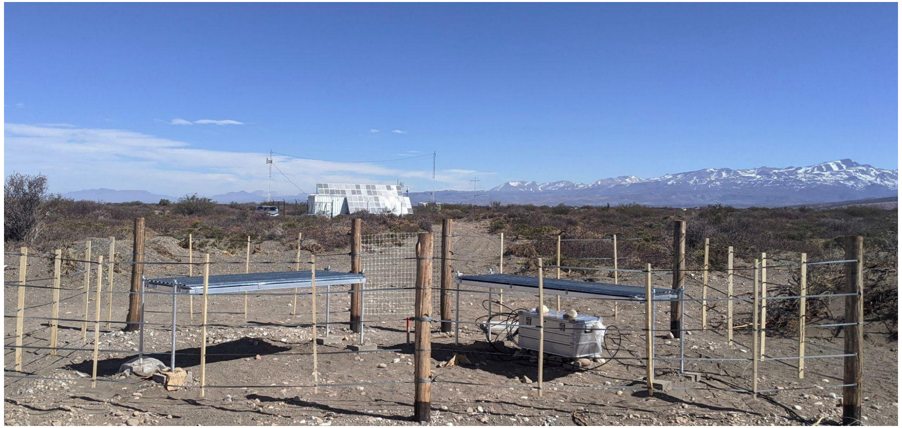
Data Analysis for Background Noise in Cosmic-Ray Air Showers

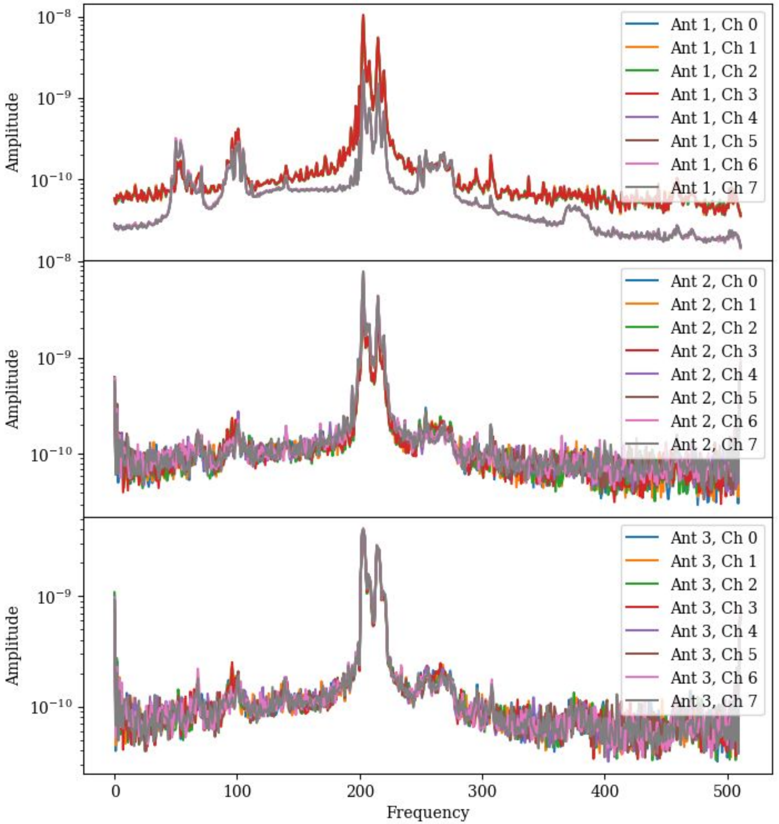


Taken from: Benn Flaggs, Alan Coleman, Frank Schroder, Hrvoje Dujmovic, Noah Goehlke, Tom Huber. (2022). “IceCube Surface Station Deployment at the Pierre Auger Observatory”. Bartol Research Institute.

Surface Station at the **Pierre Auger** Observatory

Goal:

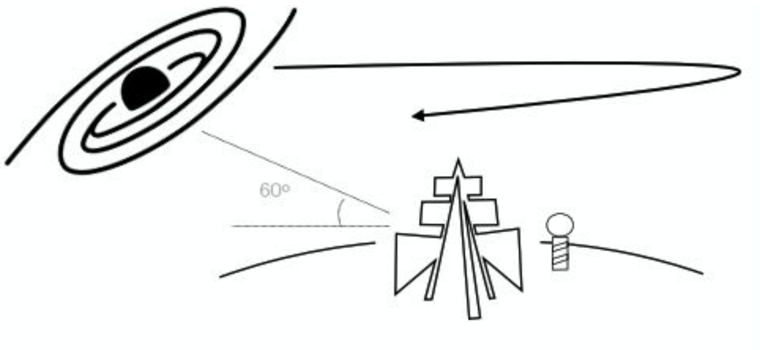
Analyze the galactic noise present in the prototype station at the Pierre Auger Observatory, enabling its utilization in calibration procedures.



Reproduced from: Carmen Merx. (2023). https://gitlab.iap.kit.edu/auger-observatory/sandboxes/cmerx/Scripts. Karlsruher Instituts für Technologie (KIT).

Radio background from the Galaxy

Under ideal conditions, the level of galactic noise received by radio antennas should only vary with the sky position of the galactic plane within the antennas' field of view.



Taken from: Roxanne Turcotte-Tardif. (2022). "Radio Measurements of Cosmic Rays at the South Pole". Karlsruher Instituts für Technologie (KIT).

Example at the IceCube

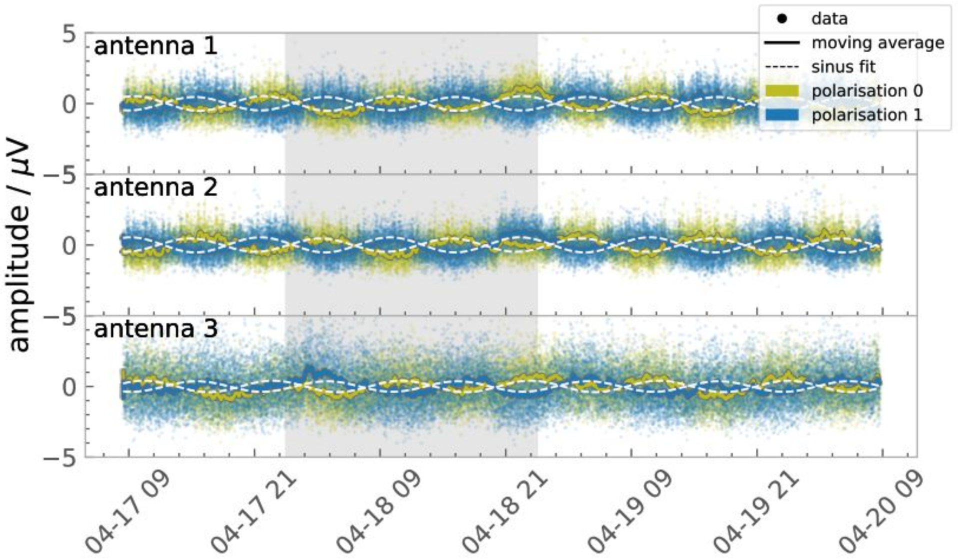


Figure 8.8: Galactic center oscillation observed in the noise level of the different antenna channels. Each channel has its averaged value subtracted. The time of the x-axis is in month-day hour format.

Converting binary files to I3 files

I = TrayInfo
G = Geometry
C = Calibration
D = Detector Status
Q = DAQ
P = Physics

Binary Files

- 2023-06-02
- 2023-06-03
- 2023-06-04

I3_converter.py

```
radio2i3(taxi_bin_filename,
output_filename,
serdes_delay=None,
serdes_timestamps=None)
```

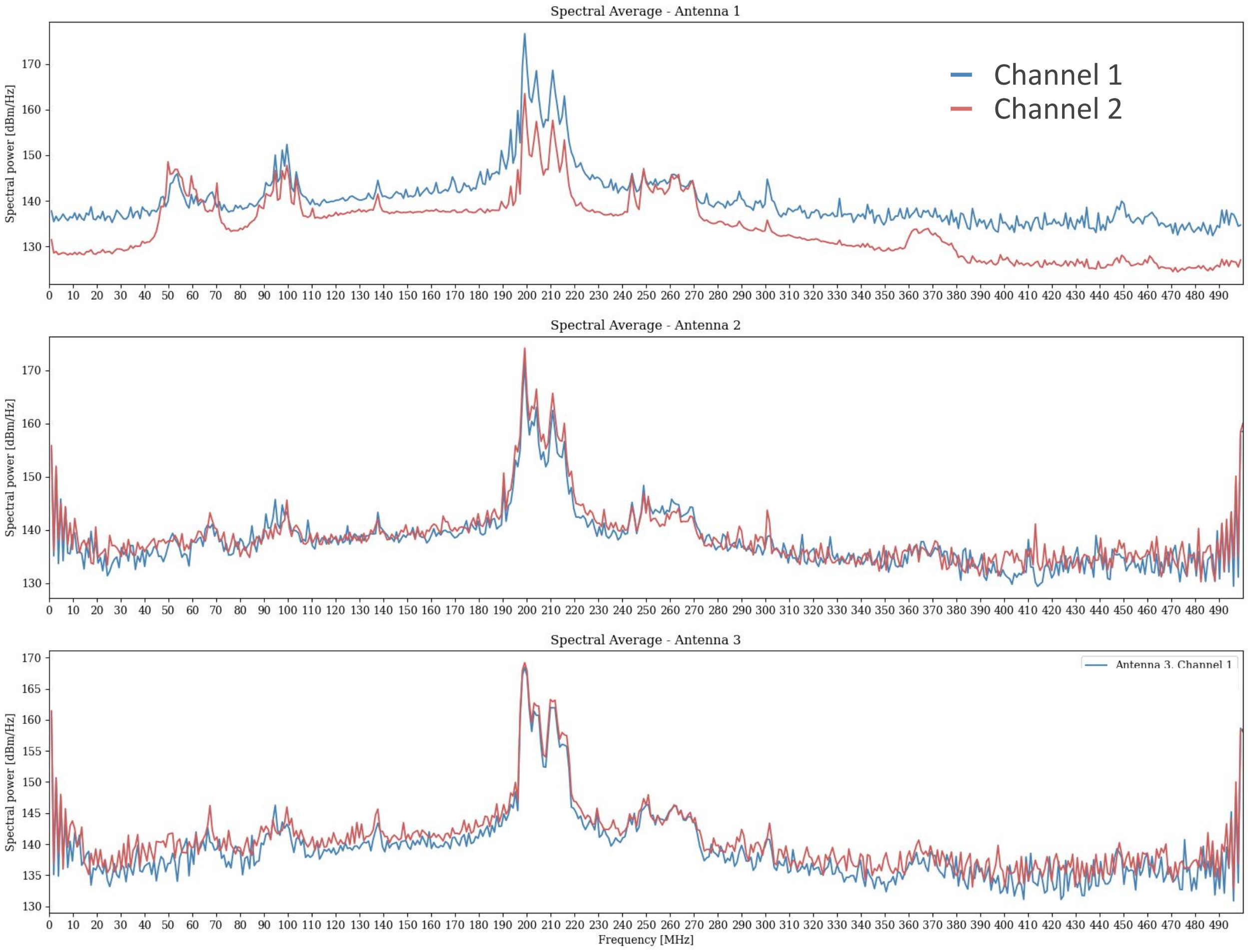
Reads in a .bin file and parses it into an I3File including all the radio waveforms and meta-data about the triggers.

I3 Files

- 001.i3.gz
- 002.i3.gz
- 003.i3.gz
- 279.i3.gz
- 004.i3.gz
- 005.i3.gz
- 006i3.gz

I3EventHeader
RadioAntennaROI
RadioTaxiWaveform
RadioTaxiTime
RadioTraceLegth
SurfaceFilters

Each Q frame represents one event and contains the waveform recorded for this event.

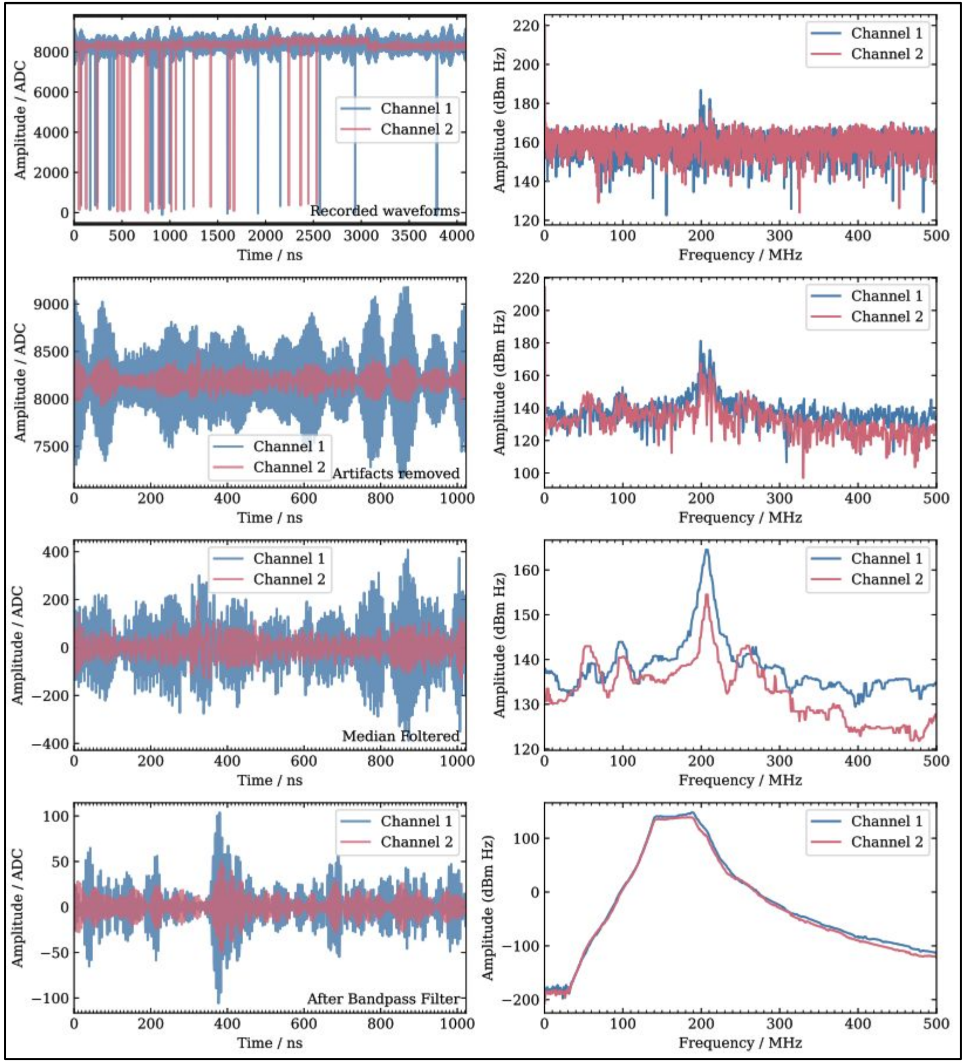


Average spectrum over all Q frames in each antenna and channel

November 25, 2022 - May 31, 2023

Regions with minimal spikes:

- **70-90 MHz**
- **110-130 MHz**
- **140-190 MHz**



Cleaning the data

- ➔ Selecting soft trigger data.
- ➔ Selecting data with trace length = 1024

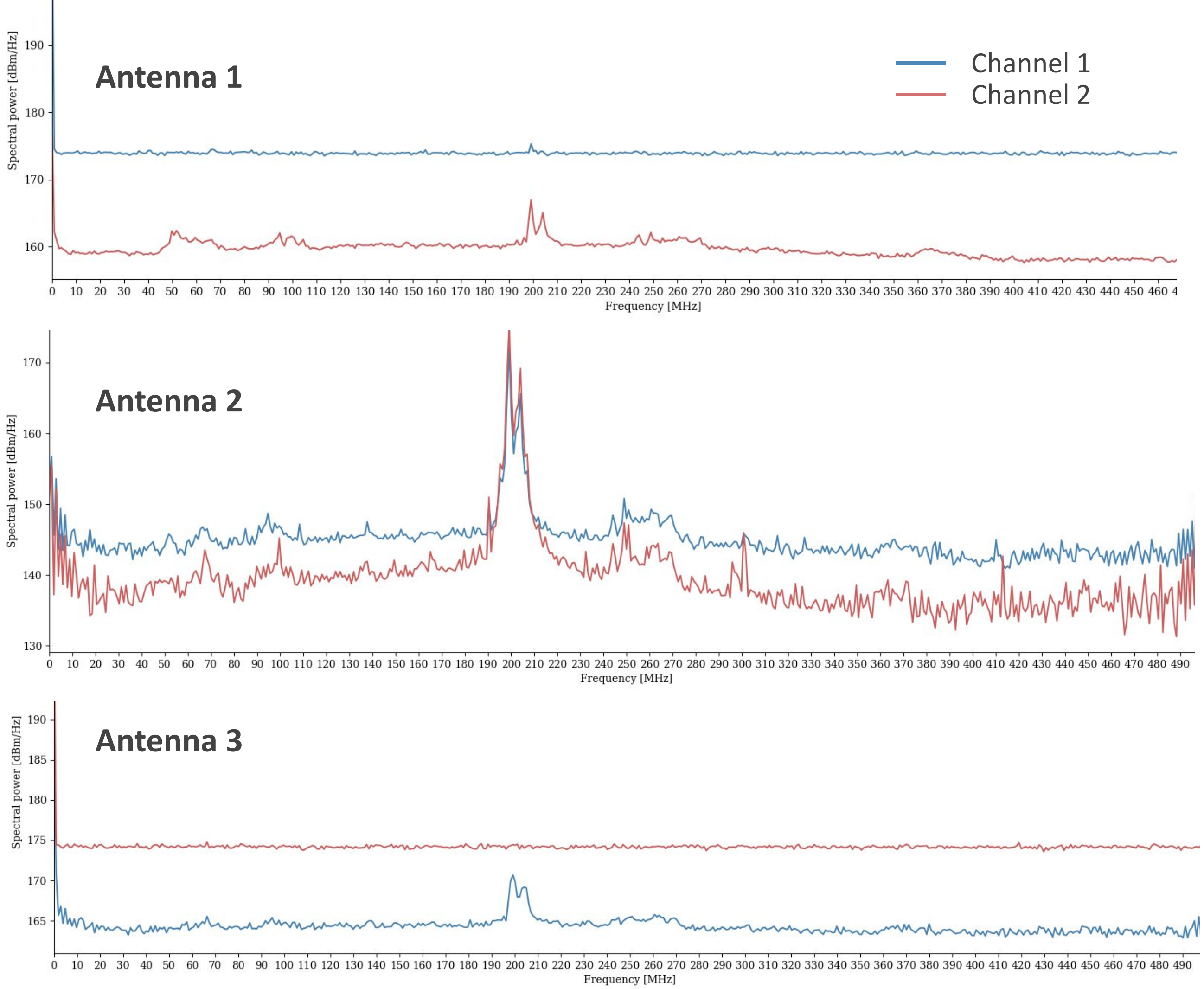
Trace Length = 0 !

New Filter:

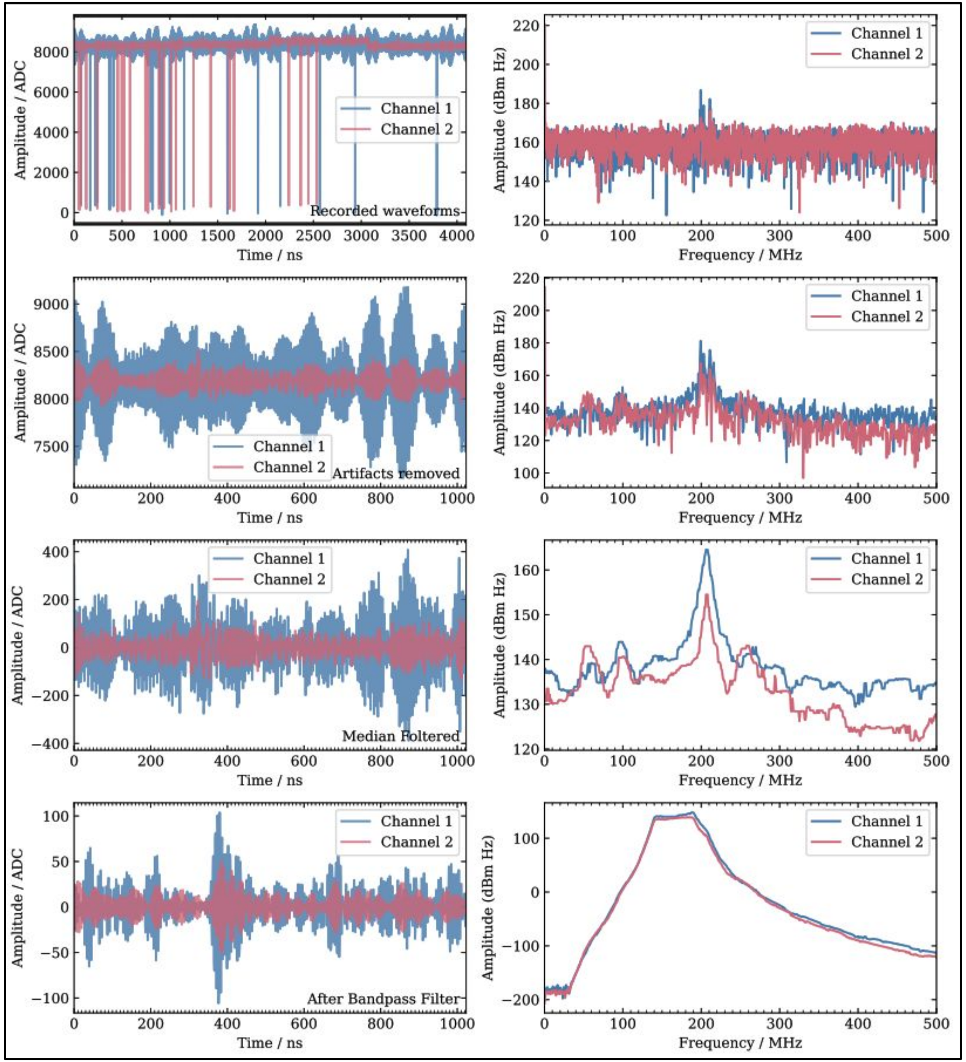
```
if TraceLength != 0:
        return True
else:
        return False
```

Average spectrum

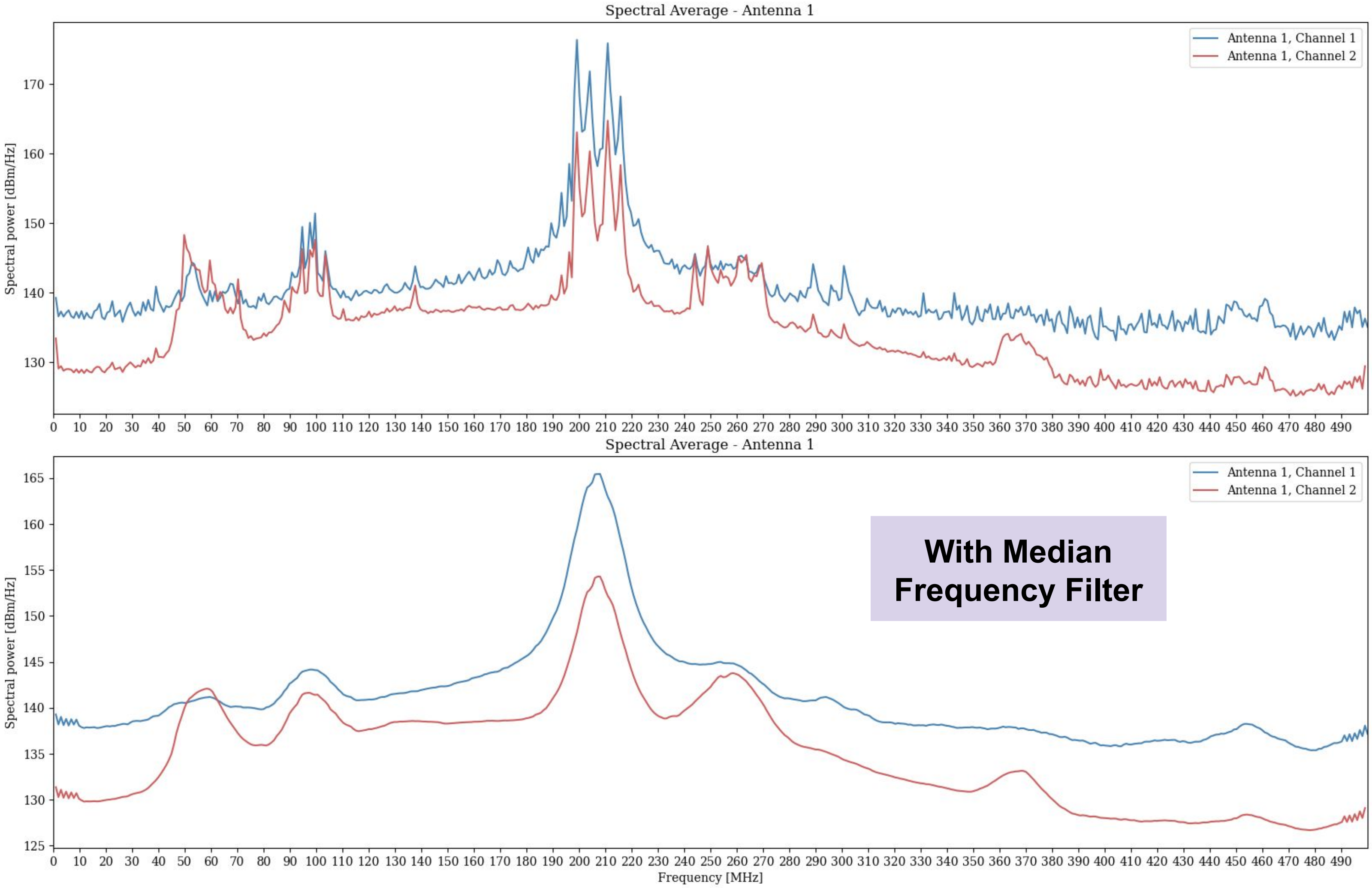
December 09 2022

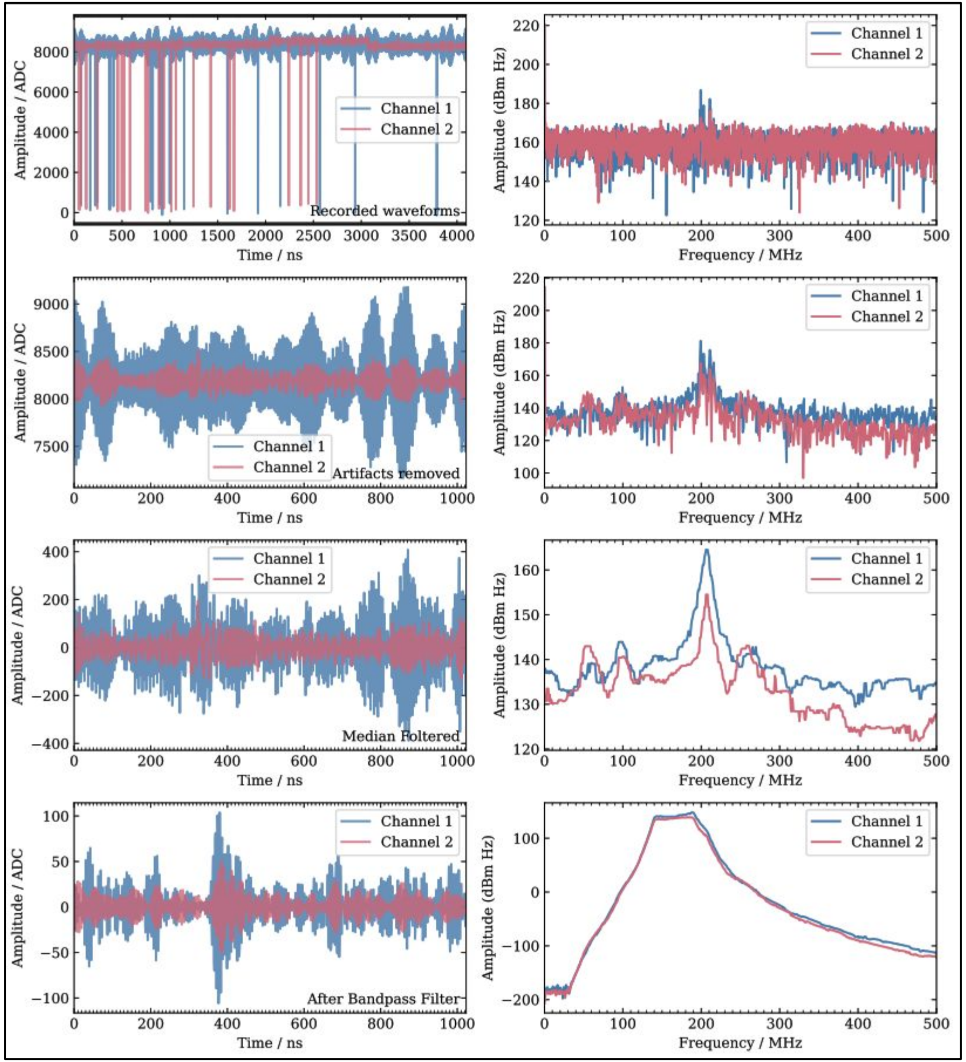


Cleaning the data



- ➔ Selecting soft trigger data.
- ➔ Selecting data with trace length = 1024
- ➔ Removing taxi artifacts.
- ➔ Median over cascades.
- ➔ Median Frequency Filter.


Spectral Average - Antenna 1
Antenna 1, Channel 1
Antenna 1, Channel 2
Spectral power [dBm/Hz]
Frequency [MHz]
With Median Frequency Filter

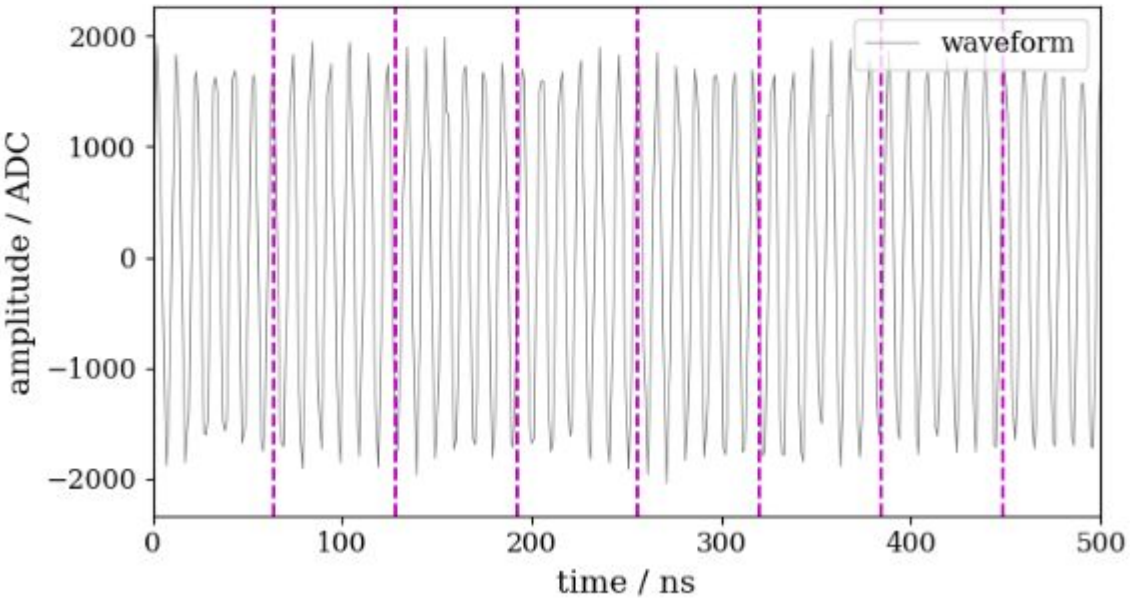


Cleaning the data

- ➔ Selecting soft trigger data.
- ➔ Selecting data with trace length = 1024
- ➔ Removing taxi artifacts.
- ➔ Median over cascades.
- ➔ Median Frequency Filter.
- ➔ Not using Electronic Response
- ➔ Applying the Bandpass filter:

  eButterworth filter

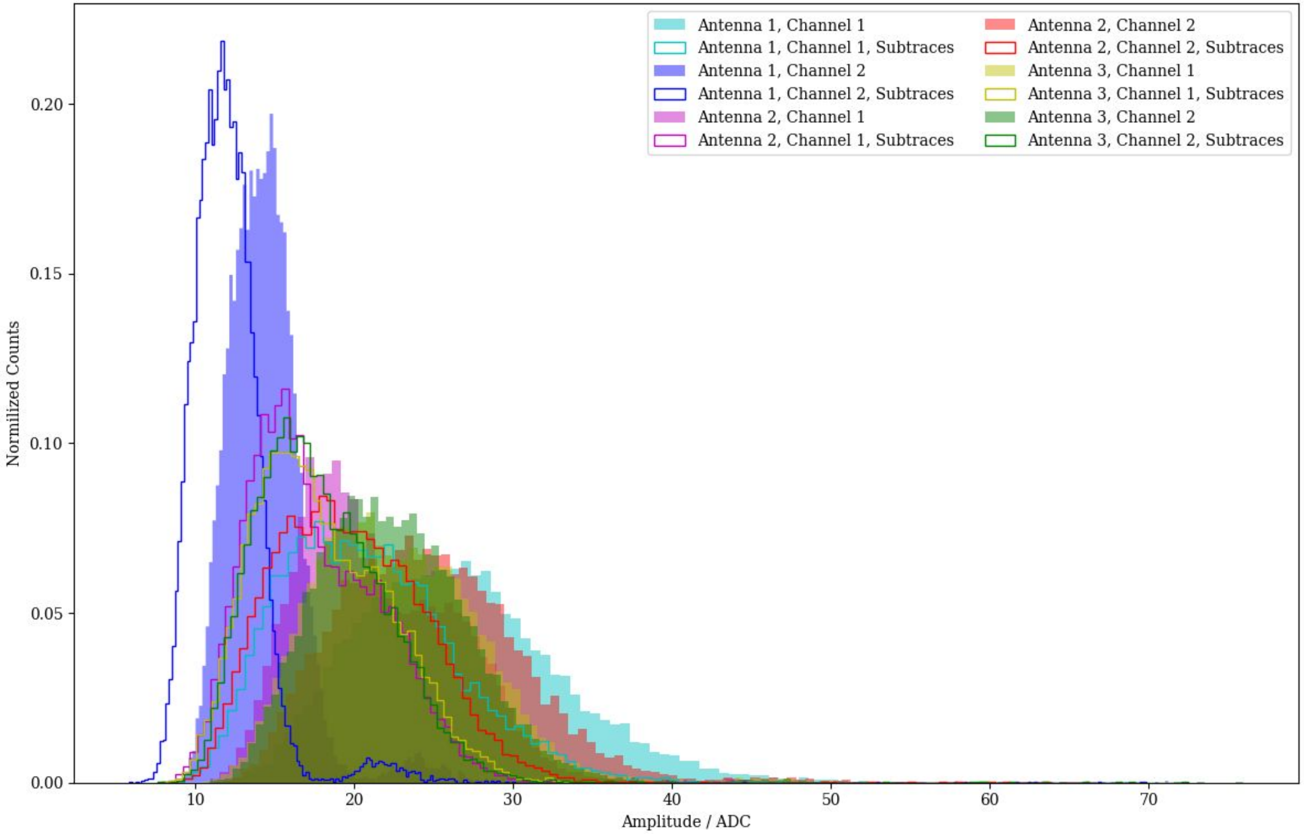
Subtraces Method



The traces are split in intervals with equal length (subtraces), then the RMS of these subtraces is calculated and then the mean of the 10 smallest RMS values is taken.

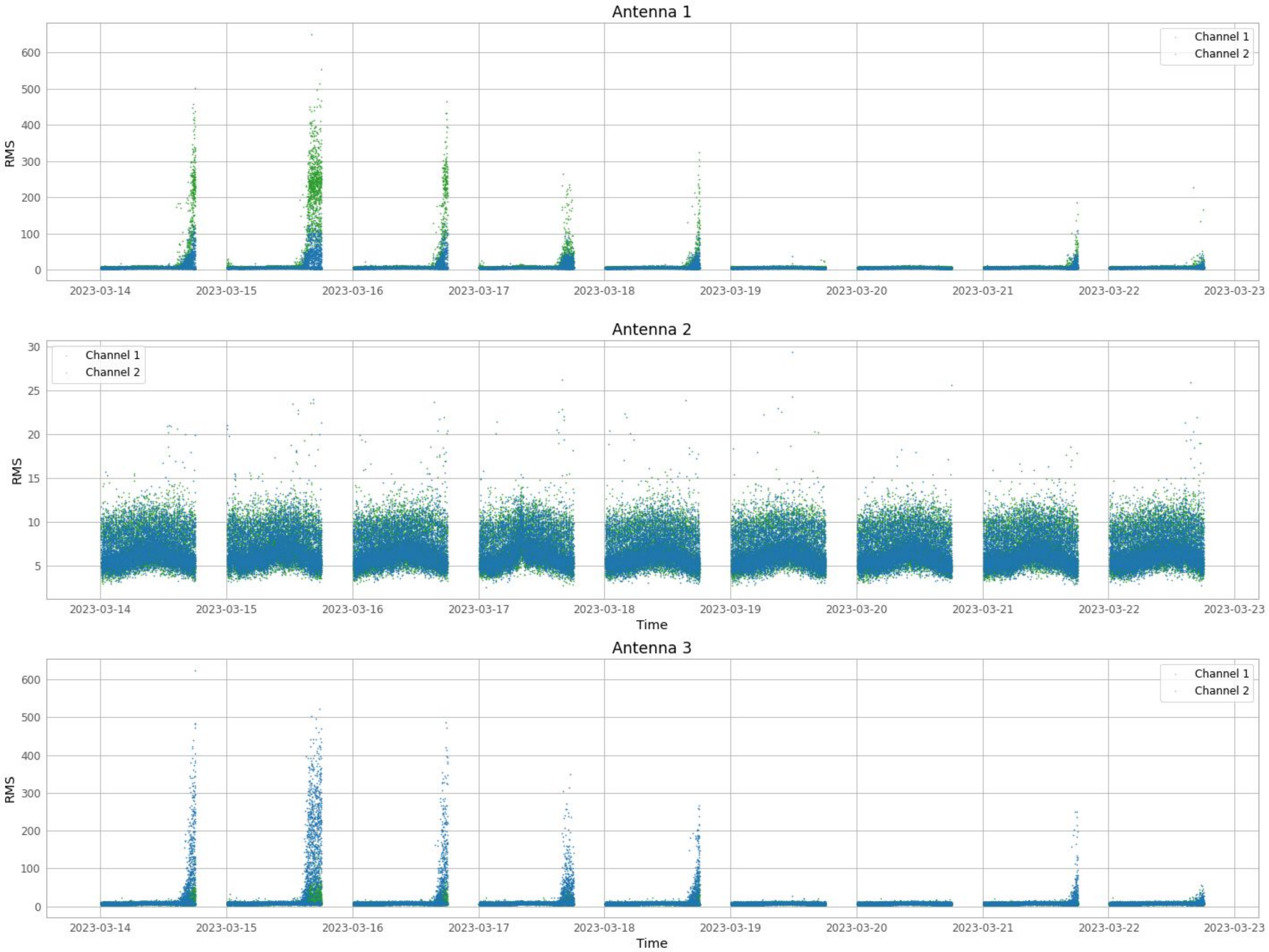
Taken from: Roxanne Turcotte-Tardif. (2022). “Radio Measurements of Cosmic Rays at the South Pole”. Karlsruher Instituts für Technologie (KIT).

Distributions of the noise level in the traces for each antenna and channel using the subtraces method and the standard RMS window



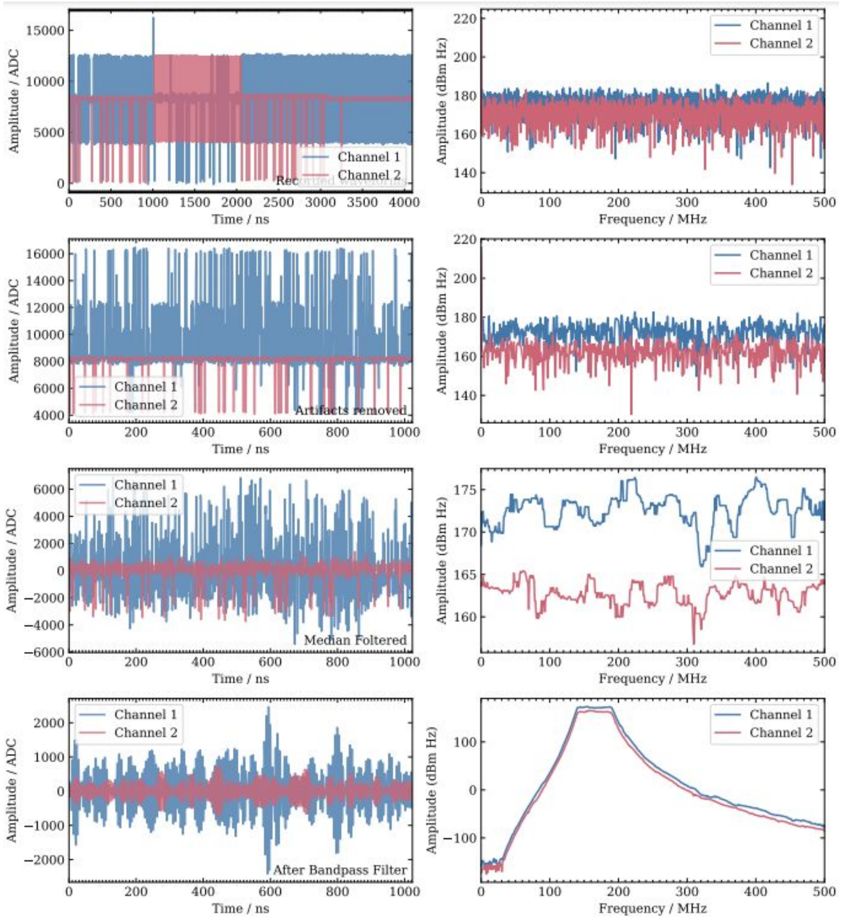
- ➔ Butterworth filter
- ➔ Interval 140-190 MHz
- ➔ 64ns subtrace

Noise level in March, 2023 for soft trigger data in each of the tree antennas and its polarizations

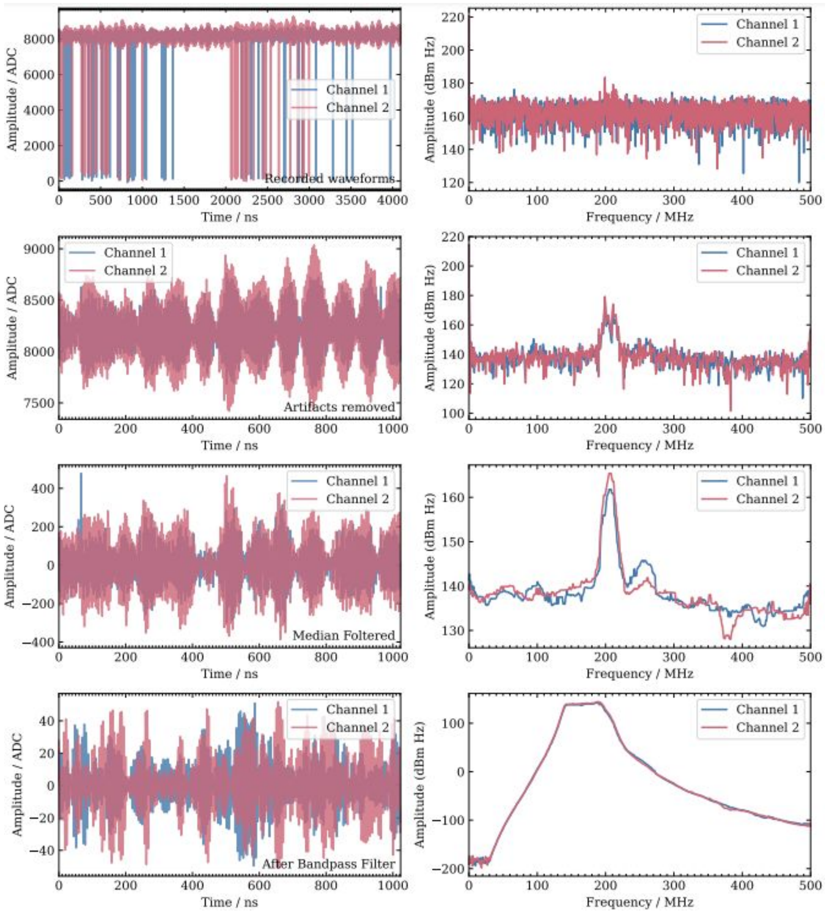


Problems with the waveforms

Antenna 1



Antenna 2



Data Set:

- Data from November 25th, 2022 to September 25th, 2023
- Number of events: 3.677.106
- Frequency Intervals:

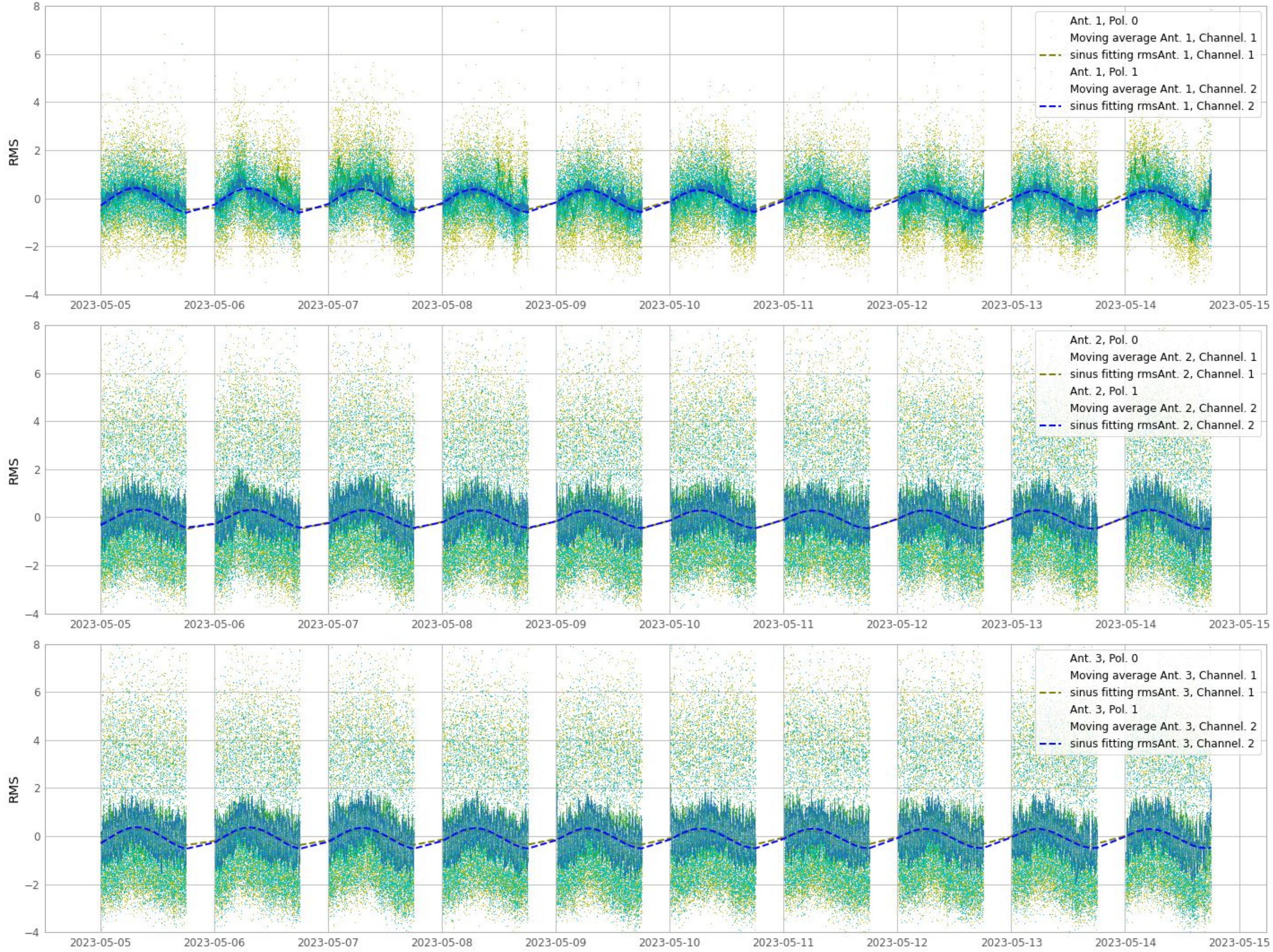
70-90 MHz
110-130 MHz
140-190 MHz

Sinusoidal Function:

Sidereal Period: 86164.0905 s

Solar Period: 86400 s

$$\underbrace{A_1 \mathrm{Sin}\left(\frac{2\pi t}{T_{\mathrm{sidereal}}} + \varphi_1\right)}_{\text{Galactic Noise}} + \underbrace{A_2 \mathrm{Sin}\left(\frac{2\pi t}{T_{\mathrm{solar}}} + \varphi_2\right)}_{\text{Other Noise}} + B$$

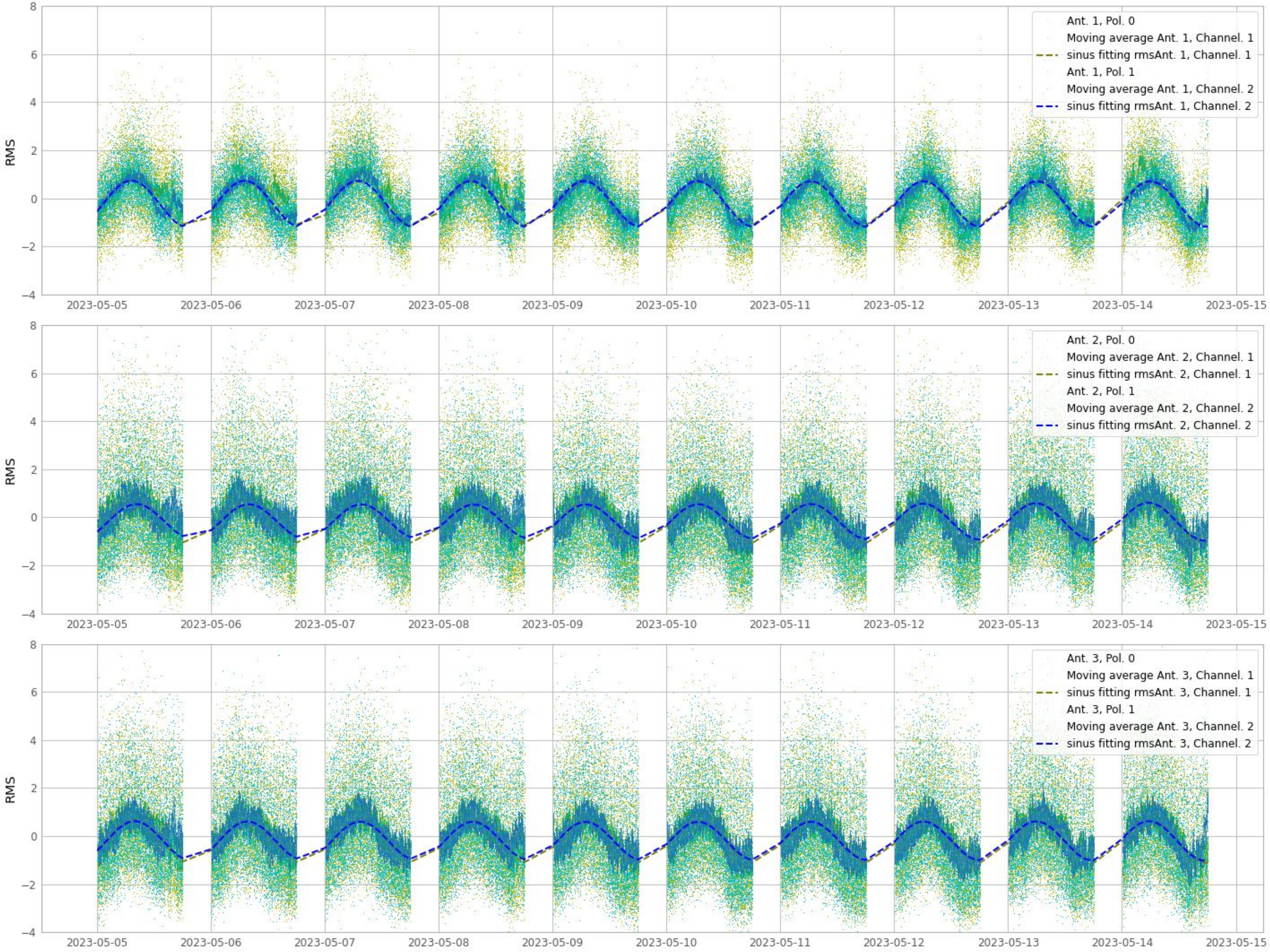


Sinusoidal fit for the RMS values in the interval 70-90 MHz

Sidereal Period: 86164.0905 s

Solar Period: 86400 s

		Channel 1	Channel 2
Antenna 1	Amp Sidereal [ADC]	0.56 ± 0.01	0.45 ± 0.01
	Phase Sidereal [deg]	-148.23 ± 0.05	-144.36 ± 0.04
	Amp Solar [ADC]	0.28 ± 0.01	0.20 ± 0.01
	Phase Solar [deg]	139.04 ± 0.11	144.98 ± 0.09
	MSE	0.45	0.19
Anntena 2	Amp Sidereal [ADC]	0.48 ± 0.01	0.42 ± 0.01
	Phase Sidereal [deg]	-139.51 ± 0.07	-139.76 ± 0.07
	Amp Solar [ADC]	0.12 ± 0.01	0.11 ± 0.01
	Phase Solar [deg]	143.82 ± 0.26	137.28 ± 0.28
	MSE	0.57	0.51
Antenna 3	Amp Sidereal	0.39 ± 0.01	0.51 ± 0.01
	Phase Sidereal	-146.28 ± 0.09	-141.93 ± 0.07
	Amp Solar	0.14 ± 0.01	0.23 ± 0.01
	Phase Solar [deg]	-218.11 ± 0.23	-213.64 ± 0.14
	MSE	0.67	0.65



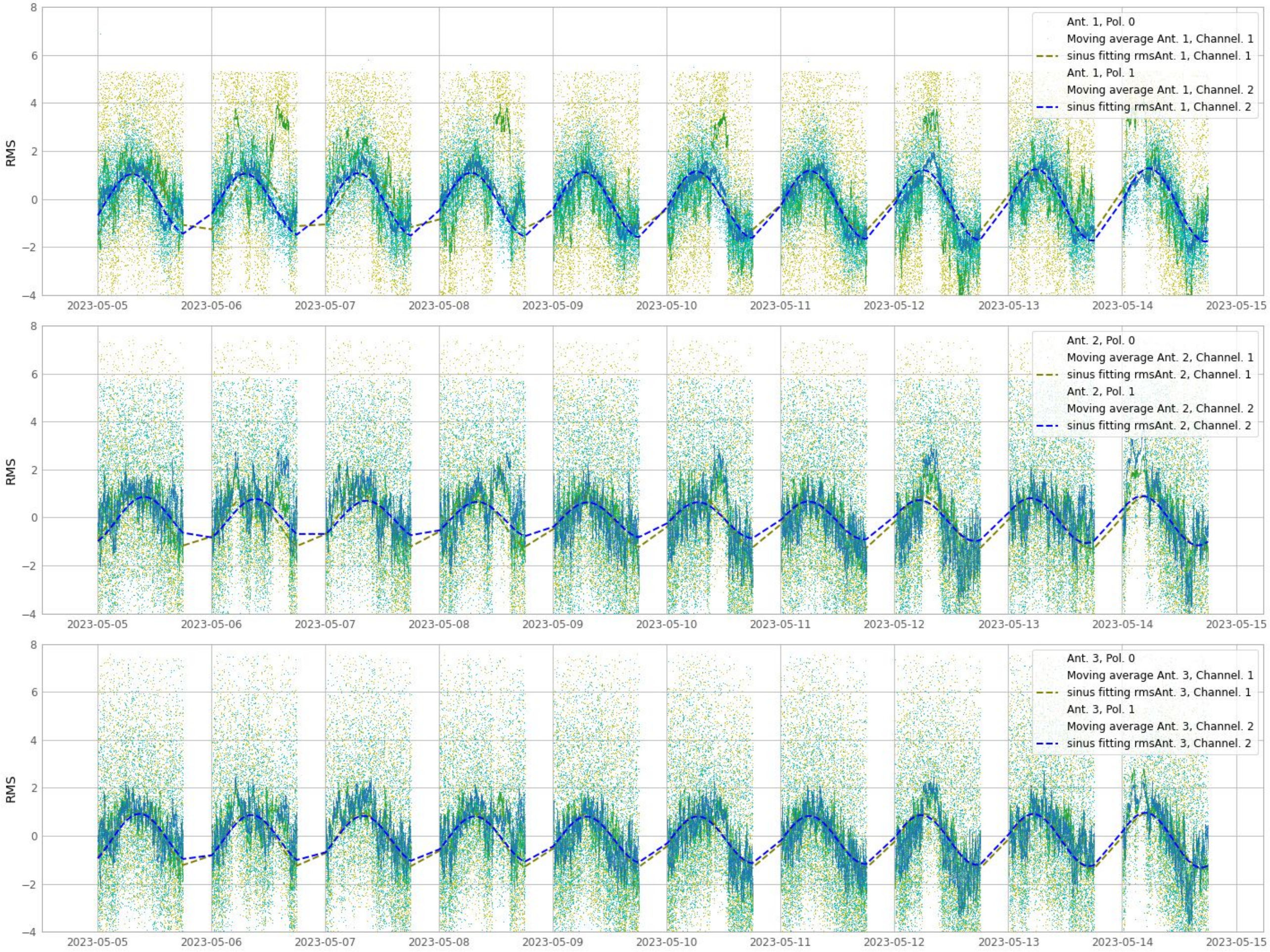
Sinusoidal fit for the RMS values in the interval 110-130 MHz

Sidereal Period: 86164.0905 s

Solar Period: 86400 s

		Channel 1	Channel 2
Antenna 1	Amp Sidereal [ADC]	0.98 ± 0.01	0.86 ± 0.01
	Phase Sidereal [deg]	-144.29 ± 0.02	-133.51 ± 0.02
	Amp Solar [ADC]	0.23 ± 0.01	0.15 ± 0.01
	Phase Solar [deg]	159.01 ± 0.11	159.28 ± 0.02
	MSE	0.39	0.16
Antenna 2	Amp Sidereal [ADC]	0.83 ± 0.01	0.70 ± 0.01
	Phase Sidereal [deg]	-137.71 ± 0.03	-139.79 ± 0.07
	Amp Solar [ADC]	0.57 ± 0.01	0.14 ± 0.01
	Phase Solar [deg]	172.61 ± 0.47	152.91 ± 0.18
	MSE	0.33	0.36
Antenna 3	Amp Sidereal	0.89 ± 0.01	0.81 ± 0.01
	Phase Sidereal	-140.55 ± 0.09	-139.97 ± 0.07
	Amp Solar	0.11 ± 0.01	0.26 ± 0.01
	Phase Solar [deg]	166.41 ± 0.23	-155.78 ± 0.14
	MSE	0.33	0.43

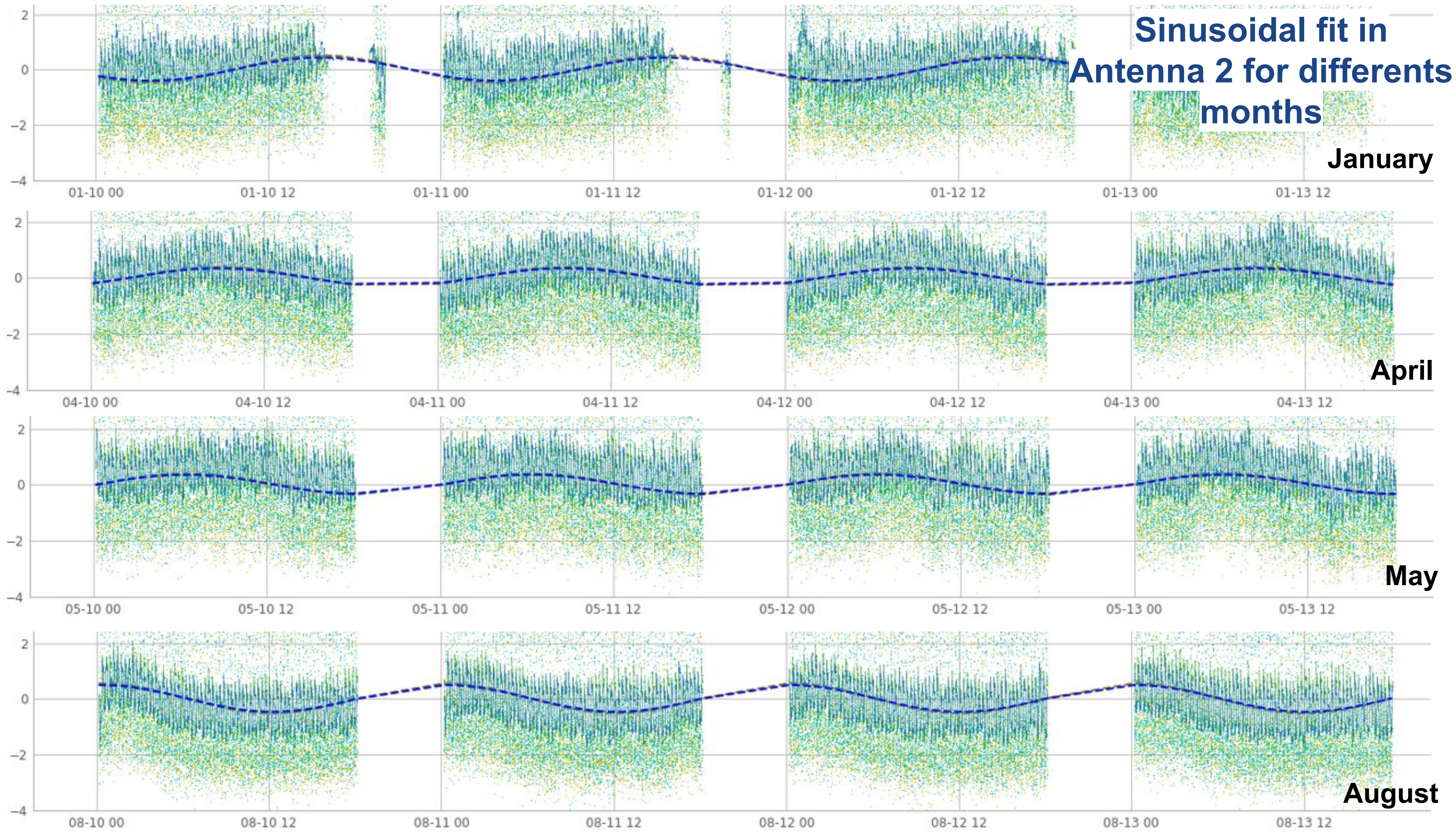
Sinusoidal fit for the RMS values in the interval 140-190 MHz



Sidereal Period: 86164.0905 s

Solar Period: 86400 s

		Channel 1	Channel 2
Antenna 1	Amp Sidereal [ADC]	1.38 ± 0.01	1.33 ± 0.01
	Phase Sidereal [deg]	-152.01 ± 0.02	-131.08 ± 0.02
	Amp Solar [ADC]	0.38 ± 0.01	0.22 ± 0.01
	Phase Solar [deg]	-219.26 ± 0.11	175.4 ± 0.02
	MSE	3.59	0.28
Anntena 2	Amp Sidereal [ADC]	1.15 ± 0.01	0.91 ± 0.01
	Phase Sidereal [deg]	-140.7 ± 0.03	-145.86 ± 0.07
	Amp Solar [ADC]	0.14 ± 0.01	0.30 ± 0.01
	Phase Solar [deg]	-177.82 ± 0.47	-215.17 ± 0.18
	MSE	0.96	1.87
Antenna 3	Amp Sidereal	1.19 ± 0.01	1.02 ± 0.01
	Phase Sidereal	-148.18 ± 0.09	-144.50 ± 0.07
	Amp Solar	0.19 ± 0.01	0.32 ± 0.01
	Phase Solar [deg]	-182.25 ± 0.23	153.85 ± 0.14
	MSE	1.46	1.31


Sinusoidal fit in Antenna 2 for differents months
January
April
May
August
01-10 00
01-10 12
01-11 00
01-11 12
01-12 00
01-12 12
01-13 00
01-13 12
04-10 00
04-10 12
04-11 00
04-11 12
04-12 00
04-12 12
04-13 00
04-13 12
05-10 00
05-10 12
05-11 00
05-11 12
05-12 00
05-12 12
05-13 00
05-13 12
08-10 00
08-10 12
08-11 00
08-11 12
08-12 00
08-12 12
08-13 00
08-13 12