Monitoring the ionospheric positioning error with a GNSS dense network

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OUTLINE

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2. From cases study...
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- Conclusions – future work

INTRODUCTION

- **Ionosphere** = main error source for all GNSS techniques, in particular precise applications (relative positioning, like Real-Time Kinematic)
- Users are **not aware** of space-weather and ionospheric conditions encountered in the field
- GOALS

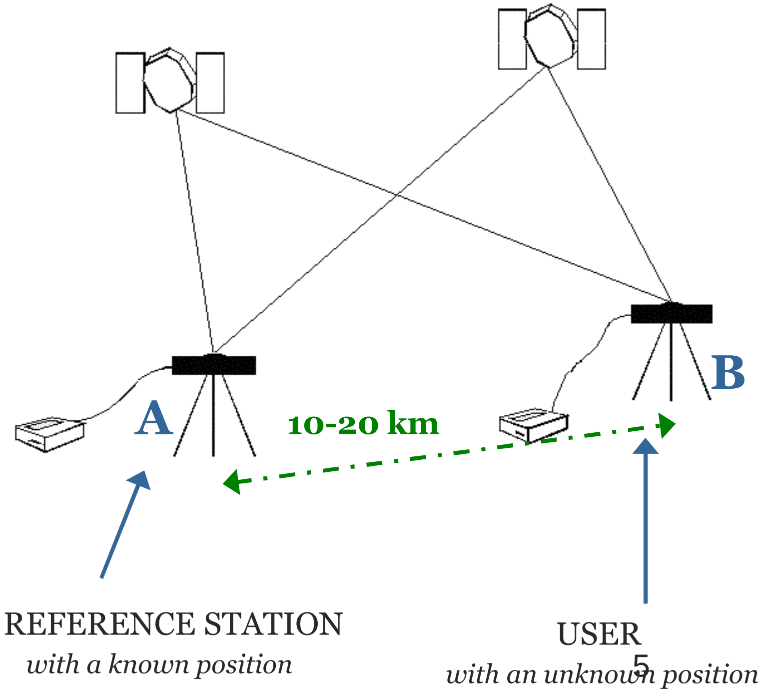
1. **detect** and **assess** the influence of iono small-scale structures on GNSS precise applications
2. **warn** users when degraded conditions are observed

1. Relative positioning with SoDIPE-RTK software

2.1. Methodology

SoDIPE-RTK ≡ "*Software for Determining the Ionospheric Positioning Error*"

- **Relative positioning** = determination of a baseline between 2 receivers with an accuracy of a few cm
- **Basic observable** = double differences of phase measurements (DD)
- **Advantages** : cancellation of all error sources common to the two stations
  → no clocks/orbit errors
  → usually, atmospheric residual errors are negligible BUT
  residual ionosphere can be a threat for high-accuracy applications



- In our case: both user and reference roles are playing by reference stations (accurate positions)

→ **Simulation** of relative positioning technique

2.1. Methodology

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

a) Form **Geometric-Free** combination of double-differenced (DD) phase measurements, neglecting multipath and noise:

$$\phi_{AB,GF}^{ij} = \phi_{AB,L1}^{ij} - \phi_{AB,L2}^{ij} \qquad [meters]$$

$$= \alpha\, STEC_{AB}^{ij} - \lambda_k N_{AB,GF}^{ij}$$

b) Compute the **ambiguity** term $N_{AB,GF}^{ij}$ considering the whole DD observation period (→ not a real-time algorithm)

c) Isolate the **ionospheric residual term** on each carrier

$$I_{AB,k}^{ij} = 40.3 \frac{STEC_{AB}^{ij}}{f_k^2} \qquad [meters]$$

2.1. Methodology

d) Using L_1 measurements only, compute the positioning error only due to the ionosphere through a **least-squares adjustment**:

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

with

- $\underline{x}$ the vector of unknowns
- A the design matrix
- P the weight matrix
- $l_{AB,k}^{ij}(t) = -I_{AB,k}^{ij}(t)$

We get **positioning error only due to the ionosphere** in topocentric coordinates (ΔN, ΔE, ΔU).

Moreover, we can express it in terms of distance:

$$\Delta D = \sqrt{\Delta N^2 + \Delta E^2 + \Delta U^2}$$

2. From cases study…

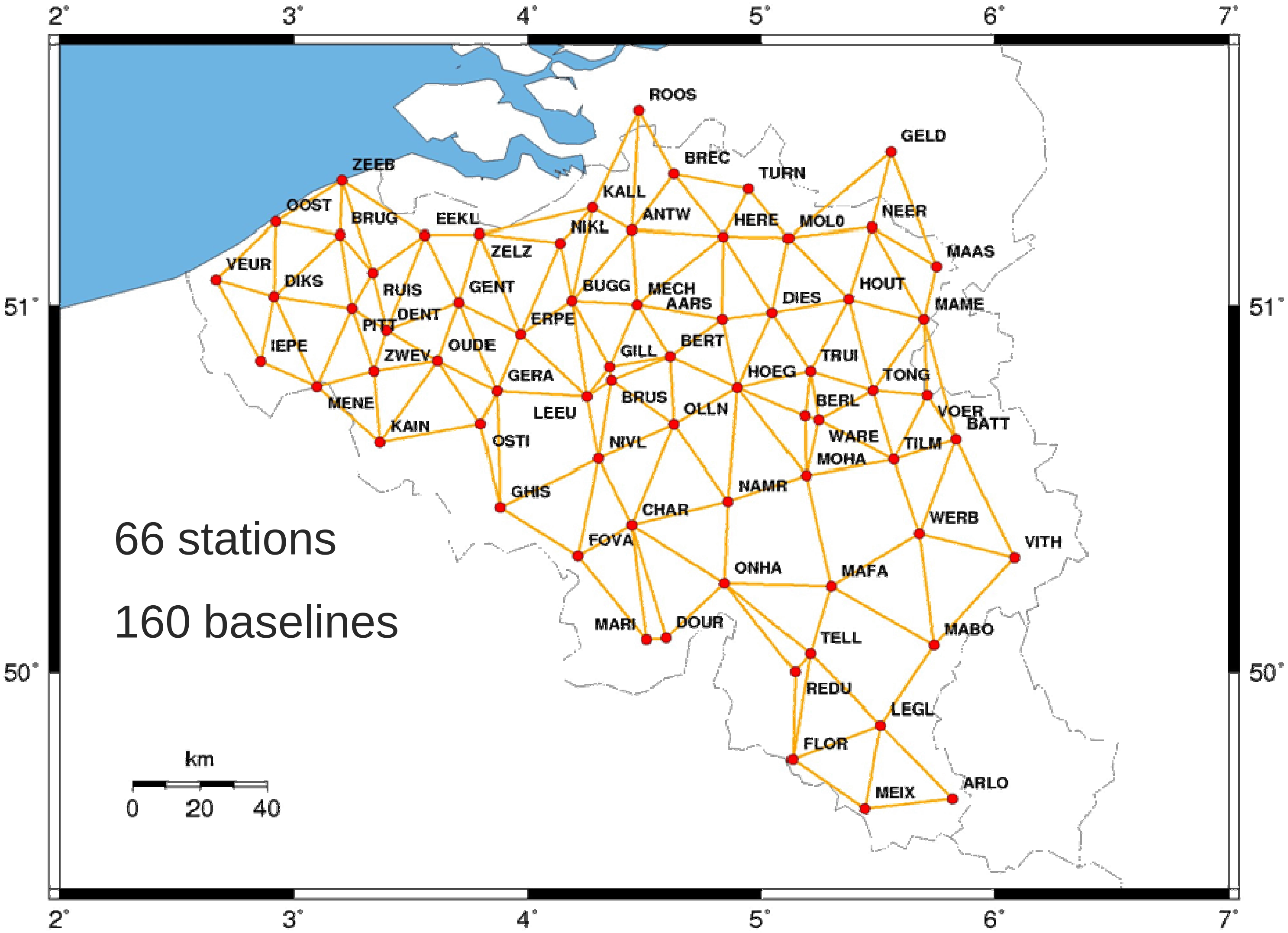
2.1. Selection of cases

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

	RoTEC max at BRUS [TECU/min]	Kp max
Quiet	0.309	0.3
Disturbed	0.837	2
Extreme	8.933	9

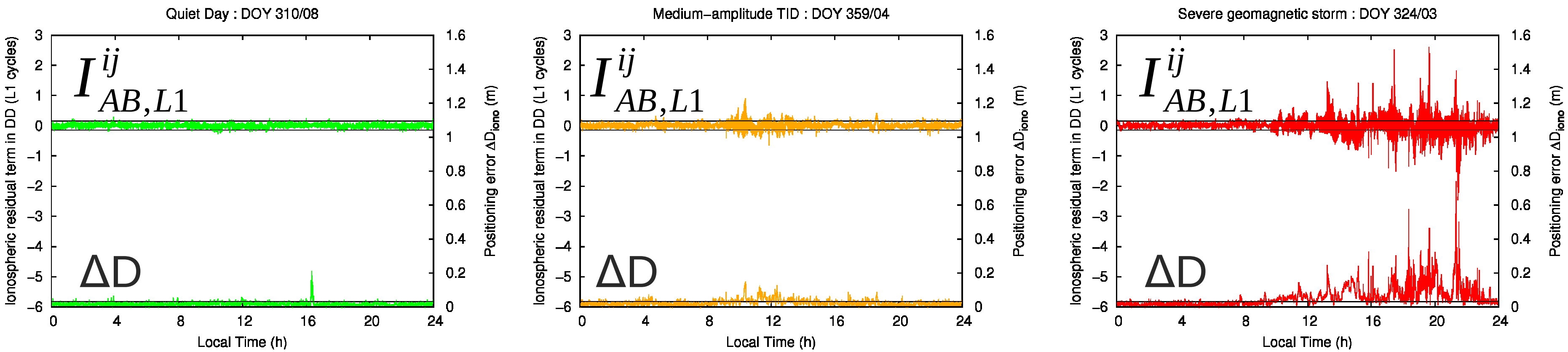
2.2. Active Geodetic Network (AGN)



66 stations

160 baselines

2.3. Results for a 11km baseline



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

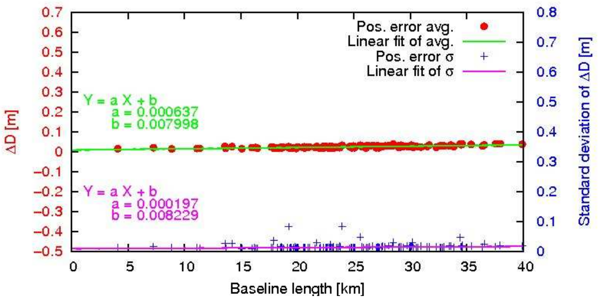
→ medium ampl. TID: **~ 15cm**

→ geomagn. storm: **~ 65 cm**

2.4. Influence of baseline length

Computation of **daily** {**Mean** (red dots) / **std. dev.** (blue crosses)} **of ΔD** for all AGN baselines

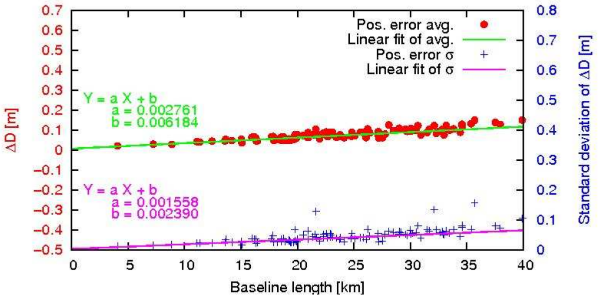
Quiet



Mean = 0.008 + 0.6 ppm [m]

SD = 0.008 + 0.2 ppm [m]

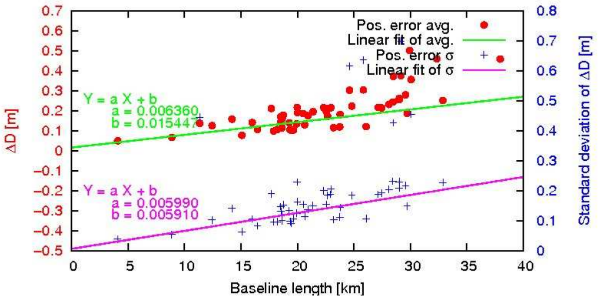
Disturbed



Mean = 0.006 + 3 ppm [m]

SD = 0.002 + 2 ppm [m]

Extreme

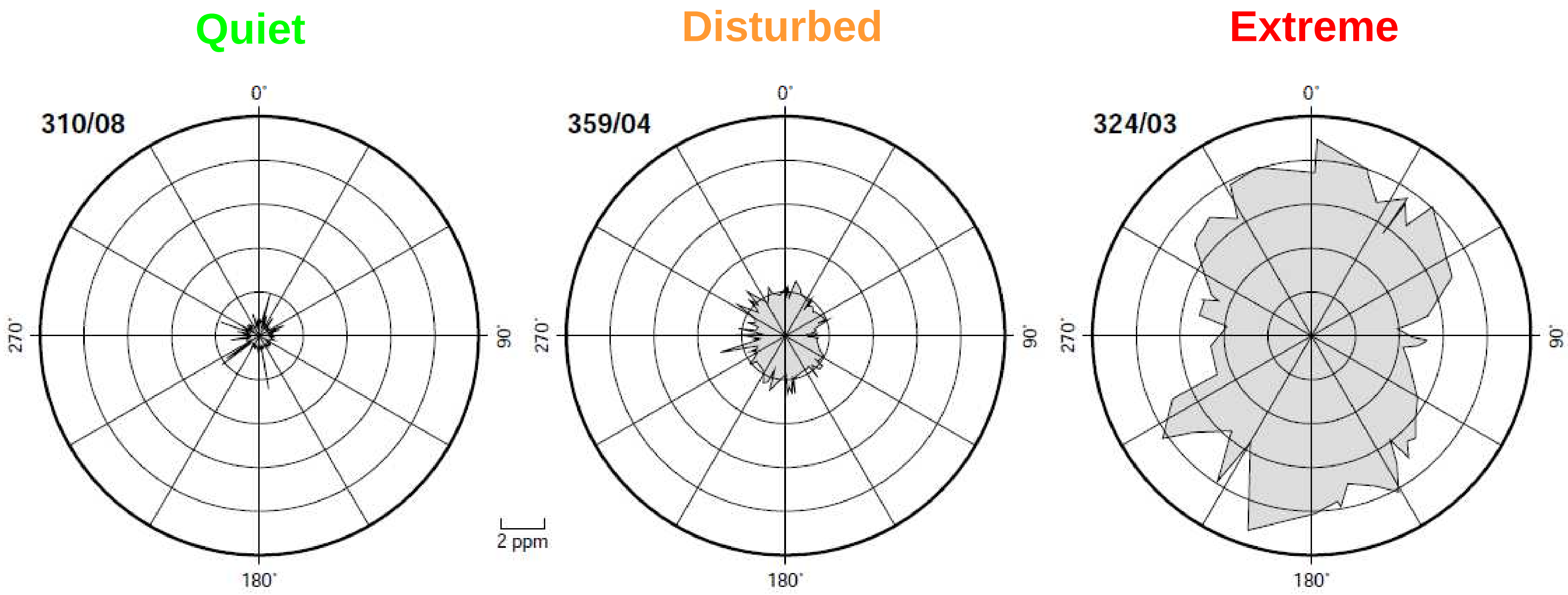


Mean = 0.015 + 6 ppm [m]

SD = 0.006 + 6 ppm [m]

2.5. Influence of baseline orientation

1. Remove the **offset** (intercept of « quiet » regression line, *i.e.* 8 mm)
2. Computing of ΔD **weighted** by baseline length (ΔD_w)
3. Compute **daily mean** and **std. dev. of ΔD_w** for all baselines



Allows to identify moving ionospheric disturbances

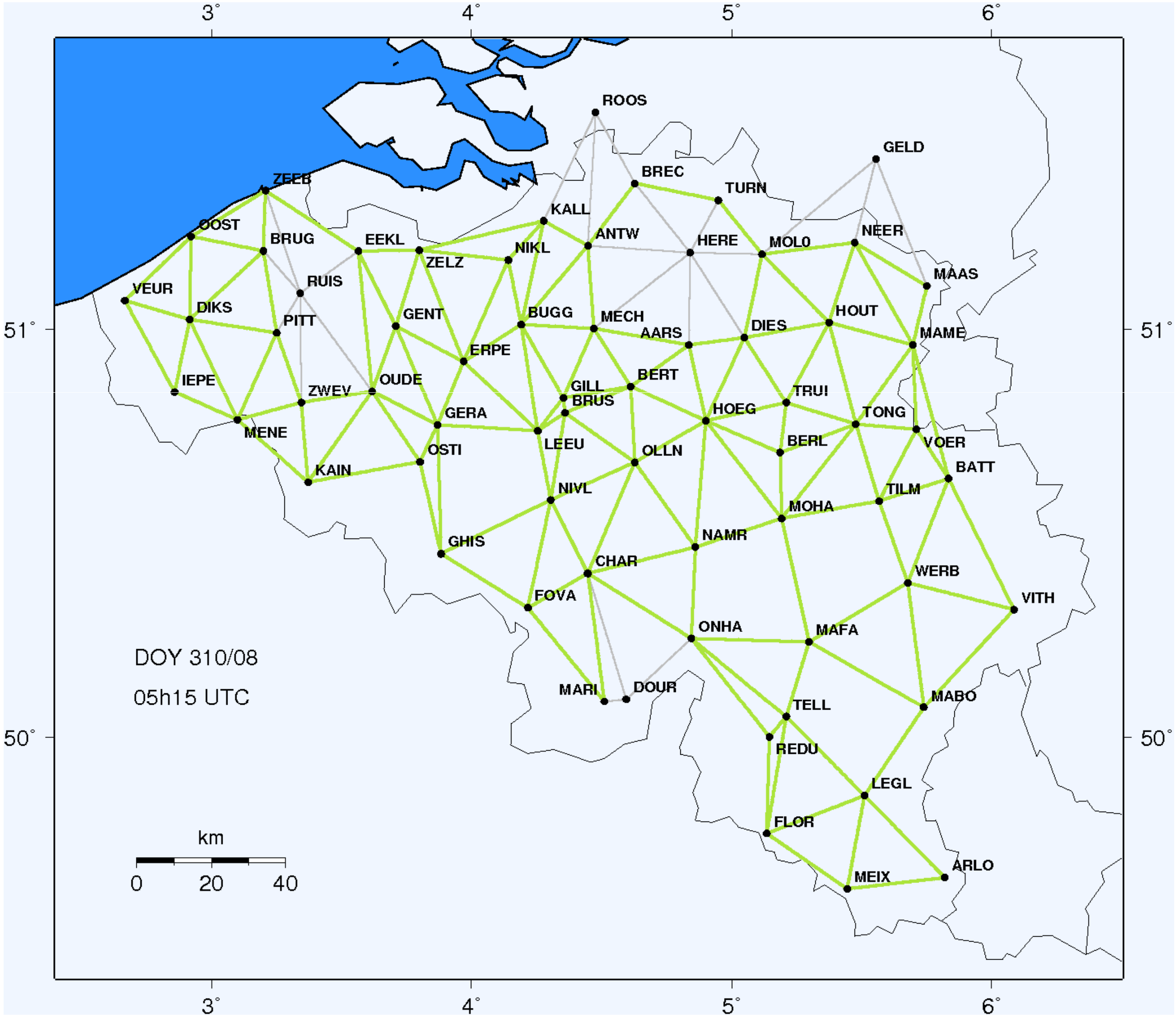
3. …to an operational web service

3.1. Data flow and software

- Getting all data from AGN stations (66 stations)
- RINEX files from **previous day**
- Assignment of a **color code** with respect to the degradation risk due to ionospheric conditions
  - **Index** used: ΔD_w
  - Computation of the **median** of ΔD_w for each 15 minutes interval
  - Four classes:
    - **Green** : nominal conditions
    - **Yellow** : active conditions
    - **Orange** : disturbed conditions
    - **Red** : extreme conditions
- 96 images and 1 animation/day
- Available soon on the public part of our website http://swans.meteo.be

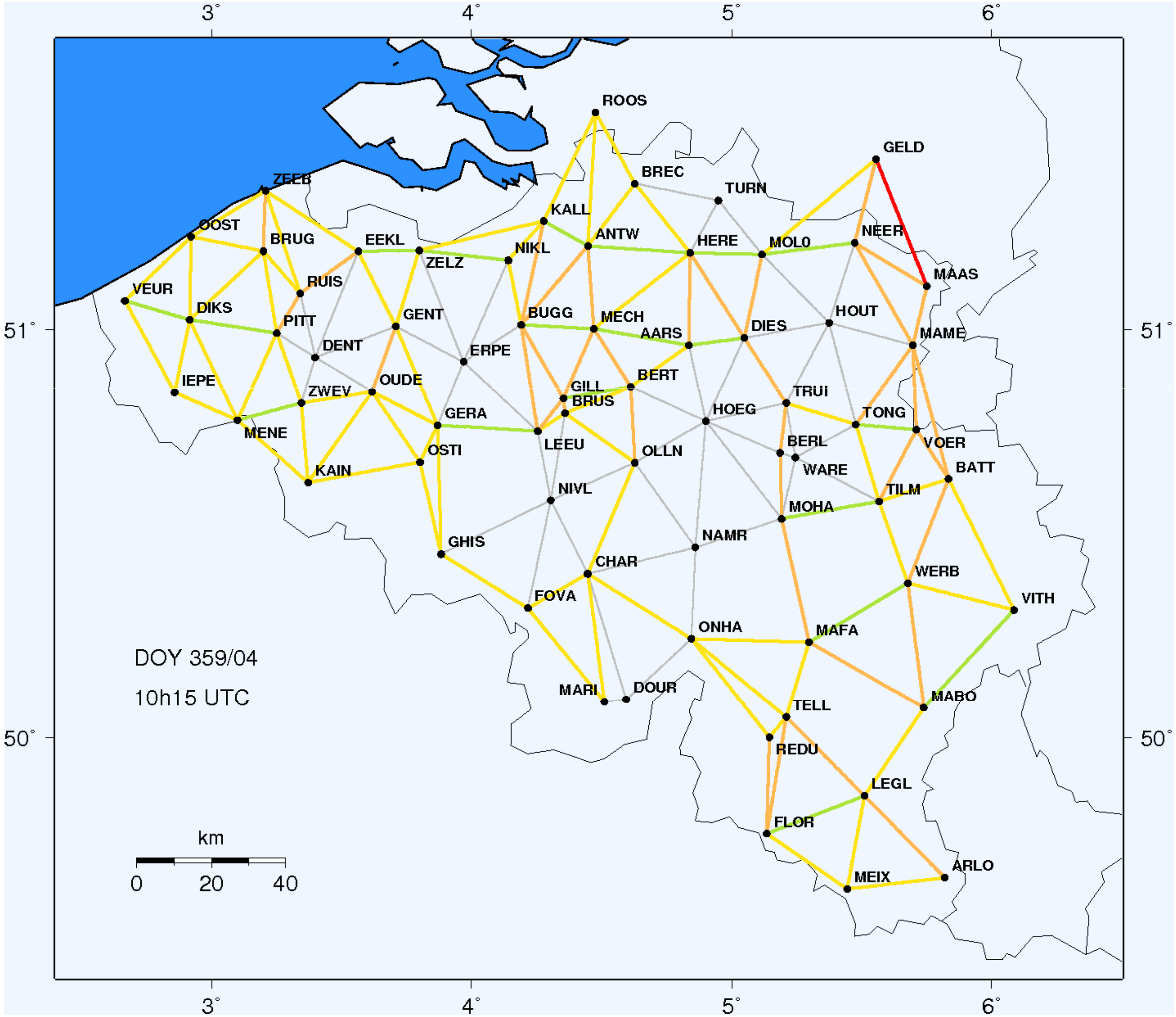
3.2. Some examples

Quiet



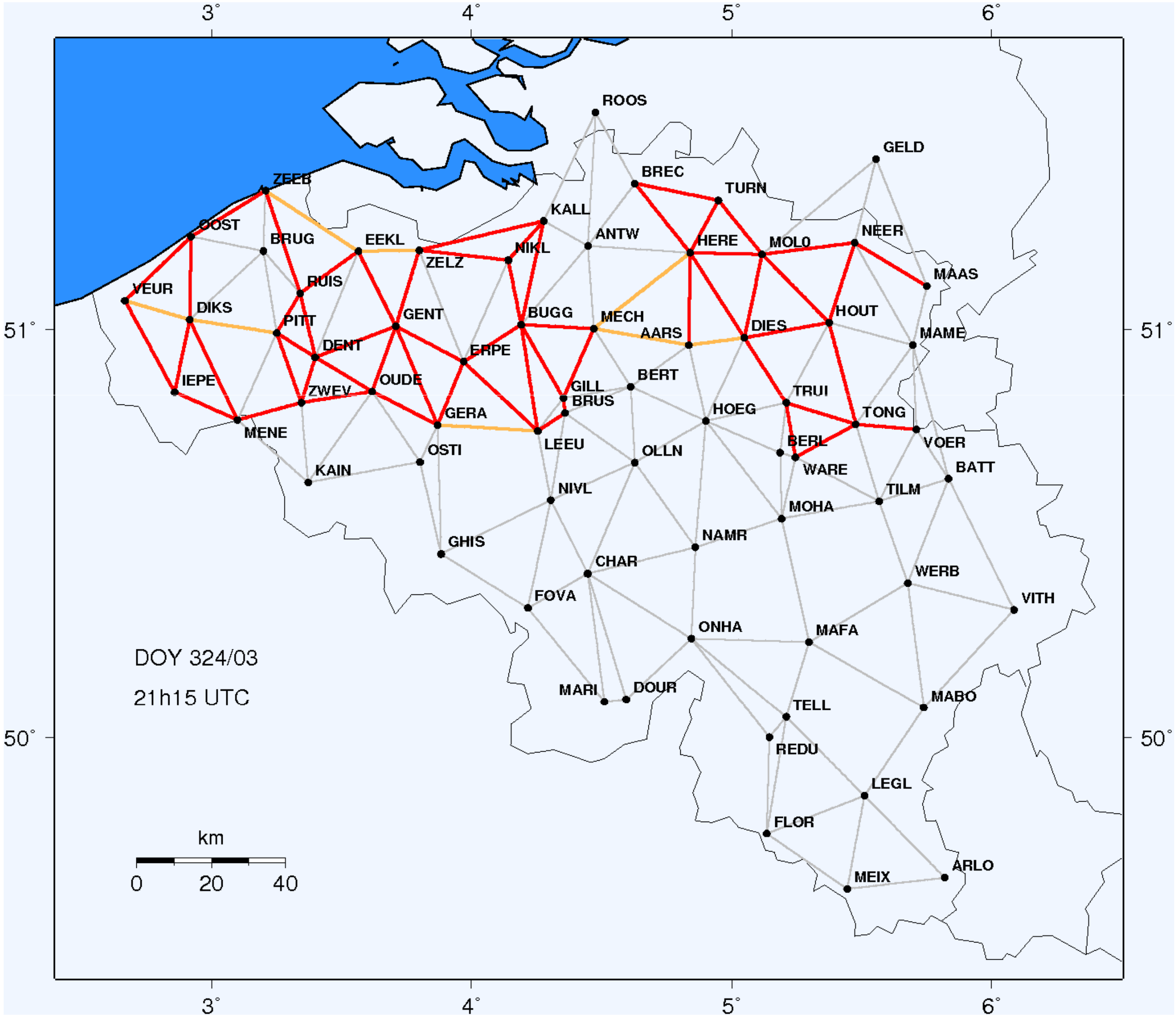
3.2. Some examples

Disturbed



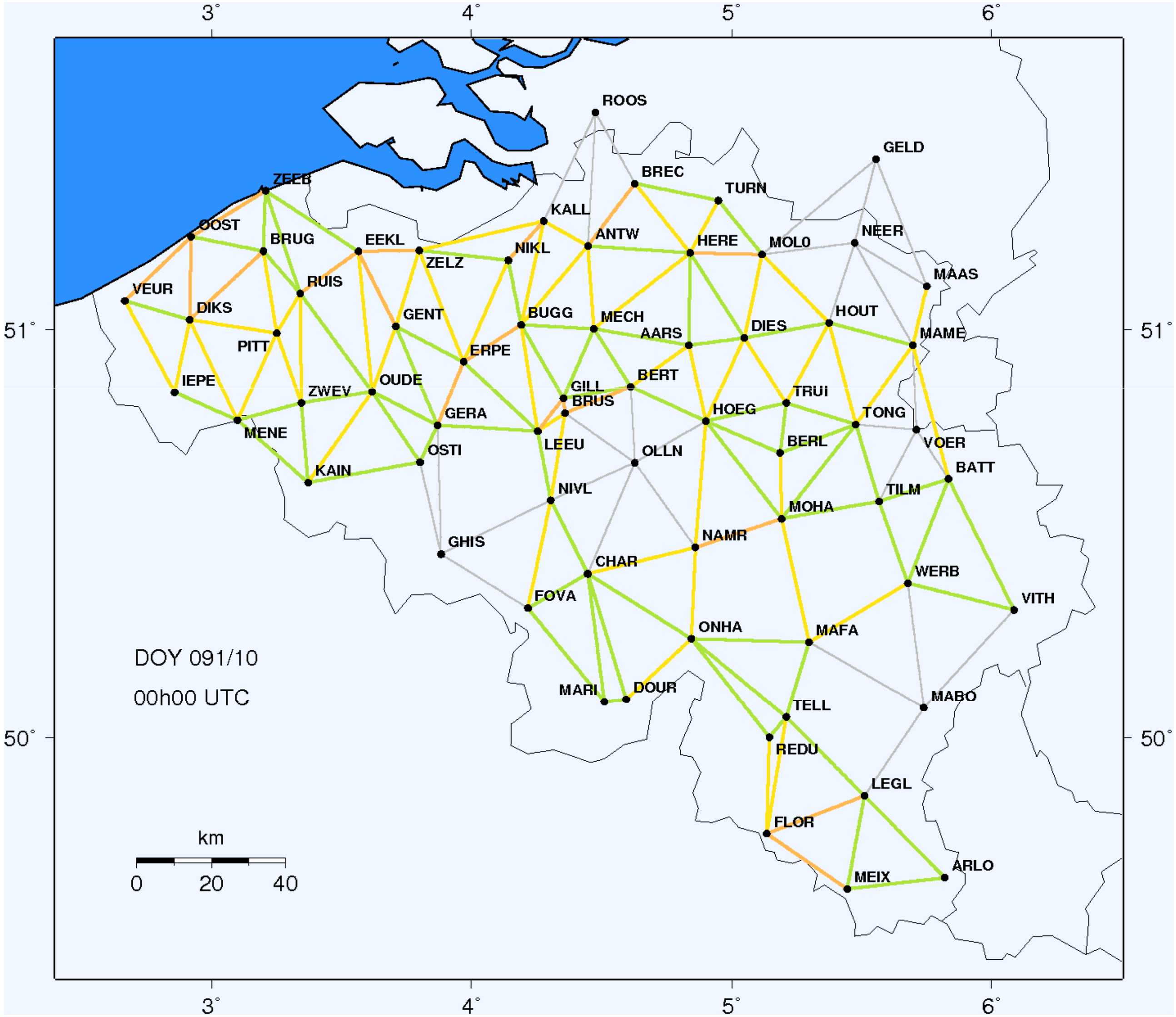
3.2. Some examples

Extreme



3.2. Some examples

April, 1st 2010



CONCLUSIONS

- Development of a **software** which allows to monitor positioning error due to the ionosphere in relative positioning → SoDIPE-RTK
- Allows **scientific studies**:

  → Understanding of the **ionospheric physics** by analyzing propagation patterns of ionospheric disturbances

- Allows to **warn users** when degraded positioning conditions are observed. At this moment, only the data from previous day are available on our website

  → warning ≡ website consultation (http://swans.meteo.be)

- **In the future**: send warnings in near real-time (e-mail, SMS)

  → the method needs to be implemented in real-time

Thank you for your attention!

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