Ionospheric variability which degrades the precision of real-time GNSS applications

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Introduction

- **Ionosphere** = main limitation to GNSS precise positioning techniques (e.g. RTK)
- Moreover, occurrence of **small-scale structures** in the ionosphere

➡ **OUR GOAL** = assess the influence of such structures on precise GNSS applications

➡ **3 STEPS** :
1. Detection of small-scale ionospheric structures (using one GNSS station) and climatological study of those structures
2. Effects of such structures on double-differences of phase measurements (case study)
3. Effects of such structures on RTK positioning (case study)

1. « One-station method »

Methodology

Objective = isolate the ***Total Electron Content*** (TEC) and its high-frequency changes (***Rate of TEC***)

Use of the « Geometric-Free » combination of phase measurements (GF) :

$$\varphi^i_{A,GF} = \varphi^i_{A,L1} - \frac{f_1}{f_2}\varphi^i_{A,L2} = 0.552\ 10^{-16}\, TEC^i_A + \underbrace{N^i_{A,GF}}_{\text{ambiguity}} + \underbrace{M^i_{A,GF}}_{\text{multipath}} + \underbrace{\varepsilon^i_{A,GF}}_{\text{noise}}$$

a) We make the difference between two consecutive epochs t_k and t_{k-1} and, if the ambiguity remains the same, we obtain the TEC temporal change **ΔTEC** :

$$\Delta TEC^i_A(t_k) = 1.812\,\frac{(\varphi^i_{A,GF}(t_k) - \varphi^i_{A,GF}(t_{k-1}))}{(t_k - t_{k-1})}$$

every 30 s

b) Then, we verticalize ΔTEC and remove the low-frequency changes using a 3rd order polynomial. The resulting quantity is called ***Rate of TEC*** (RoTEC).

c) Finally, we compute the standard deviation of RoTEC every 15 min and declare that ionospheric variability (***ionospheric* event**) is detected if :

$$\sigma_{RoTEC,15\,min} > 0.08\ TECU/min$$

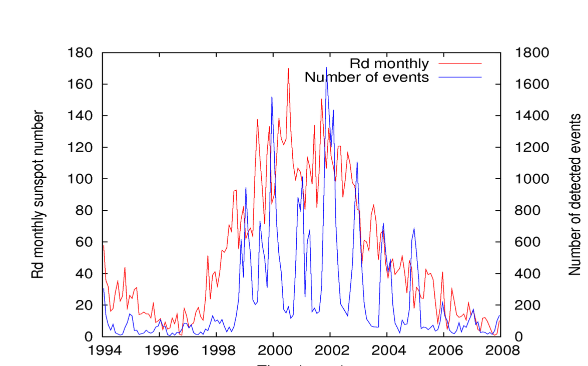
Climatological study

- GPS station of Brussels (BRUS) from 1994 to 2007 (→ more than a solar cycle)
- Counting of the number of ionospheric events in fonction of time

1. Dependence with solar cycle (solar phase)

On average, number of events is higher during solar maximum (2001, 2003) than during solar minimum (1996, 2007)...

BUT seems to present a strong monthly dependence

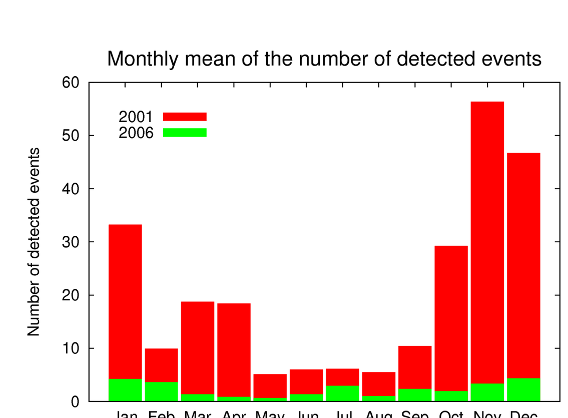


2. Seasonal dependence

Computation of the daily mean of the number of events for each month : solar max (2001) and solar min (2006) are the most representative.

➔ More small-scale structures during **autumn/winter** months

➔ Stuctures more numerous during solar max

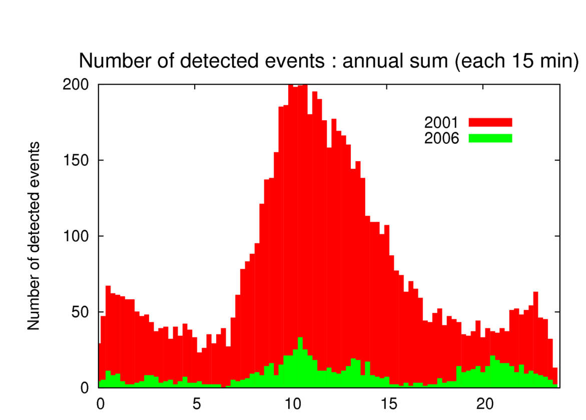


3. Local time dependence

Computation of the total number of events for each 15 min time interval : solar max (2001) and solar min (2006) are the most representative.

➔ Maximum around **10 h**

➔ Secondary max during nighttime

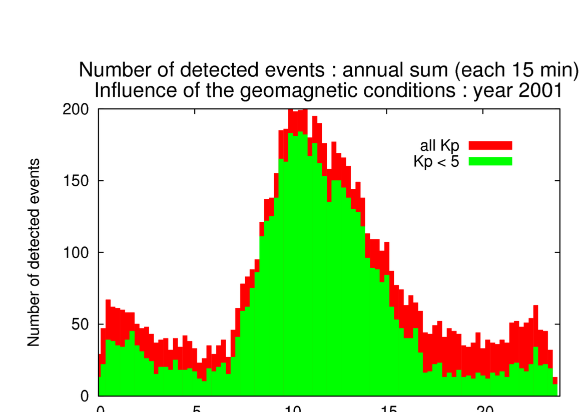


4. Type of structure detected

Computation of the total number of events for each 15 min time interval for year 2001. We consider (red) or not (green) the days for which Kp_{max} > 5 (stormy days).

➔ Offset between the 2 graphs : phenomena due to geomagnetic storms occur all the time : ***Noise-like structures***

➔ Most of structures are not connected to geomagnetic activity : ***Travelling Ionospheric Disturbances*** (TID's)



5. Conclusions

2 main types of small-scale ionospheric structures have been detected :

- **Noise-like structures** : very few and occur all the time
- TID's : numerous and are season and time-dependant. 2 main types :
  - **Daytime TID's** : around 10 h, very numerous
  - **Nighttime TID's** : between 22 h and 2 h, less numerous than daytime ones

2. Small-scale structures and double differences

Methodology

Objective = compute a quantity relative to the ionospheric activity for a given baseline

Use of the GF combination of double-differenced (DD) phase measurements :

$$\varphi^{ij}_{AB,GF} = \varphi^{ij}_{AB,L1} - \frac{f_1}{f_2}\varphi^{ij}_{AB,L2} = 0.552\ 10^{-16}\, TEC^{ij}_{AB} + N^{ij}_{AB,GF} + M^{ij}_{AB,GF} + \varepsilon^{ij}_{AB,GF}$$

a) Neglecting multipath and noise, we compute the ambiguity term $N^{ij}_{AB,GF}$ and we obtain :

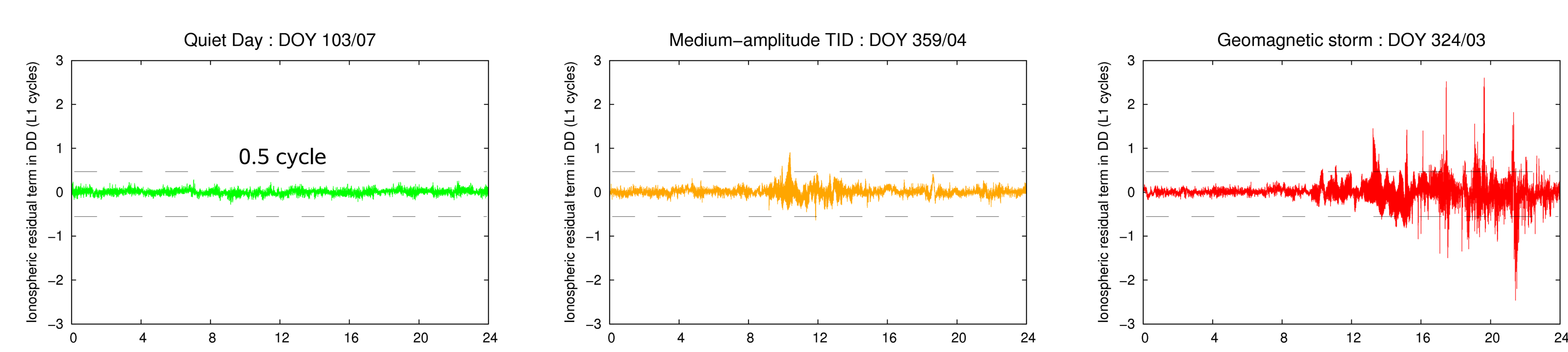
$$\varphi^{ij}_{AB,GF} - N^{ij}_{AB,GF} = 0.552\ 10^{-16}\, TEC^{ij}_{AB}$$

$I^{ij}_{AB,GF}$ = ***ionospheric residual term*** in DD (every 30 s)

b) We express this term into cycles of L_1 carrier

Results on case study

- Baseline of 11 km (GILL – LEEU) near Brussels (typical RTK baseline)
- 3 different ionospheric conditions :
  - quiet (DOY 103/07)
  - occurrence of TID (DOY 359/04)
  - occurrence of geomagnetic storm (DOY 324/03)



In case of TID's or geomagnetic storm, the residual delay due to the ionosphere is larger than 0.5 cycle → risk to fix the ambiguity to a wrong integer value → large positioning error

3. Small-scale structures and GPS-RTK positioning

Methodology

Objective = assess the part due to the ionosphere in the ***RTK positioning error***

(a) Computation of the RTK user position every 30 s using a least square adjustment : residual errors are mainly troposphere T^{ij}_{AB} and ionosphere I^{ij}_{AB}

$$\varphi^{ij}_{AB,k} - N^{ij}_{AB,k} = \frac{f_k}{c}(D^{ij}_{AB} - I^{ij}_{AB,k} + T^{ij}_{AB} + M^{ij}_{AB,k}) + \varepsilon^{ij}_{AB,k}$$

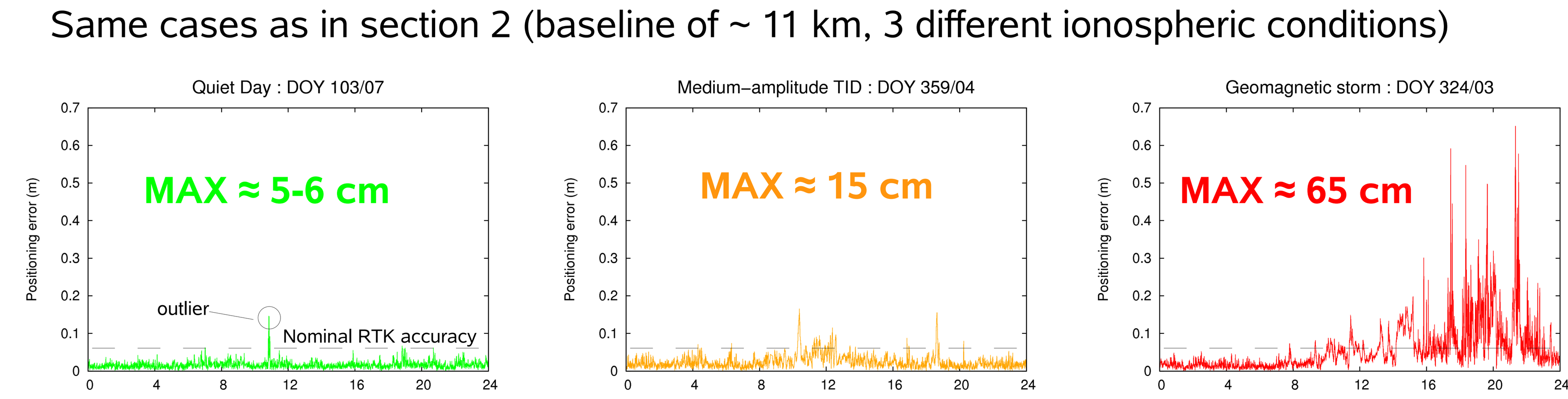
(b) Computation of the RTK user position every 30 s using a least square adjustment corrected for the ionospheric effect I^{ij}_{AB} computed in section 2 : residual error is mainly troposphere T^{ij}_{AB}

$$\varphi^{ij}_{AB,k} - N^{ij}_{AB,k} + \frac{f_k}{c} I^{ij}_{AB,k} = \frac{f_k}{c}(D^{ij}_{AB} + T^{ij}_{AB} + M^{ij}_{AB,k}) + \varepsilon^{ij}_{AB,k}$$

(c) Positioning error due to ionosphere obtained by substraction (a) - (b)

Results on case study

Same cases as in section 2 (baseline of ~ 11 km, 3 different ionospheric conditions)



4. Conclusions and future work

The small-scale ionospheric activity influences precise positioning techniques like RTK. In the future, we will establish more statistics by using the whole dataset coming from the Belgian Dense Network (more than 60 GPS stations).

Acknowledgments

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