with CETP, SA, ETH

SPECTRE

A distribution service of 2D maps of ionosphere total electronic content over Europe

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Abstract: The SPECTRE - **S**ervice and **P**roducts for ionosphere **E**lectronic **C**ontent and **TR**oposphere over **E**urope - project is a pre-operational service generating and distributing 2D maps of ionosphere total electronic content over Europe. GPS data recorded by dense station networks (EUREF, IGS...) are processed every day to generate products sampled at 30 seconds, 15 minutes, and 1 hour. Products consist in TEC at subionospheric points and grids with 2.5° resolution. The operational service is based on European GPS networks but the service can be run for any world area covered by sufficiently dense networks.
The SPECTRE products can be useful for many applications: Study of ionosphere disturbance caused by earthquakes and tsunamis, over-the-horizon radar tuning, correction of radar path delay to improve interferometry imaging for land monitoring, precise positioning with mono-frequency receivers.
Since information on the troposphere water vapour content can be extracted from GPS data, this service is intended to evolve toward a distribution service of tropospheric products.

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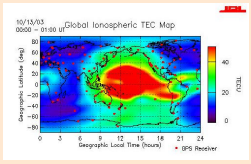
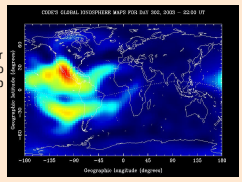
Scientific background

The Total Electronic Content (TEC) of the ionosphere depends on:

- The local time and the latitude
- The season
- Abrupt phenomena (magnetic storms)
- TEC variations: 0 → 120 TEC Units (TECU)



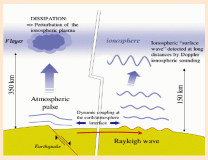
Global TEC map (2003/10/13), produced by JPL.

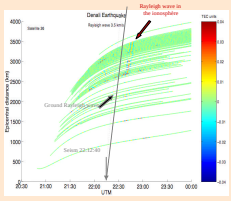


Magnetic storm over California and Mexico (2003/10/29). Map produced by CODE.

Other phenomena cause slight TEC variations (~0.01 TECU):

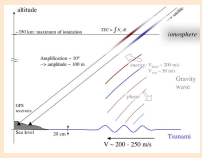
Earthquakes

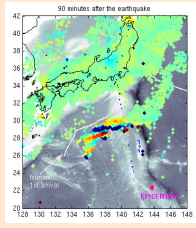




Ionospheric hodograph over California after the Denali earthquake (Alaska, 2002/11/03) filtered between 4.8 mHz and 5.8 mHz

Tsunamis





TEC variations 90 min after the Volcano Islands earthquake (M=7.6, 2000/03/28)

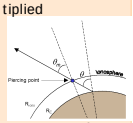
TEC variations can be estimated from GNSS measurements:

The combination of the pseudo-ranges P1 and P2 and the phase data L1 and L2, respectively at F1 (1575.42 MHz) and F2 (1227.60 MHz) gives the ionospheric delay:

$$D_{iono} = (L1-L2) - <(L1-L2)+(P1-P2)>$$

The integrated TEC along ray path, or slant TEC (STEC), is multiplied by the obliquity factor F_{ob} to have the vertical TEC (VTEC):

$$F_{ob} = \cos^{-1}(q_m) \quad q_m = \sin^{-1}\left[\left(\frac{R_E}{R_E + R_{iono}}\right)\cdot\sin(q)\right]$$



The modeling of the GPS ionospheric combination has to account for electronic errors (Differential Code Biases, DCB) of two types:
- Station (P1-P2) DCB, or Inter-Frequency Bias (IFB)
- Satellite (P1-P2) DCB or Transmitter Group Delay (TGD)

Thus, for a station-satellite observation, one has:

$$D_{iono} = \frac{VTEC}{F_{ob}} + IFB + TGD$$

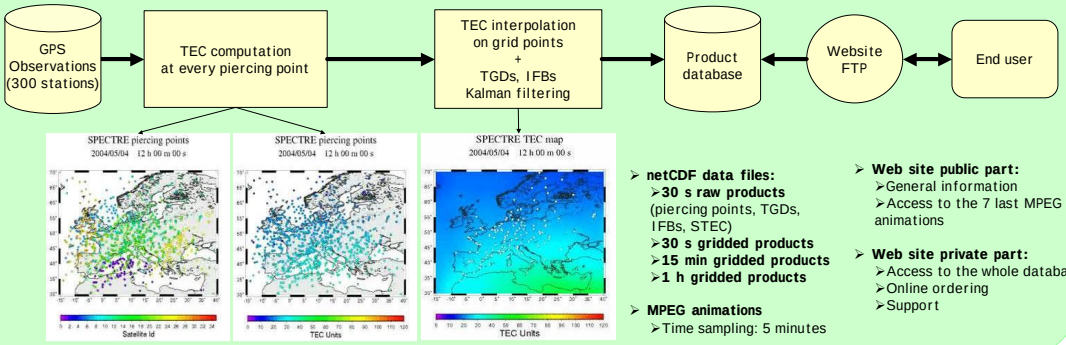
The VTEC and the biases are estimated jointly with a least-square method. In order to solve the non-uniqueness on the estimated IFBs and TGDs, one has to choose a reference station and fix its bias to 0. So the IFB and TGD estimates are relative to the reference station IFB. Moreover, we introduce a spatial correlation and a time correlation (Kalman filter) to improve the estimation stability.

The SPECTRE service

SPECTRE is a pre-operational service:
- Based on the software developed by IPGP
- Consolidated by NOVELTIS:
  - Automation
  - Archiving procedures
  - End-user interface for data ordering

Products:
- Are computed daily on a routine basis
- Are archived in our database (data since April 2004)
- Can be ordered through our web site (www.noveltis.com/spectre)

Products availability:
Interested users can register on the SPECTRE web site: www.noveltis.com/spectre/
For any information: spectre@noveltis.fr



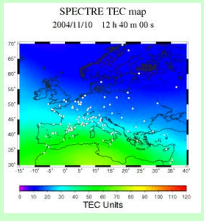
- **netCDF data files:**
  - **30 s raw products** (piercing points, TGDs, IFBs, STEC)
  - **30 s gridded products**
  - **15 min gridded products**
  - **1 h gridded products**
- **MPEG animations**
  - Time sampling: 5 minutes

- **Web site public part:**
  - General information
  - Access to the 7 last MPEG animations
- **Web site private part:**
  - Access to the whole database
  - Online ordering
  - Support

SPECTRE applications

Space weather

SPECTRE is fully adapted to the study of magnetic storms: Intensity, extension, movement with time...



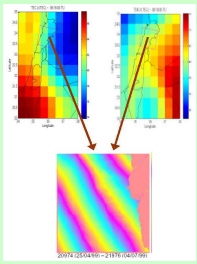
High TEC values visible on southern Europe and caused by the magnetic storm of 2004/11/10.

Seismology

The SPECTRE products could also be compared to the DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) measurements in order to study correlations between seismic events and ionosphere disturbance.

SAR interferometry

Land deformations can be easily observed by SAR interferometry by combination of two images taken at two different dates. Unfortunately variations of the TEC alter the radar path delay of each measurement and thus deteriorate the quality of the interferometry image. Therefore, the SPECTRE products can be used to correct interferometry images since variations of the path delays are related to the ionospheric TEC. The figure below is an example of such a processing. The TEC has been estimated over Lebanon at the instants of two SAR images. After processing of the TEC maps, it is possible to provide an image showing the corrections to apply to the interferometry image.



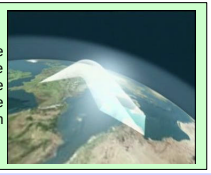
Ionospheric interferogram computed from 2 TEC maps. The corresponding correction on altitude is ~ 8 cm

Precise positioning

Mono-frequency receivers are not robust to TEC variations since the path delay of the GPS rays depends on the TEC. Therefore, knowledge of the TEC is a solution to correct data provided by cheap mono-frequency receivers and to perform precise point positioning.

Over-the-horizon radar monitoring

The range of over-horizon radars depends on the ionospheric state since the EM waves reflect on the ionosphere. Therefore, knowledge of the TEC can be helpful to get precise radar imaging or to set up the over-horizon radar parameters to observe a given area.



Conclusion and prospects:

Using dense GPS receiver networks SPECTRE can provide regional TEC maps with high spatial and time resolutions in order to study space weather (magnetic storms) and seismic (earthquakes, tsunamis) events or to improve data processing (interferometry imaging, positioning, over-horizon radar monitoring).

The SPECTRE service has been developed to provide daily TEC products (raw products and mapped products) over Europe at **30 seconds** and 2.5° resolutions.

The main prospects are to extend the SPECTRE service to **3D tomography** with the intent to produce 3D maps of ionosphere and troposphere.