GNSS-based Near Real-Time Ionospheric Monitoring over Europe Available On-Line

Royal Observatory of Belgium
GNSS Research Group

Solar-Terrestrial Centre of Excellence

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IGS Workshop
July 23 – 27, 2012
Olsztyn, Poland

Introduction

Since the beginning of the 24th Solar cycle, the Solar activity increases (maximum expected in 2013) together with the Ionospheric activity (*Bergeot et al., 2012*) (Figure 1). It requires therefore having a close eye on the ionosphere to better understand the Space Weather physics and its effects on radio communication and navigation.

In this frame, near real-time ionospheric models over Europe are now generated every 15 minutes at the Royal Observatory of Belgium (ROB). They are available on-line at www.gnss.be with a latency of 5-7 minutes with respect to the last GNSS measurement. The models are ionospheric Vertical Total Electron Content (VTEC) maps estimated on a 0.5°x0.5° grid based on Global Positioning System (GPS) observations.

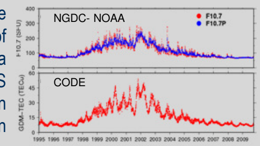


*Figure 1: **Ionospheric and Solar data during the 23rd Solar cycle.** Top: F10.7 flux observed and F10.7P from Penticton radio telescope. Bottom : Global Daily Mean TEC in TECu*

The poster introduces :

- the processing strategy used to generate the VTEC maps
- the products available on-line developed around the VTEC maps
- the comparisons with Global Ionospheric Maps (GIM) and climatological ionospheric model.

I. Method

Data

- Real-Time GPS data of 122 EUREF Permanent Network (EPN) stations (*Bruyninx et al., 2012*) (Figure 2) provided by the ROB NTRIP broadcaster (*Söhne et al., 2010*)
- Ultra-Rapid Orbits from the International GNSS Service (IGS) (*Beutler et al., 1995*)
- Satellite Differential Code Biaises (DCB) from the Center for Orbit Determination for Europe (CODE) (*Schaer et al., 1998*)

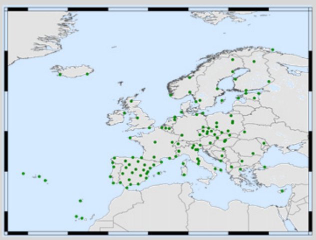


Figure 2: Real-time receiver network of the EPN

Estimation of the Total Electron Content from GNSS Data

- The Slant Total Electron Content (STEC) corresponds to the total number of electrons along a satellite-receiver path. It is expressed in TEC units (1TECu = 10^{16} electrons.m^{-2}). The STEC is estimated each 30s for each satellite/receiver pair using the geometry-free linear combination (*Bergeot et al., 2003*):

$$STEC = \frac{f_1^{\,2} f_2^{\,2}}{40.3\left(f_1^{\,2} - f_2^{\,2}\right)} * \left((P_1 - P_2) - c\,(DCB_r + DCB_s)\right)$$

P_1, P_2 : Phase-smoothed code observations (in m) at the two GNSS frequencies $f_{1,2}$
c : Speed of light
DCB_r : Receiver DCB estimated as the median over the 5 previous days using *a priori* rapid ionospheric model from CODE
DCB_s : Satellite DCB

- The STEC is then projected as a Vertical TEC (VTEC) at the Ionospheric Pierce Point (IPP) at an altitude of 450 km, using an ionospheric single thin layer hypothesis (Figure 3).

$$VTEC = STEC \cos z'$$

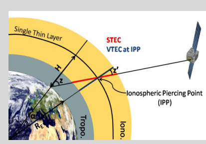


Figure 3: Geometry of the VTEC at the IPP from STEC

Data Cleaning, Filtering and Spline Interpolation

- Medians of VTEC along each satellite track are estimated, avoiding outliers and improving the distribution of the set of data.
- The spline interpolation is iterated with different degrees of smoothing, in order to perform outlier rejection (see Figure 4).
- VTEC grid : 0.5°x0.5° - 15 min
- Number of VTEC at IPP per map : 1692 ± 271
- Time-independent maps

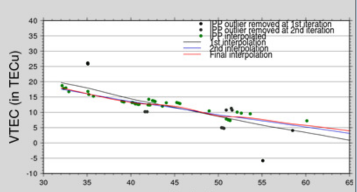


Figure 4 : Interpolation on a longitudinal slice

II.a. Ionospheric Products Available On-Line

Since December 2011, the ROB delivers Near Real-Time Ionospheric Products (Figure 5), dispatched as 3 different sub-products.

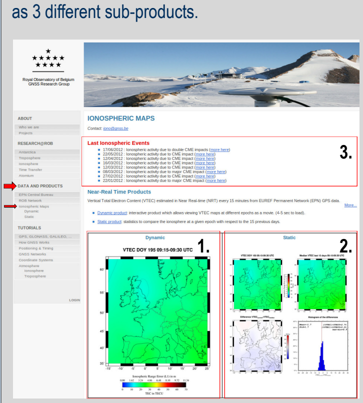


Figure 5: Web home page of the ionospheric products

1) Interactive Ionospheric VTEC Maps (Figure 6)

- Animated ionospheric VTEC maps (movie) for a requested period
- Display VTEC value at a given point and time

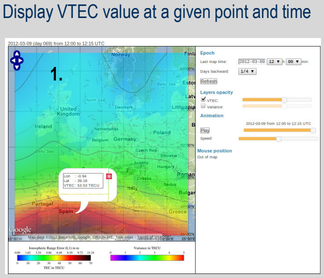
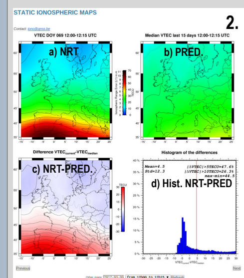


Figure 6: Interactive Ionospheric VTEC Map tool

II.b. Ionospheric Products Available On-Line



2) Statistics over the ionospheric VTEC maps :

Comparison of VTEC maps at a given time w.r.t the median of the 15 previous days (prediction model) highlighting the ionospheric activity. (Figure 7).

Figure 7: Statistical product web page with
a) VTEC map,
b) median VTEC of the 15 previous days,
c) Differences current VTEC/median VTEC,
d) Histogram of the differences

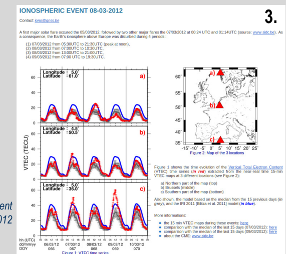


Figure 8: Web page of the event of the 07 /03/2012

3) Ionospheric Events:

- Ionospheric events are reported into dedicated web pages
- VTEC time serie of 2 days before and after the event at 3 locations in Europe, including the VTEC median w.r.t. the 15 previous days and the International Reference Ionosphere (IRI 2012) model (*Bilitza et al., 2008*) (Figure 8).

III. Comparison with Global Ionospheric Maps and Climatological Model

To test the robustness of our ROB Near Real-Time ionospheric maps, we compared them with GNSS-based CODE final GIM (latency of 5 days) (*Schaer et al., 1998*) during a ionospheric quiet day (18/01/2012) and during a disturbed day (22/01/2012) due to a Solar Coronal Mass Ejection impact.

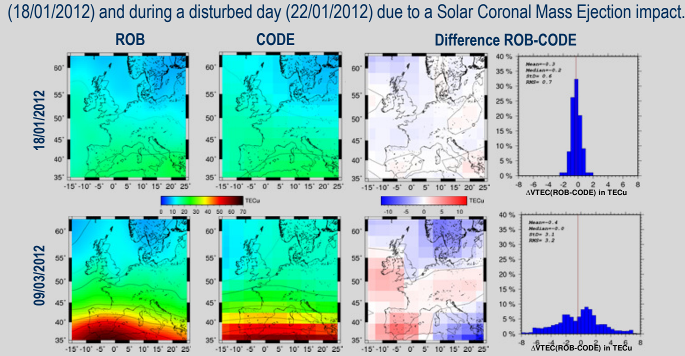


Figure 9: Ionospheric Maps of ROB (1st column) and CODE (2nd column), differences (ROB-CODE) (3rd column) and histograms of the differences; for a quiet day, the 18/01/2012 at 14:00 UTC (top row) and for a disturbed day, the 09/03/2012 at 12:00 UTC (top row) (bottom row)

- ROB maps are less smooth, fitting closer to the GNSS observations (Figure 9).
- ROB maps are not biased 0.0±1.1TECu (Figure 10) w.r.t. CODE products apart during ionospheric disturbed period (absolute bias of 2.4 ± 2.0 TECu) (Figure 9).

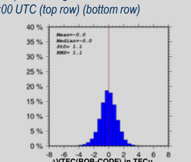


Figure 10: Differences between ROB and CODE VTEC for January 2012

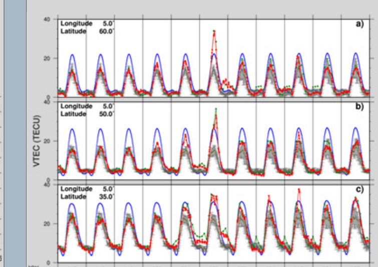


Figure 11: VTEC time series from the 17th to the 27th of January 2012 a) in the North (lon:5°; lat:61°), b) above Brussel (4.5°;51°) and c) in the South (5°;36°); ROB in red, ROB median model of the 15 previous days in grey, CODE in green, IRI in blue

VTEC extracted from ROB maps at 3 locations in January 2012 is compared with CODE GIM and the climatological model of IRI 2012 (Figure 11).

- Differences with CODE GIM and ROB VTEC are of the order of 0.0±1.3TECu in the North, 0.2±0.8TECu above Brussel and -0.9±1.5TECu in the South.
- Mainly at day time, a bias is observed w.r.t. IRI. For example at noon, there are biases of: -6.4±3.9TECu in the North, -9.5±3.2 TECu above Brussel and -5.6±4.2TECu in the South.

Conclusion

- ✓ The **Regional Near Real-Time Ionospheric VTEC Maps of ROB** with a **resolution of 0.5°x0.5°** are available **every 15 minutes** with **a latency of 5-7 minutes** at www.gnss.be/Atmospheric_Maps/ionospheric_maps.php.
- ✓ Additional web pages show the **ionospheric activity** w.r.t to the 15 previous days and identified **ionospheric events** since January 2012.
- ✓ The ROB VTEC maps allow any user within the geographical scope of the maps to estimate in near real time the **ionospheric delay** induced along the signal of any observed satellite.
- ✓ The ROB VTEC maps demonstrate a good agreement with Final Global Ionospheric Map of CODE.
- ✓ New products will be developed to satisfy both ionospheric and GNSS communities : **IONEX** format, maps of the **foF2** Critical Frequency, correlation **GPS signal to noise ratio and solar events**.

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