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# Ionospheric variability studies in Argentina

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**Abstract**

This paper reviews and extends studies on ionospheric variability performed by the Argentine scientific community. Ground based ionosonde measurements for different seasonal and solar conditions and vertical total electron content (VTEC) obtained with GPS satellite signals during a high solar activity year are used. Median, quartiles and deciles are used to specify the variability. In general, the results show that: (a) the variability is higher in low solar activity than in high solar activity, and (b) it is larger by night than by day. Moreover, is shown that could be possible specify the variability of foF2 for high solar activity and hours around noon.


*Keywords:* Ionosphere; Variability; Critical frequency; Electron content

## 1. Introduction

It is known that a good description of the variability of ionospheric magnitudes is needed in order to improve the performance of the ionospheric models (Bilitza, 2000). For many applications the users of ionospheric models need to know not only the monthly average conditions but also the expected deviations from the mean or median values.

The study of the variability can be focused (1) on the peak or profile parameters, (2) on the vertical total electron content (VTEC) or (3) investigating the electron density (Ne) at fixed heights.

Many authors have studied the variability of ionospheric parameters using different variability indexes (Aravindan and Iyer, 1990; Jayachandran et al., 1995; Mosert and Radicella, 1995; Bradley, 2000; Rishbeth and Mendillo, 2001; Gulyaeva and Mahajan, 2001; Radicella and Adeniyi, 2001; Kouris and Fotiadis, 2002; Mosert et al., 2002; Ezquer et al., 2002a; Ezquer et al., 2002b; Mosert et al., 2003; Ezquer et al., 2004; among others). Some features of the critical frequency of the F2 region (foF2) variability reported in the literature are: (a) the variability is greater during nighttime than during daytime; (b) the variability is higher in winter than in summer; (c) the variability is higher at periods of low solar activity (LSA) than during high solar activity (HSA), (d) the variability of the propagation parameter M(3000)F2 is lower than that observed in foF2.

Ezquer et al. (2004) used data of American stations and the following indexes

$$\mathrm{Cup} = \text{upper quartile/median} \tag{1}$$

$$\mathrm{Clo} = \text{lower quartile/median} \tag{2}$$

to study the variability. These authors showed that the values of the variability indexes vary with modip but not in the same way for all the cases. In summer and low solar activity conditions, during the time period (22–2) LT (local time), the behaviour of the variability index is opposite to that observed in equinox for the same conditions. Taking into account that the quartiles are not equidistant from the median value, Ezquer et al. (2004) suggest that is not convenient to give the variability range as

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$$\mathrm{VR} = \mathrm{median} + (\mathrm{upper\ quartile} - \mathrm{lower\ quartile})/2 \quad (3)$$

It seems better to develop a model for Cup and Clo in order to predict the variability range of foF2 as:

$$\mathrm{VR} = [\mathrm{median} \times \mathrm{Clo}, \mathrm{median} \times \mathrm{Cup}] \quad (4)$$

The present work has two purposes: (1) to review the ionospheric variability studies carried out in Argentine, and (2) to extend these studies trying to obtain a quantitative description of the variability of different ionospheric characteristics al least for some conditions.

In this paper the following variability indexes are also considered

$$\mathrm{Dup} = \mathrm{upper\ decile/median} \quad (5)$$

$$\mathrm{Dlo} = \mathrm{lower\ decile/median} \quad (6)$$

### *1.1. The choice of a variability index*

The first questions to choice a variability index could be: (a) What central trend parameter can be used to describe the monthly value of an ionospheric magnitude? mean? median? (b) What variability indexes should be used? indexes derived from mean and the standard deviation, or indexes derived from quartiles and or deciles?

The mean ($\mu$) and the standard deviation ($\sigma$) can be used to specify the dispersion from the central value if the probability distribution function is normal which is given by Eq. (7) (Spiegel, 1992)

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \mathrm{e}^{-(x-\mu)^2/2\sigma^2} \quad (7)$$

with $-\infty < x < \infty$

In this case a model can predict foF2 value in the following way:

| foF2 prediction | Probability |
|---|---|
| $\mu - \sigma < \mathrm{foF2} < \mu + \sigma$ | 68.27% |
| $\mu - 2\sigma < \mathrm{foF2} < \mu + 2\sigma$ | 95.45% |
| $\mu - 3\sigma < \mathrm{foF2} < \mu + 3\sigma$ | 99.73% |

The shape of the normal probability distribution law is like a "bell" which implicates that:

(1) The function is symmetrical respect to the mean value.
(2) The probability that $\mathrm{foF2} = \mu$, that is $P[\mathrm{foF2} = \mu]$, has the highest value. The more probable value is $\mu$.
(3) For a given increment of frequency ($\Delta f$), $\mathrm{P}[\mathrm{foF2} = \mu + \Delta f] = \mathrm{P}[\mathrm{foF2} = \mu - \Delta f]$.
(4) If $\Delta f' > \Delta f$, $\mathrm{P}[\mathrm{foF2} = \mu + \Delta f'] < P[\mathrm{foF2} = \mu + \Delta f]$.

In the case that the distribution is not normal, the dispersion from the central value (median) should be specified using quartiles and/or deciles. In this case a model can predict foF2 value in the following way:

| foF2 prediction | Probability |
|---|---|
| Lower quartile < foF2 < upper quartile | 50% |
| Lower decile < foF2 < upper decile | 80% |

Moreover, using quartiles and median we are sure that:

(a) The probability that the foF2 value falling between lower quartile and median is 25%
(b) The probability that the foF2 value falling between median and upper quartile is 25%

The question is: Is the foF2 probability distribution a normal distribution? Is it like a "bell"?

In order to answer this question, the occurrence of foF2 over Huancayo (−12.00, 284.70) during three years of low solar activity: 1964 ($\mathrm{Rz12} = 12$), 1965 ($\mathrm{Rz12} = 16$) and 1966 ($\mathrm{Rz12} = 50$) has been studied.

Following the recommendation given in the IRI Task Force Activity (Bilitza, 2001) the measurements obtained at that low latitude station were grouped according to (i) four time periods: (22–2), (5–7), (10–14) and (18–20) LT (LT represents local time); (ii) the four seasons: summer, winter, spring and autumn; (iii) two levels of solar activity: high solar activity (HSA) and low solar activity (LSA).

Fig. 1 illustrates as example the occurrence of foF2 values at Huancayo during summer time and low solar activity conditions. It can be seen that the shape of the distribution is not like a normal one. For example, for the period (10–14) LT the mean value of foF2 is $\mu = 8.34$ MHz and

$P[\mathrm{foF2} = \mu] = 0.14$
considering $\Delta f = 1.5$ MHz, we obtained:
$P[\mathrm{foF2} = \mu + \Delta f] = 0.05$
$P[\mathrm{foF2} = \mu - \Delta f] = 0.12$

These values show that the third feature of the normal probability distribution function mentioned previously is not fulfilled.

Taking into account the distribution is not like a normal one and that the median and quartiles have the advantage of being less affected by large deviations that can occur during magnetic storms, in this paper we use median and quartiles to specify the foF2 variability. Deciles have been also considered although they could be affected by disturbed conditions.

## 2. Data and results

### *2.1. foF2 variability studies using data from the American sector*

The data used were obtained at 12 American stations, which are shown in Table 1. These data correspond to three years of high solar activity: 1957 ($\mathrm{Rz12} = 188$), 1958 ($\mathrm{Rz12} = 189$) and 1959 ($\mathrm{Rz12} = 157$) and to the three years of low solar activity mentioned in Section 1.1 (1964, 1965 and 1966).

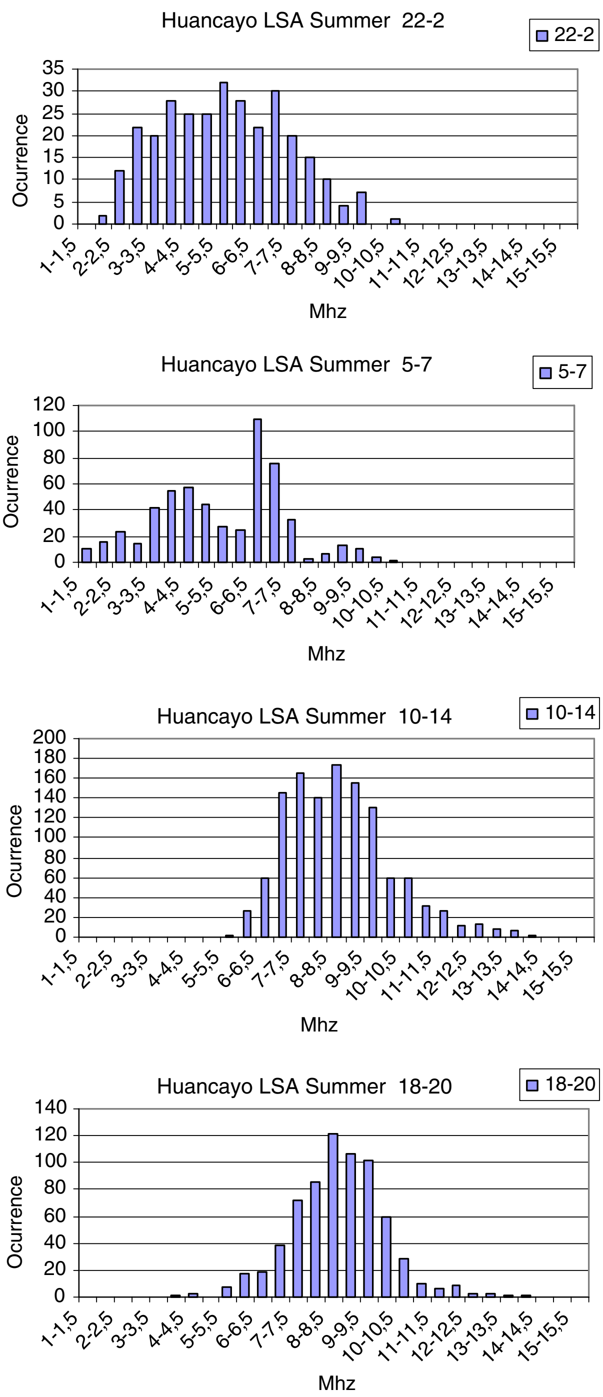


Fig. 1. Occurrence (number of observed events) of foF2 values, Huancayo, LSA, (1964, 1965 and 1966) Summer. The number of analyzed data in this figure is 2780.

The data from each station were grouped according to: (i) four time periods: (22–2), (5–7) (10–14) and (18–20) LT; (ii) the four seasons: summer, winter, spring and autumn, (iii) two levels of solar activity: high solar activity and low solar activity. Then the indexes Cup Eq. (1), Clo Eq. (2), Dup Eq. (5), Dlo Eq. (6), and (Cup–Clo) have been calculated for the different conditions. For example, Cup = 1.20 means that upper quartile is 20% greater than median and, Clo = 0.80 means that lower quartile is 20% lower than median. When Cup and Clo are close to the value 1 the variability is low, if the indexes are far from the value 1, the variability is high.

Fig. 2 shows some of the obtained results. It illustrates the latitudinal dependence of the variability indexes at LSA and spring time conditions for the four time periods. It can be seen cases where the coefficients Dup are far from Cup, suggesting that the deciles are more affected by disturbed conditions than the quartiles. Moreover, the lowest variability is observed for the time period (10–14) LT.

Fig. 3 shows the results for spring and HSA. For the four time periods, the variability is lower than that observed at LSA. An interesting point is that the variability for the time period (10–14) LT is low and almost constant for the considered stations. Except for the high latitude station, the graphic representation of Cup and Clo are lines almost horizontal. Similar situation is observed in Fig. 4 which corresponds to the time period (10–14) LT, during HSA and different seasonal conditions.

If an ionospheric model gives good predictions of the monthly value of foF2, the modelling of the indexes used in this paper would allow predict the variability range of the critical frequency of F2 region as:

[median × Clo, median × Cup] with a probability of 50%
or

[median × Dlo, median × Dup] with a probability of 80%

So, a model of Clo, Cup, Dlo and Dup would be useful.

In order to contribute to the development of that model we consider the time period (10–14) LT during HSA conditions. A linear regression for the mentioned cases has been obtained. Fig. 5 shows the results. It can be seen that for all the cases the indexes *C* vary slowly with modip. So, as a first approximation we can say that, the indexes reach the following seasonal values: autumn: Cup = 1.07, Clo = 0.93; spring: Cup = 1.06, Clo = 0.92; summer: Cup = 1.07, Clo = 0.92 and winter: Cup = 1.06, Clo = 0.93.

These results suggest that the variability range of the critical frequency of F2 region around noon (10–14) LT, over the considered latitudes and high solar activity periods could be predicted for each season as:

Autumn: [median of foF2 × 0.93, median of foF2 × 1.07], spring: [median of foF2 × 0.92, median of foF2 × 1.06], summer: [median of foF2 × 0.92, median of foF2 × 1.07], winter: [median of foF2 × 0.93, median of foF2 × 1.06,] with a probability of 50%.

The values of the variability indexes Cup and Clo proposed in this paper to quantify the variability of foF2 are only preliminary ones. Further work is being done in order to confirm these results and to extend this study to different seasonal and solar activity conditions and to other ionospheric characteristics measured in the American sector.

Table 1
Station list

| Station | Modip | Dip | Geog. Lat. | Geog. Long. (E) | Geom. Lat. | Geom. Long. |
|---|---|---|---|---|---|---|
| Puerto Rico | 41.81 | 49.90 | 18.50 | 292.90 | 29.20 | 3.00 |
| Panamá | 33.81 | 38.11 | 9.40 | 280.10 | 20.60 | 349.30 |
| Bogotá | 29.20 | 31.97 | 4.50 | 285.80 | 15.90 | 355.40 |
| Talara | 14.53 | 14.82 | −4.60 | 278.70 | 6.60 | 348.50 |
| Chiclayo | 11.27 | 11.38 | −6.80 | 280.20 | 4.40 | 350.00 |
| Huancayo | 3.27 | 3.24 | −12.00 | 284.70 | −0.70 | 354.60 |
| La Paz | −3.77 | −3.70 | −16.50 | 291.90 | −5.10 | 1.60 |
| Natal | −7.42 | −7.44 | −5.70 | 324.80 | 3.70 | 35.50 |
| Tucumán | −21.30 | −21.10 | −26.90 | 294.60 | −15.50 | 4.10 |
| Concepción | −34.28 | −35.00 | −36.60 | 287.00 | −25.20 | 357.20 |
| Pt. Stanley | −46.81 | −48.04 | −51.70 | 302.20 | −40.50 | 9.80 |
| Argentine Is. | −57.73 | −58.71 | −65.25 | 295.73 | −53.90 | 3.90 |

### *2.2. GPS-VTEC Variability studies using data from the American Sector*

Using the variability index:

$$V\% = [(\text{upper quartile} - \text{lower quartile})/\text{median}] \times 100 \quad (8)$$

Ezquer et al. (2004) showed that the variability of GPS-VTEC during daytime is lower than that observed during nighttime. Moreover, taking into account that sometimes the quartiles are not equidistant from the median value, these authors proposed new variability indexes to quantify the ionospheric variability. In this study we have analysed the variability of GPS VTEC using the variability indexes: Cup, Clo, Dup and Dlo previously mentioned.

Table 2 shows the GPS receiver locations used to obtain the vertical total electron content measurements, which have been obtained using La Plata ionospheric model, described in detail by Brunini et al. (2001). The data correspond to June (winter) of the year 1999 ($Rz_{12} = 93.0$) and September (equinox-spring) of the same year ($Rz_{12} = 102.0$).

Figs. 6a and b show the results for Riobamba, Arequipa, Tucumán and Santiago. It can be seen that the variability is higher during nighttime than during daytime. The lowest variability is observed for daylight hours at Riobamba and Arequipa (low latitude stations). Moreover, it can be seen that the coefficients Cup and Clo are almost constant for the time period (8–18) LT. Similar results were obtained for the other stations. A linear regression for these data has been done in order to obtain the values of Cup and Clo. Table 3 shows the obtained results which suggest that the variability range of VTEC over the considered latitudes for the period (8–18) LT, during high solar activity could be predicted as:

[Median of VTEC × Clo, median of VTEC × Cup], with a probability of 50%, using the values presented in mentioned table.

However these values of Cup and Clo are preliminary ones and additional studies should be done using a larger database in order to obtain indexes more representative for the all the stations.

### *2.3. Variability studies using ground based ionosonde data from the European sector*

Mosert et al. (2004) used the index (Cup–Clo) and ionosonde data obtained at Pruhonice (50.0°N, 15.0°E) during different times of the day, seasons and periods of the solar cycle to do a preliminary analysis of the variability of ionospheric characteristics foF2, M(3000)F2, foF1 and foE. The results indicated that the variability in the E and F1 regions is less than that observed in the F2 region. Moreover, the M(3000)F2 factor showed low variability.

In order to extend this variability study to other latitudes, critical frequencies of the ionospheric regions (foF2, foF1 and foE), F2 layer peak height (hmF2), propagation factor M(3000)F2, F2 layer thickness (Bo) and F2 Layer shape (B1) obtained at three European stations have been used. Table 4 shows the stations and time periods used in the study. Electron density profiles derived from ionograms using the ARTIST technique (Huang and Reinisch, 1996) have been used to obtain the ionospheric characteristics.

The analysis of the variability of the different ionospheric parameters has been done by grouping all the days of the months and years indicated in Table 4 according to: (i) four time periods: (22–02), (5–7), (10–14) and (18–20) LT that from now will be indicated as 00, 06, 12 and 18, respectively, in the tables; (ii) the three seasons: summer (July), winter (January) and equinox (April and October); (iii) three levels of solar activity (high solar activity: $Rz12 > 80$; moderate solar activity: $40 < Rz12 < 80$ and low solar activity: $Rz12 < 40$). However, the results of our analysis will be illustrated using only the years of low solar activity (LSA) and high solar activity (HSA).

Table 5a shows the results for foF2 over El Arenosillo. It can be seen that Cup–Clo values are higher around midnight (0.11–0.25) than around noon (0.09–0.18). In some cases a slight trend to be greater around sunrise and sunset is observed. Although some exceptions have been found, higher values of Cup–Clo are observed in wintertime (0.13–0.025) than in summertime (0.09–0.22) around noon and midnight. This behavior is inverted at sunrise. Cup–Clo generally presents higher values at low solar activity (0.17–0.28) than at high solar activity (0.09–0.21).

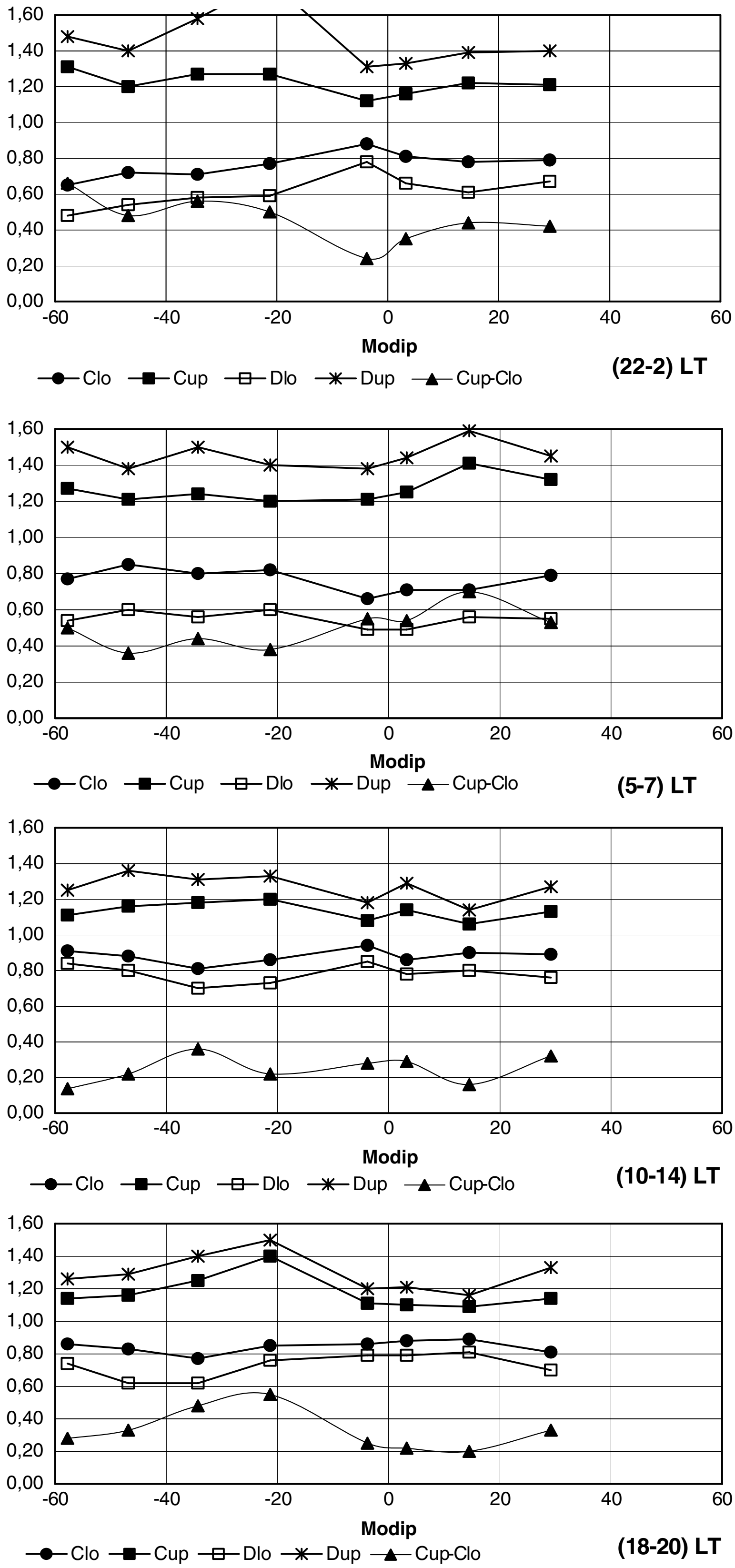


Fig. 2. Latitude dependence of variability indexes for foF2 at low solar activity at spring for the different LT hour blocks as indicated. The number of analyzed data in this figure is 20,096.

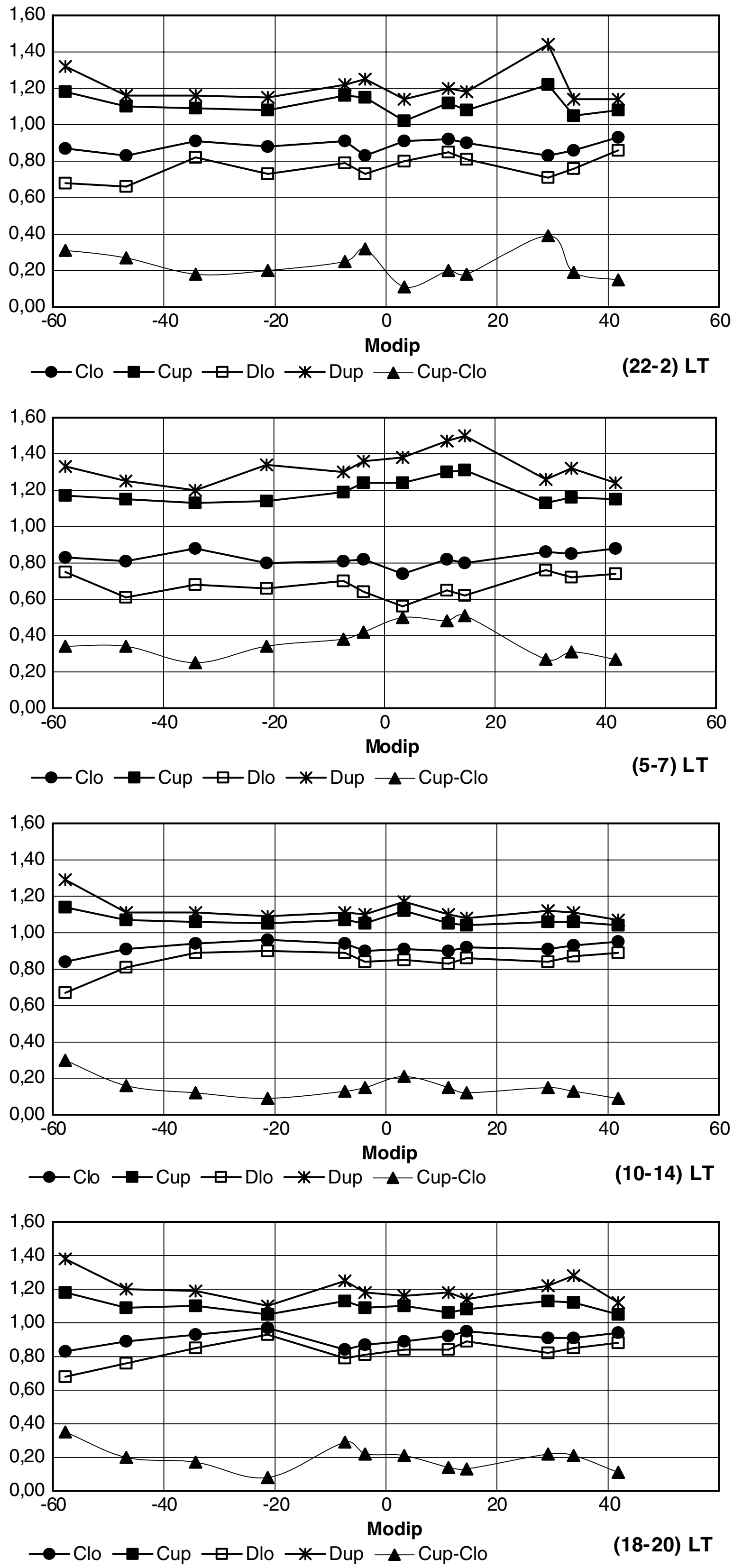


Fig. 3. Latitude dependence of variability indexes for foF2 at high solar activity at spring for the different LT hour block as indicated. The number of analyzed data in this figure is 27,910.

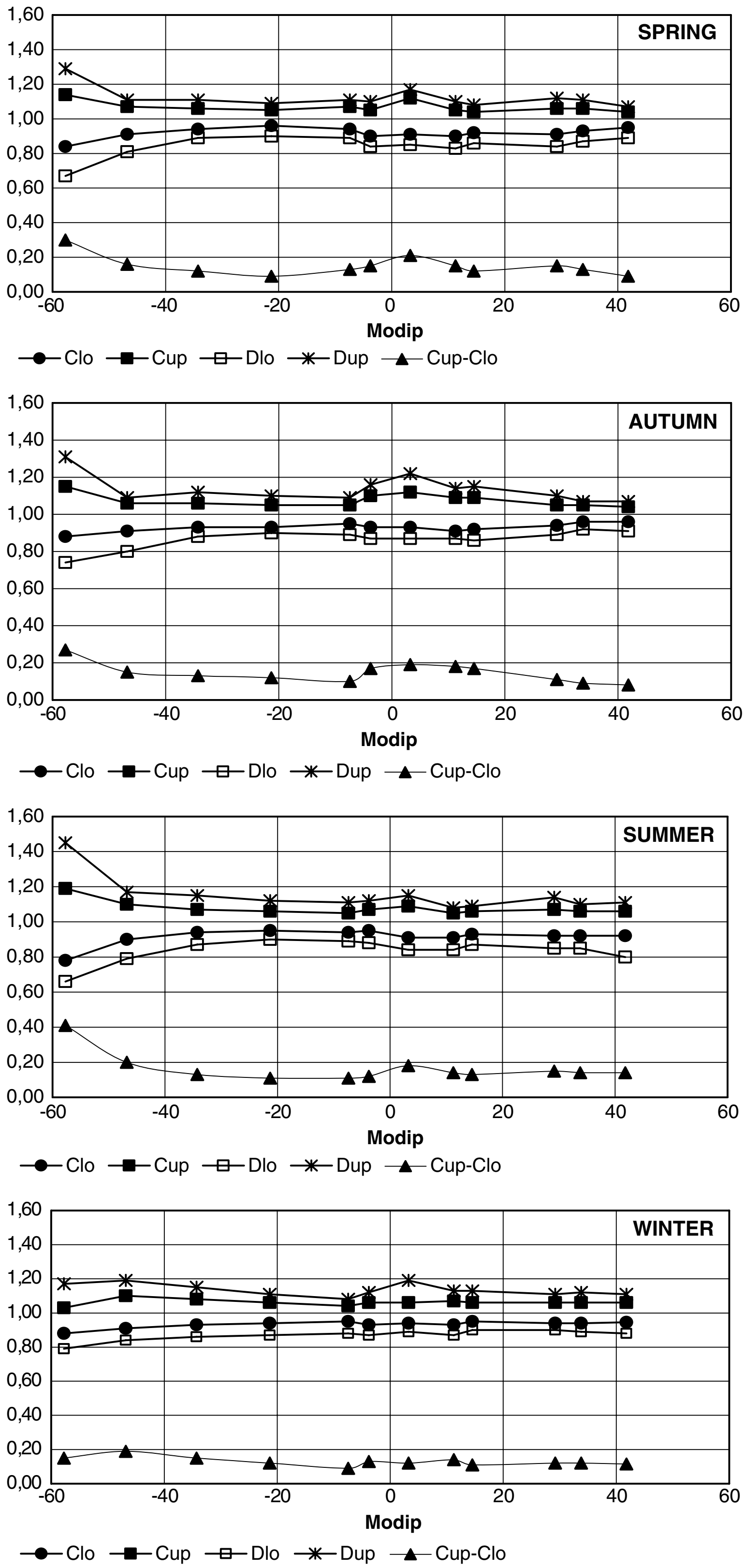


Fig. 4. Latitude dependence of variability indexes for foF2 at high solar activity for the four seasons for (10–14)LT. The number of analyzed data in this figure is 34,267.

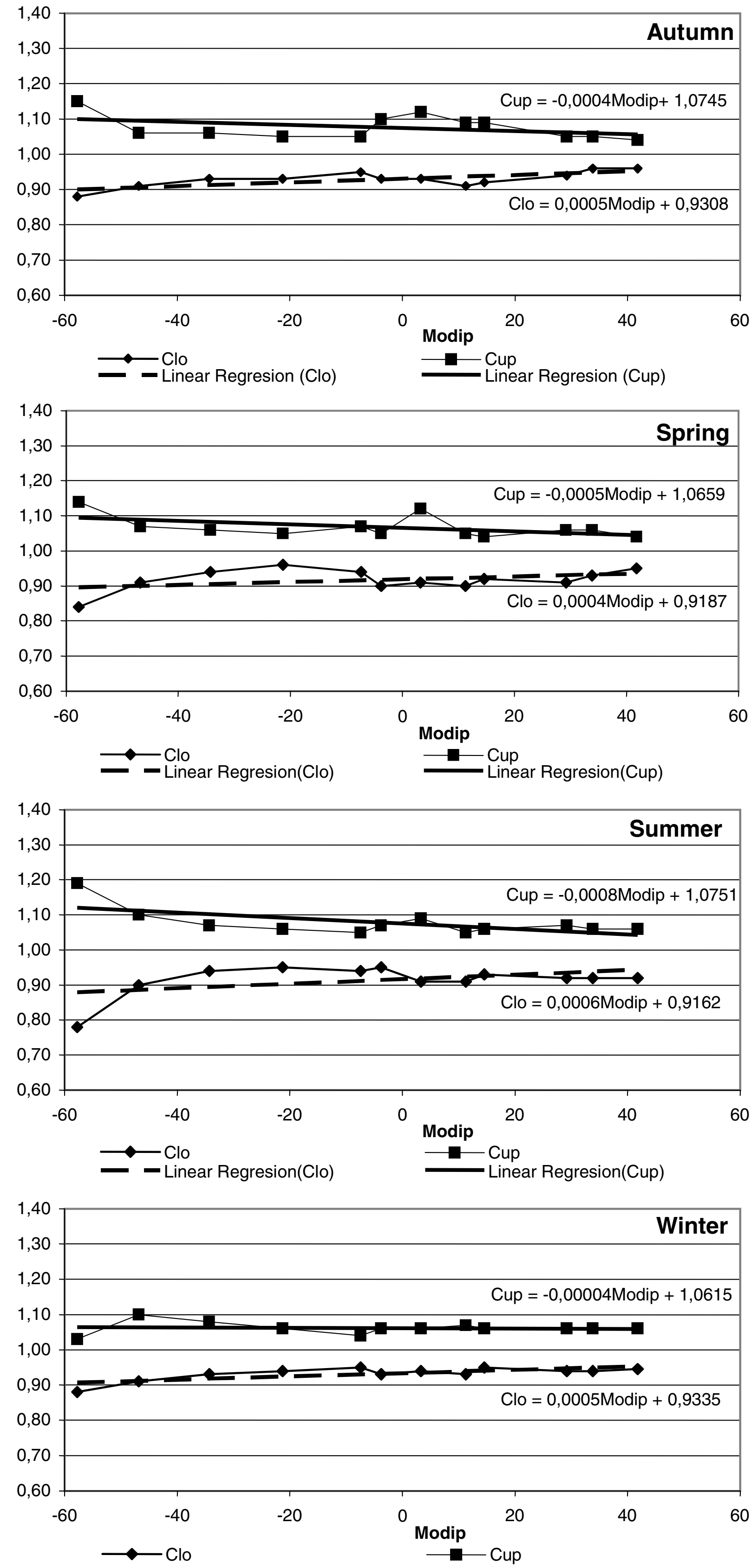


Fig. 5. Linear regression for the indexes Cup, Clo for foF2 at high solar activity at the four seasons for (10–14)LT.

Table 2
Station list

| Stations | Latitude | Longitude | Geomag. Lat. | Geomag. Lon. |
|---|---|---|---|---|
| Riobamba | −1.6 | 281.3 | 9.7 | 351.0 |
| Arequipa | −16.4 | 288.5 | −5.0 | 358.4 |
| Tucumán | −26.8 | 294.7 | −15.5 | 4.1 |
| Santiago | −33.1 | 289.3 | −21.7 | 359.2 |
| Bahia Blanca | −38.7 | 297.7 | −27.4 | 6.6 |
| Rio Grande | −53.8 | 292.2 | −42.4 | 1.6 |
| PALM | −64.7 | 295.9 | −53.3 | 4.1 |

The results for Ebro and Pruhonice, not included in this paper, show similar diurnal, seasonal and solar activity behavior but the seasonal and solar activity effect on the foF2 variability at Pruhonice is less clear than in the other stations.

The results for the height peak foF2 (hmF2) over El Arenosillo are shown in Table 5b. It can be seen that Cup–Clo values are generally lower than those observed in the corresponding ones for the parameter foF2. One exception has been found around noon in summer time at HSA. The highest values is observed at midnight (0.25) during high solar activity. Similar behavior is observed at the other two European stations.

In general, it has been found that the variability within the E and F1 regions (not shown in this paper) is lower than the variability in the F2 region. Low variability is observed for the M(3000)F2 parameter in all the three stations. Table 5c shows the results for M(3000)F2 parameter over El Arenosillo. It can be seen that the variability index ranges between 0.07 and 0.14. This behaviour of M(3000)F2 has also been reported by Ezquer et al. (2004) and Kouris and Fotiadis (2002) analyzing different locations.

Table 6a shows the results for the parameters B0 corresponding to El Arenosillo. The differences Cup–Clo are greater generally around midday (0.25–0.40) than around midnight (0.17–0.22) at the three seasons. Moreover, Cup–Clo is generally higher in winter time (0.20–0.50) and equinox (0.17–0.60) than in summer time (0.17–0.27). The behaviour of the variability of B0 with the solar activity is not clear. Only during equinox the values of Cup–Clo decrease with the solar activity. The greatest value (0.60) is found at sunrise and low solar activity during equinox.

Related to B1, Table 6b shows the results corresponding to El Arenosillo. Cup–Clo values are slightly greater around midday (0.32–0.44) than around midnight (0.20–0.37). This behaviour is not always found over Ebro. Generally, the index is lower during summer time (0.18–0.44) than in winter (0.27–0.64) and equinox (0.22–0.48). The variability decreases with the solar activity. The values range between 0.29 and 0.64 during periods of low solar activity and between 0.20 and 0.39 during high solar activity conditions.

Although the analysis of the variability of ionospheric parameters observed in the European sector will continue in order to model separately the variability indexes Cup and Clo, these results provide some features of the quantitative variability of the parameters studied.

### 2.4. Variability of the electron density at fixed heights

Mosert and Radicella (1995) studied the electron density ($N$) at fixed heights using data from South America. They used the variability index: $v$ (%) = (standard deviation/mean) × 100. Their results showed (1) minimum variability at 170–190 km for noon conditions, (2) the variability increased with height in the F2 region during nighttime and daytime hours reaching a maximum below the F2 peak, (3) at greater heights the variability tends to decrease, (4) the nighttime variability is larger than that corresponding to daytime conditions, (5) the highest value of $v$ % was found (170%) near 250 km for night, equinox and HSA. It is important to point out than in this study the electron density profiles were obtained using the Jackson inversion technique (Jackson, 1971).

Ezquer et al. (2002a) presented an analysis of the electron density at fixed height using electron density profiles obtained from two Argentine stations. The electron density profiles were derived from ionograms using the Huang and Reinisch technique (1996). The study showed, that the variability increases with height reaching a well defined maximum below hmF2. They also indicated that the highest variability was observed at 270 km for nighttime, equinox and high solar activity.

A new study of the variability of $N$ at fixed height has been done using electron density profiles (Huang and Reinisch, 1996) observed from El Arenosillo during a year of low solar activity (1995, Rz12 = 20.6) and a year of high solar activity (1999, Rz12 = 95). Fig. 7 illustrates the main results of the analysis: (1) the height of maxima variability of the electron density $N$ (hmaxVariab) at midnight is below the F2 peak height (hmF2), (2) hmaxVariab at noon is close to hmF2, (3) in general, the variability of $N$ at hmaxVariab (indicated using the index $V$%) is higher around midnight than around midday, (4) the seasonal and solar activity effects on the variability of $N$ at fixed heights needs additional studies.

## 3. Conclusions

This paper reviews and extends studies on ionospheric variability carried out in Argentina up to the present using

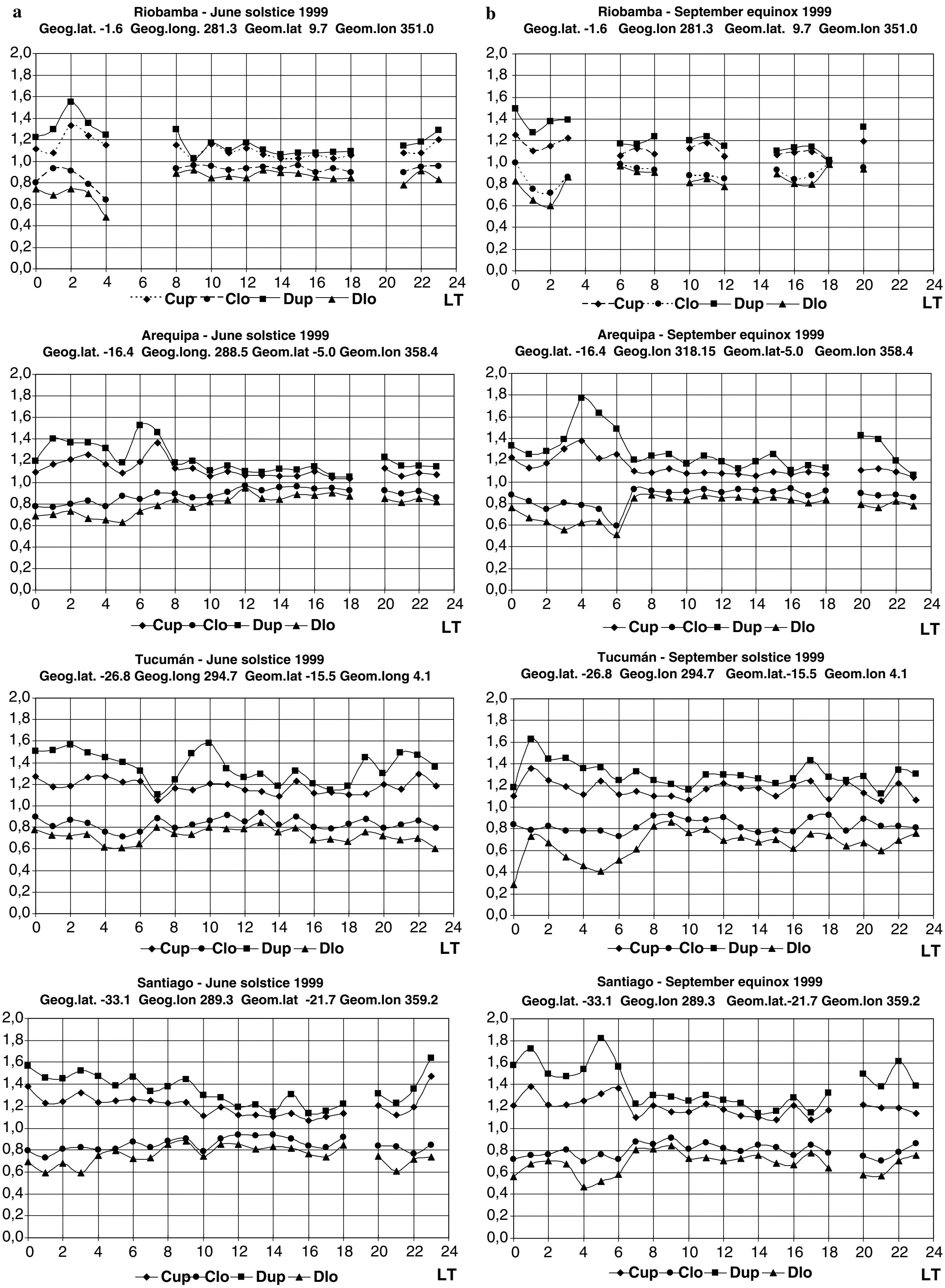


Fig. 6. (a) Variability indexes for VTEC over Riobamba, Arequipa, Tucumán and Santiago, June solstice 1999 (Rz12: 93.0). The number of analyzed data in this figure is 2234. (b) Variability indexes for VTEC over Riobamba, Arequipa, Tucumán and Santiago, September equinox 1999 (Rz12: 102.0). The number of analyzed data in this figure is 1508.

Table 3
Indexes of variability of VTEC for the time period (8–18)LT obtained using linear regression

| Station | June solstice | | September equinox | |
|---|---|---|---|---|
| | Cup | Clo | Cup | Clo |
| Riobamba | −0.0087 LT + 1.1826 | −0.0033 LT + 0.9744 | −0.0067 LT + 1.1789 | 0.0031 LT + 0.8570 |
| Arequipa | −0.0071 LT + 1.1680 | 0.0074 LT + 0.8240 | −0.0021 LT + 1.1083 | −0.0004 LT + 0.9178 |
| Tucumán | −0.0060 LT + 1.2297 | −0.0019 LT + 0.8712 | 0.0055 LT + 1.0769 | −0.0065 LT + 0.9468 |
| Santiago | −0.0114 LT + 1.2888 | 0.00009LT + 0.8858 | −0.0063 LT + 1.2312 | −0.0078 LT + 0.9305 |
| Bahía Blanca | 0.0088 LT + 1.0560 | 0.0015 LT + 0.8722 | 0.0071 LT + 1.0747 | −0.0164 LT + 1.0798 |
| Rio Grande | −0.0001 LT + 1.1309 | −0.0027 LT + 0.9295 | −0.0043 LT + 1.2395 | −0.0016 LT + 0.8417 |
| Palm | −0.0060 LT + 1.2364 | −0.0014 LT + 0.8796 | 0.0043 LT + 1.1103 | −0.0041 LT + 0.8725 |

Table 4
Station list and time periods

| Stations | Latitude | Longitude | Dip | Modip | Years | Months | Rz12 |
|---|---|---|---|---|---|---|---|
| Pruhonice | 50.0 | 15.0 | 65.0 | 55.0 | 1993 | 04, 07, 10, 12 | 75 |
| | | | | | 1994 | 10 (Fall) | 26.5 |
| Ebro | 40.8 | 0.49 | 56.1 | 48.4 | 1997 | 01, 04, 07, 10 | 23 |
| | | | | | 1998 | 01, 04, 07, 10 | 62 |
| | | | | | 2000 | 01, 04, 07, 10 | 117 |
| El Arenosillo | 37.1 | 353.2 | 52.0 | 45.5 | 1995 | 04 (Spring) | 20.6 |
| | | | | | 1993 | 01, 04, 07,10 | 56 |
| | | | | | 1999 | 01, 04, 07, 10 | 95 |

Table 5
Variability index Cup–Clo for the ionospheric parameters measured at El Arenosillo: (a) foF2, (b) hmF2 and (c) M(3000)F2 during different seasonal and solar activity conditions as indicated in each block

| Time periods (LT) | LSA | | | | HSA | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 6 | 12 | 18 | 0 | 6 | 12 | 18 |
| *(a) foF2* | | | | | | | | |
| Summer | 0.21 | 0.22 | 0.15 | 0.18 | 0.11 | 0.15 | 0.09 | 0.11 |
| Equinox | 0.21 | 0.18 | 0.18 | 0.28 | 0.19 | 0.19 | 0.14 | 0.15 |
| Winter | 0.25 | 0.17 | 0.18 | 0.23 | 0.19 | 0.14 | 0.13 | 0.21 |
| *(b) hmF2* | | | | | | | | |
| Summer | 0.08 | 0.09 | 0.15 | 0.07 | 0.25 | 0.10 | 0.16 | 0.09 |
| Equinox | 0.08 | 0.10 | 0.11 | 0.11 | 0.07 | 0.14 | 0.07 | 0.08 |
| Winter | 0.08 | 0.18 | 0.11 | 0.10 | 0.10 | 0.11 | 0.08 | 0.10 |
| *(c) M(3000)F2* | | | | | | | | |
| Summer | 0.07 | 0.11 | 0.10 | 0.08 | 0.07 | 0.15 | 0.08 | 0.08 |
| Equinox | 0.08 | 0.09 | 0.09 | 0.10 | 0.11 | 0.12 | 0.12 | 0.09 |
| Winter | 0.09 | 0.14 | 0.08 | 0.11 | 0.12 | 0.14 | 0.13 | 0.13 |

data from the American sector and from European stations.

The choice of variability indexes has been discussed. An analysis of the variability of some ionospheric characteristics has been also done using the variability indexes Cup, Clo and Cup–Clo in the case of the ground based ionosonde characteristics and VTEC. The index $V\%$ has been used to analyze the variability of the electron density at fixed heights.

With reference to the variability of foF2 over the American sector, a set of values for Cup and Clo have been proposed for the time period (10–14) LT during high solar activity conditions (Section 2.1). These indexes could be useful to develop of a variability model.

The results for the parameter VTEC over the American sector show that the coefficients Cup and Clo are almost constant for the period (8–18) LT. They also suggest that the variability range of this variable over the considered latitudes for the mentioned period could be predicted as: [median of VTEC × Clo, median of VTEC × Cup], with a probability of 50%. A table of values of Clo and Cup is proposed for different seasonal conditions during a year of high solar activity (Table 3). Nevertheless, an extension of this study is needed in order to obtain more representa-

Table 6
Variability index Cup–Clo for: (a) the thickness parameter of the F2 region, B0 and (b) the shape parameter of the F2 region, B1 at El Arenosillo for different seasons (winter, summer and equinox), four time periods (00, 06, 12 and 18) LT and two levels of solar activity (LSA, HSA)

| Time period | Solar Act. | Winter | Summer | Equinox |
|---|---|---|---|---|
| (a) B0 | | | | |
| 00 | LSA | 0.20 | 0.17 | 0.22 |
| | HSA | 0.20 | 0.20 | 0.17 |
| 06 | LSA | 0.50 | 0.18 | 0.60 |
| | HSA | 0.33 | 0.18 | 0.22 |
| 12 | LSA | 0.40 | 0.25 | 0.38 |
| | HSA | 0.27 | 0.27 | 0.26 |
| 18 | LSA | 0.29 | 0.18 | 0.37 |
| | HSA | 0.46 | 0.26 | 0.35 |
| (b) B1 | | | | |
| 00 | LSA | 0.35 | 0.37 | 0.30 |
| | HSA | 0.28 | 0.26 | 0.20 |
| 06 | LSA | 0.64 | 0.32 | 0.48 |
| | HSA | 0.27 | 0.18 | 0.29 |
| 12 | LSA | 0.44 | 0.44 | 0.33 |
| | HSA | 0.39 | 0.32 | 0.22 |
| 18 | LSA | 0.50 | 0.29 | 0.39 |
| | HSA | 0.38 | 0.32 | 0.32 |

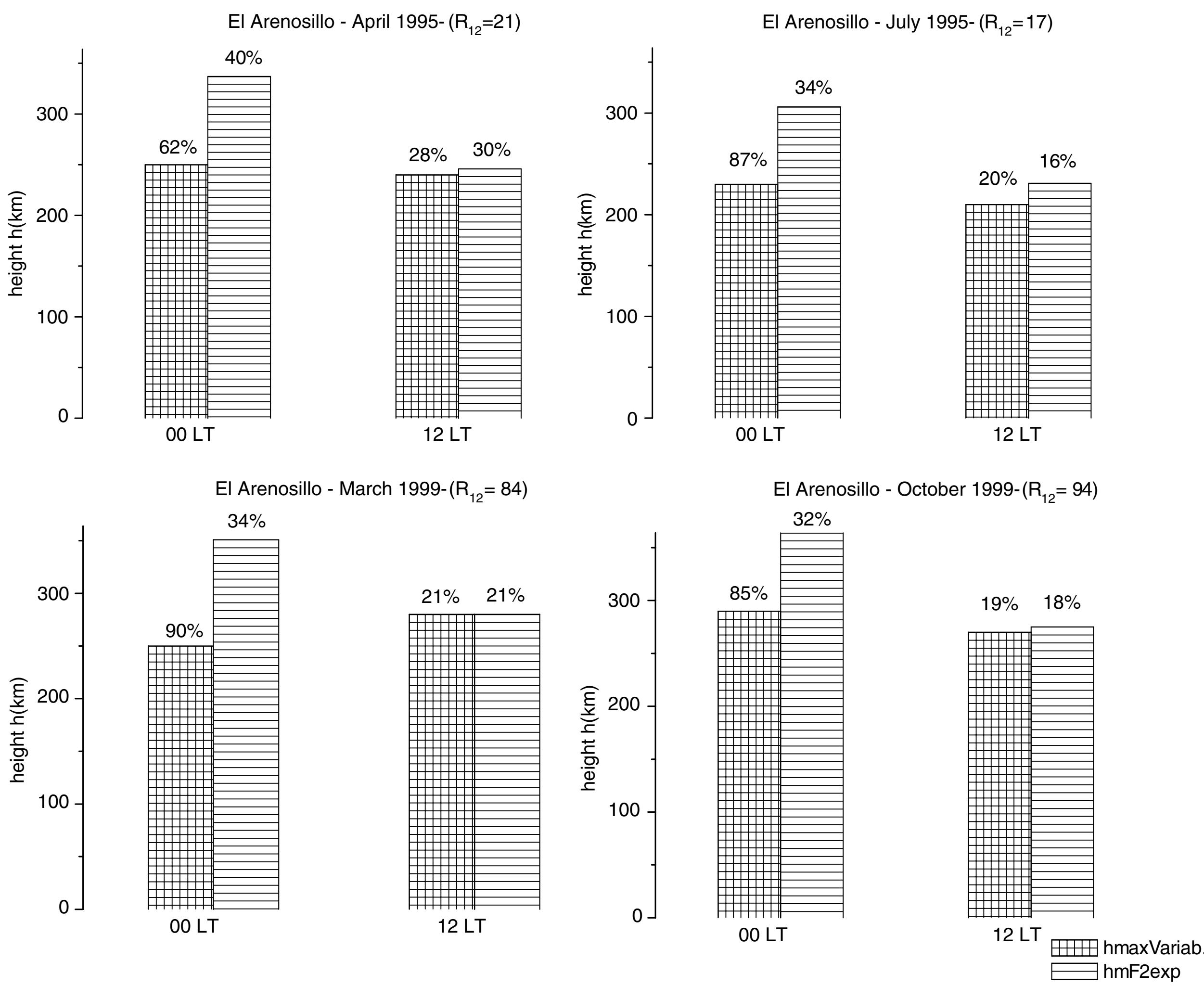


Fig. 7. Comparison between the height of the maximum variability of the electron density (hmaxVariab) and the height peak of the F2 region (hmF2exp) over El Arenosillo at two typical hours of the day (00 and 12 LT) and for different seasonal and solar activity conditions as indicated in the top of each plot. The values of the variability index $V\%$ are indicated in each case for both heights.

tive values of the coefficients Cup and Clo for VTEC for the American sector.

The analysis of the variability of different ionospheric characteristics using data from Pruhonice (50.0; 15 E), Ebro (40.4; 0.30 E) and El Arenosillo (37.1; 353.3 E) has allowed to indicate some features of the variability of the ionospheric parameters foF2, hmF2, M(3000)F2, B0 and B1. Preliminary values of the index Cup–Clo has been indicated (Tables 5a–c and 6a and b). Further work is needed in order to model separately the indexes Cup and Clo.

The studies on the variability of electron density at fixed heights carried out for the Argentine scientific community has been reviewed. The results show: (1) minimum variability at 170–190 km for noon conditions, (2) the variability increased with height in the F2 region during nighttime and daytime hours reaching a maximum below the F2 peak, (3) at greater heights the variability tends to decrease, (4) the nighttime variability is larger than that corresponding to daytime conditions, (5) the highest value of $v$ % was found (170%) near 250 km for night, equinox and high solar activity.

The investigation on the ionospheric variability is not ended in Argentine. We continue working in reaching our final objective which is to model, at least, the Cup and Clo indexes for the main ionospheric parameters as a function of the hour of the day, different seasons and different periods of the solar cycle. But, even if we have not reached the final goal of the investigation, we have pointed out some features of the ionospheric variability. The values of the variability indexes obtained by our studies can be helpful other as representative values for the locations analysed or as a contribution in the formulation of a variability model for the International Reference Ionosphere.

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