

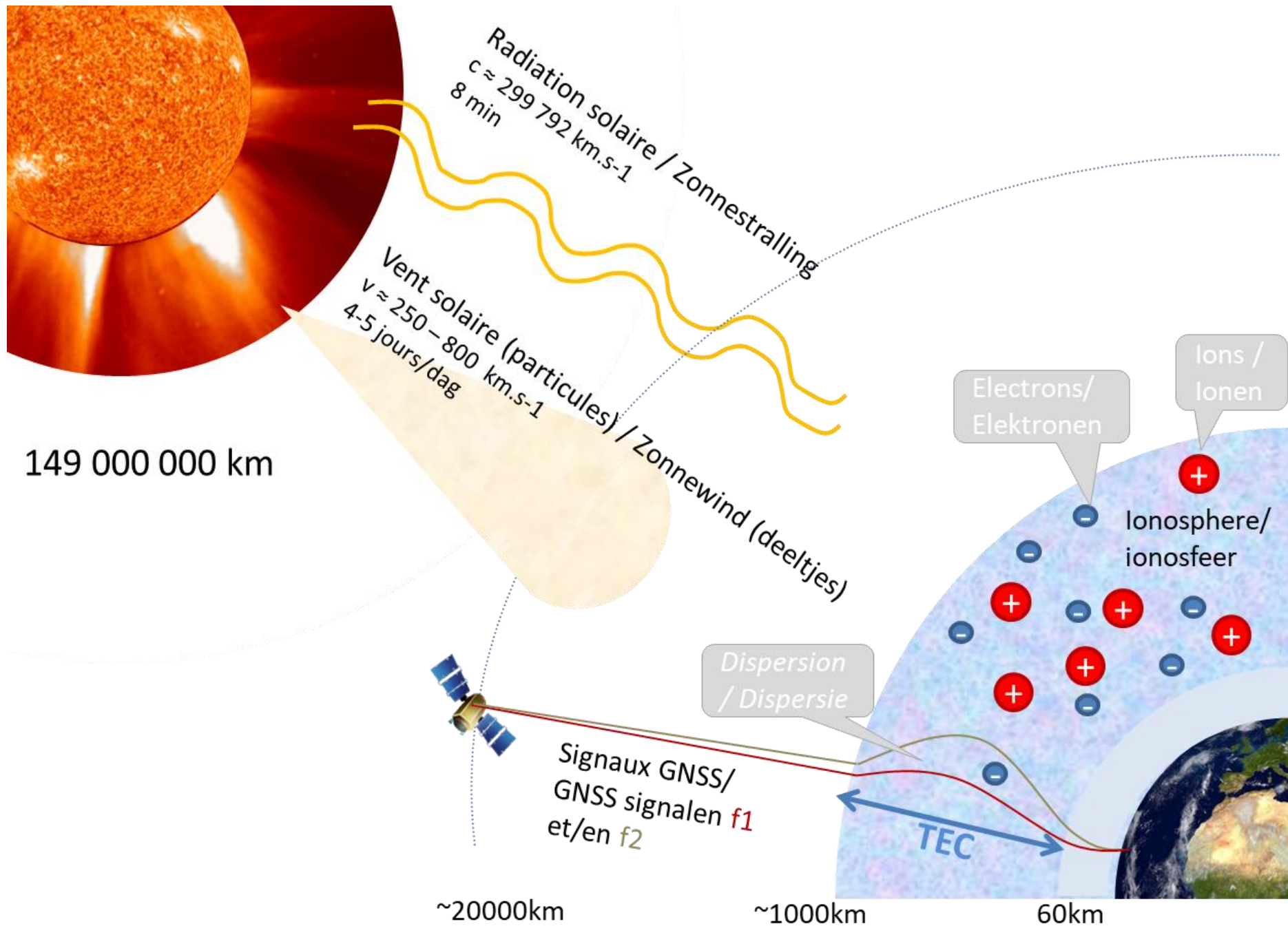
Solar-Terrestrial  
Center of  
Excellence

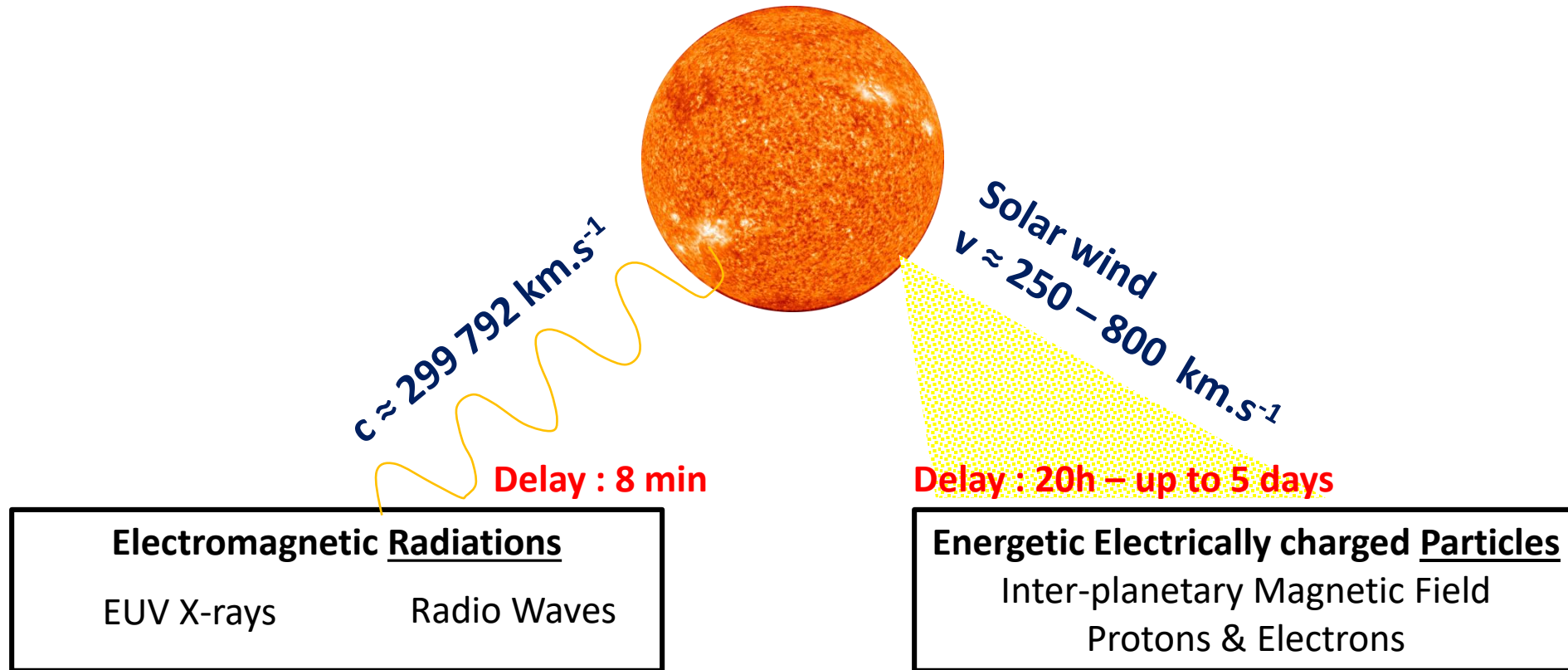


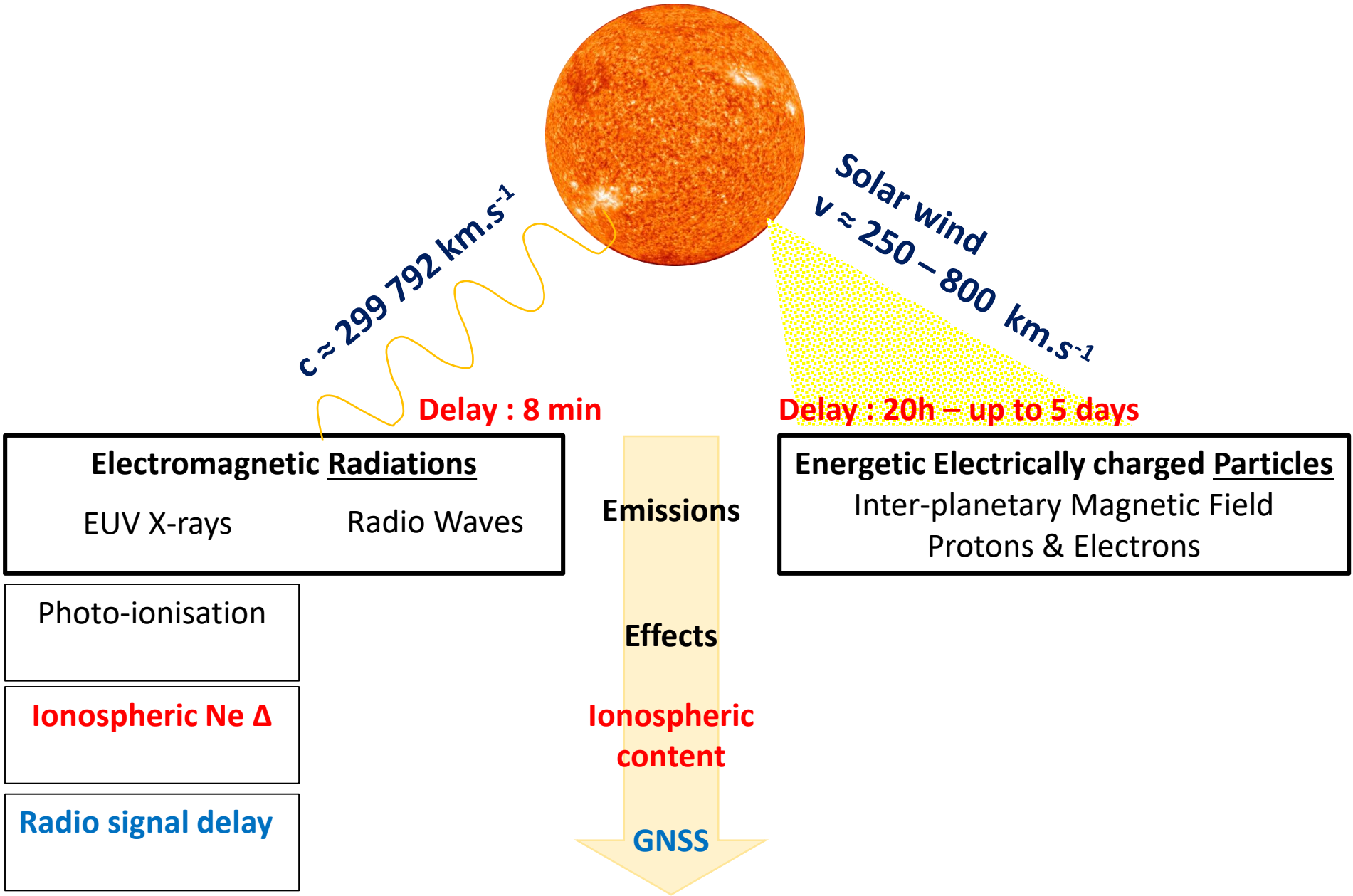
Royal Observatory  
of Belgium

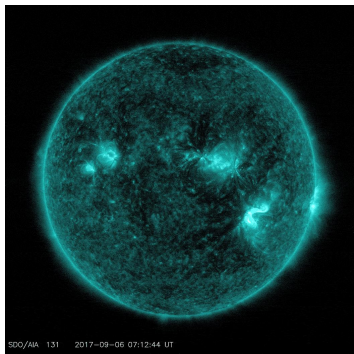
# Space Weather Monitoring based on GNSS

*J.-M. Chevalier and N. Bergeot*



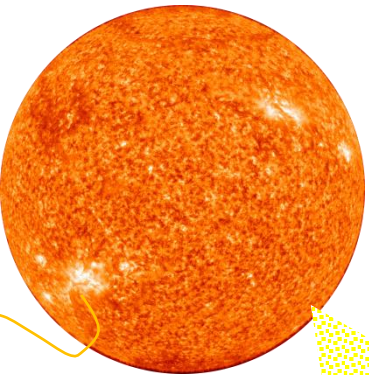






NASA

Solar Flare



$c \approx 299\,792\text{ km.s}^{-1}$

Delay : 8 min

Solar wind  
 $v \approx 250 - 800\text{ km.s}^{-1}$

Delay : 20h – up to 5 days

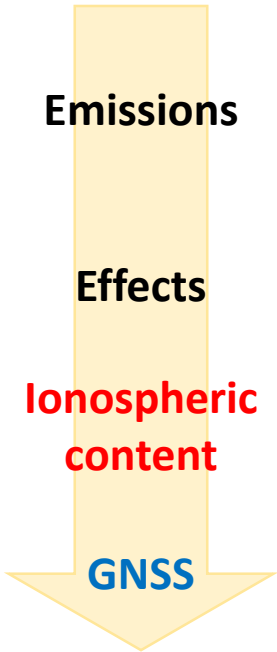
**Electromagnetic Radiations**

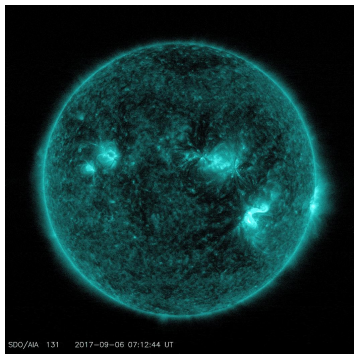
EUV X-rays      Radio Waves

**Energetic Electrically charged Particles**

Inter-planetary Magnetic Field  
Protons & Electrons

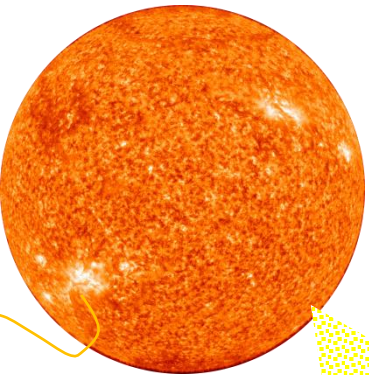
- Photo-ionisation
- Ionospheric Ne Δ
- Radio signal delay





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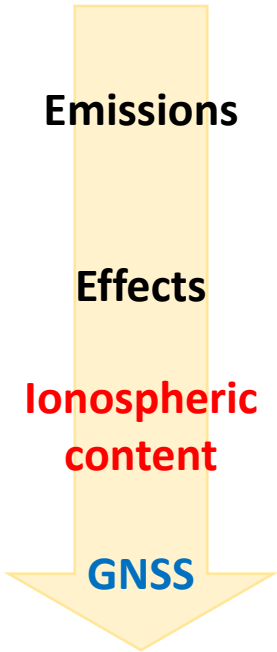
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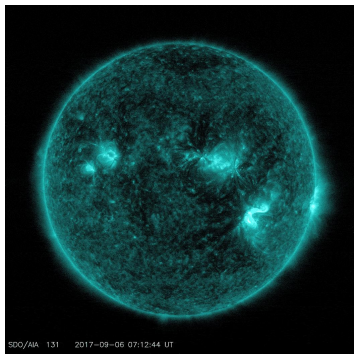
Photo-ionisation

**Ionospheric Ne  $\Delta$  –  
Scintillations**

**Radio signal delay-  
↘ Signal reception**

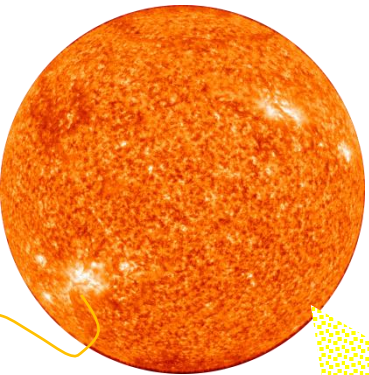






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Radio Waves

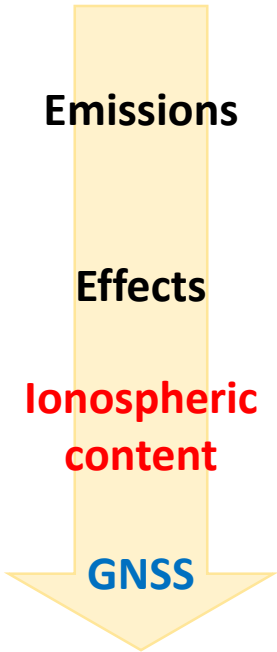
Photo-ionisation

Solar Radio Burst

**Ionospheric  $\Delta$  – Scintillations**

**Radio signal delay-  
↘ Signal reception**

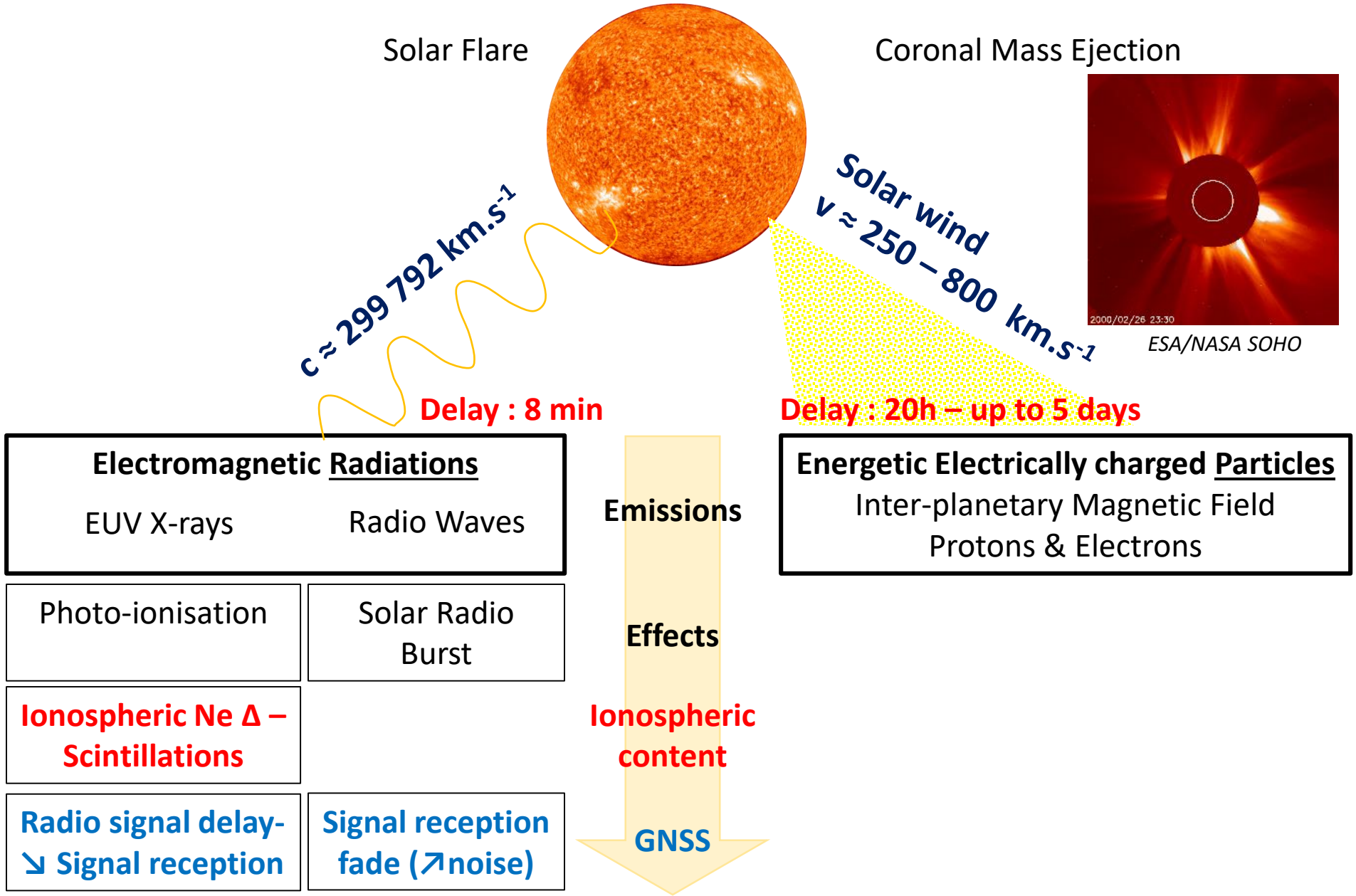
**Signal reception  
fade (↗noise)**



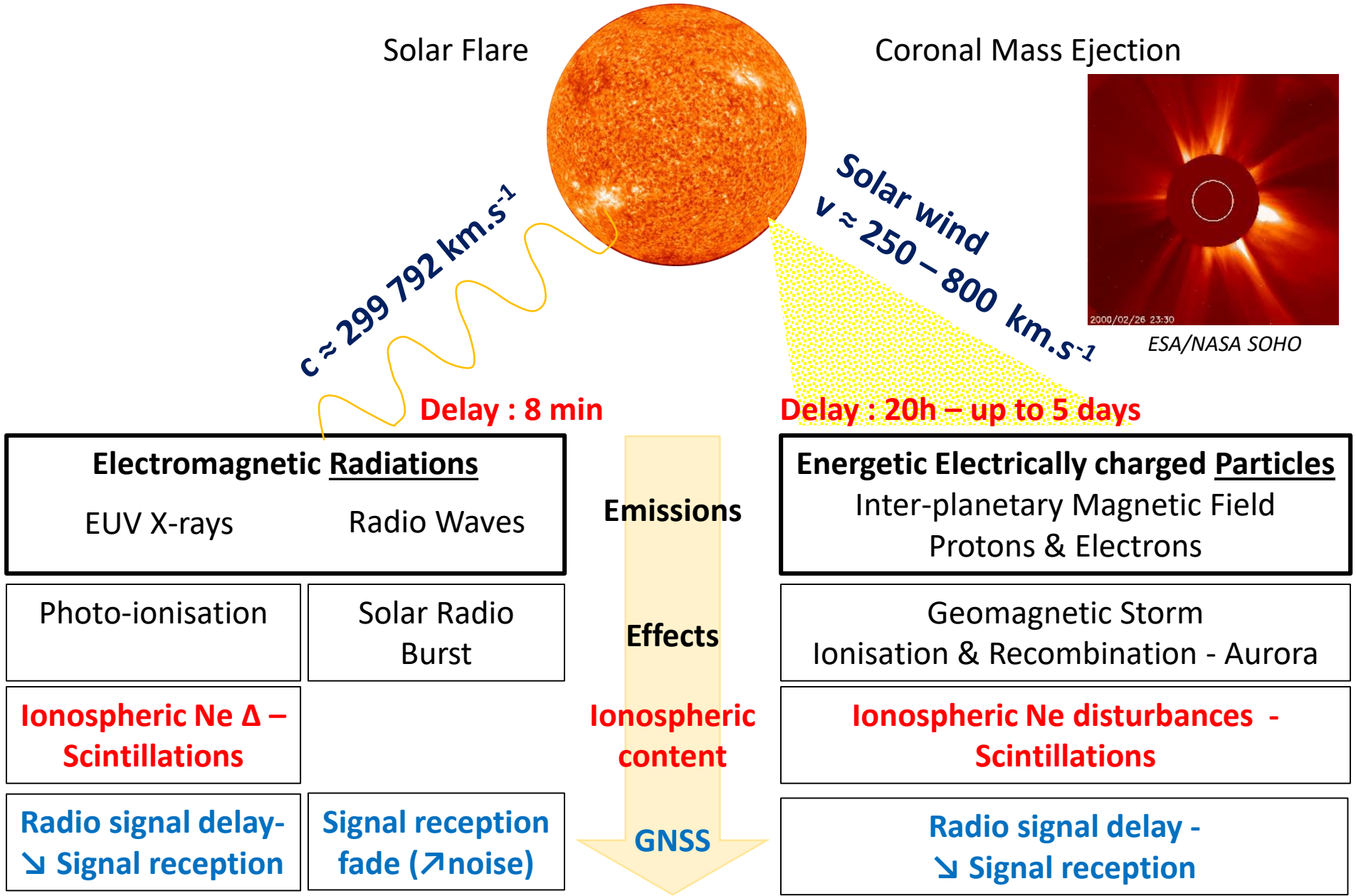
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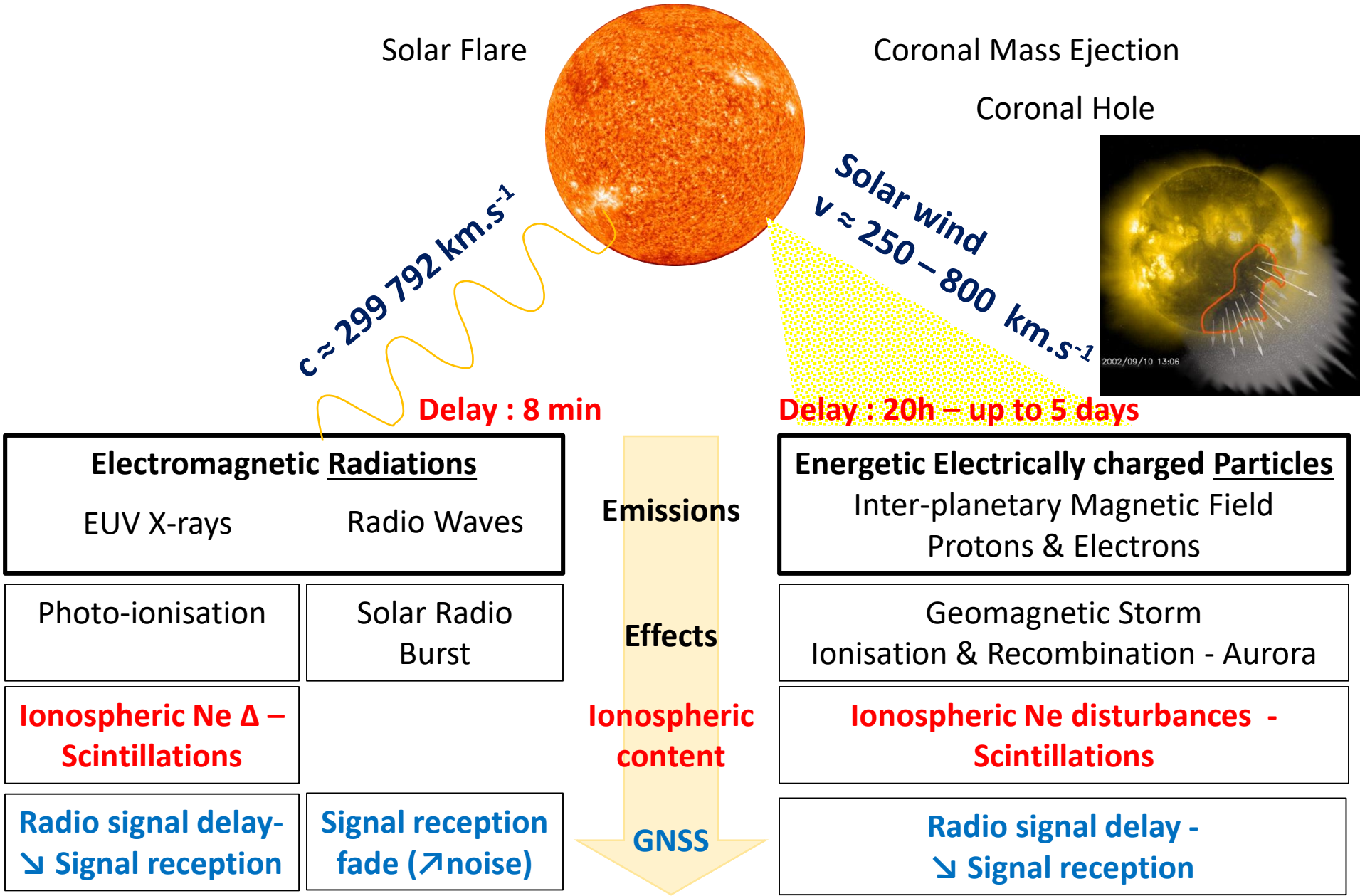
Inter-planetary Magnetic Field

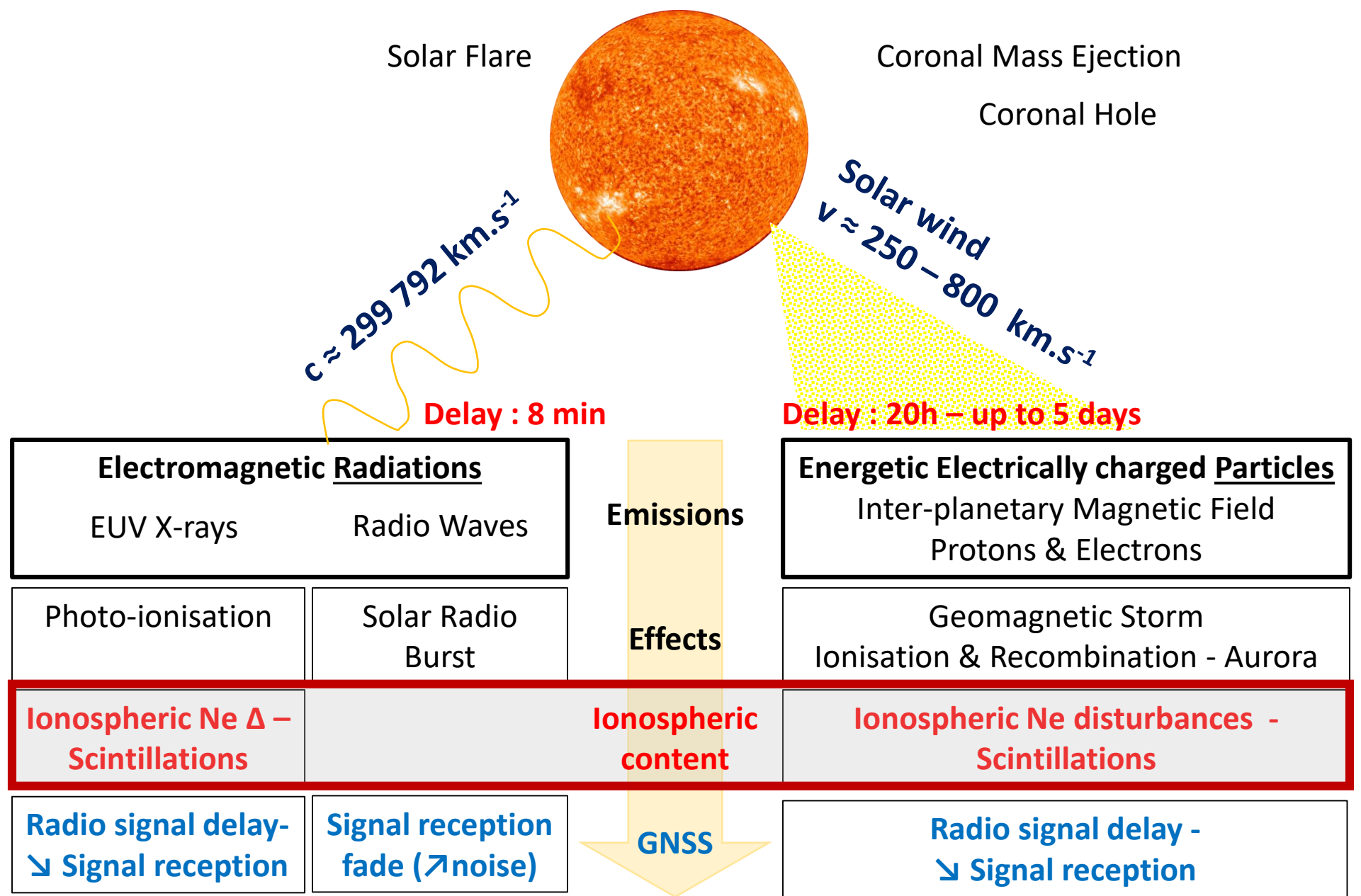
Protons & Electrons

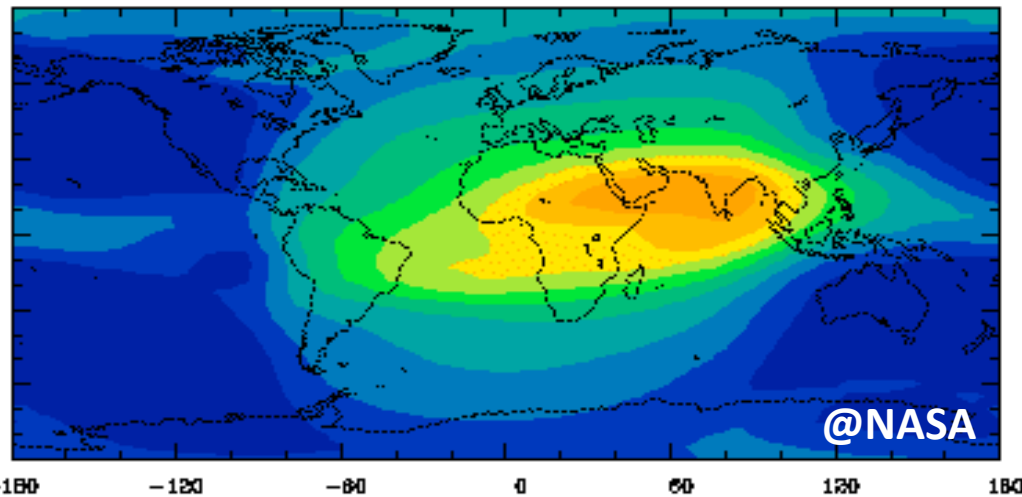
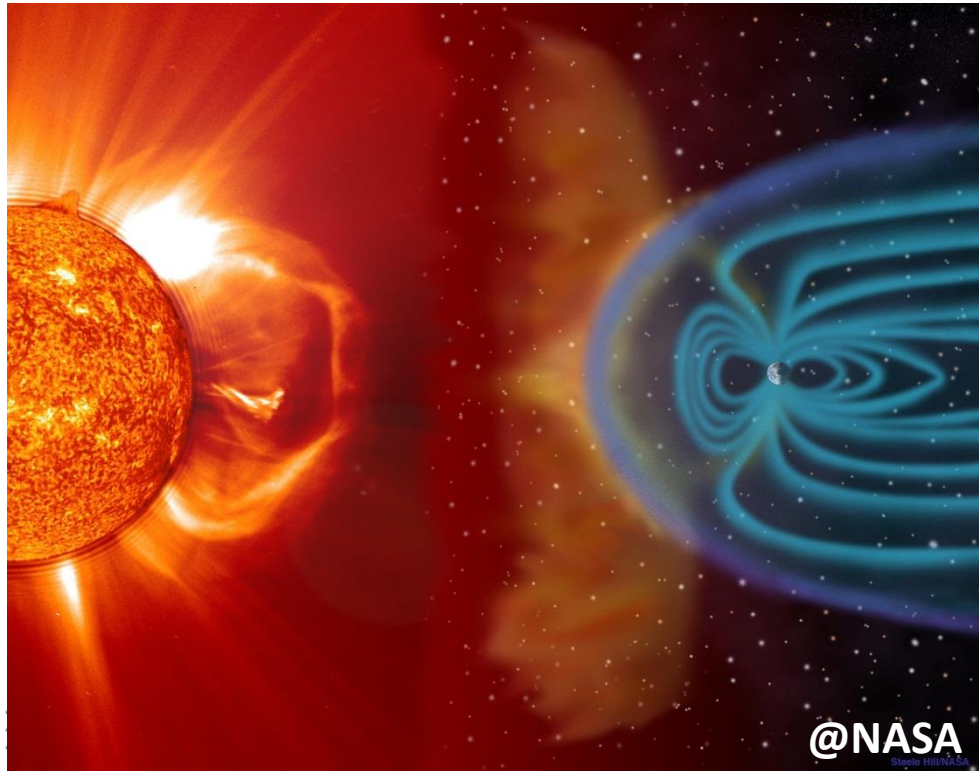








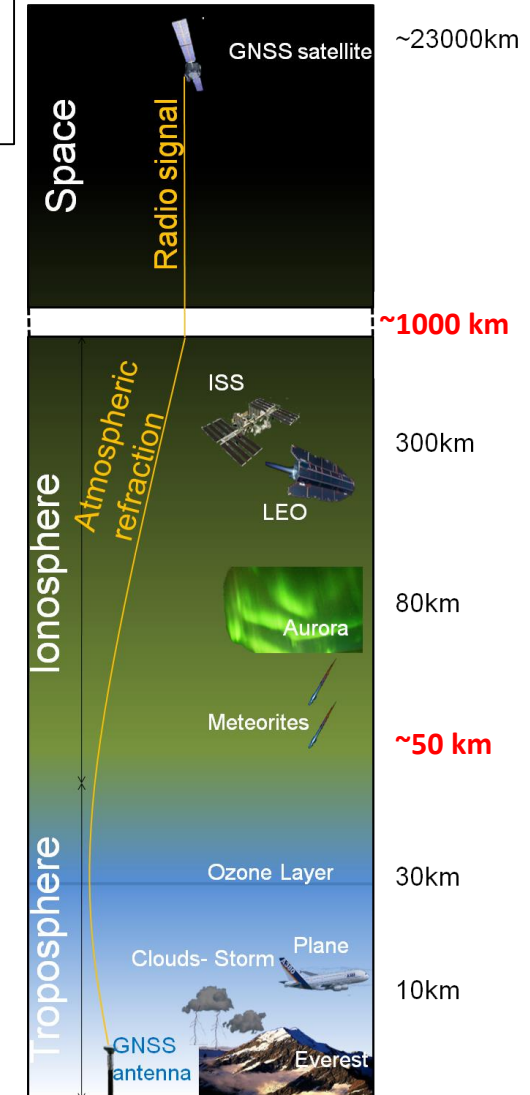




Ionised media

Plasma:

$e^- = ion^+$





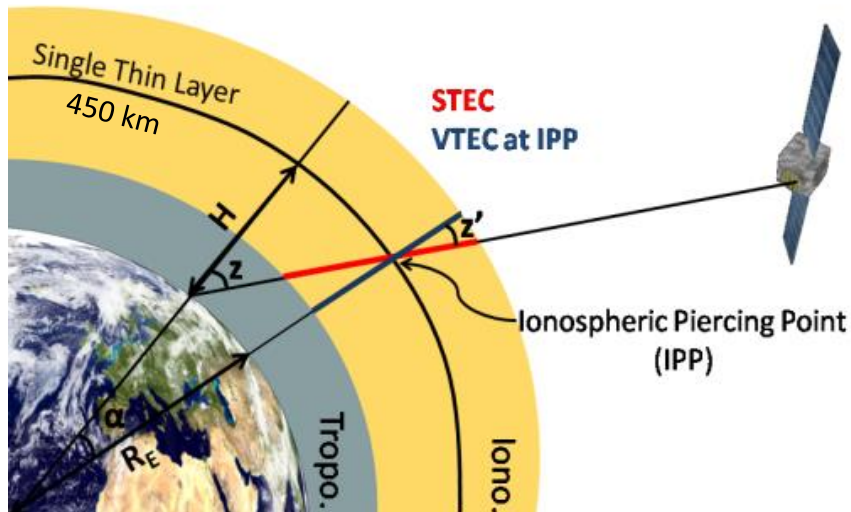
Electrically charged media affects the radio-wave propagation (depending on the frequency)

=> ionospheric delay  $I_{1,2}$

$$\text{Pseudorange } P_{1,2} = \rho_{1,2} - c\Delta t_{rec} + c\Delta t_{sat} + I_{1,2} + Tr + \delta_{1,2}^P + \epsilon_{1,2}^P$$

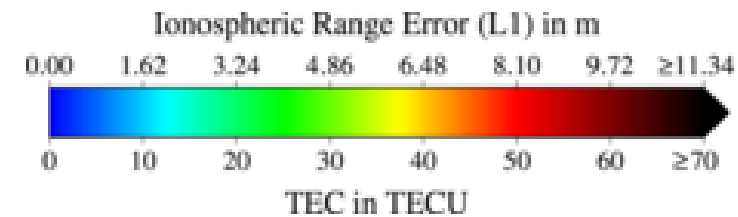
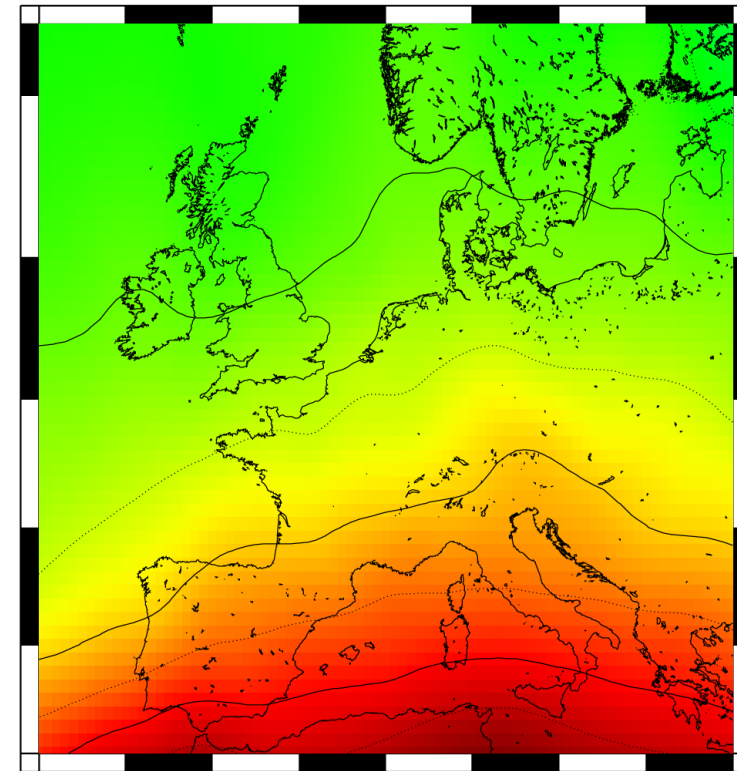
$$\text{Ionospheric delay } I_{1,2} = 40.3 \frac{STEC}{f_{1,2}^2}$$

$$\text{Slant Total Electron Content } STEC = \int_R^S N_e d$$



- Input data: real-time data from the EPN (~150 stations)
- Near real-time TEC maps over Europe  
+ variability
  - since 2012

Sampling rate	: 15 min
Grid extent	: Long W15° / E25°
	: Lat N35° / N62°
Grid resolution	: 0.5°x0.5°
Latency	: ~3 minutes





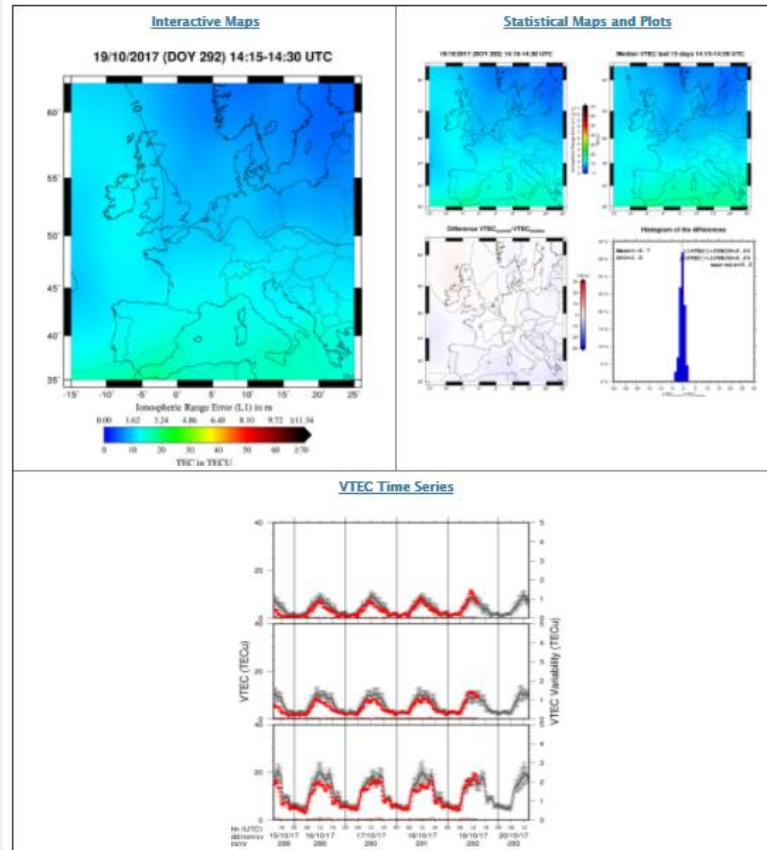
### Last Ionospheric Events

- 2017-09-07 : Ionospheric activity due to Solar Flare ([more here](#))
- 2017-09-06 : Space weather event due to Solar Radio Burst ([more here](#))
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- ... [more events here](#)

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Vertical Total Electron Content (VTEC) estimated in Near Real-Time (NRT) every 15 minutes from EUREF Permanent Network (EPN) GPS data. [More...](#)

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### Solar Radio Burst Warnings for GNSS Applications in Europe

Solar Radio Bursts (SRB) emitted at the GNSS frequencies can affect the GNSS signal reception. To detect such event, a [near-real time SRB warning system](#) with a 4-level index was set in Europe using the real-time EUREF Permanent Network.

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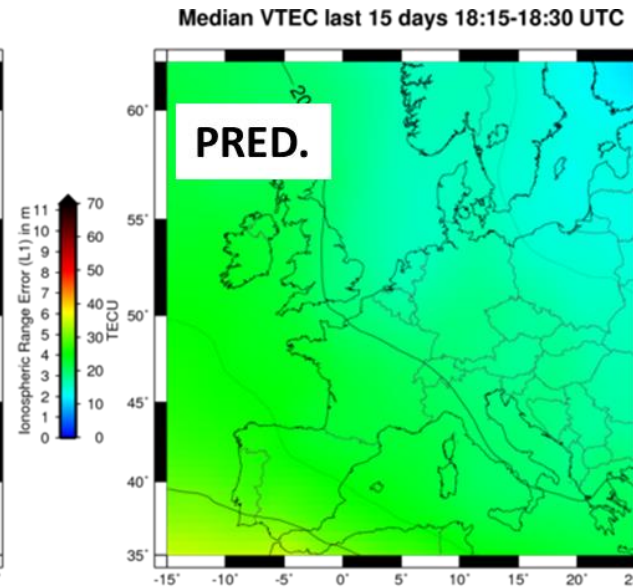
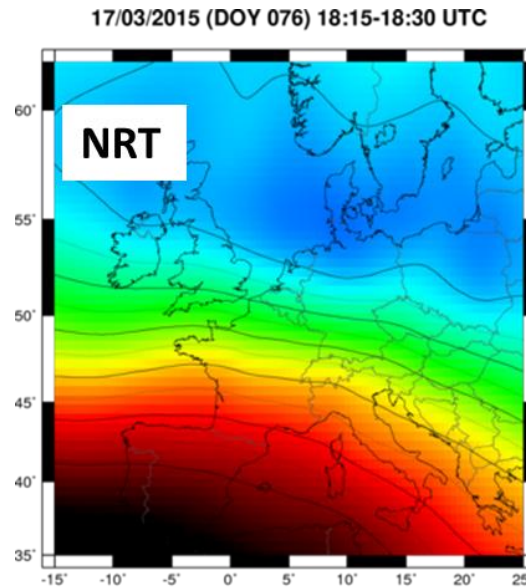
[www.gnss.be](http://www.gnss.be)

## 1) Ionospheric Total Electron Content (TEC)

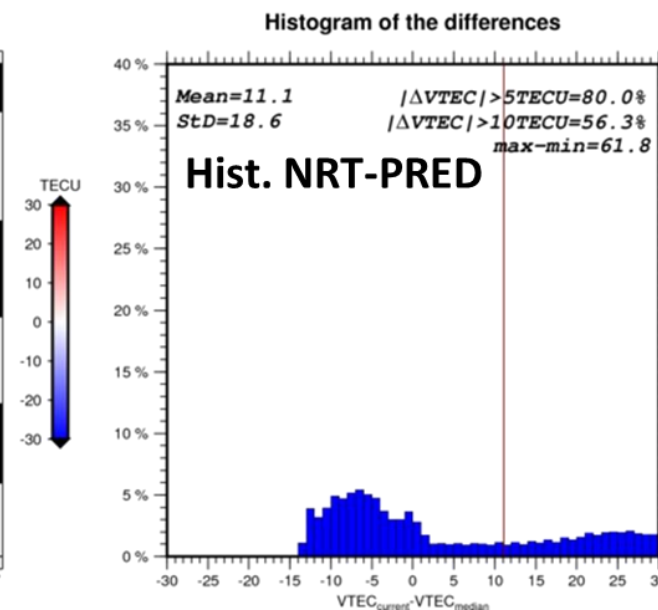
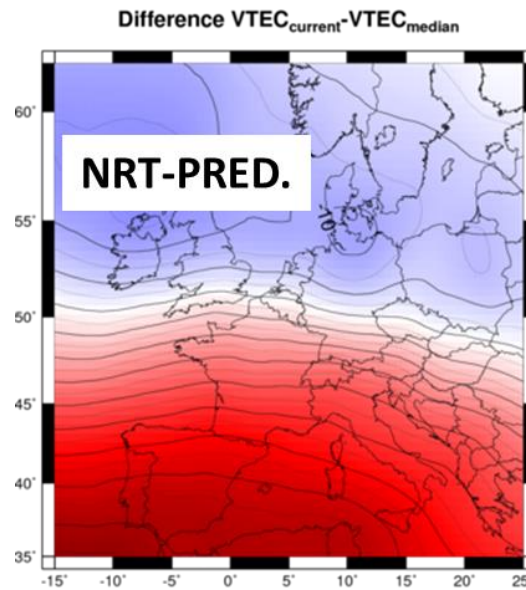
- Interactive TEC maps
- Statistical TEC maps
- TEC Time Series at 3 locations (North-Brussels-South)
- TEC Data (IONEX) <http://gnss.oma.be/gnss/products/IONEX/>
- Event Description

## 2) Solar Radio Burst (SRB)

- Warning System
- Event Description

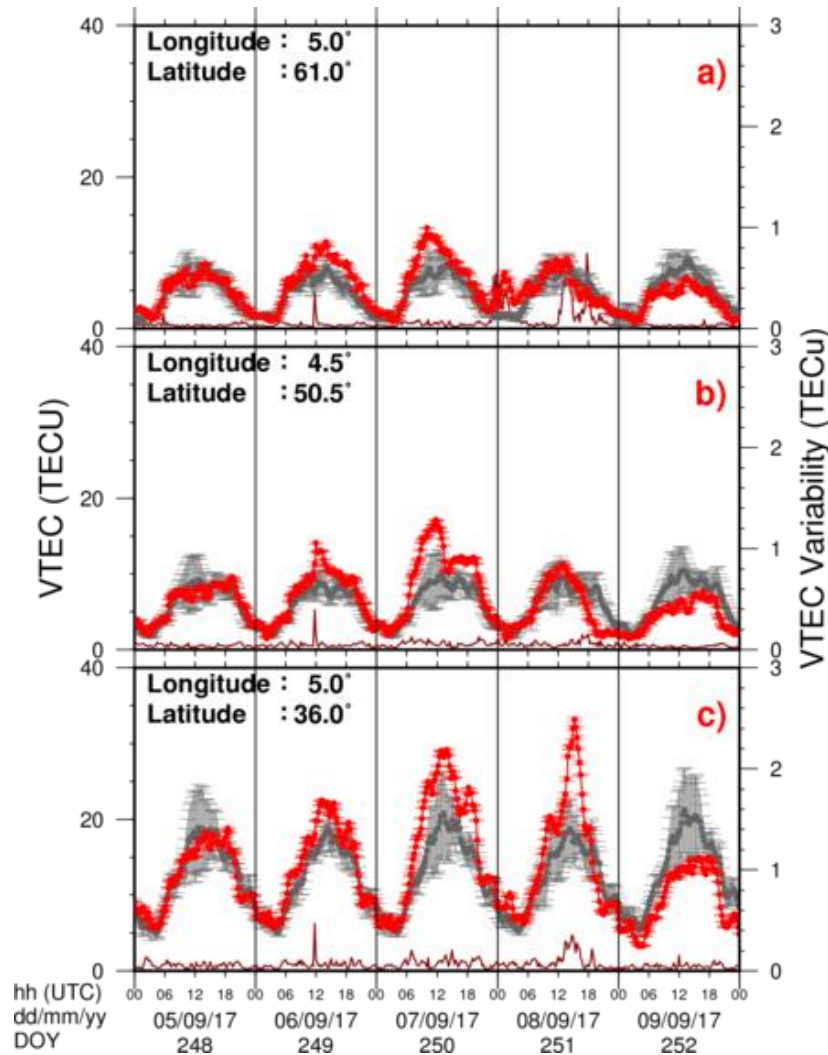


Normal ionospheric TEC behaviour : median of the VTEC for the 15 previous days



*Saint Patrick storm  
March 17<sup>th</sup> 2015 event*

**SUMMARY OF THE EVENT:** A solar flare occurred the 6/09/2017 generating a sudden small increase of TEC at noon with higher variability of TEC. The next days, the arrival of the CME generated disturbances in the North during night-time of the 7/09/2017 and at the end of the day 07/09/2017. An increase of TEC was also observed in the South the 07 and 08/09/2017. A depletion of TEC followed the following day 09/09/2017



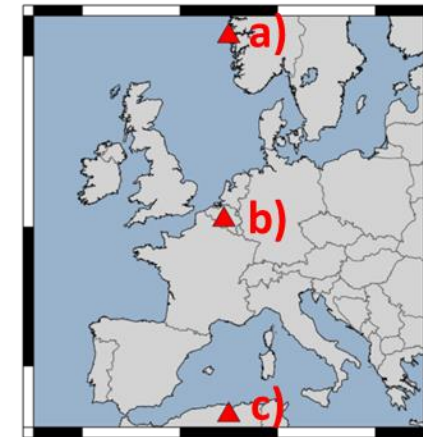
## TEC extracted from the NRT maps

**TEC current**

**15-days median TEC**

**TEC Variability**

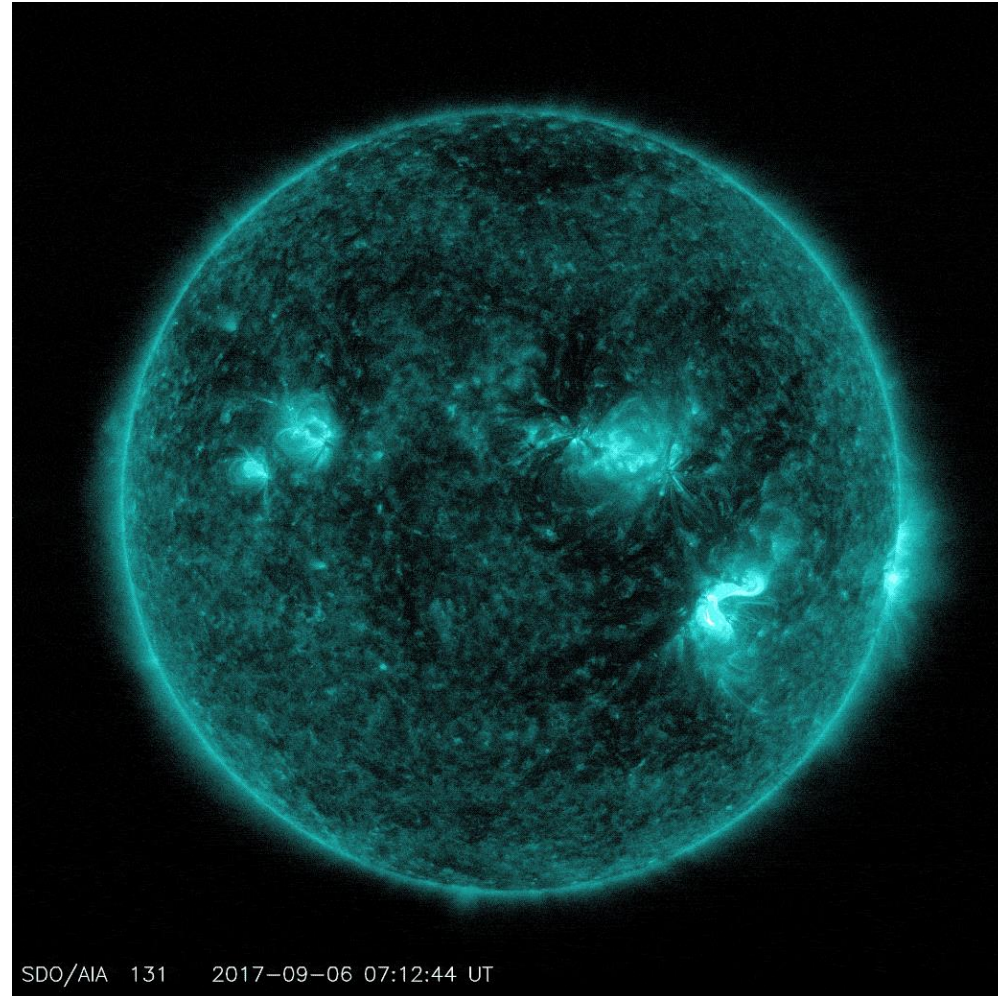
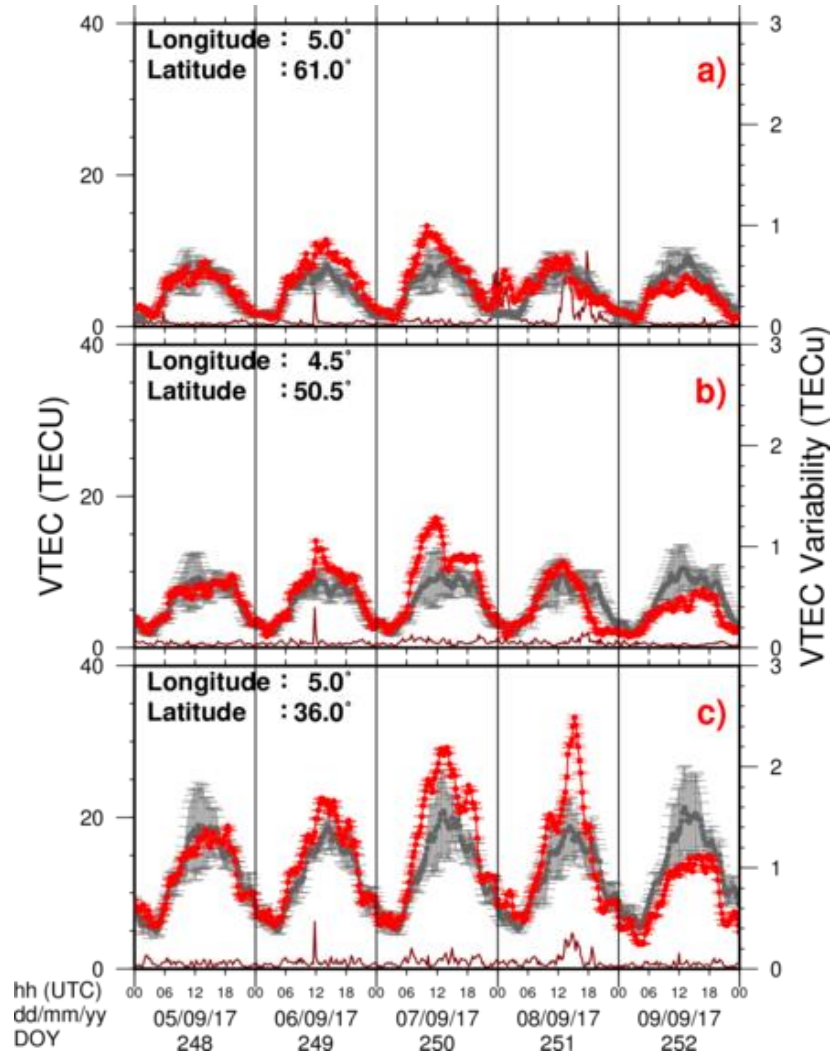
+ Links to interactive and statistical maps, and origin of the event [sidc.oma.be](http://sidc.oma.be)

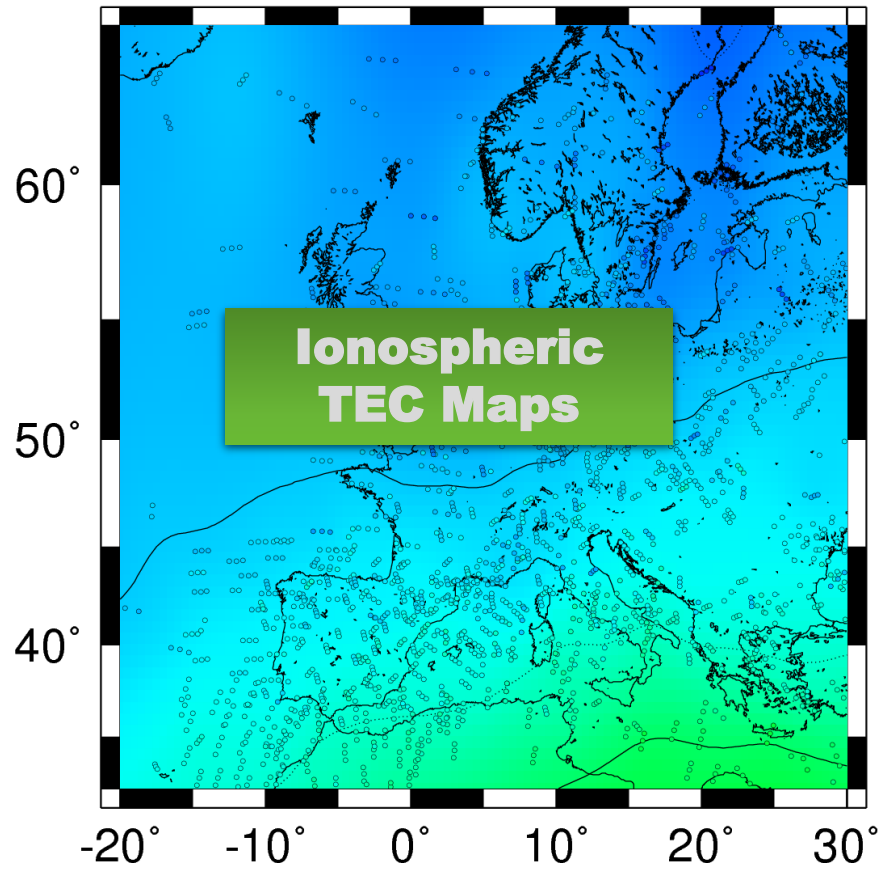


2012–2017 (43 events)



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**Climatology of  
the Ionosphere**

**Improving GNSS single  
frequency positioning**

**3D Ionosphere  
Nowcasting and  
Forecasting for  
ESA Space Situational  
Awareness**

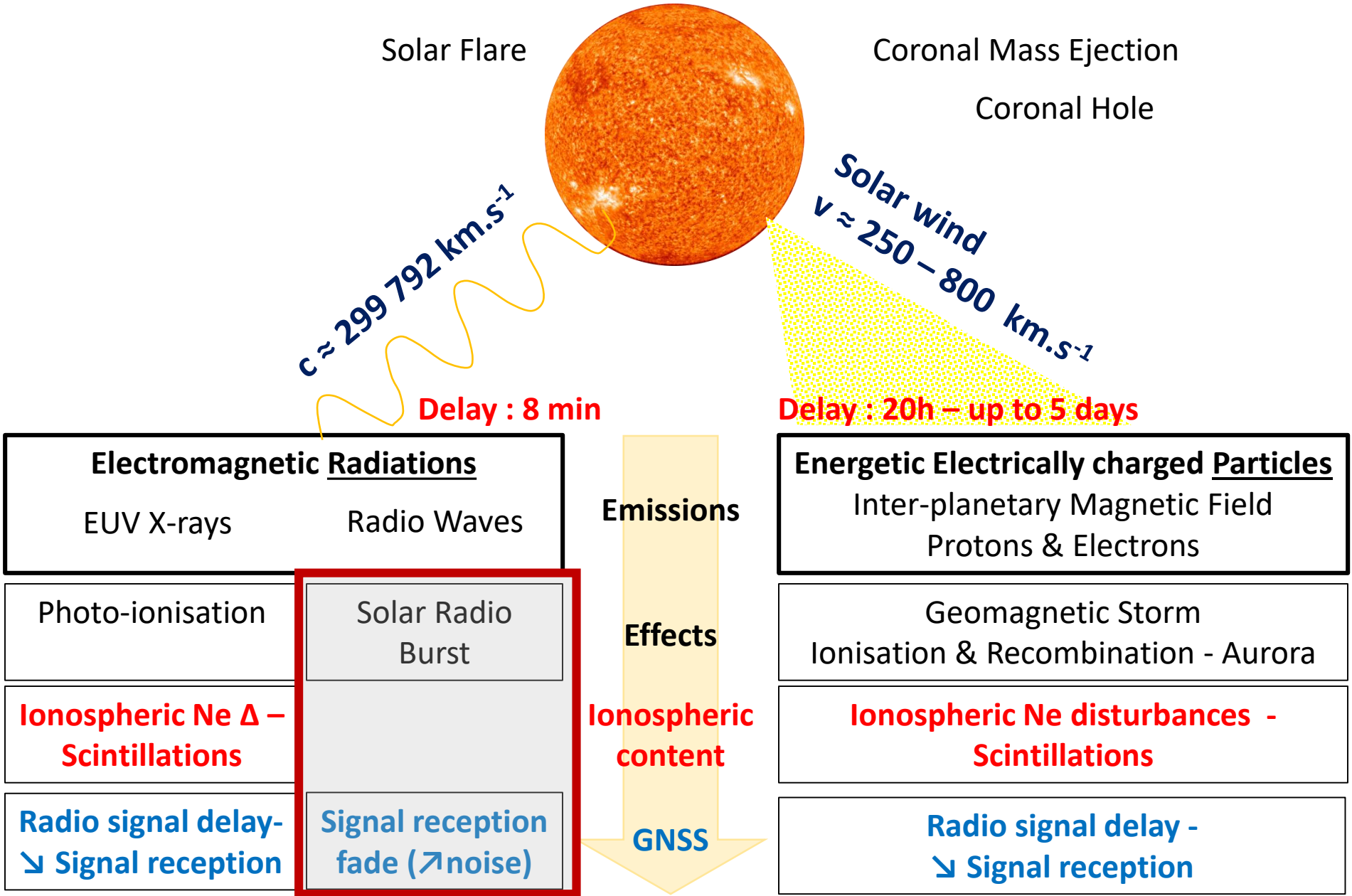


**IAG – Real-Time  
Ionospheric Monitoring  
Working Group**

**Solar Eclipse 20<sup>th</sup> Mar. 2015  
RT and post**

**Ionospheric  
TEC Maps**

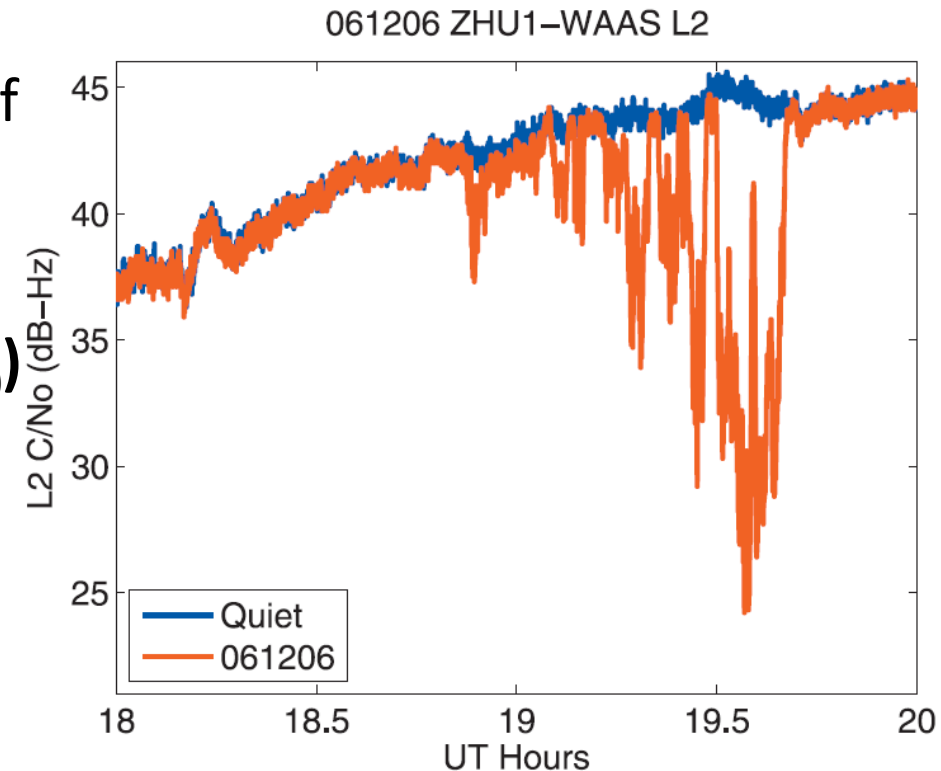


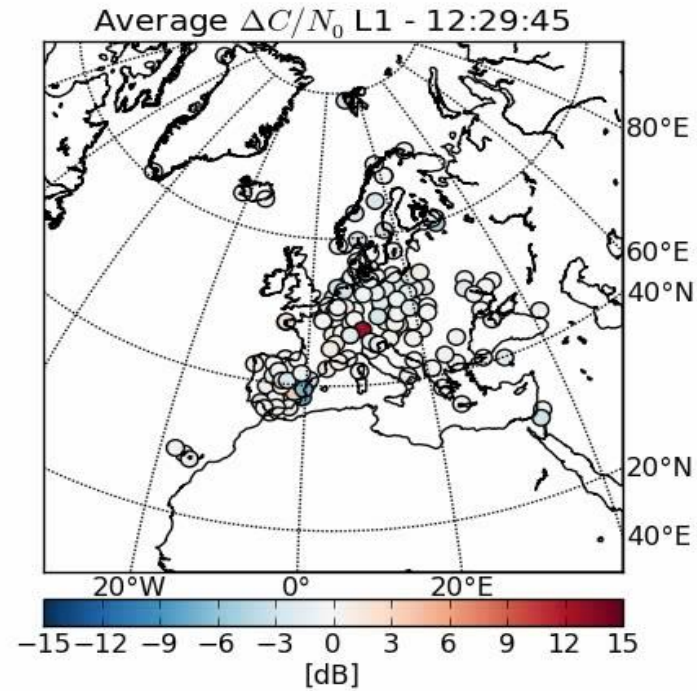
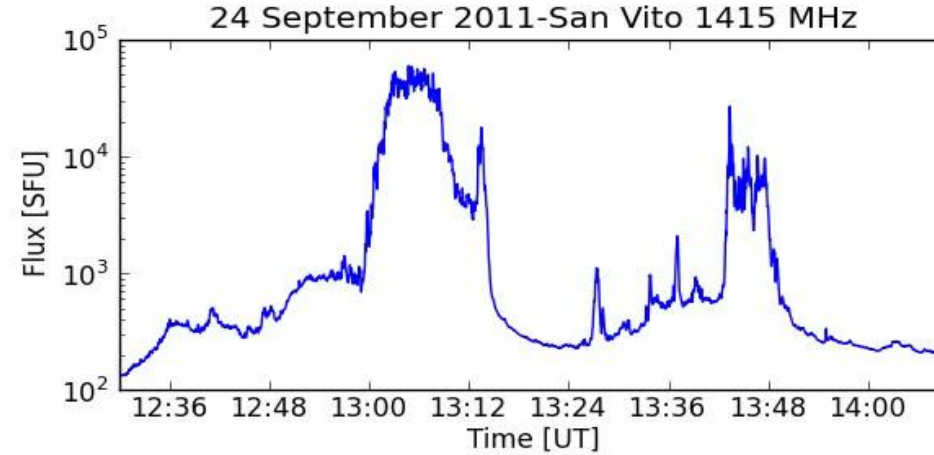


- The Sun emits in radio over a wide frequency range (from few kHz to GHz)
- Solar Radio Bursts (**SRB**) are intense radio emissions (durations from 10s to few hours)

- SRBs increase the noise level of GNSS ground stations

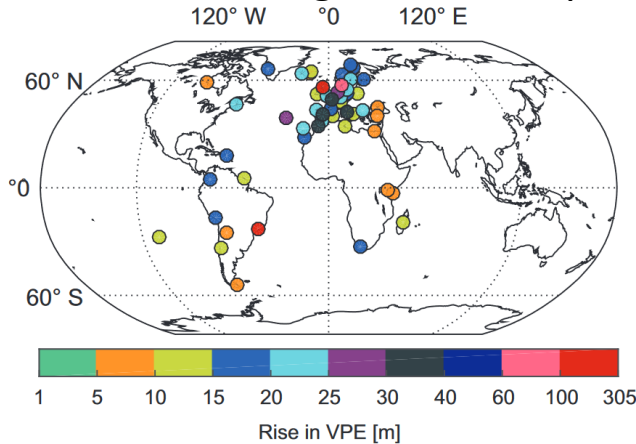
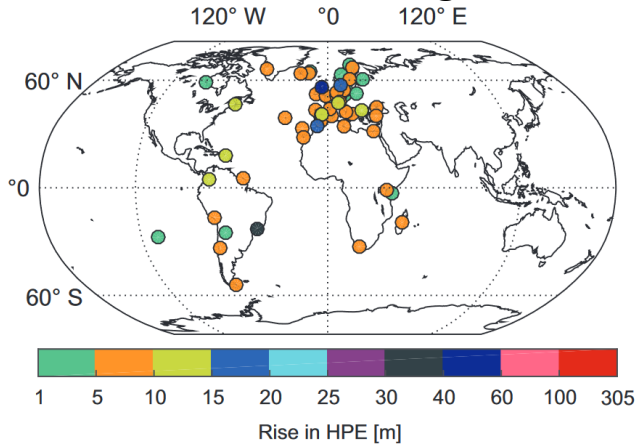
- **Carrier-to-Noise density ( $C/N_0$ )**  
[35; 55] dB-Hz



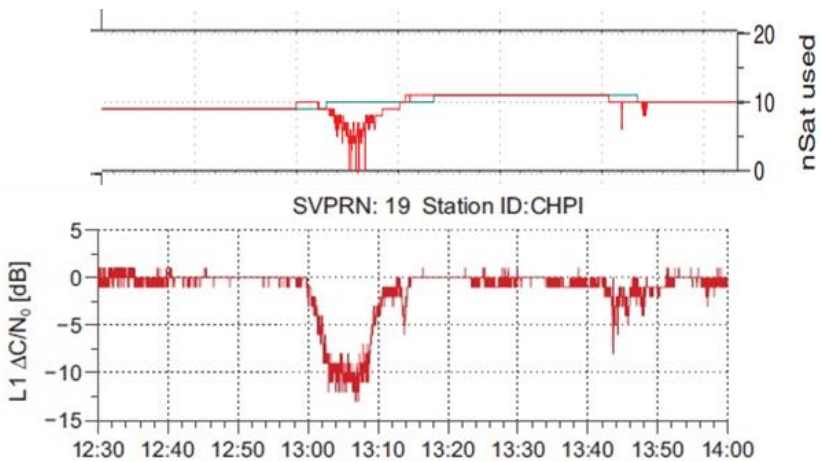


**SRB of the  
24/09/2011**  
*Muhammad et  
al. 2015*

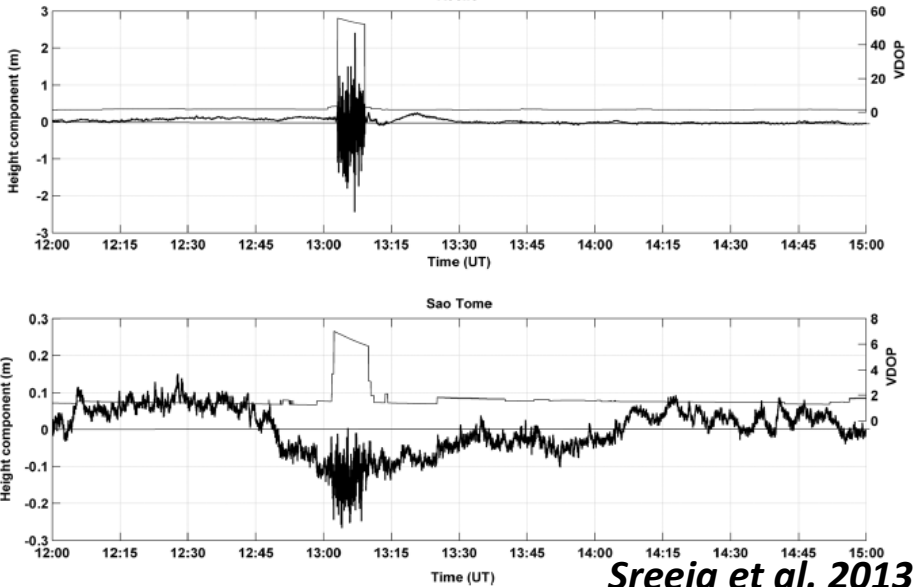
Rise in error = Positioning error during SRB – Positioning error on a quiet day



Sao Paulo, Brazil



**PPP method**



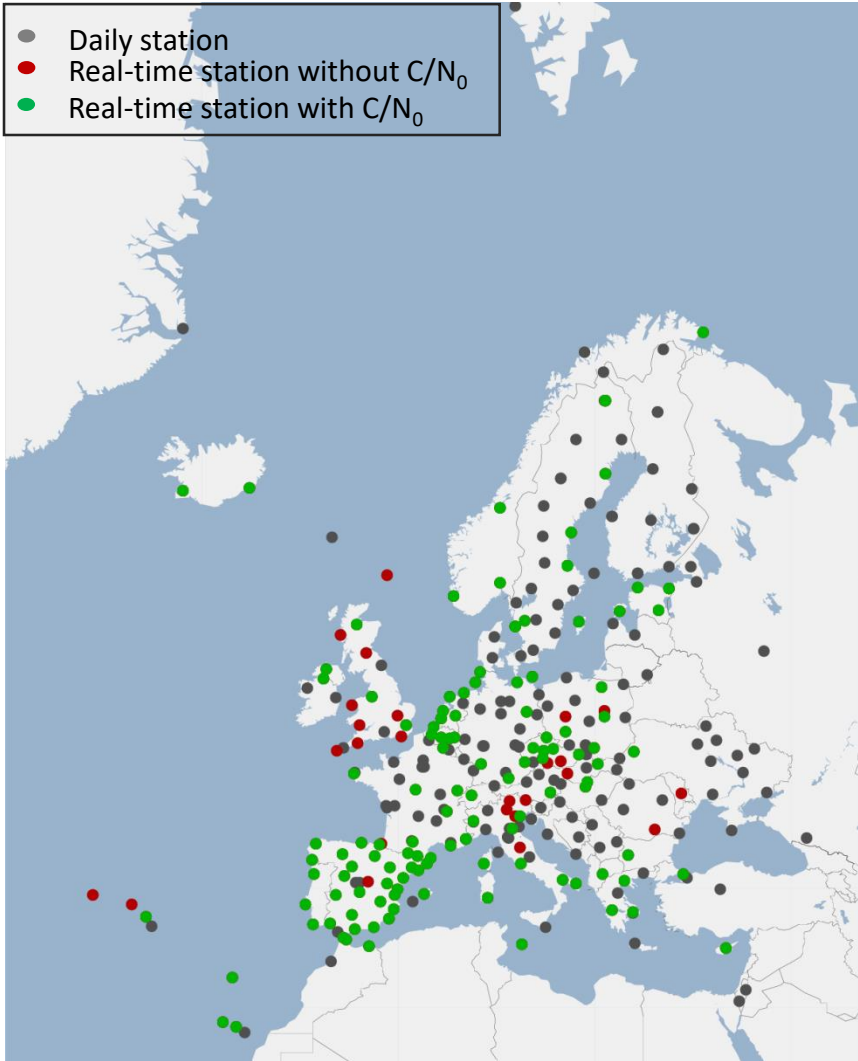
*Sreeja et al. 2013*

# RT monitoring of the abnormal fade of GNSS signal reception due to SRB at the 2 GNSS frequency bands L1 and L2

*Chevalier et al., URSI GASS 2017*

$C/N_0$  (dB-Hz) extracted from RINEX files (S1-S2)

Level	GNSS $\Delta C/N_0$ Fade		Effect
Quiet	>-1dB-Hz	none	
Moderate	-1 dB-Hz	SRB detected but should not impact GNSS applications	
Strong	-3 dB-Hz	Potential impact on GNSS applications	
Severe	-10 dB-Hz	Potential failure of the GNSS receivers	



## Last Ionospheric Events

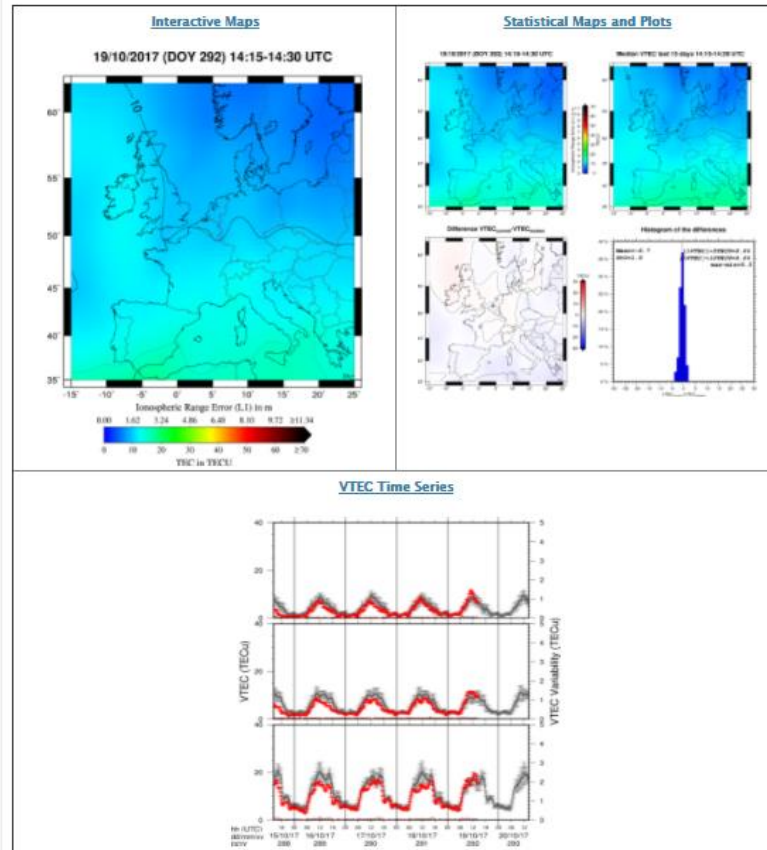
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Solar Radio Bursts (SRB) emitted at the GNSS frequencies can affect the GNSS signal reception. To detect such event, a [near-real time SRB warning system](#) with a 4-level index was set in Europe using the real-time EUREF Permanent Network.

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[www.gnss.be](http://www.gnss.be)

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- Warning System
- Event Description



[www.gnss.be](http://www.gnss.be)

## SRB WARNING SYSTEM FOR GNSS APPLICATIONS IN EUROPE

Contact: [iono@oma.be](mailto:iono@oma.be)

To receive real-time alert emails, please contact us to be added to the mailing list.

Last update : 2015-11-04 14:29:30	L1	L2
Last 15min		
Last 24h		
Last week		

Events of the last 30 days:

Frequency	Date of the maximum fade	Maximum fade (in dB/Hz)	Beginning of the event (fade < -1 dB/Hz)	End of the event (fade > -1 dB/Hz)
L2	2015-11-04 14:29:00	-5.75±2.26	2015-11-04 14:22:00	On-Going

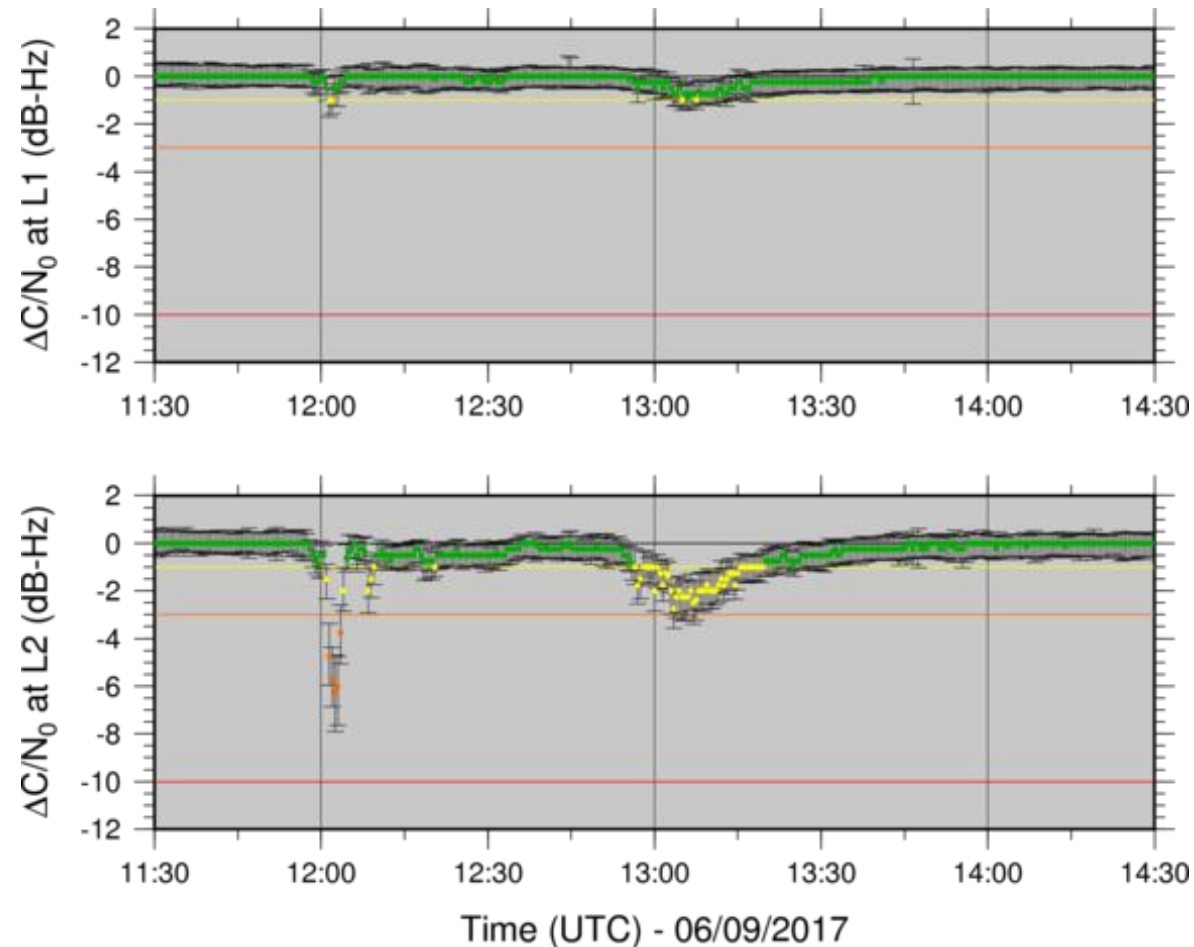
To detect Solar Radio Burst (SRB) affecting the GNSS signal reception in Europe, the carrier to noise density (C/N0) of the real-time EPN GPS network are monitored in near-real time (updated every 15 minutes). The intensity of the SRB impacts on GNSS applications are indexed at 4 levels:

- **quiet**
- **moderate** : SRB detected but should not impact GNSS applications,
- **strong** : potential impact on GNSS applications,
- **severe** : potential failure of the GNSS receivers.

### Previous SRB Events at the GNSS frequencies

- 2015-11-04 : Space weather event due to Solar Radio Burst ([more here](#))

**SUMMARY OF THE EVENT:** The solar radio bursts of the 06/09/2017 impacted the GPS signal reception at both frequencies L1 and L2. On L1, two fades above 1dB-Hz were detected at 12h01 and 12h05. On L2, a first fade above 3dB-Hz which could potentially affect the GNSS application, occurred for 3 min with a maximum of  $-6.25 \pm 1.6$  dB-Hz at 12h02. It was followed by a second lower fade above 1dB-Hz at 13h03. For additional information about the burst on a larger frequency spectrum see at [SIDC Humain Radioastronomy Station](#).



## ■ IONOSPHERE

- TEC maps (+TEC variability) over Europe since 2012 in near-real time (0.5°x0.5° grids, 15 min.)
- Visualisation of the ionospheric activity : [www.gnss.be](http://www.gnss.be)
- Data: <ftp://gnss.oma.be>
- Scientific applications : Climatology of the Ionosphere, GNSS single frequency positioning(...)

## ■ SOLAR RADIO BURST

- GNSS signal reception is monitored in real-time
- SRB Warning System
- Register at the email alert : [iono@oma.be](mailto:iono@oma.be)

Thank you