SPACE WEATHER IMPACTS on GNSS

SWIC

Collaboration of

Solar-Terrestrial Centre of Excellence

UNIVERSITY OF TWENTE. | RADIO SYSTEMS

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

SPACE WEATHER DISTURBANCES

GNNS, SATcom & Earth Observation Space Systems

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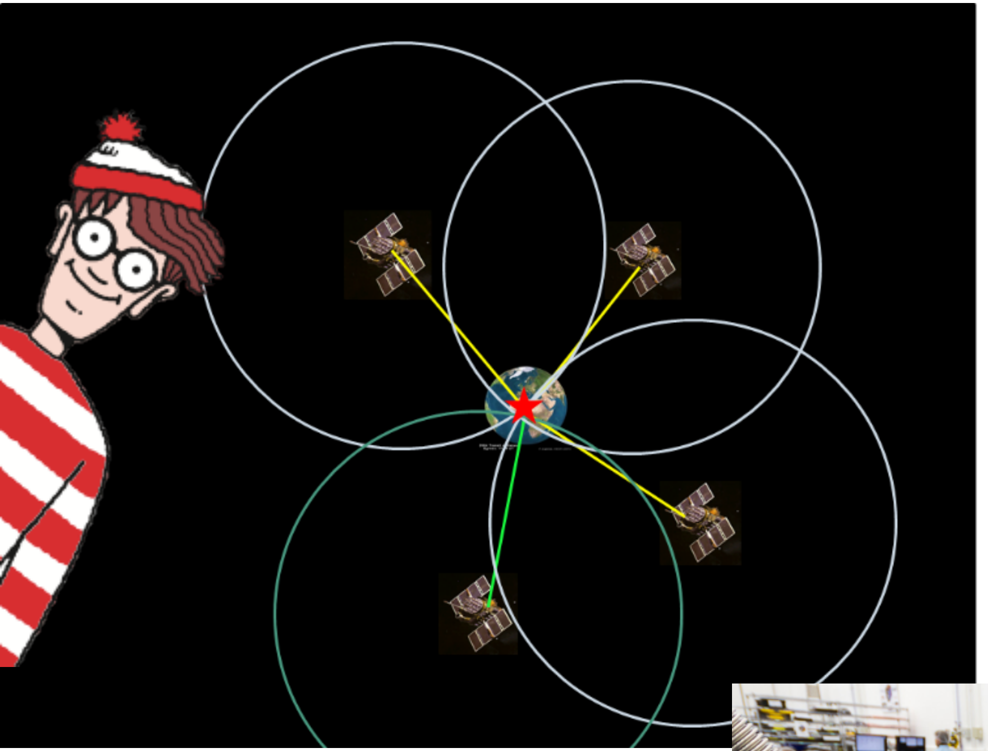
Solar-Terrestrial Centre of Excellence (STCE)

Few GNSS basics : To find your position, you first need the right Time



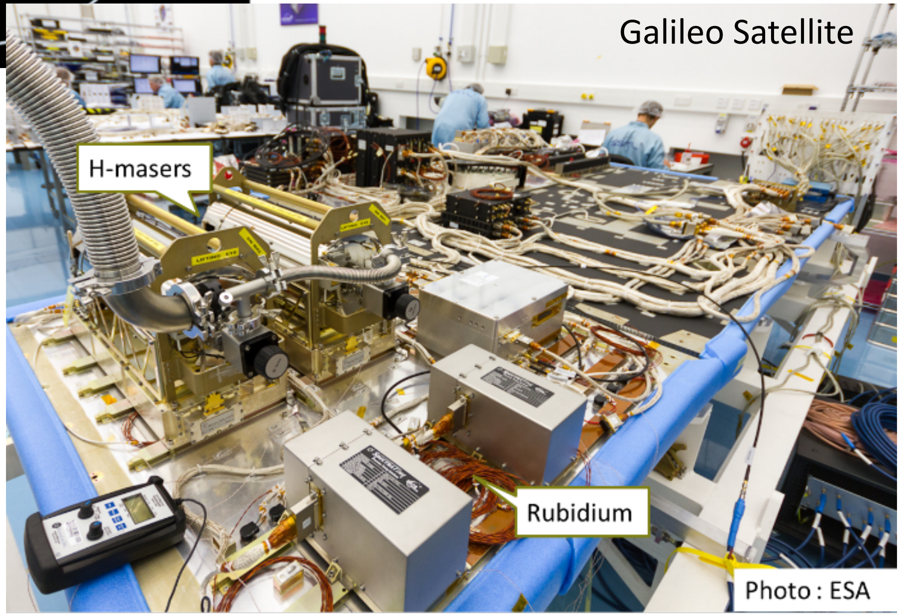
4 unknows :
- position (x, y, z)
- time synchronization (t)

→ ≥4 satellites needed
Sat. positions transmitted in nav. message

Measure of propagation time satellite-receiver for estimating the pseudo-distance satellite-receiver.

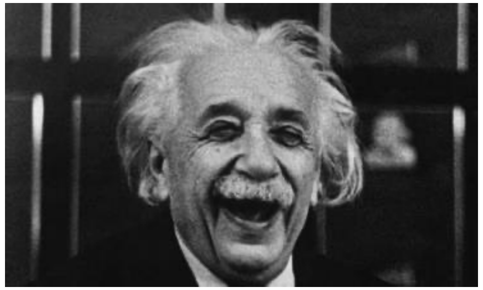
$$D = c\,(t_{rec} - t_{sat})$$

A delay of 1 ns (10^{-9} second) → 30 cm error in the pseudo-distance

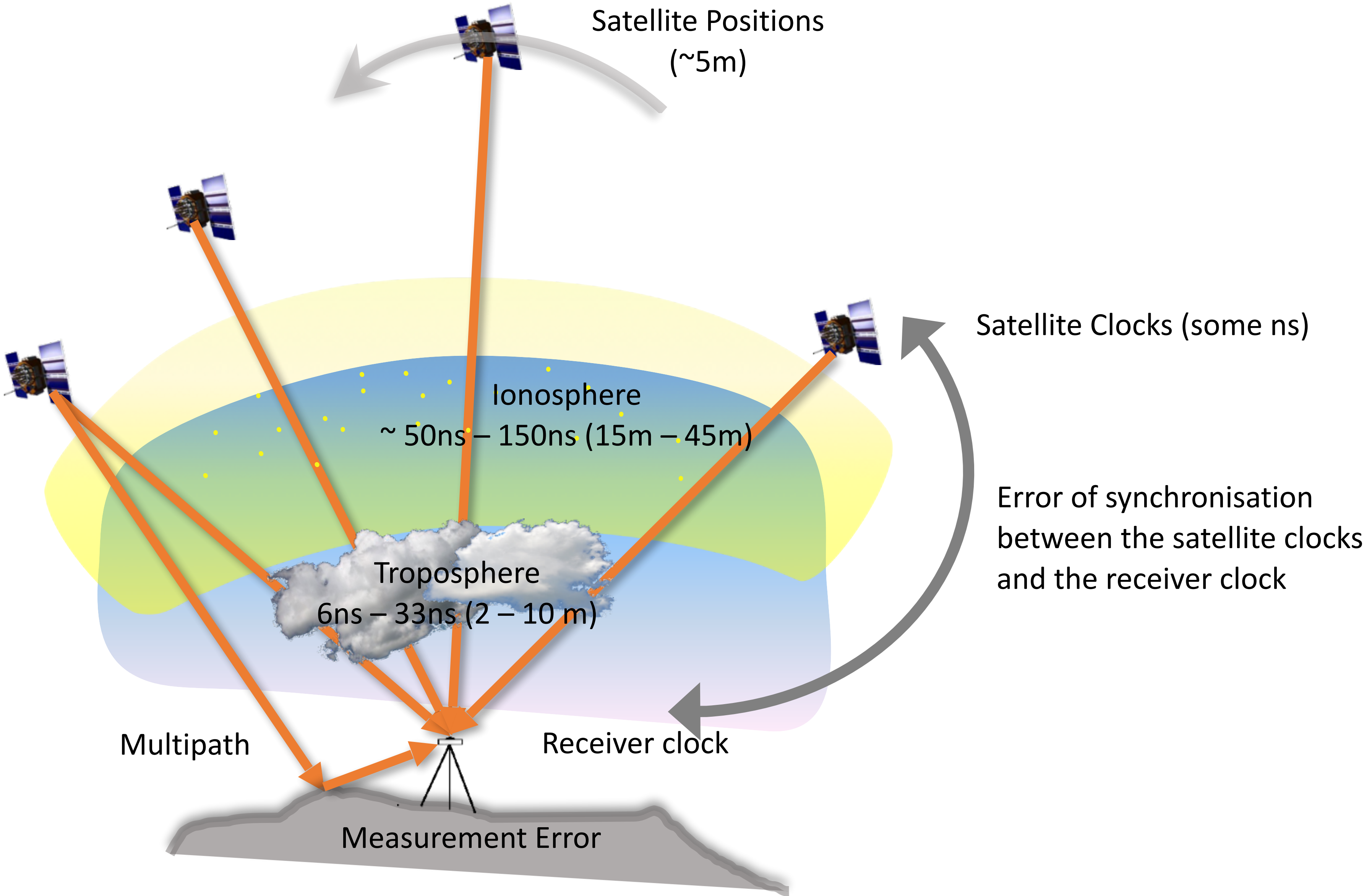


- Atomic clocks are used to generate the signal carrier
- All satellite clocks are kept synchronized in a reference atomic time scale

Race at the ns level, don't loose time on the way !
Error sources affecting the GNSS positioning quality



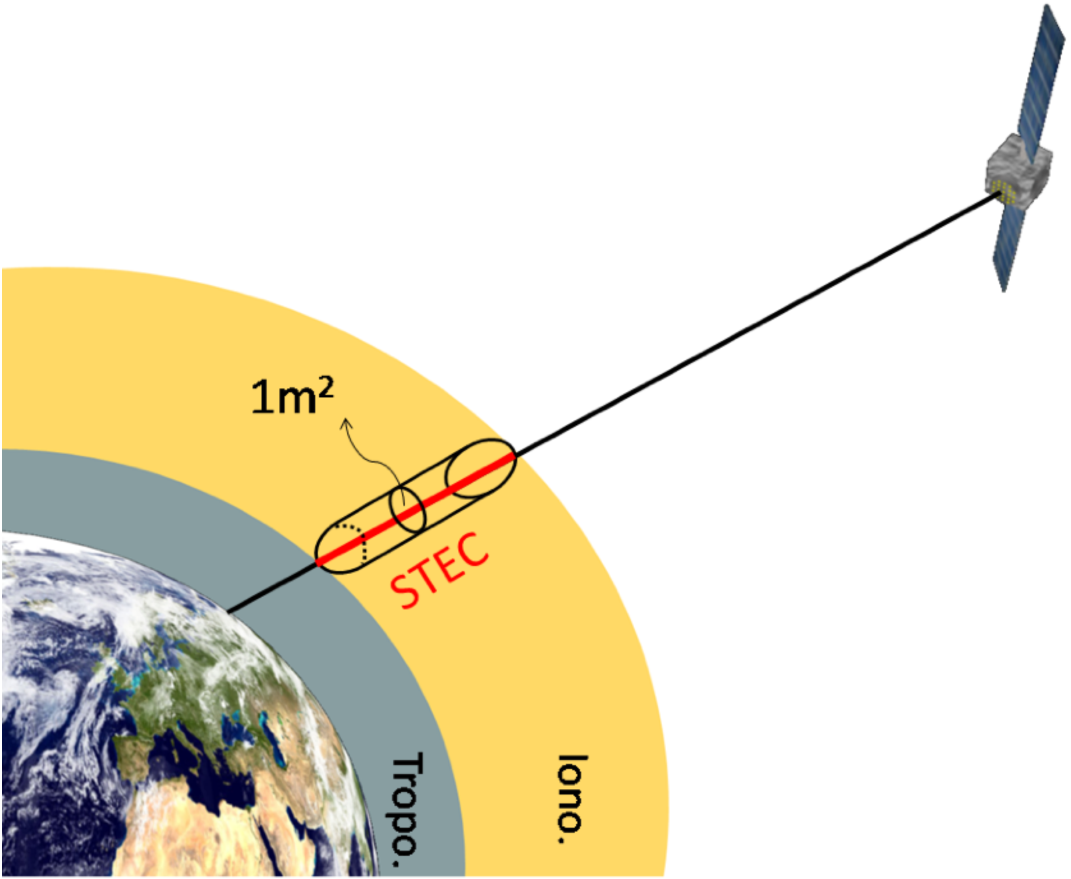
Relavistic effects are corrected in the navigation message and by the receiver, otherwise the error would increase by ~10km everyday.



GNSS vs Ionosphere

Electrically charged media affect the radio-wave propagation depending on the frequency

⇨ Ionospheric delay depends on the GNSS signal frequency



Using 2 GNSS signals at 2 frequencies:

ionosphere-free combination of L1 and L2 signals ⇨ removes 99.9% of the ionospheric delay

NO MORE IONOSPHERIC PROBLEM FOR GNSS ?

Well, still…

Civilian users
⇒ **single-frequency receivers** (mostly)

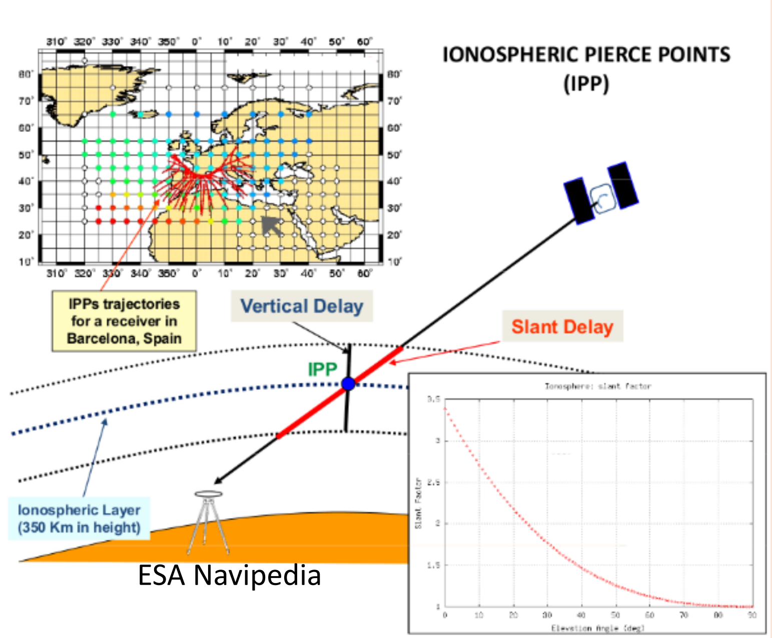
- Double-frequency receivers expensive
- GPS 2nd frequency encrypted, requiring specific technics
- New civilian signals such as GPS L2C and Galileo E5, protected for **safety-related application**
- The ionosphere free combination relies on the tracking quality of the GNSS signals (receiver, antenna, software…)

For the **GNSS single frequency users, abnormal ionospheric activity** remains a problem.
Even for double-frequency receivers, space weather events affecting the ionosphere (scintillations) or the radio frequency bands (solar radio bursts) can generate **GNSS signals fading up to the loss of lock**.

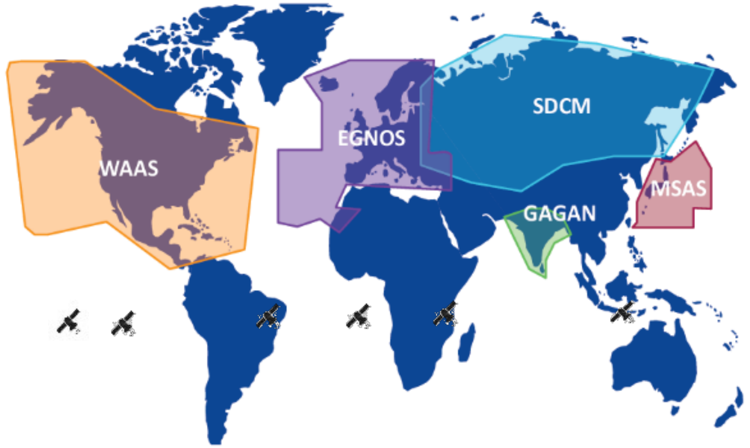
GNSS single-frequency users are not left behind for mitigating the ionospheric effect

Most common to the public

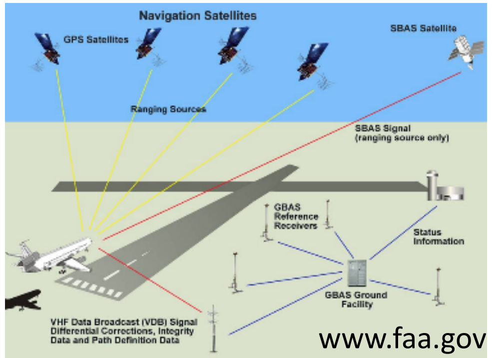
Broadcasted parameters in the navigation message for the **Klobuchar** and **NeQuick ionospheric models**, correcting **50%** of the **ionospheric range error**. Do not include space weather.



Satellite-based Augmentation Systems



Ground-based Augmentation Systems



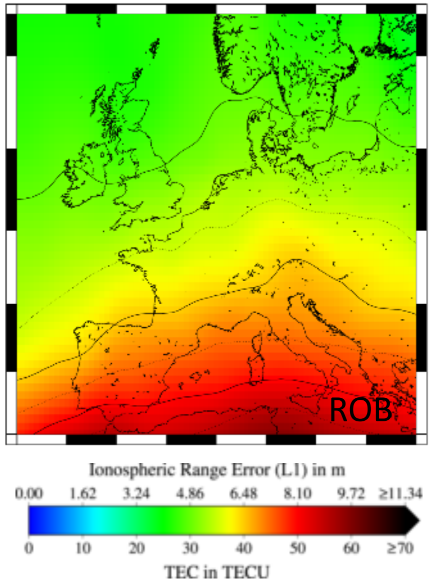
Differential GNSS

DGNSS (1-3m)

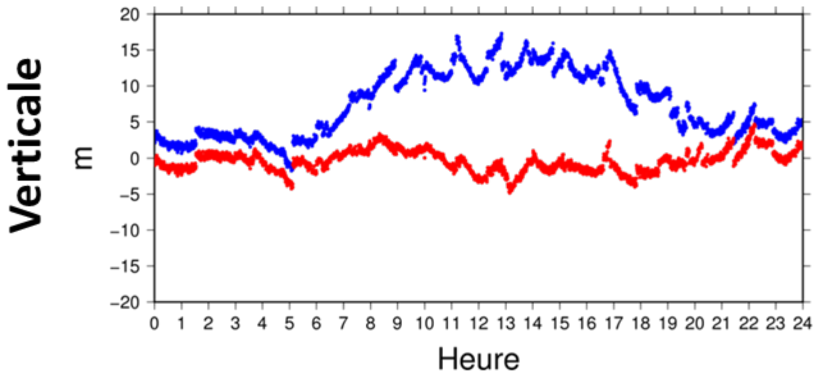
Real Time Kinematic RTK (3-10cm)

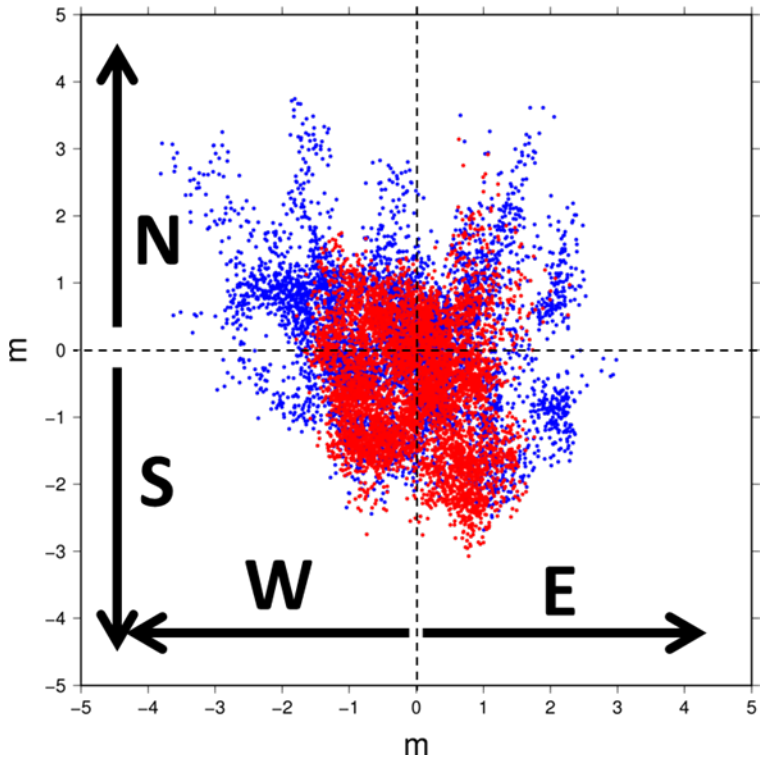
Precise Point Positioning PPP (1-10 cm)

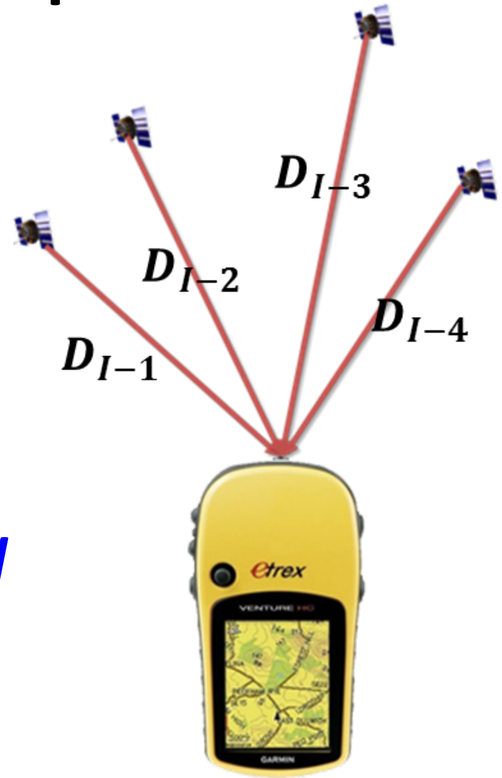
Ionospheric TEC Maps



GNSS disturbances due to Ionosphere

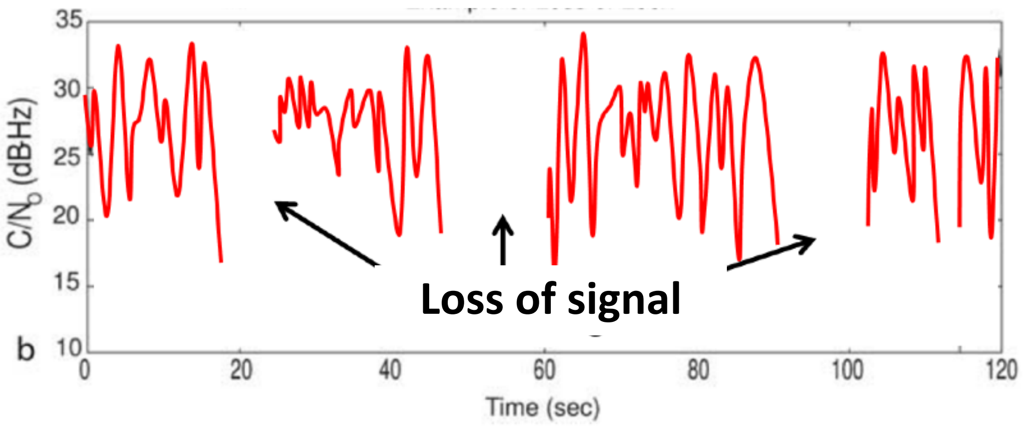






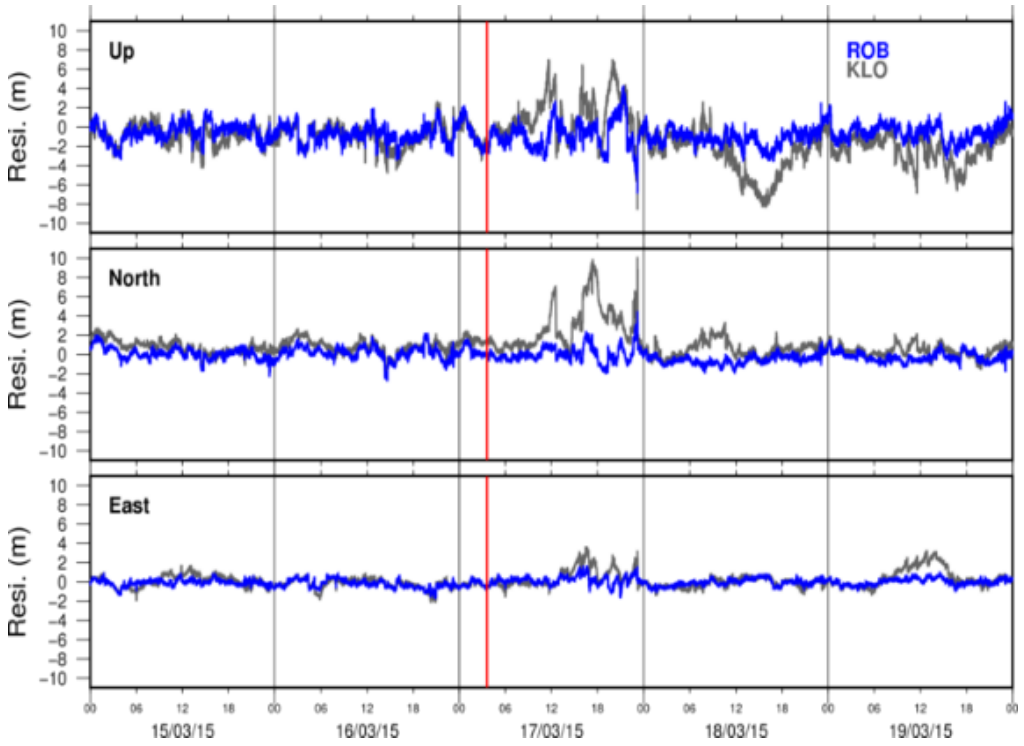
D_{Iono} corrected

D_{Iono} uncorrected



GNSS disturbances due to Ionosphere

Position of the GNSS station at Brussels during 2015 March Storm (*W. Huang and P. Defraigne*)



Correction using Klobuchar ionospheric model

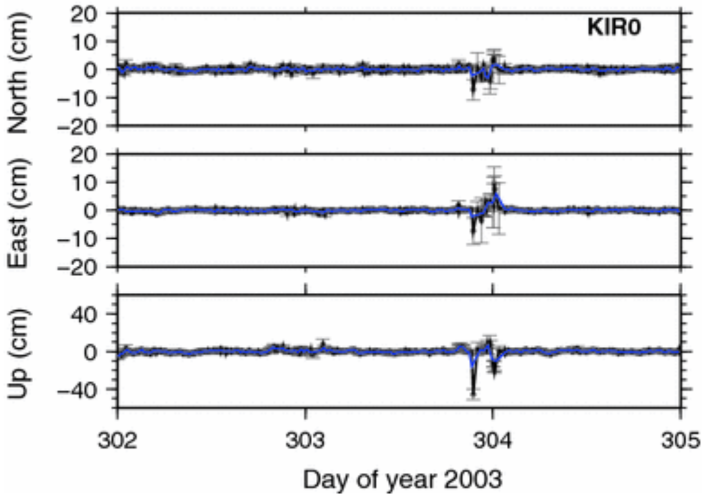
East	10 ± 80 cm
North	100 ± 140 cm
Up	120 ± 210 cm

Correction using ROB-TEC products

East	**6 ± 40 cm**
North	**9 ± 66 cm**
Up	**76 ± 150 cm**

The 2003 Halloween solar storms were so powerful that auroras were seen as far south as Texas and Florida. This aurora image was taken near Houston Texas on Oct. 29, 2003.

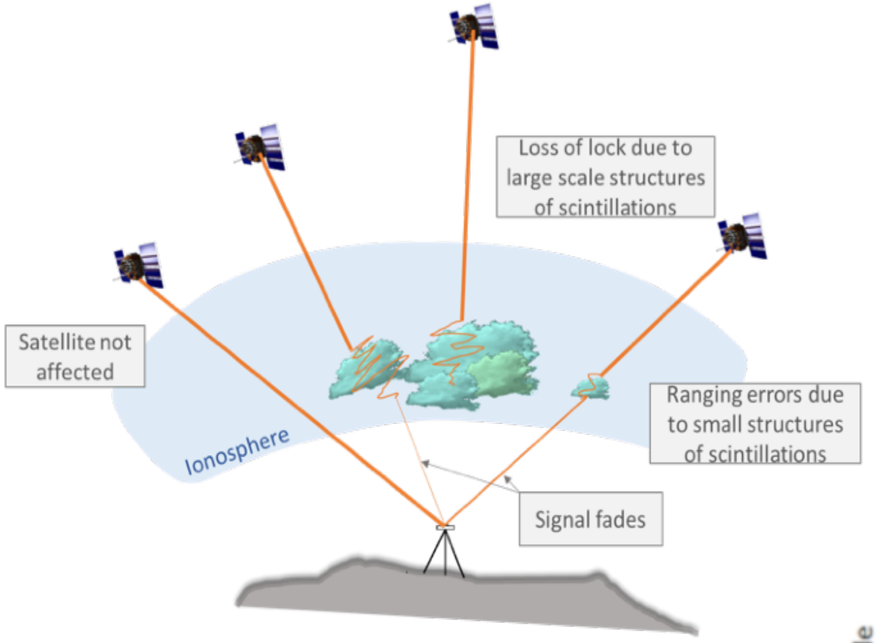
Repeatability of the kinematic positions in Northern Europe (*Bergeot et al.*)
Quiet ionosphere: in horizontal ≤1 cm
in vertical ≈2.5 cm
Halloween storm 2003:
North, East : **12.8cm and 8.1 cm**
Vertical: **26.1 cm**



	Dispersive Ionospheric Effect (GPS L1)		
Ionosphere	1st Order	2nd Order	3rd Order
100 TECU	16 m	0-2 cm	0-2 mm

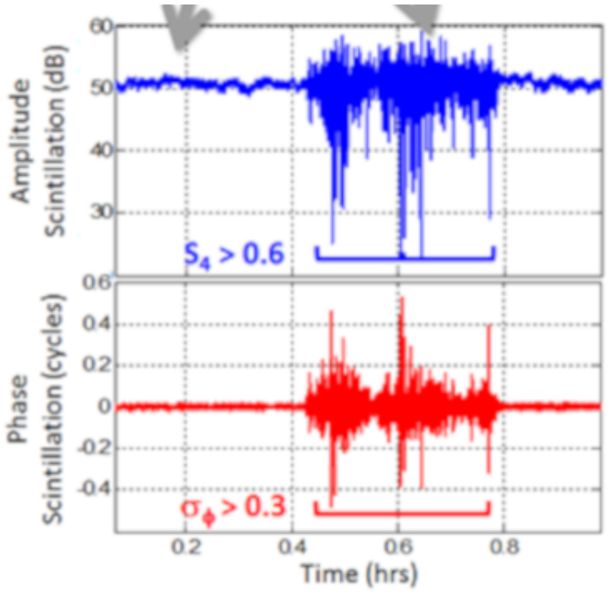
For a GNSS reference station

GNSS disturbances due to Ionosphere

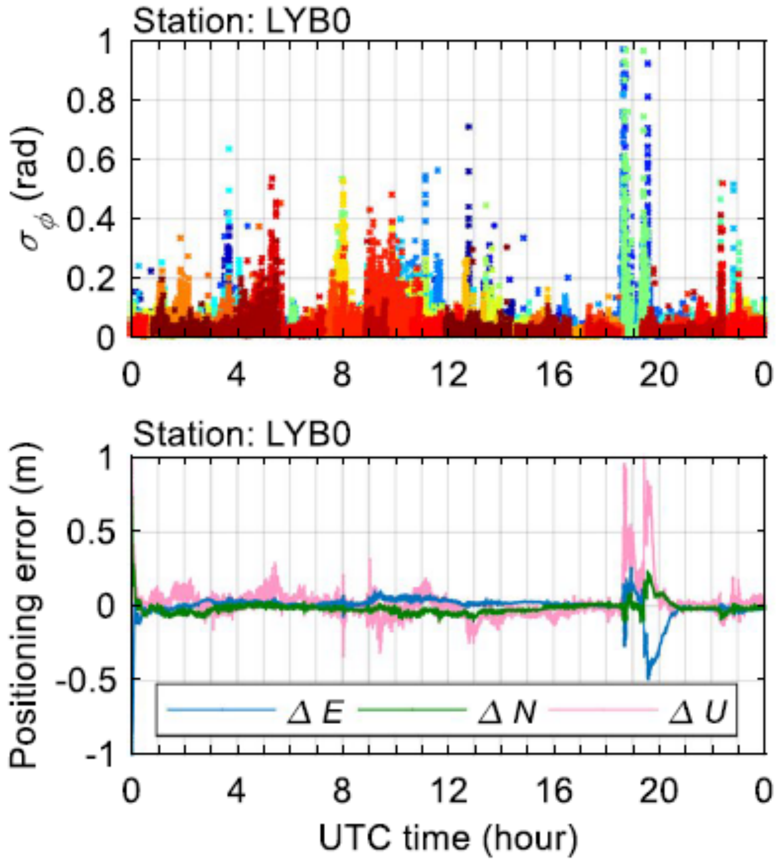


Scintillation affects the phase and the amplitude of GNSS signals, causing cycle slips up to the loss of lock.

Induce error positioning up to several meters, with worst case scenario: GNSS radio blackout.



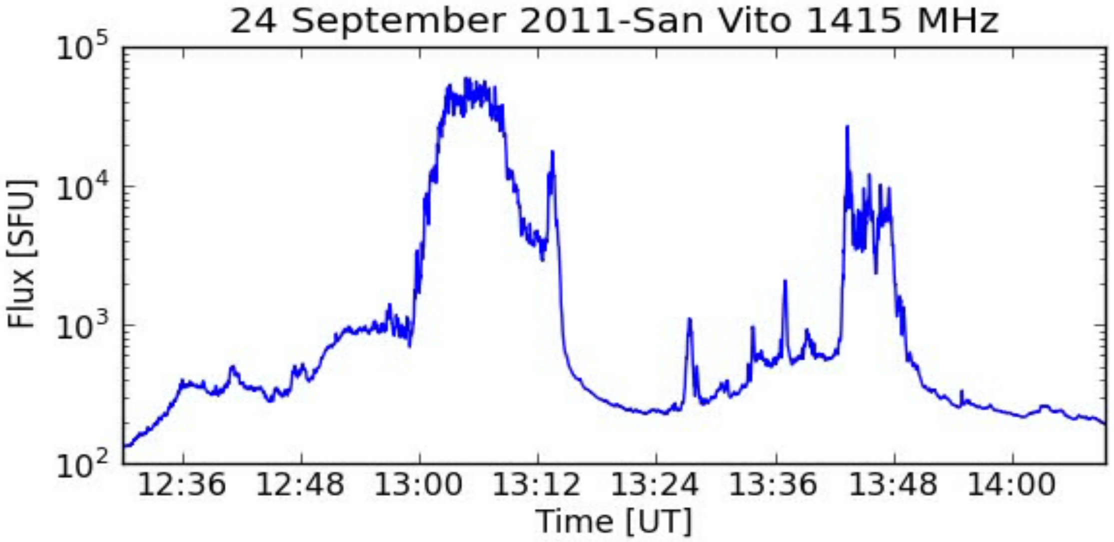
Data supplied by J.-M. Sleewaegen, Septentrio, Belgium



Scintillation index and error positioning ≥0.5m using single-frequency PPP with a reference GNSS station in Norway. Guo et al., 2020

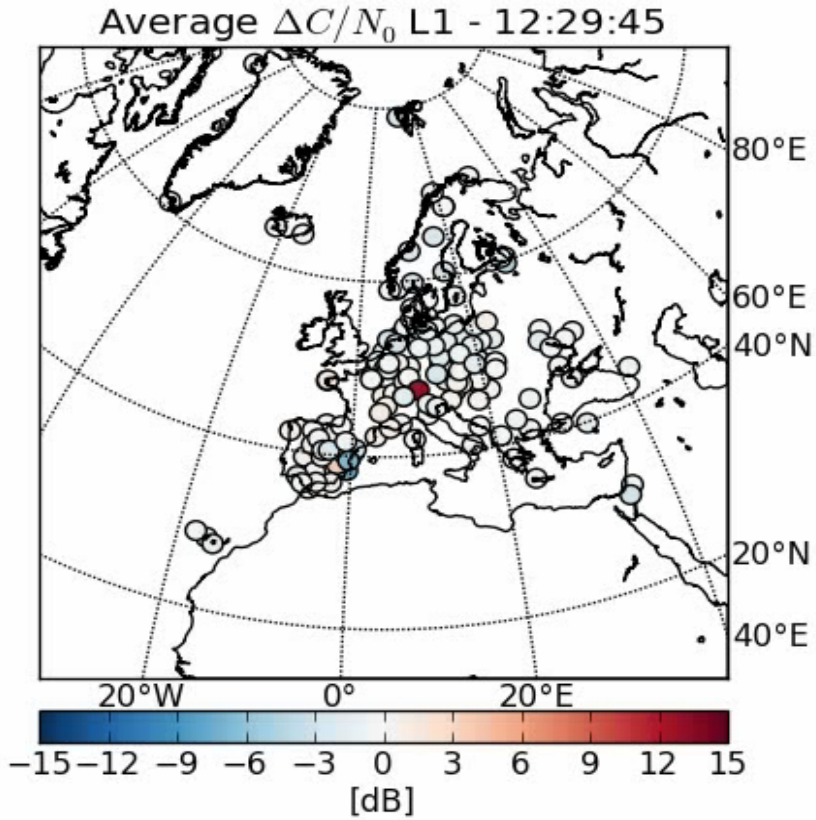
GNSS disturbances due to Solar Radio Bursts

Solar Radio Bursts (SRB) are intense radio emissions (durations from 10s to few hours)



GNSS are vulnerable to Radio Frequency Interferences as the GNSS signals received on Earth is very weak.

SRBs increase the noise level of GNSS ground stations and act as a natural jammer for the GNSS.

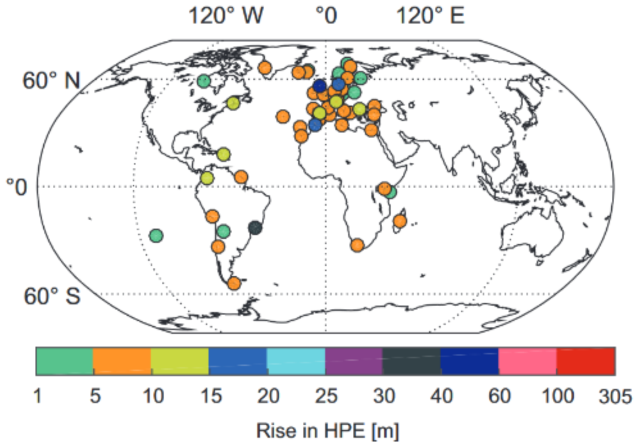


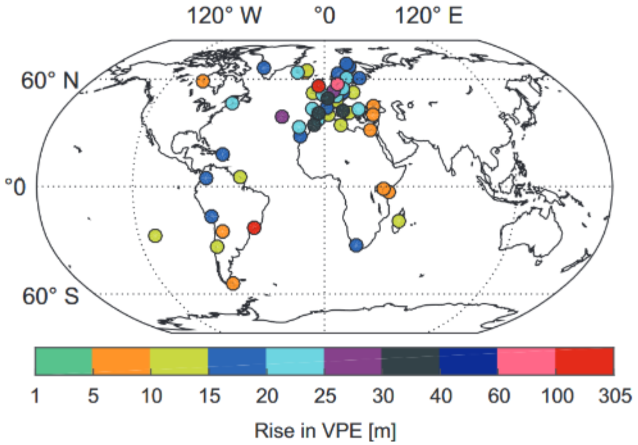
GNSS disturbances due to Solar Radio Bursts

Rise in error = Positioning error during SRB – Positioning error on a quiet day

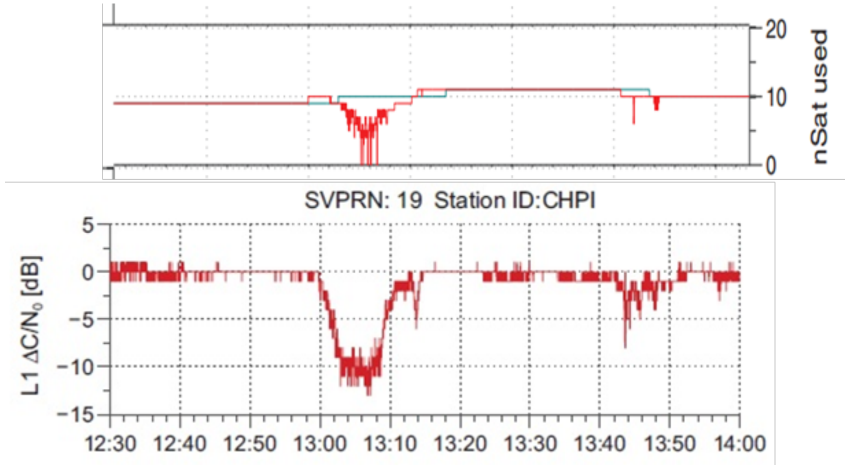
SRB of the 24/09/2011

Muhammad et al. 2015

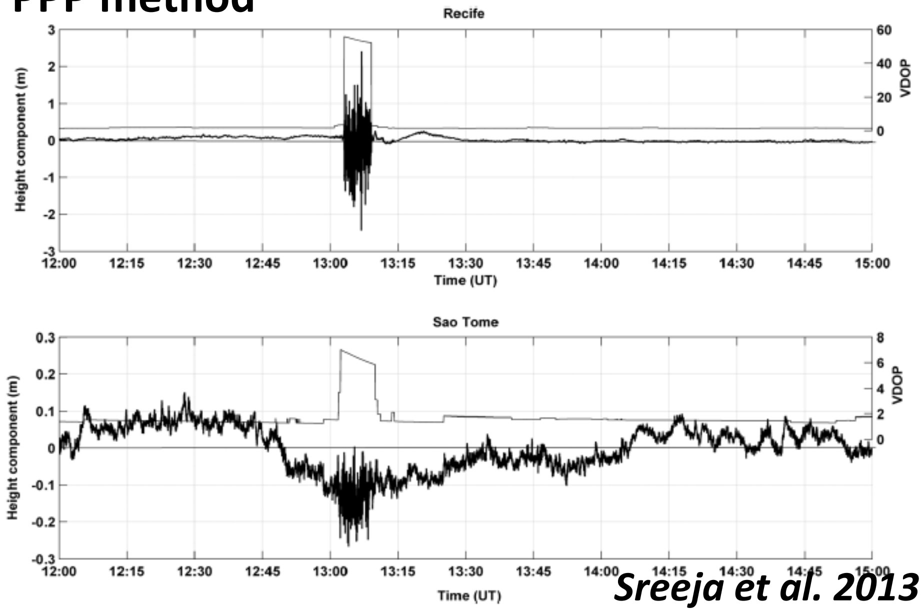




Sao Paulo, Brazil



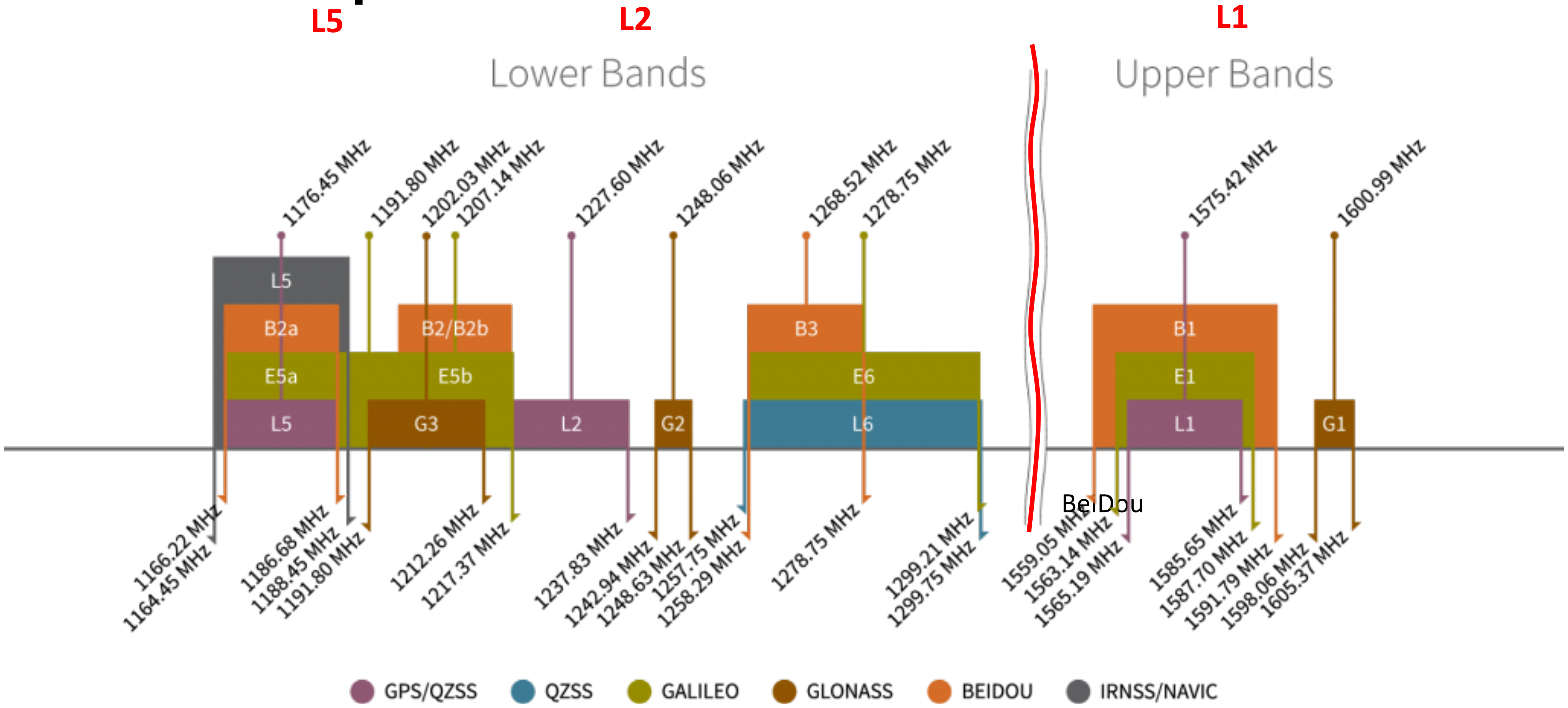
PPP method



Sreeja et al. 2013

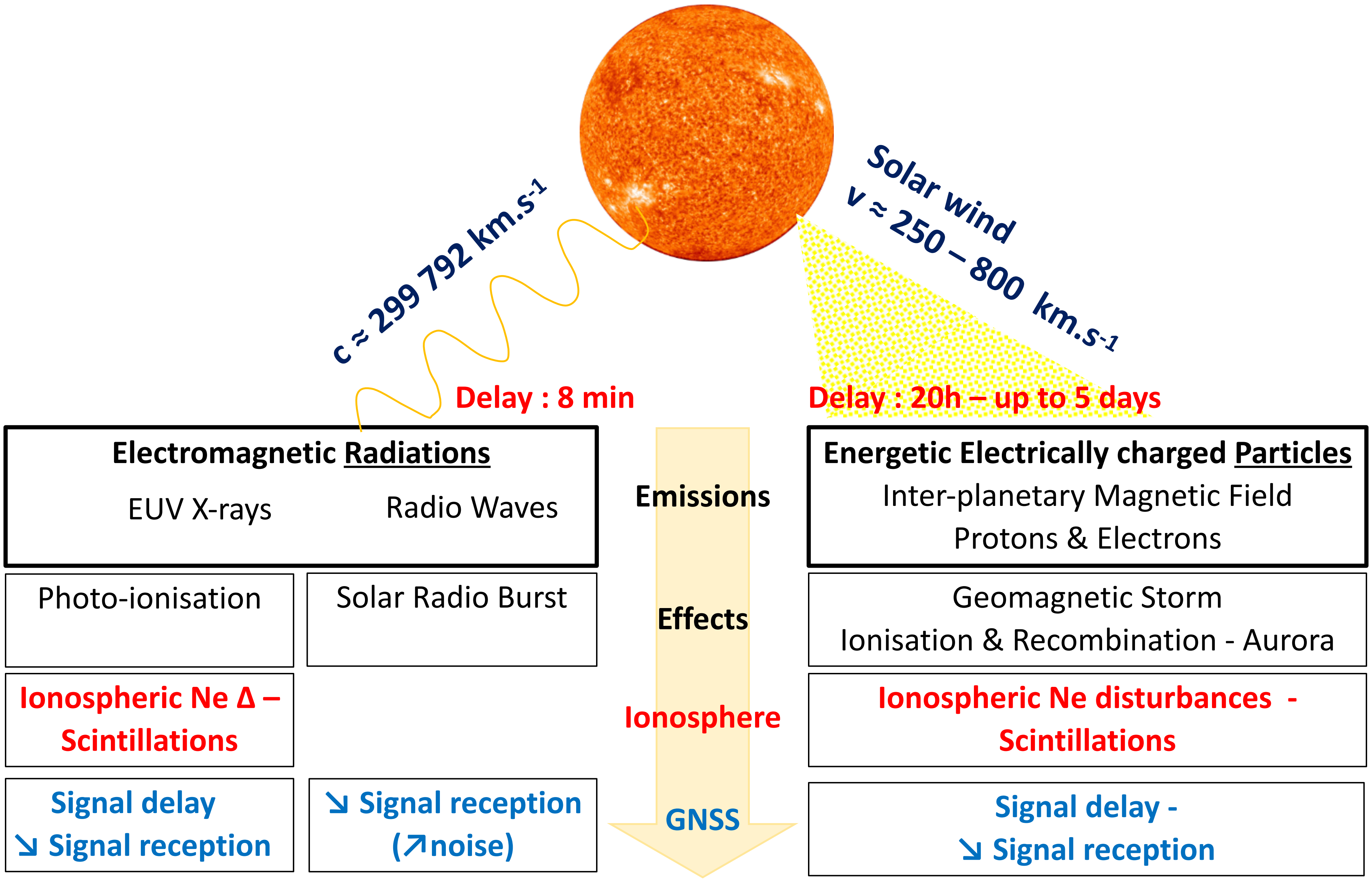
- Backup slides

GNSS frequencies



Picture from Tallysman

GNSS disturbances due to Space Weather



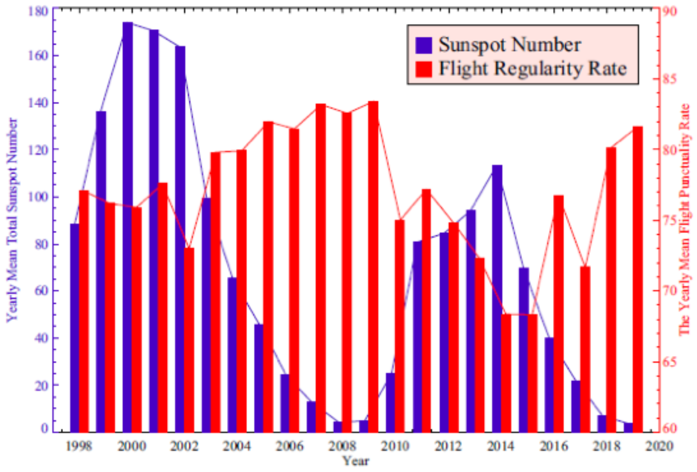
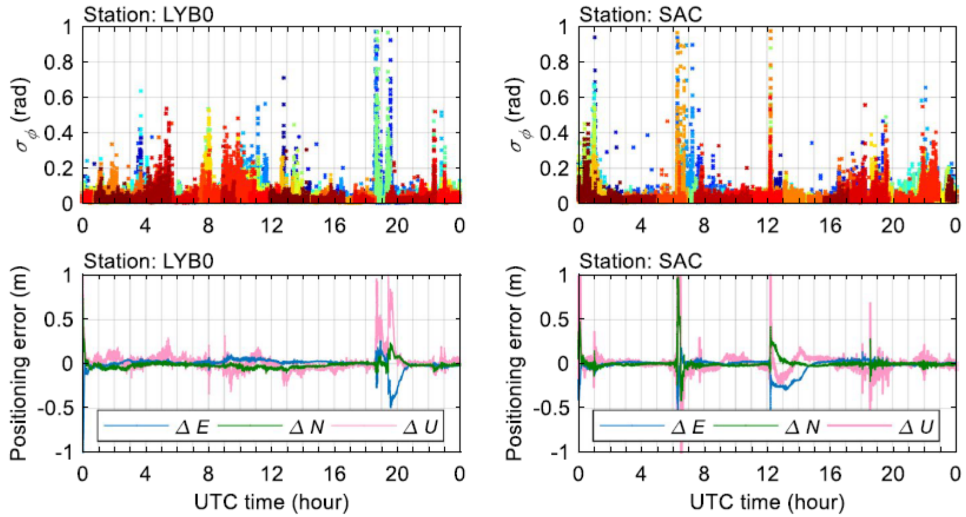


Figure 4. The yearly flight regularity rate of China (red) versus the yearly mean total sunspot number (blue) from 1998 to 2019.

Wang et al. Additional flight delays and magnetospheric–ionospheric disturbances during solar storms, Nature scientific report 2023



Guo et al., 2020 Mitigating high latitude ionospheric scintillation effects on GNSS Precise Point Positioning exploiting 1-s scintillation indices