LAHA: A FRAMEWORK FOR ADAPTIVE OPTIMIZATION OF DISTRIBUTED SENSOR FRAMEWORKS

A PH.D. DISSERTATION DEFENSE

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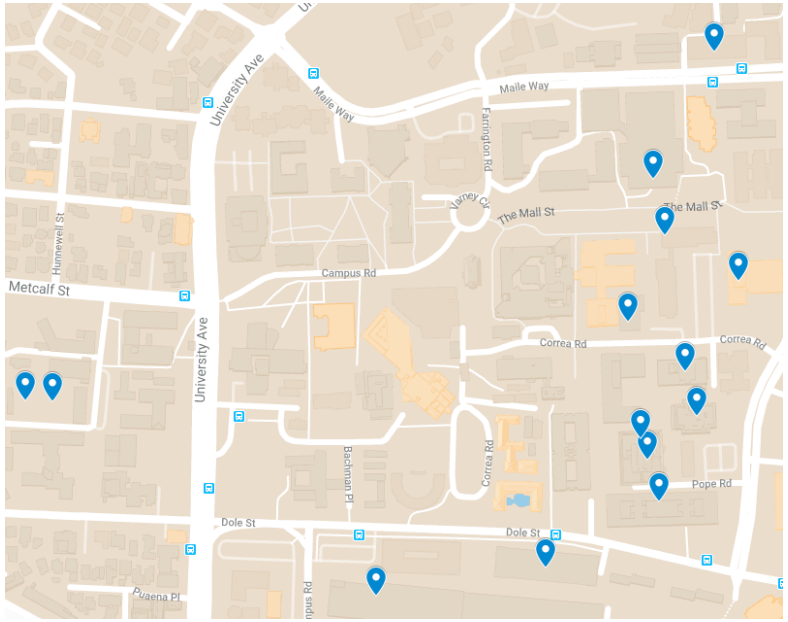
24 FEBRUARY 2020

DSNS AND DSN MANAGEMENT: THE BIG PICTURE

DISTRIBUTED SENSOR NETWORKS

- OpenPowerQuality
  - 12 kHz @ 2 bytes/sample
  - 2.1 GB/day/sensor
  - 31 GB/day/15 sensors
  - 2.1 TB/day/1000 sensors
  - **766 TB/year/1000 sensors**
- Lokahi
  - 8 kHz @ 4 bytes/sample
  - 2.7 GB/day/sensor
  - 276 GB/day/100 sensors
  - 2.7 TB/day/1000 sensors
  - **1 PB/year/1000 sensors**
- Storage Fees
  - UHM ITS: $800/TB/year
  - AWS: $240/TB/year

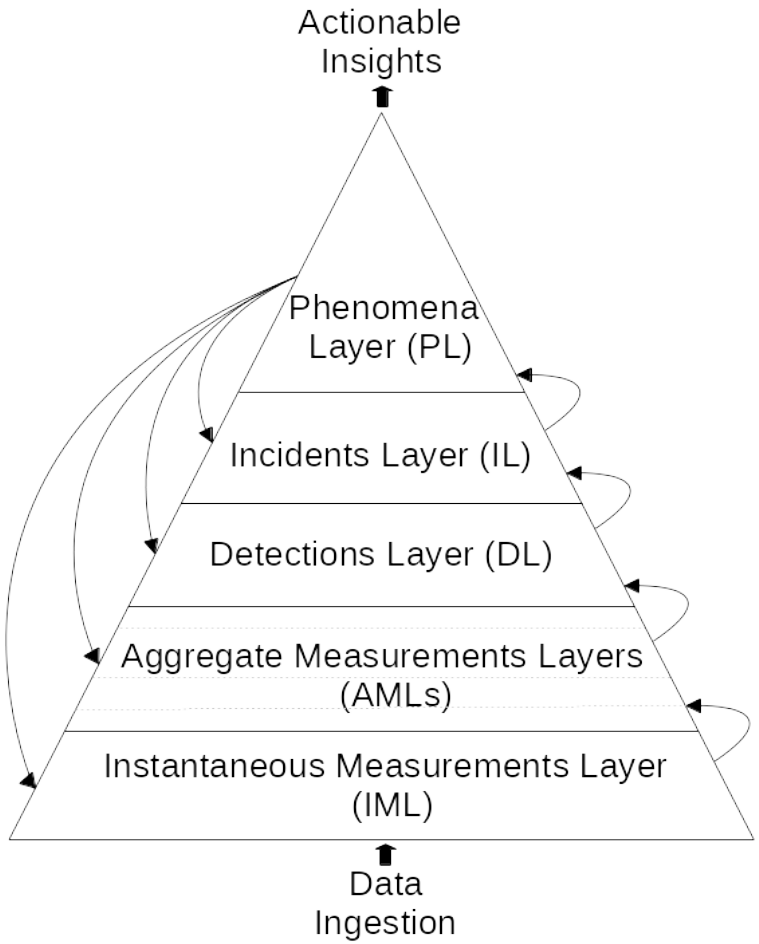


OpenPowerQuality Network

Lokahi Distributed Infrasound Network

MAJOR CLAIMS OF THE LAHA FRAMEWORK

- Laha is a general and useful framework within multiple DSN domains.
- Laha can convert primitive sensor data into actionable insights.
- Laha provides management of “Big Sensor Data” utilizing TTL with minimal system degradation.
- Laha is capable of enabling self-optimizing DSNs.

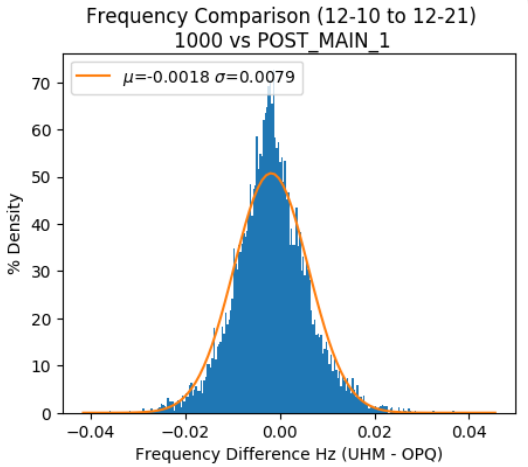


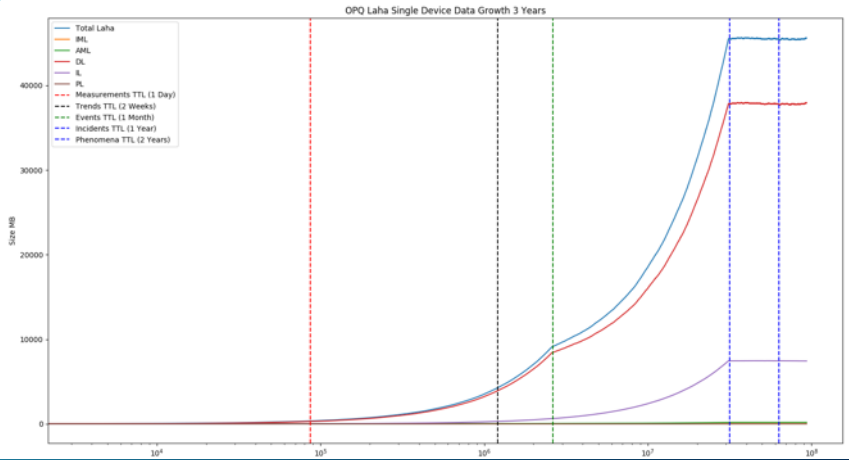
CONTRIBUTION #1: LAHA DESIGN

- Novel abstract distributed sensor framework
  - Converting primitive data into actionable insights
  - Sensor data management
  - Self-optimization capabilities

CONTRIBUTION #2: LAHA EVALUATION

- Deployment of two Laha-compatible DSNs
- Validated data collection
- Upper bounds on data storage requirements
- Several experiments that test Laha's major claims





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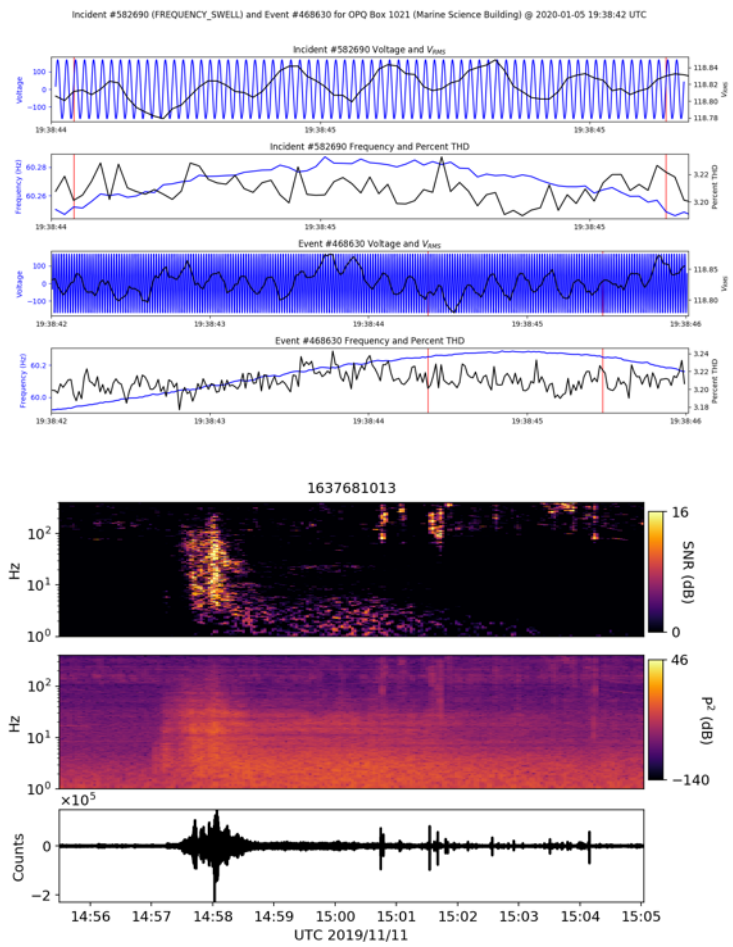
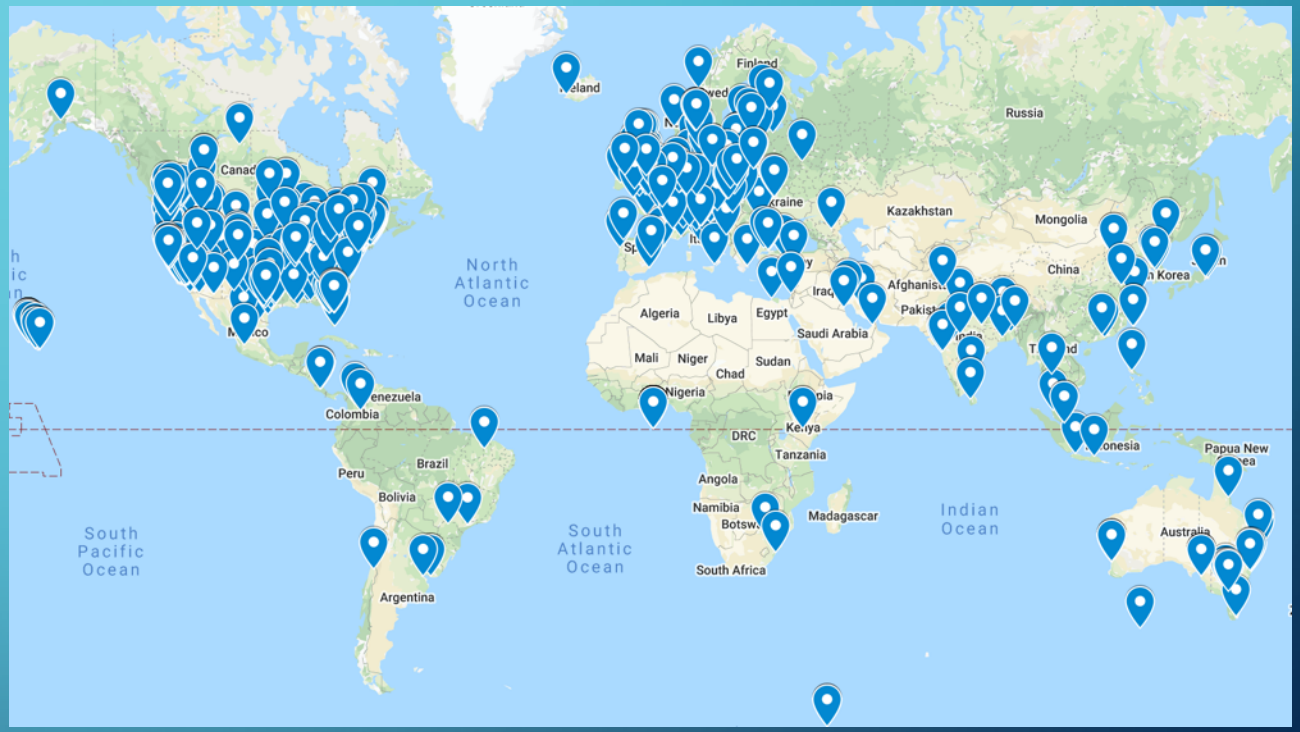


CONTRIBUTION #3: LAHA-COMPLIANT REFERENCE IMPLEMENTATIONS

- OpenPowerQuality (OPQ)
  - Distributed power quality (PQ) detection and analysis
- Lokahi
  - Distributed infrasound detection and analysis

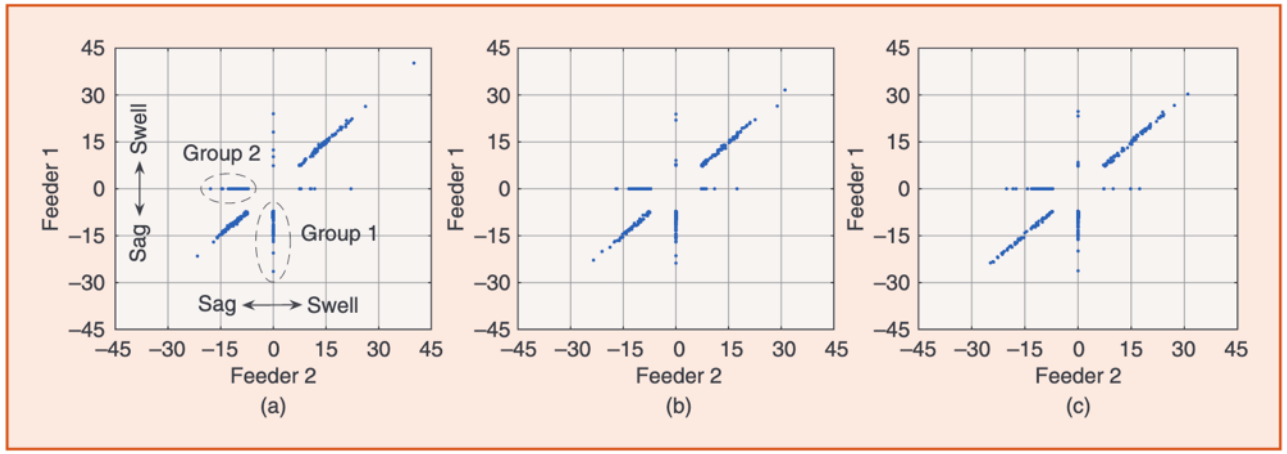
CONTRIBUTION #4: IMPLICATIONS FOR MODERN DSNS

- A set of implications for modern DSNs through the evaluation of Laha
  - Confirmation or denial of Laha's benefits in relation to DSNs
  - Other domains that Laha is useful or not useful for



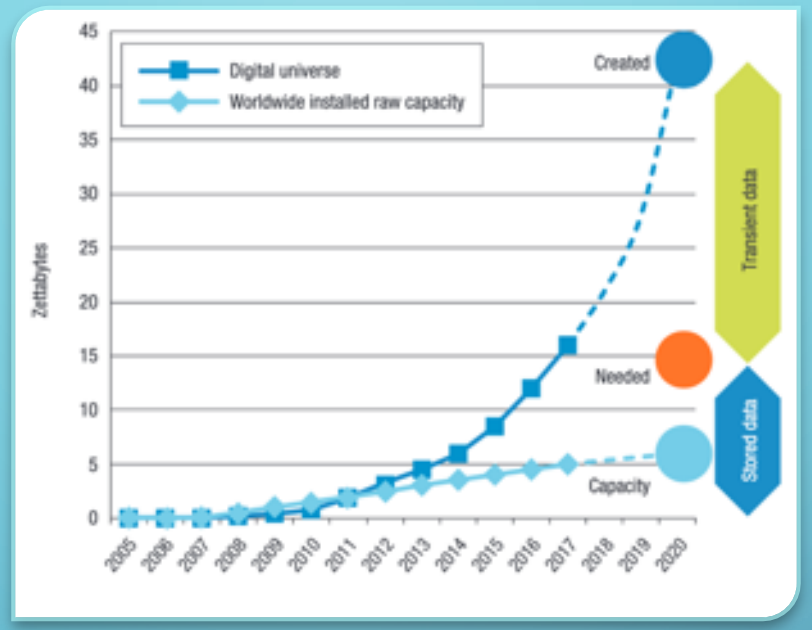
Lokahi Distributed Infrasound Network

RELATED WORK

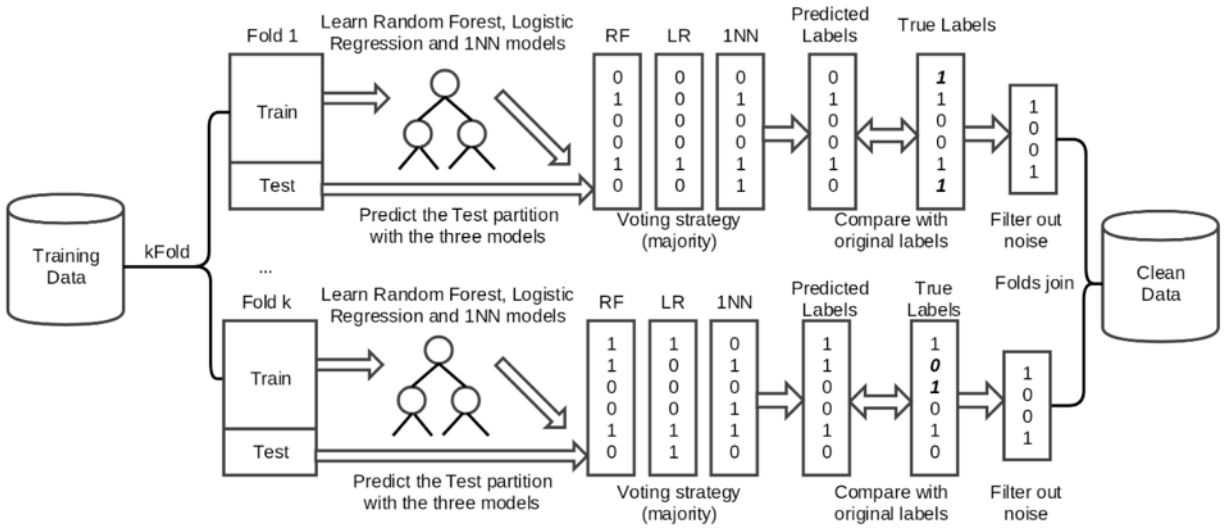


DISTRIBUTION SYNCHROPHASORS: PAIRING BIG DATA WITH ANALYTICS TO CREATE ACTIONABLE INFORMATION (MOHSENIAN-RAD ET AL. 2018)

- Big Data Analytics (Power Distribution)
- PSL (μPMU/PQube)
- Descriptive Analytics
- Predictive Analytics



IS A DATA CAPACITY GAP INEVITABLE IN BIG DATA STORAGE? (BHAT 2018)



ENABLING SMART DATA: NOISE FILTERING IN BIG DATA CLASSIFICATION (GARCIA-GIL ET AL. 2017)

RELATED WORK: DISTRIBUTED INFRASOUND DETECTION

- *Large Meteoroids as Global Infrasound Reference Events (Pilger et al 2018)*
- *How Can the International Monitoring System Infrasound Network Contribute to Gravity Wave Measurements? (Hupe et al. 2019)*
- *Infrasound for Detection, Localization, and Geometrical Reconstruction of Lightning Flashes (Farges et al. 2018)*

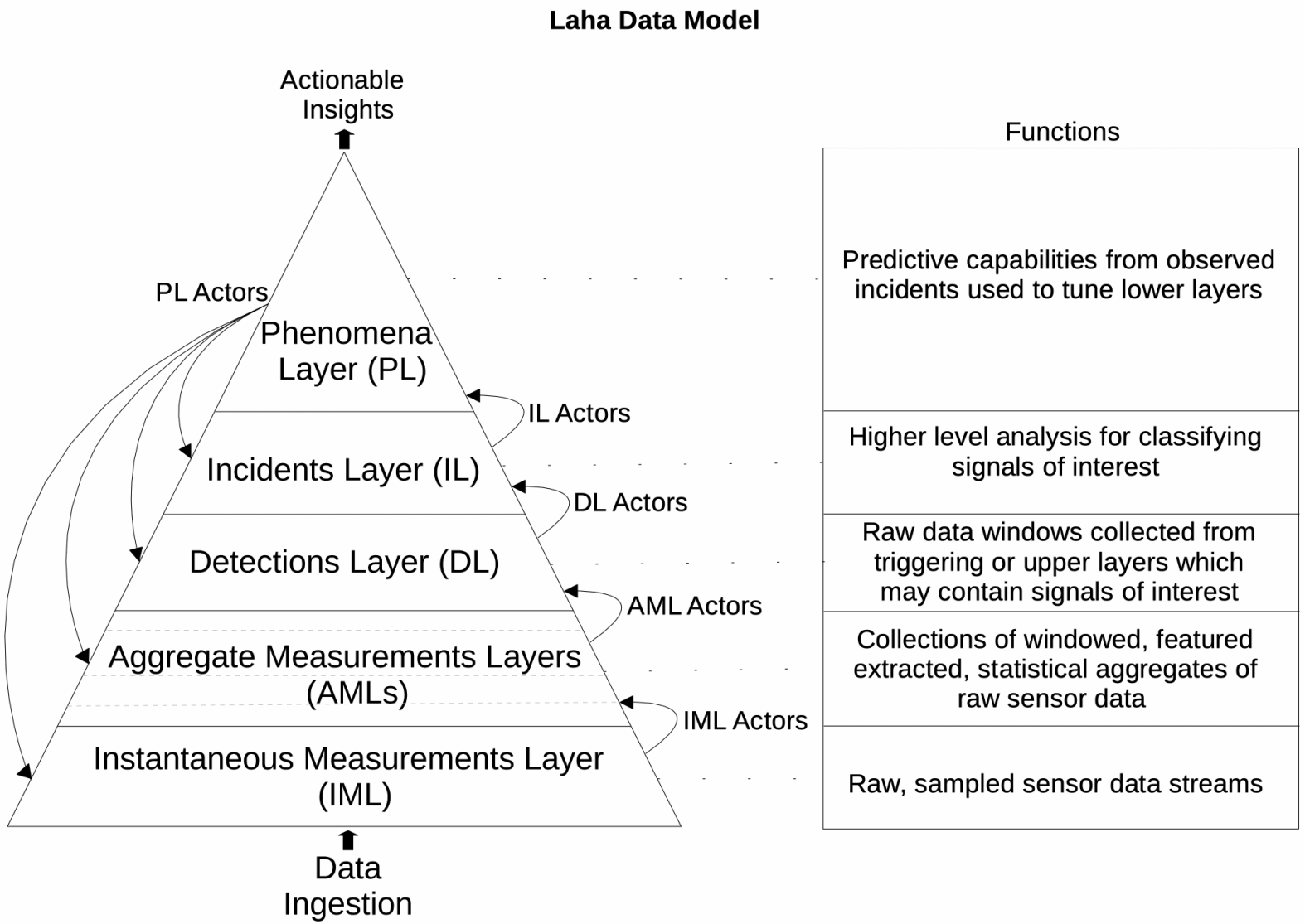
IMS Network (CTBTO)

Advances in IoT make it possible to build inexpensive distributed Infrasound networks that rival IMS.

LAHA DESIGN: CONVERTING PRIMITIVE DATA INTO ACTIONABLE INSIGHTS & SENSOR BIG DATA MANAGEMENT

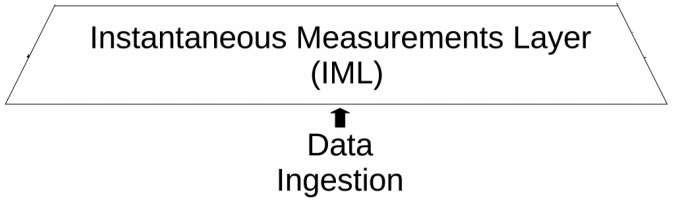
DESIGN: LAHA

- Primitive data goes in
- Actionable insights come out
- Self-optimization
- TTL

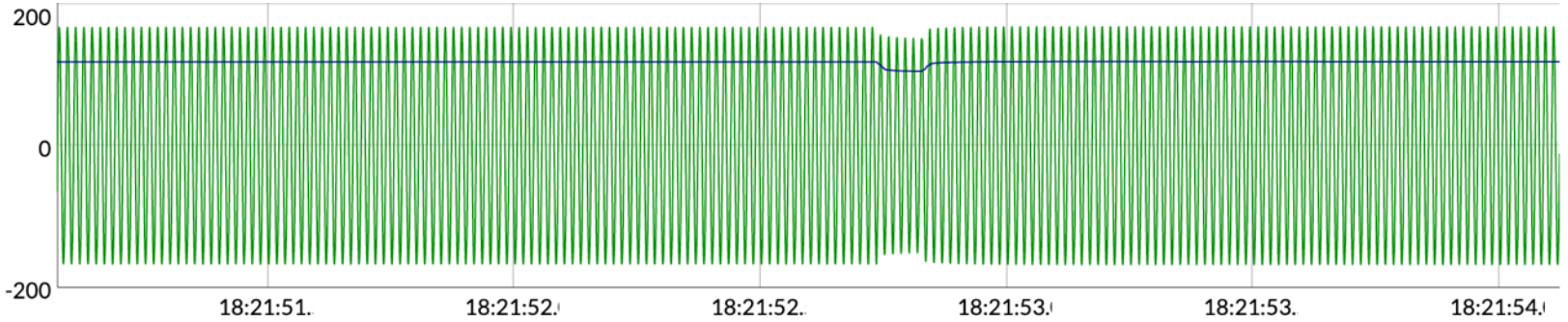


DESIGN: LAHA IML

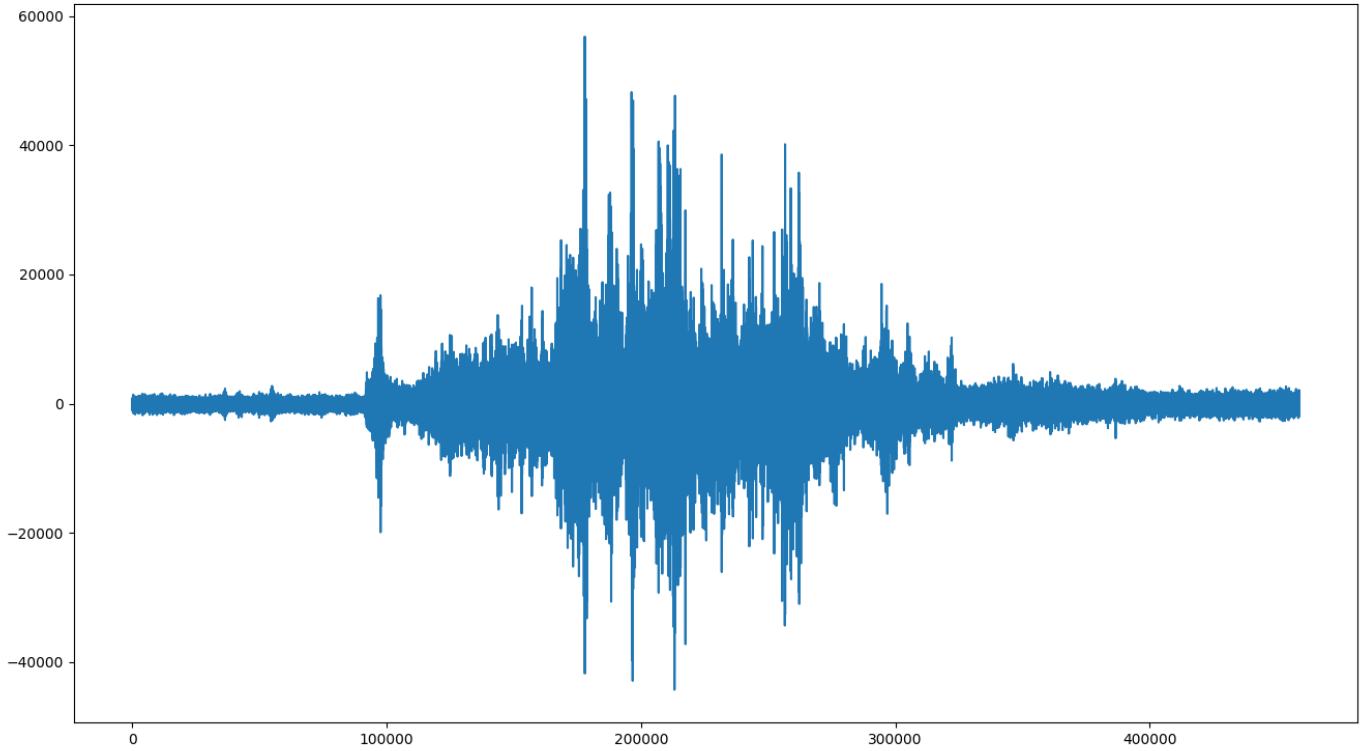
- Raw Sensor Samples
- TTL
  - 15 Minutes



OPQ IML Data

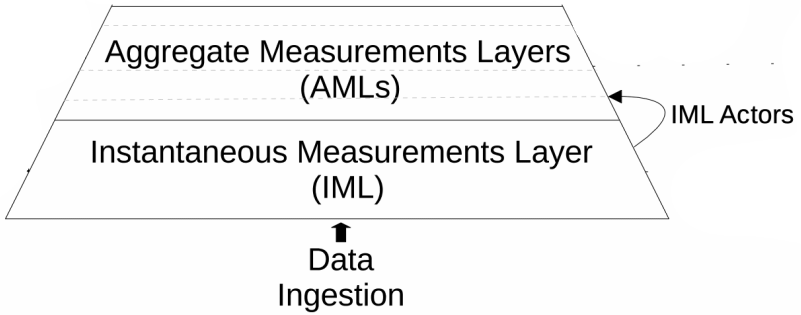


Lokahi IML Data

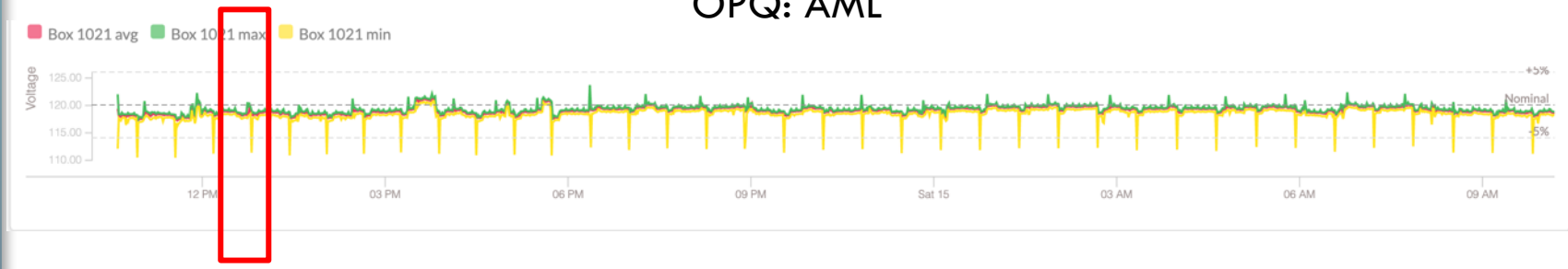


DESIGN: LAHA AML

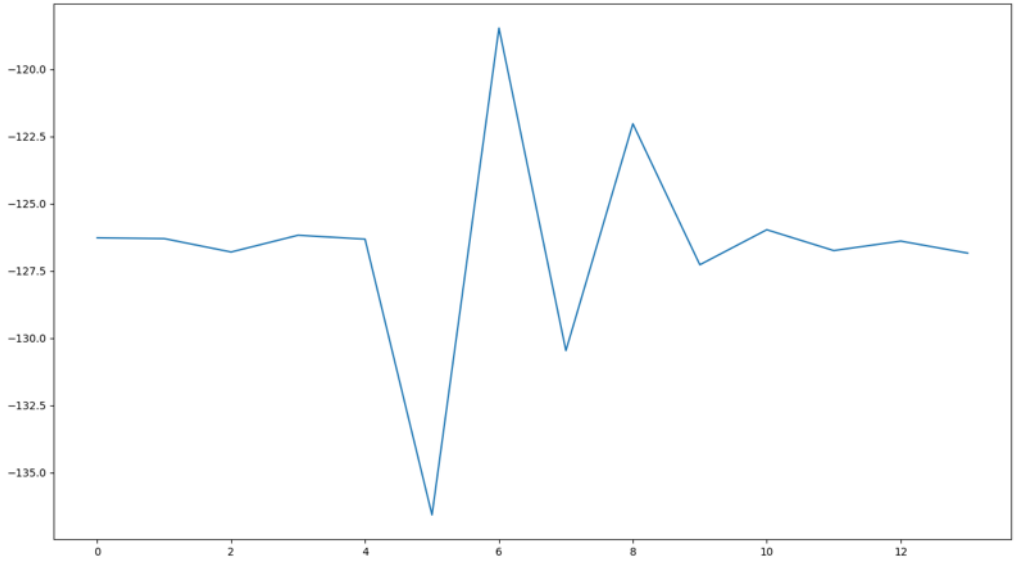
- Summary statistics of extracted features
- TTL
  - 24 Hours
  - 2 Weeks



OPQ: AML

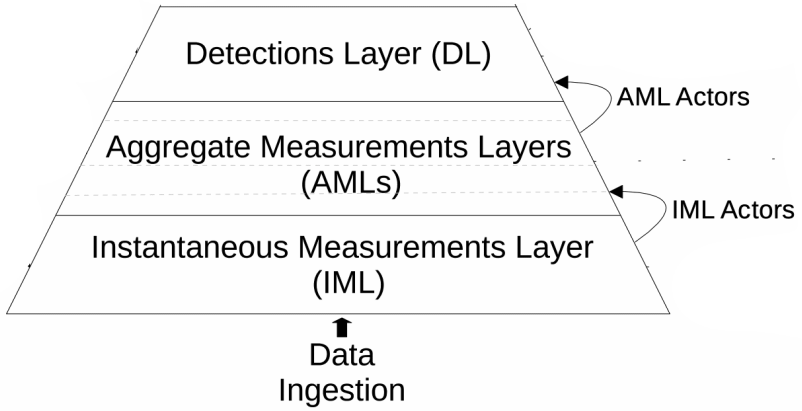


Lokahi: AML

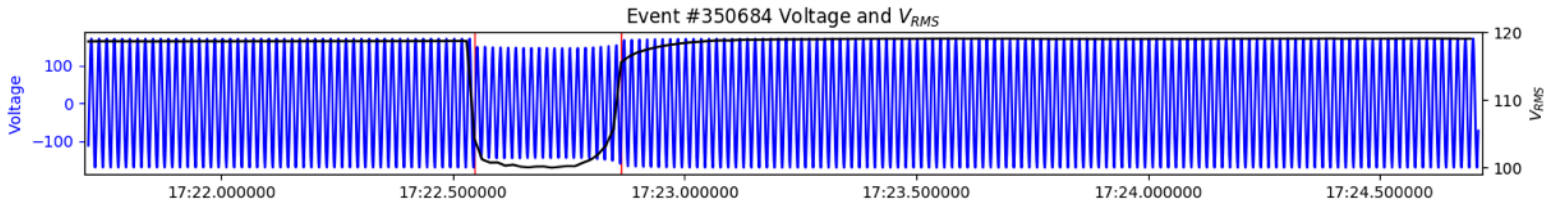


DESIGN: LAHA DL

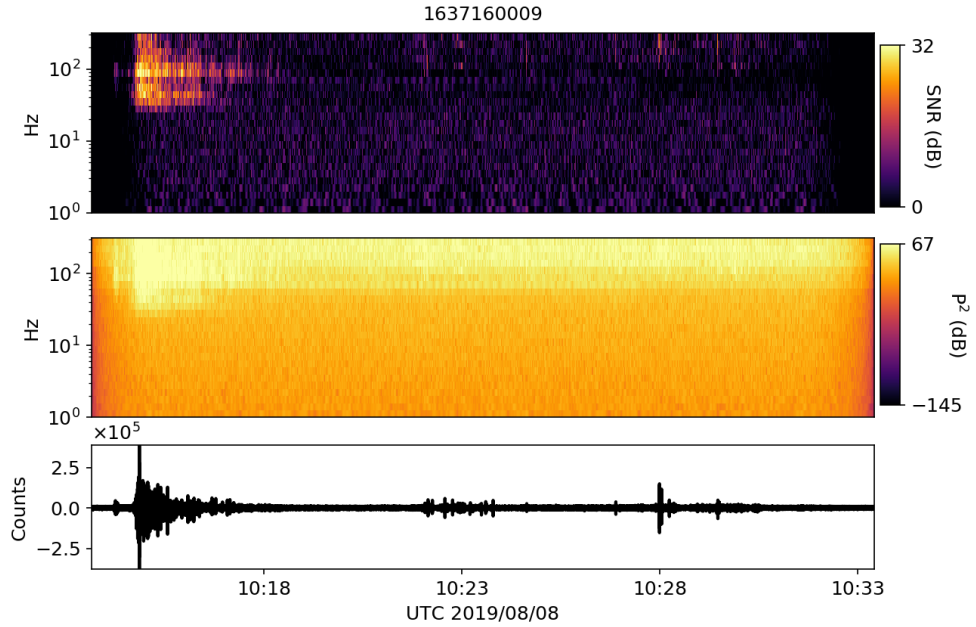
- Window containing potential signals of interest
- TTL
  - 1 Month



DL: OPQ

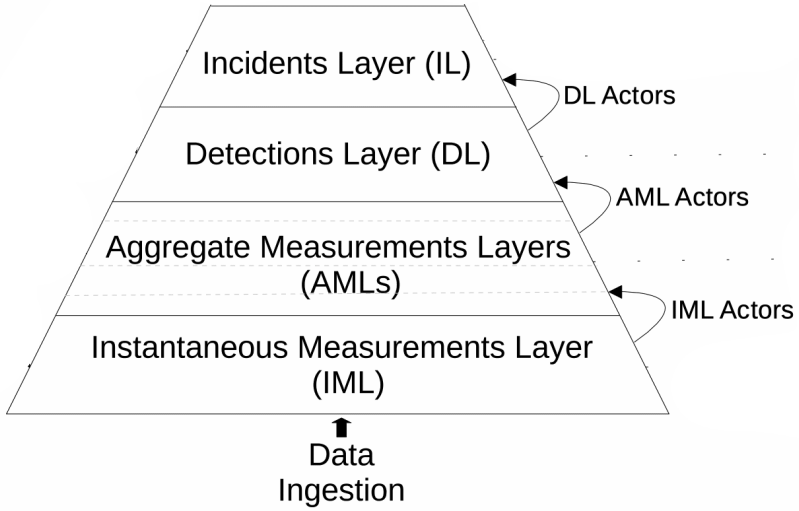


DL: Lokahi

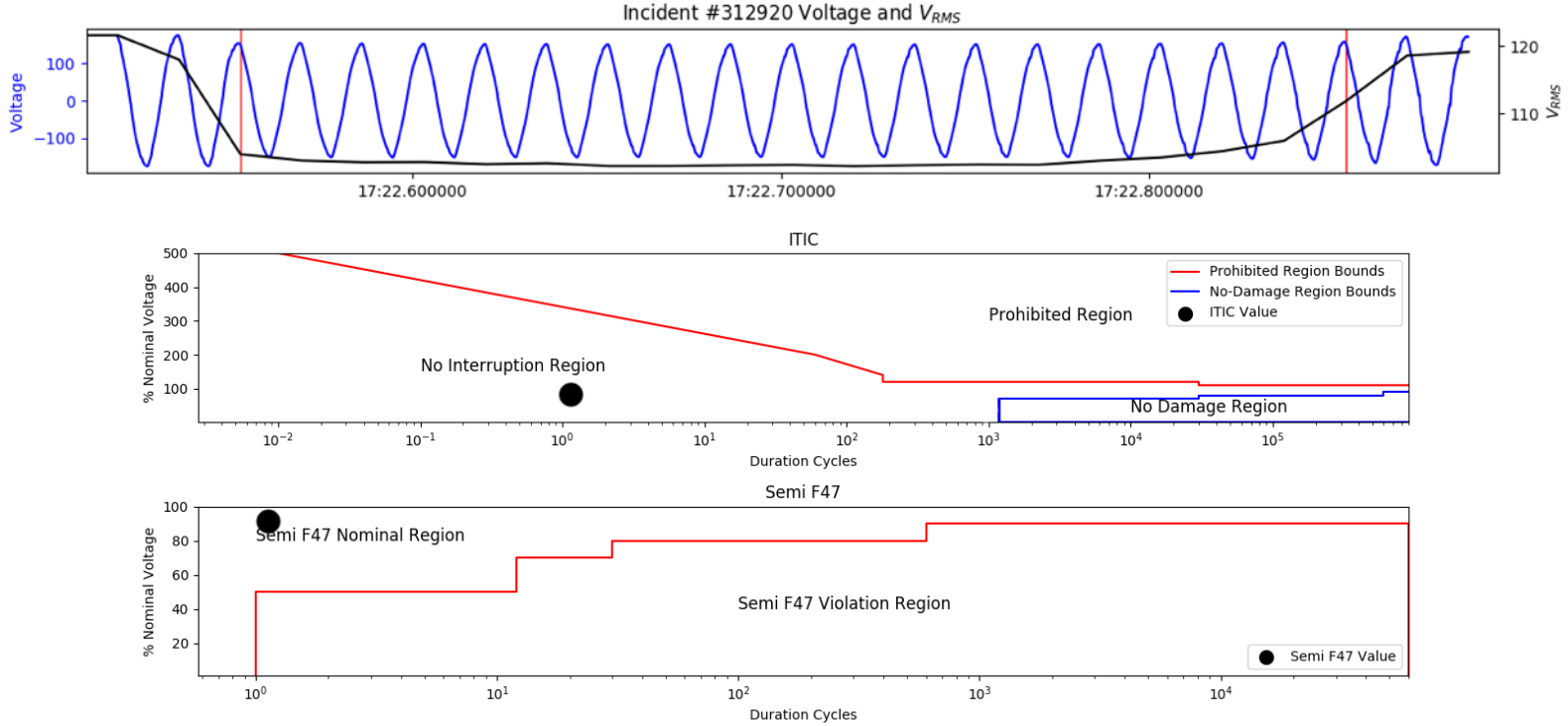


DESIGN: LAHA IL

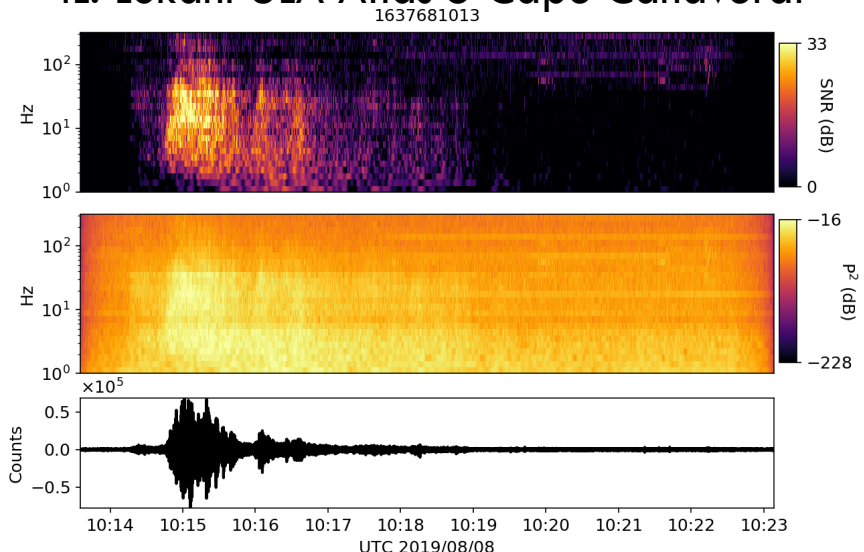
- Window containing classified signals of interest
- TTL
  - 1 Year



IL: OPQ IEEE 1159 Voltage Sag

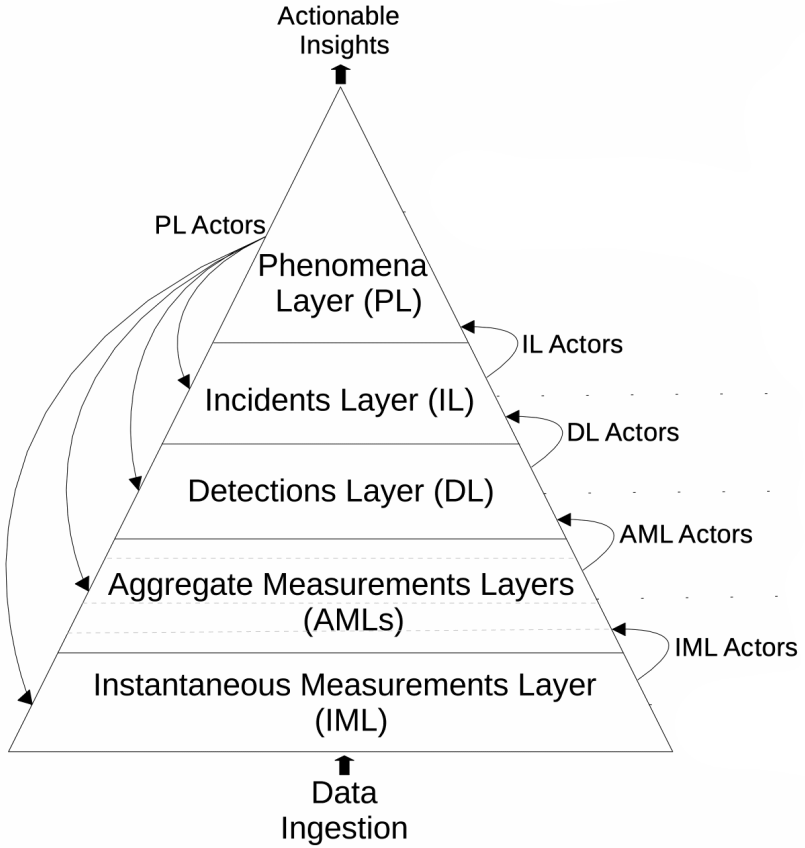


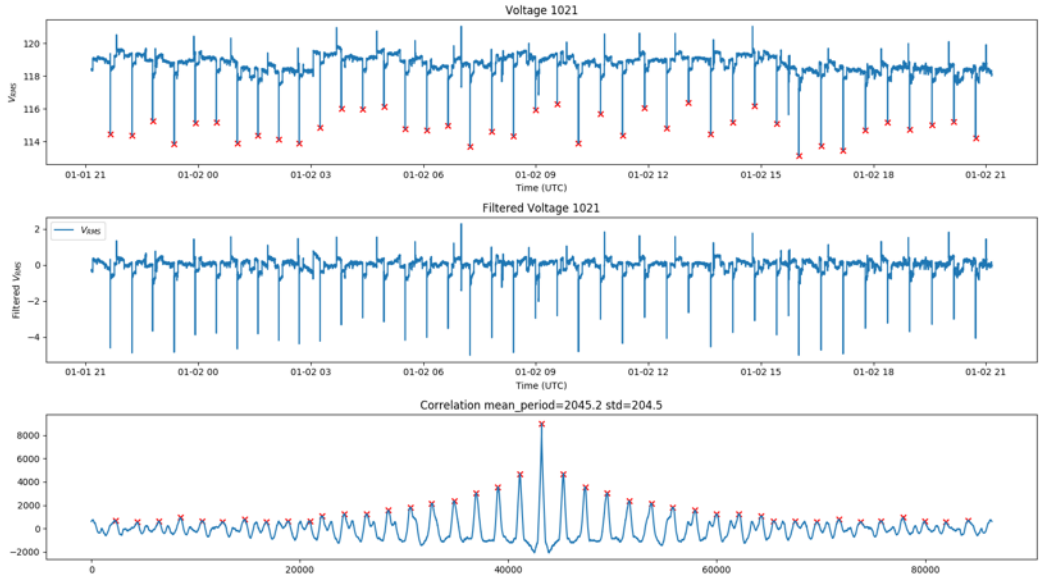
IL: Lokahi ULA Atlas 5 Cape Canaveral



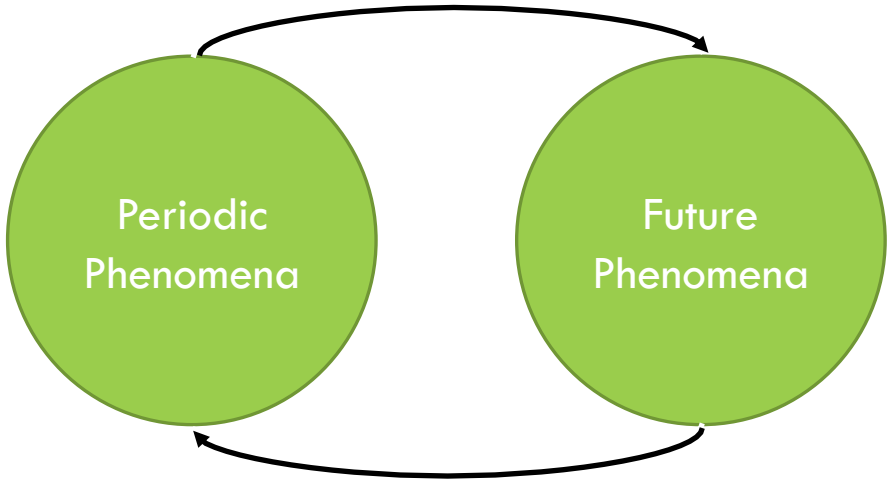
DESIGN: LAHA PL

- Actional insights
- Predictive analytics
- Data grouping
- DSN self-optimization
- TTL
  - 2 Years



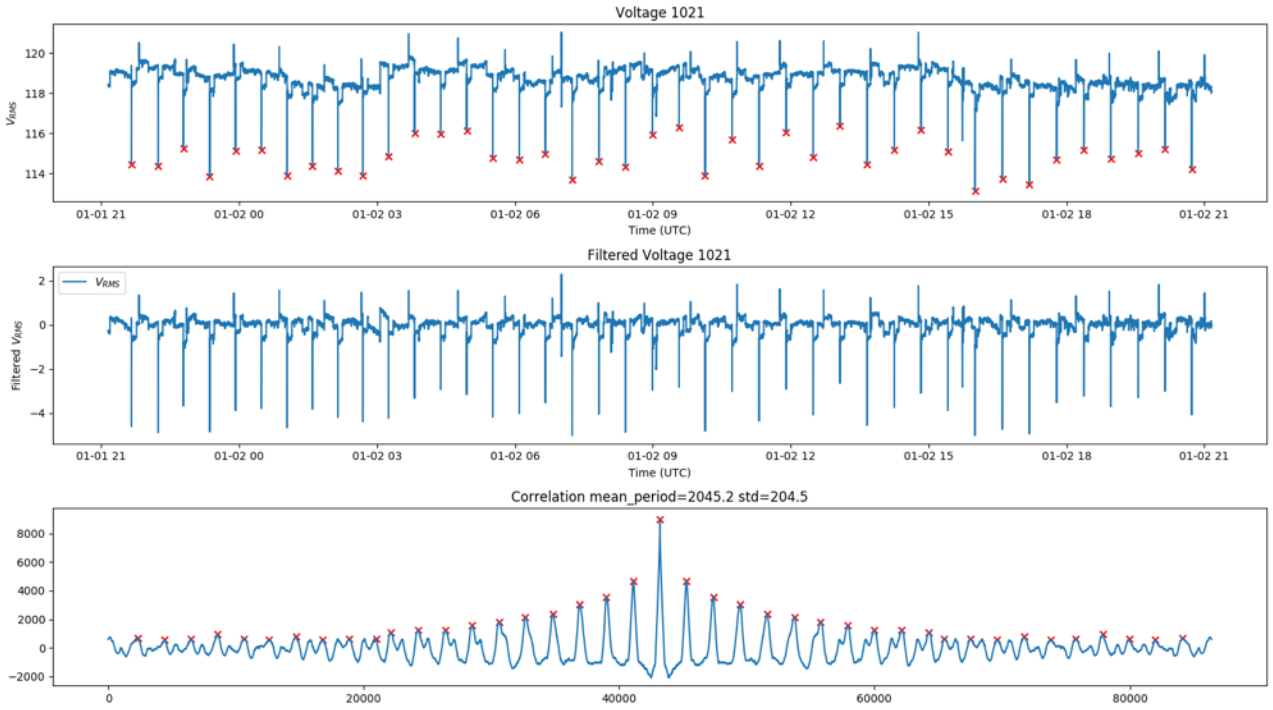


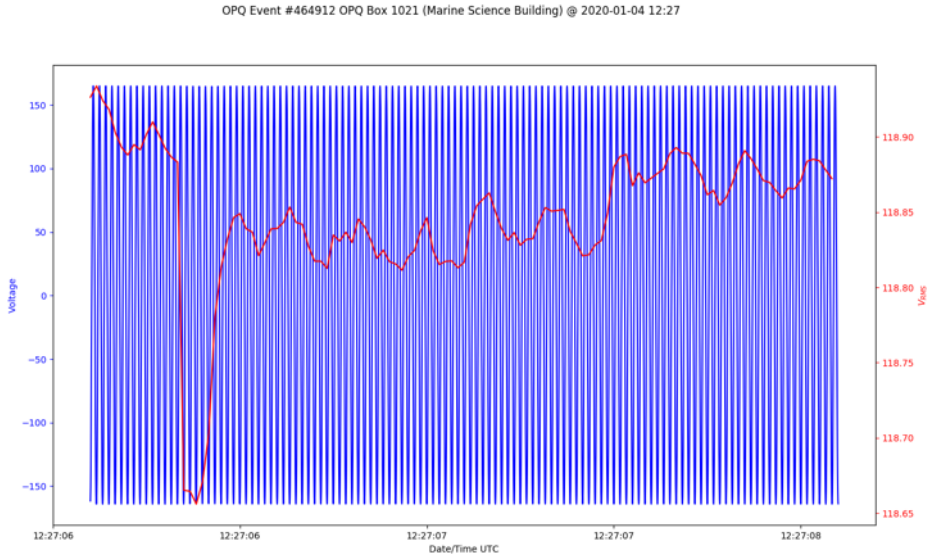
Used to create Future Phenomena



Increases Measurement rate and decrease detection thresholds enabling more accurate Periodic Phenomena

DESIGN: PERIODIC PHENOMENA

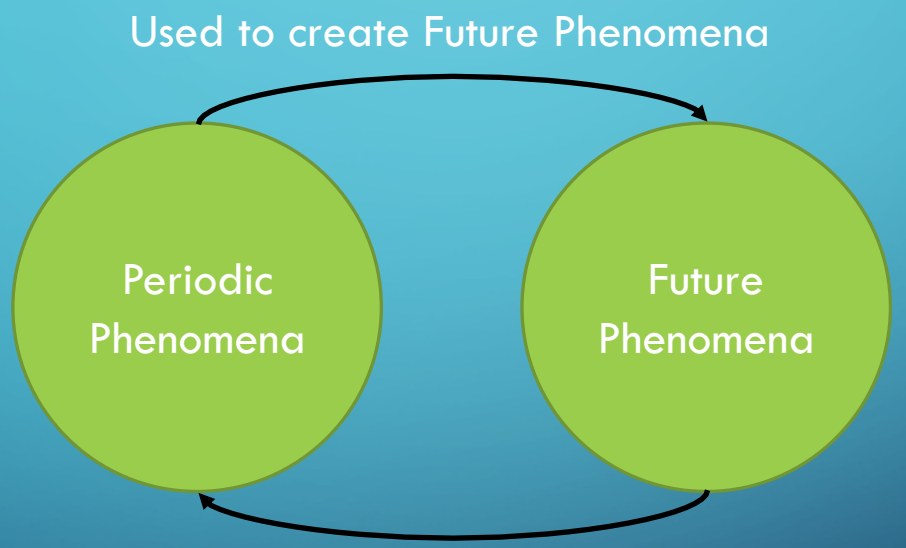


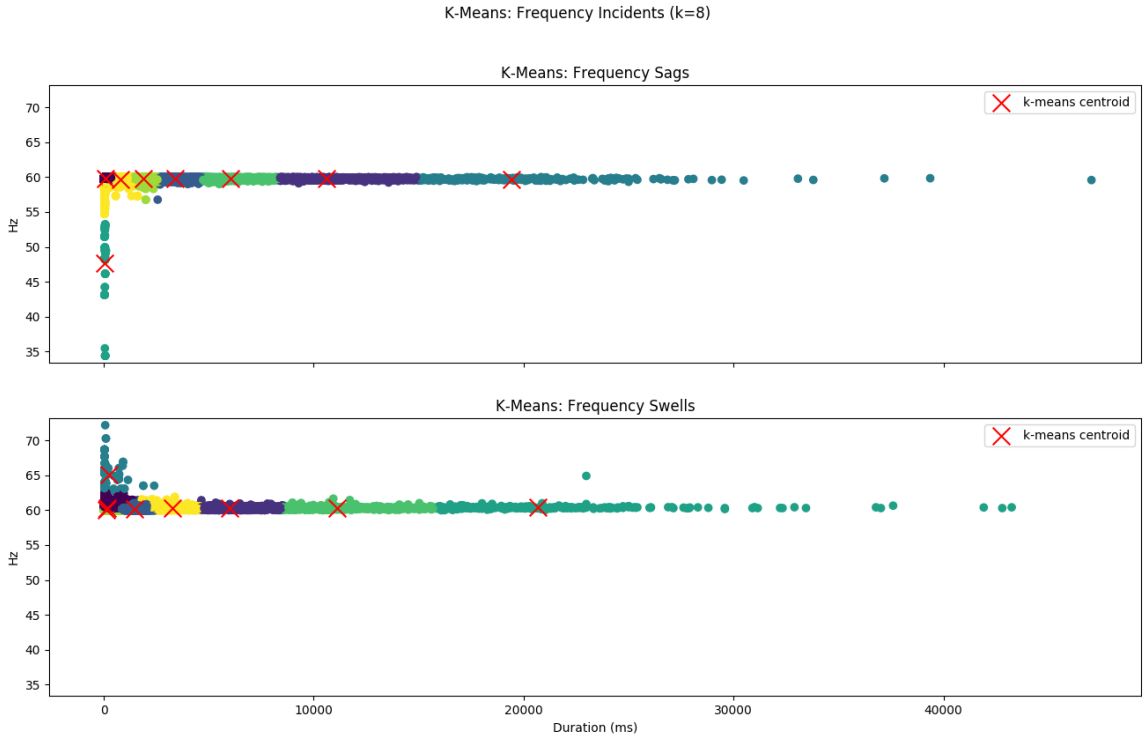


Box	Future Phenomena	Unrealized	Realized
1021	9	185	210
1003	113	52	61
1023	173	113	60
2001	91	91	0

DESIGN: FUTURE PHENOMENA

DESIGN: PERIODIC & FUTURE PHENOMENA SELF-OPTIMIZATION



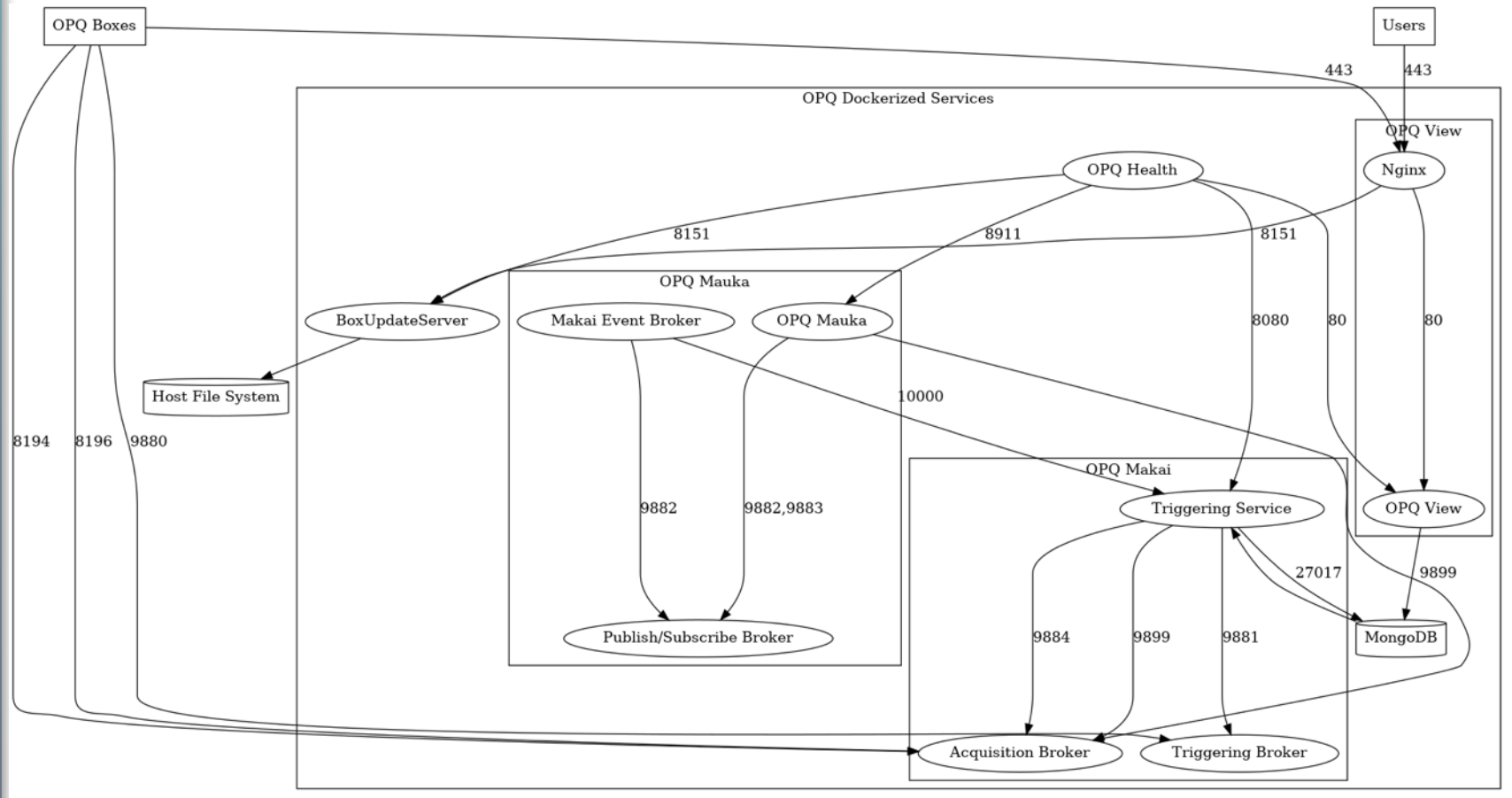


DESIGN: SIMILARITY PHENOMENA

DESIGN OF OPQ

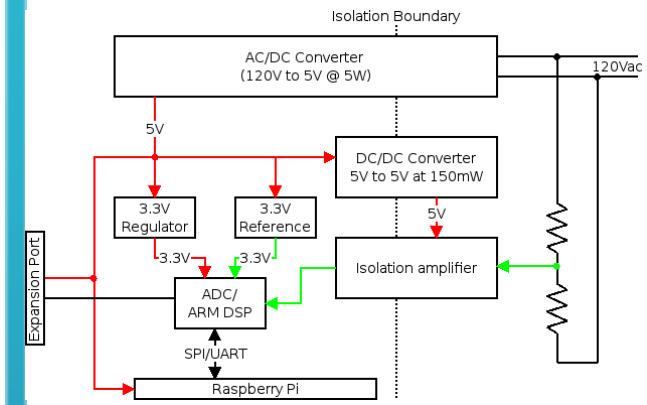
DESIGN OF OPQ

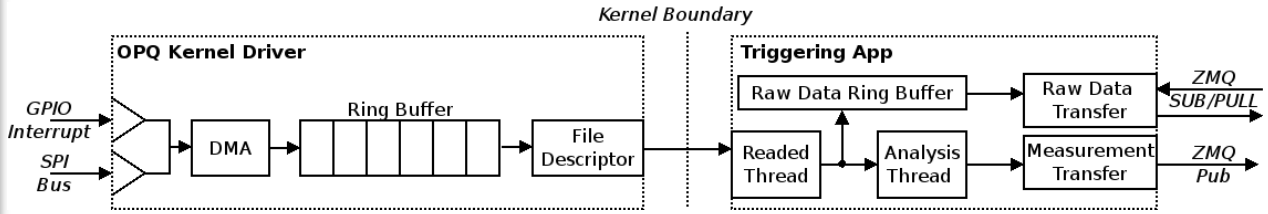
- OPQ consists of distributed services
  - Box
  - Makai/Napali
  - ***Mauka***
  - Health
  - View
  - MongoDB

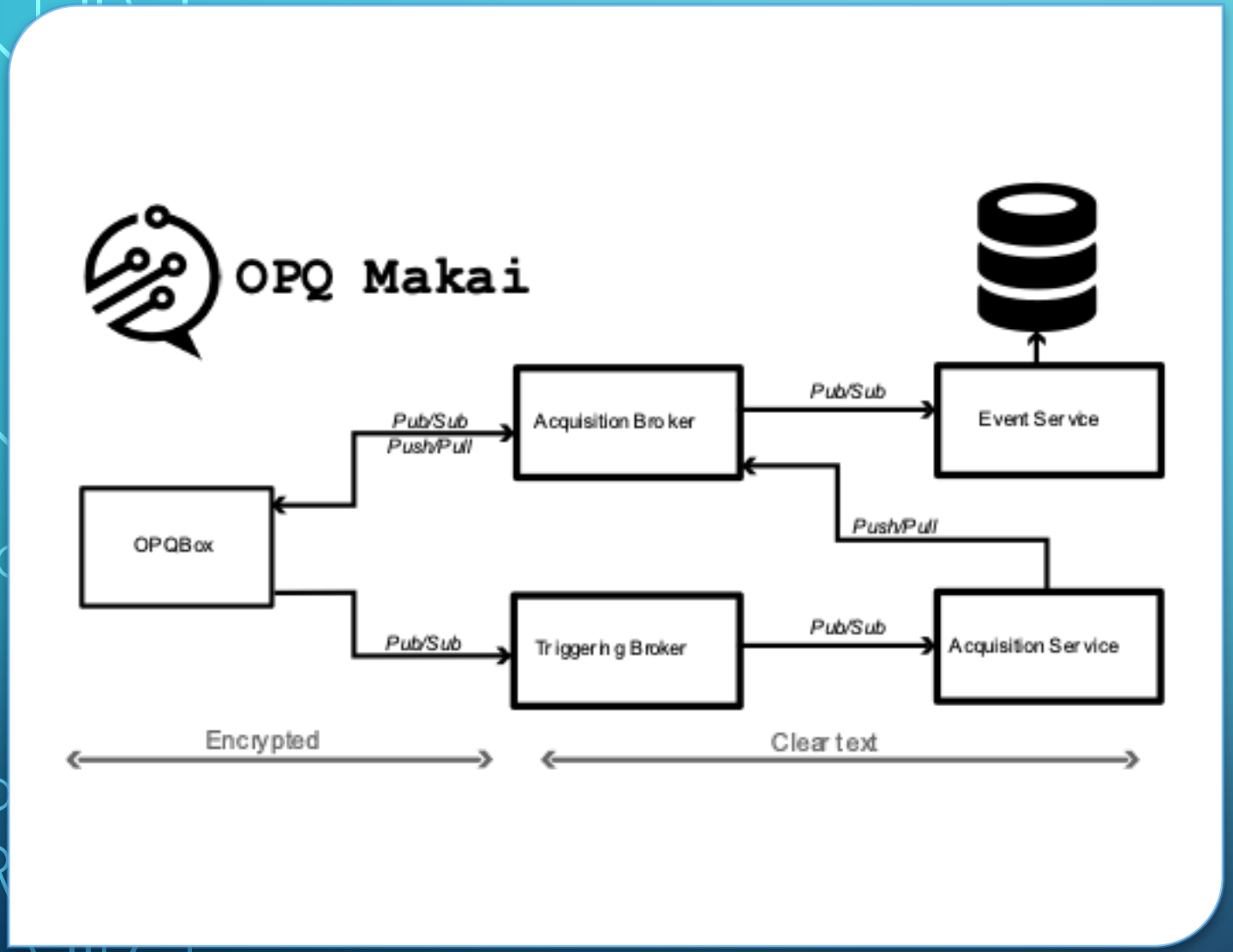


OPQ: BOX

- Open Source PQ Sensor
- 12 kHz sampling
- Wireless encrypted comms.
- Trigger based acquisition
- *Negrashov 2020*





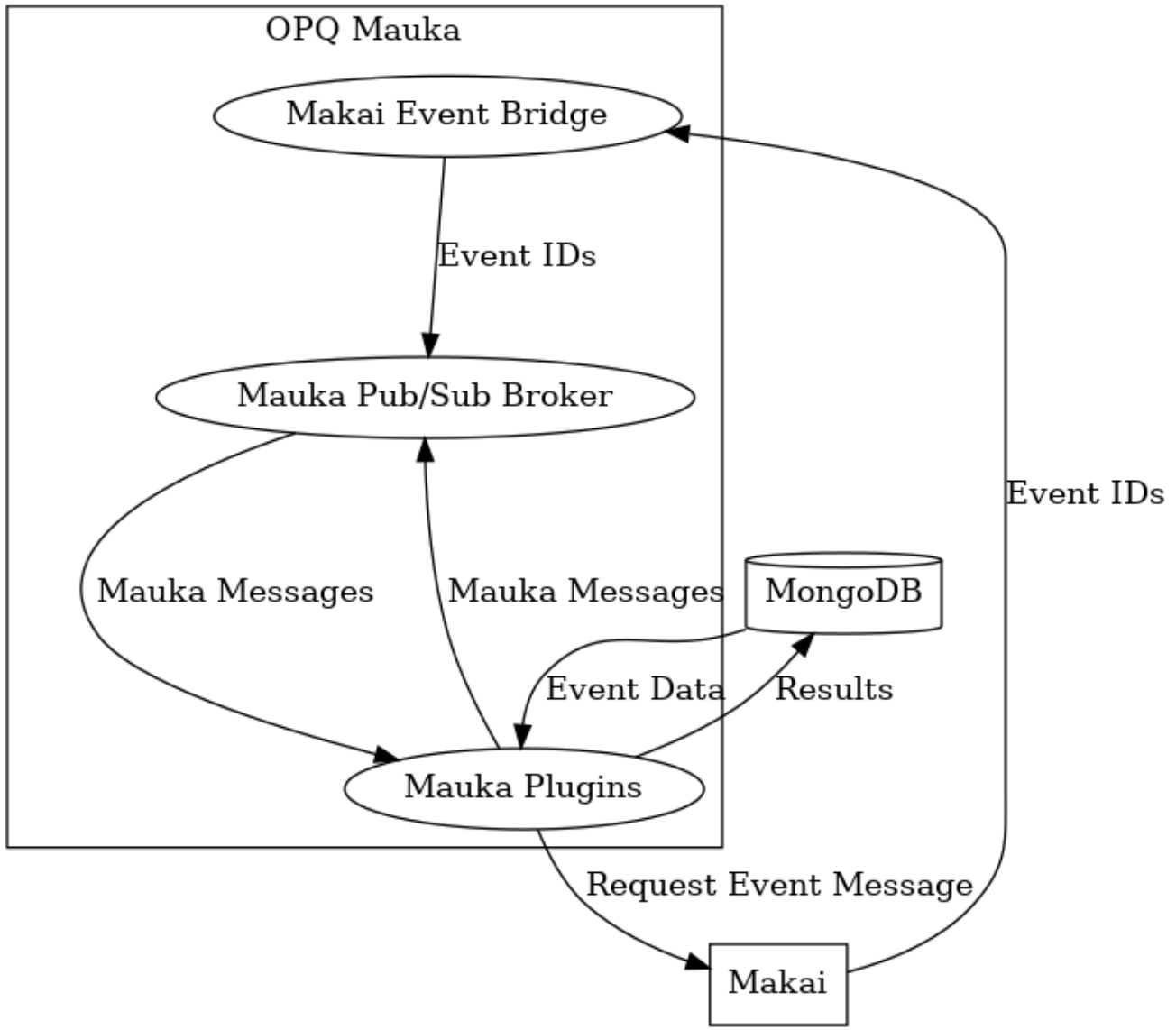


OPQ: MAKAI/NAPALI

- Data acquisition
- Triggering
- Box communication broker
- *Negrashov 2020*

OPQ: MAUKA

- PQ Analysis
- Predictive Analytics
- Garbage Collection
- PQ Plugins (Laha Actors) Providing:
  - Annotations, base, box optimization, frequency analysis, future phenomena, IEEE1159 voltage analysis, ITIC classification, GC, Makai Event service, mocking capabilities, outage detection periodicity analysis, debugging, Semi-F47 classification, system health/status, metric collection, THD analysis, threshold optimization, transient detection, and triggering

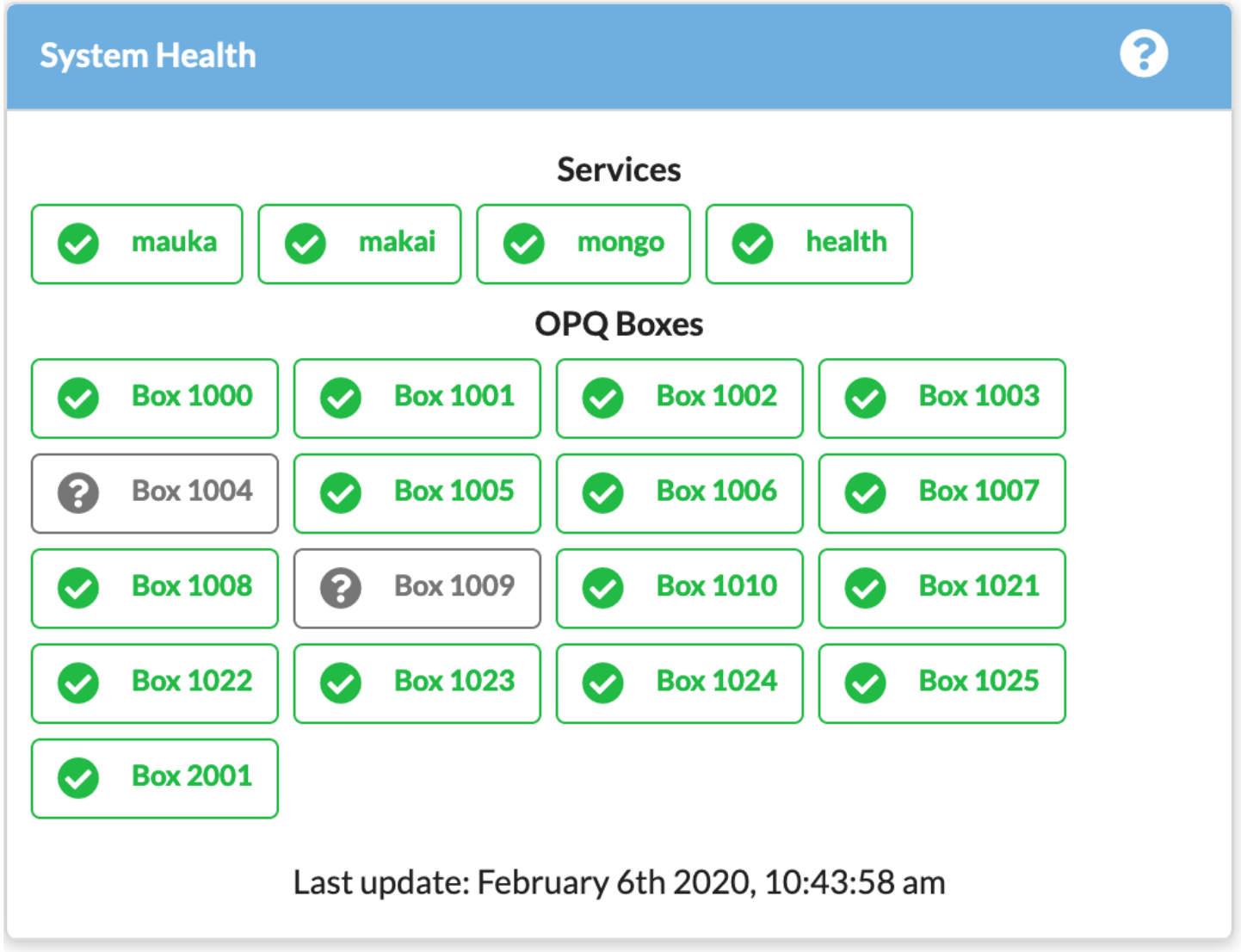


OPQ MAUKA: BY THE NUMBERS

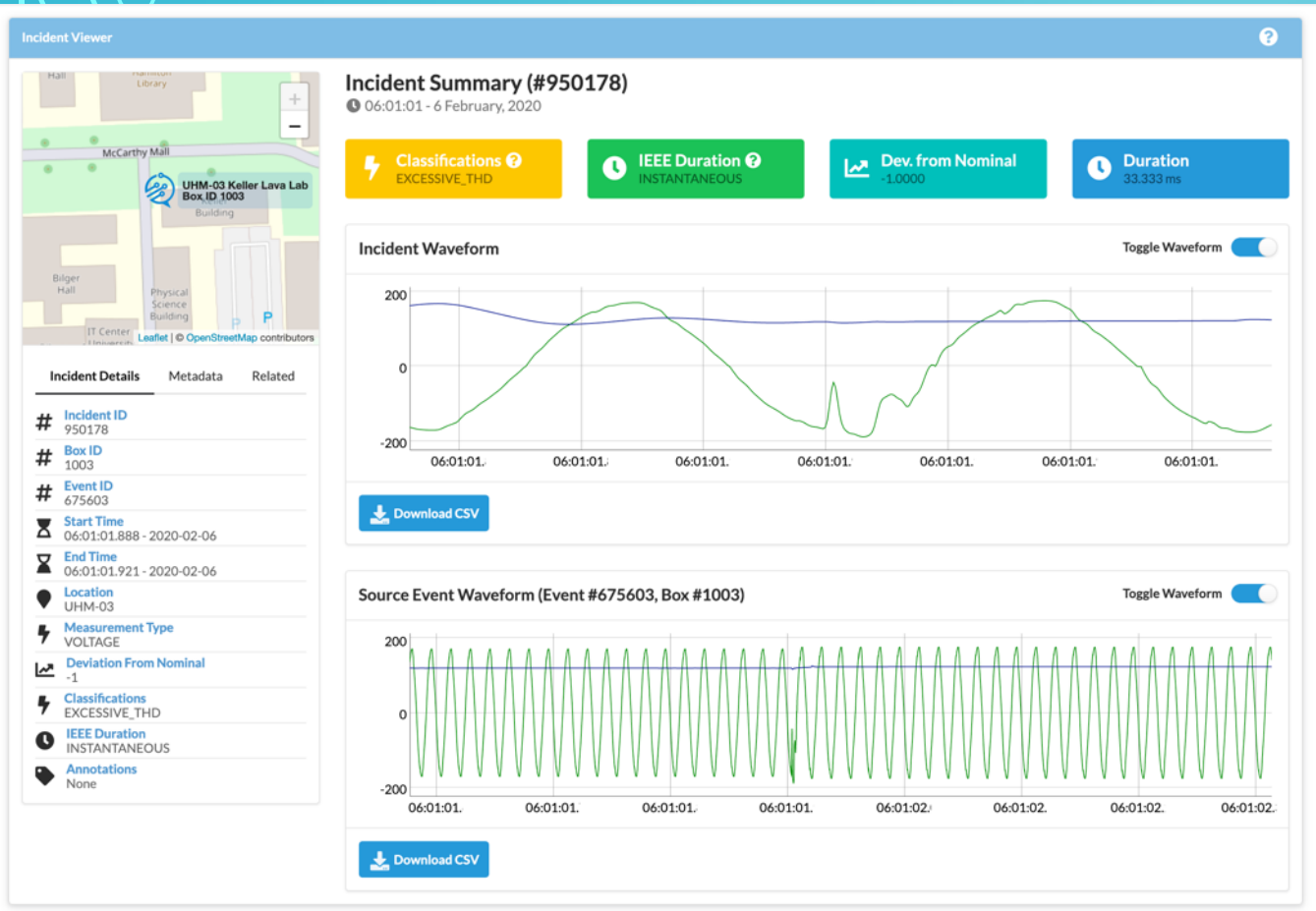
- 4+ years of development
- Python 3.7
  - ~14,000 LOC
- Rust
  - ~2,500 LOC

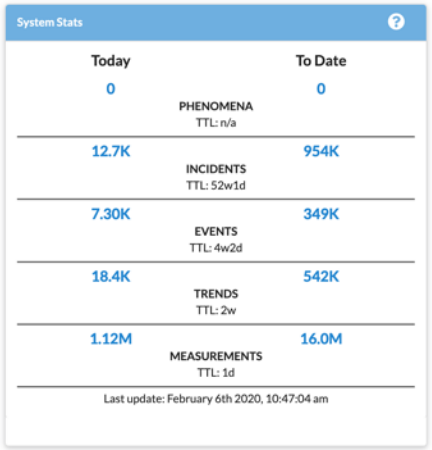
OPQ: HEALTH

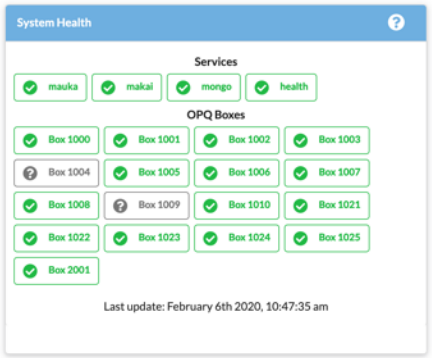
- Box Monitoring
- Service Monitoring
- Configurable Alerts

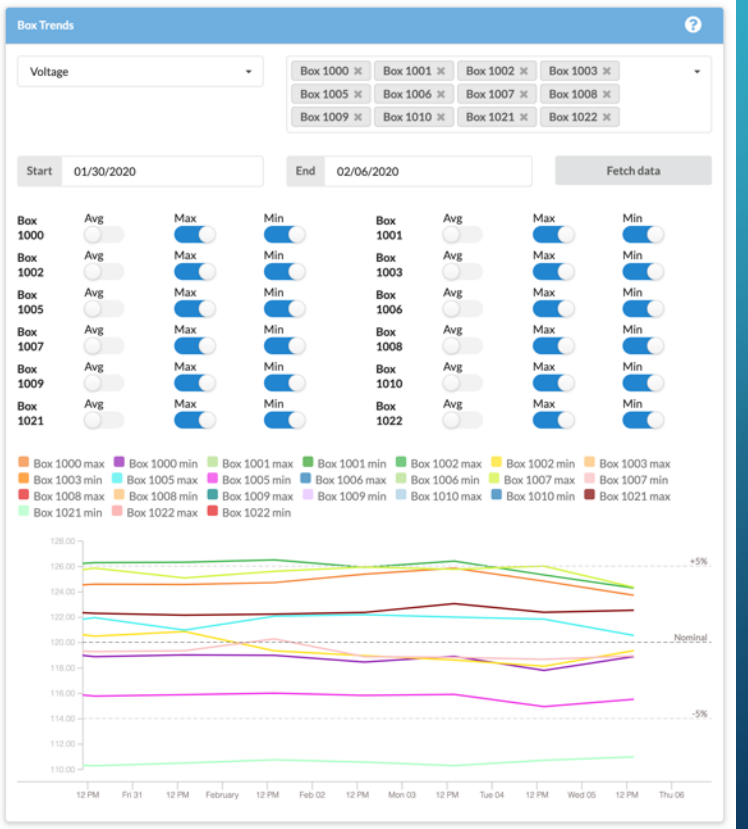


OPQ: VIEW


Incident Viewer
Incident Summary (#950178)
06:01:01 - 6 February, 2020
Classifications
EXCESSIVE_THD
IEEE Duration
INSTANTANEOUS
Dev. from Nominal
-1.0000
Duration
33.333 ms
Incident Waveform
Toggle Waveform
Download CSV
Source Event Waveform (Event #675603, Box #1003)
Toggle Waveform
Download CSV
Incident Details
Metadata
Related
Incident ID 950178
Box ID 1003
Event ID 675603
Start Time 06:01:01.888 - 2020-02-06
End Time 06:01:01.921 - 2020-02-06
Location UHM-03
Measurement Type VOLTAGE
Deviation From Nominal -1
Classifications EXCESSIVE_THD
IEEE Duration INSTANTANEOUS
Annotations None


System Stats
Today
To Date
0
0
PHENOMENA
TTL: n/a
12.7K
954K
INCIDENTS
TTL: 52w1d
7.30K
349K
EVENTS
TTL: 4w2d
18.4K
542K
TRENDS
TTL: 2w
1.12M
16.0M
MEASUREMENTS
TTL: 1d
Last update: February 6th 2020, 10:47:04 am


System Health
Services
mauka
makai
mongo
health
OPQ Boxes
Box 1000
Box 1001
Box 1002
Box 1003
Box 1004
Box 1005
Box 1006
Box 1007
Box 1008
Box 1009
Box 1010
Box 1021
Box 1022
Box 1023
Box 1024
Box 1025
Box 2001
Last update: February 6th 2020, 10:47:35 am

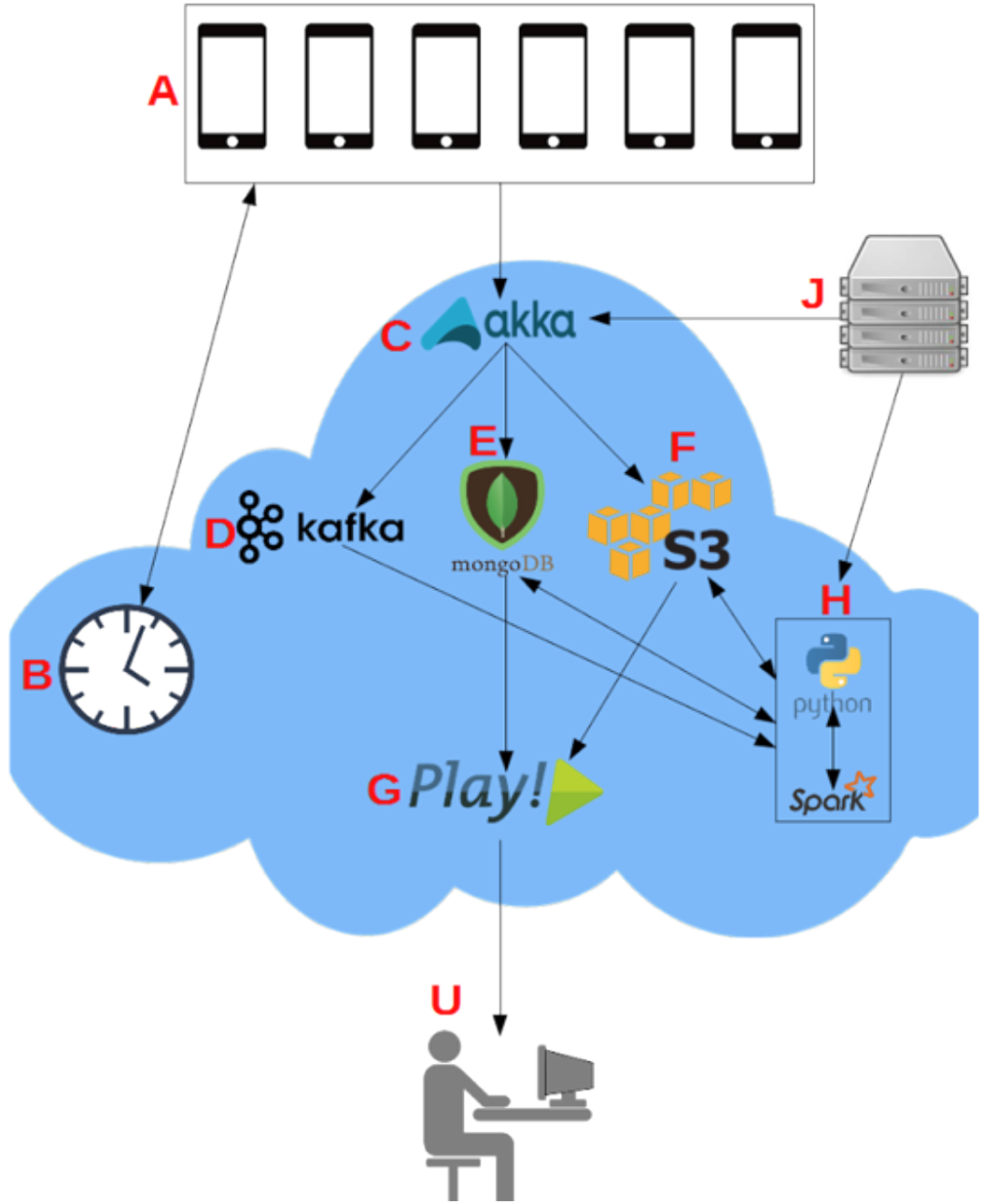

Box Trends
Voltage
Box 1000
Box 1001
Box 1002
Box 1003
Box 1005
Box 1006
Box 1007
Box 1008
Box 1009
Box 1010
Box 1021
Box 1022
Start 01/30/2020
End 02/06/2020
Fetch data
Avg
Max
Min


Box Map
Filter by Region
UHM-00
UHM-00 POST 307
Box ID: 1000
Box Name UHM-00
Box ID 1000
Location UHM-00 POST 307
Coordinates Lat: 21.297438, Lng: -157.816237
Region None
Description Batch 3
Unplugged Status false
Calibration Constant 152.1
UHM-01
UHM-01 Hamilton Library 3F
Box ID: 1001
UHM-03 120.22 V 59.998 Hz 0.0360 THD
UHM 25 117.91 V 60.015 Hz 0.0201 THD
UHM-24 121.35 V 59.995 Hz 0.0295 THD
UHM-09 No Recent Data
UHM-21 118.97 V 59.997 Hz 0.0299 THD
McCarthy Mall
Correa Road

DESIGN OF LOKAHI

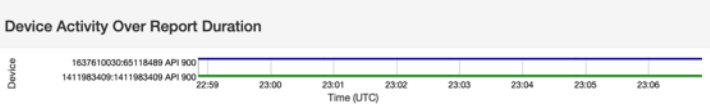
DESIGN OF LOKAHI

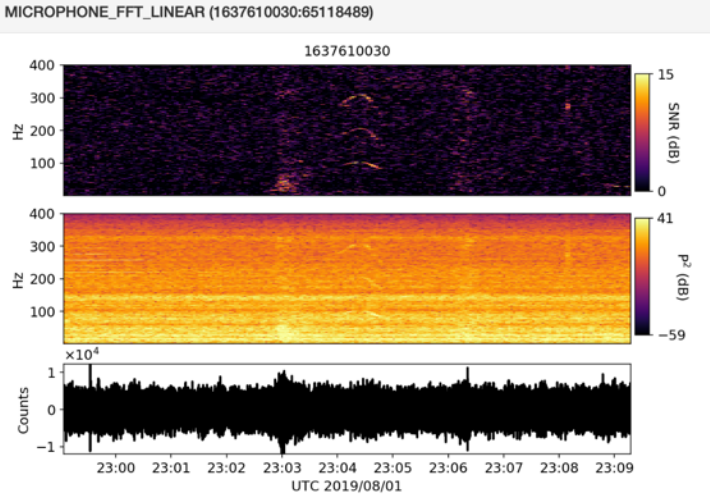
- Lokahi is made up of several distributed services
  - (A) Lokahi Sensors
  - (B) Time Synch Service
  - (C) Acquisition Service
  - (D) Collaboration Service
  - (E) Metadata Storage Service
  - (F) Storage Service
  - (G) Web Service
  - (H) Analysis Service

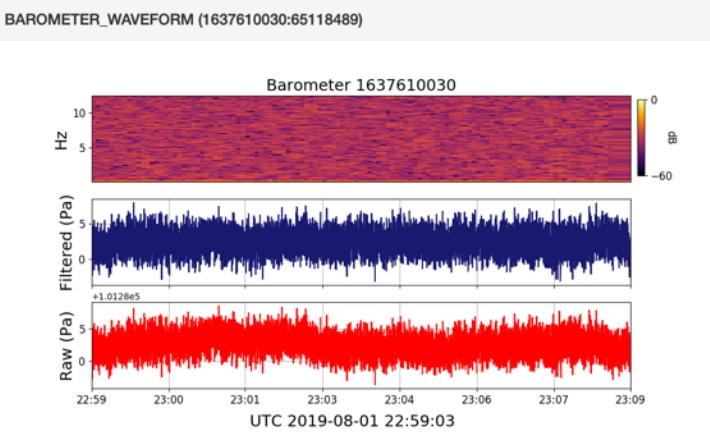


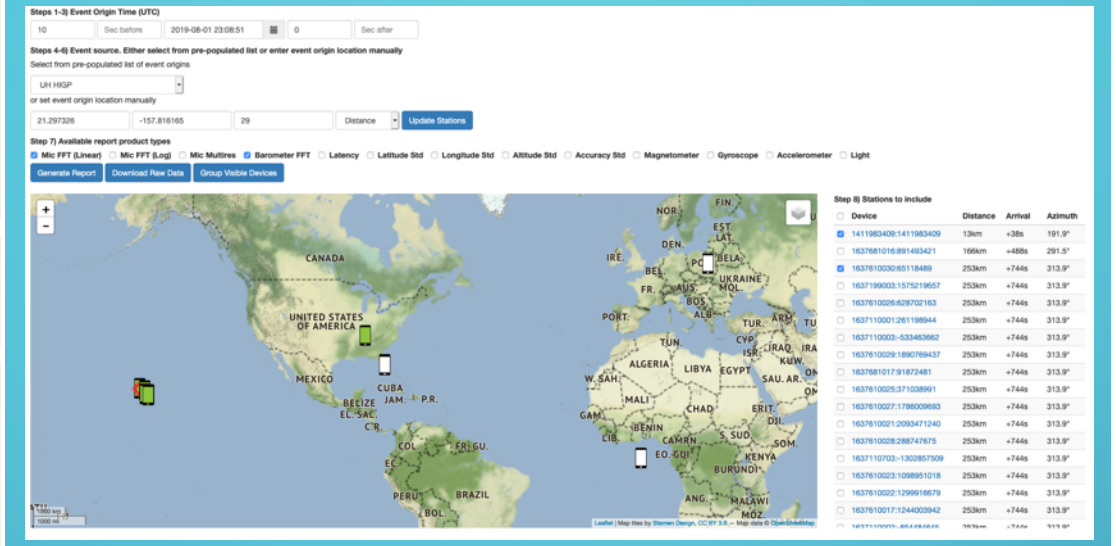
LOKAHI: SENSORS

LOKAHI: WEB









Device Health Overview

My Devices (Api 900)

Device Id	Last Received (UTC)	Min Ago	Current Privacy Policy	OS	OS Version	App Version	Sample Rate (Hz)	Details
1637110001	2019/08/01 22:35 UTC	0	PRIVATE	iOS	12.3.1	3.3.3	800.0	Details
1637110002	2019/08/01 22:36 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	800.0	Details
1637110003	2019/08/01 22:36 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	800.0	Details
1637110004	2019/08/01 22:35 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	80.0	Details
1637110005	2019/08/01 22:36 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	80.0	Details
1637110501	2019/08/01 22:36 UTC	0	PRIVATE	iOS	12.3.1	3.3.3	800.0	Details
1637110701	2019/08/01 22:35 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	80.0	Details
1637110702	2019/08/01 22:35 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	80.0	Details
1637110703	2019/08/01 22:35 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	80.0	Details
1637110704	2019/08/01 22:35 UTC	0	PUBLIC	iOS	12.3.1	3.3.3	80.0	Details
1637199002	2019/08/01 22:36 UTC	0	PRIVATE	iOS	12.2	3.3.3	800.0	Details
1637199003	2019/08/01 22:36 UTC	0	PRIVATE	iOS	12.2	3.3.3	800.0	Details
1637610016	2019/08/01 22:36 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610017	2019/08/01 22:36 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610018	2019/08/01 22:36 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610019	2019/08/01 22:36 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610020	2019/08/01 22:36 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610021	2019/08/01 22:35 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610022	2019/08/01 22:35 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610023	2019/08/01 22:35 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610024	2019/08/01 22:35 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610025	2019/08/01 22:35 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details
1637610026	2019/08/01 22:35 UTC	0	PRIVATE	Android	9	2.5.13	800.0	Details

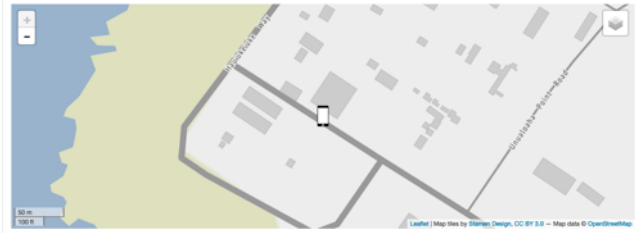
This data is crowd sourced by mobile devices! You can contribute by downloading the free InfrasoundRecorder iOS app or Android app today!
Find out more at www.redvoxsound.com.

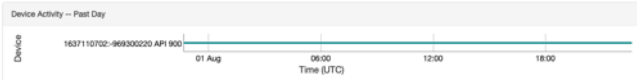
Redvox Device Details (1637110702:-969300220)

Device Id	1637110702
Device Uuid	-969300220
Last Received	2019/08/01 22:39 UTC
Min Ago	0
Location	19.728281469249104, -156.05927907873624
Battery Level %	100.0
Device Temperature C	0.0
Mic Sample Rate	80.0
Operating System	iOS 12.3.1
Device Name	Apple iPhone11,8
Acquisition Server	wss://redvox.io/acquisition/v900
Synchronization Server	wss://redvox.io/synch/v2
Authentication Server	https://redvox.io/login/mobile

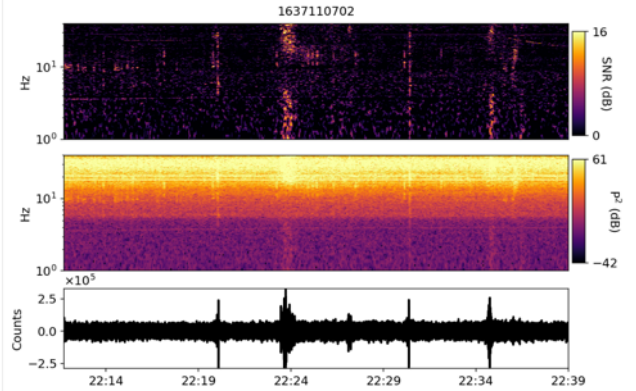
Last refreshed: 2019-08-01T22:39:46.835Z

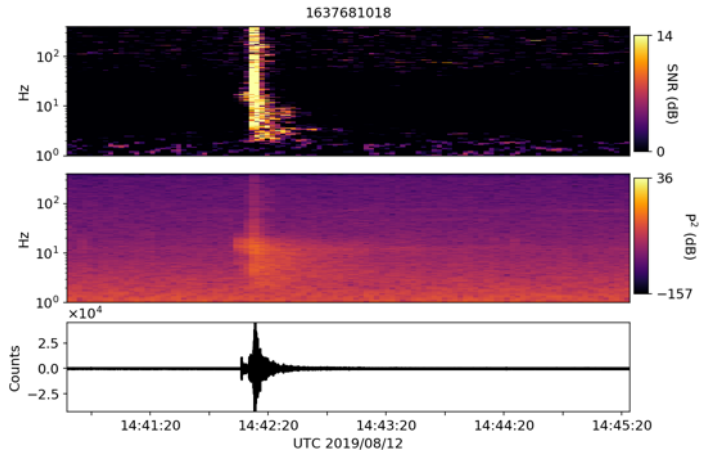
Device Location



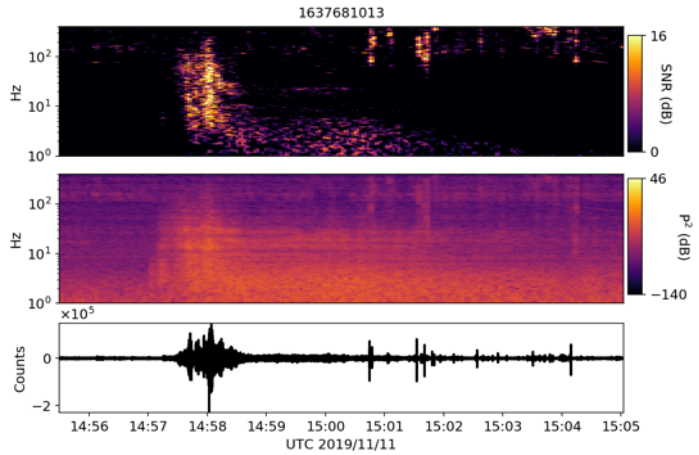


Last 27 Min. Mic FFT (1637110702:-969300220)

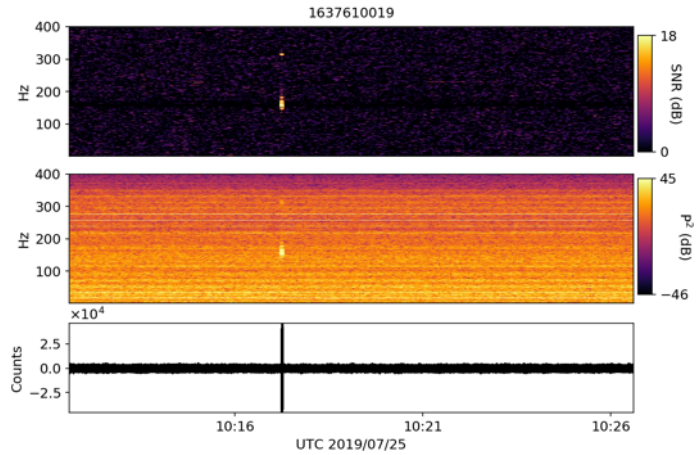




Big Island earthquake



SpaceX launch



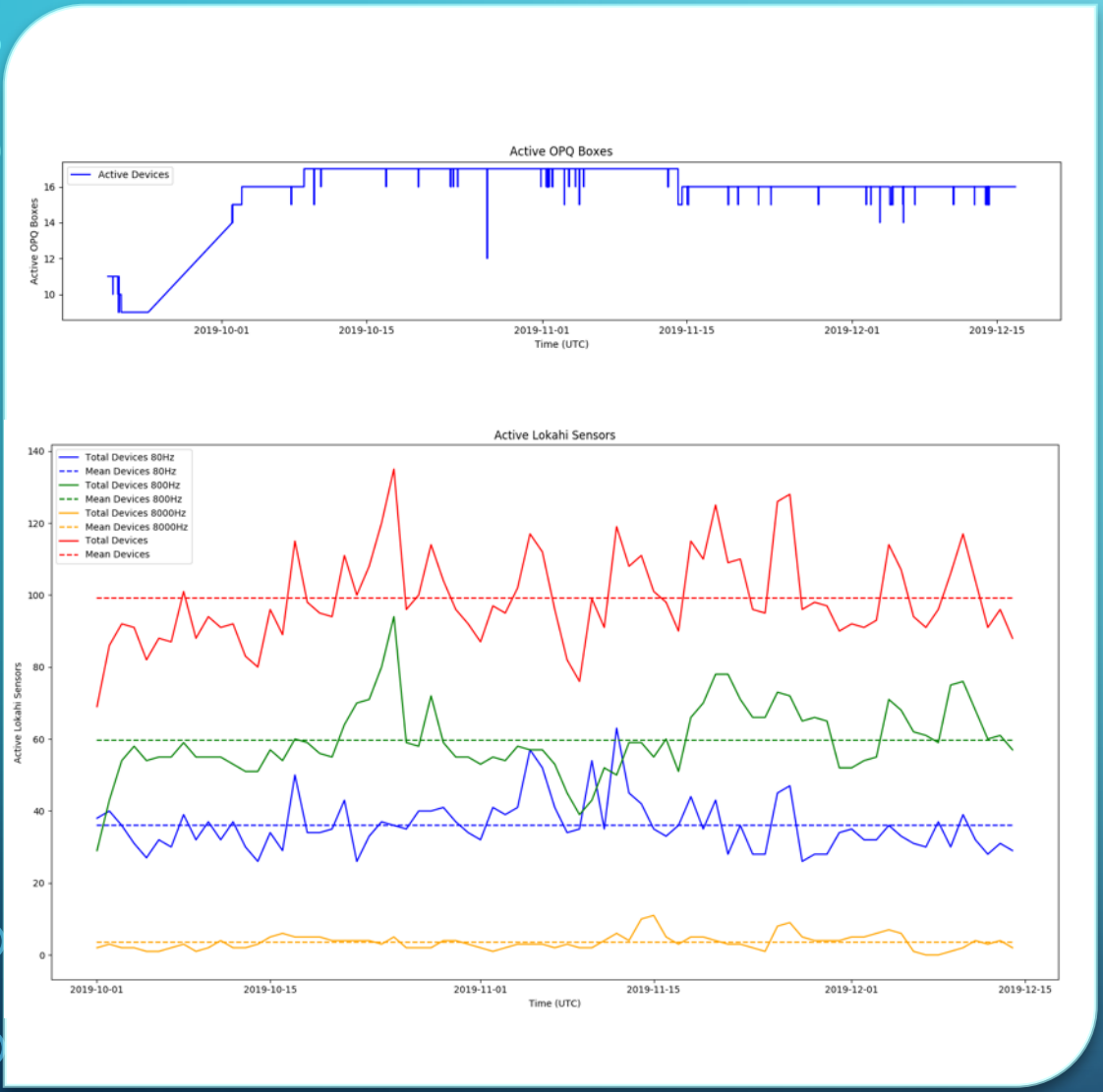
Meteor entry above Maui

LOKAHI: ANALYSIS

LOKAHI: BY THE NUMBERS

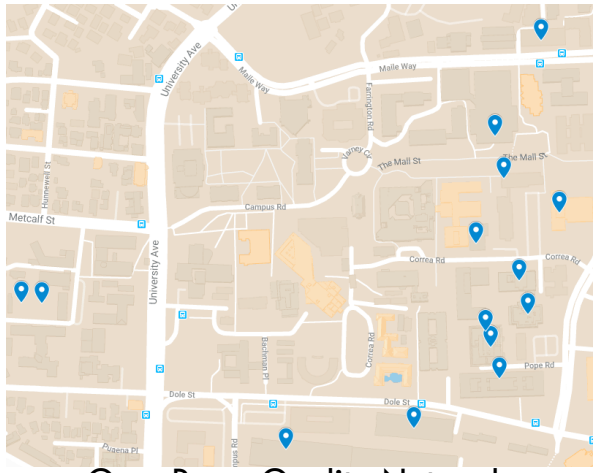
- 4+ years of development
- Acquisition service
  - Java: ~4,000 LOC
- Web service
  - Java: ~50,000 LOC
  - JS: ~5,000 LOC
- Analysis service
  - Python: ~25,000 LOC

RESULTS



PILOT DEPLOYMENTS

- September ‘19 – December ‘19
- OPQ
  - ~16 Boxes
  - UHM micro-grid
- Lokahi
  - ~100 sensors
  - Global (ad-hoc)



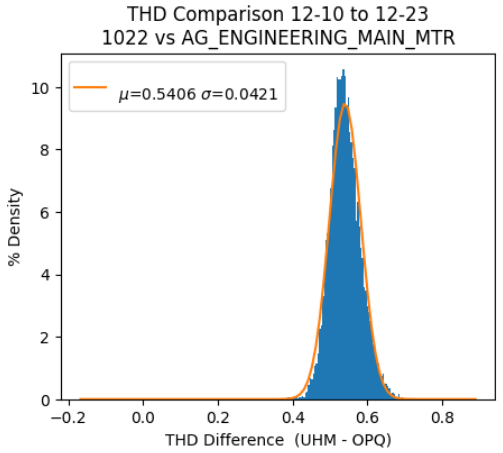
OpenPowerQuality Network

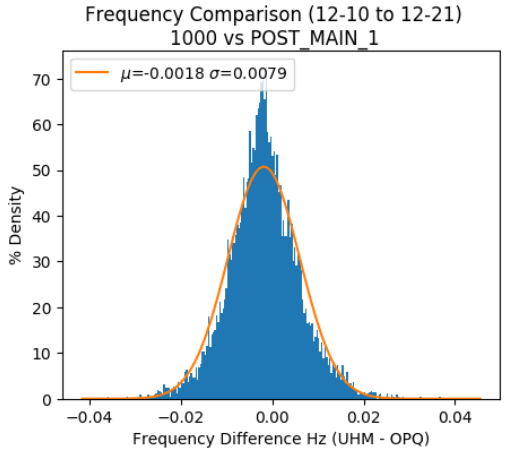
Lokahi Distributed Infrasound Network

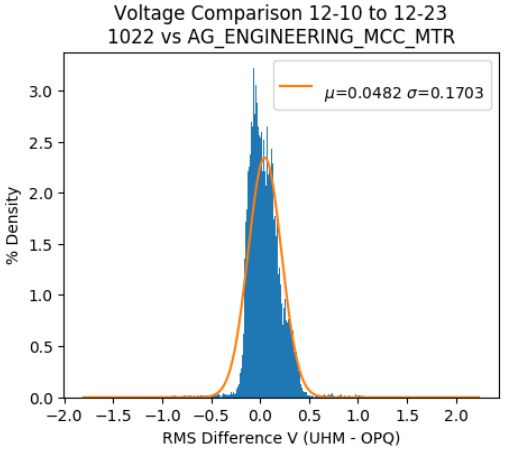
PILOT DEPLOYMENTS

- OPQ UHM Locations
  - Accessibility
  - Co-location with UHM sensors
  - Topology of UHM micro-grid
- Lokahi Locations
  - Ad-hoc public sensor data

RESULTS OF DATA VALIDATION: OPQ



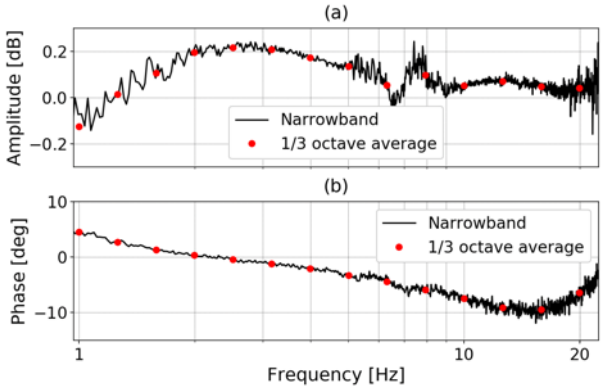


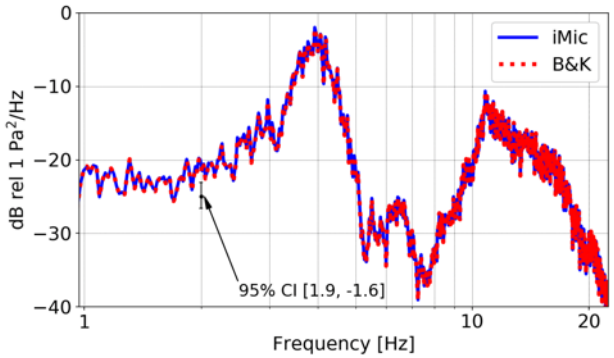


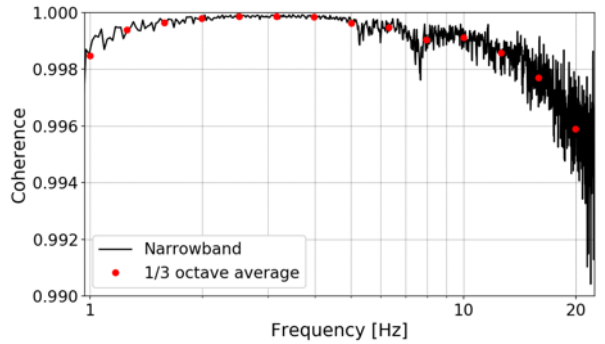
GE PQMII

- THD
  - Threshold: 5% THD
  - σ: 0.0421% THD
- Frequency
  - Threshold: 1 Hz
  - σ: 0.0079 Hz
- Voltage
  - Threshold: 6 V
  - σ: 0.1703 V

RESULTS OF DATA VALIDATION: LOKAHI





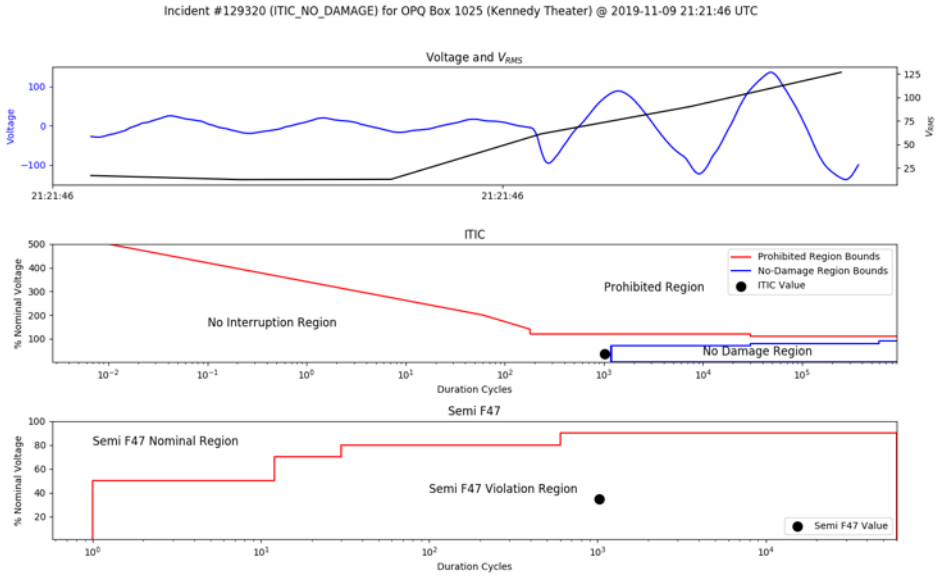


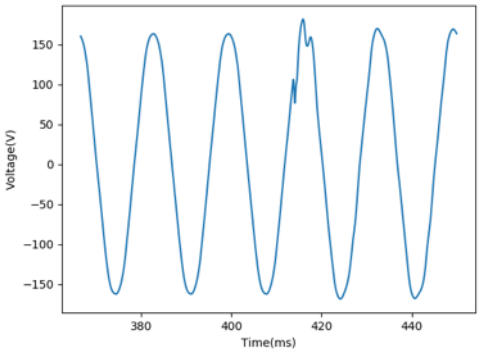
Bruel & Kjaer Microphone
Type 4193

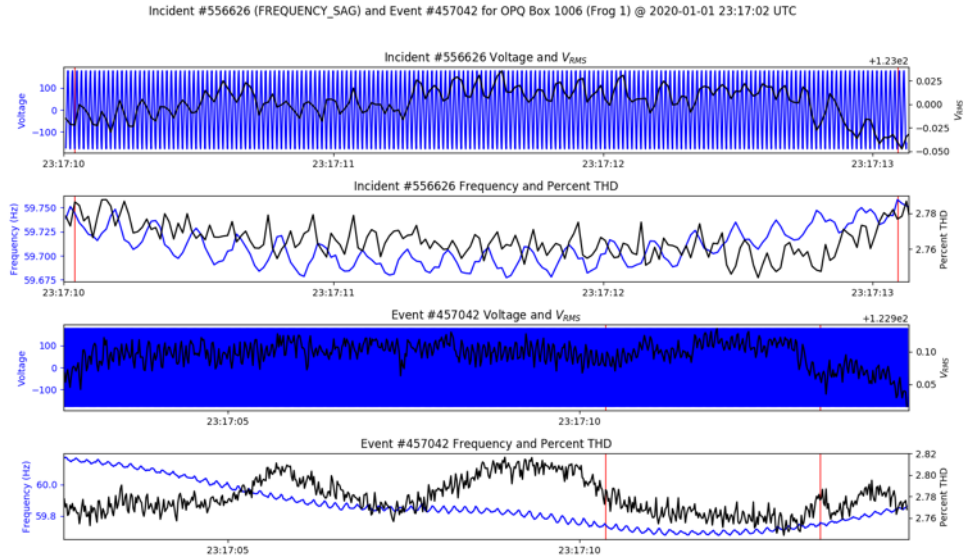
- Lokahi sensors meet the validity requirements of the IMS (>95% confidence interval)
- *Asmar 2018*

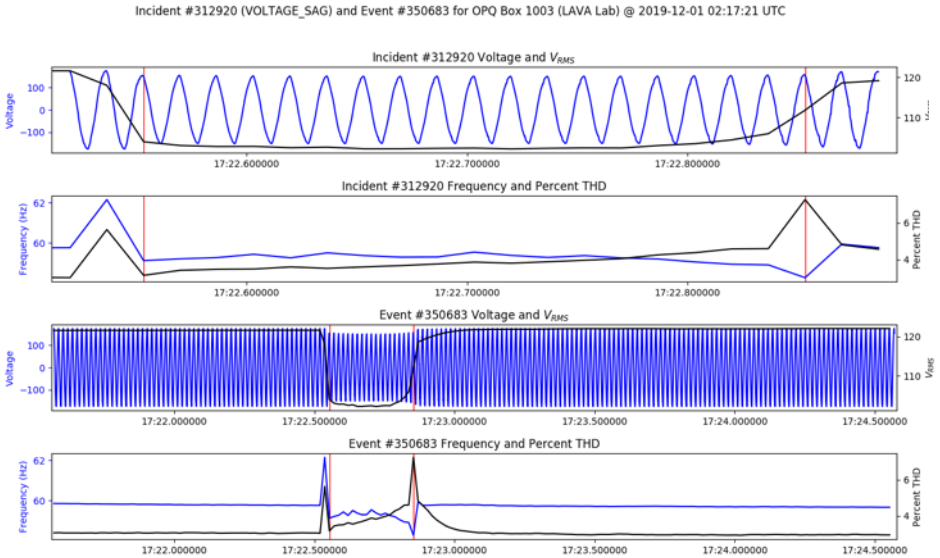
RESULTS OF GENERALITY OF LAHA: OPQ

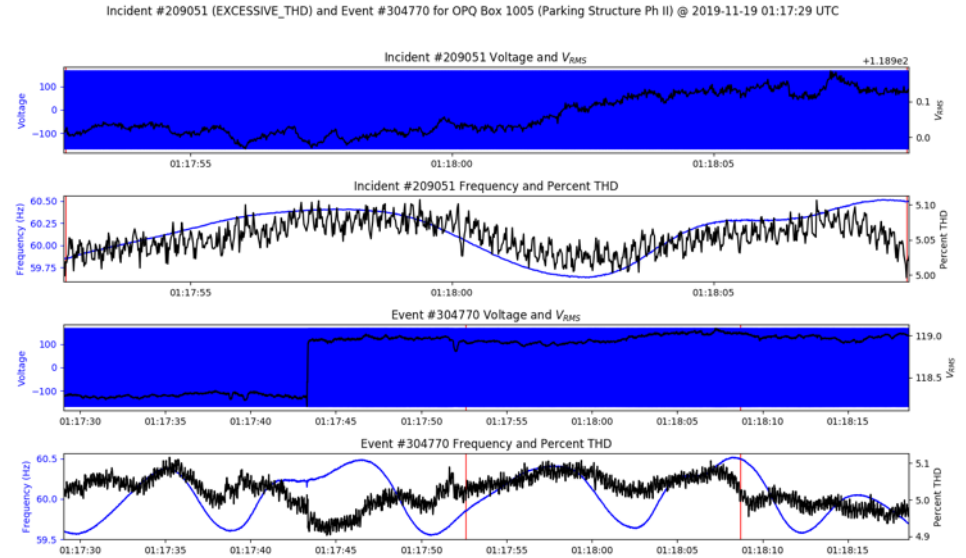
Incident Classification	Total Observed	Mean Observed / Day
FREQUENCY_SWELL	291235	3235.94
FREQUENCY_SAG	244286	2714.29
EXCESSIVE_THD	21395	237.72
VOLTAGE_SAG	620	6.89
ITIC_NO_DAMAGE	93	1.03
SEMI_F47_VIOLATION	24	0.27
VOLTAGE_INTERRUPTION	16	0.18
FREQUENCY_INTERRUPTION	14	0.16
VOLTAGE_SWELL	8	0.09





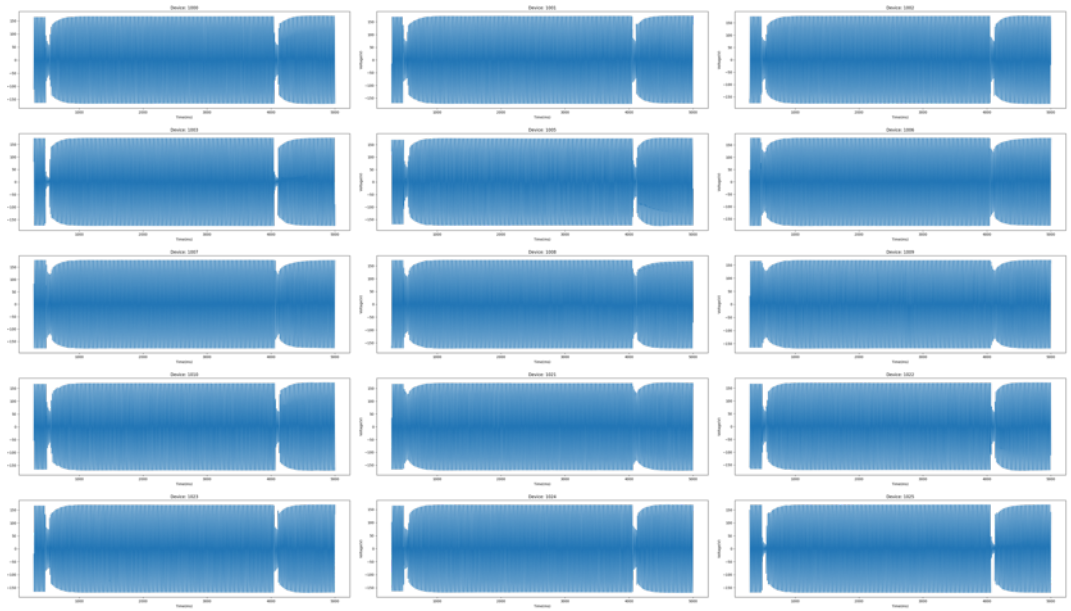






RESULTS OF GENERALITY OF LAHA: OPQ

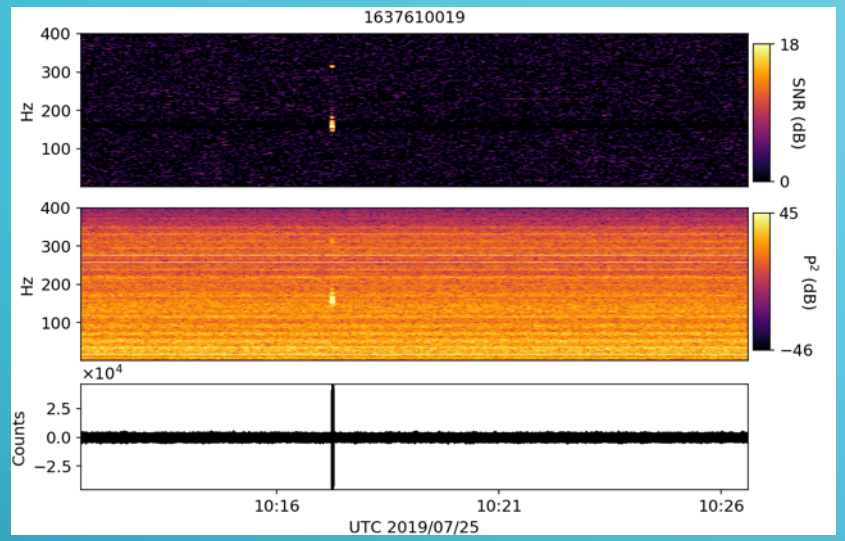
Total Events	Number of Boxes that Observed the Events
170925	1
1654	2
1109	3
853	4
593	5
416	6
354	7
246	8
203	9
160	10
162	11
130	12
169	13
210	14
477	15
463	16



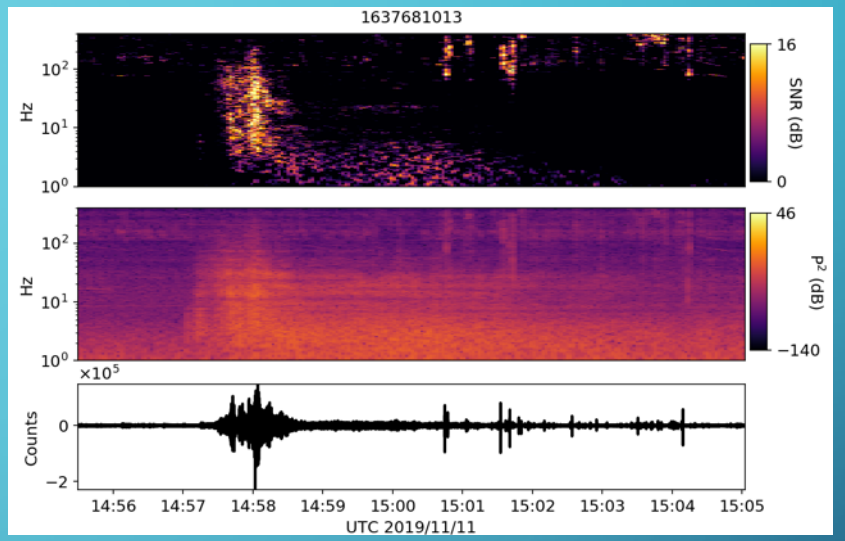
RESULTS OF GENERALITY OF LAHA: OPQ

RESULTS OF GENERALITY OF LAHA: LOKAHI

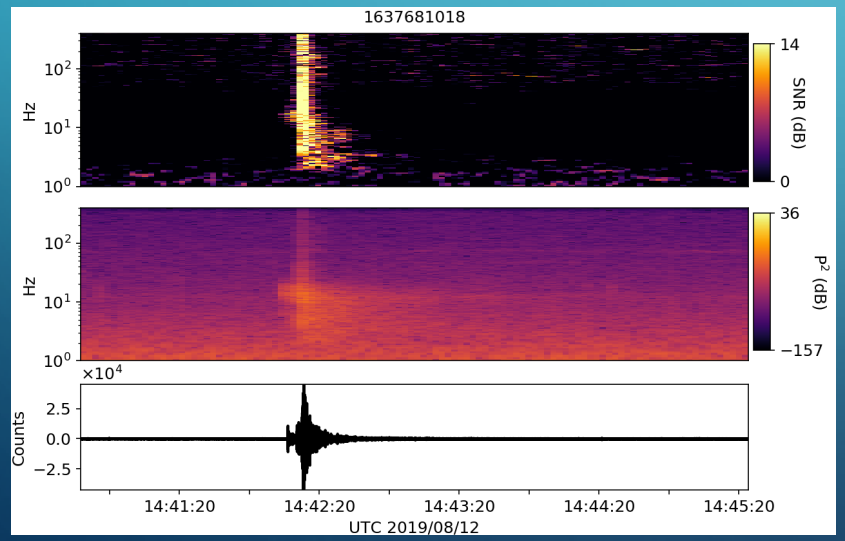
Full results available at redvox.io



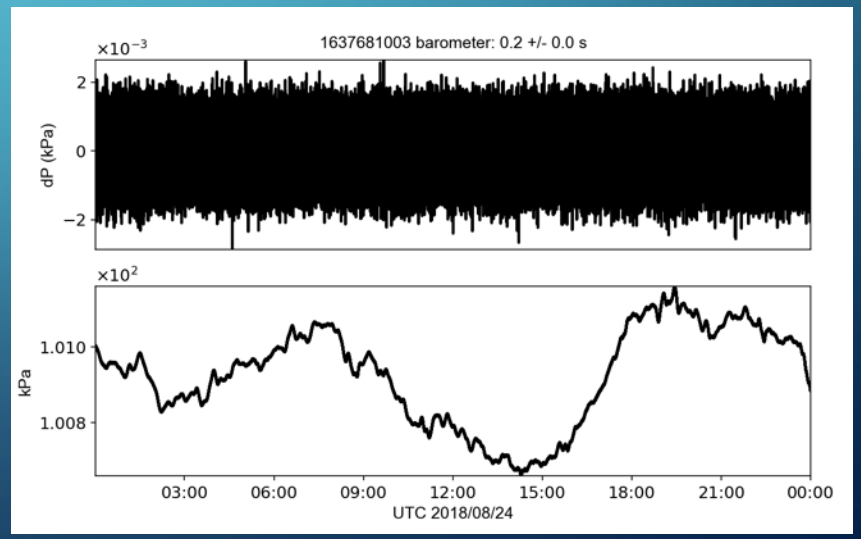
Meteor Entry over Maui



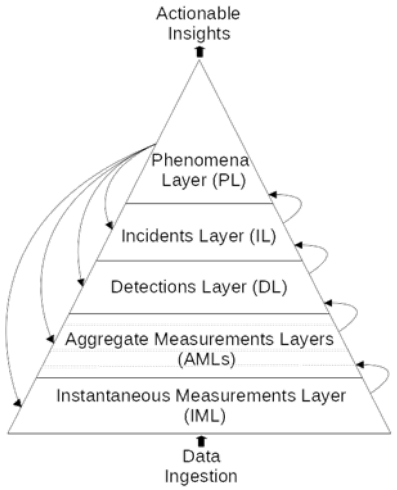
SpaceX Falcon 9



Big Island Earthquake



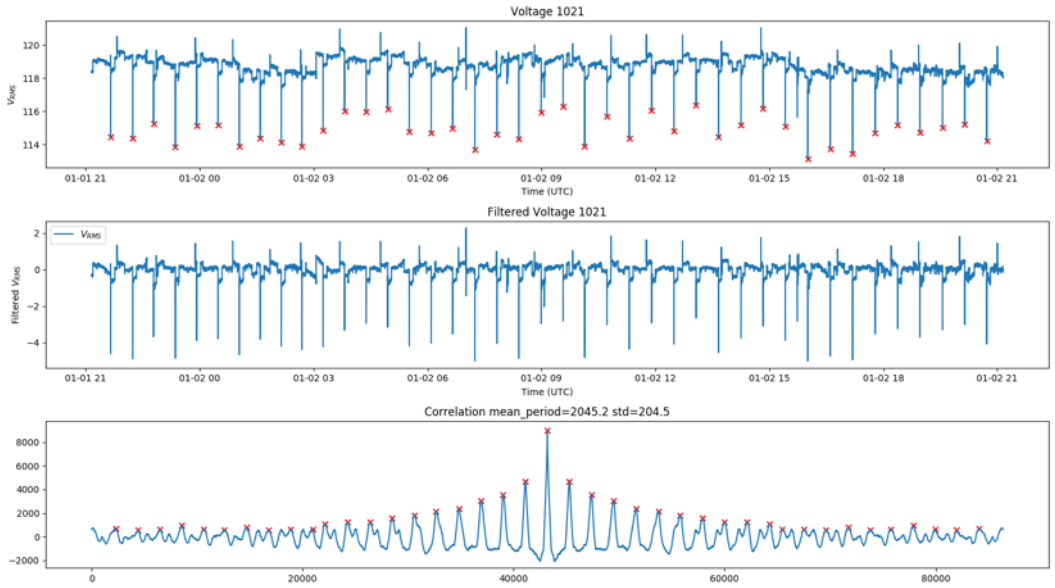
Hurricane Lane



Laha Level	OPQ	Lokahi
Phenomena	10,476	41
Incidents	415,250	41
Detections	91,449	1648
AML Trends	1,944,000	1,808,3720
AML Measurements	116,640,000	N/A
IML	1e12	6e12

RESULTS OF CONVERTING PRIMITIVE DATA INTO ACTIONABLE INSIGHTS:

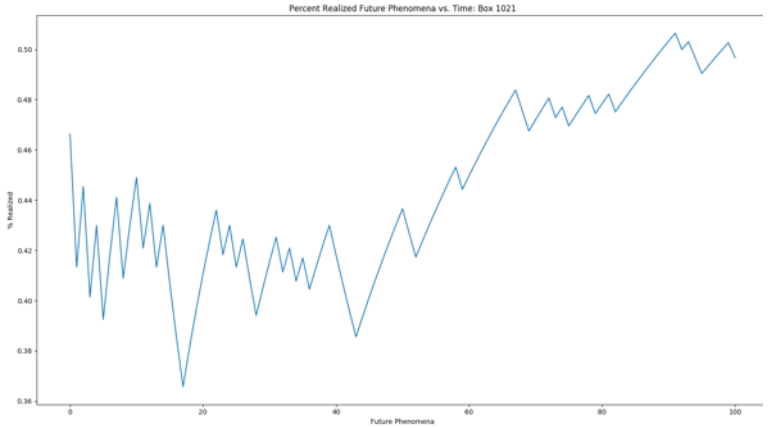
LAHA LEVEL HIERARCHY

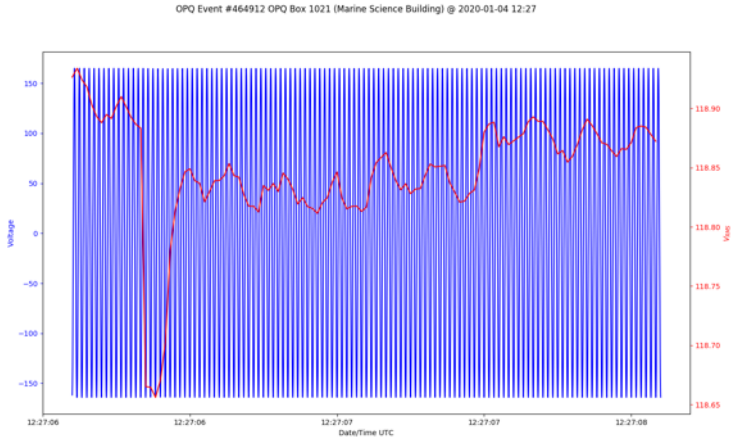


Box	Period	Std	Peaks	Periods	Events	Incidents	Mean Deviation
1021	2127.55	8.81	41	463	332	4	-3.14
1003	1406.75	81.66	17	263	11	4	1.03
1023	2017.0	60.21	5	298	47	0	-1.25
2001	2760.0	123.75	5	236	0	0	1.61

RESULTS OF CONVERTING PRIMITIVE DATA INTO ACTIONABLE INSIGHTS:

PERIODIC PHENOMENA

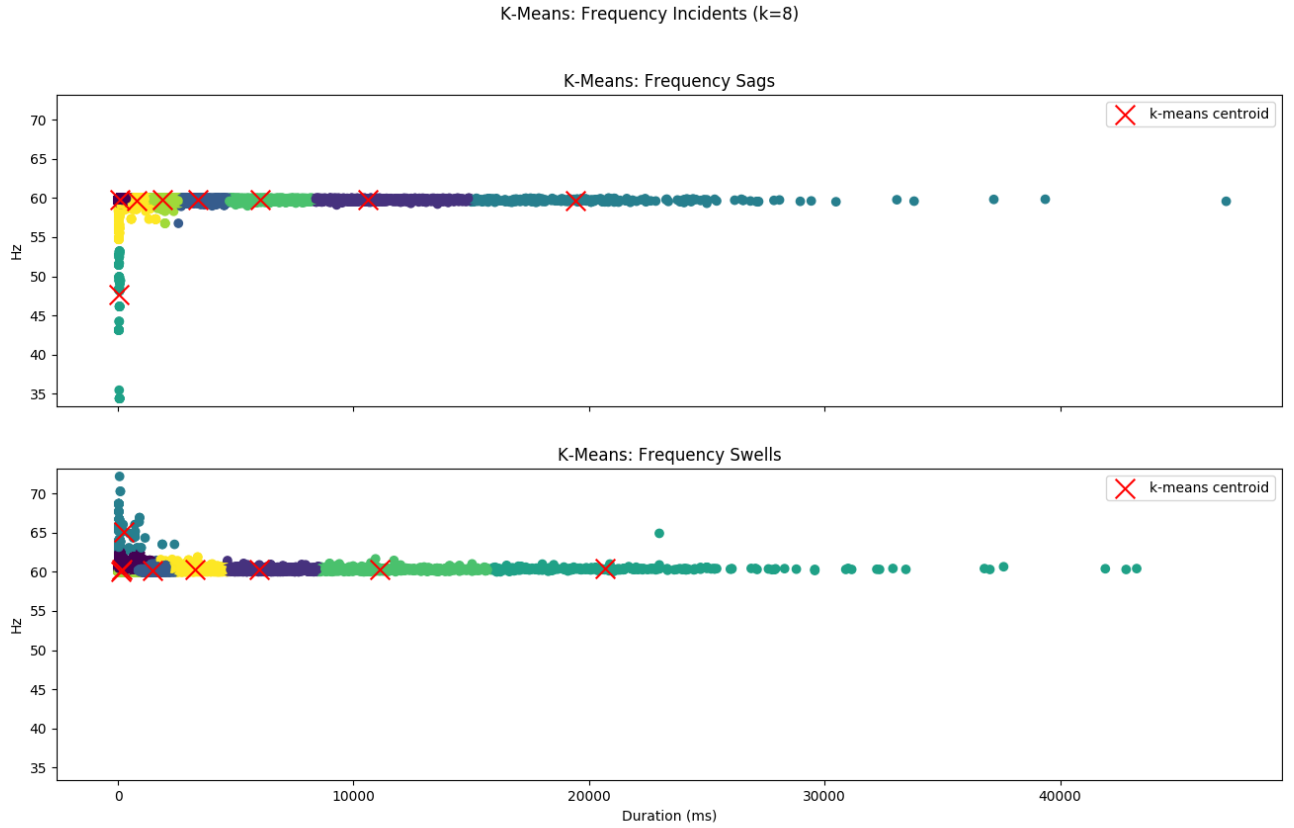




Box	Future Phenomena	Unrealized	Realized
1021	9	185	210
1003	113	52	61
1023	173	113	60
2001	91	91	0

RESULTS OF CONVERTING PRIMITIVE DATA INTO ACTIONABLE INSIGHTS:

FUTURE PHENOMENA



Cluster	Incidents	Mean Duration	Std Duration	Mean Value	Std Value
7	78577	138.63	176.19	60.10	0.06
0	95488	158.29	175.95	60.27	0.08
3	136	245.82	398.53	65.14	1.89
5	21972	1469.80	433.48	60.21	0.12
2	8954	3298.74	633.05	60.29	0.12
1	3422	6046.04	1072.05	60.31	0.11
6	1027	11297.67	2003.82	60.32	0.13
4	252	21019.67	4684.53	60.39	0.32

Cluster	Incidents	Mean Duration	Std Duration	Mean Value	Std Value
5	79	56.19	17.33	47.70	5.21
1	116769	98.91	93.97	59.84	0.08
6	35957	809.18	261.35	59.73	0.21
3	20059	1908.64	354.46	59.77	0.13
0	8931	3447.78	575.45	59.75	0.12
7	3121	6132.47	1016.73	59.74	0.13
4	1079	10780.30	1829.83	59.75	0.13
2	242	19729.35	4278.64	59.72	0.13

Type and Cluster Id	Incidents	Data Saved MB
FSag 1	116,769	319.81
FSag 6	35,957	711.42
FSwell 7	78,577	290.12
FSwell 0	95,488	397.61
Total	326,791 (-83%)	1718.96 (-2%)

RESULTS OF CONVERTING PRIMITIVE DATA INTO ACTIONABLE INSIGHTS:

SIMILARITY PHENOMENA

RESULTS OF DSN DATA MANAGEMENT

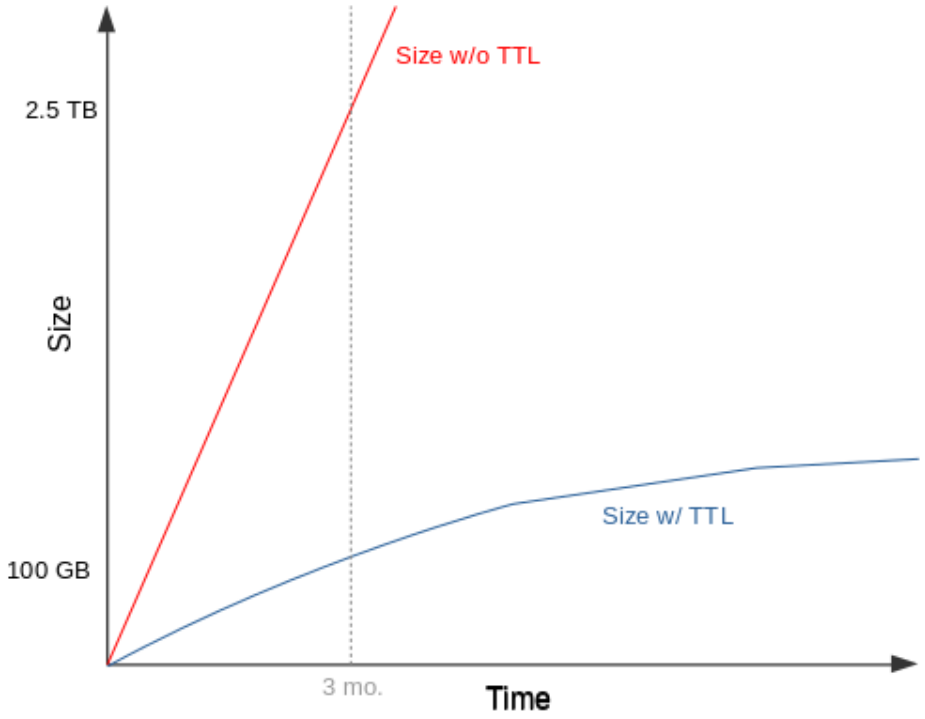
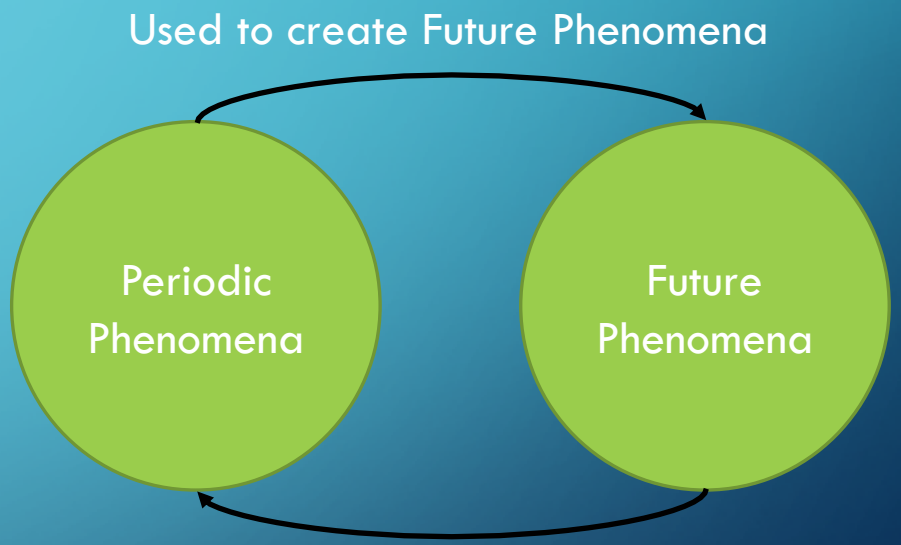


Illustration of OPQ DSN Data Management

- Estimated bounds
  - Analytical, Simulation
- OPQ (w/ TTL)
  - ~15 sensors/3 months
  - Actual: ~100 GB (w/ TTL)
  - Estimated: 2.5 TB (w/o TTL)
  - Difference: -60%
- Lokahi (w/o TTL)
  - ~100 sensors/3 months
  - Actual: 1 TB (w/o TTL)
  - Estimated: 10 GB (w/ TTL)
  - Difference: +99%

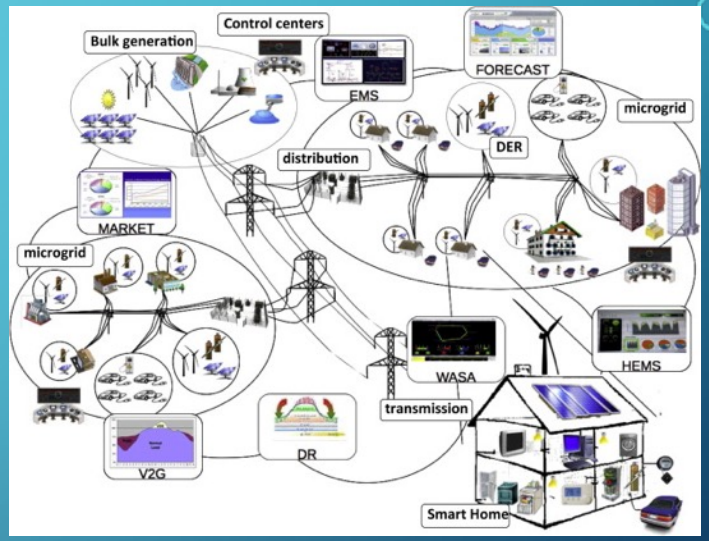
RESULTS OF DSN SELF-OPTIMIZATION

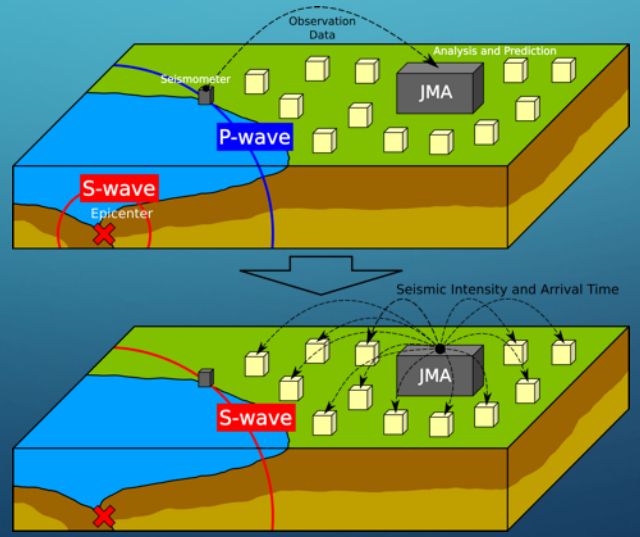
- Adaptive optimizations for triggering
  - Dynamically alter measurement rate (1Hz->6Hz)
- Adaptive optimizations for detection/classification
  - Dynamically alter thresholds
  - **37/210 predicted events are sub-threshold**

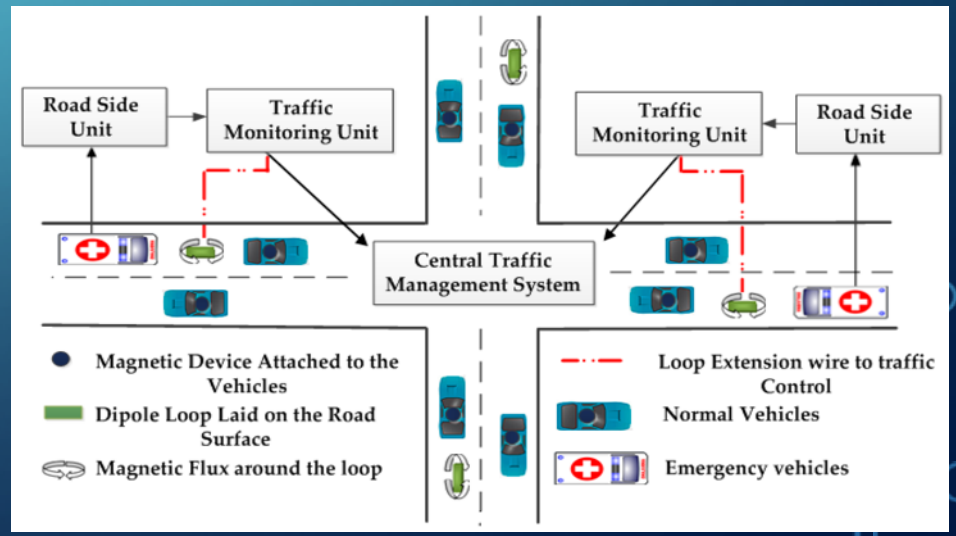


DISCUSSION ON LAHA SUITABILITY FOR DSNS

- Sensor Sampling Rate
- Network Uptime
- Signal-to-Noise
- Data Acquisition
- Sensor Availability
- Numerous Events
- Multiple Signal Classifications
- Designed for Laha
- Other DSNs

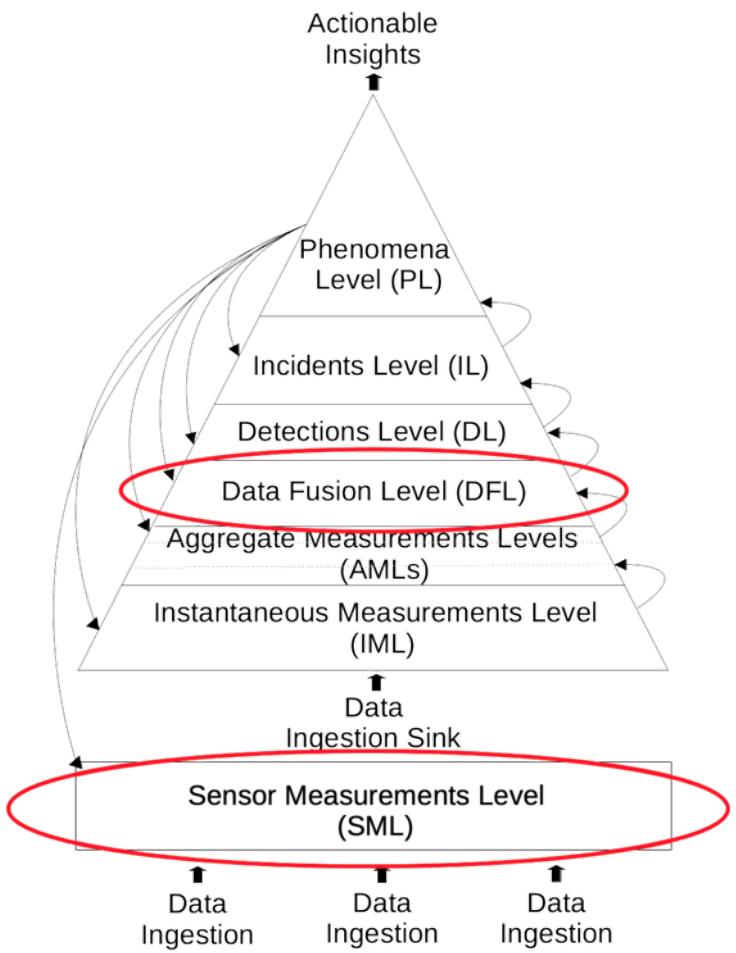






CONCLUSIONS

- Claims
  - Generality
  - Convert primitive data into actionable insights
  - Tiered Big Data management
  - DSN Self-optimization
- Contributions
  - Laha design
  - 2 Laha-compatible DSNs
  - Evaluations of DSNs
  - Implications for modern DSNs



FUTURE DIRECTIONS

- Explore how more renewable intermittent energy sources can be integrated with Hawaii's grids.
- Explore techniques for providing early detection of storms, tsunamis, volcanic eruptions, and other natural phenomena.
- Provide more opportunities for data fusion and data collaboration.

THANK YOU