An inversion method using GPS for ionospheric remote sensing

F. Crespon(1,2), V. Ducic(1), R.Garcia(1), P. Lognonné(1), E. Jeansou(2), J. Helbert(2) and G. Moreaux(2).

(1) Département de Géophysique Spatiale et Planétaire, Institut de Physique du Globe de Paris

(2) Noveltis (Toulouse)

First author email: crespon@ipgp.jussieu.fr

http://ganymede.ipgp.jussieu.fr/

Abstract:

Bistatic GPS receivers allow us to use Global Positioning System (GPS) data for ionospheric remote sensing. Therefore we can characterize the ionospheric disturbances by monitoring 2D total electronic content (TEC) maps. The SPECTRE project, Service and Products for ionosphere Electronic Content and Tropospheric Refractivity over Europe from GPS data, intends to establish a pre-operational service for distribution of TEC maps and tropospheric products over Europe. We present an inversion method, developed within the framework of the SPECTRE project, providing TEC maps and estimating satellite and station interfrequency biases. Therefore providing TEC maps over dense GPS networks we can detect solar and earth geophysical events like magnetic storms and post-seismic waves.

The SPECTRE project:

Context:

Recent developments in ionospheric remote sensing, in particular advances in techniques using the GPS, provide an unprecedented capability for monitoring the state of the ionosphere and its reaction to solar events, but also to Earth geophysical events.

Information on the water vapor content of the troposphere can also be extracted from the GPS signal. Techniques under development in research laboratories will be addressed during the project in order to characterize the precision GPS or GALILEO-derived tropospheric products and to assess their usefulness for weather forecasting.

Objectives:

The aims of the project are:

1.To set up a pre-operational service for distribution of TEC product over Europe.

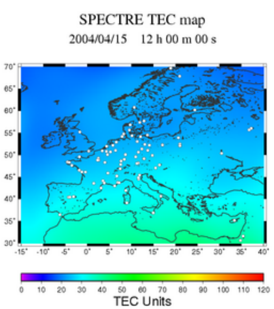
2.To make this service evolve toward a pre-operational service for distribution of tropospheric products.

3.To use equivalent systems in a laboratory context for study of post-seismic ionospheric signals over California, Japan and Europe.

4.To study the ability of dense GPS networks to monitor tsunami.

5.To consolidate technology applications and potential business outlets for ionosphere and troposphere product over Europe, in the framework of the preparation of Galileo.

6.To support research in the field of tropospheric products applicable to meteorology, with the aim of having an operational production after 2 years.



TEC products:

Several products will be provided. Daily raw data, sampled every 30 seconds and daily TEC maps which are data interpolated on a regular grid. The maps extensions are 15° West to 40° East and 30° North to 70° North, with 2.5° spatial resolution for both. Time resolution of 30s is decrease by low pass filtering to also produce 15 minutes and 1 hour maps.

Funding:

This project is funded by the French Ministry of Research, the European Space Agency (ESA), and the French Space Agency (CNES).

The inversion method:

Because of the TEC density profiles which are shown in fig.1 we assume ionospheric thin shell model.

The dispersive effect of the ionosphere on electromagnetic waves allow us to link TEC and data provided by bistatic GPS receivers. Indeed the combinations (eq.1) of pseudo ranges P1 and P2, and phase data L1 and L2 ,respectively at frequency F1 (1575.42MHz) and F2 (1227.60MHz), match to the integrated TEC along ray path.

$$D_{iono} = (L1 - L2) - \langle (L1 - L2) + (P1 - P2) \rangle \quad \text{Eq.1}$$

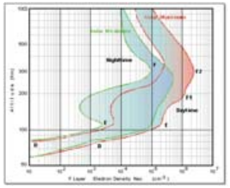


Fig.1: Density profiles of the electronic content.

The integrated TEC along ray path or slant TEC (STEC) is put up to vertical TEC (VTEC) at sub-ionospheric point, multiplying STEC by the obliquity factor Fob. This model is shown in figure 2 and Fob is defined by equation 2.

$$F_{ob} = a\cos[\theta_m] \quad \text{with} \quad \theta_m = a\sin\left[\left(\frac{R_t}{R_t + R_{iono}}\right)\sin(\theta)\right] \quad \text{Eq.2}$$

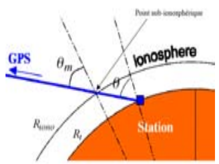


Fig.2: Ionospheric thin shell model.

The modeling of the GPS ionospheric combination has to account for the electronic errors usually referred to Differential Code Biases (DCB). There are three types of DCB:

1. Station (P1-P2)DCB or Inter Frequency Biases (IFB).
2. Satellite (P1-P2)DCB or Transmitter Group Delay (TGD).
3. Satellite (P1-C1)DCB due to C1, Y-codeless, non-cross-correlators receivers (cf IGSMAIL 3737 for further details).

So for a station-satellite couple (i,j) the model is given by equation 3. Using equation 3 as a forward problem, the 2D tomography of TEC is realized by the implementation of the least-square method.

$$D_{iono,(i,j)} = \frac{1}{F_{ob}} \times VTEC + IFB_i + TGD_j + k \times (P1 - C1)DCB_j \quad \text{Eq.3}$$

With k=1 for receiver type 3 and k=0 either.

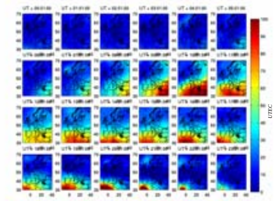
The VTEC and the DCBs are conjointly inverted. In order to solve the non-uniqueness on the estimated IFB and TGD we choose a reference station, which must be reliable, and assume its bias equals zero. So the estimates of IFBs and TGDs are relative to the IFB of the reference station. Moreover, to improve the inversion stability we introduce spatial correlation and time correlation, the latter by Kalman filtering.

As a results, we obtain TEC maps with uncertainties lower than 5%.

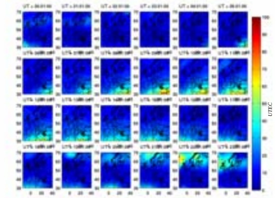
Magnetic storms monitoring:

In the end of October 2003 the intense solar activity induced one of the most violent magnetic storms of the last year. Indeed the World Data Center for Geomagnetism of Kyoto recorded two disturbance peaks respectively reaching -360 nT and -400 nT as shown the Dst index on figure 4. We monitor great variations of the TEC density over Europe correlated with the magnetic field perturbations.

Fig.4: Dst index for the end of October 2003 (WDCG - Kyoto).



Figures 5, 6 and 7 present TEC maps provided by the 2D tomography program respectively for October 29th, 30th and 31th. Note the high level of the electronic content density and specially the nighttime activities matching to auroras borealis at low latitudes (60° N).



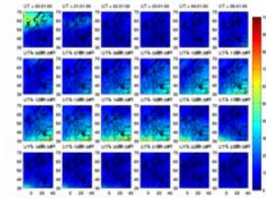


Fig.5,6 and 7: TEC maps for 10/29/2003 (top), 10/30/2003 (bottom left) and 10/31/2003 (bottom right).

Post-seismic waves detection:

As it propagates upward, the vertical velocity of the acoustic waves, generated by Rayleigh waves, is amplified due to the conservation of kinetic energy. Therefore, at low frequencies, a ground displacement of 1 mm induce a displacement of 100 m at ionospheric altitudes. By filtering the signals between 4.8mHz and 5.8mHz we can observe the waves of 200s period which disturb the ionosphere. In order to improve the signal-to-noise ratio we reduce sidereal day period's signals usually referred to "multipath" effects. Similarly to [Bock et al.,2000], the weighted mean of the day before and after the day of the seism is computed and subtracted from the day of interest. The result of this correction is presented in figure 9 for station AZRY and satellite PRN31 on South California Integrated GPS Networks (SCIGN).

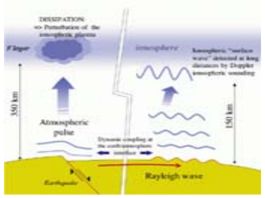


Fig.8: Earth-atmosphere coupling.

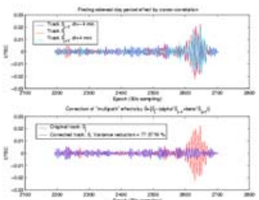


Fig.9: Correction of a multipath effect.

This data processing was realized for the seism of Denali in Alaska the November 03rd, 2002. Figures 10 and 11, [Ducic et al.,2003], respectively present the ionospheric seismograms for the November 02nd and 03rd showing propagation of post-seismic waves in ionosphere.

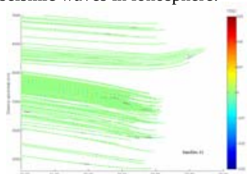


Fig.10: Ionospheric seismogram for 11/02/2002.

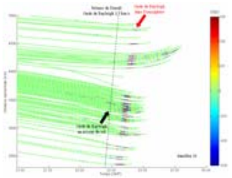


Fig.11: Ionospheric seismogram for 11/03/2002.

Conclusion and perspectives:

Using dense GPS networks and modern GPS receivers one can provide local TEC maps with high spatial and time resolution in order to monitor magnetic storms and post-seismic waves.

The main objective is to strengthen the inversion algorithm and achieve the development of 3D tomography with the intent to process tomography of the troposphere.

References: Bock Y., Nickolaidis M., and de Jonge P., 2000, Instantaneous geodetic positioning at medium distances with the Global Positioning System, J. Geophys. Res., v. 105, n. B12, 28,223-28,253, December 10.

Ducic V., J. Artru and P. Lognonné, 2003, Ionospheric remote sensing of the Denali Earthquake Rayleigh surface waves, Geophys. Res. Lett., v. 30, n. 18, doi: 10.1029/2003GL017812