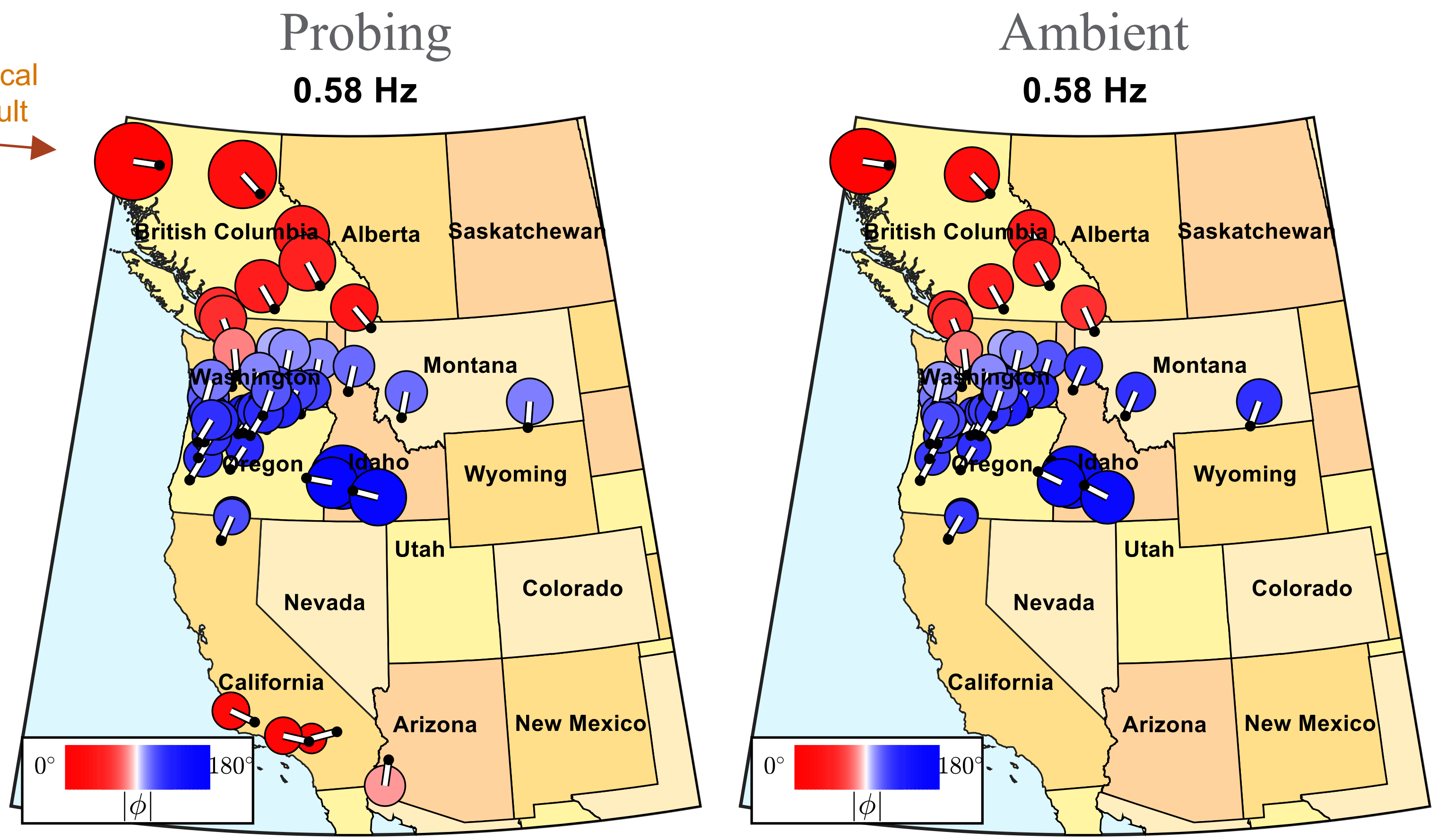
Available Datasets

Start	Duration	System Tests	Montana Disconnect	AB Disconnect	MINETTE Usable
2018-12-18 00:00	72 hours		✓		✓
2019-03-24 00:00	72 hours		✓		✓
2019-05-07 00:00	24 hours	✓			✓
2021-05-11 00:00	31 hours	✓			
2021-08-17 00:00	31 hours	✓			✓
2022-05-11 00:00	31 hours	✓			✓
2022-08-16 00:00	24 hours	✓			Before 2022-08-16 15:15
2022-12-06 00:00	48 hours		✓		✓
2023-04-17 00:00	72 hours			✓	✓
2023-05-17 00:00	72 hours	✓		✓	✓
2023-09-15 00:00	72 hours			✓	✓
2024-06-20 00:00	31 hours	✓			✓
2024-09-11 00:00	31 hours	✓			After 2024-09-11 21:14

Spectral Analysis of PDCI Probing Tests

- PDCI probing tests conducted on
  - 2024-09-12
  - 2024-06-20
  - 2023-05-17
  - 2022-05-11
- In all tests, the BCA mode is clearly identified.
- In none of the tests was a 2nd BC mode observable.

Typical result

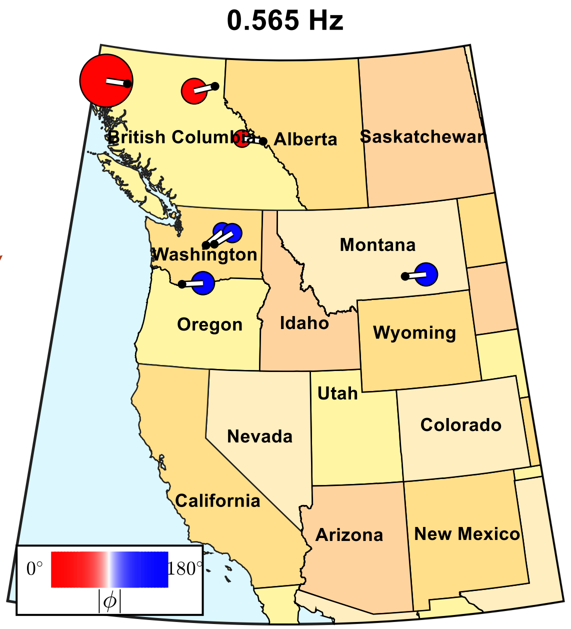


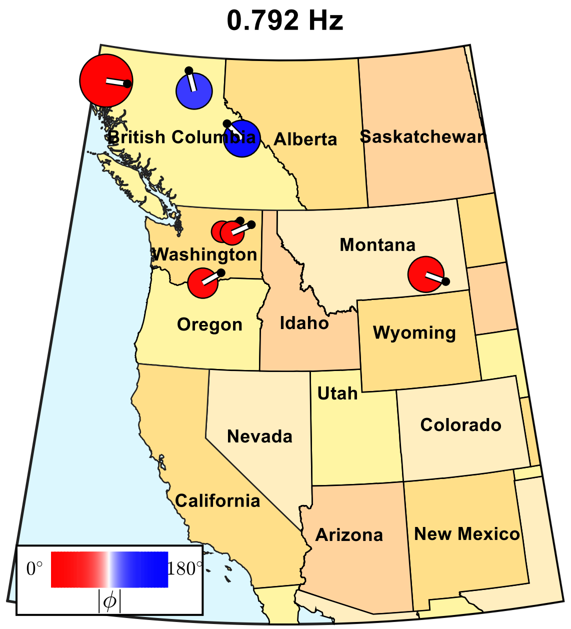
Ringdown Analysis of Transient Events

- Events that excited Kemano area of BC:
  - 5 different Chief Jo brake pulse from 2022 thru 2024
  - 3 other BC area events that significantly excited Kemano-area generators
- In 7 of the 8 events analyzed, the BCA mode is clearly identified and dominant.
- In only 2 events was the BCB mode estimated.
  - The CJB pulse on 2022-05-11 and 2023-05-17.

Estimated Modes

Freq (Hz)	Damping (%)	Residue (mHz)	Mode
0.565	22	67.70	BCA
0.792	19	24.50	BCB
0.407	5	6.1	NSB





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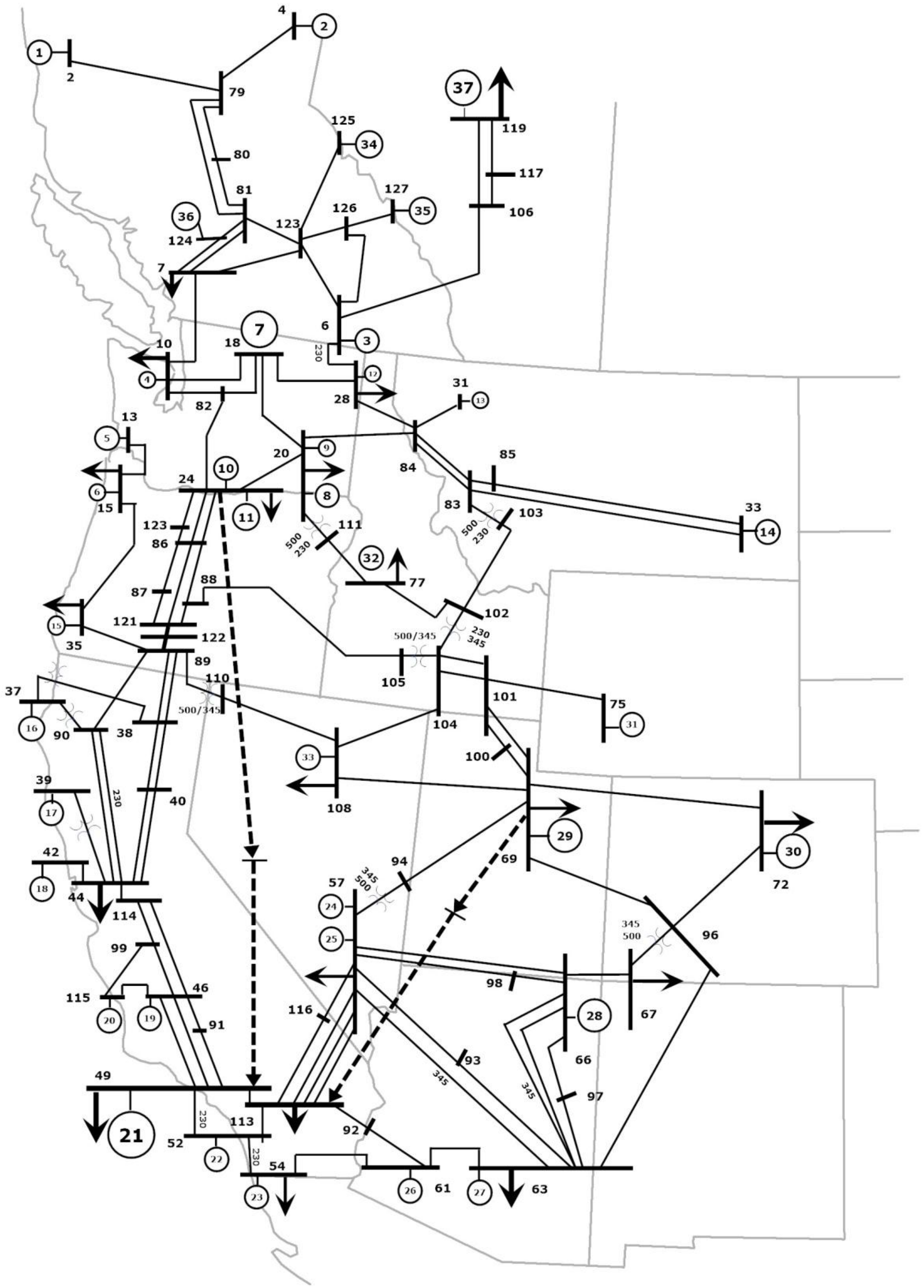
MiniWECC Modes

Mode	Freq (Hz)	Damping (%)	BC Participate?	Description
1	0.193	24.7	Minor	NSA
2	0.368	7.7	Yes	NSB
3	0.513	9.4	No	EWA
4	0.617	7.2	Yes	BCA
5	0.696	6.6	No	ID/WY/UT/NV vs. CO/CA
6	0.720	7.4	Minor	BCB1 = MT/WA vs. ID/WY/BC
7	0.777	6.5	No	MT vs. system
8	0.797	20.5	No	S-CA vs. system
9	0.926	16.9	Yes	BCB2 = Kemano/Shrum vs Mica/Revelstoke
10	0.927	9.7	No	N-CA vs. system
11	0.933	10.5	No	G32 (ID) vs. system
12	0.943	10.9	No	G5 (WA) vs. system
13	0.955	6.4		G31 (ID) vs. G32 (WY)

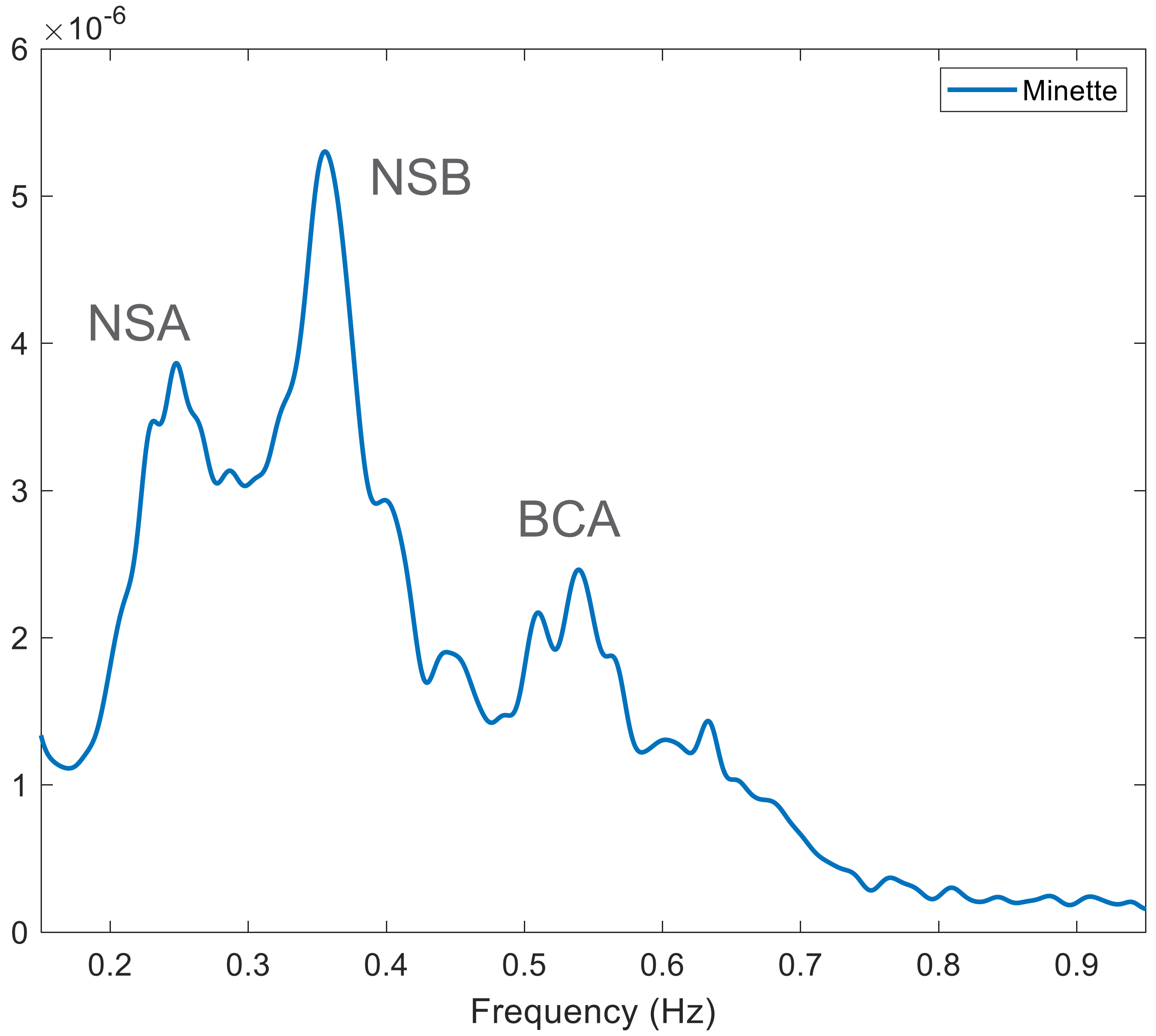


Via model-based eigenanalysis, three BC area modes identified

1. BCA = clearly dominant.
2. BCB1 = not dominant in BC; but, BC participates
3. BCB2 = local to BC area.

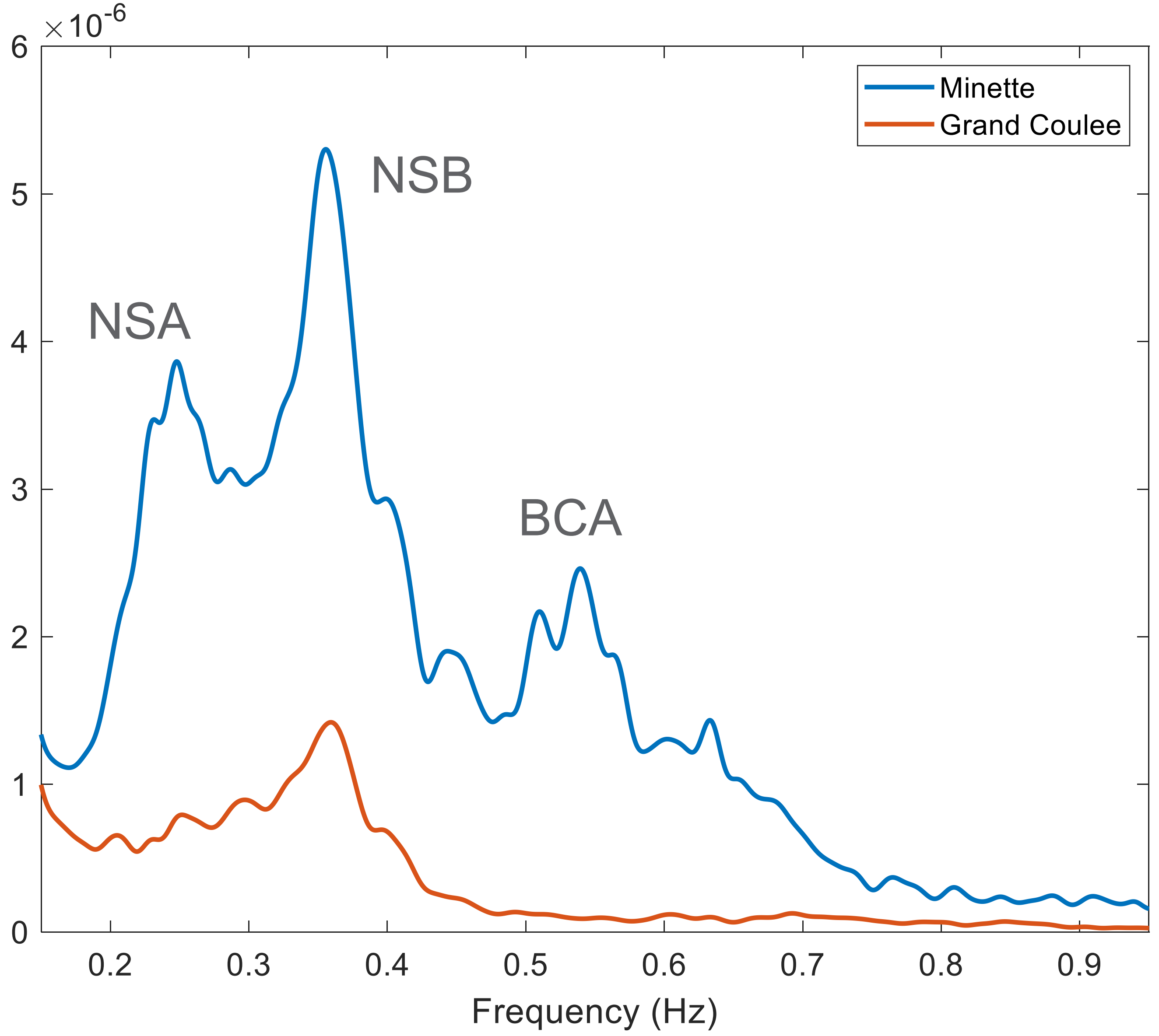
Mode Meter Signal Design

- Mode meters work best when analyzing a signal where the mode of interest is dominant
- The NSA, NSB, and BCA modes are all observable in the Minette signal



Mode Meter Signal Design

- Subtracting signals swinging **with** each other **diminishes** the mode's observability
- Subtracting signals swinging **against** each other **enhances** the mode's observability



Mode Meter Signal Design

NSA:
Minette swings
with Grand Coulee

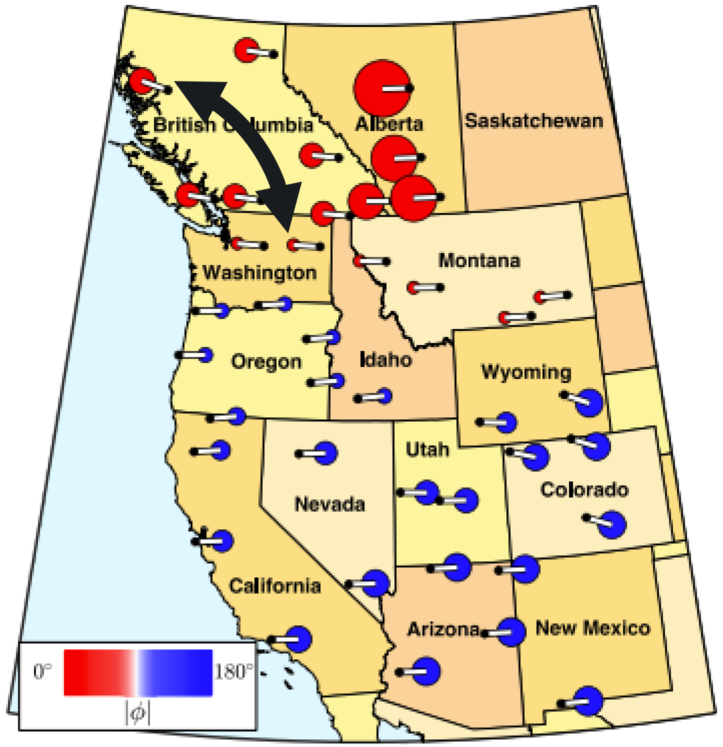


Figure 7: NSA mode shape, 0.28 Hz 17.5 %, 2020 Light Spring.

NSB:
Minette swings
with Grand Coulee

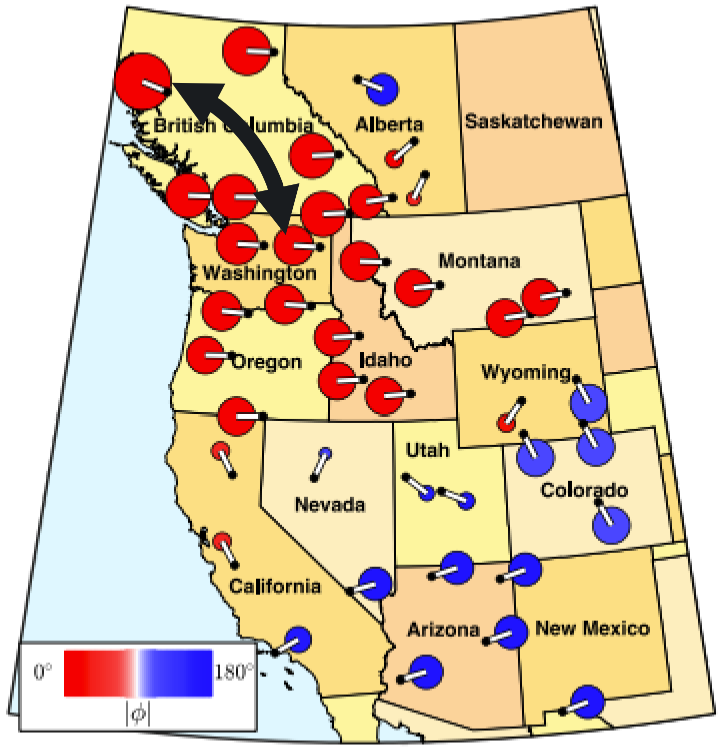


Figure 18: NSB mode shape, 0.45 Hz 12.0%, 2020 Light Spring

BCA:
Minette swings
against Grand Coulee

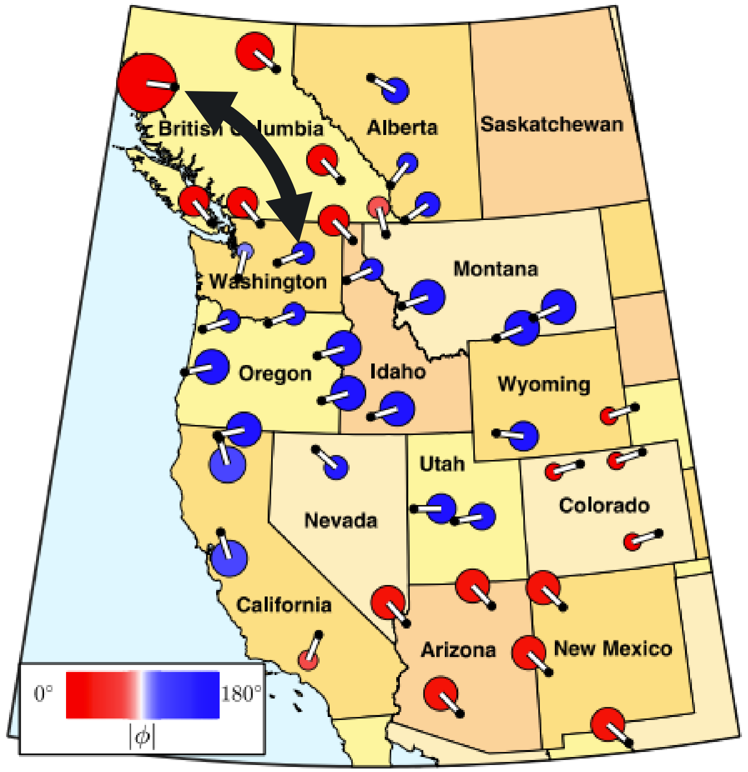
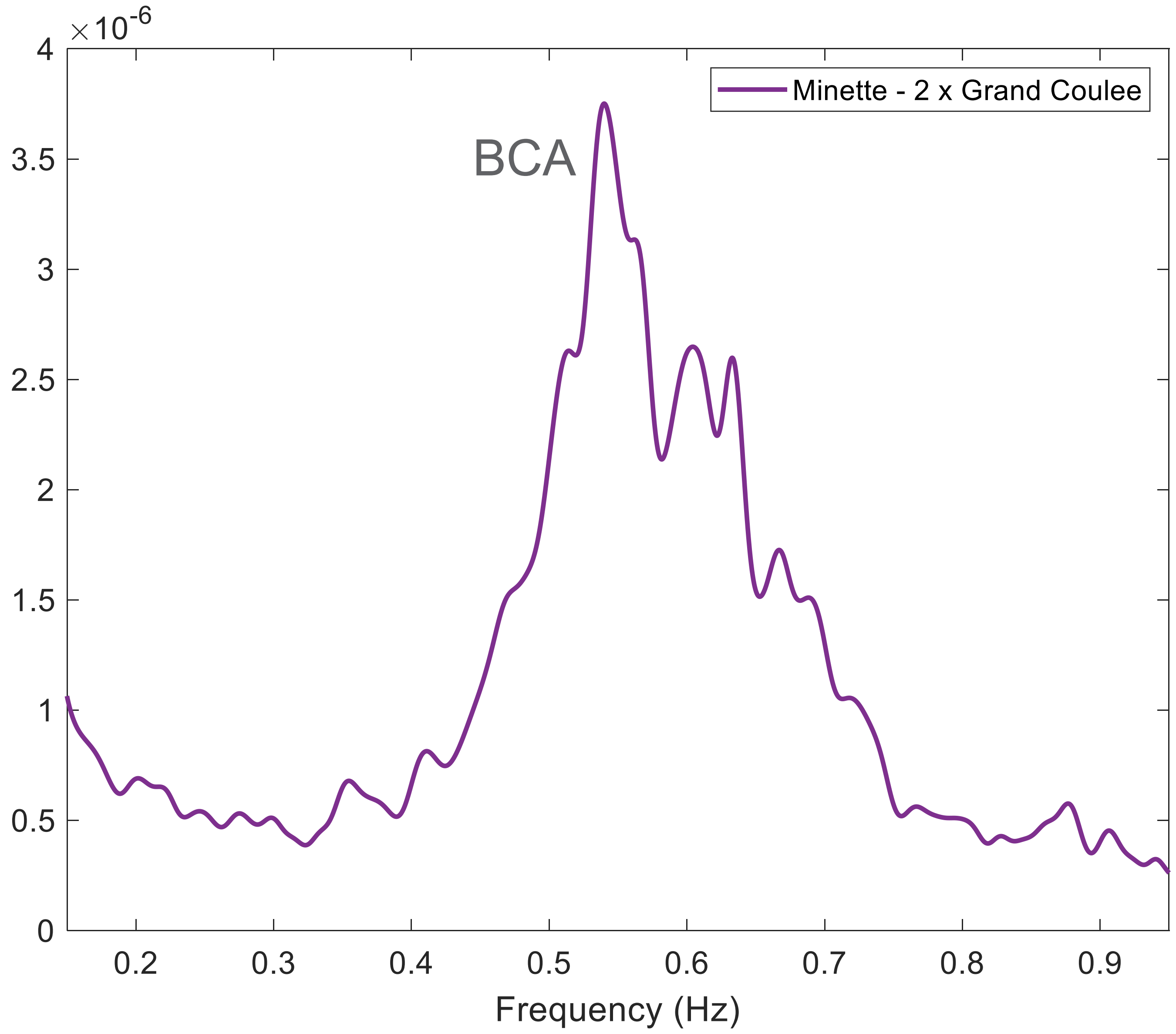


Figure 52: BCA mode shape, 0.71 Hz, 10.0%, 2020 Light Spring.

Mode Meter Signal Design

- The linear combination of signals creates an effective input signal
- Project success: mode meter signal design and configuration that can be used in commercial tools



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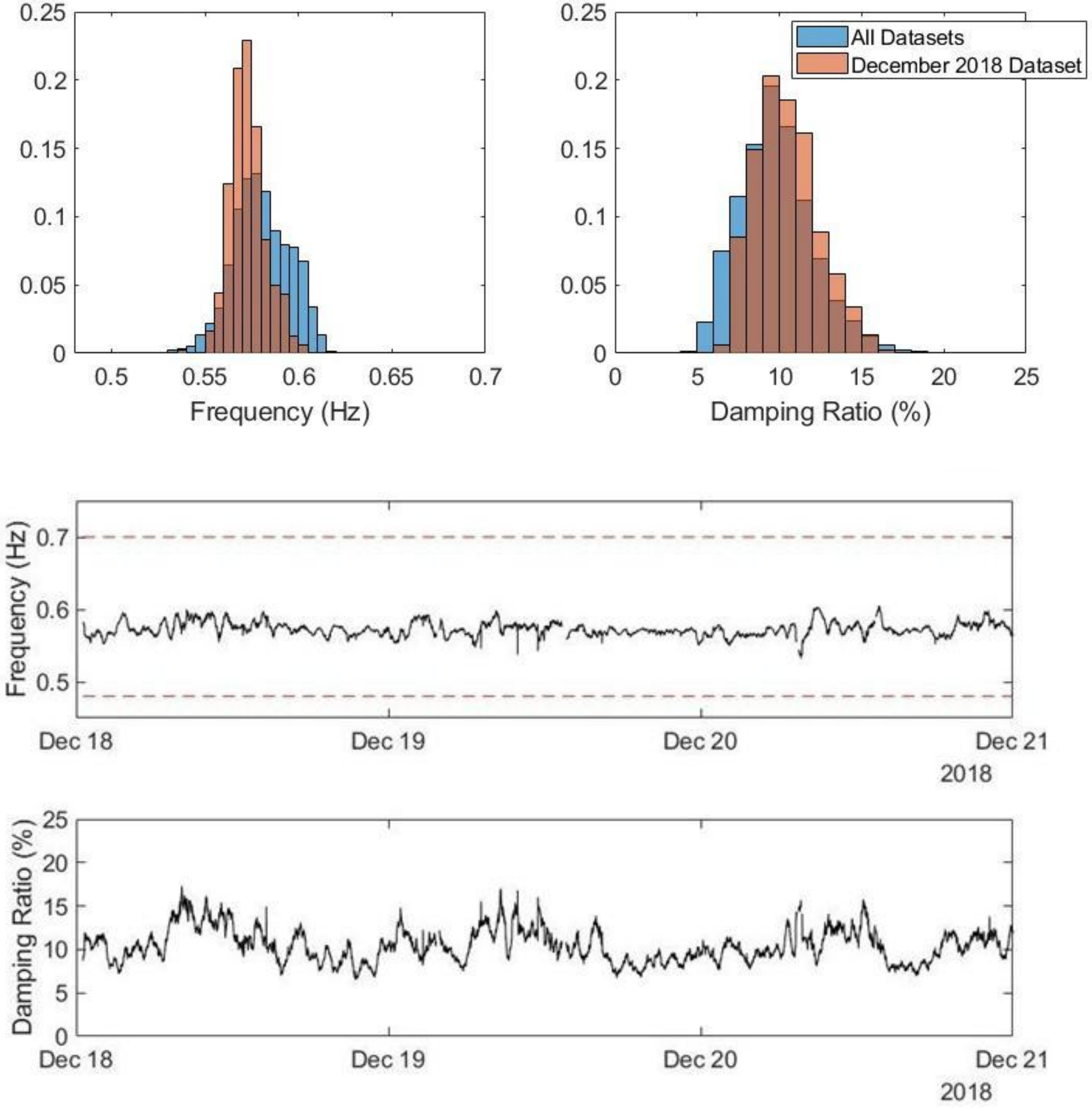
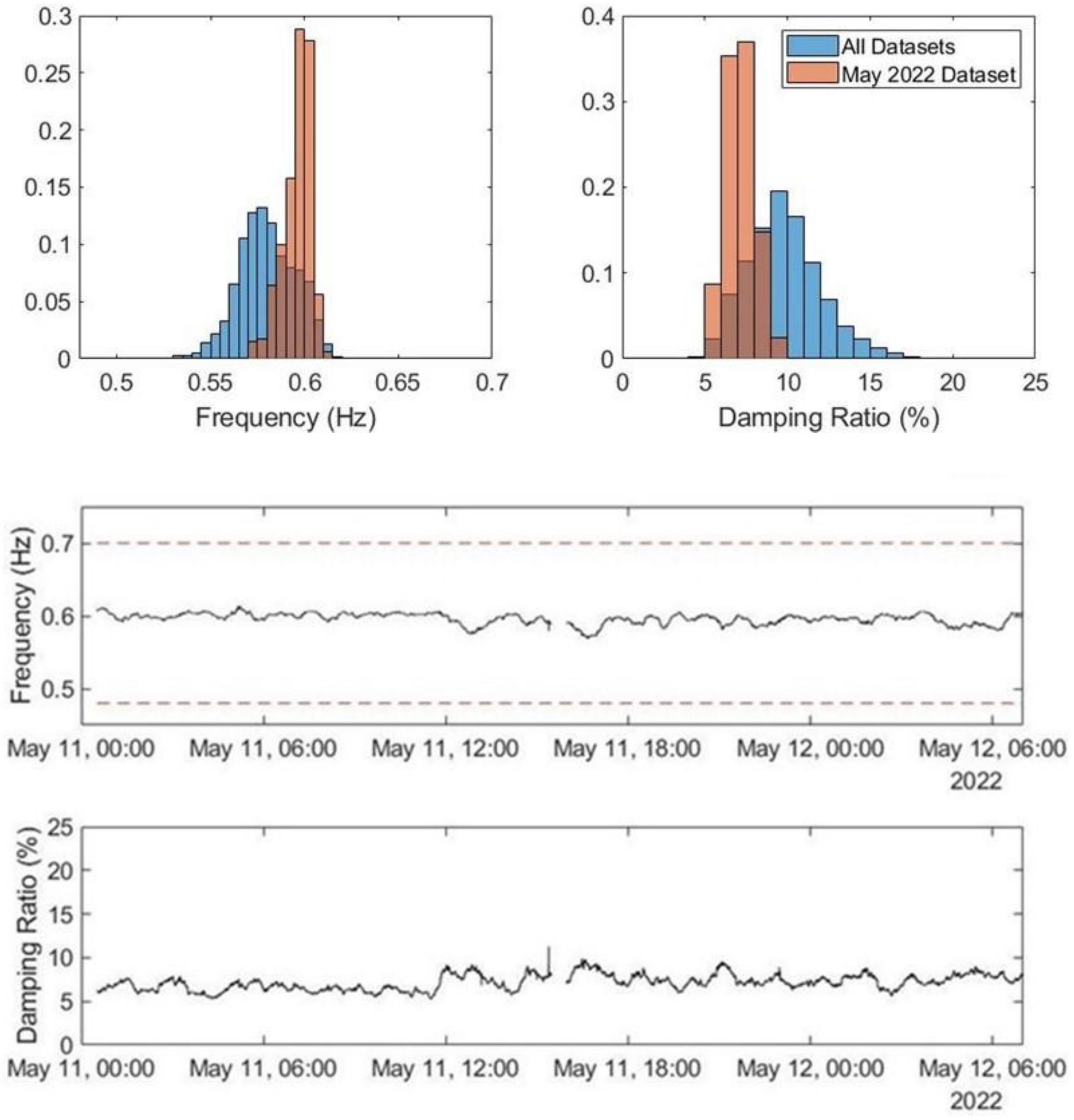
BCA Mode Meter Results: Success

- Successfully demonstrated that BCA can be tracked continuously
- Identified typical range
  - 2021 report: 0.50-0.72 Hz
  - Observed in 2025 study: 0.55-0.62 Hz



BCA Mode Meter Results: Challenge

- Results were hampered by the consistent presence of a forced oscillation (FO) at 0.6 Hz
- FOs are the result of an oscillating input, rather than the system's natural dynamics
- FOs bias frequency and damping ratio estimates



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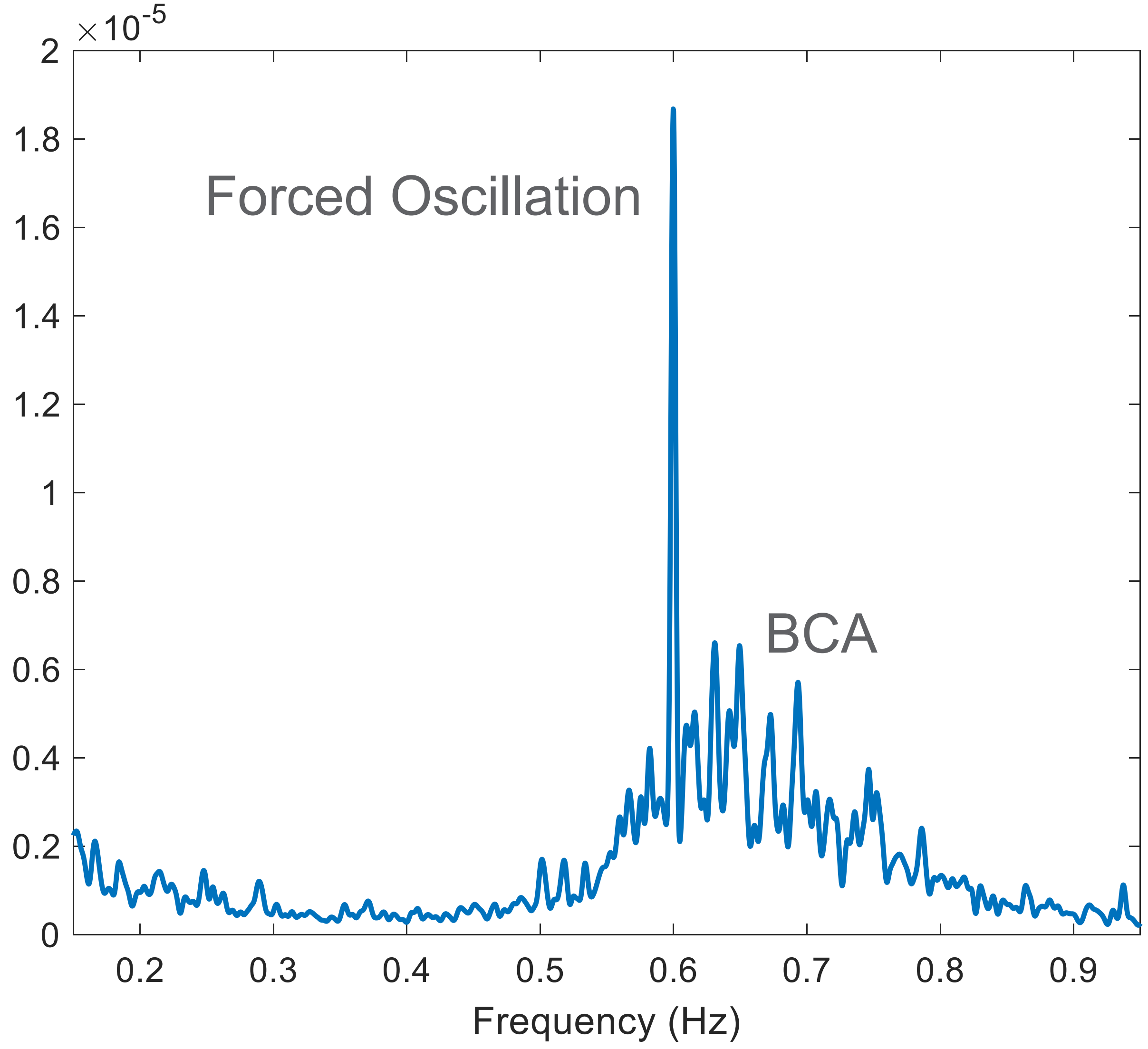
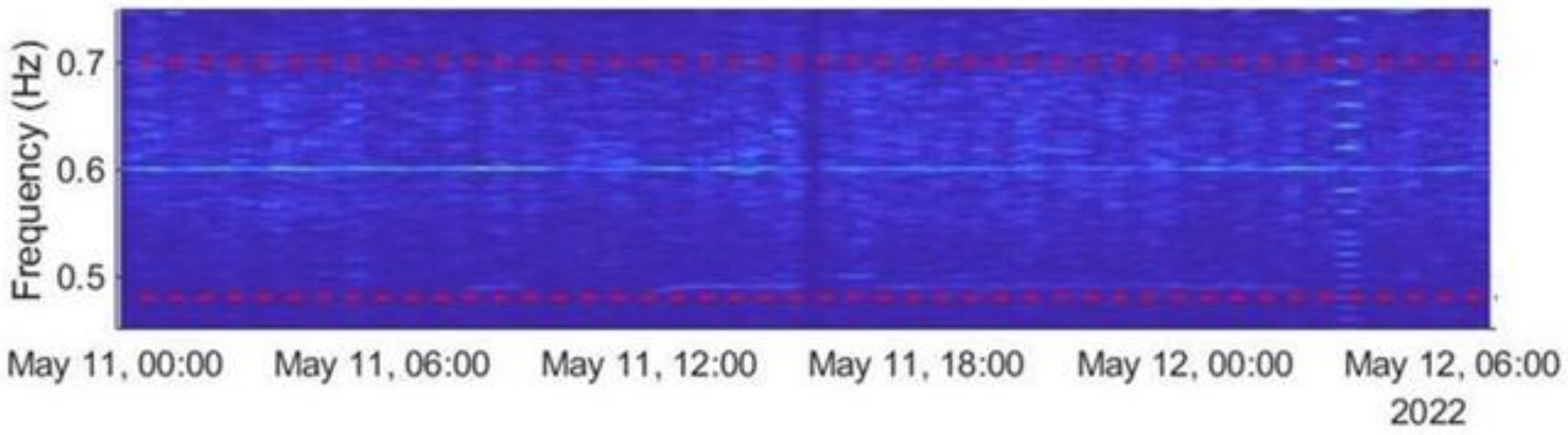




Seeking BCB

BCA: Minette swings **with** Shrum

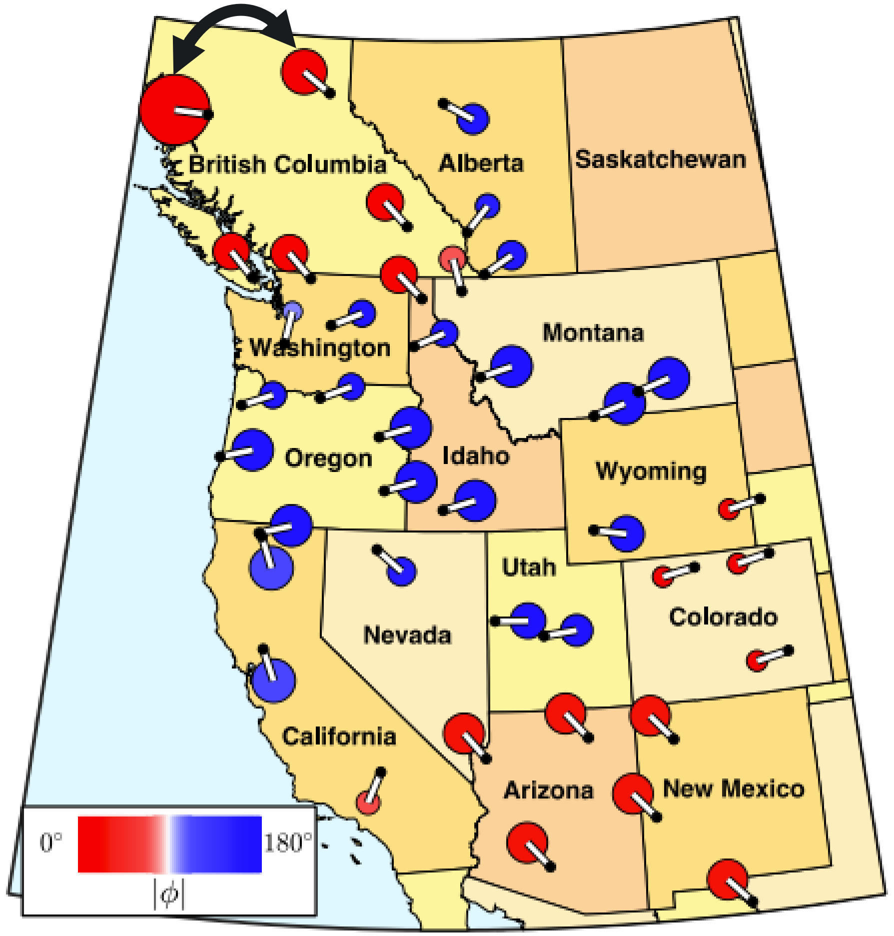


Figure 52: BCA mode shape, 0.71 Hz, 10.0%, 2020 Light Spring.

BCB: Minette swings **against** Shrum

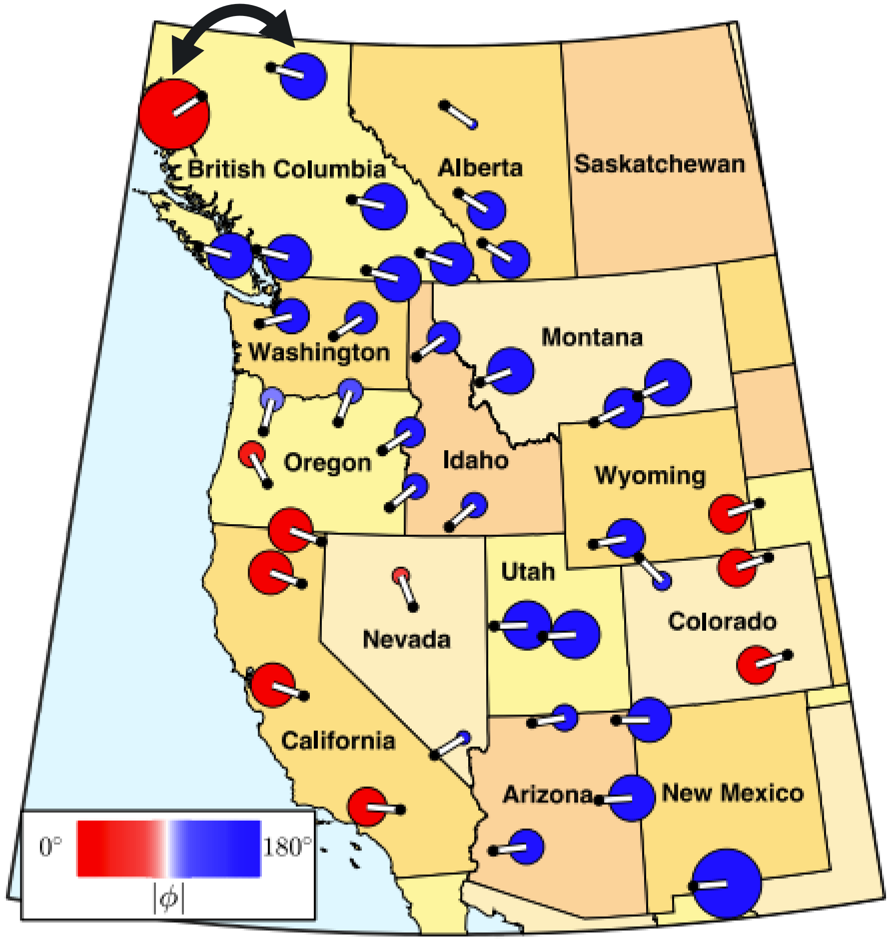
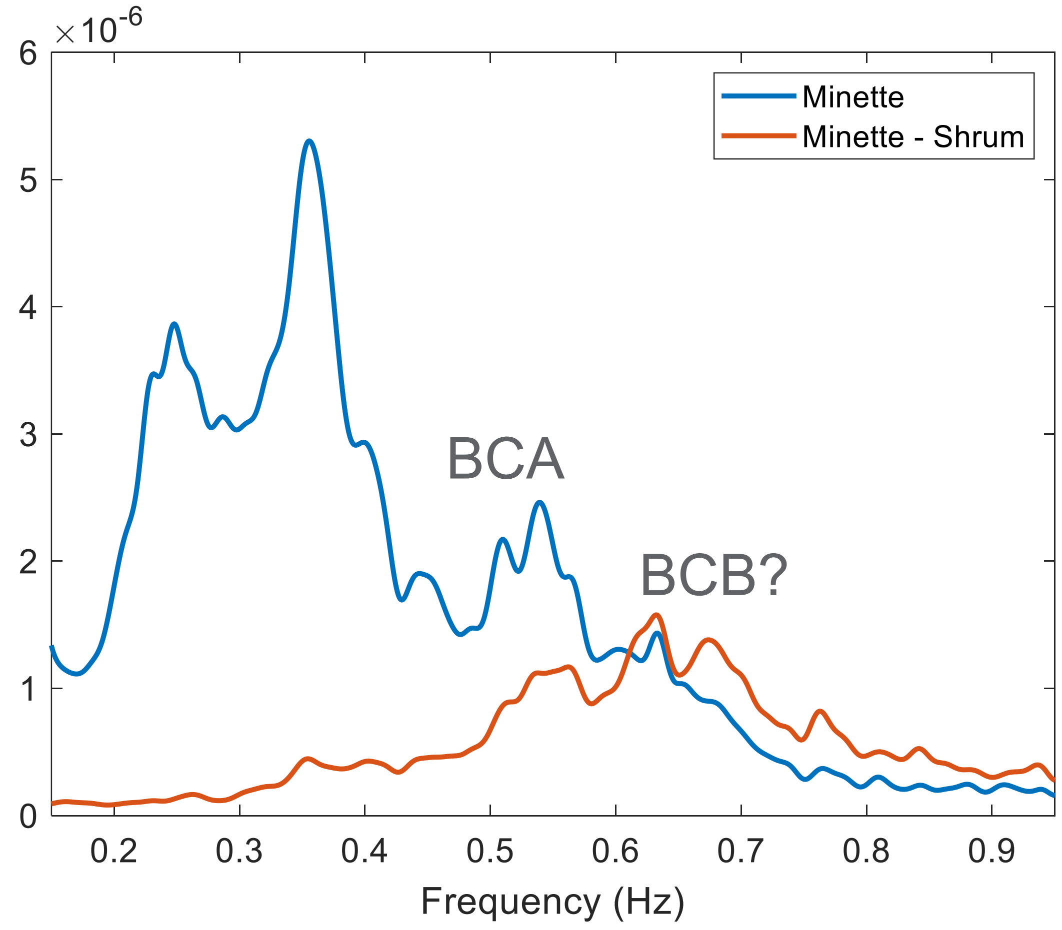


Figure 56: BCB mode shape, 0.72 Hz 12.5%, 2020 Light Spring.

BCB Results: Inconclusive

December 2022



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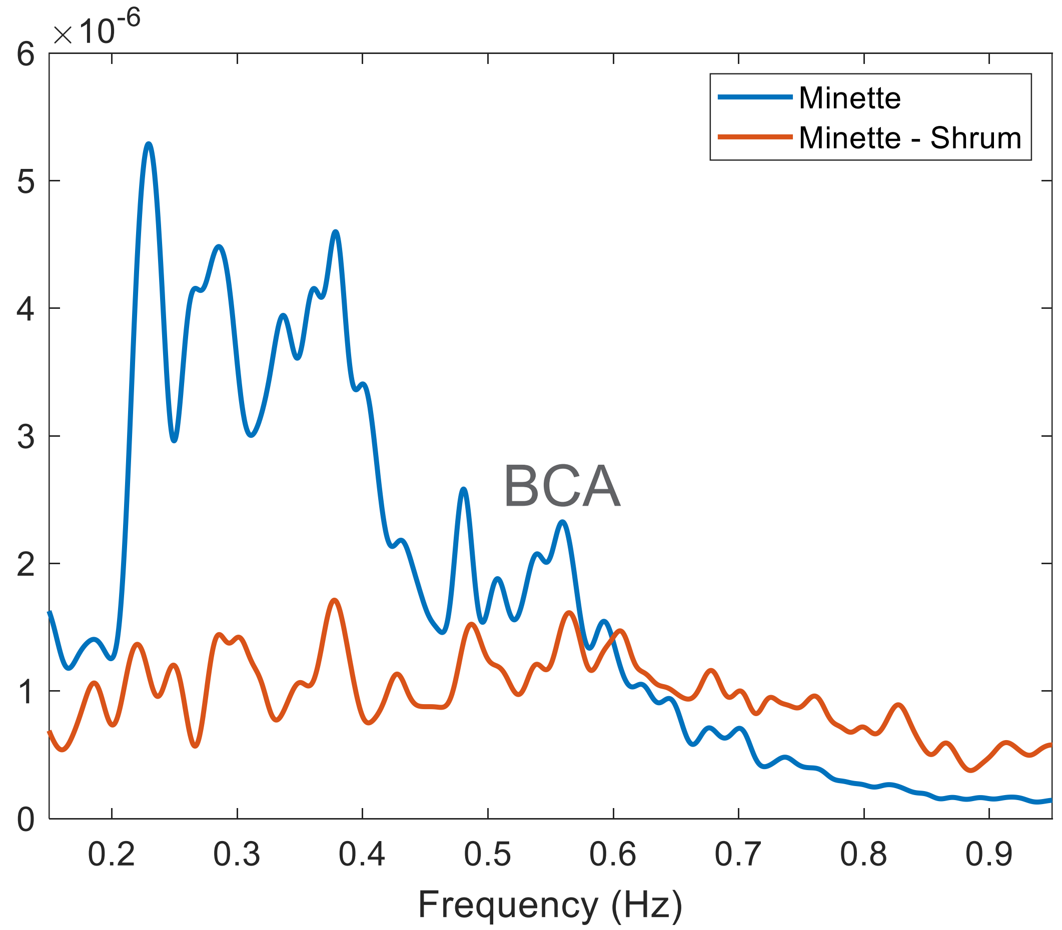


Even for cases where spectral content indicated a possible mode, analysis of the mode's shape did not consistently align with expectations for BCB

Conclusions

- BCA
  - This is clearly the dominant interarea mode centered in BC with its main "source" being the Kemano area. Typically in the 0.55 Hz to 0.62 Hz range.
  - Continuous monitoring is possible after careful signal design
  - The mode's frequency, damping, and shape remained consistent across several years
  - A persistent forced oscillation will at times bias mode meter results
- BCB
  - Theoretically, there are thousands of modes, making it essentially impossible to rule out the existence of BCB
  - In the many data sets analyzed, it only clearly showed up in one ringdown case with its amplitude being much smaller than the BCA mode.
  - Our best hypothesis is that the BCB mode exists; but, is very well damped and not very excitable.
  - High damping makes it difficult to monitor with measurements, but it also means the mode is not a reliability concern
  - At this time it does not need to be added to the list of dominant modes that require regular study

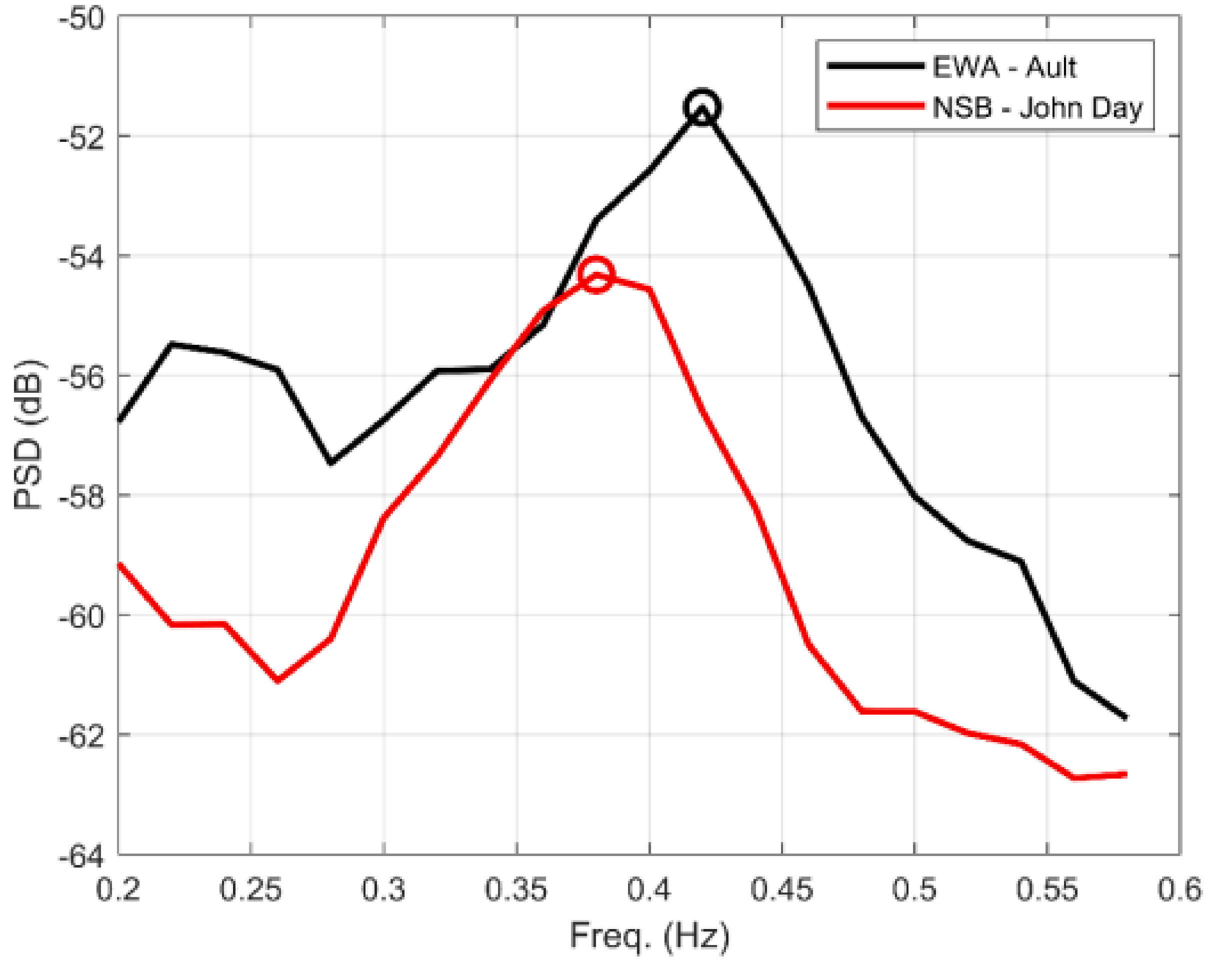
Acknowledgement

This work was funded by the U.S. Department of Energy’s Office of Electricity through its Advanced Grid Modeling (AGM) program.

Thank you

Analysis Methods

- **Spectral analysis**
  - Helpful in identifying mode frequencies at peaks in the spectrum
- Correlation analysis
  - Useful for distinguishing between modes at similar frequencies
- Spectral mode shape estimation
  - Reveals the grouping of generators participating in the mode
- Mode meter
  - Enables continuous tracking of a mode's frequency and damping ratio using ambient (non-event) data
- Ringdown analysis
  - Mode properties excited by a transient
- Eigen-analysis of MiniWECC system
  - Investigates theoretical possibilities



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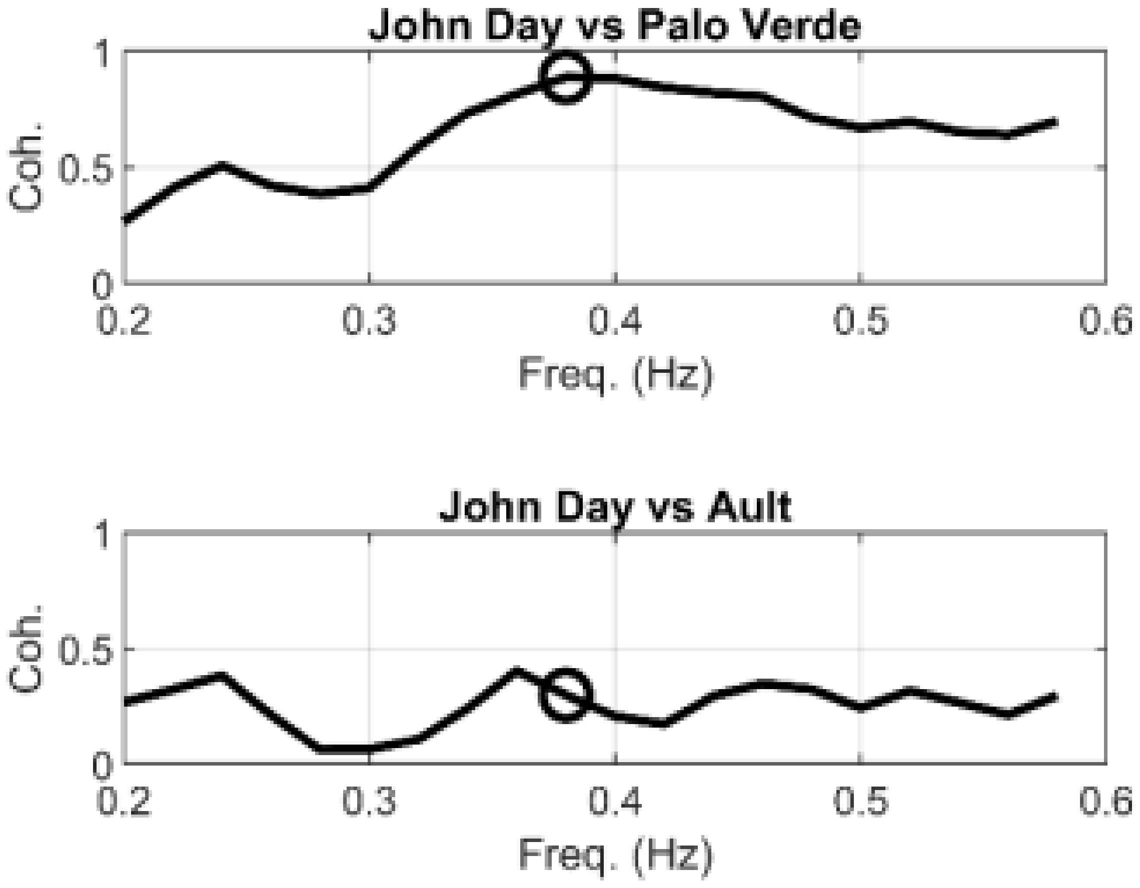

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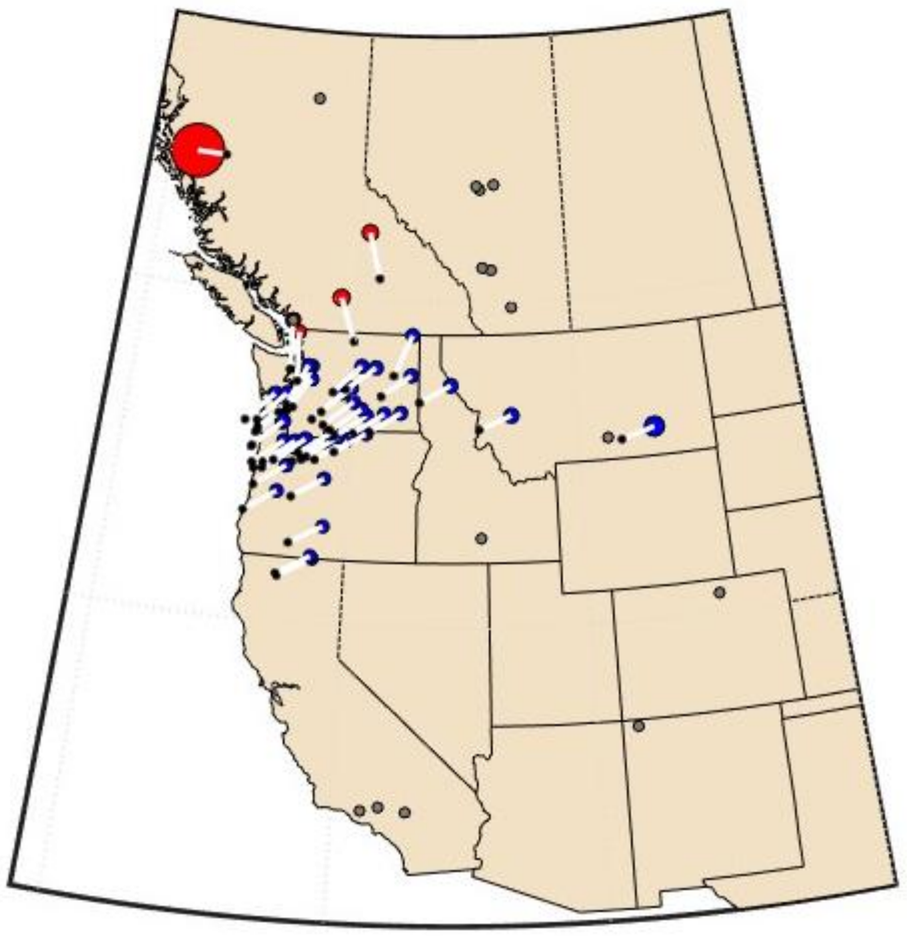

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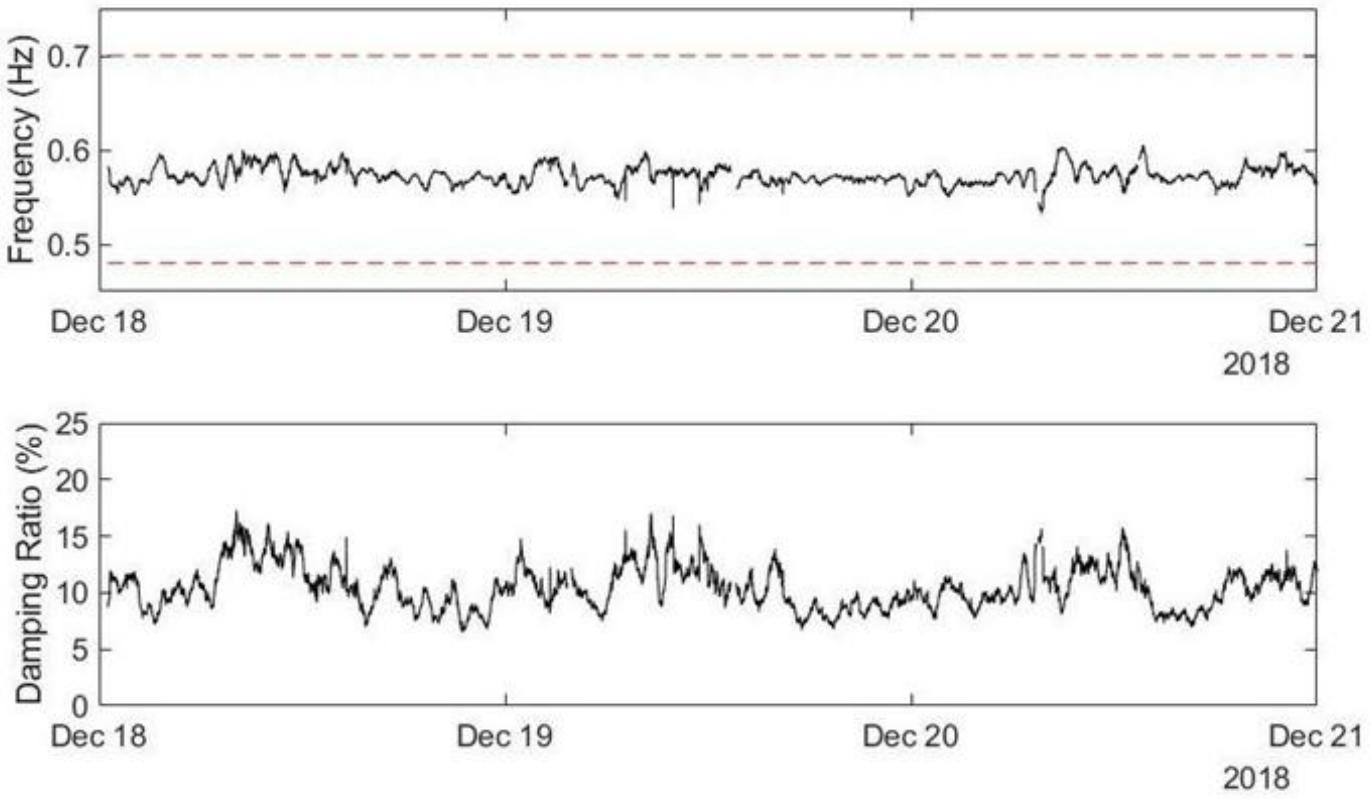

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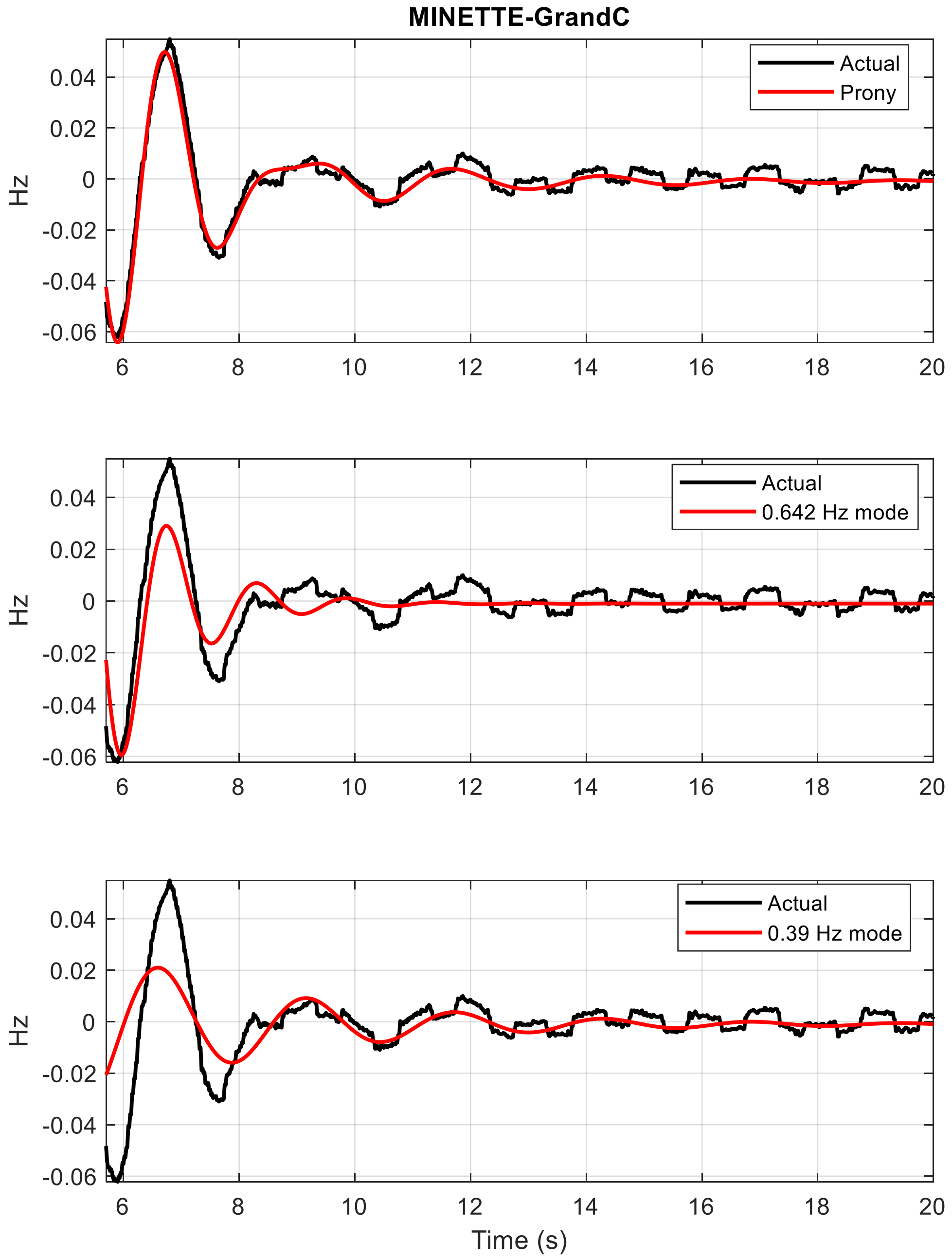

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