

Citizens Broadband Radio Service Sharing Ecosystem Assessment

National Advanced Spectrum and Communications Test Network

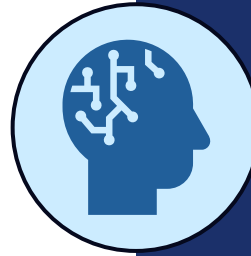
Aric Sanders, Thao Nguyen, Todd Schumann,
Duncan McGillivray



The National Advanced Spectrum and Communications Test Network

NASCTN Mission

To provide, through its partners, **robust test processes** and **validated measurement data** necessary to develop, evaluate and deploy spectrum sharing technologies that can *thoughtfully* **improve access to the spectrum** by both federal agencies and non-federal spectrum users.



Develop scientifically rigorous test plans and new methodologies with independent technical experts



Coordinate access to key test facilities, and commercial and federal equipment and capabilities



Provide validated data and models for use within the spectrum community

NASCTN Program

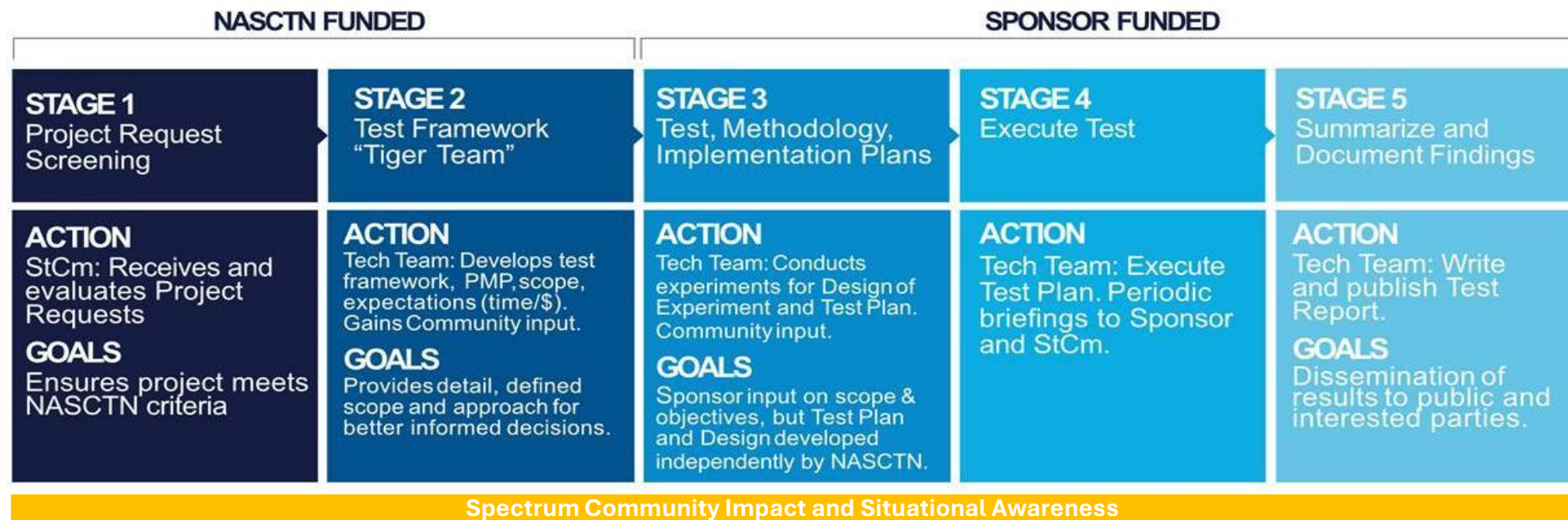
NASCTN is hosted by NIST CTL at the Department of Commerce - Boulder Laboratories

- Provides scientific, transparent oversight to ensure rigor and integrity in test methods and approaches
- Manages outreach to stakeholders
- Coordinates all aspects of NASCTN test activities
- Hosts interdisciplinary teams to address multi-variate spectrum challenges



Framework for NASCTN Test Projects

- Follow an open, transparent and comprehensive process for developing *independent*, scientifically based test plans, facilitating access to member test ranges and laboratories, protecting controlled information, and validating test results before findings are reported.
- NASCTN does not make policy recommendations
- The five-stage Framework serves as a common architecture across NASCTN's diverse projects.



Test Request Submission & Evaluation Criteria

NASCTN invites industry and government requests for spectrum testing and measurement project that advance broader U.S. spectrum goals.

<https://www.nist.gov/ctl/nasctn/project-submission>

- **Evaluation Process** Independent technical experts review requests against core criteria to recommend NASCTN acceptance or referral to government/FFRDC partners.
- **Key Decision Criteria**
 - **Trusted Oversight** - Requires a neutral, scientific, and transparent agent.
 - **Feasibility** - Testing can be delivered effectively and on time.
 - **Rigor & Scrutiny** - Demands high-integrity measurements that hold up under review.

CBRS SEA Project

Acknowledgements

- Special thank you to core partners that have enabled, contributed, and strengthened the test campaigns:
 - DOW CIO, DON CIO, USMC IC4, NSWCC-DD
 - Government and Industry members of the CBRS I-JWG, WInnForum, OnGo Alliance
- Sensor Hosts:
 - Hampton University, Port of Norfolk, NAS Oceana, Virginia DOT
 - USMC Camp Pendleton, US Coast Guard Rescue 21 Program, US Navy Pt Loma, US Navy San Clemente Island, USS Midway Museum

Contributors to the CBRS SEA Program

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NTIA/ITS *Robert Ballard, Douglas Boulware, Michael Cotton^, Rebecca Dorch^, Joel Dumke, Bradley Eales, Justin Haze, Peter Mathys, Anthony Romaniello^, Todd Schumann*

NASA LaRC *Jay Ely, Charmaine Franck^, Steven Harrah, C. Lee Joyce*

MITRE *Keith Hartley, Elyssa Kaplan, Mark Krangle, Robert Scheeler^*

^ persons now in pursuit of other endeavors

NASCTN CBRS SEA

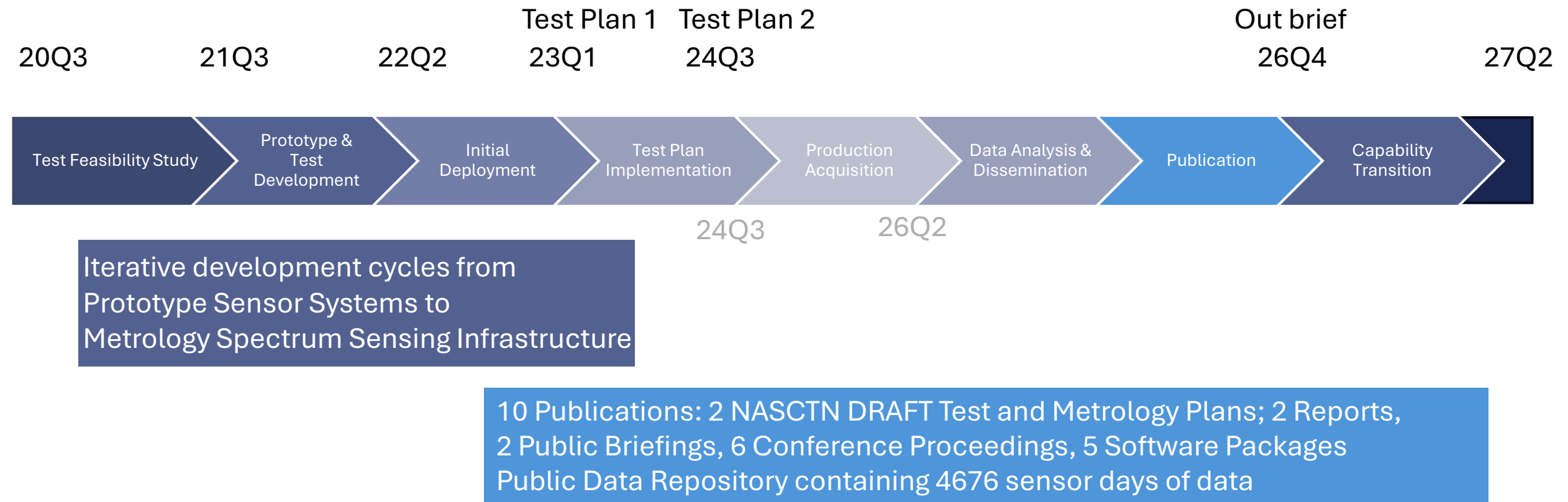


Collect data required for Defense Information Systems Agency (DISA) to ascertain the effectiveness of the sharing ecosystem between CBRS systems as managed by Spectrum Access Systems (SASs), and Department of War (DoW) systems as monitored by Environmental Sensing Capabilities (ESCs). Provide insight into the sharing ecosystem's effectiveness and track changes in the spectrum environment over time.

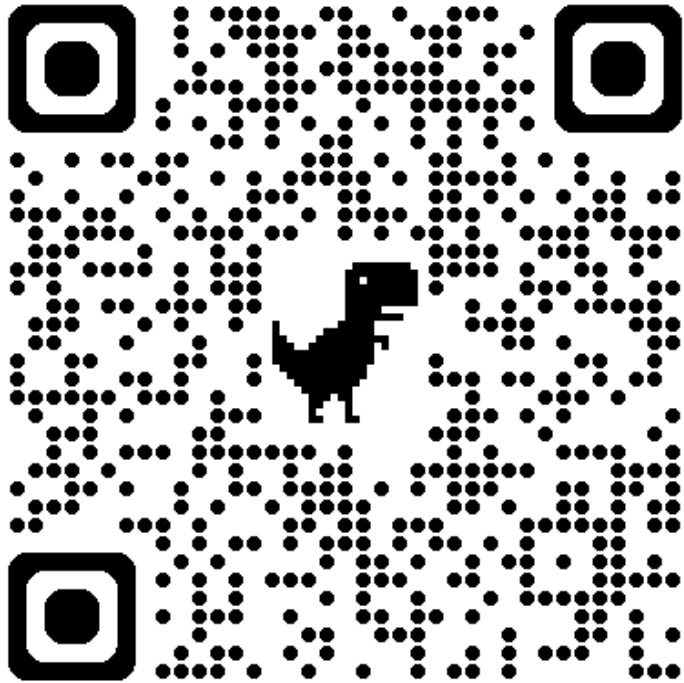
Outcomes

- Advancing American Led Standards – WInnForum, SCOS IEEE 802.15.22.3, ANSI C63.26
- Answering: Can spectrum within CBRS be shared effectively and can the sharing be quantified
- Spectrum Science R&D
 - Traceable reference dataset with applications in AI/ML
 - Quantifying the importance of ground truth data in interference modeling and prediction
 - Aggregate emissions considerations in protecting Federal Incumbents
 - Advancing measurement practices in spectrum monitoring

SEA overarching Timeline

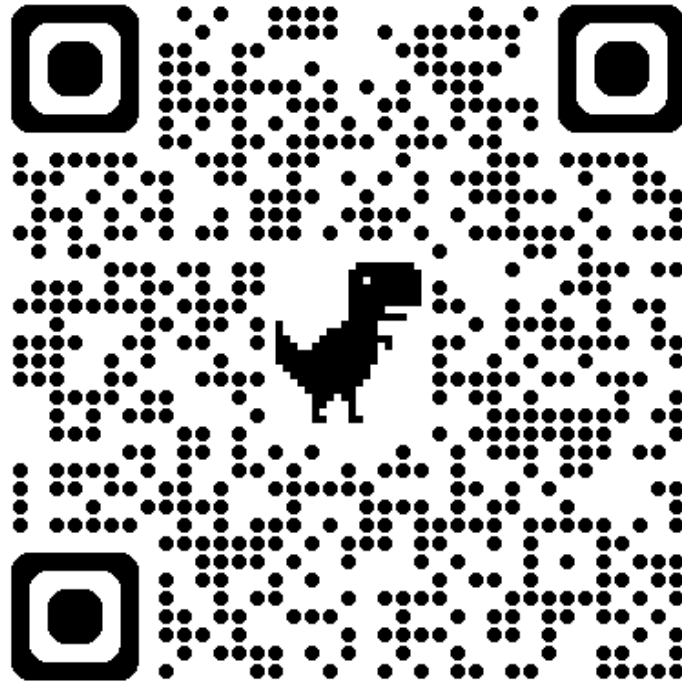


Data Access



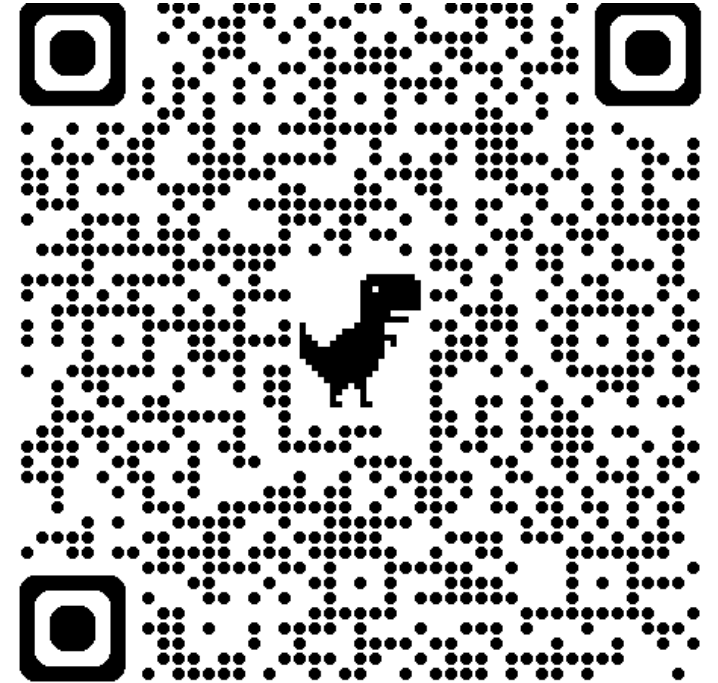
<https://pages.nist.gov/SEA-DATA/>

Data Manual



<https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2359.pdf>

Sensor Documentation



<https://www.mitre.org/sites/default/files/2026-01/PR-25-3159-spectrum-monitoring-sensor-radio-service-assessment.pdf>

Published Proceedings

- D. G. Kuester, A. W. Romaniello and P. Mathys, "Cyclostationary Channel Power Measurements for CBRS Coexistence Assessment," *2024 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, Boulder, CO, USA, 2024, pp. 300-301, accessible online: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10464971>.
- J. R. Mruk, T. T. Nguyen, M. K. Forsyth, D. A. McGillivray and D. G. Kuester, "Spectrum Monitoring System Deployment Site Analysis Using Realistic Radiation Patterns," *2025 19th European Conference on Antennas and Propagation (EuCAP)*, Stockholm, Sweden, 2025, pp. 1-5, accessible online: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10999562>.
- T. Schumann, "Advanced Interference Analysis Measurements of Real-World Spectrum Sharing Environments, " *2025 IEEE International Symposium On Electromagnetic Compatibility, Signal and Power Integrity (EMC+SIPI)*, Raleigh, NC, USA, 2025
- T. T. Nguyen, D. A. McGillivray, A. W. Sanders, T. Schumann, "Modeling and Measurement of NASCTN SEA Sensors in CBRS Ecosystem ," *2026 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, Boulder, CO, USA, 2026, pp. 408, accessible online: <https://usncursi.org/archive/nrsm/2026/papers/1322.pdf>.
- T. Schumann, A. W. Sanders, D. A. McGillivray, "Modeling and Measurement of NASCTN SEA Sensors in CBRS Ecosystem ," *2026 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, Boulder, CO, USA, 2026, pp. 411, accessible online: <https://usncursi.org/archive/nrsm/2026/papers/1283.pdf>.
- A. W. Sanders, T. Schumann, " NASCTN CBRS SEA High-Fidelity Data Products for ML-Based Signal Classification ," *2026 International Symposium on Advanced Radio Technologies (ISART)*, Boulder, CO, USA, 2026 Accessible online: <https://its.ntia.gov/media/dlvpgkwp/isart26-nasctn-cbrs-sea-data-final-updated.pdf>.

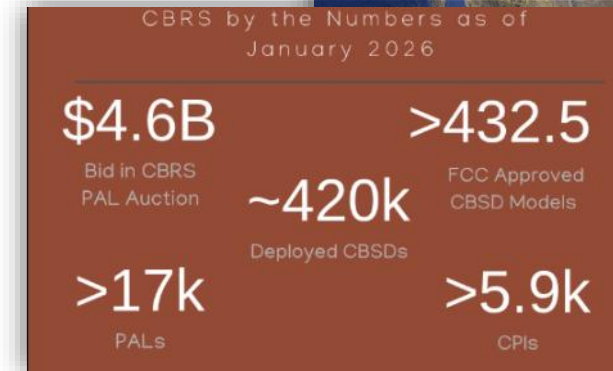
Publications being finalized

- **NIST TN NASCTN CBRS SEA Modeling Methodology Report**
- **NIST TN NASCTN CBRS SEA Data Insights Report (“Final Report”)**
- NIST TN Noise Based Power Calibration Techniques for Mid-Band Radio Frequency Sensors
- NTIA TR Spectrum Characterization and Occupancy Sensing Applied to the CBRS SEA Program
- *Conference Proceedings*
 - Verification of Spectrum Sensors via Flown RF Payload

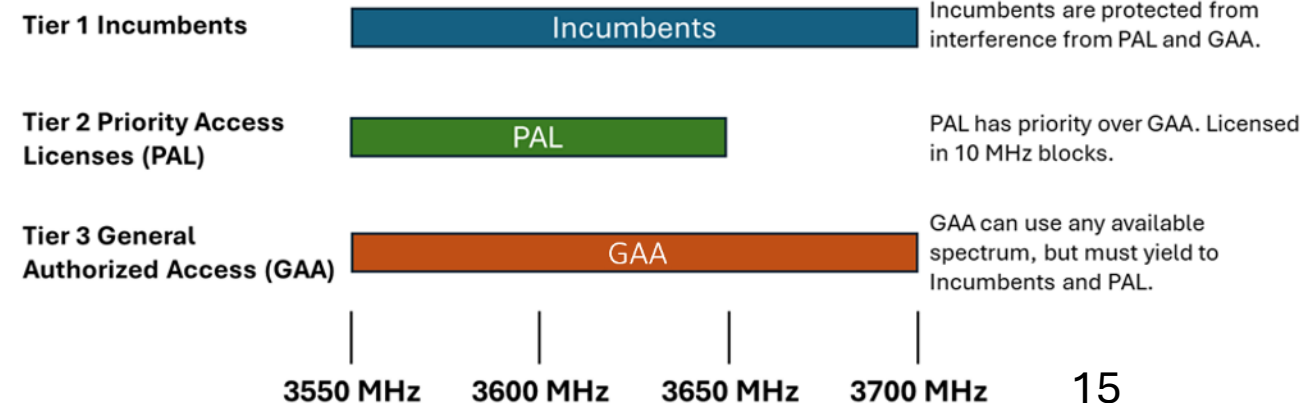
Citizens Broadband Radio Service (CBRS)

The Citizens Broadband Radio Service (CBRS) is the “first of a kind” dynamically shared spectrum ecosystem, implemented nationwide.

- **Shared band, 3 tier approach** - Incumbent, Priority Access License, General Authorized Access
- **Sharing stipulations** - FCC part 96
- **Environmental Sensing Capability (ESC)** detects incumbents and **Spectrum Access Systems (SAS)** coordinates spectrum access
- Sharing is coordinated in **Dynamic Protection Areas (DPA)s**: E-DPA (serviced by ESCs), P-DPA (database/portal based), and GB/Always-On DPA (ground base/always on)

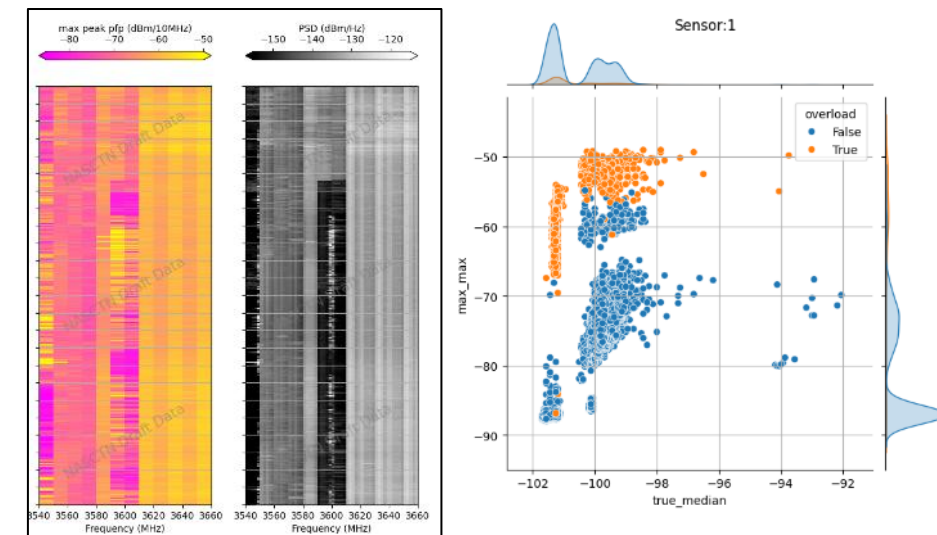
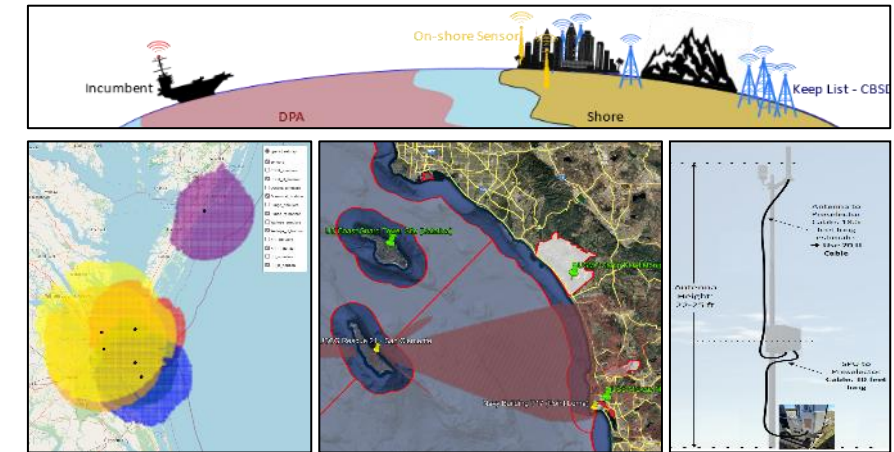


<https://winnforum.org/wp-content/uploads/2026/08/CBRS-Ecosystem-Jan-2026.png>

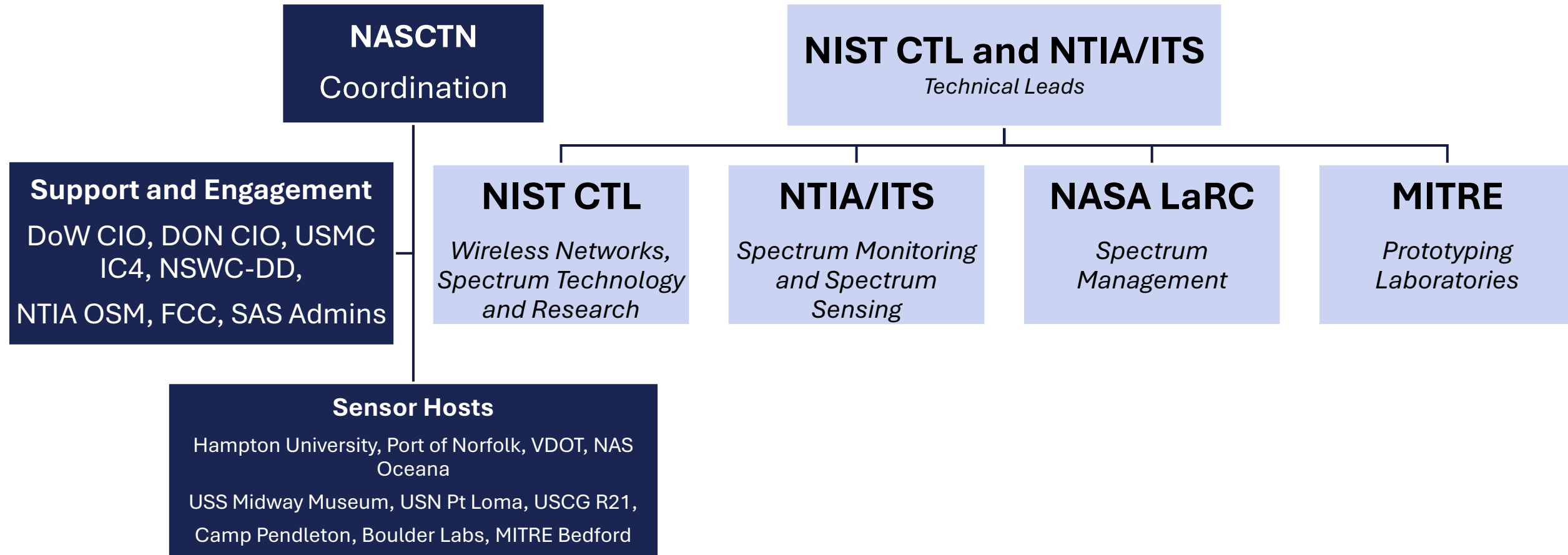


Sharing Ecosystem Assessment Test Framework – Project Approach

- **Task 1 – Passive Observation in the CBRS Band in Vicinity of Coastal Dynamic Protection Areas (DPAs)**
 - Characterize aggregate emissions within the CBRS band 3550-3700 MHz in the vicinity of at least two Coastal DPAs, with and without DPA activations
 - Assess ecosystem performance to timely respond, and measure increase in background emission due to wireless system deployments over time
- **Task 2 – Passive Observation in the CBRS Band in Always-On DPAs**
 - Characterize aggregate emissions within the CBRS band 3550-3700 MHz in at least one Always-On DPA or ground-based DPA (GB-DPA)
 - Assess ecosystem performance to limit CBRS emissions in the Always-On DPA
- **Task 3 – Long Term Data Analysis and Support**
 - Collection and analysis of Passive Observations throughout sensor deployment
 - Support transfer of data to a DoW data repository



Teaming & Implementation



Implementation



Highly automated, leave-behind sensor network for *longitudinal in-situ study of RF emissions and traceable RF power* in the CBRS Band



Reproducible RF systems architecture on COTS hardware and *open-source software stacks and published signal processing*



Marry measurement data with expectations from modeling and simulation as per *WinnForum Reference Implementations*, the underlying model for CBRS



Broad coordination and collaboration with government and industry groups to provide insights from Dynamic Protection Area (DPA) and Always On DPA with relevance to DoW operations

Key Challenges

Ground Truth

- Incumbent presence and spectrum usage is impractical to corroborate
- CBRS SEA sensors are not collocated with ESCs

Passive sensing

- Non-impact on the CBRS ecosystem operations

CBRS criteria thresholds

- Detection fidelity requirements leads to high number of unique detection events
- Interference protection thresholds within eDPA are beyond thermal limit of practical spectrum monitors

Extended monitoring vs sensor survivability

- System design trade space between long-term continuous monitoring vs one-off measurements in harsh environments

Aggregate emissions protection thresholds

- Calculations are not readily mappable to physical validation: antenna patterns, neighborhood distance considerations

Limitations of CBRS SEA Insights



- Can not measure the protection criteria at protection points
 - -6 dB I/N, reference antenna patterns, neighborhood distances
- Can not correlate to ESC field of views and whisper zones
- Limited number of sites and scenes of view
- Siting biased towards ecosystem response and sharing activity

Key Achievements

Validated sensor network longitudinally with high reliability

- Key regions: Norfolk VA (DPA: East-1), San Diego CA (DPAs: West-13 & West-14), USMC Camp Pendleton (Always On DPA)

Publicly available longitudinal spectrum dataset

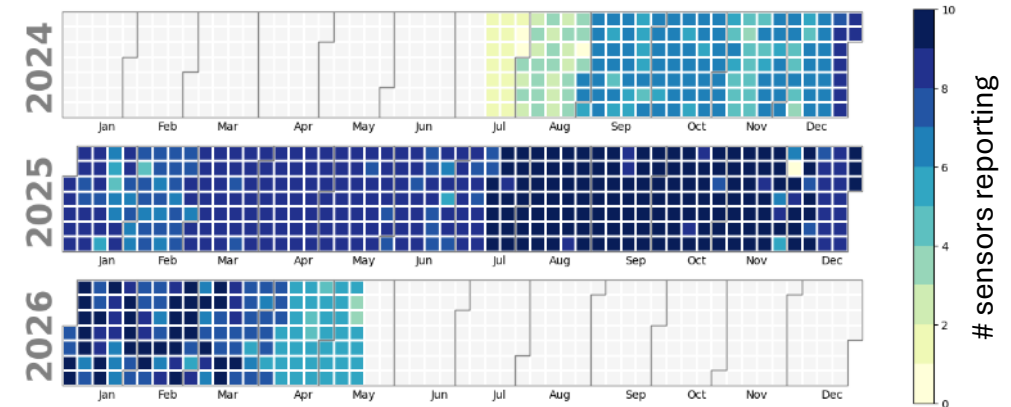
- Novel edge computed data products
- Calibrated, traceable power metrics
- Applied classifier to allow for conditional analyses
- Standardized to SigMF

In-depth modeling

- Comparison of predicted aggregate emissions using census sourced, obfuscated, and real cellular laydowns
- Implemented WInnForum Reference models (CBRS 1.0 & 2.0)
- Connected modeling with measurements
- Extended reference models for modelling informed sensor fielding

Analytics of cellular emissions

- Longitudinal ecosystem insights
- Instantaneous analysis of cellular
- Measurement approaches to testing of assumptions in cellular emissions



NASCTN CBRS SEA Network

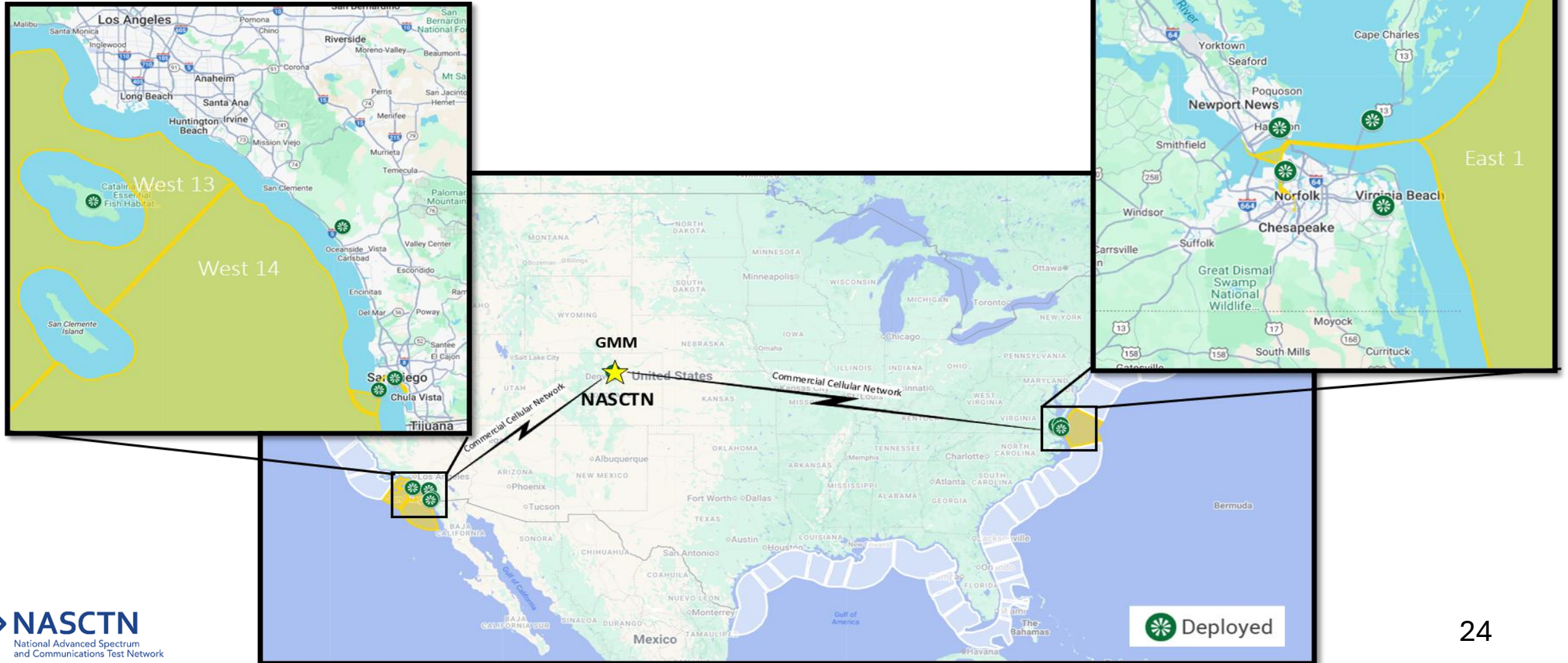
Aric Sanders, PhD

Sensor Highlights

- *Professional open-source design and integration* through MITRE – Bedford Laboratories (<https://www.mitre.org/sites/default/files/2026-01/PR-25-3159-spectrum-monitoring-sensor-radio-service-assessment.pdf>)
- *Traceable to NIST* Calibrated and referenced to NIST's thermal noise radiometer (<https://www.nist.gov/programs-projects/thermal-noise-metrology>)
- *Authority To Operate network* through NTIA / ITS
- *Leverages NTIA/ITS's reference implementation* of the Spectrum Characterization and Occupancy Sensing (SCOS) sensor standard. (IEEE 802.15.22.3)
- *Hourly field calibration* through NIST traceable on-board RF thermal noise reference
- *Portable lab to field uncertainty characterization methodology* demonstrated and in preparation for publication
- *Deployed sensor investigation and monitoring* through NASA Langley

NASCTN SEA Sensor Locations

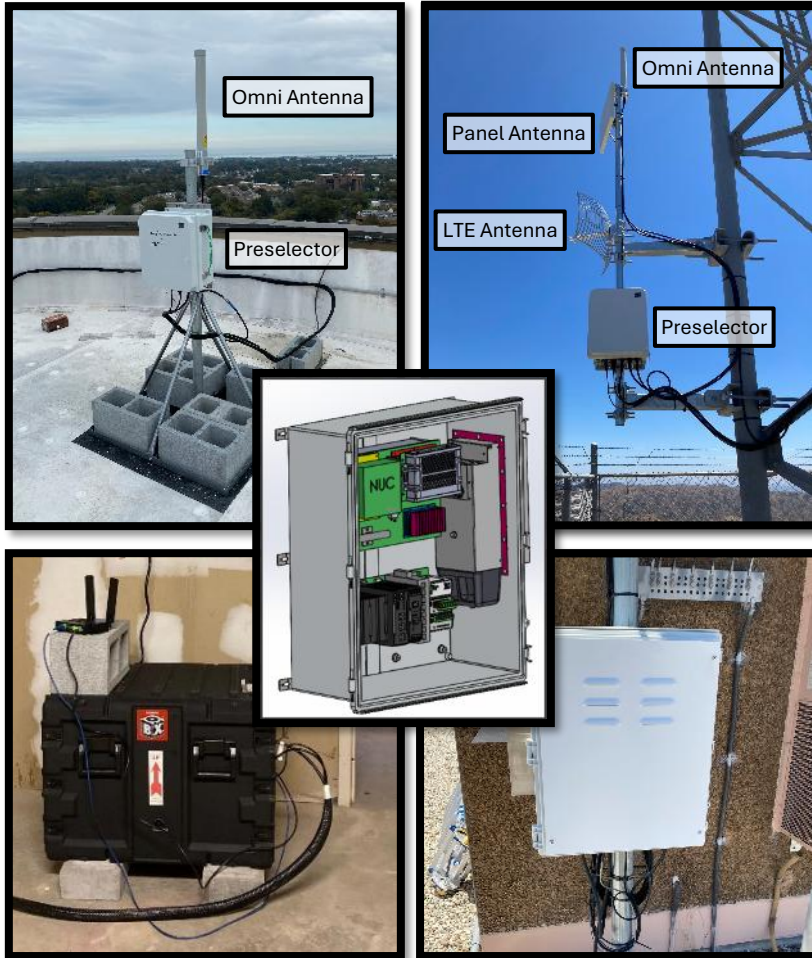
9 different locations: 4 East Coast, 4 West Coast, 1 Boulder, in 12 configurations
> 95% reliability, 4767 + sensor days, retrieved in near real-time



SEA Sensor Systems – at a Glance

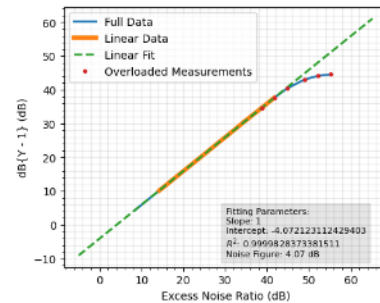
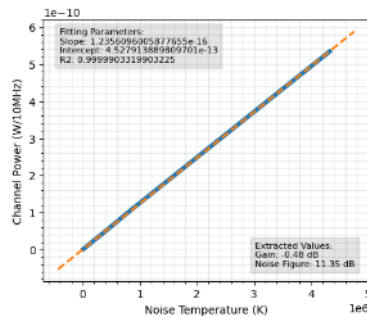
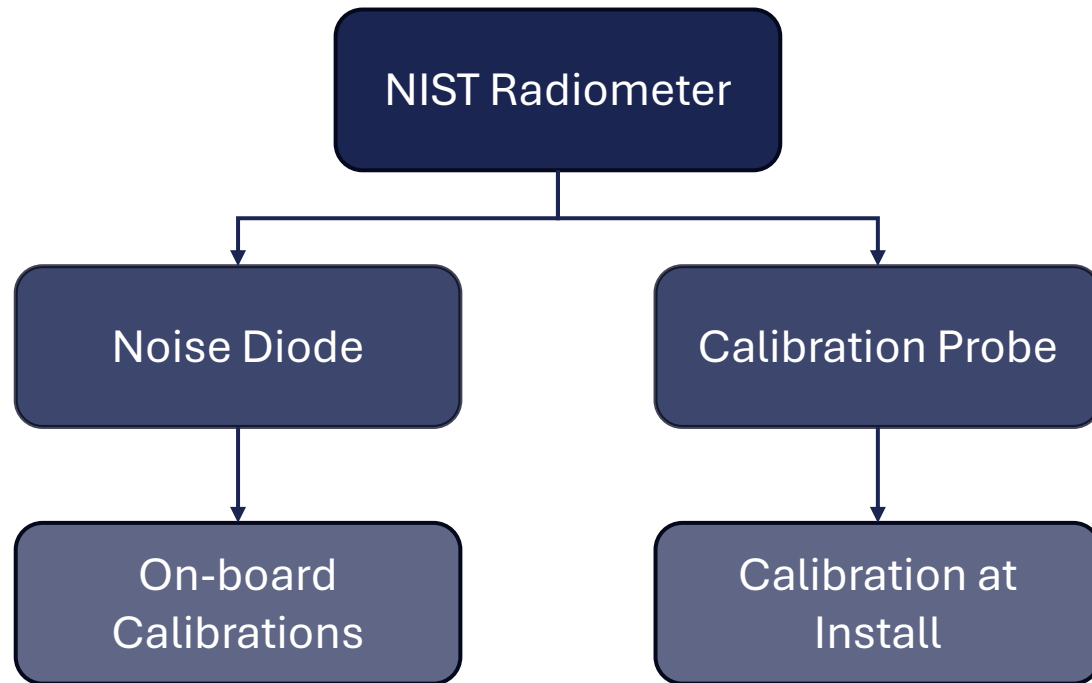
Split System

All-Outdoor System



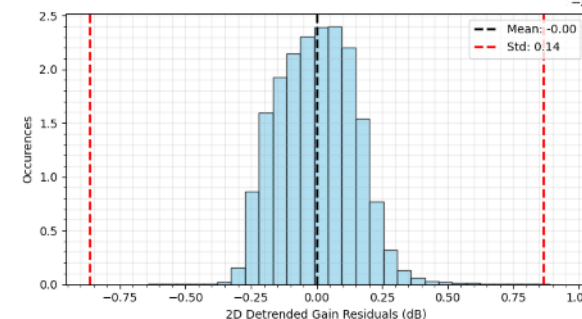
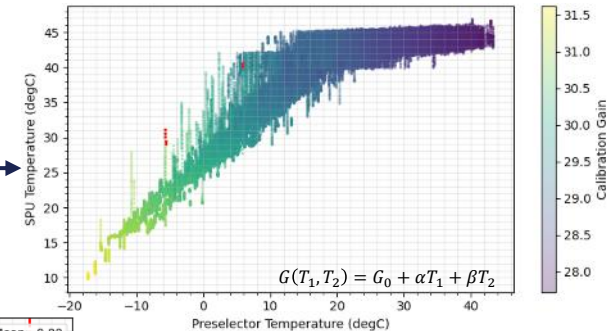
Parameter		Typical Value		Conditions	Note
RF System	Frequency Range	3530 – 3710 MHz			Additional channels on either edge of CBRS
	Gain	31.5 dB		Channel 8 (3620 – 3630 MHz) RSA Settings: Preamp: Enabled Reference level: -25 dBm Input attenuator: 0 dB	
	Input-Referred Noise Power	-98 dBm/10 MHz			Additional dynamic range settings to adjust noise and overload levels
	Input 1 dB Compression Point (w/ CW Stimulus)	-48 dBm			
Antenna	Type	Omni (360°)	Panel (15°)		<i>GMM sensor variation</i> 90° Sector Gain: 17 dBi Pol: +, - 45° Slant Pol Vert: 6°
	Gain	9 dBi	20 dBi		
	Polarization	Vertical	Vertical		
	Vertical 3 dB Beamwidth	11°	14°		

Calibration and Validation

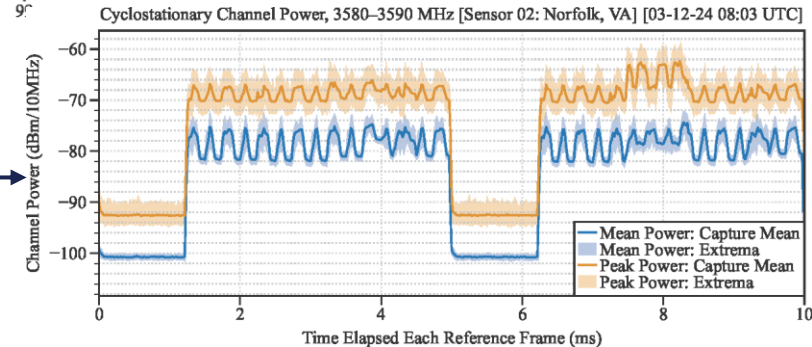
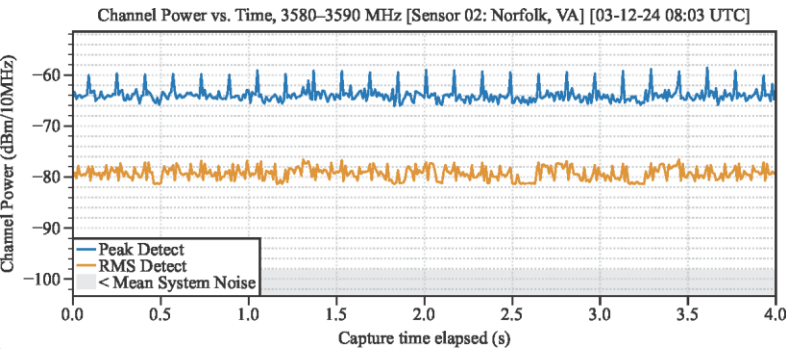
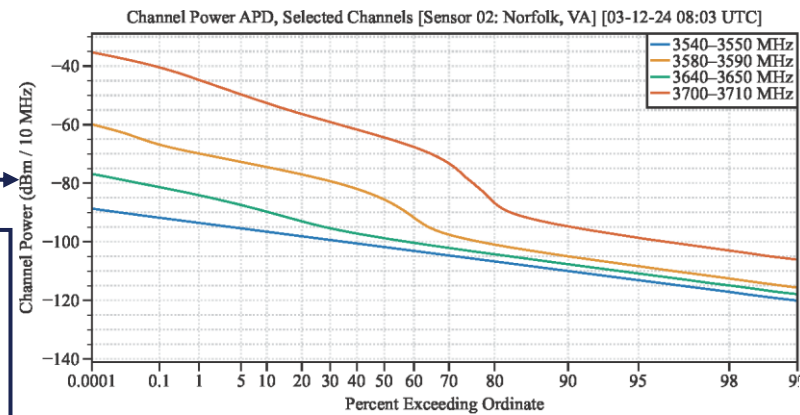
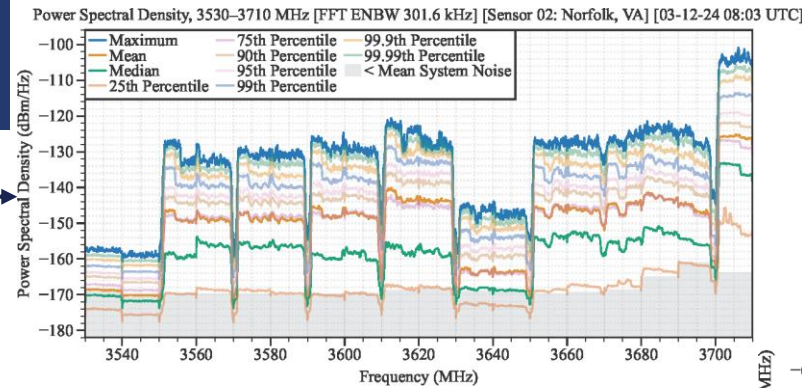
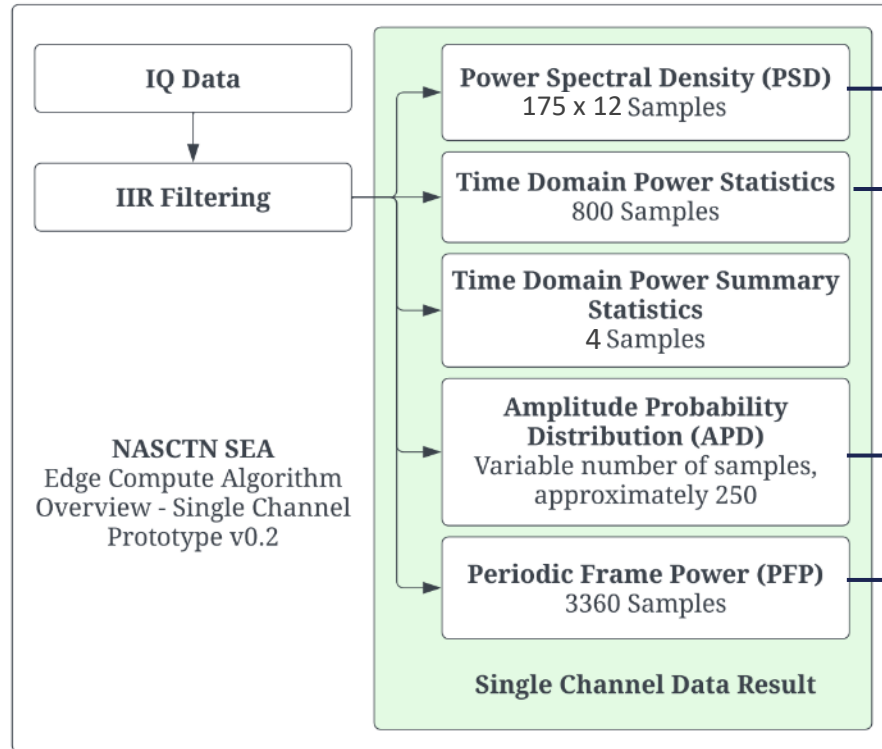


Data Validation Checklist

1. Ensure valid frequency list
2. Remove data from known sensor failures
3. Remove mixed attenuation actions
4. Remove data before VBA calibration was applied
 - Midway and Pendleton are post-applied
5. Remove data from short schedules (< 24 hours)
6. Remove calibration outliers
 - Unbiases the calibration trending
7. Remove deviations from calibration detrending



Edge Data Products



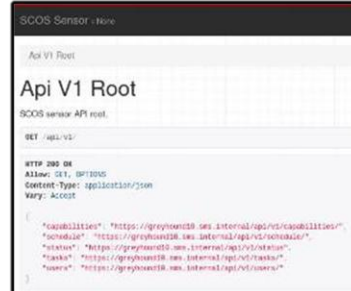
MEASUREMENT

3530 MHz – 3710 MHz measured in 10 MHz channels with 4-second dwell times

Data Collection and Transport

SCOS Sensor

- Universal API for a sensor that is hardware agnostic
- Decouple the hardware from the software
- Standardized to IEEE 802.15.22.3
- <https://github.com/NTIA/scos-sensor>



SigMF Metadata

- Common metadata for data outputs from sensors
- Aggregate data across multiple projects and efforts
- Single “ingester” for all datasets
- <https://github.com/sigmf/SigMF>
- <https://github.com/NTIA/sigmf-ns-ntia>

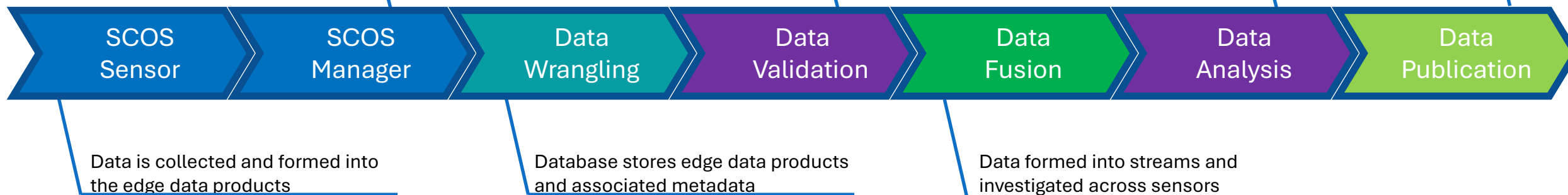
- [ntia-algorithm](#) describes the measurement performed (detectors, algorithms, etc)
- [ntia-core](#) adds generally useful metadata fields
- [ntia-diagnostics](#) provides metadata to describe system diagnostic information.
- [ntia-emitter](#) gives information about the emitter being measured
- [ntia-environment](#) gives information about the environment around a sensor or emitter
- [ntia-nasctn-sca](#) provides metadata used within NASCTN Sharing Ecosystem Assessment project.
- [ntia-scos](#) provides metadata for the NTIA Spectrum Characterization and Occupancy Sensing (SCOS) implementation
- [ntia-sensor](#) defines hardware components and settings
- [ntia-waveform](#) provides metadata to describe measured or transmitted waveforms

SCOS manager centralizes the data

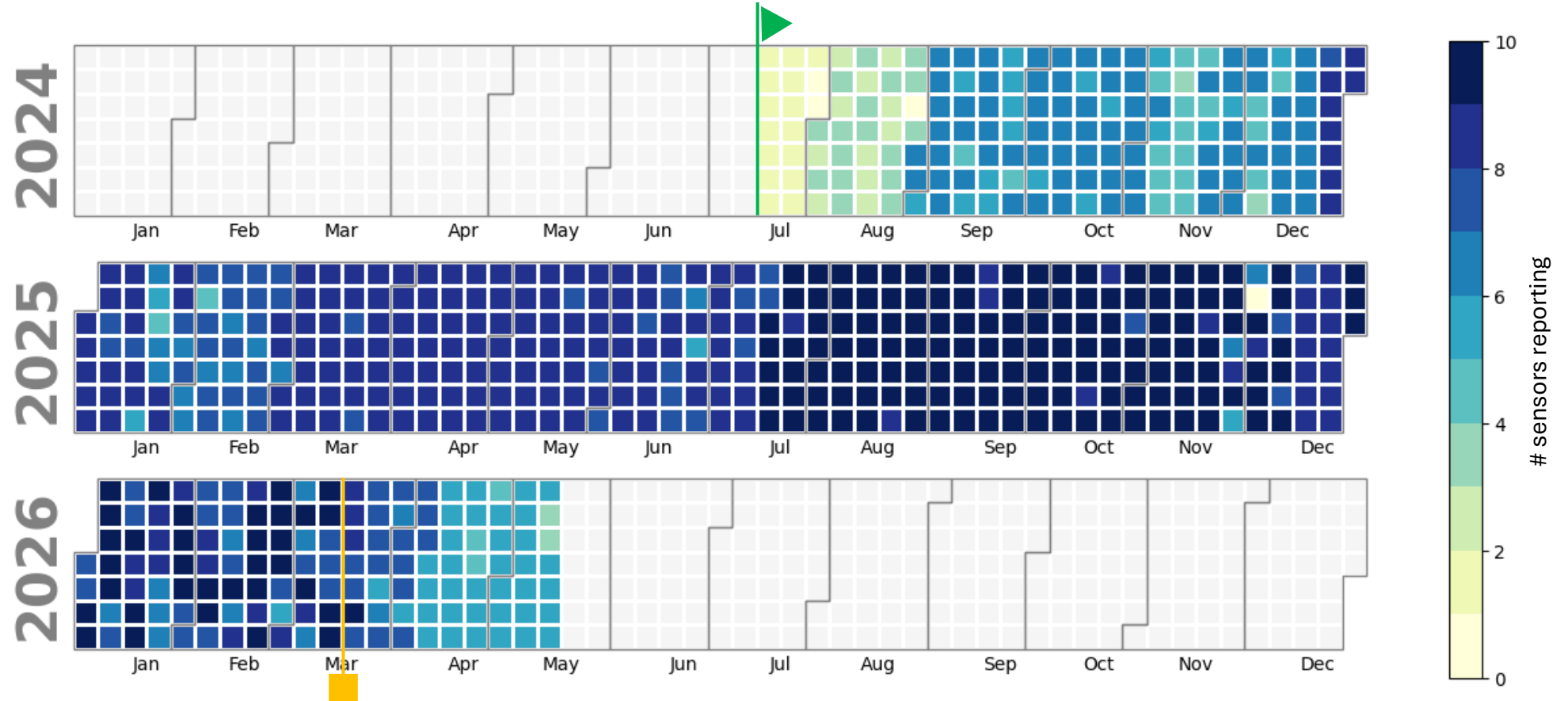
Entries are validated to ensure the data is of publishable quality and suitable for further analysis

Intermediate data products are constructed based on analysis of edge data products

The data is published in a medium that is accessible to the public



Publicly Available Sensor Days



Operating 10 sensor configurations

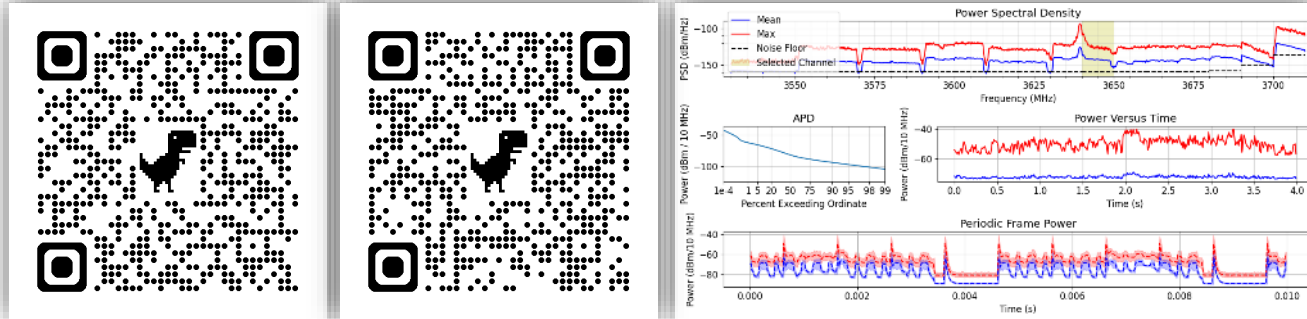
4767 unique sensor days;

Data sets are of CBRS 1.0 and CBRS 2.0 sharing

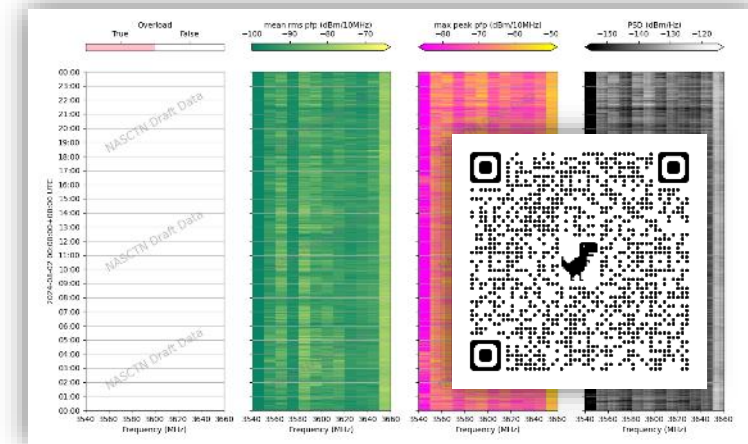
Select sensors operating with dual antenna fields of regard

Data Visualization and Manipulation Tools

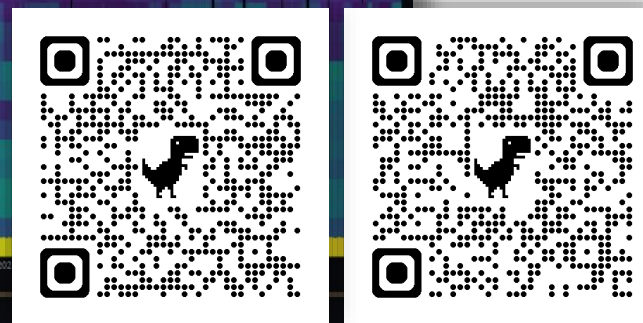
Python Scripting Tools



Summary Images with Public URLs



Rapid Browser and Summary Data Set



Modeling Insights

Thao Nguyen, PhD

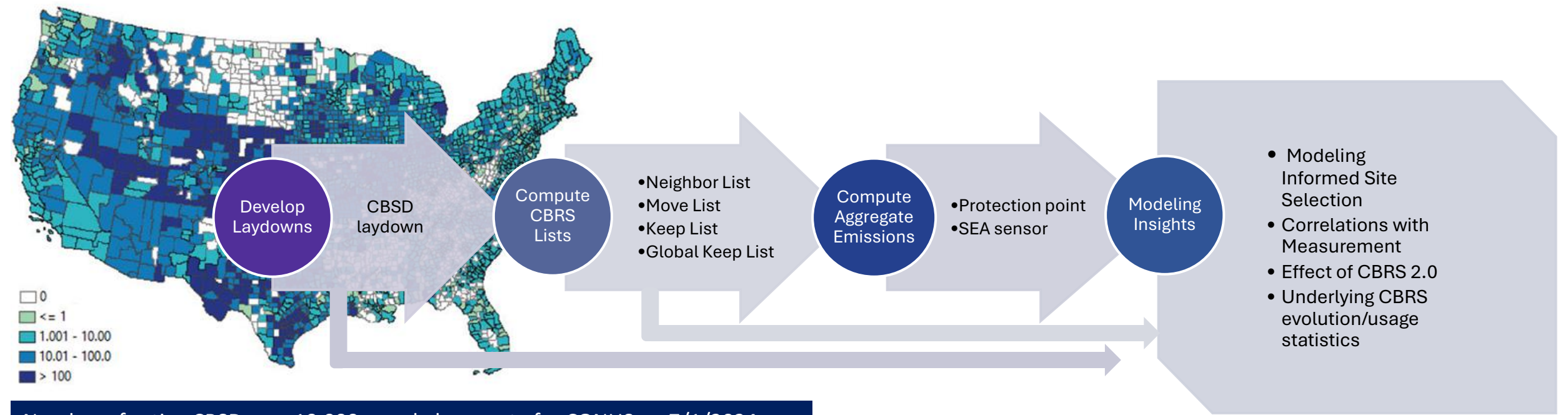
NASCTN SEA Modeling

PROGRAM OBJECTIVE

Provide data-driven insight into CBRS sharing effectiveness and changes over time.

MODELING ROLE

Use CBSD deployment data and WInnForum models to estimate quantities that can be compared with field measurements.



Number of active CBSDs per 10,000 people by county for CONUS on 7/1/2024

<https://www.ntia.gov/report/2024/analysis-aggregate-cbrs-sas-data-april-2021-july-2024/county-data>

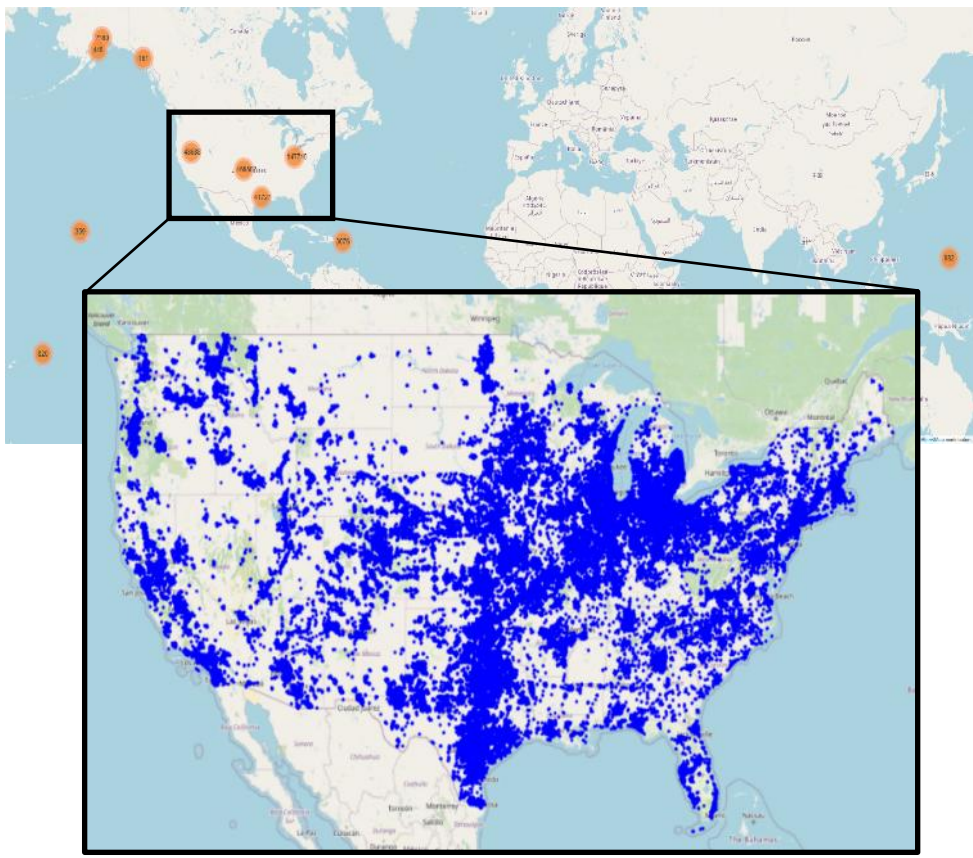
Modeling Effort Highlights

- Coordinated with NTIA/ITS, NTIA/OSM, and CBRS I-JWG to obtain and integrate industry deployment data of CBSDs
 - Population-based, obfuscated Full Activity Dump (FAD), and FAD datasets
- Extended WInnForum reference modeling
 - Antenna patterns, sensor field-of-view calculations
- Implemented CBRS 1.0 and CBRS 2.0 DPA models
 - DPA move lists and aggregate emission estimates
- Connected modeling with measurements
 - Site selection and modeled-to-measured comparisons

Modeling Capabilities

CBSD DEPLOYMENT

Full Activity Dump (FAD) data from SAS Administrators
CBSD registration and grant information: max EIRP, frequency, bandwidth, etc.

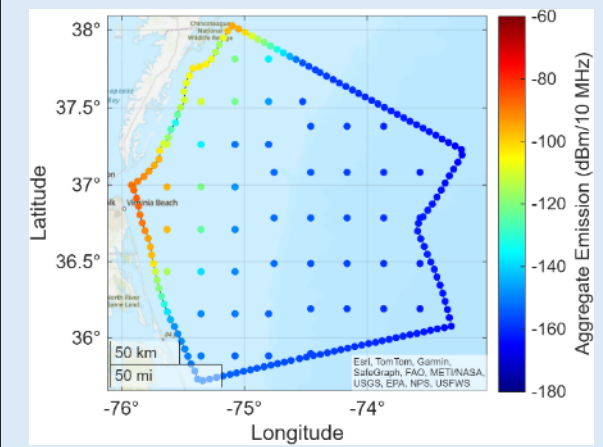
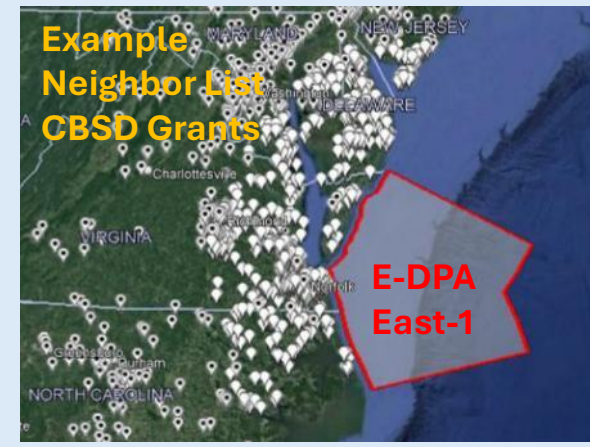


IMPLEMENTATION

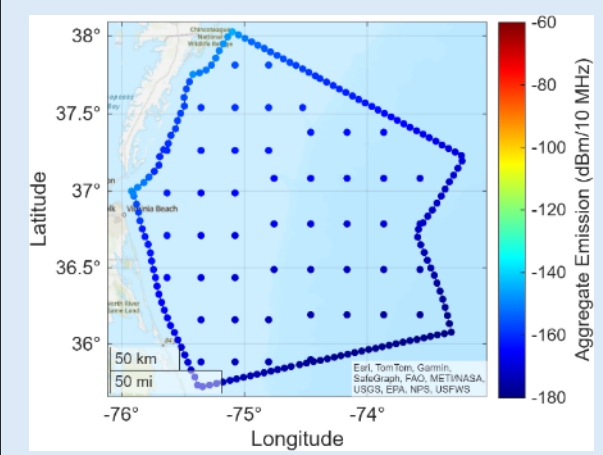
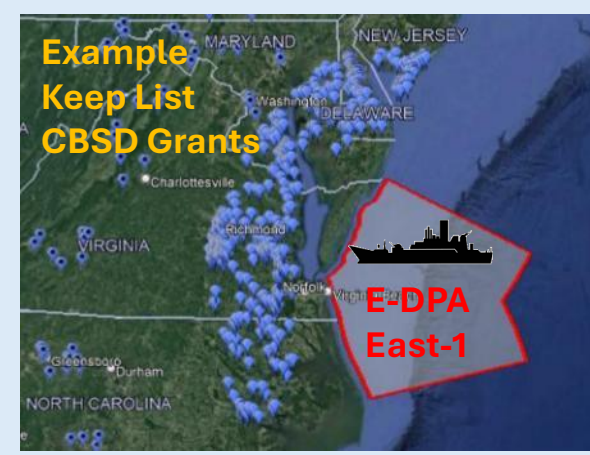
WinnForum's reference **DPA Move List** algorithm and **interference calculations**

- **CBRS 1.0** implementation
- **CBRS 2.0** implementation

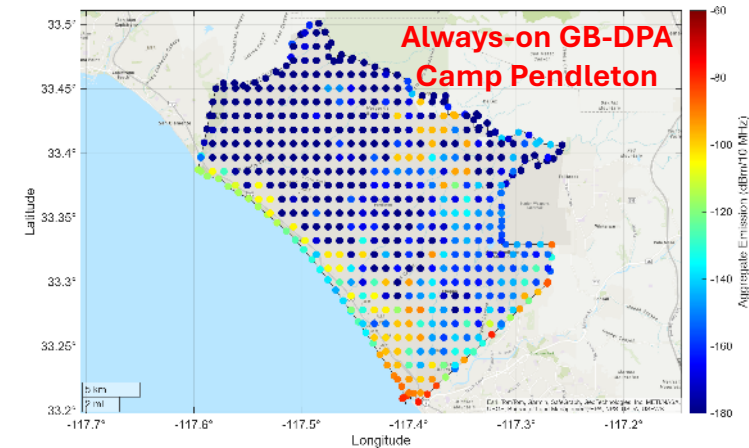
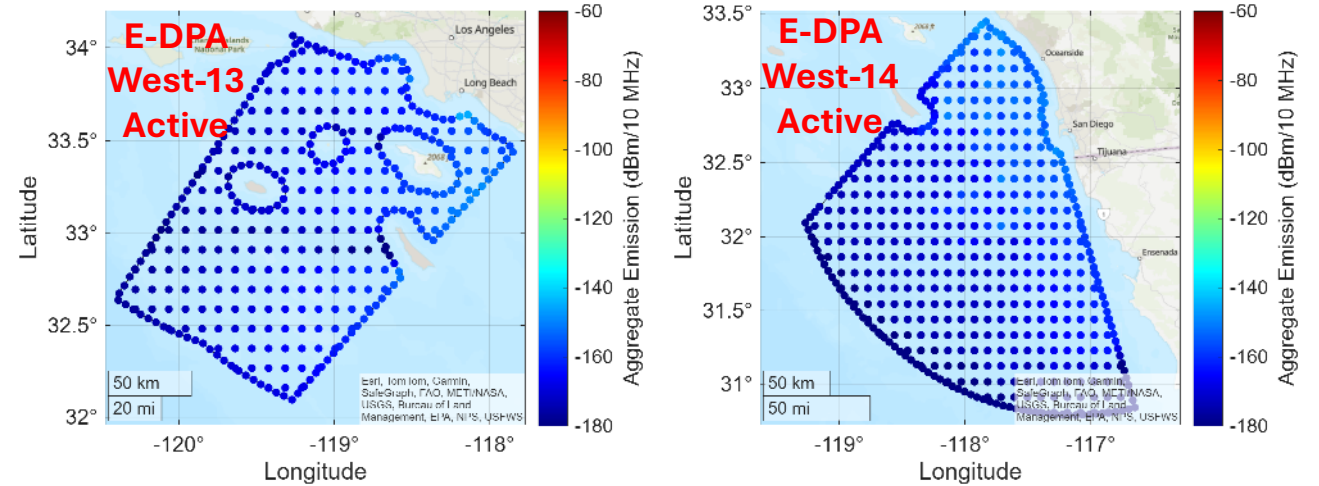
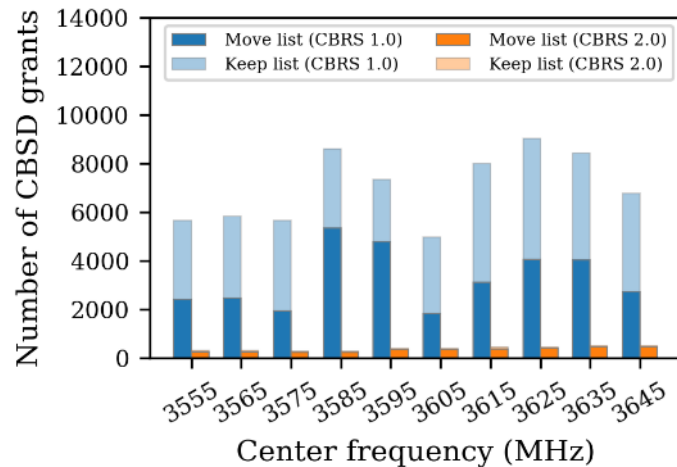
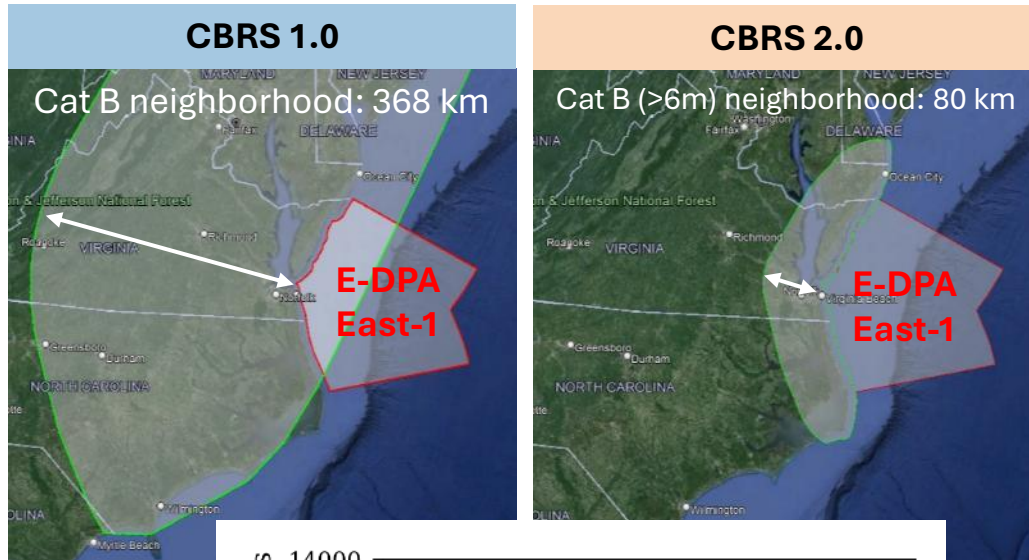
DPA Inactive



DPA Active



Understanding Impacts of CBRS 2.0



CBRS 2.0 substantially changes which CBSDs are included in DPA protection calculations and the resulting aggregate emission estimates.

RF Horizon Modeling Tool

SITE SELECTION

Estimate the geographic region over which CBSD signals are expected to exceed sensor sensitivity

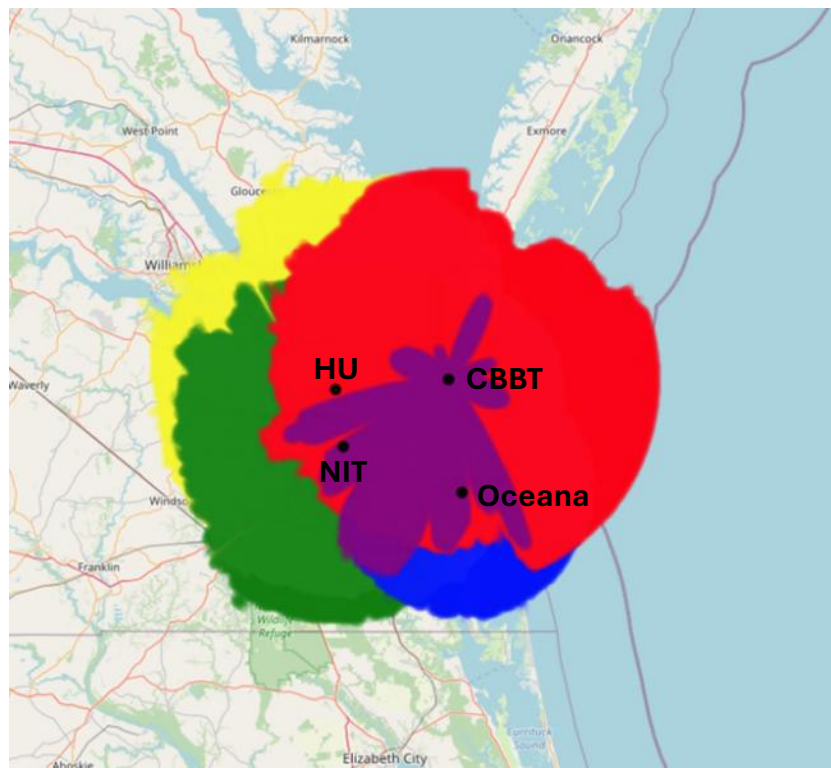
WINNFORUM's ESC WHISPER ZONE

Leverage WinnForum's approach for computing ESC's "whisper zone"

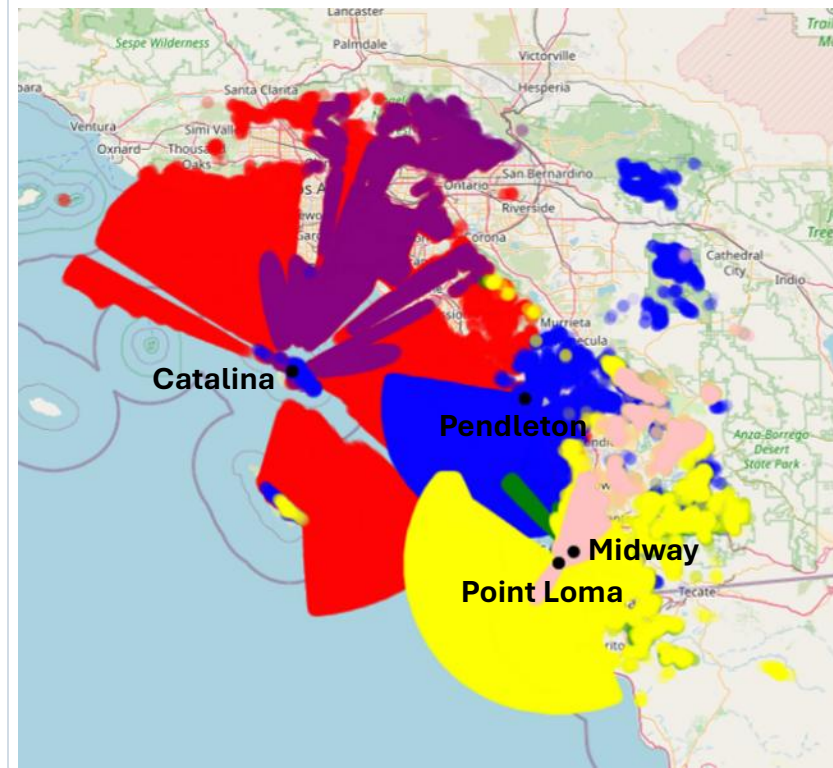
SENSOR PARAMETER CONFIG

Adjust parameter configurations suitable for NASCTN sensor design and deployment

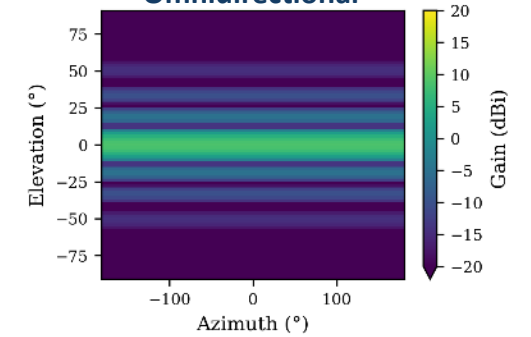
East Coast



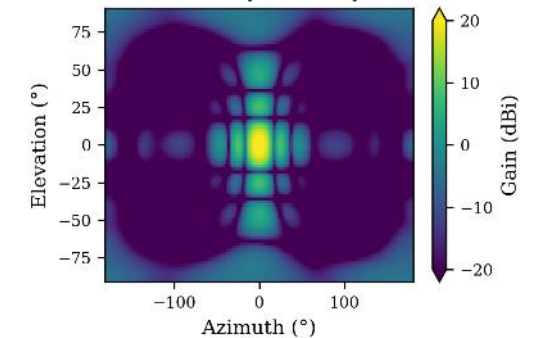
West Coast



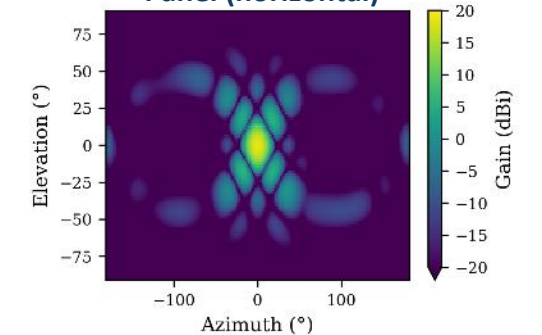
Omnidirectional



Panel (vertical)



Panel (horizontal)

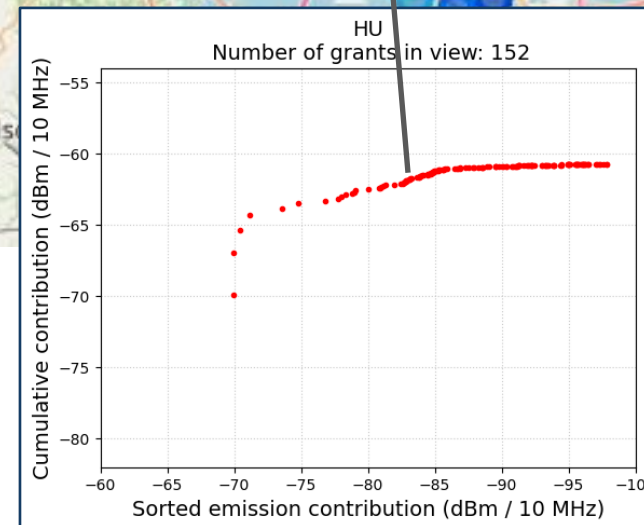
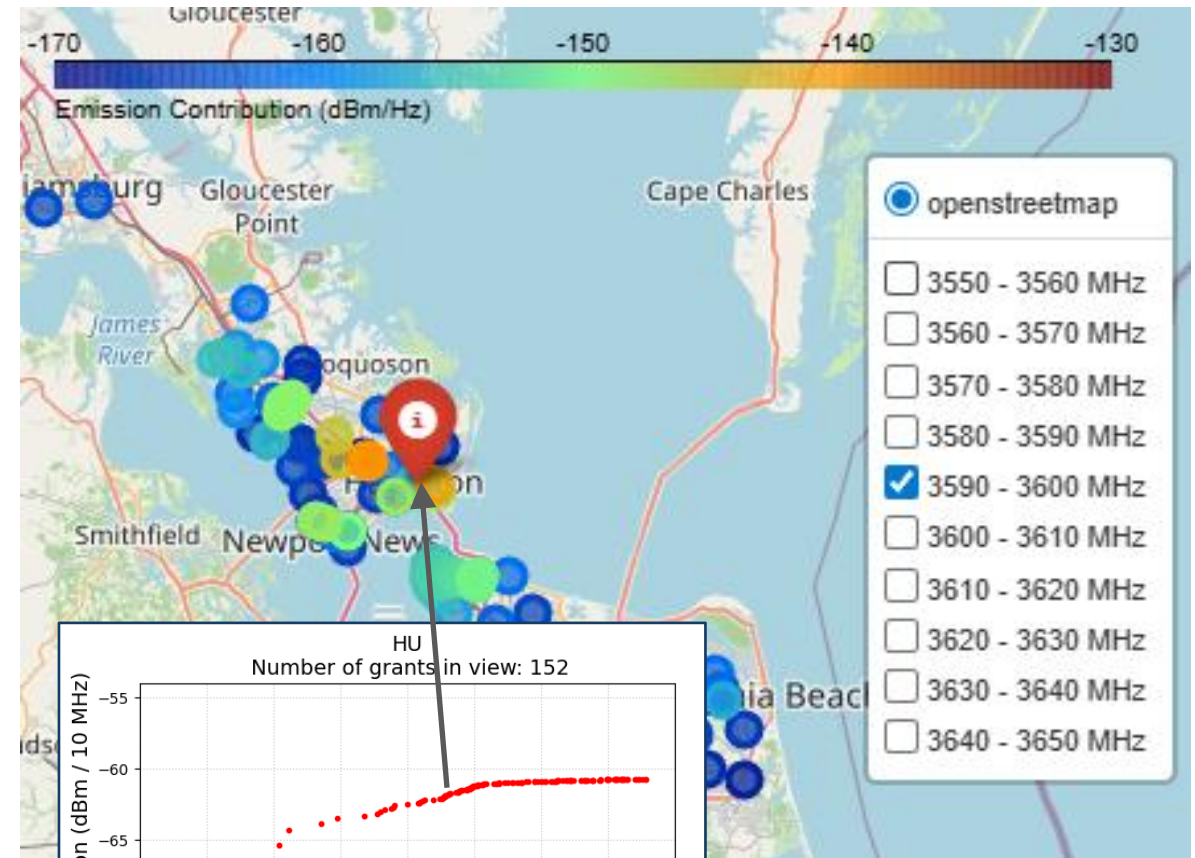


Modeled Sensor Data

AGGREGATE EMISSION CALCULATION

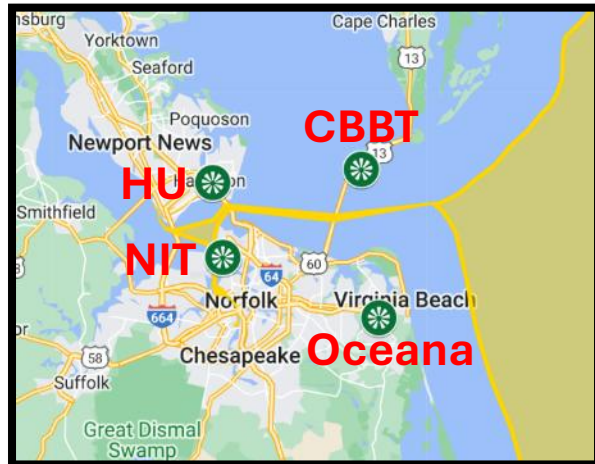
- Estimate the aggregate power level received at a SEA sensor location from CBSD grants operating on each 10 MHz channel within 3550 - 3650 MHz
- Perform both CBRS 1.0 and CBRS 2.0 implementations

Step	Calculation
1	Compute emission contribution I_i (dBm) of an individual CBSD grant i to the sensor s $I_i \text{ (dBm)} = EIRP_i - L_i + G_{s,i}$
2	Compute aggregate emission $I_{(mW)}$ from N neighboring CBSD grants to the sensor s $I_{(mW)} = \sum_{i=1}^N I_i \text{ (mW)} = \sum_{i=1}^N 10^{I_i \text{ (dBm)}/10}$
3	Convert aggregate emission $I_{(mW)}$ to log scale $I_{(dBm)}$ $I_{(dBm)} = 10 \log_{10} I_{(mW)}$



Collected SEA Sensor Data

East Coast Sensor Locations



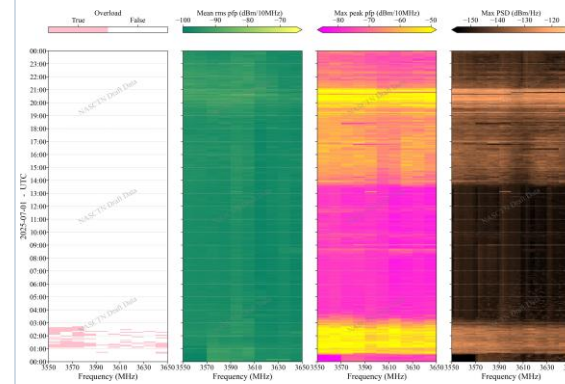
Sensor Measurements:

Various data products collected at SEA sensors to evaluate the sharing ecosystem.

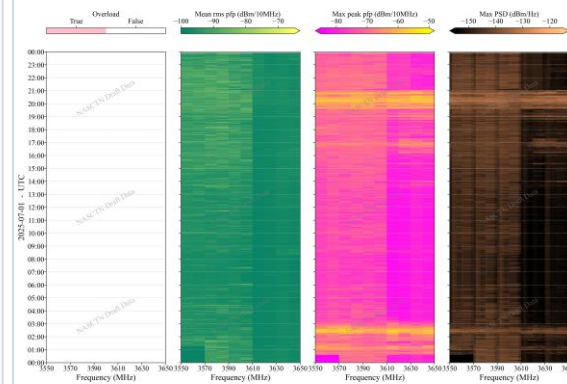
Frequency Range (used for modeling)

3550 – 3650 MHz

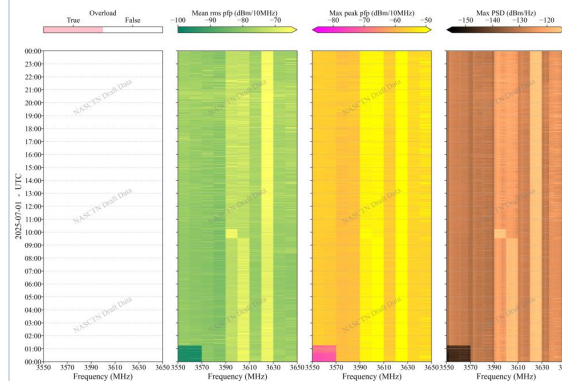
CBBT — Omnidirectional



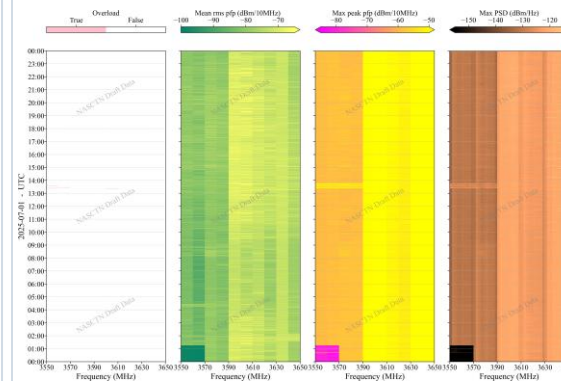
CBBT — Directional



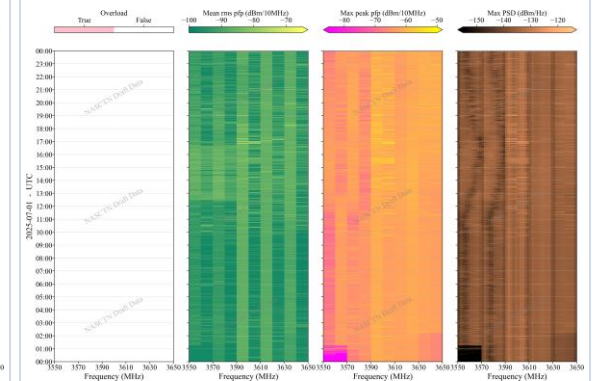
HU — Omni



NIT — Omni



Oceana — Omni



Modeled and Collected Data Comparison

MODELED vs. COLLECTED SENSOR DATA

Objective:

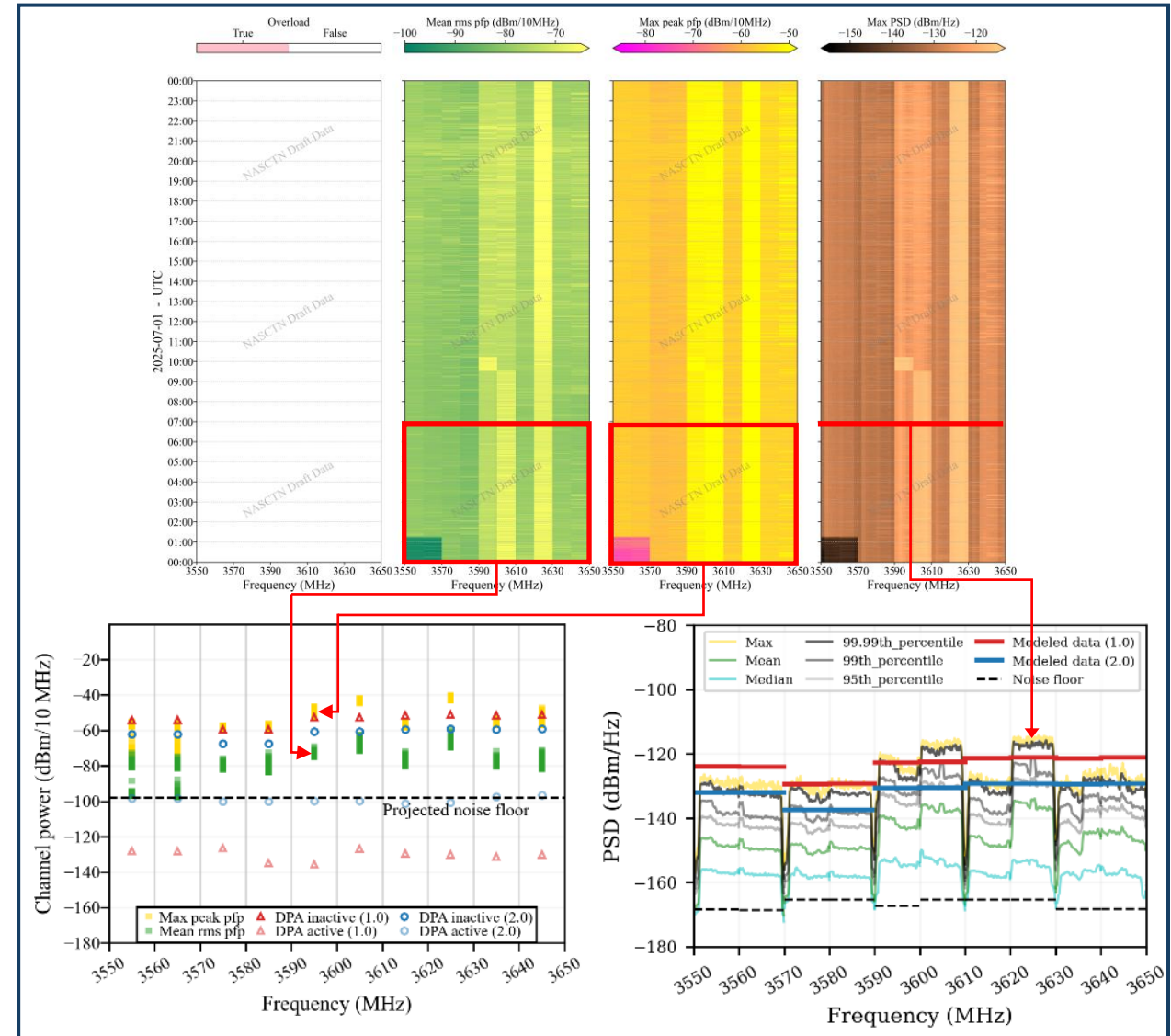
Compare modeled aggregate emissions with collected sensor data to gain insight into modeling assumptions and sources of uncertainty

Measured data:

- Max and mean channel powers extracted during selected time windows
- PSD traces (max, mean, median, 99.99th percentile) at selected time instances

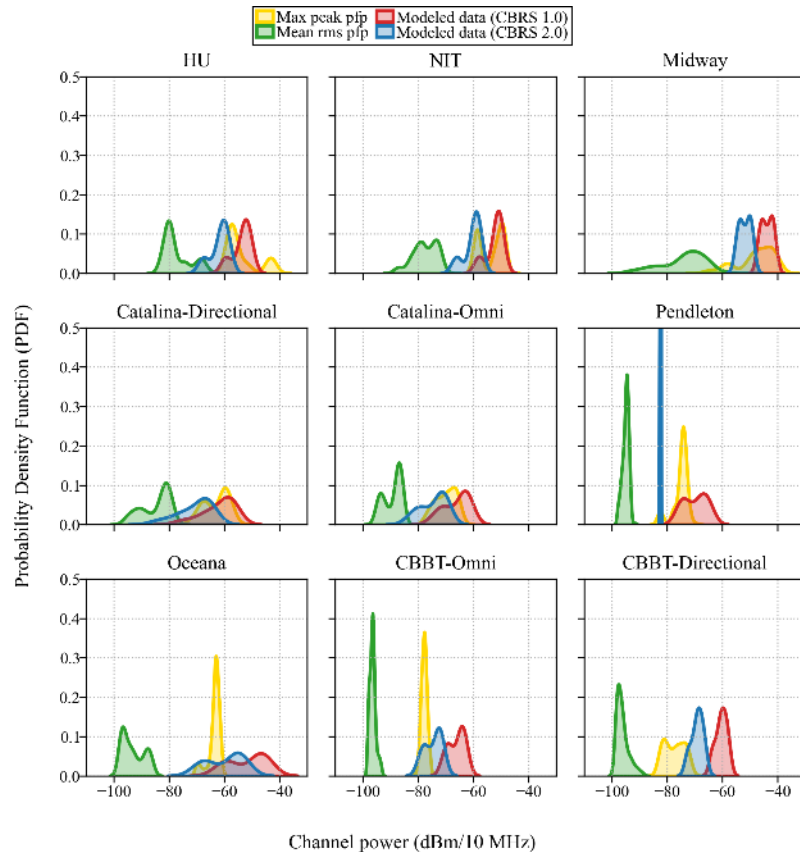
Modeled data:

- Aggregate power level estimated for each 10 MHz channel during DPA active/inactive states
- Both CBRS 1.0 and CBRS 2.0 implementations

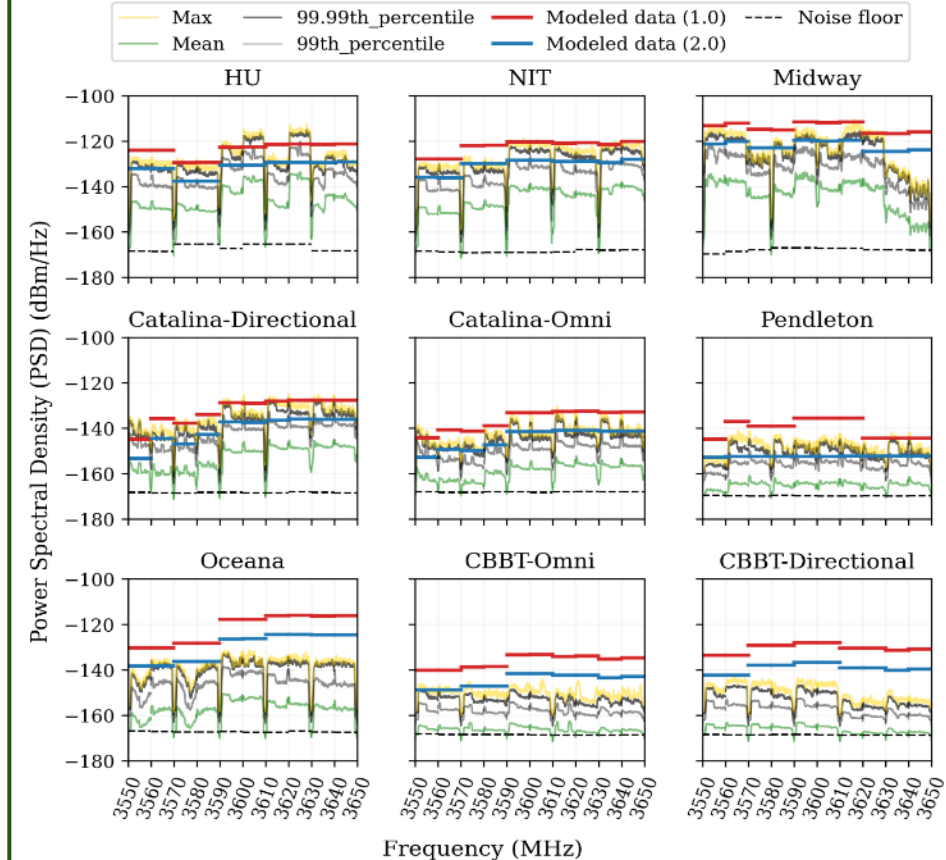


Modeled and Collected Data Comparison

Channel Power Distributions



PSD Traces

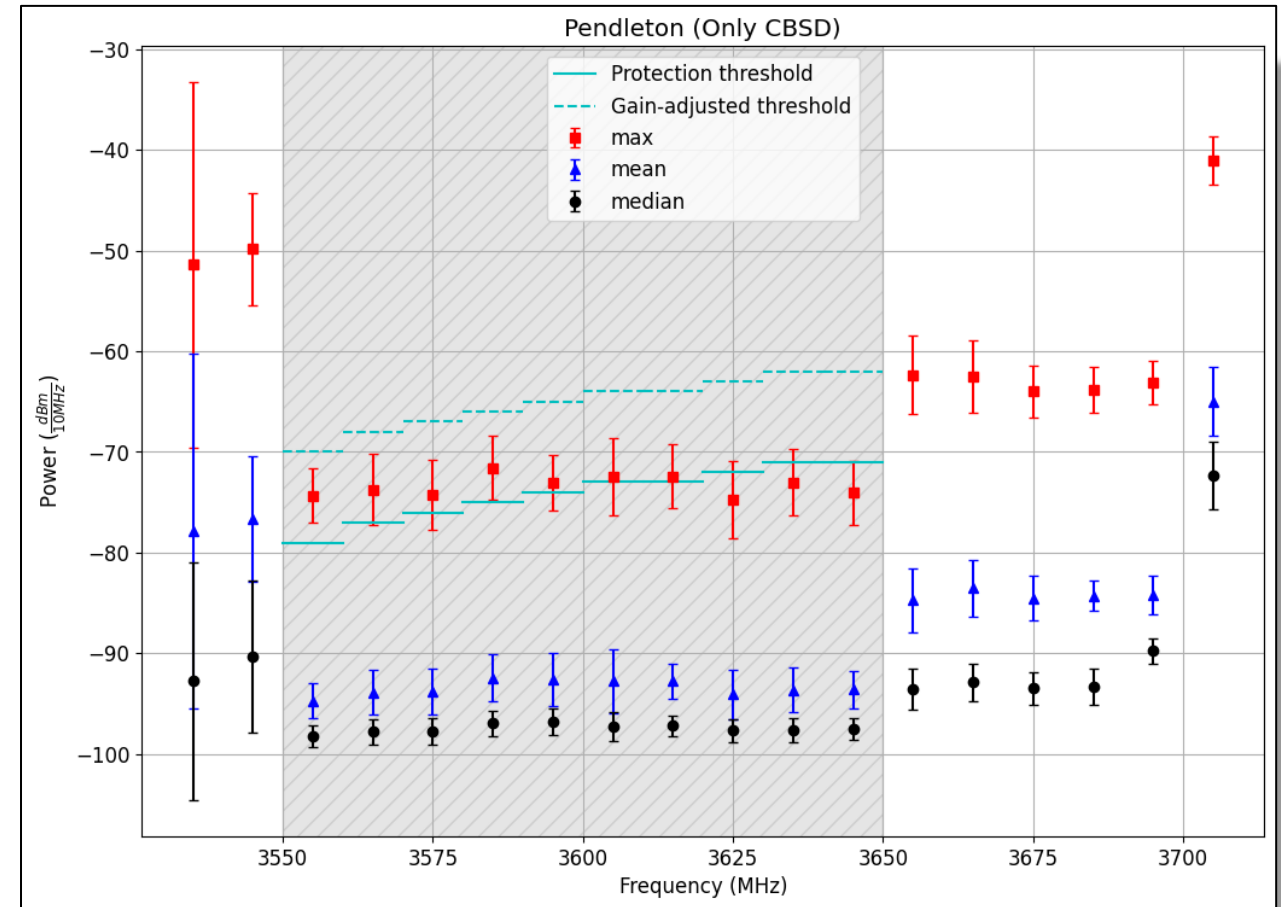


FINDINGS: Modeled-to-measured relationships vary by site and channel

- CBRS 1.0: Predictions trend to near or above maximum measured PSD levels
- CBRS 2.0: Lower than CBRS 1.0; typically, between the measured mean and the 99.99th percentile PSD traces

USMC Camp Pendleton - Always On GB-DPA

- Compare measured CBSD power statistics with channel-specific protection thresholds in 3550 -3650 MHz
- Adjust protection thresholds by 9 dB to account for the gain difference between the SEA sensor and reference antennas
- **Measured maximum CBSD power remained below the gain-adjusted protection threshold across all evaluated channels**



Modeling Insights & Opportunities

TECHNICAL UNCERTAINTIES & MODELING ASSUMPTIONS

- CBSD deployment and operational data
 - FAD temporal snapshot vs. real-time dynamics
 - Database EIRP vs. actual transmit power
- Propagation and clutter model approximations
- Fixed duty cycle and network loading assumptions
- Reference vs. operational algorithmic implementations
- Aggregate emission uncertainties

OPPORTUNITIES

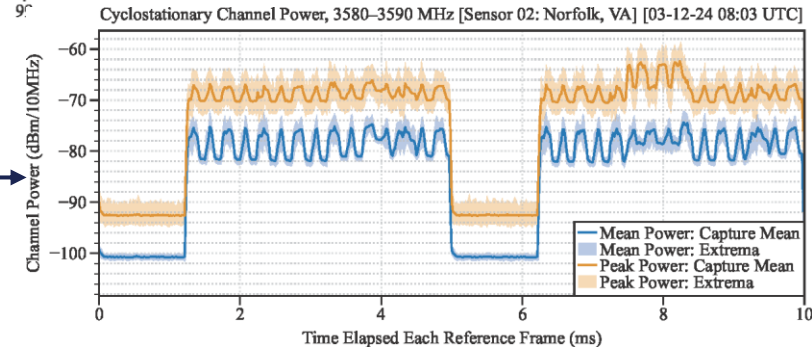
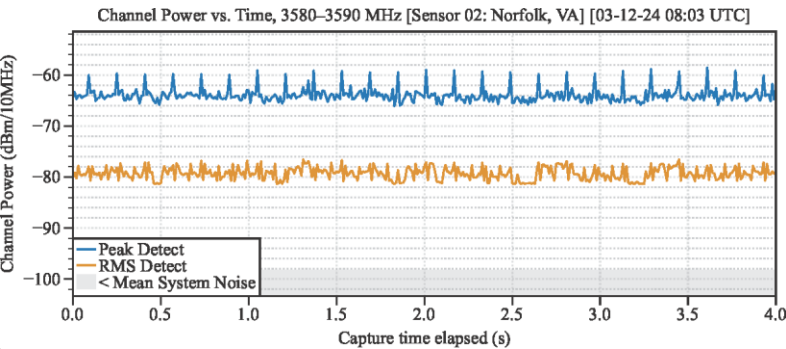
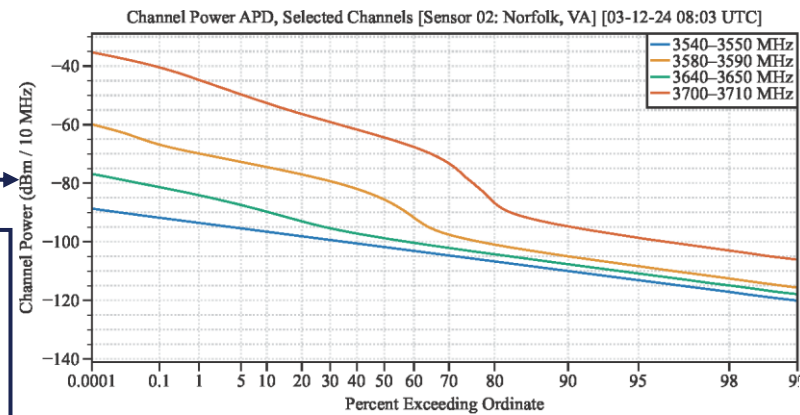
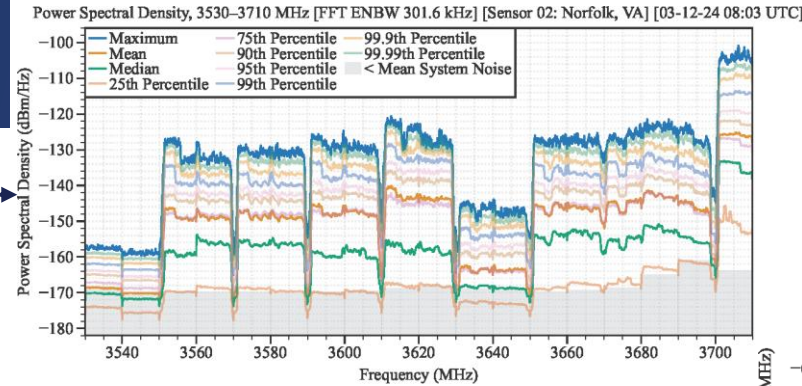
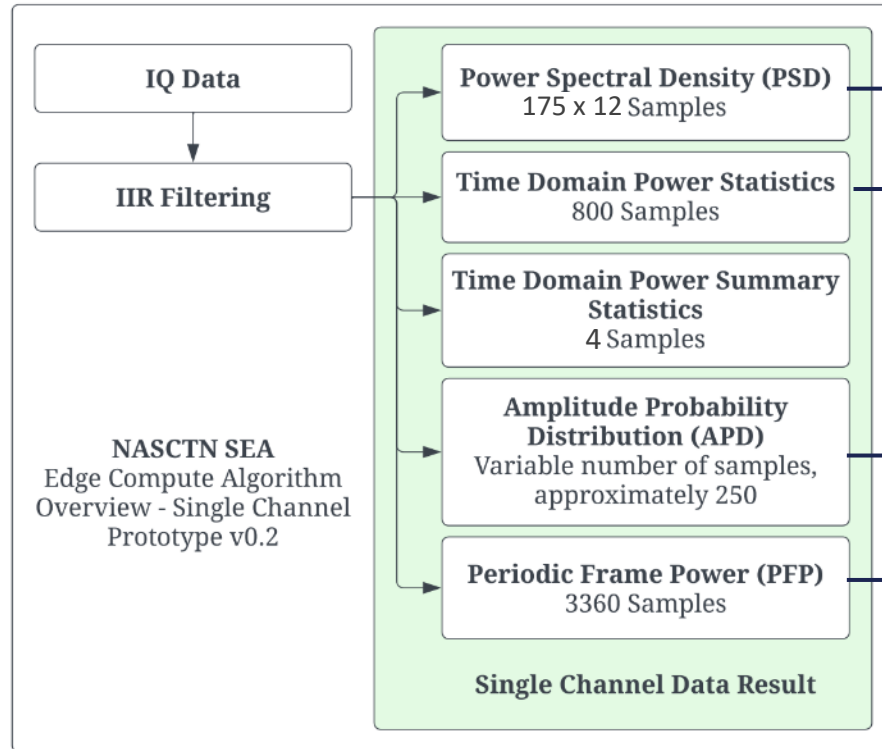
- Evaluate additional dates and longer periods
- Verify and supplement FAD parameters with actual CBSD operating information
- Refine aggregate emission modeling to capture spatial, temporal, and spectral behavior across heterogeneous deployments
- Further evaluate antenna, propagation, clutter, duty cycle, and network loading assumptions

Modeling + measurement together provide the strongest basis for understanding and improving dynamic spectrum sharing.

Longitudinal Data Analyses

Todd Schumann, PhD

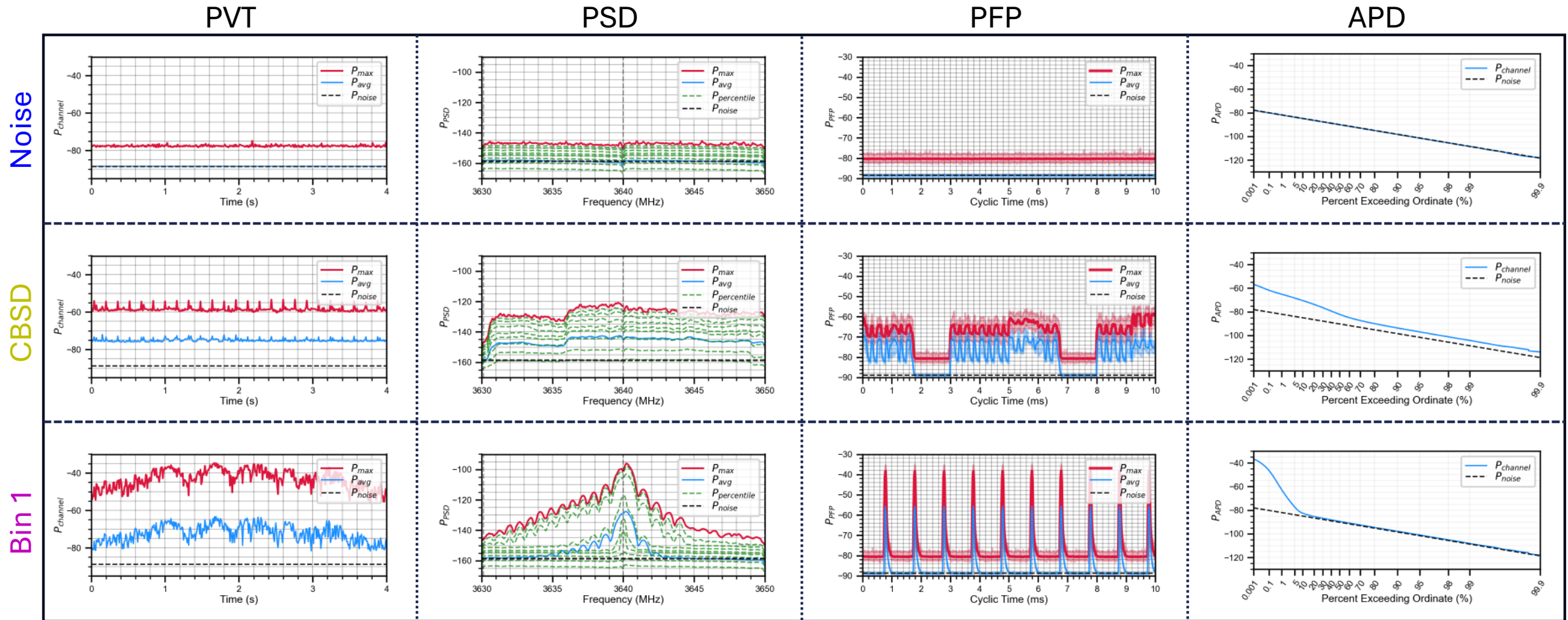
Edge Data Products



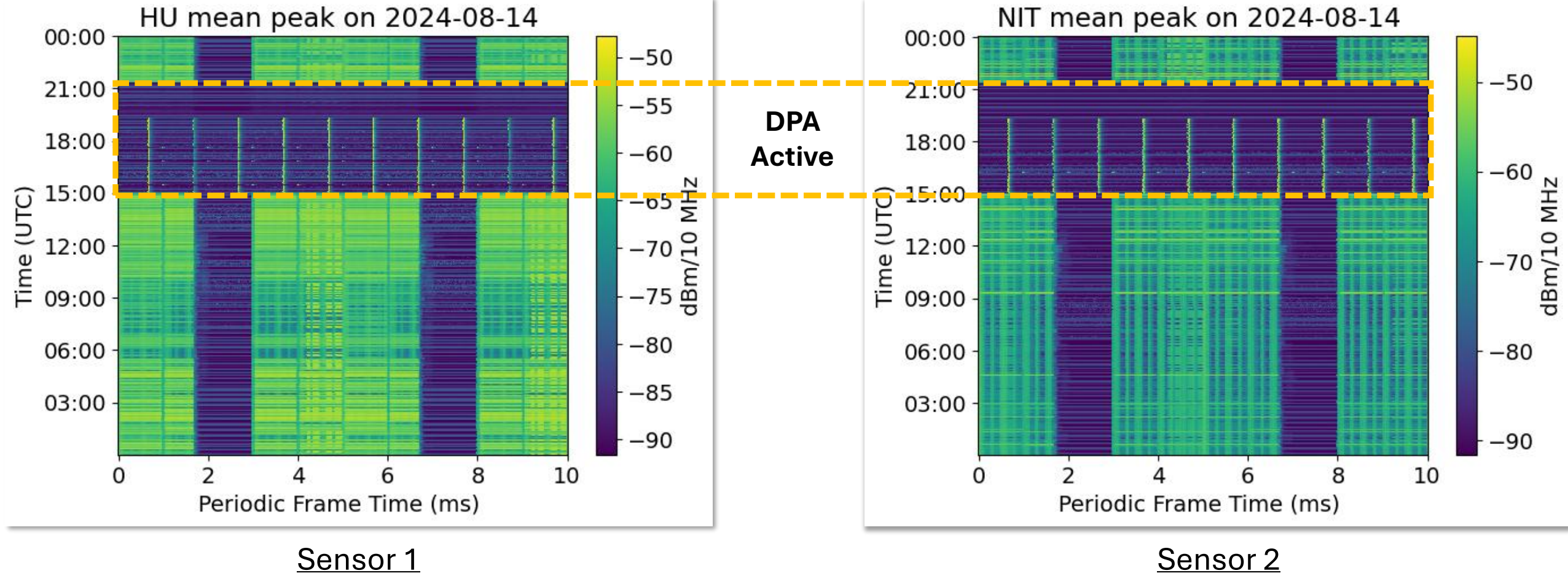
MEASUREMENT

3530 MHz – 3710 MHz measured in 10 MHz channels with 4-second dwell times

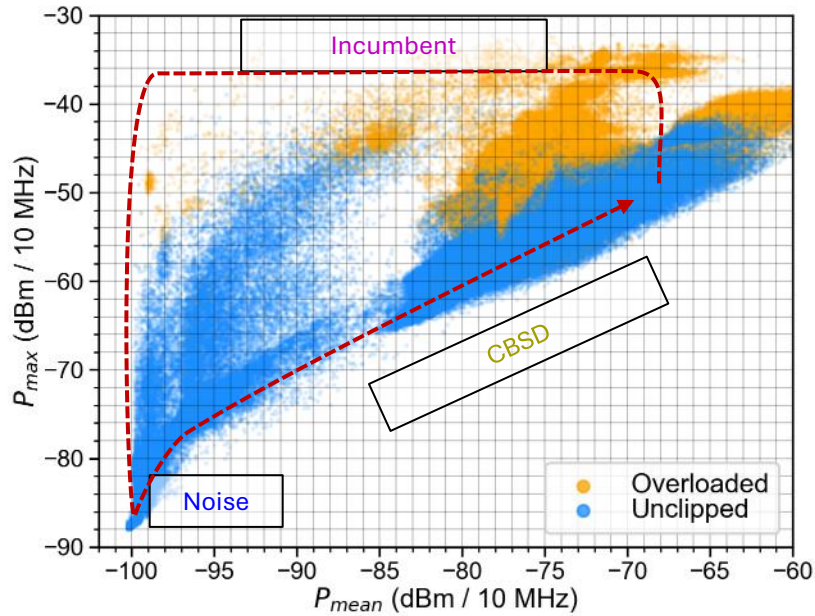
Signal Signatures Through the Data Products



DPA Activation



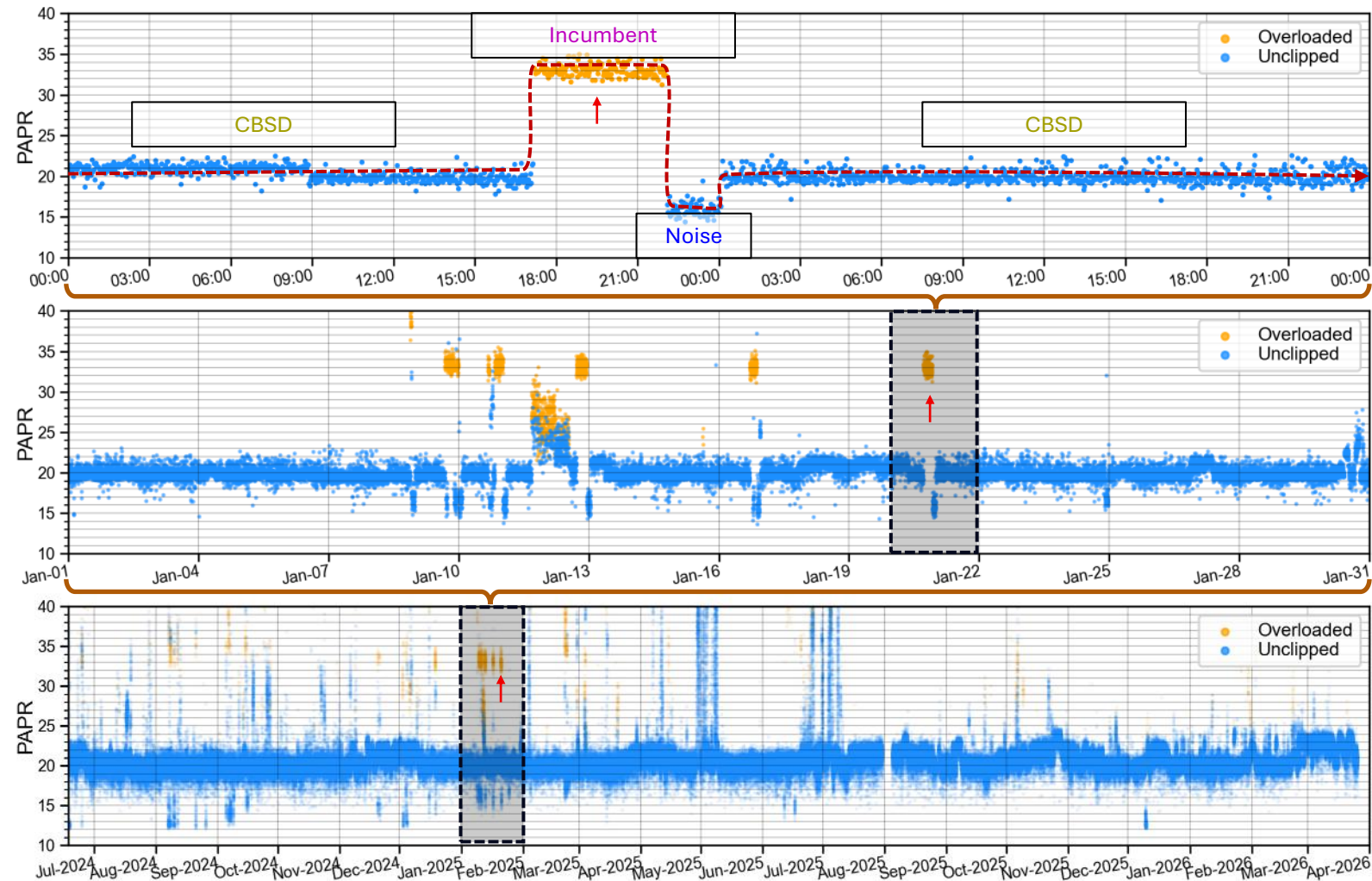
PAPR Analysis of Probable Vacate Events



Peak-to-Average Power Ratio (PAPR)

Signal	Peak Power	Average Power	PAPR
CBSD	Medium	Medium	Medium
Incumbent	High	Low	High
System Noise	Low	Low	Low

PAPR can be used as a coarse signal identifier to track probable vacate events



Classifiers of Appropriate Resolution

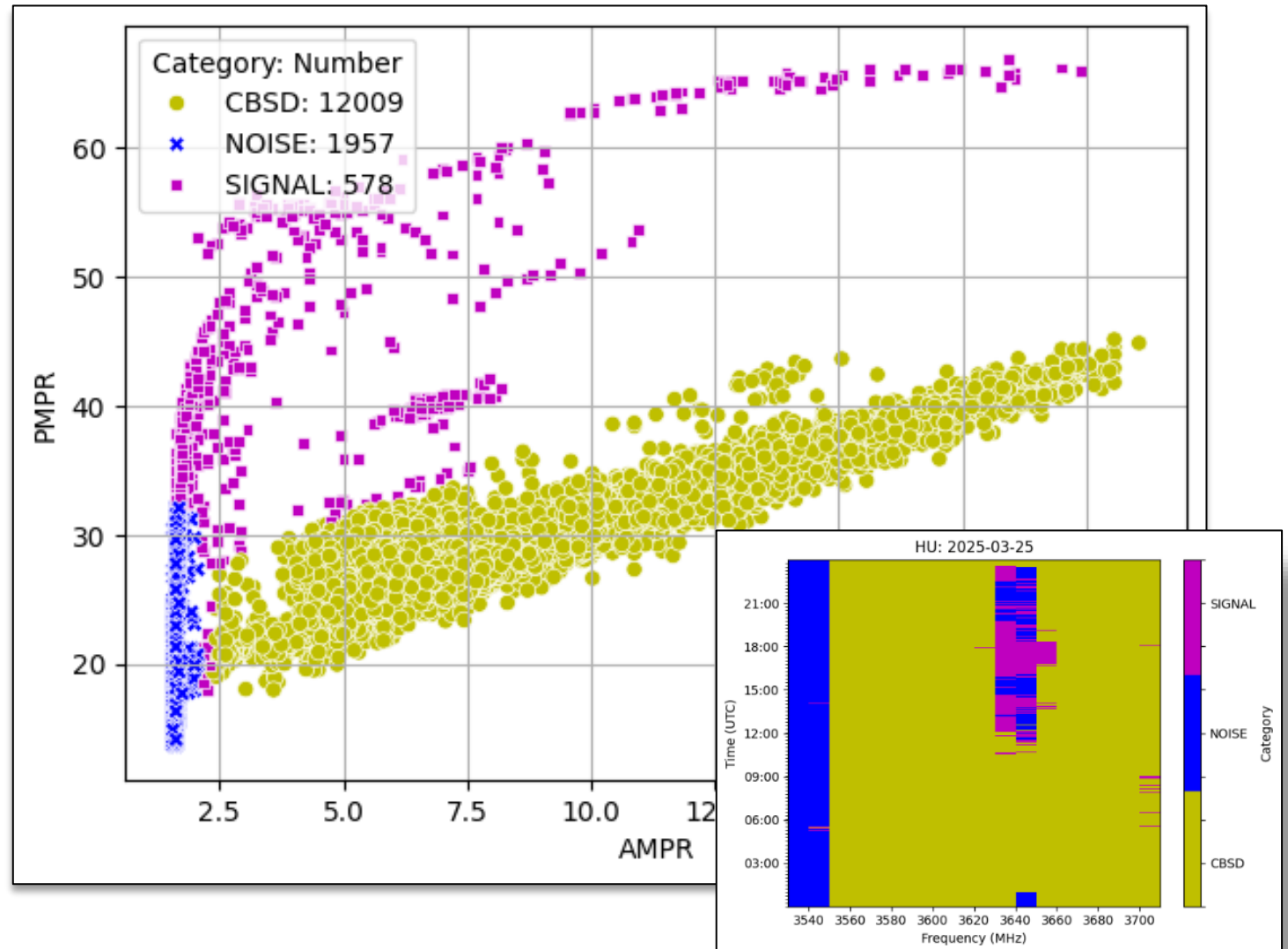
CREATION OF HIGH VALUE DATA STREAMS

Use of metrics that inform ecosystem behaviors

- Peak-to-median power ratio (PMPR)
- Average-to-median power ratio (AMPR)

REQUIREMENT

Protect proprietary and sensitive information

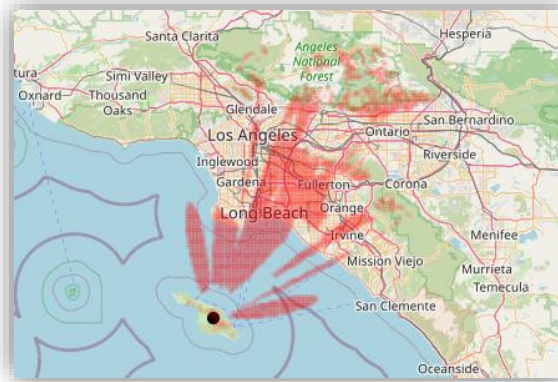


Longitudinal Analyses

CBRS ECOSYSTEM

Operates to respond to incumbent signals and vacates accordingly.

Labeled datasets give insights into the accumulated emission types



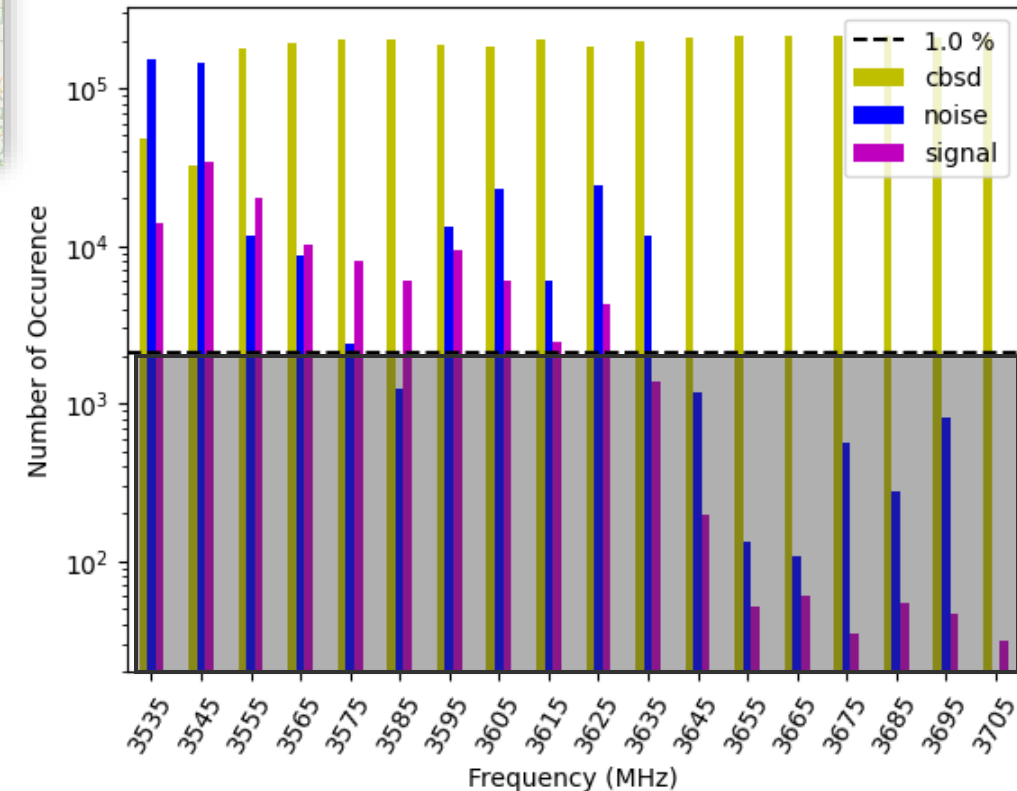
1.0 % THRESHOLD EXAMPLE

- Serves as reasonable estimate of classifier uncertainty on the entirety of the dataset
- Guides the percentage of dominant sources of emissions

CBRS CHANNELS

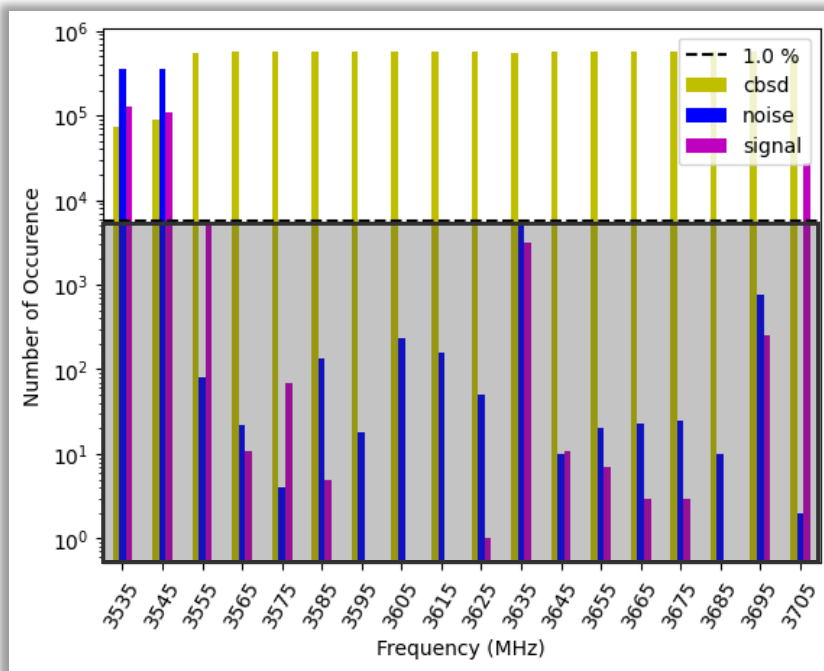
Mixture of signals in CBRS by lower 100 MHz and upper 50 MHz is consistent with CBRS sharing ecosystem dynamics

560 sensor-days of Catalina-Directional

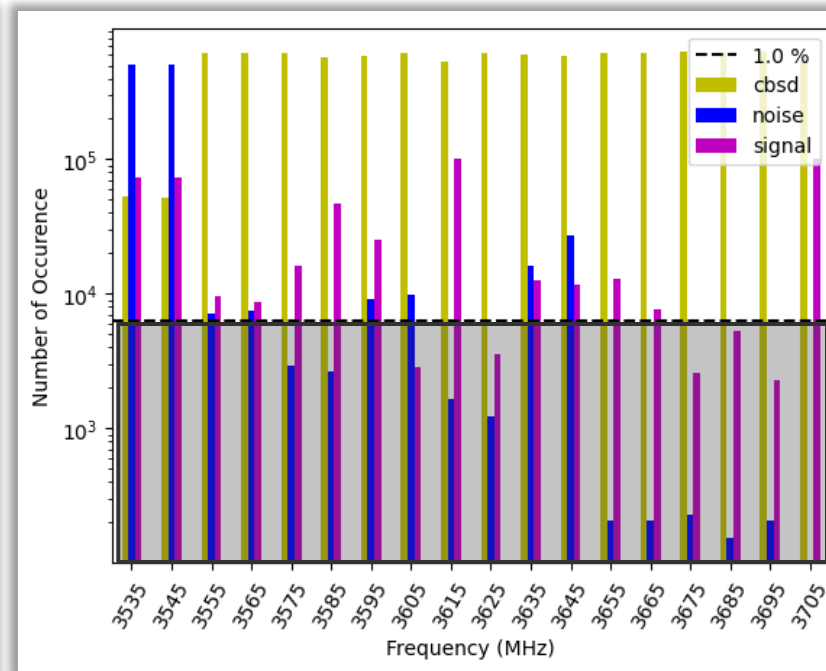


Longitudinal Analyses by Region

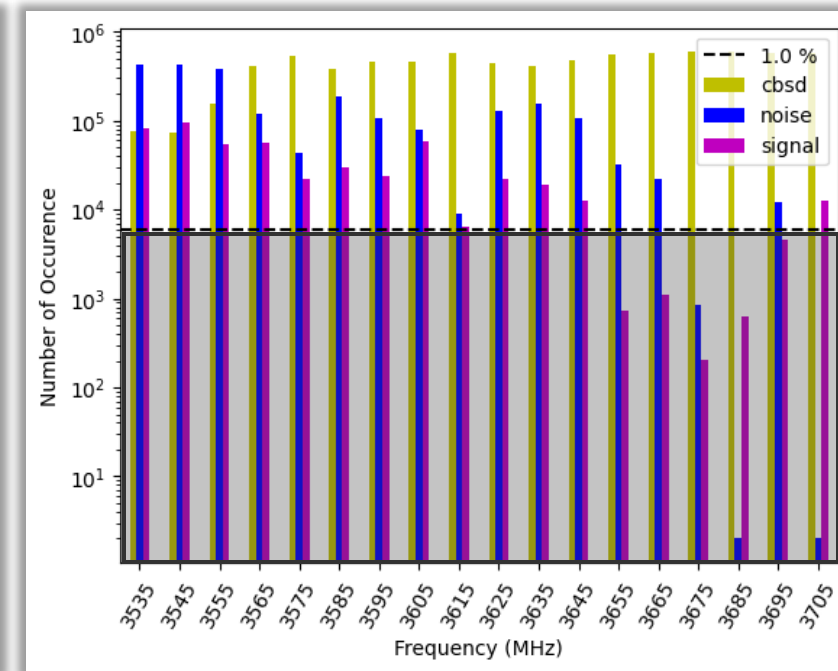
Control (GMM)
595 sensor days



East Coast (HU)
604 sensor days

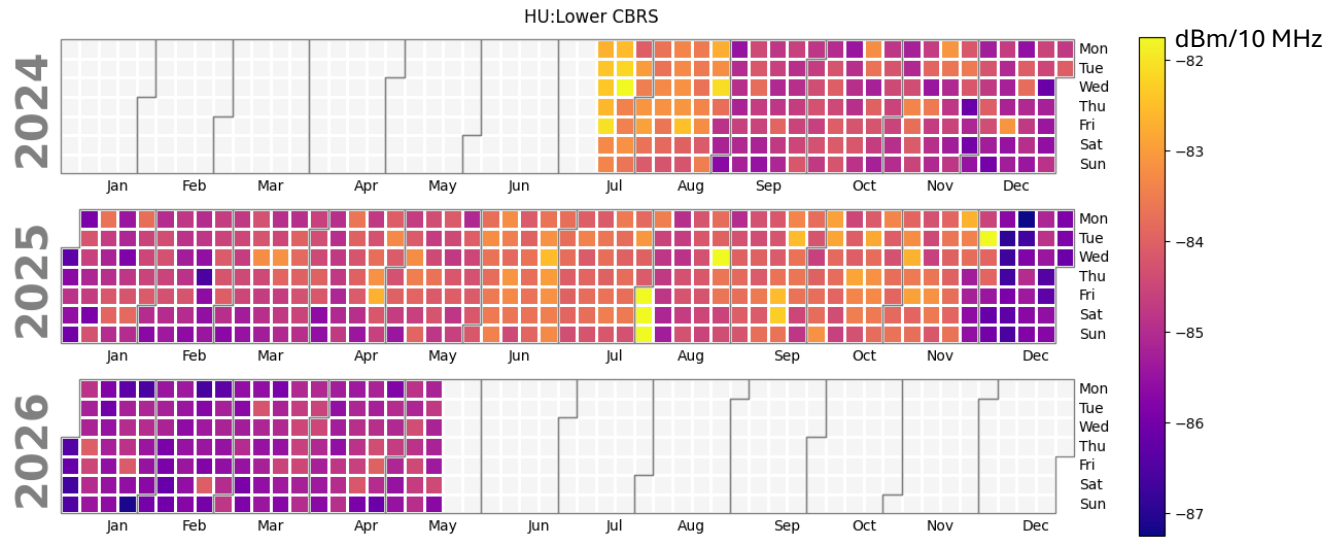


West Coast (Midway)
607 sensor days



Control sensor establishes the 1% threshold

Power History of CBRS



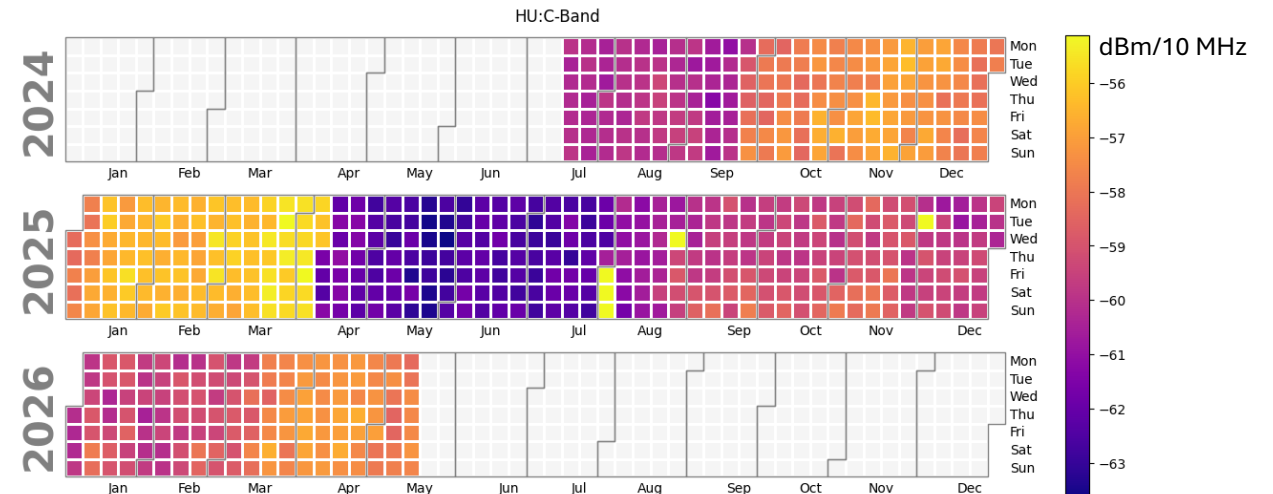
POWER HISTORY IN THE CBRS ECOSYSTEM

Gives insights into Power trends

Data is derived from mean power of CBSD labeled data for a given day across 100 MHz in lower CBRS and 50 MHz in upper CBRS

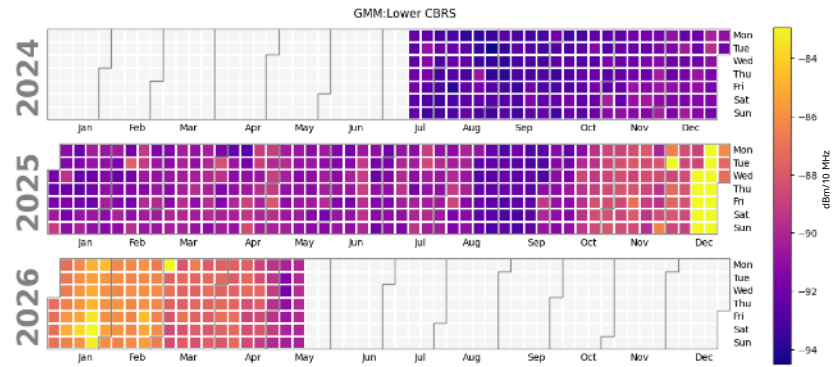
COMPARISON ACROSS BANDS

Serves as juxtaposition to portions of 3.45 Band and C-Band

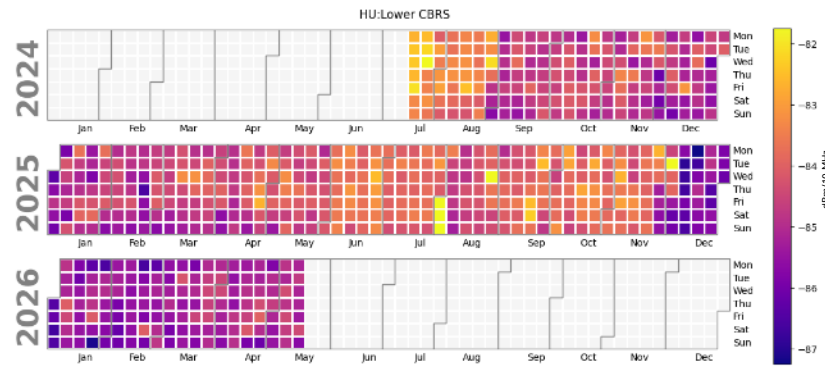


Power History of CBRS by Region

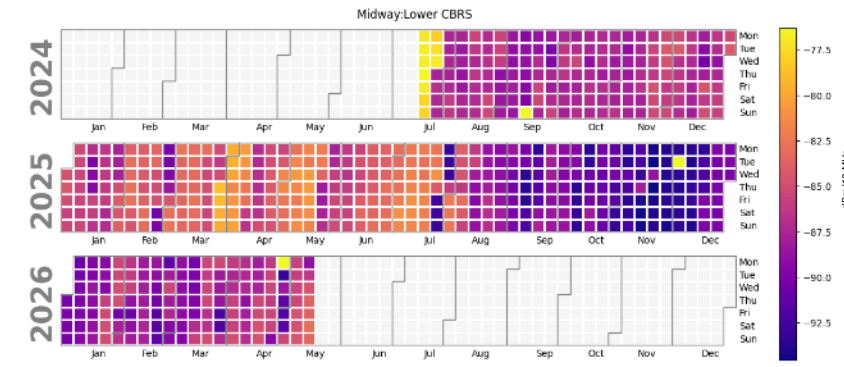
Control (GMM)



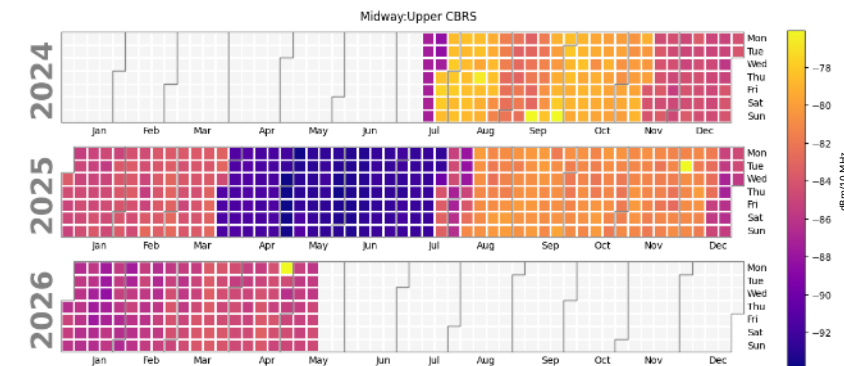
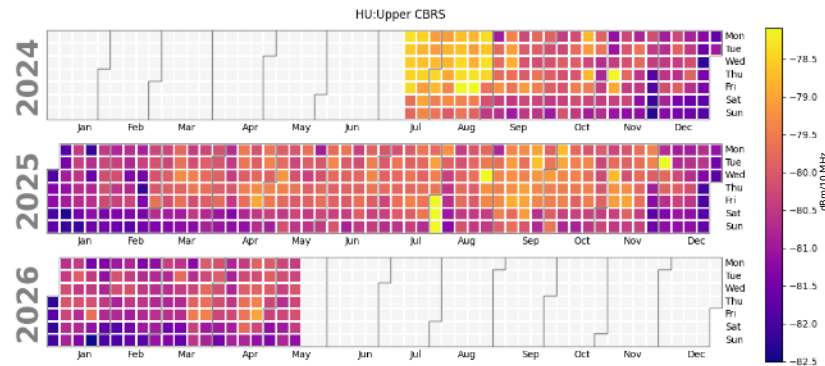
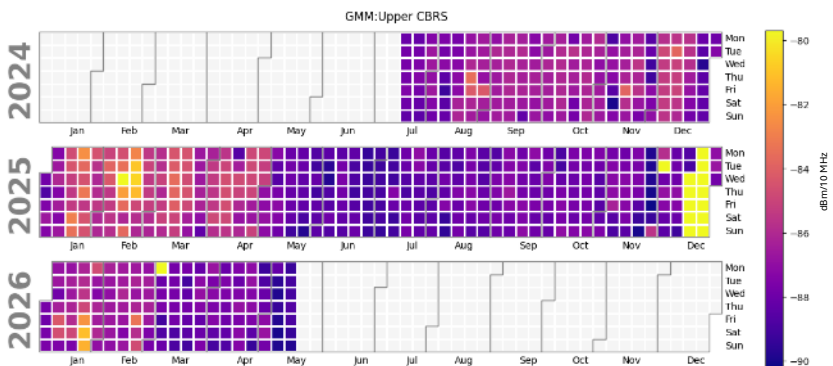
East Coast (HU)



West Coast (Midway)



Shared CBRS (3550-3650 MHz)

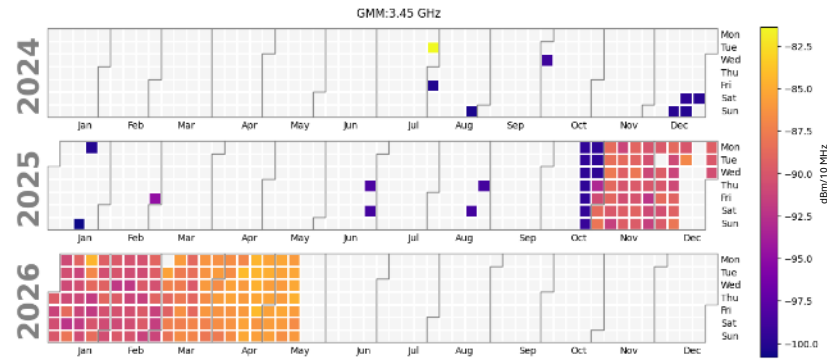


Upper CBRS (3650-3700 MHz)

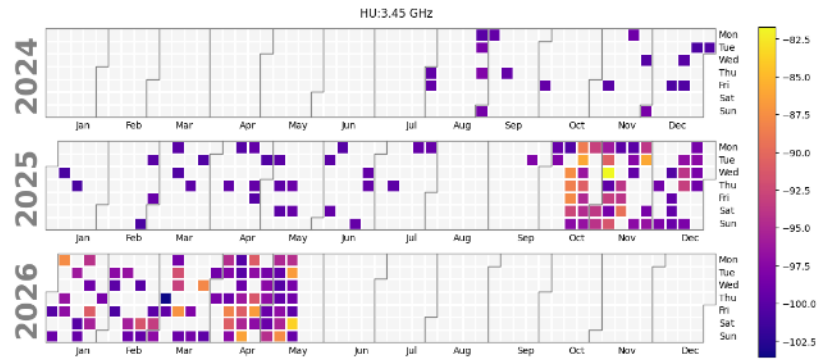
Adjacent Band Insights by Region

partial 3.45 GHz and partial C-Band

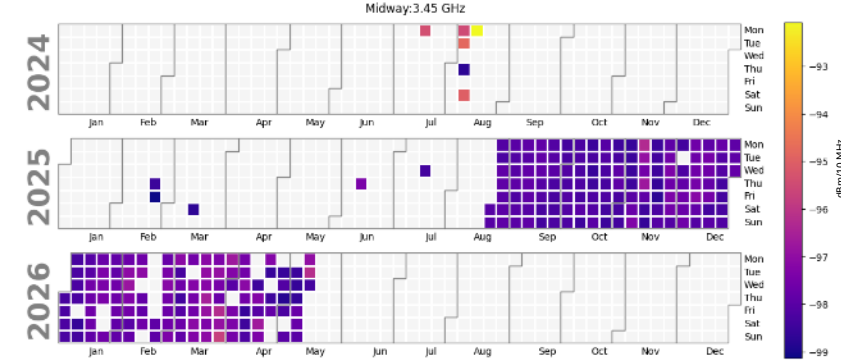
Control (GMM)



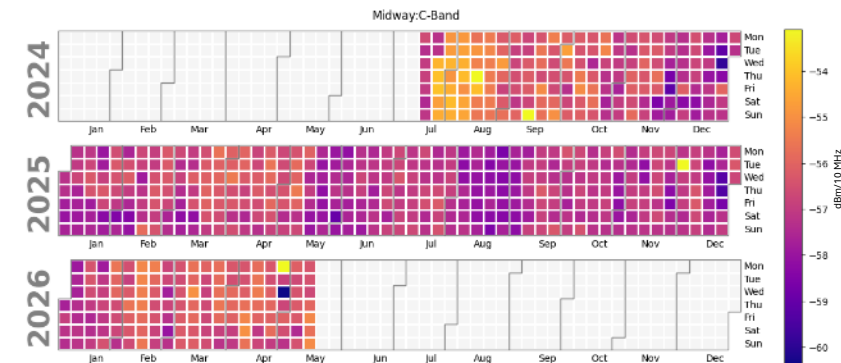
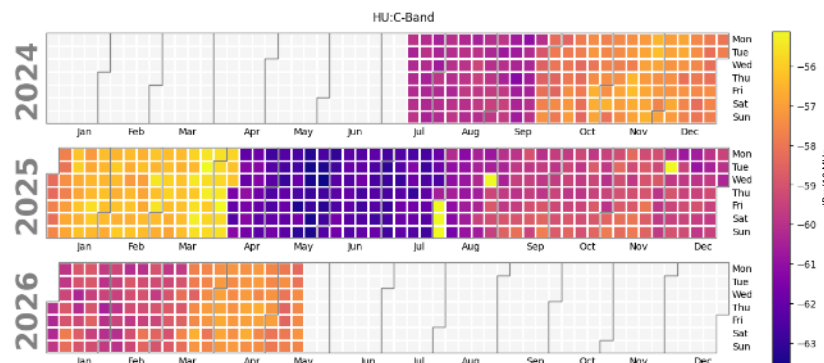
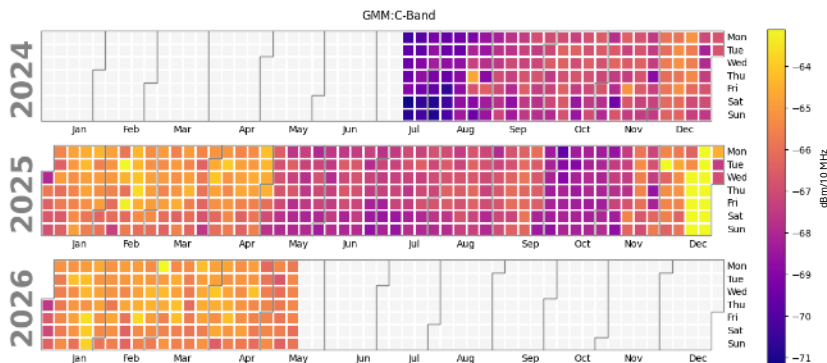
East Coast (HU)



West Coast (Midway)



3.45 GHz (3530-3550 MHz)



C-Band (3700-3710 MHz)

Forensic Analyses

Todd Schumann, PhD

Motivation for Additional Forensic Analyses

Utility of Forensic Analyses

- Study behaviors
 - Technology specific, ecosystem rules, etc.
- Investigate specific technologies
 - E.g. analysis of communication technologies such as cellular and WiFi is different
- Inform future spectrum sharing scenarios
 - Exploration of rules and IPCs based on measured properties
- Validate assumptions
 - Translation of power-based metrics can be coupled with forensic analyses to other scenarios

Amplitude Probability Distribution (APD)

- **Arbitrary Technology**: Operates on channels as a whole without a specific technology
- **Channel Based**: Statistical view of the entire CBRS channel

View from receiver perspective

Periodic Frame Power (PFP)

- **Specific Technology**: Operates on the properties of the cellular technology
- **Cellular frame**: Statistical view specifically of the cellular frame

View from transmitter perspective

With the dataset containing these data in all captures, the forensic analyses can also be performed longitudinally

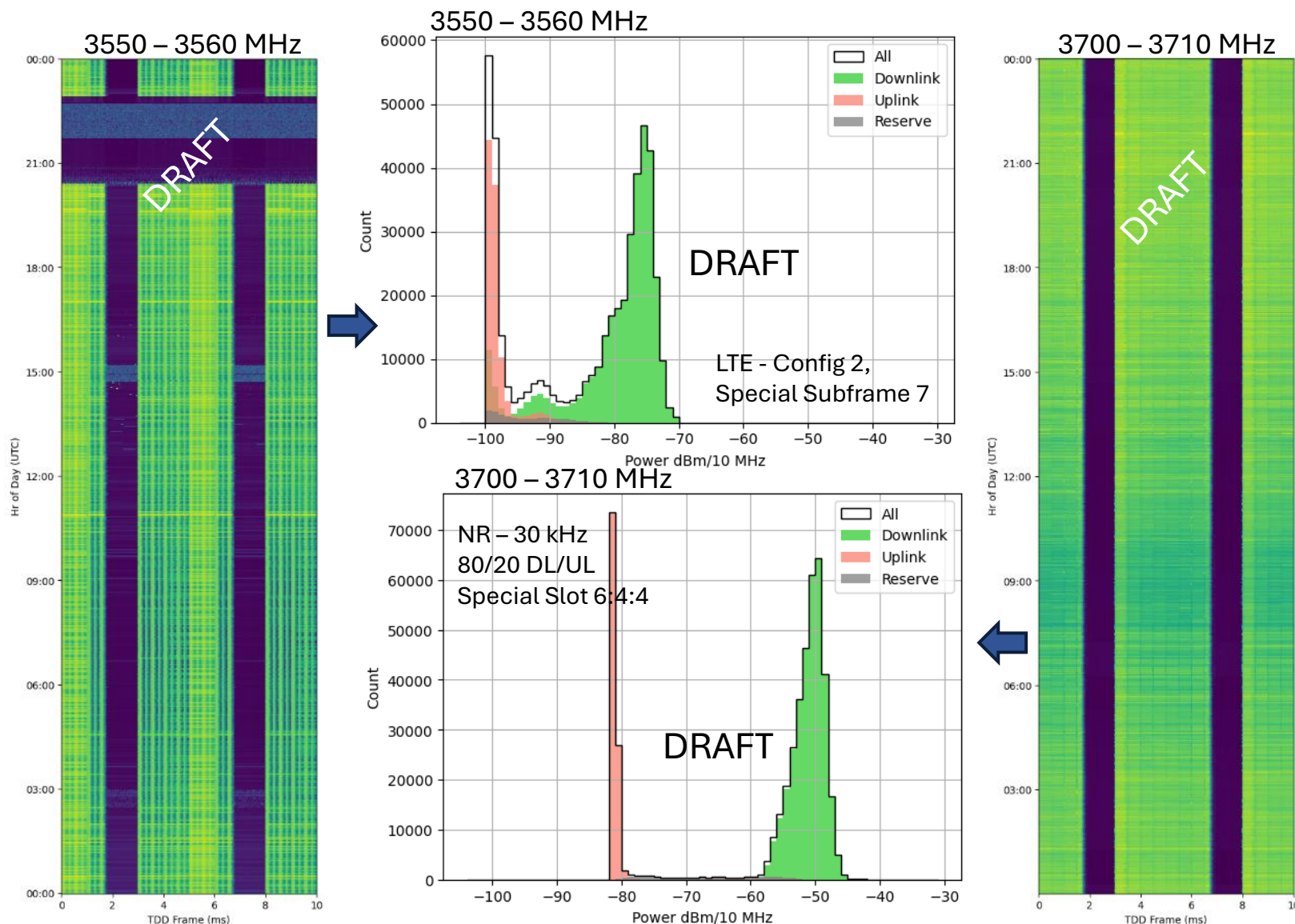
PFP Downlink and Uplink Discrimination

ALIGNED PERIODIC FRAME POWER

Post processing of cellular frame data allows for identifying the DL/UL portions in 4G and 5G and perform conditional longitudinal studies

CONDITIONAL STUDY

Improves understanding of underlying distributions and assumptions of aggregation



Change Points Within the Cellular Resource Grid

Chose PFP Statistic and Detector

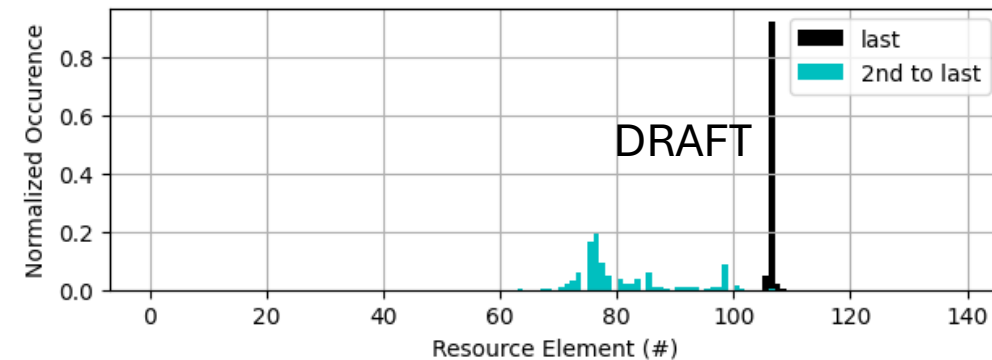
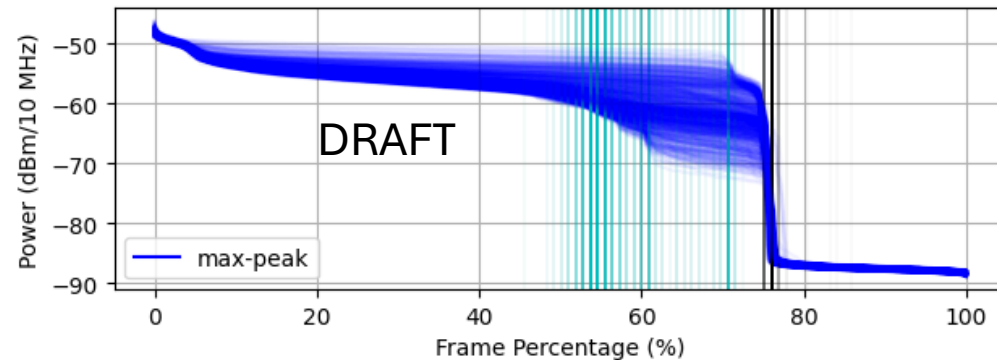
Sort Descending

Detect Change Points

Histogram Change Points

Sorted PFP

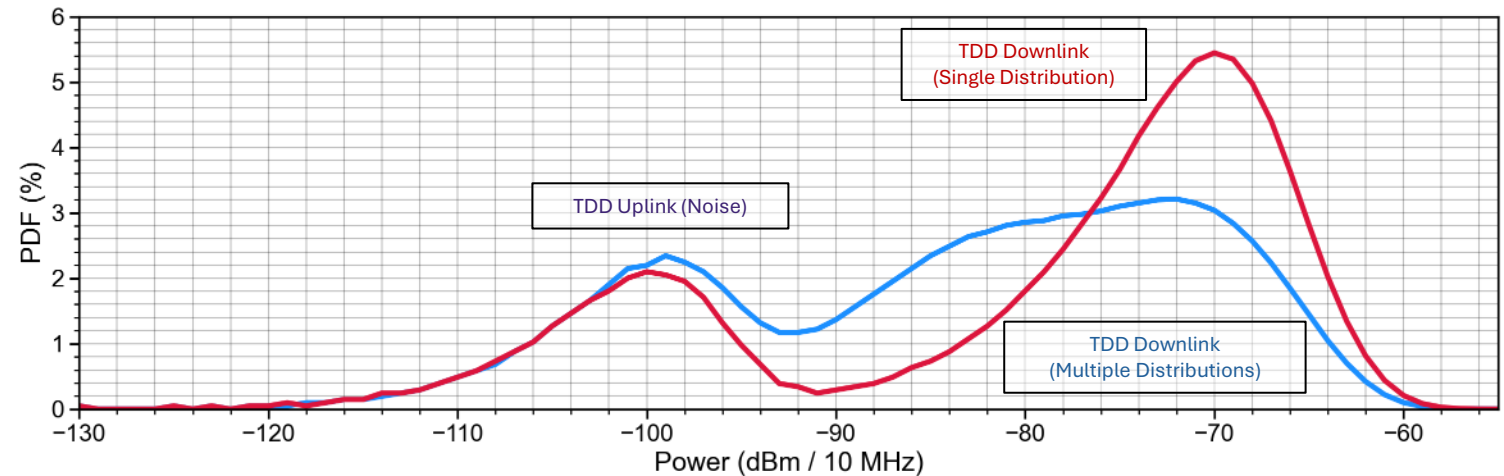
- **Choose Statistic and Detector:** Choice of max/mean/min and peak/RMS based on application
- **Sort Descending:** Create a complimentary cumulative distribution function (CCDF) to map detector power to the percentage of the frame (blue)
- **Detect Change Points:** Mark points of high slope change indicating a spread in utilized resources
- **Histogram Change Points:** Create histogram of the change points to map the PFPs to frame utilization



Channel Statistics with the APD

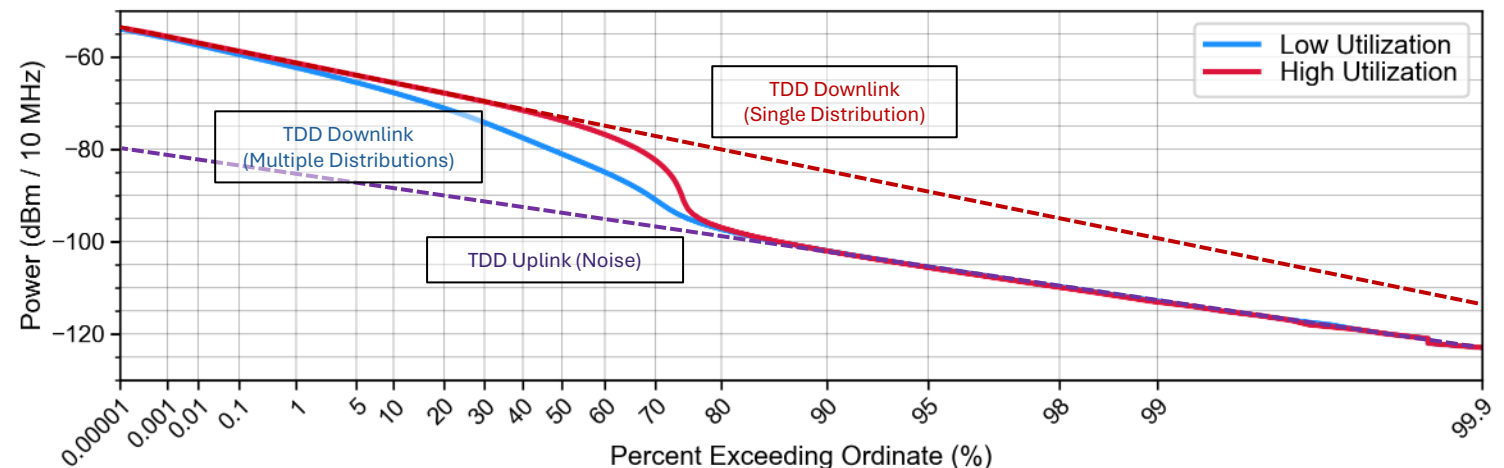
Probability Density Function (PDF)

- **Signal Statistics:** Probability of a given power level
- **Noise:** The TDD structure and little uplink give a noise distribution
- **Low Utilization (blue):** Channel power within the downlink is split into multiple distributions
- **High Utilization (red):** Channel power within the downlink transitions to a single distribution

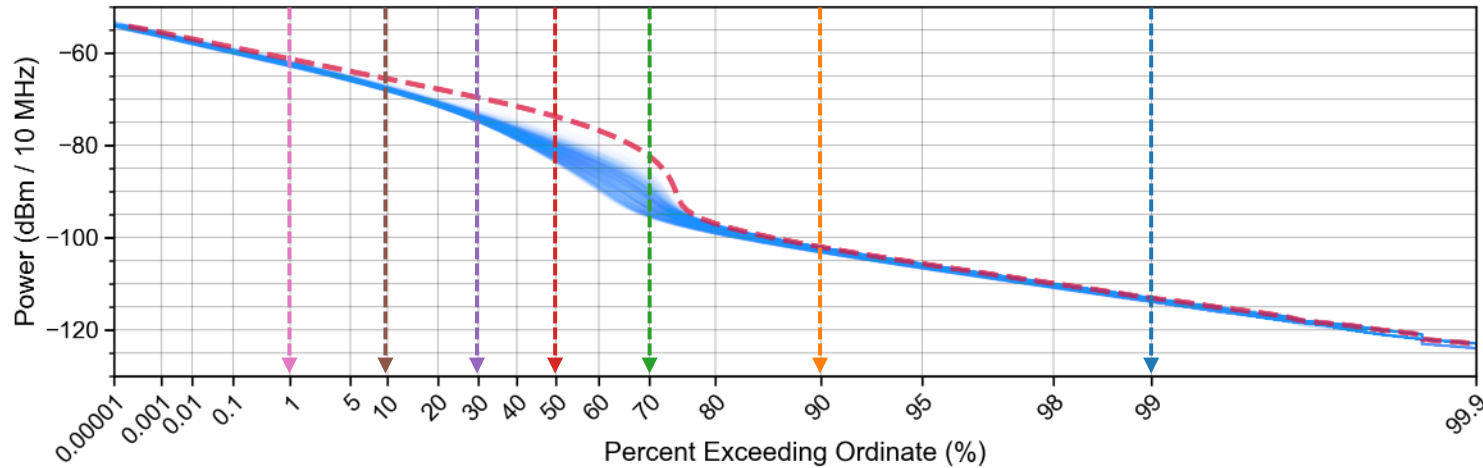


Amplitude Probability Distribution (APD)

- **Rayleigh Axes:** Scales the x-axis such that underlying Gaussian trends are linear (e.g. noise)
- **Noise:** The noise from the uplink follows the linear trend with unity slope
- **Low Utilization (blue):** With multiple distributions, the downlink does not follow a linear trend
- **High Utilization (red):** As the channel utilization increases, the downlink approaches Gaussian

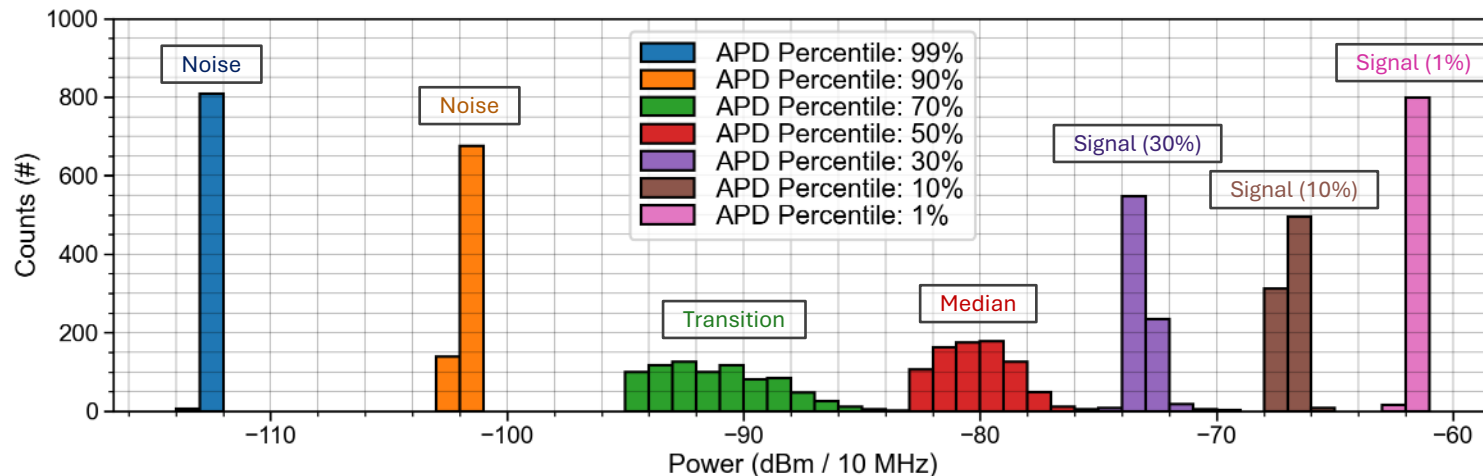


APD Percentiles



Longitudinal APD Analysis

- **Longitudinal APDs:** APDs of channels can be aggregated together for analysis
- **Resource Utilization:** In comparison to the capture with high utilization (red), the bowing inwards indicates lower utilization (blue)
- **Tracking Utilization:** The channel utilization can be tracked throughout the day (or longer)

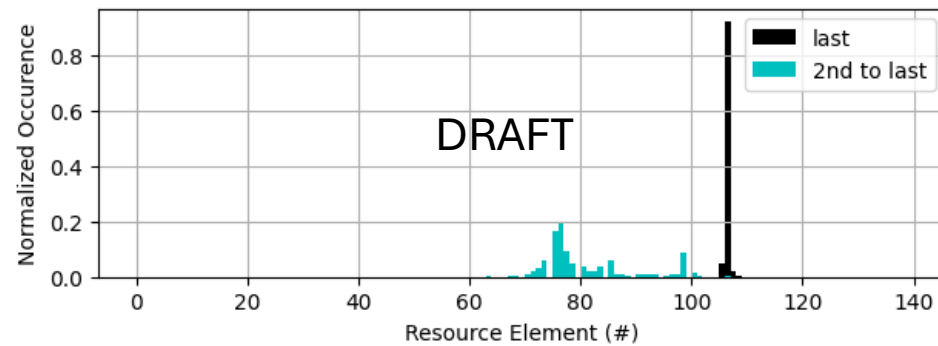
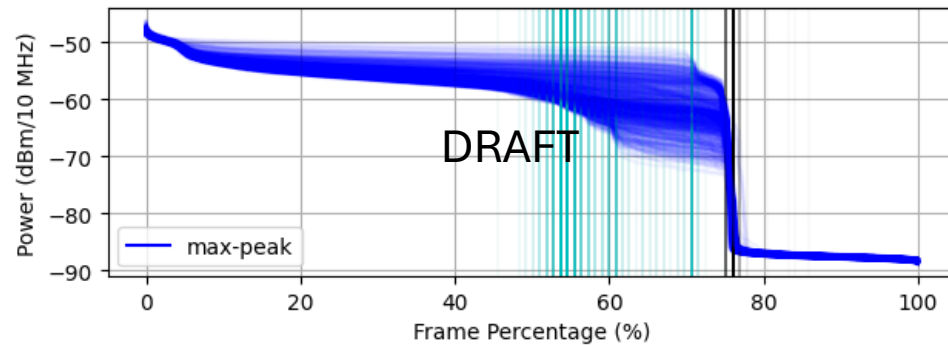


APD Percentiles

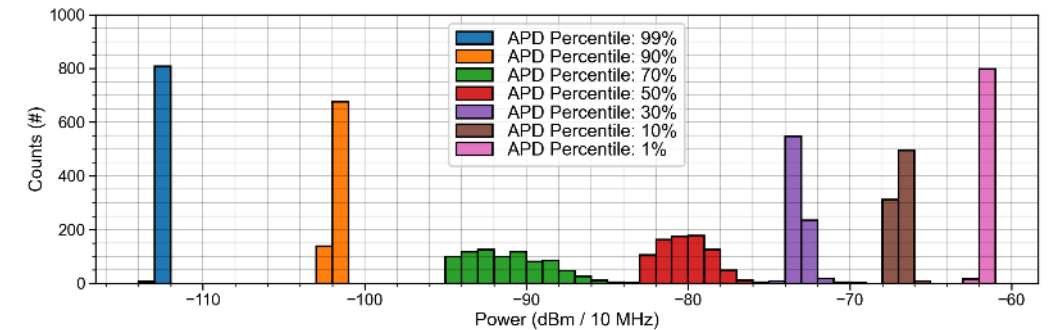
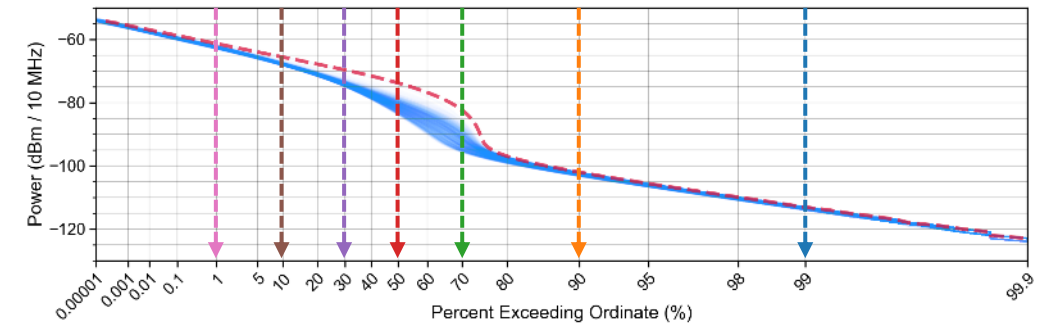
- **APD Percentile Limits:** Vertical cross sections of the APDs can be taken at relevant protection thresholds
- **Percentile Histograms:** Indicates the probability that a channel will have a power at a percentile
- **Interference Protection Criteria (IPC):** Measure variation of the protection thresholds across time

Complimentary Analyses

Resource Utilization Statistics (PFP)



Channel Power Statistics (APD)



CBSD Power Model



Close Out

Recap

Validated sensor network longitudinally with high reliability

- Key regions: Norfolk VA (DPA: East-1), San Diego CA (DPAs: West-13 & West-14), USMC Camp Pendleton (Always On DPA)

Publicly available longitudinal spectrum dataset

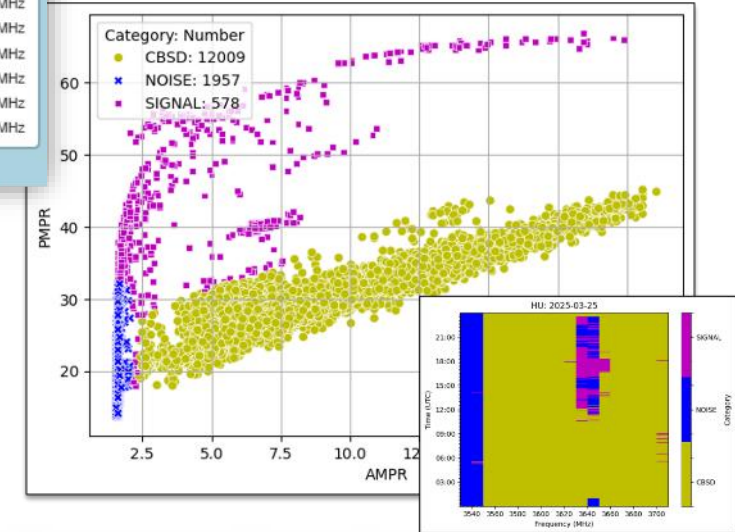
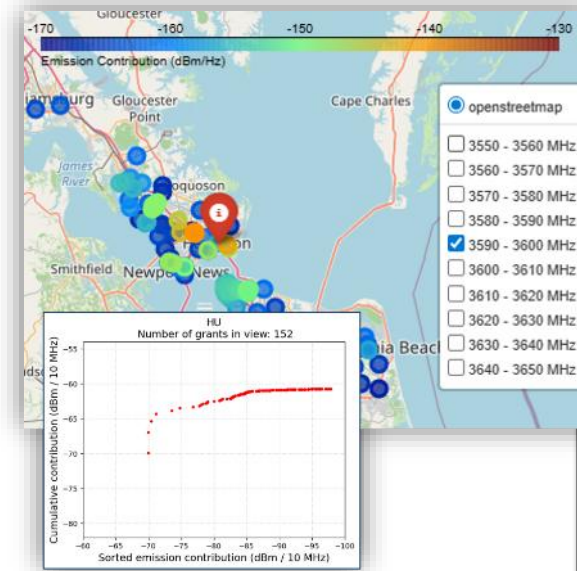
- Novel edge computed data products
- Calibrated, traceable power metrics
- Applied classifier to allow for conditional analyses
- Standardized to SigMF

In-depth modeling

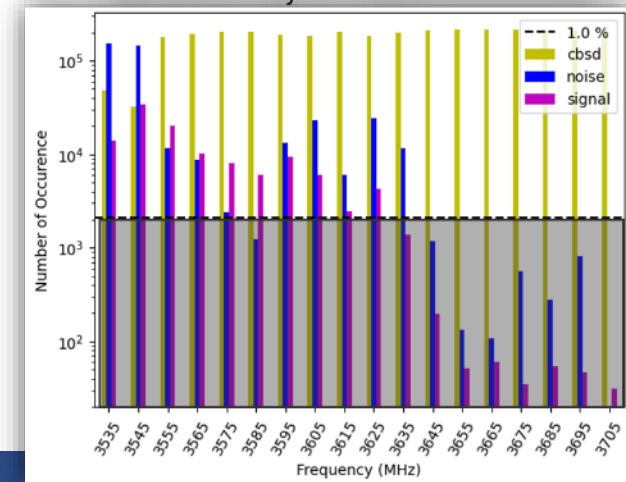
- Comparison of predicted aggregate emissions using census sourced, obfuscated, and real cellular laydowns
- Implemented WInnForum Reference models (CBRS 1.0 & 2.0)
- Connected modeling with measurements
- Extended reference models for modelling informed sensor fielding

Analytics of cellular emissions

- Longitudinal ecosystem insights
- Instantaneous analysis of cellular
- Measurement approaches to testing of assumptions in cellular emissions



560 sensor-days of Catalina-Directional



Call to Action

- Stakeholders
 - Cross comparisons with internal information
 - Test assumptions of cellular emissions against validated data
- Academia
 - Reference data set and training data sets
 - Investigate ML / AI tools
 - Dynamic spectrum sharing algorithm training
- Make use of our code repositories to ease accessibility
- Find us at MILCOM 2026, URSI 2027

Thank You

