Using the EUREF Permanent Network to Monitor the Ionosphere

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Introduction

The major disturbances in the ionospheric state are due to Solar eruptions which induce geomagnetic (super)-storms. Moreover, the study of rapid variations in the ionospheric state over Europe is essential for applications in the field of geophysics, space weather research and it can also provide valuable information in support of radio system transmissions.

Furthermore, the occurrence frequency of solar sunspots, and consequently ionospheric activity, will increase in the next years due to the beginning of the 24^{th} sunspot cycle. Consequently, GNSS errors will be larger and single frequency GNSS users will need ionospheric models with a high resolution in both time and space domains to correct the ionospheric delay during rapid events such as geomagnetic storms.

Presently, the ionospheric models based on GNSS data are represented as Global Ionospheric Maps (GIM) of Total Electron Content (TEC). These TEC maps are estimated each 2h on a 2.5°/5° grid (e.g. CODE IGS analysis center IONEX products [Schaer, 1998]). Because the TEC varies at a higher order in time and space domain during a geomagnetic storm, the ROB is developing a method to estimate a hourly 1°/1° TEC grid above Europe.

In this study we describe the method used to model the ionosphere based on GPS data from the EUREF Permanent Network (EPN) GNSS stations. We focused on two distinct periods: (1) during the Halloween geomagnetic storm of October 30^{th}, 2003; (2) during normal ionospheric activity in 2008. We present the data and the method used to estimate the TEC maps as well as a comparison with the CODE products.

VTEC map estimation over Europe

The EPN [e.g. Bruyninx, 2004] is composed of continuously observing GNSS stations since 1996. The number of stations in this network is growing with a mean of +14 stations/year between 1996 and 2009. Mid 2009, the EPN is composed of up to 220 stations over Europe.

To estimate the Vertical Total Electron Content over Europe, we used the GPS zero difference geometry-free (L4) code and phase observations which contain only the ionospheric TEC parameter and the differential inter-frequency hardware delays called Differential Code Biases (DCB) of the satellites and receivers. The receiver DCBs where estimated using the Bernese v5.0 [Dach et al., 2007], while the satellites DCBs where taken from the monthly estimation of CODE analysis center [Schaer, 1998]. Then we estimated the VTEC in TEC Unit (TECU) at the piercing point (PP) of the ray path with a ionospheric thin layer hypothesis at an altitude of 450km. The VTEC at each PP is estimated each 30s between each satellite and each receiver. Due to the increase of the number of stations in the EPN (157 in 2003 and 195 in 2008), the cumulative number of VTEC estimated at each PP each 5mn over Europe is 8500 in 2003 and 13500 in 2008. In a second step, we estimated the mean value of the hourly 1°/1° VTEC maps (figure 1) as well as its RMS which mainly gives a quantification of the variation of the VTEC value in each grid cell during the hour. Due to the important number of stations, less than 1% of the grid cells have no VTEC data during the day. Consequently, we do not use any interpolation to estimate ionospheric maps.

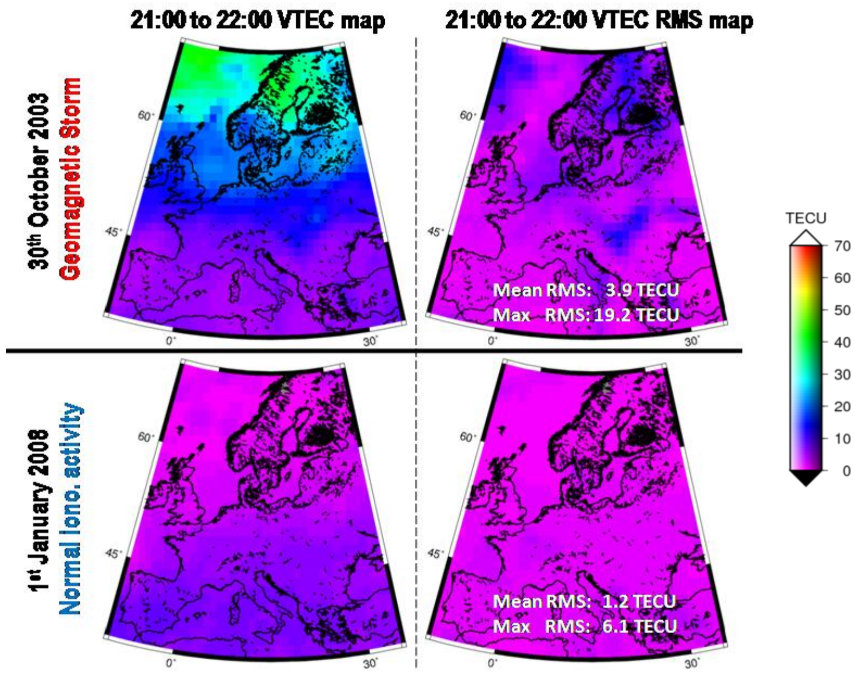

Figure 1: Hourly 1°/1° grid ionospheric model over Europe between 21:00 and 22:00 UT in TEC unit (TECU). Left: VTEC maps, Right: RMS maps; top: October 30th, 2003 during a geomagnetic storm; bottom: January 1st, 2008 during normal ionospheric activity.

As we can see, during the October 30th, 2003 geomagnetic storm, the mean RMS is larger (3.9 TECU) than during normal ionospheric activity (1.2 TECU). This is due to rapid variations in the TEC, and consequently in the ionospheric state, during the geomagnetic storm.

Comparison with Global Ionospheric Maps (GIM)

To validate our results, we compared our VTEC maps with Global Ionospheric Maps (GIM) GPS-based products. The comparison is made using the CODE products available from ftp://ftp.unibe.ch/aiub/CODE/ [Schaer, 1998]. The CODE GIM products are global VTEC maps estimated from more than 200 globally distributed GNSS stations and they are represented as spherical harmonics coefficients.

The comparison between the ROB and CODE products during a day with normal ionospheric activity (January 1st, 2008) shows differences of 0.1±1 TECU. No bias between the two products is observed and 96% of the differences are lower than 2 TECU and 74% lower than 1 TECU. However, on the 30th October 2003, when rapid changes in the ionospheric state due to Solar flares occurred, the differences are estimated to 1±3 TECU. A mean bias of 1 TECU between the two products is observed and only 70% of the differences are lower than 2 TECU and 40% are lower than 1 TECU. This must be caused by the smoothing of the ionospheric signal in the CODE GIM which uses spherical harmonics for the global representation of the VTEC on a 2.5°/5° grid each two hours while in our products we do not interpolate the data. This causes especially problems when performing regional studies.

Conclusion

The EPN network allows to estimate hourly VTEC and its RMS on a 1°/1° grid over Europe. The RMS of the VTEC maps gives information on high frequency (in time and space) ionospheric disturbances which can be significant during epochs of high ionospheric activity like geomagnetic storms. The ROB products are in good agreement with the GIM products during normal ionospheric activity. However, during high variations of the TEC in the ionosphere, e.g. during a geomagnetic storm, the ROB products allows to better detect rapid changes in the ionospheric state compared to global products.

References

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