# COMPARISON OF IONOSPHERIC IONIZATION MEASUREMENTS OVER ATHENS USING GROUND IONOSONDE AND GPS DERIVED TEC VALUES

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## ABSTRACT

A systematic comparison is performed between the ionosonde derived ITEC and GPS-TEC data for Athens coordinates, showing a general daytime agreement, although a systematic deviation of ITEC towards lower values during nighttime hours is present. The diurnal variation of their residual values (dTEC) is compatible with the dayside plasmasphere depletion and nightside refilling. The comparison between the ionospheric and total slab thickness demonstrates characteristics compatible with the seasonal effect on the plasmaspheric content. Their different response to intense geomagnetic storms was also attributed to the plasmasphere. In summary, additional evidence was presented to verify that dTEC corresponds to plasmaspheric content.

## INTRODUCTION

Total Electron Content (TEC) is a key parameter that describes the major impact of the ionised atmosphere on the propagation of radio waves, which is crucial for terrestrial and Earth-space communications including navigation satellite systems such as GPS, GLONASS and the future GALILEO system. A standard technique to determine TEC is the use of dual frequency GPS measurements. This technique measures the electron content along a slant signal path, from which a vertical TEC is found by simple geometric corrections [1]. As the orbit altitude of GPS satellites is ~20,000km, GPS derived TEC corresponds to the total electron content (bottomside, topside and plasmaspheric) and it is most sensitive to topside ionospheric and plasmapheric processes. Recently, a new method was proposed [2] to measure the vertical ionospheric electron content is the ionogram-derived electron content. The ionogram provides the information to directly calculate the vertical electron density profile up to the peak of the F2 layer. The profile above the peak is approximated by an α-Chapman function with a scale height that is derived from the profile shape at the F2 peak. The ionosonde TEC, or ITEC, is then calculated as an integral from 0 to ~1000 km over the entire profile. A preliminary ITEC validation was performed by comparing ITEC with TEC values derived from incoherent scatter radar and geostationary satellite beacon measurements at middle latitudes and with TOPEX measurement at the equator, showing very good agreement [2,3]. It was also shown that ITEC is generally within ~10% of the satellite TEC. At first thought this difference may be interpreted as the plasmaspheric content, but this interpretation needs to be verified [4,5].
In this paper we compare the Athens Digisonde ITEC values with GPS derived TEC for Athens coordinates (GPS_TEC) from TEC maps produced by DLR/IKN over Europe using GPS observables. The aim of this study is to determine the source that causes the difference between ITEC and GPS_TEC especially at night, analyzing the behavior of their residual values dTEC throughout a period of six months and studying the variation of the ionospheric and total slab thickness with season and geomagnetic activity.

## COMPARISON BETWEEN IONOSONDE TEC AND GPS TEC

A comparison between the two data sets was performed for the first six months of 2001, indicating very good agreement between ITEC and GPS_TEC values especially during the day. The time plot of ITEC, GPS_TEC (red line) and Dst-index, in 30 min time resolution is presented for March 2001 (Fig. 1) as an indicative case. During March 2001 the geomagnetic conditions during the first 17 days were quiet, whereas at the end of the month a major storm occurred. The systematic shift of GPS_TEC at night towards grater values is probably due to the plasmaspheric fluxes since the GPS satellite is at 20,000 km and therefore measures most of plasmaspheric content. The ITEC parameter by its derivation gives a measure of the bottomside and topside ionospheric electron content up to 1000 km.

## DAILY VARIATION OF PLASMASPHERIC ELECTRON CONTENT

To determine the source of the difference observed between the two TEC estimates, we investigate the daily pattern variation of the median values of dTEC parameter for six sequential months. The results are given in Fig. 2. A red line of best fit is sketched through the plotted points to show the general behavior of the dTEC parameter throughout a day.

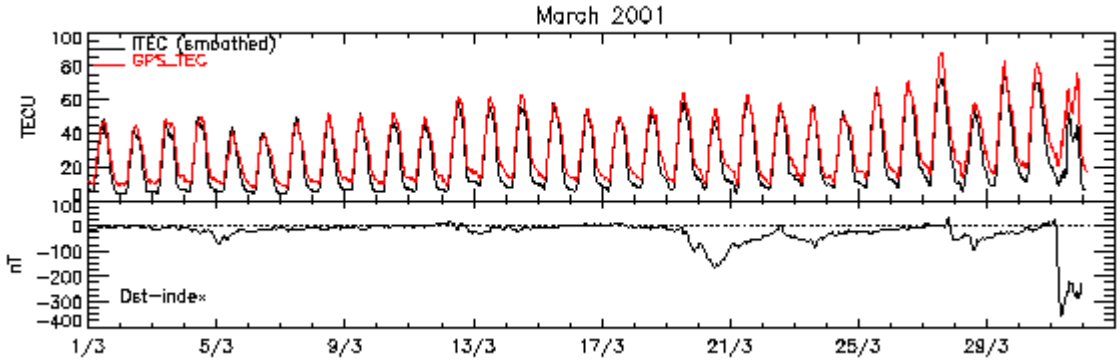


Fig. 1. The time plot of ITEC and GPS_TEC parameter over a whole month (March 2001). The Dst index is shown in the bottom of the figure to indicate the level of geomagnetic activity.

The RMS of the median dTEC values for the given month and the mean value of the Ap index are indicated at the bottom right corner of each plot. These curves correspond to the diurnal variation in electron content at ~1,000 km to 20,000 km, which covers most of plasmasphere. The maximum depletion of electron content is observed around local noon. Successive refilling is seen in the afternoon with its maximum at 1800-2000 LT depending on the season (i.e. sunset time). This is consistent with the plasmaspheric content daily variation. An exception is observed in April, when an enhancement of the electron content between 1000LT and 1400LT. This maybe due to the enhanced geomagnetic activity occurred during this month. Actually four intense magnetic storms were occurred during this month.

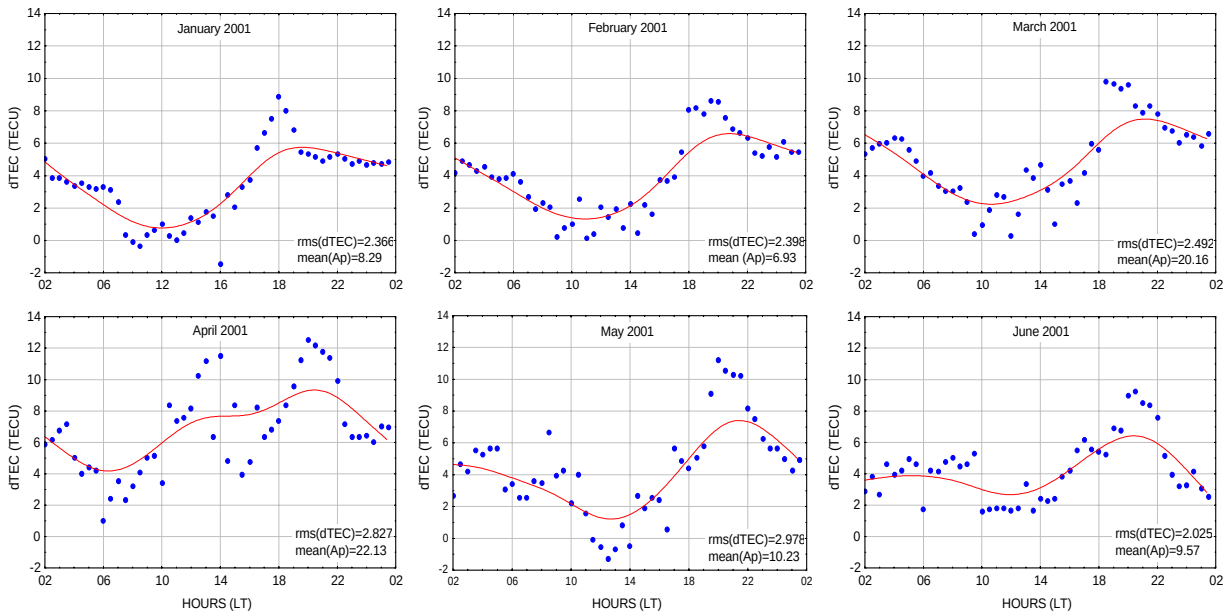


Fig. 2. The diurnal variation pattern of the median residual values dTEC for six sequential months. A red line of best fit is sketched through the plotted points to show the general behavior of the dTEC electron content throughout a day.

Results of the plasmaspheric electron content variation, determined from the difference between GPS TEC and Faraday rotation TEC were also presented in [6]. The general daily variation pattern of the equinoctial plasmaspheric TEC from Salisbury in 1994 is similar to the variation of the dTEC parameter. All the above give strong evidence supporting the idea that dTEC corresponds to plasmaspheric content.

## DAILY VARIATION PATTERN OF SLAB THICKNESS

Slab thickness may be regarded as the depth of an imaginary ionosphere, which has the same TEC as the actual ionosphere and uniform electron density equal to the maximum electron density of the actual ionosphere. Slab thickness indicates the electron density versus height profile. For instance the sharper the peak electron density, the smaller is the

slab thickness. The slab thickness is calculated using both GPS_TEC and ITEC parameters, according to the following formulas:

$\tau = \alpha \cdot \frac{GPS\_TEC}{f_o F2^2}$, computed using GPS_TEC, and $\tau_I = \alpha \cdot \frac{ITEC}{f_o F2^2}$, computed using ITEC, with α=806.45, where GPS_TEC and ITEC are given in TEC units, $10^{16}m^{-2}$, foF2 in MHz and τ in km. According to their definition, τ includes the electron contents of both the ionosphere (up to ~1000km) and most of the plasmasphere (from 1000 to 20000 km). On the other hand, $\tau_I$ includes information on the bottomside and topside ionosphere only. Fig. 3 shows the diurnal plots of the median values of slab thickness parameters τ (red) and $\tau_I$ (blue), from January 2001 to June 2001. We observe a large difference during nighttime hours, which is most prominent in winter months. This is attributed to the plasmasphere. It is interesting to note that between ~0900LT to 1400LT the two parameters τ and $\tau_I$, are almost equal, which is in agreement with the idea of thinning of plasmasphere in the dayside in winter. In spring months (April, May) the difference between the two parameters exists in all local times, with greater values at night. In June, which is a summer month this difference is almost stable during the whole day, with a small increase at dusk hours, which indicates a conservation of plasmaspheric content during night-time also. This is in agreement with the daily pattern of the plasmaspheric content estimated for June 2001 (Fig. 2). The plasmaspheric content during June exhibits the least variation (minimum rms(dTEC)) comparing to the other months presented in Fig.2.

The $\tau_I$ parameter exhibits a diurnal variation indicative of the effect of the diurnal variation of the thermospheric temperature. The variation of the τ parameter can be regarded as a superposition of a diurnal curve with maximum at noon that corresponds to the thermospheric temperature variation and of a second diurnal curve with a double peak at dusk and at dawn that corresponds to the plasmasphere content.

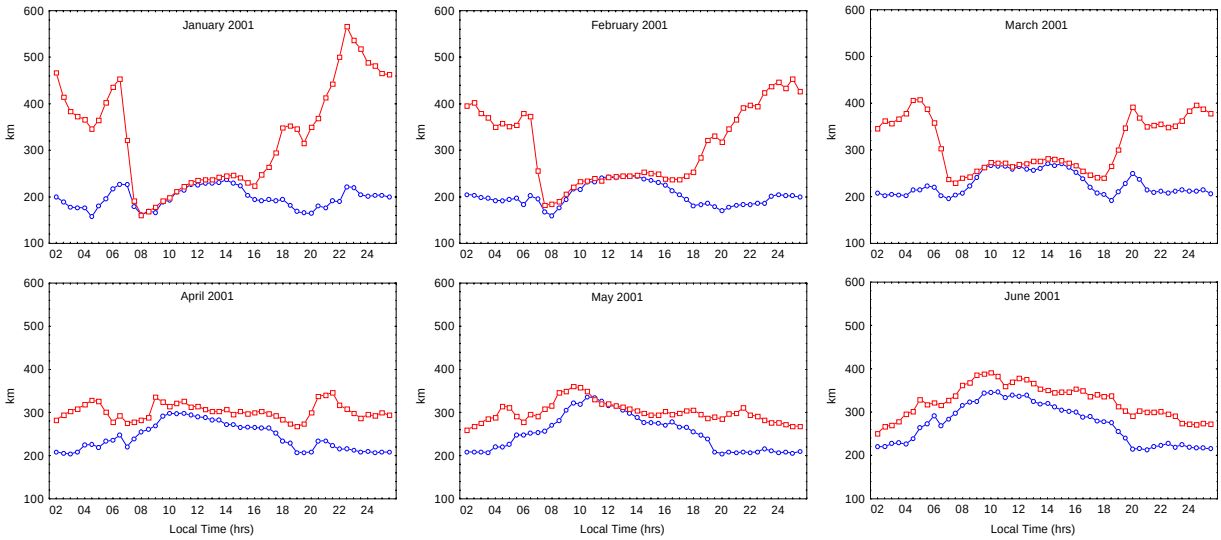


Fig. 3. The daily variation pattern of the slab thickness parameters τ (red line) and $\tau_I$ (blue line), extracted from the monthly median values.

## RELATION OF PLASMASPHERIC CONTENT WITH GEOMAGNETIC ACTIVITY

So far we present additional evidence to verify that dTEC corresponds to plasmaspheric content. The outflow of plasma from the ionosphere is one of the main factors that determine the size, shape and the dynamics of the plasmasphere, which vary strongly according to the level of magnetospheric activity. During periods of low activity the plasmasphere becomes saturated with upflowing of ionospheric plasma. When the magnetosphere is disturbed by a magnetic storm, enhanced convection erodes the outer plasmasphere, capturing plasma in the afternoon-dusk sector and transporting it outward and sunward toward the magnetopause. Following erosion, which can last hours to tens of hours, plasma flowing upward along magnetic field lines from the conjugate ionosphere begins to refill the depleted plasmasphere. Refilling the plasmasphere typically requires several days. In order refilling to occur, the counterstreaming plasma must be thermalized and trapped. To investigate in a first approximation the dependence of the dTEC parameter from the geomagnetic activity, we perform a visual correlation between the daily Ap-index and the daily value of the standard deviation of the dTEC from the monthly medians (Fig. 4), during the six-month interval, from January to June 2001. A good correlation between the two parameters is obvious with a time delay of several days, which might corresponds to the time of the plasmasphere refilling after a major geomagnetic storm event, like those occurred on March and April 2001.

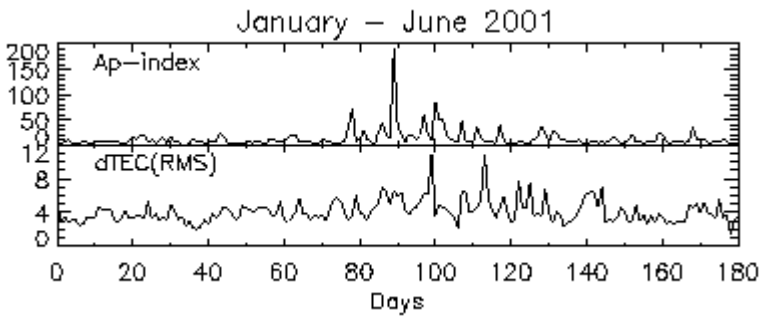


Fig. 4. A visual correlation between the daily Ap-index and the daily value of the standard deviation of the dTEC from their corresponding monthly medians, during the six-month interval, from January to June 2001.

Finally the different response of the total and ionospheric slab thickness was investigated. The results are shown in Fig. 5 for two intense storms. The first one with gradual development occurred on October 2000; the second one was an impulse storm recorded on April 2001. The abrupt increase of the total slab thickness at the main phase of the storm, comparing to the almost undisturbed values of the ionospheric slab thickness is an indication that $\tau$ parameter is strongly influenced by the plasmasphere; the sudden intensification of the solar wind - magnetosphere coupling causes an increase in convection and the inward movement of the separatrix, freeing some of the plasma previously bound on close Earth-encircling trajectories to follow open convective paths toward the dayside magnetopause.

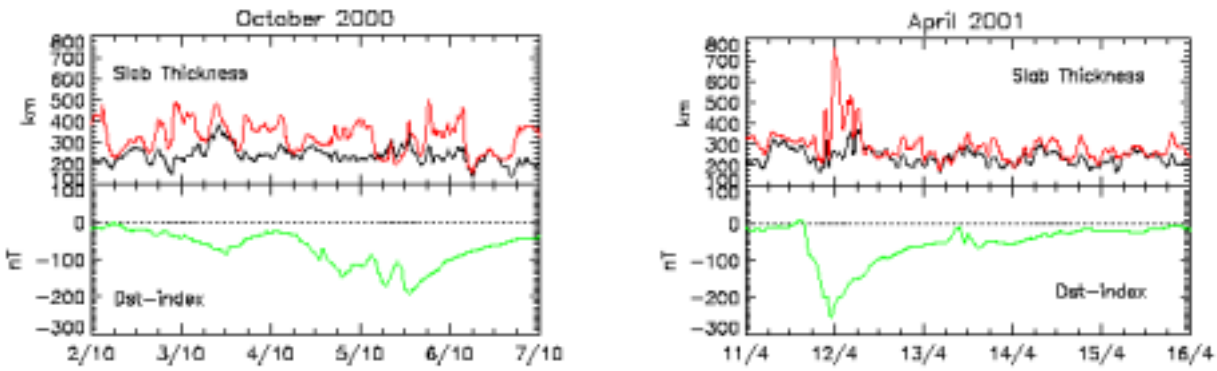


Fig. 5. The behavior of the slab thickness parameters $\tau$ (red line) and $\tau_I$ (black line), during two intense storm events occurred on October 2000 (left diagram) and on April 2001 (right diagram).

**SUMMARY**

We present additional evidence to demonstrate that the residual values between the GPS and ionosonde derived TEC parameters correspond to the plasmaspheric content.

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