Day-to-day changes in experimental electron density profiles and their implications to IRI model

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Abstract

The electron density variability at fixed heights is studied for use in the International Reference Ionosphere IRI model. Monthly median, upper and lower quartile values were obtained for f_oF2, *hm*F2, B0 and B1 as deduced from ionograms. The IRI electron density profiles established with these values were then compared with the median and quartiles at fixed heights. Results are shown for the three ionospheric stations E1 Arenosillo (37.1 N, 353.3 E), Tucuman (26.9 S, 294.6 E) and San Juan (31.5 S, 290.4 E) as a function of solar activity, season and local time.

As found by other authors the height of maximum variability, *hv*max, is located below the peak electron density height (*hm*F2) in all the cases. Values of differences between *hm*F2 and *hv*max are analized.

Variability defined as the interquartile difference and *hv*max results are calculated from experimental electron density profiles measured at the three stations.

Keywords: Variability-Quartile-Median-IRI; Electron density profiles; Ionosphere

1. Introduction

One of the aims of the International Reference Ionosphere Task Force Activities held at Abdus Salam ICTP is to develop a model of variability for IRI users. The focus so far has been to study the peak (f_oF2, *hm*F2) and profile (B0, B1) parameters variability which determines the whole profile variability. In the last years, several authors (Alazo et al., 2003; Lazo et al., 2003; Mosert et al., 2003; Adeniyi and Radicella, 2003) have estimated and analyzed the deviation from the monthly mean for specified conditions to model the variability of these ionospheric parameters.

Continuing this earlier work, this study focuses on two main goals. First of all, to find out how the parameters f_oF2, *hm*F2, B0 or B1 affect the altitudinal changes in electron density variability. Median, upper and lower quartiles of the electron density values at fixed heights will be compared with the IRI electron density profiles obtained using the corresponding median, upper and lower quartiles of the peak and profile parameters for each hour, month, year and location.

The second aim is to analyze the electron density variability at fixed heights for three ionospheric stations

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using experimental electron density profiles corresponding to different ionospheric conditions. As has been recommended by the IRI Task Force Activity, we use the inter-quartile range as measure for the day-to-day variability which is defined as follows:

$$\mathrm{IQC} = (\text{Upper quartile} - \text{Lower quartile})/\text{median}. \quad (1)$$

Lower, middle and upper quartile are defined as those values that mark the 25%, 50% and 75% points of the data distribution. Similar studies have been

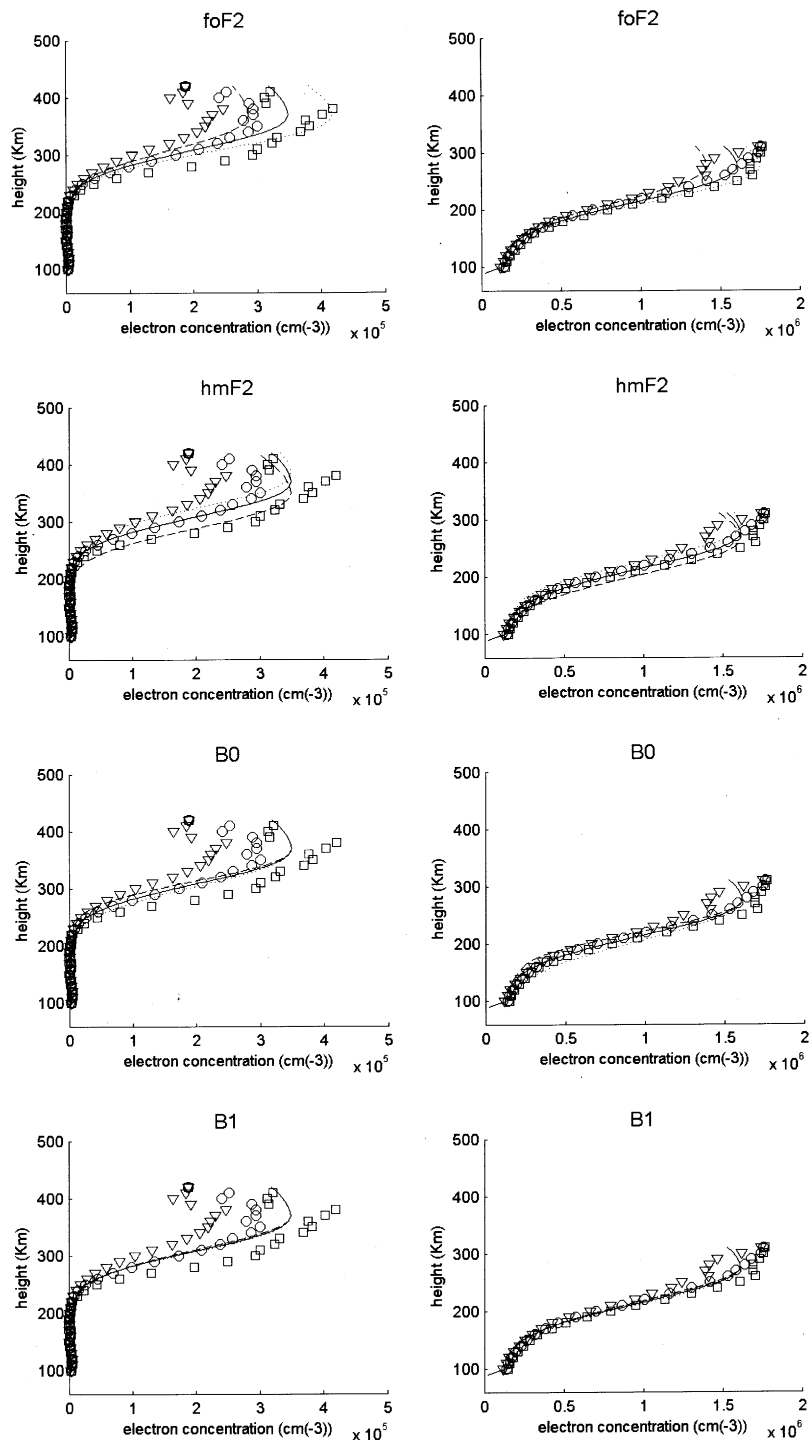

Fig. 1. Median (circle shaped points), upper (square shaped points) and lower quartiles (triangle shaped points) of electron density profiles measured in October 1999 (high solar activity) at 00 LT (left column) and 12 LT (right column) with El Arenosillo digisonde. These are compared with the IRI profiles calculated using the median (solid line), upper (dotted line) and lower (dashed line) quartiles of peak and profiles parameters obtained by the digisonde. The separate rows from top downwards show profiles for median and quartile values respectively of f_oF2, *hm*F2, B0 and B1, with in each case the other profile parameters being taken as the median values.

presented in the last years to determine the ionospheric variability at fixed heights. Mosert de Gonzalez and Radicella (1995) and Radicella et al. (1994) show the following results: (1) the relative variability of electron density increases with height in the F2 region with a maximum below the F2 peak, (2) there is a minimum of variability at about 180–210 km altitude around noon, (3) the night-time IQC is apparently larger than during day-time, (4) the day-time variability is larger at lower solar activity than at high solar activity and the opposite occurs above 220 km by night-time and (5) the relative variability has a clear dependence on solar zenith angle.

Solé and Altadill (1997) determined the ionospheric variability at fixed heights using data from a low solar activity year for the Ebro Observatory station (40.4 N,

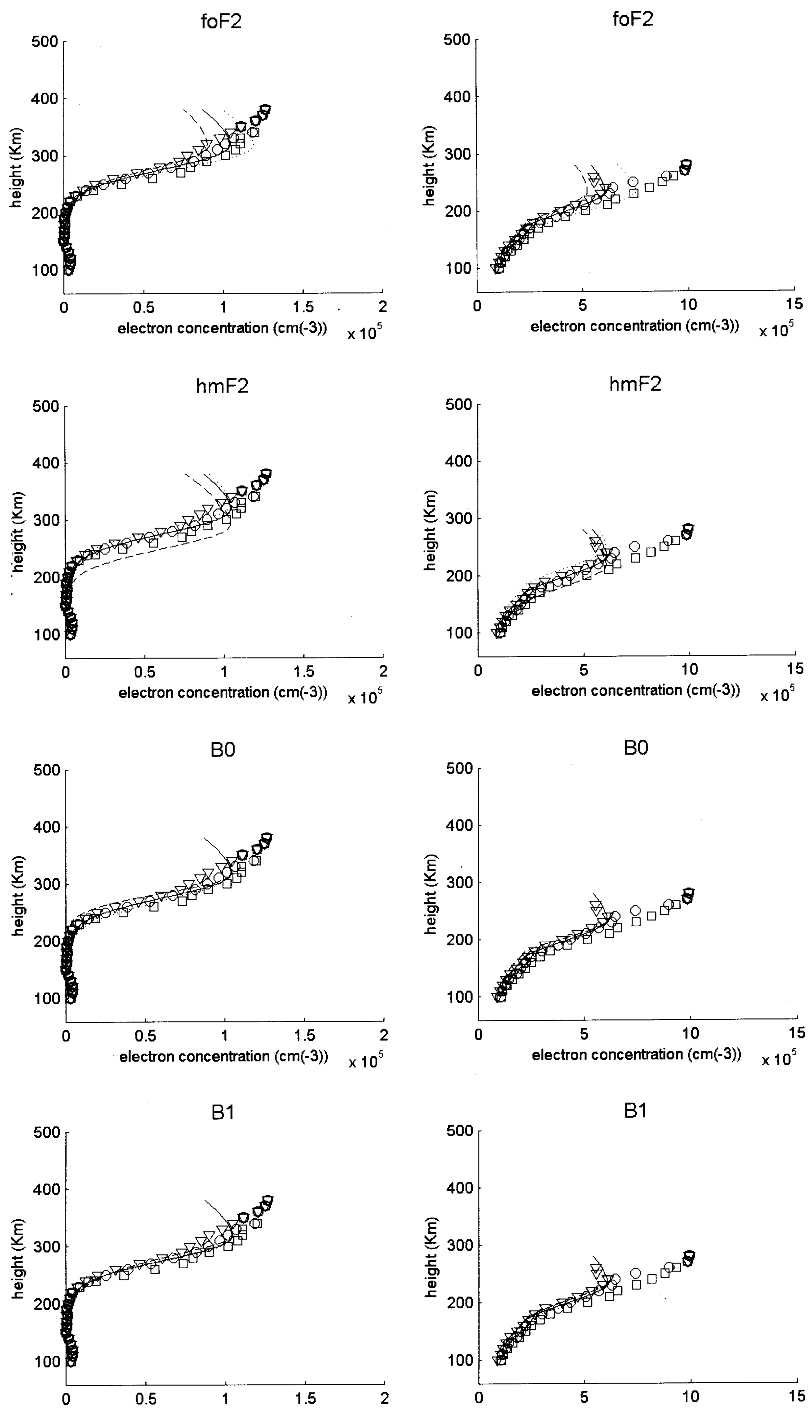

Fig. 2. Same as in Fig. 1, at El Arenosillo for October 1995 (low solar activity).

0.3 E). In this case, three parameters, which are obtained with upper and lower deciles and its standard deviation, are considered to define the absolute and relative variability. The main results they have found about the relative variability are that: (1) it increases with altitude during daytime, but decreases during night time, (2) during daytime, it shows a relative minimum between 120 and 150 km and it minimizes near or at F2 peak during night time, (3) it has a minimum around midday, (4) it is larger in winter and smaller in summer, during night time.

Ezquer et al. (2002) considered low magnetic activity data sets from two South American ionospheric stations and a relative variability coefficient based on the standard deviation value. Their results show that: (1)

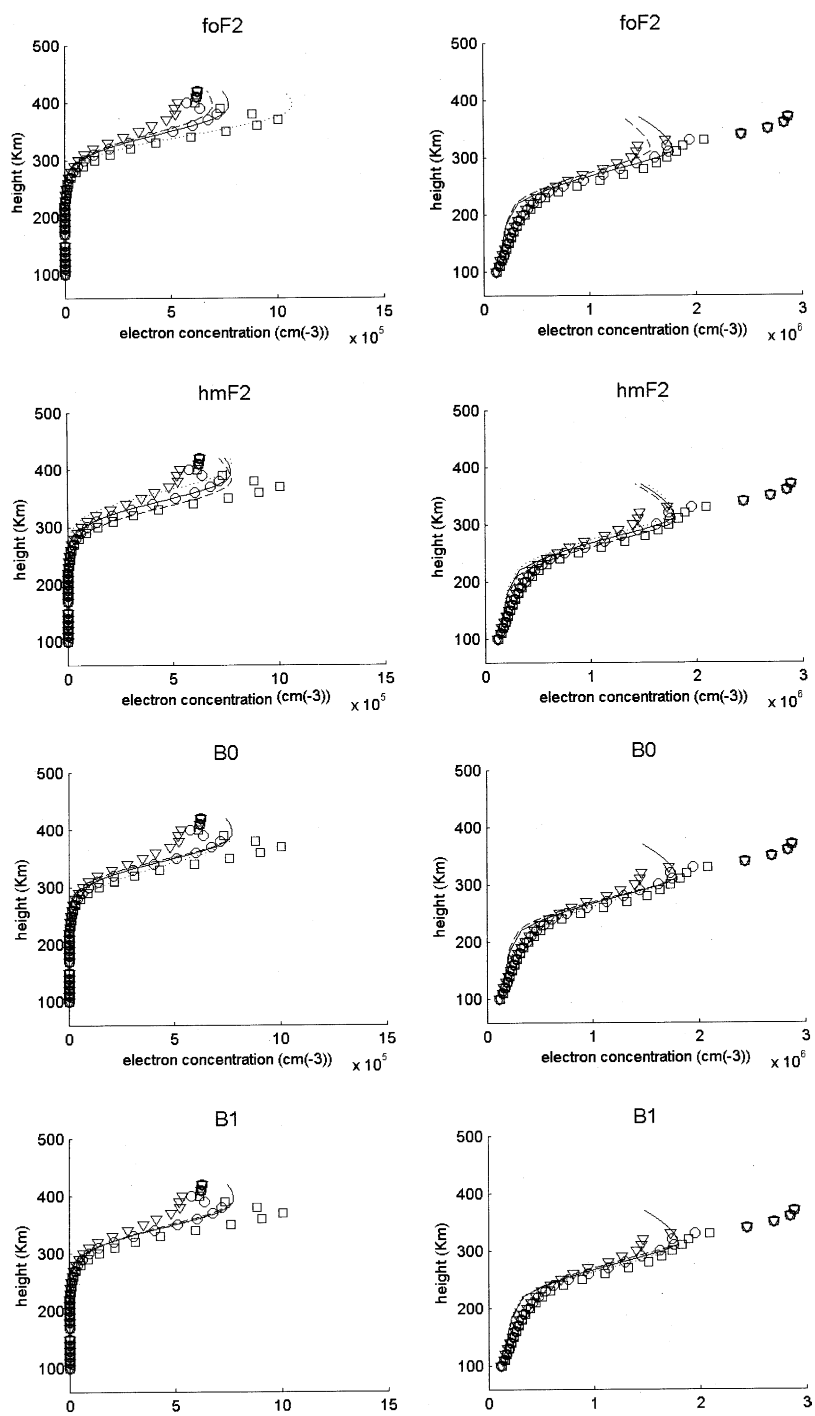

Fig. 3. Same as in Fig. 1, at San Juan for October 1971 (middle solar activity).

at midnight the variability increases with height reaching a maximum below the peak density; (2) the highest variability was observed at 280 km for night equinox and high solar activity; (3) by noon, the variability decreases with increasing solar activity; (4) the variability is larger by night than by day above 220 km, below that altitude this behavior is reversed.

2. Data section

In order to reach the two goals described in the previous section, ionospheric parameters (peak and profiles parameters) and bottomside electron density profiles obtained with digisondes are analysed. The three digisondes chosen in this study are located in San Juan

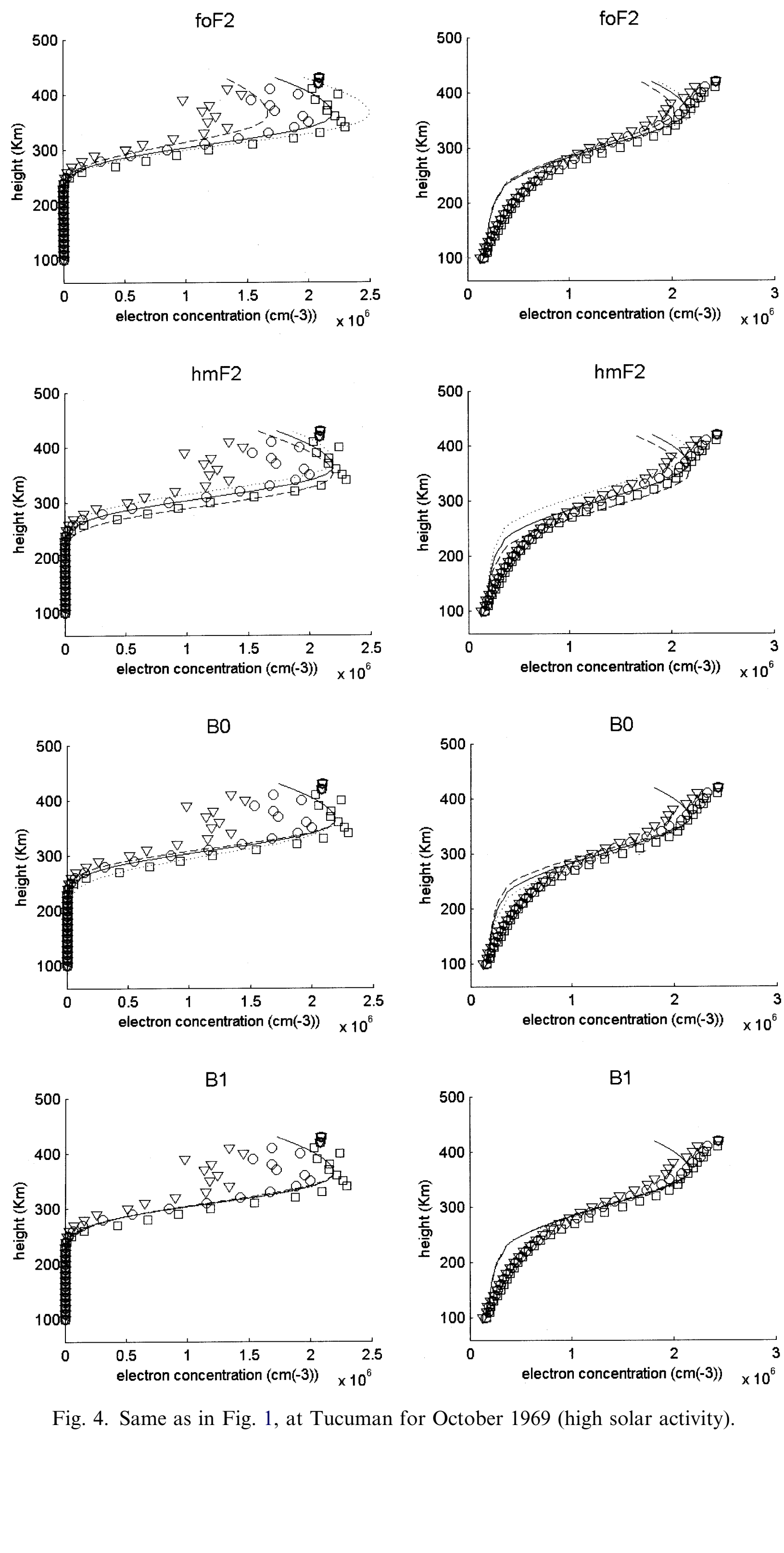

Fig. 4. Same as in Fig. 1, at Tucuman for October 1969 (high solar activity).

(31.5 S, 290.4 E), El Arenosillo (37.1 N, 353.3 E) and Tucuman (26.9 S, 294.6 E). They cover mid-latitude and crest regions and Northern and Southern Hemispheres. Different conditions have been studied taken into account diurnal (00, 06, 12, 18 LT), seasonal (January, April, July, October) and solar activity (high, low) variability.

Since the ionospheric data base available for Tucuman is smaller than those from San Juan and El Arenosillo and considering that these two locations have the same geographic latitude but in different Hemisphere, results shown in this paper correspond mainly to these two stations. However, a similar behavior is also presented at Tucuman.

3. Methodology

3.1. Median, upper and lower quartiles of electron density profiles processing

All the experimental electron density profiles were obtained by applying the ionogram inversion technique NHPC (Huang and Reinisch, 1995) to about 1600 digital ionograms. Before this process, the ionograms were manually corrected.

From these profiles, median, upper and lower quartiles of daily electron concentration values at fixed heights were obtained for each year, month and hour. Therefore, we calculated three electron density values for each height: median, upper and lower quartiles of electron upper and lower density. Taking into account these three values for all the height range, median, quartiles *profiles* were processed averaging values at 10 km interval. These *three profiles* will be compared with the IR1 profiles that are obtained as described in the IRI profile processing section.

3.2. Ionospheric parameters calculation

Peak parameters, f_oF2 and *hm*F2, and profile parameters, B0 and B1 were extracted from the edited ionograms and the individual experimental electron concentration profiles. Median, upper and lower quartiles of these parameters for each hour, month and year were calculated. These peak and profile parameters were used as input in the IRI profile processing.

3.3. IRI profile processing

Median, upper and lower IRI profiles for f_oF2 were calculated using the following ionospheric parameters for each hour, month and year:

- IRI f_oF2 median profile: calculated using median f_oF2, *hm*F2, B0 and B1 values.
- IRI f_oF2 upper profile: calculated using upper f_oF2 and median *hm*F2, B0 and B1 values.
- IRI f_oF2 lower profile: calculated using lower f_oF2 and median *hm*F2, B0 and B1 values.

The same procedure is repeated for the ionospheric parameters *hm*F2, B0 and B1. These three profiles will be compared with the corresponding median, upper and lower quartiles of the electron density profiles deduced from the measured ionograms.

The IRI version used to calculate the electron concentration profiles was directly downloaded from the web page: http://nssdcftp.gsfc.nasa.gov/models/ionospheric/iri/. Due to the large number of cases processed, some changes were made to simplify the data input of the program. As a consequence, the experimental ionospheric parameters, f_oF2, *hm*F2, B0 and B1, were introduced automatically from a file into the IRI model.

3.4. Electron density variability at fixed heights

The second aim of this paper, the analysis of the altitudinal changes in electron density variability, was studied using the measured bottomside electron density profiles. The variability parameter, IQC, defined in the previous session, was calculated every 10 km. Results for different conditions will be discussed in the following section.

4. Results

Examples of median, upper and lower quartiles of electron density profiles (circle, square and triangle points in the plots) and median, upper and lower quartiles IRI model profiles (solid, dotted and dashed lines in the plots) corresponding to f_oF2, *hm*F2, B0 and B1 obtained by the method explained before are plotted in Figs. 1–4 for El Arenosillo (high and low solar activity), San Juan (medium solar activity) and Tucuman (high solar activity). In each figure the right column shows daytime results and the left column nighttime results. The four panels in each column show the effects of f_oF2 (uppermost panel), *hm*F2, B0 and B1 (lowest panel), respectively. The IRI curves in the uppermost panel, for example, were obtained by using the median, upper and lower quartile of f_oF2 and the median for the rest of the parameters. The plots show that the parameter with the greatest influence on the electron density is the critical frequency f_oF2. This is well illustrated in Fig. 1. The three IRI profiles calculated with the median, upper and lower quartiles f_oF2 values (solid, dotted and dashed lines in the plots of the first row) reproduces well the electron density variability at fixed heights (circle, square and triangle points). It is also important to point out that the parameters B0 and B1 (3rd and 4th panels in each row) have a negligently small effect on the variability of the electron density profile (median, upper and lower quartiles IRI curves are undistinguishable).

These examples indicate that the variability of the electron concentration profile could be reproduced reasonably well by a model of the f_oF2 variability based on median and upper and lower quartile conditions. However, the combination of f_oF2 and *hm*F2 variability seems to be a better approximation. Further studies will include the effect of combining these ionospheric parameters variability in the electron density profile variability.

With regard to the study of the electron density variability at fixed heights, the parameter IQC is calculated from the experimental bottomside profiles for the different conditions. Figs. 5 and 6 show the IQC values at El Arenosillo and San Juan for different solar activities, seasons and hours.

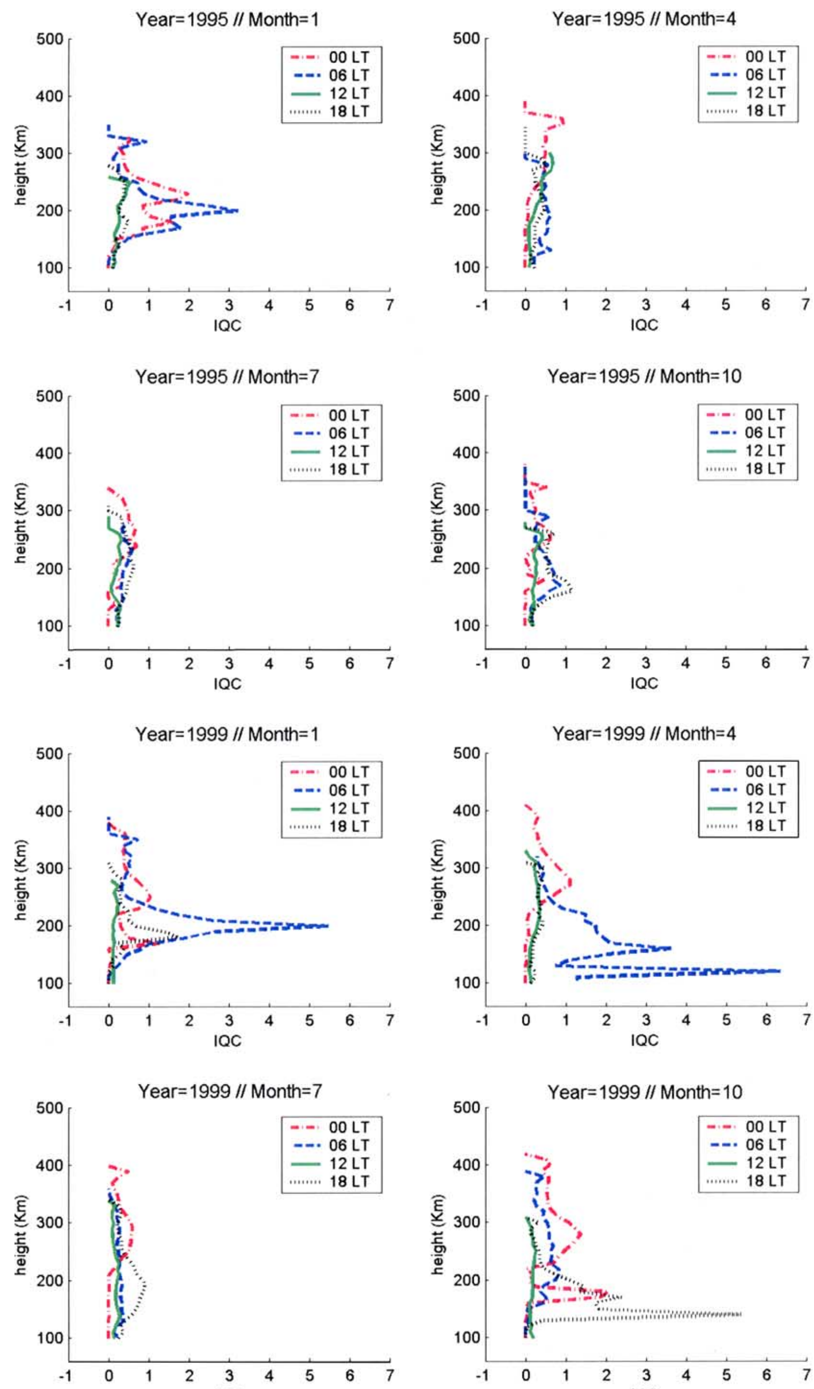

Fig. 5. IQC values at El Arenosillo for 1995 (low solar activity) and 1999 (high solar activity), different season and hour.

As can be seen, the relative variability expressed by IQC generally reaches the highest value below the peak density *hm*F2. The value of *hm*F2 is extracted from the median of electron density profile. The median of the distance between the peak density *hm*F2 and the height were IQC is maximum (hereafter *hv*max) is 105 km for our conditions.

Moreover, the diurnal variation of the maximum of IQC (IQCmax) generally presents a maximum at night time (00 and 06 LT) and a minimum at midday and the seasonal variation reaches the smallest values during summer. The distance between *hm*F2 and the *hv*max increases with the solar activity.

In general, it was found that IQC reaches its largest values at high solar activity (1969, 1981, and 1999) at heights between 120 and 220 km. In relation to the seasonal variability at fixed local time, highest values correspond to autumn and winter for 00 and 18 LT.

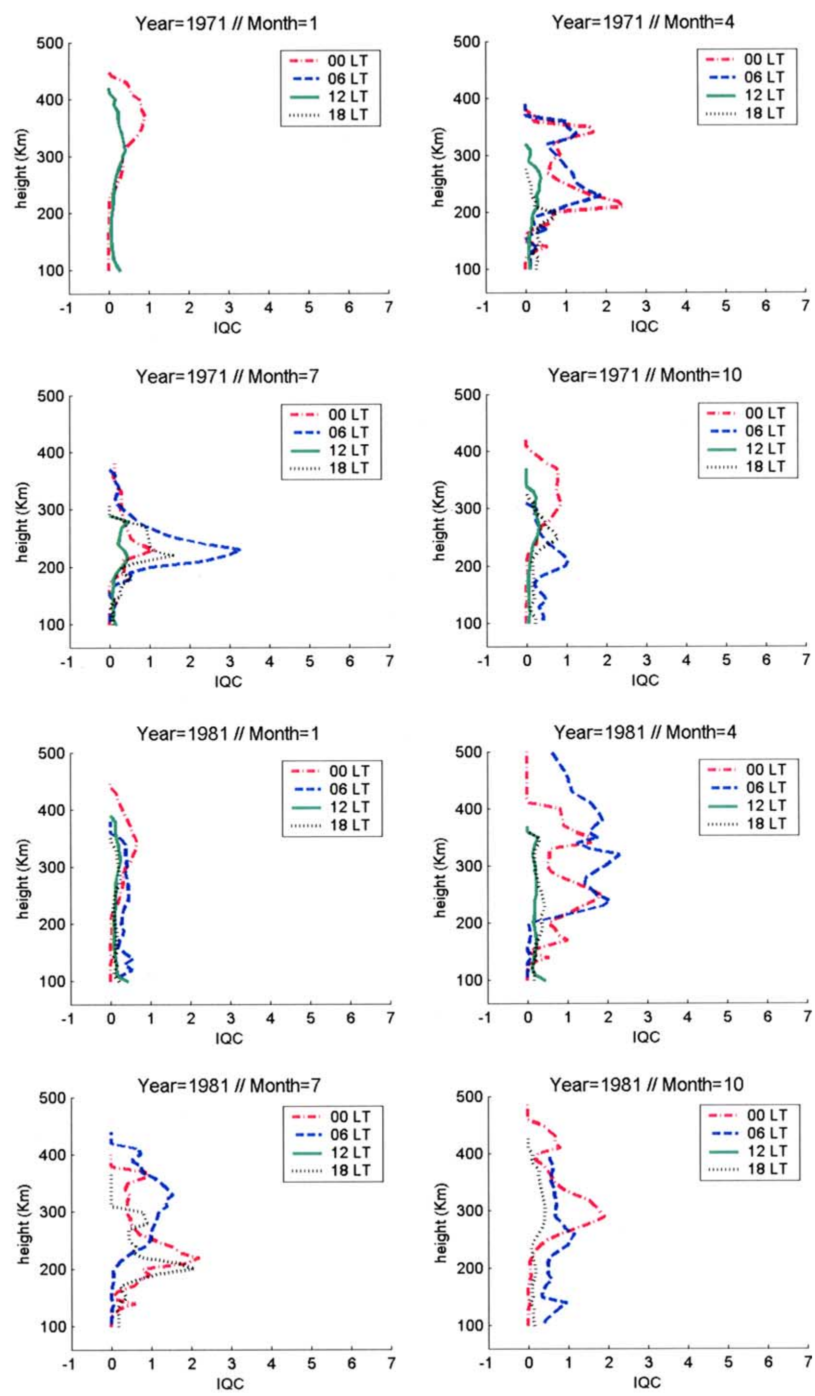

Fig. 6. IQC values at San Juan for 1971 (middle solar activity) and 1981 (high solar activity), different season and hour.

5. Conclusions

The results of our study could be summarized as follows:

- f_oF2 variability is the dominant factor that determines the variability of the whole electron density profile.
- The highest relative variability, expressed by the interquartile difference divided by median value, is located around 105 km below *hm*F2, increasing when the solar activity increases.
- The diurnal variation of the highest relative variability generally exhibits a minimum around noon with peaks at midnight (00 LT) and dawn (06 LT).
- The seasonal variation of the relative variability presents a maximum at autumn and winter for 00 and 18 LT.
- The relative variability is maximum at high solar activity and it is located between 120 and 220 km.

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