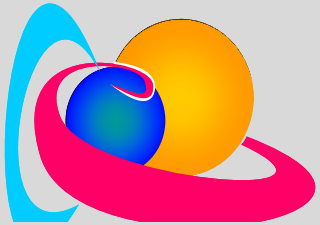


Solar-Terrestrial
Center of Excellence

Royal Observatory
of Belgium

New Near-Real Time Ionospheric Products Based on Real-time EPN Data

N. Bergeot, J.-M. Chevalier

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

P. Defraigne and W. Aerts

Ionospheric activity

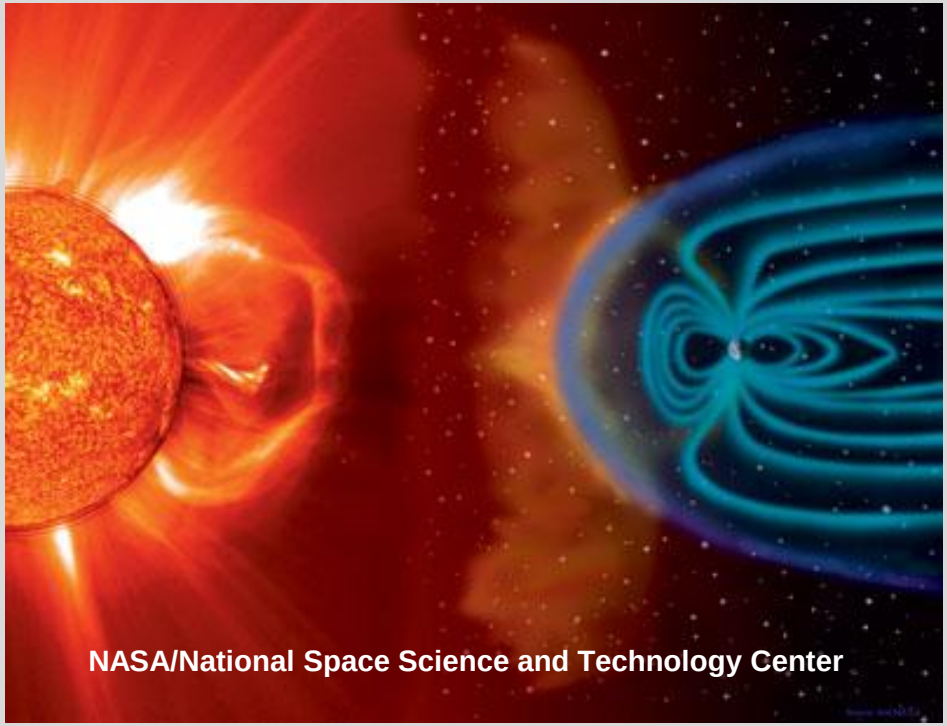
Ionosphere (50-1000km):

- 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)

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



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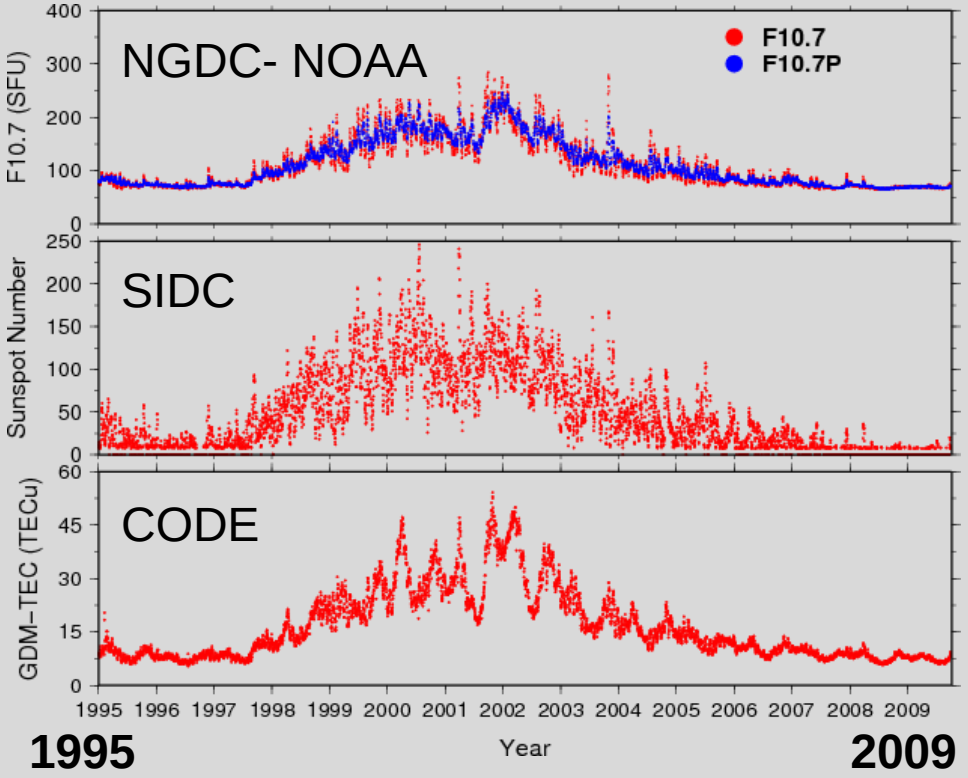
$$I = \frac{40.3}{f^2} TEC$$

cm to > 100 m



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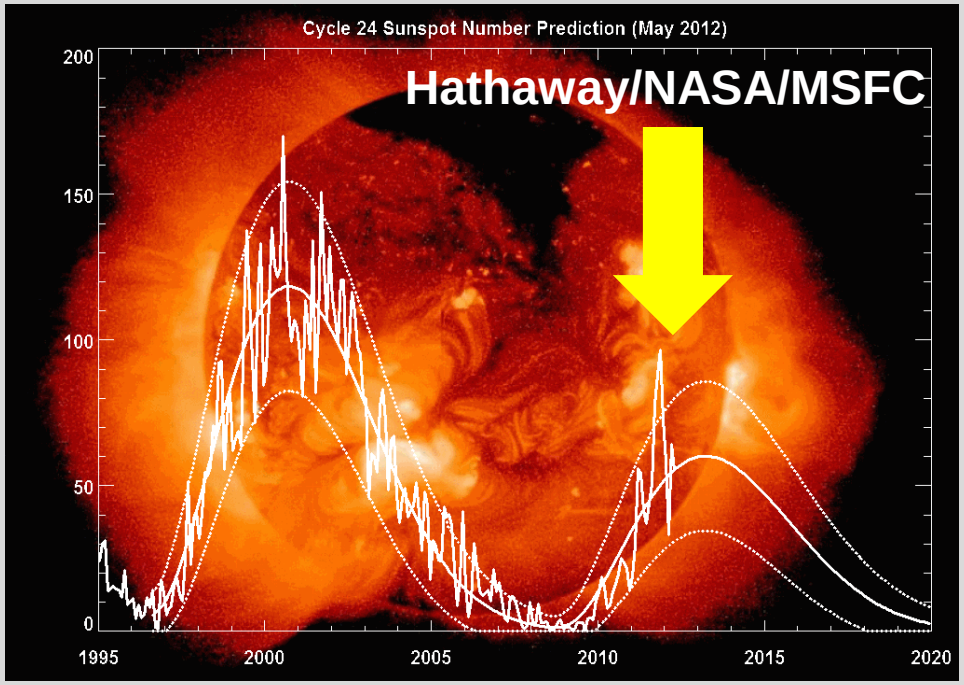


Ionosphere and GPS data:

Total Electron Content (TEC)

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

cm to > 100 m

This presentation

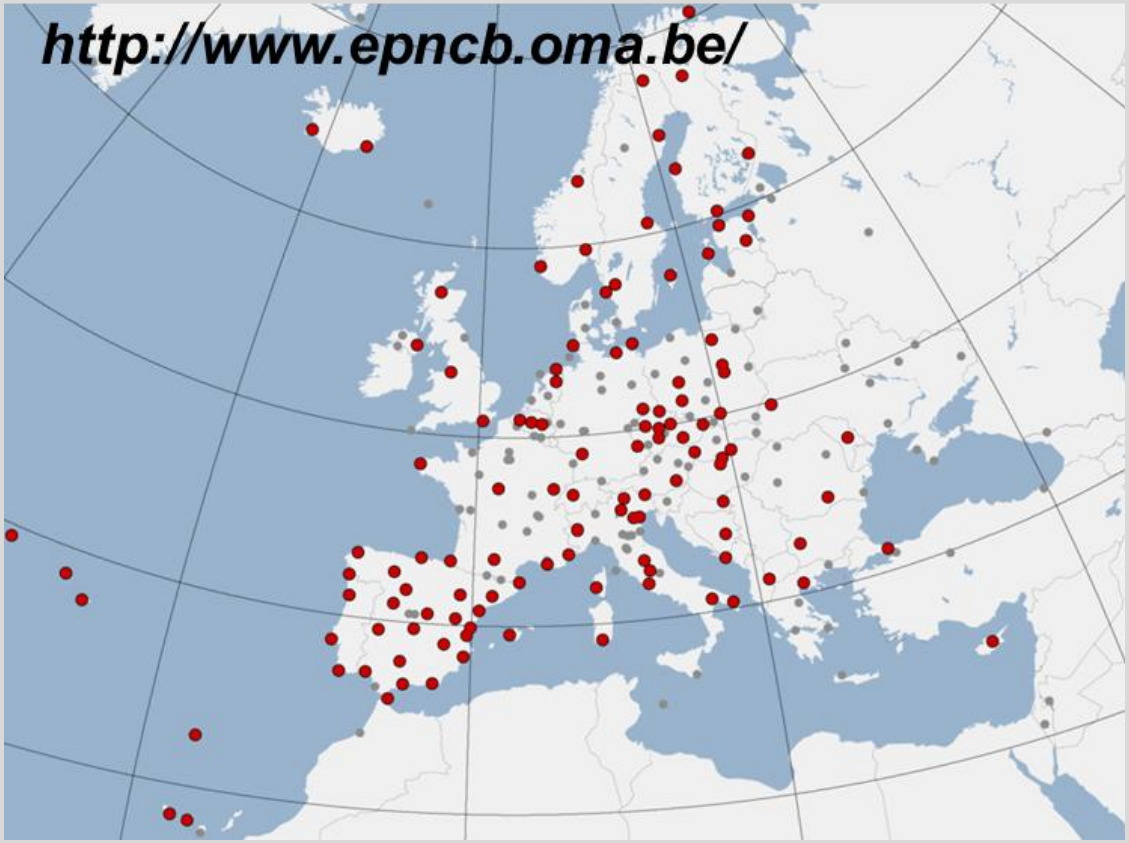
- Development of a method to estimate in Near-real time (NRT) **the ROB TEC** from GPS data over Europe
- Products already online (gnss.be)
- Products under development

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

[e.g. Söhne et al. 2010]

European Permanent Network (EPN)

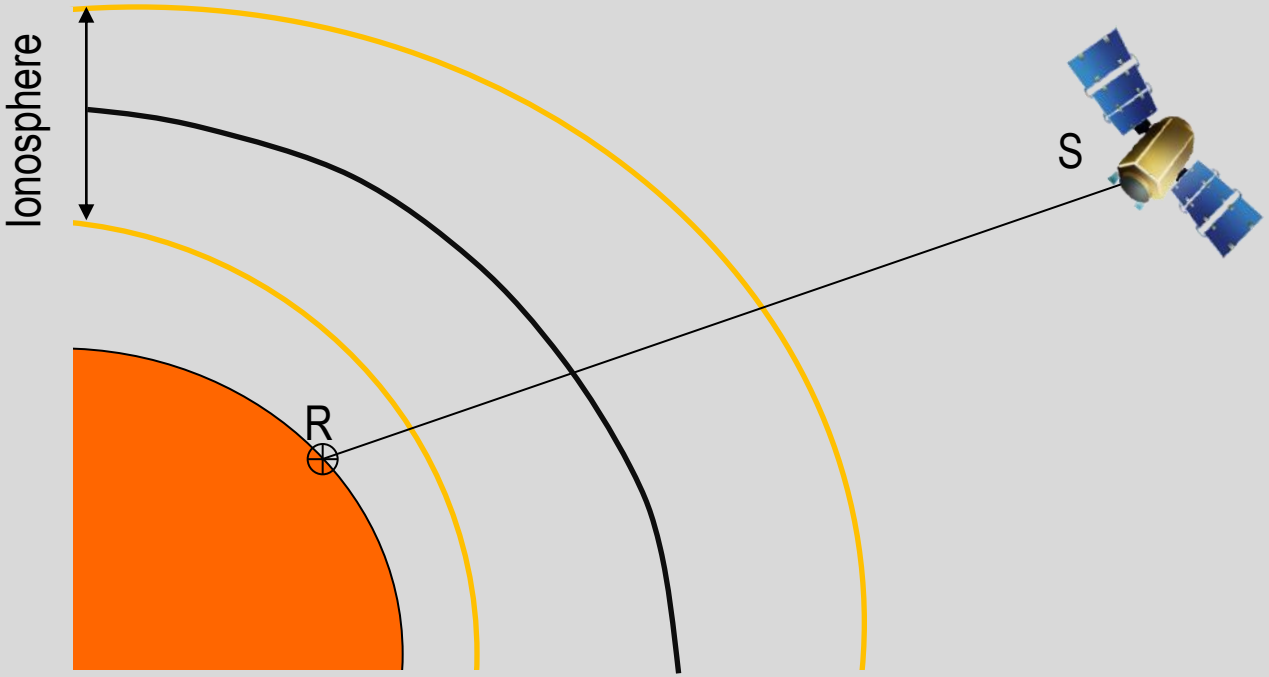
- Continuously observing GNSS stations since 1996
- Presently: ~ 250 stations over Europe
- **NRT : Presently ~ 120 stations**



Ionospheric monitoring from EPN NRT GPS data

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

Geometry-free linear combination



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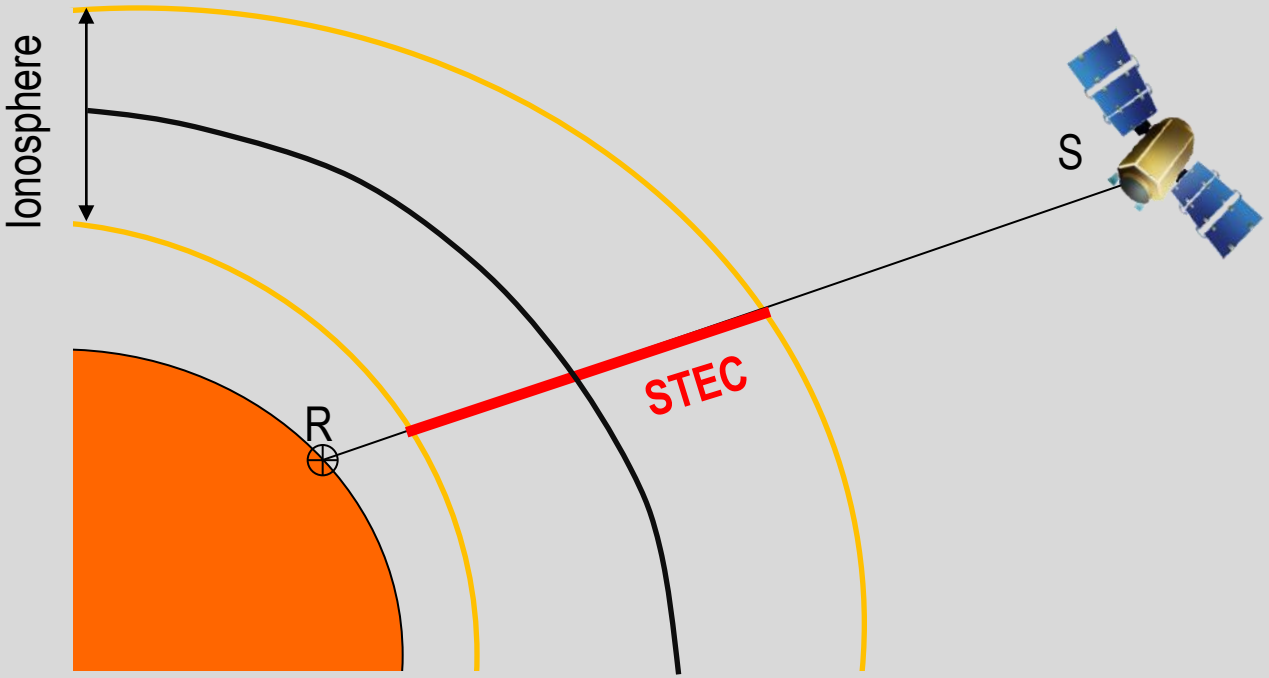
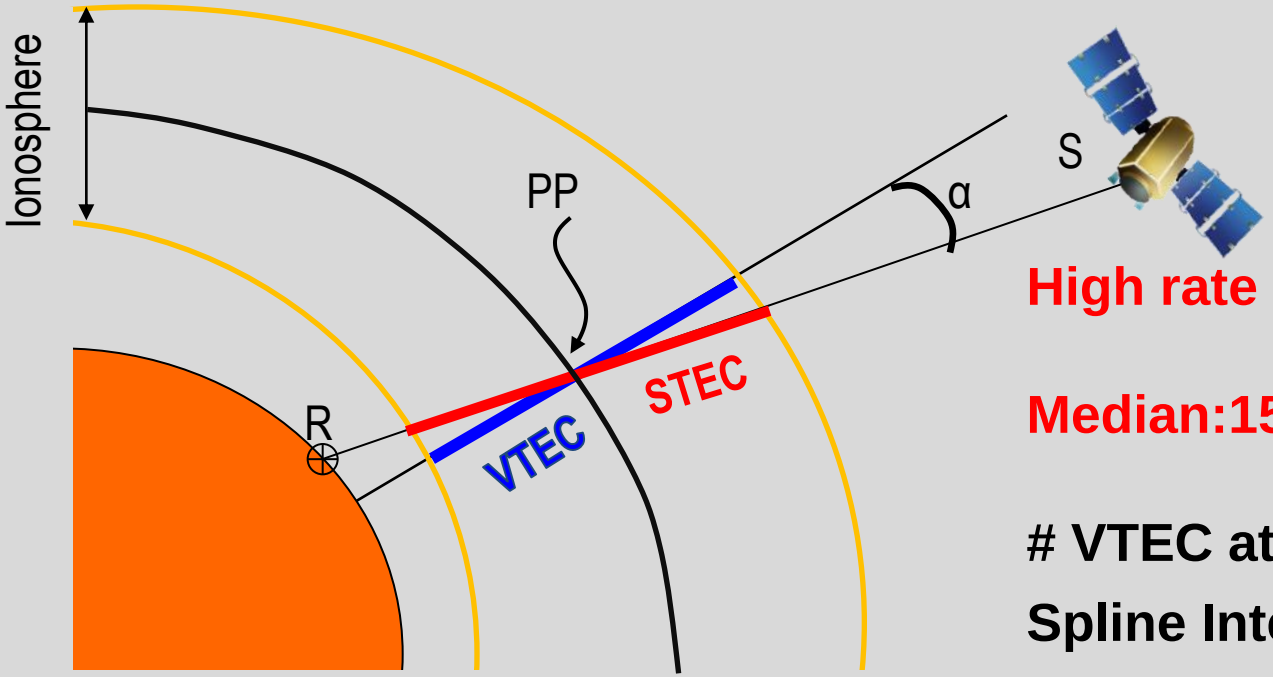


Ionospheric monitoring from EPN NRT GPS data

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

$$VTEC = STEC \times \cos(\alpha)$$



High rate NRT EPN GPS data

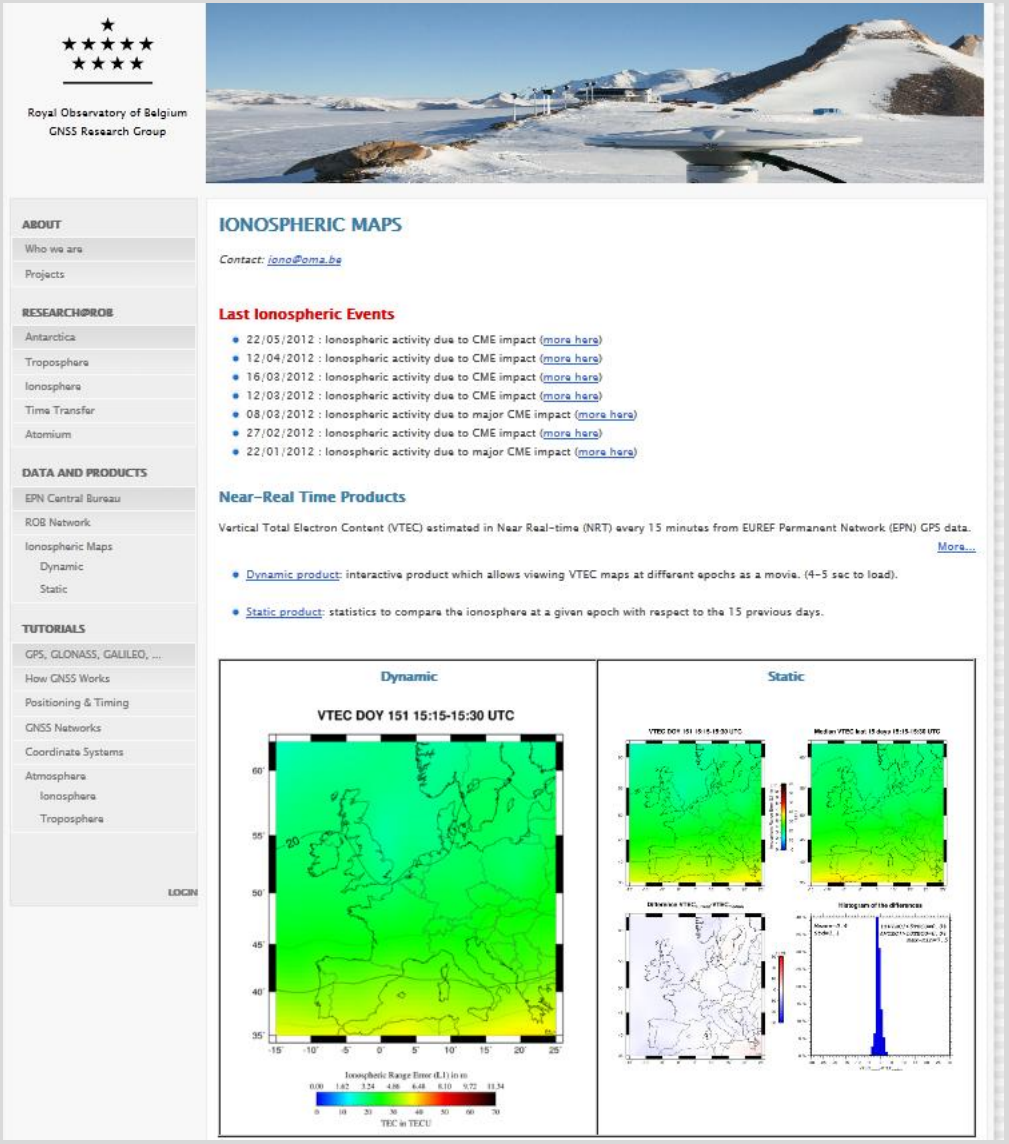
Median:15min.of VTEC/Rec/Sat

 # VTEC at PP : 1692 ± 271.

Spline Interpolation.

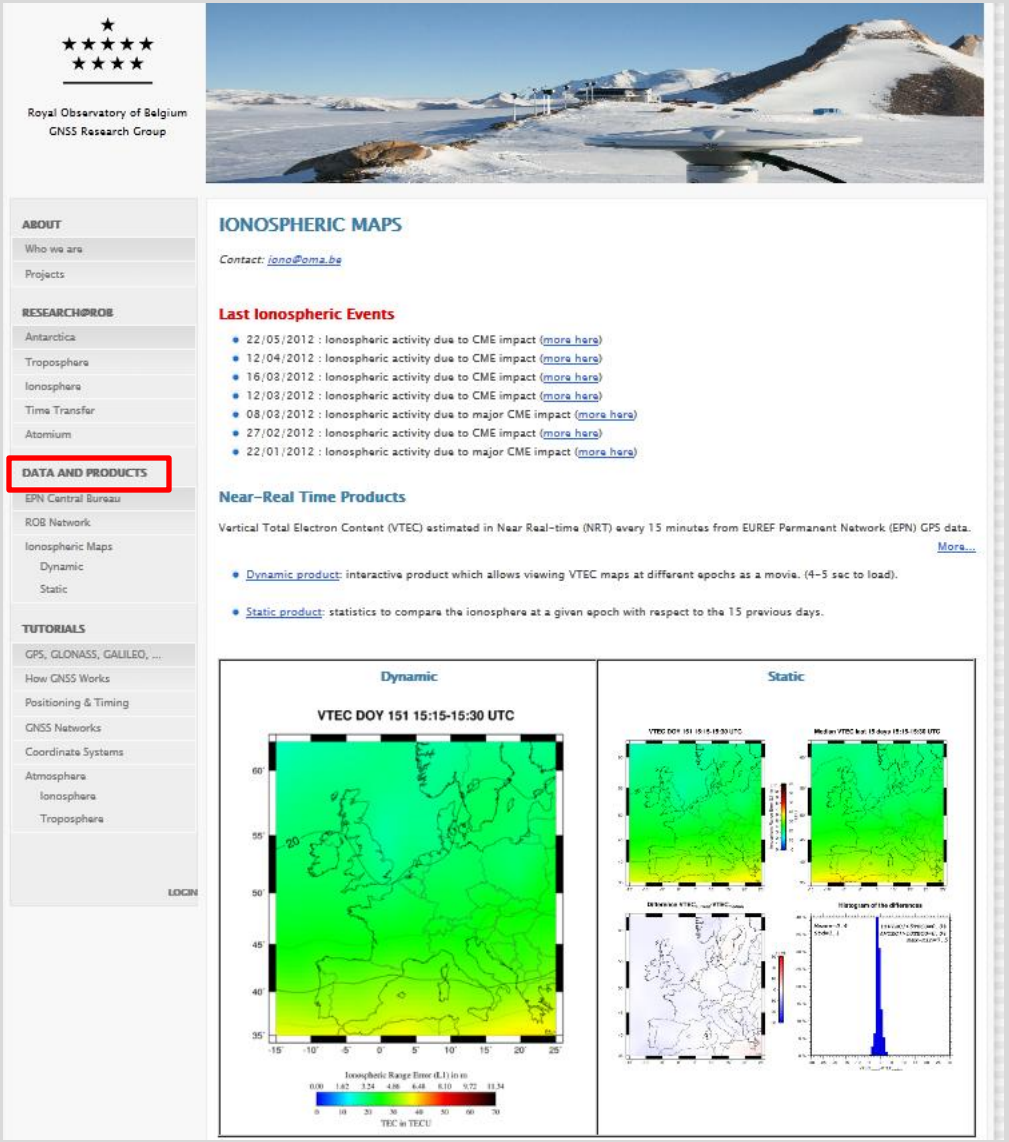
VTEC grid : 0.5°x0.5° - 15 min.

Products available on-line



http://www.gnss.be

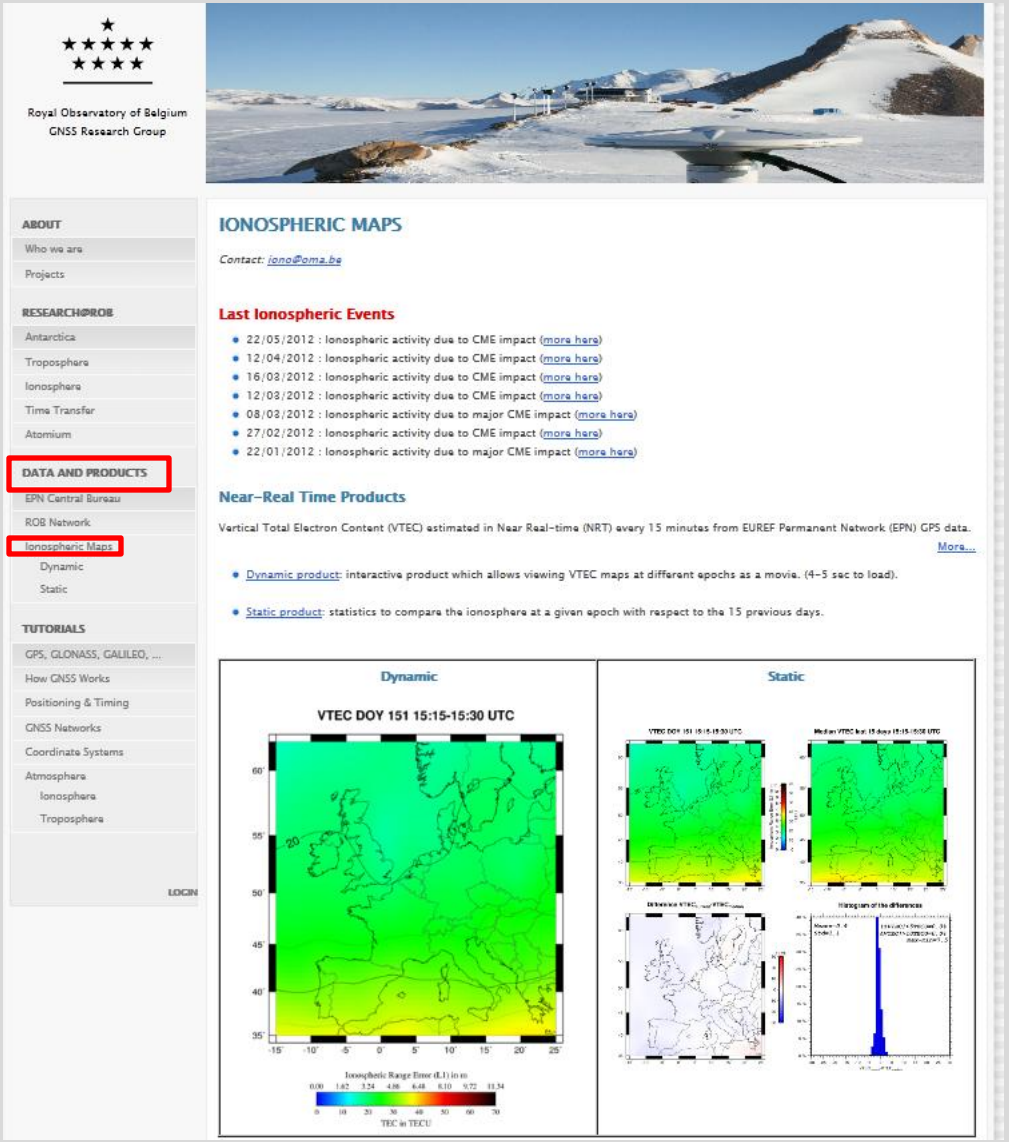
Products available on-line



http://www.gnss.be

DATA AND PRODUCTS

Products available on-line



http://www.gnss.be

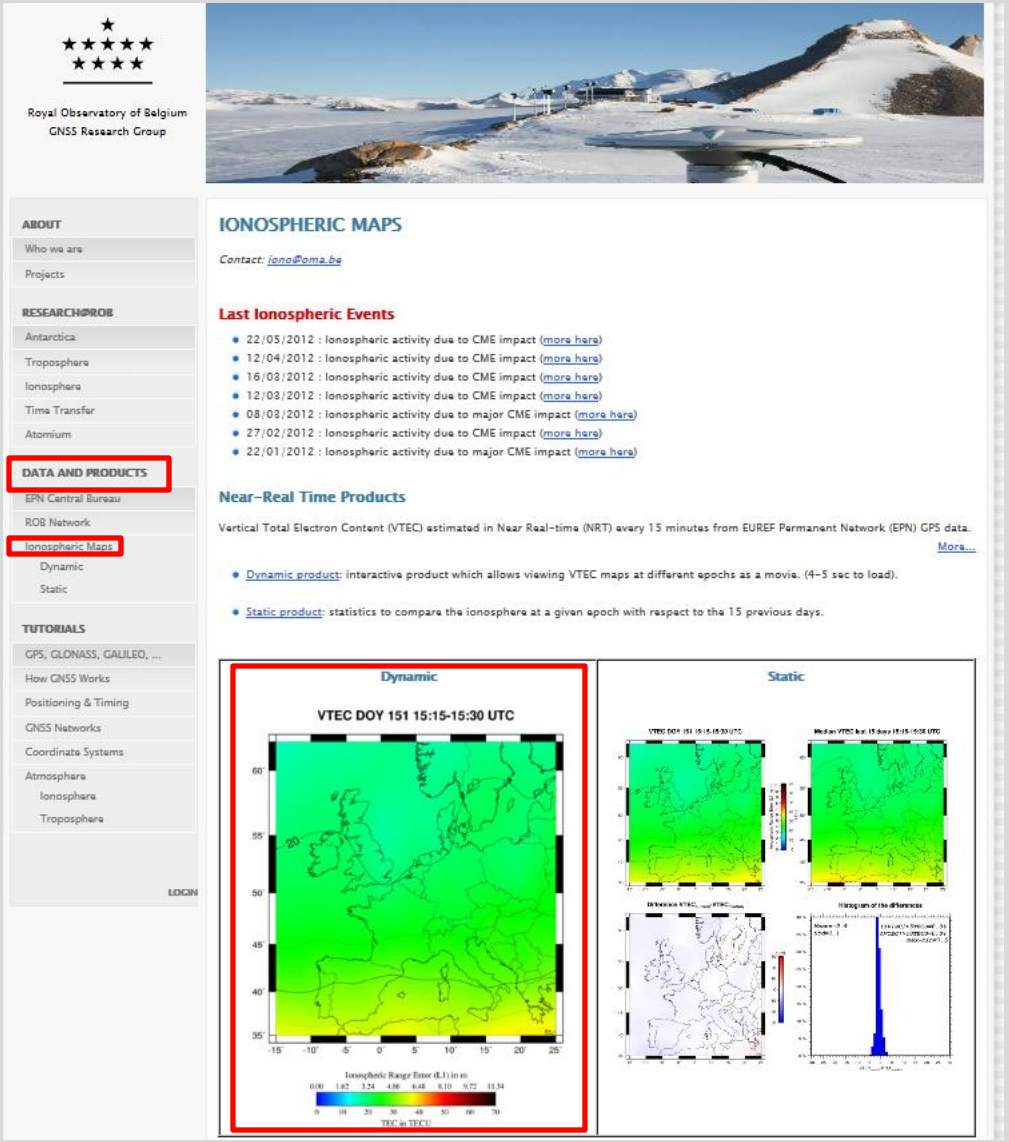
DATA AND PRODUCTS

- **IONOSPHERIC MAPS**

Latency : ~7-10 min.

Time independent maps.

Products available on-line

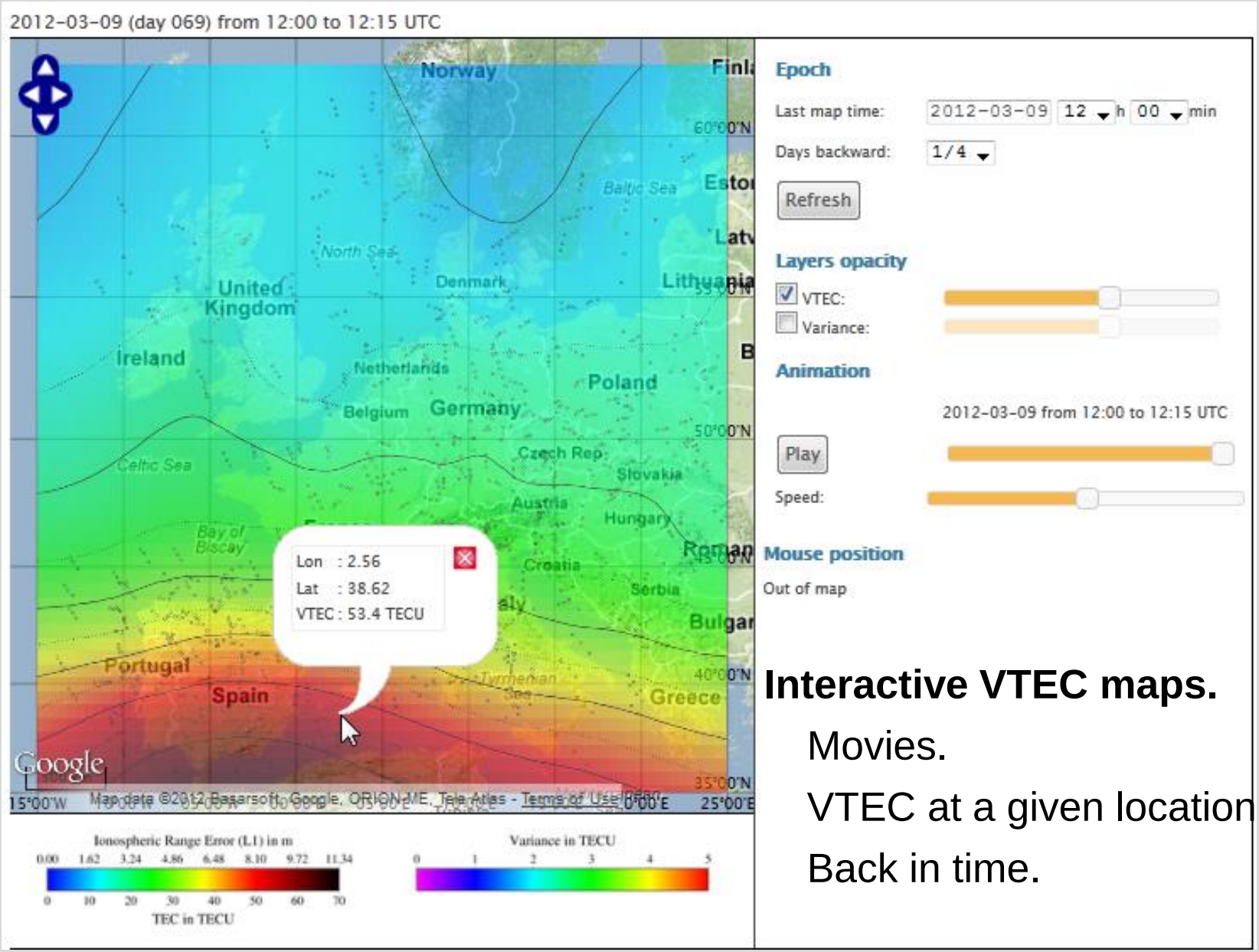


http://www.gnss.be

DATA AND PRODUCTS

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

Products available on-line



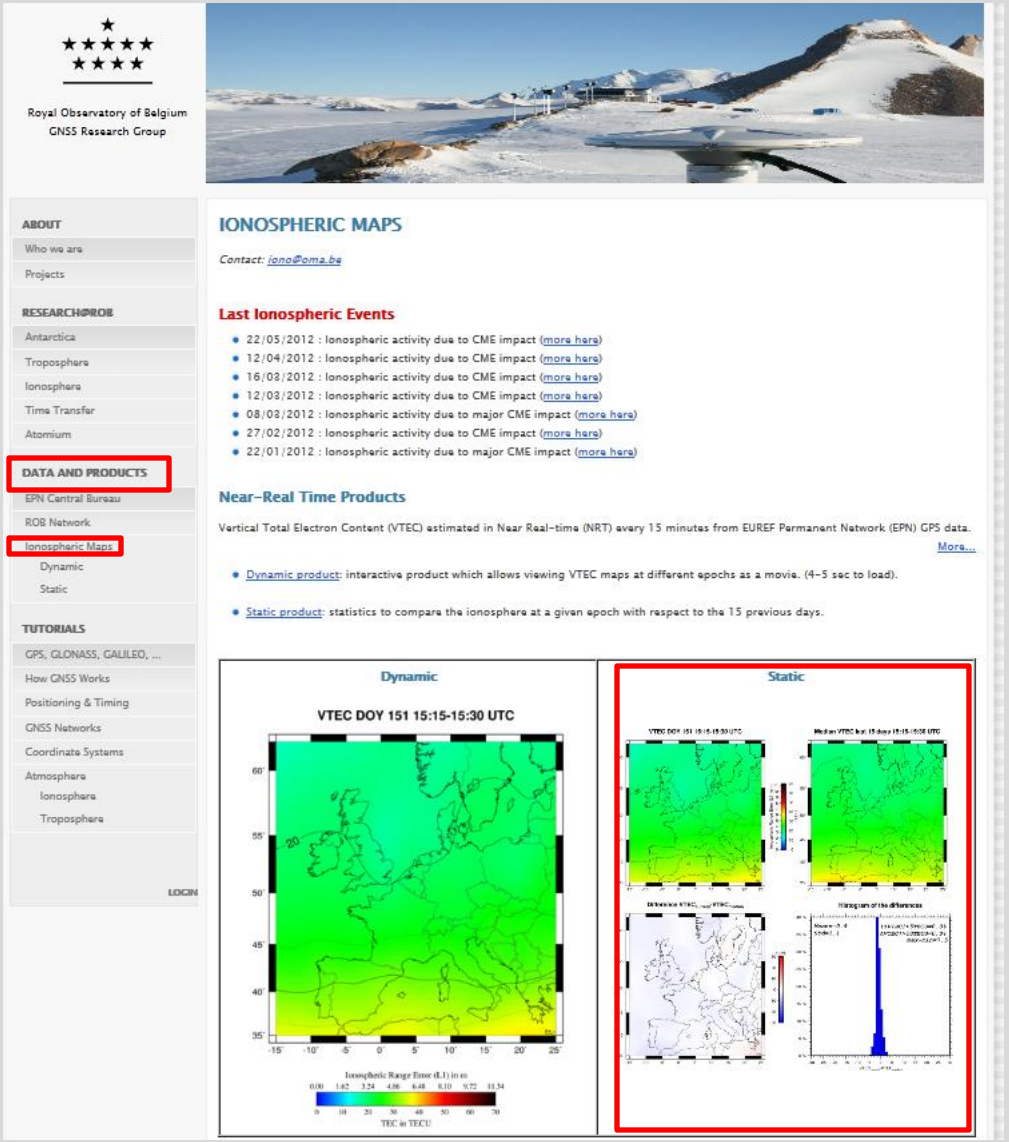
Interactive VTEC maps.

Movies.

VTEC at a given location.

Back in time.

Products available on-line

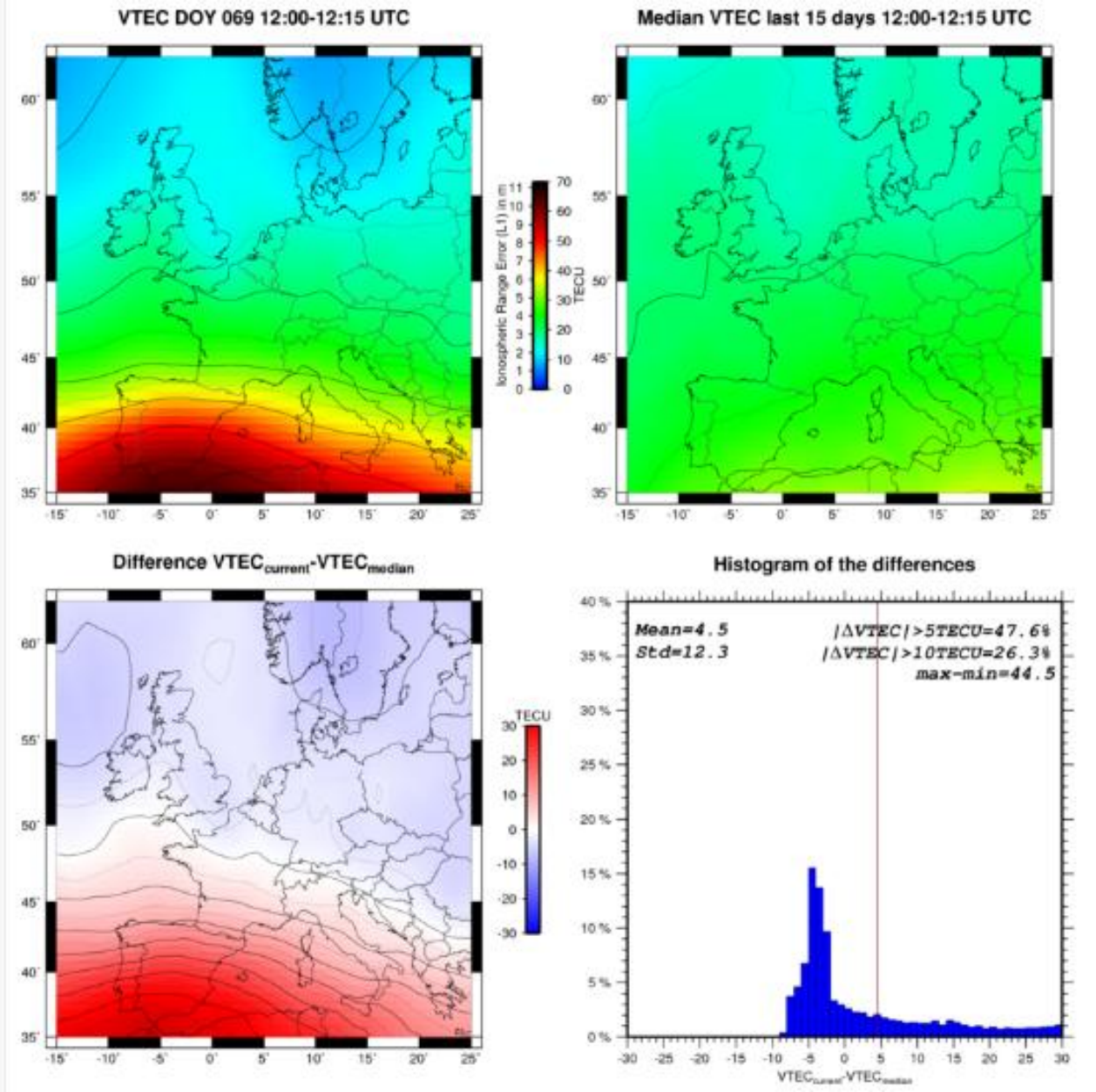


http://www.gnss.be

DATA AND PRODUCTS

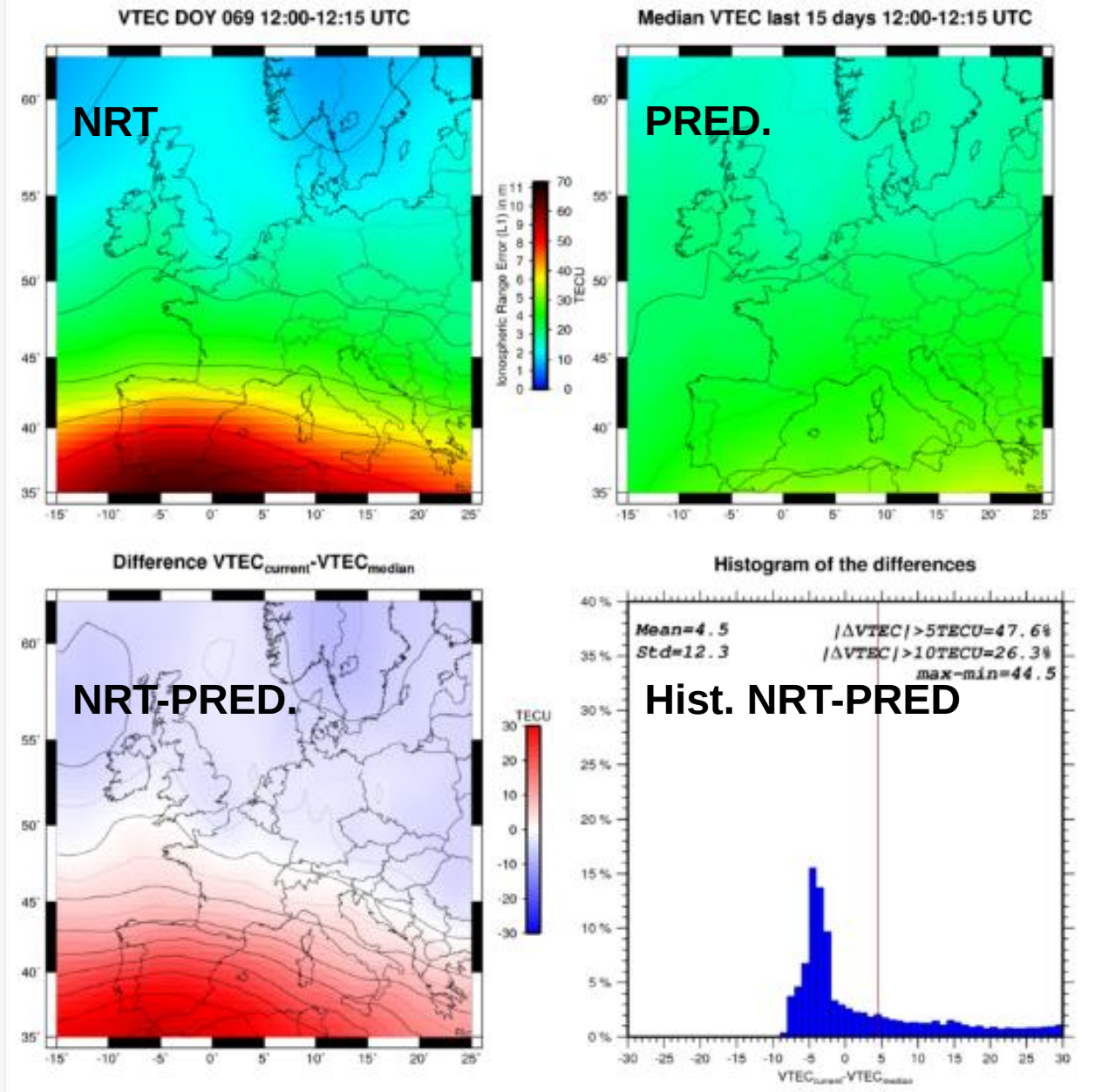
- **IONOSPHERIC MAPS**
  - **DYNAMIC**
  - **STATIC**

Products available on-line



Statistical products.

Products available on-line

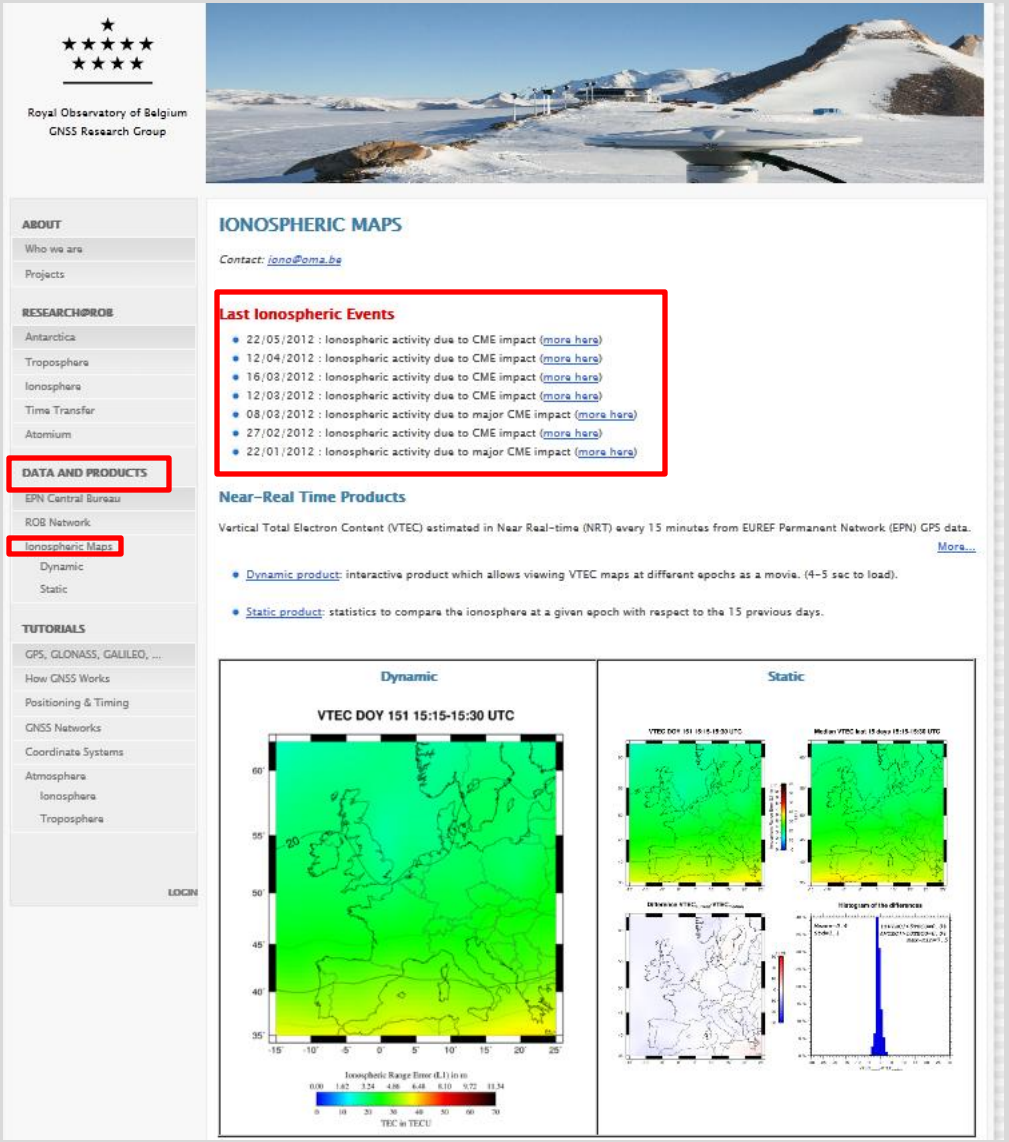


Statistical products

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

IONOSPHERIC EVENT 08–03–2012

Contact: iono@oma.be

A first major solar flare occured the 05/03/2012, followed by two other major flares the 07/03/2012 at 00:24 UTC and 01:14UTC (source www.sidc.be). As a consequence, the Earth's ionosphere above Europe was disturbed during 4 periods :

(1) 07/03/2012 from 05:30UTC to 21:30UTC (peak at noon),
(2) 08/03/2012 from 07:00UTC to 10:30UTC,
(3) 08/03/2012 from 13:00UTC to 21:00UTC,
(4) 09/03/2012 from 07:00 UTC to 19:30UTC.

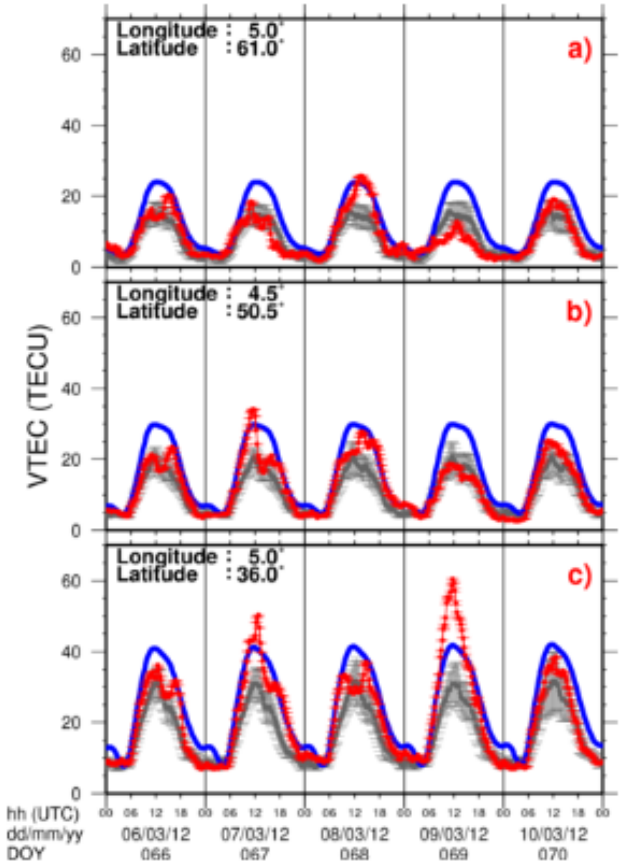


Figure 1: VTEC time series

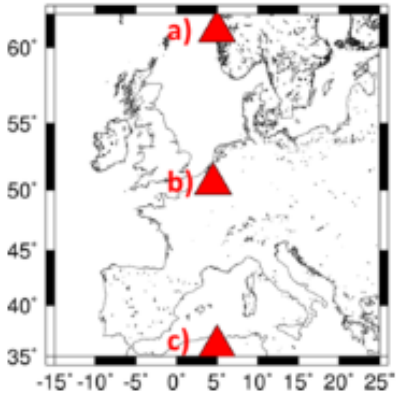


Figure 2: Map of the 3 locations

Figure 1 shows the time evolution of the Vertical Total Electron Content (VTEC) time series (*in red*) extracted from the near-real time 15-min VTEC maps at 3 different locations (see Figure 2):

a) Northern part of the map (top)
b) Brussels (middle)
c) Southern part of the map (bottom)

Also shown, the model based on the median from the 15 previous days (*in grey*), and the IRI 2011 [Bilitza et al. 2011] model (*in blue*).

More informations:

- the 15 min VTEC maps during these events: here
- comparison with the median of the last 15 days (07/03

Time-series extracted from the NRT maps

Prediction

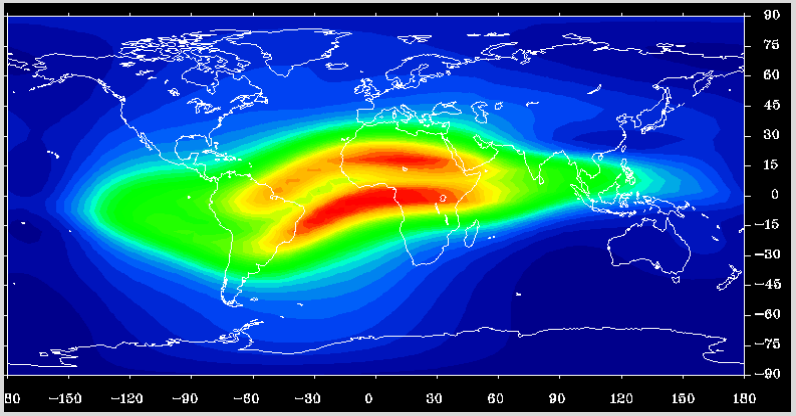
Observations

IRI 2012 [Bilitza et al. 2011]

Comparison with other ionospheric models

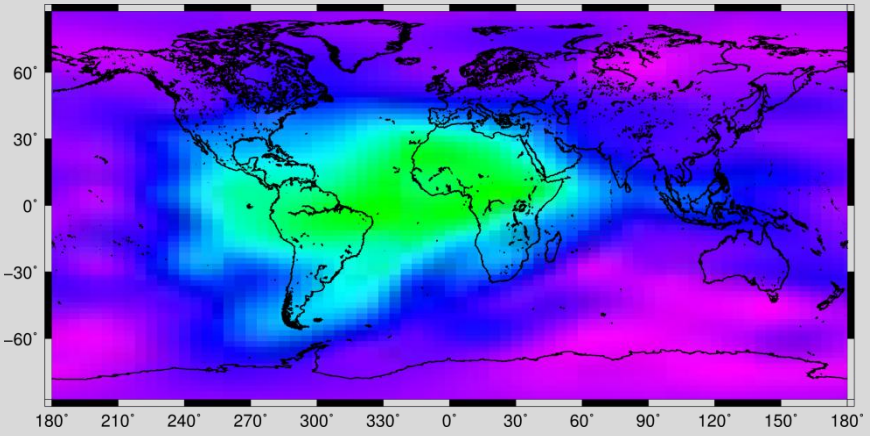
International Reference Ionosphere
NASA model iri.gsfc.nasa.gov
IRI 2012 *[Bilitza et al. 2011]*

Empirical climatological ionospheric model



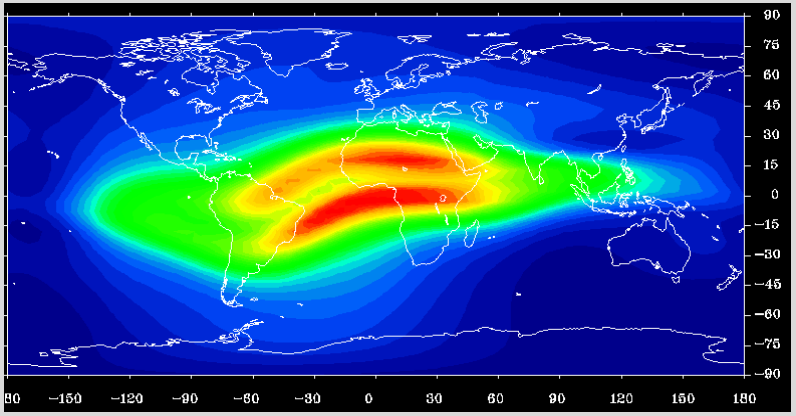
CODE Final GIMs - IONEX
Bern ftp.unibe.ch
[Schaer et al. 1998]

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



Comparison with other ionospheric models

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



IRI
Very smooth

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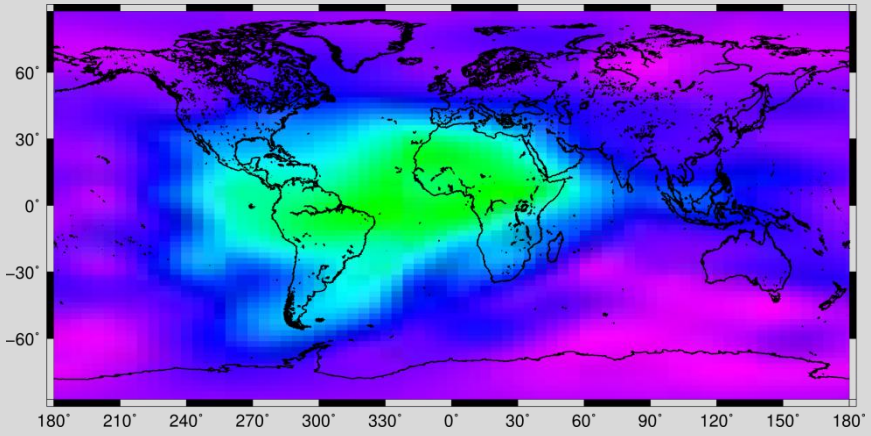
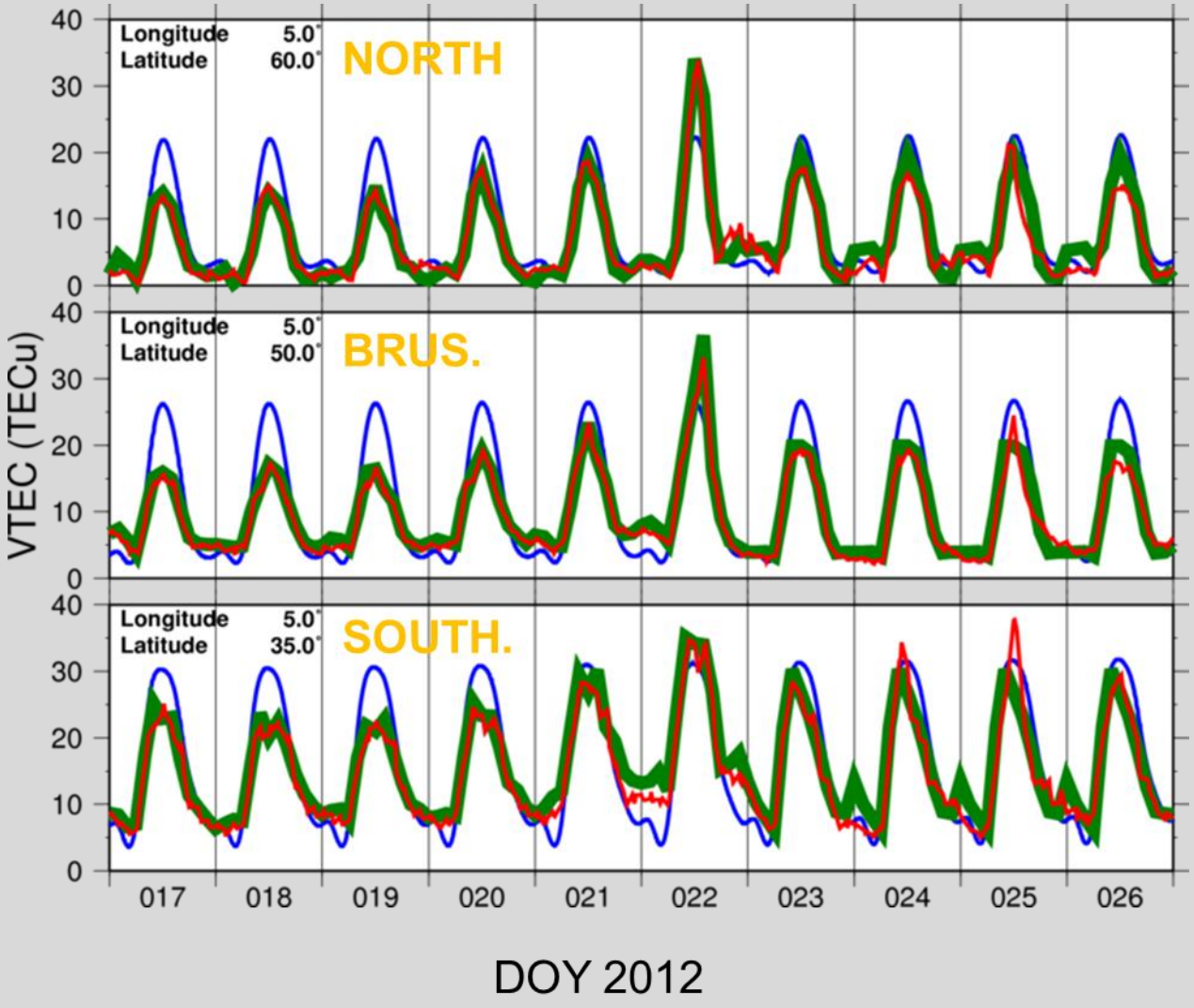


CODG
Slightly smooth

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

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

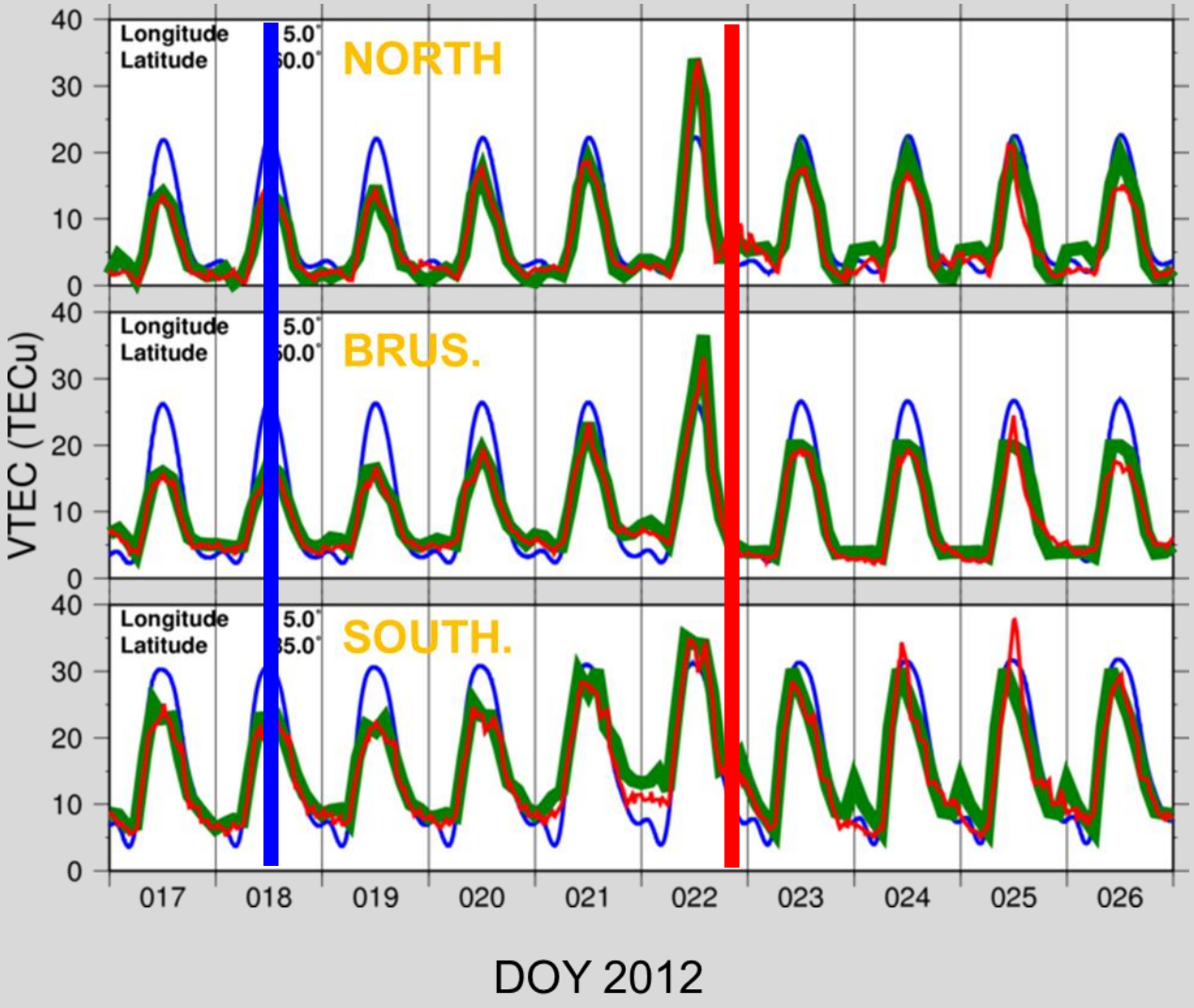
12:00 UTC

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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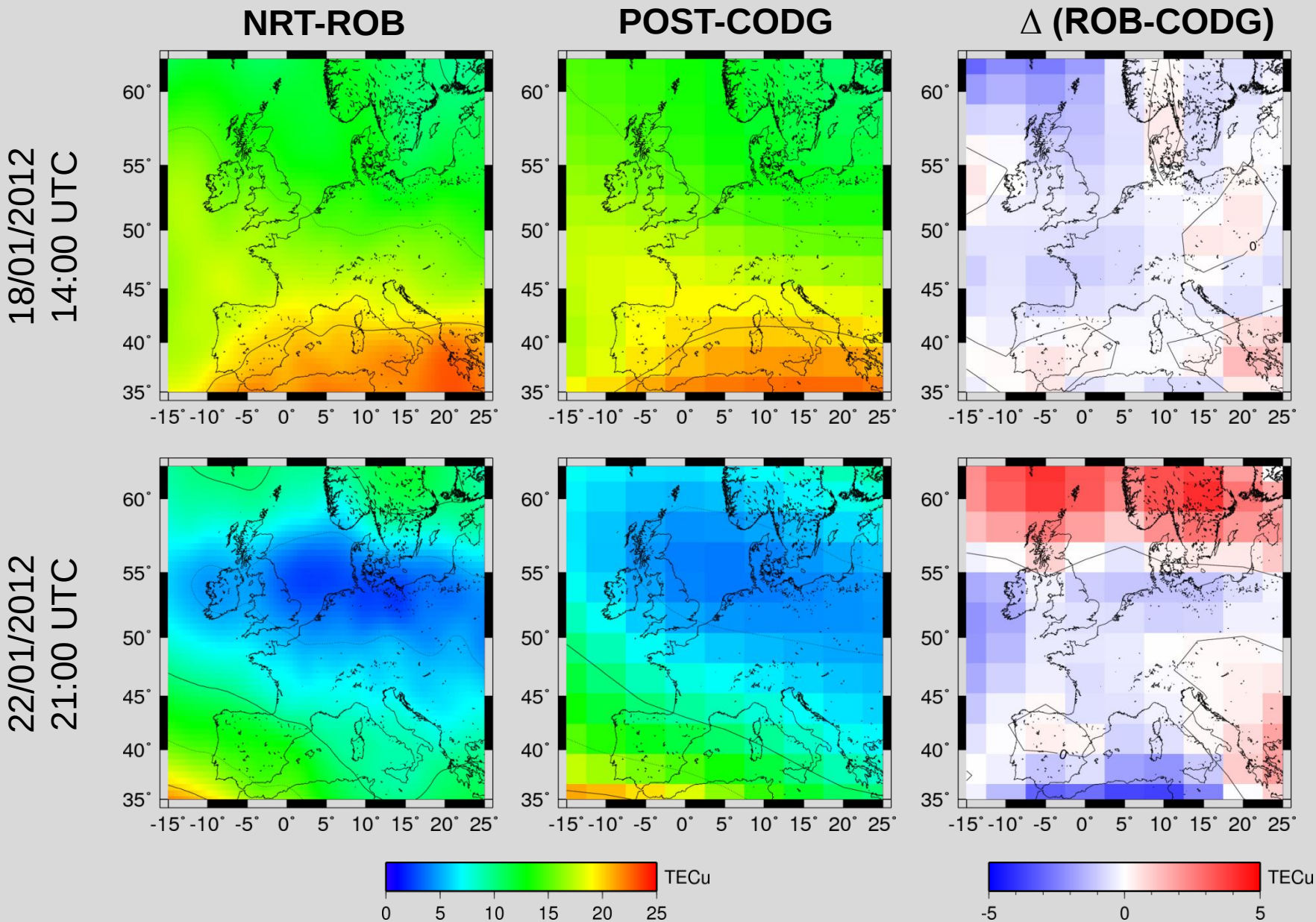
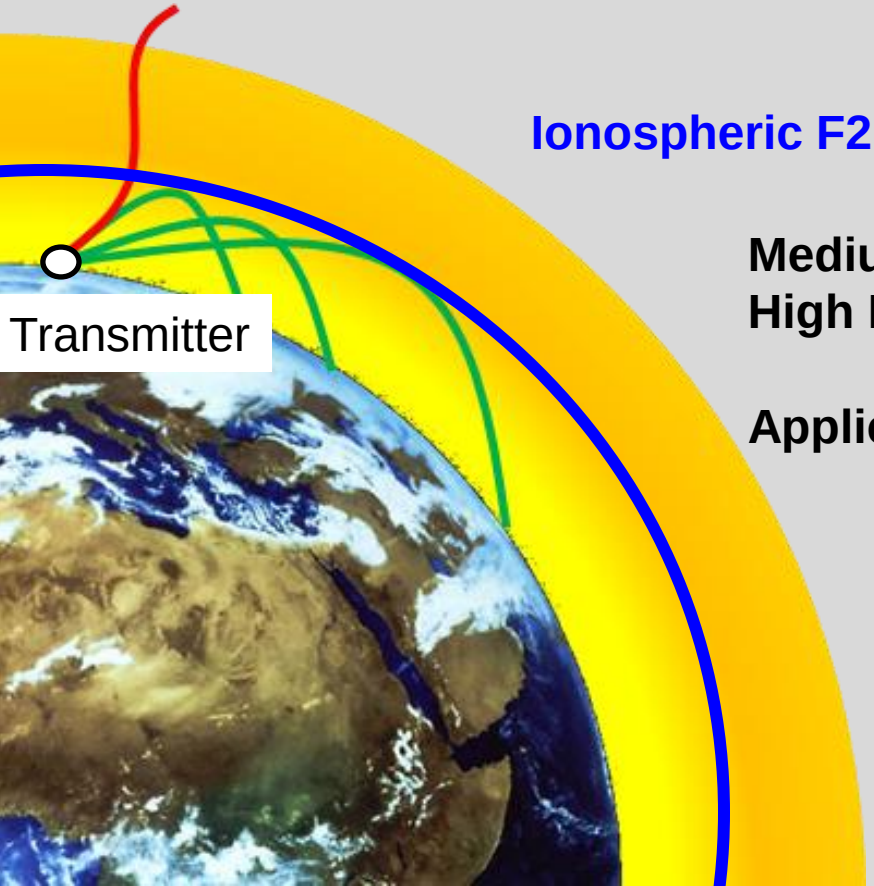


Products under development

F2 Critical frequency = foF2



Ionospheric F2 layer ~ 300-400 km.

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

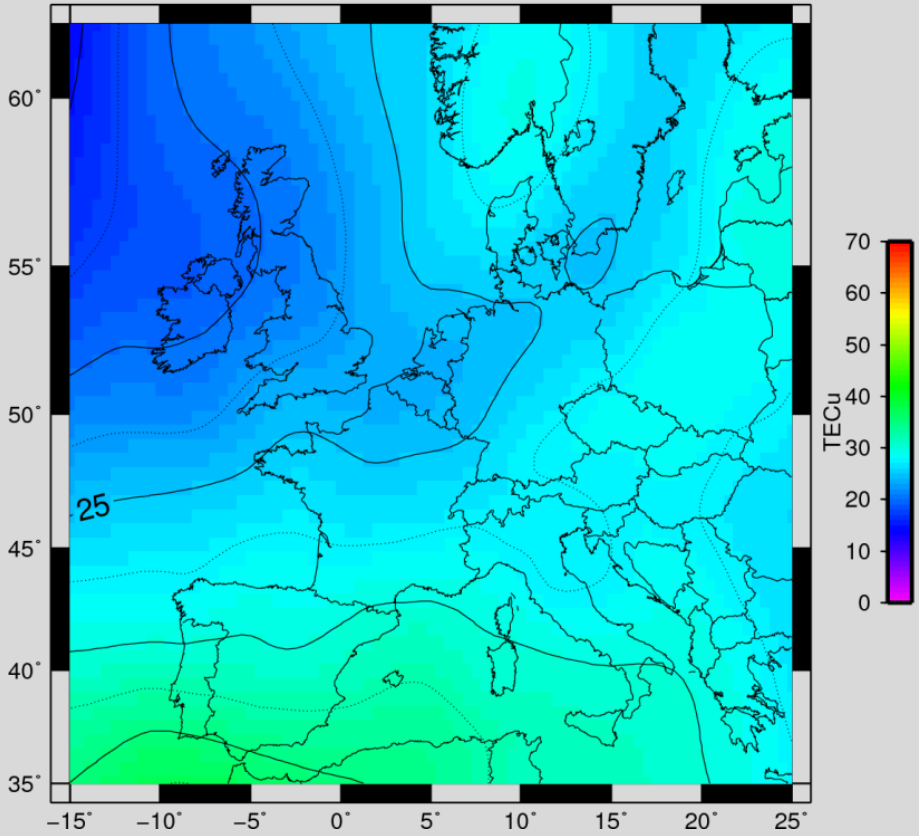
Applications : Aviation, amateur radio ….

< foF2 = Reflexion

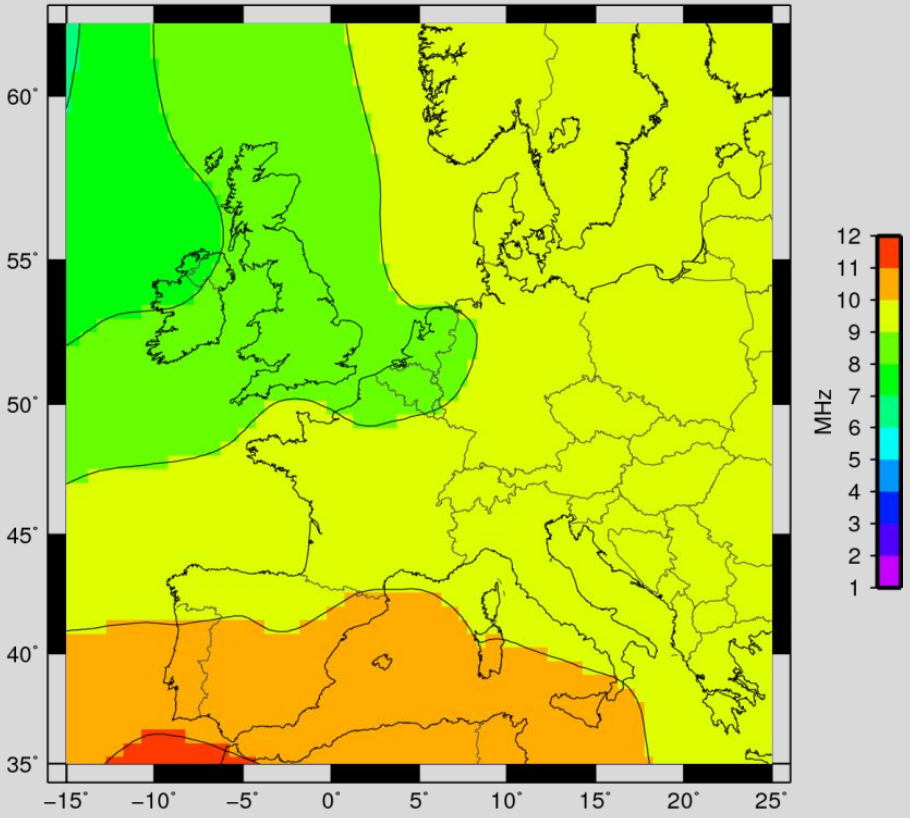
> foF2 = Refraction

F2 Critical frequency = foF2

NRT-VTEC ROB maps

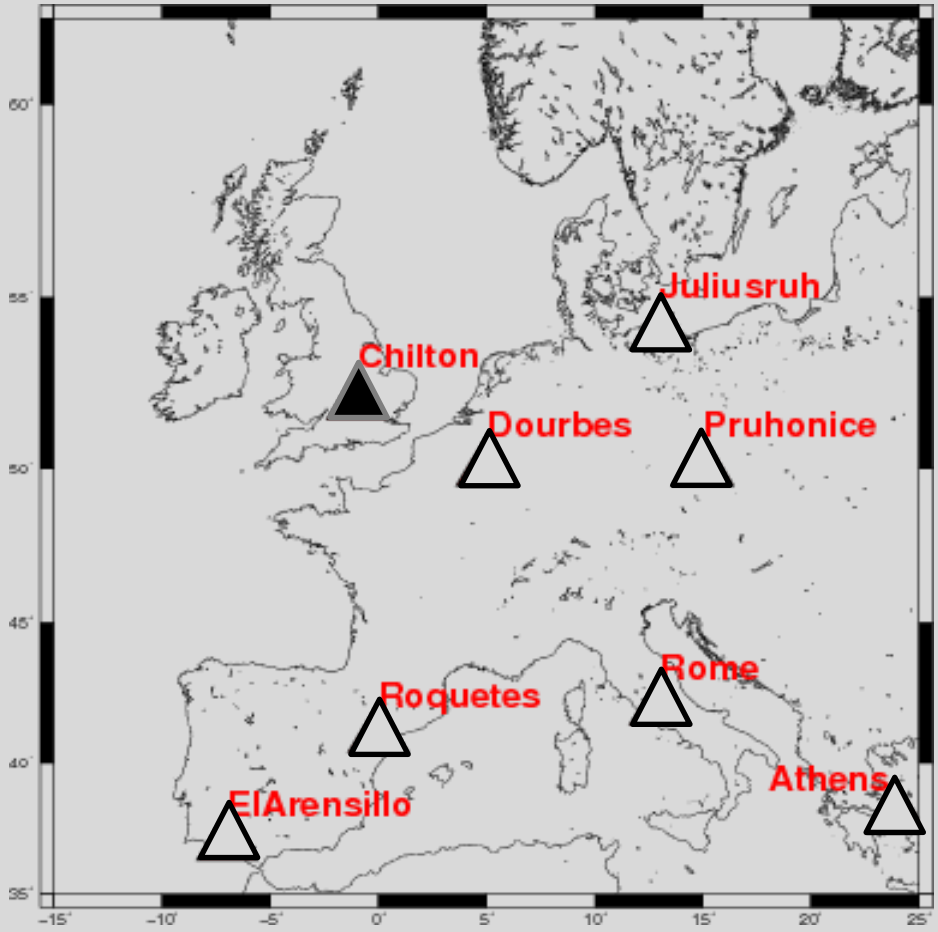


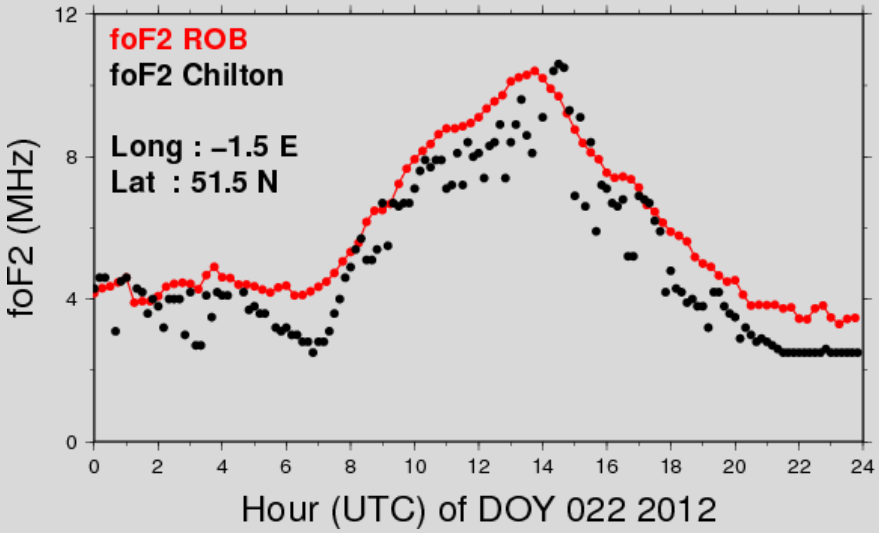
NRT-foF2 ROB maps



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

F2 Critical frequency = foF2





Differences with Chilton ionosonde

31 days in Jan. 2012
Each 15 min

REL. Δ : 13 ± 17 %
ABS. Δ : 0.6 ± 0.5 MHz

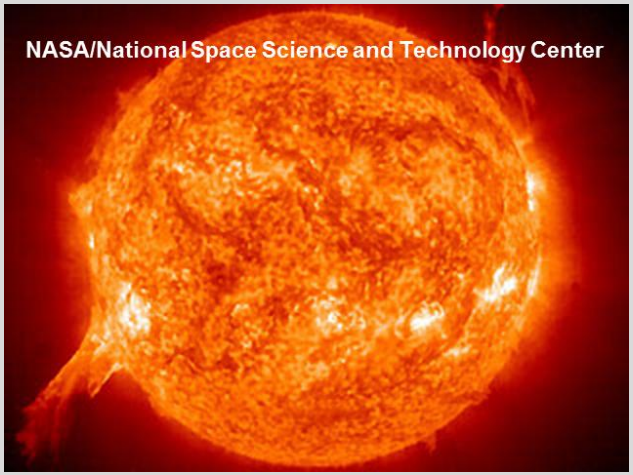
Useful for MF and HF reflexion

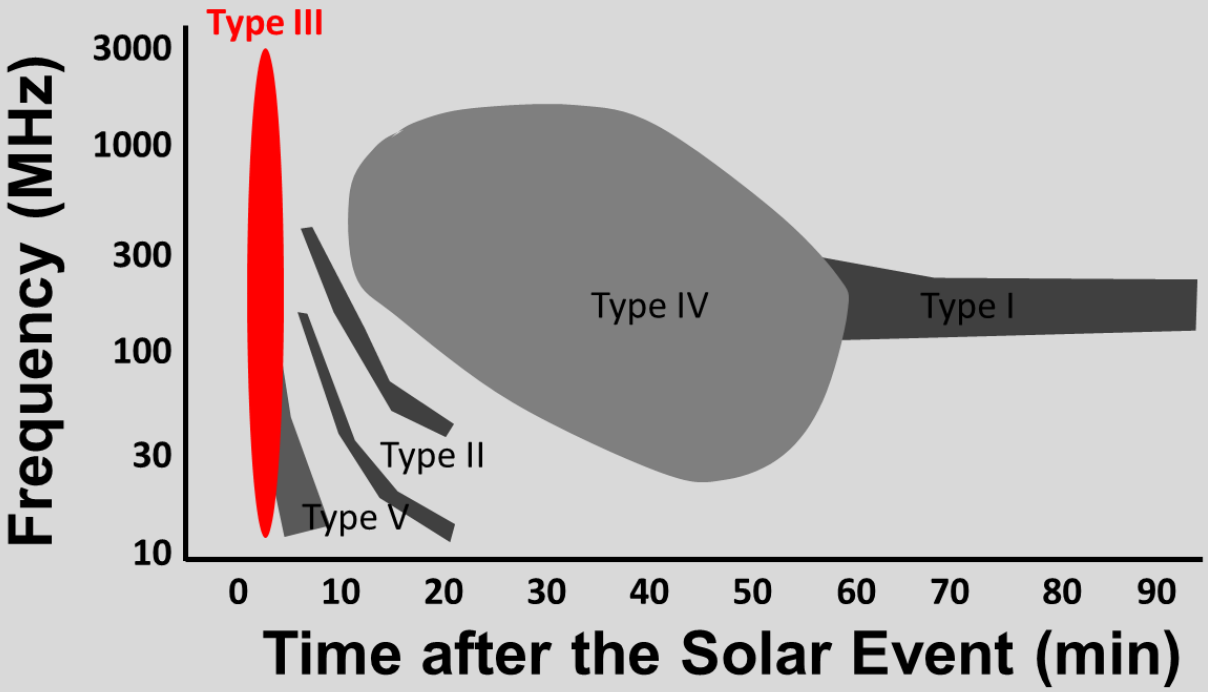
Study of the GPS Signal/Noise

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





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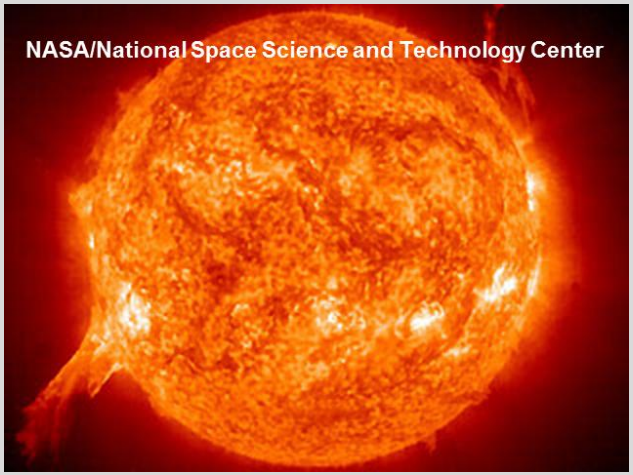

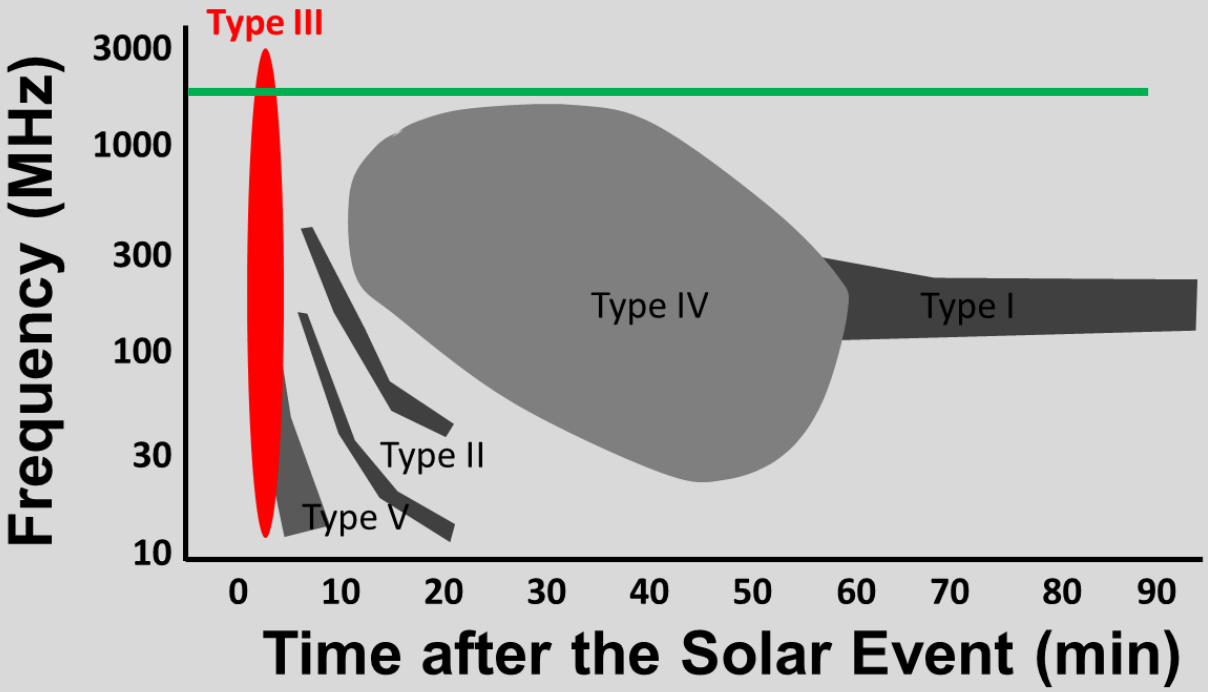

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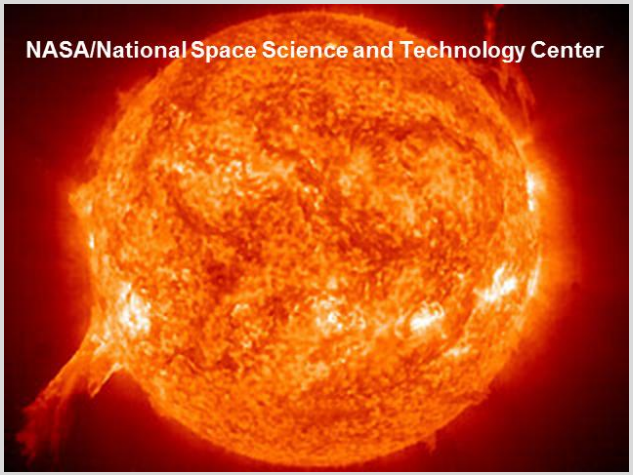
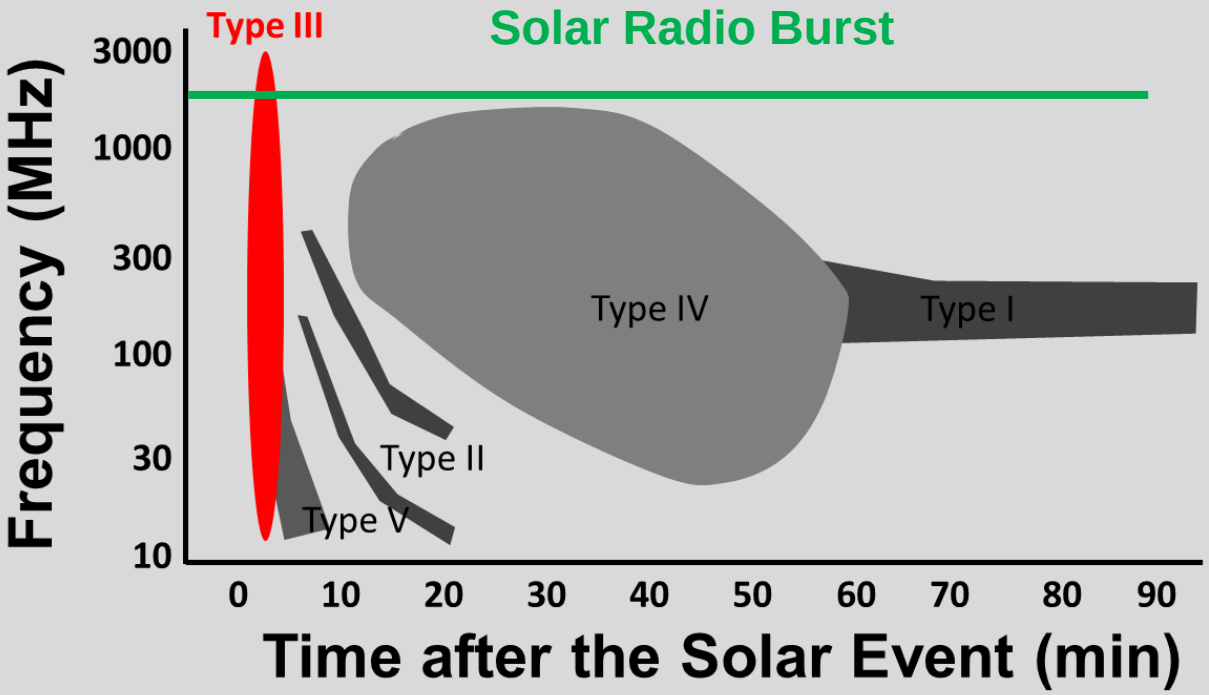
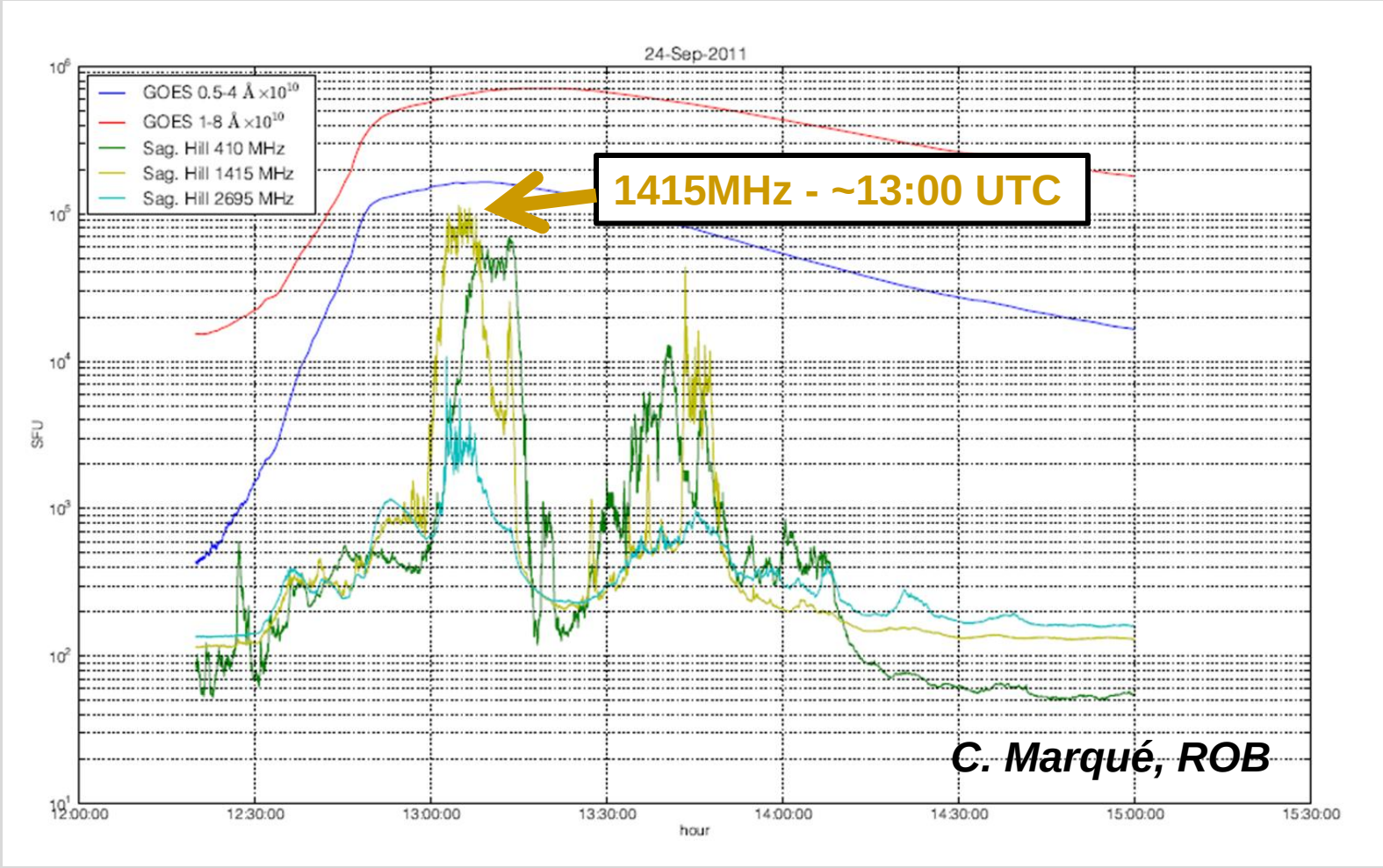


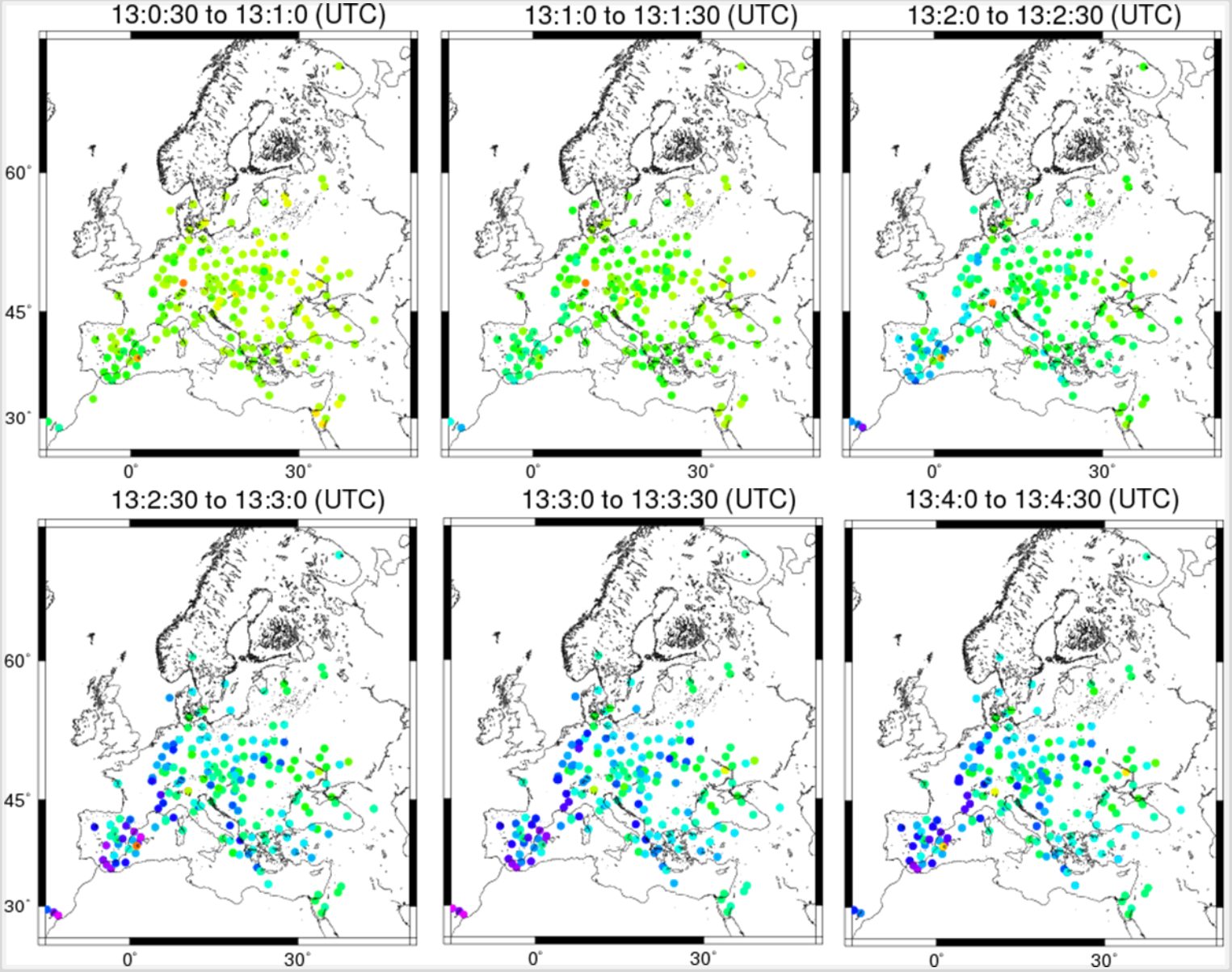


Study of the GPS Signal/Noise

Frequencies emitted by the Sun 24-09-2011



Study of the GPS Signal/Noise



Conclusions and perspectives

- NRT-VTEC ROB maps each 15min. (0.5°x0.5°). Latency 7-10 min.
- Use of EPN NRT GPS data from ROB [& BKG] NTRIP Broadcaster.
- Products available on **gnss.be**

  Densification of NRT GPS stations in Northern Part of Europe.
- Products under development (S/N, foF2).

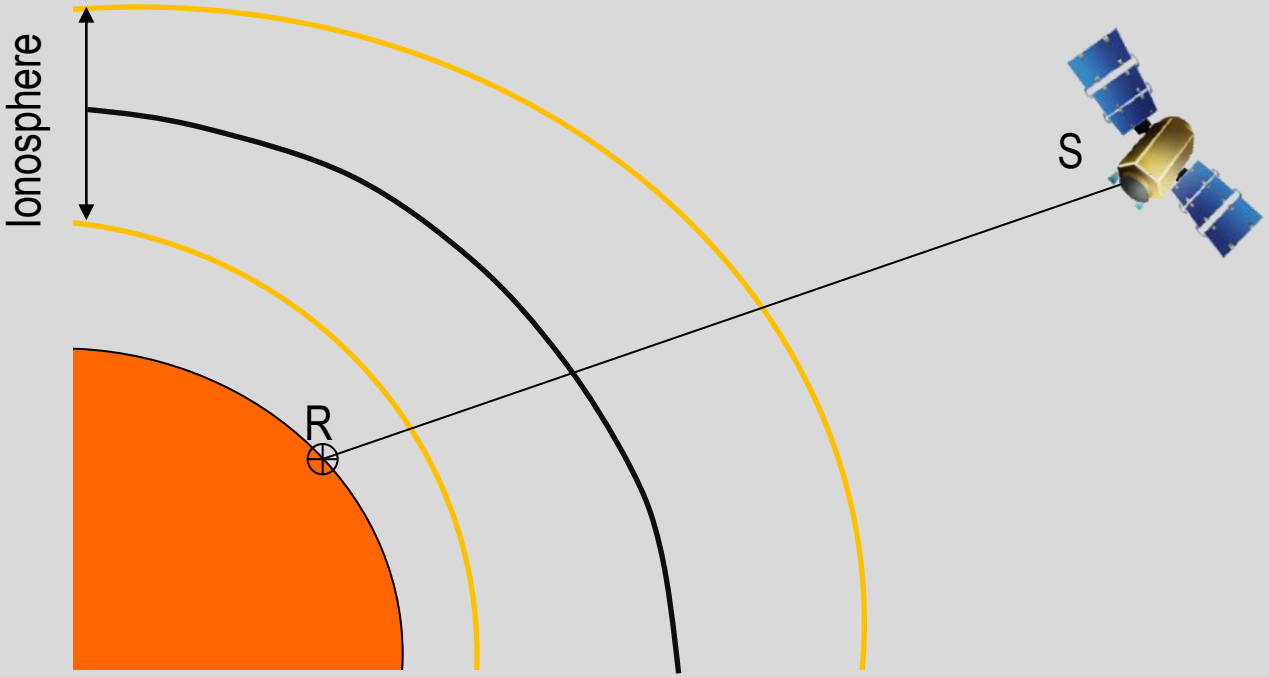
  ROB NRT **IONEX** will be also provided.

iono@gnss.be

Ionospheric monitoring from EPN NRT GPS data

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

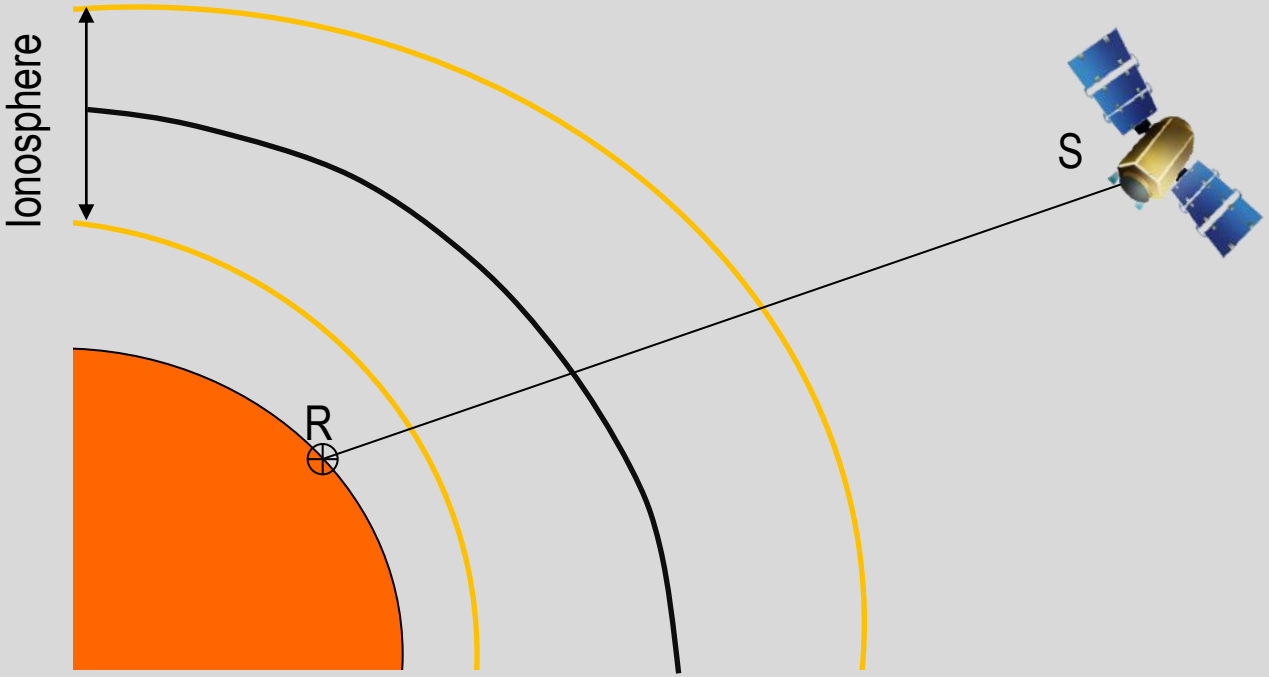
Zero-difference phase-smoothed (P_1 and P_2) code observations



Ionospheric monitoring from EPN NRT GPS data

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

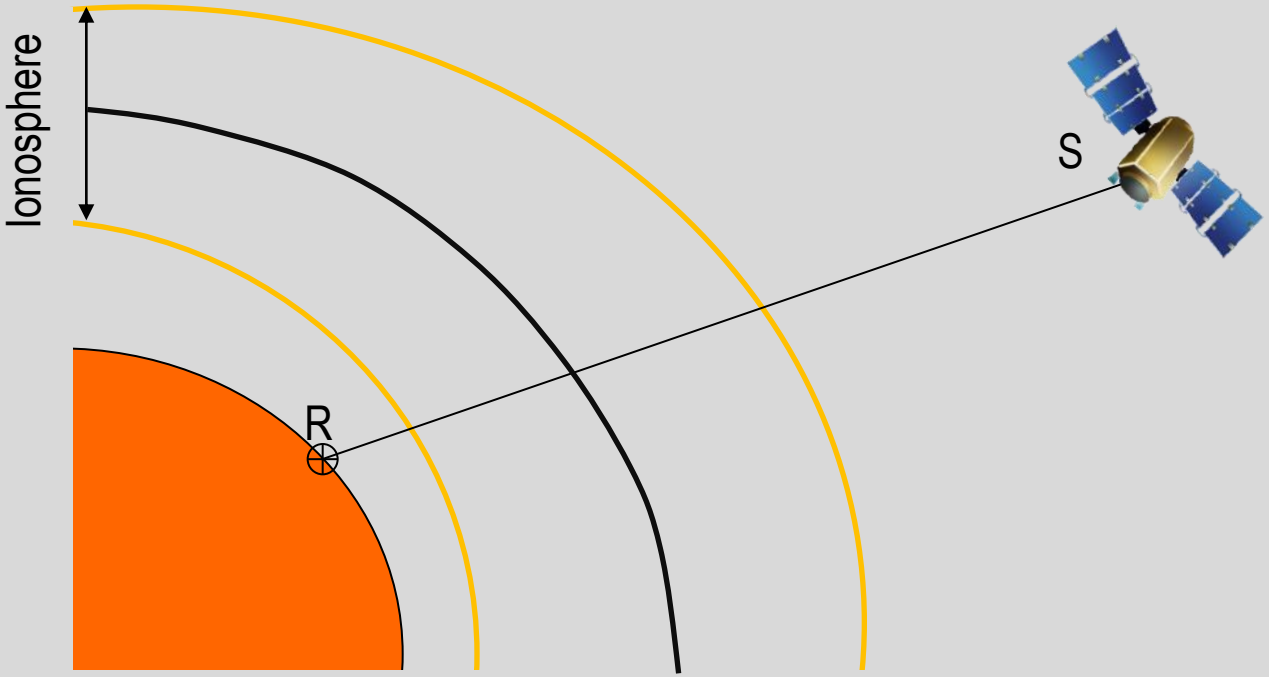
DCB^s : estimation from CODE analysis centre [Schaer et al. 1998]
Rapid IONEX (IONosphere map EXchange).



Ionospheric monitoring from EPN NRT GPS data

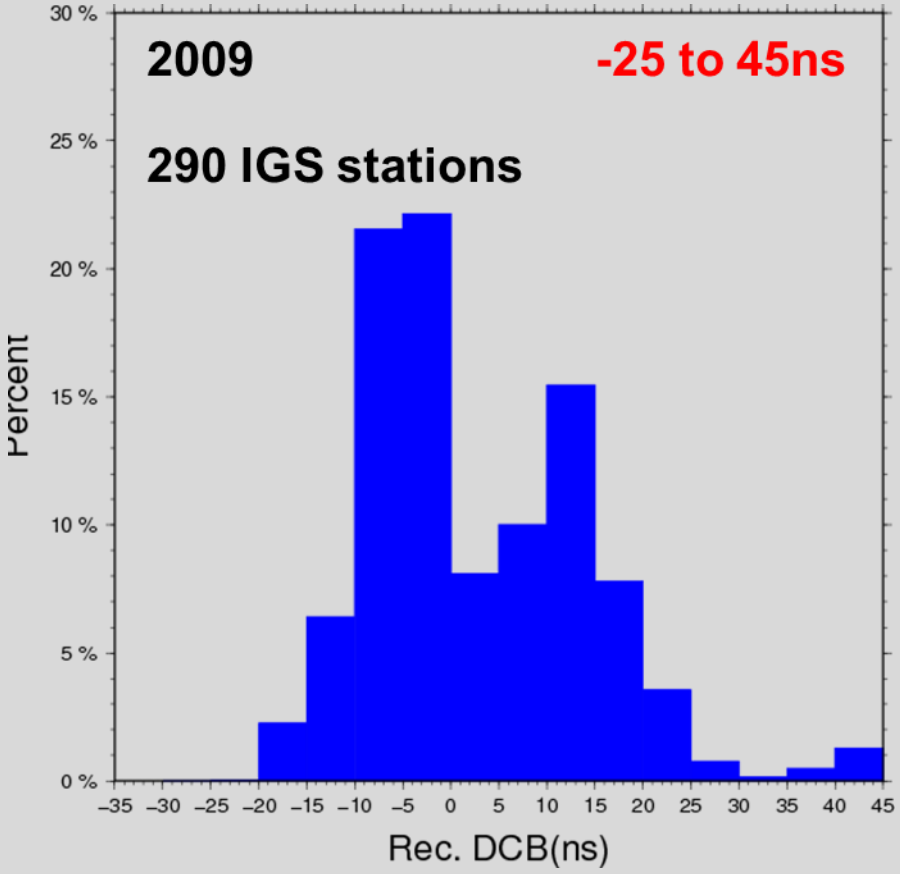
$$P_2 - P_1 + DCB^s + DCB_r = 40.3\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)STEC$$

DCB_r : estimation using *a priori* ionospheric models (Rapid IONEX)

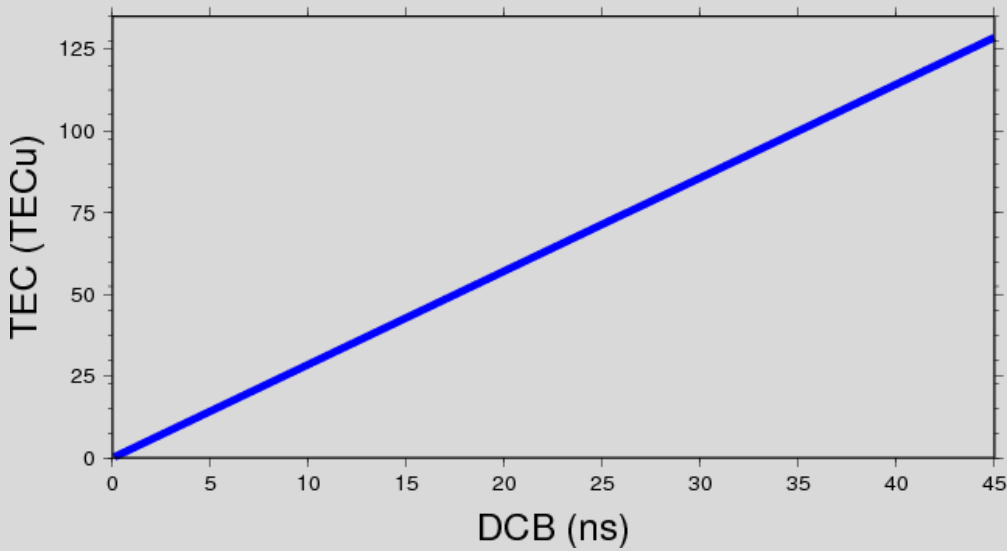


Receiver Differential Code Biases

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



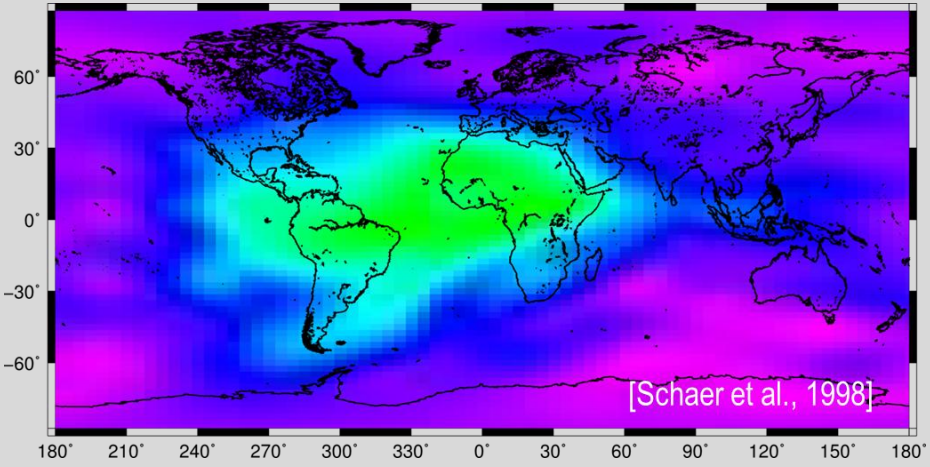
45 ns
128 TECu



Receiver Differential Code Biases use in NRT

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

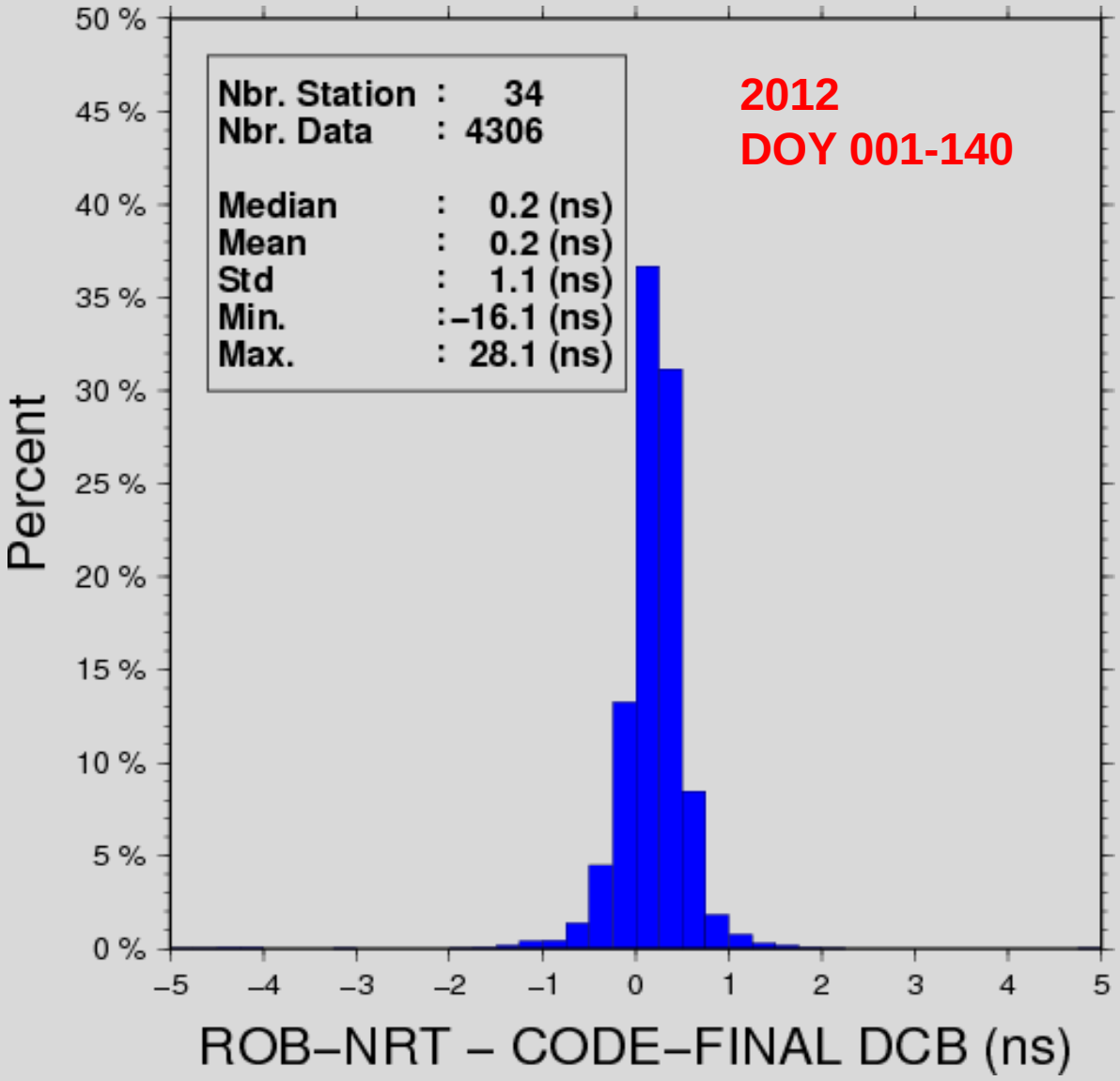
- Global Ionospheric Maps (GIM) of VTEC (5°x2.5°x2h, 2-9 TECu)
- CODE rapid products (~ 24h)
- ~120 globally distributed stations
- GLONASS and GPS constellations
- Linear interpolation in space and time



$DCB_r(j)$=

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).

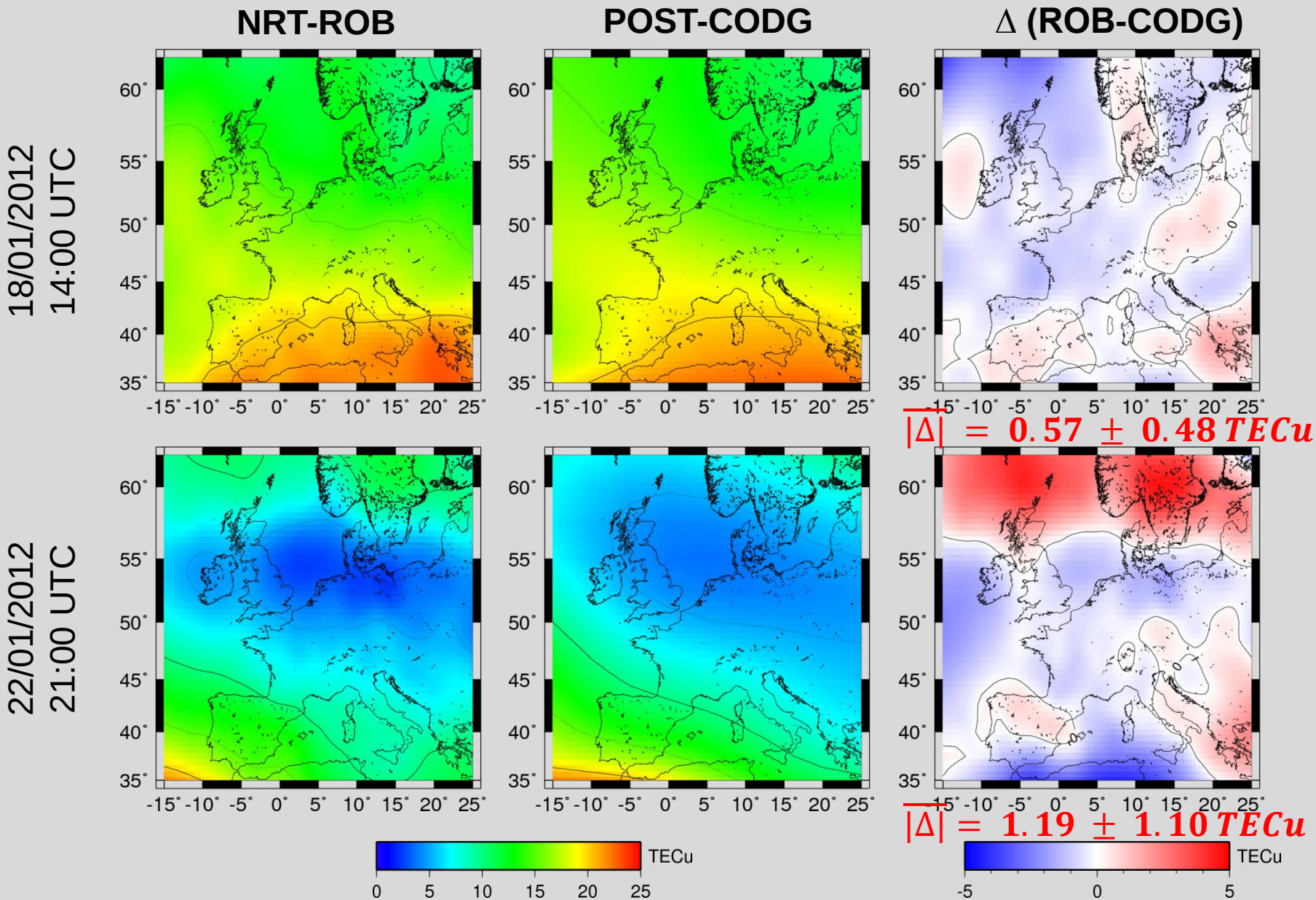
34 stations from the IGS.

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

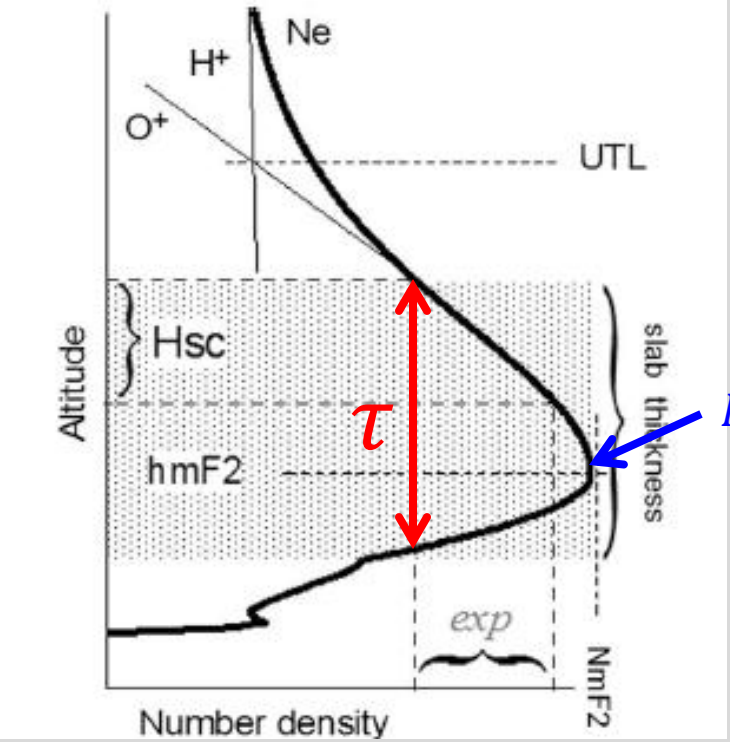
Biases = 0.2 ns (~0.5 TECu)

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

Comparison with other ionospheric models



F2 Critical frequency = foF2



From Stankov et Warnant, 2009

Davies, 1990:

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

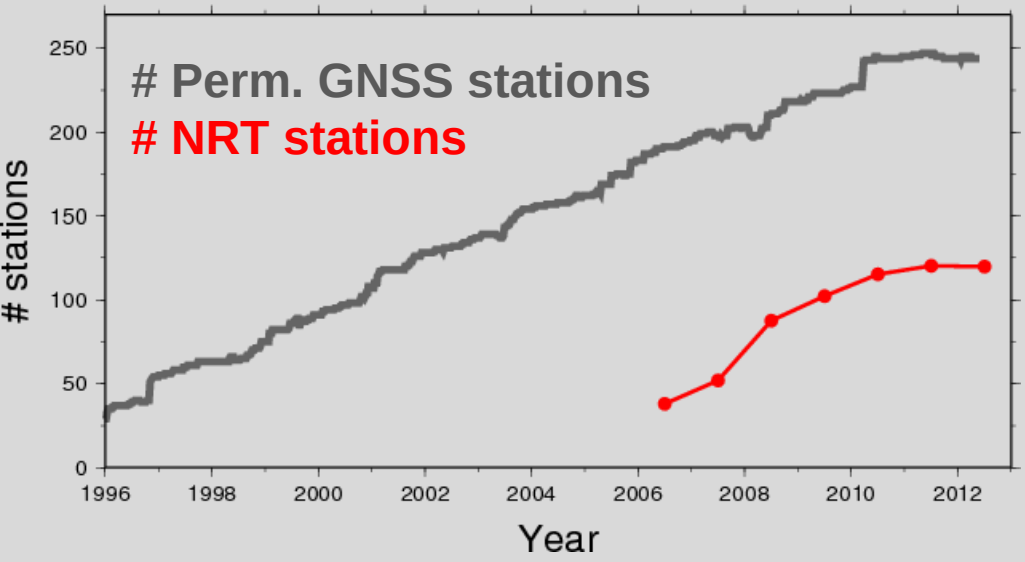
NmF2
Scaled IRI 2012

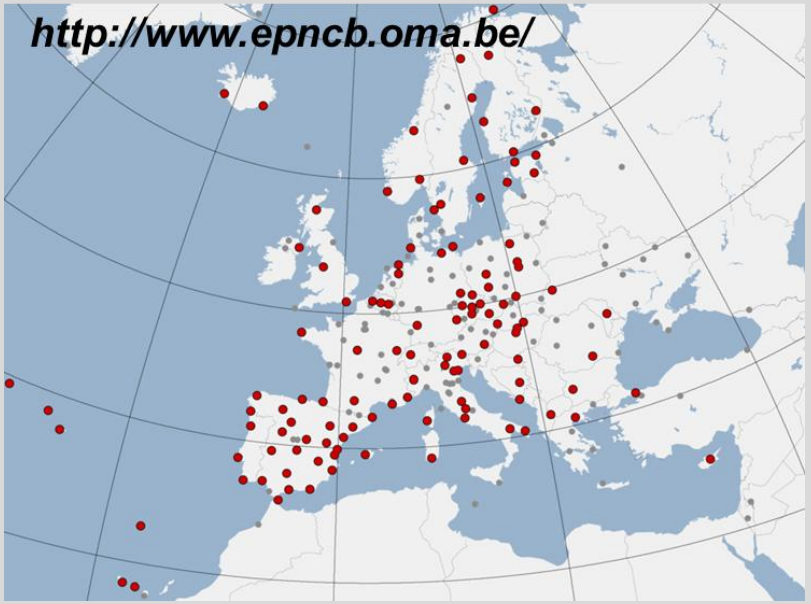
$$\tau = \frac{VTEC}{foF2^2 \times 1.24 \times 10^{-6}}$$

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

European Permanent Network (EPN)

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





EPN (European Permanent Network)