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Comparisons of IRI TEC predictions with GPS and digisonde measurements at Ebro

M. Mosert [a,*], M. Gende [b], C. Brunini [b], R. Ezquer [c,d], D. Altadill [e]

[a] CASLEO-CONICET, Avda.España 1512 Sur, 5400 San Juan, Argentina
[b] FCAG, Observatorio Astronómico,UNLP, La Plata, Argentina
[c] Lab. de Ionósfera, UNT, CONICET, Avda. Independencia 1800,4000 Tucumán, Argentina
[d] GASuR, Fac.Reg.Tucumán, UTN, Rivadavia 1050,4000 Tucumán, Argentina
[e] Observatori de l'Ebre,(CSIC-URL), Carretera de Lóbservatori 8 E43896 Roquetes, Spain

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Abstract

Vertical TEC measurements obtained with GPS satellite signals (GPSTEC) and total electron content derived from ionograms (ITEC) are compared with the latest version of the International Reference Ionosphere, IRI-2000 (IRITEC). Digisonde data from the Ebro station (40.8°N, 0.5°E) recorded during two years of high solar activity 2000 ($Rz_{12} = 117$) and 2001 ($Rz_{12} = 111$) are used in the study. The results obtained with the three techniques are similar, and as expected, the GPS TEC values are greater than those obtained with the digisonde measurements. The IRI predictions generally overestimate the ITEC values. The diurnal and seasonal variations of the plasmaspheric electron content are also analyzed.

Keywords: Total electron content; IRI model

1. Introduction

The total electron content TEC is the ionospheric parameter that has the largest effect on radio waves that pass through the ionosphere. The availability of TEC measurements is important to the development of ionospheric models such as the International Reference Ionosphere, IRI (Bilitza, 2001). Historically, most TEC measurements have used the Faraday rotation technique (Davies, 1980), incoherent scatter radar measurements, and TOPEX surface reflections.

Recently, Huang and Reinisch (2001) introduced a new technique for estimating the total electron content from ground-based ionosonde data. Since an ionosonde cannot measure the topside electron density profile it is modeled by an α-Chapman function with a constant scale height that is derived from the bottom side shape around the F2 peak. ITEC is then calculated by integrating over the entire height profile. This technique has been tested against incoherent scatter radar, Faraday, and TOPEX TEC measurements showing a good agreement at middle and low latitudes.

The increase in availability of TEC data over the last 10 years has largely come from a rapid increase in the number of Global Position System TEC data (GPSTEC) over land. Compared with the long record, almost 50 years of ionospheric observation from ground-based measurements, the TEC record from GPS is relatively short. However the increase in the number of GPS sites provides now an important data base to study the ionosphere.

Many studies are found in the literature that report comparisons of total electron content obtained by different

* Corresponding author. Tel.: +54 264 421 3653; fax: +54 264 421 3693.
E-mail addresses: mmosert@casleo.gov.ar (M. Mosert), claudio@fcaglp.unlp.edu.ar, mgende@fcaglp.fcaglp.unlp.edu.ar (M. Gende), rezquer@herrera.unt.edu.ar (C. Brunini), scytec@frt.utn.edu.ar (R. Ezquer), daltadill@obsebre.es (D. Altadill).

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techniques at different locations and comparisons of TEC measurements with predictions of models such as the IRI model (Bilitza et al., 1998; Belehaki et al., 2003, 2004; Ezquer et al., 1998, 2004; Gulyaeva et al., 2002; Huang and Reinisch, 2001; Jodogne et al., 2004; Jakowski et al., 1998; Mosert et al., 2004; Orús et al., 2003; Sethi et al., 2001).

The objective of this paper is to compare the IRI-2000 TEC predictions, IRITEC (Bilitza, 2001) with GPSTEC and ITEC measurements from Ebro (40.8°N, 0.5°E). A preliminary study of the diurnal and seasonal variations of the plasmapheric electron content is also done.

2. Data used

Vertical incidence ionograms from Ebro (40.8°N, 0.5°E) recorded by a DGS 256 during two years of high solar activity (2000, Rz12 = 117 and 2001, Rz12 = 111) were used to calculate the integrated total electron content, ITEC, (Huang and Reinisch, 2001). The database includes hourly ionograms obtained during the representative months of the four seasons: January (winter), July (summer), October (fall) and April (spring). The individual electron density profiles corresponding to a given month and hour have been used to obtain the monthly median values of the integrated total electron content, ITEC (Huang and Reinisch, 1996, 2001).

The corresponding IRI TEC predictions (IRITEC) were calculated with the last version of the model (Bilitza, 2001) and using the measured characteristics of the F2 peak, foF2 and hmF2, as inputs to the model. Both TEC values (ITEC and IRITEC) were obtained integrating the electron density profile up to a height of 1000 km.

The monthly median values of the vertical GPS TEC measurements (GPSTEC) were derived from oblique GPS signals using La Plata Ionospheric Model, LPIM (Brunini et al., 2001). GPSTEC represents the TEC up to ~20,000 km (height of the GPS satellites), which includes the major part of the plasmaspheric electron content.

3. Analysis of the results

3.1. Comparing ITEC, GPSTEC, and IRITEC

Fig. 1 shows the comparison of the monthly median values of ITEC, GPSTEC, and IRITEC (in TEC units of $10^{16}\,m^{-2}$ = TECU) at Ebro for the months of January and July, representing winter and summer months, respectively, for the years 2000 and 2001, which was a period of high solar activity. Fig. 2 shows the same comparisons for the equinoctial months April and October, representing spring and fall. Fig. 3 illustrates the seasonal variations of the three estimations: (a) ITEC, (b) GPSTEC, and (c) IRITEC. From the analysis of these figures the diurnal

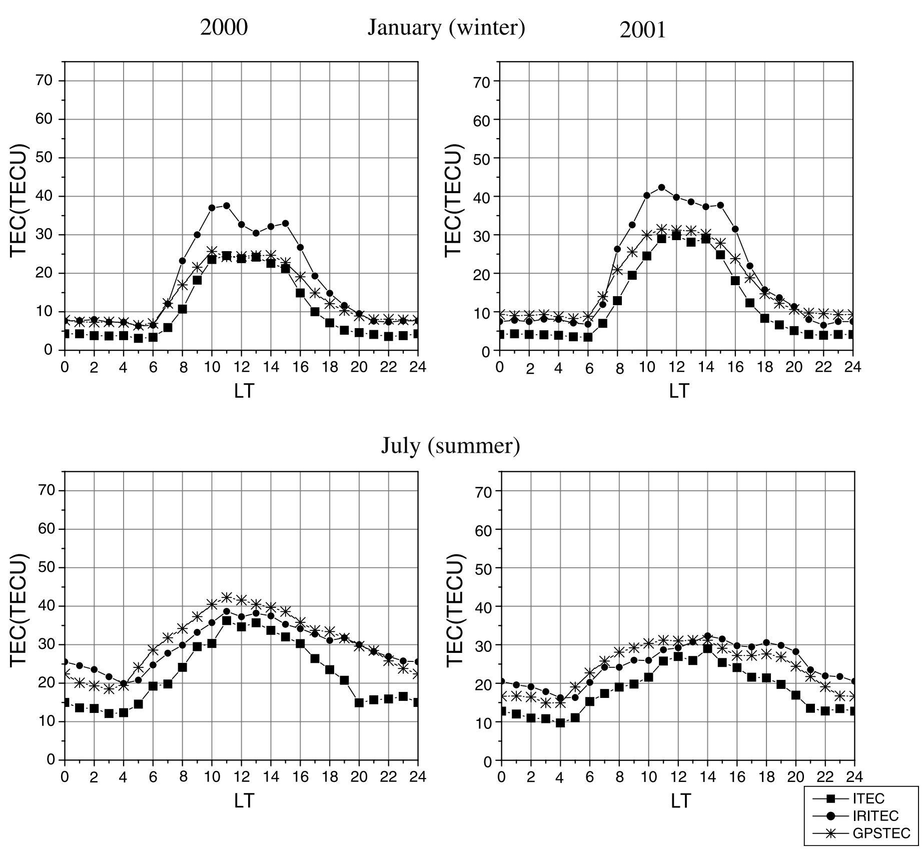

Fig. 1. Diurnal variation of the monthly median values of ITEC, GPSTEC and IRITEC (in TEC units of $10^{16}\,m^{-2}$ = TECU) at Ebro for the representative months of winter (January) and summer (July) during the years 2000 (Rz_{12} = 117) and 2001 (Rz_{12} = 111).

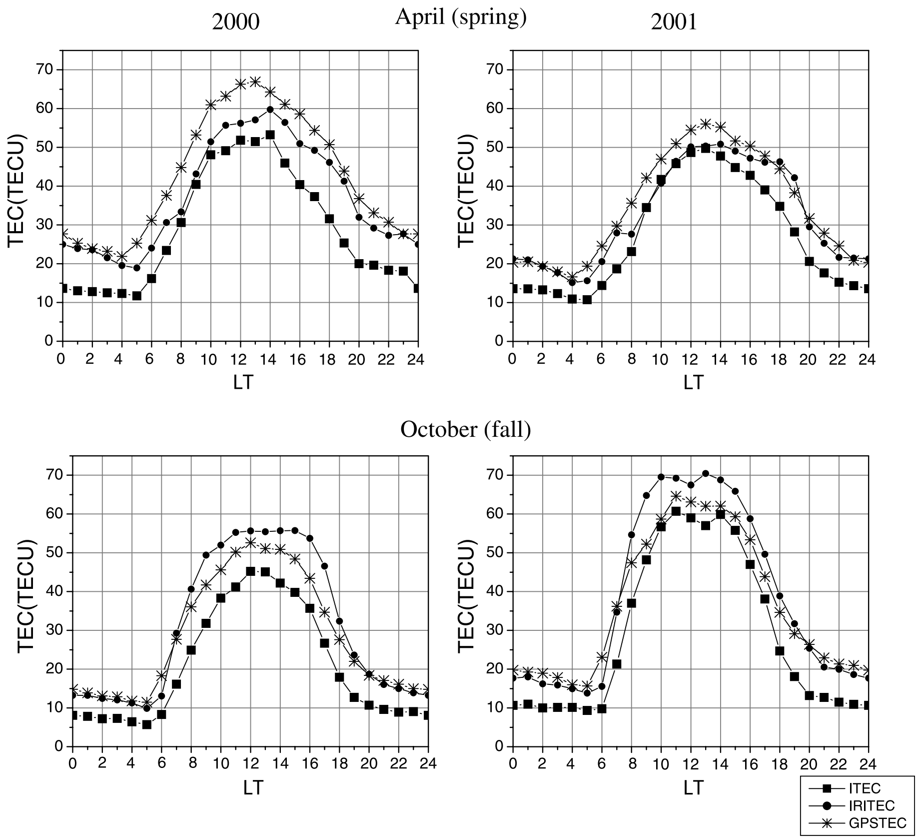

Fig. 2. Diurnal variation of the monthly median values of ITEC, GPSTEC and IRITEC in TECU at Ebro for the representative months of spring (April) and fall (October) during the years 2000 ($Rz_{12} = 117$) and 2001 ($Rz_{12} = 111$).

and seasonal behavior of the TEC estimations can be determined. It can be seen that:

(1) The diurnal variations of the median values obtained with the three techniques are quite similar. The TEC increases gradually from hours of minimum TEC (05-06 LT) in all the seasons reaching maximum values around midday. At sunset the TEC values begin to decrease reaching minimum values around sunrise. The diurnal maximum is almost flat during summer, but relatively sharp during winter and equinox for the three TEC estimations (Figs. 1 and 2).

(2) The diurnal variations of GPSTEC and ITEC show the good correlation between both techniques. The GPSTEC values, as expected, are larger than the ITEC values in the four seasons of the two high solar activity years (Figs. 1 and 2). The quantitative differences DTEC = GPSTEC–ITEC, that can be considered as a measure of the plasmaspheric contribution (Belehaki et al., 2003, 2004), will be analyzed in Section 3.2.

(3) The IRI predictions overestimate the ITEC values in all the seasons during the 2 years. During winter and fall the model also overestimates the GPSTEC values. The IRITEC values exceed ITEC by 3–10 TECU during nighttime and 0–15 TECU during daytime, depending on the season (Figs. 1 and 2). In other words, the percentage differences range between 30% and 125% for nighttime and between 0 and 64% around noon. Greater discrepancies between ITEC values and IRI predictions are observed in winter at nighttime (85–125%) and the minimum ones in summer around midday (7–8%).

(4) Both TEC measurements (ITEC and GPSTEC) generally show lower values in winter than in summer, although this winter–summer difference is not evident around noon in 2001.The two TEC measurements present the largest daytime peaks in the two equinoctial months. For nighttime hours, largest TEC values are also observed in summer (Figs. 3a and b).

(5) The shape of the seasonal variation of the IRITEC predictions is, in general, similar to those observed in the electron content obtained with the two techniques: (a) The equinoctial peaks are also observed in the two years, and (b) the winter values are lower than the summer ones, except during the time period 08-16 LT during the year 2001 where this behavior is inverted (Fig. 3c).

Taking into account that the most contribution of TEC comes from the topside electron density profile, these results suggest that the discrepancies between IRITEC and ITEC values can be attributed to the shape of the topside IRI profile.

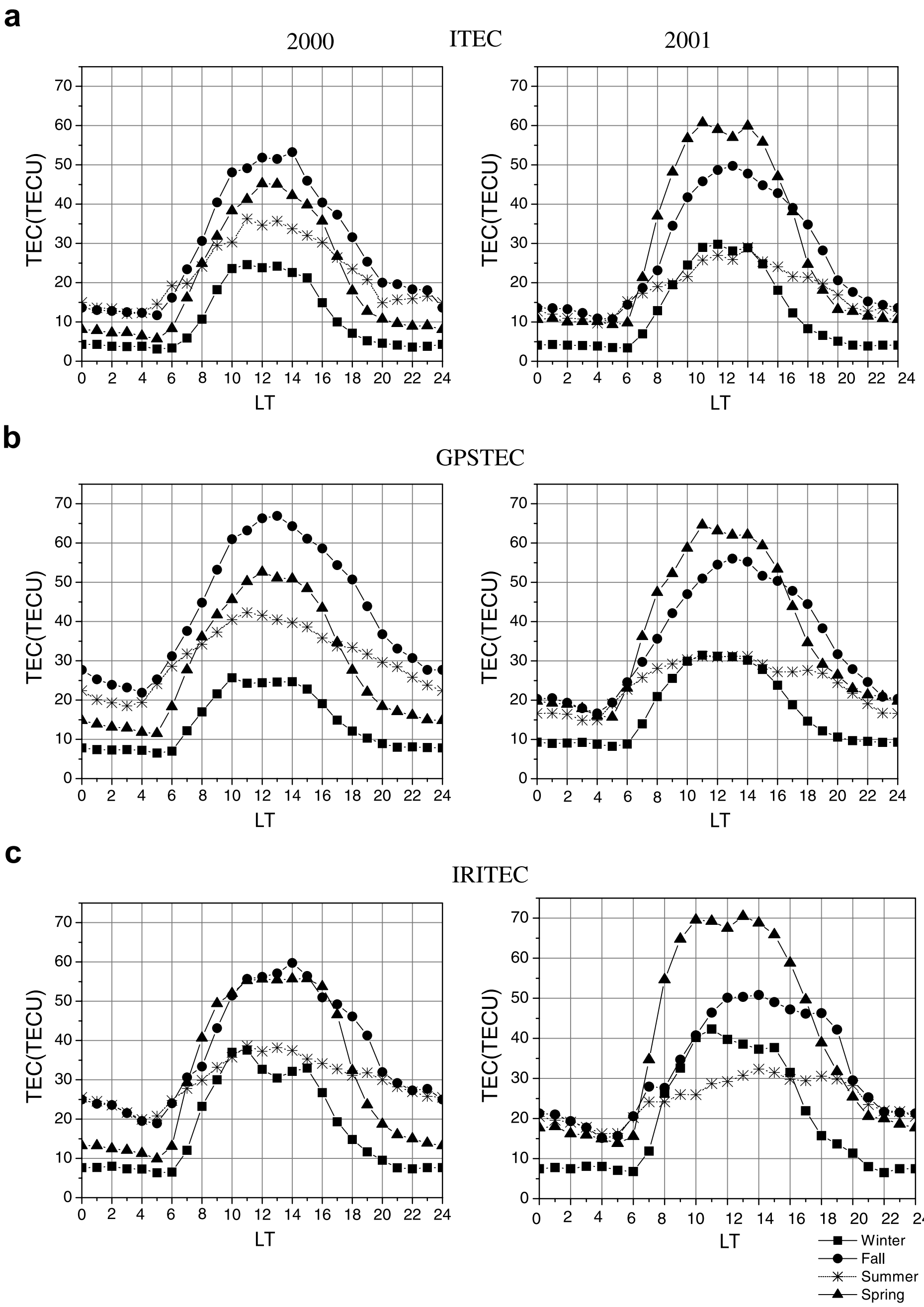

Fig. 3. Seasonal variation the three TEC estimations in TECU during the years 2000 ($Rz_{12} = 117$) and 2001 ($Rz_{12} = 111$): (a) ITEC, (b) GPSTEC, (c) IRITEC.

3.2. *Analysis of the differences between GPSTEC and ITEC values*

As mentioned in Section 3.1, the differences between the monthly median values of GPSTEC and the corresponding median values of ITEC, DTEC = GPSTEC-ITEC, represents the electron content from 1000 km to approximately 20,000 km, and can be considered an estimate of the plasmaspheric electron content (Belehaki et al., 2003, 2004).

Fig. 4 shows the curves corresponding to the diurnal variations in the DTEC values. In summer and winter, DTEC is generally lower around noon (0–7 TECU) than at night (2–15 TECU). The day–night differences are less clear in the equinoctial months. The largest differences generally occur around sunrise and sunset in all seasons. During the periods of maximum DTEC the GPSTEC values exceeds the ITEC values by 6–19 TECU depending on the season. The maximum value of DTEC (19 TECU) is observed at sunset in spring during the year 2000.

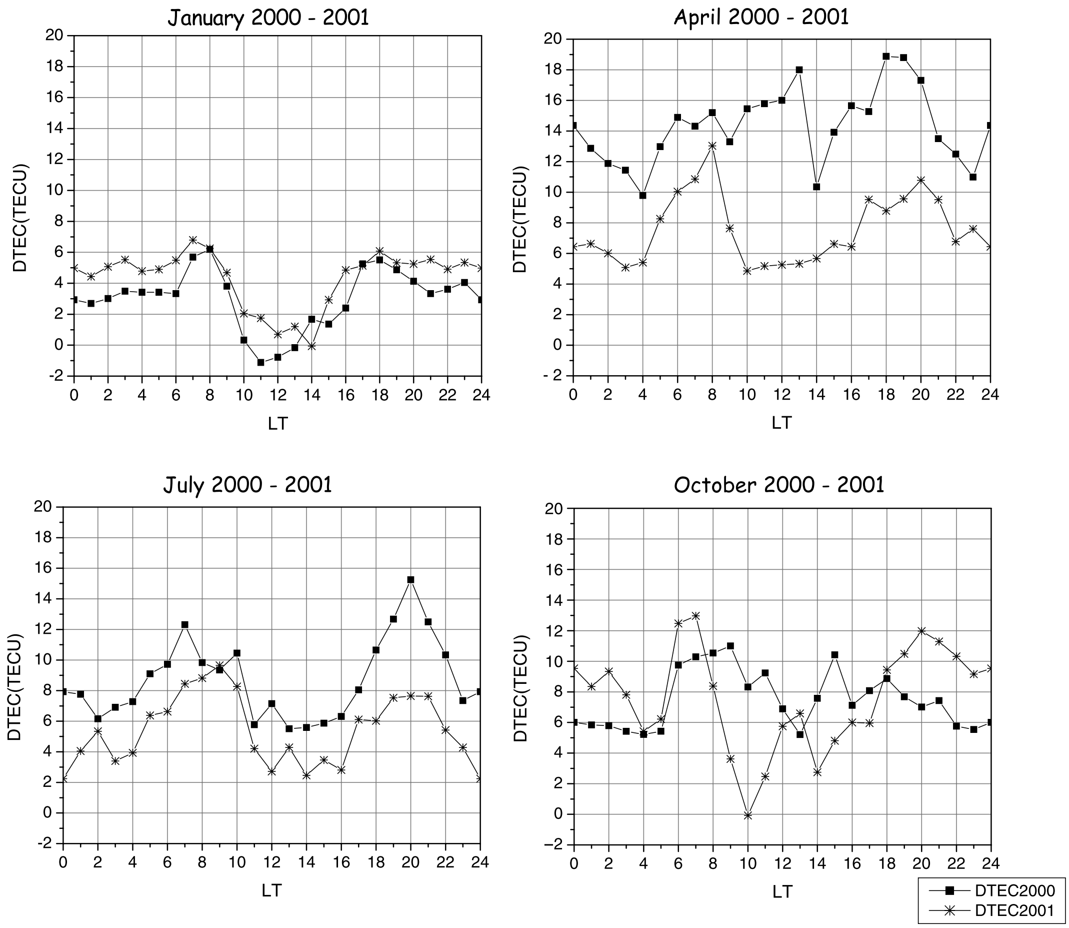

Fig. 4. Diurnal variation of DTEC = GPSTEC-ITEC in TECU during the four seasons and the two years of high solar activity as indicated in the top of each plot.

In 2000, DTEC shows a clear seasonal behavior (Fig. 5). The values are lower in winter (0–6 TECU) than in summer (6–15 TECU). The largest values are observed in April (10–19 TECU). In 2001, the behavior is not exactly the same as observed in the year 2000: the winter values are not always lower than the summer ones especially around midnight, and the largest values are observed in October during nighttime, while the daytime behavior is less clear.

Figs. 6 and 7 illustrate the variations of monthly values of DTEC in percentage, DTEC%, where DTEC% = (DTEC/GPSTEC) × 100. Fig. 6 depicts the diurnal variation of DTEC%. In general the DTEC % values are lower around midday than around midnight in the two years studied. During nighttime (19–05 LT) the DTEC % values range from 40% to 58% depending on the season. At midday the percentage differences vary from 0% to 27%. Fig. 7 clearly shows the seasonal differences in the variation of DTEC%. During the year 2000, the nighttime values are generally lower in summer (30–40%) than in winter (36–51%).The equinoctial values do not show a clear behavior. The daytime values (09–16 LT) are lower in winter (0–16%) than in summer (14–26%), reaching their largest values in spring (15–28%).

During the year 2001 the seasonal behavior of nighttime DTEC% values is similar to that observed in the year 2000: greater values in winter (50–61%) than in summer (15–36%) with intermediate values in the other two seasons (30–55%). In the time period 09–14 LT the winter values (0–20%) are also lower than the summer ones (8–33%).

It is important to point out that the negative values of DTEC and DTEC% are due to systematic errors of the observational techniques, and they are always present in hours where DTEC is close to zero around midday. For this reason the negative values have not been taken into account in our analysis.

The diurnal and seasonal variations of the percentage contribution of plasmapheric electron content to the total electron content calculated using ITEC derived from digisondes and GPS TEC data are similar to those reported by Belehaki et al. (2004) analyzing TEC measurements obtained at Athens (38.0°N; 23.5°E) during the time period October 2000–September 2001, explaining the variations of the plasmaspheric electron content in terms of exchange ionospheric–plasmaspheric ionization.

4. Summary

This paper studies the diurnal and seasonal behavior of the total electron content obtained using ITEC values

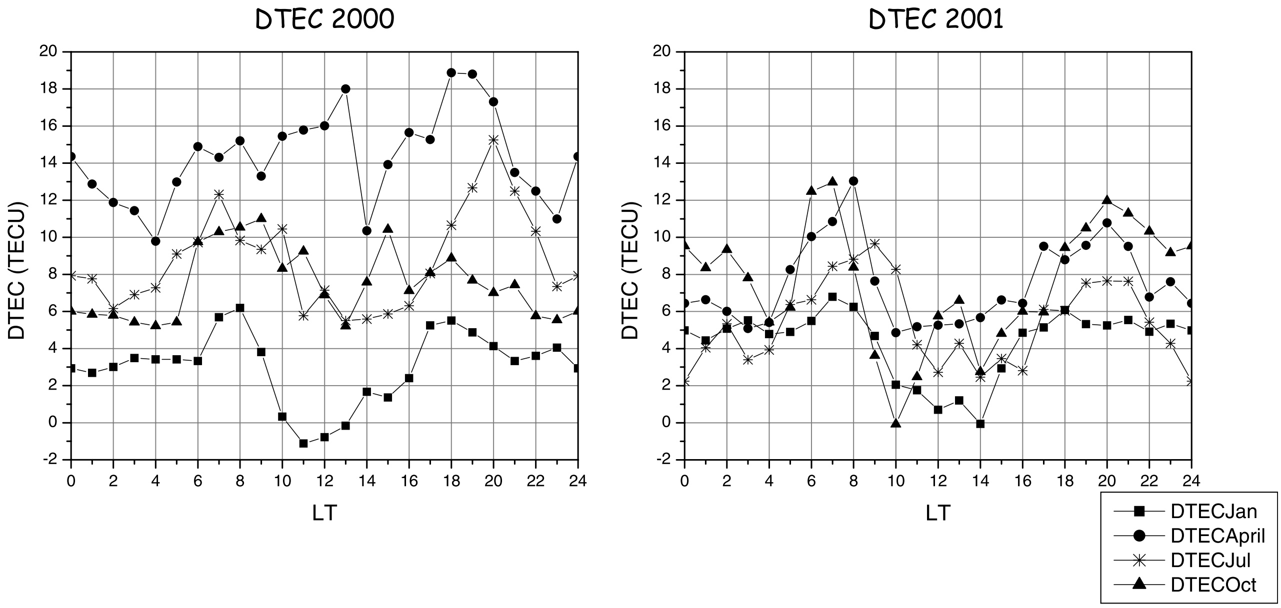

Fig. 5. Seasonal variation of the DTEC in TECU during the years 2000 ($Rz_{12} = 117$) and 2001 ($Rz_{12} = 111$) as indicated in the top of each plot.

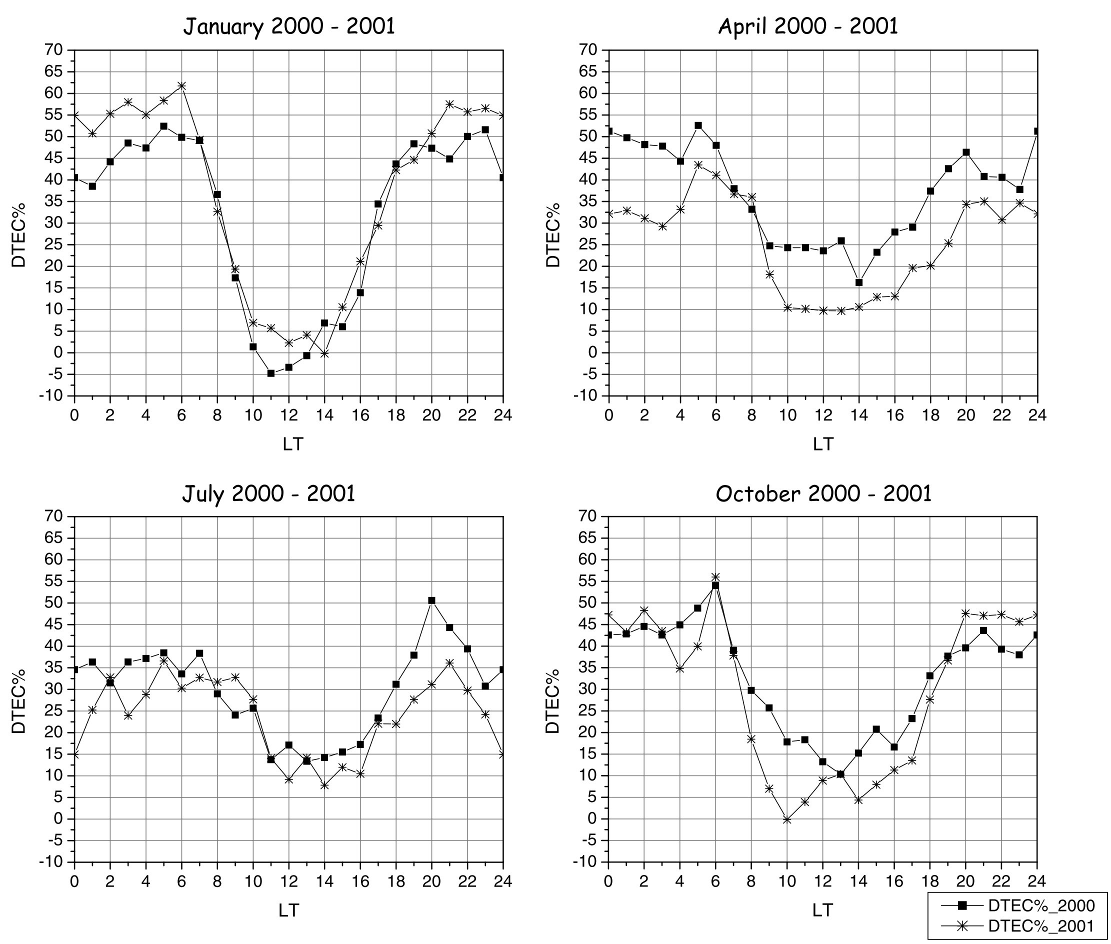

Fig. 6. Year-to-year variation of DTEC in percentage (DTEC%) for the four seasons in 2000 and 2001.

calculated using the Reinisch and Huang (2001) technique and GPS TEC measurements derived from oblique GPS signals using the La Plata Ionospheric Model LPIM (Brunini et al., 2001). The data base includes TEC measurements recorded during four seasons at Ebro (40.8°N, 0.5°E) during a period of high solar activity 2000 ($Rz_{12} = 117$) and

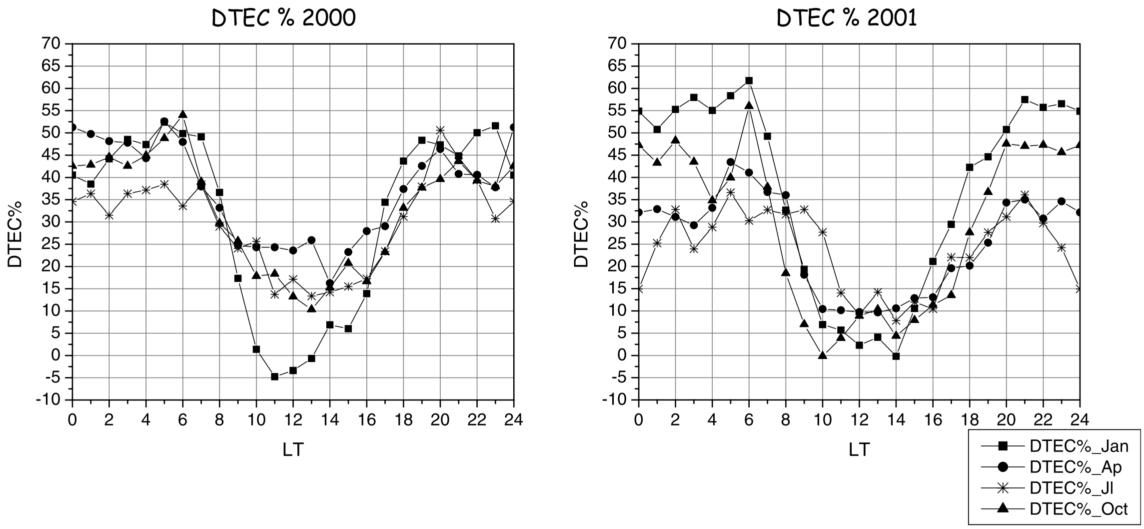

Fig. 7. Seasonal variations of the DTEC values in percentage (DTEC%) during the two high solar activity years (2000 and 2001) as indicated in the top of each plot.

2001 ($Rz_{12} = 110$). Monthly median values of ITEC and GPSTEC have been used to compare the TEC estimates with the corresponding IRI-2000 model predictions (Bilitza, 2001).The comparisons show that, in general, the IRI predictions overestimate the ITEC values and in some cases the GPS TEC values. The largest overestimations between IRITEC predictions and ITEC values are observed in winter at nighttime hours (85–125%), and the smallest in summer at midday (7–8%). These differences can be attributed to the shape of the topside IRI profile.

As expected, the GPSTEC values are greater than the ITEC measurements. The differences between the electron content obtained by the two techniques, considered as a measure of the plasmaspheric contribution, have been analyzed as a function of the hour of the day and seasons. A well-defined diurnal and seasonal behavior has been found. Our results are in agreement with those reported by Belehaki et al. (2004) using data from Athens (38.0°; 23.5°).

Although this study has used a limited database, it shows that it is possible to estimate the behavior of the plasmaspheric electron content in places where ionospheric soundings are carried out simultaneously with GPS measurements.

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