EUROPEAN COMMISSION

Impact of Ionospheric Scintillation on Commercial GNSS Timing Receivers

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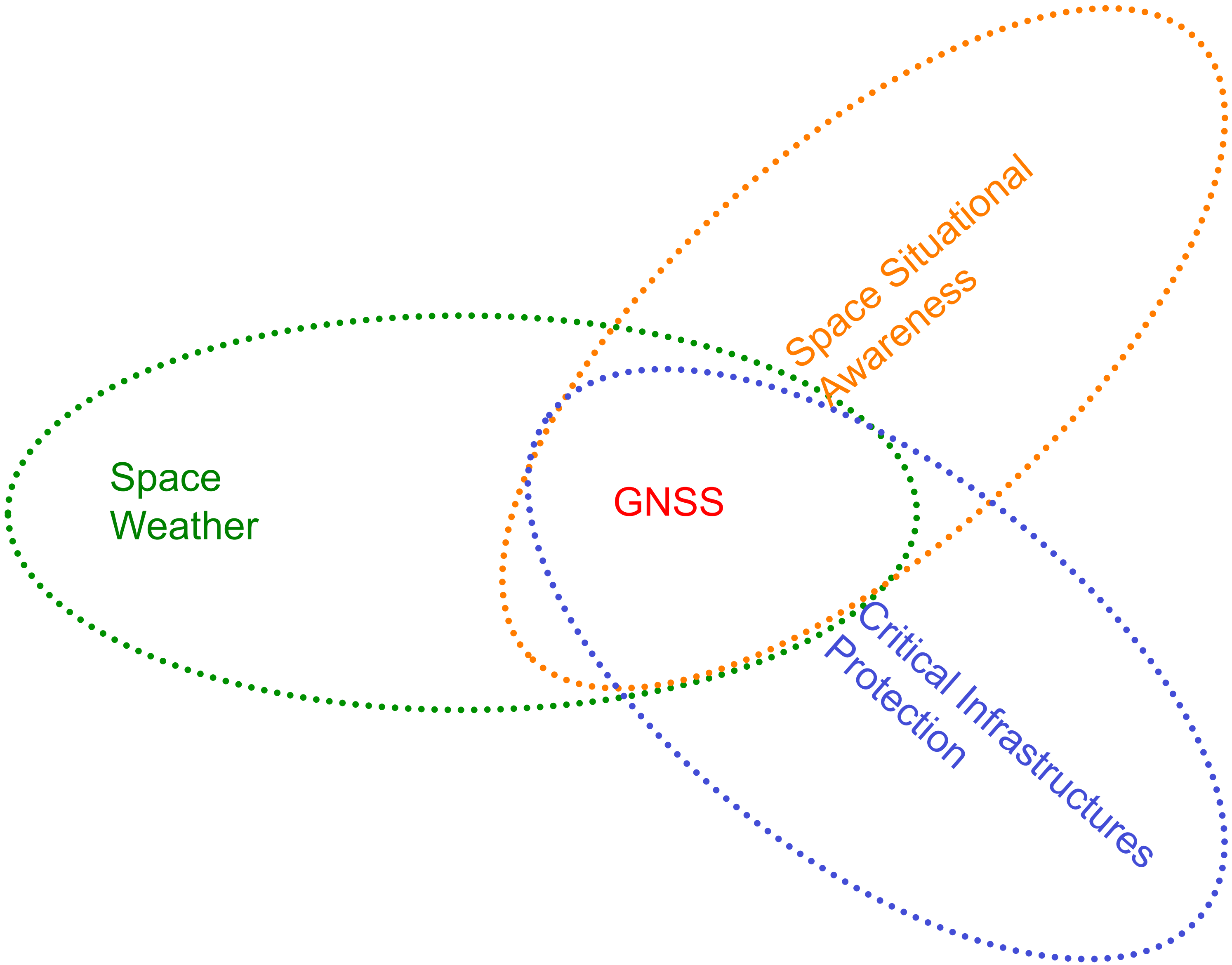
Outline

- Background
- GNSS is a Critical Infrastructure
- Facilities
- Space weather related activities:
  - Assessment of the resilience of timing receivers
  - Monitoring of ionospheric scintillation
  - EM modelling of the ionospheric scintillations
- Concluding Remarks

Why GNSS?


Space Situational Awareness
Space Weather
GNSS
Critical Infrastructures Protection

Background

- IPSC is currently investigating the vulnerabilities of GNSS systems to:
  - anthropogenic interference sources (e.g., DBV-T, RFI, …)
  - natural interference sources (e.g., space weather)
- Ground critical infrastructures are vulnerable (e.g., those relying on GNSS-based services for precise timing and synchronization)
  - Country-wide fixed and wireless networks (i.e., internet), the power grid (PMU), banking services, stock markets (time stamping with 5 ms accuracy), and sea, air, rail and road transportation networks,…

GNSS is a Critical Infrastructure

Common Main Recommendations

- GNSS should be classified as a Critical Infrastructure
- A GNSS interference geolocating and reporting system shall be deployed
- Hardening of GNSS receivers and antennas
- Establish GNSS backup systems to guarantee PNT operations (e.g, aviation)
- Establish new standards for more resilient GNSS receivers
- Quantify the impact on critical timing and synchronization services

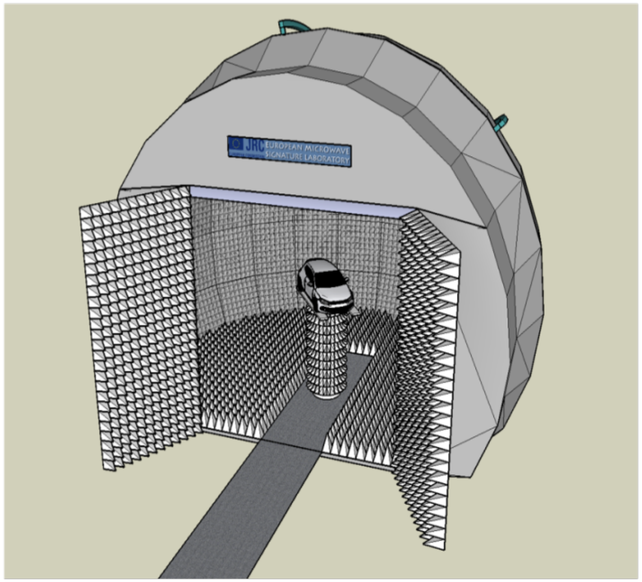
Methodology

Analysis:

- Allan Deviation, Modified Allan Deviation, RMS Time Interval Error, Max Time Interval Error: **metrics used in Telecommunications**

Tools:

- tests of professional timing receivers and GPS clocks
- experiments in conducted and radiated mode (use of an **anechoic chamber**)
- tests in free run and with difference levels of RFI



Example Results

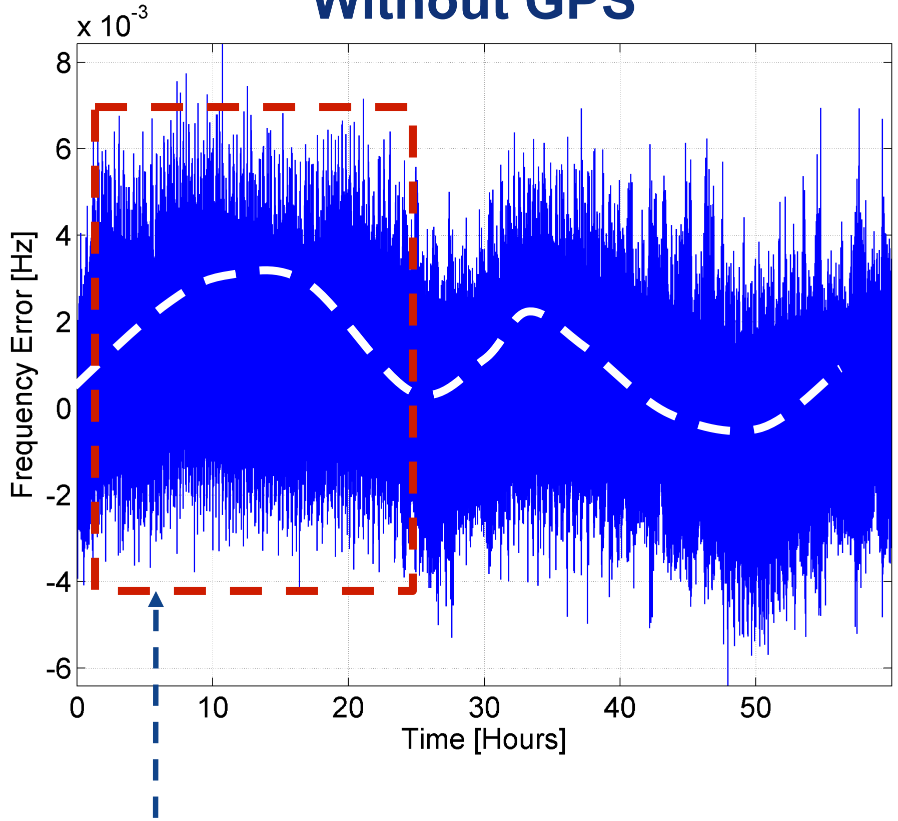
High-end time server used to provide accurate time to telecommunication networks

Tests in free run and with a CWI interference centered at the GPS L1 band

Dedicated antenna with integrated down-converter (provides additional defenses against tampering)

Effect of a GPS Outage

Without GPS

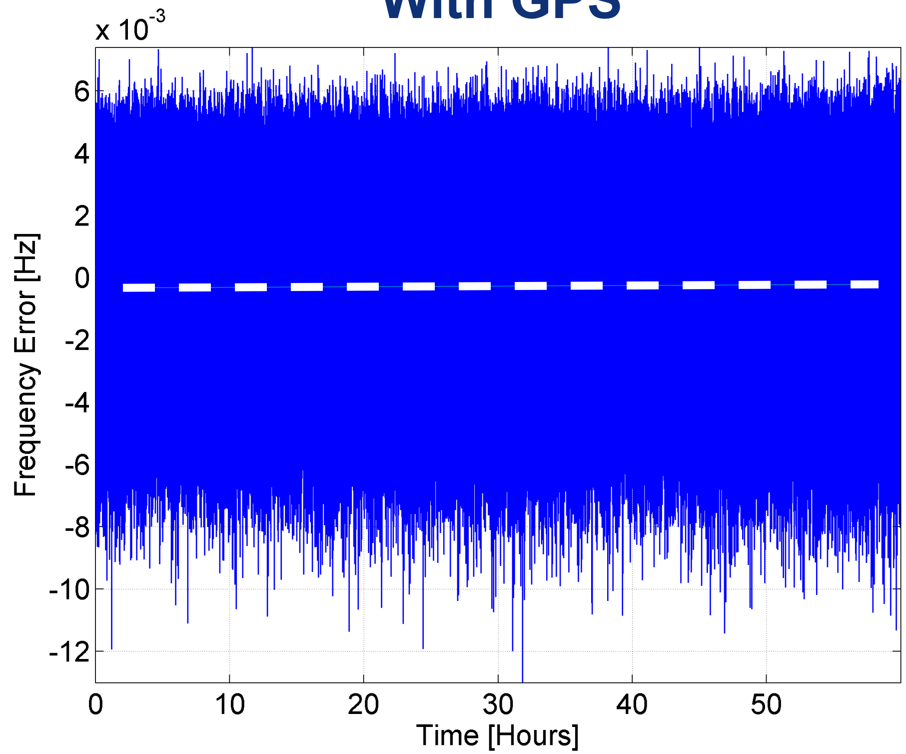


24h windows: phenomena likely related to day/night environmental changes (e.g./ temperature)

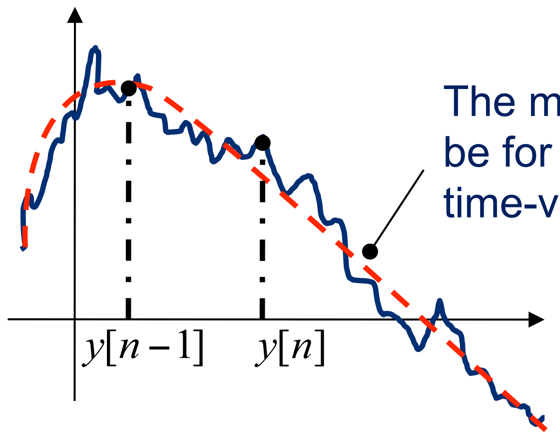
Without GPS, time drifts are present in the collected frequency measurements

Performance quickly degrades when using local oscillators of low quality

With GPS



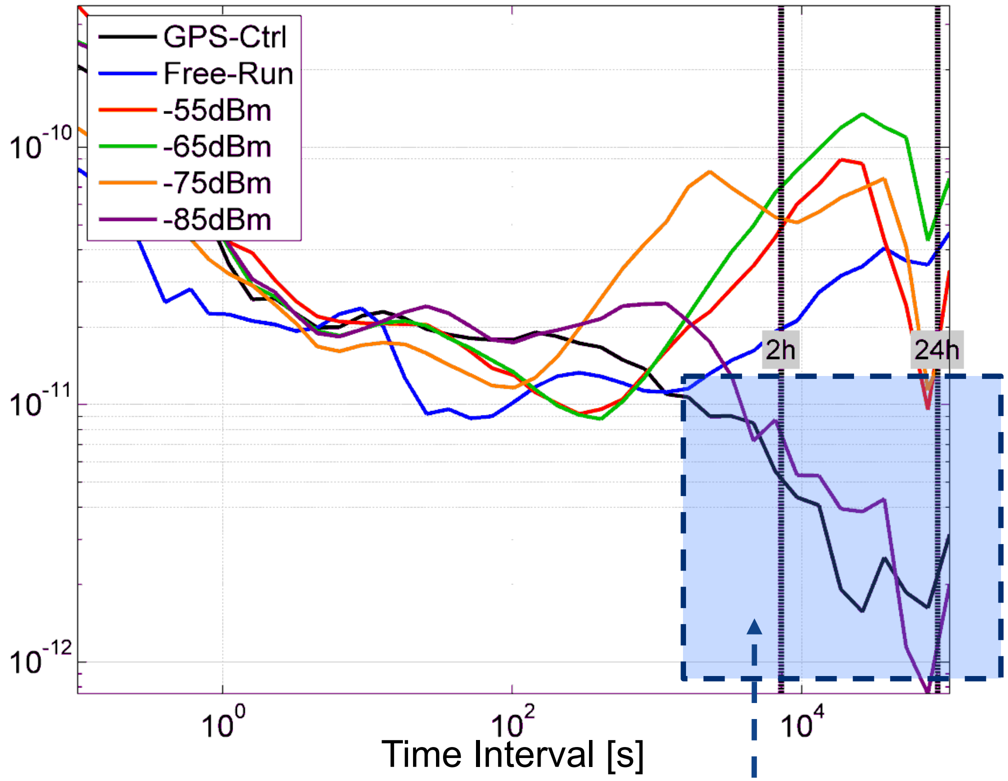
Allan Deviation



The mean can be for example time-varing

$$\sigma_A = \sqrt{\frac{1}{2(N-1)}\sum_{n=1}^{N-1}\left(y[n]-y[n-1]\right)^2}$$

Average deviation between frequency measurements taken at subsequent time instants

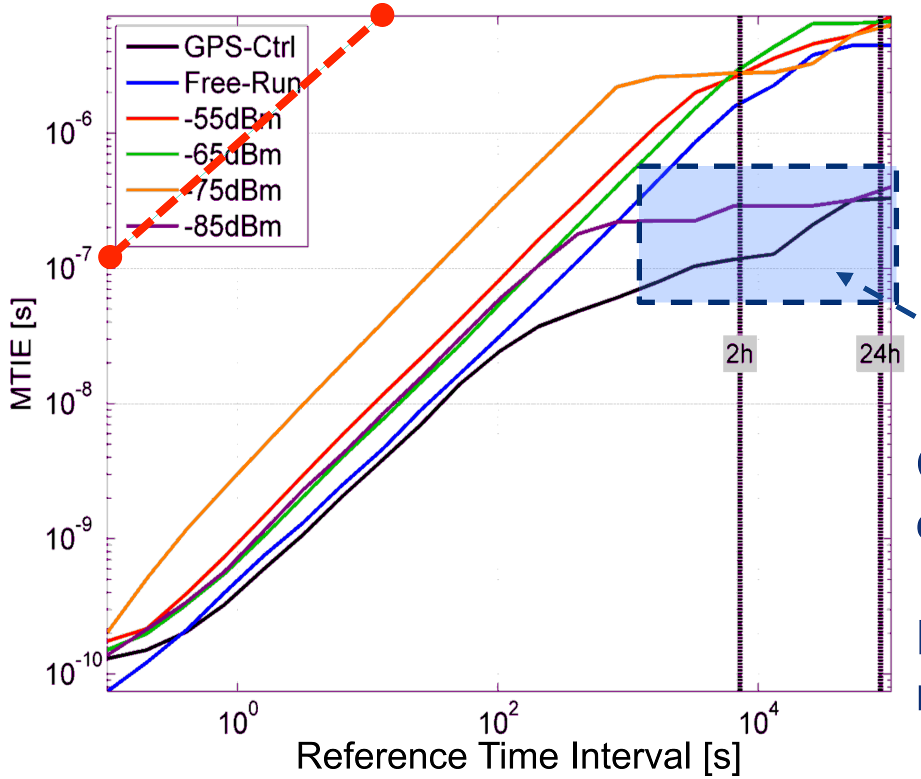


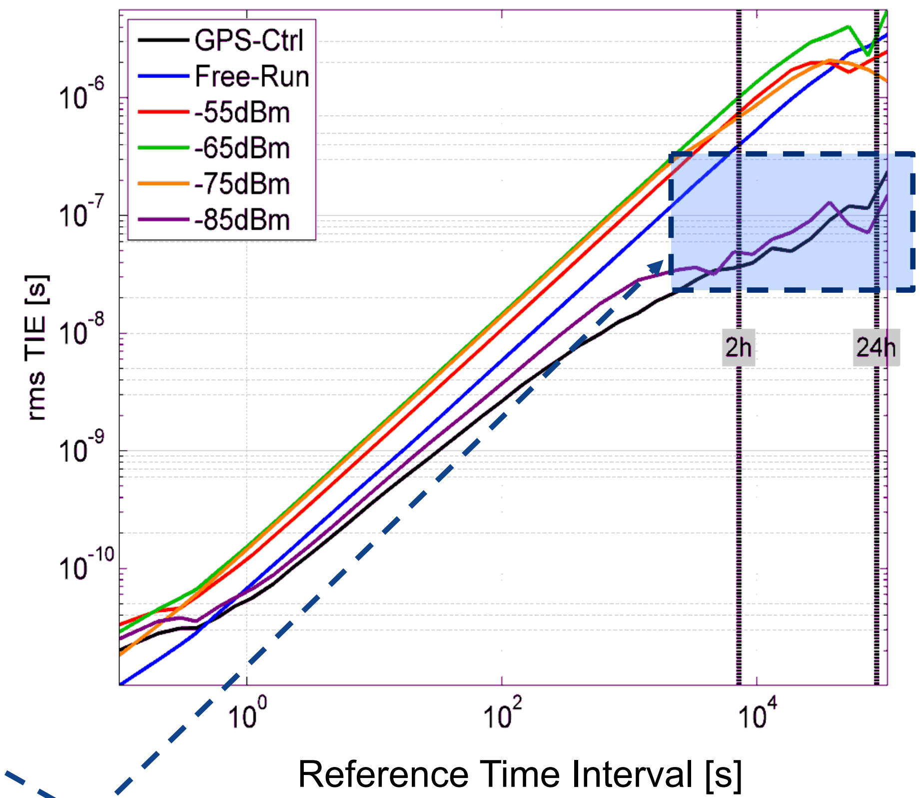
When available, GPS updates significantly improve the long term stability of the frequency source

A CWI at the L1 GPS center frequency with a power as low as **-75 dBm** is able to make the time server switch to free run mode **(GPS denial)**

Time Interval Errors

Time interval error: error committed in measuring a reference time interval with respect to an ‘ideal’ clock (in this case the Symmetricom 8040 Rubidium Frequency standard)



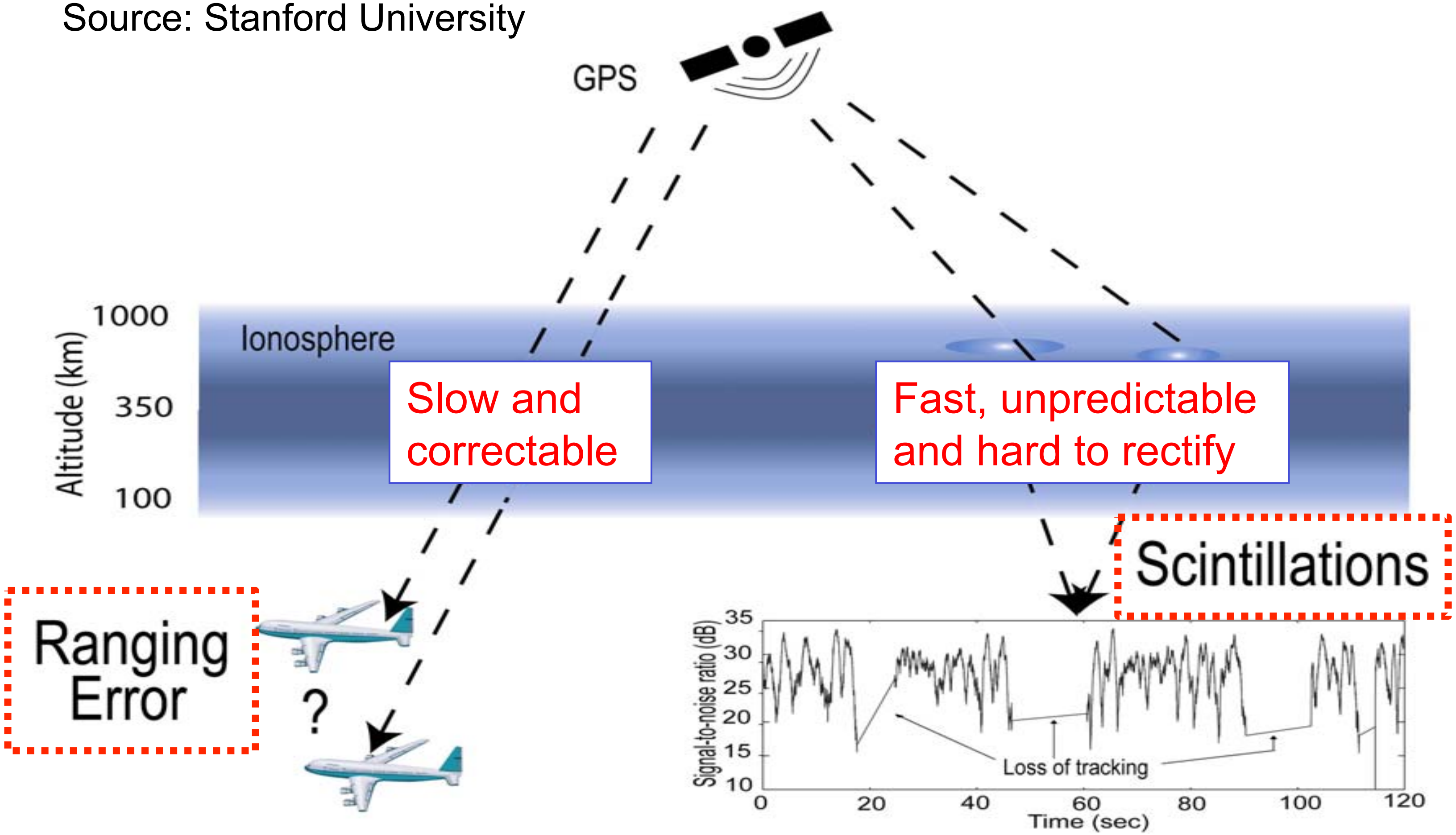


GPS updates: effective reduction of timing errors on medium to large time intervals

High-end time server, good performace in free run mode as well

What is an ionospheric scintillation?

Source: Stanford University



Ionospheric Range Delay result from normal signal propagation through the ionosphere.

Scintillations result from severe ionospheric signal scattering.

Amplitude Fading or signal to noise degradation are caused by solar radio bursts.

What is S4?

- **Scintillation = rapid fluctuations in:**
  - **Phase**
  - And/or **Amplitude**

Don't forget this!

$$s(t) = A(t)e^{j\phi(t)} + n(t)$$

- **S4 is a measure of amplitude scintillation**

$$S_4 = \sqrt{\frac{Var\left[A(t)^2\right]}{E\left[A(t)^2\right]^2}}$$

- **Two basic approaches considered**

1. Using C/N_0 measurements

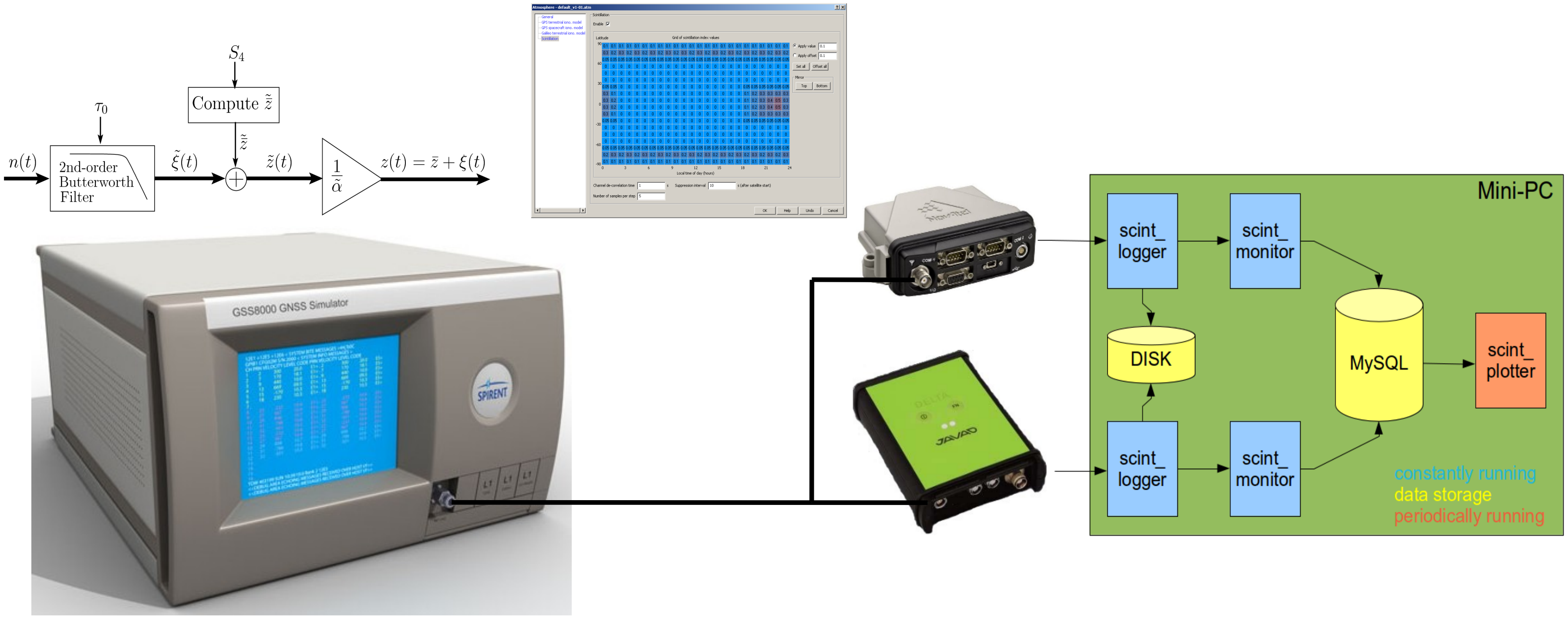
$$C/N_0 = \frac{E\left[A(t)^2\right]}{E\left[n(t)^2\right]}$$

2. Using I/Q values from correlators

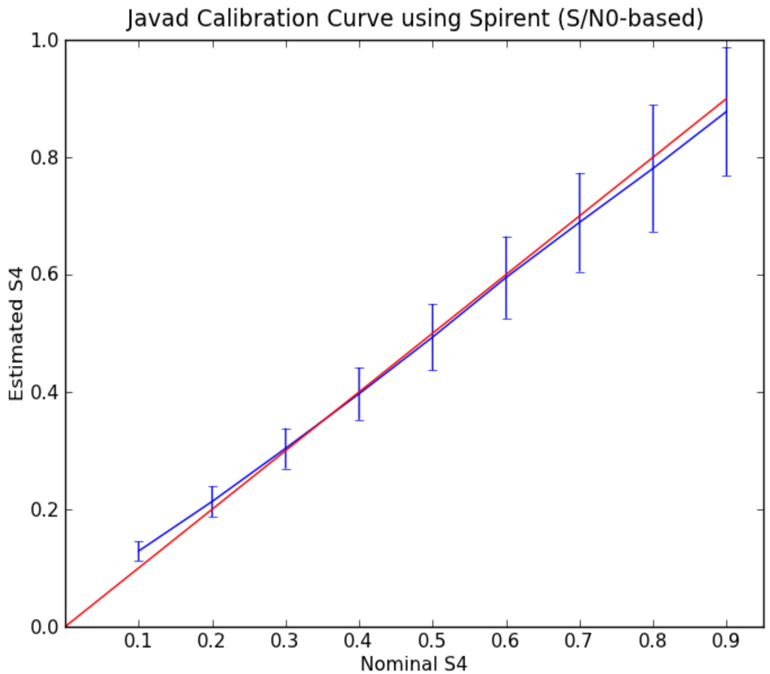
$$I + jQ = \frac{1}{T}\int_0^T c(t)A(t)e^{j\delta\phi(t)} + c(t)n(t)dt \approx \bar{A}e^{j\delta\bar{\phi}} + \eta$$

Spirent GSS8000

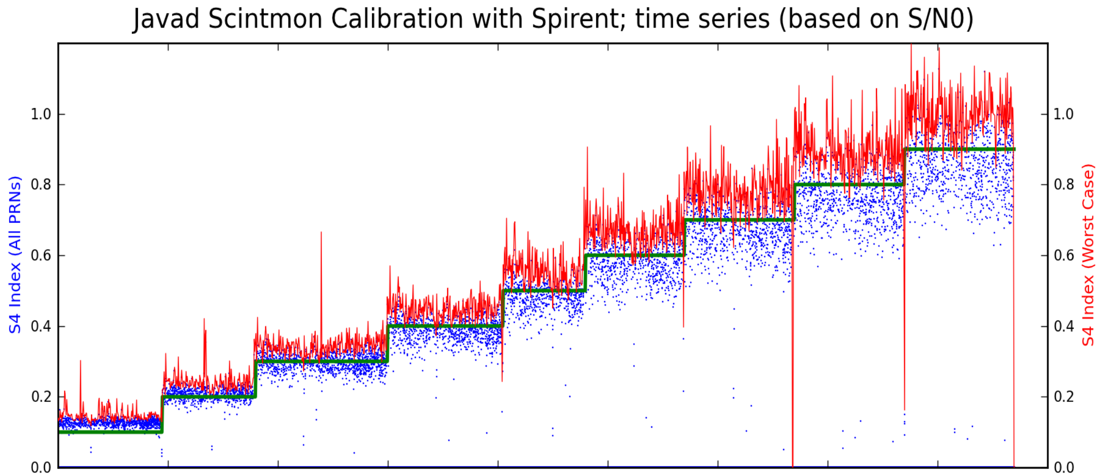
- Configured with same scintillation model
- All SVs configured with same S4 (same S4 from all points in the sky)
- Again receivers fed in conducted mode



Javad – C/N_0 Computation

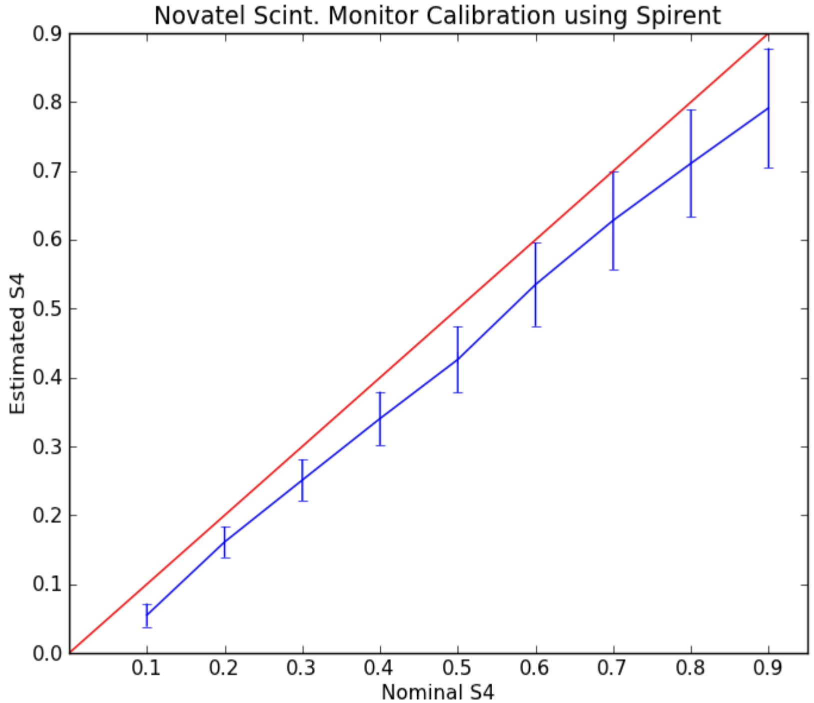


- Left:
  - Excellent agreement again
  - Surprisingly good in fact
  - C/N_0 estimator = black box
    - Model is good

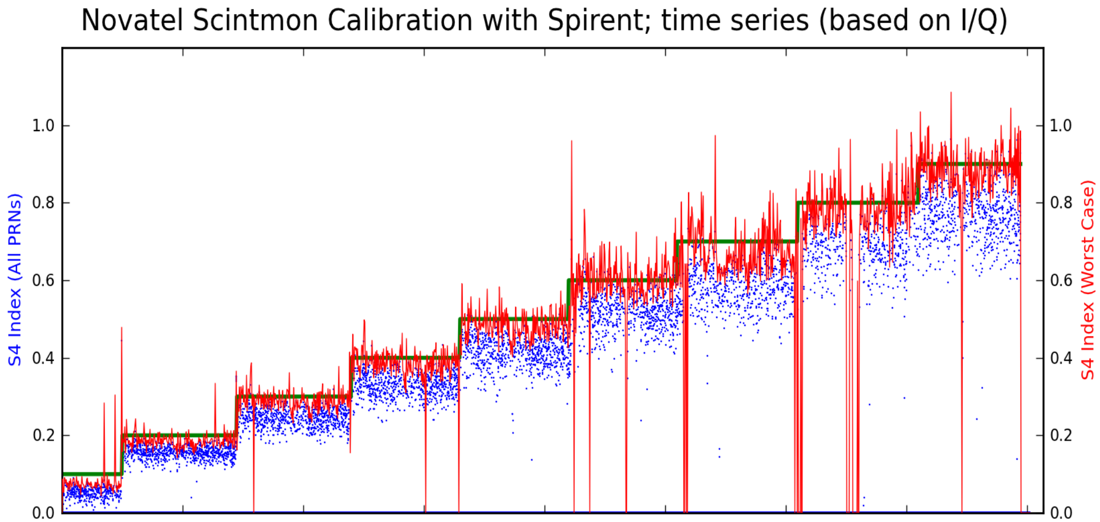


- Right:
  - “Spikes” in same places
  - Issue with detrending?

NovAtel – C/N_0 Computation

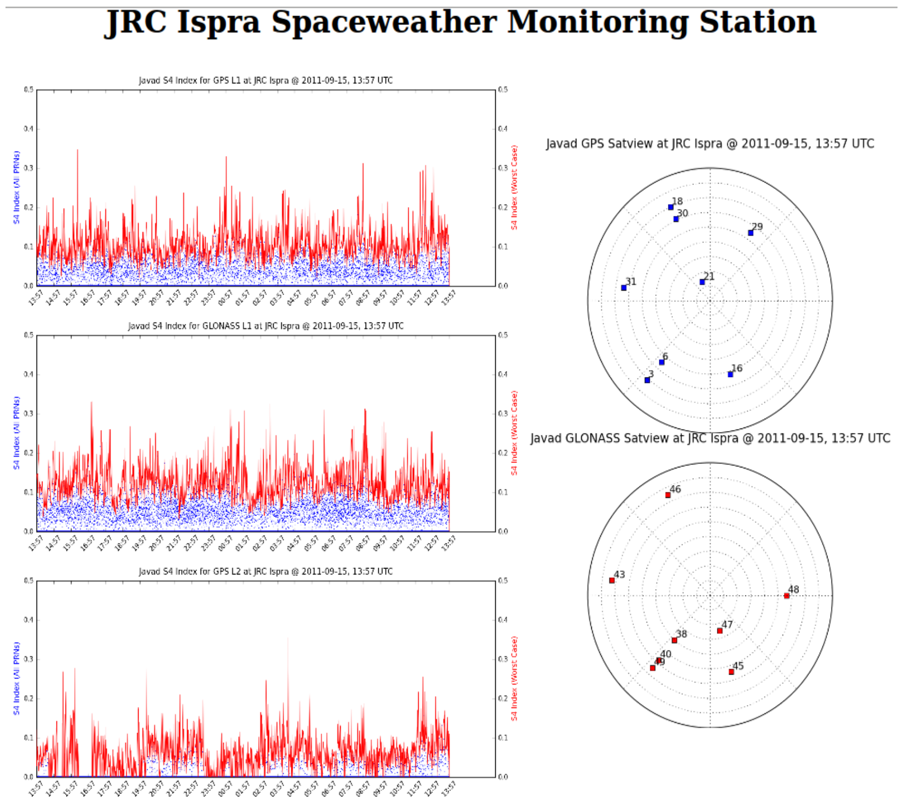


- Left:
  - Poorer agreement in this case
  - Impact of unknown C/N_0 computation algorithm
  - But, easily calibrated out

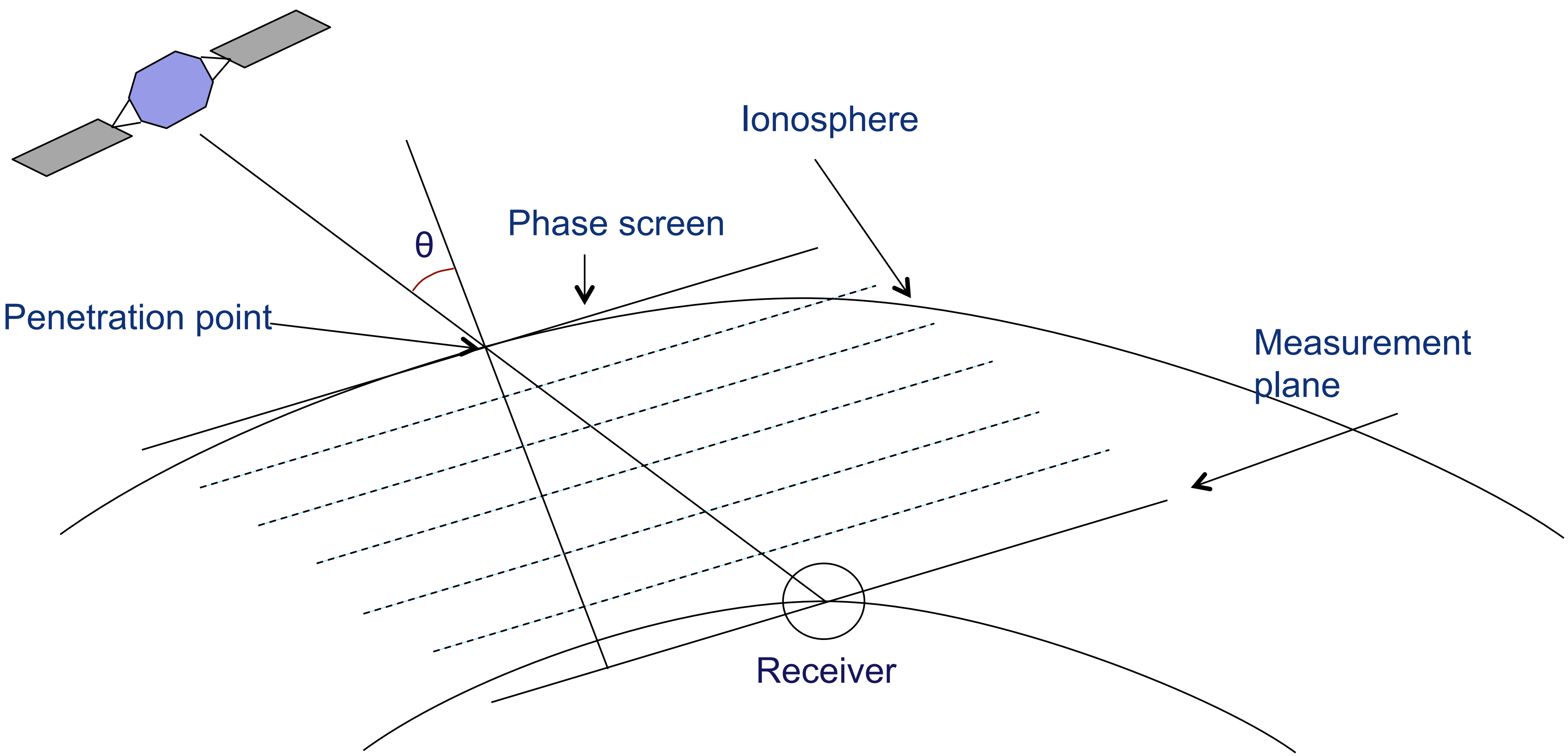


The JRC Scintillation Monitor

- Proposed algorithms implemented on a real-time, 24 hour scintillation monitor
- Installed at Ispra (~ 45 degrees North)



Phase Screen Model

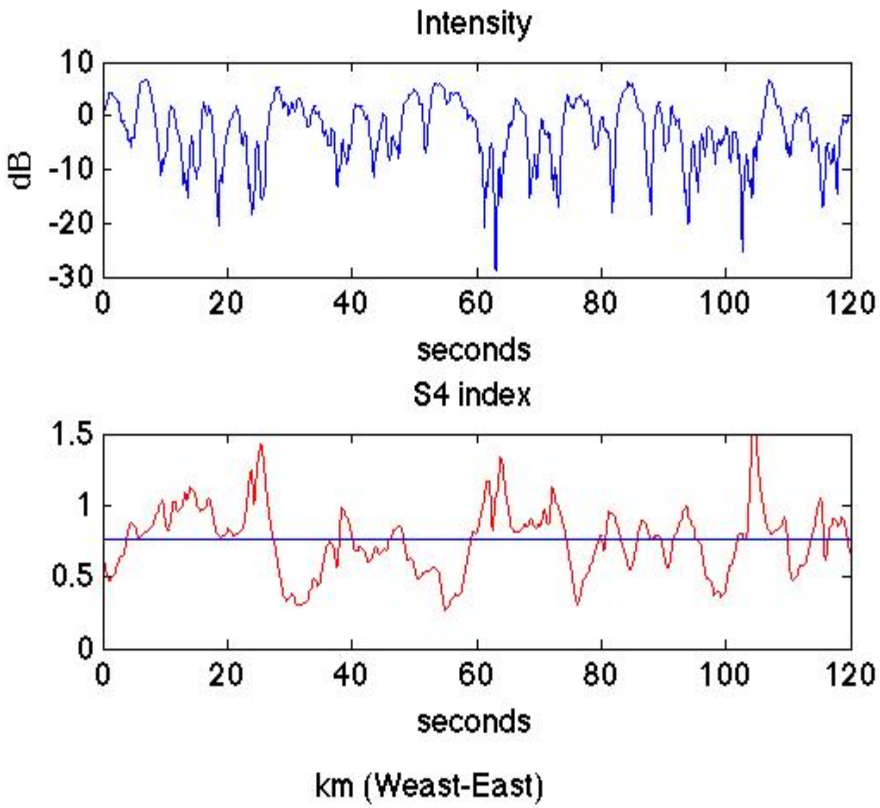


- Measurement plane moves due to satellite and ionosphere disturbances displacement
- Measurement plane results are converted into time series by means of its effective velocity

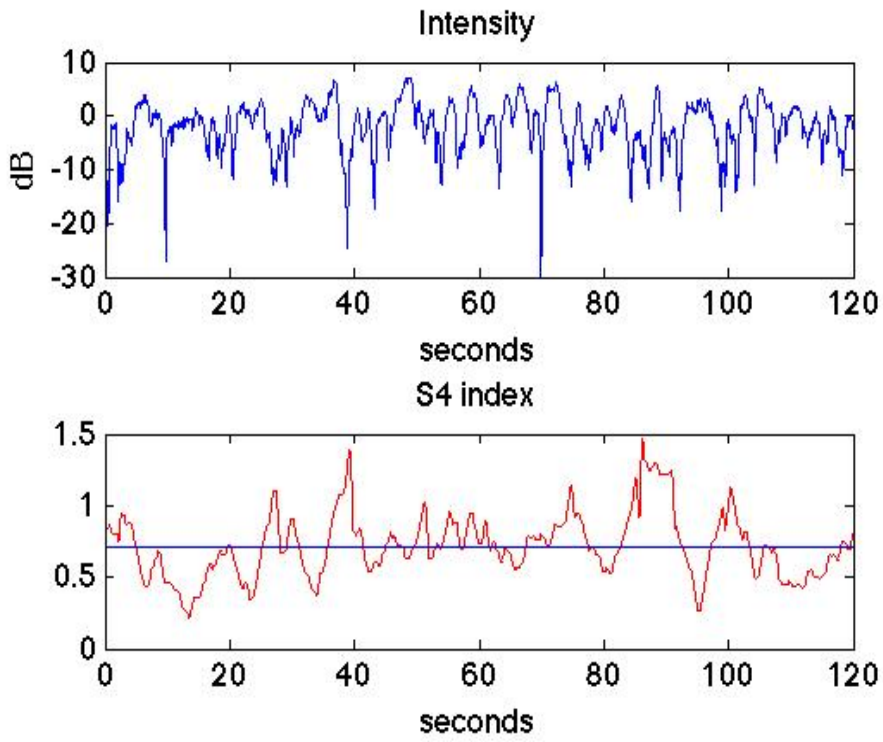
Example Scintillation Event

- **Results, oblique incidence and anisotropic structure**

PRN6



PRN9



Concluding Remarks

- The JRC has the capabilities to test GNSS receivers and GPS clocks under several scenarios such as a temporary outage or presence of RFI
- Focus of the activity is on the quantitative assessment of the impact of anthropogenic and natural interference sources
- Extensive tests conducted on 7 different GPS clocks/time servers used in the telecom sector
- The **quality of the local oscillator** determines the performance of a GPS clock in case of an temporary outage or in the presence of RFI
- Work is on-going to test receivers under amplitude scintillation, using signal generators and collecting raw IF datasets in the Equatorial region
- A phase screen model of the ionosphere will be used to create synthetic IF datasets with adjustable S4 and time decorrelation coefficients