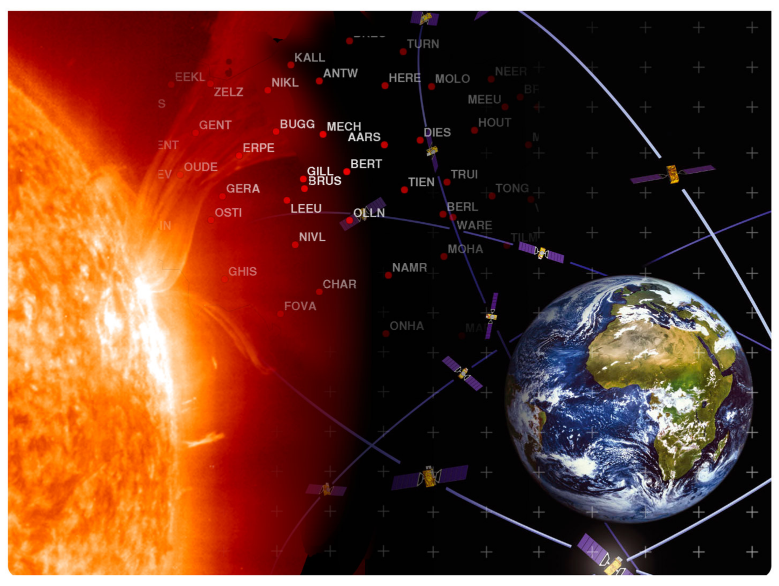

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A GPS/GNSS dense network used to monitor ionospheric positioning error

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1. Introduction

GPS/GNSS networks are, for the last few years, quickly expanding their density all over the surface of the globe. The present idea is to use this density in order to assess the effect of ionospheric disturbances on relative positioning but also to monitor their propagation patterns. Local variability in the ionospheric electron density can dramatically affect the reliability of GPS/GNSS real time applications. In particular, Traveling Ionospheric Disturbances (TID's) or plasma instabilities due to geomagnetic storms can induce strong disturbances in relative positioning. It is therefore useful to develop an integrity monitoring service based on a GPS/GNSS dense network.

2. Methodology

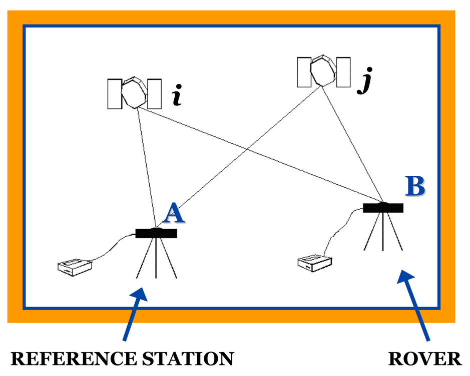
Objective = compute the **positioning error** only due to the **ionosphere** for a given baseline

➡ ***SoDIPE-RTK:*** *Software for Determining Ionospheric Positioning Error on Real-Time Kinematic*

a) Building ionospheric residual term in **double differences** (DD) of phase measurements:

$$\phi^{ij}_{AB,k} = (\phi^i_{A,k} - \phi^i_{B,k}) - (\phi^j_{A,k} - \phi^j_{B,k})$$
$$= D^{ij}_{AB} - I^{ij}_{AB,k} + T^{ij}_{AB} + M^{ij}_{AB,k} + \lambda_k N^{ij}_{AB} + \varepsilon^{ij}_{AB,k}$$

Geometry, Ionosphere, Troposphere, Multipath, Ambiguity, Noise



Use of the "**Geometric-Free**" combination to isolate the ionospheric effect. Then, neglecting multipath and noise, we obtain:

$$\phi^{ij}_{AB,GF} = \phi^{ij}_{AB,L1} - \phi^{ij}_{AB,L2}$$
$$= 40.3\left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right) STEC^{ij}_{AB} + \lambda_k N^{ij}_{AB}$$

If ambiguities are fixed, we get ionospheric residual term on each carrier:

$$I^{ij}_{AB,k} = 40.3\frac{STEC^{ij}_{AB}}{f_k^2}$$

b) Positioning error only due to the ionosphere:

- *The ionospheric residual error is removed from DD.*
- *The positions obtained with and without ionospheric correction are compared.*

Least-squares adjustement of all DD in view at the epoch considered:

$$\underline{l} = A\underline{x} \iff \underline{x} = (A^T P A)^{-1} A^T P \underline{l} \quad \text{with}$$

N = Normal Matrix

$$l_k(t) = -I^{ij}_{AB,k}(t)$$

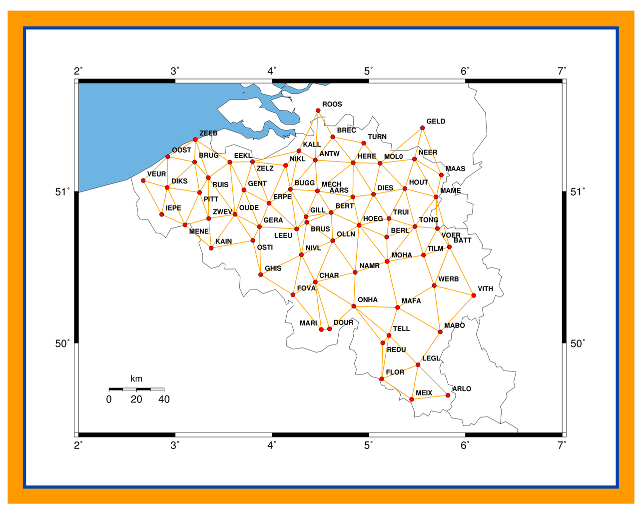
- A The design matrix
- $\underline{l}$ The observations vector
- P The weight matrix
- $\underline{x}$ The unknowns vector

Positioning error only due to the ionosphere in topocentric coordinates: $(\Delta N, \Delta E, \Delta H)$

And also in terms of distance: ΔD with $\Delta D = \sqrt{\Delta N^2 + \Delta E^2 + \Delta H^2}$

3. Active Geodetic Network

Our approach has been applied, as a proof of concept, on the Belgian dense network. This network called Active Geodetic Network (AGN) is composed of 66 GPS (dual-frequency) stations. Since we are dealing with relative positioning, we have to form baselines between these 66 receivers. A common approach is creating baselines using the Delaunay triangulation, which ensures that all triangles of stations are as much as possible equilateral. In our study, we decided to select all baselines smaller than 40 km.



4. Results

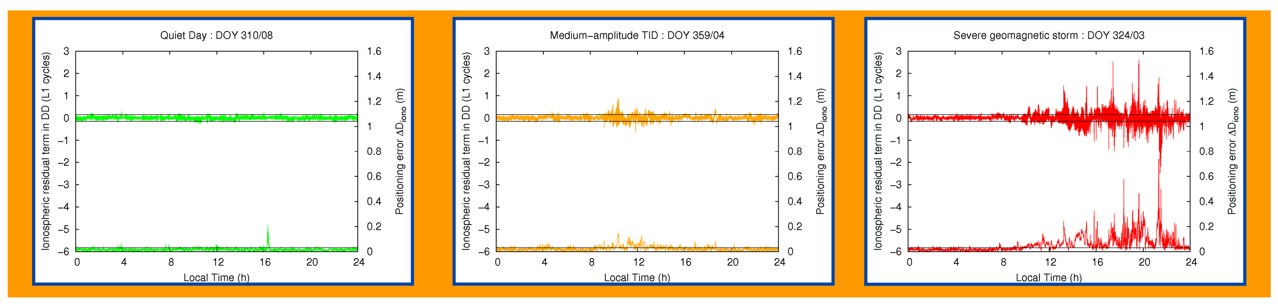
A. Selection of the days

We select 3 different (typical) ionospheric conditions :

- **quiet** (DOY 310/08)
- occurrence of medium amplitude TID (DOY 359/04) → **disturbed**
- occurrence of geomagnetic storm (DOY 324/03) → **extreme**

With RoTEC max at BRUS [TECU/min]: 0.309 - 0.837 - **8.933**
And Kp max: 0.3 - 2 - **9**

B. Results for a 11 km baseline

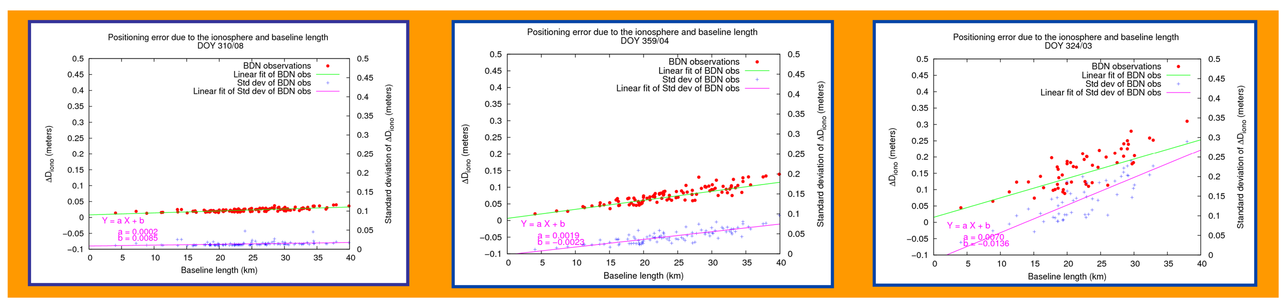


During TID's or geomagnetic storms, the positioning error only due to the ionosphere (ΔD) is significantly larger than the nominal value (**3 cm**).

Maximum values are: **~ 15cm** for a MSTID and **~ 65 cm** for a geomagnetic storm

C. Effect of baseline length

Computation of **daily** {**mean** (red dots), **standard deviation** (blue crosses)} **of ΔD** for all AGN baselines



	Quiet	Disturbed	Extreme
Mean =	0.008 + 0.6 ppm [m]	0.006 + 3 ppm [m]	0.015 + 6 ppm [m]
SD =	0.008 + 0.2 ppm [m]	0.002 + 2 ppm [m]	0.006 + 6 ppm [m]

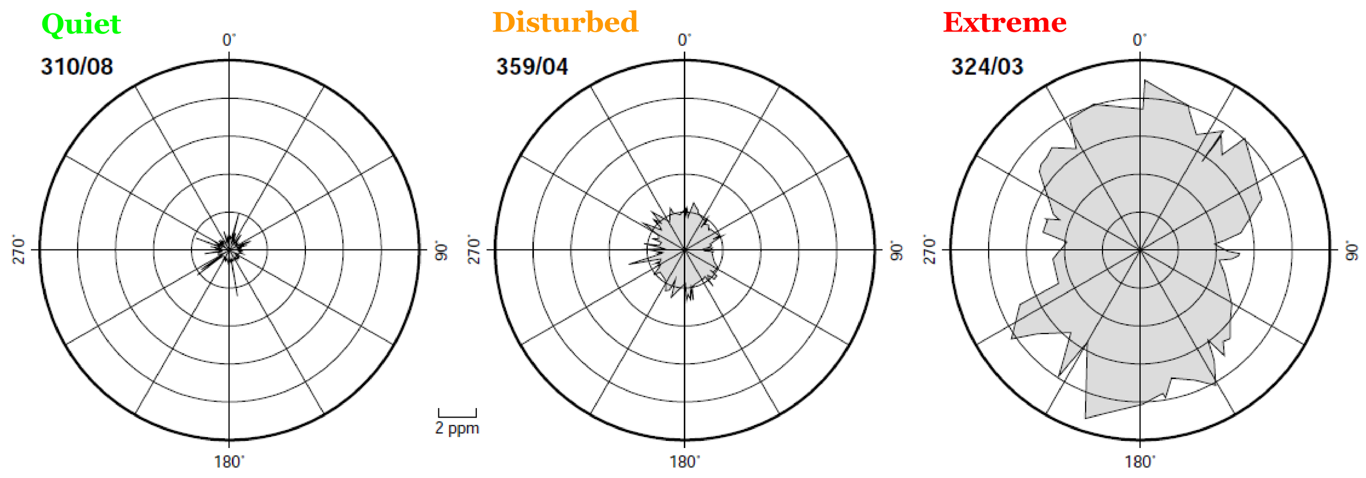
D. Effect of baseline orientation

Polar plot obtention:

a) Remove the **offset** (intercept of « quiet » regression line, *i.e.* 8 mm)

b) Computing of ΔD **weighted** by baseline length (ΔD_w)

c) Compute **standard deviation of ΔD_w** for all baselines



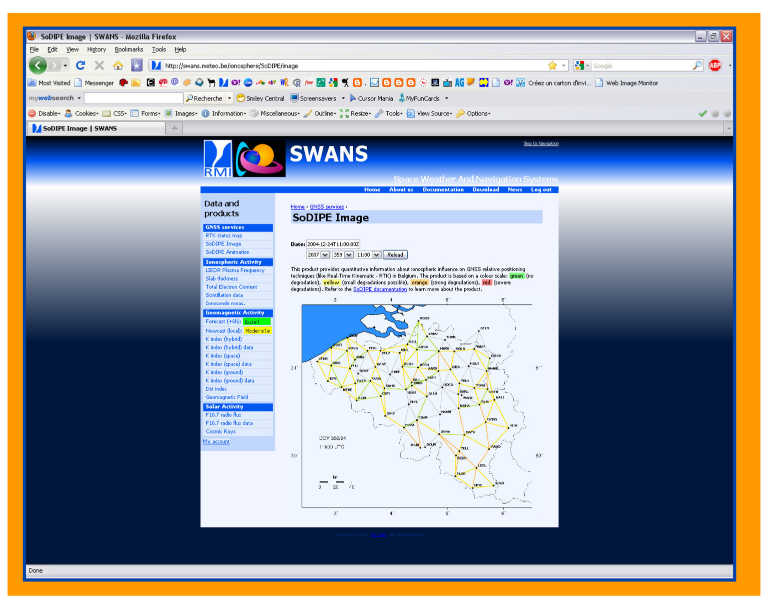
Allows to identify moving ionospheric disturbances

- DOY 310/08 - **Quiet**: $\sigma_{\Delta D}$ values are for each baseline rather low and almost isotropic
- DOY 359/04 - **Disturbed**: the polar plot shape presents a **North-South** preferential orientation: this direction is generally affected by larger errors (> 2 ppm) than other ones
- DOY 324/03 - **Extreme**: same but larger effect than in the typical MSTID case (359/04)

5. Product

We are developing a web service dedicated to GPS/GNSS relative positioning users based on SoDIPE-RTK. Every 15 min, a thematic map is produced showing each AGN baseline in a given color ranging from **green** (quiet conditions) to **red** (extreme conditions). This user-friendly application allows registered users to assess and vizualize current ionospheric conditions in the area covered by the whole network.

- **Green**: no ionospheric threat
- **Yellow**: minor ionospheric threats
- **Orange**: major ionospheric threats
- **Red**: extreme ionospheric conditions



6. Conclusions

SoDIPE-RTK allows us to assess in a quantitative way the influence of ionospheric small-scale variability on relative GNSS applications. We observed that the positioning accuracy mainly depends on the ionospheric activity but also on the baseline length and orientation. The sharpest TEC gradients are indeed observed for baselines oriented parallel to the direction of disturbance propagation. Our web service based on the AGN appears then to be an useful application of a GPS/GNSS dense network and will be extended to other networks in a near future.

REF: *Lejeune S., Wautelet G., Warnant R. (2010 – under review): Ionospheric effects on relative positioning within GPS dense network, GPS solution.*