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BarcelonaTECH, Spain

Key points for Precise Navigation under Scintillation Conditions

J.M. Juan, J. Sanz, G. González-Casado, A. Rovira-Garcia
Research Group of Astronomy and Geomatics (gAGE),
Universitat Politècnica de Catalunya (UPC), Barcelona, Spain

A. Aragon-Angel
European Commission Joint Research Centre,
Institute for the Protection and Security of the Citizen, Ispra, Italy

Contents

1.- Introduction

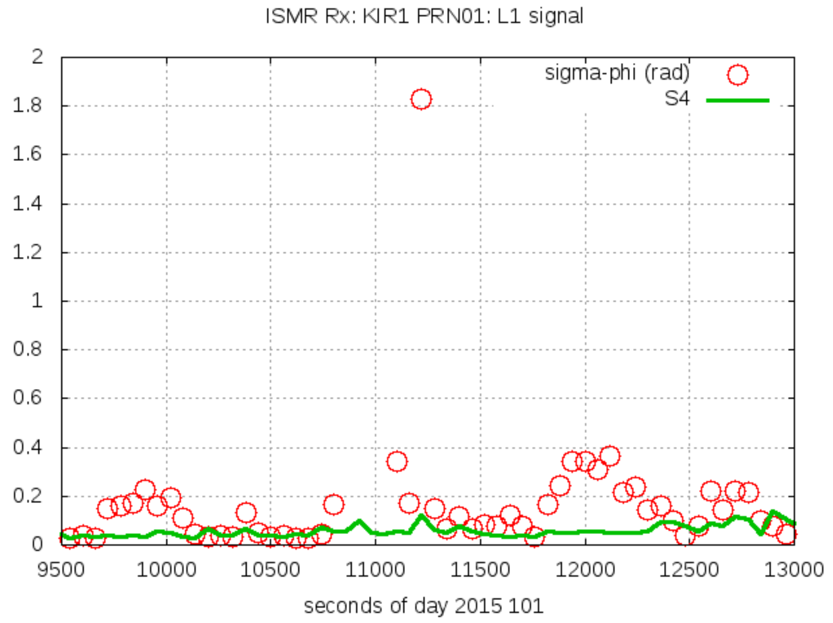
- Ionospheric scintillation is a challenging problem for GNSS users, degrading the navigation *of both, dual and single frequency solutions*
- It happens when the GNSS signals pass through ionospheric irregularities, producing rapid changes in the *refraction* index. When such ionospheric irregularities are at scale lengths below 400m, *diffractive effects* on the signal appear. All these effects can lead to cycle-slips, loss of GNSS signals and increased noise.
- Scintillation is experienced at *high latitudes* mostly associated to space weather or geomagnetic storms and at *low latitudes* after the sunset. *But both types of scintillation are quite different*.
- In this presentation we are going to characterize the scintillation phenomena, from the navigation point of view and to assess the feasibility of high accuracy positioning under scintillation conditions.

2.- High latitude scintillation

- It is produced by fast variations on the refractive index, associated to *fast moving* (up to several km/s) *large-scale irregularities*. As result, *fast variations of STEC, with time scales of few seconds are experienced*.

- It causes fast fluctuations on the carrier phase (large σ_ϕ), while the amplitude of the signal is not strongly affected (low S4 values).

- Although phase shifts rapid enough can challenge the receiver's tracking loops. *Usually they do not produce frequent carrier cycle-slips.*

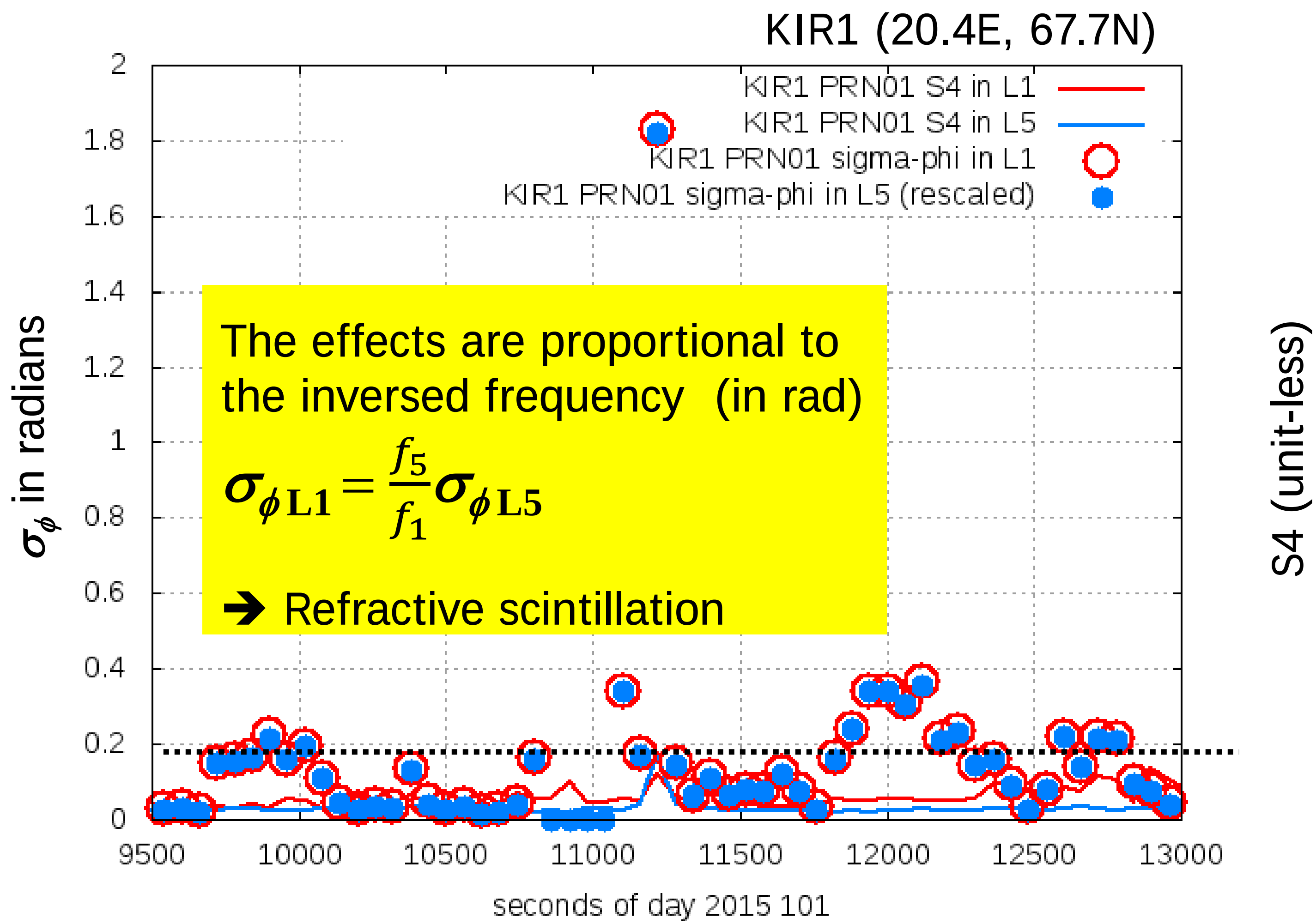


$\sigma_\phi > 1.8$ rad → Strong scintillation

S4 < 0.2 → Low

High latitude scintillation

Example with an ISMR Rx (KIR1)

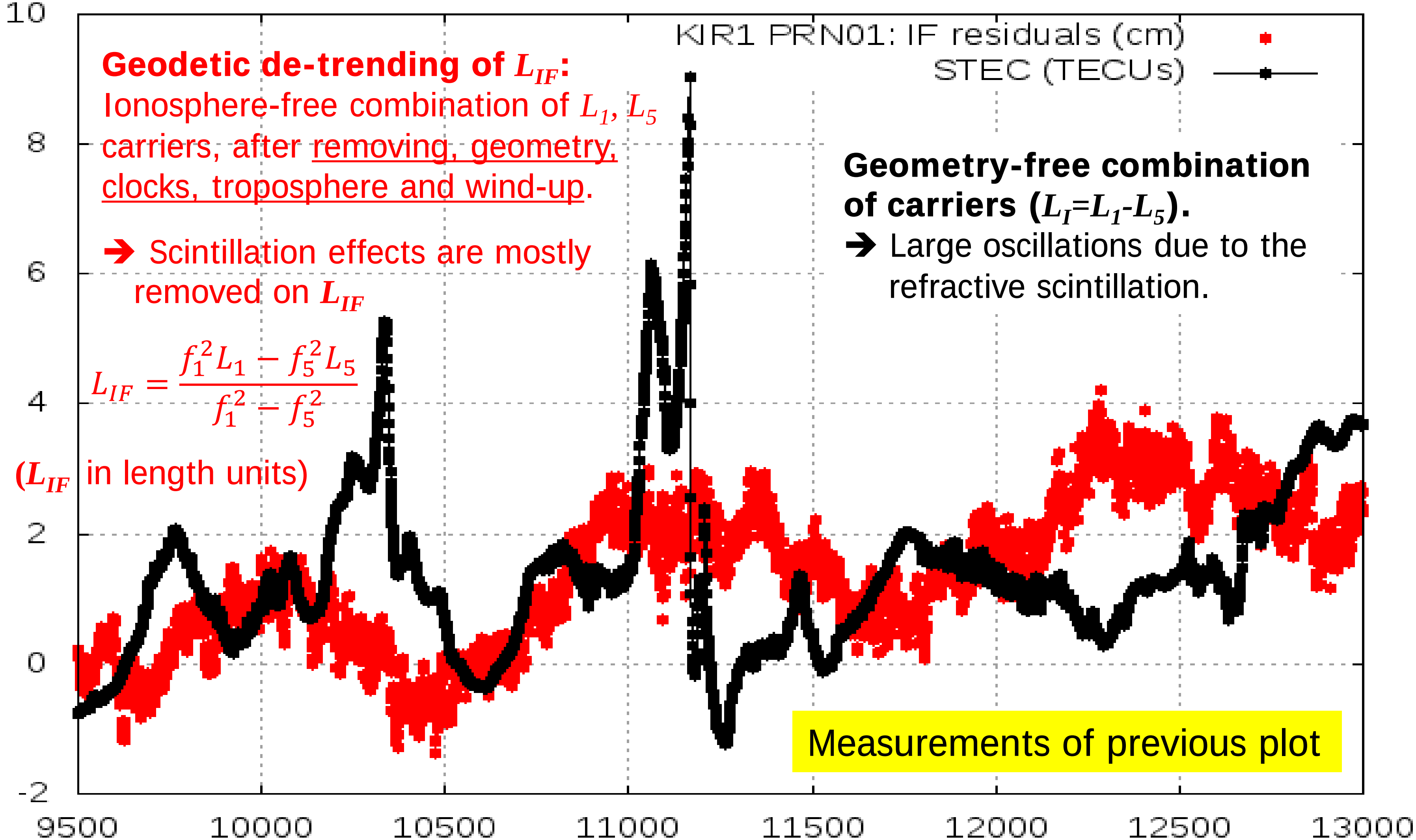


The effects are proportional to the inversed frequency (in rad)

$$\boldsymbol{\sigma}_{\phi \mathbf{L1}} = \frac{f_5}{f_1} \boldsymbol{\sigma}_{\phi \mathbf{L5}}$$

➔ Refractive scintillation

High latitude scintillation
Example with an ISMR Rx (KIR1)



Geodetic de-trending of L_{IF}: Ionosphere-free combination of L_1, L_5 carriers, after removing, geometry, clocks, troposphere and wind-up.

➔ Scintillation effects are mostly removed on L_{IF}

$$L_{IF} = \frac{f_1^2 L_1 - f_5^2 L_5}{f_1^2 - f_5^2}$$

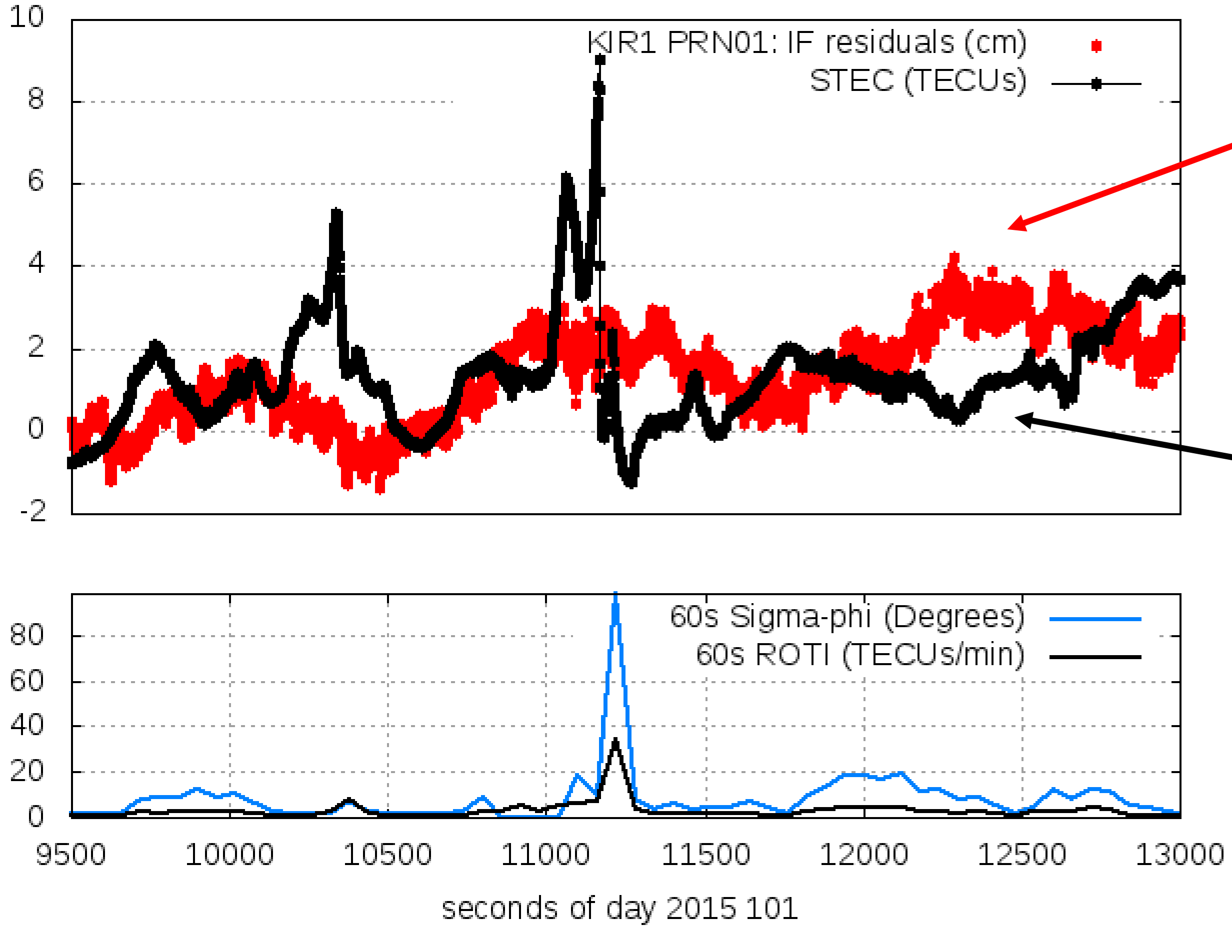
(L_{IF} in length units)

Geometry-free combination of carriers (L_I=L_1-L_5).

➔ Large oscillations due to the refractive scintillation.

Measurements of previous plot

High latitude scintillation
Example with an ISMR Rx (KIR1)

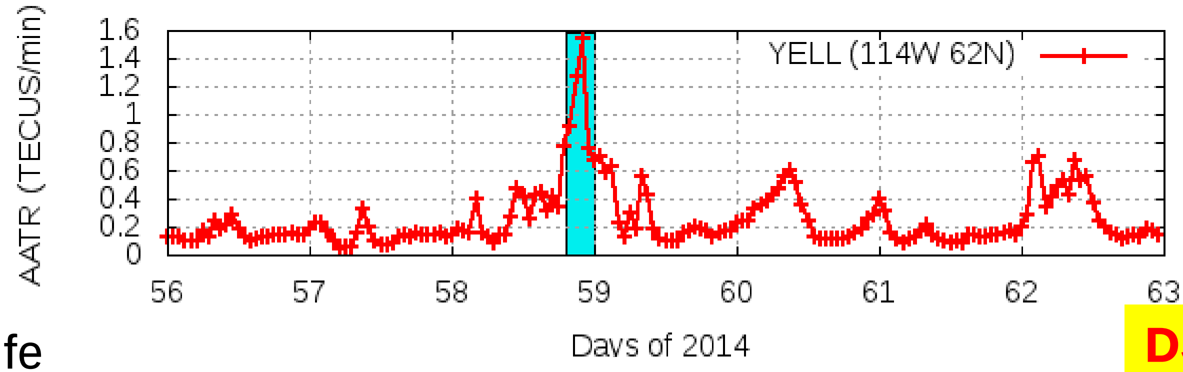


Iono-Free
- No cycle-slips
- 2-freq users can navigate with the Iono-Free comb.

STEC
- Large temporal and spatial gradients make difficult to compute ionospheric corrections for 1-freq. users

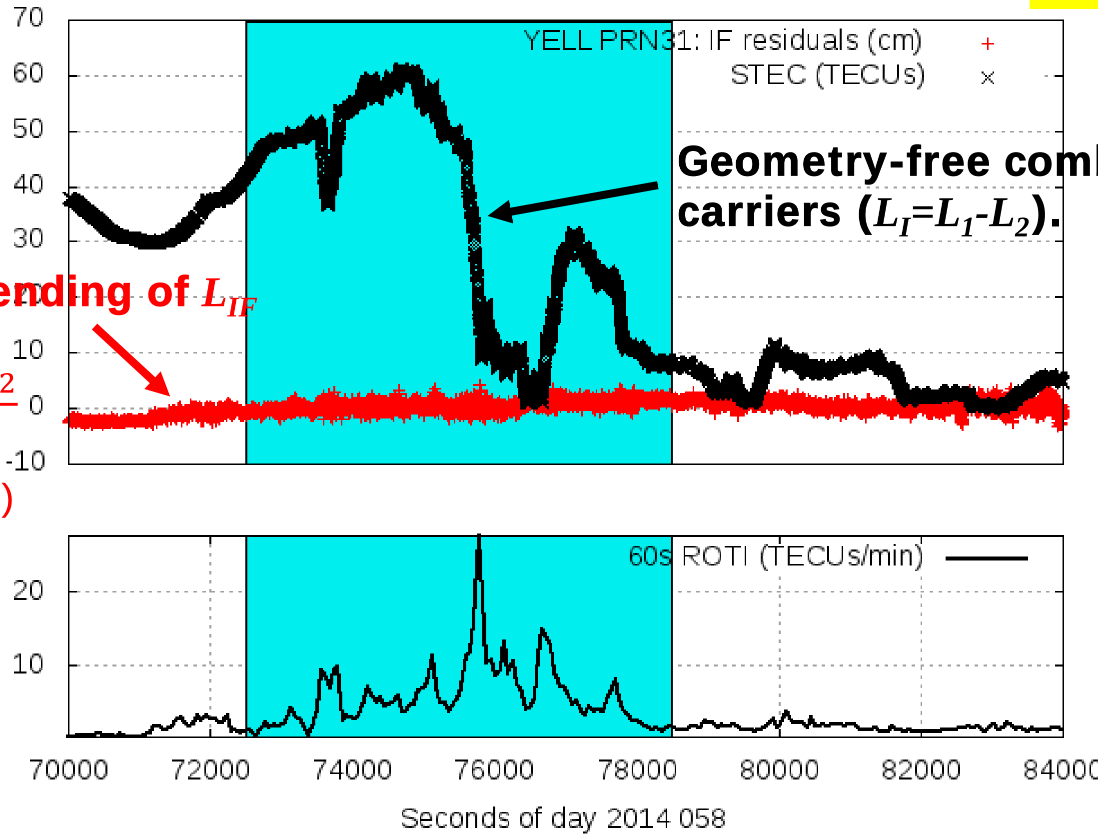
High latitude scintillation

Navigation under strong scintillation



Yellowknife

DST= -100nT



Geometry-free combination of carriers (L_I=L_1-L_2).

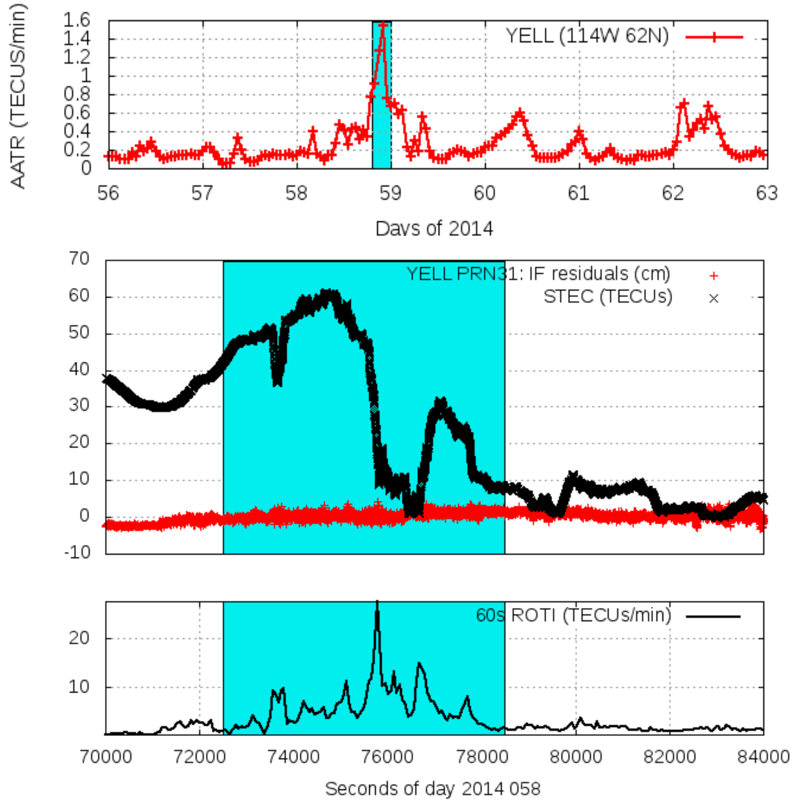
Geodetic de-trending of L_{IF}

$$L_{IF} = \frac{f_1^2 L_1 - f_2^2 L_2}{f_1^2 - f_2^2}$$

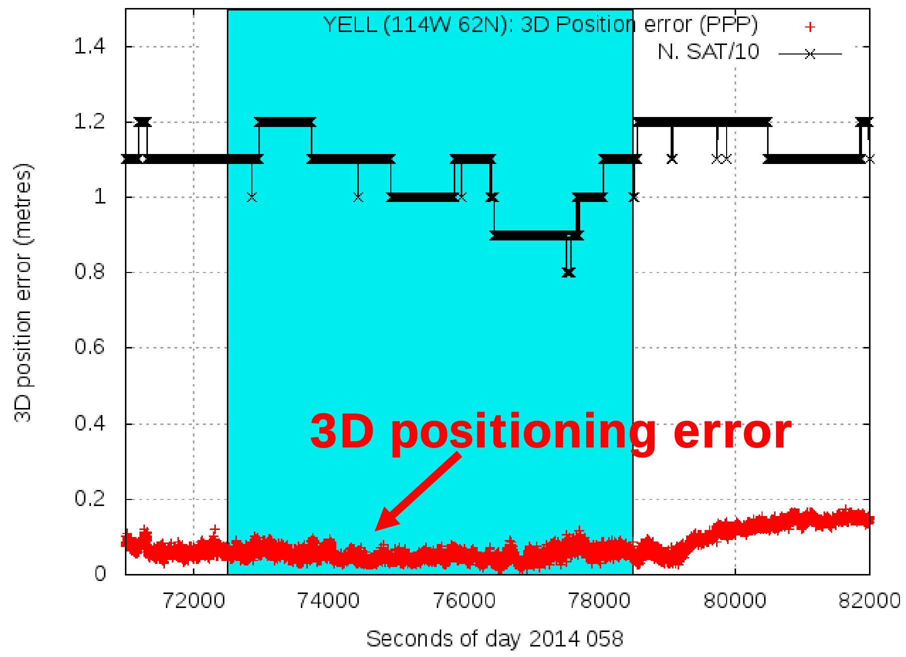
(L_{IF} in length units)

High latitude scintillation

Navigation under strong scintillation



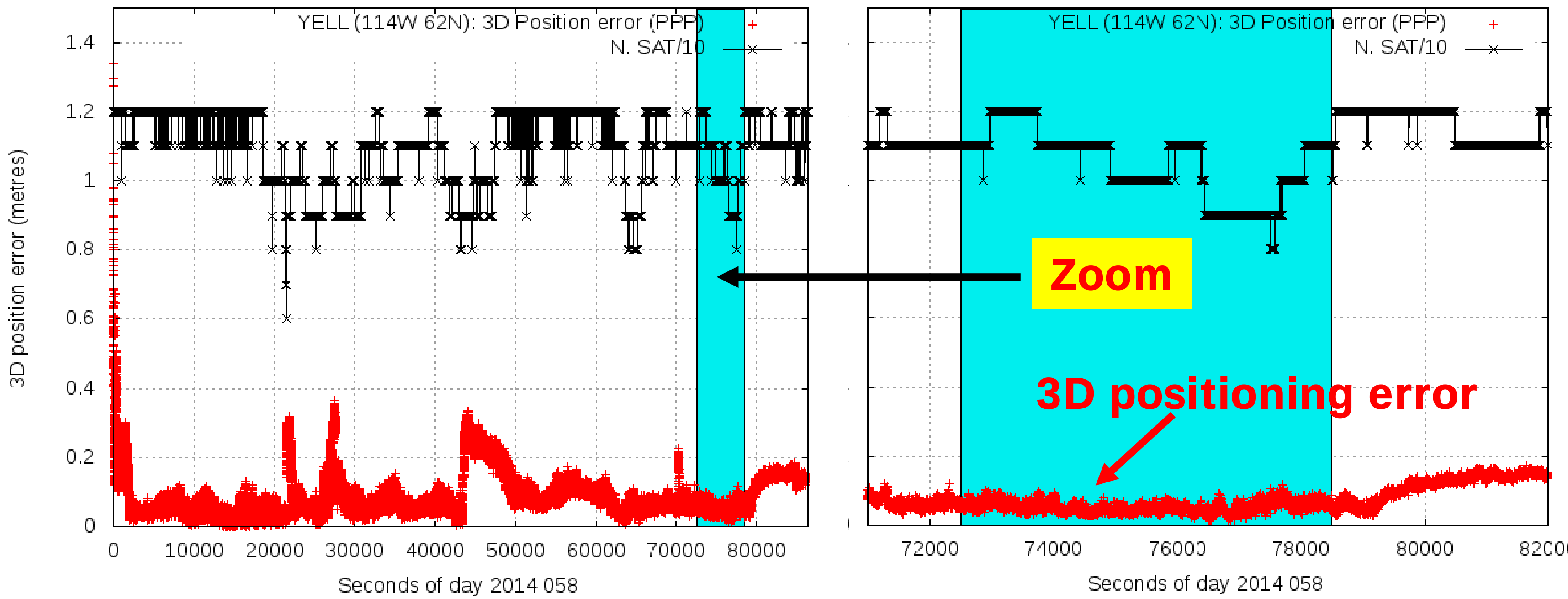
Navigation performance with L_{IF}



Being mostly refractive scintillation and not producing large number of cycle-slips, dual frequency users can navigate also during high ionospheric activity. But, due to the large space-temporal gradients it is challenging for single frequency users.

High latitude scintillation
Navigation under strong scintillation

Navigation performance with L_{IF}



Being mostly refractive scintillation and not producing large number of cycle-slips, dual frequency users can navigate also during high ionospheric activity. But, due to the large space-temporal gradients it is challenging for single frequency users.

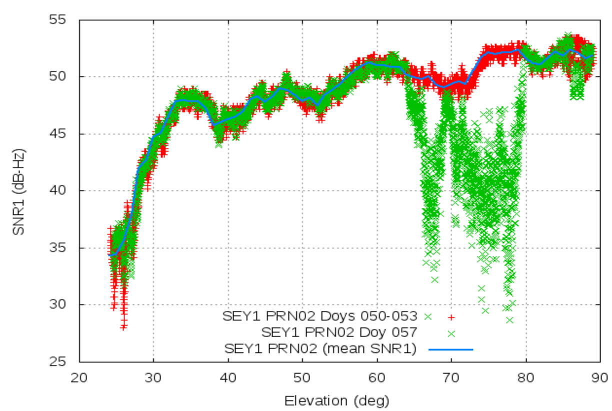
3.- Low latitude scintillation

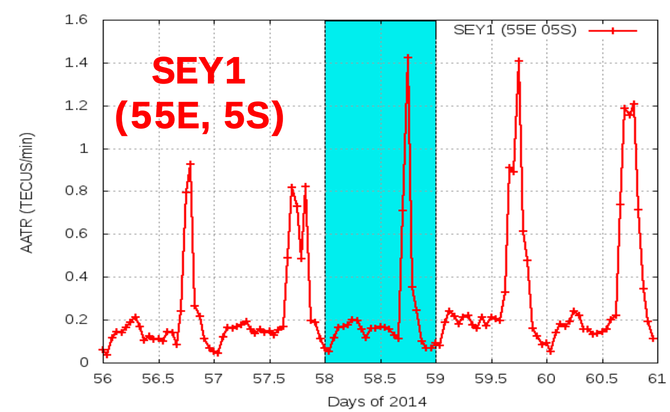
- Among the previous effects, in low latitude, ionospheric irregularities at scale lengths of below 400 m are experienced (Fresnel length for GNSS signals). Then, the signals are scattered (*diffracted*) reaching the receiver through multiple paths.

- This diffractive effect can seriously challenge the GNSS receivers, causing signal power fades, which results in large variations of signal amplitude (and then high S4 values), and experiencing fast phase fluctuations. They can cause signal loss and frequent *cycle slips*.

- It appears after sunset and last for several hours. It has a seasonal component, being most intense at the equinoxes.

Large SNR fading due to the diffractive scintillation on DoY 057, 2014





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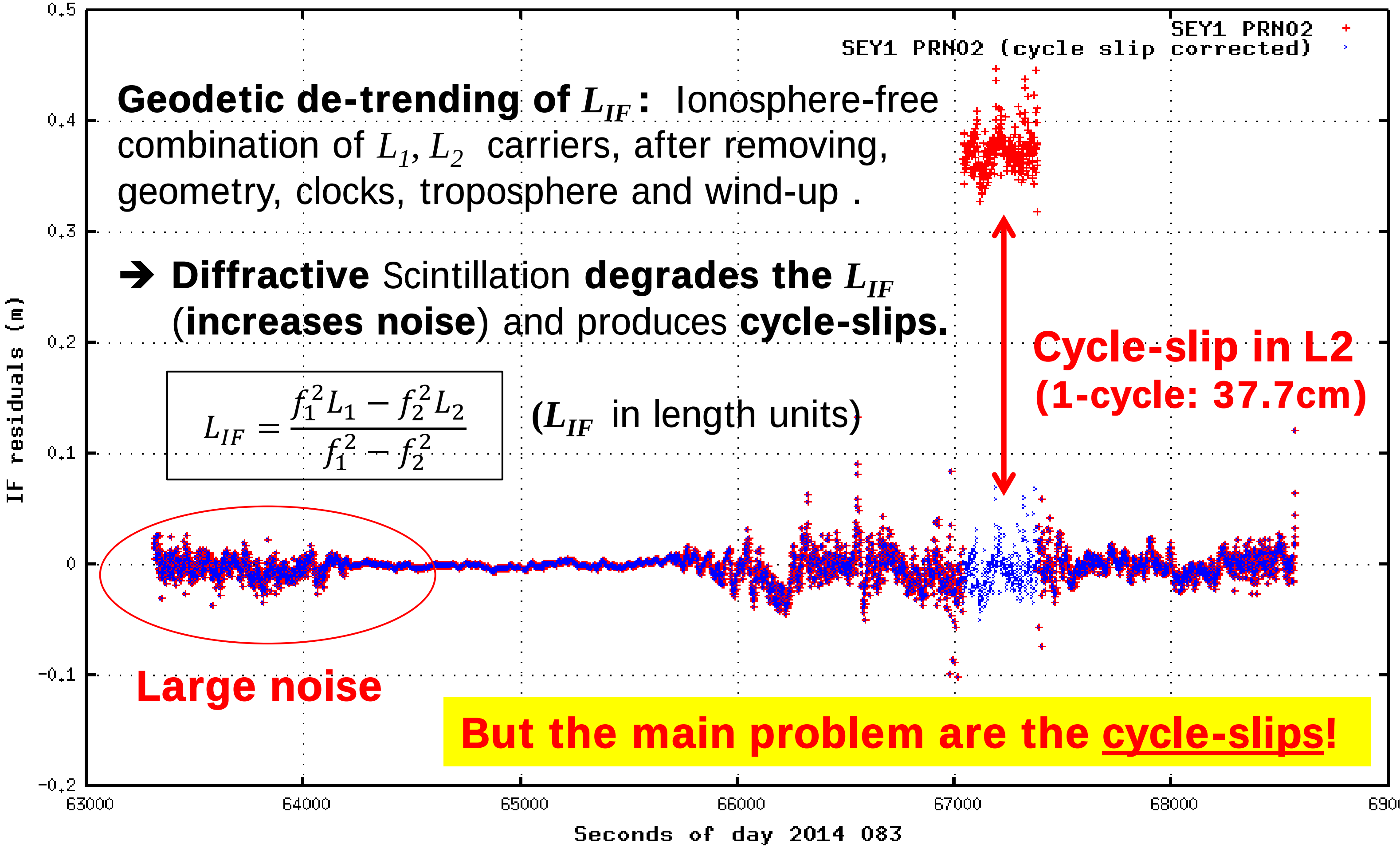
Low latitude scintillation

Effect on the L_{IF} combination



Geodetic de-trending of L_{IF}: Ionosphere-free combination of L_1, L_2 carriers, after removing, geometry, clocks, troposphere and wind-up .

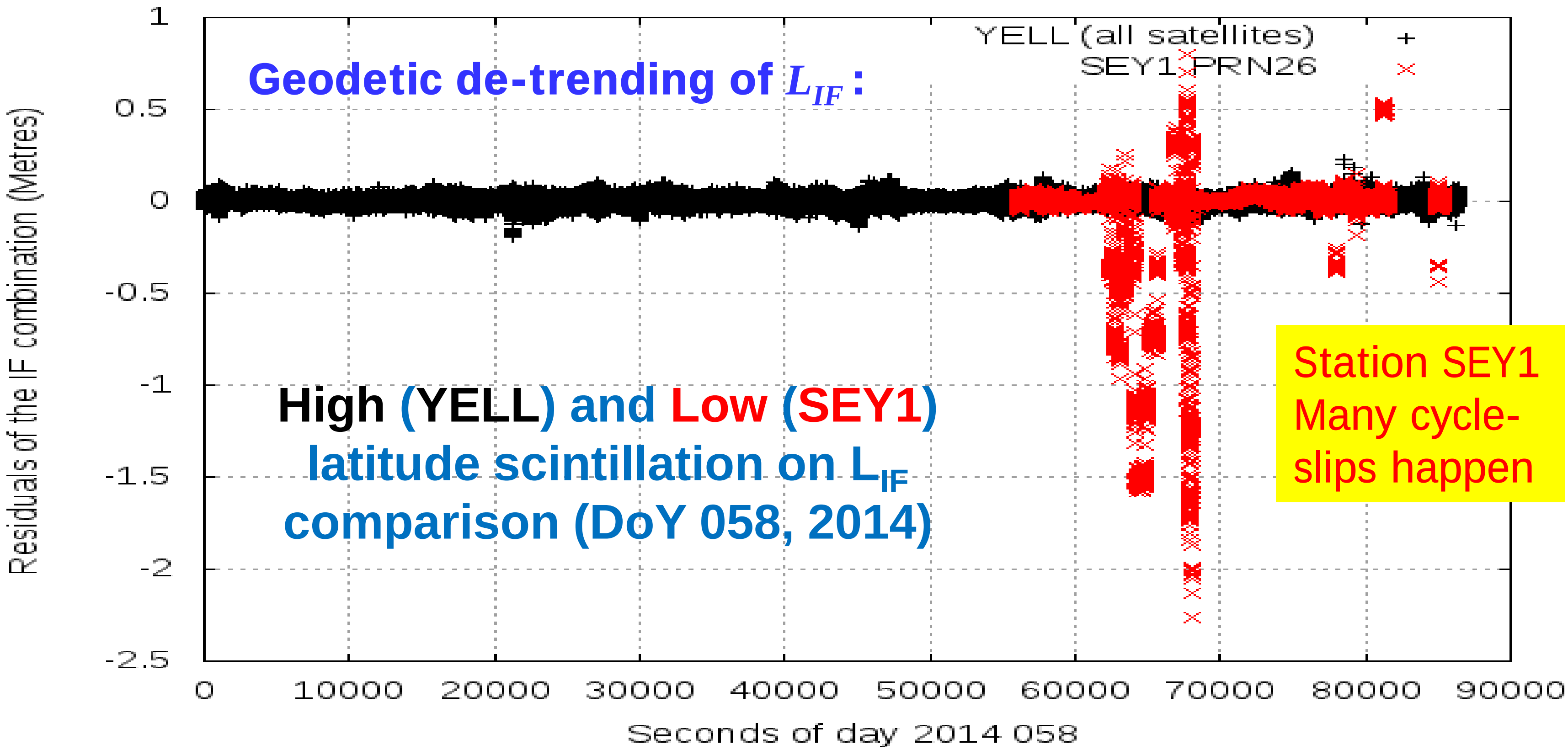
➔ **Diffractive** Scintillation **degrades the L_{IF}** (**increases noise**) and produces **cycle-slips.**

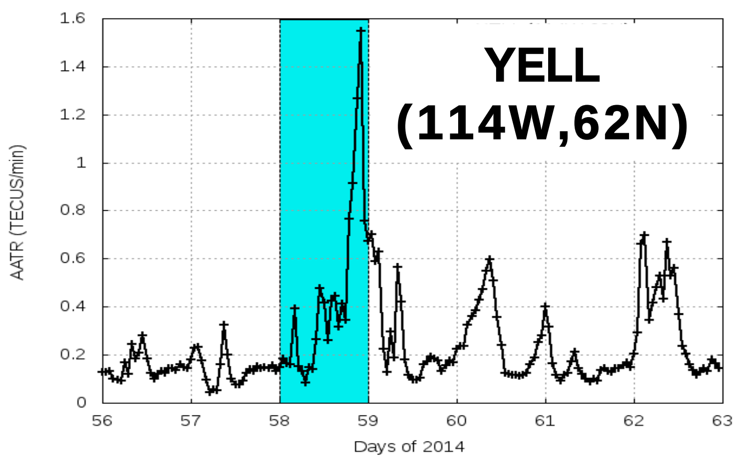
$$L_{IF} = \frac{f_1^2 L_1 - f_2^2 L_2}{f_1^2 - f_2^2}$$

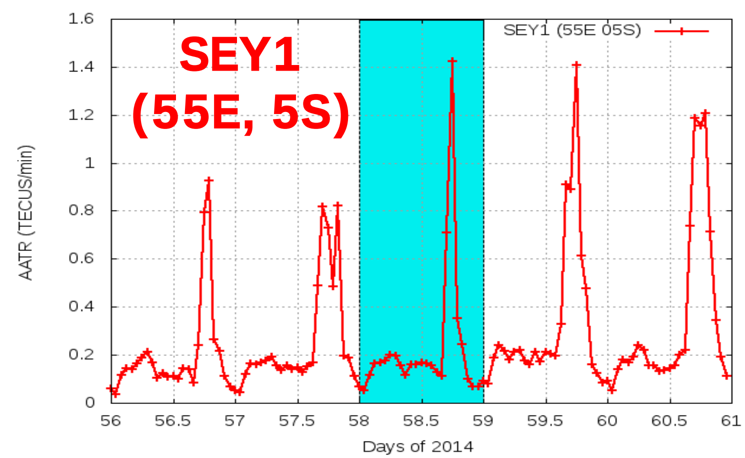
(**L_{IF}** in length units)

But the main problem are the <u>cycle-slips</u>!

The geodetic de-trending of L_{IF} allows to depict the increased noise and the 1-cycle jump.







They are small cycle-slips (involving just 1 cycle in L1 or L2), being difficult to detect!

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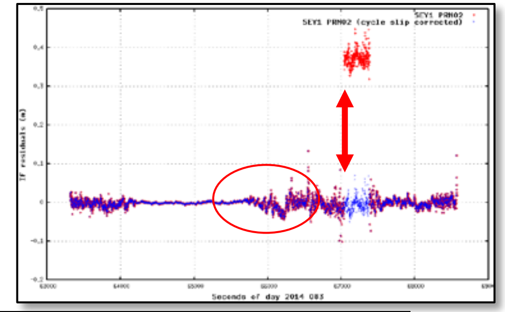
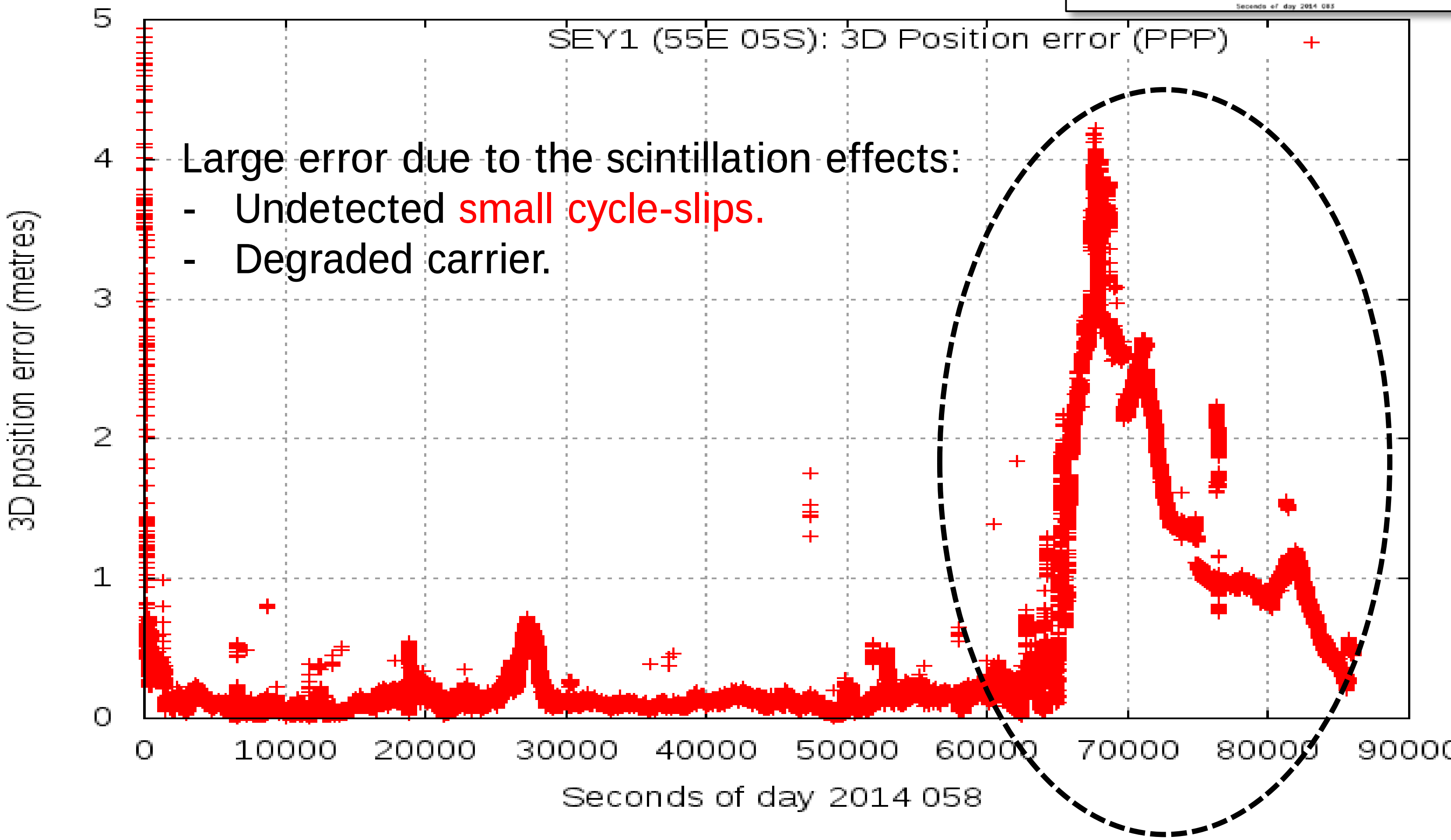
Low latitude scintillation

Navigation example





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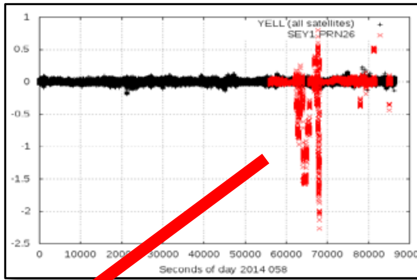
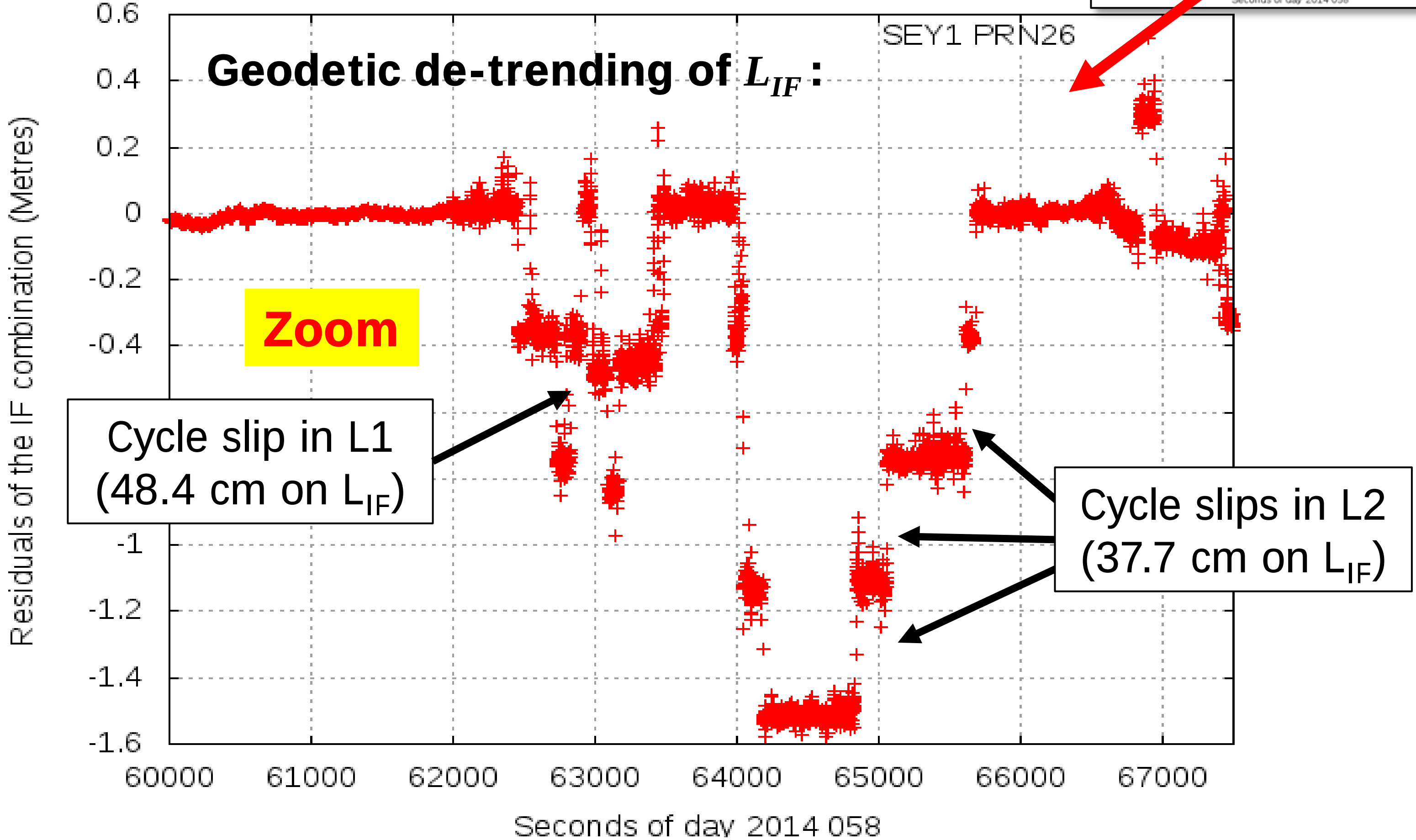
Low latitude scintillation
Navigation example

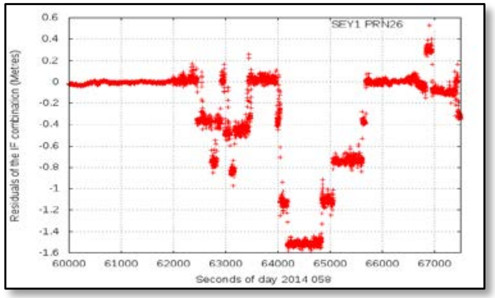


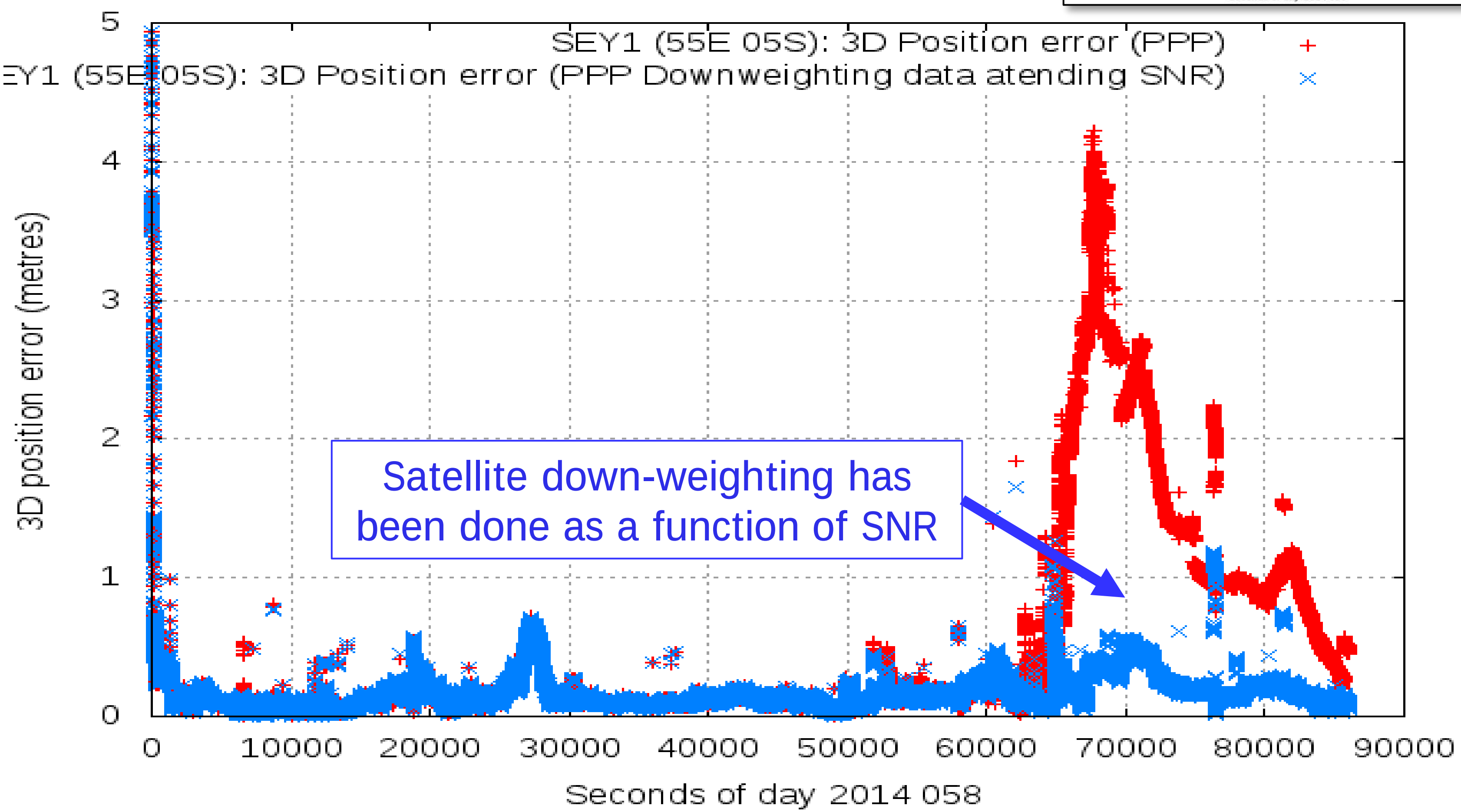


With a geodetic de-trending of L_{IF}, it is possible to distinguish between these 1-cycle jumps occurring in L1 (0.484 m) and L2 (0.377 m)

Low latitude scintillation

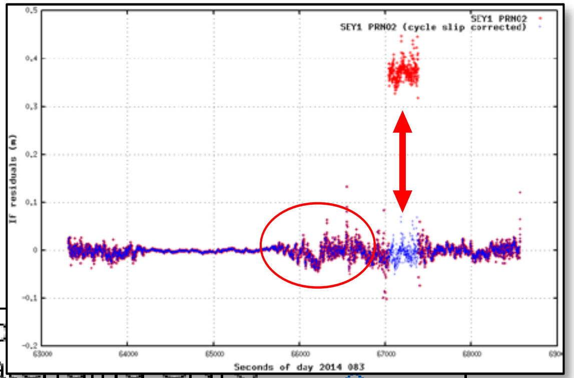
Navigation example

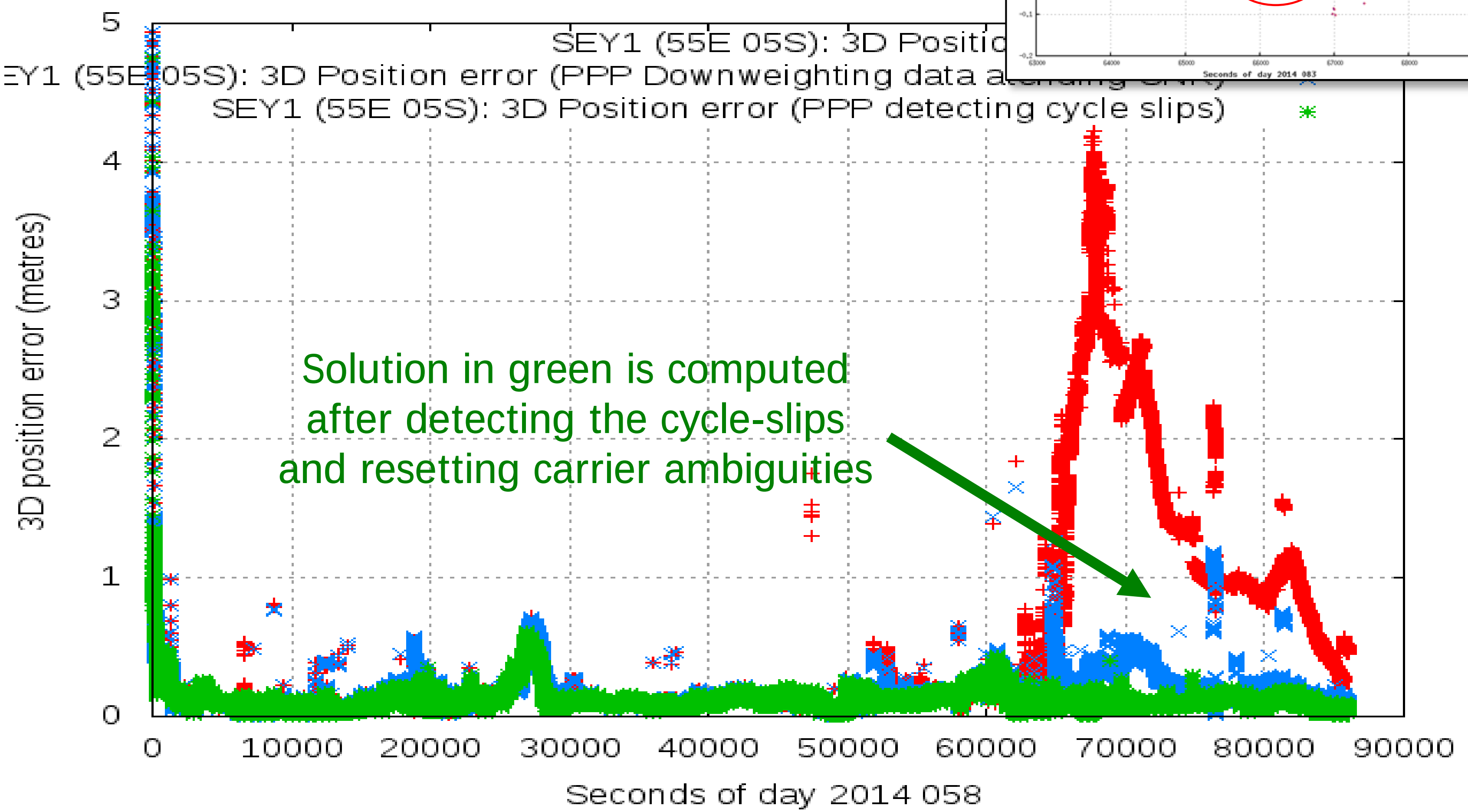




Low latitude scintillation

Navigation example

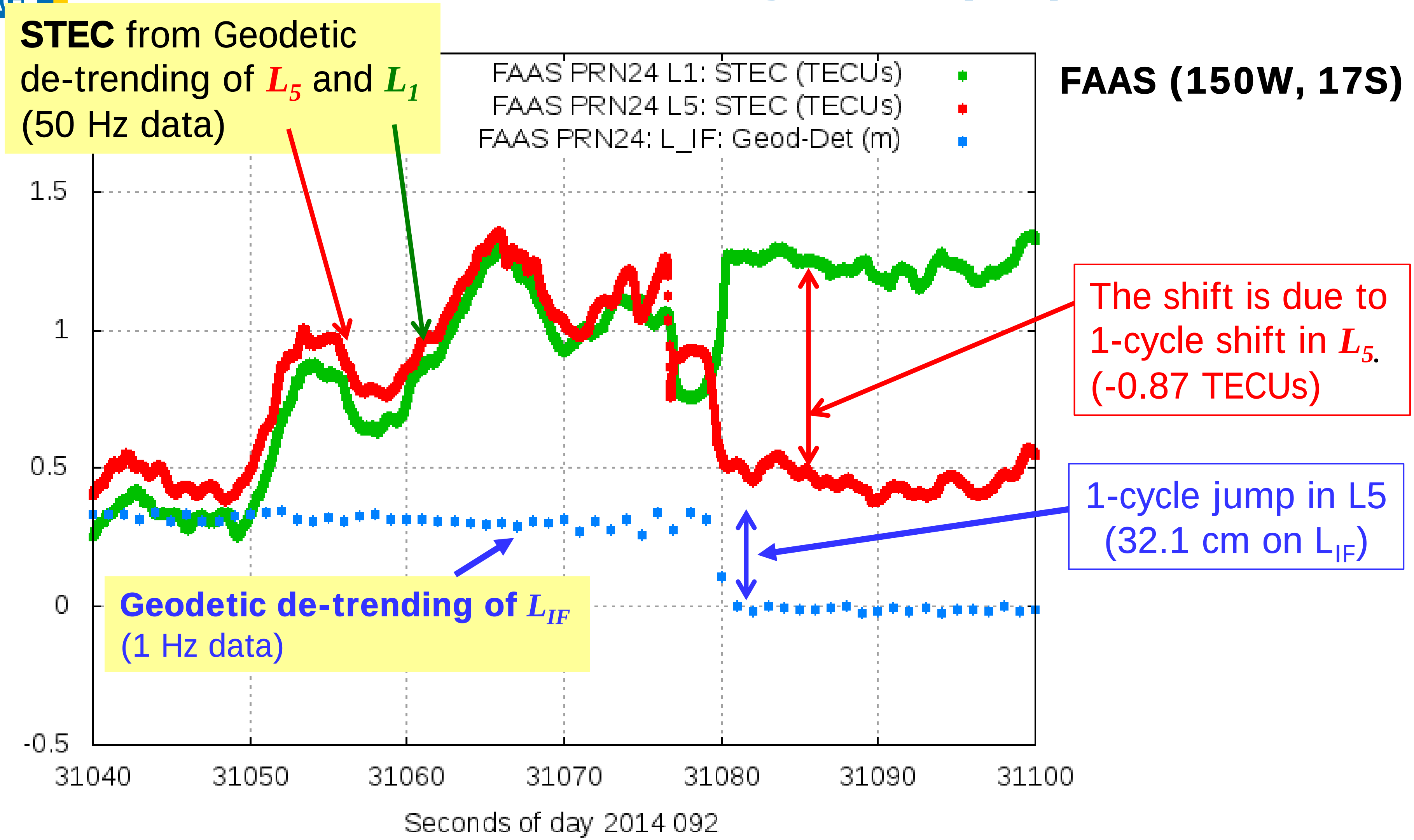




The challenge is to detect 1-cycle jumps “in real-time”.

Although the equatorial scintillation increase the carrier noise, high accuracy navigation with dual-frequency signals is possible, if the cycle-slips are detected

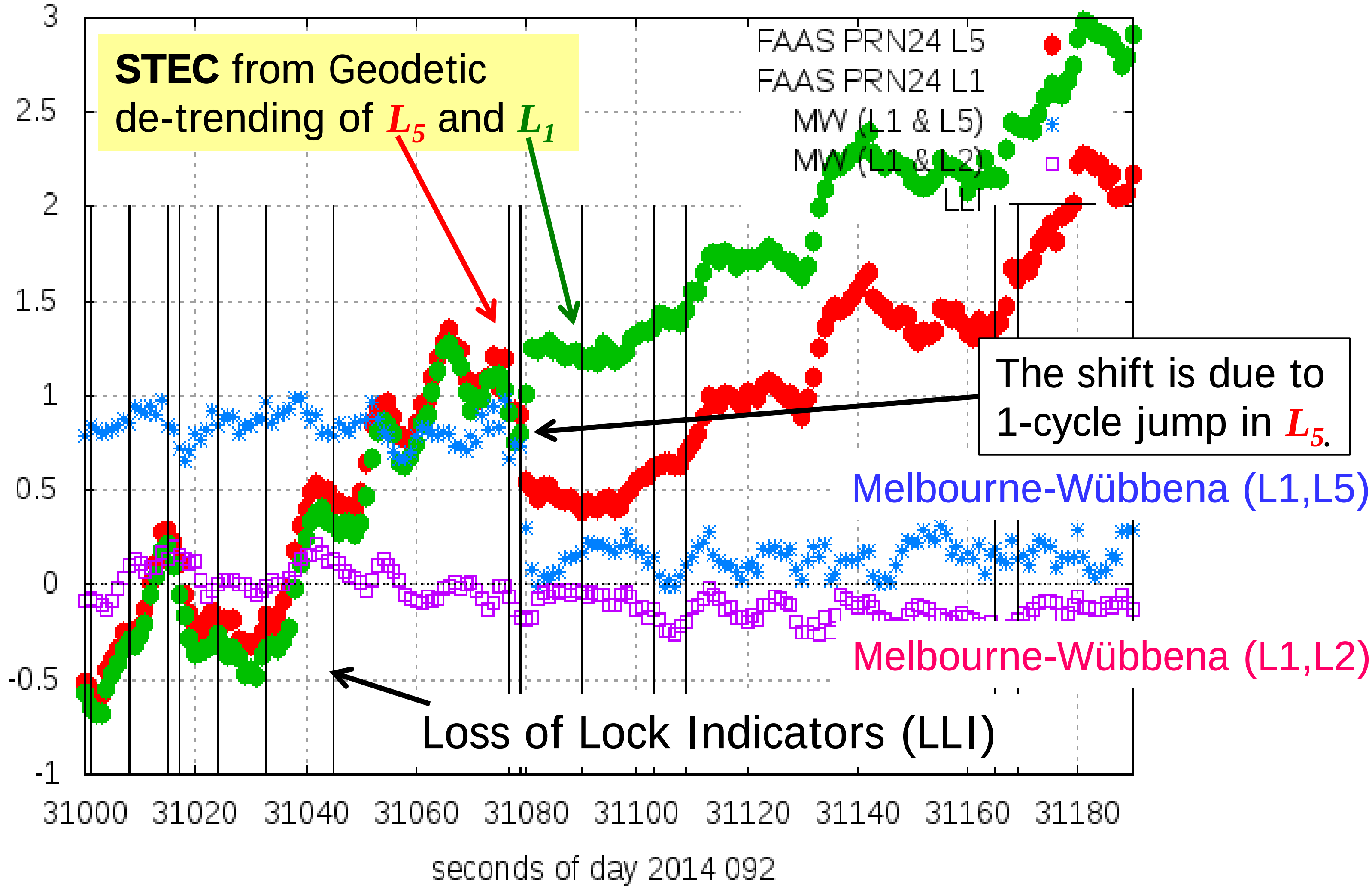
How these cycle-slips perform?



With 50Hz measurements, the geodetic de-trending of L1 and L5 carriers allows to depict the trend producing the 1-cycle shift. It last for several tens of milliseconds.

Low latitude scintillation

How 1-cycle jumps can be detected at 1Hz?



Some internal information for receiver can be used, but is it reliable?

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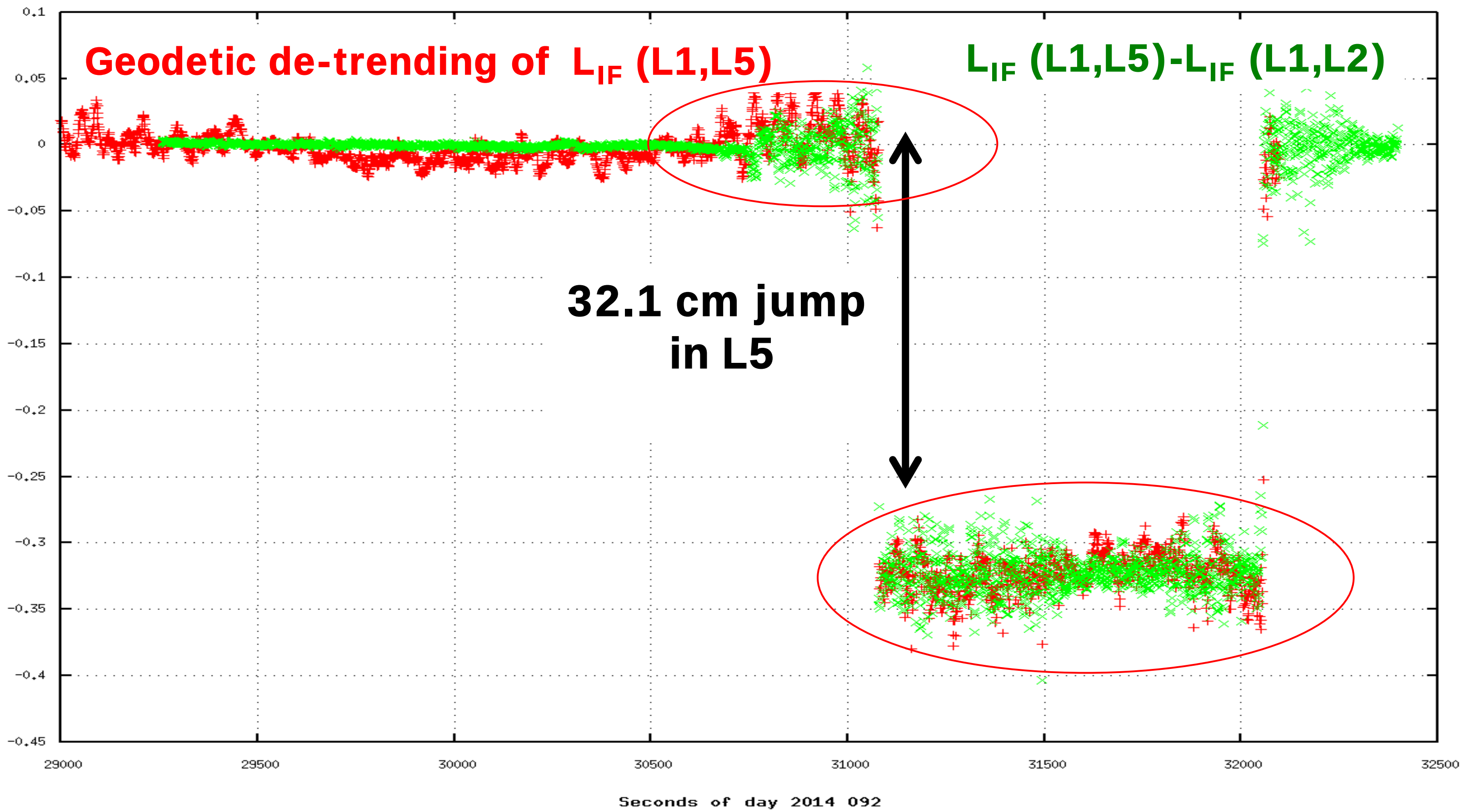
FAAS (149.6W, 17.4S) ISMR receiver: PRN24



With three frequency systems, the combination geometry-free and Ionosphere-Free can be explored as **a real-time** reliable detector of 1-cycle jumps.

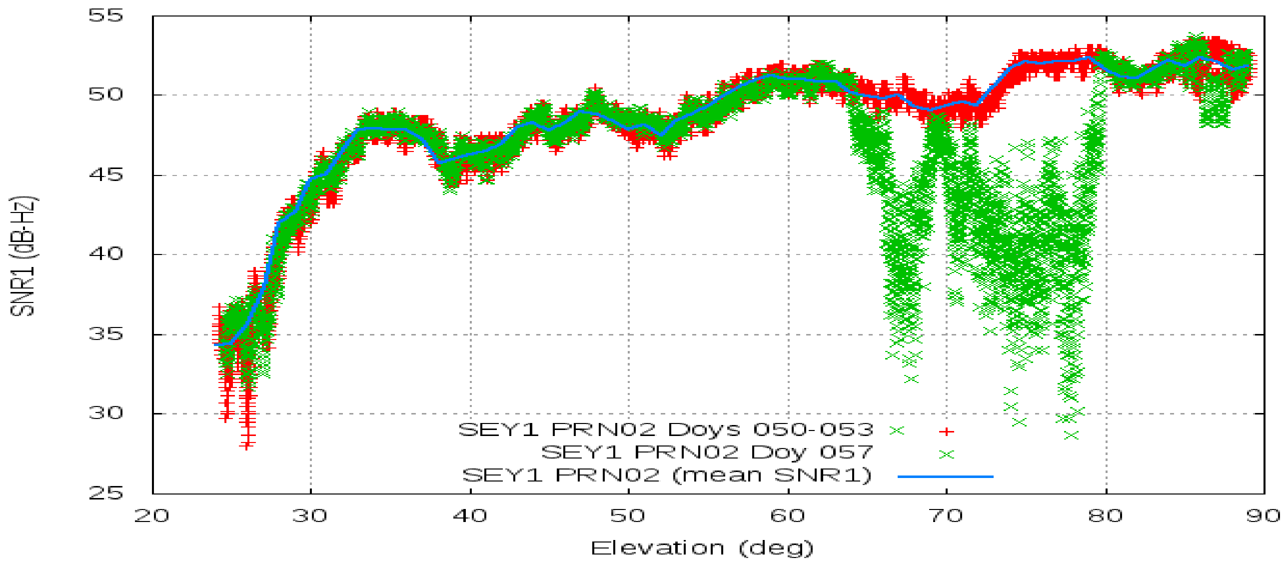
This picture illustrates the accuracy of the **geodetic de-trending over L_{IF}**

4.- Conclusions

- The Geodetic de-trending of L_{IF} has been proven to be a powerful tool to analyze scintillation effects.
- High latitude, scintillation is less likely to cause signal loss and usually does not produces large number of cycle-slips.
  - It is mostly refractive, and then, dual frequency users can navigate also during high ionospheric activity.
  - But, due to the large space-temporal gradients it is challenging for single frequency users.
- Low latitude is a more difficult scenario were scintillation can lead frequent cycle-slips and loss of GNSS signals.
  - Multi-constellation helps under GNSS signals loss.
  - It is challenging to detect 1-cycle jumps in real-time.
  - The carrier noise is increased, but high accuracy navigation with dual-frequency signals is still possible, provided that the cycle-slips are detected in a reliable way.

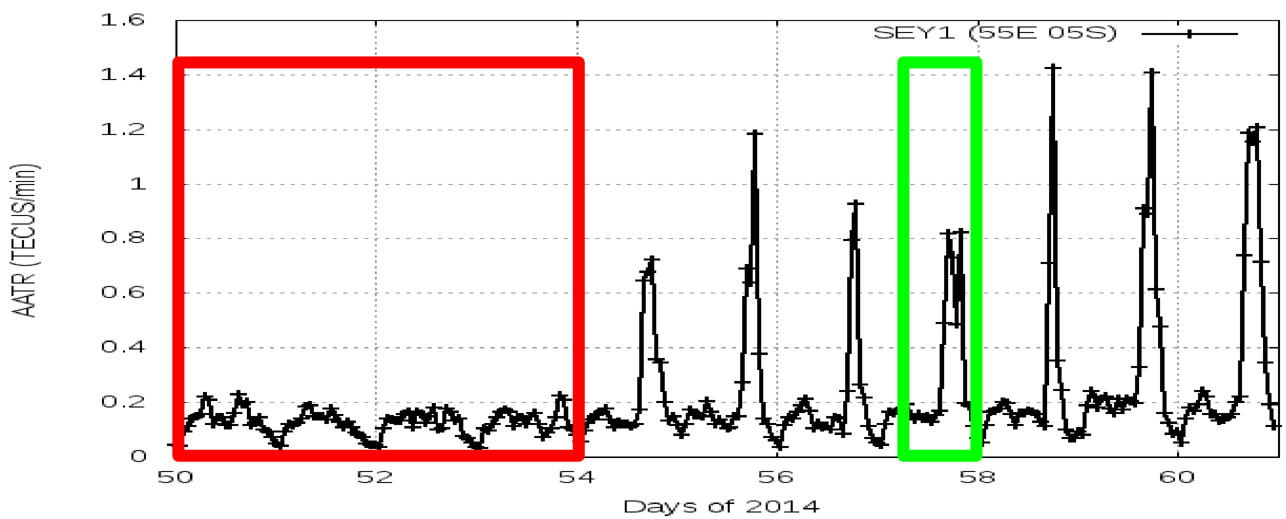
Thank you

Low latitude scintillation
Amplitude fading



In red the values over the days 050-053, with lower solar activity

Large SNR fading due to the diffractive scintillation on DoY 057



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Low latitude scintillation
How small cycle slips can be detected?