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Semiempirical model of the ionospheric maximum electron concentration for South American middle latitudes

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RESUMEN

Se propone un modelo muy simple que da valores horarios de la máxima concentración electrónica en la ionosfera, representativa de las condiciones del verano, invierno y los equinoccios, para niveles de actividad solar tanto altos como bajos. La concentración de electrones se determina como la suma de dos términos, uno relacionado con los procesos fotoquímicos y difusivos y el otro con los mecanismos de transporte. Se dan expresiones analíticas simples para estos dos términos y los valores de la frecuencia crítica en la región F calculados usando estos términos se comparan con los valores observados en la isla de King George, Antártica y en Concepción, Chile.

PALABRAS CLAVE: Ionosfera, N_m, modelo.

ABSTRACT

A simple model giving hourly values of the ionospheric maximum electron concentration, representative of summer, winter and equinox conditions for both high and low solar activity level is proposed. Electron concentration is determined as the sum of two terms, one related to photochemical and diffusive processes and the other to transport mechanisms. Simple analytical expressions for these two terms are given, and F-region critical frequency values calculated using them are compared with values observed at King George Island, Antarctica, (62.2°S; 58.8°W), and Concepción, Chile (36.8°S; 73.0°W).

KEYWORDS: Ionosphere, N_m, model.

1. INTRODUCTION

Although theoretical and empirical models to determine peak electron concentration at a given place and time have been known for a long time (e.g. Anderson *et al.*, 1989), they are usually quite complex. Most of them require an atmospheric model specified to considerable detail (e.g. Berkey *et al.*, 1987), or rely on long series of spherical harmonic functions and associated numerical coefficients fitted to observed values (e.g. CCIR, 1967). Other simpler models do not give peak electron concentration values to the required accuracy for some applications (e.g. Rose and Martin, 1978).

The approach followed here assumes that conceptual models based on simple chemical and physical processes, as suggested by Risbeth (1986), are still worth pursuing. In section 2 proposed analytical expressions for both photochemical-diffusive and transport related terms are given, which are extensions of some expressions found for a single station study (Arriagada *et al.*, 1990). In section 3 values of F-region critical frequency determined using these new equations are compared with those observed at King George Island, Antarctica, (62.2°S; 58.8°W), and Concepcion, Chile, (36.8°S; 73.0°W).

2. PROPOSED MODEL

Photochemical-diffusive term N_m

This term is derived by numerical solution of the electron concentration continuity equation with photochemical and diffusive contributions, at the height of peak electron concentration,

$$\frac{dN_m}{dt} = q - L_Q - L_d$$

where the rate of change of peak electron concentration depends on:

q = rate of production, assumed to be the Chapman production function for grazing incidence,

L_Q = rate of chemical loss, assumed to depend on ion-atom interchange reactions only, thus proportional to electron concentration, and

L_d = rate of loss by diffusive vertical transport, also assumed to be proportional to electron concentration.

The differential equation to be numerically integrated is then

$$(dN_m/dt) = q_o \exp(1 - z_m - \exp(-z_m) Ch(x,\chi)) - c_N N_m \beta_o \exp(-Kz_m),$$

where q_o is the rate of production for vertical incidence ionization at the height of the peak production, which is assumed to depend only on the solar activity level as

$$q_o = 902.775\ (1 + 0.0054\ R)$$

R is the twelve-month running mean international sunspot number. Values for q_o at low solar activity level are consistent with those quoted by Ganguly *et al* (1980). Ch(x,χ) is the grazing incidence Chapman function. The height of peak electron concentration, z_m, is taken as that given from the following equations:

Sunrise: $z_m = \ln Ch(x, \chi) + c_{z1}$

Daytime: $z_m = (1/K+1)) \ln (\beta_o/(d_o L_e))$

Nighttime: $z_m = (1/(K+1)) \ln (\beta_o/(d_o L_s)$

Values adopted for constants $K, \beta_o, d_o, c_N, c_{z1}, L_e, L_s$ are those quoted by Rishbeth (1967) and they are given in the Table.

For a given location, season and solar activity level specified by geographic latitude, solar declination (0°, 19.1° and -18.1° for equinox, winter and summer, and sunspot number (20 and 100 for low and high level), the numerical integration iteration is started assuming arbitrary initial values for local time, t_o, and peak electron concentration, N_o. Using an iteration time step of 0.25 hour, values of N_m are then determined for a 24 hour period. If N_m for t_o + 24 hours differs from N_o by less than 2%, the calculated N_m values are adopted. Otherwise further 24 hour iterations are performed till this threshold is reached.

Transport related term ΔN_m

Values of ΔN_m are determined as

$$\Delta N_m = 1.24.10^4 \left[C_o + C_1 \cos \frac{2\pi}{24}(t - 3.18\phi_1) + C_2 \cos \frac{4\pi}{24}(t - 1.9\phi_2)\right]$$

The amplitude coefficients, C_i, and the phase angles ϕ_i, are calculated using the following equations:

$$C_o = 2.39\ (1 - 0.024X)\ (1 - 0.017\delta)\ (1 + 0.0167R)$$

$$C_1 = 0.2\ (0.307X - 1)\ (1 - 0.012\delta)$$

$$C_2 = 0.5\ (1 + 0.026\delta)$$

$$\phi_1 = 0.39\ (1 + 0.01698\delta)\ (1 + 0.0216R)$$

$$\phi_2 = 9.09\ (1 - 0.0144X)\ (1 + 0.041\delta)\ (1 + 0.0044R)$$

where X is the modified magnetic dip of the location ($X = \tan^{-1}(I/\sqrt{\cos\lambda})$; I magnetic dip, λ geographic latitude) and δ is solar declination. There is no clear relation between the time-of-day dependency of ΔN_m and that of published meridional neutral-atmosphere wind data representative of F-region heights (Canziani *et al.*,1990; Buonsanto, 1991 and Hedin *et al.*, 1991).

3. RESULTS

Using the proposed model equations, F-region critical frequencies were determined for winter, equinox and summer conditions corresponding to both low and high solar activity level, at King George Island and Concepción. These values are compared with observed seasonal hourly medians in Figures 1 and 2.

Best results are found for King George Island at low solar activity level. Typical diurnal variations observed during summer, with minima occurring in the afternoon, are also well reproduced by the model for high solar activity level. The time of least critical frequency observed at Concepción is accurately predicted by the model for all conditions. However, large differences between observed and model values are found, particularly at the time of maximum during winter for Concepción at low solar activity level, and during equinox for high level at King George Island.

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Table

Proposed model constants of photochemical-diffusive term for all seasons and solar activity levels.

K	β_o ($10^{-2}S^{-1}$)	d_o ($10^{-5}S^{-1}$)	L_e	L_s	Sunrise c_N	Day c_N	Night c_N	c_{z1}
1.75	1	2.5	0.8	0.15	1.25	1.25	1.6	0.25

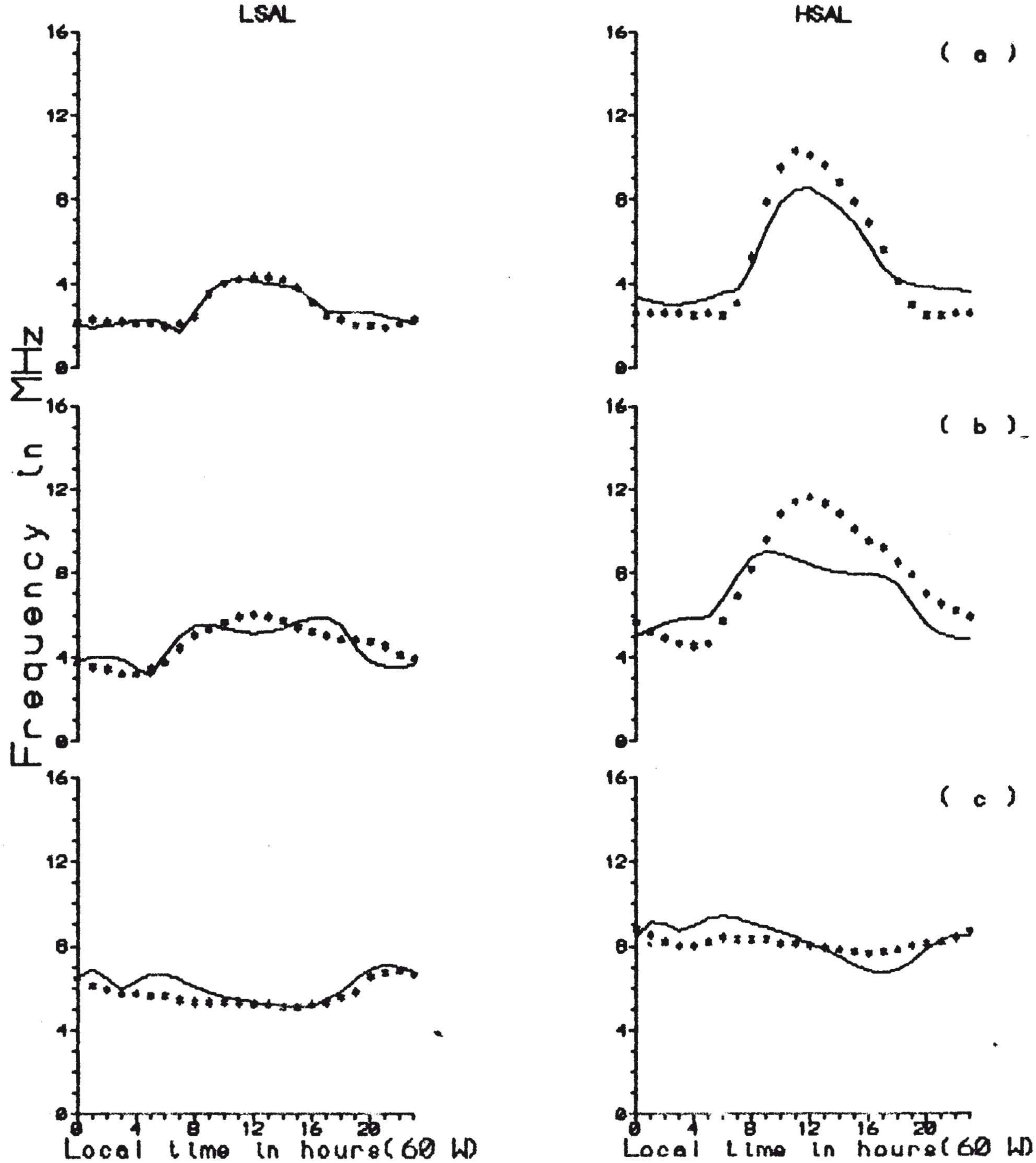

Figure 1. Daily variation of observed seasonal median critical frequency for King George Island (62.2 S; 68.8 W), Antarctica and those calculated with proposed semiempirical model. (LSAL) Low solar activity level (1986). (HSAL) High solar activity level (1989). (a) Winter (M.J.J.A.).(b) Equinox (M.A.S.O.) (c) Summer (N.D.J.F.).

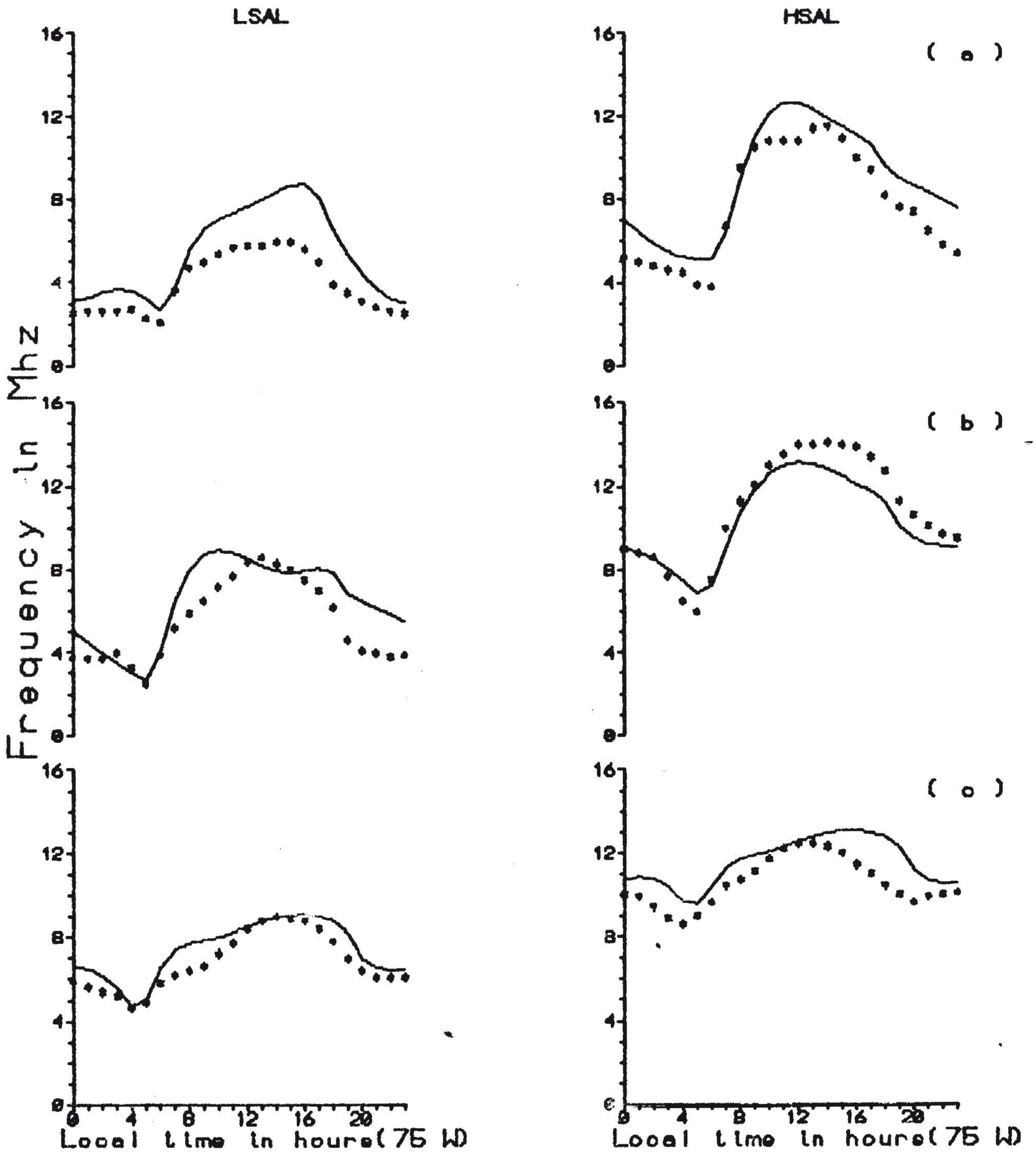

Figure 2. Daily variation of observed seasonal median critical frequency for Concepcion (36.8S; 73.0W) and those calculated with proposed semiempirical model. (LSAL) Low solar activity level (1963, 1964, 1965, 1976). (HSAL) High solar activity level (1958, 1959, 1969, 1970 1979, 1980). (a) Winter (M.J.J.A.).(b) Equinox (M.A.S.O.) (c) Summer (N.D.J.F.).

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