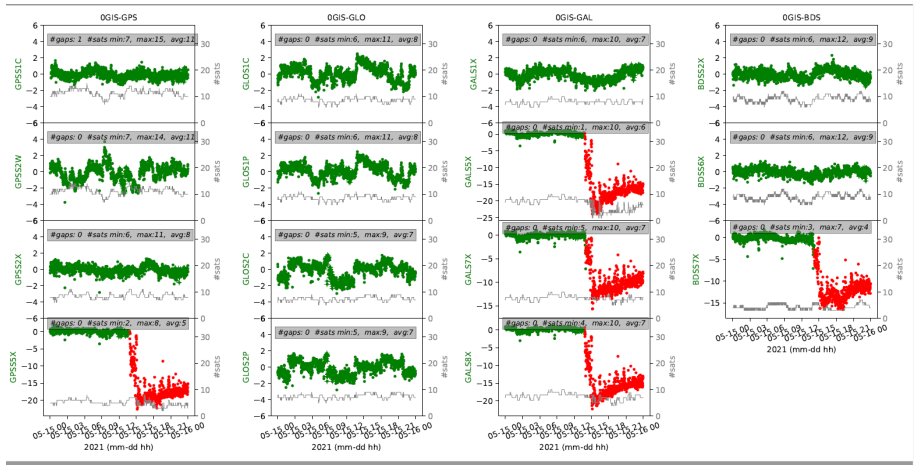
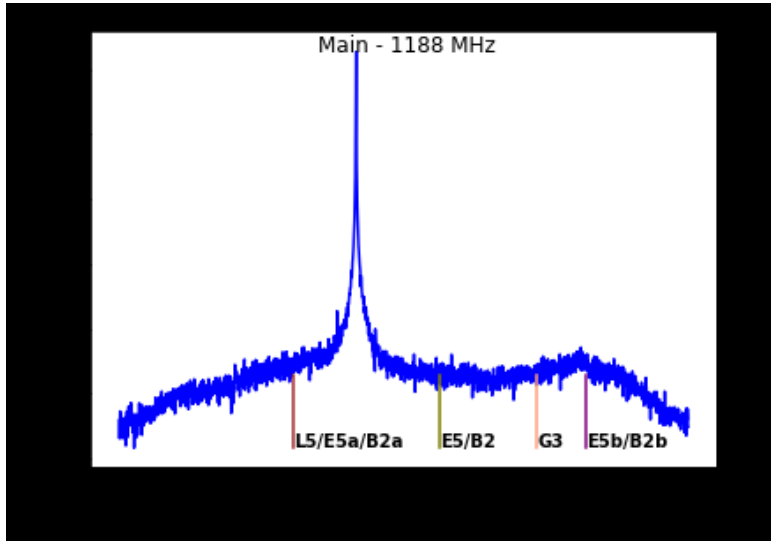




Monitoring and detection of GNSS signal interferences using SWEPOS – The Swedish CORS network

Nordic Geodetic Commission General Assembly: Planet Ocean and Geodesy

Copenhagen September 5-8, 2022

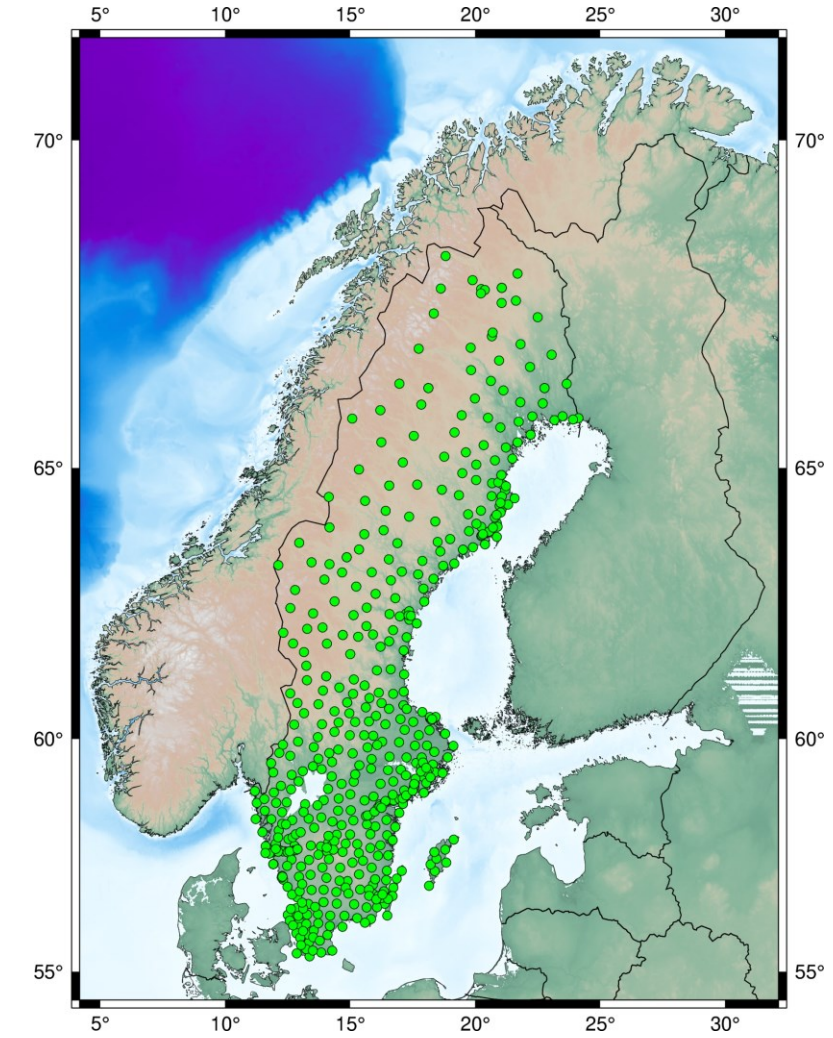
Kibrom Ebuy Abraha

Outline

- SWEPOS – The Swedish national network of permanent GNSS stations
- GNSS interference threats
- GNSS signal disturbances monitoring and detection at SWEPOS
  - Goals and description
  - Demonstration on simulated interference waves
  - Real signal interference incidents

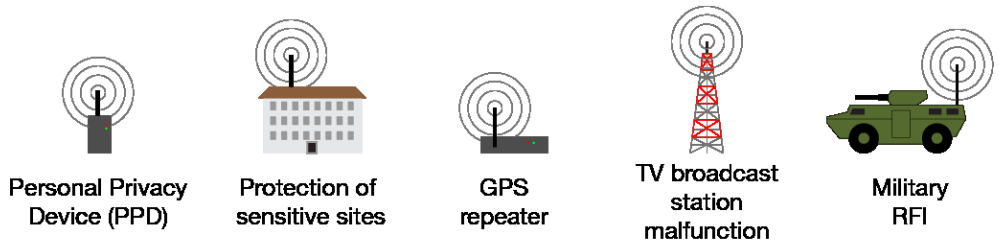
SWEPOS®

- Swedish national network of permanent GNSS stations
- Provides range of applications
  - NRTK correction for real-time applications
  - Data for geoscientific and meteorological research
  - Backbone of the Swedish national geodetic reference frame (SWEREF 99)
- Operates 500+ stations
  - 465 part of the NRTK
  - 27 part of the EPN and 8 part of the IGS
- Equipped with antennas and receivers which enable the network to track GPS, GLONASS, Galielo(GAL), Beidou (BDS) signals
- NRTK corrections based on GPS+GLO+GAL
- BDS will be included (work in progress)
- Quality, integrity and continuity of a service is highly dependent on the quality of the data
  - **SWEPOS GNSS signal disturbance monitoring**

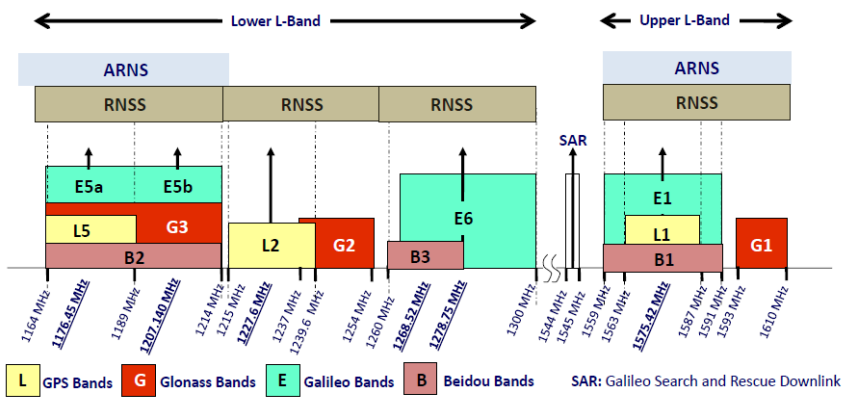


GNSS interference threats

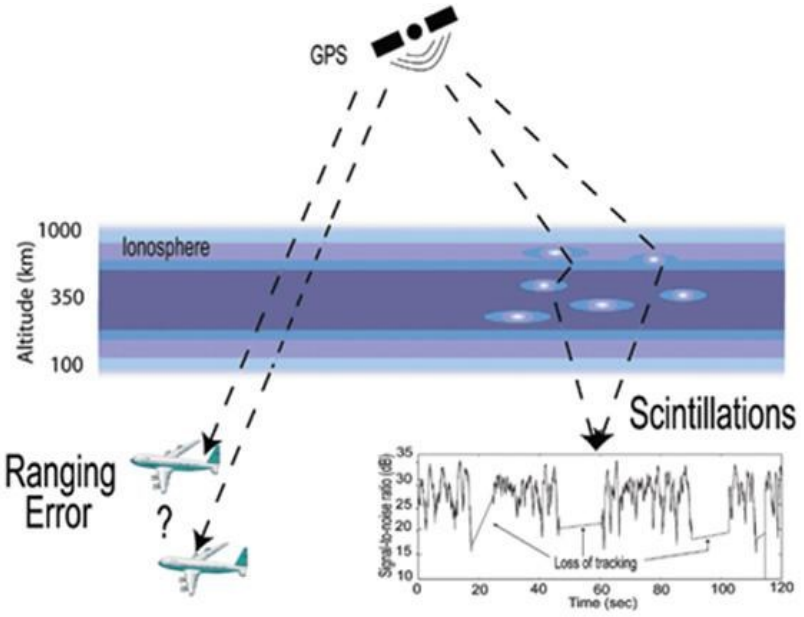
- GNSS signals have low power which can easily be disrupted
- Wider frequency bands
- Increased (un)intentional sources
  - Unintentional
    - Ionospheric scintillations
    - Radio Frequency Interference (RFI)
    - GNSS receiver, antenna
  - Intentional
    - Jamming – Disrupts your signal
    - Spoofing – Falsifies your position



https://safetyfirst.airbus.com/gnss-interference/



https://gage.upc.edu/gnss_book/



http://www.nap.edu/catalog/12507.html

SWEPOS GNSS Signal disturbance monitoring and detection - Goals

Monitor

- Monitoring of anomalous events
- Using GNSS geodetic infrastructure – SWEPOS (not external monitoring system)
- Characterizing GNSS signals
- Monitoring signal strength
- Consistency check

Detect

- Detect anomalous events
- Classify anomalous events
- Multipath? Equipment failure? RFI?

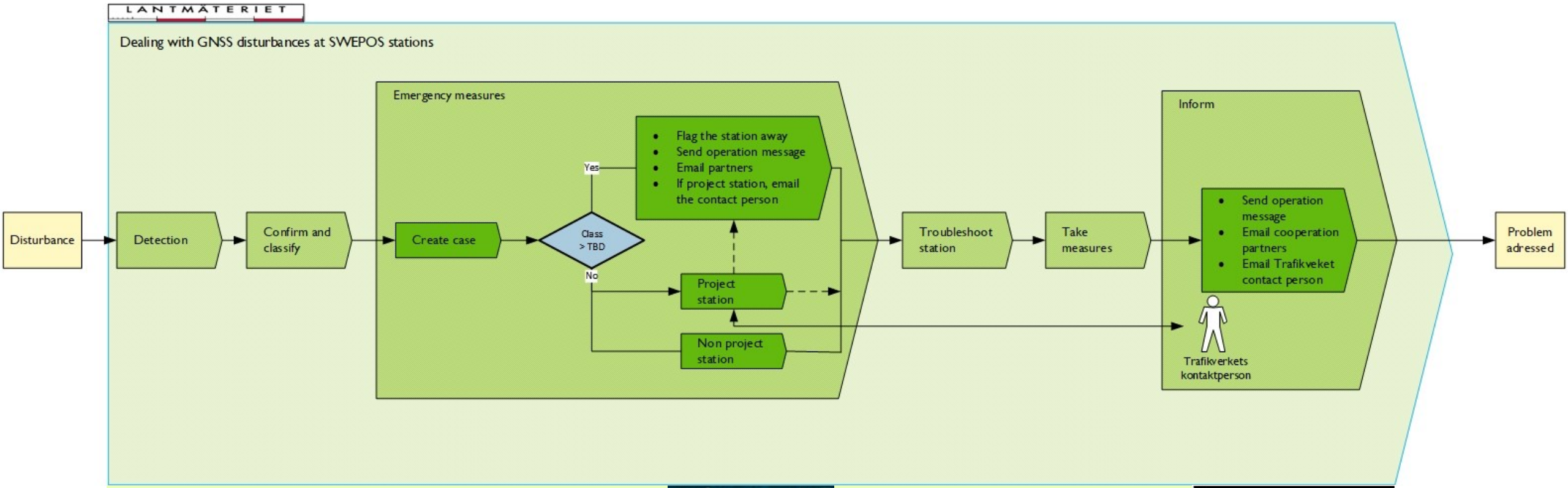
Respond

- Contain the event
- Geolocate the source
- Assess the impact and continuity of the event
- Mitigate it
  - Receivers, softwares
- Inform users

Unmitigated interference

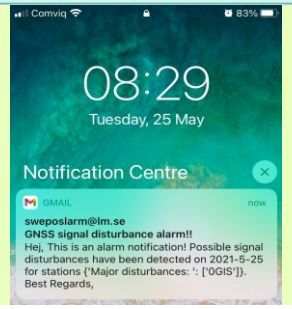
- Flag off the station
- Move the station
- GNSS dependent Infrastructures should have a clear plan of recovering their system in the event of large scale attacks and have other alternatives.

SWEPOS data QC
GNSS Signal disturbance monitoring and detection

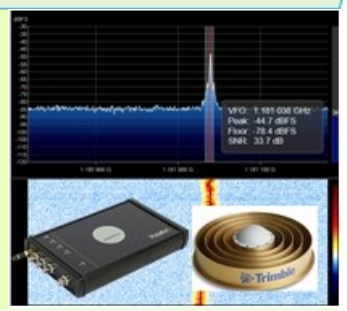


Monitors GNSS signal quality of the SWEPOS network

- SNR history and characteristics
- Multi-GNSS multi-frequency
- Knowledge of reachable satellites for a given receiver
- Different receivers and close-pair stations
- Automatic Gain Control (std of variations)
- Detection of RFI which causes complete loss of signals



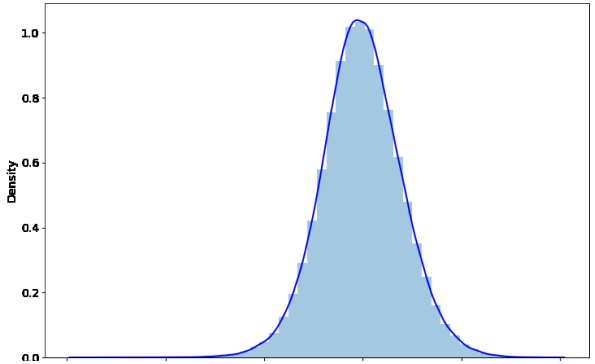
- On-site investigations – test equipment
- Reporting to PTS (Swedish Post and Telecom Authority) – playing a role to the national security

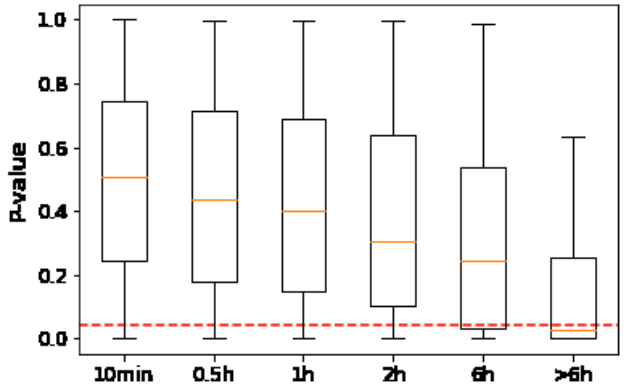


SNR residuals characteristics

- Model SNR for each satellite (it takes receiver, elevation, azimuth and other dependent effects into account)
- Get SNR residuals (model – data) for each satellite

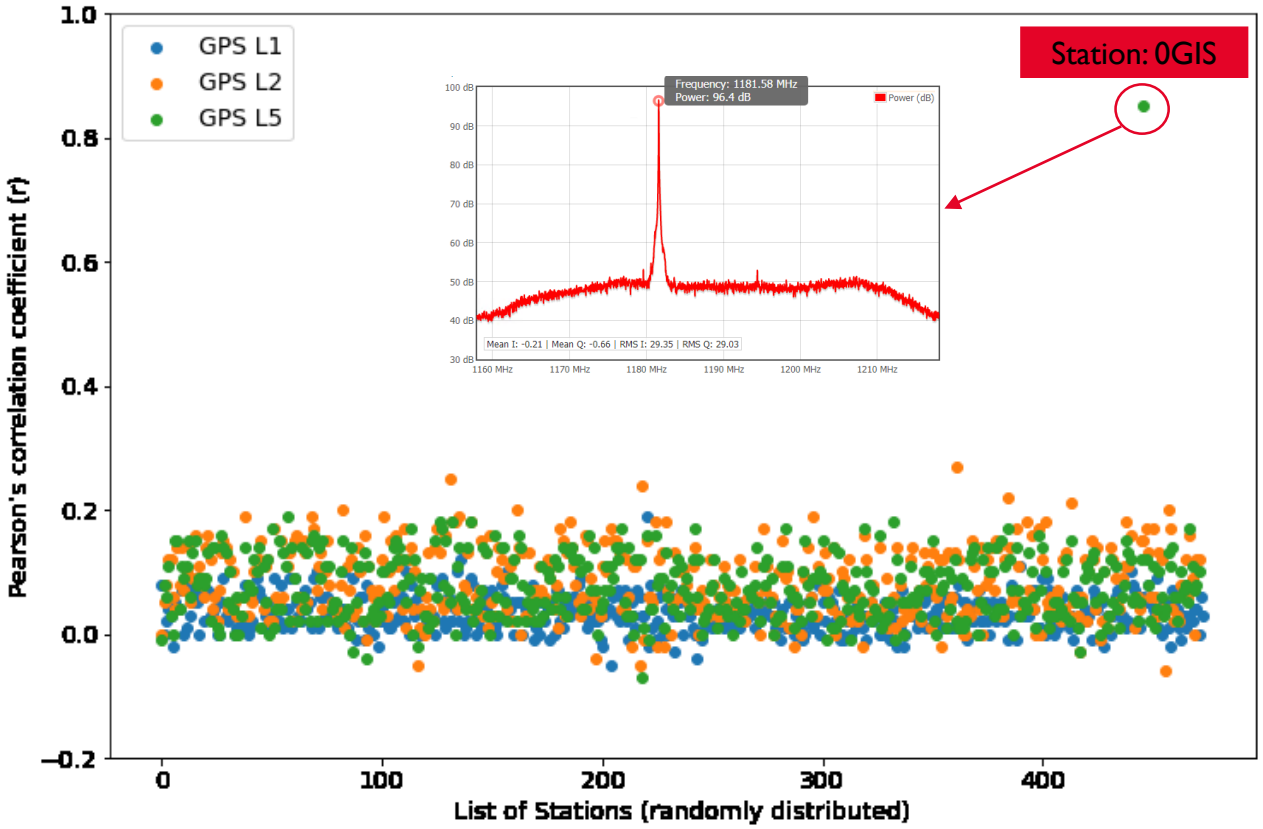
- SNR changes slowly unless interference is present
- Over a short period of time SNR can be treated as a stationary process
- Normally distributed
  - Shapiro-Wilk normality test of SNR residuals
  - Null hypothesis – residuals are normally distributed
  - Null-hypothesis is rejected for p-value < 0.05 (red-dotted line)
  - SNR residuals normally distributed over shorter periods
  - Over longer periods (longer than 6 hours), p-values fall below 0.05 for most of the stations





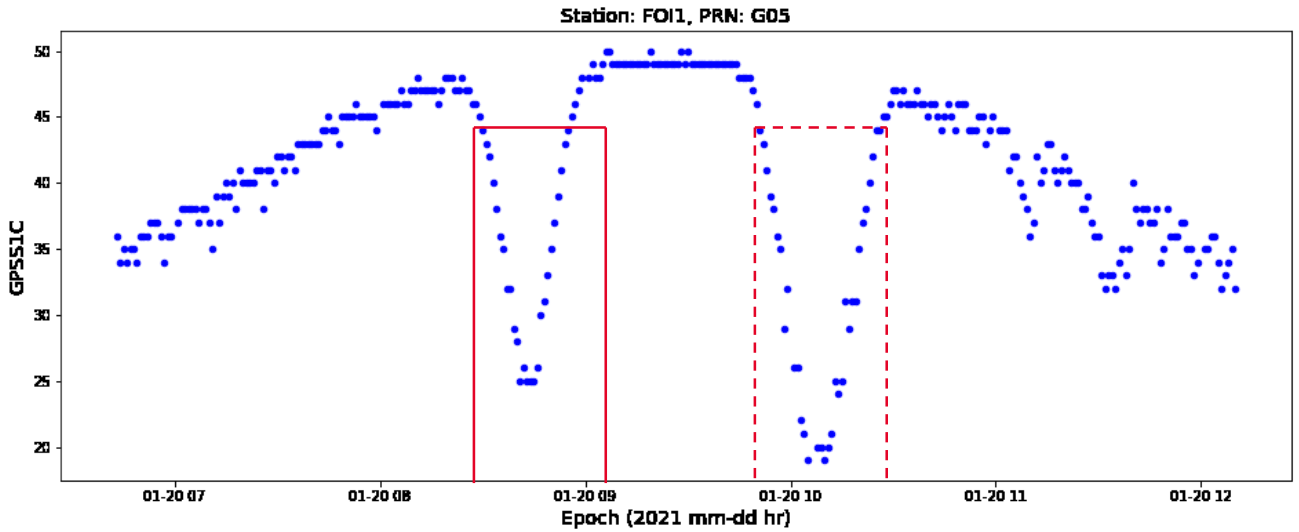
SNR residuals characteristics

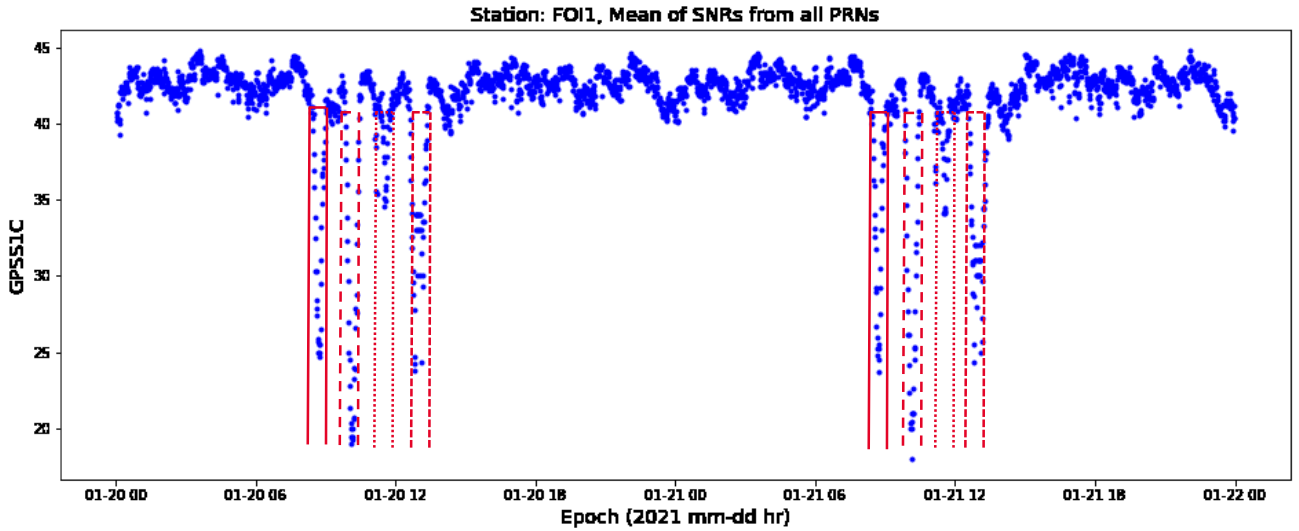
- Cross correlation of SNR residuals among simultaneously



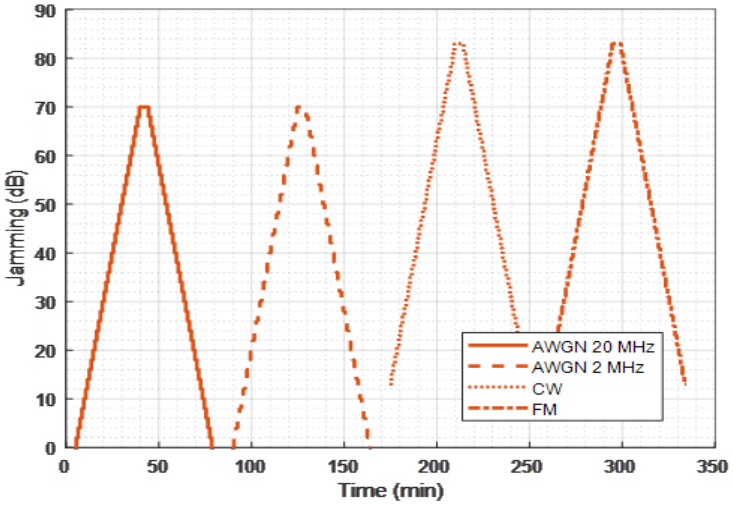
Key points of the detection system:

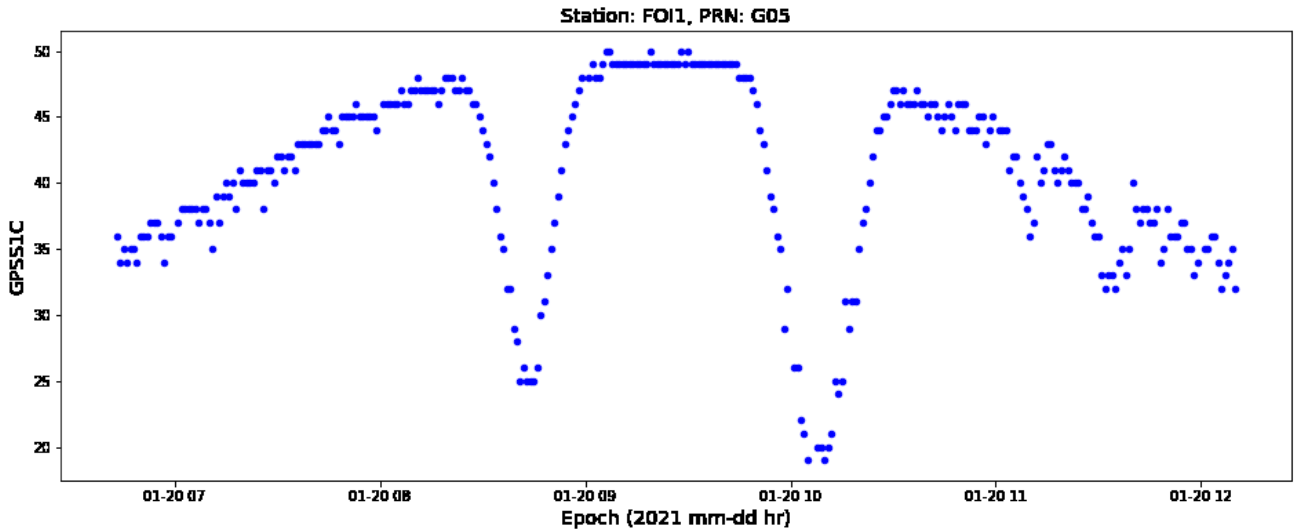
- In the presence of interference
  - Noise level increases, results in SNR drops
  - SNR are correlated among tracked satellites
    - SNR drops due to signal attenuation e.g., by trees and ionospheric scintillations won't be correlated among simultaneously tracked satellites
  - Std variations of AGC
- Demonstration of the above points with simulated interference waves

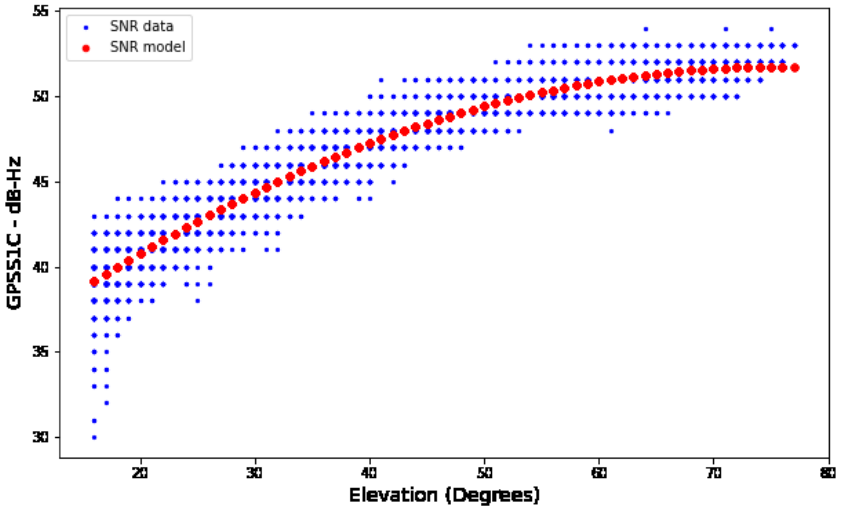


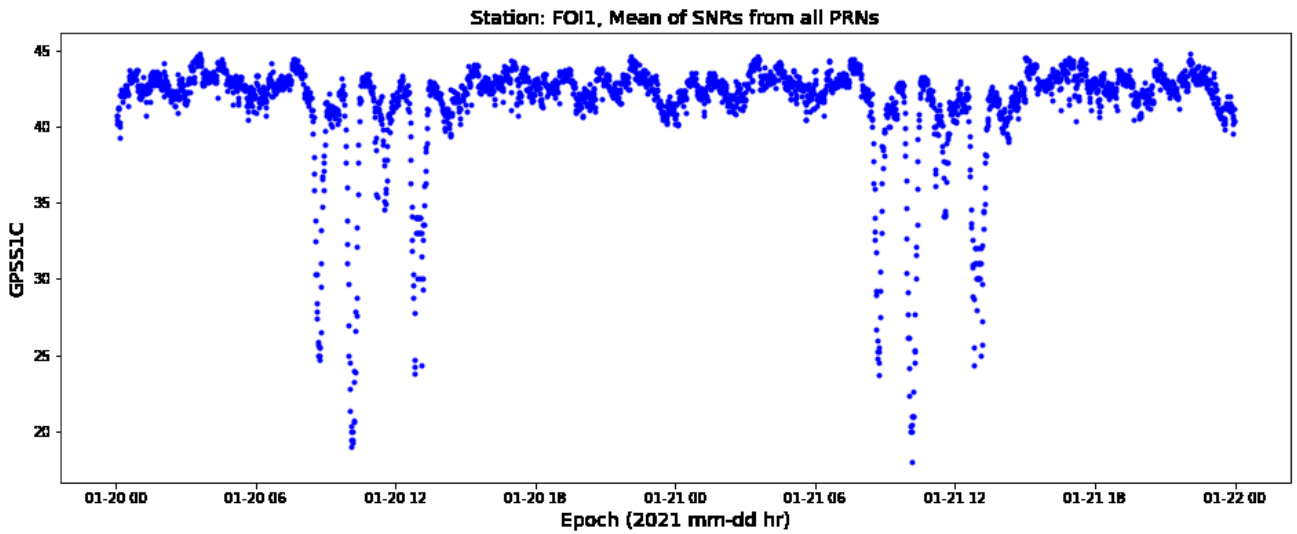


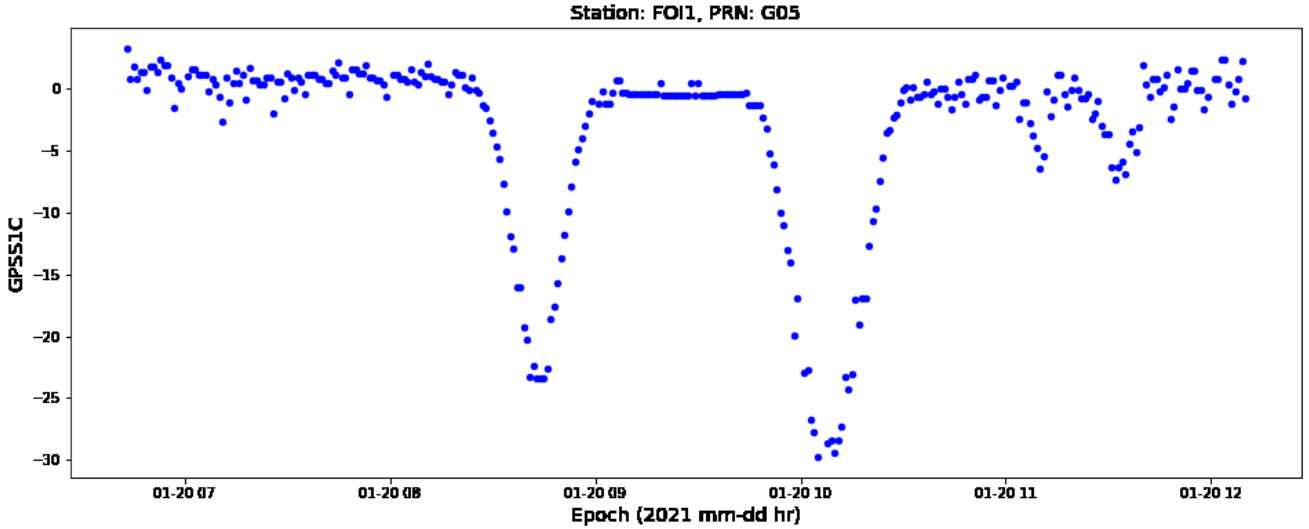
- FOI, the Swedish Defense Research Agency, simulated interreference waves in a controlled environment
- Four different interference waveforms centered at GPS L1 (1575.42 MHz)
  - Additive white Gaussian noise (AWGN) with 20 MHz bandwidth
  - AWGN with 2 MHz bandwidth
  - Continuous wave (CW) unmodulated carrier
  - Frequency modulated (FM) wave

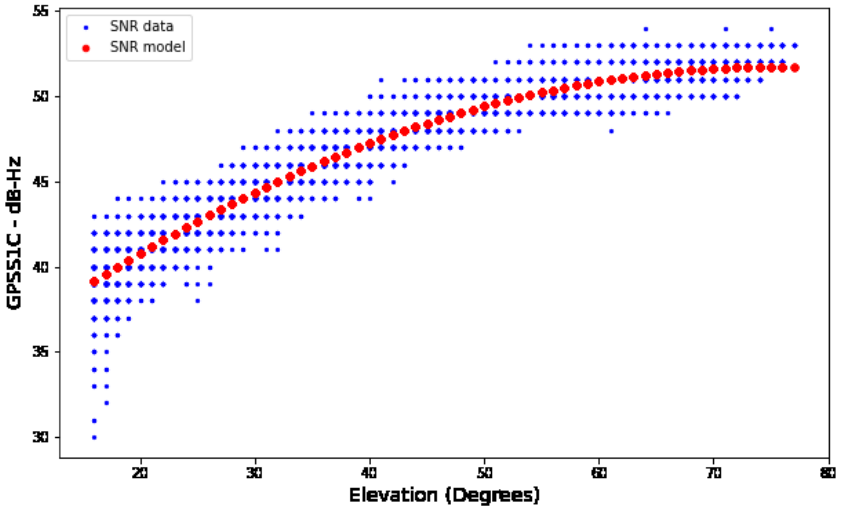


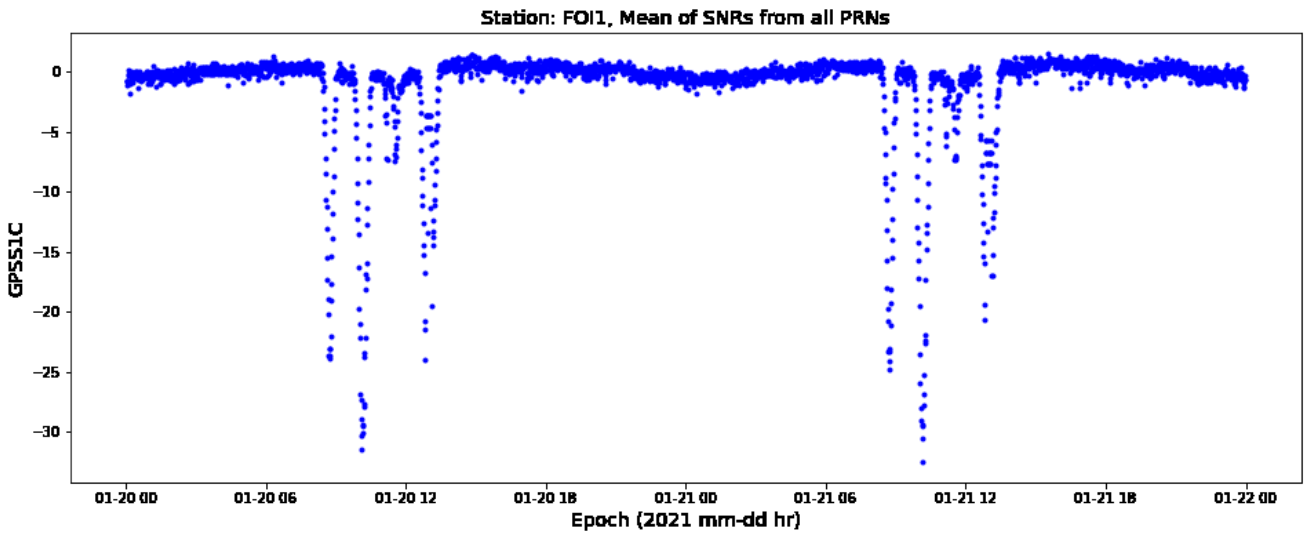

Station: FOI1, PRN: G05
GPS S1C
Epoch (2021 mm-dd hr)
01-20 07
01-20 08
01-20 09
01-20 10
01-20 11
01-20 12

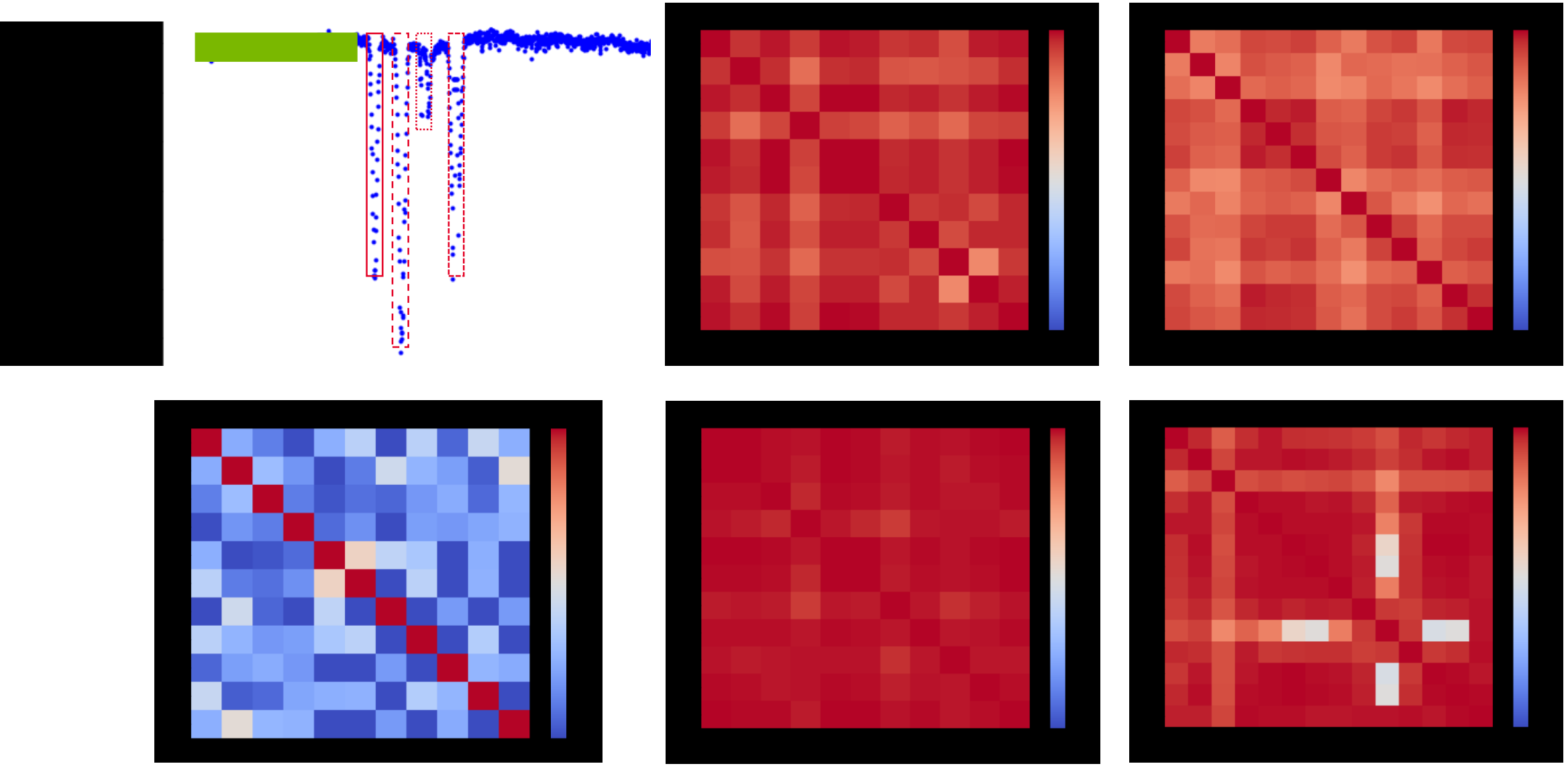

SNR data
SNR model
GPS S1C - dB-Hz
Elevation (Degrees)


Station: FOI1, Mean of SNRs from all PRNs
GPS S1C
Epoch (2021 mm-dd hr)
01-20 00
01-20 06
01-20 12
01-20 18
01-21 00
01-21 06
01-21 12
01-21 18
01-22 00

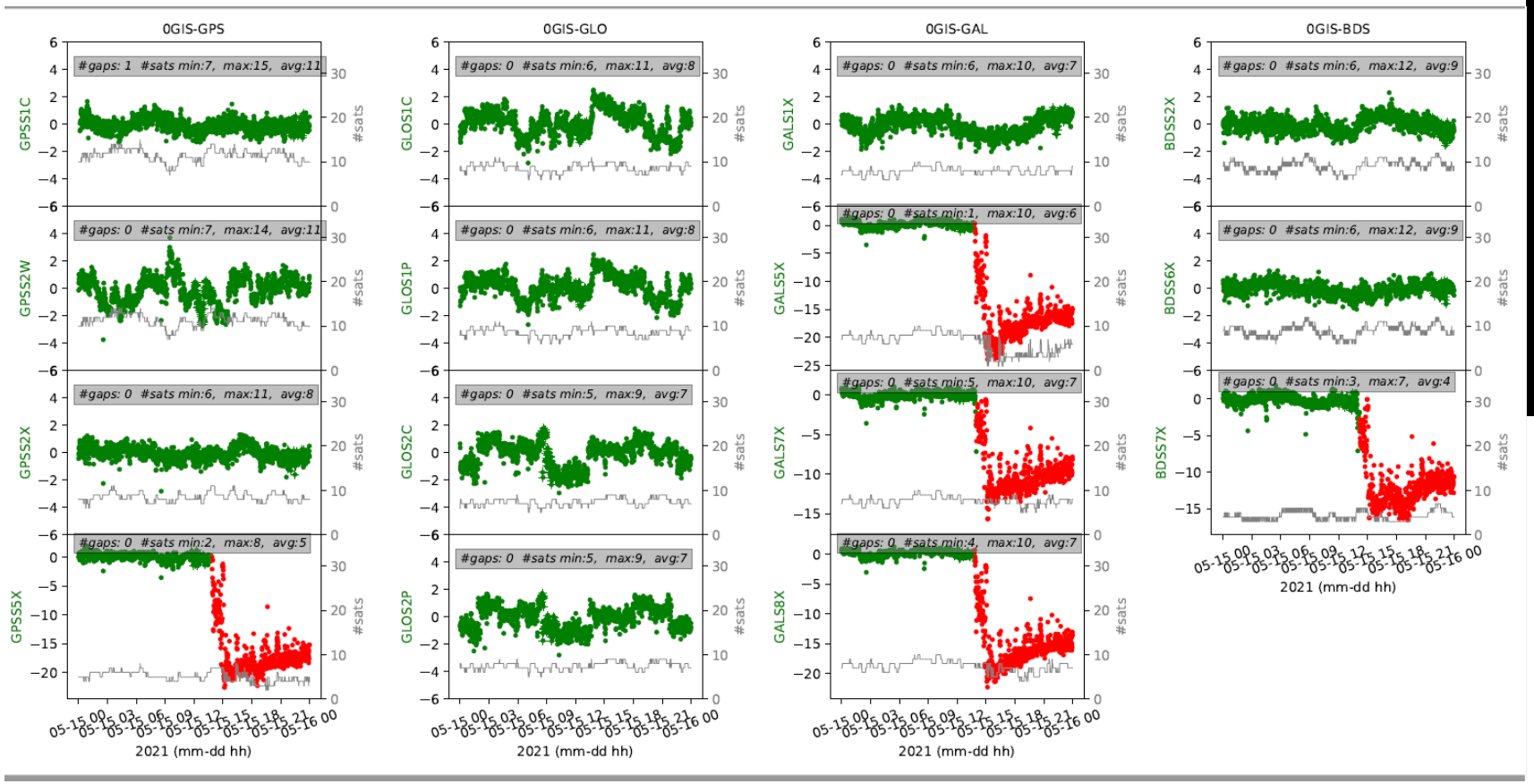

Station: FOI1, PRN: G05
GPSS1C
0
−5
−10
−15
−20
−25
−30
01-20 07
01-20 08
01-20 09
01-20 10
01-20 11
01-20 12
Epoch (2021 mm-dd hr)

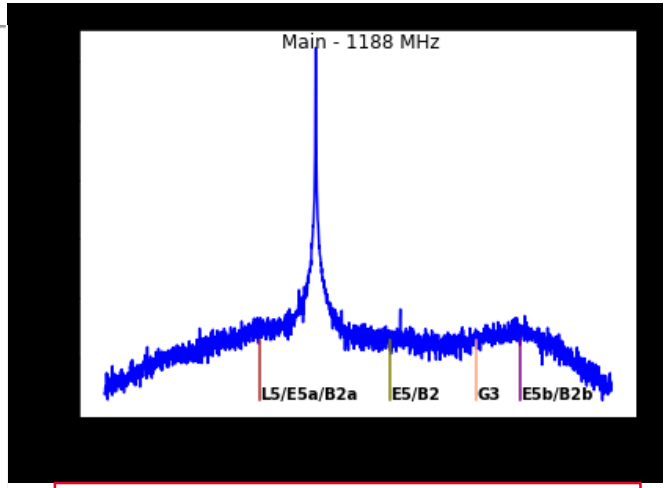

SNR data
SNR model
GPSS1C - dB-Hz
55
50
45
40
35
30
20
30
40
50
60
70
80
Elevation (Degrees)


Station: FOI1, Mean of SNRs from all PRNs
GPSS1C
0
−5
−10
−15
−20
−25
−30
01-20 00
01-20 06
01-20 12
01-20 18
01-21 00
01-21 06
01-21 12
01-21 18
01-22 00
Epoch (2021 mm-dd hr)



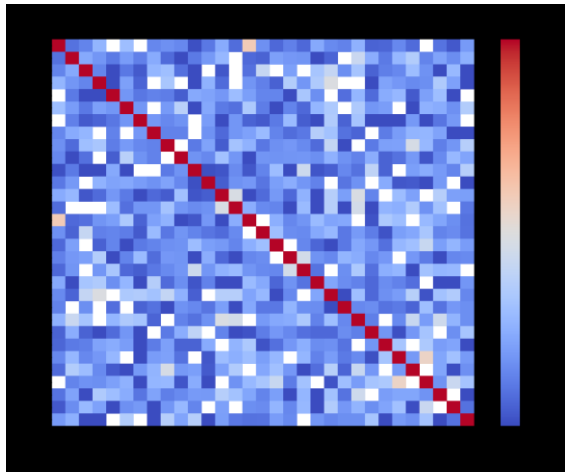
Real signal interference incidents at Grisselham (0GIS)

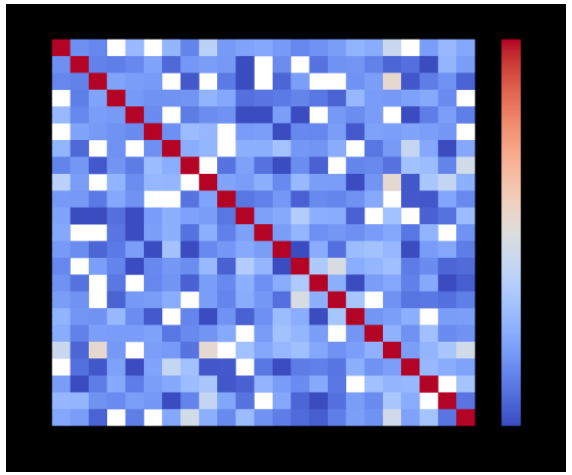


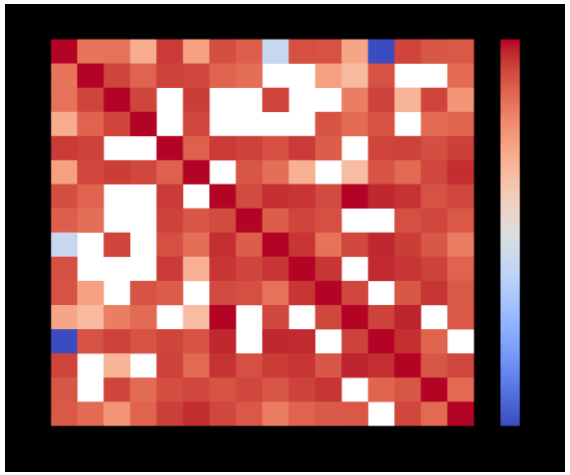


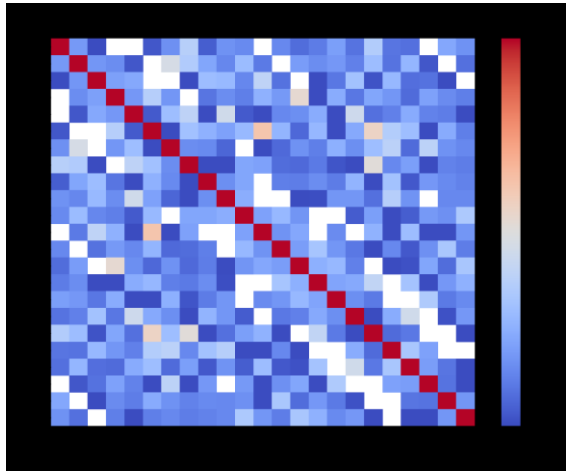
- RFI centered at 1181.0 MHz
- Affected a wideband (-5 MHz to +26 MHz)
  - L5/E5a/B2a – 1176.45 MHz
  - E5b/B2b – 1207.14 MHz
  - E5/B2 - 1191.795

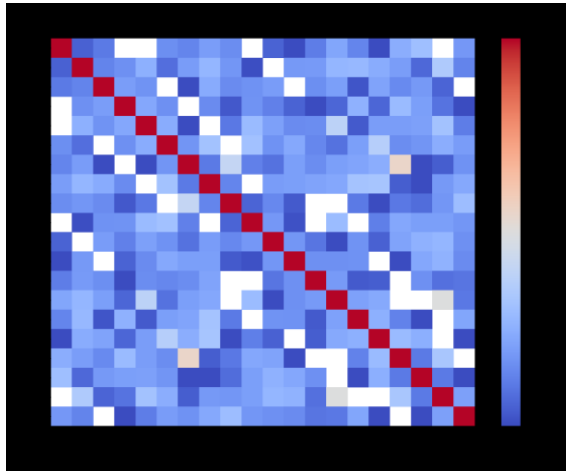
Grisslehamn (0GIS)



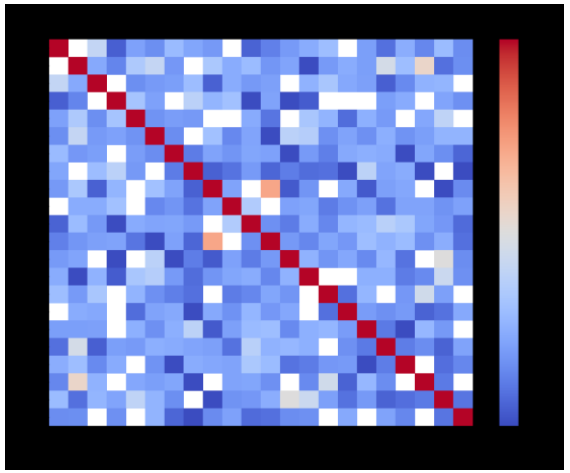
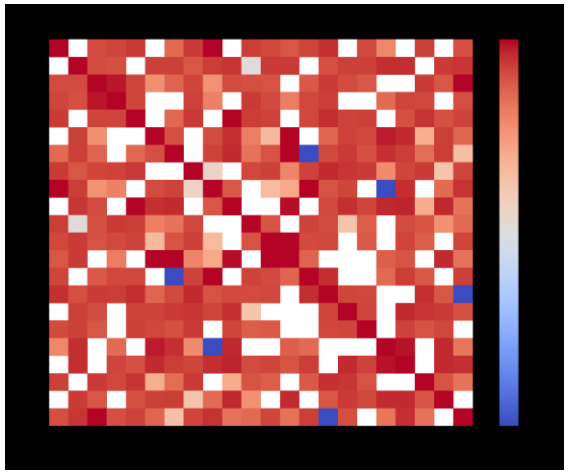
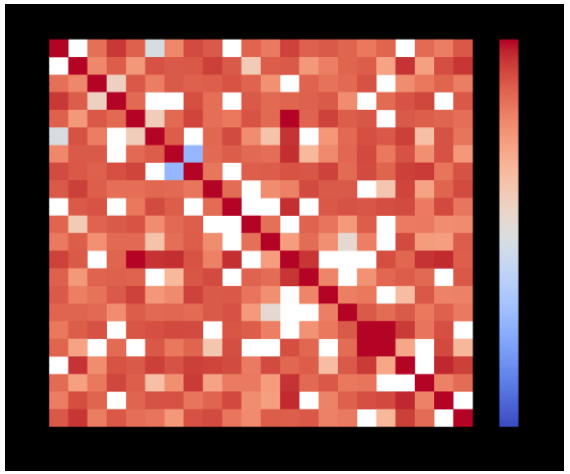
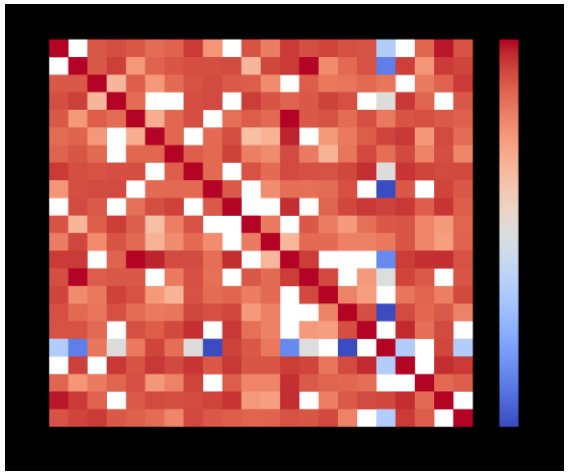
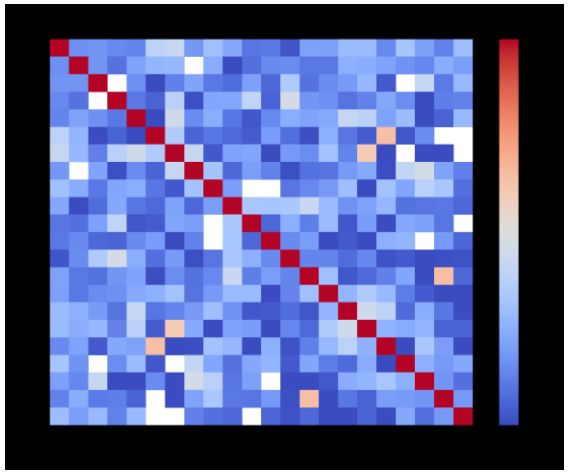
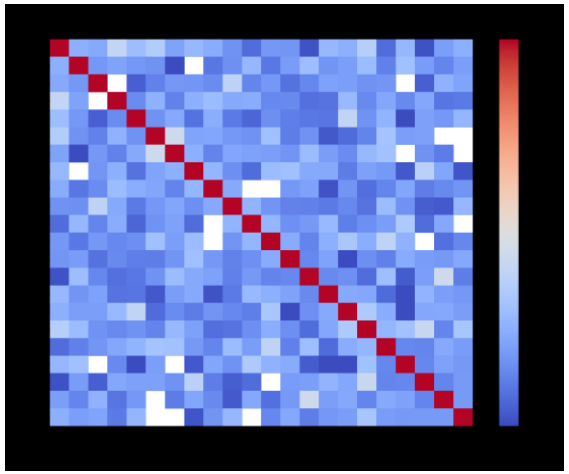
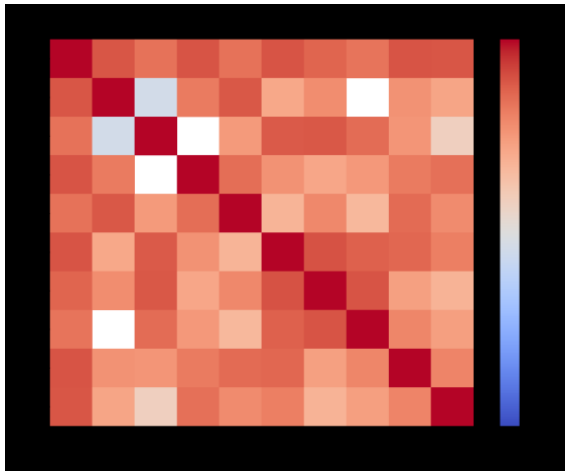








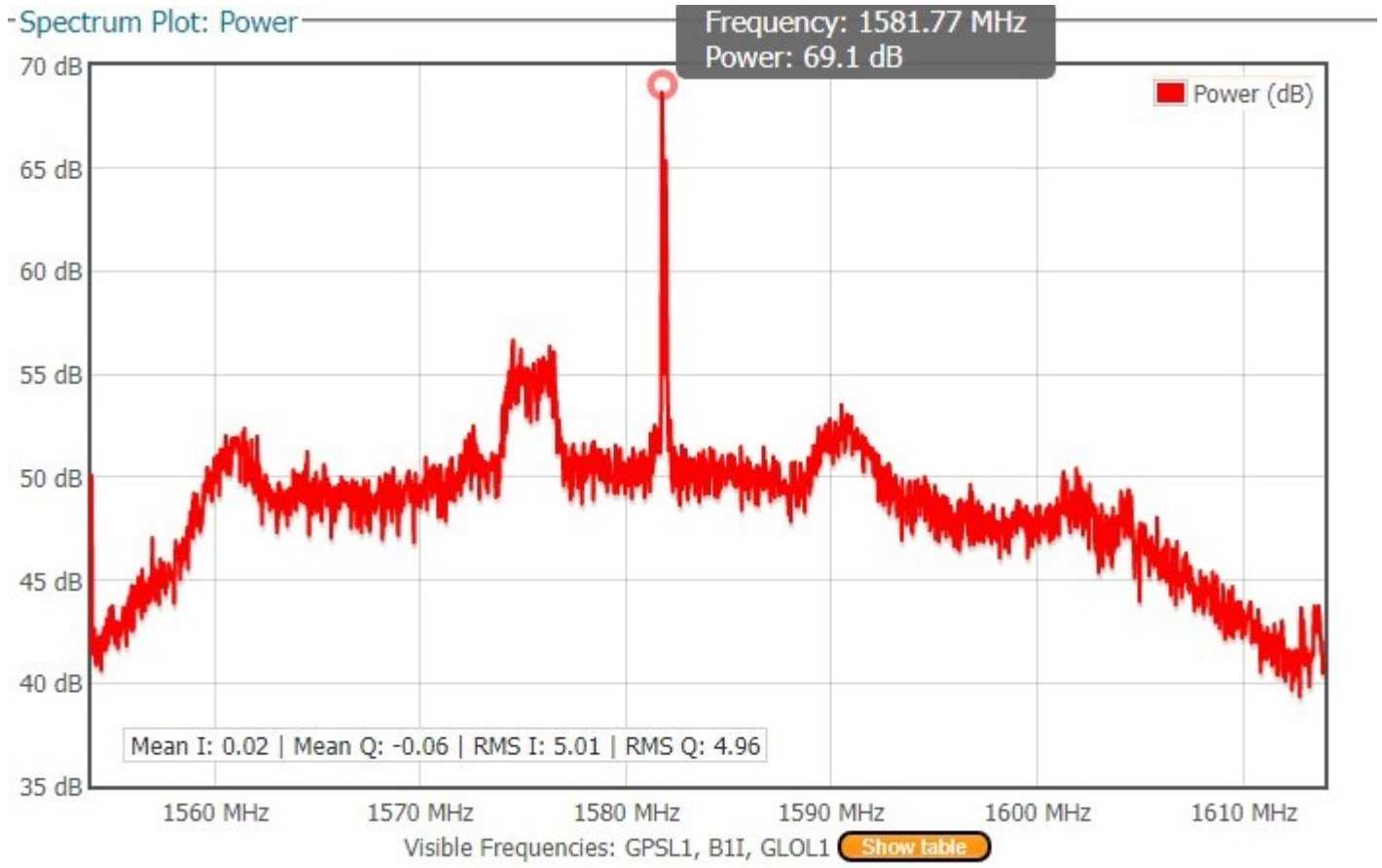
Grisslehamn (0GIS)

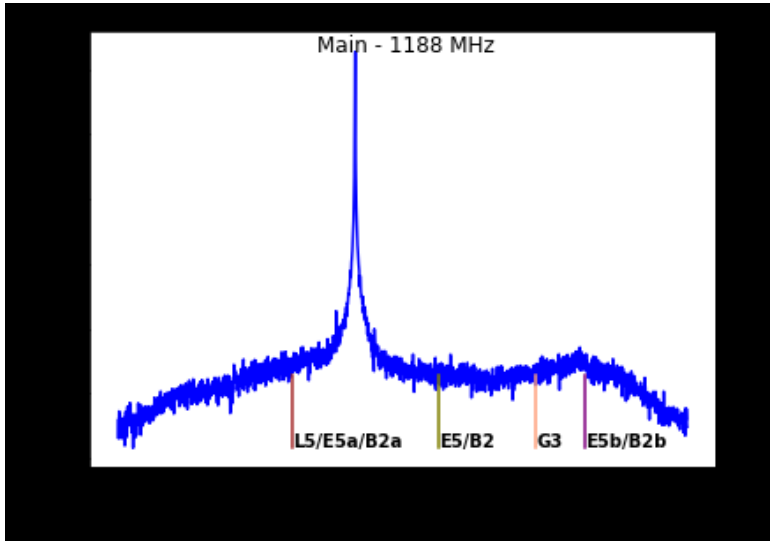
- PTS attempted to geolocate
- Source not located
- Geolocating RFI source is complex

L1 disturbance – source located and contained

- RFI centered at 1581 MHz (~L1)
- 20-30 dBHz above the noise floor
- 5-6 MHz away from L1 center
- Affected GPS/GLO/GAL L1
- Detected at more than one station.
- Didn't have a major import on the performance of the station
- Source was located and contained, GPS repeater in a lab



Takeaway!



- The SWEPOS disturbance detection system
  - Continuous improvement
  - Web interface
  - Use more data types
  - Better algorithms
  - Detected disturbances on all frequencies
    - Weak – no actual effect
    - Strong – complete lose of signals, e.g.,
      tracking no Galileo Satellites, poor station performance in the NRTK
    - Short-term – stayed few minutes
    - long-term interreferences – stayed for months
    - Mostly L5 disturbances
    - Strong L5 centered disturbances make Galileo out of use
- Monitor-Detect-Respond
  - GNSS dependent Infrastructures should have a clear plan of recovering their system in the event of large-scale attacks and have other alternatives.
  - The goal is to protect critical GNSS and GNSS-dependent infrastructures against emerging (un)intentional threats; we should also use the same infrastructure for autonomous signal-situation awareness of threats.
  - Receiver manufacturers should consider interference threats when developing high-end GNSS receivers.
    - Users should make this part of a procurement when making receiver purchases