p://dx.doi.org/10.22564/rbgf.v11

A MODIFIED ALGORITHM TO CALCULATE $hpF2$ FROM IONOGRAMS

I.S. Batista, E.R. de Paula, M.A. Abdu and M.G.S. Aquino

Instituto Nacional de Pesquisas Espaciais - INPE
Caixa Postal 515 12201-970, São José dos Campos, SP, Brasil

Comparisons between the height of the F layer peak ($hmF2$), derived using a true height analysis method, and the $hpF2$ approximation are used for two Brazilian low latitude stations to derive a modified algorithm to obtain the F layer peak height from ionograms as the virtual height, $h'F$, where the relation $hmF2 = h'F(f = c.foF2)$ holds. The c factor shows a local time dependence, as well as variations with season, sunspot number and latitude.

UM ALGORITMO MODIFICADO PARA CALCULAR $hpF2$ A PARTIR DE IONOGRAMAS *É feita uma comparação entre a altura do pico da camada F ($hmF2$), deduzida usando um método de conversão de altura virtual em altura real, e o parâmetro $hpF2$, para duas estações brasileiras em latitudes baixas. A diferença entre as alturas obtidas pelos dois métodos é usada para deduzir um algoritmo modificado, no qual a altura do pico da camada F ionosférica é obtida através da expressão $hmF2 = h'F(f = c.foF2)$, onde $h'F$ é a altura virtual da camada F e $foF2$ é a freqüência crítica da camada. O fator c apresenta variações com a hora local, com a estação do ano e com a latitude.*

INTRODUÇÃO

The height of the ionospheric F layer peak ($hmF2$) and its density ($NmF2$) are very important parameters, widely used in different research and practical applications, and the ionograms from bottomside sounders are the most abundant source of those parameters. While the peak density is easily obtained from ionograms, the determination of the height of the F layer peak demands some extra effort. The true height analysis, such as the POLAN code (Titheridge, 1985), provides reliable determination of $hmF2$ (see also Paul, 1967), within ±5 km. However, the methods based on true height analysis are rather time consuming, and only a small fraction of the recorded ionograms are analyzed using them. For this reason, the processing of data in applications requiring large geographical and local time coverage is generally performed using approximate methods that are simpler than the true height analysis, but less precise.

One of these approximations uses the assumption that the F layer profile can be represented by a parabola near its peak in such a way that the height of the parabolic F layer peak ($hpF2$) can be obtained directly from ionograms as the value of $h'F$ read at a sounding frequency f corresponding to 0.834 times

$foF2$ (Piggott and Rawer, 1978; Booker and Seaton, 1940), that is:

$$hpF2 = h'F(f = 0.834foF2). \quad (1)$$

Another approximation was developed by Shimazaki (1955), where the height of the F layer peak is obtained as a function of the ionospheric transmission factor M(3000)F2, the maximum usable frequency for a propagation path of 3000 km supported by F2-layer reflection. Shimazaki's formula is given by:

$$F2[M(3000)] = 1490/M(3000)F2 - 176. \quad (2)$$

Subsequent works have introduced modifications in Shimazaki's formula, mainly with the intent to add corrections for retardation by underlying layers (Bradley and Dudeney, 1973; Bilitza et. al., 1979). A comparison of the height of the maximum electron density of the F2-layer from real height analysis and estimates based on M(3000)F2 for one day of data in Logan, Utah (41.6°N, 111.6°W) was made by Berkey and Stonehocker (1989).

In the present work we compare the F layer height parameter $hmF2$, deduced using POLAN, with $hpF2$ and $hmF2[M(3000)]$, all deduced from ionograms registered over Fortaleza (4°S, 38°W) and over Cachoeira Paulista (23°S, 45°W), for the months of March and December, 1988, representative of local equinox and summer, respectively. Further, the comparison between $hmF2$(POLAN) and $hpF2$ is used to derive a new algorithm to obtain $hpF2$ values from ionograms, that represent better approximations to the real peak height of the F2 layer for the low latitude stations used in this work. Table 1 shows the period of data used for each station, as well as the mean value of the international sunspot number (RI) and F10.7 flux for each month.

DATA ANALYSIS

In Fig. 1 we show the comparison of $hmF2$(POLAN), $hpF2$ and $hmF2[M(3000)]$ monthly

Table 1. Data periods, stations and corresponding solar activity parameters

Períodos de dados, estações e parâmetros de atividade solar correspondentes

Month	Station	RI	F10.7
Dec. 79	Fortaleza	176.3	197.1
Mar. 80	Fortaleza	126.2	166.2
June 80	Fortaleza	157.3	199.3
Mar. 86	Fortaleza	15.1	76.2
June 86	Fortaleza	1.1	69.7
Dec. 86	Fortaleza	6.8	72.6
Mar. 88	Fortaleza	76.2	113.8
Mar. 88	C.Paulista	76.2	113.8
Dec. 88	Fortaleza	179.3	193.5
Dec. 88	C.Paulista	179.3	193.5

means for March and December 1988, over Fortaleza and Cachoeira Paulista. We can see that the best correlation between the three parameters is obtained during nighttime, when very few underlying ionization is present. As was already shown by Batista et al. (1991), during nighttime $hmF2[M(3000)]$ and $hpF2$ are almost coincident and each of them can be used to represent the F layer peak height with an error not greater than 20 km. During daytime, however, the errors are much larger. The use of Bradley and Dudeney (1973) formula to correct $hmF2[M(3000)]$ will improve the results over Fortaleza, but not over Cachoeira Paulista (Batista et. al., 1991).

Modification of the Algorithm to Calculate $hpF2$

The parameter $hpF2$ has been extensively used in ionospheric works to represent the real F2 peak height (de Paula et. al., 1981; Abdu et al., 1990). In order to improve the results given by this parameter over Fortaleza and Cachoeira Paulista we have developed a modified algorithm to calculate $hpF2$ based on the following criteria. The constant $c = 0.834$ in Eq. (1) must be modified in such a way that

$$hpF2(TW) = hmF2(POLAN) = h'F(f = c.foF2), \quad (3)$$

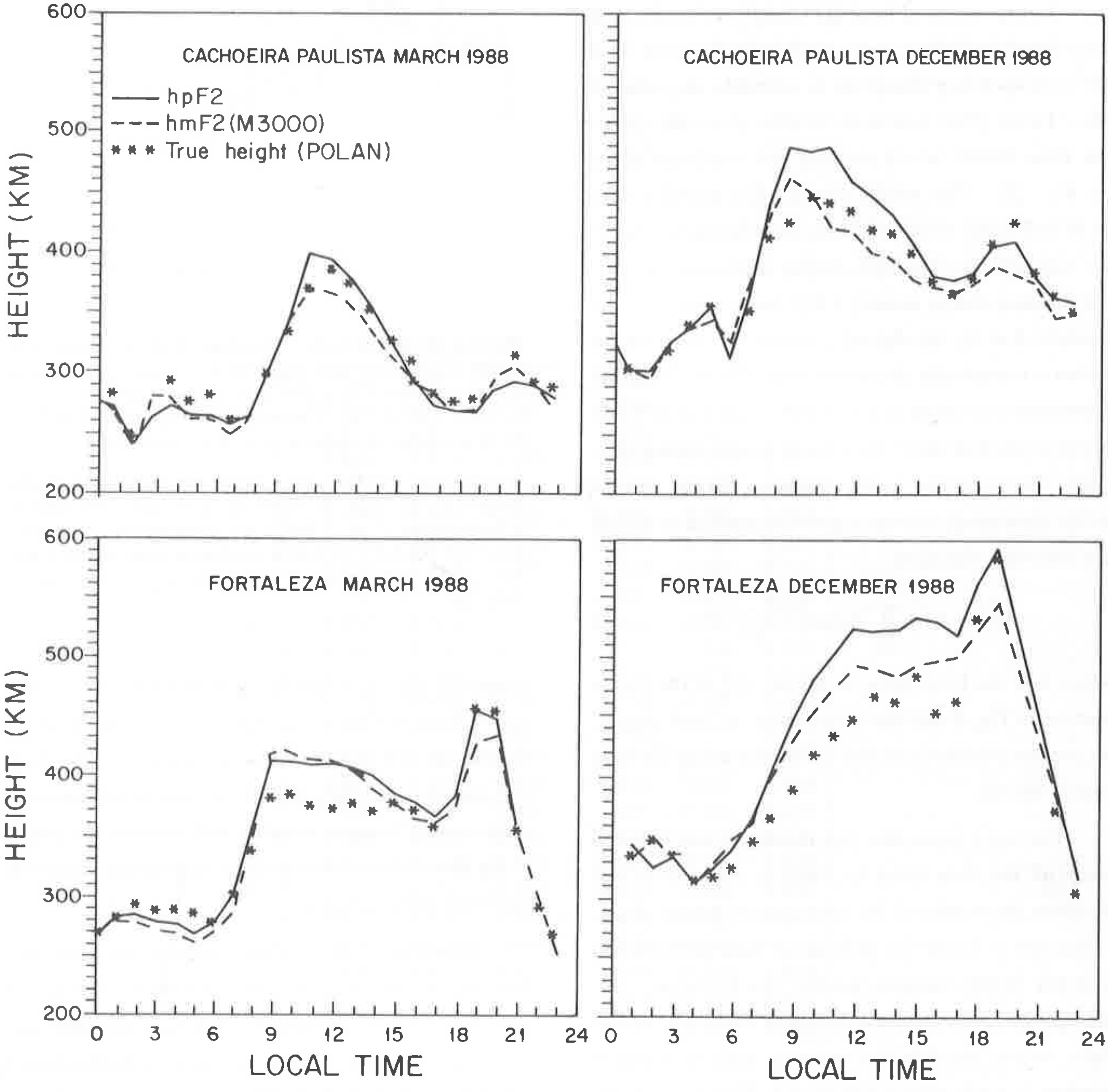

Figure 1. Comparison between F2 layer parameters *hpF*2, *hmF*2[M(3000)] and *hmF*2(POLAN) over Cachoeira Paulista and Fortaleza.

Comparação entre os parâmetros da camada F2 hpF2, hmF2[M(3000)] e hmF2(POLAN) sobre Cachoeira Paulista e Fortaleza.

where $hpF2(TW)$ is the height of the F layer peak density obtained by this work.

Hourly values of $hmF2$(POLAN) for each set of data listed in Table 1 were used in conjunction with the corresponding ionogram to calculate the value of the c factor (that now is a variable, generally different from 0.834) which satisfies the condition given by Eq. (3). The results for the five quietest days of March 1980, over Fortaleza, are shown in Fig. 2. As was already expected, during nighttime the factor assumes values around 0.834 (represented by the straight line in the figure). However, the c factor shows a remarkable diurnal variation that should be taken into account in order to derive $hpF2$ that would better represent the F layer peak height during daytime. The solid line in Fig. 2 represents the best fit to the data using a linear regression method to adjust the following equation

$$c(t) = a_0 + \sum_{i=1}^{n} a_i cos \frac{2\pi(t-\phi_i)^i}{24}, \qquad (4)$$

where t is the local time, in hours, $c(t)$ is the factor plotted in Fig. 2 and the amplitudes, a_i, and phases, ϕ_i, are the parameters to be calculated using the least square fitting.

The same procedure just described was followed using all the data listed in Table 1. Figures 3a and 3b show the results of the least square fitting to calculate the c factor for periods of high (1979/1980) and low (1986) sunspot number for Fortaleza. Although we observe some seasonal variation of the data, we can see that the variation with the sunspot number is much more pronounced. This is more evident in Fig. 4, where the c factor is plotted for three different levels of solar activity. Table 2 shows the hourly values of the c factor for Fortaleza for high (SMAX) and low (SMIN) solar activity levels, for the months of March, June and December, representative of equinox, winter and summer, respectively.

Fortaleza (-7^o magnetic dip) is located near the magnetic equator, while Cachoeira Paulista (-29^o magnetic dip) is a low latitude station. The c factors calculated for each of these two stations show significant differences as shown in Fig. 5. The diurnal variation on the c factor, as well as its variation with season, sunspot number and latitude are essentially due to the variation of the underlying ionization with the solar radiation.

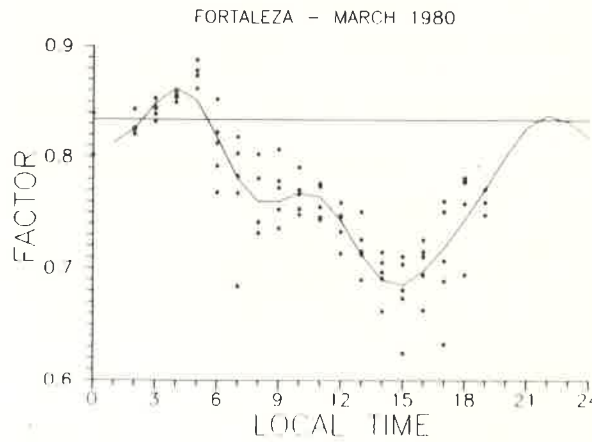

Figure 2. Local time variation of the c factor that satisfies Eq. (3). The value of $h'F$, that corresponds to a frequency $f = c.foF2$ in the ionogram, is equal to $hmF2$(POLAN). The solid line represents the best fit of a cosine expansion (Eq. 4) to the data.

Variação do fator c, em função da hora local, o qual satisfaz a Eq. (3). O valor de h'F, que corresponde à frequência f = c.foF2 no ionograma, é igual a hmF2(POLAN). A curva contínua representa o melhor ajuste aos dados de uma expansão em cossenos (Eq. 4).

Based on all the periods analyzed, we have constructed a data base for the coefficients of Eq. (4) (amplitudes and phases) for equinox, summer and winter periods, and for low, medium and high sunspot number, over Fortaleza. With this data base the diurnal variation of the c factor can be easily obtained from Eq. (4), for each characteristic period. This modified c factor can be used in connection with the corresponding ionogram in such a way that Eq. (3) is satisfied and a modified $hpF2$ that better represents the F layer peak height is obtained.

In order to use the new c factor in manual ionogram scaling, it is necessary to construct tables of

Table 2. Hourly values of the "c factor" for Fortaleza.

Valores horários do "fator c" para Fortaleza.

	SMAX			SMIN		
LT	MAR	JUN	DEC	MAR	JUN	DEC
1	0.813	0.848	0.801	0.859	0.872	0.856
2	0.825	0.847	0.817	0.849	0.893	0.867
3	0.848	0.851	0.835	0.878	0.933	0.887
4	0.862	0.859	0.840	0.906	0.948	0.897
5	0.851	0.857	0.825	0.885	0.897	0.873
6	0.818	0.834	0.799	0.804	0.784	0.813
7	0.781	0.791	0.776	0.704	0.662	0.740
8	0.760	0.745	0.763	0.647	0.593	0.692
9	0.760	0.716	0.754	0.663	0.601	0.685
10	0.768	0.706	0.738	0.724	0.648	0.705
11	0.764	0.700	0.710	0.772	0.675	0.720
12	0.743	0.680	0.680	0.770	0.653	0.709
13	0.713	0.647	0.661	0.730	0.608	0.682
14	0.690	0.621	0.662	0.699	0.595	0.670
15	0.685	0.626	0.680	0.712	0.647	0.694
16	0.697	0.667	0.709	0.760	0.744	0.748
17	0.719	0.727	0.740	0.809	0.836	0.801
18	0.744	0.776	0.772	0.834	0.883	0.829
19	0.772	0.798	0.804	0.841	0.889	0.830
20	0.802	0.800	0.831	0.858	0.882	0.822
21	0.827	0.801	0.844	0.893	0.886	0.824
22	0.838	0.812	0.837	0.928	0.896	0.838
23	0.832	0.831	0.818	0.931	0.894	0.851
24	0.818	0.845	0.801	0.898	0.879	0.855

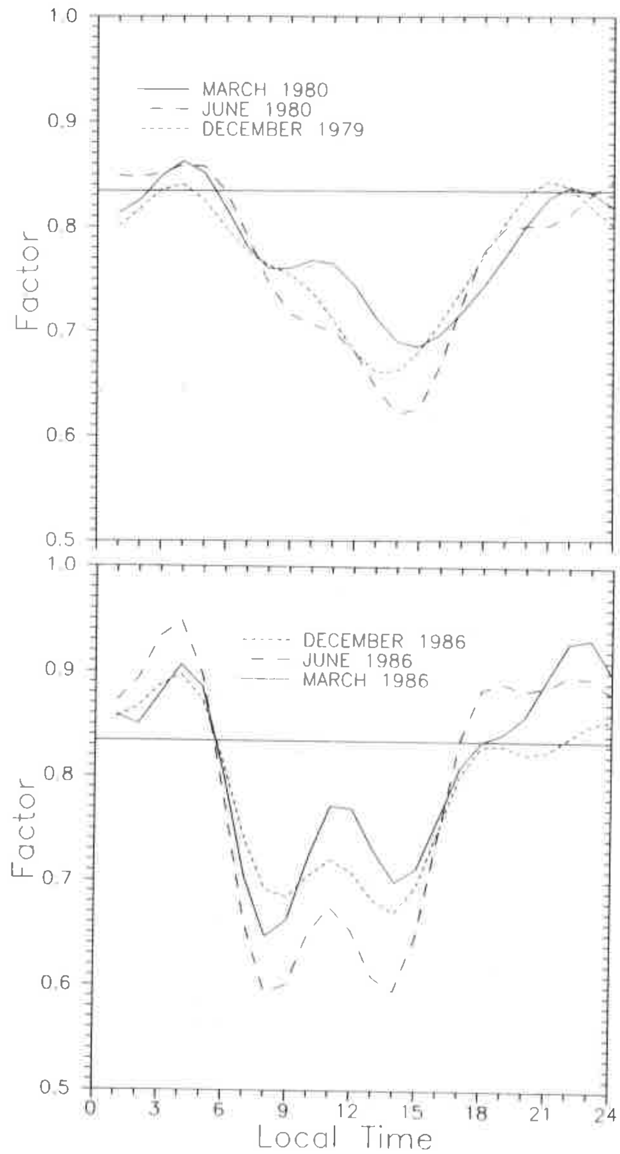

Figure 3. Seasonal variation of the *c* factor for high (1979-80) and low (1986) solar activity over Fortaleza.

Variação sazonal do fator c para períodos de alta (1979-80) e baixa (1986) atividade solar sobre Fortaleza.

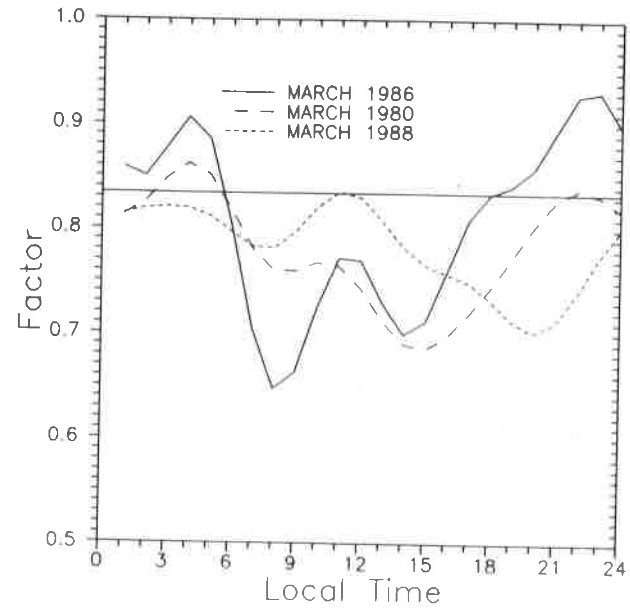

Figure 4. Variation of the *c* factor with the solar activity, over Fortaleza.
Variação do fator c com a atividade solar sobre Fortaleza.

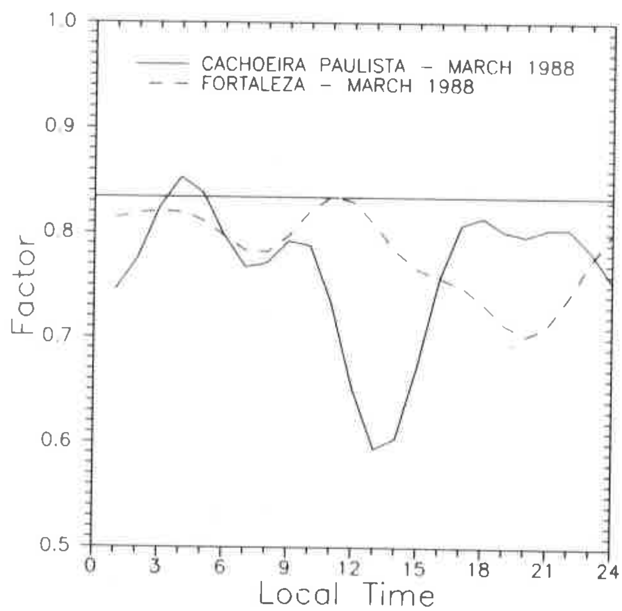

Figure 5. Local time variation of the *c* factor for two different latitudes.

Variação do fator c com a hora local para duas latitudes diferentes.

hourly values, one for each season and for three different levels of solar activity. In stations where the ionogram scaling is performed by using a digitizing table connected to a microcomputer, the use of the new c factor becomes much simpler than in the manual scaling, because the computer program that is used to scale the data can easily read the data base used to generate the c factor as a function of time, season sunspot number and latitude, and the c factor can be calculated directly by the computer program (Eq. 4).

CONCLUSIONS

The use of $hpF2$ to represent the height of the F layer peak over low latitude stations can lead to results that overestimate the real height by more than 50 km during daytime. In this work we have developed a modified algorithm to calculate $hpF2$ from ionograms, based on $hmF2$ from two low latitude stations. Besides the local time variation, the c factor here determined to calculate $hpF2$ shows seasonal, latitudinal and solar cycle variation, as should be expected because the $hpF2$ is influenced by underlying ionization that, on its turn, is under the influence of the solar ionization. The use of this modified algorithm can greatly improve the estimations of $hmF2$ from ionograms.

ACKNOWLEDGEMENTS

This work was partially financed by CNPq under processes 300915/92-6 and 500003/91-2.

REFERENCES

ABDU, M.A., WALKER, G.O., REDDY, B.M., SOBRAL, J.H.A., FEJER, B.G., KIKUCHI, T., TRIVEDI, N.B. and SZUSZCZEWICZ, E.P. (1990) Electric Field Versus Neutral Wind Control of the Equatorial Anomaly Under Quiet and Disturbed Conditions: A Global Perspective From SUNDIAL 86. Ann. Geophys., 8, 419-430.

BATISTA, I.S., de PAULA, E.R., ABDU, M.A. and KANTOR, I.J. (1991) Comparative Study of Ionogram F2 Peak Height From Different Techniques. Geofisica Internacional, 30, 249-252.

BERKEY, F.T. and STONEHOCKER, G.H. (1989) A Comparison of the Height of the Maximum Electron Density of the F2 Layer From Real Height Analysis and Estimates Based on M(3000) F2. J. Atmos. Terr. Phys., 51, 873-877.

BILITZA, D., SHEIKH, N.M. and EYRIG, R. (1979) A Global Model for the F2-Peak Using M3000 Values from the CCIR Numerical Maps. Telecomm. J., 46, 549-553.

BOOKER, H.G. and SEATON, S.L. (1940) Relation Between Actual and Virtual Ionospheric Height. Phys. Review, 57, 87-94.

BRADLEY, P.A. and DUDENEY, J.R. (1973) A Simple Model of the Vertical Distribution of Electron Concentration in the Ionosphere. J. Atmos. Terr. Phys. 35, 2131-2146.

de PAULA, E.R., KANTOR, I.J. and ABDU, M.A. (1981) A Comparative Study of the CCIR Predictions of foF2 and hmF2 over Brazil. Telecomm. J., 48, 589-593.

PAUL, A.K. (1967) Ionospheric Electron-Density Profiles with Continuous Gradients and Underlying Ionization Corrections. I. The Mathematical-Physical Problem of Real-Height Determination From Ionograms. Radio Sci., 2, 1127-1133.

PIGGOTT, W.R. and RAWER, K. (1978) URSI Handbook For Ionogram Interpretation and Reduction. World Data Center A, Report UAG-23A, Boulder, CO, USA.

SHIMAZAKI, T. (1955) World-Wide Daily Variation in the Height of the Maximum Electron Densities of the F2 layer. J. Radio Res. Labs., Japan, 2, 85-97

TITHERIDGE, J.E. (1985) Ionogram Analysis With the Generalised Program POLAN. World Data Center A, Report UAG-93, Boulder, CO, USA, 194 pp.

Submetido em 15.03.93
Revisado em 17.06.93
Aceito em 17.06.93
Editor responsável V.W.J.H. Kirchhoff