ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2008) xxx–xxx

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

On the time of minimum ionization in the F2 region

R.G. Ezquer [a,b,c,*], M.A. Cabrera [a,b], M. Mosert [c,d], S.M. Radicella [e], Y. Migoya Orué [a]

[a] *GASuR, Facultad Regional Tucumán, Universidad Tecnológica Nacional, Rivadavia 1050, 4000 S.M.Tucumán, Argentina*
[b] *Laboratorio de Ionósfera, Dto. de Física, Universidad Nacional de Tucumán, Independencia 1800, 4000 S.M.Tucumán, Argentina*
[c] *CONICET, Rivadavia 1917, 1033 Capital Federal, Argentina*
[d] *CASLEO, Avda España 1512-Sur, 5400 San Juan, Argentina*
[e] *ARPL, ICTP, via Beirut 7, Trieste, Italy*

Received 18 April 2007; received in revised form 25 June 2007; accepted 3 July 2007

Abstract

Using measurements of the critical frequency of F2 region (f_oF2) the validity of the International Reference Ionosphere model to predict the time of minimum ionization is checked. Data obtained at different ionospheric stations have been considered. The CCIR and URSI options are used to model calculations. For CCIR option the results show that good predictions were obtained for about 40% of the considered cases. For the rest of the considered data, the model predicts the minimum at times earlier than that observed in the measurements. The percentages of good predictions obtained with URSI option are lower than those corresponding to CCIR one.

Keywords: Ionosphere; F2 region; Critical frequency; Ionospheric model

1. Introduction

Several models physical, empirical and semiempirical (e.g. Anderson, 1973; Barghausen et al., 1969; Bent et al., 1976; Llewellyn and Bent, 1973; Bilitza, 1990; Bilitza et al., 2000; Anderson et al., 1987) have been developed to predict ionospheric variables. One of the most used empirical models is the International Reference Ionosphere (IRI) (Bilitza, 1990; Bilitza et al., 2000). The IRI has undergone several years of critical checking and improving by the International Science Community. Comparison among IRI predictions and different ionospheric measurements as maximum electron density (NmF2) and its height (hmF2), electron density (*N*) profile, total electron content (TEC), electron and ion temperature have been done (Bilitza et al., 2000; Bhuyan et al., 2002; Ezquer et al., 2002; Figurski and Wielgosz, 2002; Leitinger et al., 2002; Adeniyi et al., 2003; Bradley, 2003; Medeiros et al., 2003, among others).

In previous works, Ezquer et al. (1996, 2003) used measurements of the critical frequencies of the ionospheric regions (f_oE, f_oF1 and f_oF2) and propagation parameter M(3000)F2 obtained at South American stations to check the validity of IRI model as predictor of those frequencies and hmF2. Ezquer et al. (1996) found good f_oE and f_oF1 modelled values. The degree of accuracy among experimental and calculated f_oF2 values was lower than those observed for the other frequencies, which is due to higher variability in the F2 region. The results obtained by Ezquer et al. (2003) suggest that, in general, the standard option of the model gives good hmF2 modelled values at South American latitudes. Few cases showed deviation between calculated and experimental hmF2 values greater than 15%.

In the framework of IRI Task Force Activity meetings, studies on time of minimum f_oF2 predicted by IRI have been required. In this paper, in order to extend the IRI validation studies we compare the time of minimum in f_oF2

* Corresponding author. Address: GASuR, Facultad Regional Tucumán, Universidad Tecnológica Nacional, Rivadavia 1050, 4000 S.M.Tucumán, Argentina.
E-mail addresses: rezquer@herrera.unt.edu.ar (R.G. Ezquer), mmosert@casleo.gov.ar (M. Mosert).

0273-1177/$34.00 © 2008 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2007.07.049

Please cite this article in press as: Ezquer, R.G. et al., On the time of minimum ionization in the F2 region, J. Adv. Space Res. (2008), doi:10.1016/j.asr.2007.07.049

given by IRI with that observed at stations in the American sector, Japan, Philippines and Australia.

2. Data and results

Data obtained at the American stations shown in Table 1, correspond to high (1958 and 1959) and low (1964 and 1965) solar activity.

Measurements obtained at stations placed at Japan, Philippines and Australia shown in Table 2, which correspond to 1965, 1966, 1975, 1976 and 1977 (low solar activity – LSA); and 1968, 1969 and 1970 (high solar activity – HSA), are also considered.

In this work, median is used as monthly value because it has the advantage of being less affected by large deviations in the value of f_oF2 that can occur during magnetic storms.

To obtain f_oF2 modelled values we used the CCIR and URSI options of IRI model.

Fig. 1 shows cases where good predictions of the time of minimum in f_oF2 value were observed at the American sector.

Sometimes the model predicts the minimum in f_oF2 at earlier times than those observed in the measurements. Figs. 2 and 3 show examples corresponding to the American sector for which the difference between predicted and observed time of minimum in f_oF2 is 1 and 2 h, respectively.

Some of worst results are illustrated in Fig. 4 where is difficult to see the time of the minimum value of f_oF2.

Table 1
American station list

Station	Geog. La.	Geog. Lo.	Geom. La.	Geom. Lo.
Puerto Rico	18.50	292.90	29.20	3.00
Panamá	9.40	280.10	20.60	349.30
Bogotá	4.50	285.80	15.90	355.40
Talara	−4.60	278.70	6.60	348.50
Chiclayo	−6.80	280.20	4.40	350.00
Huancayo	−12.00	284.70	−0.70	354.60
La Paz	−16.50	291.90	−5.10	1.60
Natal	−5.70	324.80	3.70	34.50
San Pablo	−23.50	313.50	−13.00	21.90
Tucumán	−26.90	294.60	−15.50	4.10
Buenos Aires	−34.50	301.50	−23.30	10.10
Concepción	−36.60	287.00	−25.20	357.20
Pt. Stanley	−51.70	302.20	−40.50	9.80
Islas Argentinas	−65.25	295.73	−53.90	3.90

Table 2
Asiatic–Australian stations list

Station	Geog. La.	Geog. Lo.	Geom. La.	Geom. Lo.
Wakkanai	45.39	141.68	35.33	206.45
Yamagawa	31.20	130.60	20.36	198.25
Manila	14.39	120.59	3.09	189.76
Vanimo	−2.70	141.30	−12.53	211.57
Townsville	−19.30	146.70	−28.39	219.28
Hobart	−42.90	147.30	−51.61	224.92

We calculated the difference between predicted and observed time of minimum f_oF2 as follows:

$$\Delta t_{\min} = t_{\min\,\mathrm{IRI}} - t_{\min\,\exp} \quad (1)$$

where $t_{\min\ \mathrm{IRI}}$ is the time of minimum in f_oF2 given by the model and $t_{\min\ \exp}$ is that obtained from the measurements.

Table 3 shows the results for the American sector corresponding to the high solar activity year 1958. The white cells correspond to good model predictions. The results where the absolute value of difference between predicted and observed time of minimum in f_oF2 ranges from 0.5 to 1 h are shown in grey cells and those with values greater than 1 h are shown in black cells. The dashed cells correspond to the cases without experimental data. For URSI option, it can be seen that the good predictions are more frequent for the northern stations. This table shows that better predictions are obtained with the CCIR option. The worst results correspond to the high latitude stations. In general, the model gives the minimum in f_oF2 at times earlier than that observed in the data.

Table 4 corresponds to American sector and the low solar activity year 1965. Few good predictions are observed with the URSI option.

Related to the other network, Tables 5 and 6 show the results for LSA and HSA, respectively. Only Wakkanai shows $\Delta t_{\min}$ absolute values greater than 1.5 h for few cases. Again, better predictions are obtained with CCIR option.

The results for all the considered cases are shown in Figs. 5 and 6. It can be seen that, for HSN, CCIR gives good predictions for 60% and 52% of the considered cases for the American and Asiatic-Australian networks, respectively, while URSI gives good predictions for 30% and 23% of the cases. For LSA these percentages are 38% and 39% for CCIR option and 11% and 23% for URSI option.

These results show that the sunrise minimum in f_oF2 is often shifted by 1 or even 2 h compared to the CCIR and URSI f_oF2 model; fewer such cases are seen with the CCIR model. A likely cause could be the use of a Sector Local Times instead of Solar Local Times for ionosonde data that were used in developing the CCIR and URSI maps.

3. Conclusions

A study on the validity of the International Reference Ionosphere model to predict the time of minimum ionization has been done.

Data obtained in the American sector, Japan, Philippines and Australia have been considered.

With CCIR option, the results show that good predictions were obtained for about 50% and 40% of the considered cases for high and low solar activity, respectively. For the other cases, in general, the model predicts the minimum at times earlier than that observed in the data. The percentages of good predictions obtained with URSI option are lower than those corresponding to CCIR one.

Please cite this article in press as: Ezquer, R.G. et al., On the time of minimum ionization in the F2 region, J. Adv. Space Res. (2008), doi:10.1016/j.asr.2007.07.049

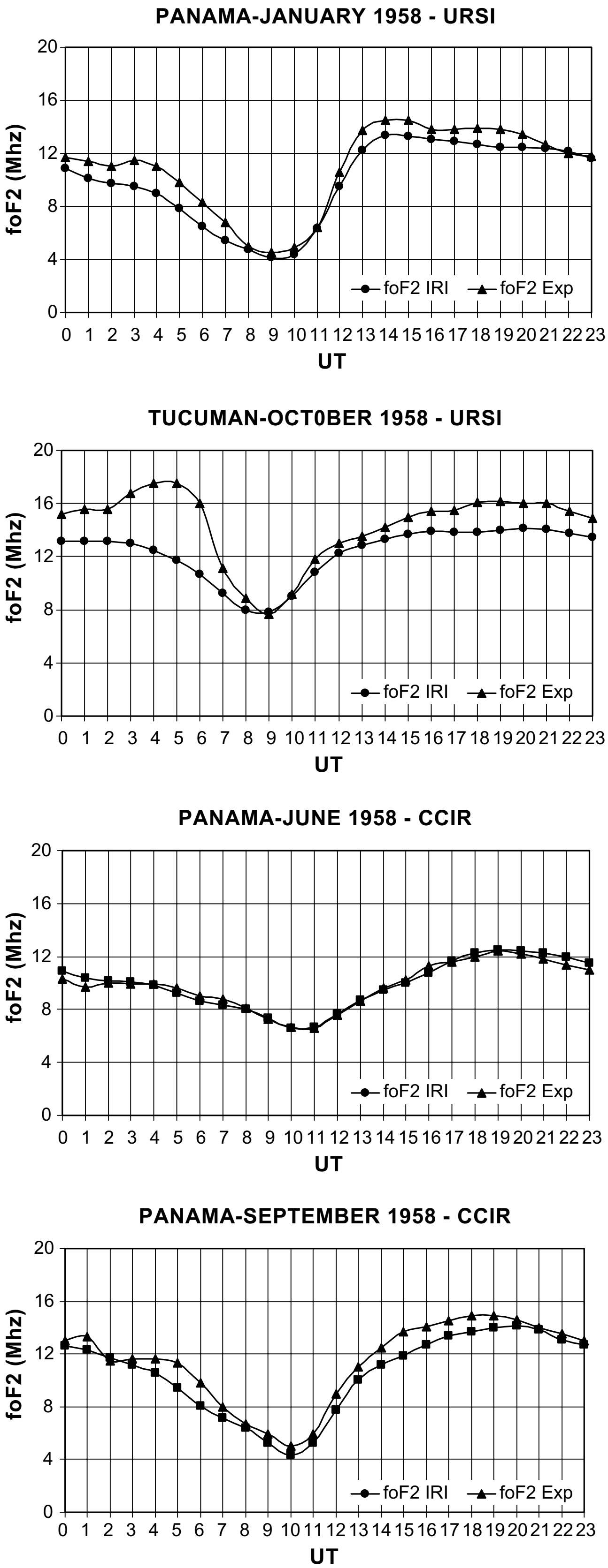

Fig. 1. Predicted and observed time of minimum f_oF2. American sector. Good predictions.

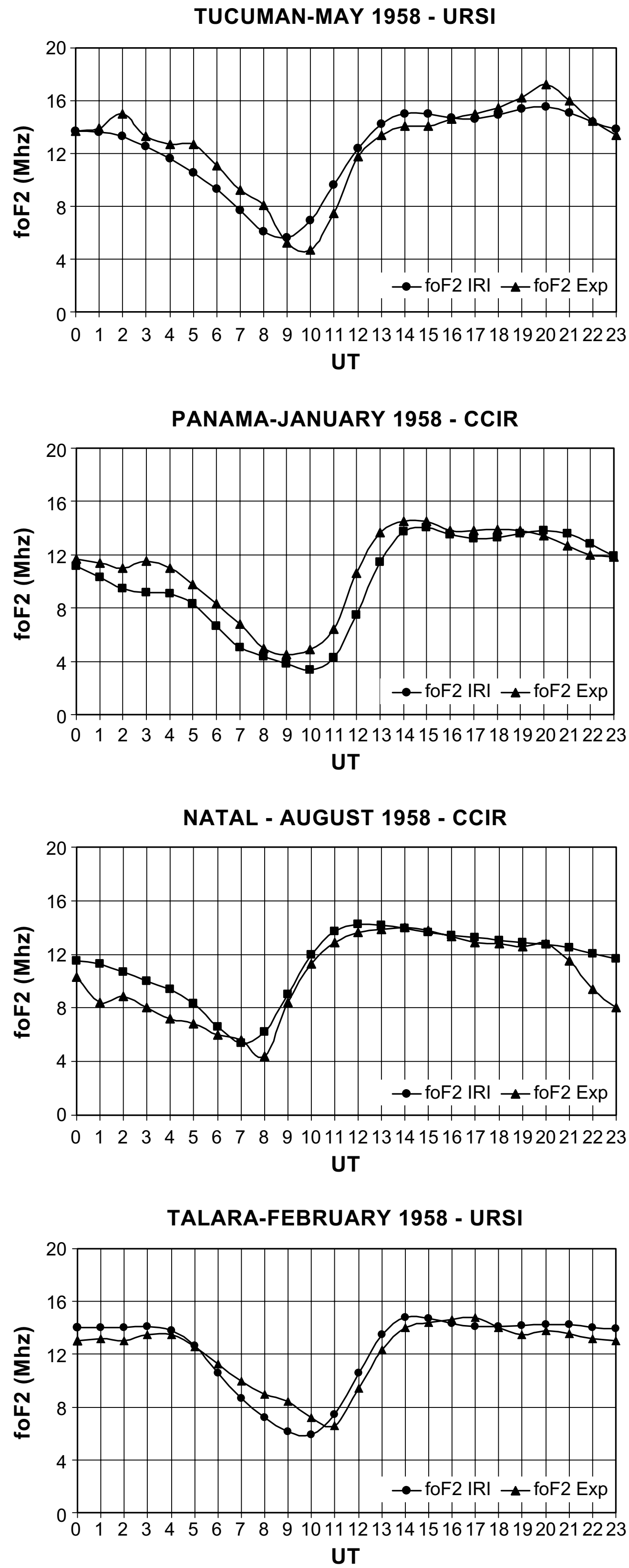

Fig. 2. Predicted and observed time of minimum f_oF2. American sector. Weak predictions.

Please cite this article in press as: Ezquer, R.G. et al., On the time of minimum ionization in the F2 region, J. Adv. Space Res. (2008), doi:10.1016/j.asr.2007.07.049

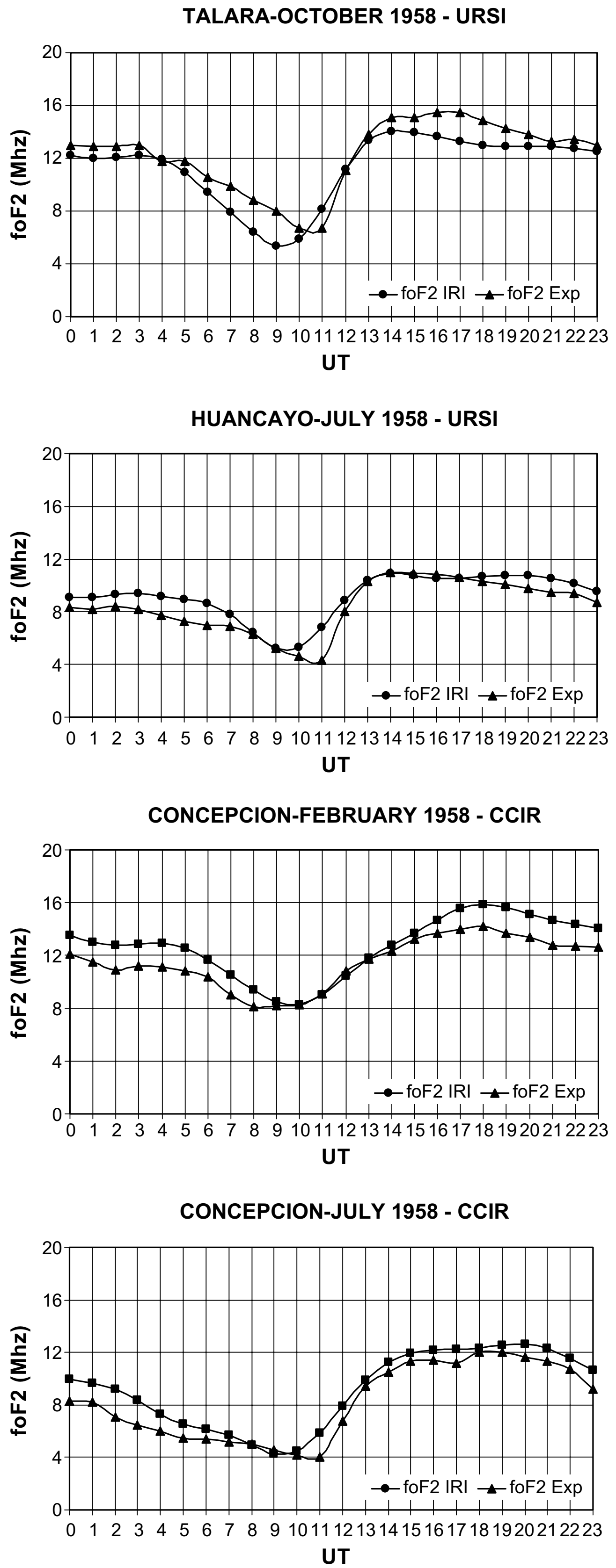

Fig. 3. Predicted and observed time of minimum f_oF2. American sector. Bad predictions.

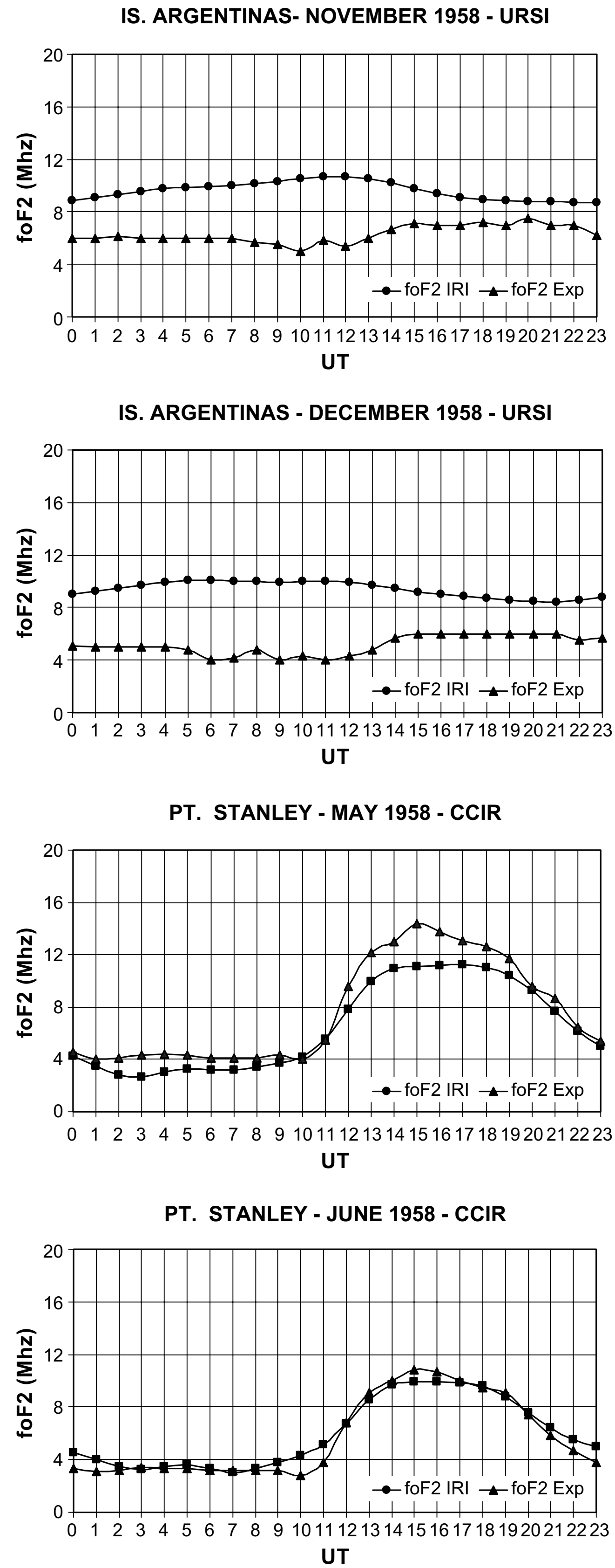

Fig. 4. Predicted and observed time of minimum f_oF2. American sector. Worst cases.

Table 3
$\Delta t_{min} = t_{min\,IRI} - t_{min\,exp}$, in hours

URSI	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
PT. RICO	1	0	0	0		-1	0	-1	0	0	1	1
PANAMA	0	-1	0	-1	0	-1	0	-1	0	-1	-1	0
BOGOTA	0	-1	-1	-1	-1	0	0	0	-1	-1	0	0
TALARA		-1	-1	-1	-1	-1	-1	-1	-1	-2	-1	-1
CHICLAYO	-1	-1	-1	-1	-1	-1	-1		-1	-1	-1	-1
HUANCAYO	-1	0	-1	-1	-1	-1	-2	-1	-1	-1	-1	-1
LA PAZ	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	1
NATAL			1	-1		0	-1	-1	-1	-0.5	0	0
SAN PABLO									-1			
TUCUMAN	0	0	-1	0	-1	-1	-1	-1	0	0		0
BS.AS.												
CONCEPCION	0	1	0	-1	-1	-1	-2	-1.5	-1	0	0	0
PT. STANLEY	1	-1	-2	-1.5	-2	-2	-2	-2	-1	0	0	0
IS. ARGENTINAS	-3	-1	-3	1	2	4	4	-1	1	-3	12	10

Dashed cells: No data

CCIR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
PT. RICO	1	0	0	0		-1	0	-0.5	0	0	1	1
PANAMA	1	0	0	0	1	0	0	-1	0	0	0	1
BOGOTA	1	0	0	0	0	0	0	0	0	-1	0	0
TALARA		-1	-1	0	0	0	-1	-1	-1	-1	0	0
CHICLAYO	0	-1	-1	-1	0	0	-1		0	0	0	0
HUANCAYO	0	0	0	0	0	0	-1	0	0	0	-1	0
LA PAZ	0	0	-1	-1	0	0	0	0	-1	0	0	1
NATAL			-0.5	-0.5		1	-1	-1	-1	-1	0	0
SAN PABLO									0			
TUCUMAN	0	0	-1	0	-1	-1	0	-1	0	0		0
BS.AS.												
CONCEPCION	0	2	0	0	0	0	-2	-0.5	-1	0	0	0
PT. STANLEY	0	0	-1	-2.5	-4	-4	-3	-4	-1	0	-1	-1
IS. ARGENTINAS	5	-1	5	1	2	5	3	0	2	-2	0	8

Dashed cells: No data

American sector. High solar activity year 1958.

Table 4
$\Delta t_{min} = t_{min\,IRI} - t_{min\,exp}$, in hours

URSI	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
PT. RICO												
PANAMA												
BOGOTA	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1.5	-1
TALARA	-1	-1	-1.5	-1	-1	-0.5	-1	-1	-1.5	-1	-0.5	0
CHICLAYO												
HUANCAYO	-1	-1	-1	-1	-1	-2	-1	-1	-1	-1	-1	-1
LA PAZ	-1	0	-1	-1	-1	-0.5	-1	-1	-1.5			
NATAL												
SAN PABLO												
TUCUMAN					-1	-1.5	-1	-1	0	0	-0.5	0
BS.AS.												
CONCEPCION	0	-1	-1	-1	-2		-2	-2	-1	0	0	-1
PT. STANLEY	0	-0.5	-1	-2	-2.5	-3	-2.5	-2	-2	-1.5	0	0
IS. ARGENTINAS	-1	-12	-0.5	-1	-3	-3	-3	-3	-2	0	6	-3

Dashed cells: No data

CCIR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
PT. RICO												
PANAMA												
BOGOTA	-1	0	0	0	0	0	0	0	-1	-1	1.5	-1
TALARA	0	0	-1	-0.5	-1	-0.5	-1	-1	-1	0	0.5	1
CHICLAYO												
HUANCAYO	-1	0	0	0	0	-1	-1	-0.5	0	-1	-1	-1
LA PAZ	0	0	-1	-1	-0.5	1	0	-0.5	-1			
NATAL												
SAN PABLO												
TUCUMAN					-1	-1	-0.5	-1	0	0	0.5	0
BS.AS.												
CONCEPCION	0	0	0	0	-1		-1	-1	0	0	0	-1
PT. STANLEY	-1	0	0	-3	-3.5	-4	-3	-3	0	-2	-1	0
IS. ARGENTINAS	-8	-12	-1	-1	-3	-1	-1	-4	-3	-1	-11	-5

Dashed cells: No data

American sector. Low solar activity year 1965.

Please cite this article in press as: Ezquer, R.G. et al., On the time of minimum ionization in the F2 region, J. Adv. Space Res. (2008), doi:10.1016/j.asr.2007.07.049

Table 5
$\Delta t_{min} = t_{min\,IRI} - t_{min\,exp}$, in hours

URSI	WAKKANAI	YAMAGAWA	MANILA	VANIMO	TOWNSVILLE	HOBART
JANUARY	-2	0	0	-0.5	0	-0.5
FEBRUARY	-2	-1	0	0	0	-0.5
MARCH	-1	0		-1	0	-1
APRIL	-1	-1	-1		-1	-1
MAY	-1	-1	-1			
JUNE		-1	-1			
JULY	-1		-1	-1		
AUGUST		-1	-1	-1		-1
SEPTEMBER	-1	-1	-1	-1	-0.5	-1
OCTOBER	-1	-1	-0.5	-1	-1	0
NOVEMBER	-1	0	-0.5	-1	-0.5	0
DECEMBER	-2	-1	-0.5	-0.5	0	0

Dashed cells: No data

CCIR	WAKKANAI	YAMAGAWA	MANILA	VANIMO	TOWNSVILLE	HOBART
JANUARY	-1	0	0	-0.5	0	-0.5
FEBRUARY	-1	-1	0	0	0	-0.5
MARCH	-1	0		-0.5	0	-0.5
APRIL	-1	0	-1		0	-1
MAY	-1	0	-1			
JUNE		0	-1			
JULY	-1		-1	-1		
AUGUST		0	-0.5	-1		-1
SEPTEMBER	0	0	-1	-0.5	0.5	-0.5
OCTOBER	-1	0	-0.5	0	-0.5	0
NOVEMBER	-1	0	-0.5	0	0	0
DECEMBER	-2	-1	-0.5	0	0	-0.5

Dashed cells: No data

Asiatic–Australian sector. Low solar activity year 1966.

Table 6
$\Delta t_{min} = t_{min\,IRI} - t_{min\,exp}$, in hours

URSI	WAKKANAI	YAMAGAWA	MANILA	VANIMO	TOWNSVILLE	HOBART
JANUARY	-2	0	-0.5	-1		0
FEBRUARY	-1	0	-0.5	-1		0
MARCH	-1	0	0	-1	0	-0.5
APRIL	-1	0	0	-1	-1	-0.5
MAY	-1	0	0	-1	-0.5	-1
JUNE	0	0	-1	-1	1	-1
JULY	-1		-0.5	-1		-1
AUGUST	-1	0	0	-1	0	
SEPTEMBER	-1	0	-0.5	-1	-0.5	-0.5
OCTOBER	1	-0.5	-0.5	-1.5	1	-0.5
NOVEMBER	-1	0	0	0	-0.5	
DECEMBER	-2	1	-0.5	1	0	0

Dashed cells: No data

CCIR	WAKKANAI	YAMAGAWA	MANILA	VANIMO	TOWNSVILLE	HOBART
JANUARY	-2	0	-0.5	0		0
FEBRUARY	0	0	-0.5	0		0
MARCH	-1	0	0	0	0	-0.5
APRIL	0	-0.5	0	0	0	-0.5
MAY	-1	0	0	-1	0.5	-1
JUNE	0	0	0	-1	0	0
JULY	0		0	-1		0
AUGUST	0	0	0	-1	-1	
SEPTEMBER	-1	0.5	0	-1	0.5	-0.5
OCTOBER	1	0	0	-1	-0.5	-0.5
NOVEMBER	-1	0	0	0.5	0	
DECEMBER	-2	1	0	1	0	-0.5

Dashed cells: No data

Asiatic–Australian sector. High solar activity year 1968.

Please cite this article in press as: Ezquer, R.G. et al., On the time of minimum ionization in the F2 region, J. Adv. Space Res. (2008), doi:10.1016/j.asr.2007.07.049

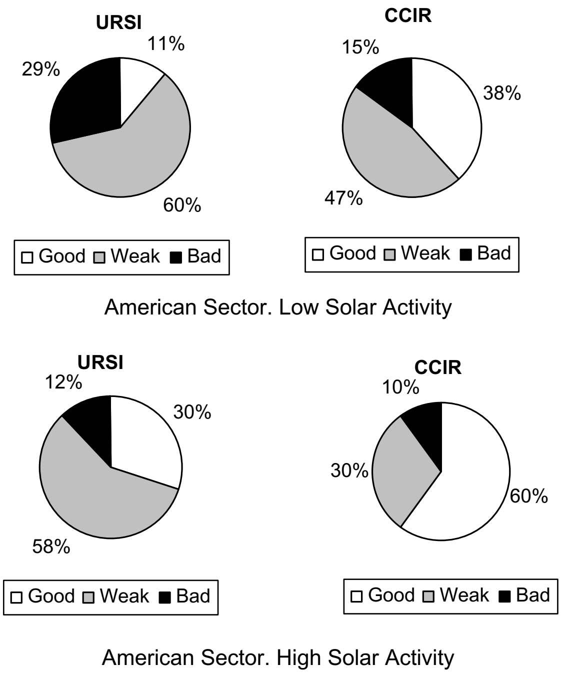

Fig. 5. Percentage of cases with good, weak and bad predictions. Topside: LSA; bottom side: HSA. American sector. All considered cases.

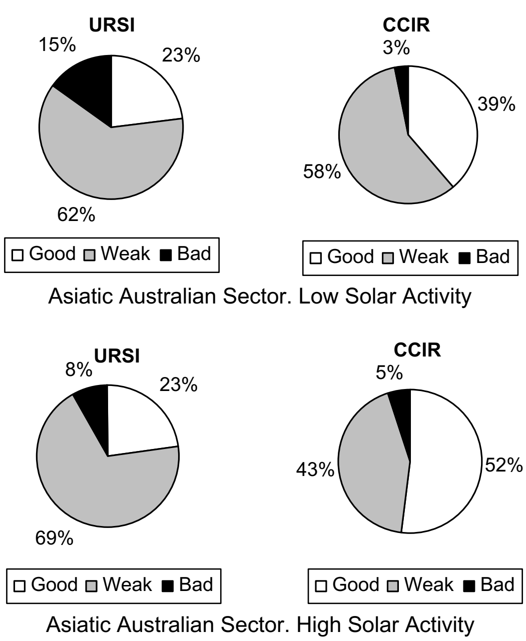

Fig. 6. Percentage of cases with good, weak and bad predictions. Topside: LSA; bottom side: HSA. Asiatic-Australian sector. All considered cases.

Cases with $\Delta t_{\min}$ absolute values greater than 1 h have been observed, particularly for high latitudes in the American sector.

In order to improve the performance of IRI model, additional studies considering other stations and conditions are needed.

References

Adeniyi, J.O., Bilitza, D., Radicella, S.M., et al. Equatorial F2-peak parameters in the IRI model. Adv. Space Res. 31 (3), 507–512, 2003.

Anderson, D.N. A theoretical study of the ionospheric F-region equatorial anomaly: II. Results in the American and Asian sectors. Planet. Space Sci. 21, 421–428, 1973.

Anderson, D.N., Mendillo, M., Hertniter, B. A semiempirical low latitude ionospheric model. Radio Sci. 22, 292–306, 1987.

Barghausen, A.L., Finney, J.W., Proctor, L.L., et al. Predicting long-term operational parameters of high frequency sky-wave telecommunication systems. ESSA Tech. Rept. ERL 110-ITS 78, Boulder, Colorado, 1969.

Bent, R.B., Llewelyn, S.K., Nesterczuk, G., et al. The development of highly successful worldwide empirical ionospheric model its use in certain areas of space communications and world-wide total electron content investigations. In: Goodman, J. (Ed.), Effect of the Ionosphere on Space Systems and Communications, Springfield, VA, pp. 13–28, 1976.

Bilitza, D., International Reference Ionosphere, Rep. NSSDC/WDC-A-R&S 90-22. National Space Science Data Center/World Data A for Rockets and Satellites, pp. 43–77, 1990.

Bilitza, D., Radicella, S.M., Reinisch, B.W., et al. New B0 and B1 models for IRI. Adv. Space Res. 25 (1), 89–95, 2000.

Bradley, P. Ingesting a sporadic-E model to IRI. Adv. Space Res. 31 (3), 577–588, 2003.

Bhuyan, P.K., Kakoty, P.K., Garg, S.C., et al. Subrahmanyam, electron and ion temperature and electron density at +10° magnetic latitudes from SROSS C2 measurements over India and comparison with the IRI. Adv. Space Res. 29 (6), 865–870, 2002.

Ezquer, R.G., Oviedo, R.del.V., Jadur, C.A. Ionospheric predictions for South American latitudes. Radio Sci. 31, 381–388, 1996.

Ezquer, R.G., Cabrera, M.A., Mosert, M., et al. Comparison between measured electrón density at 600 km of altitude and IRI predictions. Adv. Space Res. 29 (6), 883–886, 2002.

Ezquer, R.G., Scidá, L., Mansilla, G.A., et al. F2 region maximum electron density height predictions for South American latitudes. Radio Sci. 38 (4), 15.1–15.11, 2003.

Figurski, M., Wielgosz, P. Intercomparison of TEC obtained from the IRI model to the one derived from GPS measurements. Adv. Space Res. 30 (11), 2563–2568, 2002.

Leitinger, R., Radicella, S.M., Hochegger, G., et al. Diffusive equilibrium models for the height region above the F2 peak. Adv. Space Res. 29 (6), 809–814, 2002.

Llewellyn, S.K., Bent, R.B. Documentation and description of the Bent ionospheric model, AFCRL-TR-73-0657, AD 772733, Air Force Cambridge Research Laboratory, Bedford, MA, 1973.

Medeiros, R.T., Souza, J.R., Abdu, M.A., et al. Comparisons of IRI model and electron density data for the sub-equatorial station, Natal. Adv. Space Res. 31 (3), 557–561, 2003.

Please cite this article in press as: Ezquer, R.G. et al., On the time of minimum ionization in the F2 region, J. Adv. Space Res. (2008), doi:10.1016/j.asr.2007.07.049