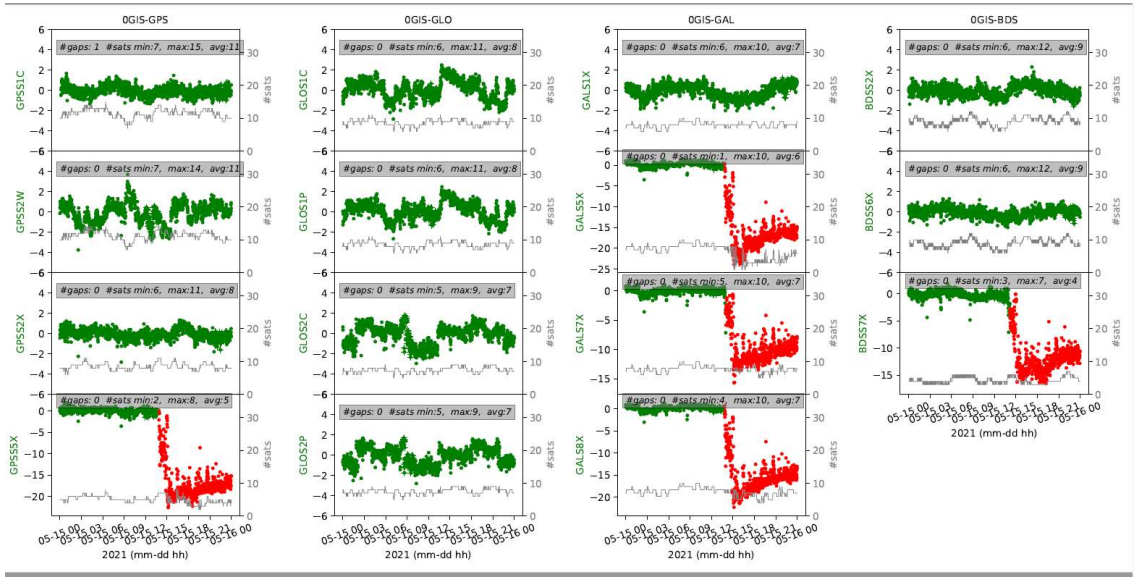
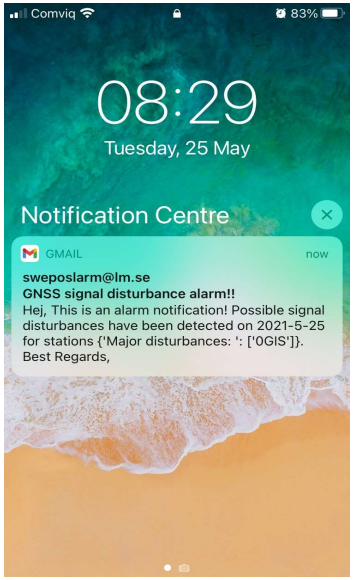
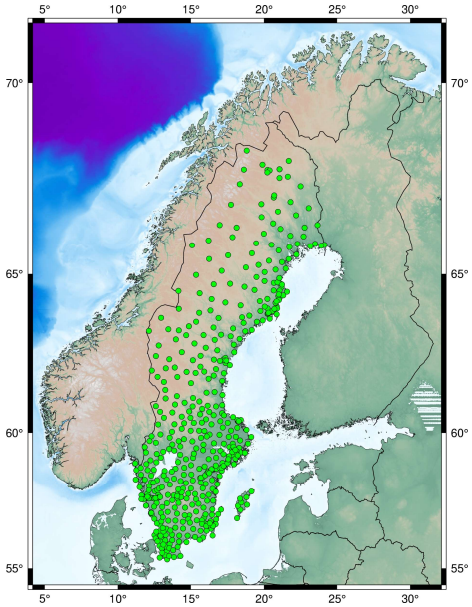



# SWEPOS DATA QUALITY MONITORING

## GNSS Signal Disturbance Detection System

Kibrom Ebuy Abraha
LANTMÄTERIET

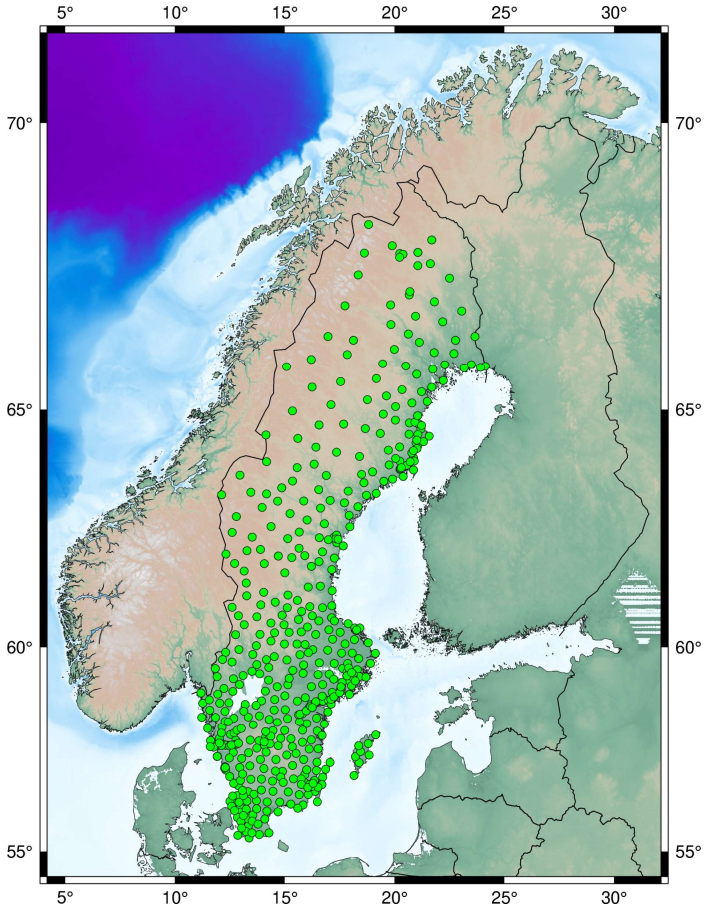
**Swedish Board of Radio Navigation (RNN) webinar on**
**"Autonomous Systems – Performance and Reliability", December 8 2021**

# Outline

- SWEPOS
- Goals of SWEPOS signal disturbance monitoring
- GNSS Error sources
- GNSS Signal Disturbances Detection System at SWEPOS
  - 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
  - 463 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
- RTK 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**



# SWEPOS signal disturbance monitoring – Goals

- SWEPOS operations
  - GNSS signal disturbance monitoring, e.g, due to
    - Signal obstructions, cycle slips and multipath
      - e.g., new buildings, snow accumulation, tree foliage
    - (Un)intentional interreferences
    - Hardware failures

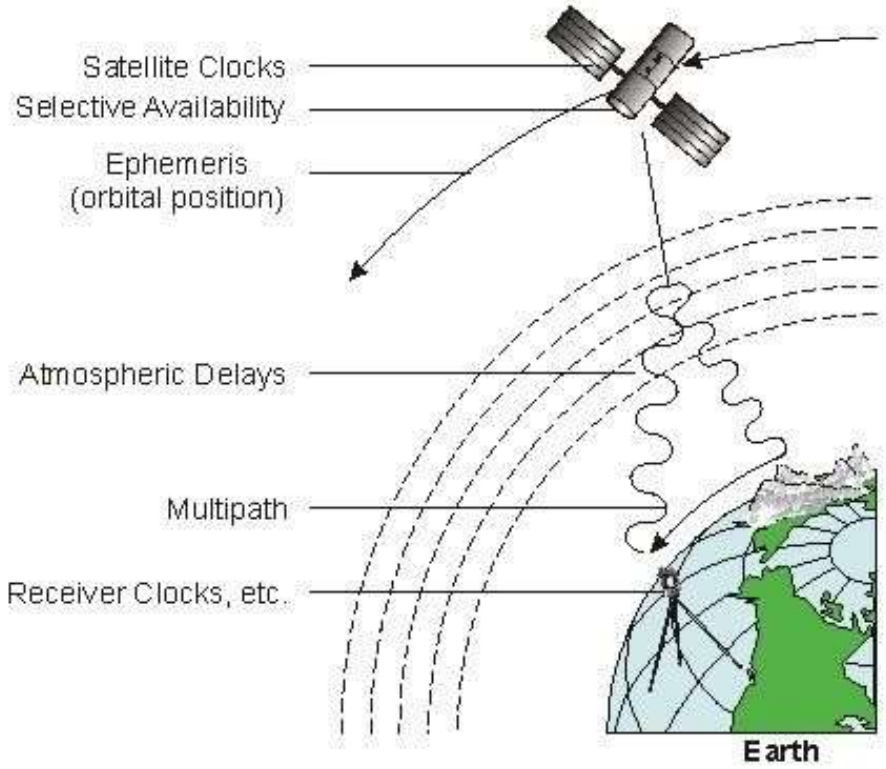
- RFI monitoring
  - Use the SWEPOS network to monitor signal interferences in Sweden
    - Situational awareness, characterizing and geolocating of RFI sources
      - PTS (Swedish Post and Telecom Authority)
    - Mitigation
      - Receivers' mitigation capability
      - NRTK software data/station handling
      - Flagging off affected station from the NRTK

# GNSS Error Sources

1. Space/Satellite specific
2. Atmosphere specific
3. Station specific

## Station Specific

1. Station environment
   - Reflecting objects
   - Blocking objects
   - Interference
2. Station equipment
   - Receiver, antenna, splitter e.t.c



# Receiver performance in mitigating errors

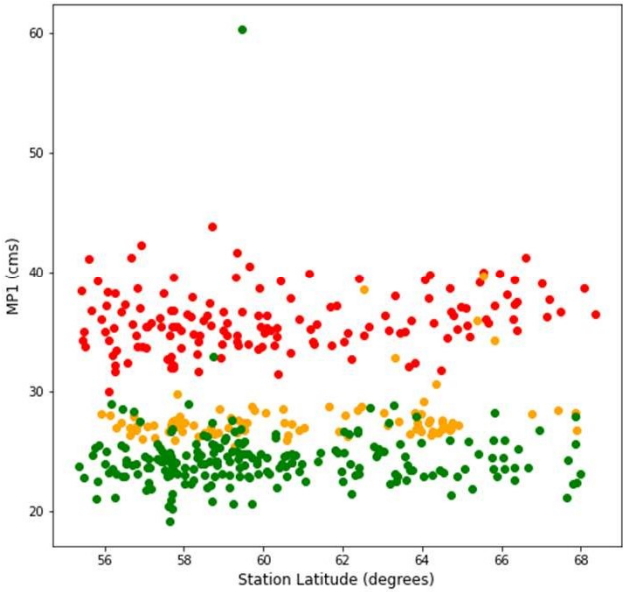
Key points:

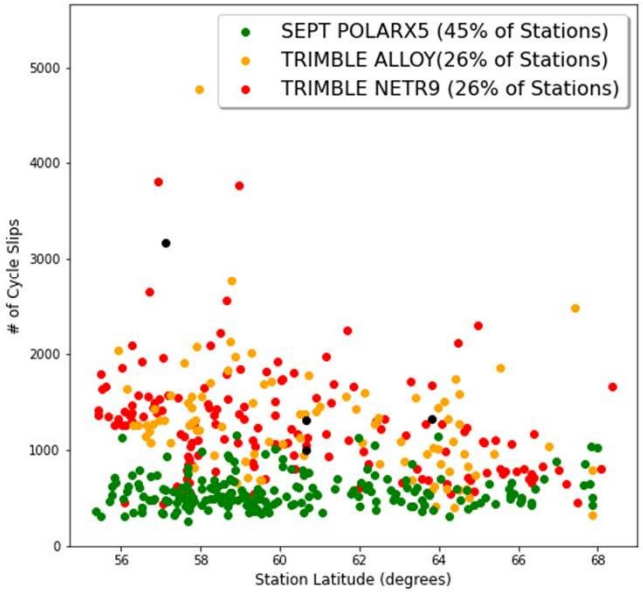
- Receiver performance varies
- PolaRx5 mitigates MPs better
  - An algorithm which performs well in short delay multipath
- Trimble Alloy
  - Improved multipath mitigation technology

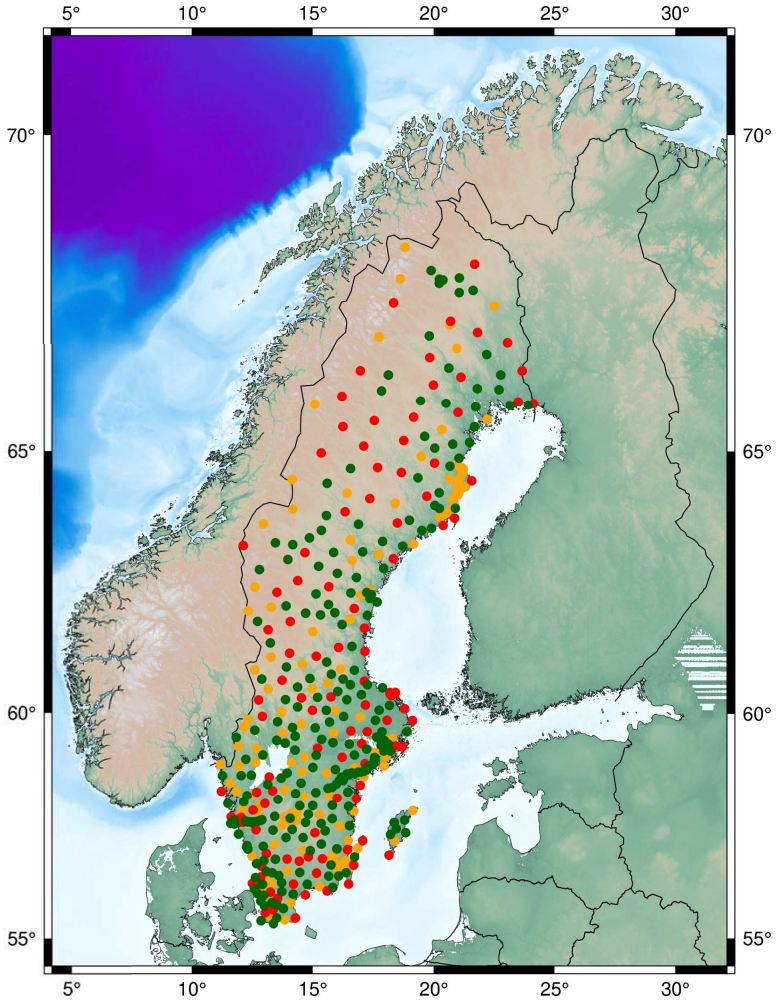
Trimble NetR9

Trimble Alloy

Sept. PolaRx5

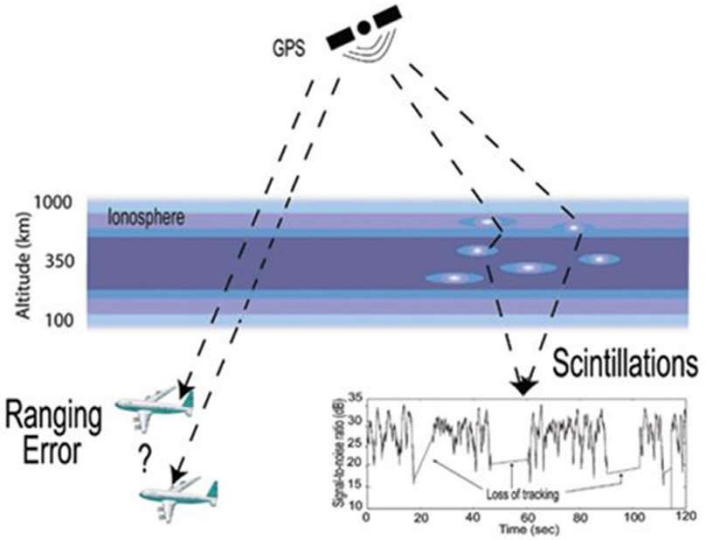


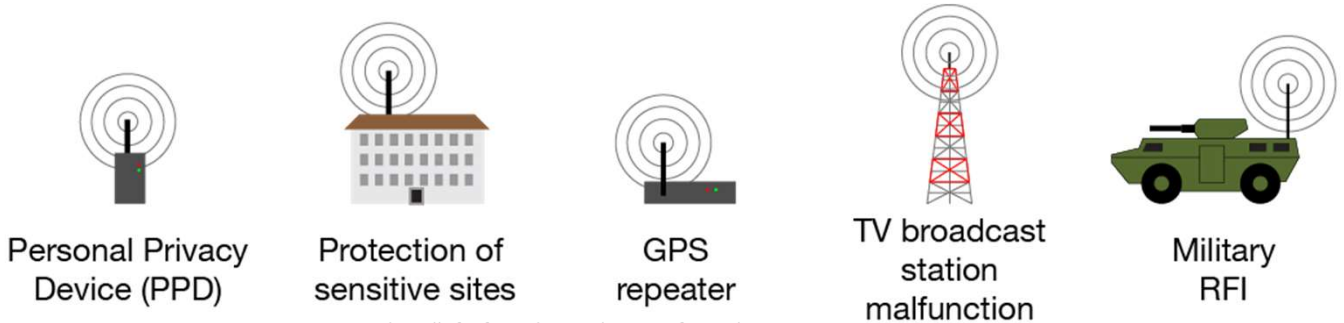



# Sources of GNSS signal disturbances

- GNSS signals have low power which can easily be disrupted
- Unintentional
  - Ionospheric scintillations
  - Radio Frequency Interference (RFI)
- Intentional
  - Jamming – Disrupts your signal
  - Spoofing – Falsifies your position




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




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

## SWEPOS GNSS signal disturbance system

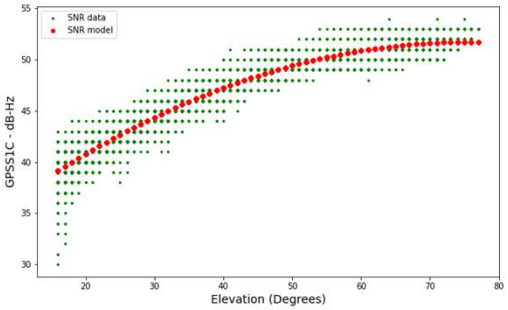
- It is near-real time SNR-based GNSS disturbance detection system
- Monitors GNSS signal strength of the SWEPOS network
  - SNR history and characteristics
  - Multi-GNSS multi-frequency
  - Knowledge of reachable satellites for a given receiver
  - Different receivers and close-pair stations
- Sends alarms
- Persistent disturbances may get a visit for on-site investigations and/or equipment changes
- Reports them to PTS (Swedish Post and Telecom Authority) – playing a role to the national security
- Detected hundreds of RFI
  - Weak – No actual effect
  - Strong – Complete lose of signals, tracking no Galileo Satellites, poor station performance in the NRTK
  - Short-term – Stayed few minutes
  - long-term interreferences – Stayed for more than five months

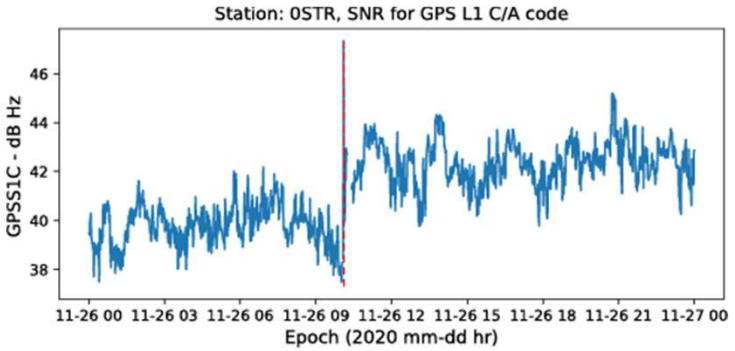
# SNR-based GNSS disturbance detection at SWEPOS

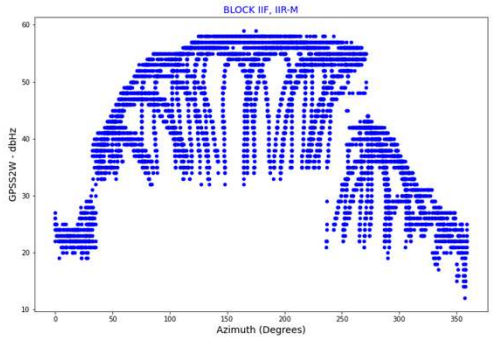
- Elevation dependency
- Azimuth dependency (e.g., GPS Flex power)
- Antenna, splitter and receiver dependency

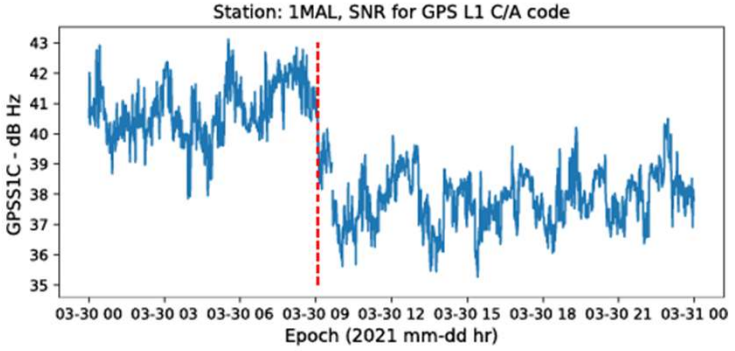
- Model SNR for each satellite (it takes receiver, elevation, azimuth and other dependent effects into account)

- Get SNR residuals (Model – data) for each satellite



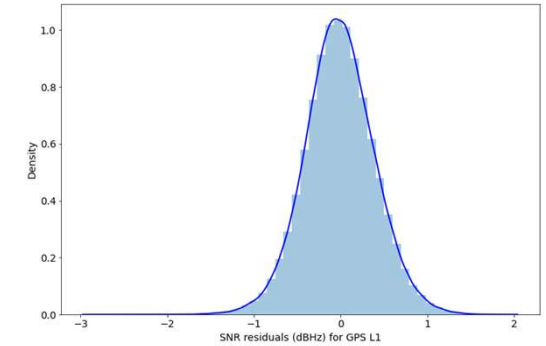



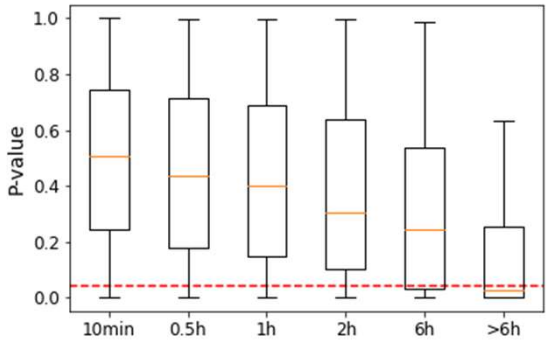




Red-dotted lines show antenna splitter changes.

## SNR residuals characteristics

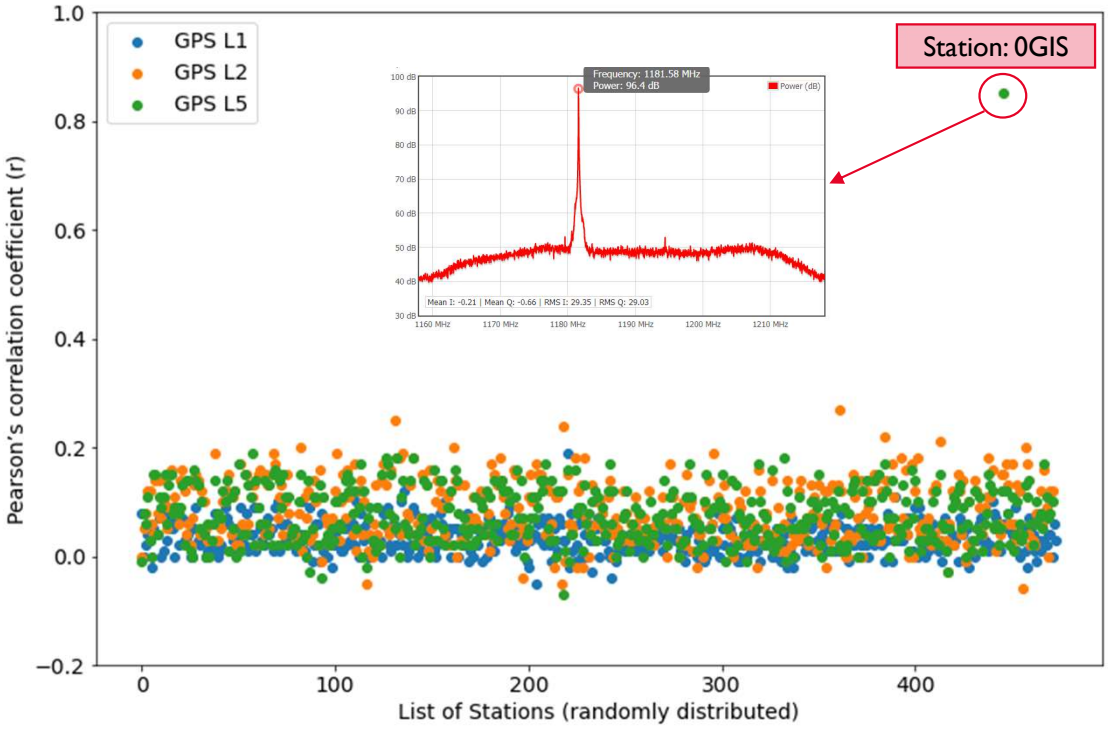
- It changes slowly unless interference is present
- Over a short period of time SNR can be treated as a stationary process
- Normally distributed
    - Shapiro-Wilk normality test of SNR residuals
    - Null hypothesis – residuals are normally distributed
    - Null-hypothesis is rejected for p-value < 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



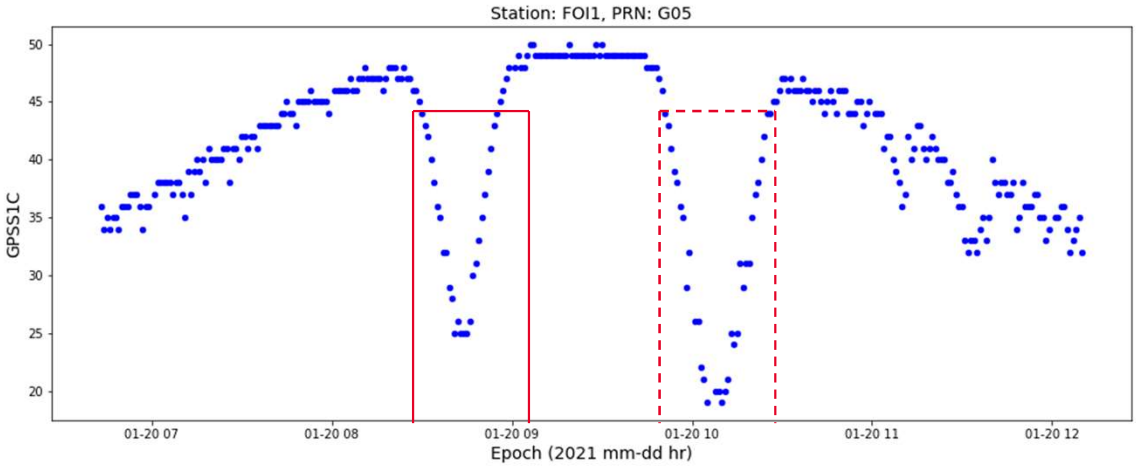
## SNR residuals characteristics

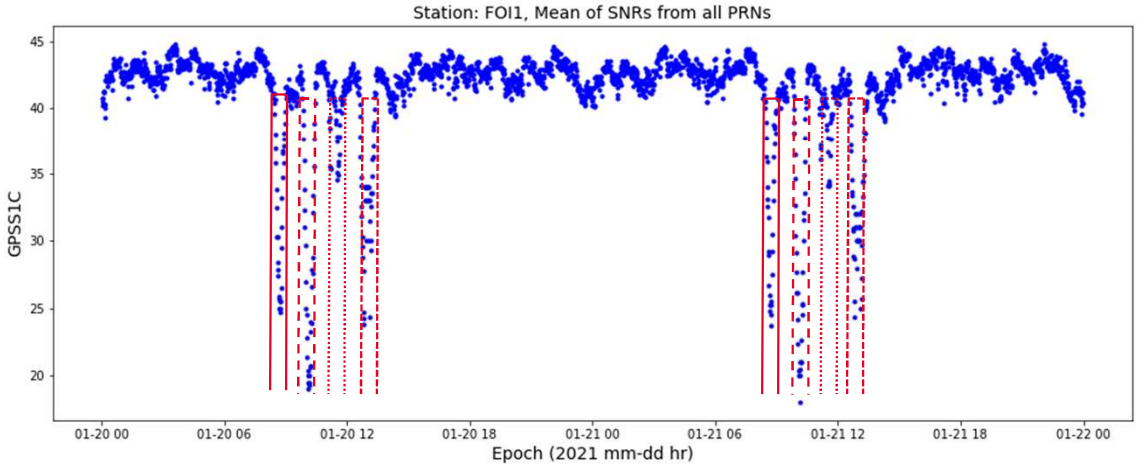
- Cross correlation of SNR residuals among simultaneously tracked satellites.



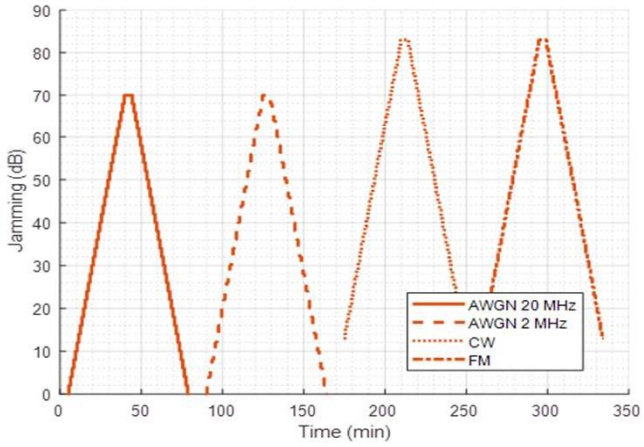

### Key points of the detection system:

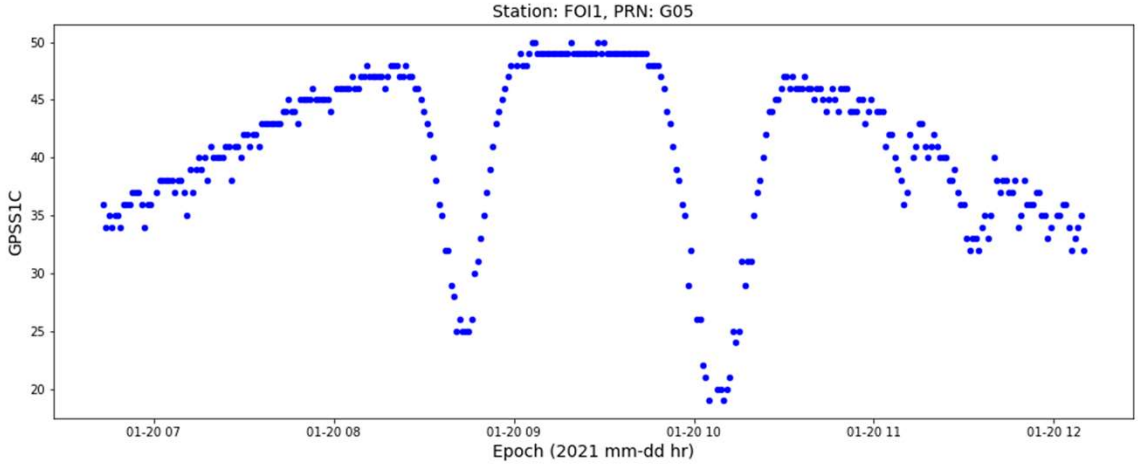
- In the presence of interference
  - Noise level increases, results in SNR residual drops
  - SNR residuals are correlated among tracked satellites
    - SNR drops due to signal attenuation e.g., by trees and ionospheric scintillations won't be correlated among simultaneously tracked satellites
- Demonstration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

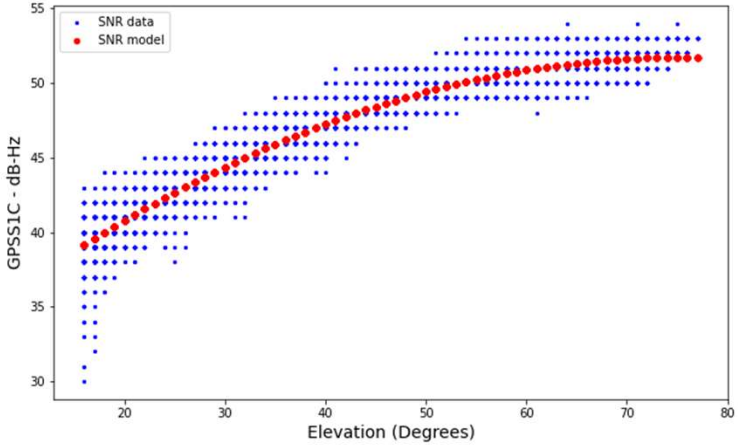


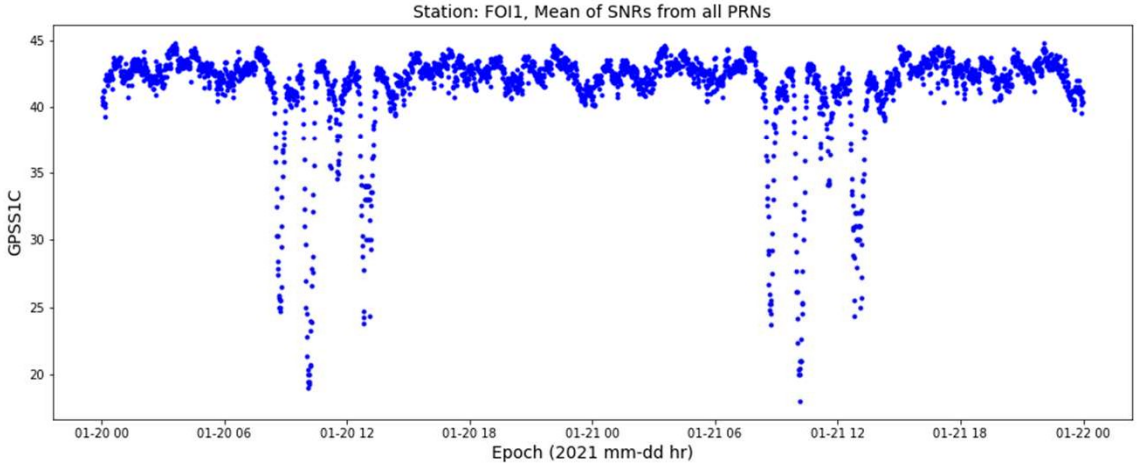



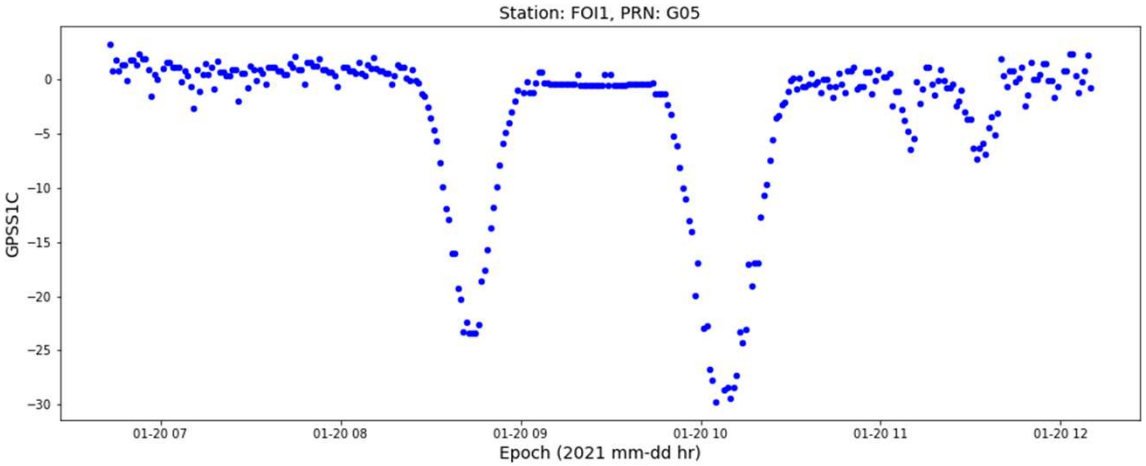

- FOI, the Swedish Defense Research Agency, simulated interreference waves in a controlled environment
- Four different interference waveforms centered at GPS L1 (1575.42 MHz)
  - Additive white Gaussian noise (AWGN) with 20 MHz bandwidth
  - AWGN with 2 MHz bandwidth
  - Continuous wave (CW) unmodulated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

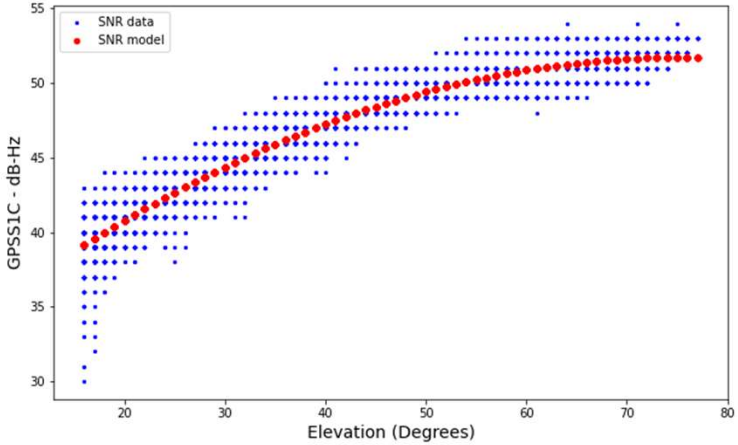


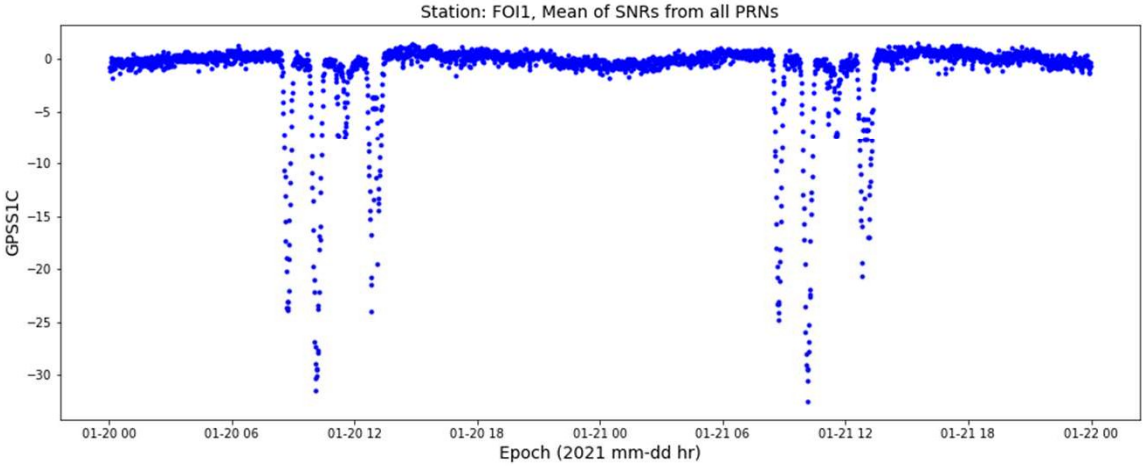

Station: FOI1, PRN: G05
GPSS1C
Epoch (2021 mm-dd hr)
01-20 07
01-20 08
01-20 09
01-20 10
01-20 11
01-20 12


SNR data
SNR model
GPSS1C - dB-Hz
Elevation (Degrees)


Station: FOI1, Mean of SNRs from all PRNs
GPSS1C
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)

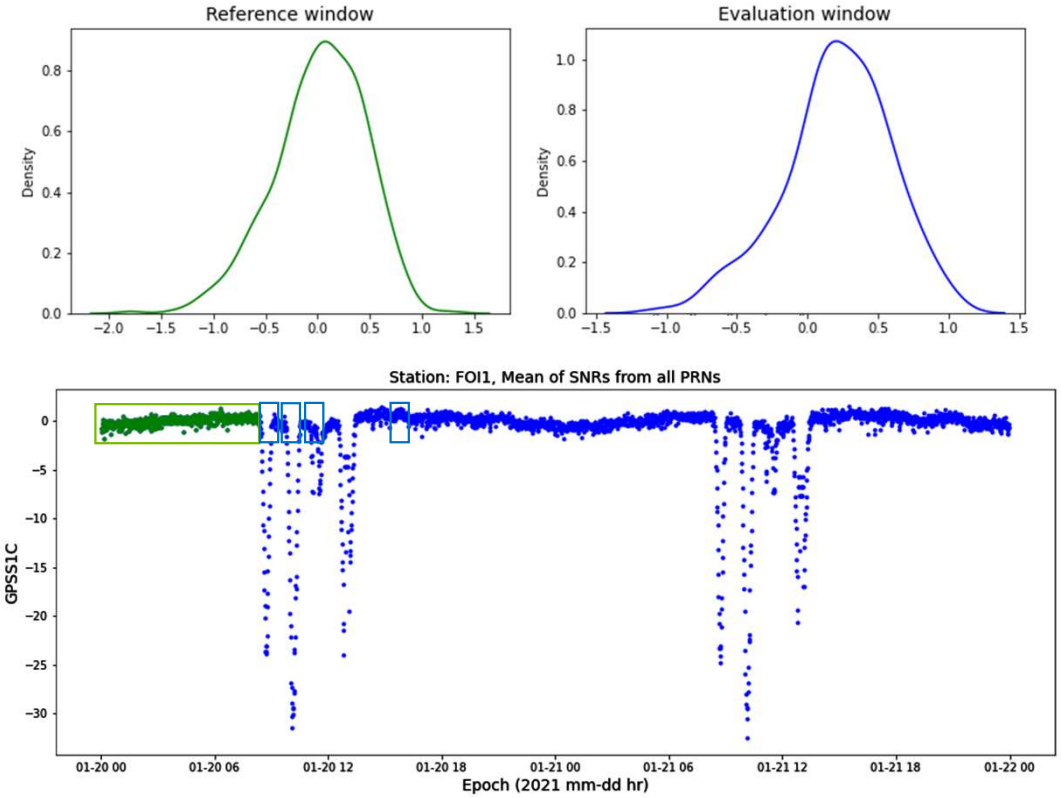

Station: FOI1, Mean of SNRs from all PRNs
GPSS1C
0
−5
−10
−15
−20
−25
−30
01-20 00
01-20 06
01-20 12
01-20 18
01-21 00
01-21 06
01-21 12
01-21 18
01-22 00
Epoch (2021 mm-dd hr)

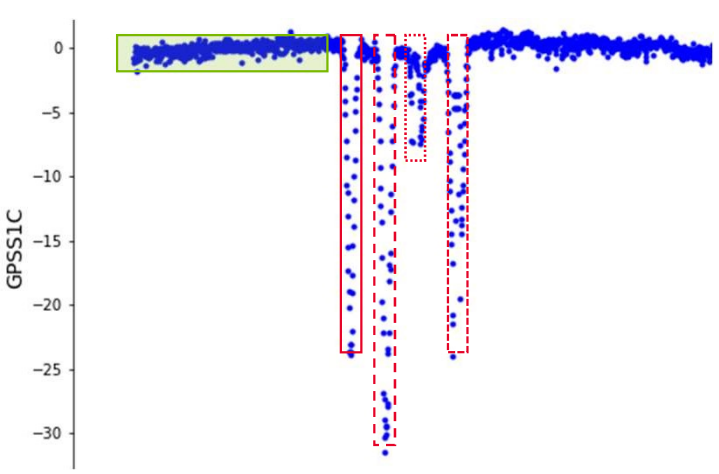
## Reference Window - RW:

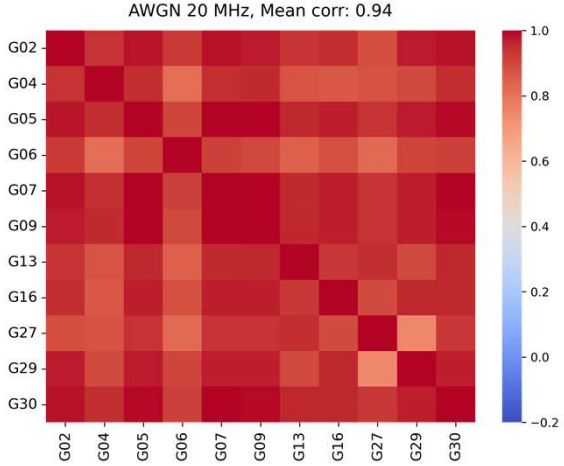
1. Data which is not subject to disturbance or interference
2. It should be from several hours/days of data
3. SNR model is developed

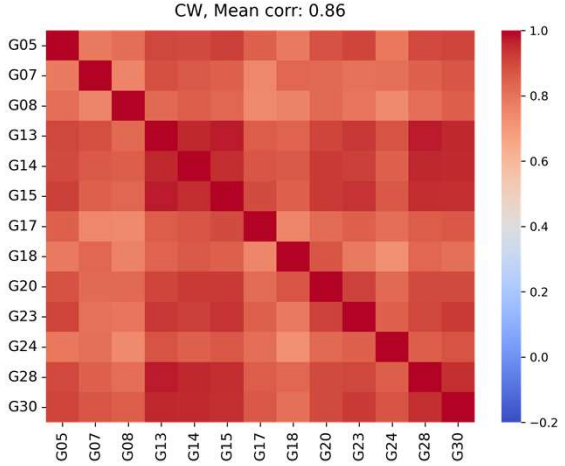
## Evaluation Window - EW:

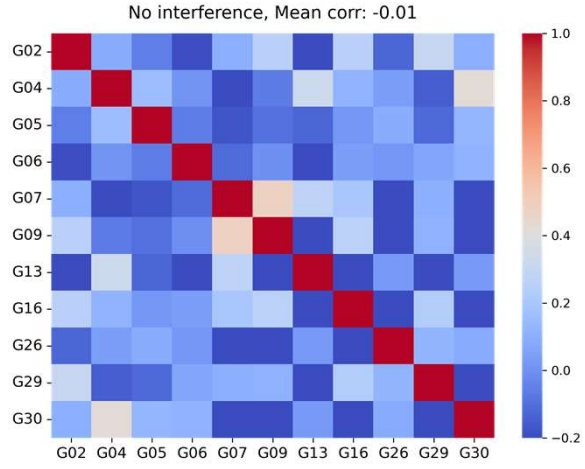
1. EW size selection – 10 secs, 10 minutes
   1. A tradeoff between acceptable variance and time delay
   2. Longer EW would mask short duration jammers
2. Fit to RW model, get EW residuals and compare with RW distribution
3. Interference is reported according to a defined threshold
   1. SNR residual drops compared to a RW
   2. SNR residual cross correlation among simultaneously tracked satellites

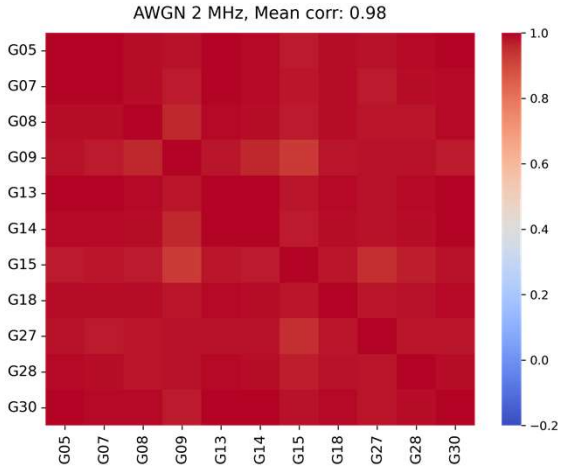


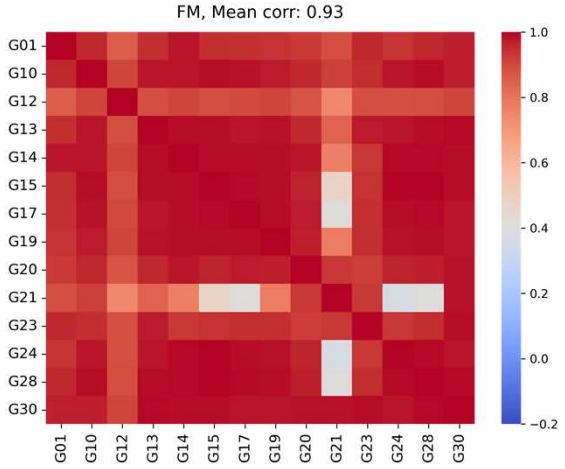

GPSS1C
0
−5
−10
−15
−20
−25
−30


AWGN 20 MHz, Mean corr: 0.94
G02 G04 G05 G06 G07 G09 G13 G16 G27 G29 G30
1.0 0.8 0.6 0.4 0.2 0.0 −0.2


CW, Mean corr: 0.86
G05 G07 G08 G13 G14 G15 G17 G18 G20 G23 G24 G28 G30
1.0 0.8 0.6 0.4 0.2 0.0 −0.2

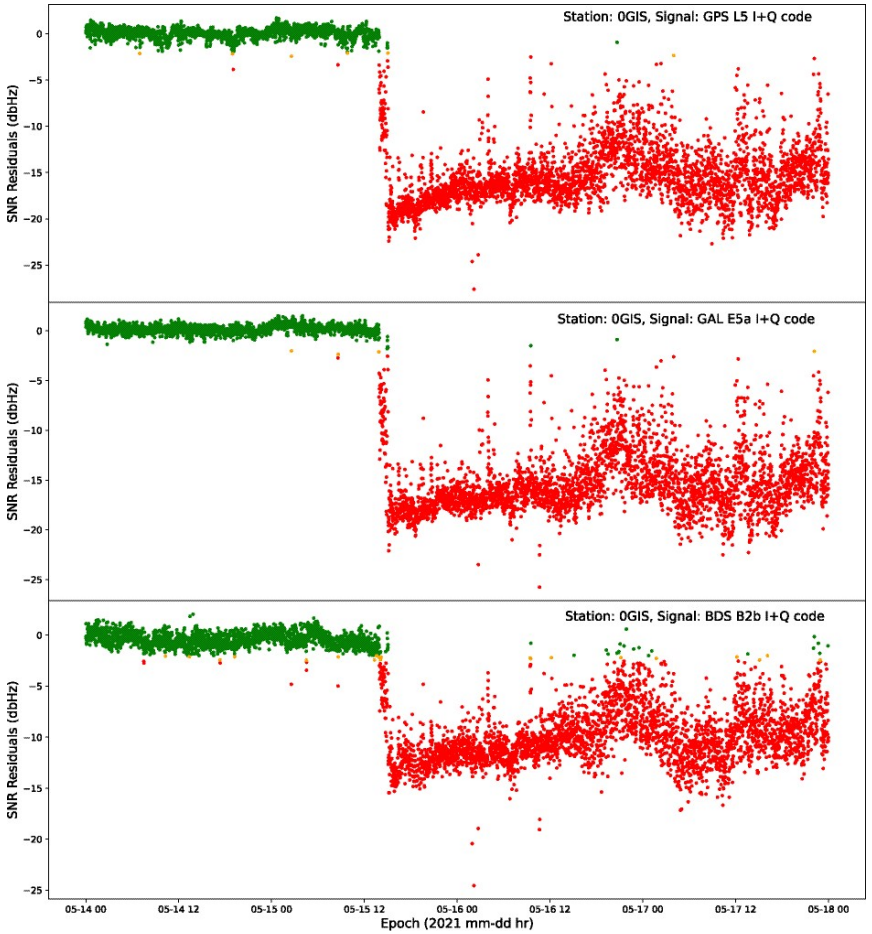

No interference, Mean corr: -0.01
G02 G04 G05 G06 G07 G09 G13 G16 G26 G29 G30
1.0 0.8 0.6 0.4 0.2 0.0 −0.2


AWGN 2 MHz, Mean corr: 0.98
G05 G07 G08 G09 G13 G14 G15 G18 G27 G28 G30
1.0 0.8 0.6 0.4 0.2 0.0 −0.2

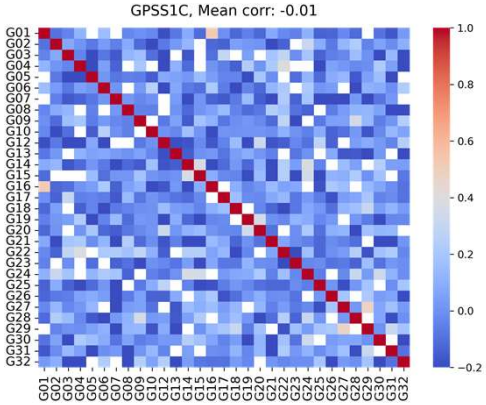

FM, Mean corr: 0.93
G01 G10 G12 G13 G14 G15 G17 G19 G20 G21 G23 G24 G28 G30
1.0 0.8 0.6 0.4 0.2 0.0 −0.2

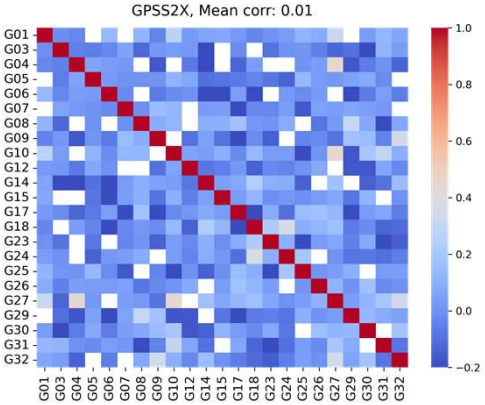
## Real signal interference incidents

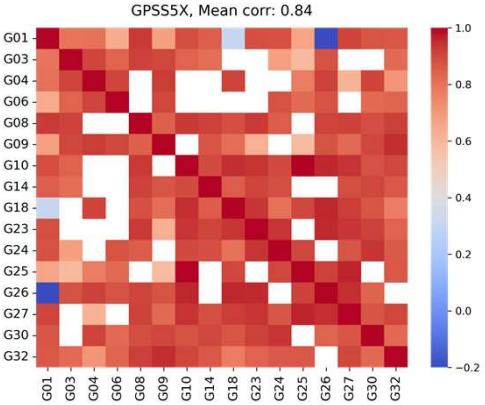

- Location: Grisslehamn, Norrtälje Municipality, Stockholm County
- Receiver: Trimble NetR9/ Sept. PolarX5
- Antenna: JAVRINGANT_DM OSOD/NONE

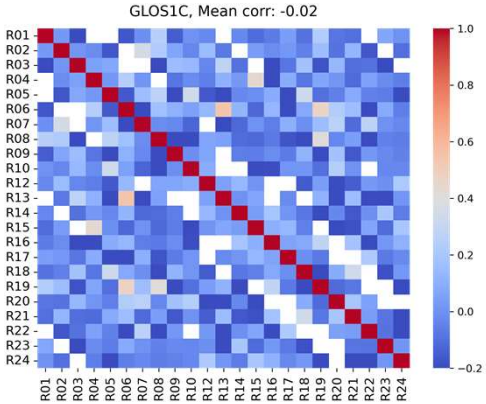


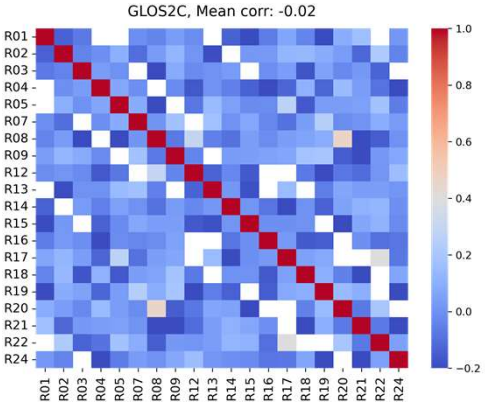
# Grisslehamn (0GIS)



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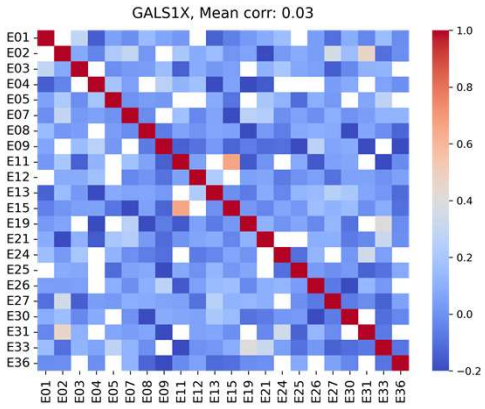
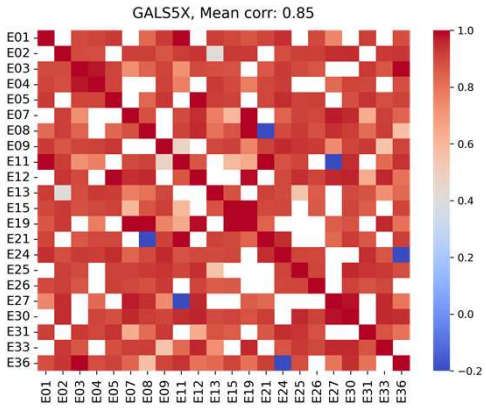
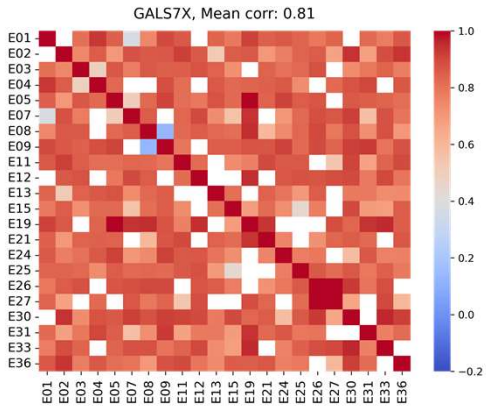
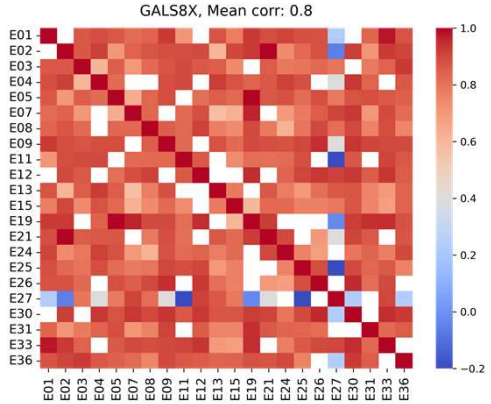
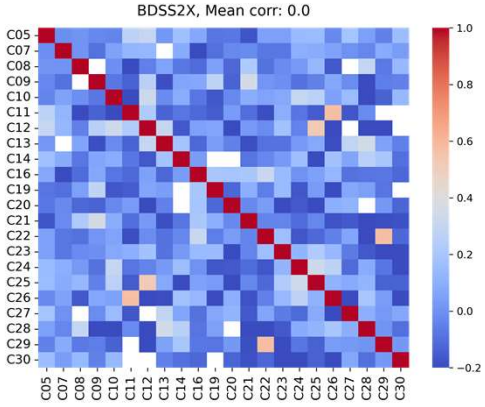
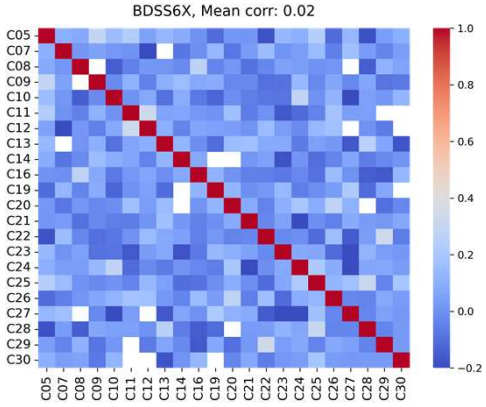


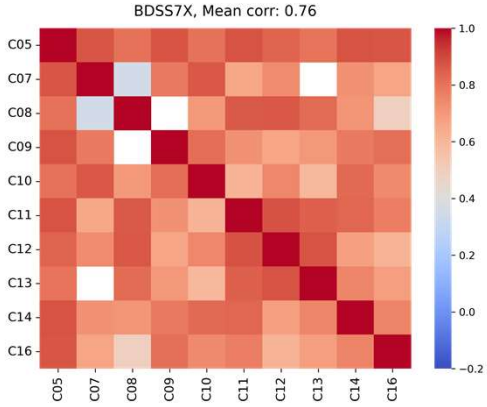



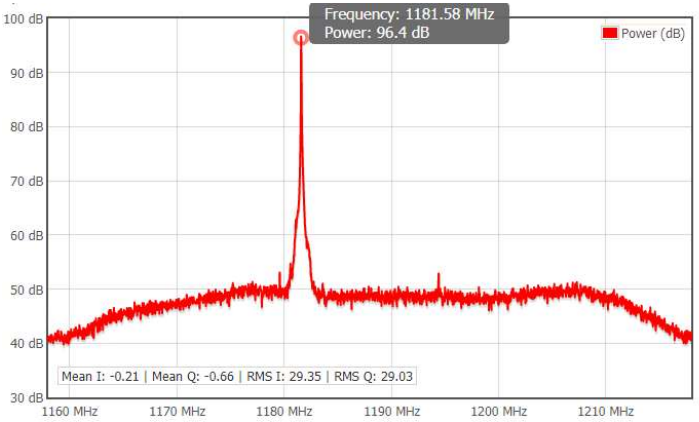



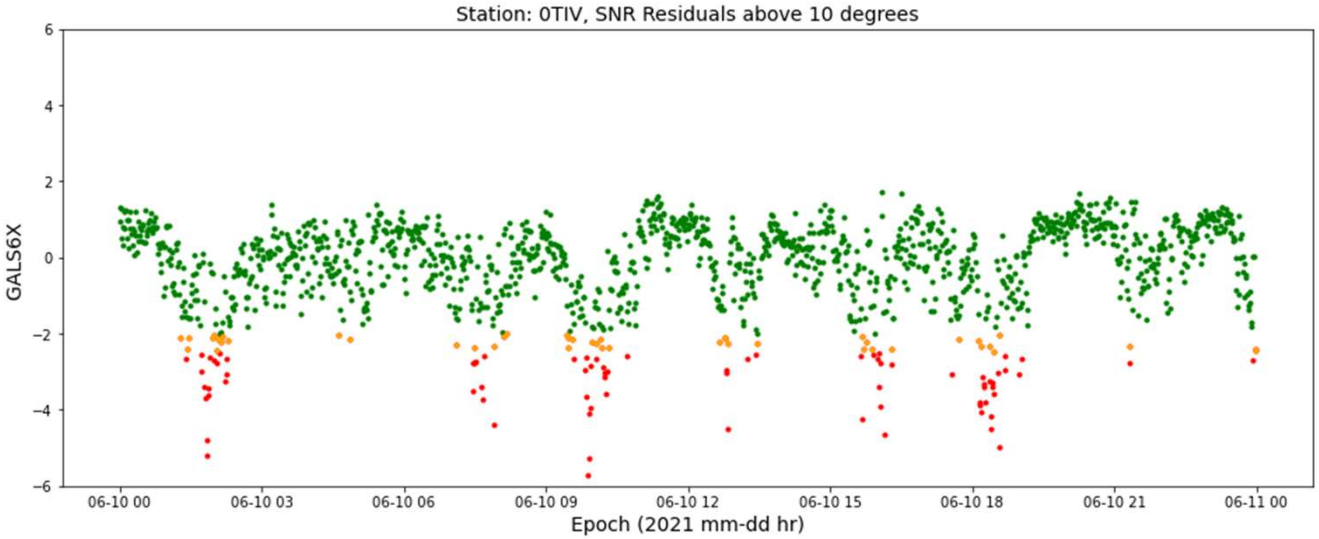



# Grisslehamn (0GIS) – 5.5 months of disturbances – The story

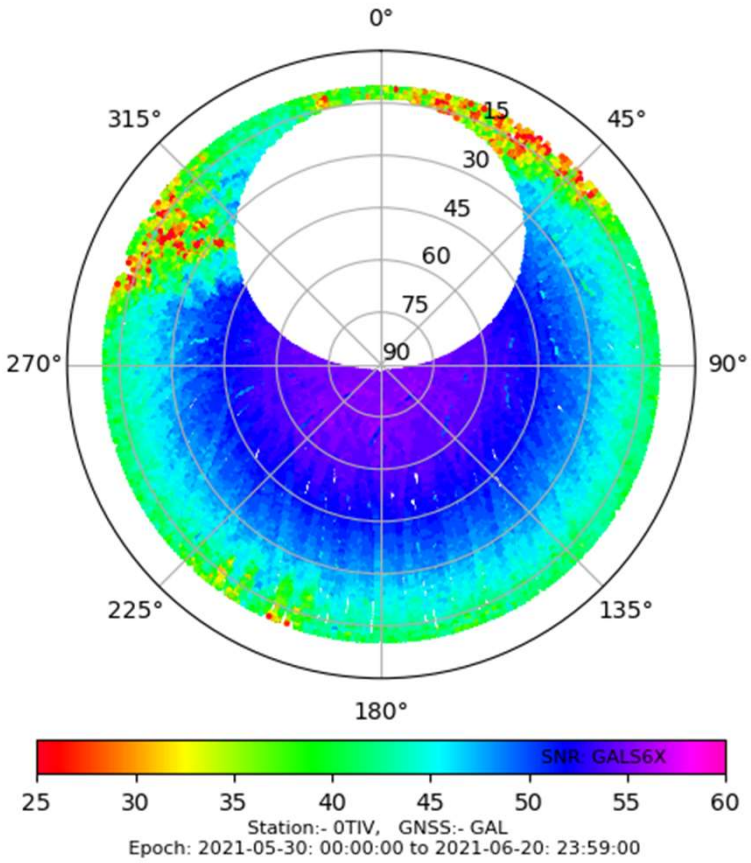
- A disturbance was detected on L5 signal which started on a Saturday 2021-05-15, at 15:50 local time. It had a Trimble NetR9 receiver
- Septentrio PolaRx5 receiver was sent and installed in parallel on 05-20
- SDR – Software Defined Radio show a strong signal
- Septentrio spectral analysis showed it was a narrow band interference centered at 1181.0 MHz but was slightly changing over time (E.g. at 1182.8 MHz on 06-01) .
- But its effect covers a wideband (-5 MHz to +26 MHz)
  - GPS L5, GAL E5a, BDS B2a – 1176.45 MHz
  - GAL E5b, BDS B2b – 1207.14 MHz
  - GAL E5a + E5b,  BDS B2a + B2b - 1191.795
- Reported the case to PTS on 2021-05-24
- PTS has visited the station on 2021-06-03 and they claimed that they have located the source to a boat. The boat had a theft protection with GPS tracker on it.
- The boat owner took the boat on a trip the next day, but the disturbance continued.
- Two other boats were suspected
- The disturbance disappeared on its own on 2021-10-26 (after 5.5 months), but the two boats were still at the pier and powered.
- Unsolved mystery – geolocating RFI is complex

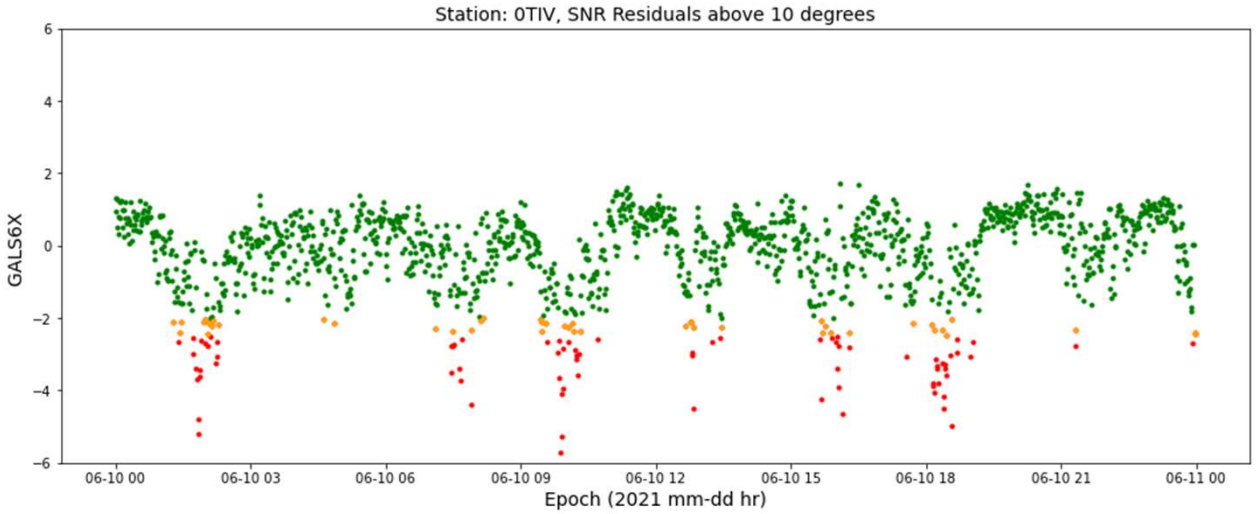


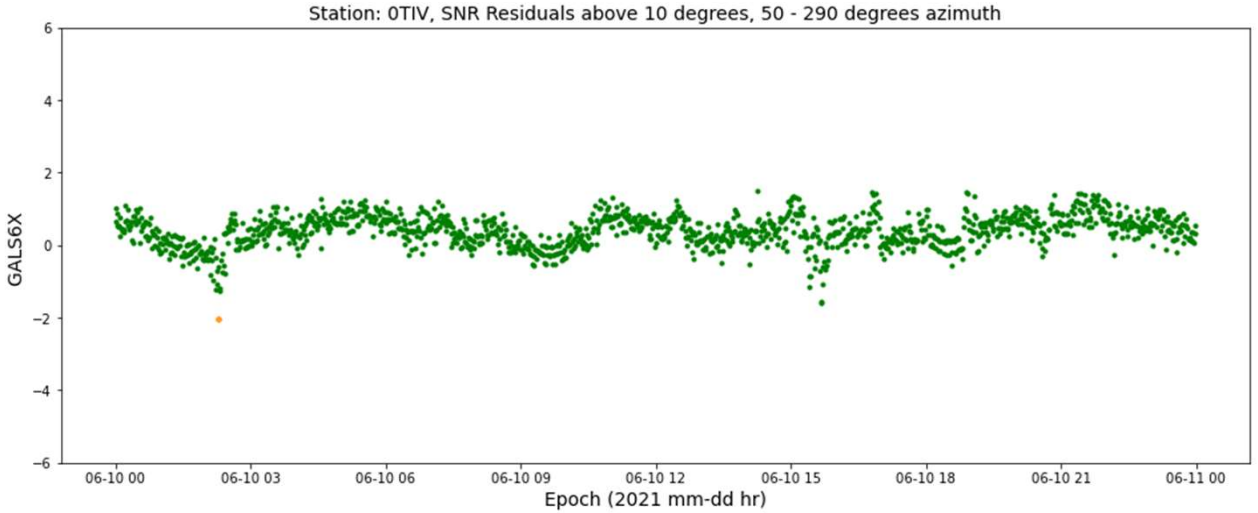
# Non-RFI disturbances, signal attenuation by trees

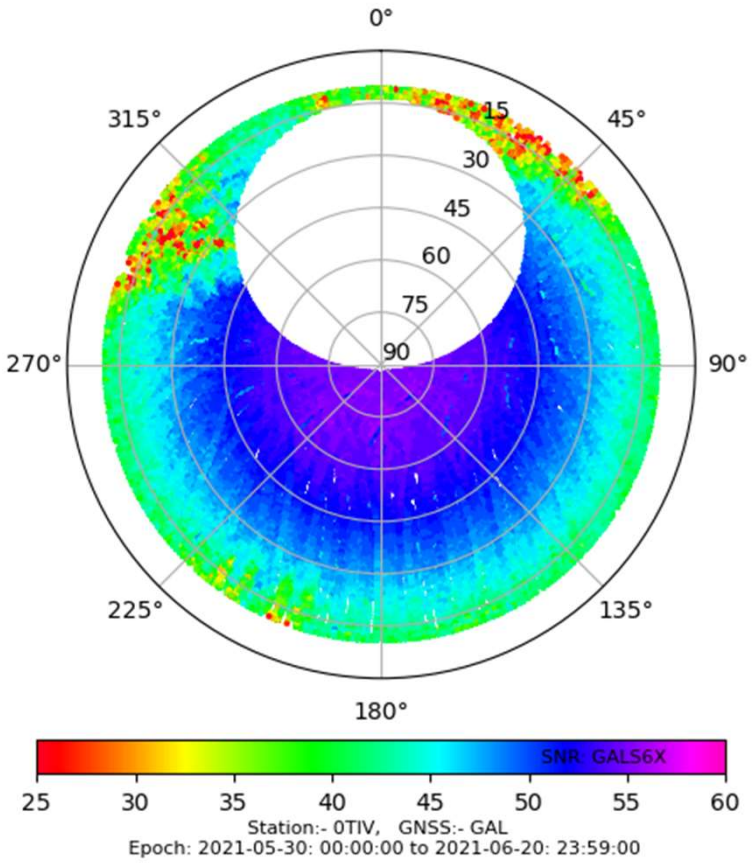

- Location: In a school building in Tived, Örebro County
- Receiver: Trimble Alloy
- Antenna: Trimble Choke ring (TRM59800.00 OSOD)

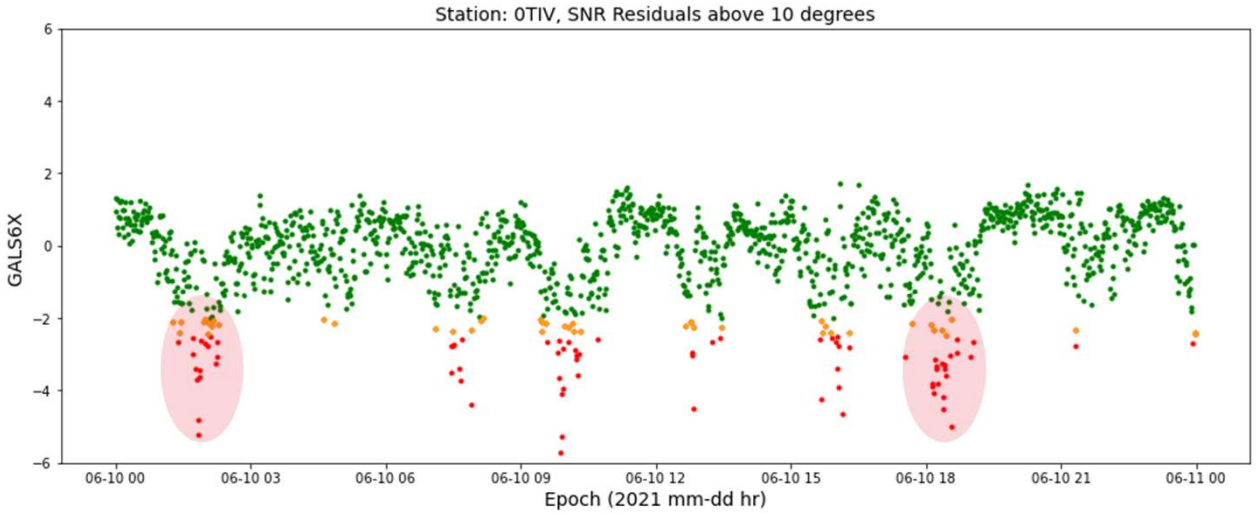


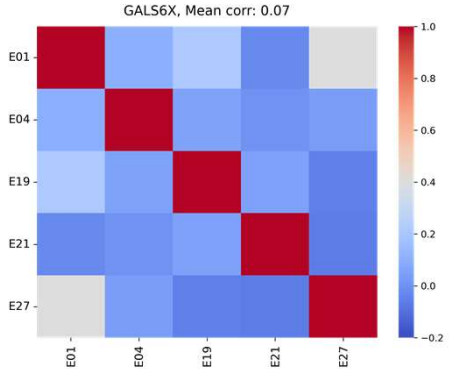



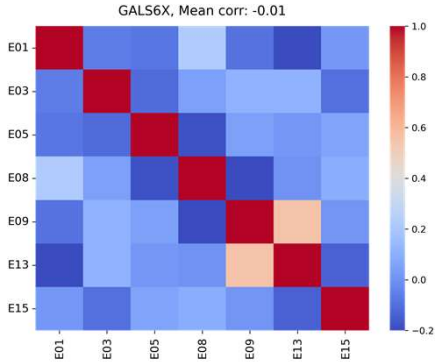




- Affects all signals
- Directional – In a certain azimuth
- Spectrum shows nothing
- SNR drops not correlated across satellites




- Affects all signals
- Directional – In a certain azimuth
- Spectrum shows nothing
- SNR drops not correlated across satellites

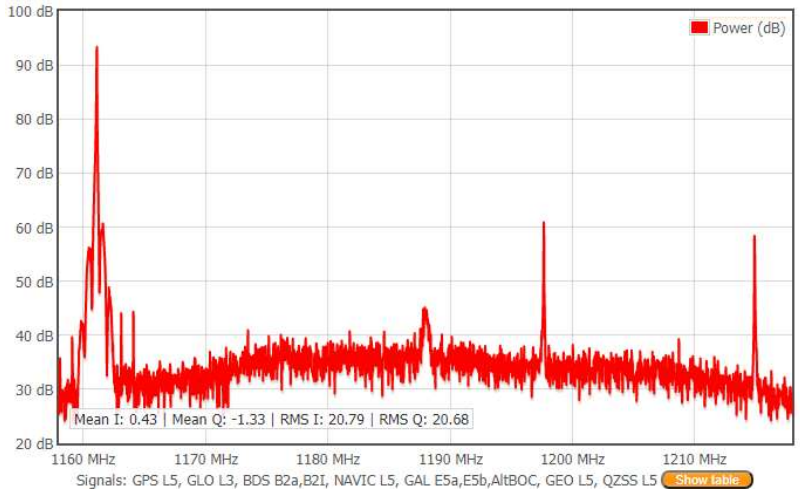
## Next steps

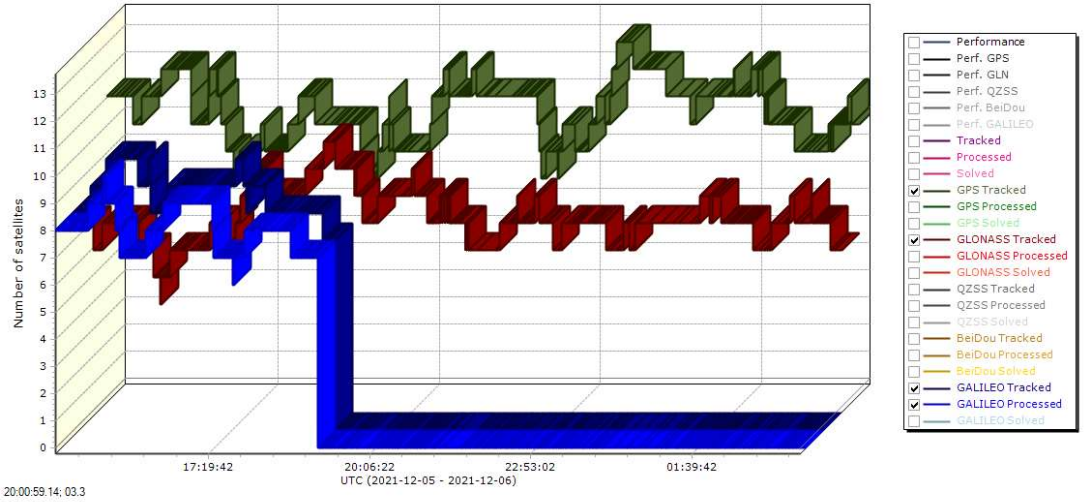
- Improved detection system, which makes use of additional pre- and post-correlation parameters, such as Automatic Gain Control (AGC)
- Web-based service
- Real-time
- Multipath Filtering?
  - Currently removing low elevation data

# More real signal interference incidents!

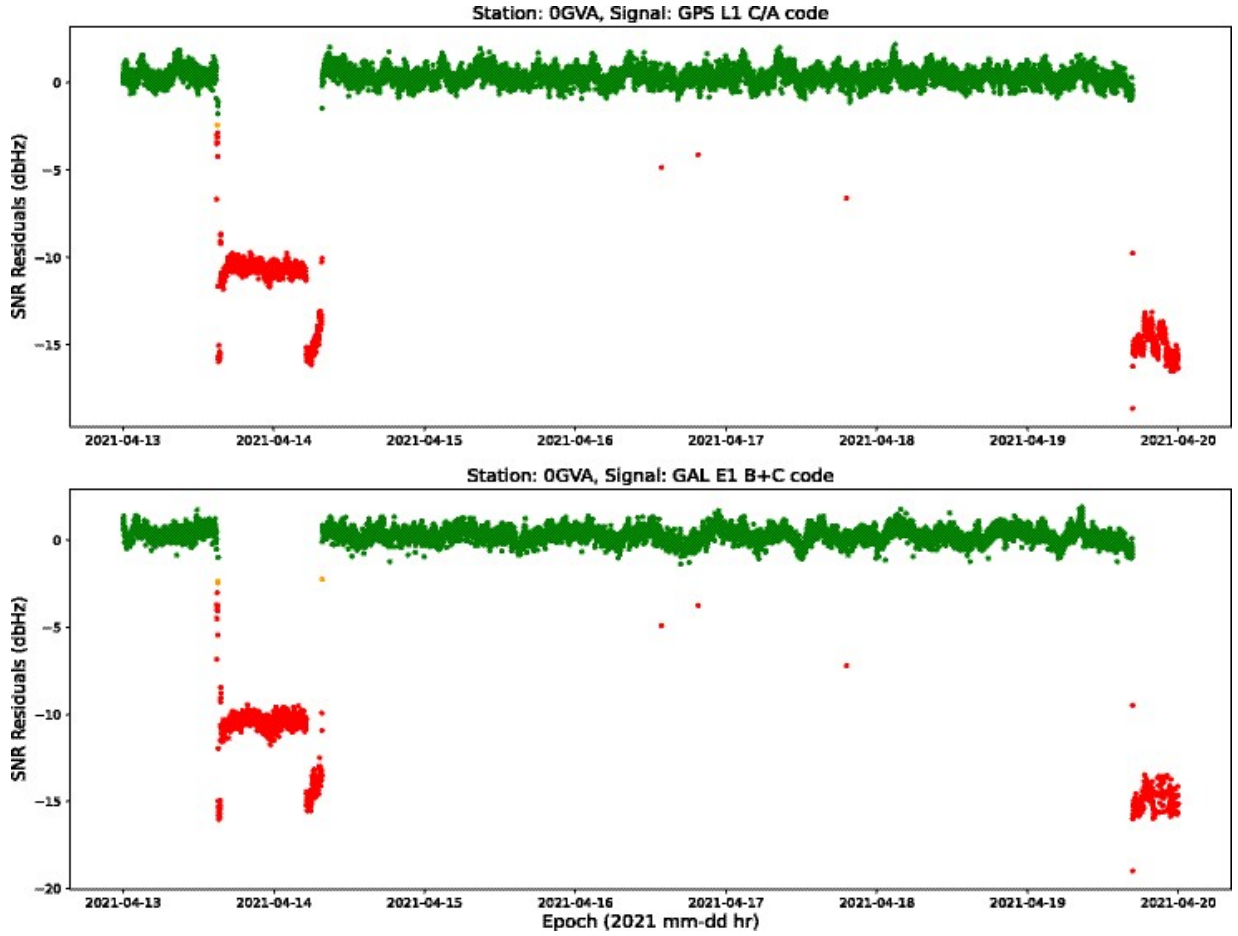
# Rosvik (0ROS) – GPS L5, GAL E5/E5a/E5b, BDS B2a disturbances

- L5 band signals were lost
- No Galileo satellites were being tracked

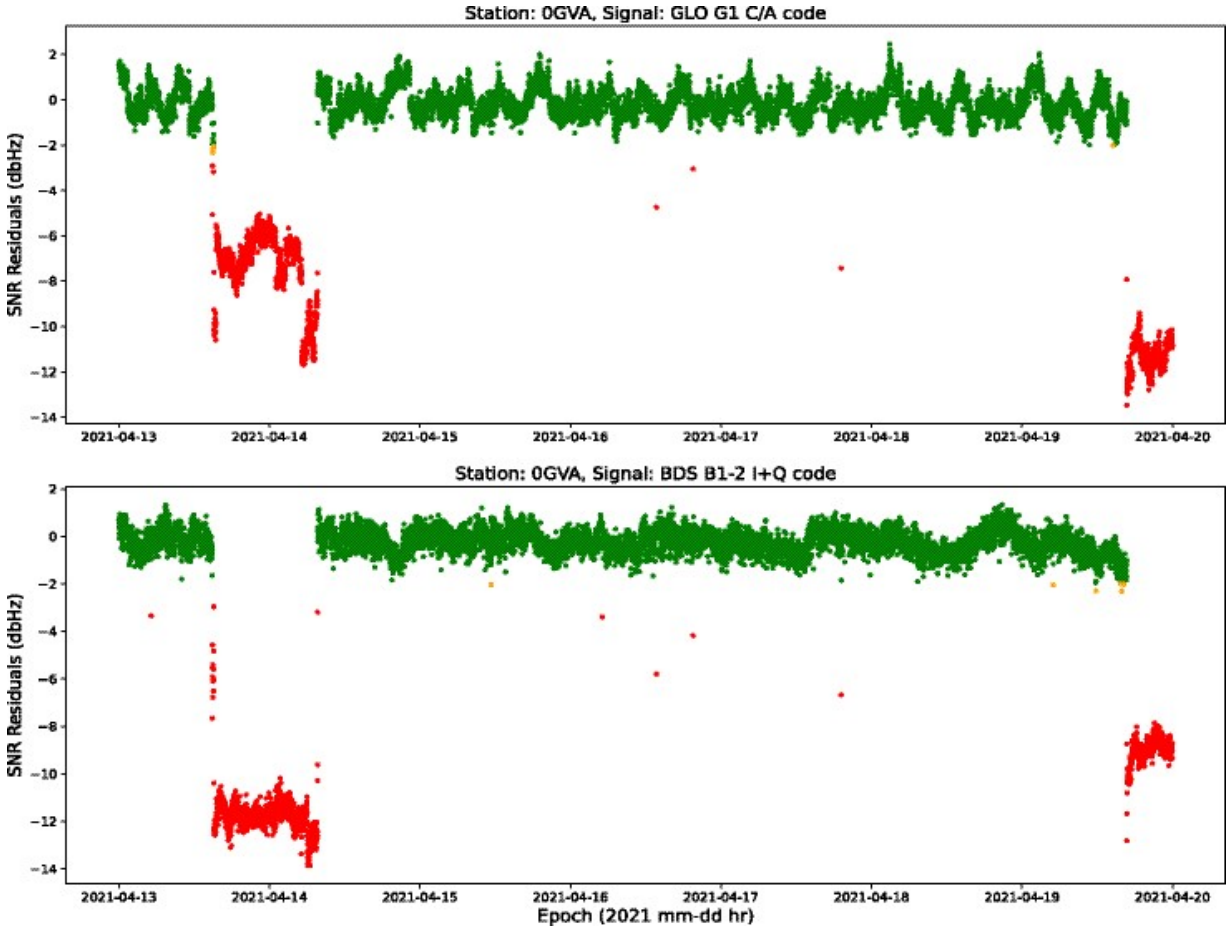


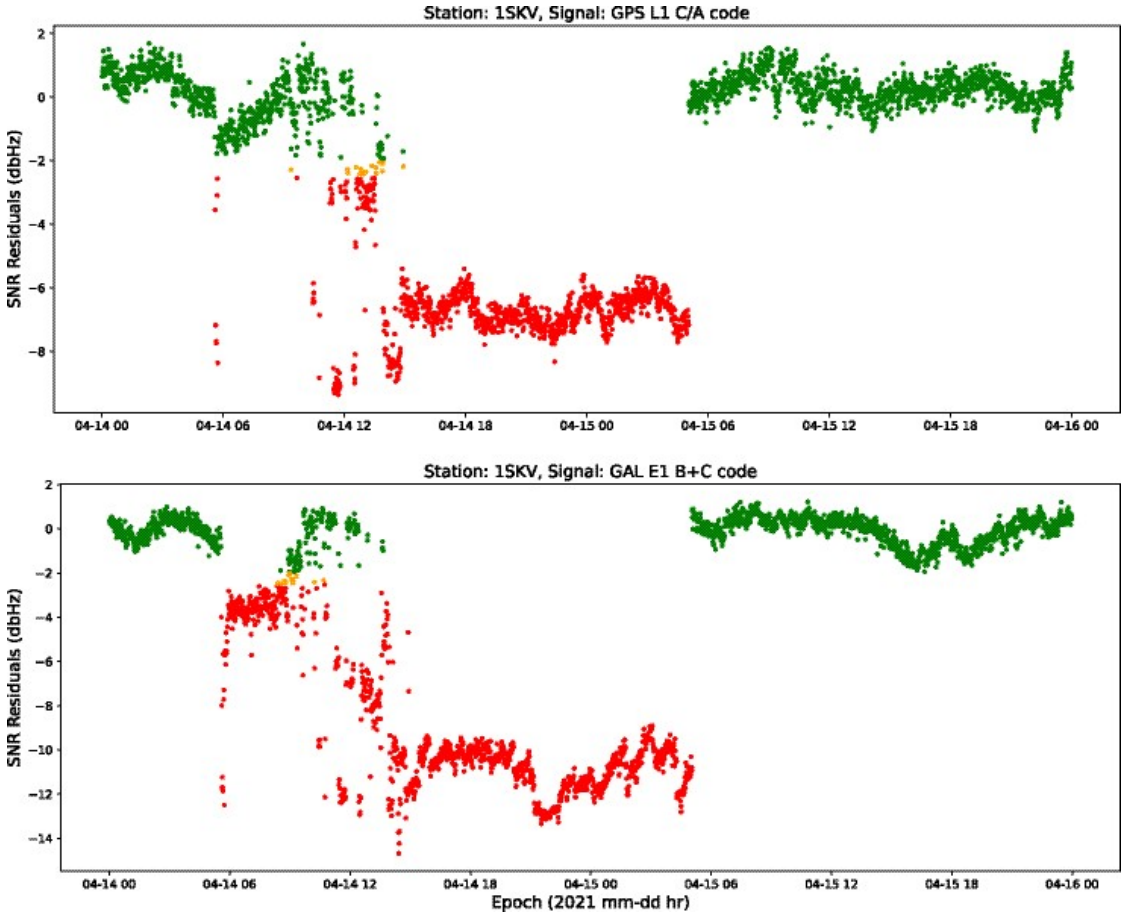
# Gällivare (0GVA) – GPS L1, GAL E1 disturbances



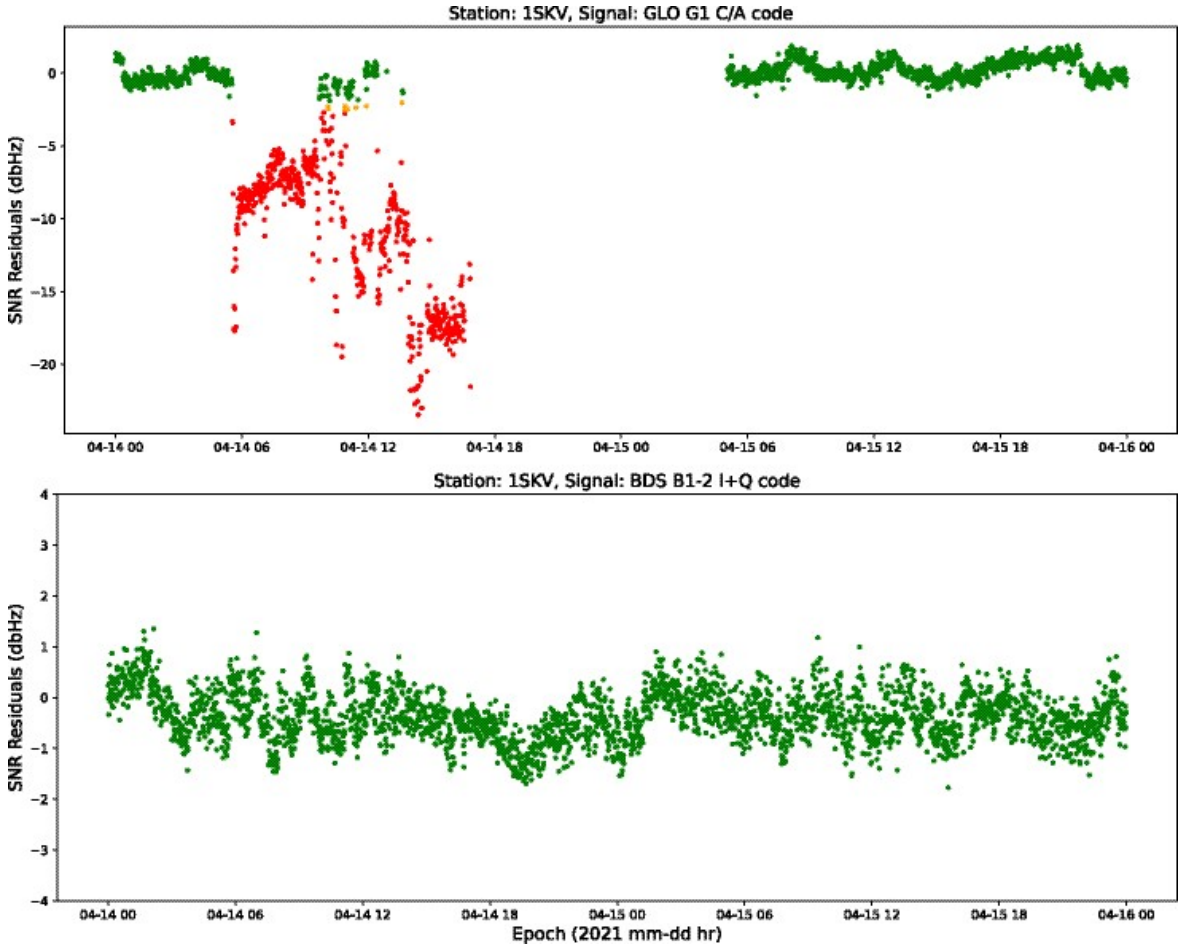
# Gällivare (0GVA) – GLO G1, BDS B1-2 disturbances



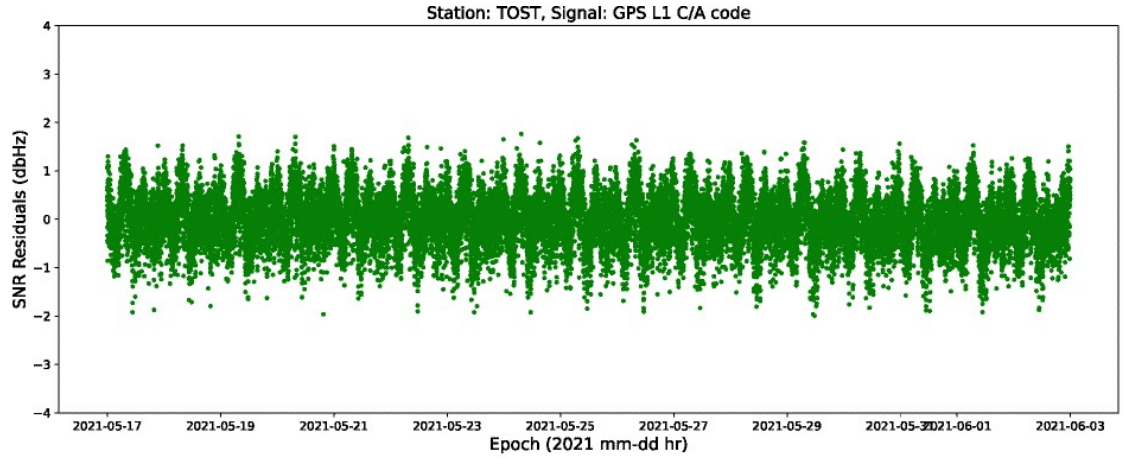
# Skövde (1SKV) – GPS L1, GAL E1 disturbances

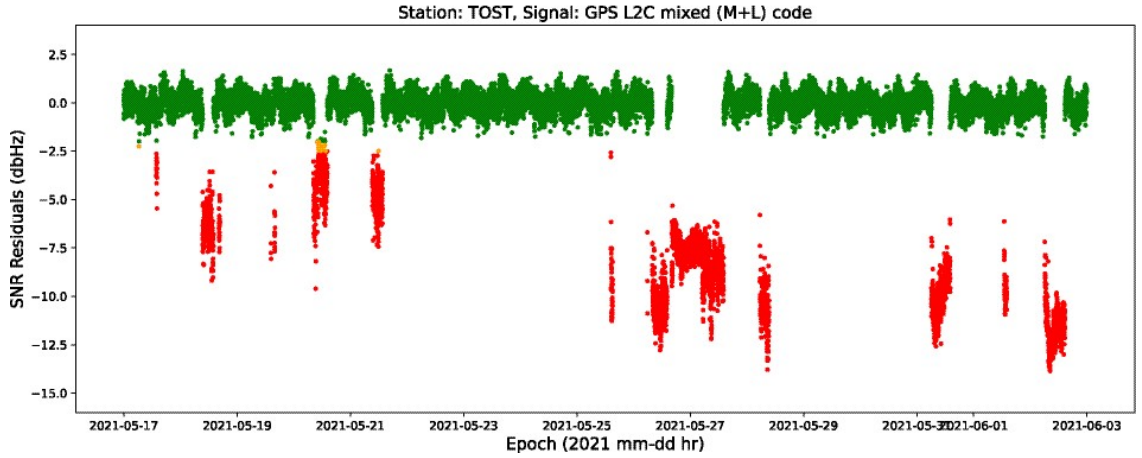


# Skövde (1SKV) – GLO G1 disturbances

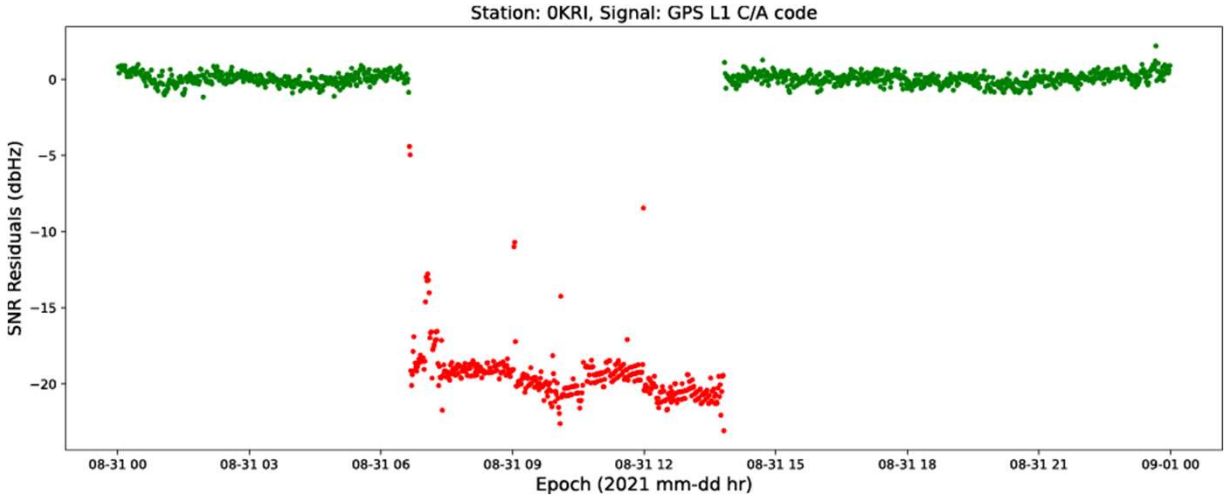


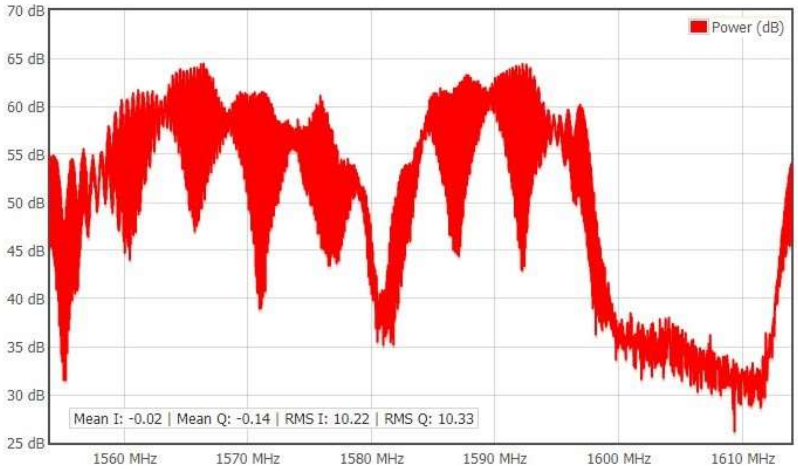
# Östra Frölunda (TOST) – L2 disturbance



# Kristianstad (0KRI) – L1 disturbances



# Mockfjärd (0MOC) – All except L1 disturbances