Geofísica Internacional (1996), Vol. 35, Num. 1, pp. 77-81

Morphological characteristics of ionospheric E layer over El Cerrillo station, Mexico during magnetically quiet conditions

E. A. Araujo Pradere[1], L. Lois Menéndez[2] and H.J. Durand Manterola[1]
[1] *Instituto de Geofísica, UNAM, Mexico.*
[2] *Instituto de Geofísica y Astronomía. CITMA., La Habana, Cuba.*

Received: February 24, 1995; accepted: November 22, 1995.

RESUMEN

Se describe la región E de la ionosfera observada en la estación ionosférica de El Cerrillo, México bajo condiciones magneto tranquilas y para diferentes niveles de actividad solar. Se obtiene que su comportamiento es típico de una región en equilibrio fotoquímico y puede ser bien descrita a partir de la Teoría de Capa Simple de Chapman. Si se elimina la suposición de atmósfera isotérmica y se consideran gradientes de escala de altura constantes dH/dh≈0.2, los valores del exponente N, encontrados por regresión lineal entre la frecuencia crítica y el ángulo cenital del Sol, son muy semejantes a los predichos por la teoría de Chapman. Sus máximos valores de frecuencia (concentración) se encuentran un poco después del mediodía local y dependen fuertemente del nivel de actividad solar. Bajo condiciones diurnas, foE se incrementa entre 7 y 10 veces, teniendo la máxima razón durante períodos de Baja Actividad Solar. Se observa una clara tendencia de incremento de foE con la actividad solar.

PALABRAS CLAVE: Ionosfera, morfología, aeronomía.

ABSTRACT

We have used foE data obtained during magnetically quiet conditions to describe the behavior of the E region at El Cerrillo, Mexico. This region is in photochemical equilibrium and its shape fits the parabolic geometry of Chapman's theory. If the isothermal assumption is relaxed and constant gradients of scale heights dH/dh≈0.2 are assumed, the exponent N of a linear regression matches closely Chapman's predictions. Maximum values of foE occur slightly after local noon, and depend on the level of solar activity. During daytime foE rises 7 to 10 times, with the highest rate of increase occurring during Low Solar Activity periods. There is a clear tendency for foE to increase with solar activity.

KEY WORDS: Ionosphere, morphology, aeronomy, E layer.

1. INTRODUCTION

Research on the structure and behavior of the local ionosphere is a first step toward modeling and understanding the ionospheric system. In Mexico, one ionospheric station has been in operation for 30 years; however, only one study of its data has been conducted (Pérez de Tejada, 1973). This paper attempts to continue this work in the direction of deriving local models that meet scientific requirements. We describe the E region morphology as a first step towards obtaining a local ionosphere model.

2. DATA AND METHODS

We select hourly - daily values of foE from the data obtained at the C-4 radio sounding station in El Cerrillo (ϕ=19° 19'N, λ=99° 32'W), near Toluca, Mexico. Magnetic index k_p and solar parameter Rz were used as auxiliary data to define the level of geomagnetic perturbation and of solar activity, respectively.

The data selection was conditioned by the quality of the information in the periods of observation. We took into account the amount of data available in each period, and we excluded periods of equipment malfunction.

We also took into account the phase of solar activity. We defined High Solar Activity (HSA) as Rz≈140 and Low Solar Activity (LSA) as Rz≈20. We also used data from intermediate levels of solar activity, nominally Rz≈40 - 80. Finally we assumed $k_p \leq 3$, wich implies a quiet condition of the magnetosphere. Thus we avoided geomagnetic field perturbations.

For convenience we chose the year 1960 as HSA, the winter of 1975 and the summer of 1973 as LSA, and the winter of 1962 and 1983 and the summer of 1975 and 1972 as intermediate levels of solar activity.

In the frame of Chapman's theory (Chapman, 1931), we started from the result for the relationship between critical frequency (fo) and zenithal angle (χ):

$$fo \propto (\cos\chi)^n \qquad (1)$$

where n = 0.25 is obtained from theory. In this work we call the Chapman index N. From the linear regression plot of $\ln|f_o|$ *vs* $\ln|\cos\chi|$ we find the slope φ of the best fitting straight line. The exponent will be given by N = tan φ, which equals the Chapman index.

3. RESULTS

Figure 1 shows foE daily variations at El Cerrillo, for various levels of solar activity and for different seasons as a function of Local Meridian Time (LMT) between 0700 and 1800 LMT. Observe that the behavior of the E region in summer, winter and equinoxes agrees with the general parabolic shape of Chapman's theory. This is expected due to the minor importance of transport processes at this height. The maximum values of foE change with solar activity.

The foE mean values reach their maxima at local noon, 3.2 Mhz in winter and 3.6 Mhz in summer for LSA (Figure a), and 3.9 and 4.1 Mhz for HSA (Figure b). In each case foE decays more or less symmetrically about the maximum.

The low levels coincide approximately with sunrise and sunset. These levels are defined by the technical limitations of the radio sounding station and by the interference in the area. They are not true minimum levels; the E layer has actually a night time existence with lower values of 0.4 - 0.6 Mhz ($2\text{-}4 \times 10^9$ cm^{-3}) as obtained from the International Reference Ionosphere (IRI) (Rawer *et al.*, 1978).

In conclusion, during daytime foE rises by a factor of 7 to 10, with the highest rates of increase occurring during LSA. On some days, foE values can reach even higher values due mainly to magnetic perturbations, transients and ionization transport.

In general, E layer has a regular behavior. Changes in electronic density are similar from day to day. From a seasonal or cyclic point of view, there are no important variations in this parameters, even when peak values are reached during summer or the equinoxes, and during HSA periods. The maximum magnitudes of foE in summer exceed by 0.3 Mhz the maximum magnitudes in winter, and they increase by 0.6 Mhz from LSA to HSA.

In winter this layer is recorded between 0700 - 1600 LMT, while in summer and equinox it is recorded between 0700 - 1800 LMT. The difference is due to the fact that daytime is longer during summer and equinoxes. Thus the frequency values exceed the station threshold sensitivity during a longer period.

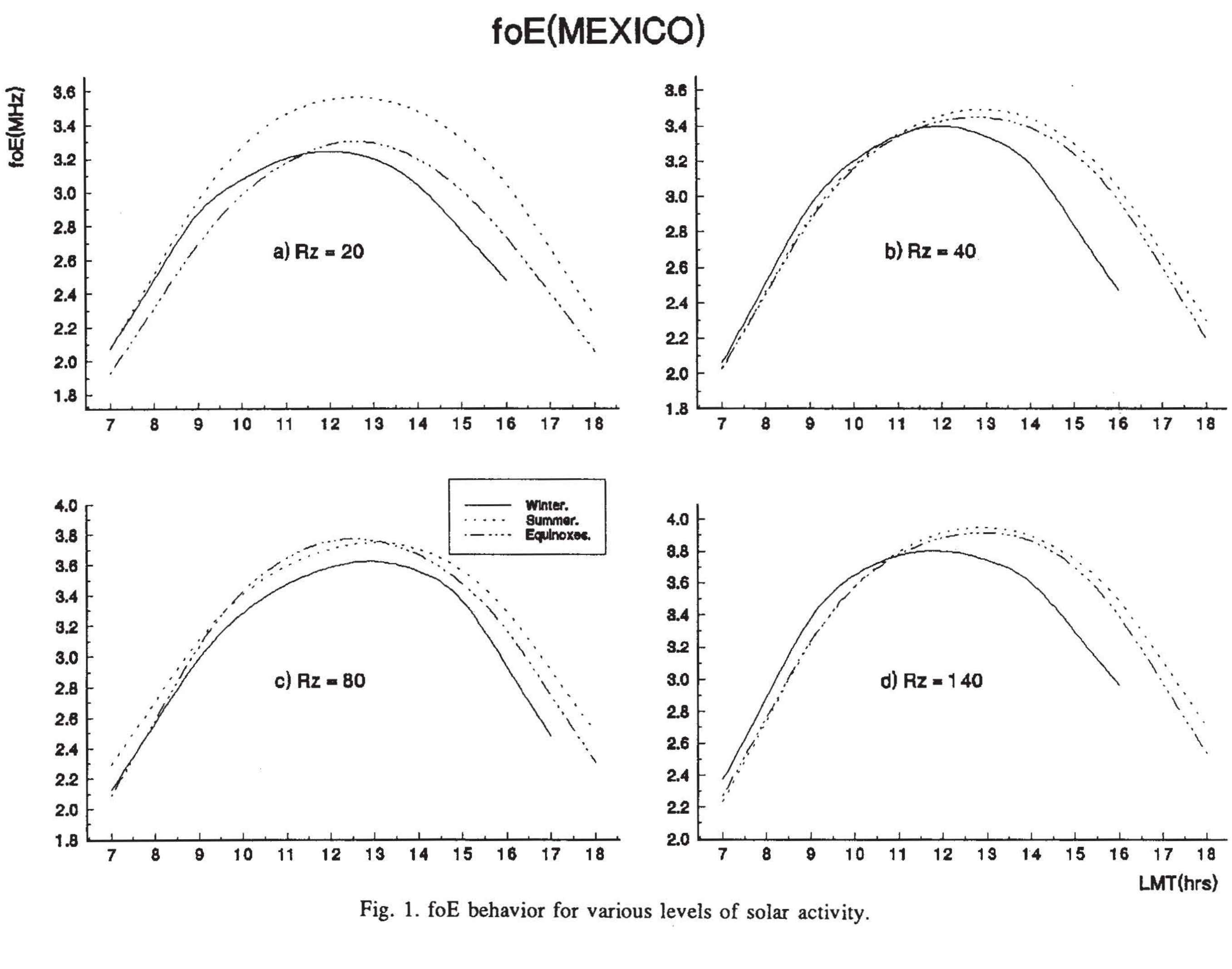

Fig. 1. foE behavior for various levels of solar activity.

Using photochemical theory in the E layer, we may assume $\partial N/\partial t = 0$ and regard this layer as a simple Chapman layer in equilibrium. This justifies, among other things, a slight displacement of the foE peak from local noon because of the time constant $(2\alpha Nm)^{-1} \approx 10$ minutes introduced by the recombination coefficient (Appleton, 1937). The actual E layer does not behave like the Chapman model because of perturbations of the photochemical equilibrium by transport processes and the dependence of the recombination coefficient on height.

We compute the exponent of Eq. (1) for the local E layer data by the procedure described in Section 2. Results for summer and winter, and for various levels of solar activity, are shown in Table 1. In this table the Chapman index of the E region for different conditions is close to N ≈ 0.30 which is slightly larger than Chapman's theoretical value ($n = 0.25$). This agrees with results obtained by many other researchers (Tremellen and Cox, 1947; Lazo y Palacio, 1974).

Table 1

E-layer Chapman index values in winter and summer, during various levels of solar activity.

SEASON/YEAR	LEVEL OF SOLAR ACTIVITY	CHAPMAN INDEX
Winter 1975	$Rz \approx 20$	N=0.30
Summer 1973		N=0.33
Winter 1962	$Rz \approx 40$	N=0.32
Summer 1975		N=0.32
Winter 1983	$Rz \approx 80$	N=0.32
Summer 1972		N=0.30
Winter 1960	$Rz \approx 140$	N=0.31
Summer 1960		N=0.32

The differences between theoretical and actual values of the Chapman index may be explained by the existence of a positive gradient of the scale height H (Rishbeth and Garriot, 1969). This difference modifies the exponent of (1) by a factor $(1 + \Gamma)$, where $\Gamma = dH/dh \approx 0.2$ in agreement with thermospheric models. Thus, changes in the recombi–

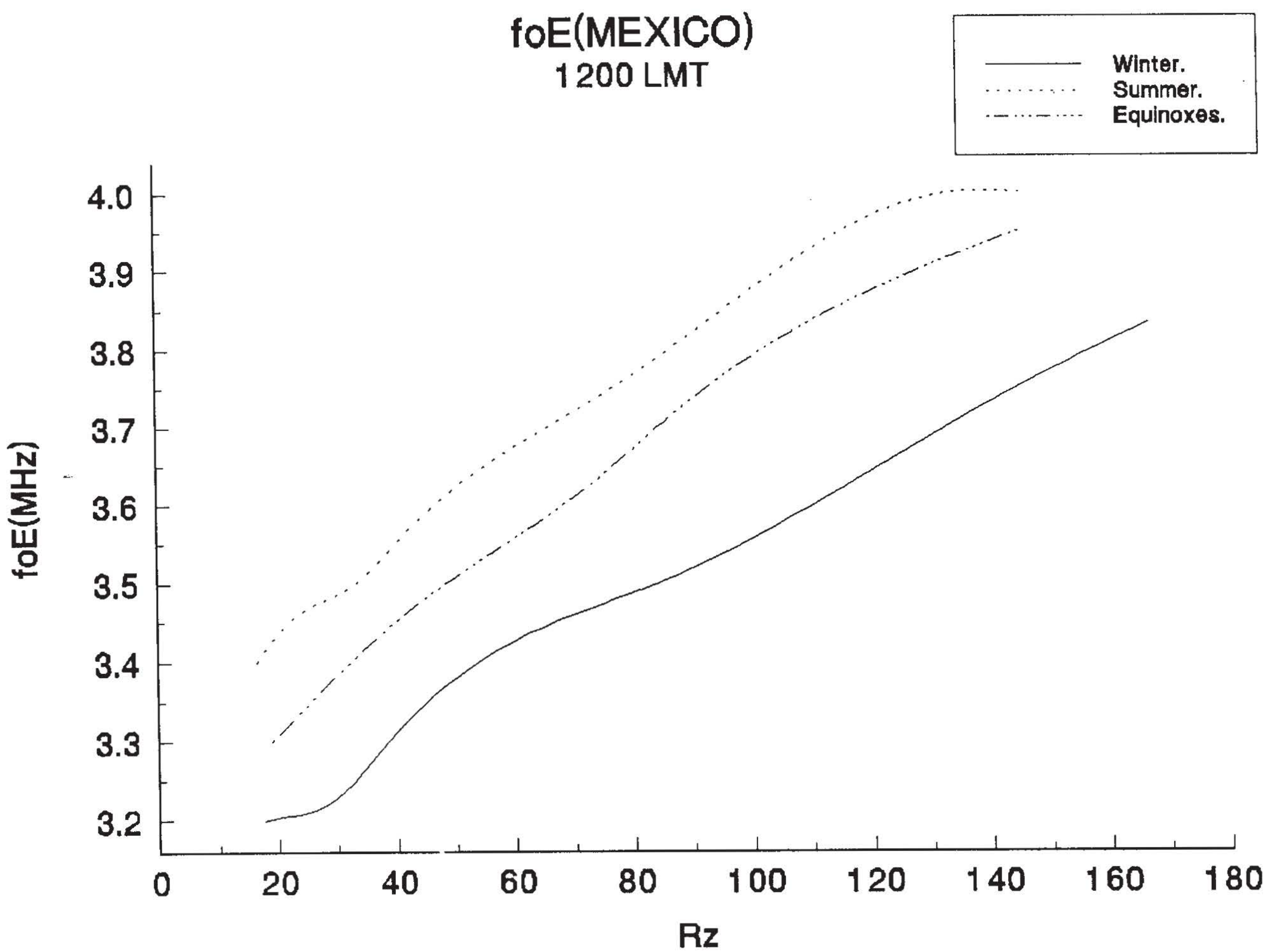

Fig. 2. foE (1200 LMT) dependence with solar activity.

nation coefficient (α) with height may be taken into account.

The change in foE values at local noon with solar activity in summer, winter and equinoxes is shown in Figure 2. There is a clear tendency for foE to increase with solar activity as expressed by sunspot numbers (Rz) or by other solar parameters (Minnis and Bazzard, 1960).

The seasonal behavior of foE during extreme conditions of solar activity is shown in Figures 3 and 4. There are no seasonal anomalies (no foE maximum values in winter) nor is there a semiannual tendency (no foE maximum values at equinox). Maximum values of critical frequency stay within the same interval throughout the year. Variations of the critical frequency may be more important at greater heights, but at E-layer levels they cannot be detected due to the minor role played by the change of composition. In the inset, maxima are slightly shifted towards local noon, and the typical parabolic behavior of the layer in photochemical equilibrium (solar controlled) is present throughout the year.

The presence of secondary maxima and minima is a consequence of deviations from some of Chapman's assumptions, e.g., solar radiation is not monochromatic and the neutral atmosphere is not a simple absorbent gas.

4. CONCLUSIONS

The E region over El Cerrillo, Mexico is in photochemical equilibrium, except during rapid variable phenomena. In general it fits very well the Chapman theory of a simple layer.

If the isothermal assumption is eliminated and constant gradients of scale height dH/dh≈0.2, are assumed, the exponent N found from regression matches closely Chapman's predictions with a high coefficient of correlation.

Maximum values of foE always appear slightly after local noon, and depend on the level of solar activity. During daytime conditions foE rises 7 to 10 times, with the highest rates of increase occurring during LSA periods. There is a clear tendency for foE to increase with solar activity.

ACKNOWLEDGMENTS

This work was partially supported by fellowships from SRE and DGIA - UNAM, Mexico. The authors wish to thank SCT, Mexico, for providing various facilities used in this study.

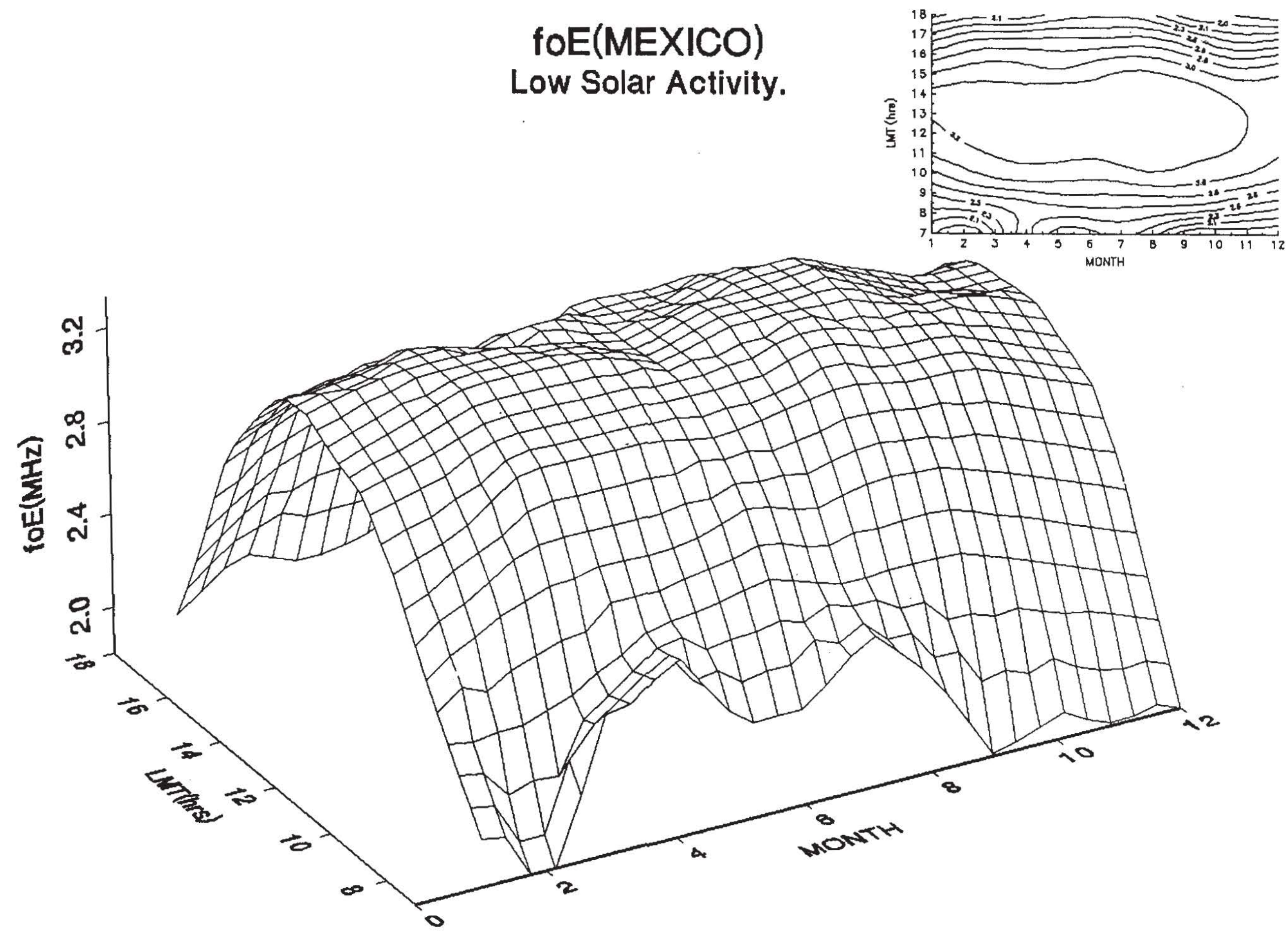

Fig. 3. foE seasonal behavior during LSA.

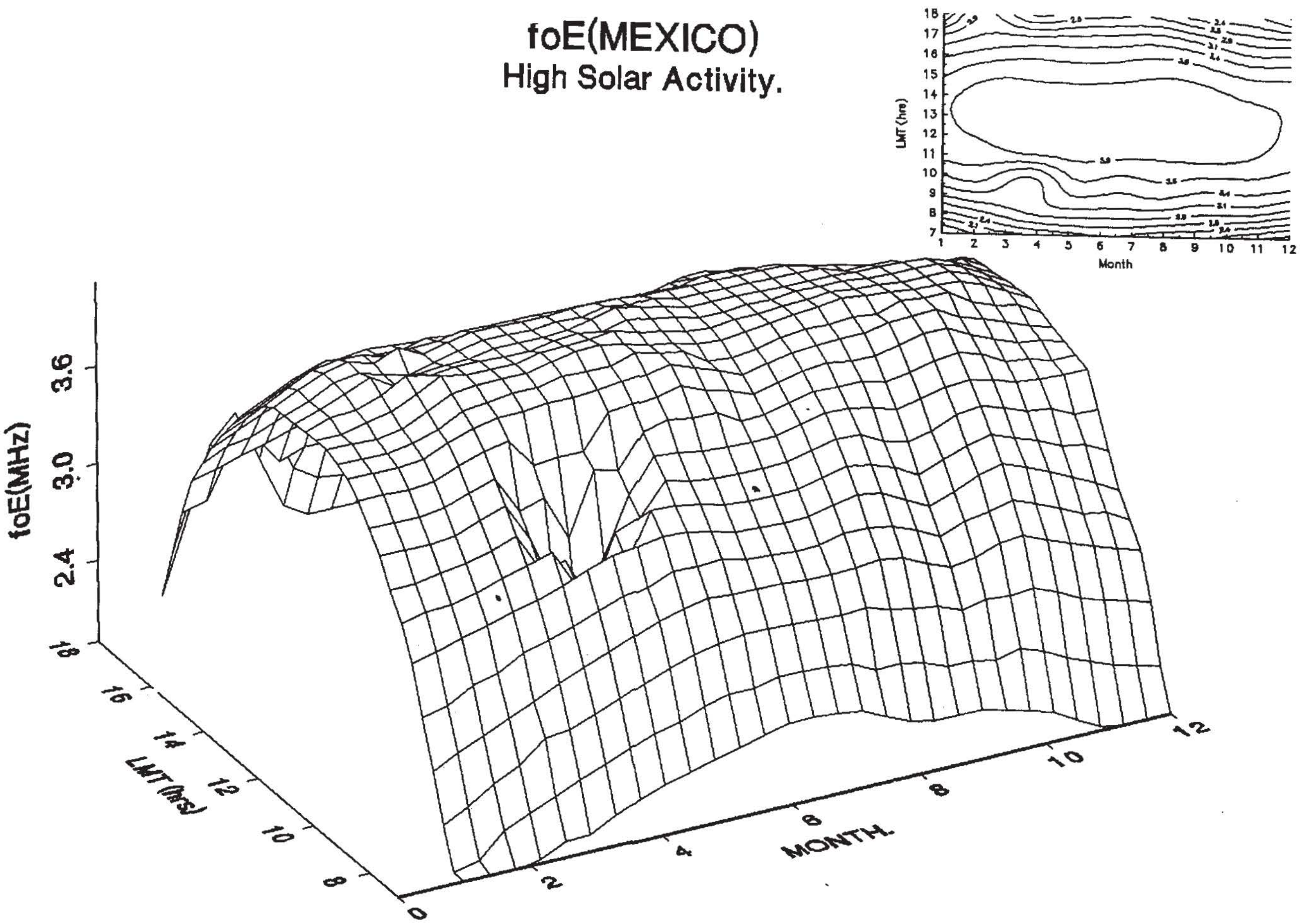

Fig. 4. foE seasonal behavior during HSA.

BIBLIOGRAPHY

APPLETON, E. V. 1937. Regularities and irregularities in the ionosphere. Proc. Roy. Soc. A162, 451-479.

CHAPMAN, S., 1931. The absorption and dissociative or ionizing effect of monochromatic radiation in an atmosphere on a rotating earth. Proc. Phys. Soc. 43, 26-45.

LAZO, B. and L. PALACIO, 1974. La capa F2 de la ionosfera sobre Cuba en periodos de máxima y mínima actividad solar. *Rev. Comunic. 15*, 51-58.

MINNIS, C. M. and G. H. BAZZARD, 1960. A monthly ionospheric index of solar activity based in F2-layer ionization at eleven stations. *J. Atmosph. Terr. Phys. 18*, 297-305.

PEREZ DE TEJADA, H., 1973. Características estadísticas de la ionosfera en México. Secretaría de Comunicaciones y Transporte.

RAWER, K., S. RAMAKRISHNAN and D. BILITZA, 1978. International Reference Ionosphere 1978. Report URSI.

RISHBETH, H. and O. K. GARRIOT, 1969. Introduction to ionospheric physics. Academic Press. N.Y.

TREMELLEN, K. W. and J. W. COX, 1974. Influence of wave propagation on planning of short-wave communication. Proc. Inst. Elect. Eng. 94 - IIIA, 200-219.

E. A. Araujo Pradere[1], L. Lois Menéndez[2] and H.J. Durand Manterola[1]

[1] *Instituto de Geofísica. UNAM. Ciudad Universitaria. Del. Coyoacán, 04510 México, D. F., México.*

[2] *Instituto de Geofísica y Astronomía. CITMA. Ave. 212 # 2906. La Lisa. Ciudad Habana. Cuba.*