The International Beacon Satellite Symposium *BSS2010*
P. Doherty, M. Hernández-Pajares, J.M. Juan, J. Sanz and A. Aragon-Angel (Eds)
Campus Nord UPC, Barcelona, 2010

UNDERSTANDING THE OCCURRENCE OF MID-LATITUDE IONOSPHERIC IRREGULARITIES BY USING GPS, IONOSONDE AND GEOMAGNETIC MEASUREMENTS

Gilles Wautelet⋆, Marcio Aquino†, Sandrine Lejeune⋆, Stan Stankov⋆ and Rene Warnant⋆

⋆Royal Meteorological Institute of Belgium
Avenue Circulaire, 3
1180 Brussels, Belgium

†University of Nottingham
Institute of Engineering Surveying and Space Geodesy (IESSG)
University Park, Nottingham, NG7 2RD, UK

Key words: Ionosphere, GPS, TEC, Climatology.

Abstract. A statistical analysis of TEC irregularities detected at GPS station of Brussels from 1994 up to now has been performed. On this basis, external data sources like geomagnetic indices, GPS scintillations data and ionograms have been used to explore the origin of irregularities detected.

1 INTRODUCTION

Nowadays, more and more applications rely on Global Navigation Satellite Systems (GNSS) like GPS, GLONASS or the future Galileo. In particular, techniques that allow centimeter-level accuracy like Real-Time Kinematics (RTK) are in high demand in surveying, building, farming, and other industries.

The RTK positioning method is called relative because the user needs to refer its own measurements (rover receiver) to a reference station for which the position is accurately known. As the vector linking the two receivers is small (usually less than 30 km), both stations are assumed to be affected in the same way by different error sources like atmospheric errors. However, small-scale gradients in the ionosphere can be the origin of large positioning errors, and constitute therefore the main limitation to the reliability and integrity of such techniques. In this paper, we present a climatological study of ionospheric small-scale irregularities based on long-term (since 1994) GPS measurements at Brussels. We study the origin of these irregularities and investigate their occurrence and behaviour using also ionospheric vertical incidence sounding, geomagnetic and scintillation measurements.

2 TEC IRREGULARITIES AT BRUSSELS: CLIMATOLOGICAL STUDY

Total Electron Content (TEC) rate of change at a single GPS station is monitored by using the Geometric-Free (GF) phase combination φ_{GF}:

$$\varphi_{GF} = \varphi_1 - \frac{f_1}{f_2}\varphi_2$$

$$= 0,552.10^{16} STEC + M_{GF} + N_{GF} + \epsilon_{GF} \quad (1)$$

with φ_k the phase measurement on carrier L_k, f_1 and f_2 the carrier frequencies, STEC the slant TEC expressed in TEC units, or TECu (1 TECu = $10^{16} electrons/m^2$), M_{GF} the multipath term in GF, N_{GF} the GF ambiguity term and σ_{GF} the noise on GF combination.

Making the difference between two consecutive epochs t_k and t_{k1} and assuming that no cycle slip occurred between those two epochs, we obtain the STEC temporal change called DSTEC at t_k:

$$\Delta STEC(t_k) = \frac{STEC(t_k) - STEC(t_{k-1})}{t_k - t_{k-1}} \quad (2)$$

Then, $\Delta STEC$ is verticalized and low-frequency changes in the temporal series (due partially to the satellite movement on the ionosphere) are removed by using a 3_{rd} order polynomial. The resulting quantity is called Rate of TEC (RoTEC).

Finally, we compute the standard deviation of RoTEC ($\rho RoTEC$) every 15 min and declare that an ionospheric event is detected if $\rho RoTEC \geq 0.08 TECU/min$. More information about the method used can be found in[2].

The climatological study of small-scale ionospheric structures is realised by using GPS measurements made at Brussels station (BRUS) over the period 1994-2008, which covers more than a solar cycle (11 years in average). We count the number of ionospheric events within different timescales: monthly sums over the entire solar cycle and yearly sum every 15 min interval to describe local time behaviour. Results can be summarized as follows (see figure 1):

1. Irregularities are more numerous during high solar activity periods (e.g. 2000 & 2002) than during low activity ones (e.g. 2006 & 2007).

2. Irregularities are more numerous during autumn and winter months, even during low solar activity periods.

3. Irregularities occur mainly during daytime with a maximum around 10 A.M. (local time) and show a secondary maximum of occurrence during nighttime (peak time varies with year considered).

3 USE OF EXTERNAL DATA SETS

The explanation of the temporal behaviour of irregularities detected can be investigated by analyzing different external datasets like geomagnetic indices, GPS scintillation indices and ionospheric vertical incidence soundings.

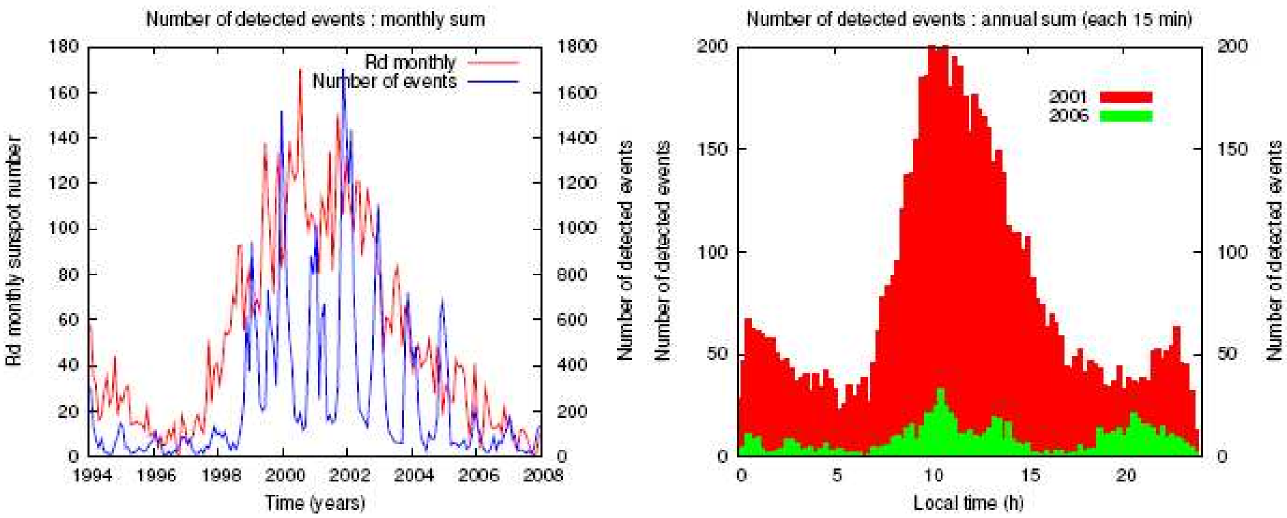

Figure 1: Number of ionospheric events detected over a whole solar cycle (*left*) and within specific years (2001 for solar max. and 2006 for solar min.) as a function of local time (*right*)

3.1 Two main types of structures

We analysed the occurrence and behaviour of ionospheric irregularities during both geomagnetically quiet and active periods. To separate active from quiet geomagnetic conditions, we used definitive values of the geomagnetic index K from local observatory measurements (Dourbes, 50.1^o N, 4.6^o E). We found that the local-time behaviour has the same distribution shape (max. around 10 A.M. during autumn/winter months) as during geomagnetically disturbed days. That means that ionospheric plasma irregularities which are not due to geomagnetic phenomena are the most frequent sources of disturbances detected by GPS. These structures have been identified as Medium-Scale Travelling Ionospheric Disturbances, or MSTIDs.

3.2 Influence of Solar terminator

Solar terminator is known to generate Atmospheric Gravity Waves (or AGWs) which cause MSTIDs. In this context, we study the relationship between the Solar terminator time and the appearance of MSTIDs to investigate the existence of a recurring pattern of ionospheric irregularities due to the day/night alternation.

3.3 Ionograms analysis

TEC irregularities detected correspond to changes in the electron density profile. Therefore, this paper would connect some ionospheric disturbances detected by GPS (cases study) and digital ionospheric soundings from the station of Dourbes. Ionograms are used to interpret temporal changes in TEC for given satellites.

3.4 Scintillations data

During ionospheric storms, large noise-like fluctuations in RoTEC values were observed using GPS data. Since 2006, an ionospheric scintillations GPS receiver (installed by the Uni- versity of Nottingham) is continuously operating at Dourbes. Another aim of this paper is to investigate the possible correlation between ionospheric storms detected at Brussels (mid-latitude region) and ionospheric scintillations through corr. S4 and SigmaPhi60 indices.

4 CONCLUSIONS

Mid-latitude TEC irregularities are detected using GPS data since 1994. A climatological study of their occurrence have been performed and show that the major part of these irregularities is not due to geomagnetic phenomena. The validation of the results uses external data like ionospheric vertical incidence soundings and scintillation measurements.

5 ACKNOWLEDGEMENTS

This research is supported by the Belgian Science Policy (BELSPO) and the Belgian Solar- Terrestrial Centre of Excellence (STCE).

REFERENCES

[1] Wautelet G., Lejeune S., Warnant R., Effects of ionospheric small-scale structures on GNSS, Proceedings of IRST 2009, Edinburgh, UK, pp. 196-200, (2009).

[2] Warnant R., Pottiaux E., The increase of the ionospheric activity as measured by GPS, Earth Planets Space, 52, pp. 1055-1060, (2000).

[3] Aquino M., Rodrigues F. S., Souter J., Moore T., Dodson A., Waugh S., Ionospheric scintillation and impact on GNSS users in Northern Europe: Results of a 3 year study, Space Communications, 20(1/2), pp. 17-30, (2005).