Anomalies in the Radio Neutrino Observatory Greenland

Zack Meyers
Copenhagen, July 20, 2023
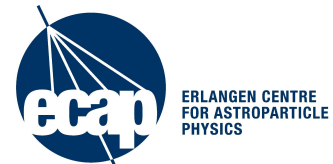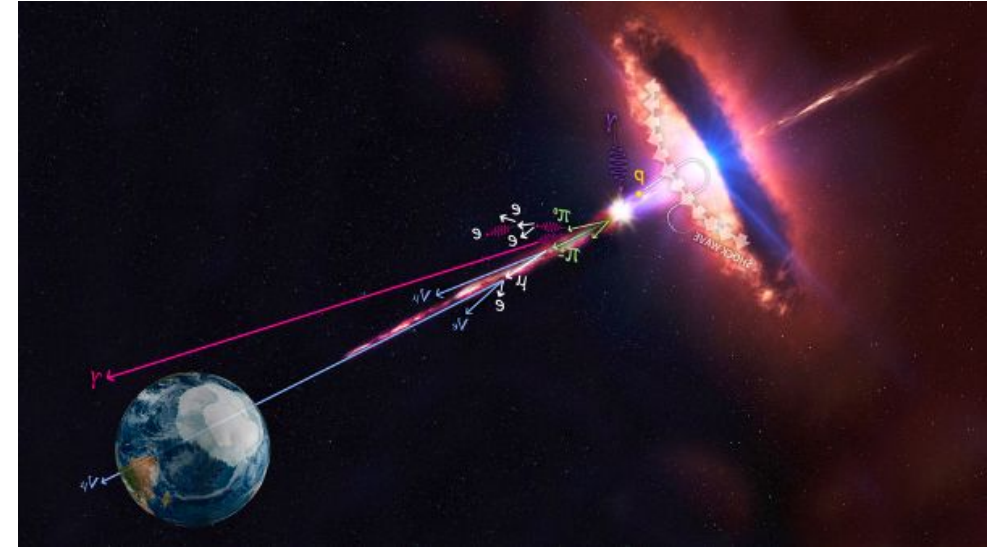
The Radio Neutrino Observatory Greenland
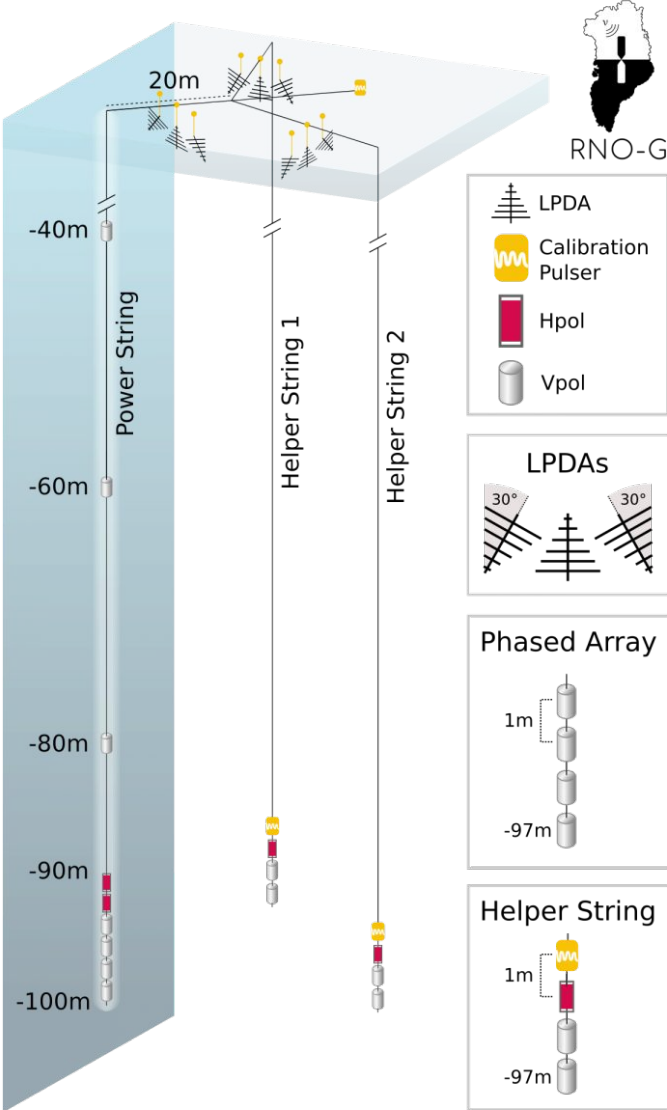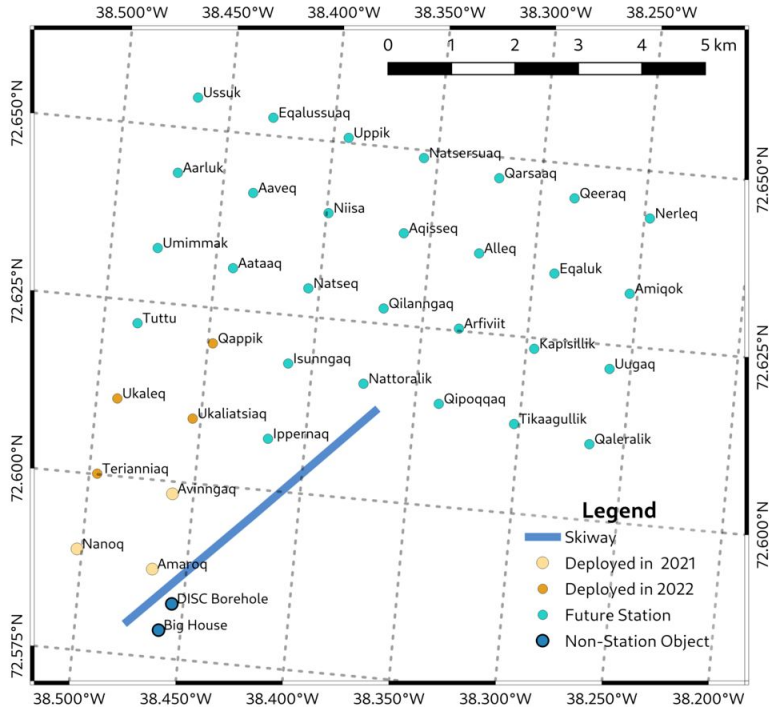
RNO-G

The Radio Neutrino Observatory Greenland
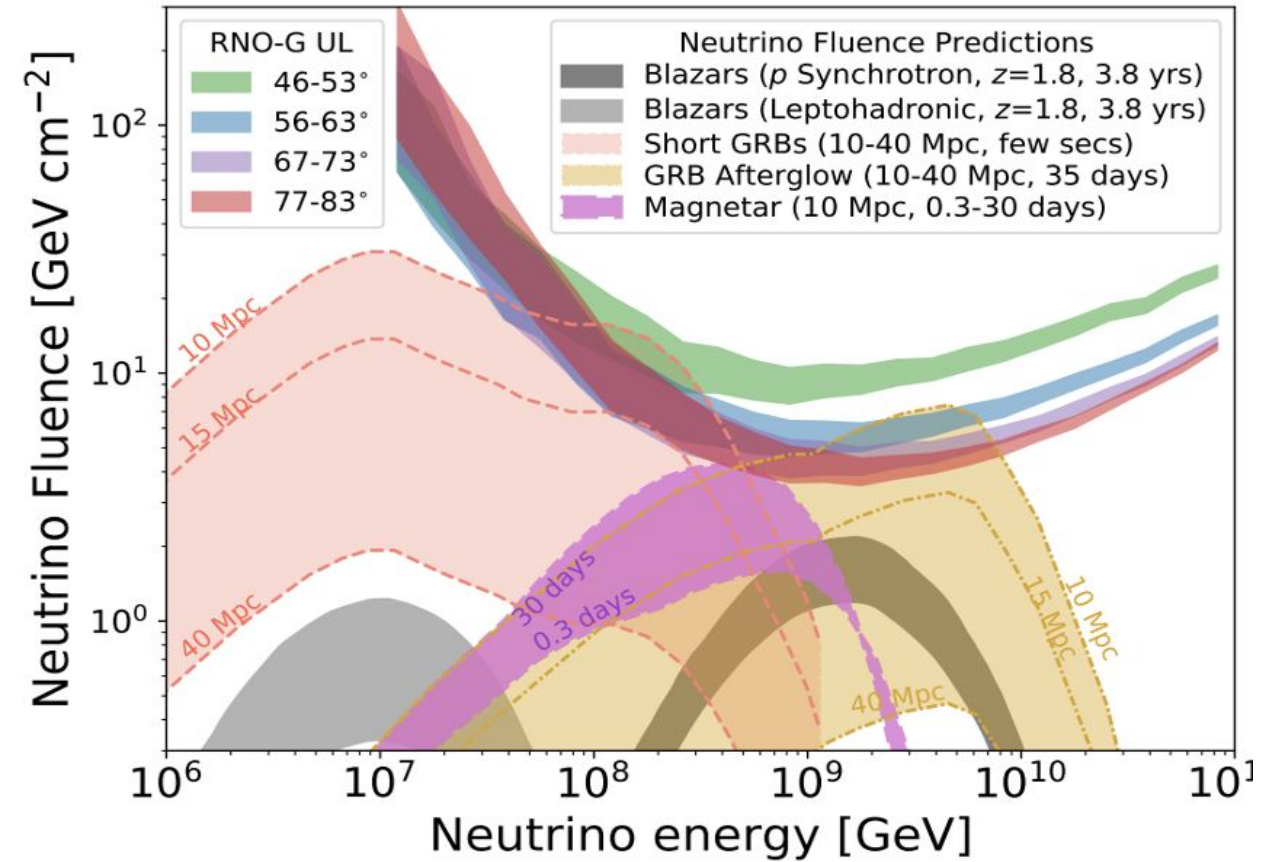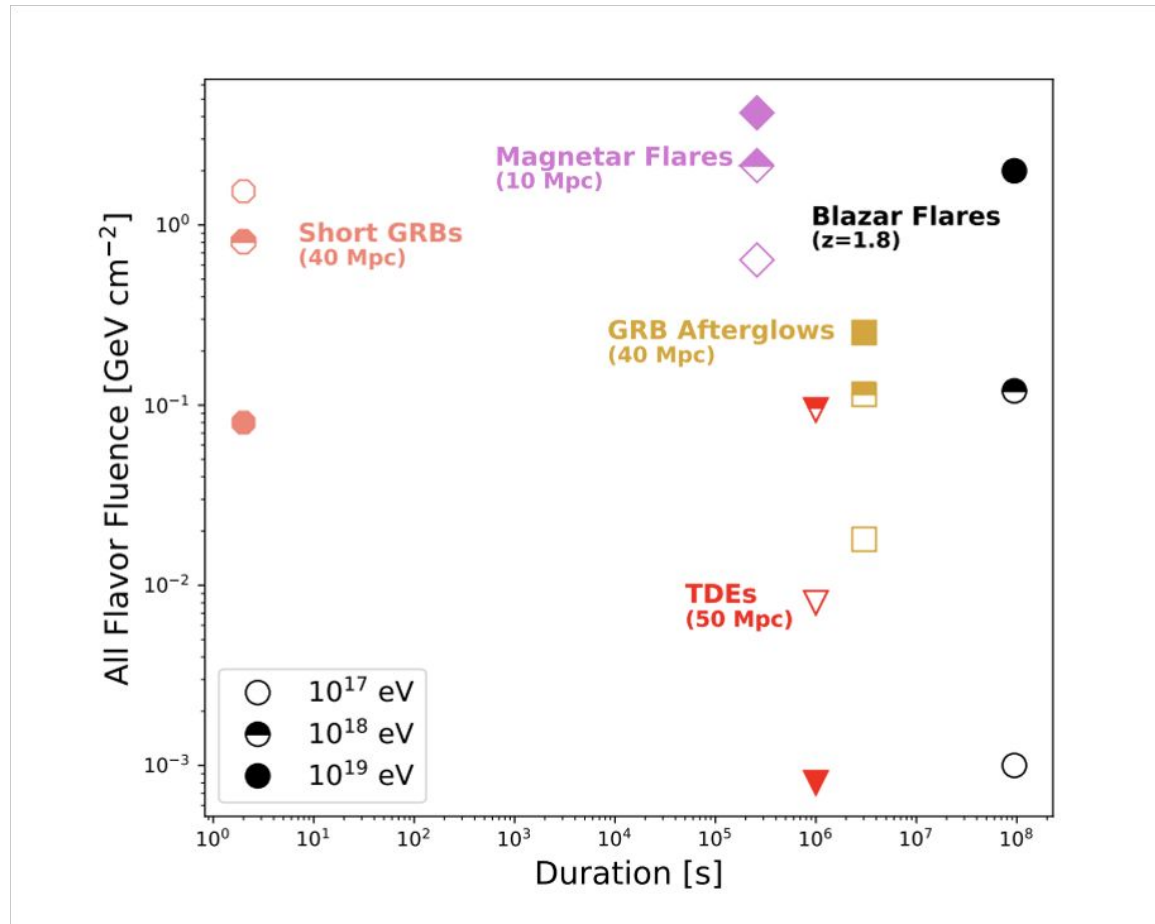
Why do we like Neutrinos

The Radio Neutrino Observatory Greenland

Askaryan Effect

The Radio Neutrino Observatory Greenland

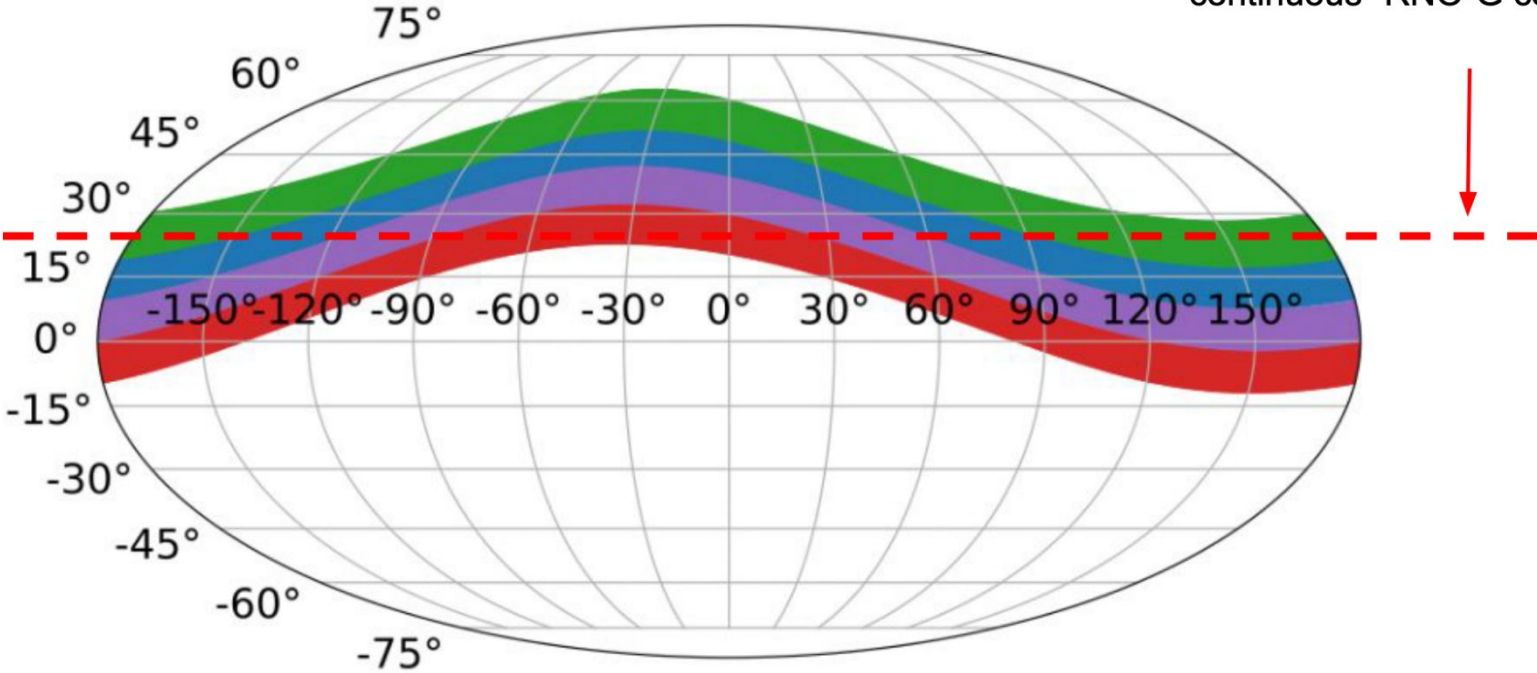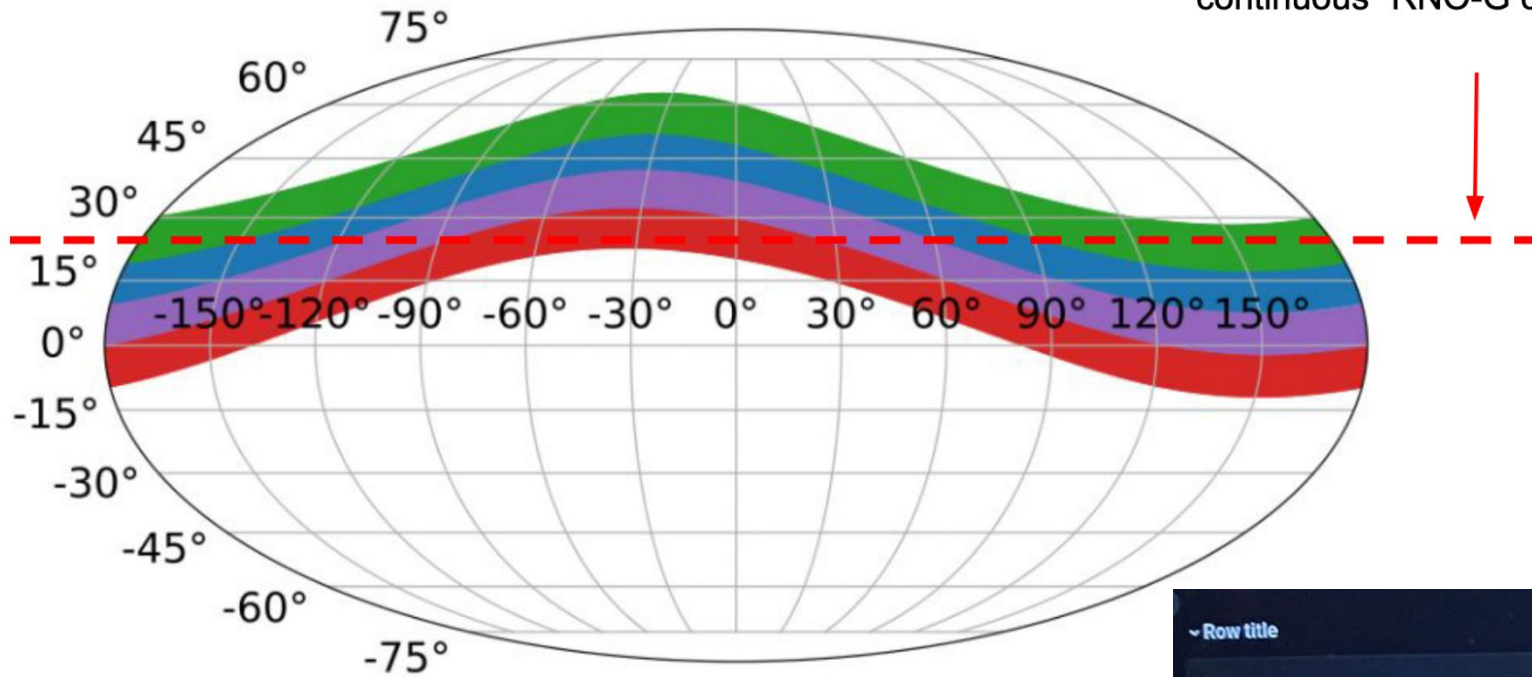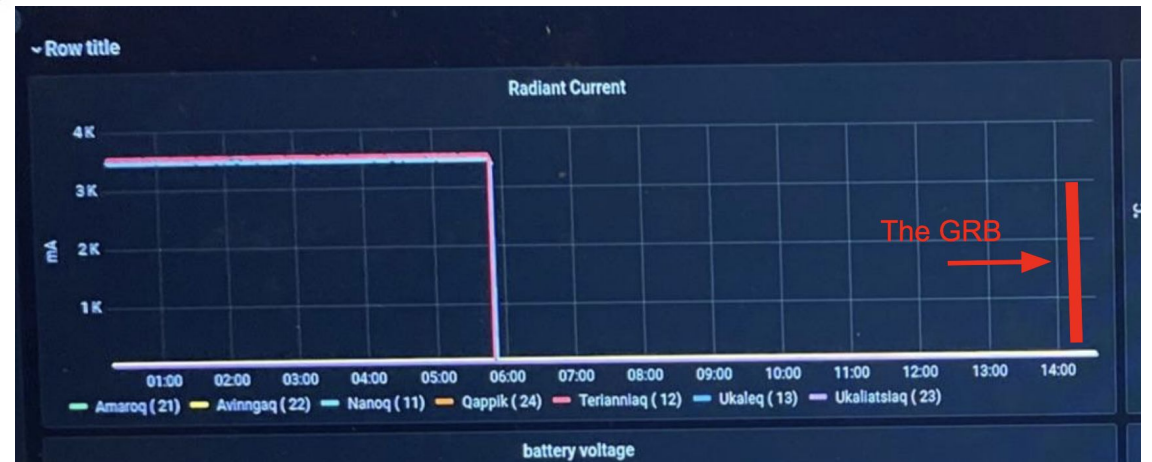## Progenitors and Sensitivities

GRB 221009A

(non-)detection

GRB declination (19 deg)

One of the only dec bands with
"continuous" RNO-G coverage

GRB 221009A

(non-)detection

GRB declination (19 deg)

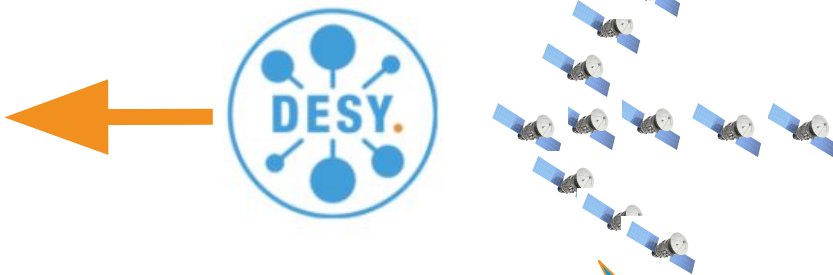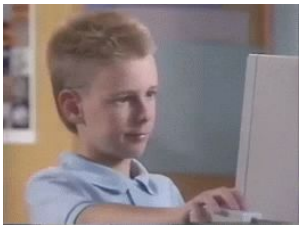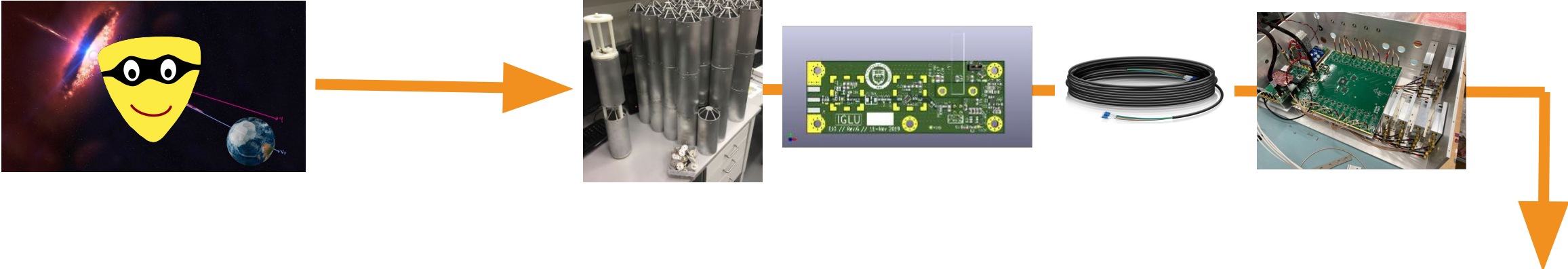One of the only dec bands with "continuous" RNO-G coverage
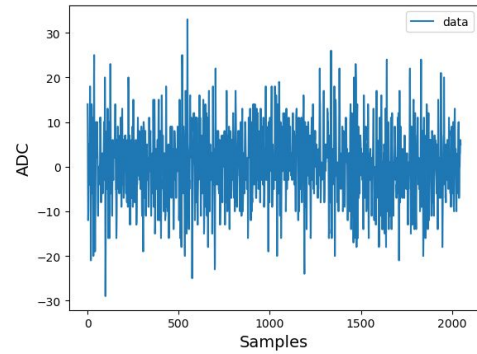

From B.Clark, 2022

Signal Chain

From the cosmos to your computer

10%

1% to 5%?

Anomaly Detection

Using STFT Mosaic of Phased Array

Anomaly Detection

Using STFT Mosaic of Phased Array

Anomaly Detection

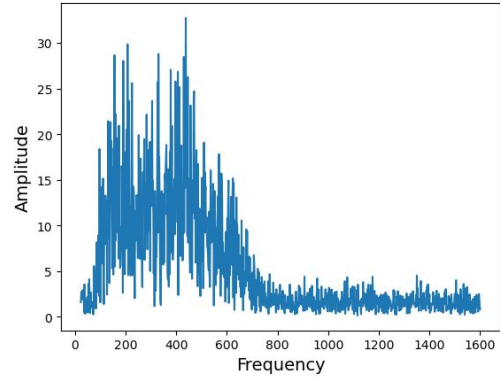## Using STFT Mosaic of Phased Array
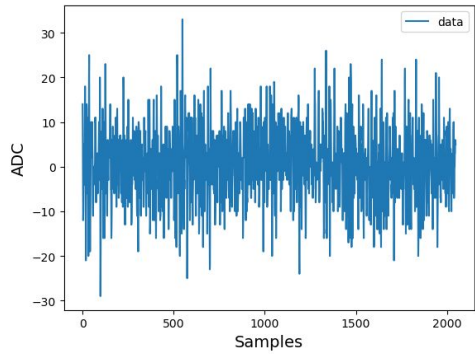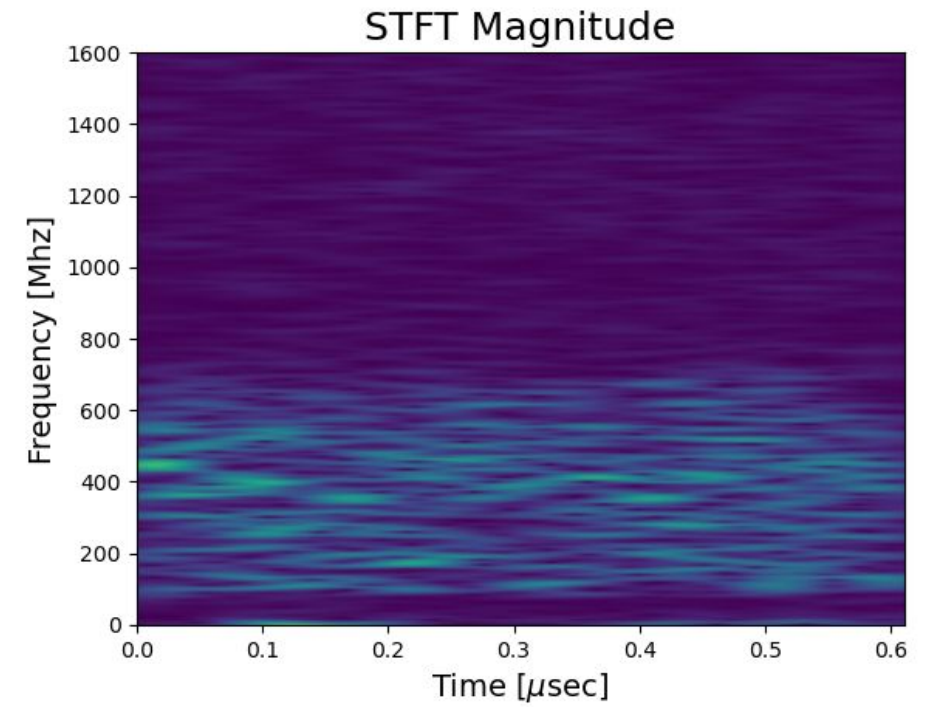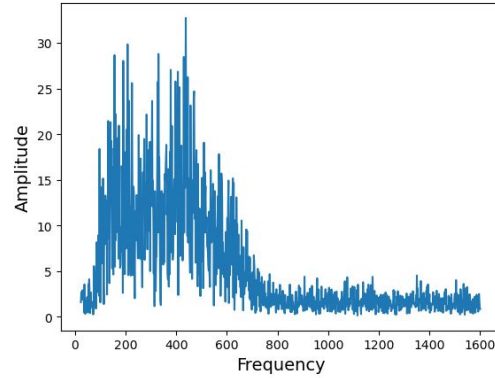
Anomaly Detection
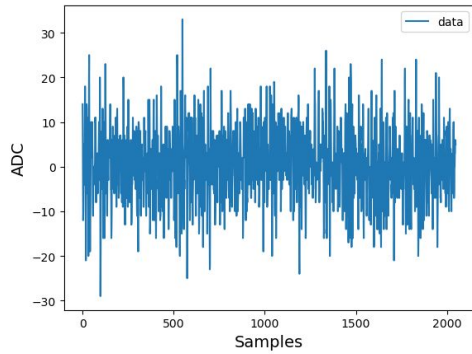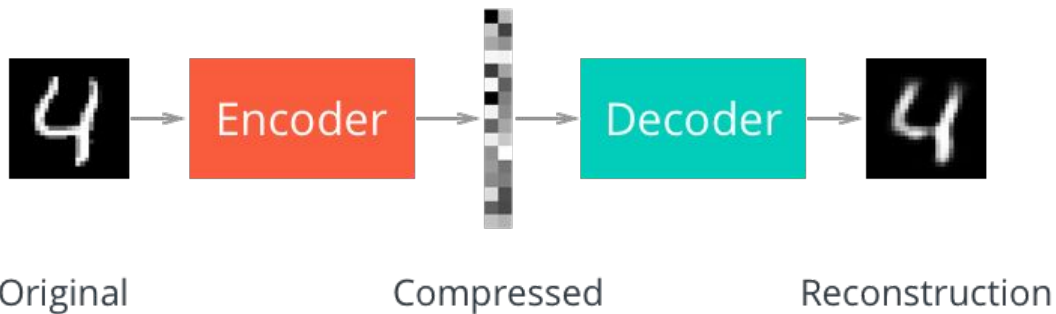
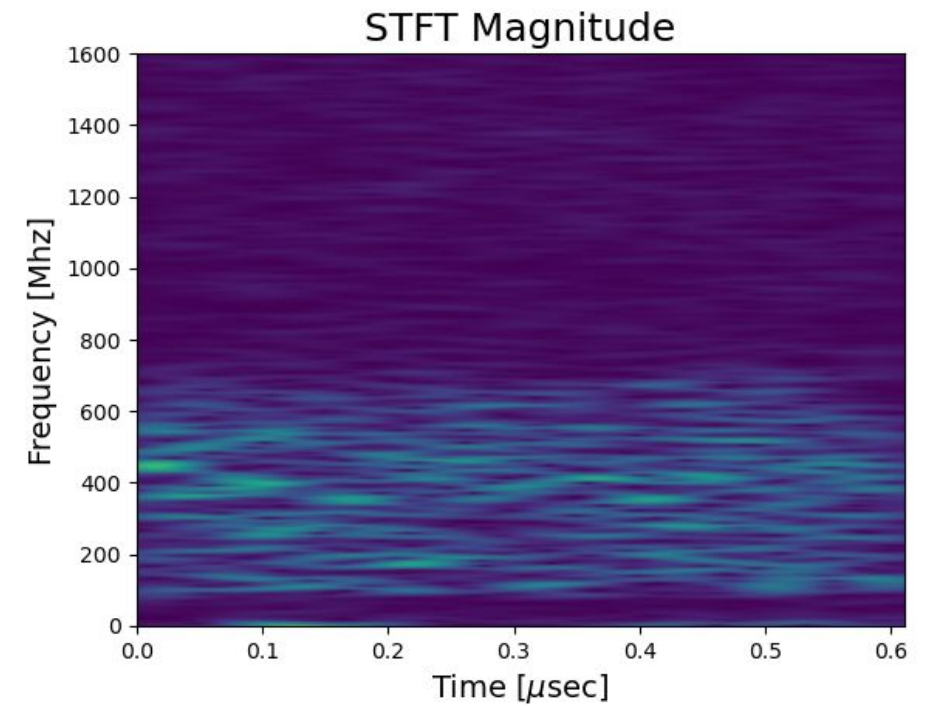## Using STFT Mosaic of Phased Array

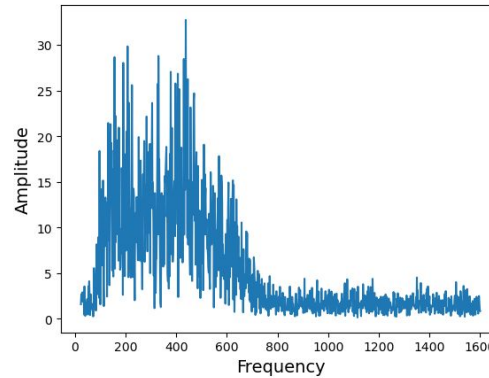# Anomaly Detection

Using STFT Mosaic of Phased Array
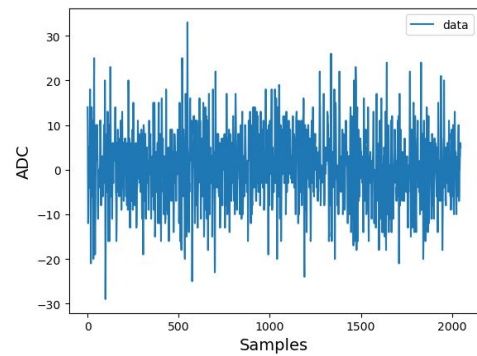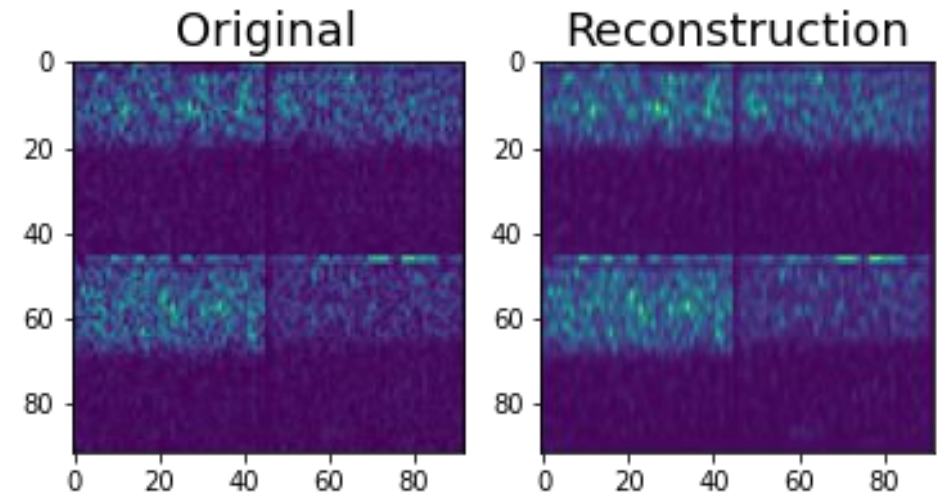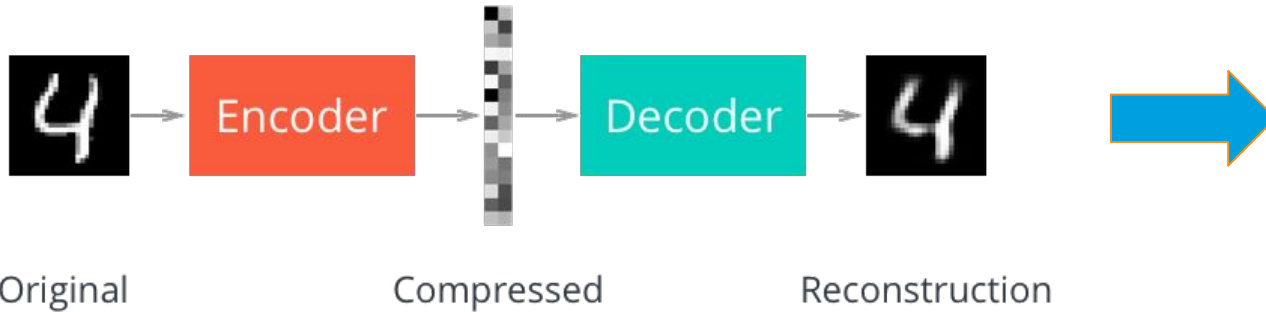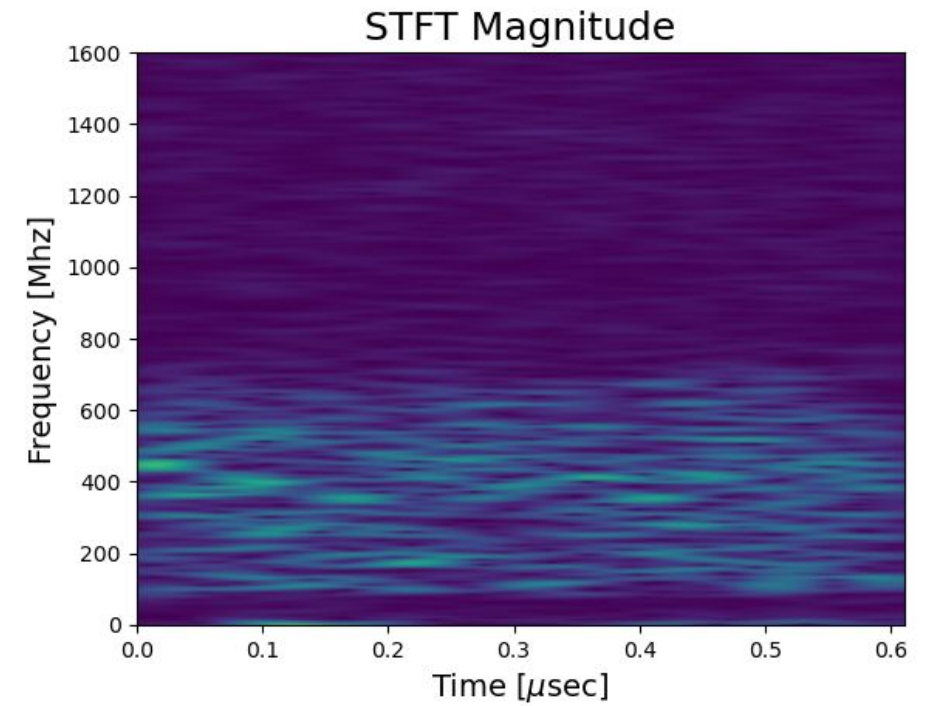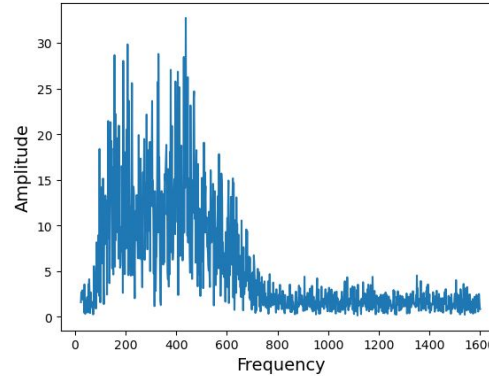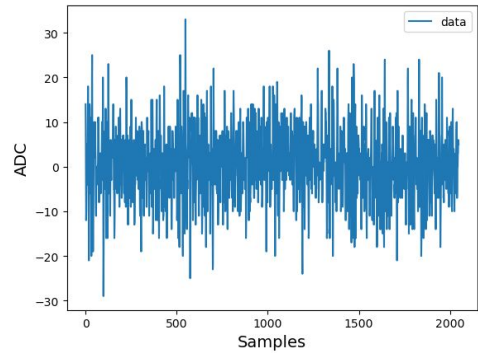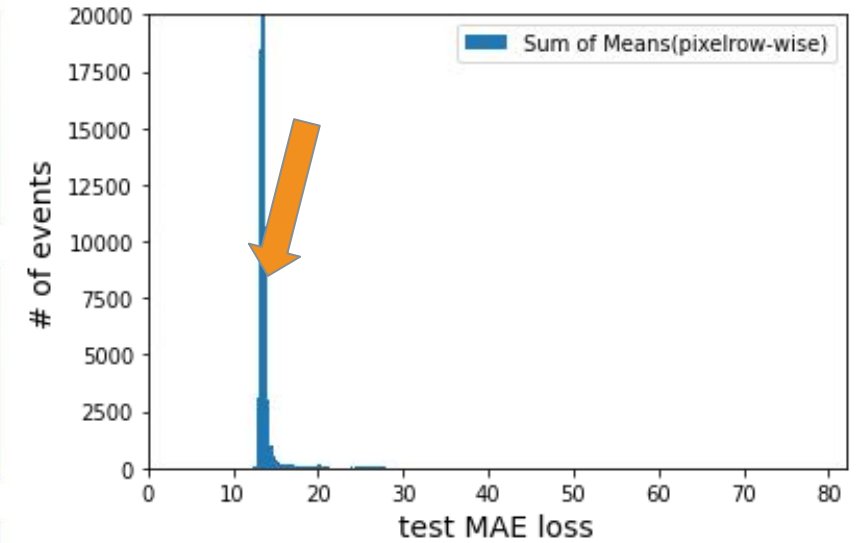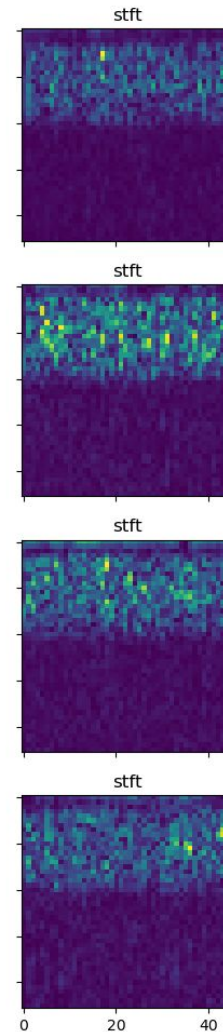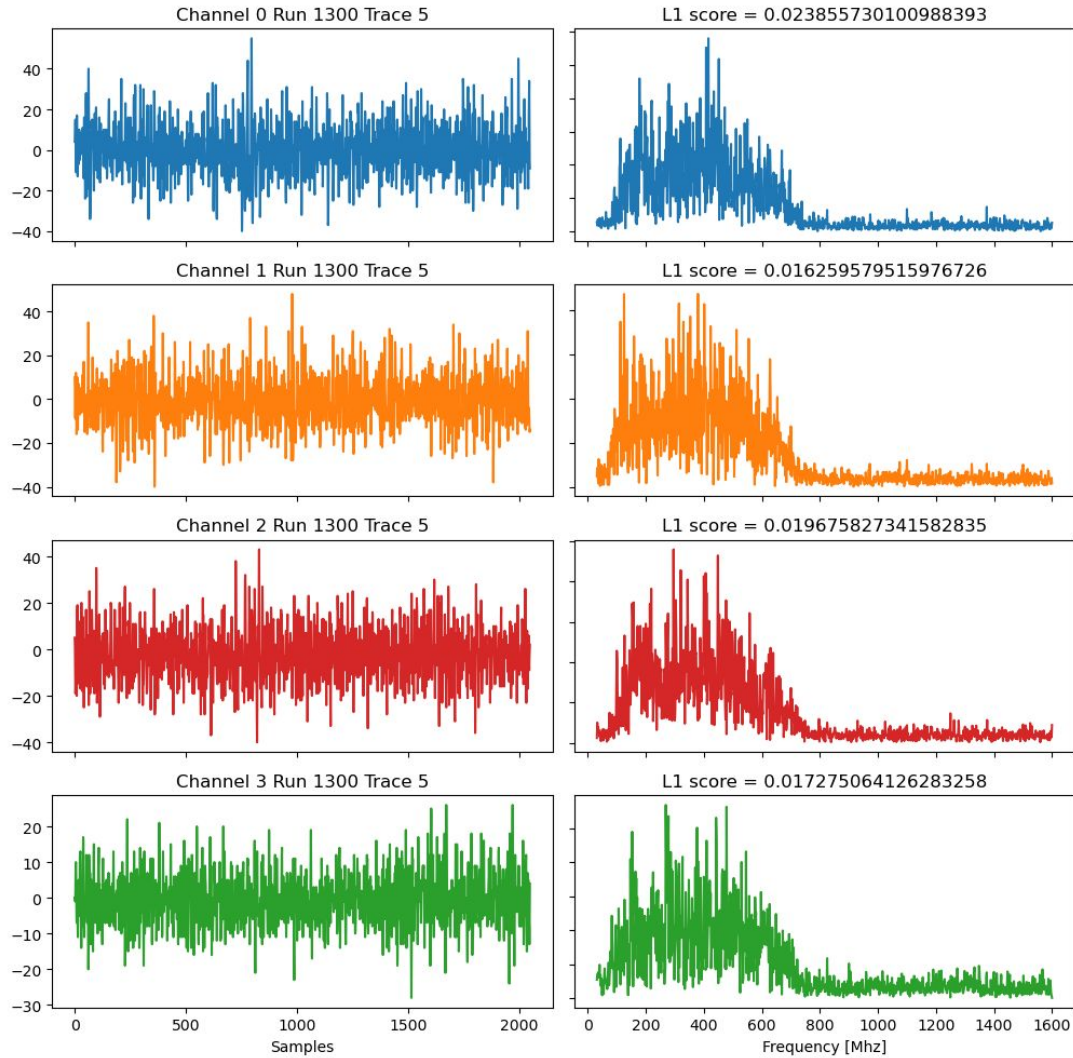
Anomaly Detection

Thermal Noise

Anomaly Detection

Continuous Wave (CW)
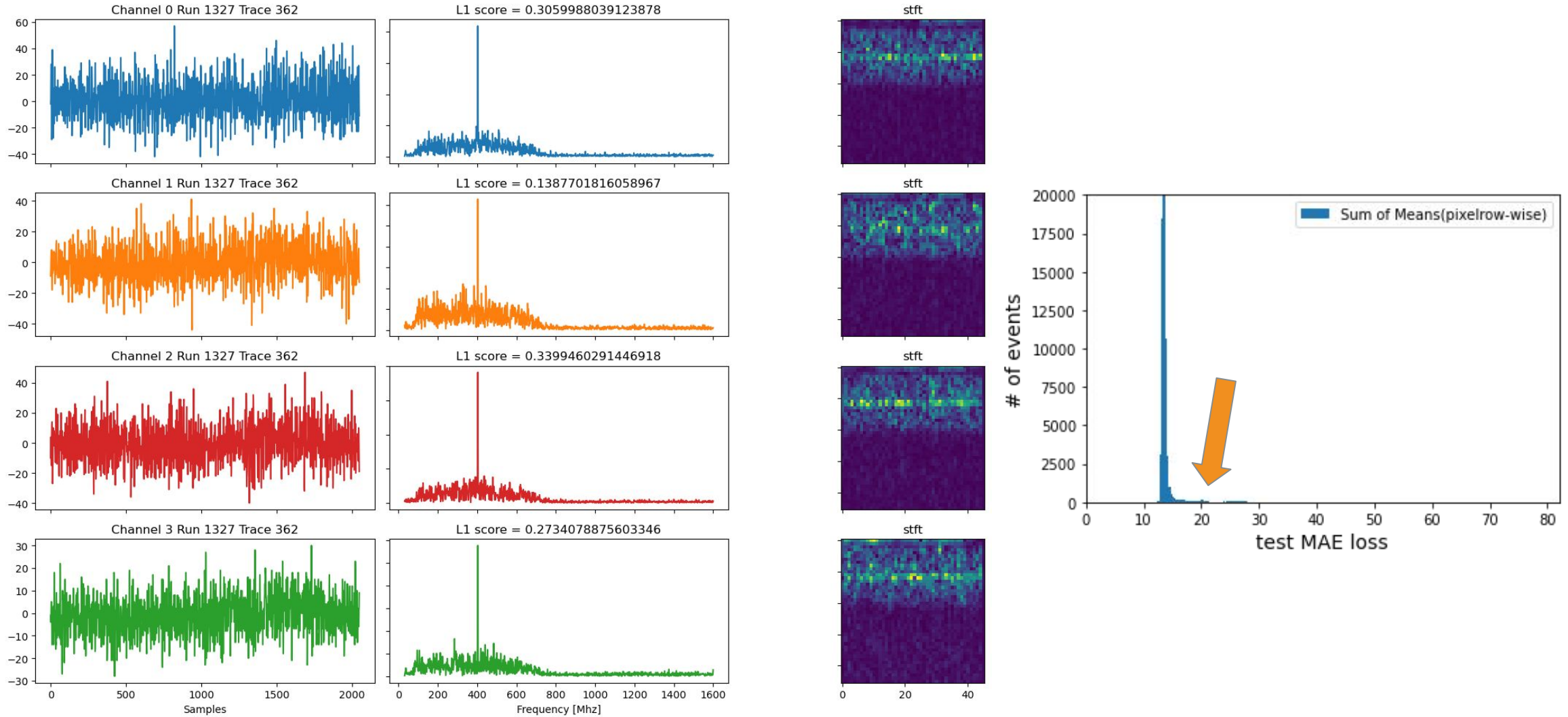
Anomaly Detection

Calibration Pulsing
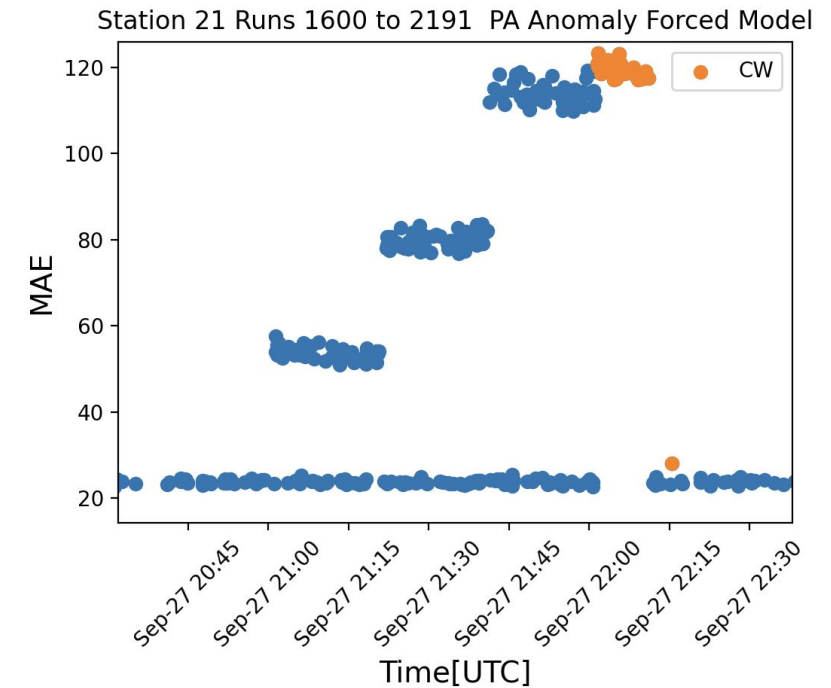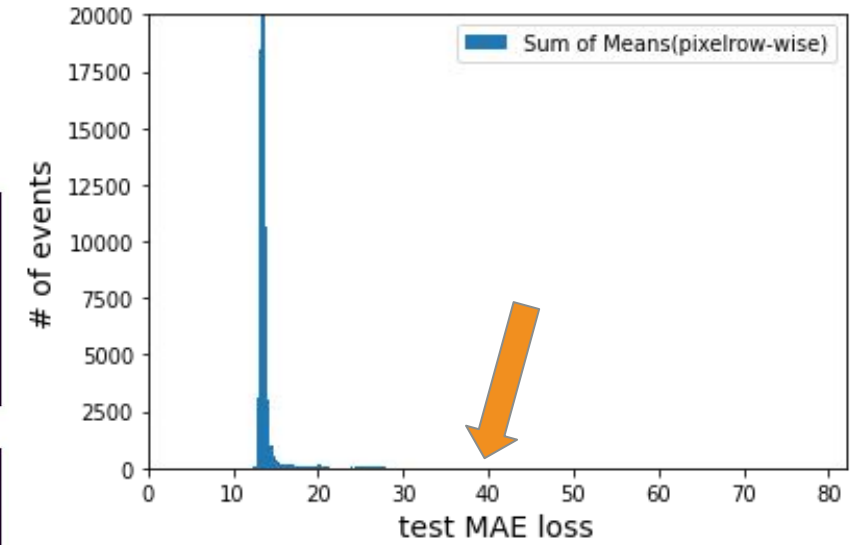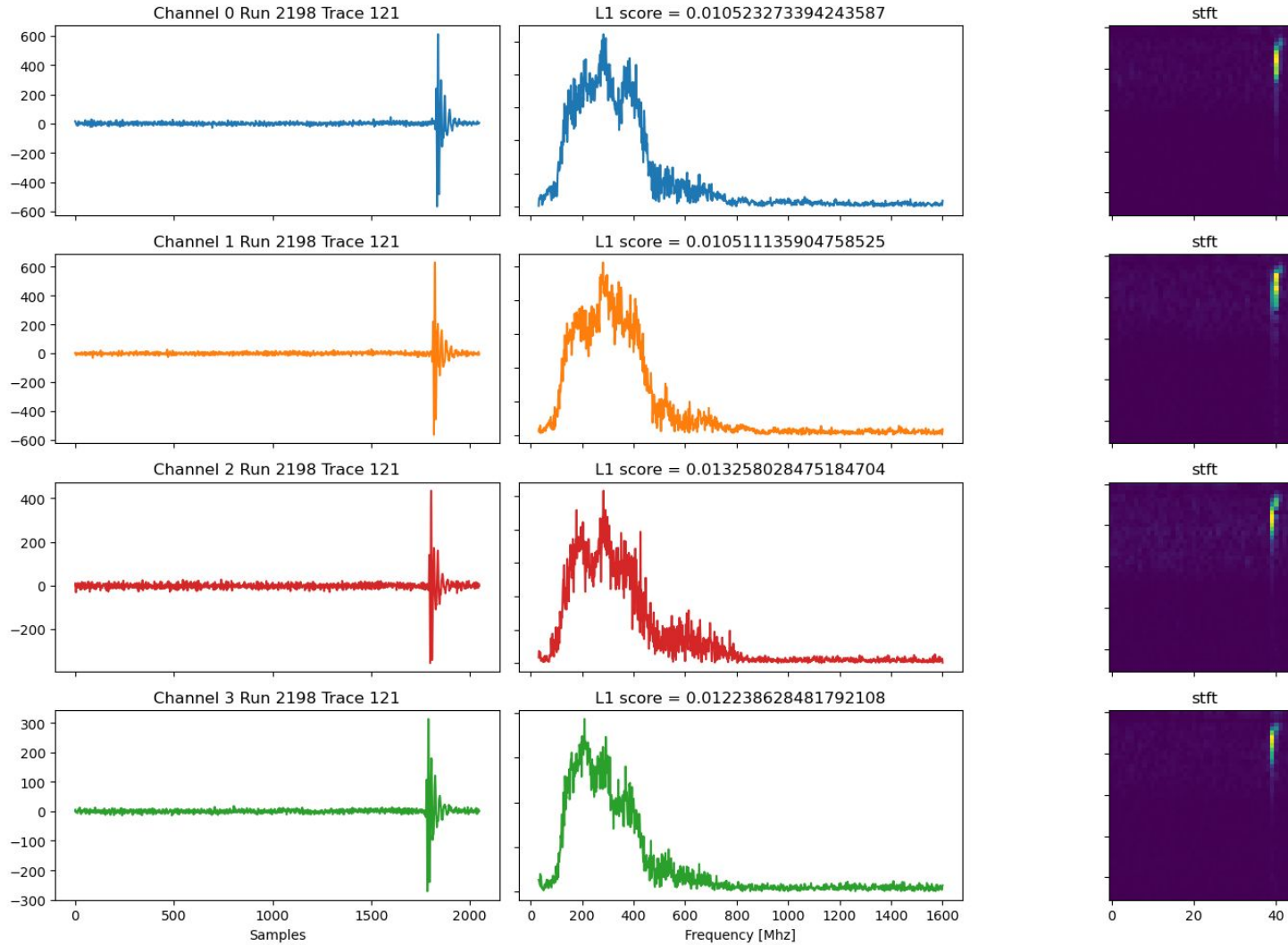
Anomaly Detection

Storm? Ice Quakes?
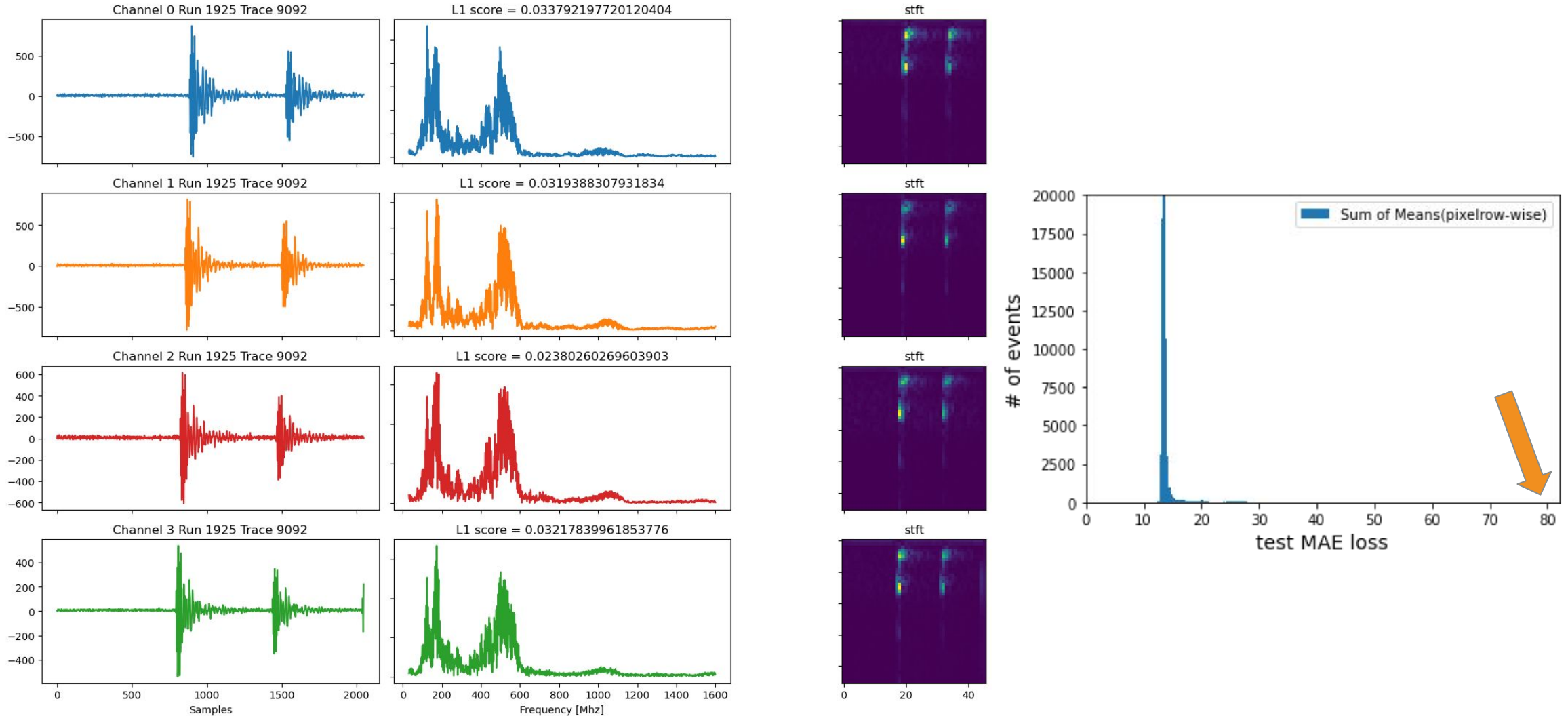
Snowmobiles?

September 10th – Snowmobile?

Station 21 Runs 1924 to 1931 PA Anomaly Forced Model
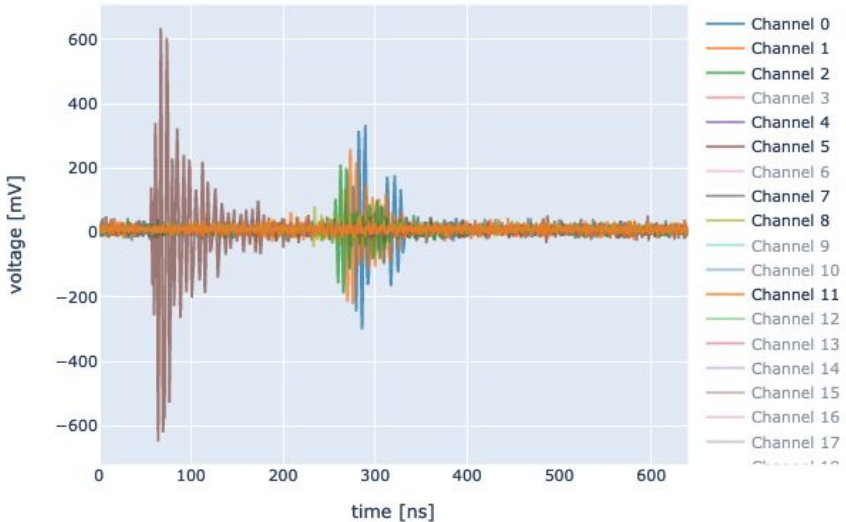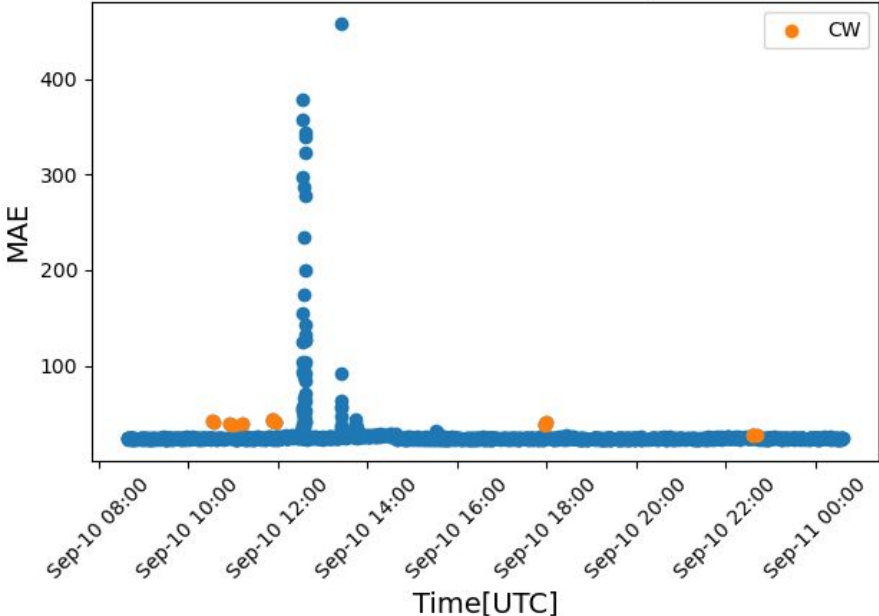
Station 13 Runs 817 to 822 PA Anomaly Forced Model
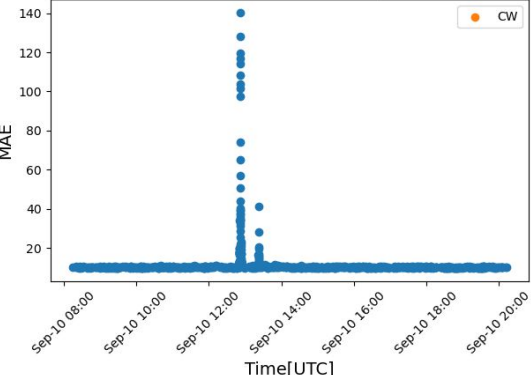
Station 22 Runs 1849 to 1853 PA Anomaly Forced Model
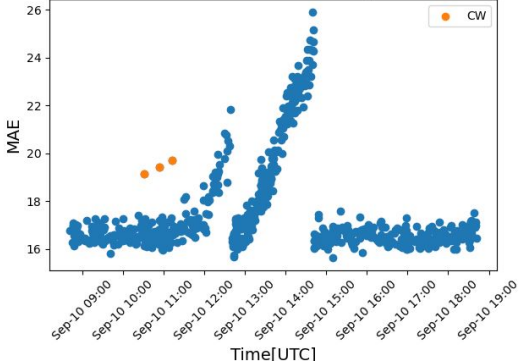
Station 11 Runs 1527 to 1531 PA Anomaly Forced Model
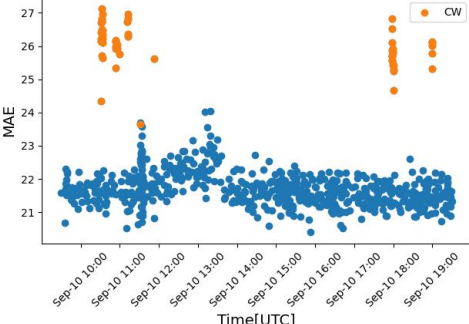
Station 23 Runs 835 to 839 PA Anomaly Forced Model
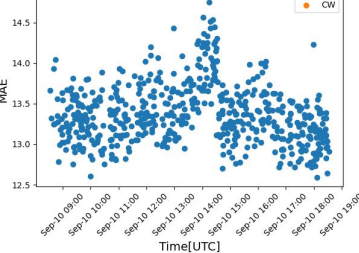
Station 24 Runs 675 to 679 PA Anomaly Forced Model
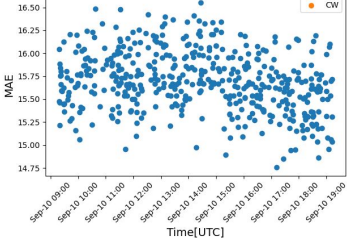
Snowmobiles!

Ice Sat Traverse
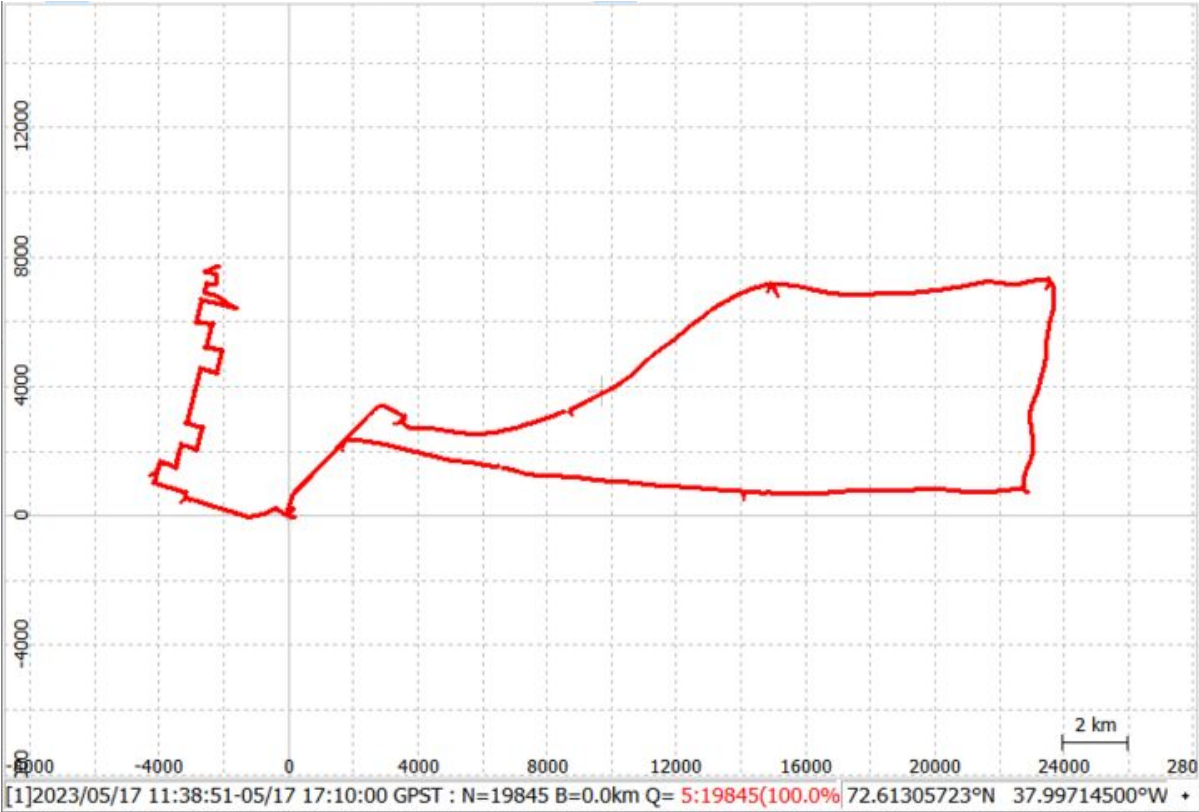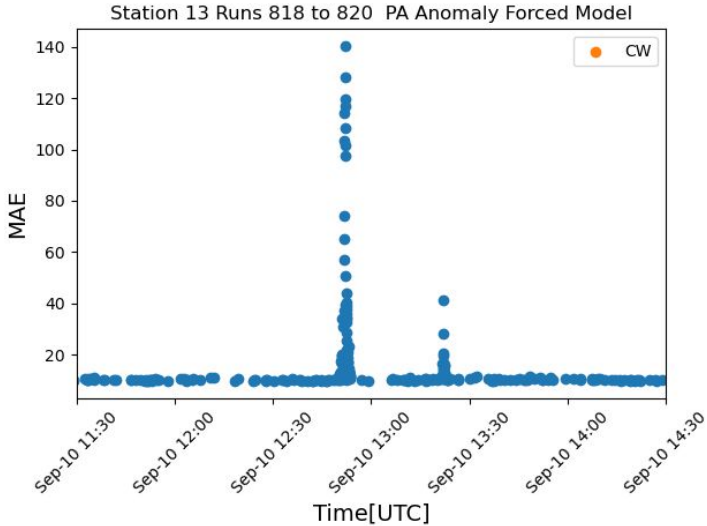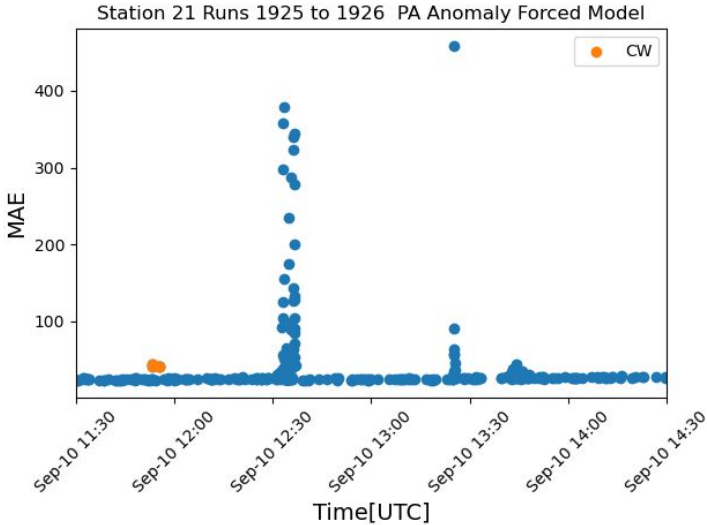
Block Offsets

Station 13 channel 3 suffers from frequent block offsets
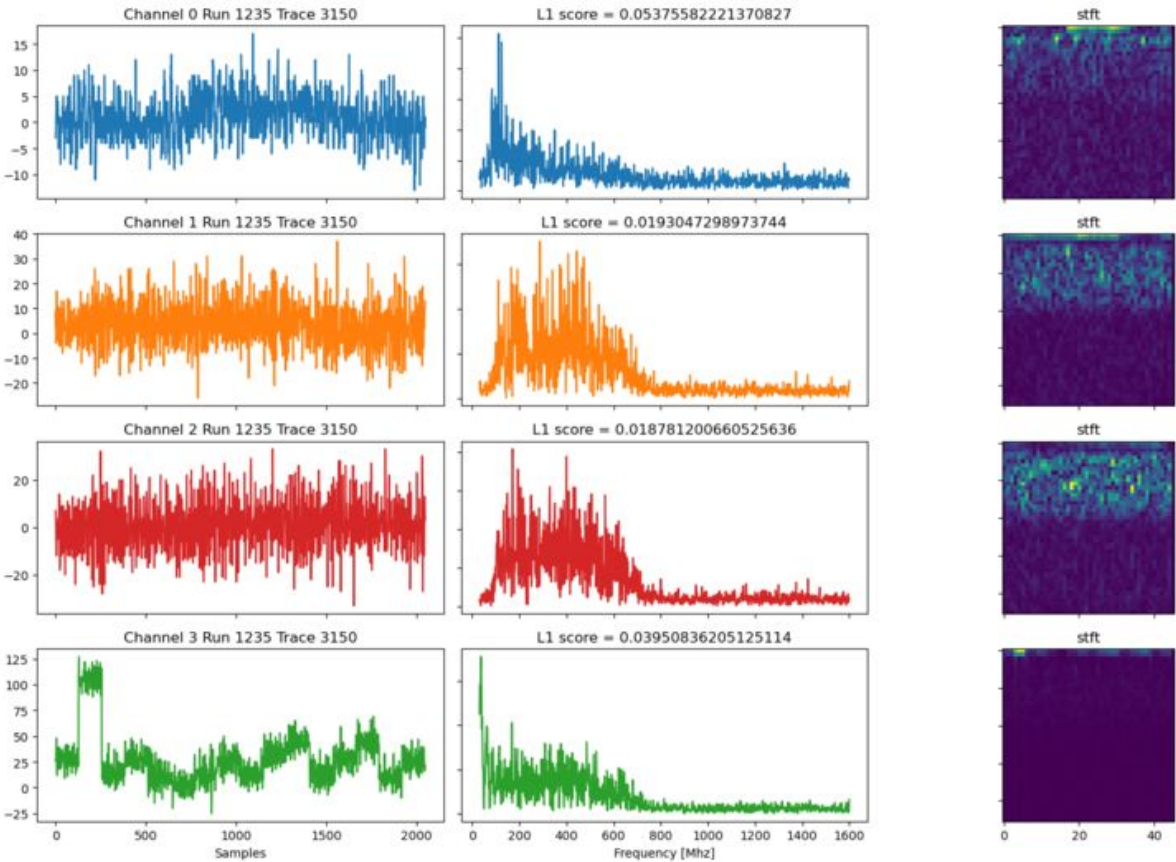
- **LAB4D digitizes in 16 blocks of 128 samples**
- **Probably due to unstable bias in the supplied voltage**
- **Fixable in level 1 calibration**

Block Offsets

Station 13 channel 3 suffers from frequent block offsets
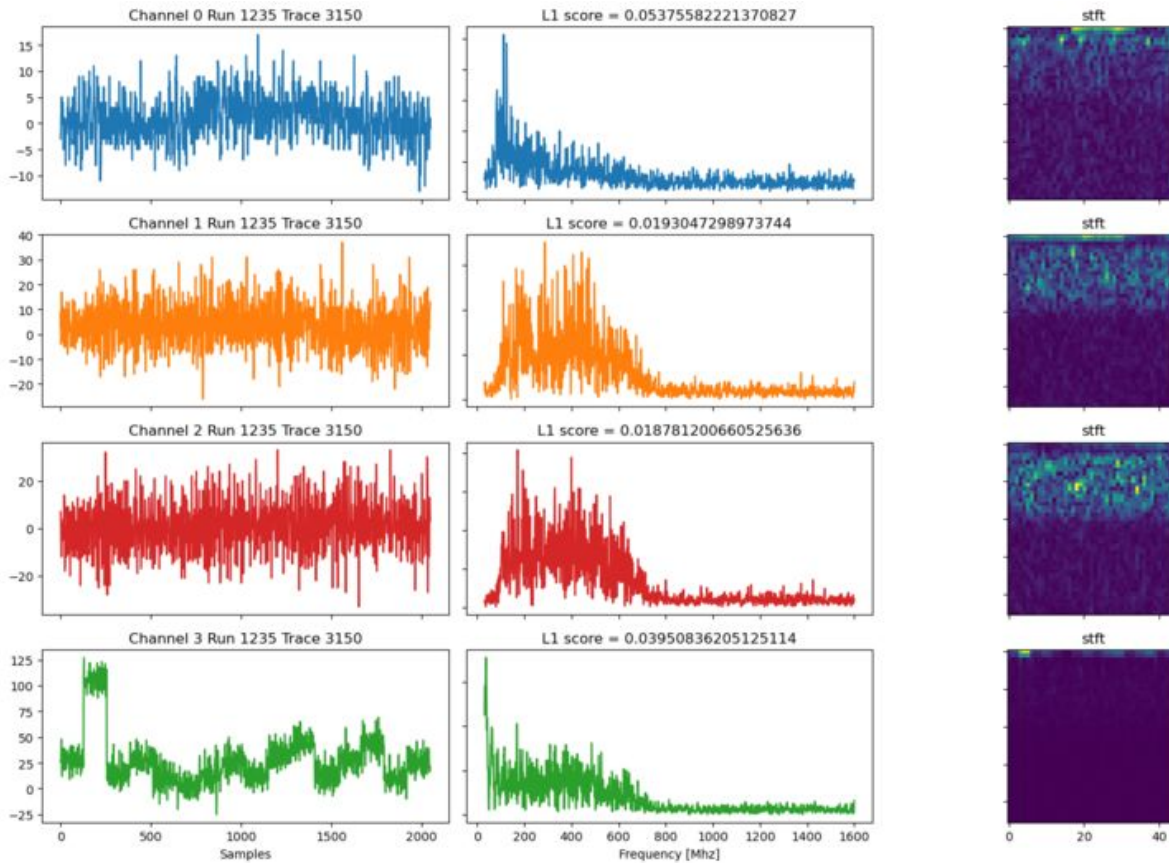
- **LAB4D digitizes in 16 blocks of 128 samples**
- **Probably due to unstable bias in the supplied voltage**
- **Fixable in level 1 calibration**

MITIGATED

Another Anomalous Event in 21 on April 19

MEGA Block offsets. Glitching can occur
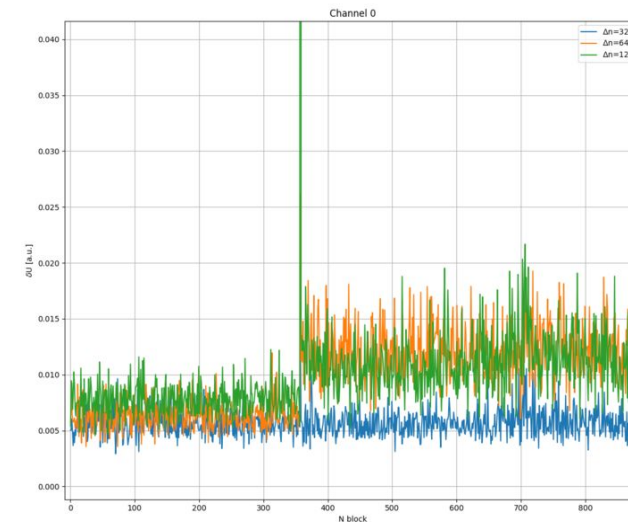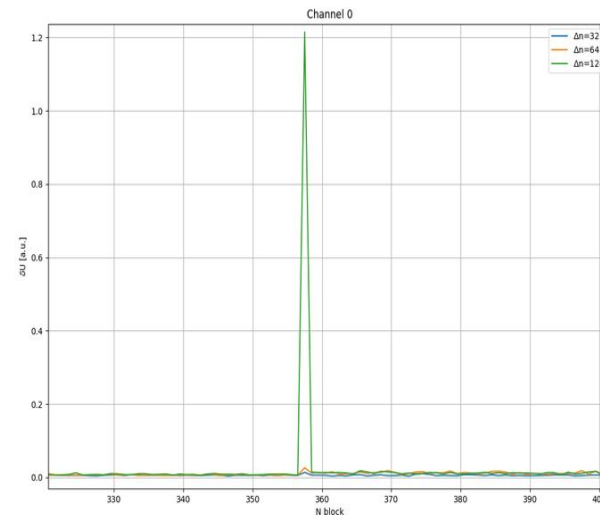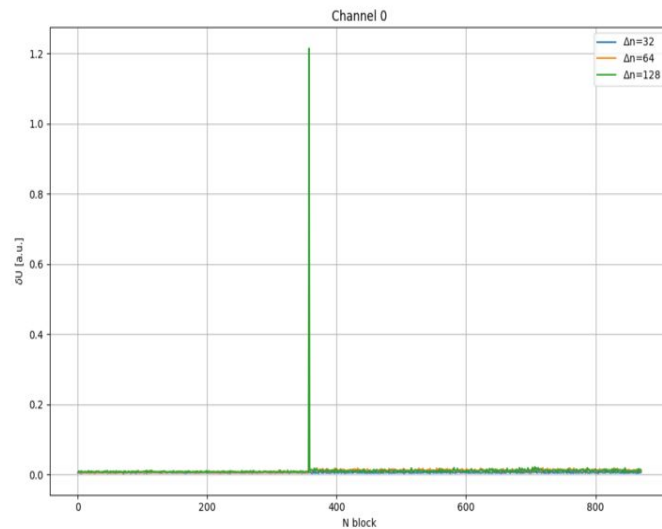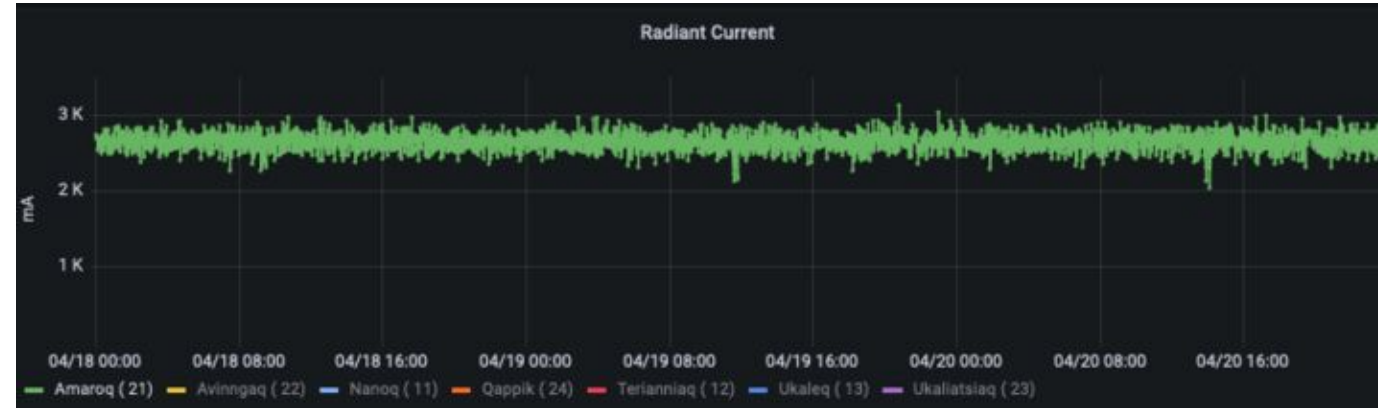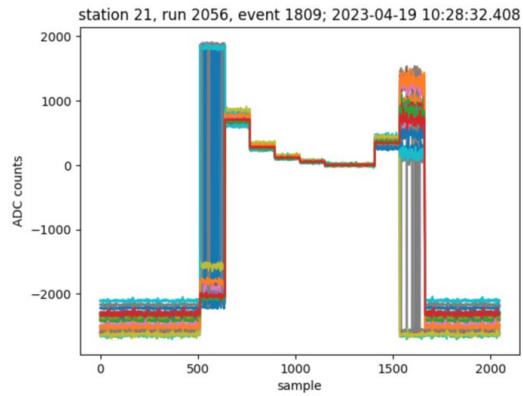
Another Anomalous Event in 21 on April 19

MEGA Block offsets. Caused by loss of power?
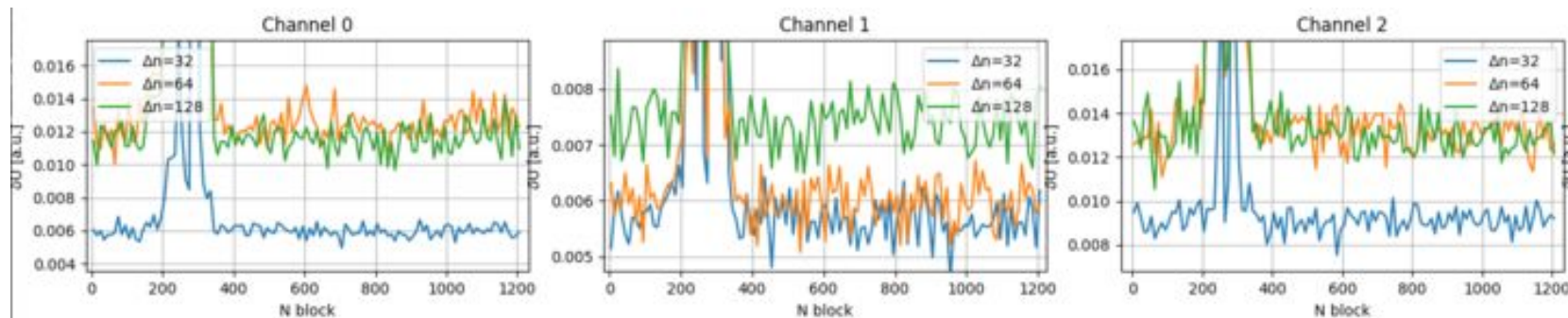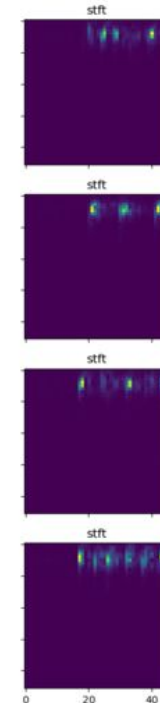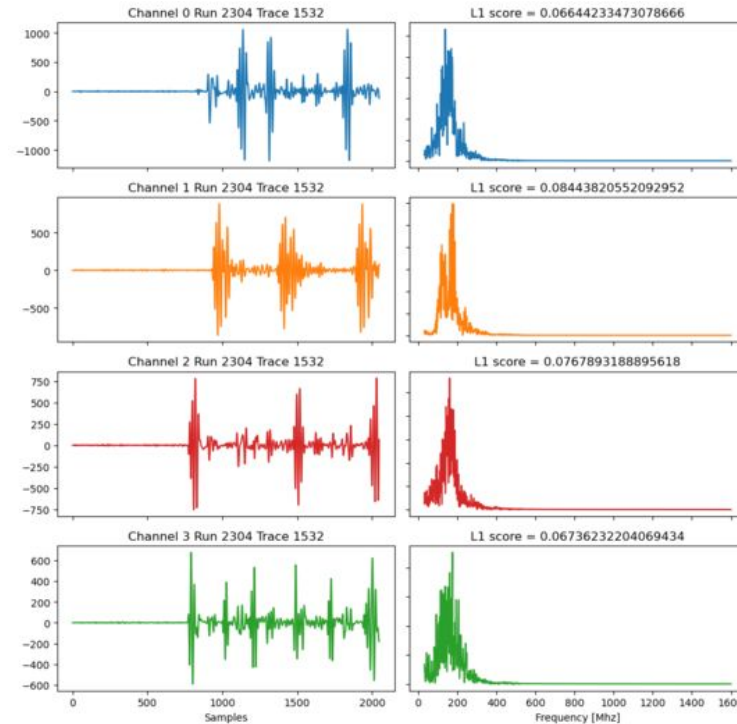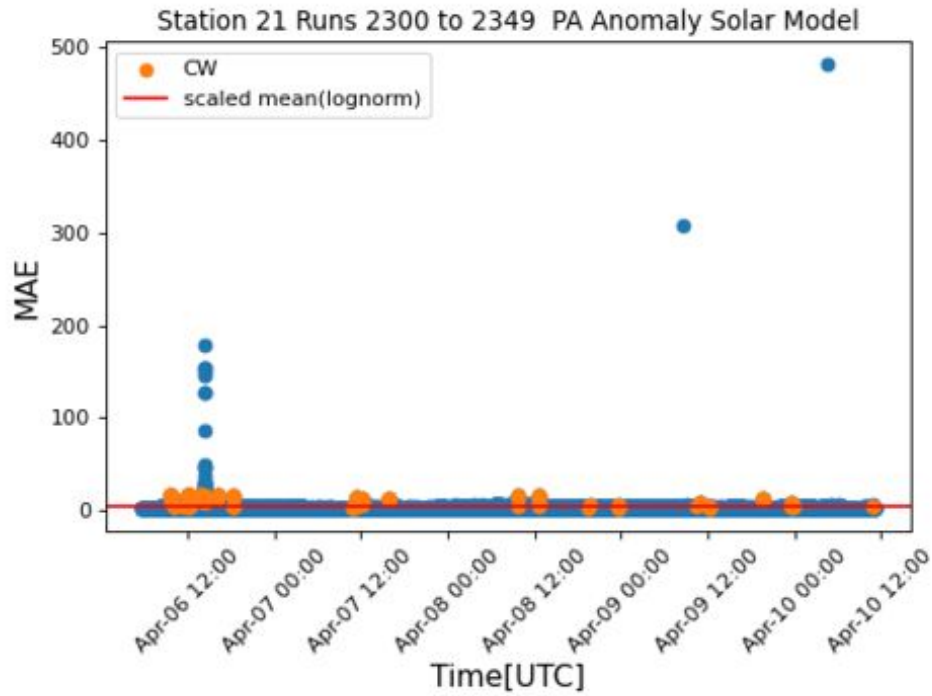
Another Anomalous Event in 21 on April 19

MEGA Block offsets. Caused by loss of power?
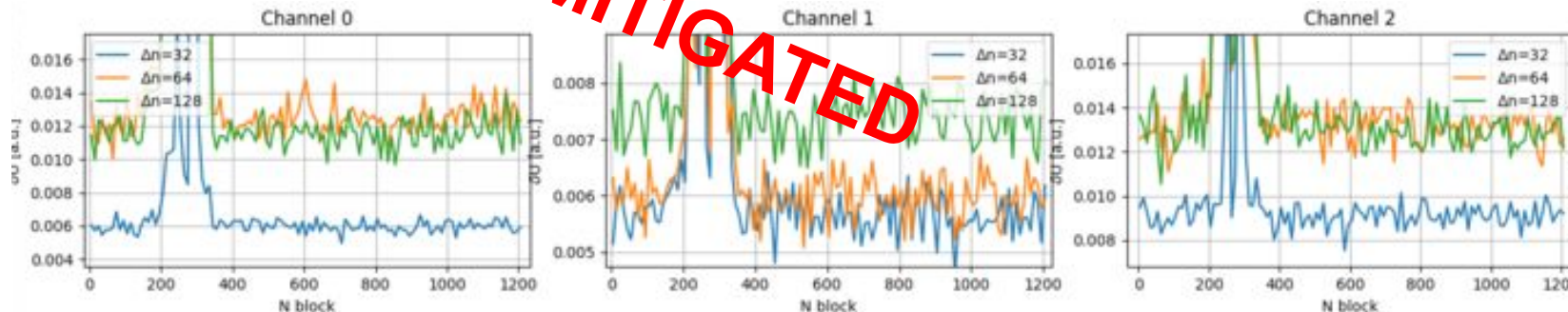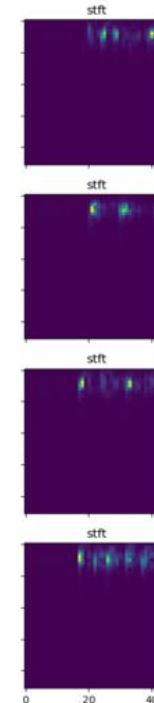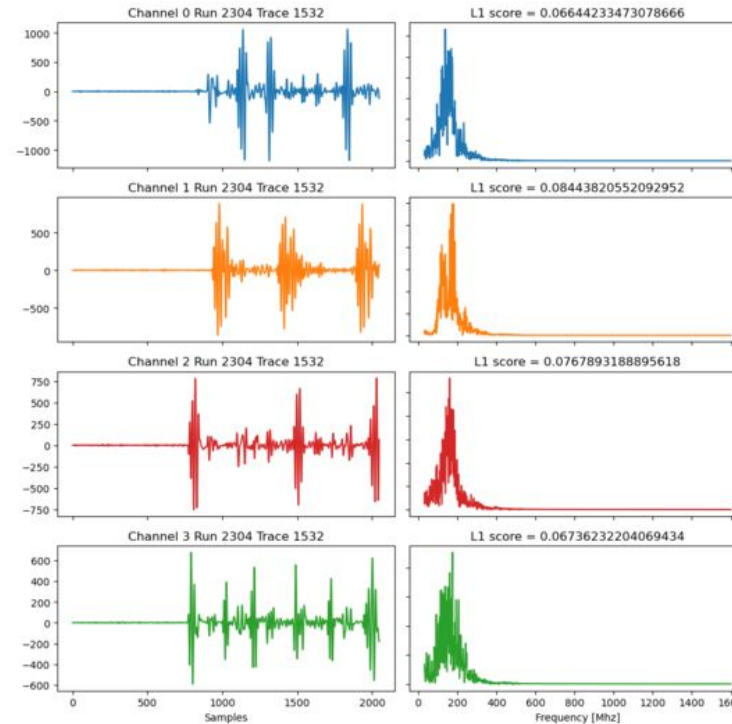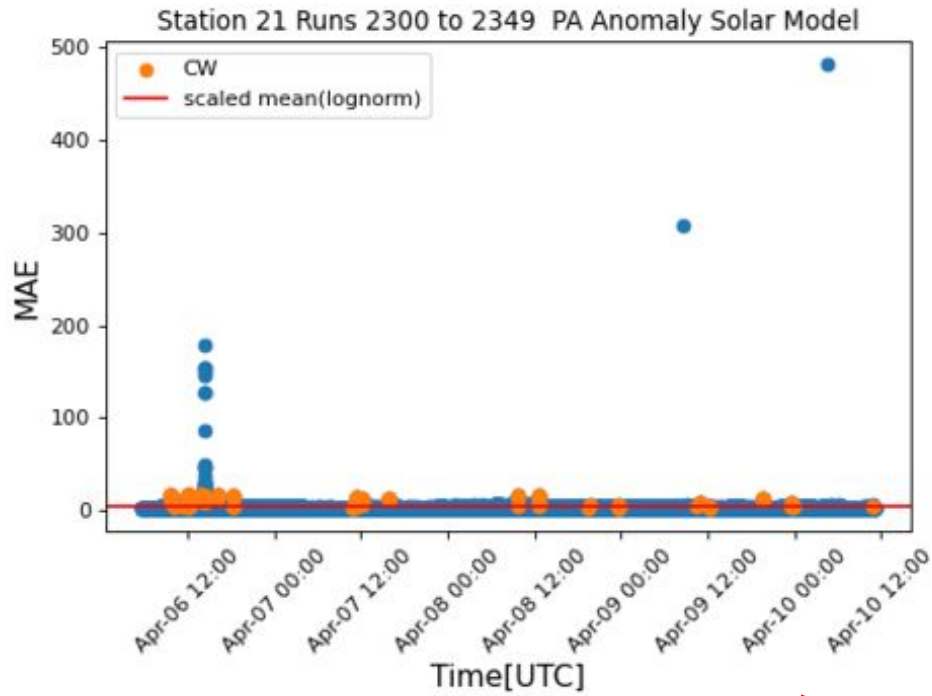
Anomaly Detection

Anomalous Low Threshold Event
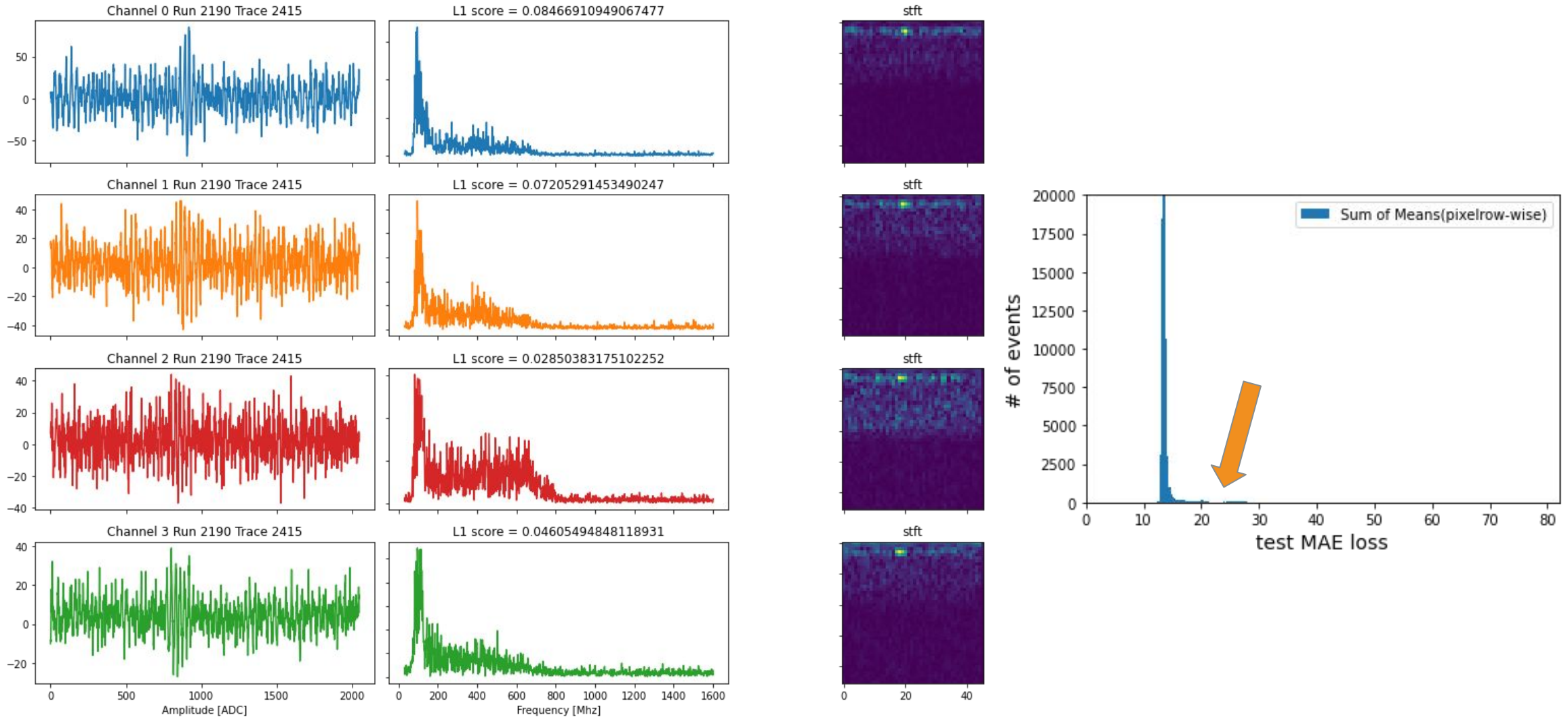
"Anomalous Low Threshold event"

Type II Solar Flare
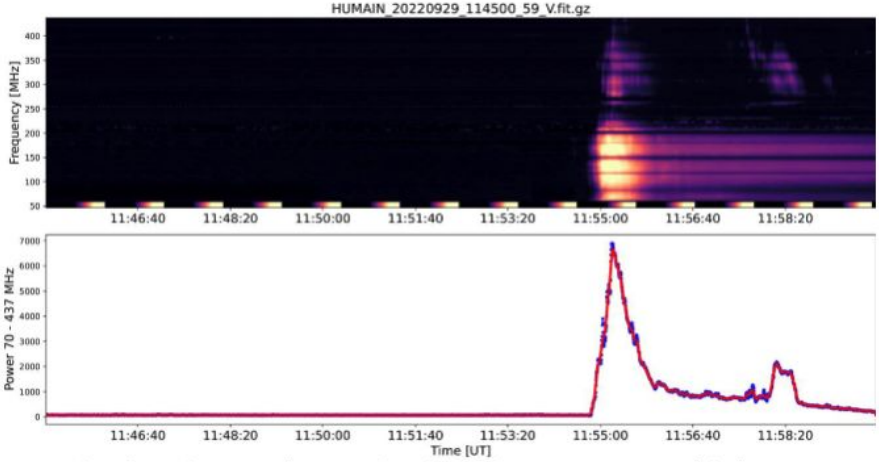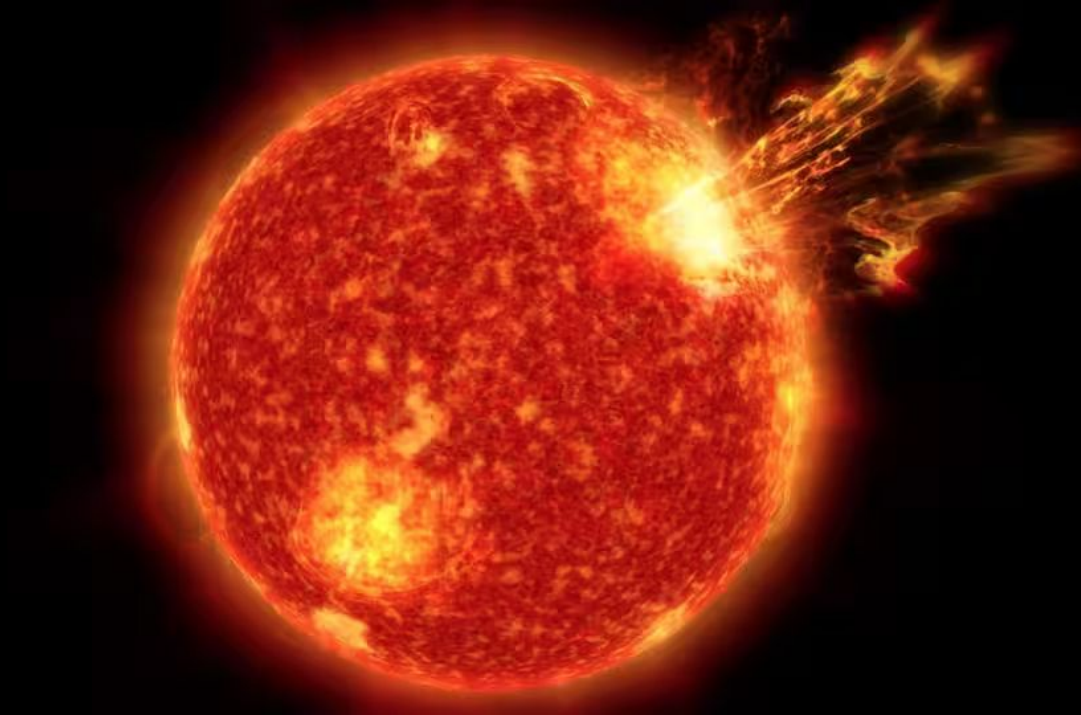
"Solar Model"
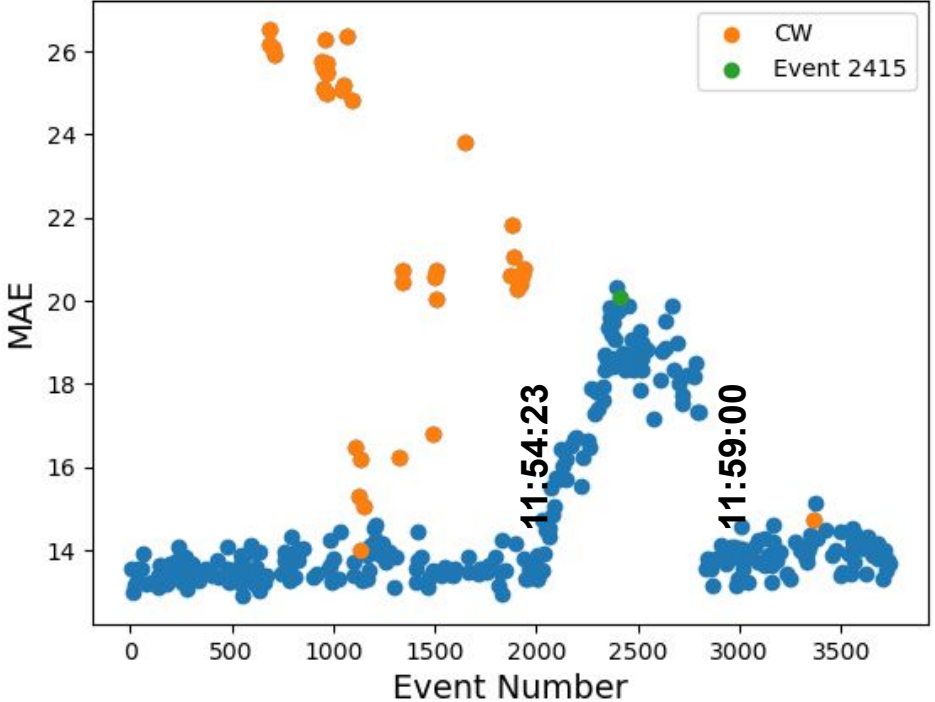
Butterworth filter 25 - 250 MHz
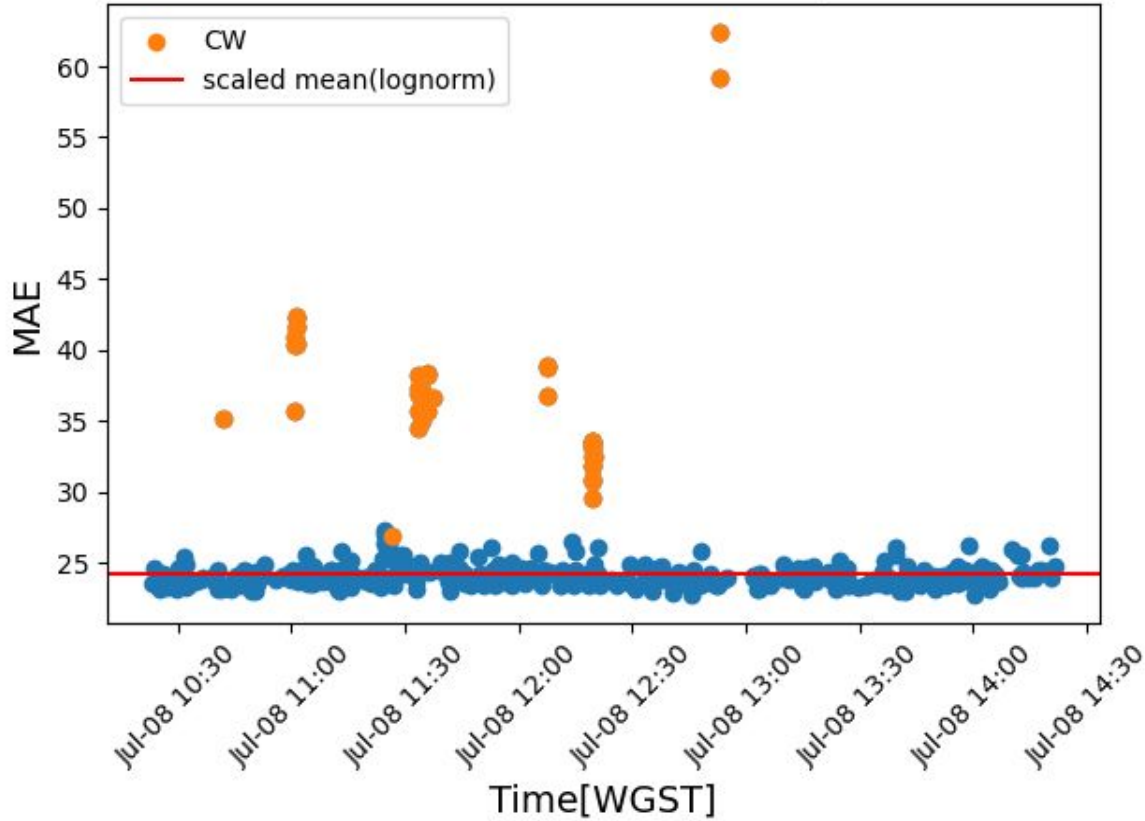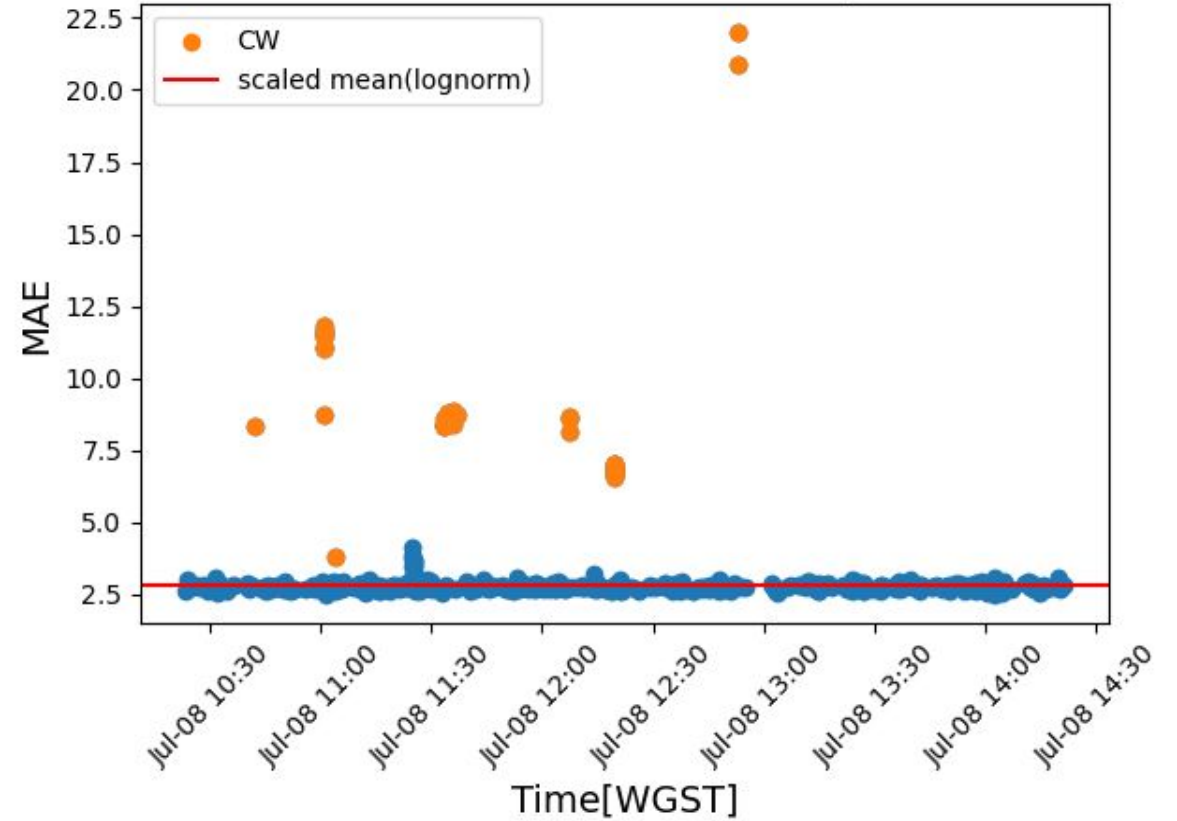
More Solar Bursts

Another strong event

Station 23 Runs 1357 to 1398 PA Anomaly Solar Model

Station 11 Runs 2105 to 2124 PA Anomaly Solar Model

Station 13 Runs 1185 to 1204 PA Anomaly Solar Model

Station 24 Runs 1080 to 1099 PA Anomaly Solar Model
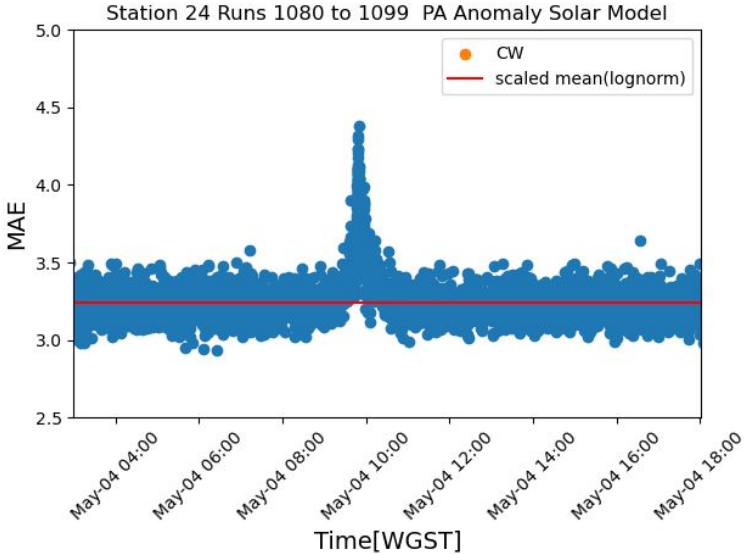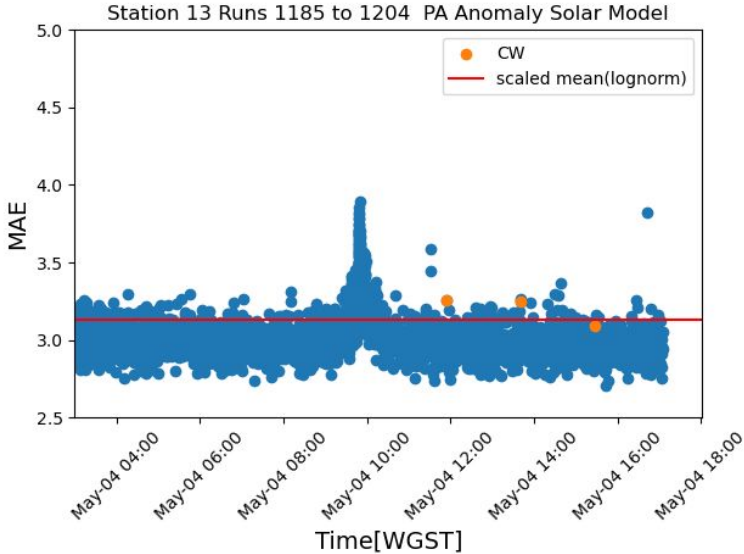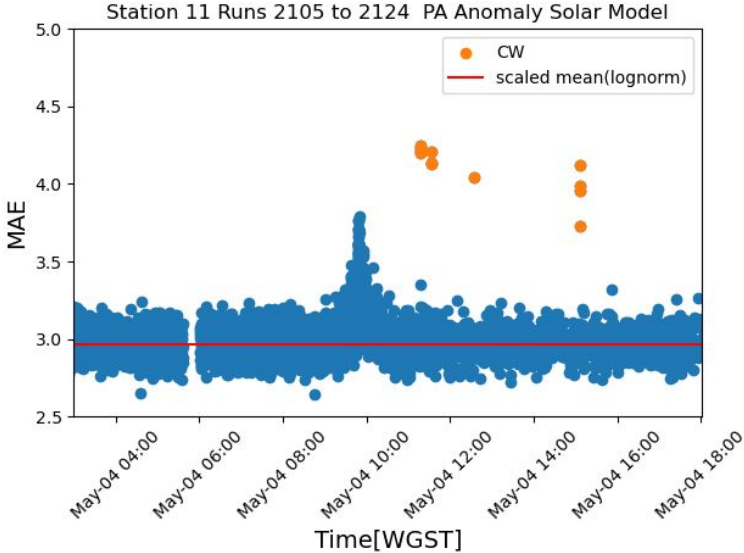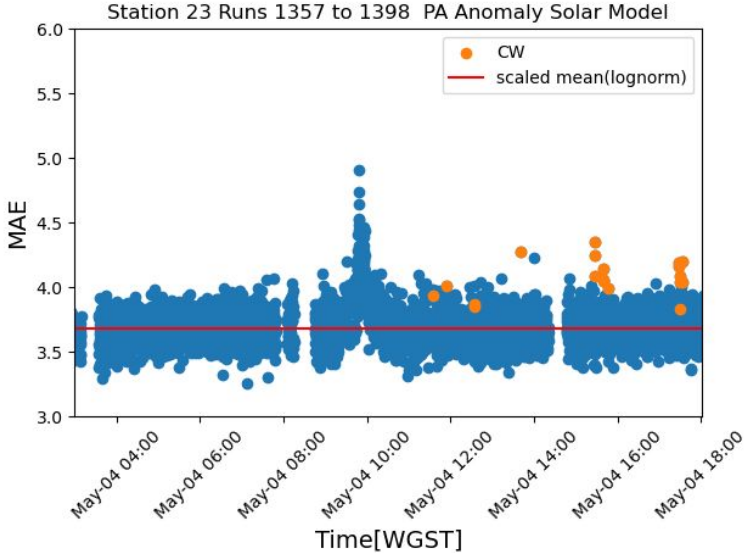
Sim Station 23

Are Neutrinos Anomalous
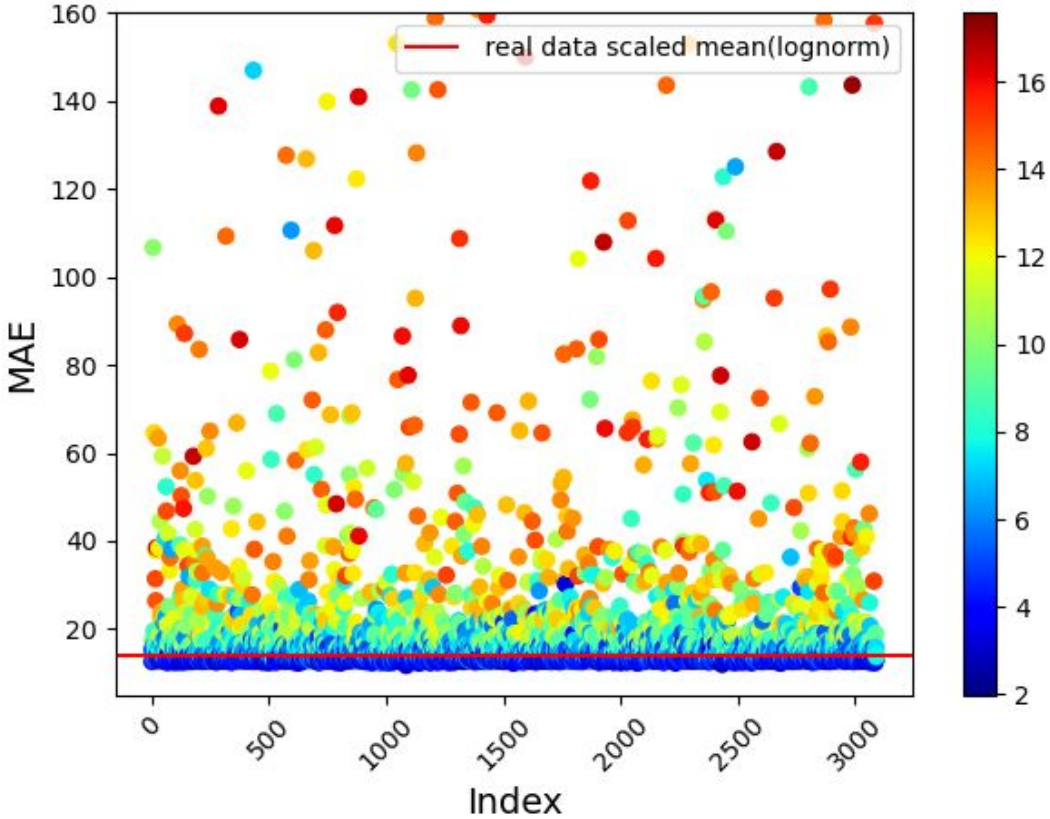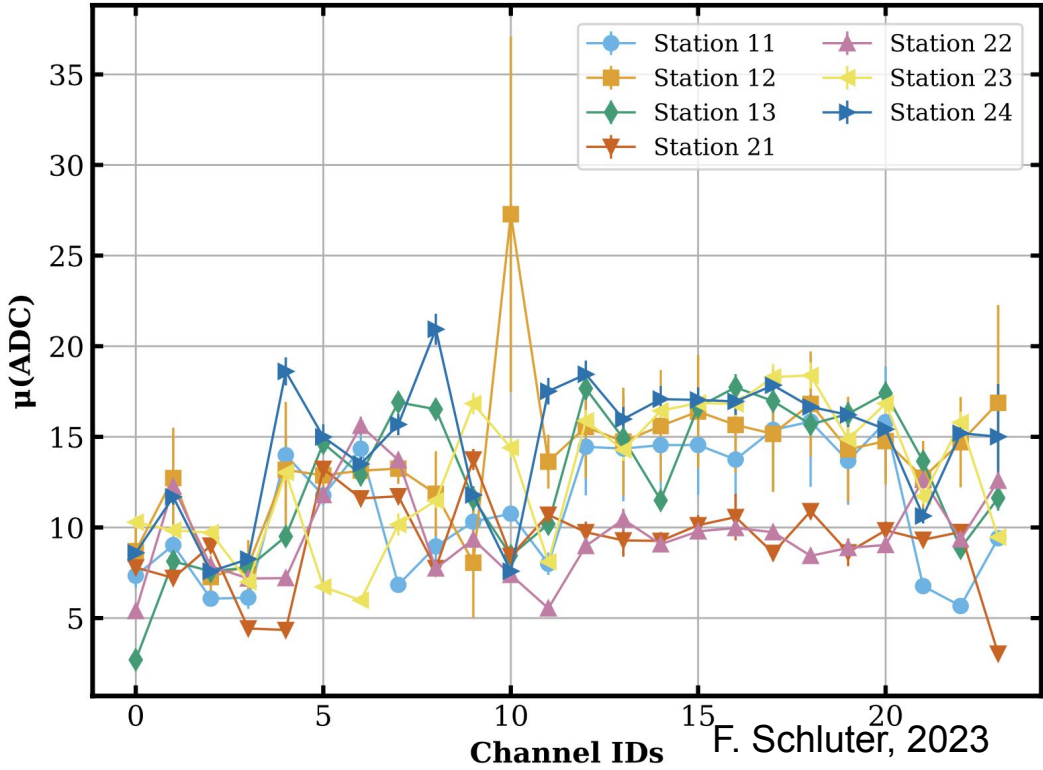
F. Schluter, 2023

Prioritization

Neutrinos left over in the sample


```
Full Sample
    |
Remove CW
    |
Prioritize high
MAE
```
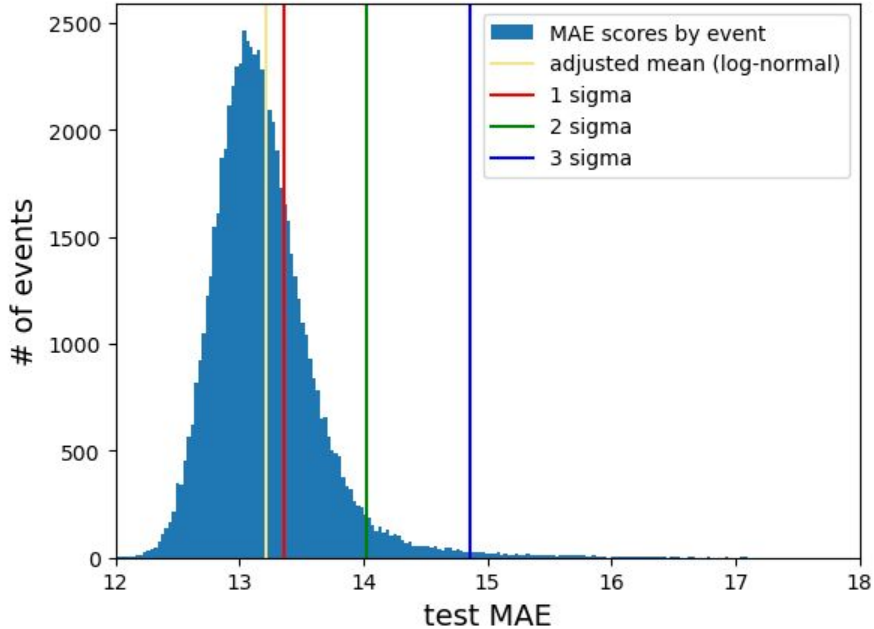
	# of events	# of simulated Neutrinos	Neutrino Purity
Full Sample	68596	3092	0.043
MAE cut mean	28590	2338	.077
MAE cut aggressive	90	977	0.44

Prioritization

Neutrinos left over in the sample


```
Full Sample
    |
Remove CW
    |
Prioritize high
     MAE
```
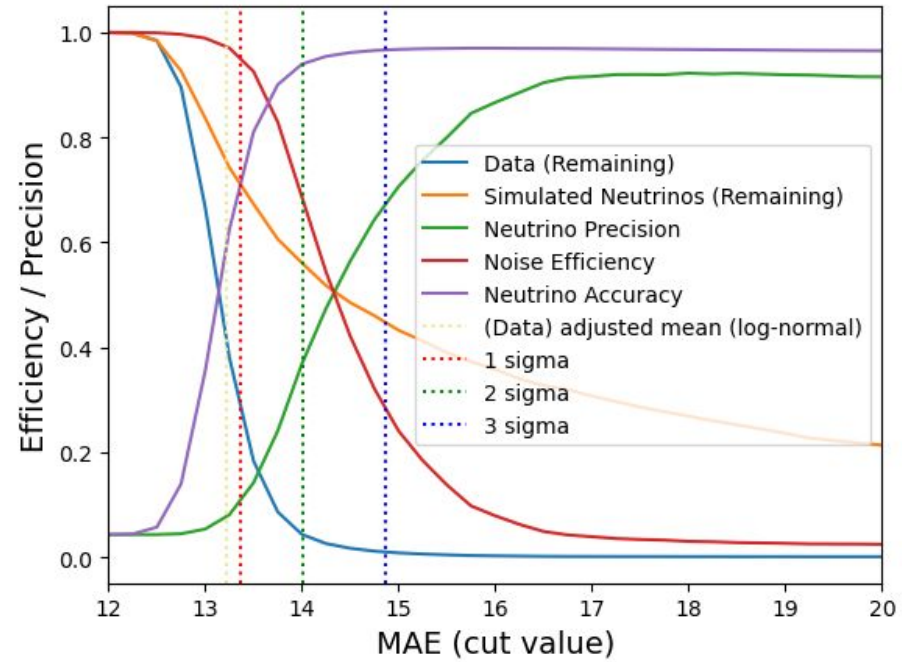
	# of events	# of simulated Neutrinos	Neutrino Purity
Full Sample	68596	3092	0.043
MAE cut mean	33083	2407	.077
MAE cut aggressive	90	977	0.44

Neutrino-ish Signal

THIS IS NOT A NEUTRINO
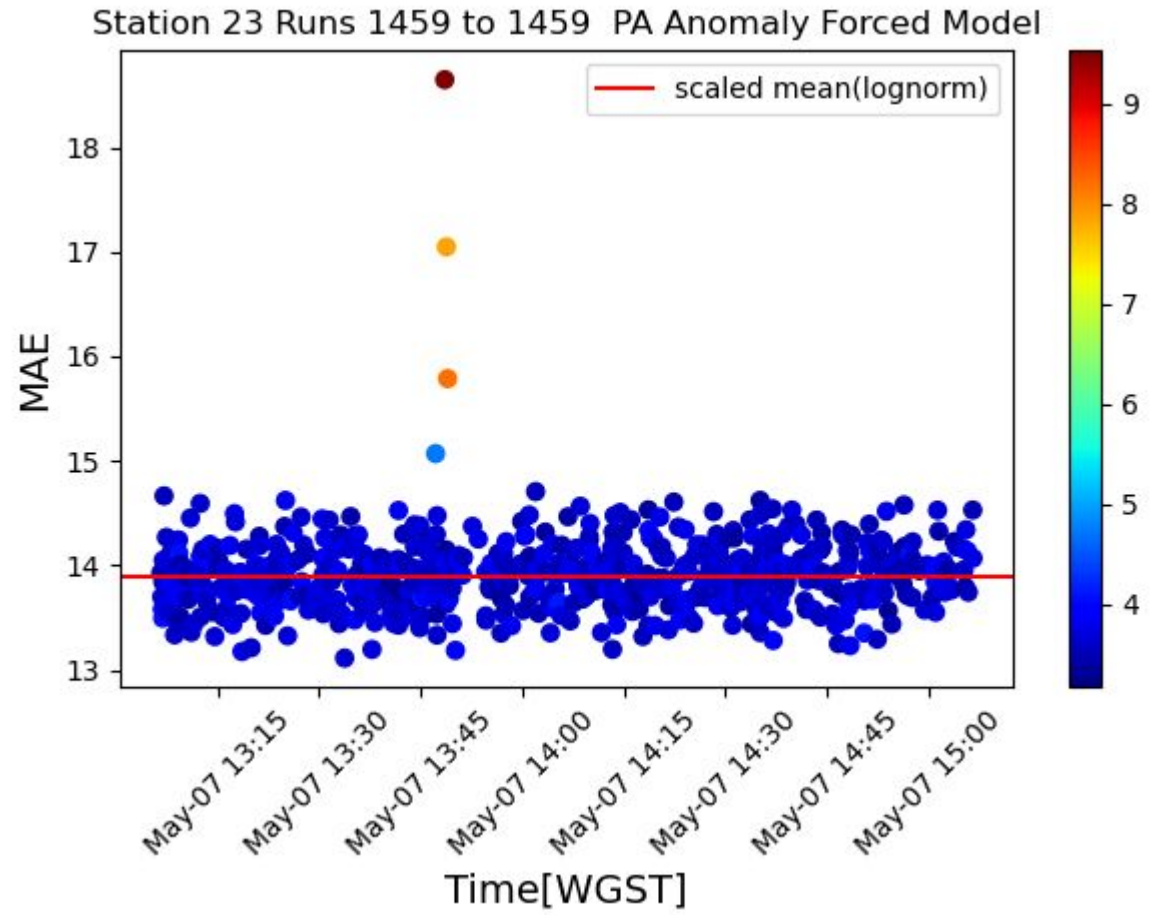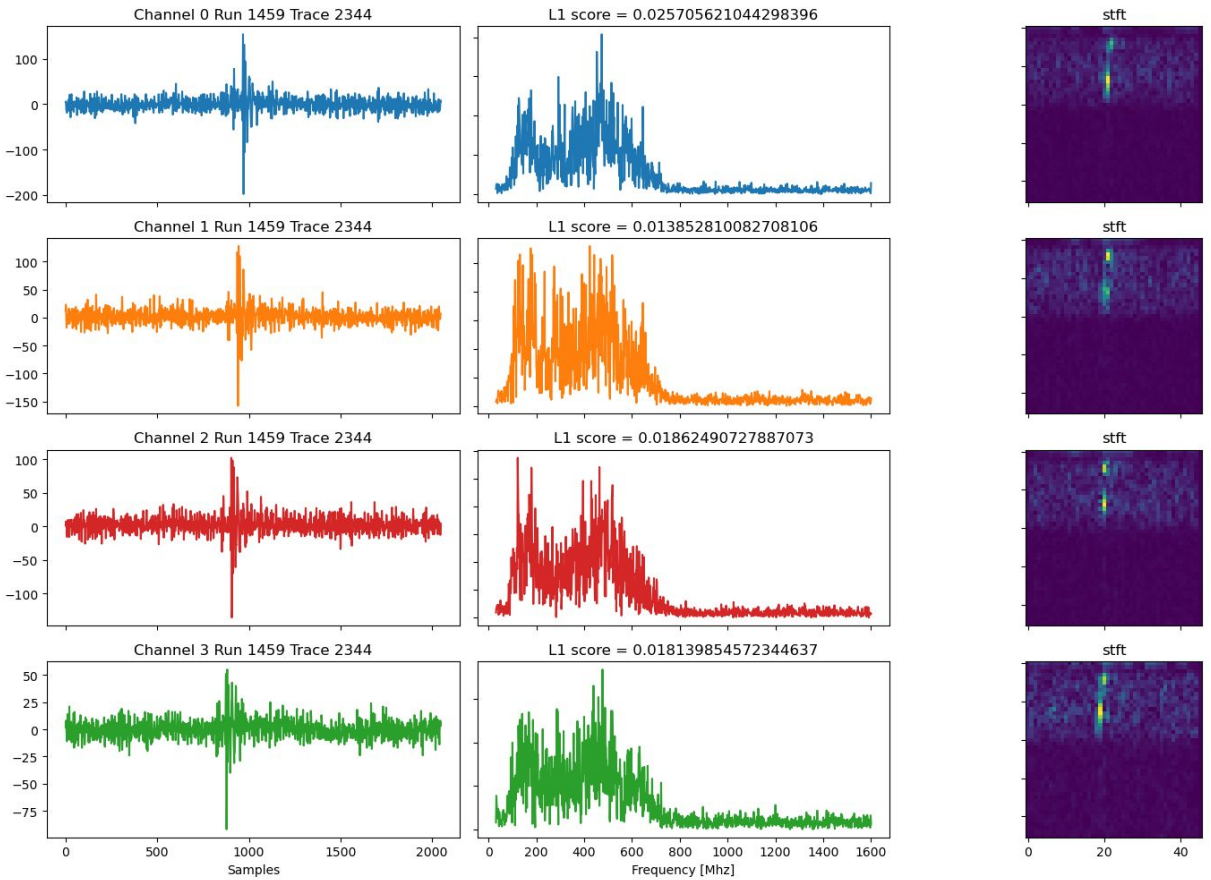
Neutrino-ish Signal

….but it does kind of look like one

Cosmic Ray Candidates

Surface Candidates (748 run 793(*Aldrin* .69)) (1718 run 1091(*Armstrong* .87))

MAE Loss = 36.55507278442383

MAE Loss = 60.0619010925293
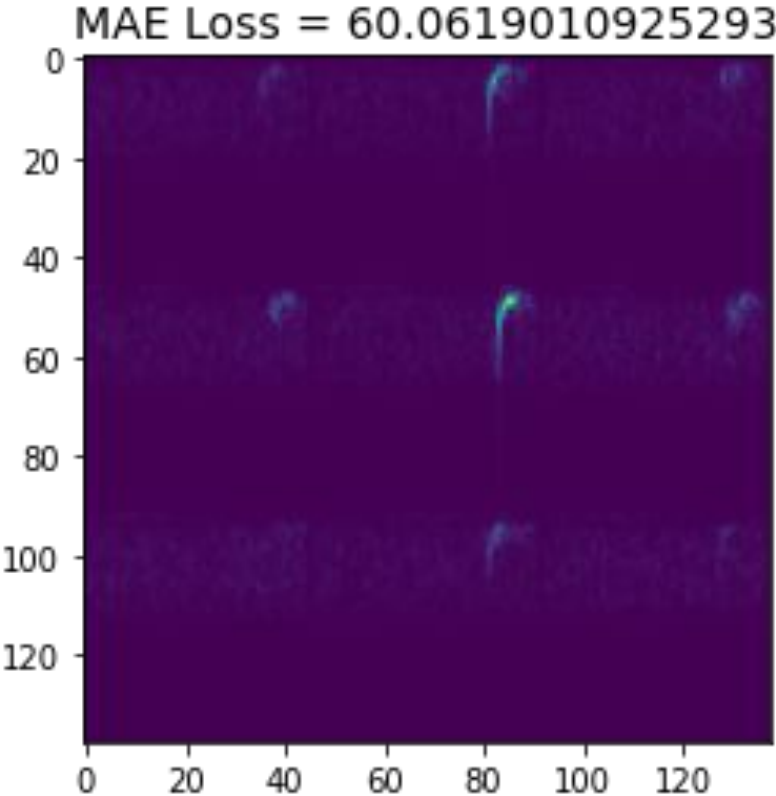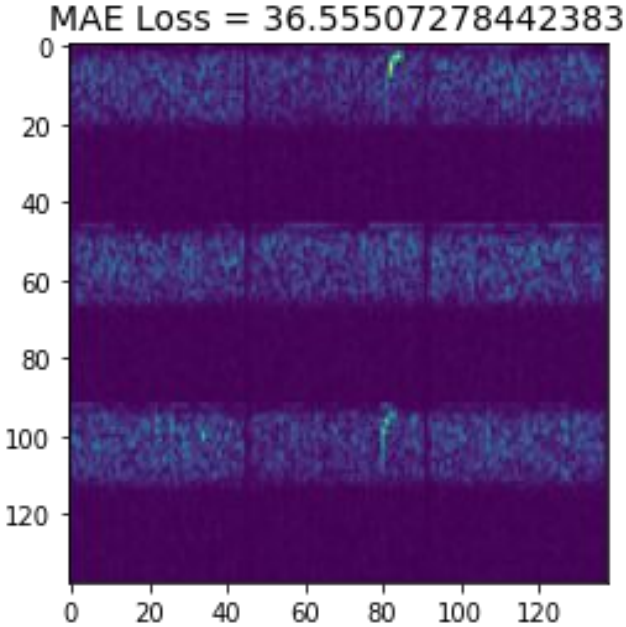
Summary

Anomalies, station 24
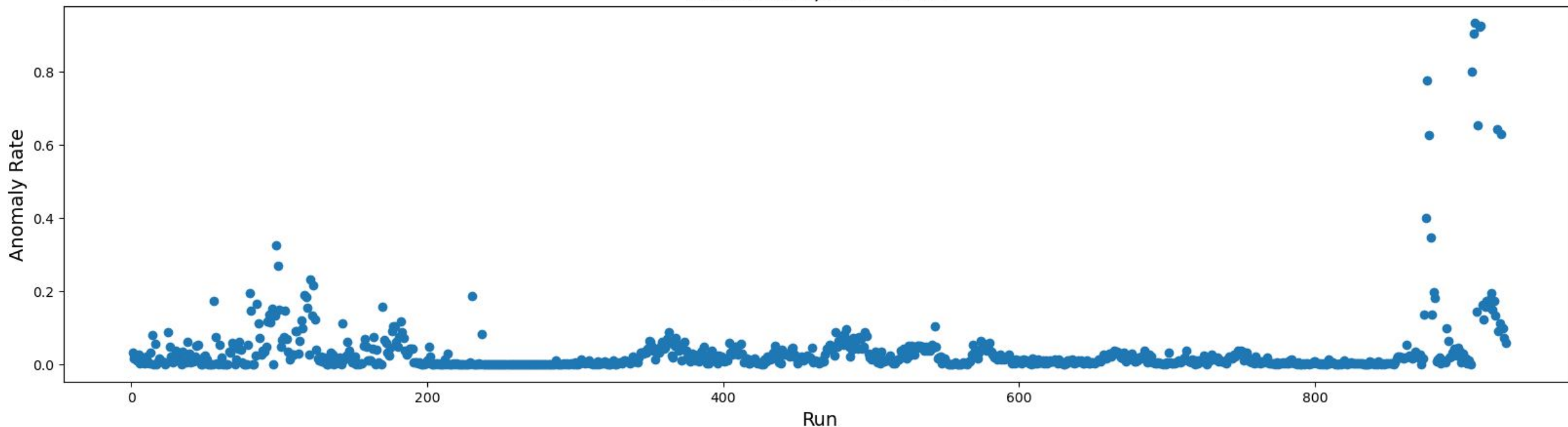
- **Neutrinos (simulated) and Cosmic Ray Candidates are highly anomalous**

- **New noise classes / glitches discovered and mitigated**

- **Active Sun can be used as calibration source, characteristic burst shapes**

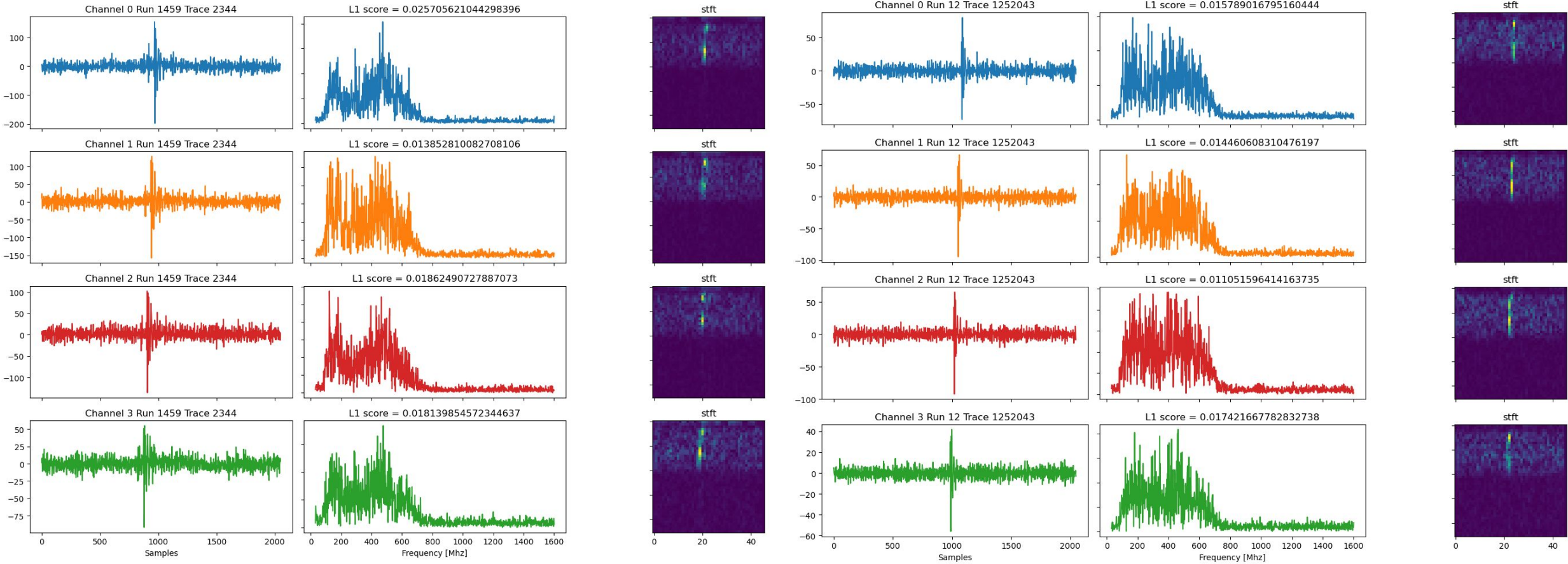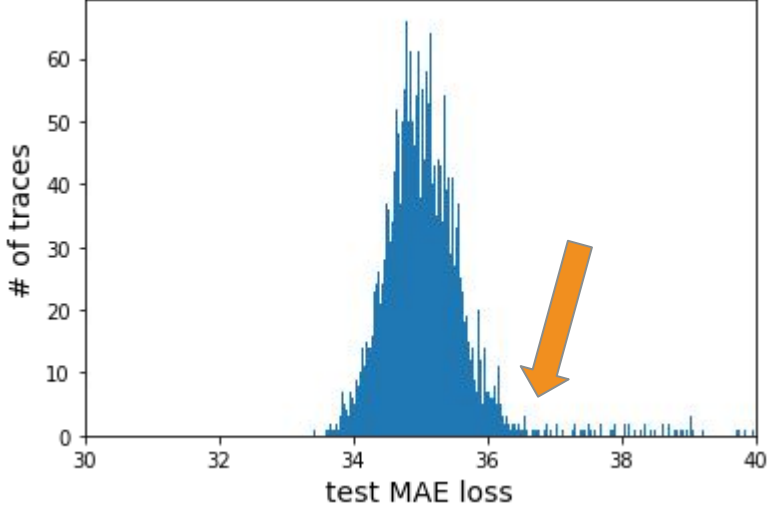- **Only one component of filtering and Multi-Messenger Response**

- **Models are simple – more complex 3D and impulsivity parameters for better efficiency**

Bonus Slides

Data Overview

Data rates

- Most triggered events are noise:

  - Expect <~ 1 neutrino / full RNO-G / year

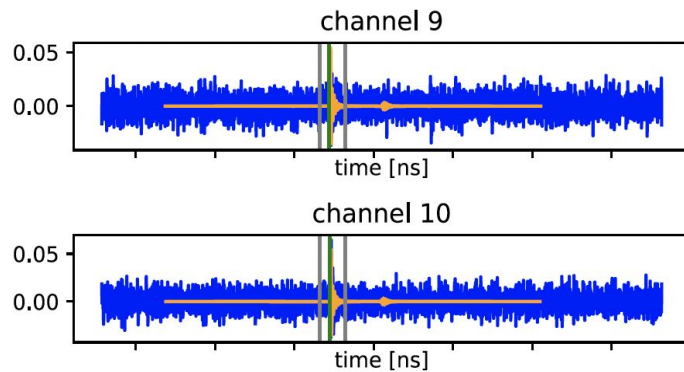 - Expect O(1) cosmic ray events in surface component / day

  - other physics backgrounds: Sun, Galaxy

  - Thermal noise fluctuations

  - Anthropogenic and hardware induced noise (intermittent, up to ~10 Hz)
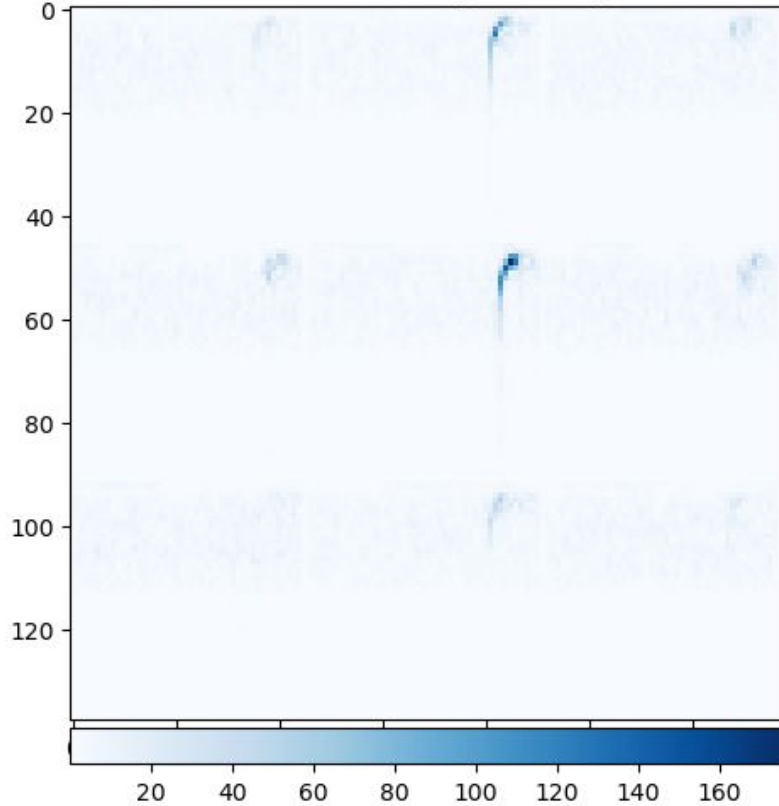
Rate   Ability to simulate

- Signal pulses near threshold

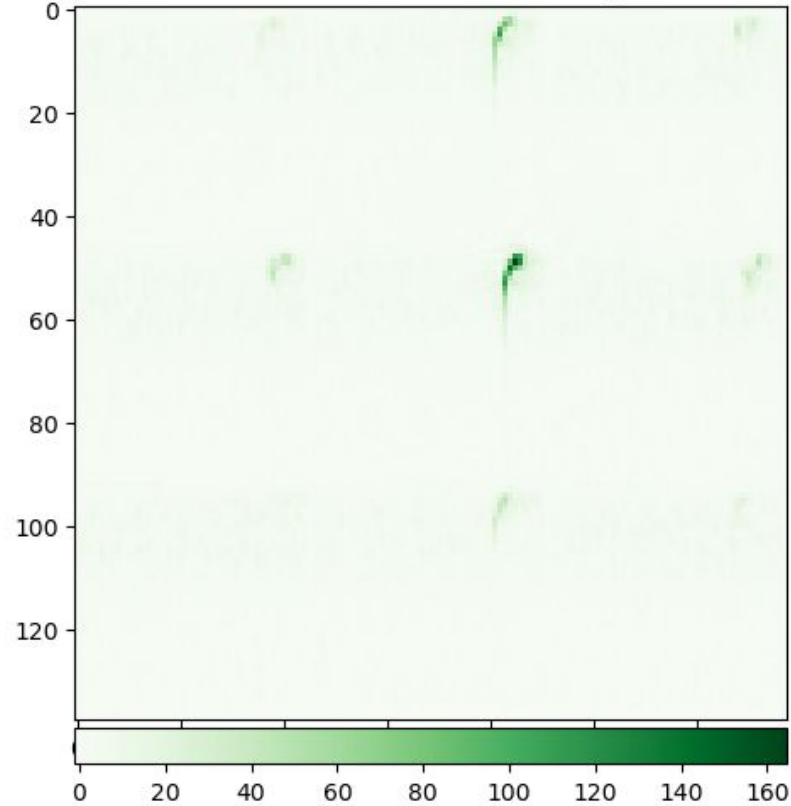- Characteristic polarized bipolar pulses convovled with hardware response

MAE calculation

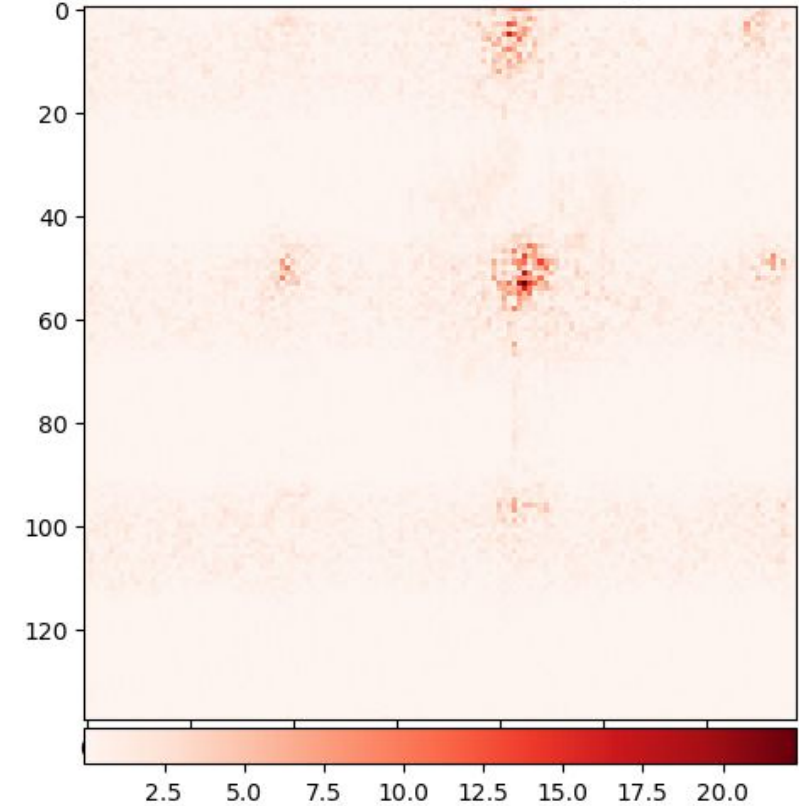## Sum of mean pixel difference per time slice

CW Noise

Simple CNN Classification
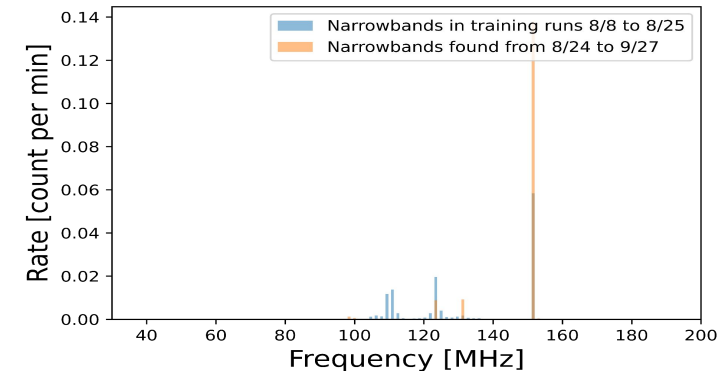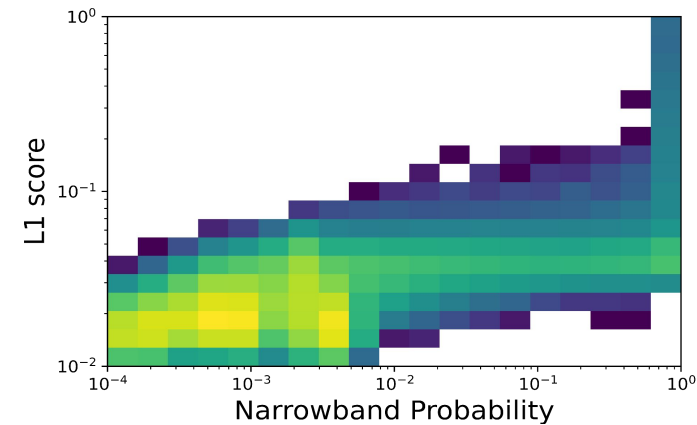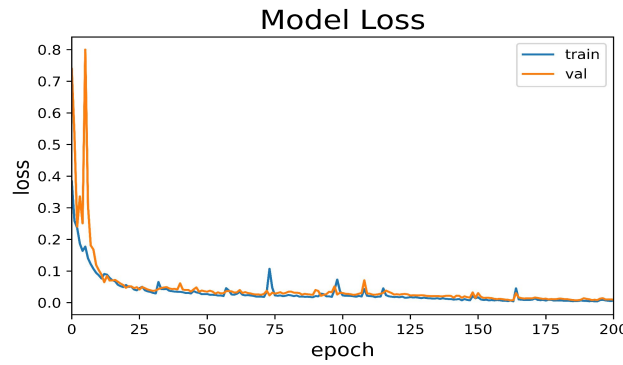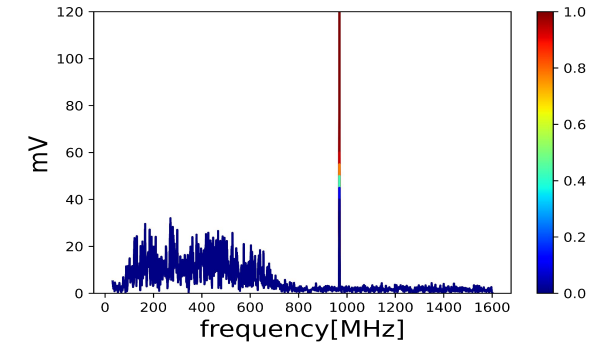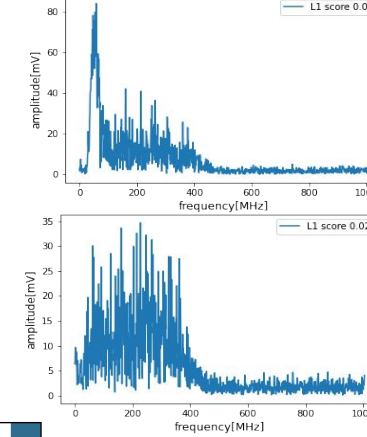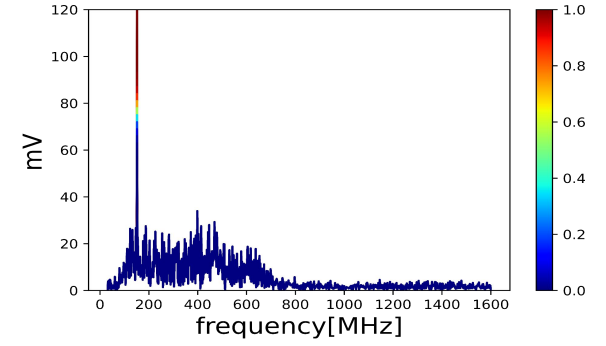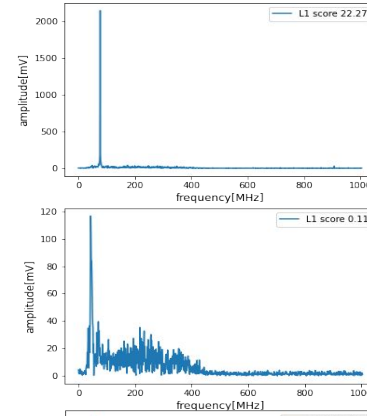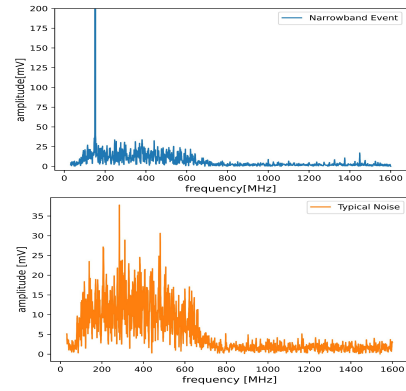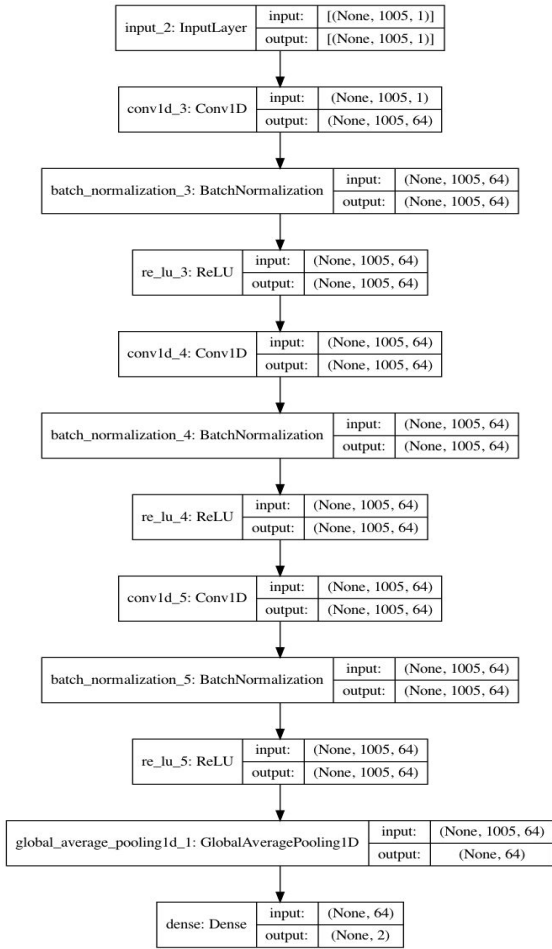
Anomaly Detection Update

Anomalous Event Rolling Invariance
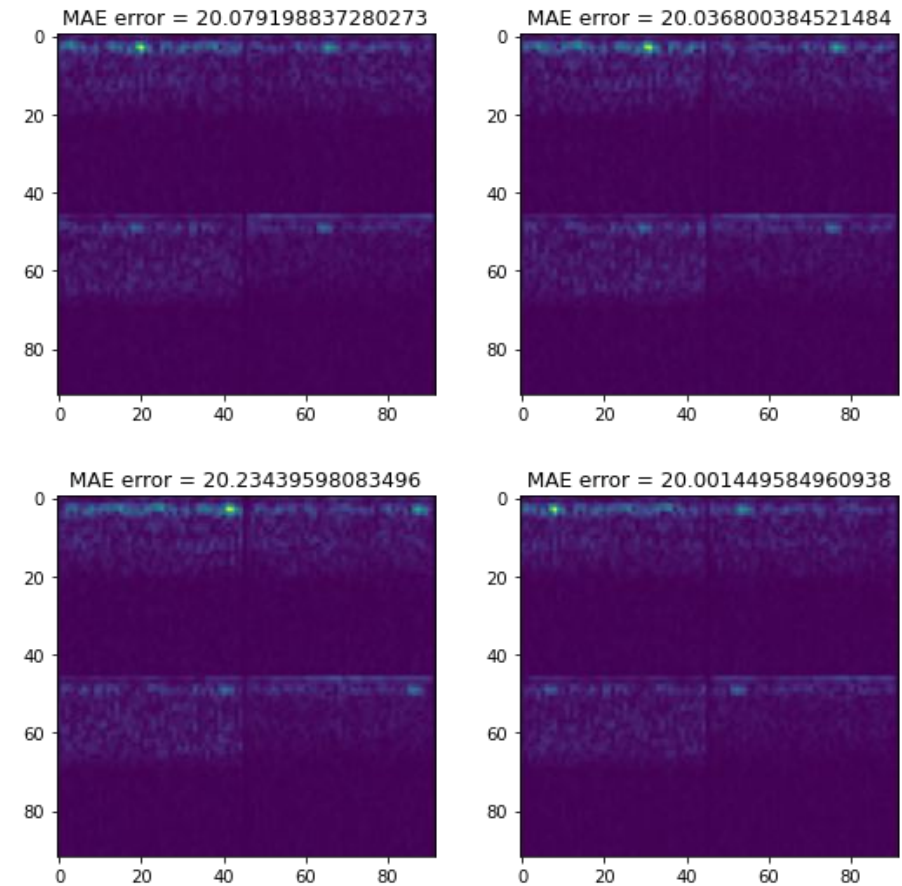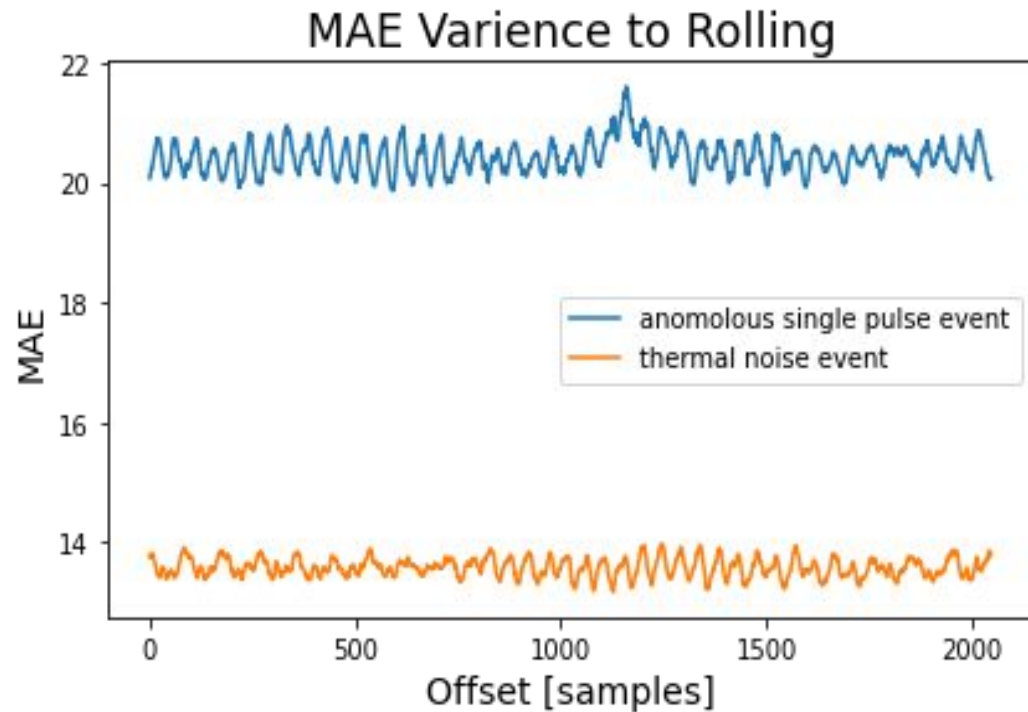
Anomaly Detection

Deep Benchmarks
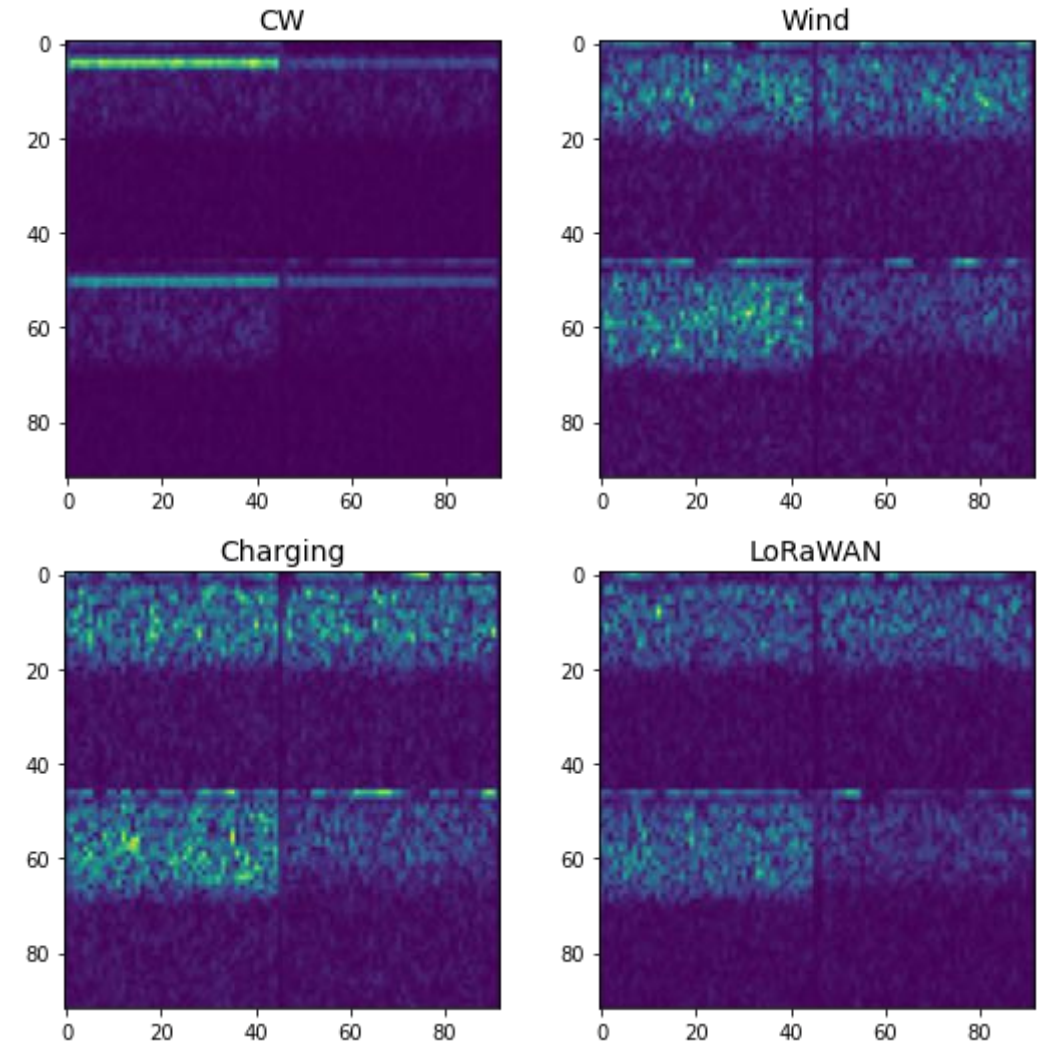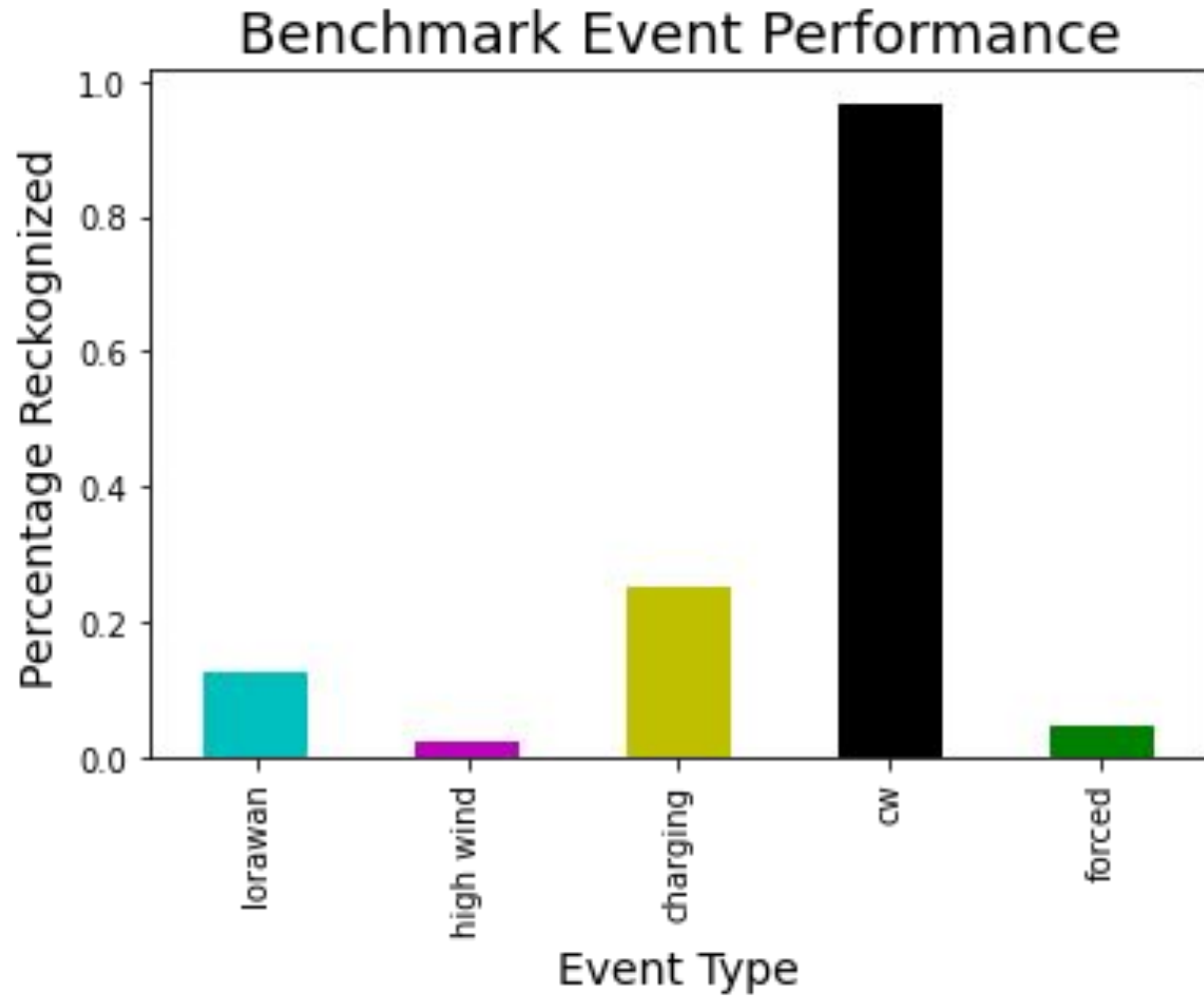
Anomaly Detection

Surface Noise Benchmarks
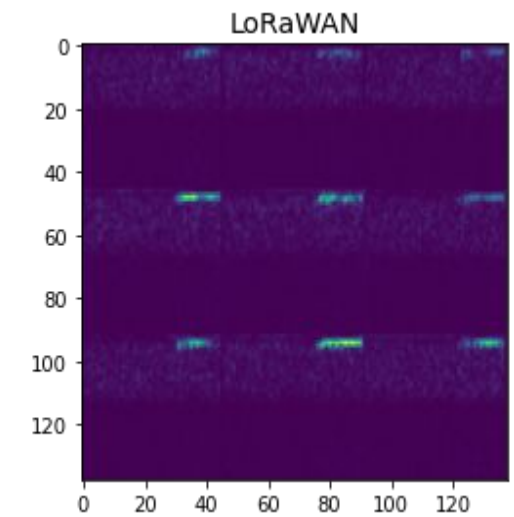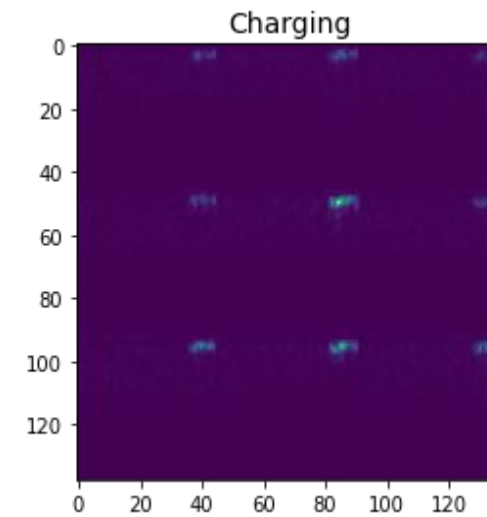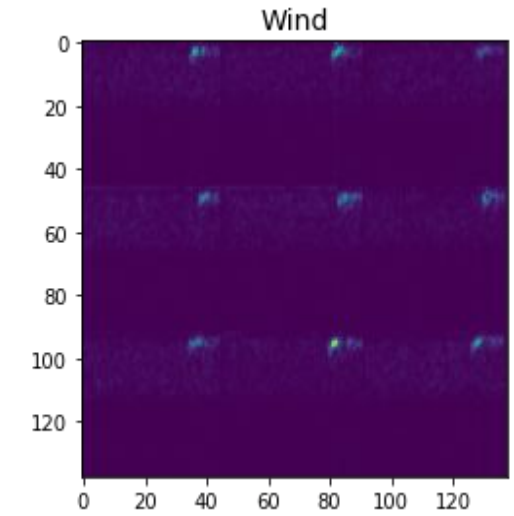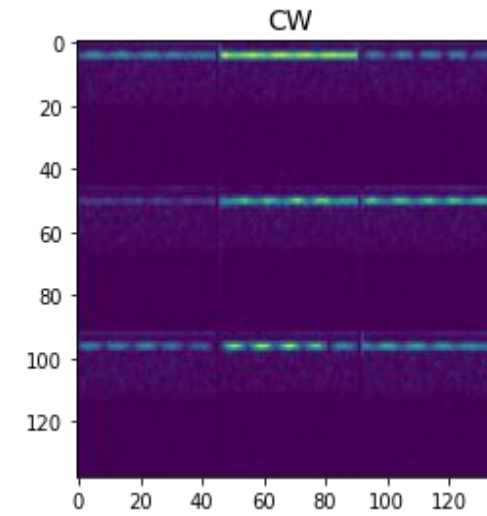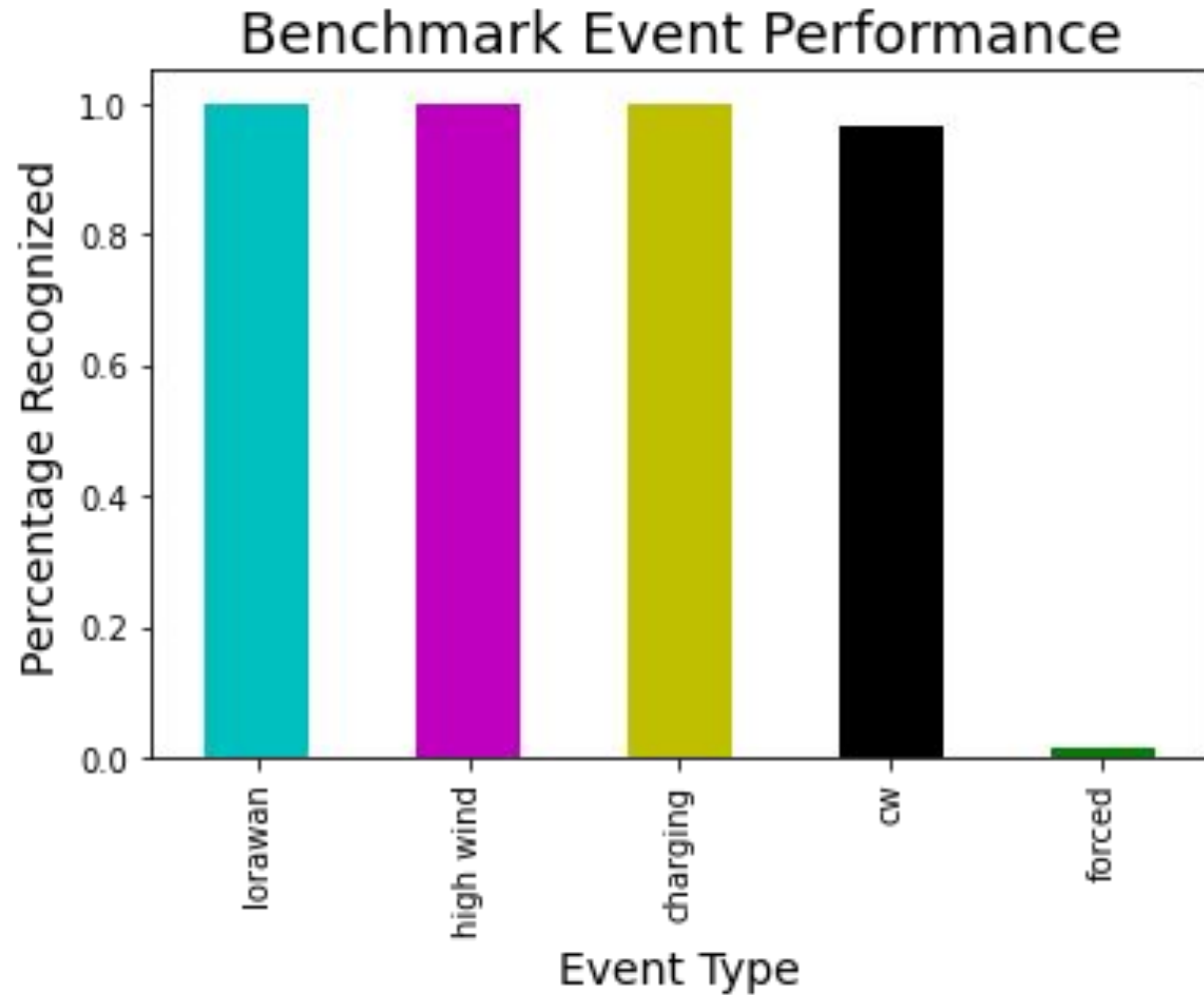
Anomaly Detection

Surface Noise Benchmarks
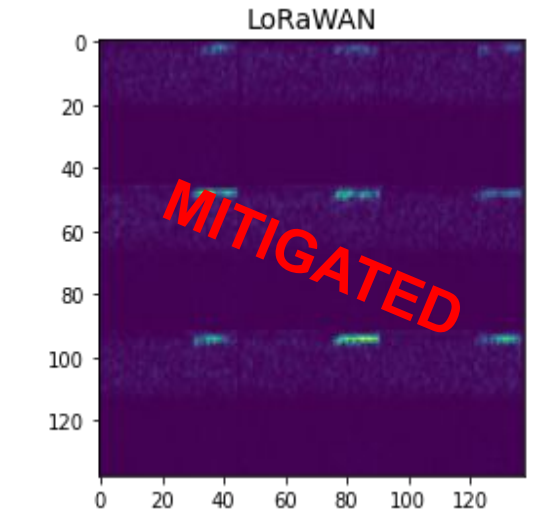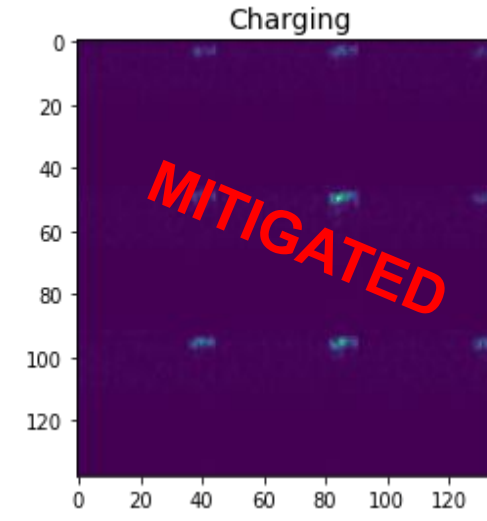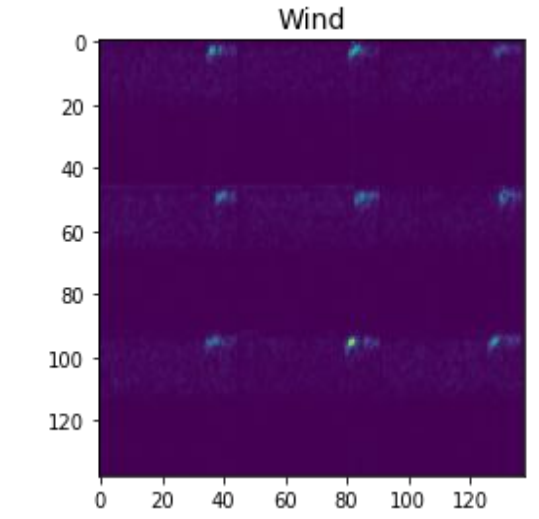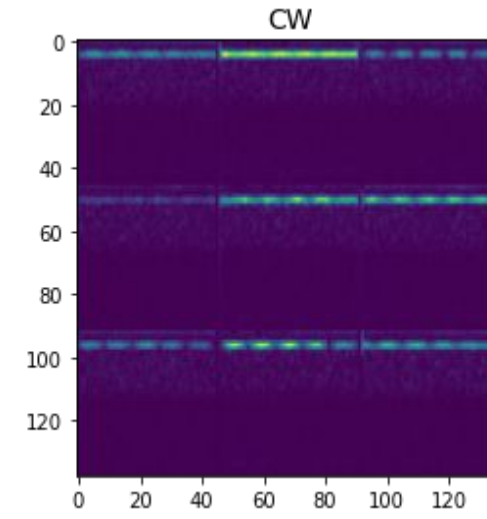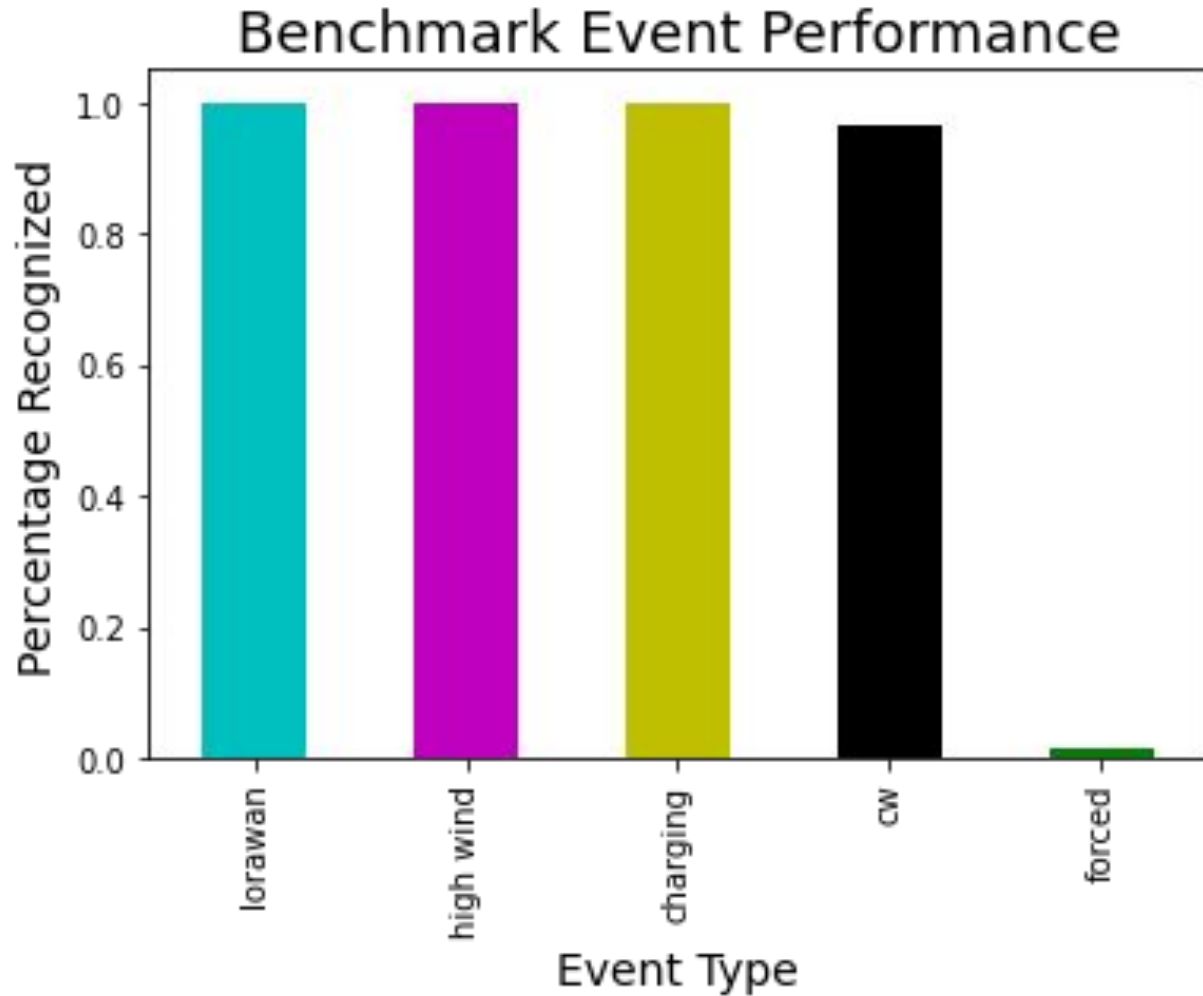
"Anomalous Low Threshold Event"

Forced triggers vs "Quiet Periods"
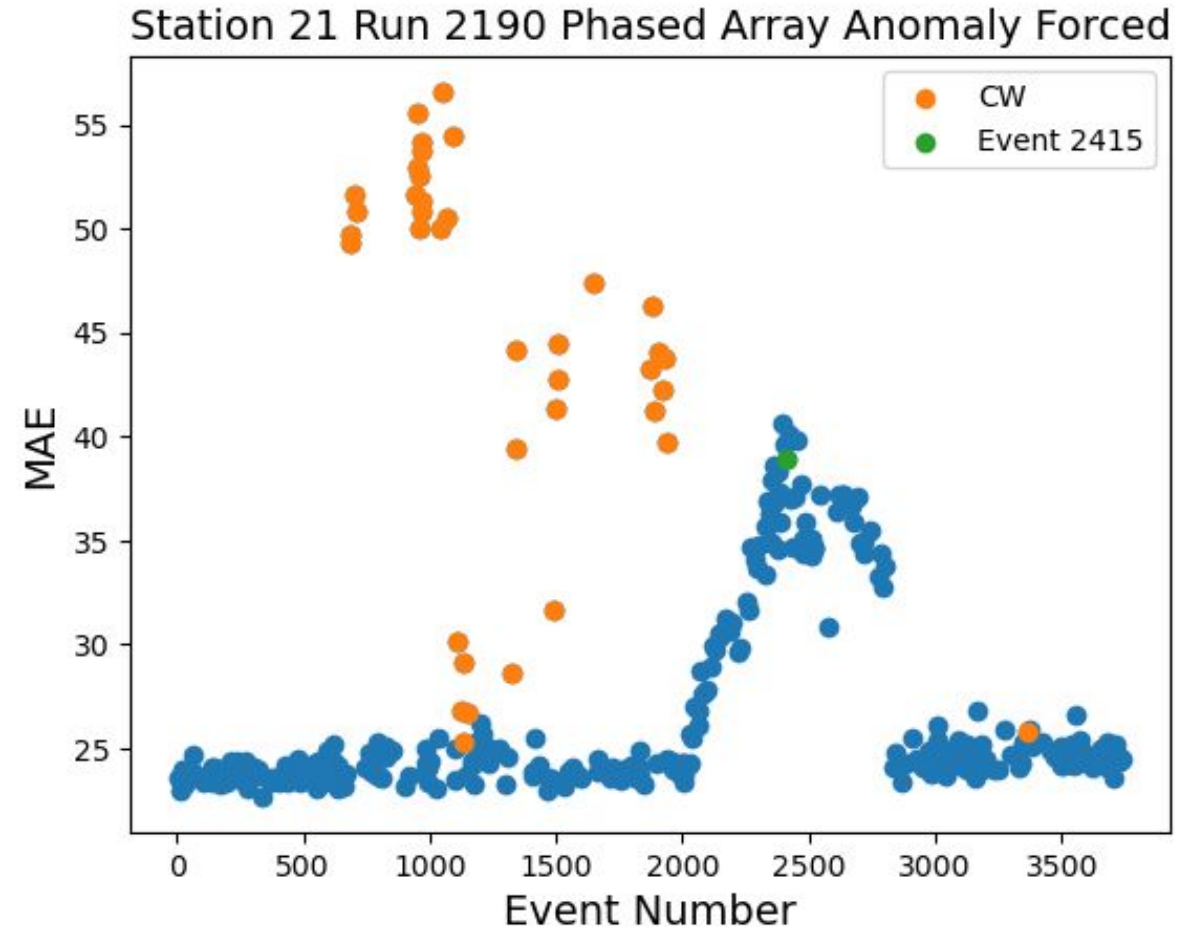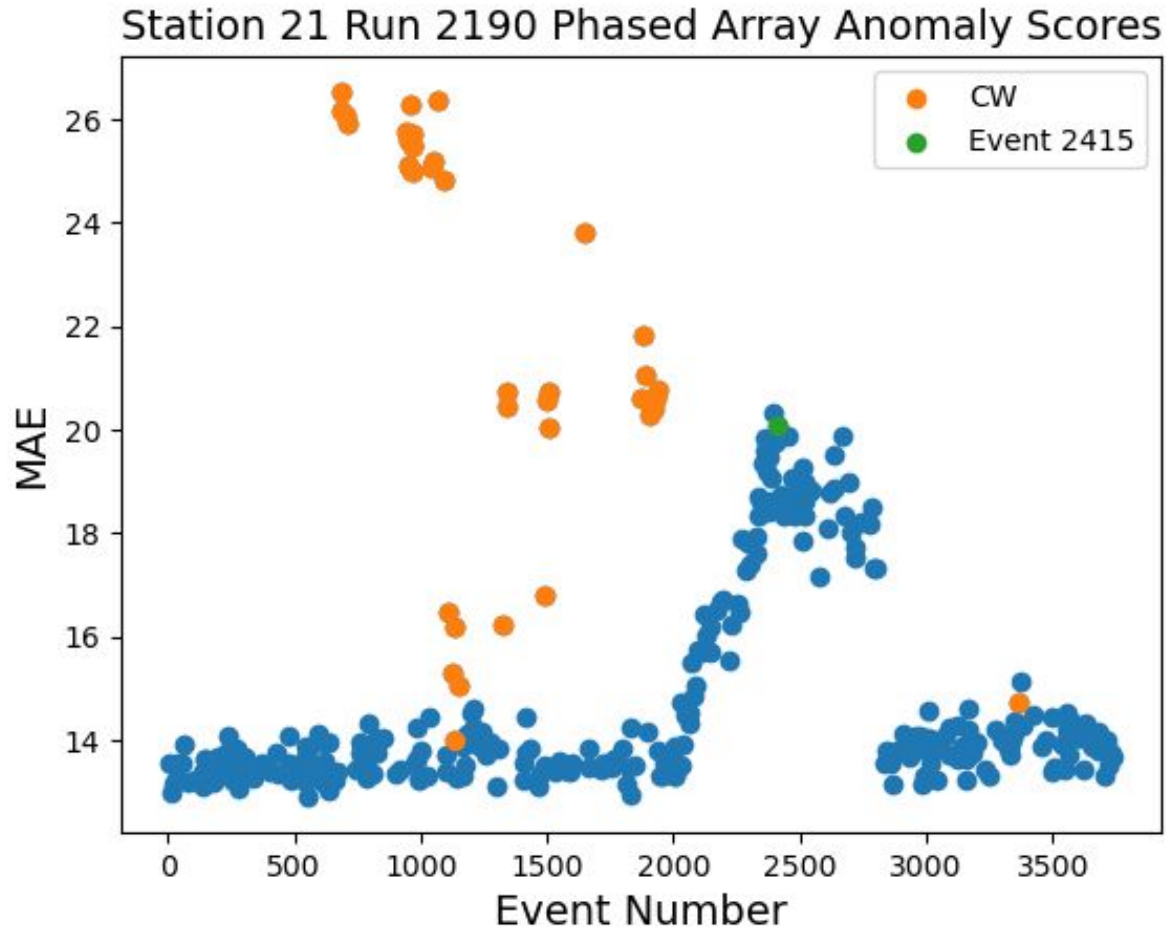
Snowmobiles / Ice Sat Traverse
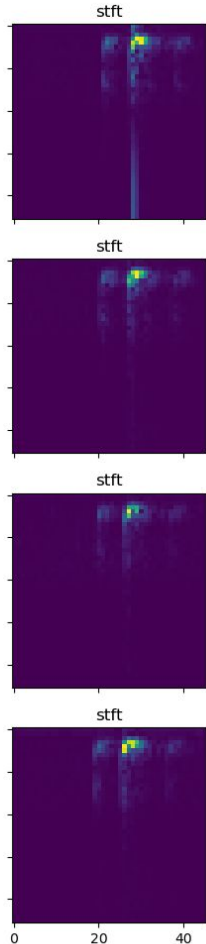
"Anomalous Low Threshold Event"

Reconstruction / Coming from above
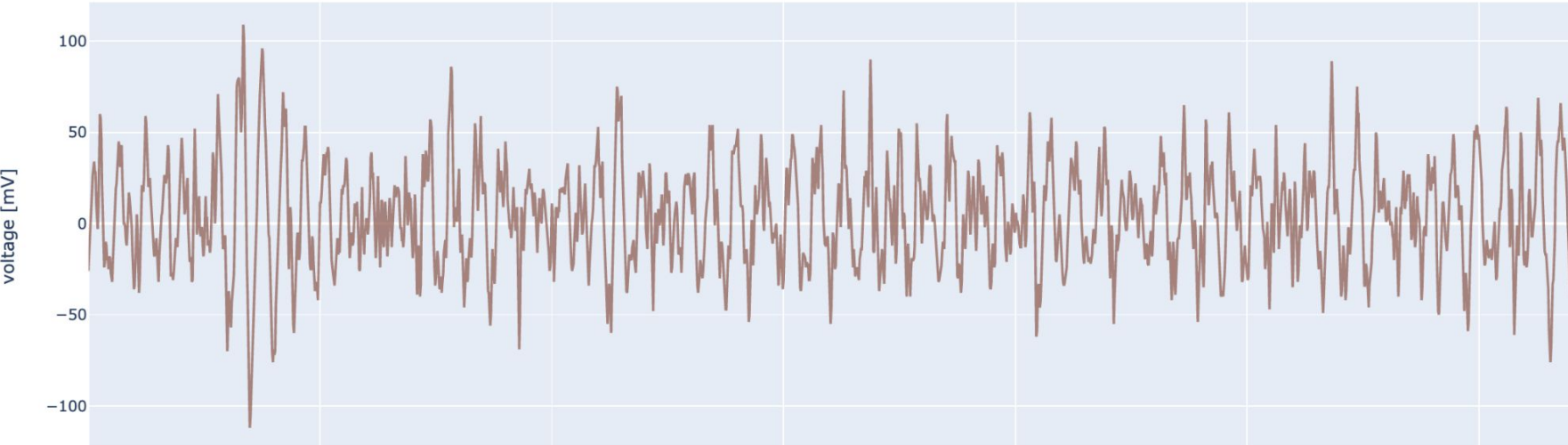
"Solar Model"

Butterworth filter 25 - 250 MHz

Anomaly Detection

Going 3D

L1 score = 0.016494025158550286

Anomaly Detection

Going 3D

L1 score = 0.016494025158550286
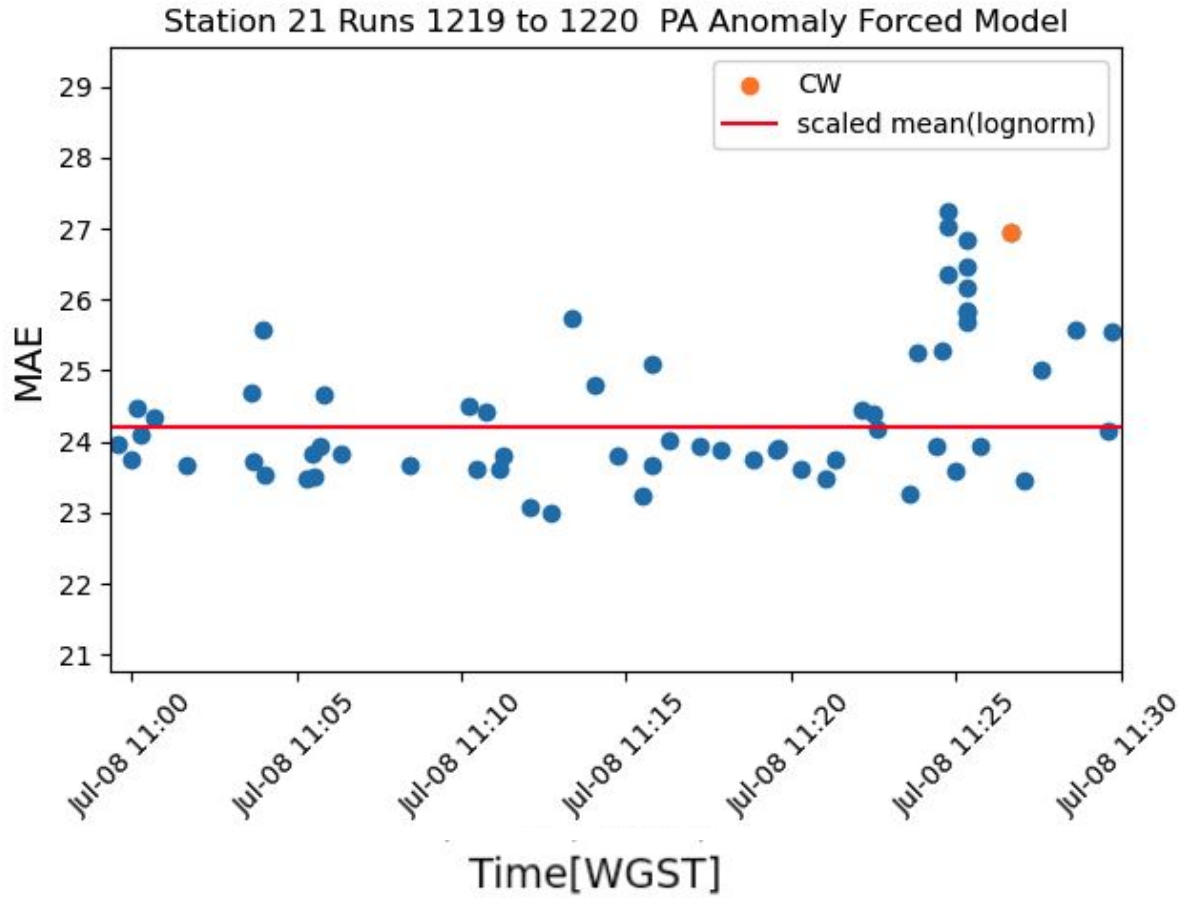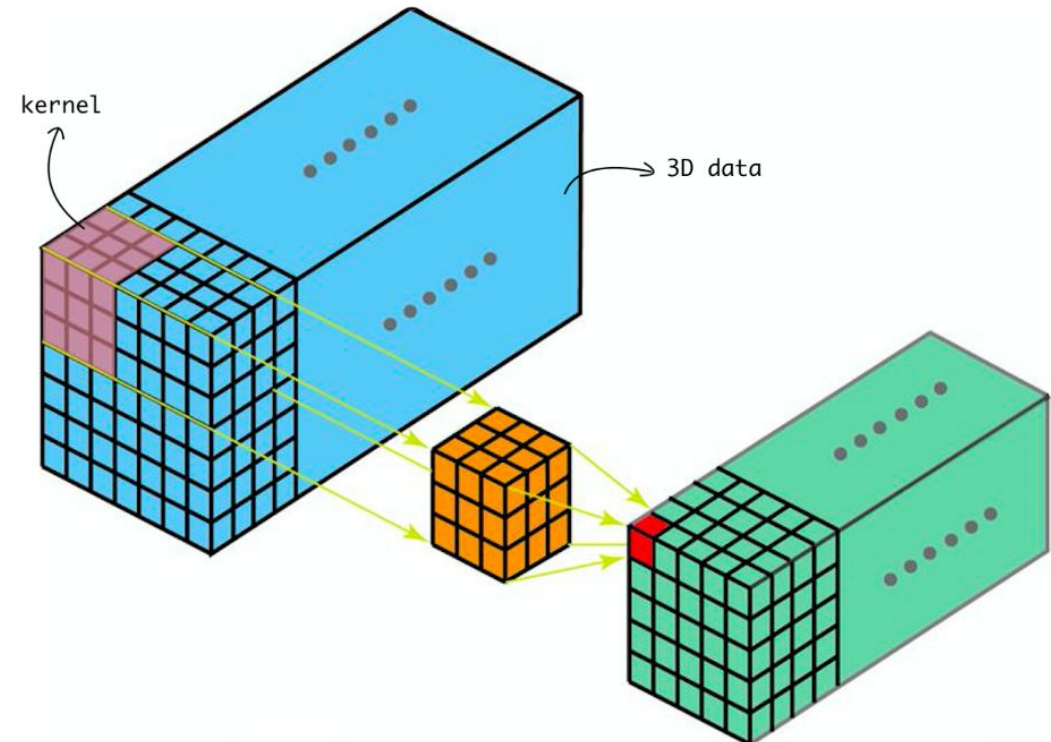
Anomaly Detection

Going 3D

```
Model: "sequential"
_____
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 92, 92, 32)        2080
_____
dropout (Dropout)            (None, 92, 92, 32)        0
_____
conv2d_1 (Conv2D)            (None, 46, 46, 16)        131088
_____
conv2d_transpose (Conv2DTran (None, 46, 46, 16)        65552
_____
dropout_1 (Dropout)          (None, 46, 46, 16)        0
_____
conv2d_transpose_1 (Conv2DTr (None, 92, 92, 32)        32800
_____
conv2d_transpose_2 (Conv2DTr (None, 92, 92, 1)         33
=================================================================
Total params: 231,553
Trainable params: 231,553
Non-trainable params: 0
_____
```
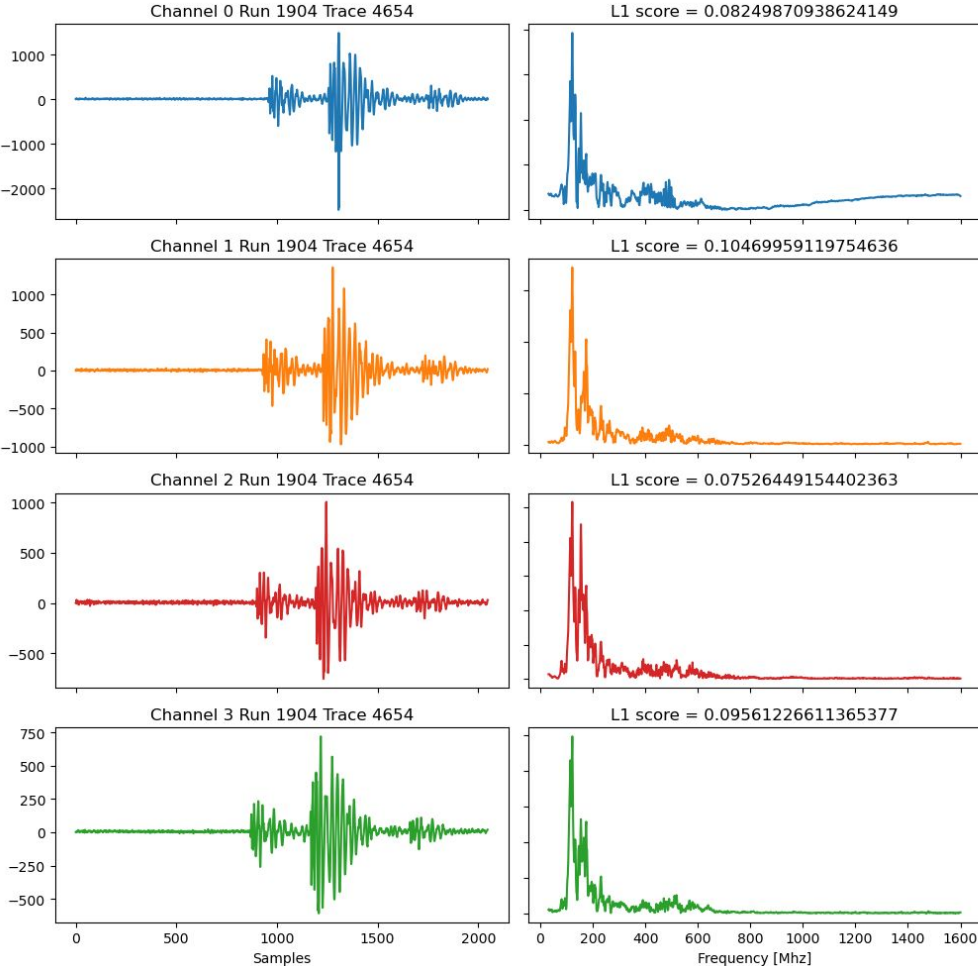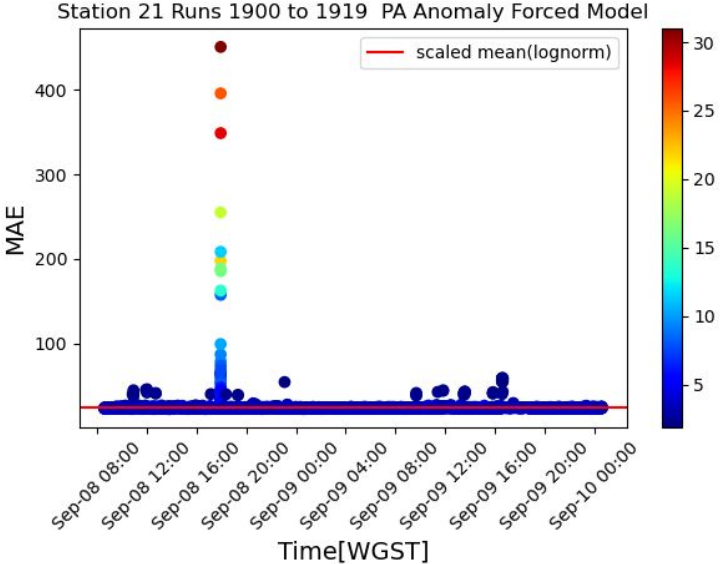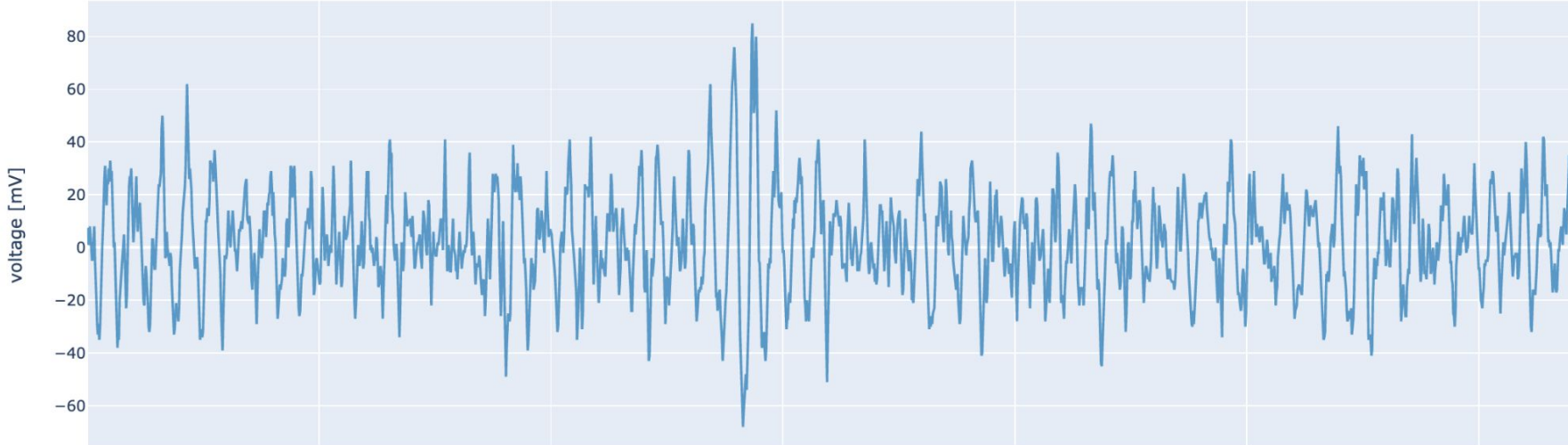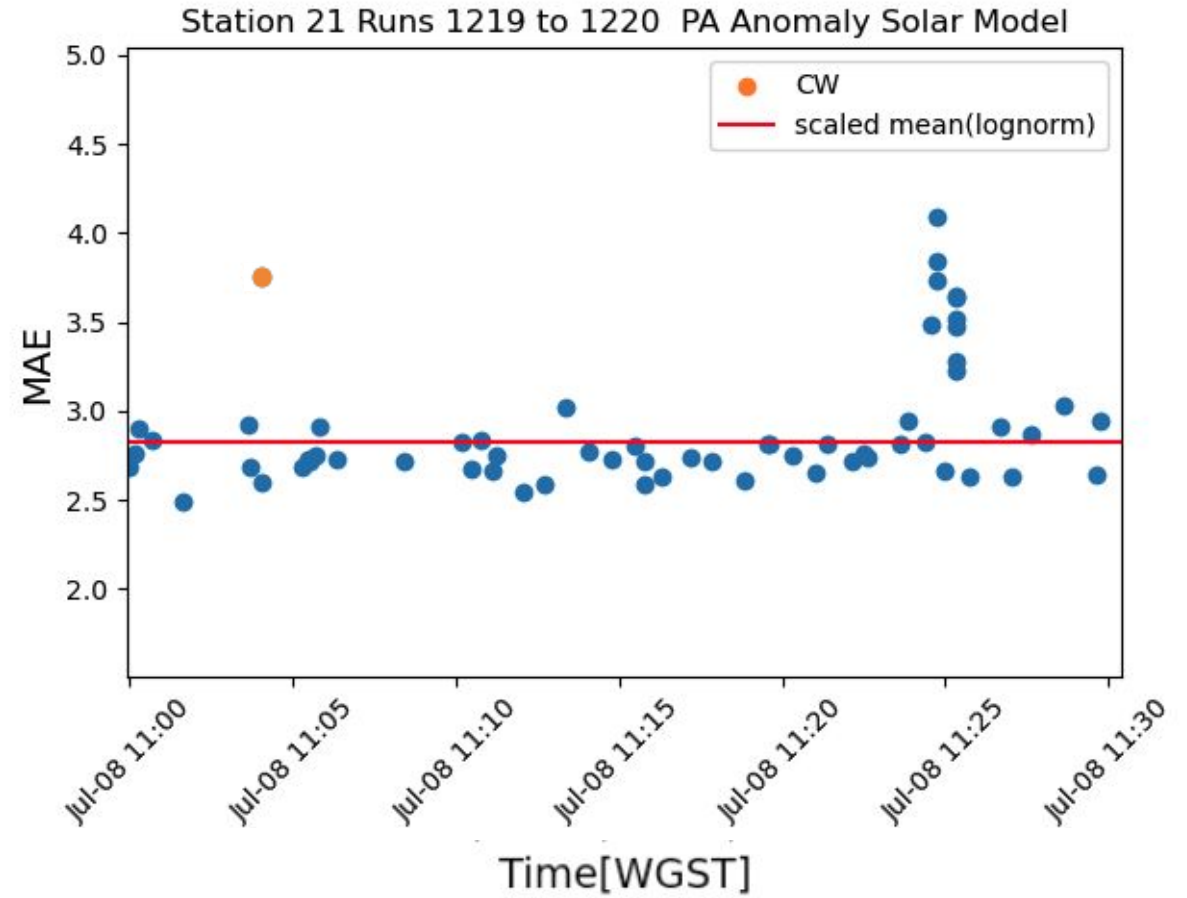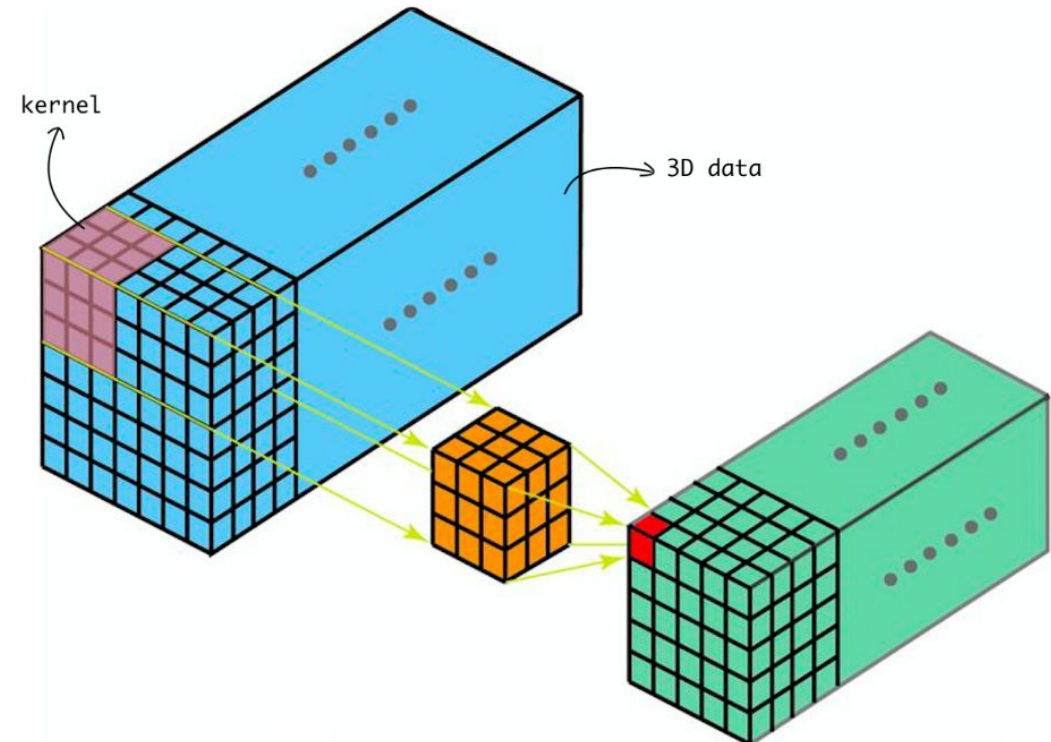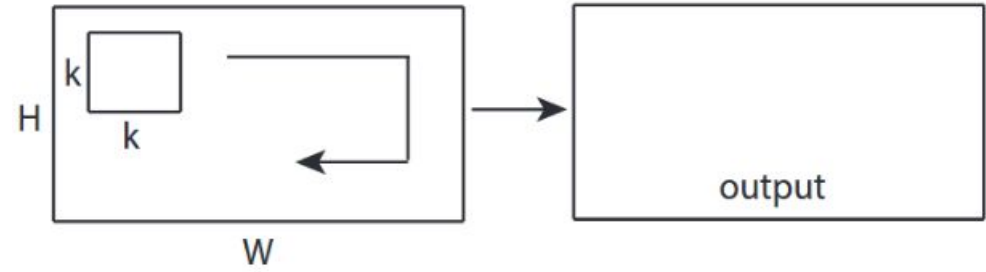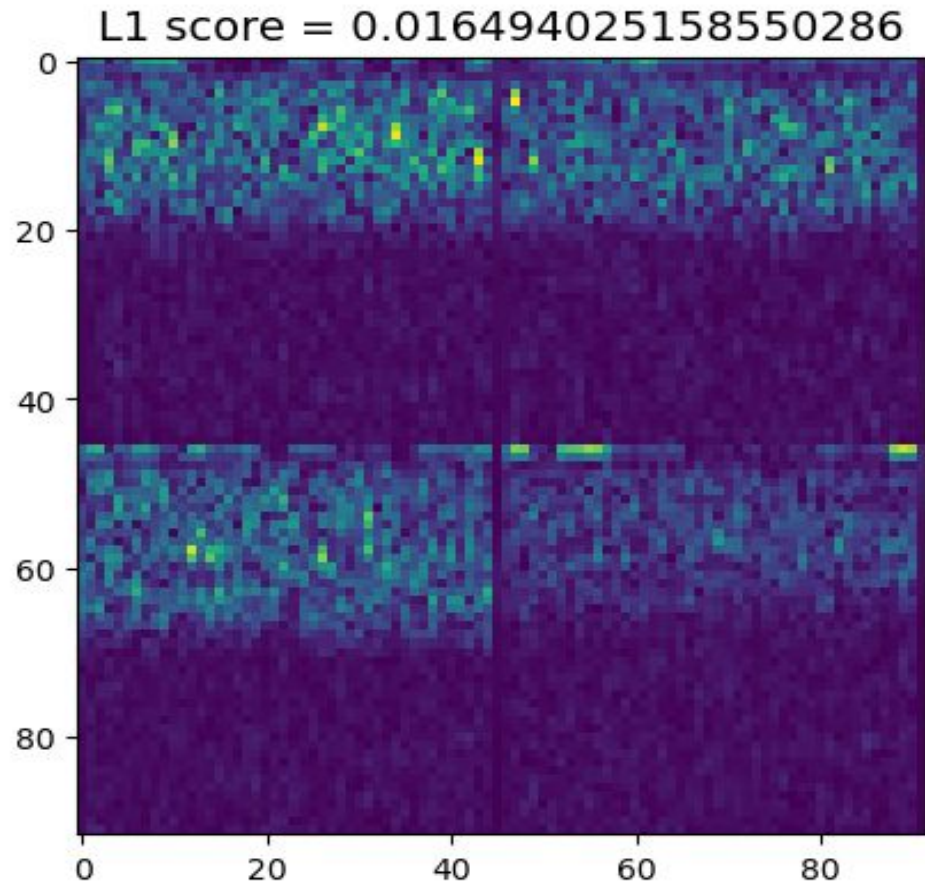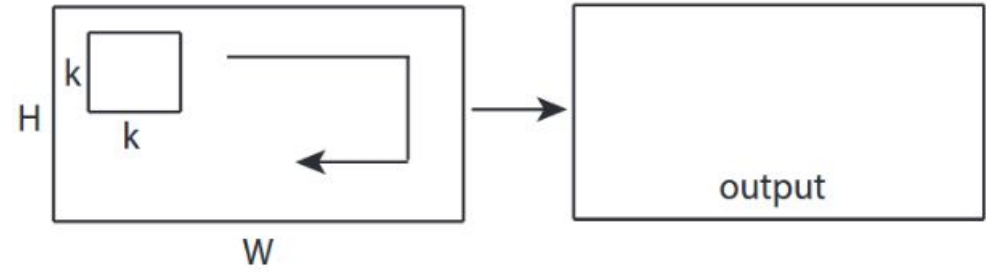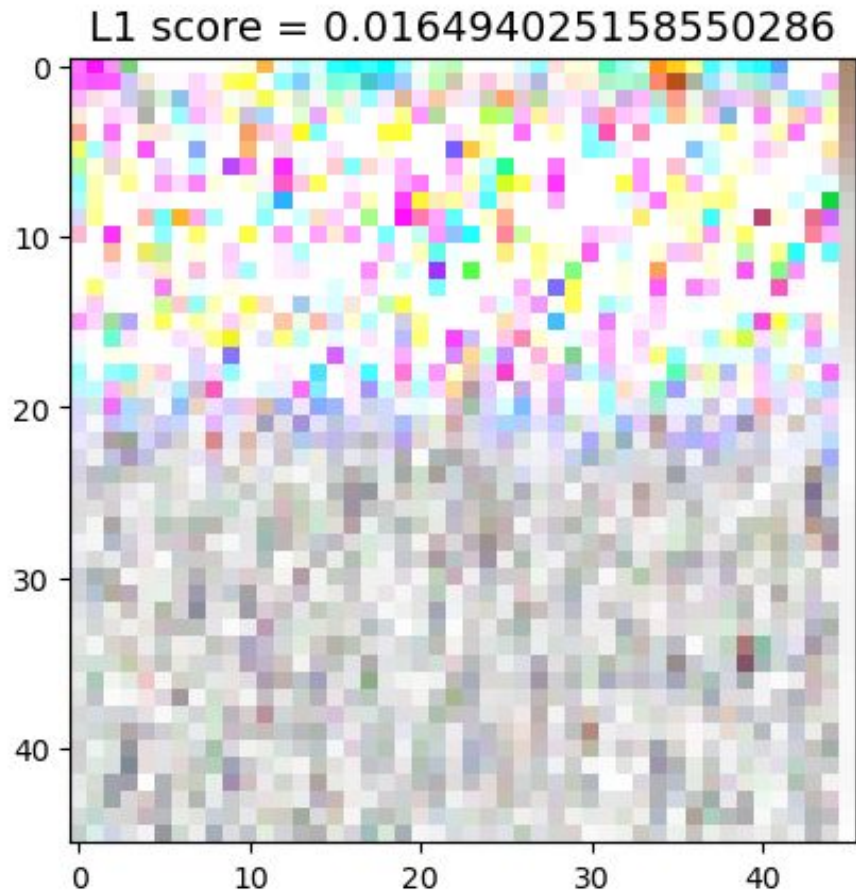
```
Model: "sequential_7"
_____
Layer (type)                 Output Shape              Param #
=================================================================
conv3d_10 (Conv3D)           (None, 46, 46, 4, 32)     16416
_____
dropout_14 (Dropout)         (None, 46, 46, 4, 32)     0
_____
conv3d_11 (Conv3D)           (None, 23, 23, 2, 16)     2097168
_____
conv3d_transpose_14 (Conv3DT (None, 46, 46, 4, 16)     1048592
_____
dropout_15 (Dropout)         (None, 46, 46, 4, 16)     0
_____
conv3d_transpose_15 (Conv3DT (None, 46, 46, 4, 32)     262176
_____
conv3d_transpose_16 (Conv3DT (None, 46, 46, 4, 1)      2049
=================================================================
Total params: 3,426,401
Trainable params: 3,426,401
Non-trainable params: 0
_____
```
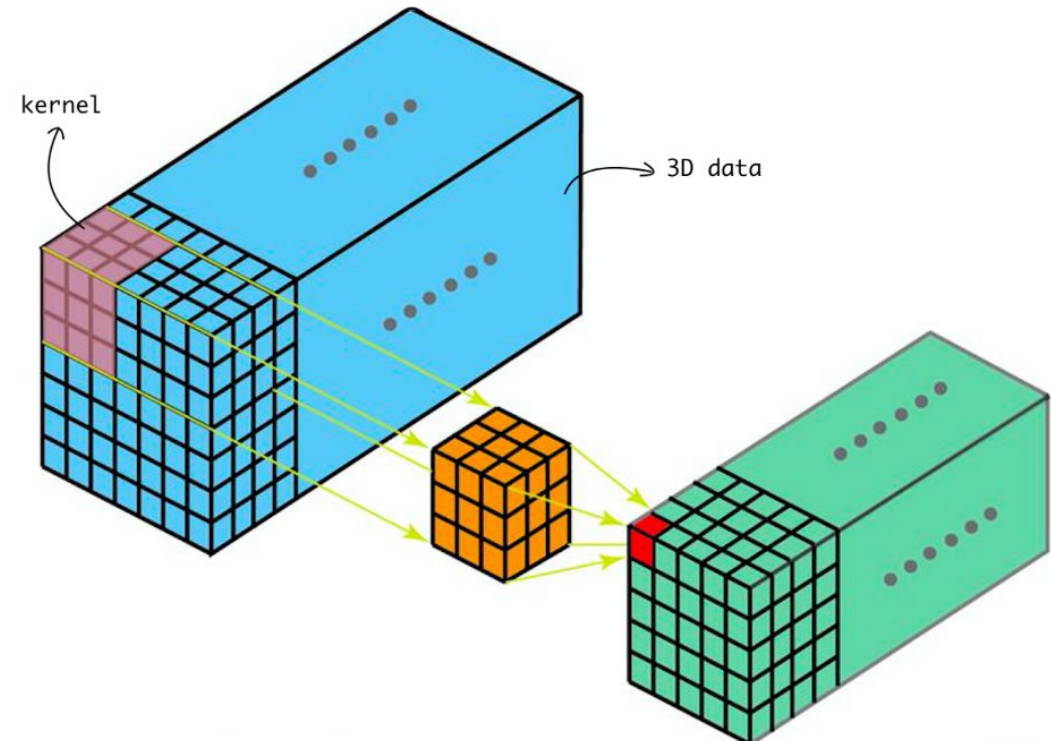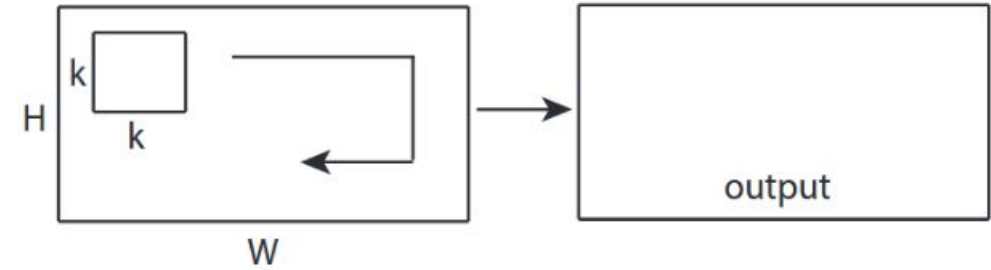
Anomaly Detection Update

Going 3D

2D Mosaic

3D Tensor