Solar-Terrestrial
Center of Excellence

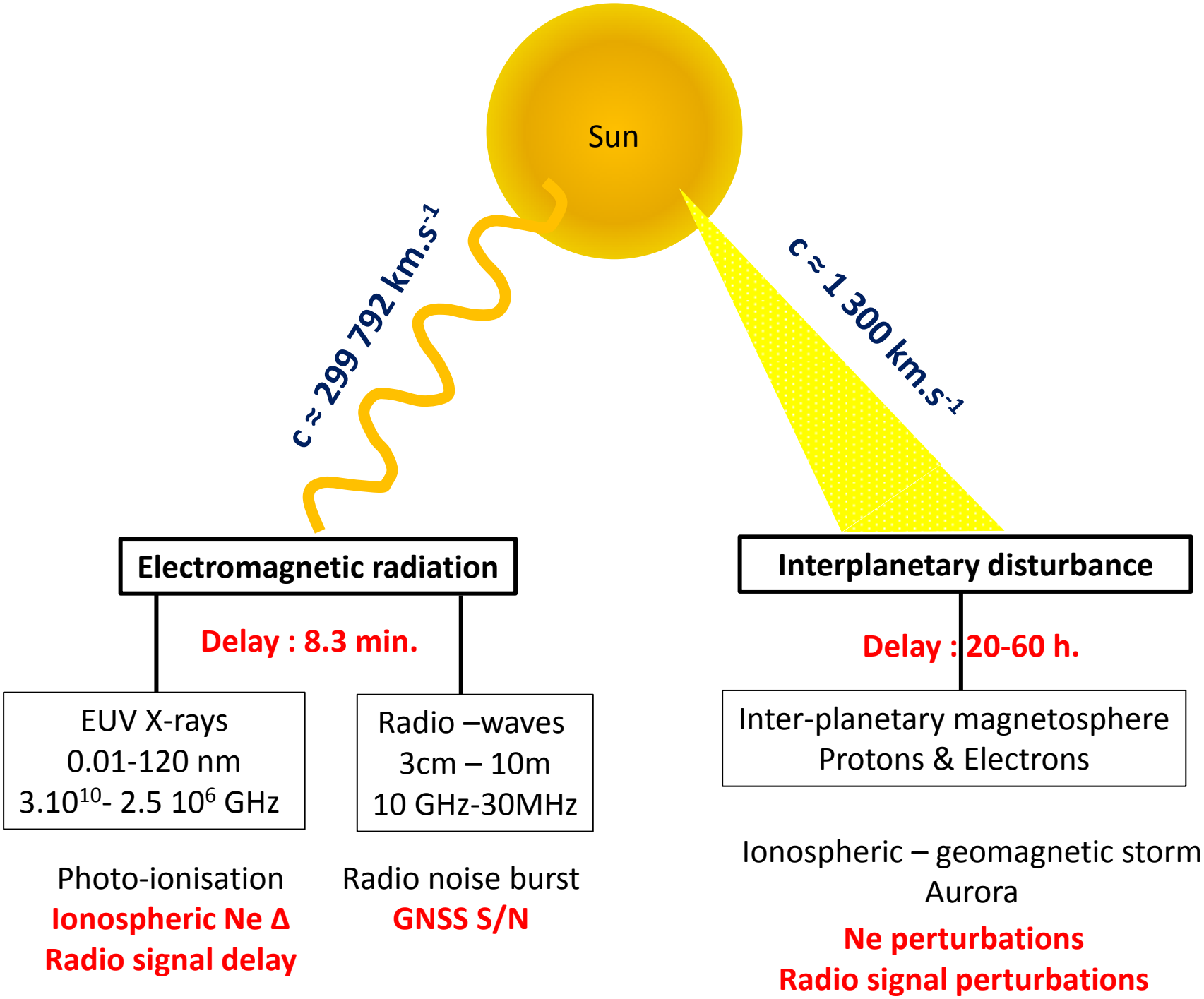
Royal Observatory
of Belgium

Space Weather products and studies based on EPN GNSS data at ROB

N. Bergeot, J.-M. Chevalier

C. Bruyninx, E. Pottiaux, Q. Baire, J. Legrand,

P. Defraigne and W. Aerts


Sun
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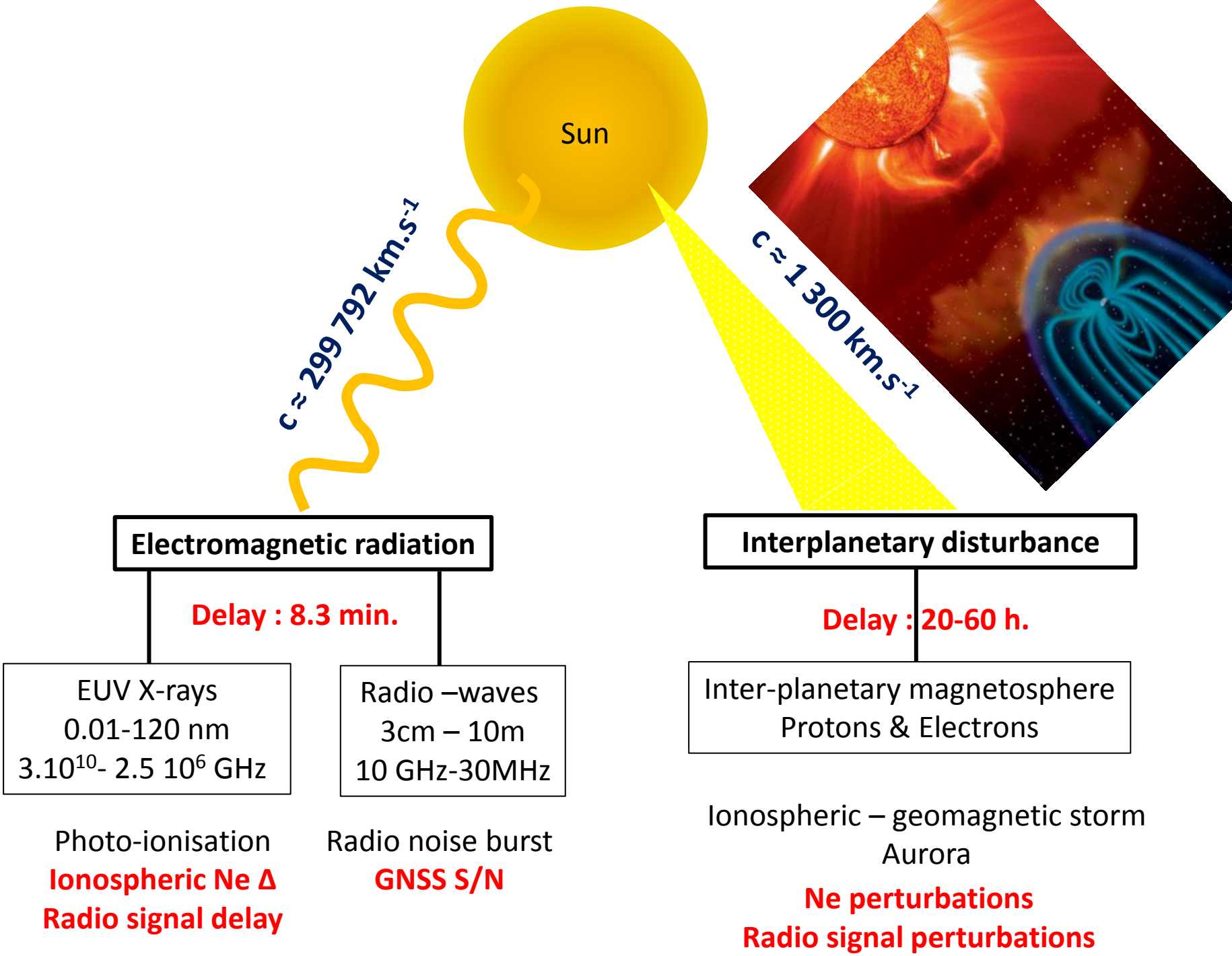
c ≈ 1 300 km.s-1
Electromagnetic radiation
Delay : 8.3 min.
EUV X-rays
0.01-120 nm
3.10^10- 2.5 10^6 GHz
Radio –waves
3cm – 10m
10 GHz-30MHz
Photo-ionisation
Ionospheric Ne Δ
Radio signal delay
Radio noise burst
GNSS S/N
Interplanetary disturbance
Delay : 20-60 h.
Inter-planetary magnetosphere
Protons & Electrons
Ionospheric – geomagnetic storm
Aurora
Ne perturbations
Radio signal perturbations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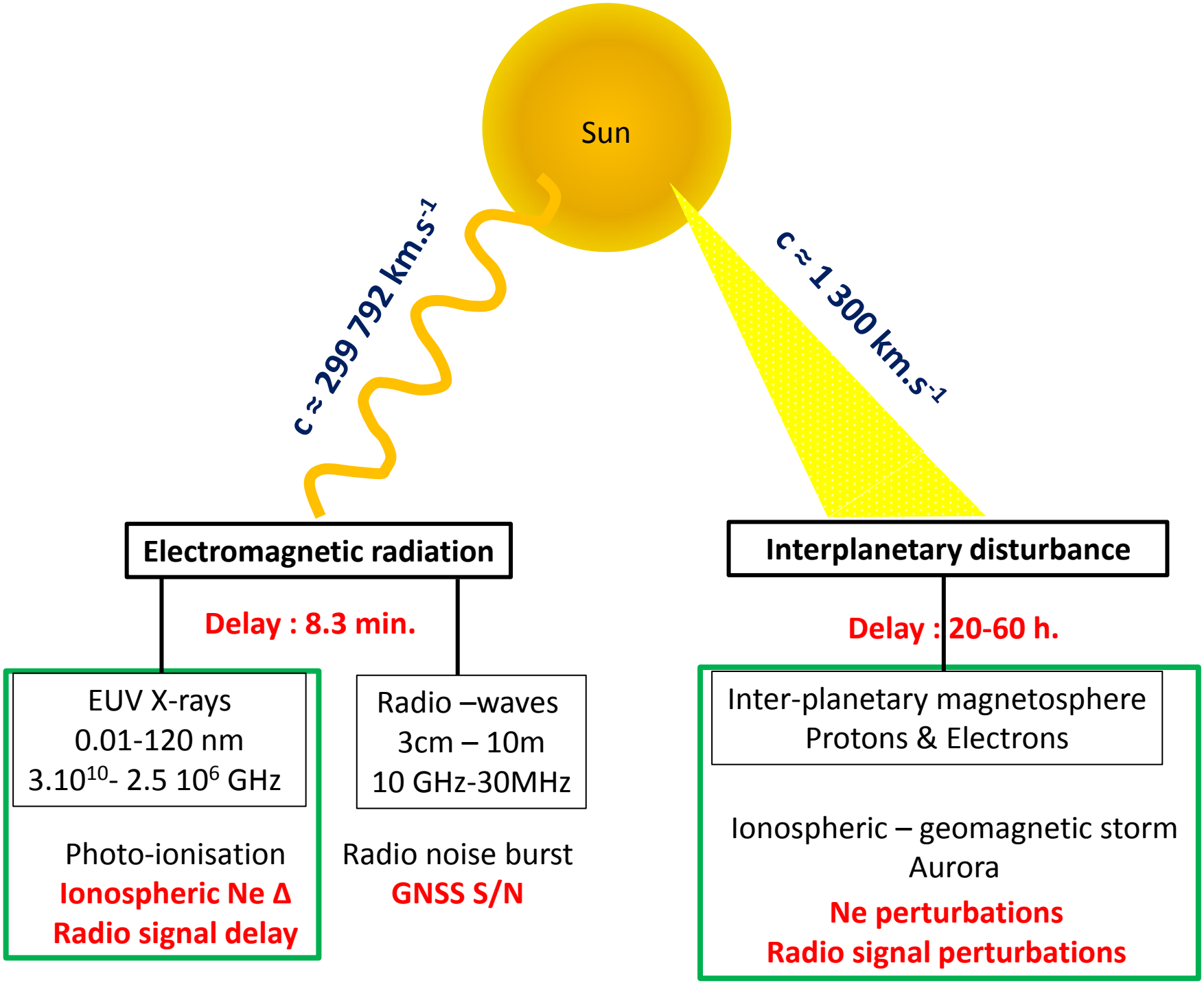
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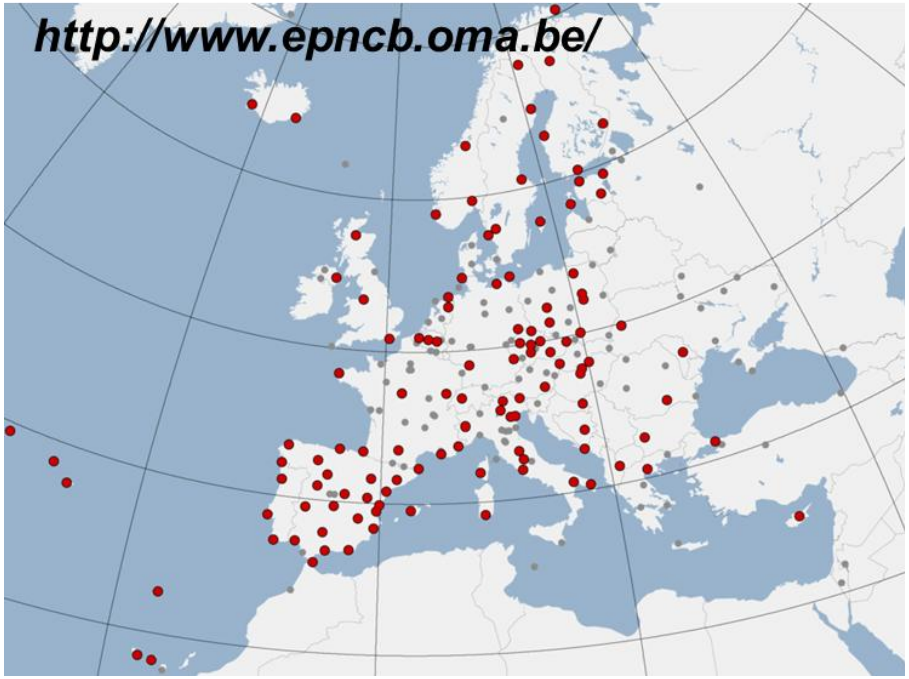
On-line products based on GNSS data

European Permanent Network (EPN)

- Continuously observing GNSS stations since 1996
- Presently: ~ 250 stations over Europe
- **RT : Presently ~ 120 stations**



Real-time data from the EUREF Permanent Network (EPN) provided by the ROB [- BKG] NTRIP broadcaster

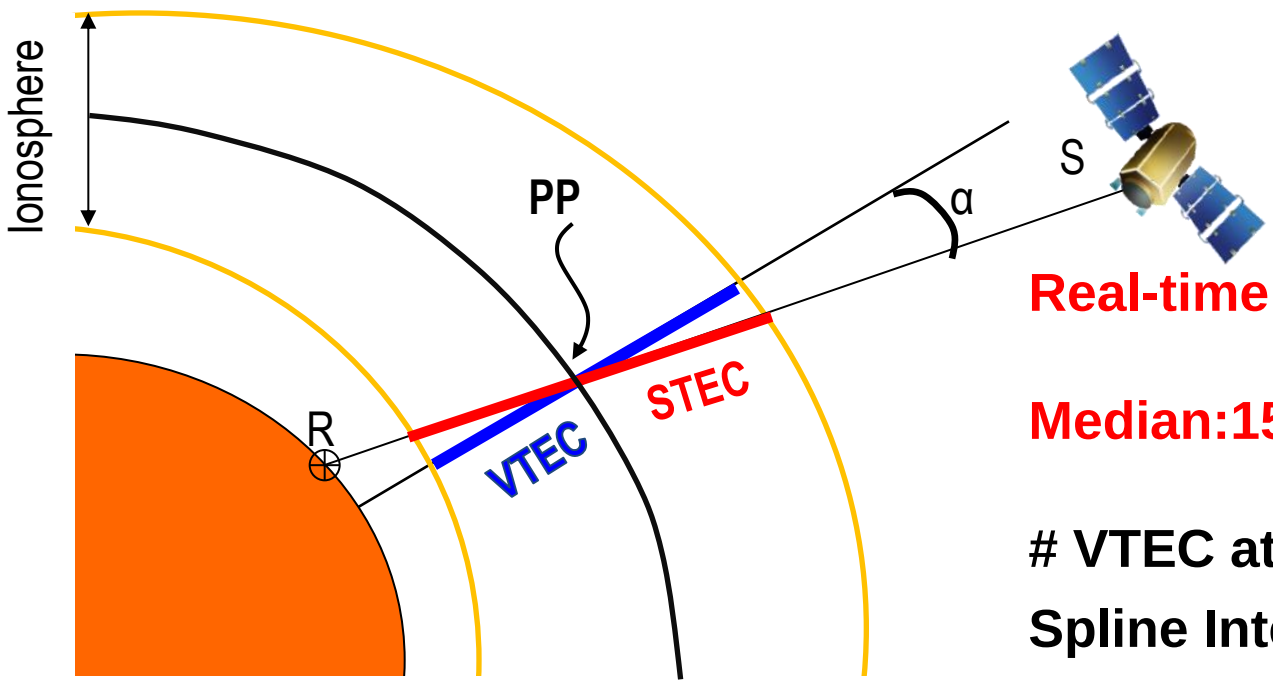
[e.g. Söhne et al. 2010]

Ionospheric monitoring from EPN NRT GNSS data

$$P_2 - P_1 + DCB^s + DCB_r = 40.3\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)\underline{STEC}$$

$$\underline{VTEC} = \underline{STEC} \times \cos(\alpha)$$

1TECu = 10^{16}e$^-$.m^{-2}



Real-time EPN GNSS data

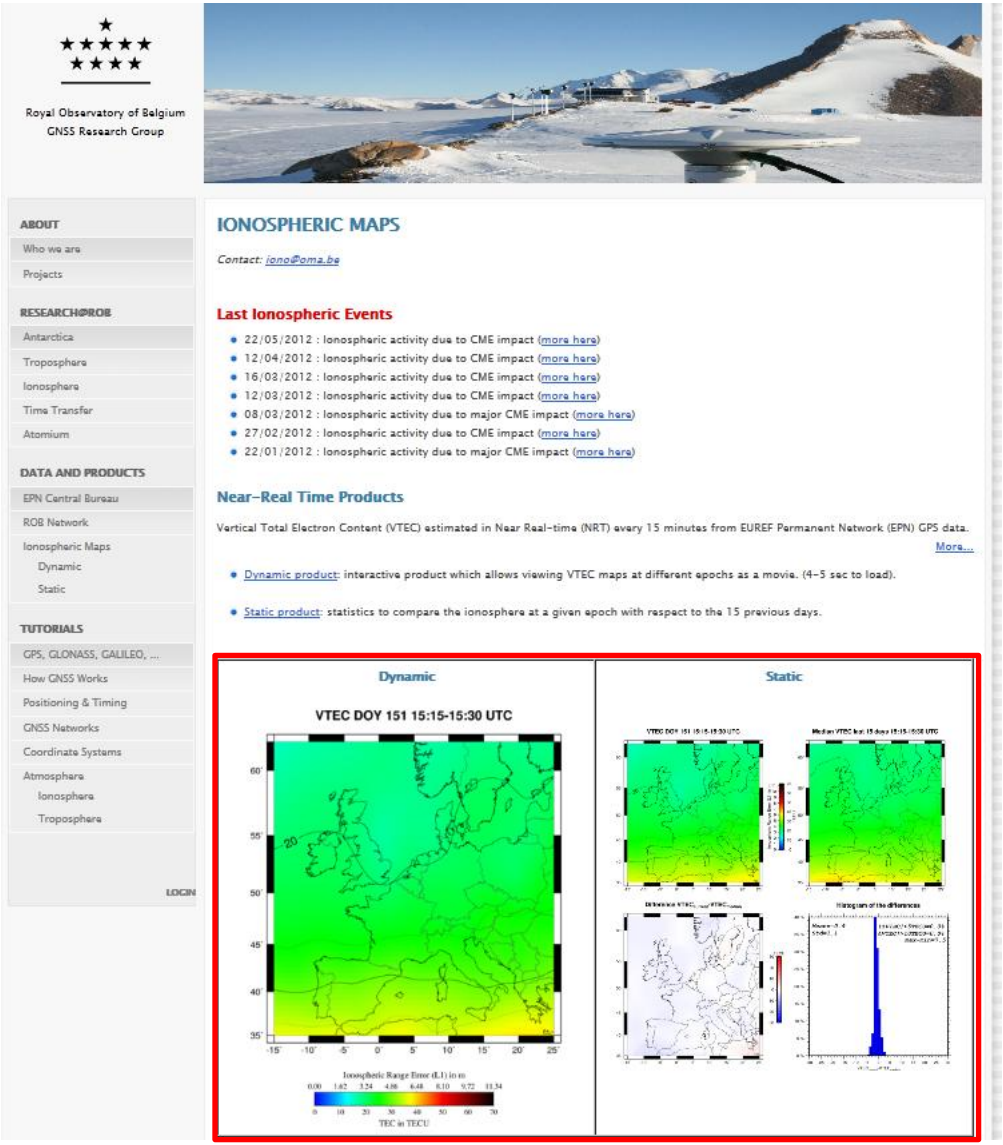
Median:15min.of VTEC/Rec/Sat

 # VTEC at PP : 1692 ± 271.

Spline Interpolation.

VTEC grid : 0.5°x0.5° - 15 min.

Products available on-line

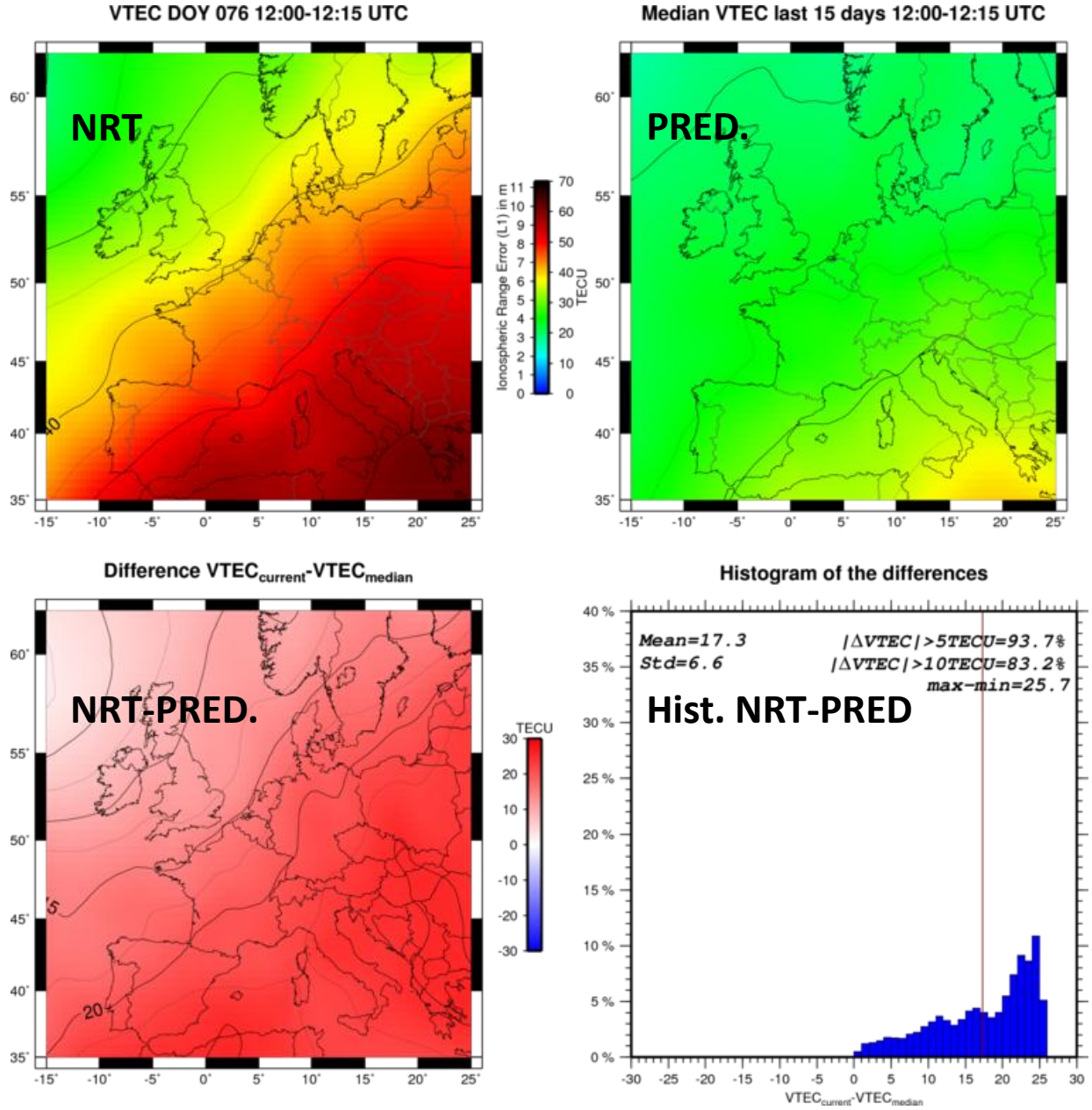


http://www.gnss.be

DATA AND PRODUCTS

- **IONOSPHERIC MAPS**
  - **DYNAMIC**
  - **STATIC**

Products available on-line



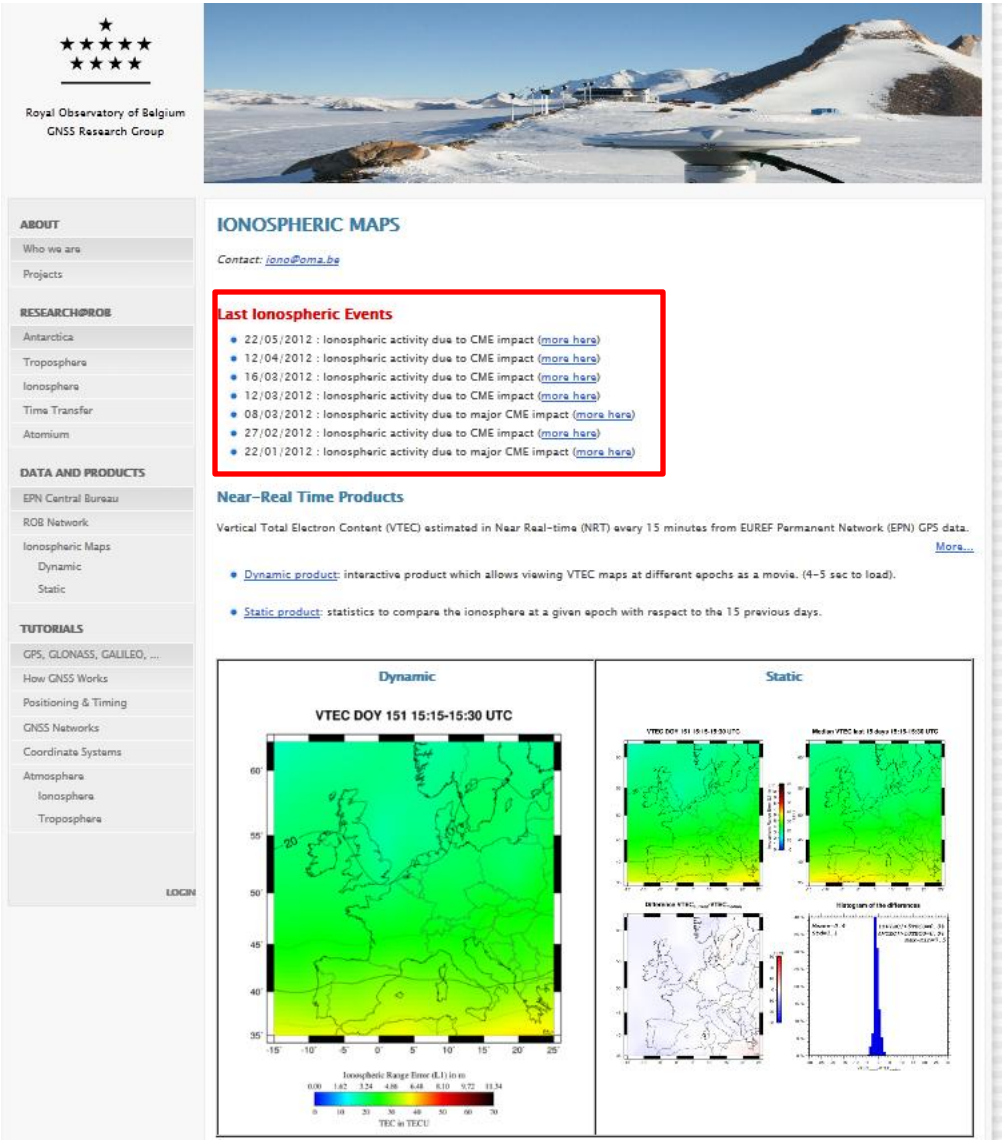
March 17th 2013 event

Statistical products

Prediction :

Median of the VTEC for the 15 previous days.

Products available on-line



http://www.gnss.be

DATA AND PRODUCTS

- IONOSPHERIC MAPS
  - DYNAMIC
  - STATIC
- **IONOSPHERIC EVENTS**

Products available on-line

ftp://gnss.oma.be/

IONosphere map EXchange format (**IONEX**) [Schaer et al. 1998]

ftp://gnss.oma.be/gnss/products/IONEX/yyyy/ddd/

File format : ROBRdddhmm.yyI.Z

yyyy	: year
ddd	: DOY
h	: UTC hour of the DOY (A = 00, B = 01 .... X = 23)
mm	: minutes of the hour (00,15,30 or 45)
yy	: last digit of the year (e.g. 13 presently)

e.g. ROBR136H45 .13I.Z

Near-real time ionospheric products

DIAS, SWANS

Newsletters

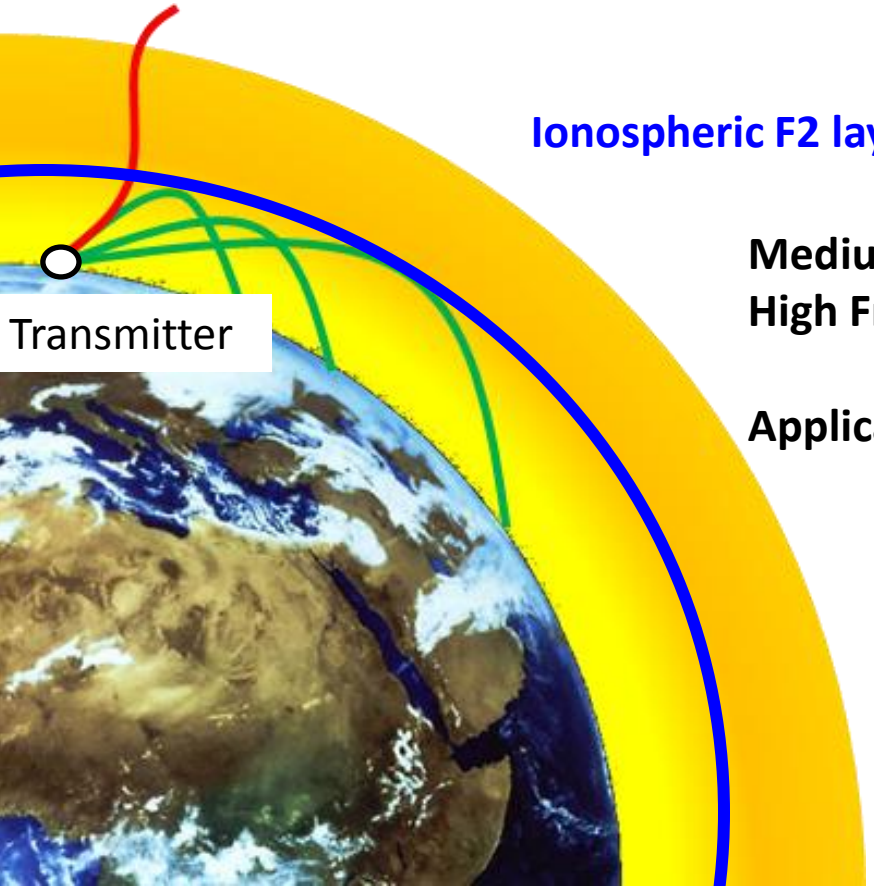
STCE weekly ionospheric TEC time-series

Research

GNSS single frequency, radio science

Products under development

F2 Critical frequency = foF2



Ionospheric F2 layer ~ 300-400 km.

Medium Frequency (0.3-3MHz)
High Frequency (3-30MHz)

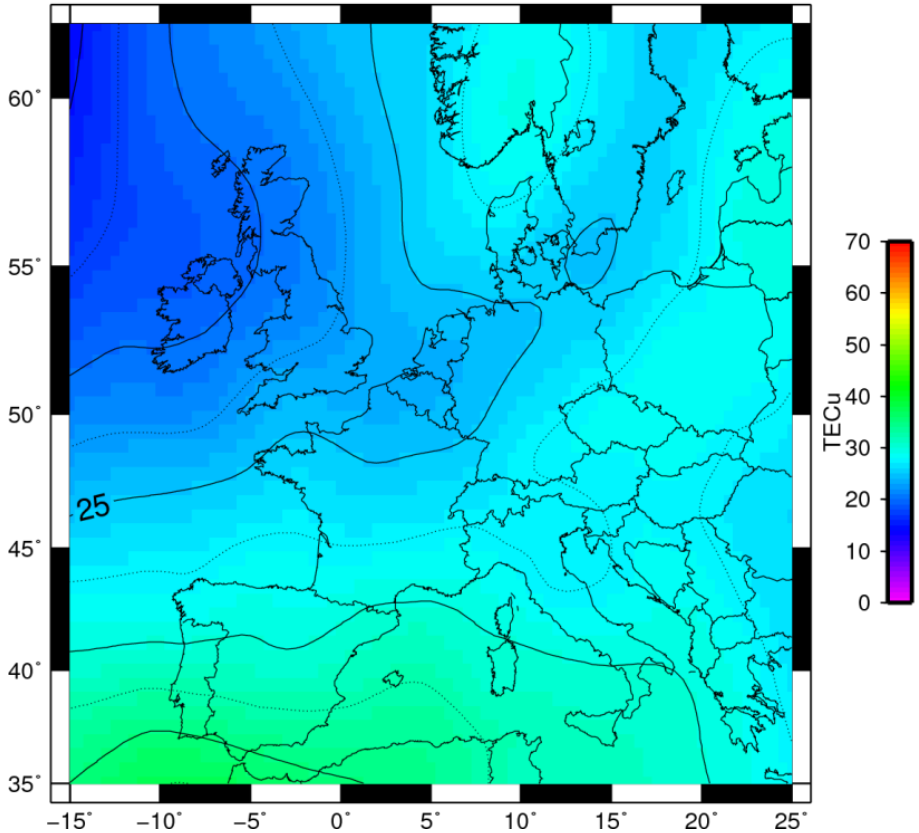
Applications : Aviation, amateur radio ….

< foF2 = Reflexion

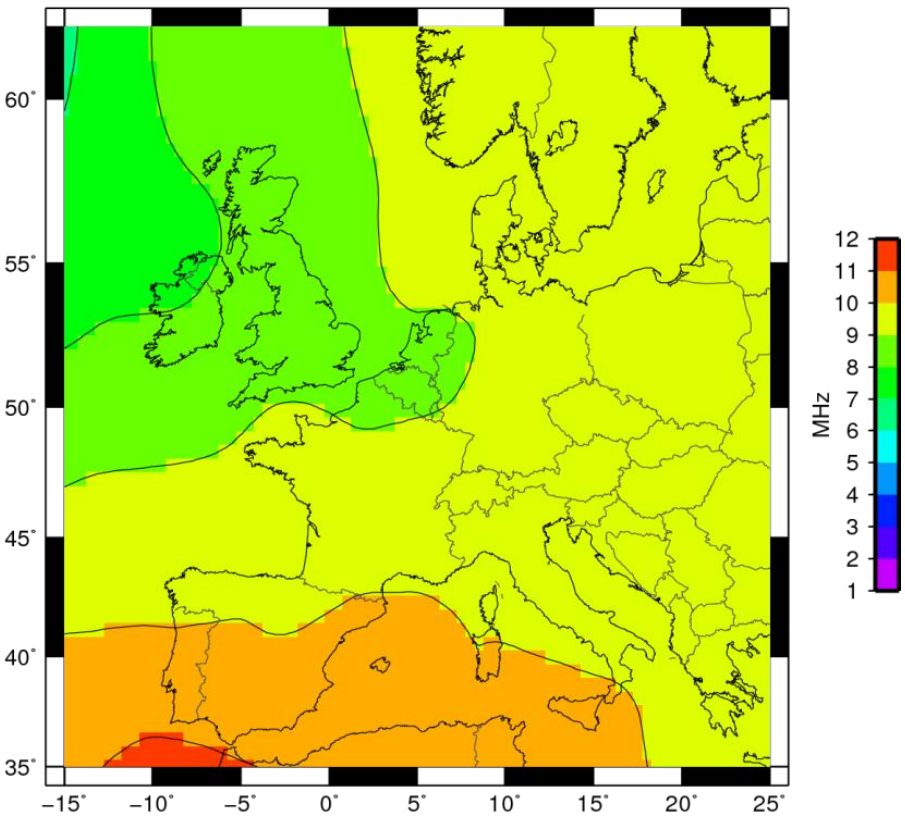
> foF2 = Refraction

F2 Critical frequency = foF2

NRT-VTEC ROB maps

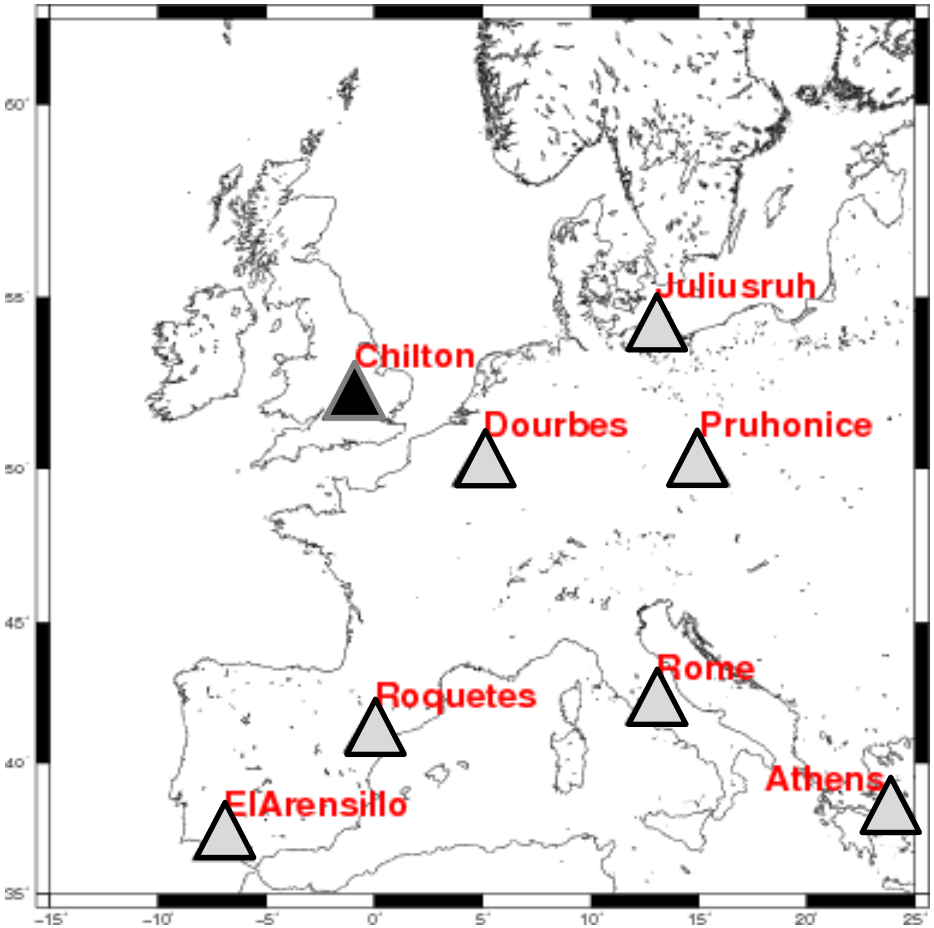


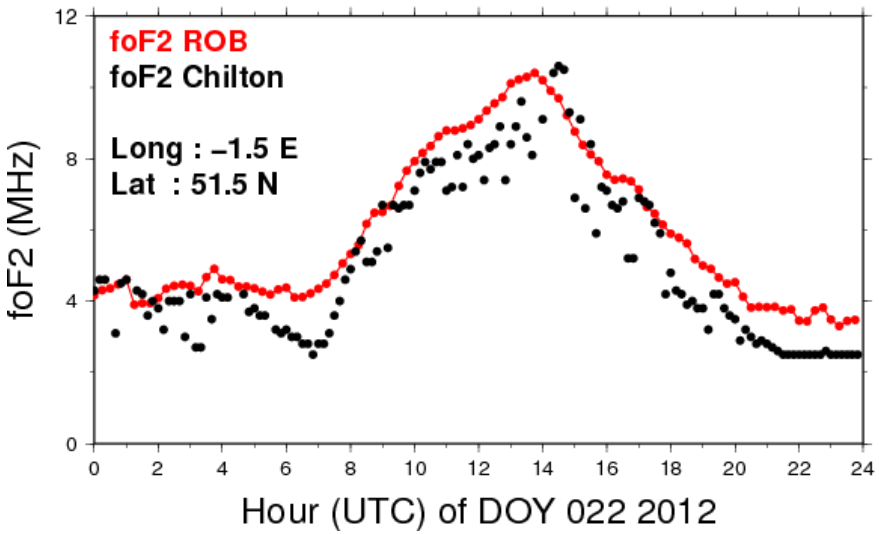
NRT-foF2 ROB maps



NRT – FoF2 each 15min. on a 0.5°x0.5° grid

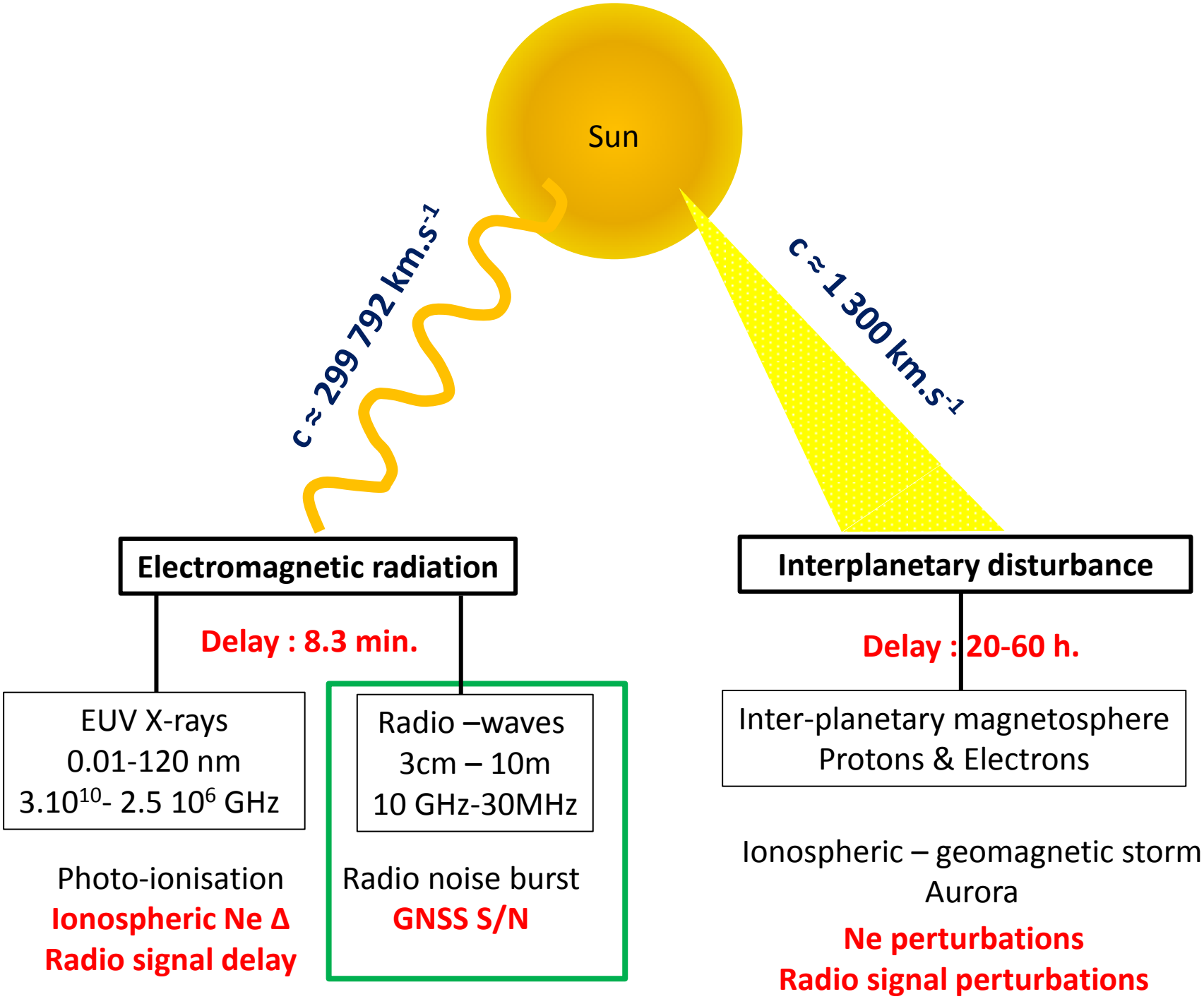
F2 Critical frequency = foF2





31 days in Jan. 2012
Each 15 min – 0.5°x0.5° grid

REL. Δ : 13 ± 17 %
ABS. Δ : 0.6 ± 0.5 MHz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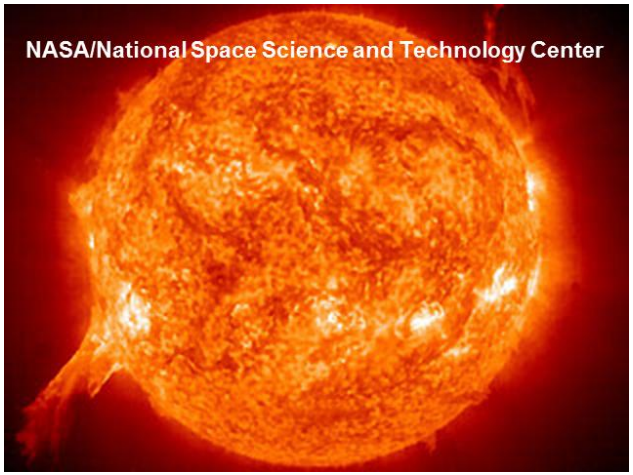
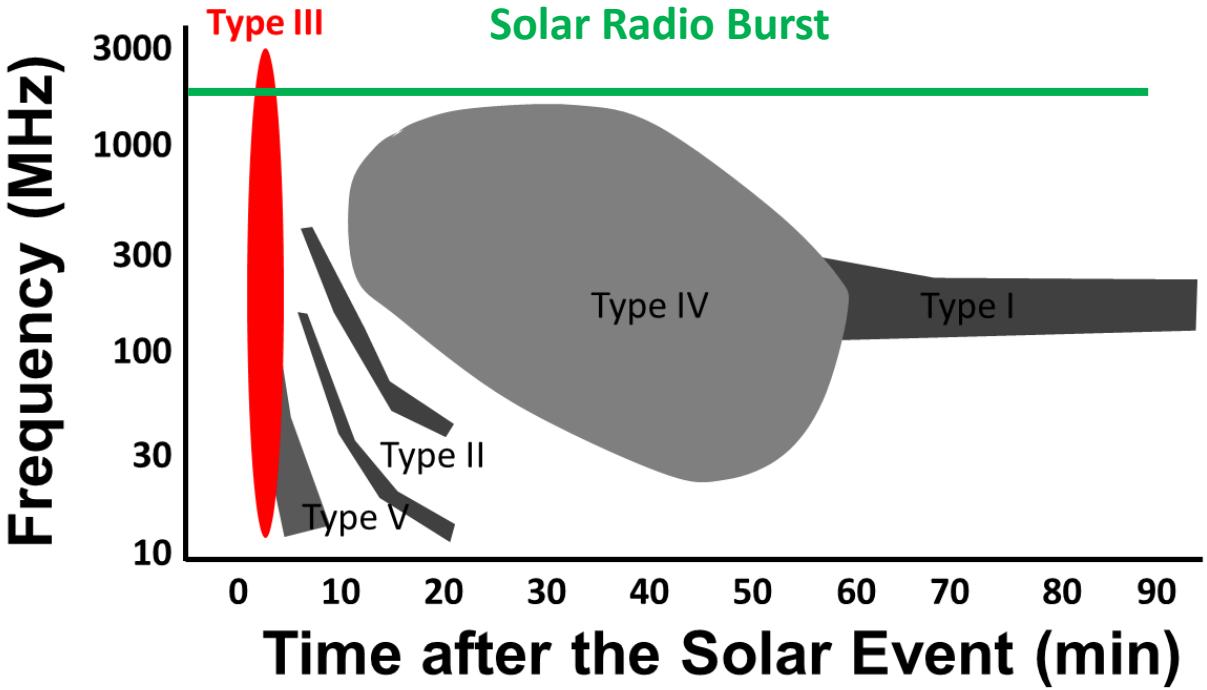
Study of the GNSS Signal/Noise

L1 and L2 Signal to Noise Ration (SNR) = S1 S2 observables RINEX observations files

S1/S2 in dB-Hz for the two GPS frequency.

- L1= 1575.42 MHz
- L2= 1227.60 MHz

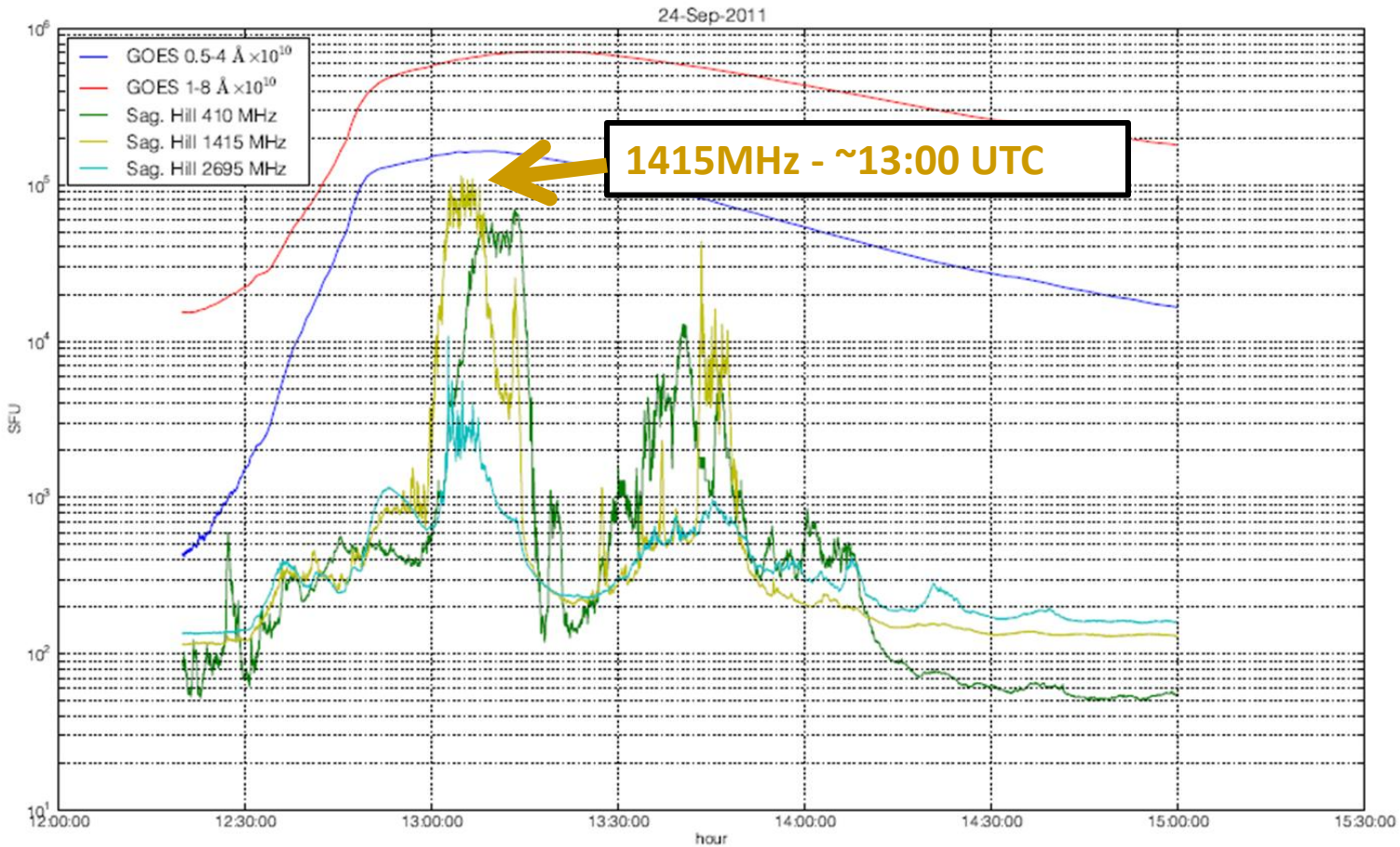




Study of the GNSS Signal/Noise

Frequencies emitted by the Sun 24-09-2011

Marqué et al. 2012



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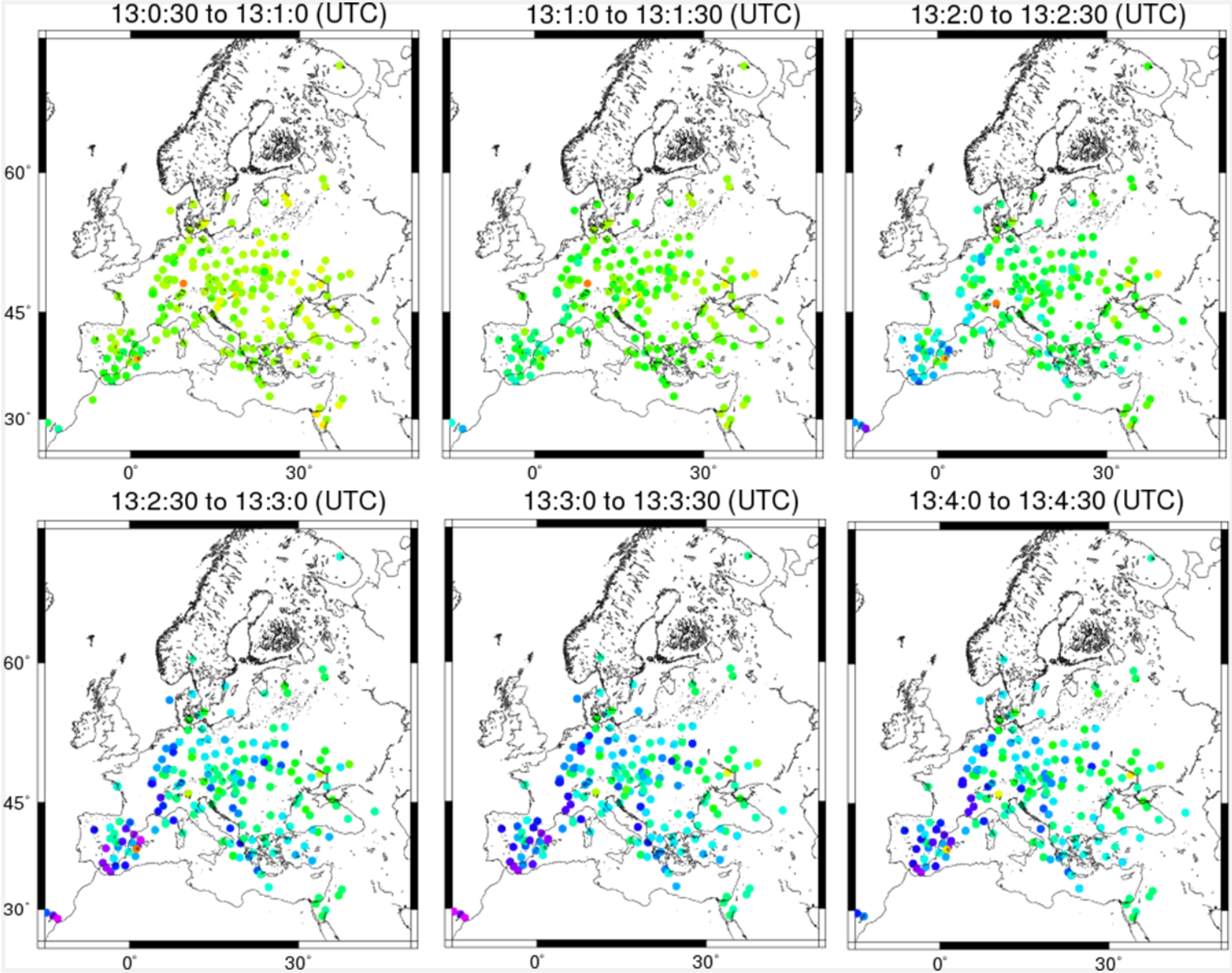

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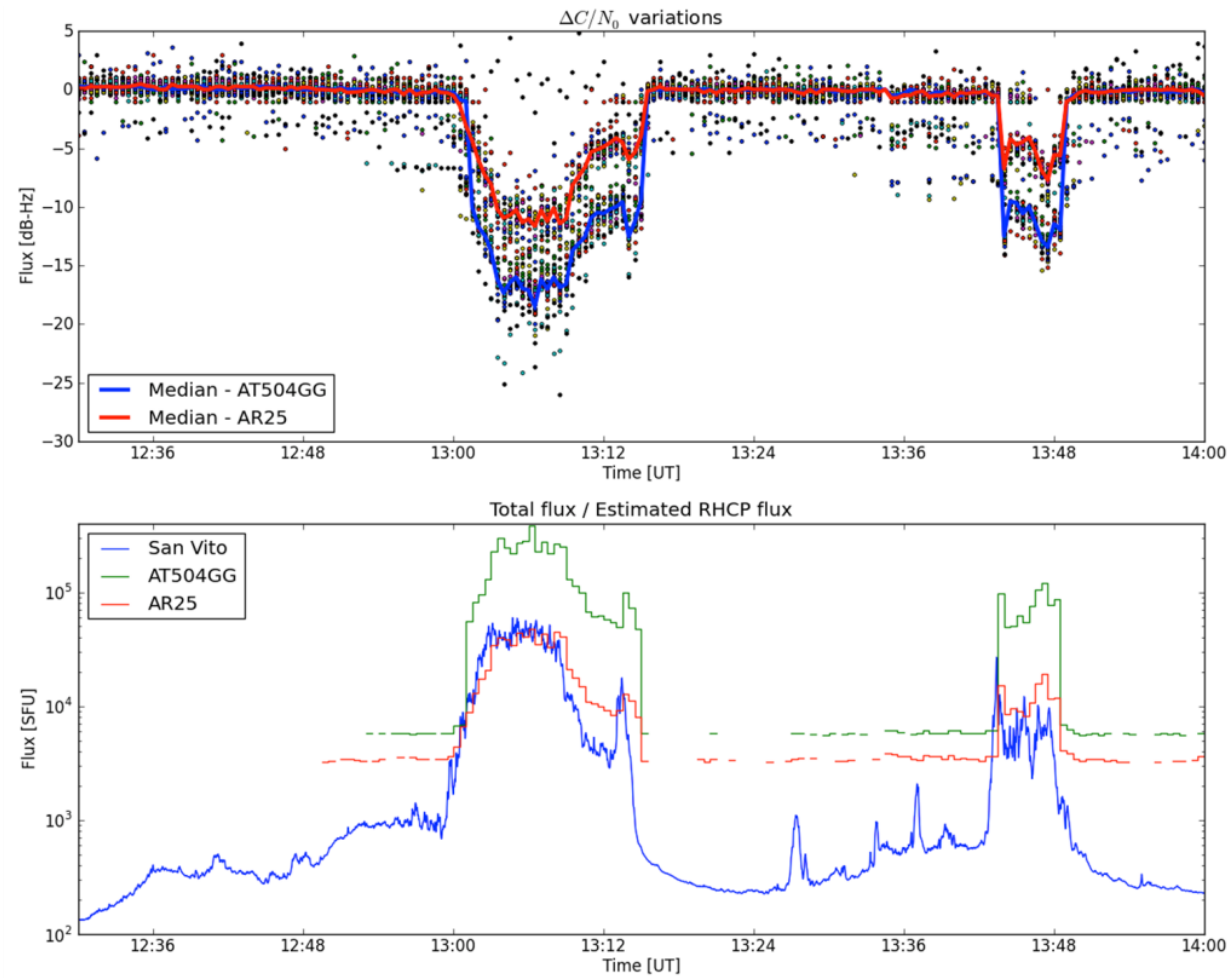


$\Delta C/N_0$ *drop (top) & estimated RHCP flux (bottom)*

$$F_{sun}[SFU]=N_0[W/Hz] \times \Delta C/N_0 / A_{eff}[m^2] / 10^{-22}$$

Conclusions and perspectives

- NRT-VTEC ROB maps each 15min. (0.5°x0.5°). Latency 2-10 min.
- Use of EPN NRT GNSS data from ROB [& BKG] NTRIP Broadcaster.
- Products available on **gnss.be**

  Densification of RT GNSS stations in Northern Part of Europe.

  Increase of S/N data in RT.
- Products under development (S/N, foF2).

iono@gnss.be

ftp://gnss.oma.be/

http://www.gnss.be

Tenth European Space Weather Week

November 18 - 22, 2013, Antwerp, Belgium

SPACE WEATHER EFFECTS ON HF AND TRANS-IONOSPHERIC RADIO WAVE PROPAGATION

Ioanna Tsagouri, David Altadill, Nicolas Bergeot, Michael Pezzopane

http://www.stce.be/esww10/

Deadlines

Abstract submission: May 31, 2013
Registration early bird: Oct 1, 2013
Fair stand submission: Nov 1, 2013

Ionospheric activity

Ionosphere (50-1000km):

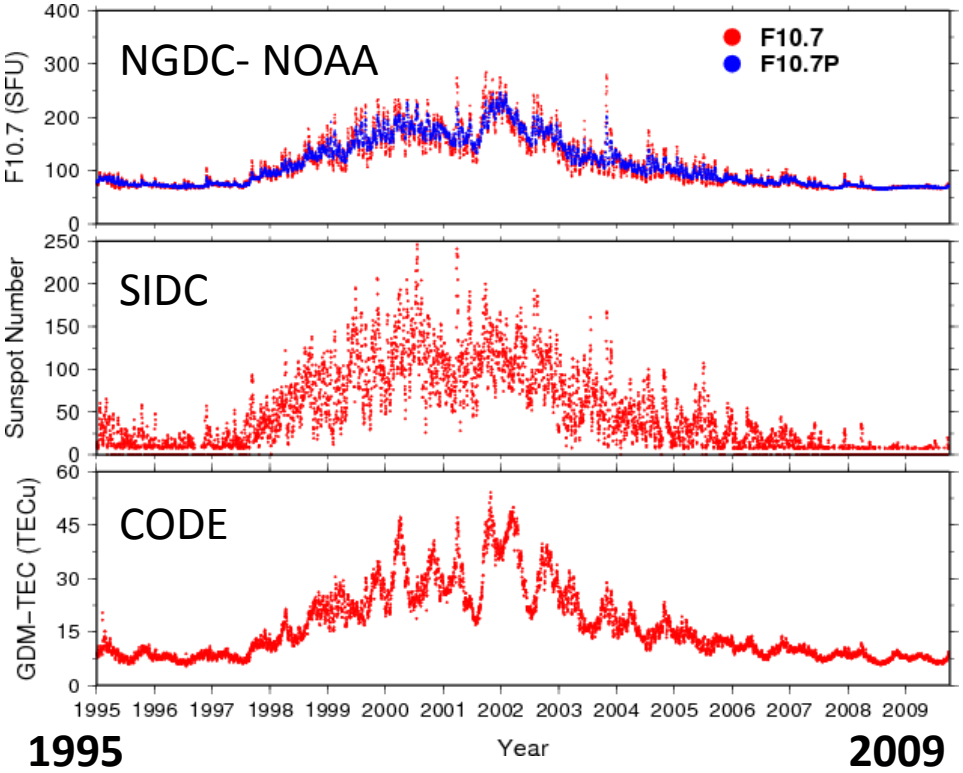
- First order of ionospheric state variation: Solar radiation (photoionization)
- Major disturbance in the ionospheric state: CME impact
  - Affects the radio waves propagation with respect to free electrons content
  - Error in GNSS positioning applications
  - Space weather research

Ionosphere and GPS data:

Total Electron Content (TEC)

$$I = \frac{40.3}{f^2} TEC$$

1TECu = $10^{16} e^{-}.m^{-2}$



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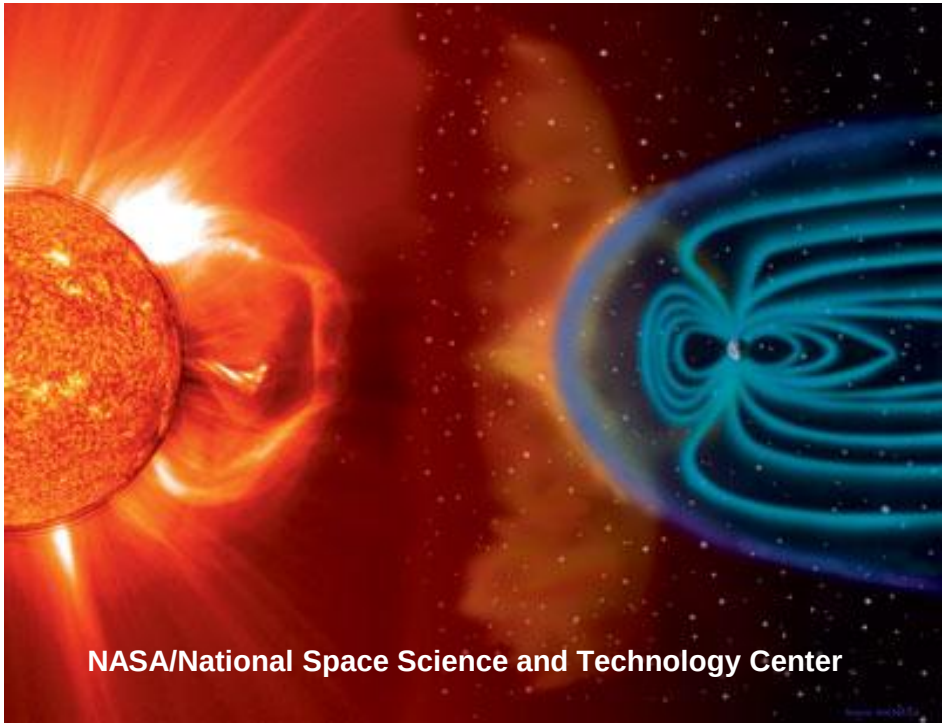


Products available on-line

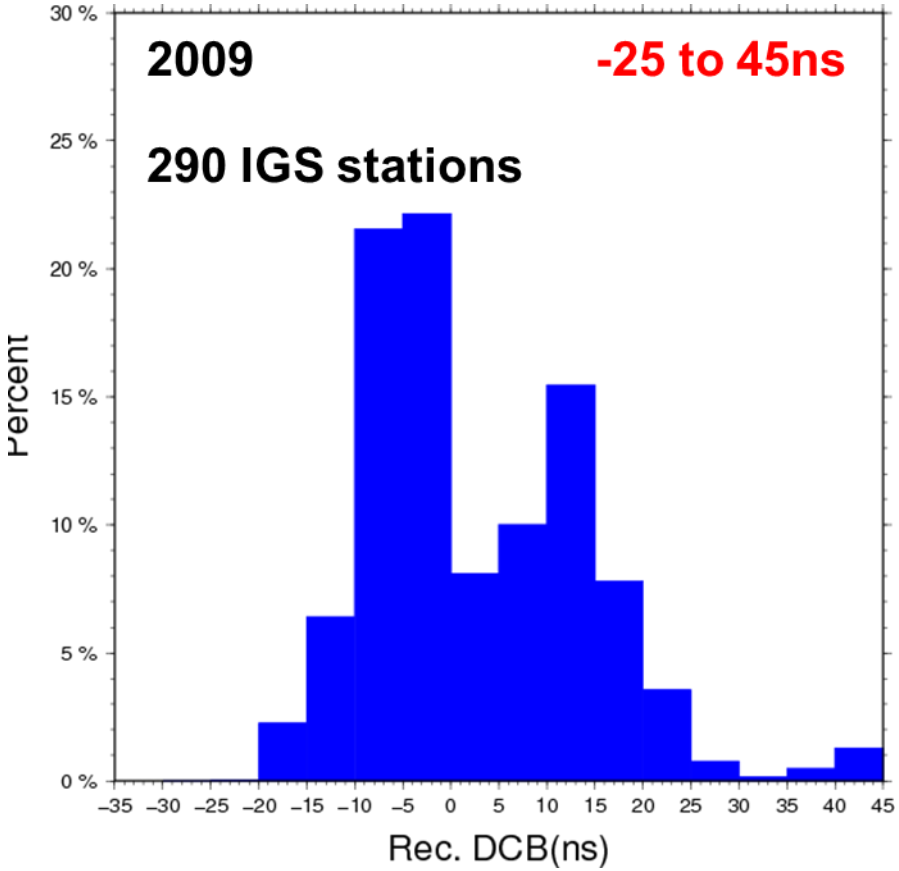
ftp://gnss.oma.be/

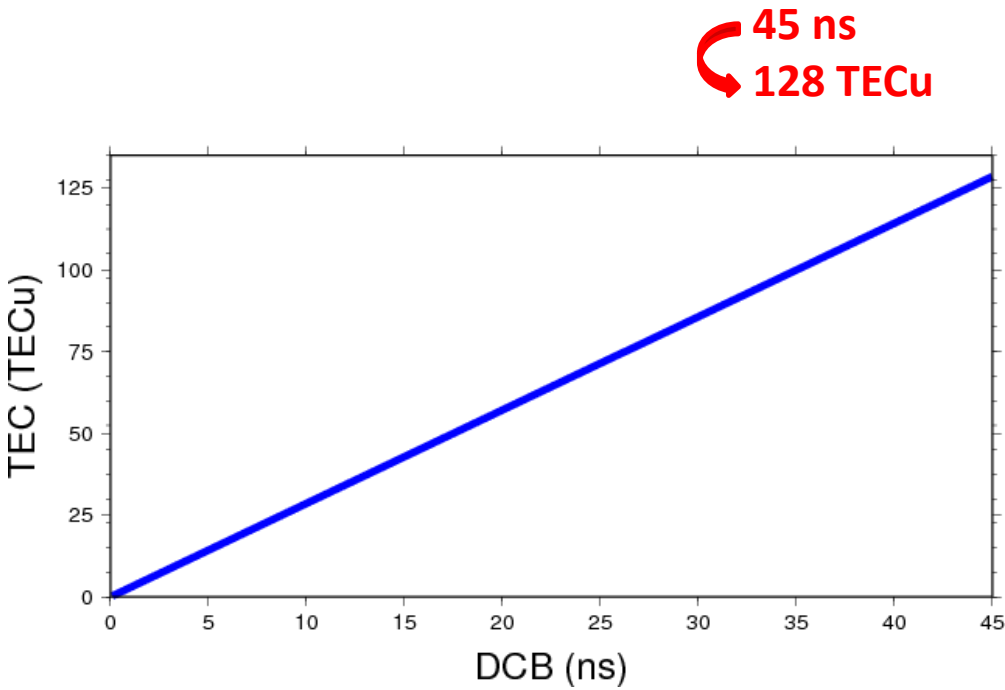
IONosphere map EXchange format (**IONEX**) [Schaer et al. 1998]

```
  1                                                       START OF TEC MAP
2013     5     7    13    30     0                       EPOCH OF CURRENT MAP
  35.0 -15.0  25.0   0.5 450.0                           LAT/LON1/LON2/DLON/H
314  317  322  326  331  337  342  347  352  357  361  365  369  373  377  380
384  386  388  390  391  392  393  393  393  394  395  397  400  403  406  409
413  417  421  424  428  431  434  437  440  442  445  447  449  451  453  455
457  459  460  461  462  463  464  465  466  467  468  469  469  470  471  472
473  475  476  478  480  482  483  485  487  488  489  491  491  492  492  493
493
  35.5 -15.0  25.0   0.5 450.0                           LAT/LON1/LON2/DLON/H
305  309  313  318  323  328  334  339  344  348  353  357  361  365  369  373
377  380  382  383  384  386  387  387  388  389  391  393  395  398  401  404
407  411  415  418  421  424  427  430  433  435  438  440  442  445  447  449
451  452  454  455  456  456  457  458  459  460  461  462  463  464  464  465
466  468  469  471  473  475  477  479  481  482  483  484  485  486  486  486
486
  36.0 -15.0  25.0   0.5 450.0                           LAT/LON1/LON2/DLON/H
298  301  305  310  315  320  325  331  336  340  345  349  353  357  361  365
369  372  375  377  378  379  380  381  382  384  386  388  390  393  396  399
402  405  408  412  415  418  420  423  425  428  430  433  435  438  440  442
444  446  447  448  449  450  451  452  453  454  455  456  456  457  458  458
459  461  462  464  467  469  471  473  474  476  477  478  479  480  480  480
480
  36.5 -15.0  25.0   0.5 450.0                           LAT/LON1/LON2/DLON/H
290  293  297  302  306  312  317  322  328  333  337  341  345  349  353  358
362  365  368  370  371  373  374  375  376  378  380  383  386  388  391  394
396  399  402  405  408  410  413  415  418  420  422  425  428  430  433  435
437  439  440  442  443  444  445  446  447  447  448  449  450  450  451  452
453  454  456  458  460  462  464  466  468  469  470  471  472  473  473  473
```

Receiver Differential Code Biases

$$P_2 - P_1 + DCB^s + \boxed{DCB_r} = 40.3\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)STEC$$

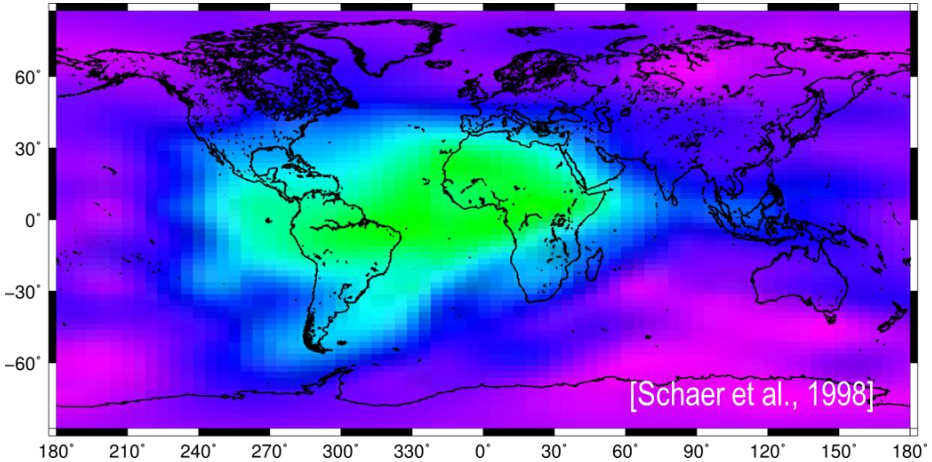




Receiver Differential Code Biases use in NRT

$$\boxed{P_2 - P_1 + DCB^s} + \boxed{DCB_r} = 40.3\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)\boxed{STEC}$$

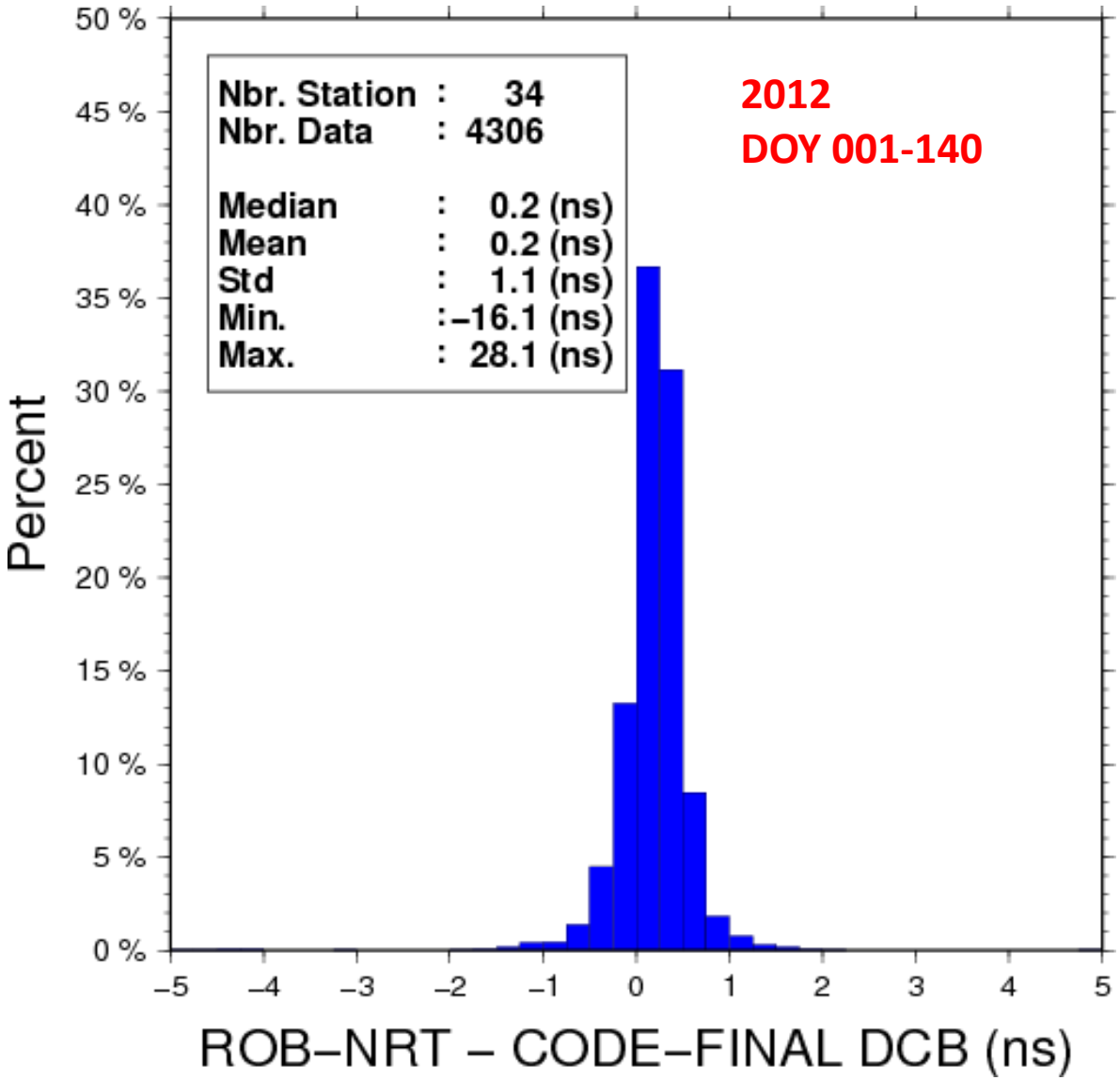
- Global Ionospheric Maps (GIM) of VTEC (5°x2.5°x2h, 2-9 TECu)
- CODE rapid products (~ 24h)
- ~120 globally distributed stations
- GLONASS and GPS constellations
- Linear interpolation in space and time



$DCB_r(j)$=

MEDIAN [$DCB_r(j-2)$, $DCB_r(j-3)$, $DCB_r(j-4)$, $DCB_r(j-5)$, $DCB_r(j-6)$]

Receiver Differential Code Biases



Comparison with CODE Final product (~5-6 days).

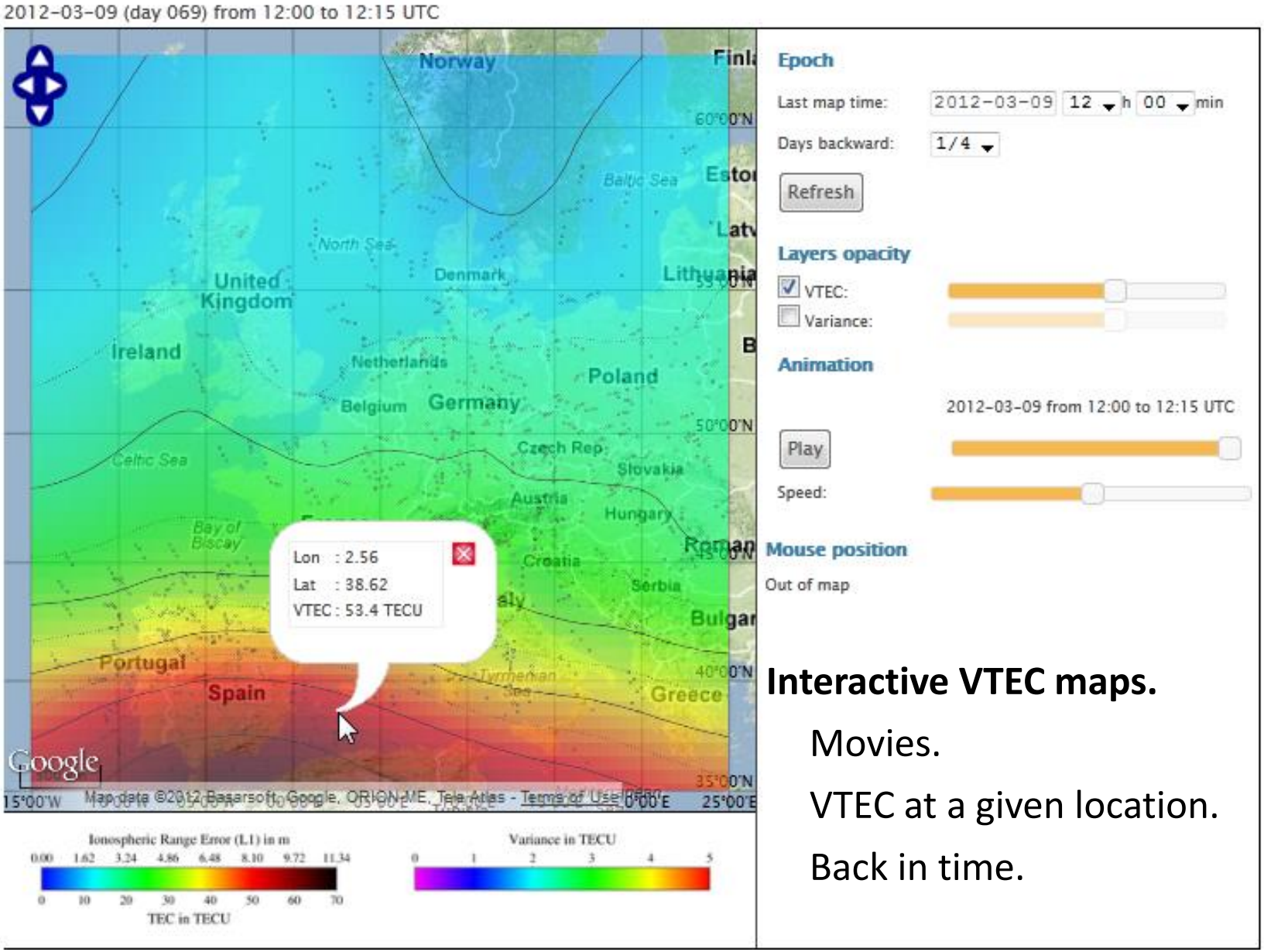
34 stations from the IGS.

0.3 ns ~ 1 TECu (60%)
0.7 ns ~ 2 TECu (94%)

Biases = 0.2 ns (~0.5 TECu)

Lower than the precision of the TEC estimation (2-3 TECu)

Products available on-line



Interactive VTEC maps.

Movies.

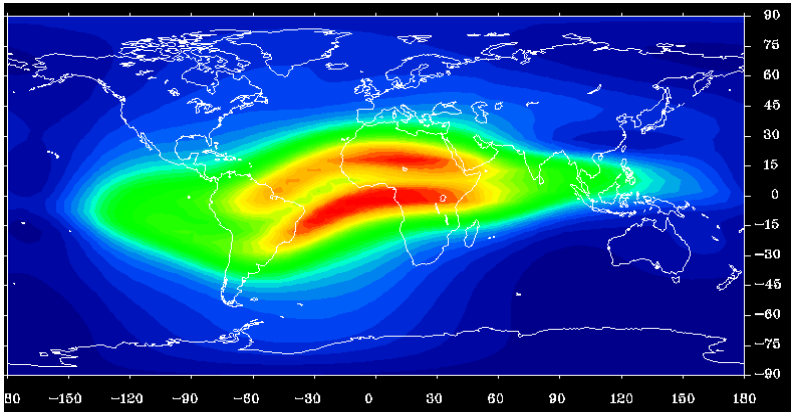
VTEC at a given location.

Back in time.

Comparison with other ionospheric models

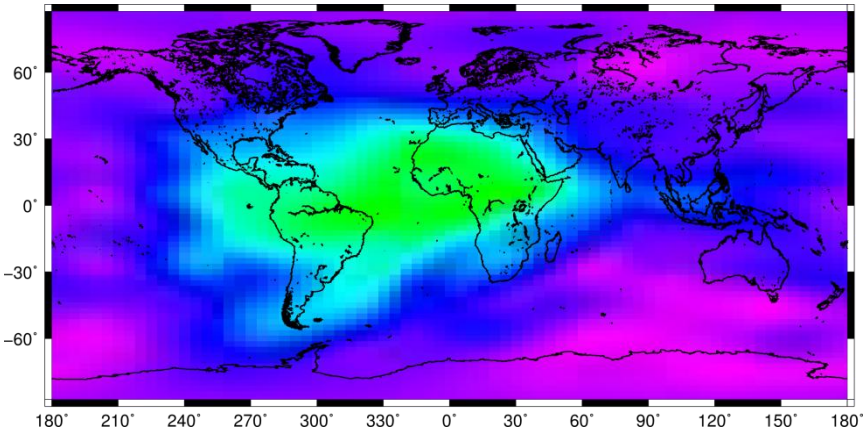
International Reference Ionosphere NASA model iri.gsfc.nasa.gov
IRI 2012 *[Bilitza et al. 2011]*

Empirical climatological ionospheric model



CODE Final GIMs - IONEX
Bern ftp.unibe.ch
[Schaer et al. 1998]

Post-processing of GNSS data (5-6 days)
~280 GNSS stations (GPS+GLONASS)
2.5°x5° - 2h
Spher. Harmonics. (n,m=15)



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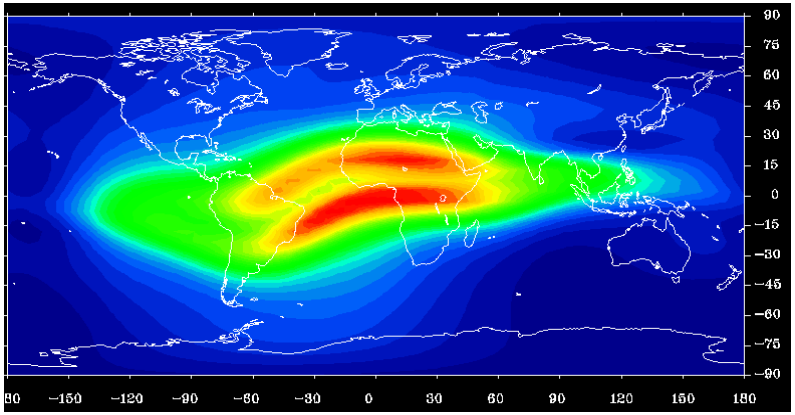

IRI
Very smooth

CODE Final GIMs - IONEX
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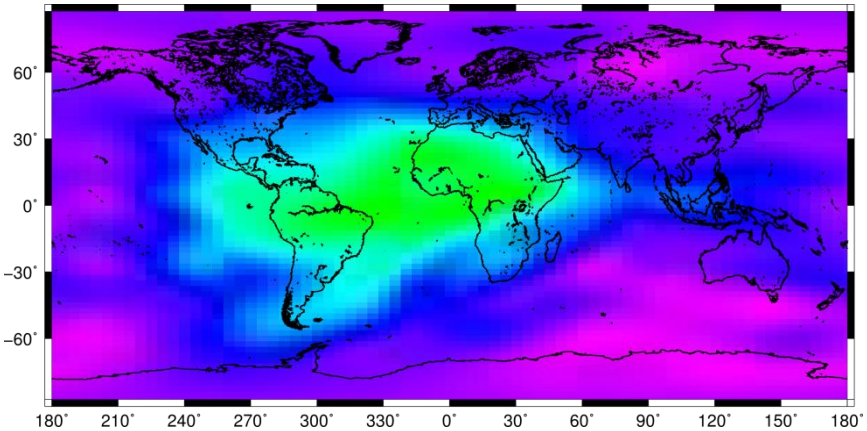
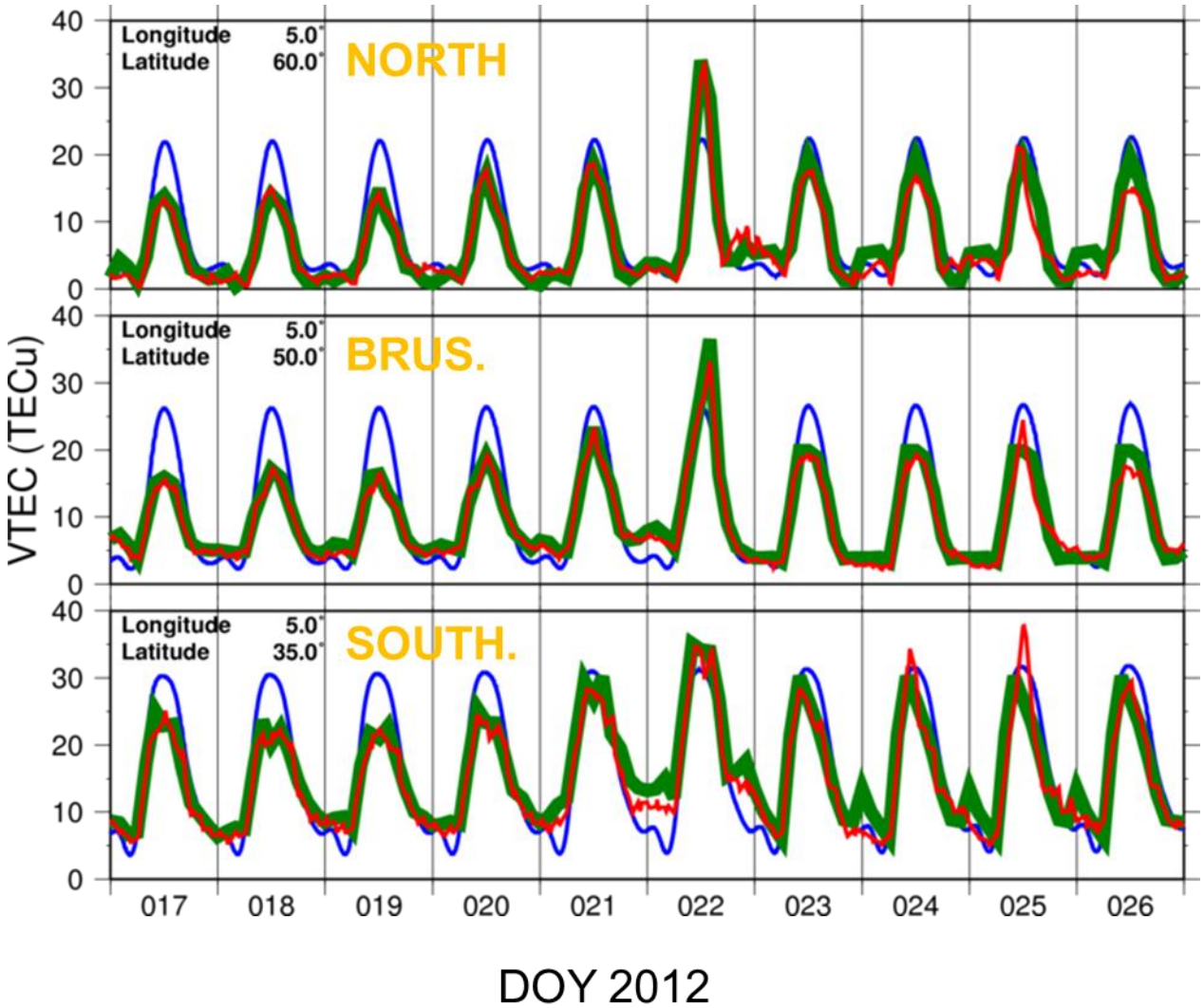
[Schaer et al. 1998]



CODG
Slightly smooth

Comparison with other ionospheric models



$VTEC_{ROB}$-$VTEC_{CODG}$

North : 0.0 ± 1.3 TECu

Brus. : 0.2 ± 0.8 TECu

South : -0.9 ±1.5 TECu

$VTEC_{ROB}$-$VTEC_{IRI}$

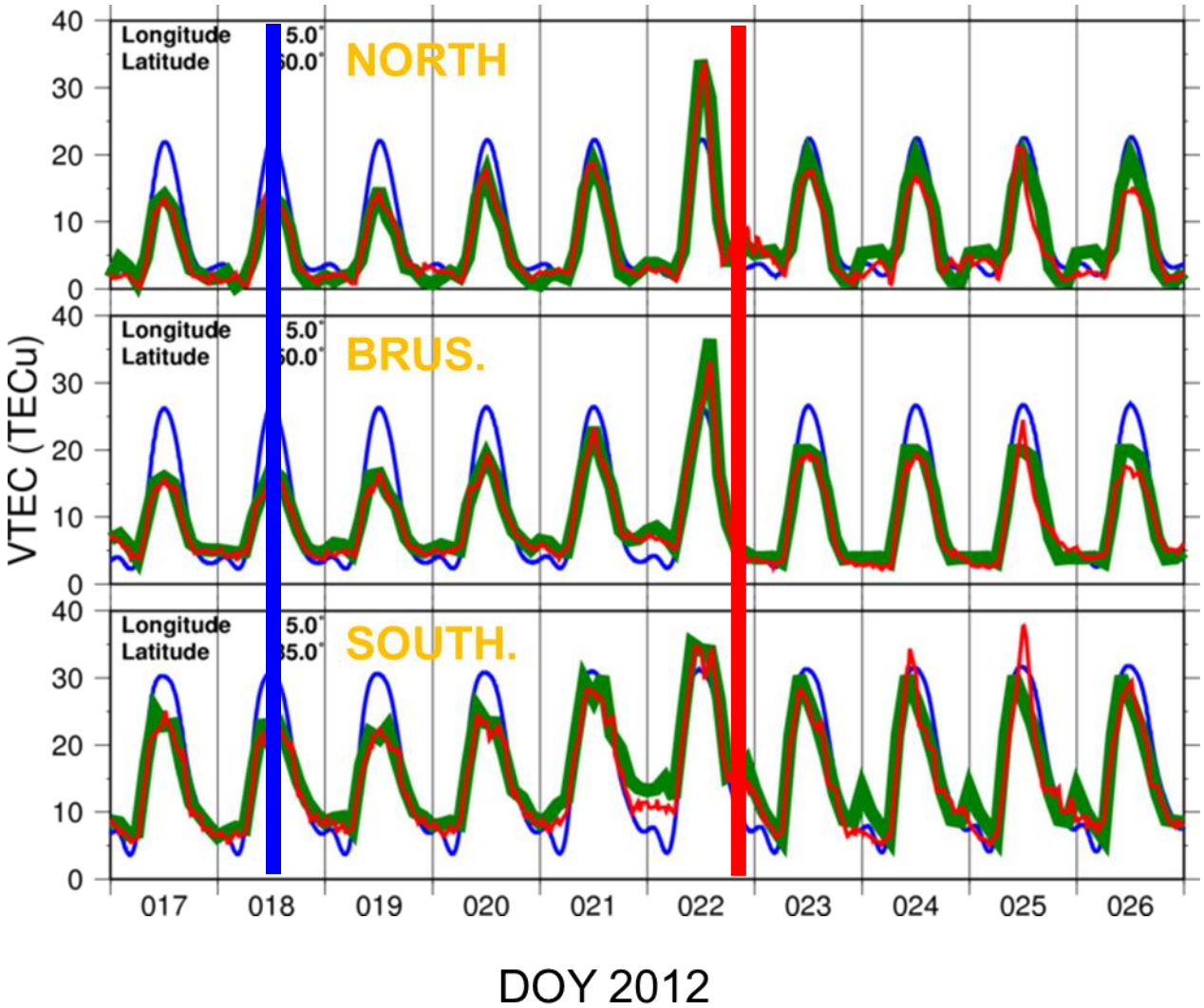
12:00 UTC

North : -6.4 ± 3.9 TECu

Brus. : -9.5 ± 3.2 TECu

South : -5.6 ± 4.2 TECu

Comparison with other ionospheric models



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$VTEC_{ROB}$-$VTEC_{IRI}$

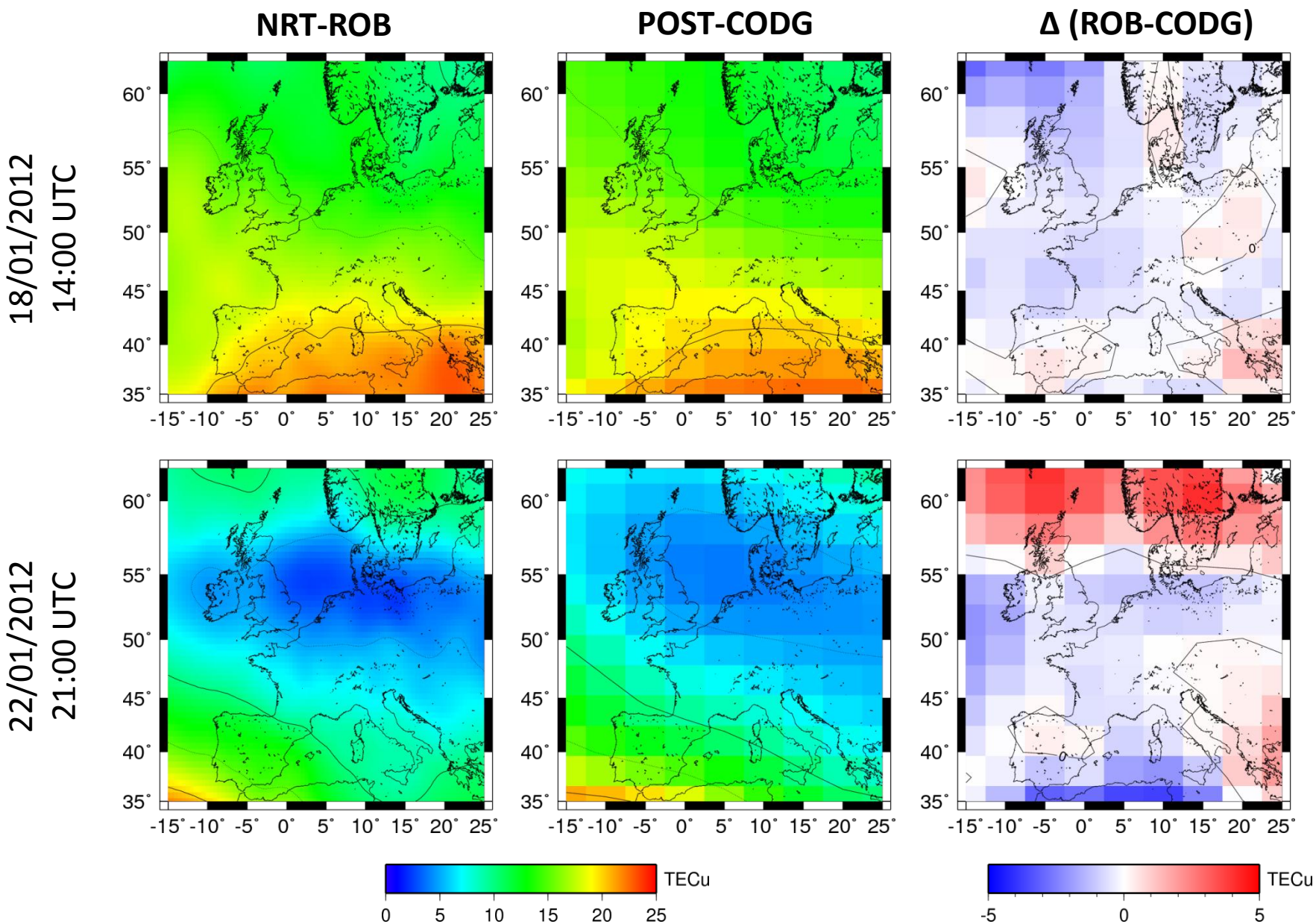
12:00 UTC

North : -6.4 ± 3.9 TECu

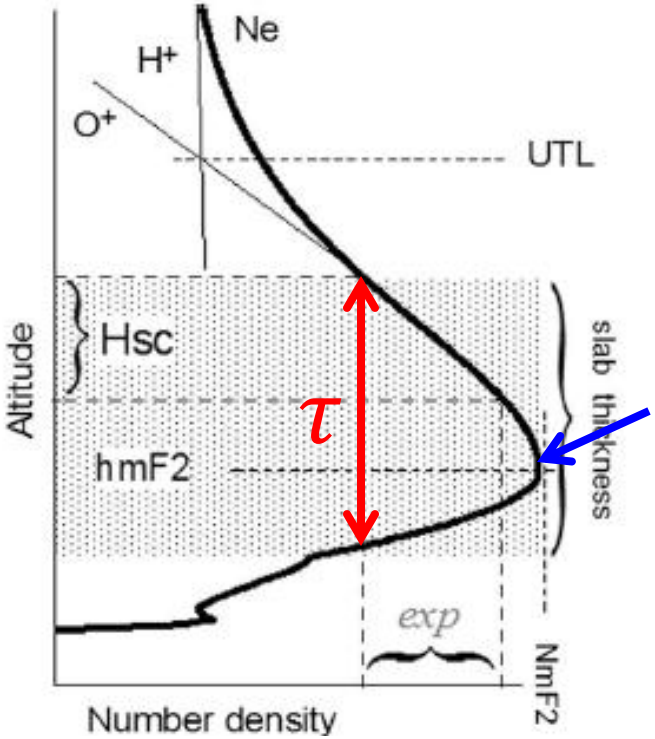
Brus. : -9.5 ± 3.2 TECu

South : -5.6 ± 4.2 TECu

Comparison with other ionospheric models



F2 Critical frequency = foF2



From Stankov et Warnant, 2009

Davies, 1990:

$$\tau = \frac{VTEC}{NmF2}$$

NmF2
***Scaled IRI* 2012 [Bilitza et al. 2011]**

$$\tau = \frac{VTEC}{foF2^2 \times 1.24 \times 10^{-6}}$$

foF2	: F2 critical frequency in MHz
τ	: Ionospheric slab thickness in m
VTEC	: Vertical Total Electron Content in e^-/m^2
NmF2	: Maximum electronic concentration in e^-/m^3

Products available on-line

IONOSPHERIC EVENT 2013-03-17

Contact: iono@gnss.be

SUMMARY OF THE EVENT: The ionosphere was disturbed over Europe the 17/03/2013 with an abnormal increase of Total Electron Content (TEC) followed by a decrease the 18/03/2013. These ionospheric disturbances were due to the Solar Coronal Mass Ejection (CME) of the 15/03/2013, altering the geomagnetic activity to its storm level (k=5) on the 17/03/2013 (more information at: www.sidc.be).

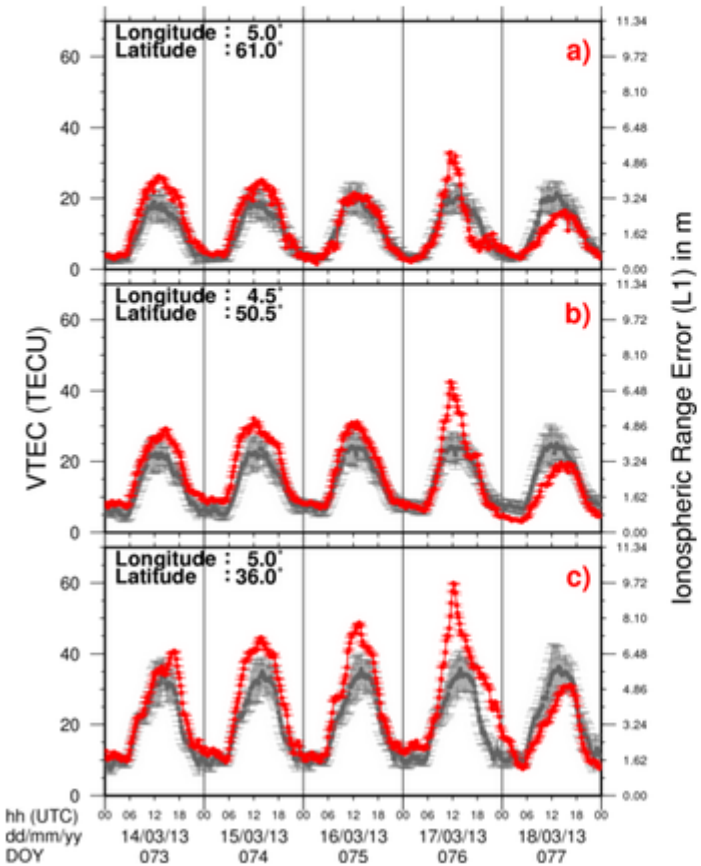


Figure 1: VTEC Time Series

Figure 2: Map of the 3 locations

*Figure 1 shows the time evolution of the Vertical Total Electron Content (VTEC) (**in red**) extracted from the near-real time VTEC maps at 3 different locations (Figure 2): a) Northern part (top), b) Brussels (middle) and c) Southern part (bottom). Also shown, the model based on the median from the 15 previous days (**in grey**).*

About this event, see also:

- **VTEC maps during this event: here**
- **Comparisons with the median of the last 15 days: here**
- about the origin of the ionospheric disturbances: www.sidc.be and www.swans.meteo.be.

Time-series extracted from the NRT maps

Prediction

Observations