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Behavior of the bottomside electron density profile over Pruhonice

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Abstract

Ionosonde data obtained at Pruhonice (50.0°N; 15.0°E) during different times of the day, seasons and periods of the solar cycle are used to study the behavior of the F2 thickness and shape parameters, B_0 and B_1, respectively. Experimental values of both parameters are compared with the predictions of the latest version of the International Ionosphere Reference, IRI-2000. A preliminary analysis of the variability of the ionospheric parameters f_oF2, M(3000)F2, f_oF1 and f_oE is also done using the variability index Cup–Clo = interquartile range/median. The study shows that: (i) the IRI Gulyaeva B_0 option reproduces better the experimental electron density profiles than the B_0-Table option, (ii) the new values introduced for B_1 in the IRI-2000 model are more realistic than the constant value of three adopted by the IRI-90 and IRI-95 versions, (iii) the variability in the E and F1 regions is less than that observed in the F2 region, (iv) the M(3000)F2 factor exhibits low variability. Additional studies will be done in order to contribute to the development of a model for the variability indices used in this study.

Keywords: Electron density profiles; Variability

1. Introduction

The bottom-side electron density in the International Reference Ionosphere (IRI) model (Bilitza, 1990, 2001) is described in terms of several characteristics such as the critical frequencies f_oF2, f_oF1 and f_oE and their corresponding heights among others parameters. In particular the F2 region is represented by the formula introduced by Ramakrishnan and Rawer (1972)

$$N(h)/N_m\mathrm{F2} = \exp(-X^{B_1})/\cos hX \quad \text{with}$$
$$X = (h_m\mathrm{F2} - h)/B_0,$$

where N_mF2 and h_mF2 are the electron density and height of the F2 peak and B_0 and B_1 are the thickness and shape parameters of the F2 region, respectively. There are two options provided by the IRI model for the parameter B_0: (i) a table of values deduced from ionosonde data (B_0-Table) and (ii) a second option based on Gulyaeva's (Gulyaeva, 1987) model for the half-density height.

The new version of the IRI-2000, has been recently presented (Bilitza, 2001). New models for the B parameters, B_0 and B_1, have been introduced as a result of the IRI task force activities carried out in the International Centre of Theoretical Physics (ICTP), Trieste, Italy. A new IRI B_0-Table is presented based on ionosonde measurements from low and mid latitude stations recorded during different seasonal and solar activity conditions.

For the shape parameter B_1, the new IRI-2000 model recommends a value of 1.8 for the daytime and 2.6 for the nighttime instead of the constant value of 3 used by the IRI-90 (Bilitza, 1990) and IRI-95 (Bilitza, 1997) versions.

Usually radio users consider the median values as a reference for the normal or quiet ionosphere. These

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median conditions are reasonably well predicted by many models for the electron density profile, such as the IRI model. However, they are inadequate to describe the day-to-day variability of the parameters. Of particular interest is to the IRI working group is the introduction of a model for the variability of the more important ionospheric parameters. Several authors have published papers on ionospheric variability mostly using, the percentage standard deviation as a variability index amongst other indices (Rishbeth, 1993; Rastogi and Alex, 1987; Mosert and Radicella, 1995; Zhang and Radicella, 1996; Rishbeth and Mendillo, 2001; Kouris and Fotiadis, 2002; Mosert et al., 2003; Ezquer et al., 2004, among others).

The purpose of the present paper is to analyze the behavior of bottomside electron density profiles observed at Pruhonice (50.0°N; 15.0°E), a station not used in the formulation of the new B_0-Table of the latest IRI-2000 version. Comparisons between experimental B_0 and B_1 values and the corresponding IRI predictions have been done. A preliminary study of the variability of some important ionospheric parameters is also presented using indices derived from quartiles.

2. Data and methodology

Table 1(a) shows the database used in the analysis of bottom-side electron density profiles measured over Pruhonice (50.0°N; 15.0°E; Dip: 65.1; Modip: 55). It includes ionograms recorded every two hours during the months and years indicated in Table 1(a). It is important to point out that these specific time periods were chosen because we had already calculated the electron density profiles derived from the corresponding ionograms.

The experimental monthly electron density profiles average representative profile (ARP) with their corresponding B_0 and B_1 values have been obtained from ionograms using the NHPC program (Huang and Reinisch, 1996). The corresponding IRI-2000 predicted profiles have been calculated using both IRI B_0 options (B_0-Table and Gulyaeva) and introducing the experimental ARP values of f_oF2 and h_mF2 as inputs in the model.

Table 1(b) shows the time periods used in the variability study of the ionospheric parameters f_oF2, f_oF1 and f_oE. As it can be seen ionograms measured under different temporal and solar activity conditions have been included. In the case of the factor M(3000)F2 the same set of ionograms has been used but there is no data available during high solar activity conditions.

The analysis of the variability of the different ionospheric parameters: f_oF2, M(3000)F2, f_oF1 and f_oE, have been done by grouping the hourly ionospheric parameters measured during all the days, months and years indicated in Table 1(b) according to: (i) 4 time periods centered around 00, 06, 12 and 18 LT, LT represents local time; (ii) the 3 seasons: summer (May, June, July and August), winter (January, February, November and December) and equinox (March, April, September and October); (iii) the two levels of solar activity (high solar activity, HSA and low solar activity, LSA).

Table 1
Data used

Year	Month	R_{12}
(a) Electron density profiles analysis		
1994	October	26
1996	January	10
1997	May	18
1998	January	44
1998	March	53
1998	July	65
1990	January	151
1990	April	149
1990	July	141
1990	October	142
(b) Variability study		
1980	January–December	154
1981	January–December	141
1990	January	151
1985	January–December	18
1986	January–December	14
1987	January–December	32

As it is known the diurnal, seasonal and solar activity variations of ionospheric characteristics are better represented by using monthly median values and their corresponding upper and lower quartiles than by using the monthly averages and their corresponding standard deviations. In previous papers (Mosert et al., 2003; Ezquer et al., 2004) two variability indices were introduced in order to analyze the ionospheric variability: Cup = upper quartile/median and Clo = lower quartile/median. In this first step of the study of the variability over Pruhonice, the difference Cup–Clo has been used to quantify the ionospheric variability as a function of the hour, season and solar activity.

3. Results

Fig. 1 shows the comparisons between the experimental monthly B_0 values (ARP values) obtained at Pruhonice and those predicted by the IRI-2000 model using the two B_0 options (B_0-Table and B_0 Gulyaeva) from 00.00 to 22.00 LT for different seasons (summer, equinox and winter) and different solar activity conditions (low solar activity (LSA) and high solar activity (HSA)). As an indication of the natural variability of the ionosphere the standard deviations of the data are also shown. We can see the following:

(1) When Gulyaeva option is used, the IRI model provides B_0 values, which in general agree better with the experimental ones than when the B_0-Table option

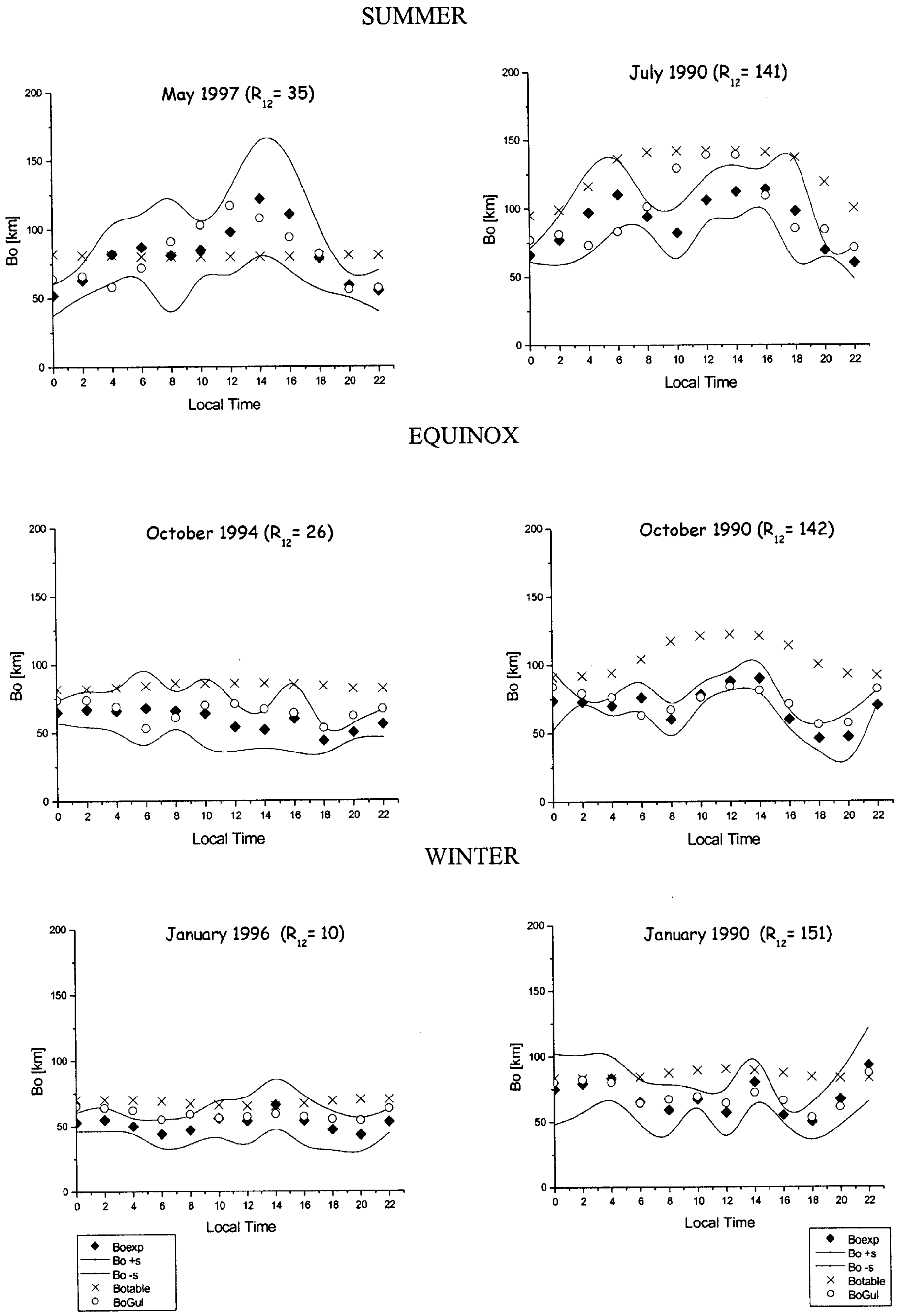

Fig. 1. Comparison of IRI predicted B_0 (B_0-Table: crosses, B_0 Gulyaeva: circles) and experimental (ARP) B_0 values (diamonds) at Pruhonice for different conditions (as indicated in the top of each plot). The standard deviations of the data are also shown (lines).

is chosen. Particularly during high solar activity conditions, the B_0-Table option overestimates the B_0 value in summer and equinox during the daytime.

(2) Although some exceptions have been found, the B_0 Gulyaeva values reproduce the data to within one standard deviation. The exceptions have been found in the summer of the HSA year (July 1990) during the daytime hours 10, 12 and 14 LT.

(3) Some cases are observed in which both options provide similar results.

Fig. 2 shows the comparisons of the IRI-2000 B_1 predictions and the experimental (ARP) B_1 values for different seasonal and solar activity conditions. The constant B_1 value of 3 adopted by the IRI-90 and IRI-95 versions (Bilitza, 1990, 1997) is also shown. Note that the IRI-2000 model provides more realistic values of B_1 than the former versions. In general the new IRI model reproduces the experimental B_1 values better particularly during daytime.

Comparisons of experimental electron density profiles at Pruhonice and both IRI-2000 predictions (B_0-Table and Gulyaeva option) for different conditions as indicated in the top of each plot are shown in Fig. 3. It is important to point out that this figure presents only the cases in which the ARP profiles were calculated with a number of days in the month not lower than 15 days. The analysis indicates once more, that, in general, the B_0 Gulyaeva option reproduces the observations at Pruhonice better than the B_0-Table option.

Fig. 4 shows plots the variability index, Cup–Clo, for different ionospheric parameters (f_oF2, $M(3000)F2$, f_oF1 and f_oE) at Pruhonice. The different seasonal and solar activity conditions and 4 time periods centered around 00, 06, 12 and 18 LT are shown. Note that values of f_oF1 and f_oE are missing during hours in which these parameters are not usually present and that in the case of the parameter $M(3000)F2$ there is no data available during HSA. The analysis reveals:

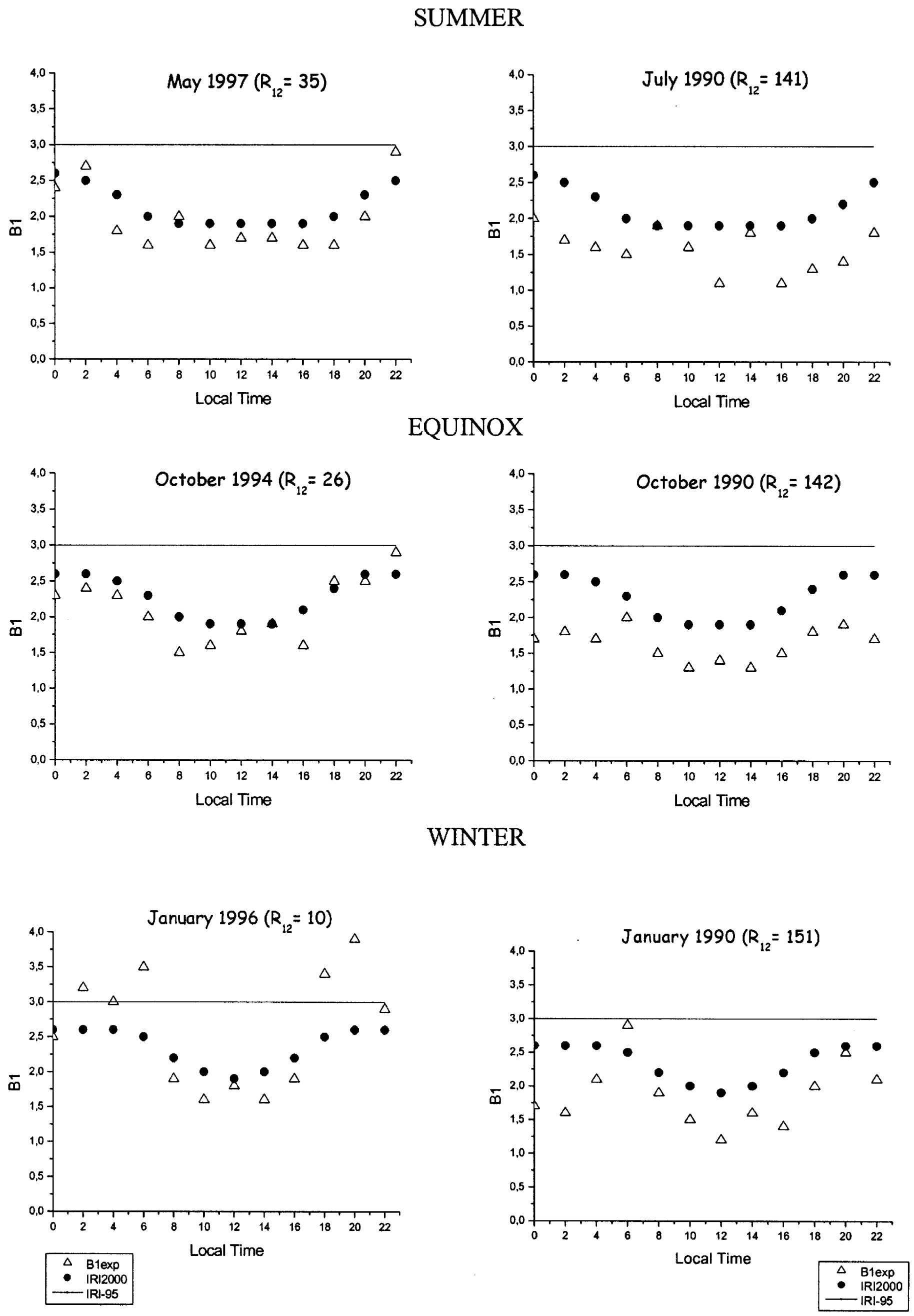

Fig. 2. Comparison of the IRI-2000 B_1 (points) and experimental (ARP) B_1 values (triangles) at Pruhonice for different conditions (as indicated in the top of each plot). The constant IRI-95 B_1 value of 3 (line) is also shown.

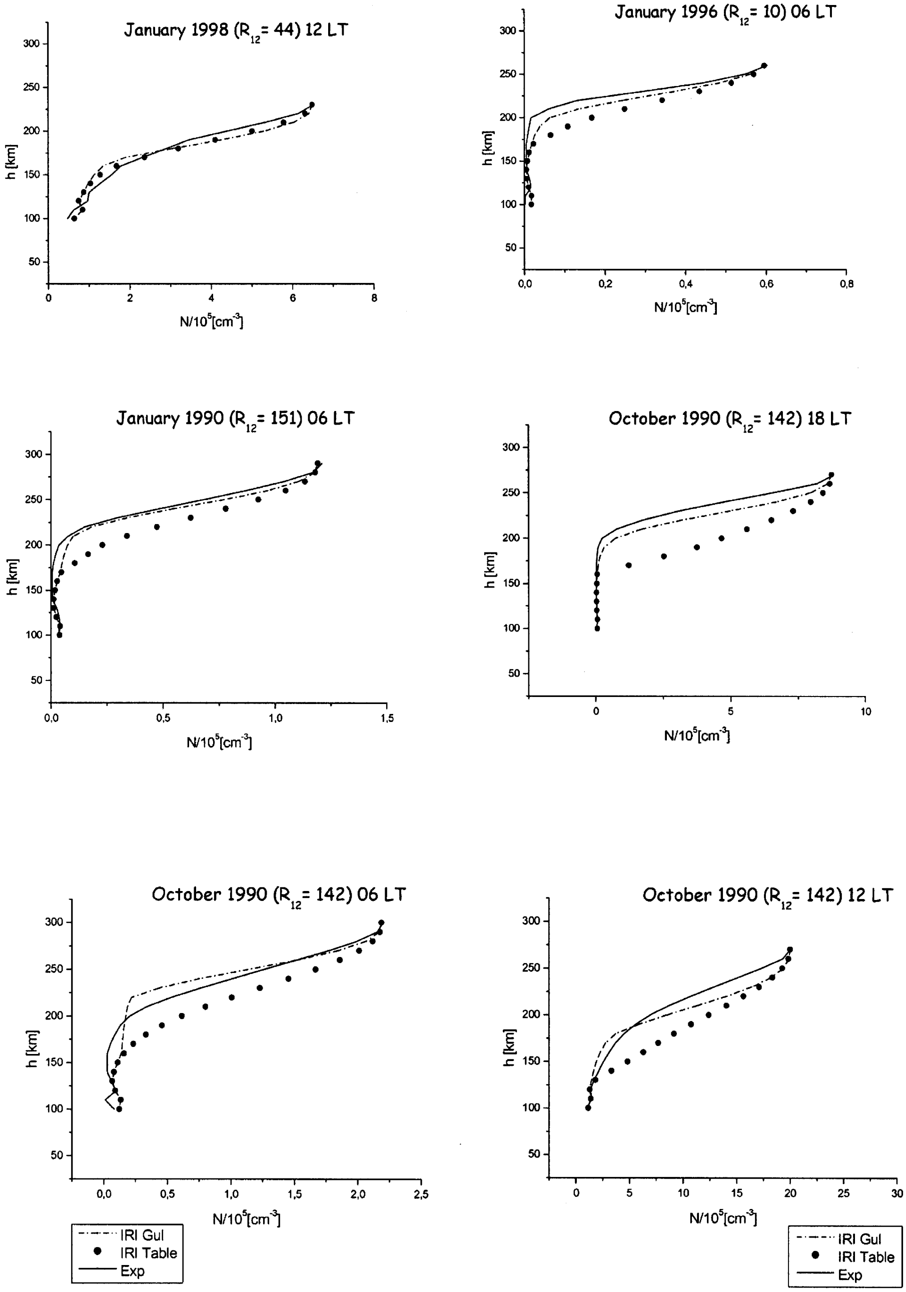

Fig. 3. Comparison of IRI –2000 predicted (B_0-Table: points, B_0 Gulyaeva: dashed line) and experimental (ARP) electron density profiles (full line) at Pruhonice for different conditions (as indicated in the top of each plot).

(1) In general, the variability of f_oF2 is greater than the variabilities observed in f_oF1, f_oE and M(3000)F2. The variability index Cup–Clo usually ranges between: (a) 0.03 and 0.27 in the F2 region, (b) 0.02 and 0.10 in the F1 region (only an exception has been found at sunrise during equinox and LSA, where the variability index reached a value of 0.20), (c) 0.01 and 0.13 in the E region around noon (higher values of the index Cup–Clo are observed at 06 LT in equinox: 0.16 for LSA and 0.20 for HSA), (d) 0.03 and 0.05 for the parameter M(3000)F2 (only a value of 0.10 has been found at sunrise during wintertime).

(2) The day/night behavior of the variability of f_oF2 is less clear than that found by Mosert et al. (2003) in a previous analysis using data from Argentine stations and from El Arenosillo and by Ezquer et al. (2004) using data from the American sector in which the variability index Cup–Clo is generally higher around midnight

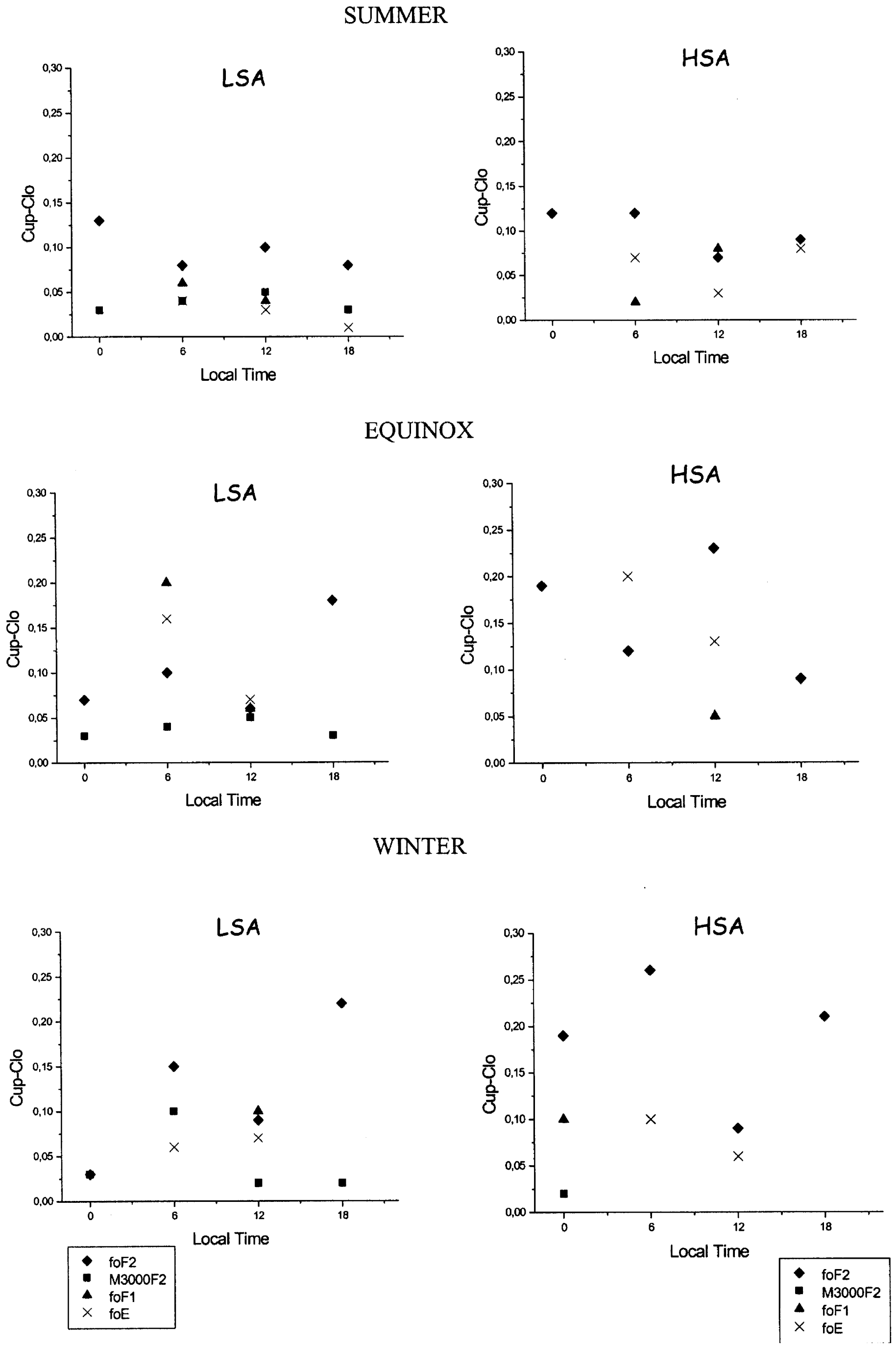

Fig. 4. Comparison of the variability of different ionospheric parameters at Pruhonice (f_oF2: diamonds, M(3000)F2: squares, f_oF1: triangles, f_oE: crosses) using the variability index: Cup–Clo for different seasonal and solar activity conditions (as indicated in the top of each plot) and for 4 time periods centered around 00, 06, 12 and 18 LT. Note that f_oF1 and f_oE values are missing during hours in which these parameters are not usually present and that in the case of the parameter M(3000)F2 there is no data available during HSA.

than around midday. This behavior has been only found at Pruhonice in summer (LSA and HSA). The value of Cup–Clo ranges between 0.03 and 0.19 at midnight and between 0.06 and 0.23 at noon.

(3) The variability of f_oF2 generally produces at HSA greater values during the wintertime (0.03–0.26) than during the summertime (0.07–0.12). During LSA this behavior is not observed around midnight.

(4) The solar activity effect on the variability of f_oF2 at Pruhonice is not always the same as that observed in the analysis done by Mosert et al. (2003) and Ezquer et al. (2004) in which the Cup–Clo value tends to be higher during LSA than during HSA. At Pruhonice the variability index is in general greater during HSA (with values between 0.07 and 0.26) than during LSA (with values ranging between 0.03 and 0.22).
(5) The day-to-day variability within the E and F1 regions is less than the variability of f_oF2 as it was indicated in the item (1). However, some exceptions have been found: the parameter f_oE produces a high variability index at sunrise during equinox for the two levels of solar activity reaching a Cup–Clo value of 0.20. The same situation is observed for f_oF1 during LSA when this parameter is present.
(6) In the E region the variability index is greater at equinox than during the other seasons and it generally increases with solar activity. The seasonal and solar activity effects on the variability in the F1 region are not clear.
(7) For the parameter M(3000)F2 low variability is observed. The results show that the index Cup–Clo usually ranges between 0.02 and 0.05 indicating that it practically does not vary with time and season. Only one case is observed in which the index reaches a value of 0.10 (at sunrise in wintertime at low solar activity). This feature of the low variability of M(3000)F2 with time and season has been also reported by Ezquer et al. (2004) and by Kouris and Fotiadis (2002) when analyzing different locations.

Similar behavior of the variability of f_oF2 has been also reported by Ezquer et al. (2004) in a variability study in which data from the American sector were used. However these authors reported a greater variability of f_oF2 than that observed at Pruhonice.

It is important to point out that the variability analysis using data from Pruhonice is only a preliminary one. Moreover, although the relative index Cup–Clo provides a measure of the monthly variability of the ionospheric parameters, it is not sufficient since it does not describe the asymmetric distribution of the data with respect to the monthly median (Ezquer et al., 2004). The fact that the upper and lower quartiles are not equidistant from the median value suggests that it is more convenient to analyze the Cup and Clo values separately. Additional studies will be done in order to develop a model of the variability indices Cup and Clo and introducing additional variability indices derived from the upper and lower deciles.

4. Summary

Bottomside electron density profiles derived from ionograms recorded at Pruhonice (50.0°N; 15.0°E) have been compared with those predicted by the IRI-2000 model using the two B_0 options (B_0-Table and Gulyaeva). In particular the behavior of the B parameters in the F region, B_0 (thickness parameter) and B_1 (shape parameter), have been analyzed.

A preliminary study of the day-to-day variability of the ionospheric parameters, f_oF2, M(3000)F2, f_oF1 and f_oE, is also presented.

The database used includes ionograms measured at Pruhonice during different hours of the day, seasons and periods of the solar cycle (Table 1).

The bottomside electron density profile analysis reveals:

(1) When Gulyaeva option is used, the IRI-2000 model generally provides B_0 values, which are in better agreement with the experimental (ARP) B_0 ones than when the B_0-Table is chosen (Fig. 1). The comparison of the experimental (ARP) electron density profiles with two IRI predicted electron density profiles confirms this result (Fig. 3).
(2) In general, the new IRI-2000 version reproduces the experimental (ARP) B_1 values better than the former versions IRI-90 and IRI-95 (which adopted the constant B_1 value of 3), particularly during daytime (Fig. 2).

The variability study of the ionospheric parameters using the index Cup–Clo (Fig. 4) shows:

(1) The day-to-day variability of the parameters f_oE and f_oF1 is generally less that that observed in f_oF2. The variability index Cup–Clo ranges generally between 0.03 and 0.27 in the F2 region, between 0.02 and 0.10 in the F1 region and between 0.01 and 0.13 in the E region. Only high variability (0.20) has been found in f_oF1 and f_oE around sunrise at equinox.
(2) Low variability is observed in the M(3000)F2 parameter with values of the variability index between 0.02 and 0.05 indicating that it does not vary with time and season. Only one case has been observed in which Cup–Clo reaches a value of 0.10 (at sunrise in wintertime at low solar activity).
(3) The effect of the season on the variability of the pararheters is not clear.
(4) In general the variability of f_oF2 and f_oE increases with the solar activity.

The results of this study and earlier analysis (Mosert et al., 2003; Ezquer et al., 2004; Kouris and Fotiadis, 2002, among others) could help to develop a variability model. However, further investigations are needed in order to resolve some conflicting results related to the time and solar activity variation of the variability.

Additional analysis will be also done using variability indices derived from upper and lower deciles.

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