

Space Weather influence on satellite based navigation and precise positioning

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Summary

- What this talk is NOT :
 - Detailed statistics about all possible ionospheric (SW) effects on all possible GNSS applications
- Effect of the ionosphere on 2 differential applications : DGPS and Real Time Kinematic
 - Illustrate the fact that the type of ionospheric phenomena which play a role in the error budget depends very much on the application
- There is no simple relationship between a given ionospheric activity (TEC) and the positioning error.
 - A given ionospheric activity (TEC) will not always result in the same positioning error

From navigation to high accuracy geodesy (1/2)

- GNSS signals are used in the frame of many different positioning techniques :
 - Absolute or differential
 - Code and/or carrier phase measurements
 - Real time or post-processing
 - The accuracy ranges from a few mm (high accuracy geodesy) to a few m (navigation).
- The effect of the ionosphere (SW) on GNSS signal propagation remains one of the main error sources for most of the positioning techniques

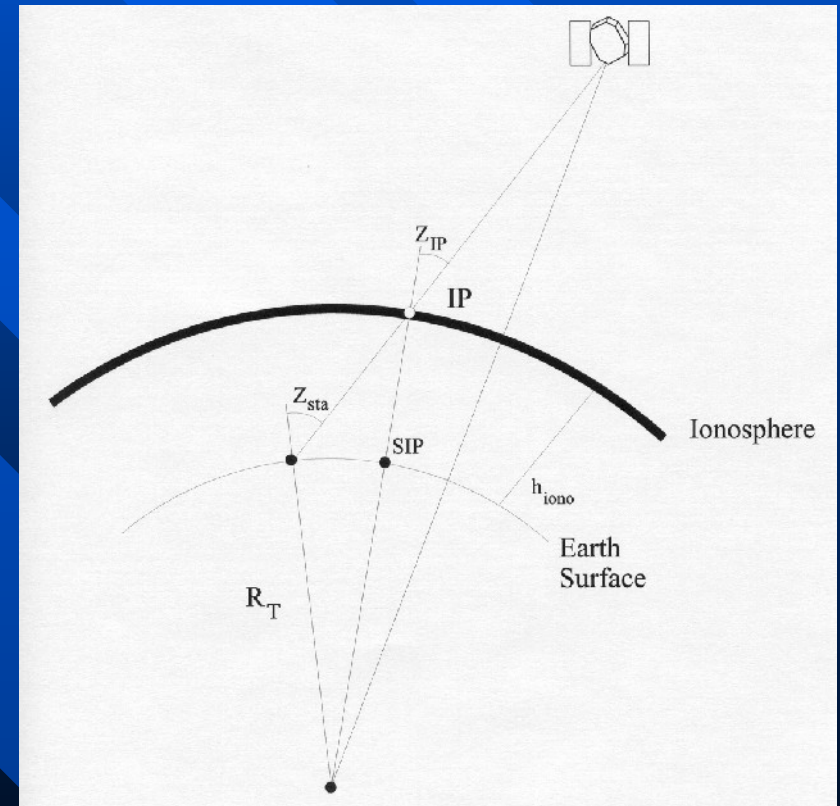
From navigation to high accuracy geodesy (2/2)

- The data processing algorithms strongly depend on the positioning technique used.
 - ➔ « residual » ionosphere effect which affects the position depends on the technique used
- Four categories of applications :
 - Absolute navigation (5 – 20 m)
 - Differential navigation (DGPS, 1-5 m)
 - Field geodesy (Real Time Kinematic or RTK, few cm)
 - High accuracy geodesy (a few mm)

SW and Absolute Positioning

- The ionosphere is the origin of a delay in GNSS radio signal propagation
- This effect of this delay on (apparent) signal path, I (m) :

$$I = \frac{40.3}{f^2} \frac{VTEC^{IP}}{\cos(Z^{IP})}$$



SW and differential positioning (1/2)

- Combines the measurements made by a minimum of 2 receivers (stations) to remove common error sources
- Based on the assumption that measurements made by 2 «neighbour» receivers are affected in the same way by the different error sources (in particular ionospheric errors)
- The ionosphere residual effect on differential positioning :

$$I_{12} = \frac{40.3}{f^2} \left(\frac{VTEC_1^{IP}}{\cos(Z_1^{IP})} - \frac{VTEC_2^{IP}}{\cos(Z_2^{IP})} \right)$$

SW and differential positioning (2/2)

$$I_{12} = \frac{40.3}{f^2} (VTEC_1^{IP} (\frac{1}{\cos(Z_1^{IP})} - \frac{1}{\cos(Z_2^{IP})}) + \frac{1}{\cos(Z_2^{IP})} (VTEC_1^{IP} - VTEC_2^{IP}))$$

- In other words, the residual ionospheric error on one individual receiver-to-satellite path depends on :
 - the vertical TEC ;
 - the vertical TEC difference (gradient) between the 2 stations (IP);
 - the GPS constellation geometry.
- The error on the position depends on how the individual ionospheric residual errors will “combine” in the data processing algorithm (least squares) which uses all satellites in view

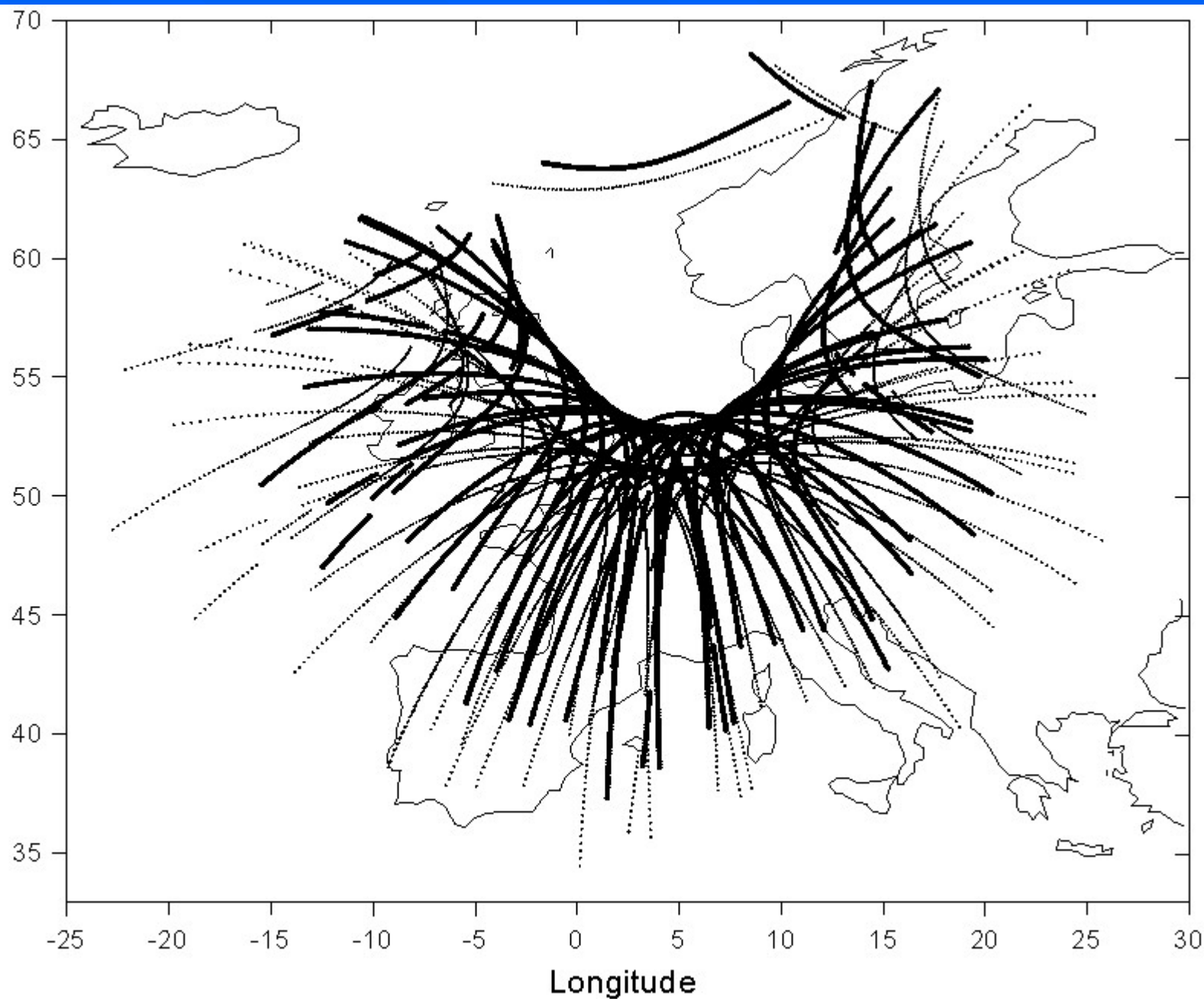
SW and DGPS (1/2)

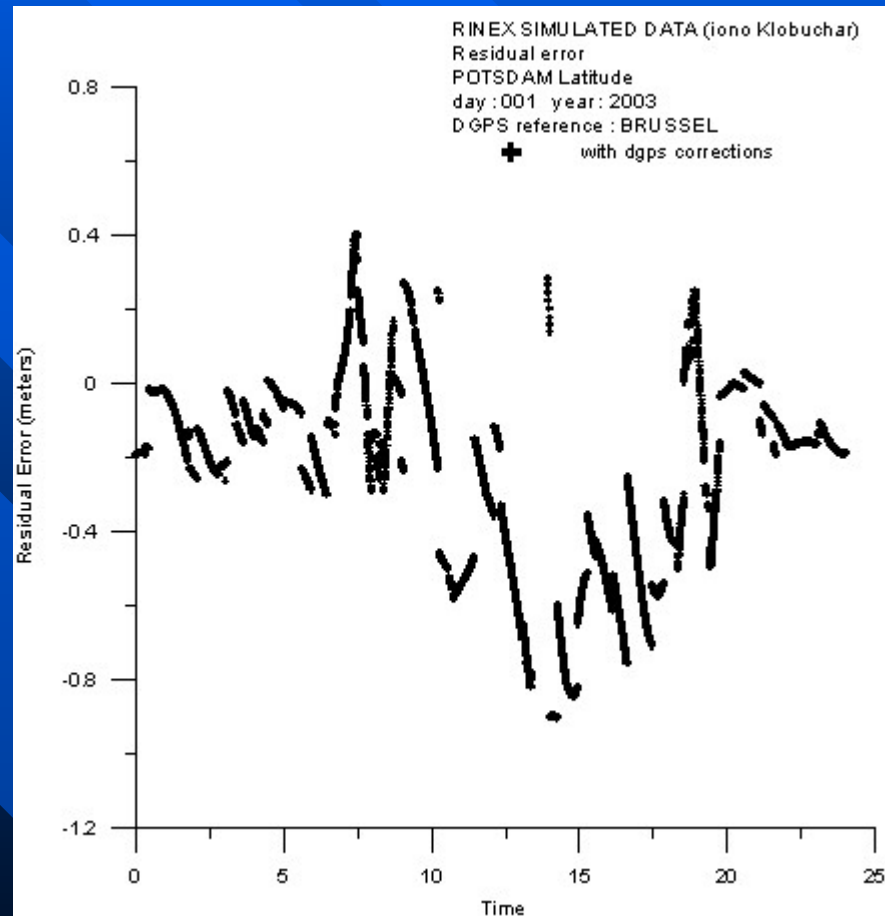
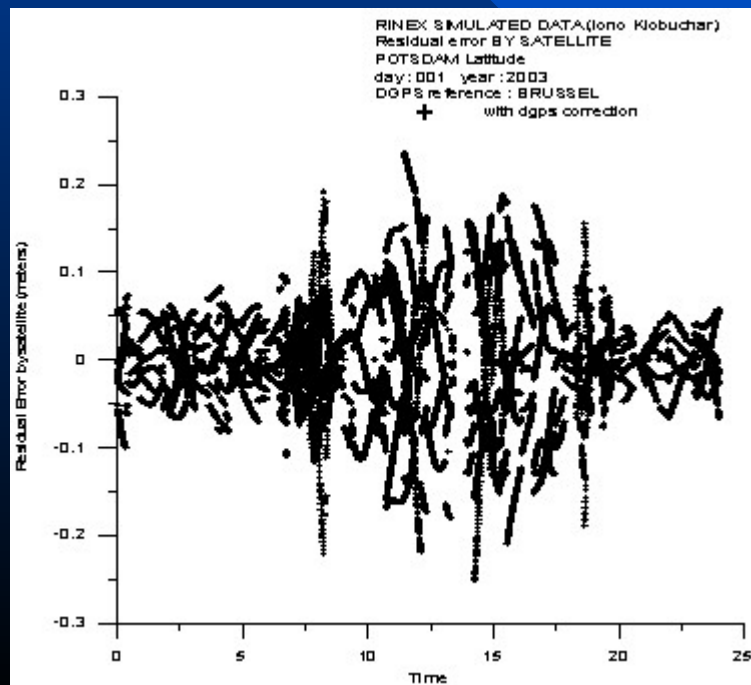
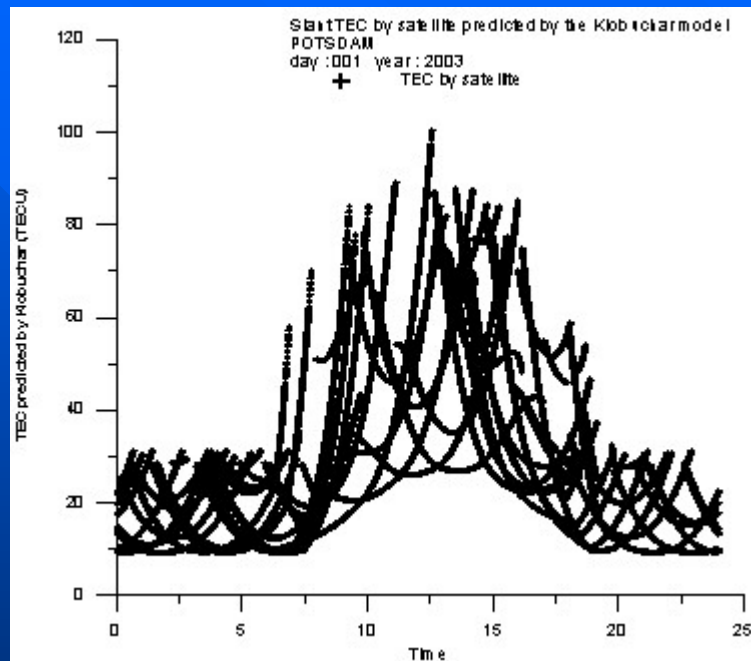
- DGPS (= Differential GPS) allows to measure positions in real time with an accuracy of a few meters
- Based on (ranging) code measurements
- Uses the corrections broadcast by a reference station
- The accuracy depends mainly on the distance between the observer and the reference station
- Distances up to 1000 km (w.r.t. the reference station) can be considered

SW and DGPS (2/2)

- Provided the distances (up to 1000 km) and the accuracy (a few meters), only (strong) large scale gradients in TEC will have an influence
- At mid-latitudes, large scale gradients having a potential influence on DGPS error budget are mainly observed at solar maximum or during geomagnetic storms
- BUT NOT ONLY these gradients influence the final position
 - TEC (gradient) maps can only give a rough idea of the error on the final user position

Latitude





SW and Real Time Kinematic (1/2)

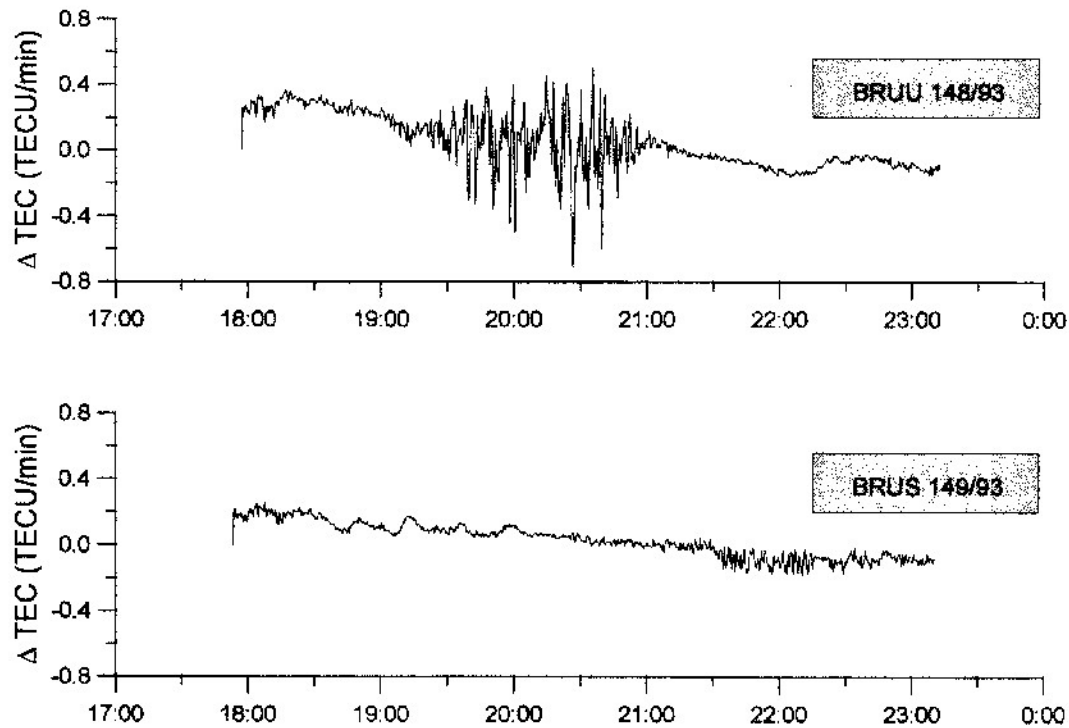
- RTK (Real Time Kinematic) allows to measure a mobile user position in real time with an accuracy of a few centimetres
- Based on carrier beat phase measurements (which are ambiguous)
- Mobile receiver uses the measurements (and the corrections) broadcast by a reference station
- The accuracy depends on the distance between the observer and the reference station

SW and Real Time Kinematic (2/2)

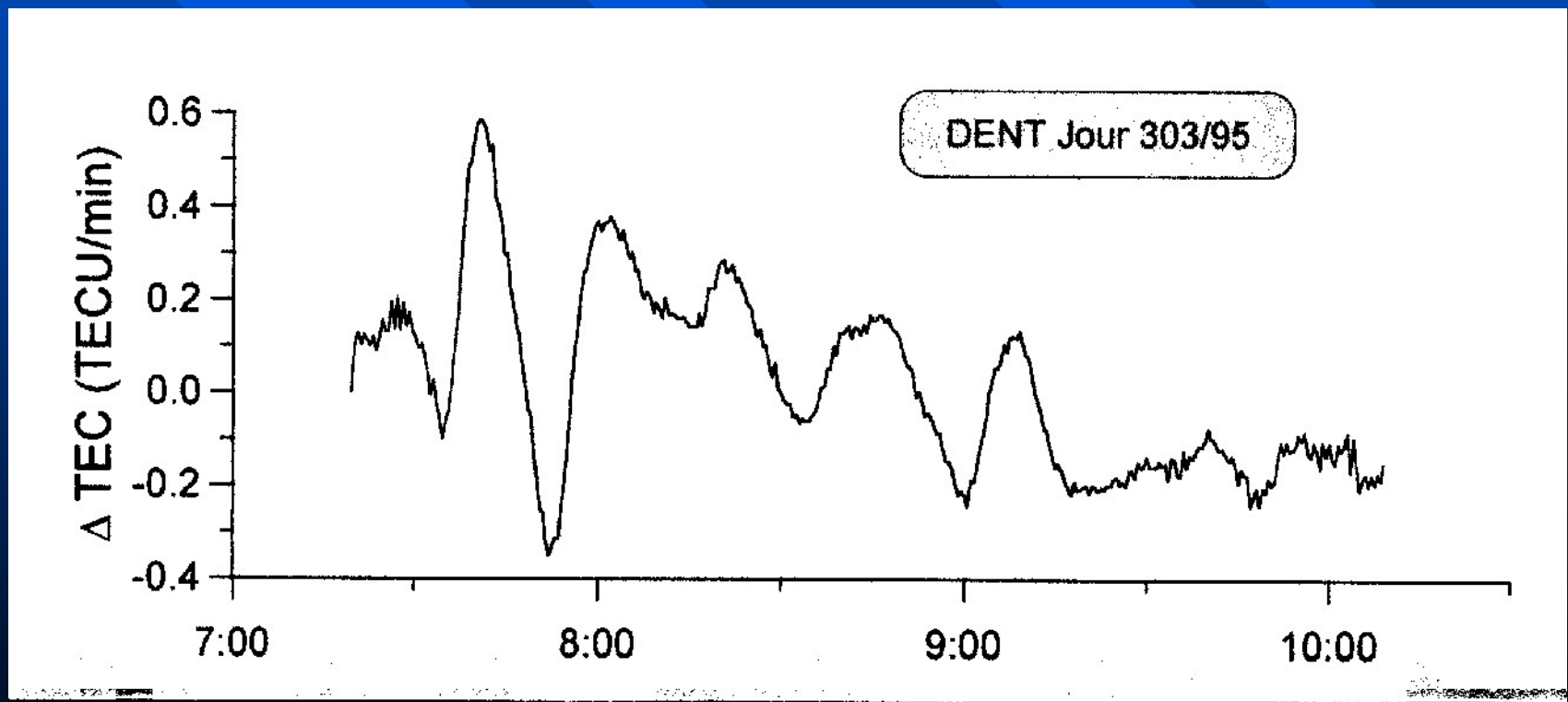
- Distances up to 10-20 km can be considered (mainly depending on ionospheric conditions)
- Ambiguities are solved during a (static) initialization procedure (search technique is based on the stochastic model)
- Usually : assumption that there is no residual (ionospheric) error in the differenced observations
- Provided the distances (up to 20 km) and the accuracy (a few centimetres), small scale gradients in TEC will have an influence on the error budget
- At mid-latitude, small scale gradients in TEC are mainly due to TID's and "ionospheric noise"

Small-scale structures

- « noise-like » structures in TEC :



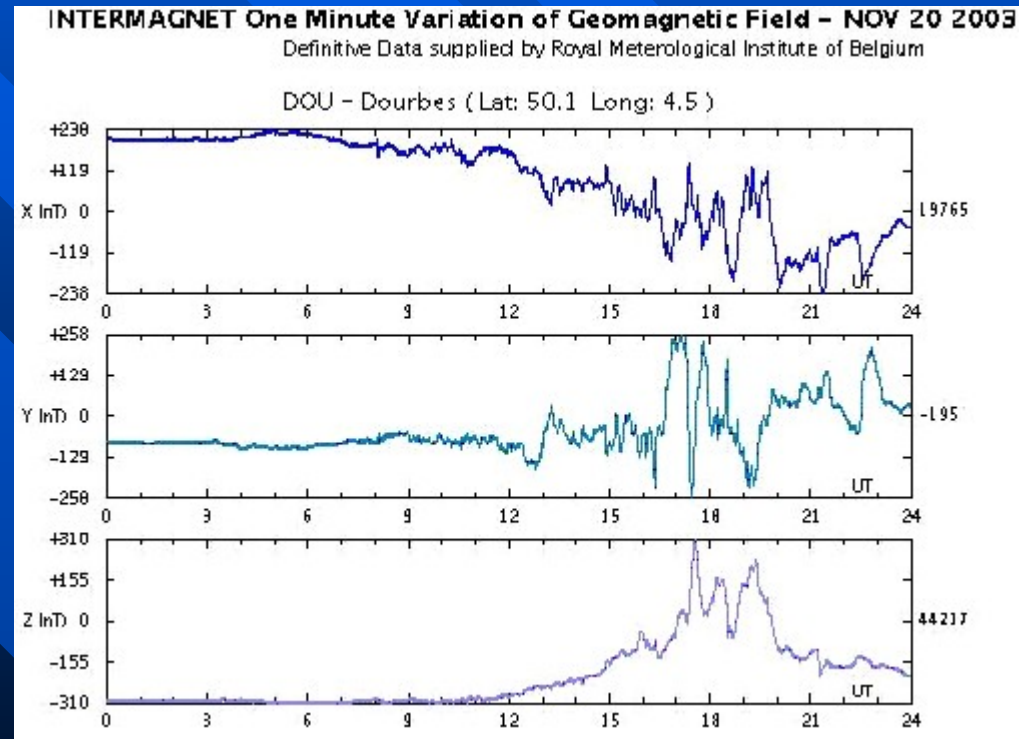
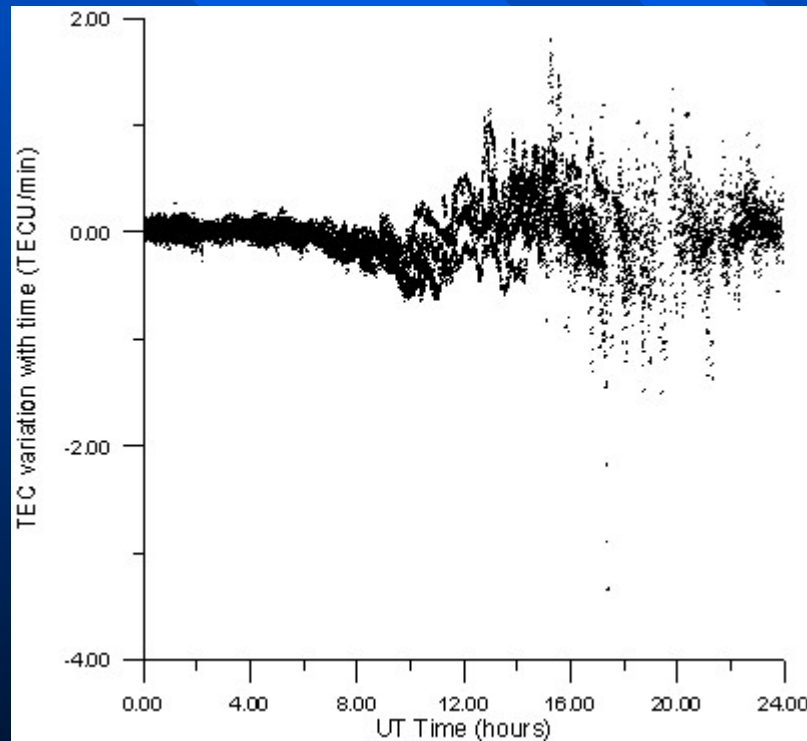
■ Travelling Ionospheric Disturbances

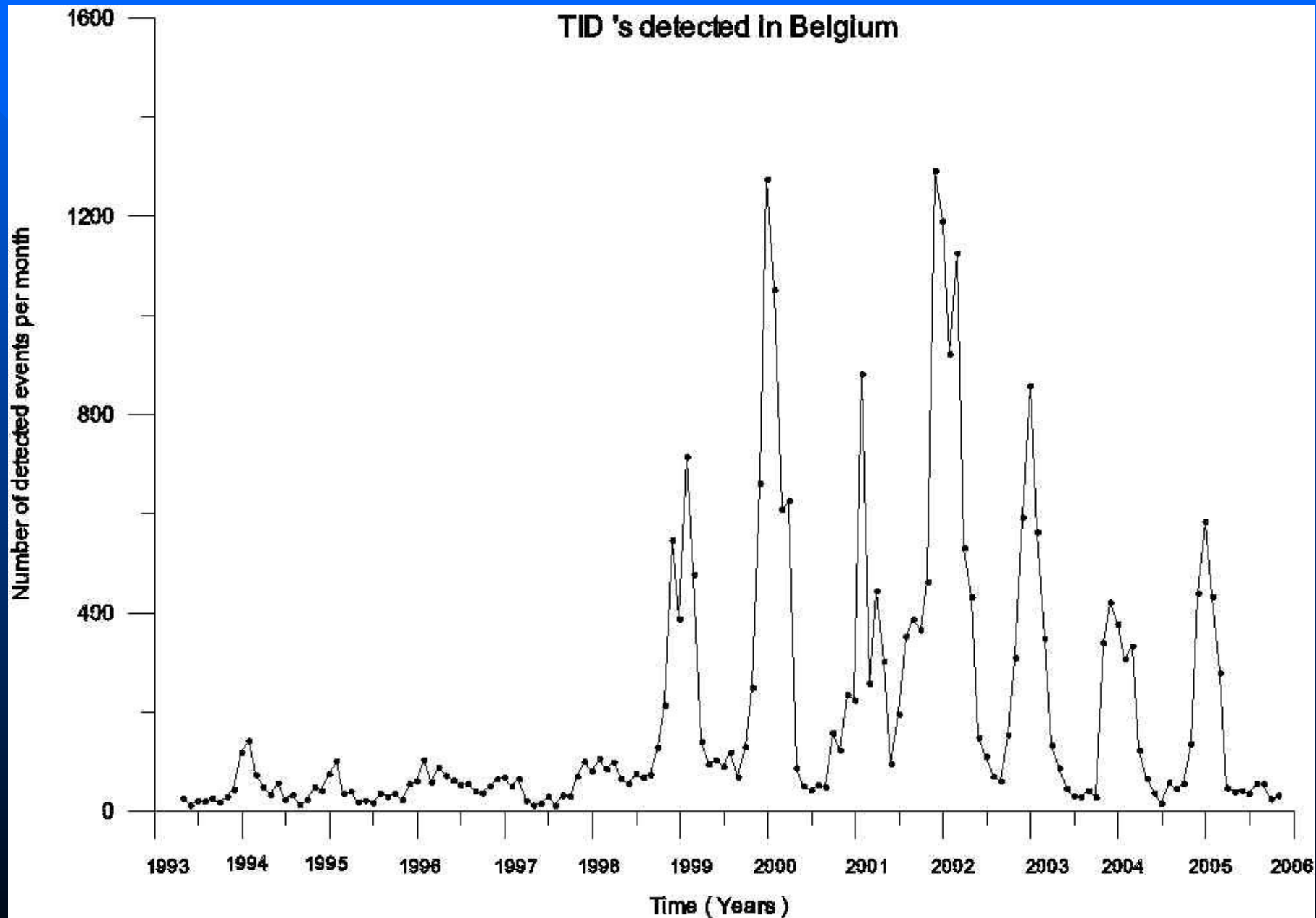


Small scale structure climatology

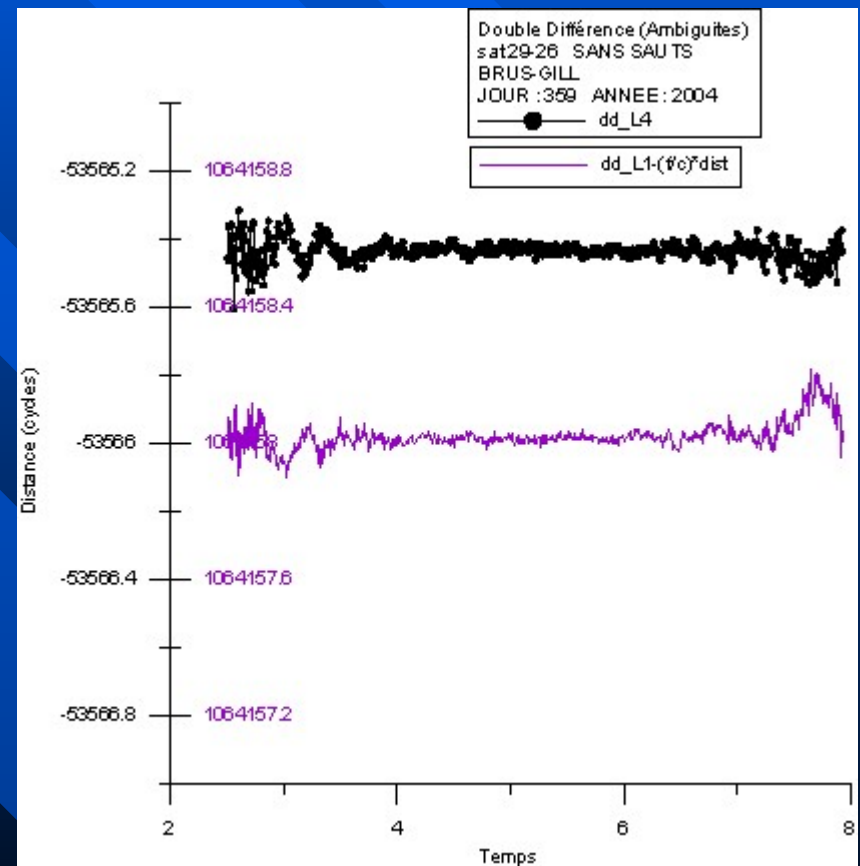
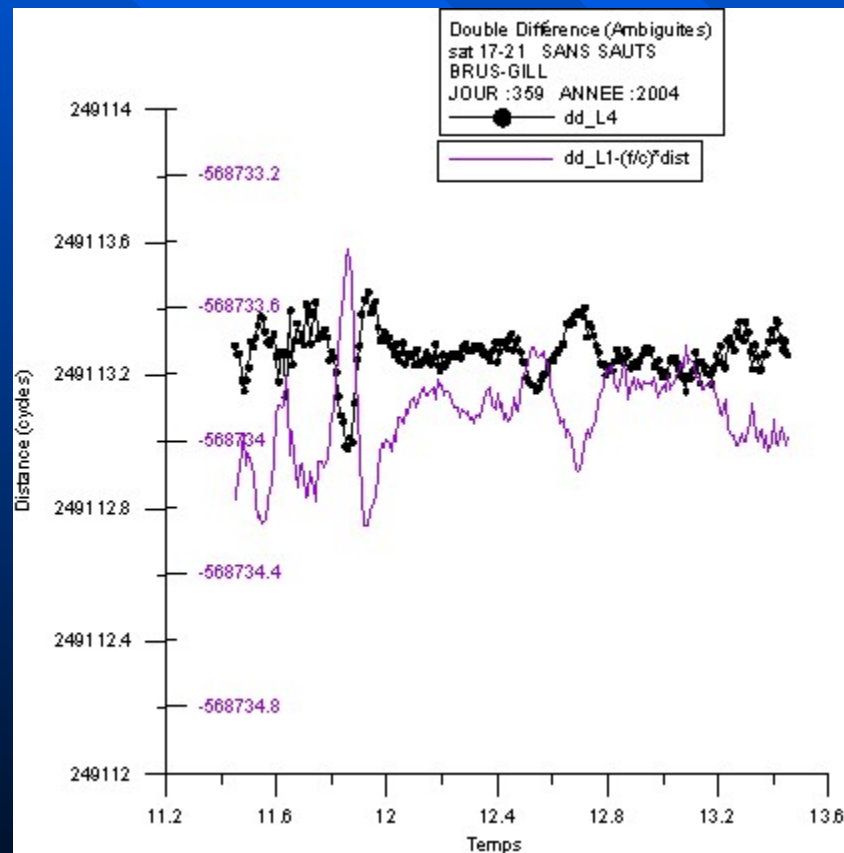
- Frequency of occurrence depends on solar activity.
- Are strongly related to **Space Weather** and, in particular, to geomagnetic storms (Kp index).
- Severe geomagnetic (ionospheric) storms are the origin of strong « noise-like » TEC variations which severely degrade real-time solutions (ambiguity resolution).
- BUT : there are also strong TID's during so-called quiet ionosphere activity periods which can give strong residual errors even on short distances (4 km baselines)

Geomagnetic storms and TEC variability





TID's and ambiguity resolution (1/2)



TID's and ambiguity resolution (2/2)

- Rather difficult to predict how such TID's will affect ambiguity resolution process
- As 1 cycle is about 20 cm, incorrectly solved ambiguities can result in errors of several decimeters (even during «quiet» ionospheric activity)
- (Strong) TID's are observed even at solar minimum and they have an annual peak during winter time

Conclusions

- Ionospheric phenomena which have to be taken into account in the mitigation techniques depend very much on the application (large scale/small scale TEC)
- TEC (and all his « drivers » - from SW activity) is the main parameter but satellite geometry is also very important → ??? TEC maps ?????
- No simple relationship between ionospheric activity and the positioning error (geometry, ambiguity search, least square process)

→ A given ionospheric activity will NOT ALWAYS result in the same positioning error