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The ionospheric F region over El Cerrillo, Mexico in magnetically quiet conditions

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RESUMEN

Este trabajo describe el comportamiento de las capas F1 y F2 ionosféricas sobre El Cerrillo, México, a partir de datos de foF1 y foF2, seleccionados bajo condiciones magneto-tranquilas. Encontramos que la capa F1, en períodos de baja actividad solar, tiene un comportamiento semejante a la capa E. En alta actividad solar, los máximos de foF1 aparecen cerca de los equinoccios y los mínimos cerca de los solsticios. Esto es un preámbulo del claro efecto semianual que se observa en la capa F2. La capa F2 tranquila, en general, presenta el mismo comportamiento que el descrito por diversos autores, observándose las anomalías típicas de una región de este tipo. En este sentido, son claramente observables la depresión de las 0500 LMT, la anomalía estacional (en alta actividad solar) y la variación semianual.

PALABRAS CLAVE: Ionosfera, morfología, aeronomía, región F.

ABSTRACT

Using data of foF1 and foF2 selected under magnetically quiet conditions, the behavior of the F1 and F2 layers over El Cerrillo, Mexico is described. The F1 layer has a similar behavior to the normal E layer with respect to solar control, especially during periods of low solar activity. During high solar activity, maxima appear near the equinoxes and minima near the solstices. This is a result of the semiannual effect observed in the F2 layer. The depression at 0500 LMT, the seasonal anomaly during high solar activity, and the semiannual variation are all clearly observed.

KEY WORDS: Ionosphere, morphology, aeronomy, F1 layer, F2 layer.

1. INTRODUCTION

The F region extends from an altitude of 140 km until at least 10^3 km. This region has been intensively studied, mainly due to its influence on the propagation of radio waves. Transport processes are of increasing importance and prevail over the photochemical behavior which is typical of lower layers.

The F region is divided into two layers F1 and F2. The F1 layer does not exist at night as it is not possible to observe a peak or maximum between the F2 layer and the E layer that could be identified as the F1 layer.

Day-time hourly values of foF1 and foF2 were selected for the radio sounding station "El Cerrillo" (ϕ = 19° 19'N, λ = 99° 32' W), Toluca, Mexico. The magnetic index Kp and the solar parameter Rz were used to define the level of geomagnetic perturbation and of solar activity.

2. DATA AND METHODS

The data selection was conditioned by the quality of the information in the periods of observation and by the amount of data available in each period.

In addition, we took into account the phase of solar activity. High Solar Activity (HSA) periods are defined by Rz ≈ 140 and Low Solar Activity (LSA) periods by Rz ≈ 10. We also used data from intermediate levels of solar activity (Rz ≈ 40 - 80). We finally adopted Kp ≤ 3, which implies a magnetically quiet state. In this way, we avoid atypical behavior of the ionosphere due to geomagnetic field perturbations.

We fit the local E layer by Chapman's theory (Chapman, 1931):

$$fo \propto (\cos \chi)^{1/4} \tag{1}$$

where fo is the critical frequency, χ is the zenith angle and n = 1/4 is the Chapman index. We used the selected data to find the actual exponent (N) by the following procedure. From a linear regression plot of ln/fo/ vs. ln/cosχ/ we find the slope of the best-fit straight line ϕ. The exponent will be given by N = tan ϕ.

In order to estimate the error it was assumed that the dominant frequency corresponding to the determination of the average hourly values of foE was of the order of ± 0.5 MHz, which yields an error in the Chapman index of ± 0.025. The error in the scale height gradient is of order ± 0.1.

3. RESULTS

3.1. F1 Layer

Table 1 shows the values of the Chapman index for layer F1 corresponding to different seasons and levels of solar activity. During winters of high solar activity no values appear, as under these conditions the F1 layer is not well developed. It becomes a light inflection of the F2 layer known as the "L pass". Therefore it is not possible to obtain reliable data regarding frequency or concentration.

Table 1

F1 layer Chapman index values in winter and summer, during various levels of solar activity.

SEASON YEAR	LEVEL OF SOLAR ACTIVITY	CHAPMAN INDEX
winter 1976	Rz ≈ 10	N = 0.18
summer 1964		N = 0.20
winter 1964	Rz ≈ 20	N = 0.19
summer 1976		N = 0.18
summer 1968	Rz ≈ 100	N = 0.19
summer 1979	Rz ≈ 140	N = 0.20

The Chapman index of N ≈ 0.2 agrees with the assumption that in the F1 layer there occurs the transition from the quadratic law of electron recombination αN_e^2, to the linear law, βN_e. As β diminishes with height, $N_e$max will vary more slowly with respect to its dependence upon the zenith angle (χ) than for the theory of a simple Chapman layer. This explains the difference in the index. Experimental measurements of the ionic composition of the atmosphere with rockets (Anderson, 1971; Allen *et al.*,1981) confirm this transition from a quadratic law to a linear law at altitudes of 160 - 200 km.

This explains the bifurcation of the F region into the F1 and F2 layers. As the speed of recombination diminishes with height faster than the speed of ionization, a greater concentration of ions occurs at high altitude. The diffusion of ions downward occurs more quickly than the ionization or recombination; hence the concentration of electrons diminishes with height.

Figures 1 and 2 show the seasonal behavior of the F1 layer's critical frequency (foF1) for high and low solar activity. In Figure 1, there are slight maxima during the equinoxes with low solar activity and maximum values around local noon. These values reach wider limits than those of the E layer (Araujo-Pradere *et al.*, 1995), i.e., 4.0 and 3.8 MHz for winter and summer and minima of solar activity, and 5.7 and approximately 6.0 MHz for high solar activity. The values at sunrise are minimal in winter, increasing almost parabolically during the remaining months. Thus during low solar activity the F1 layer behaves in a similar way to the E layer.

Figure 2 shows the values of foF1 for high solar activity. The structure and behavior of the F1 layer is very different. The tendency towards a parabolic form is highly deformed. The layer is only well defined between May and September, and its diurnal occurence is much shorter (0900 - 1700 LMT) than during LSA. There are local, irregular minima and maxima which are not accounted by theory. These irregularities are explained by transport processes at these heights, more than in the E layer, and by the transition between the linear and the quadratic laws of recombination.

During low solar activity, the highest values of foF1 are observed for the equinoxes and in summer. The differences are small with the remaining months. During high solar activity, the maxima are centered on the equinoxes and the minima occur at the solstices, which is consistent with the marked semiannual effect in the F2 layer above Mexico.

The cyclic variation of foF1 shows that the values during high solar activity exceed the values during low activity by up to 2.0 MHz. Also, the critical frequency of the F1 layer exceeds the corresponding E layer frequencies by 0.8 -1.0 MHz and 1.2 - 3.0 MHz for low and high solar activity, respectively.

3.2. F2 layer

The characteristic isofrequencies and the 3-D surface plot that describe the diurnal variation of foF2 in extreme periods of solar activity are shown in Figures 3 and 4. The values increase from a minimum around 0500 LMT to a peak around local noon, then they fall during the afternoon and the night. Secondary maxima are observed particularly in the interval from 0100 to 0300 LMT.

The depression at 0500 LMT is characteristic of the ionograms in Mexico and, in general, in middle and low latitudes. The rapid increment in the electron temperature (Te) at local sunrise is probably the cause of this effect. Since the scale height (H) is proportional to Te (H= kT/mg), an increase in H produces an expansion of the layer, a reduction of the electron concentration (N_e) and an enhanced head input per mass element which permits increases of Te (Schunk and Nagy, 1978).

The principal maximum is exclusively observed after noon during low solar activity (1300- 1700 LMT), but it may fall before or after noon during high solar activity. It occurs earlier, for any season of the year, upon increasing solar activity; and it occurs in the extreme hours during the solstices (earliest at winter and latest at summer). Lastly, the diurnal variation is more irregular during summer of LSA, when large peaks are seen, than in winter. This could be related to the seasonal variation of the thermospheric, which causes a more compact F2 layer in winter.

The maximum value of concentration in the F2 layer is NmF2= 1.24×10^{10} (foF2)^2, where foF2 is given in MHz and NmF2 in m^{-3}. It is 2 to 3 times greater during high solar activity, with a maximum in winter (3.0) and a minimum in summer (2.2). Maximum values of concentration are greater at the equinoxes -especially the autumnal- for both periods of solar activity.

The most probable cause of these variations is the change in atmospheric composition due to unequal heating of the hemispheres. This mechanism is more effective during high solar activity.

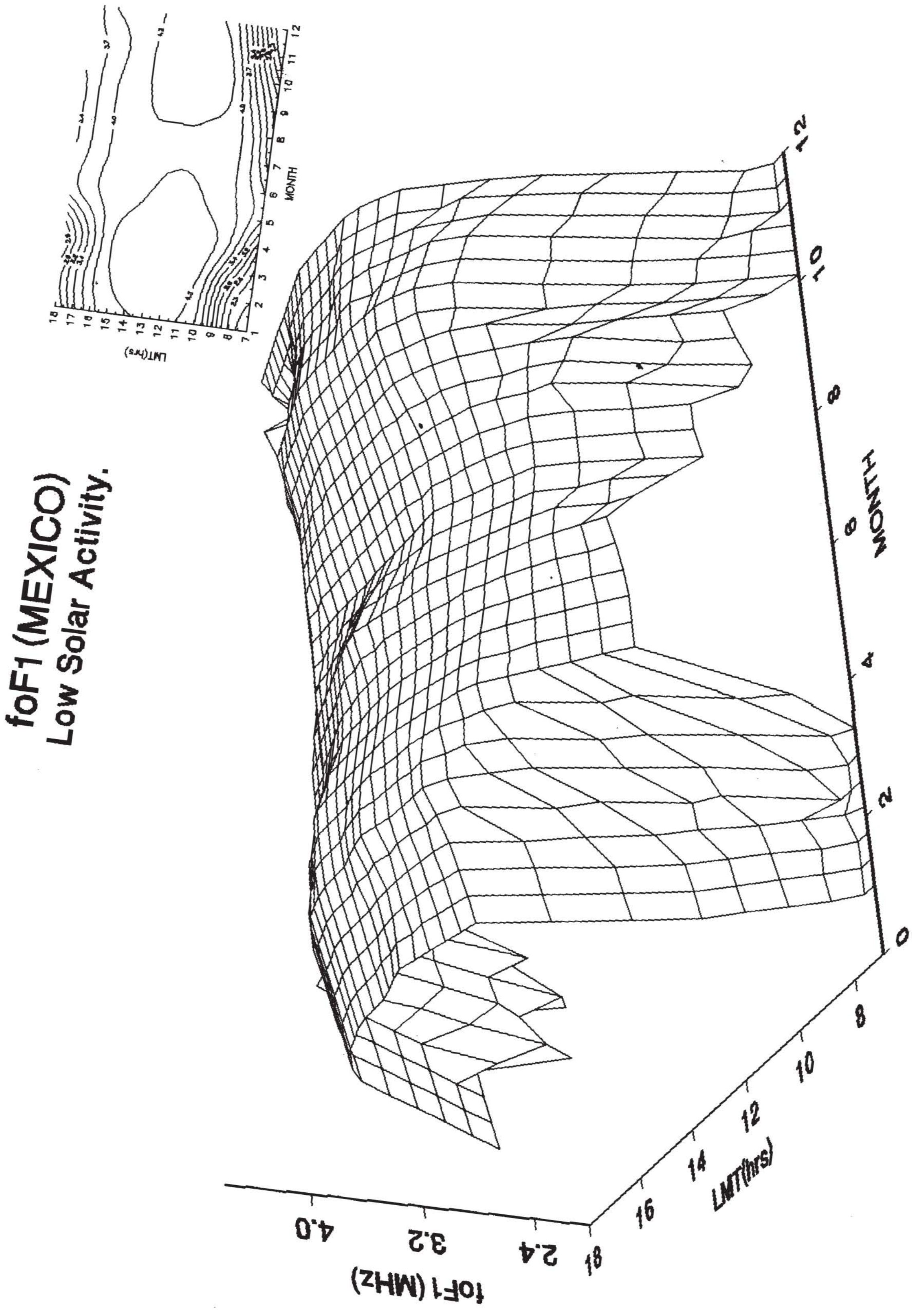

Fig. 1. foF1 seasonal behavior during low solar activity.

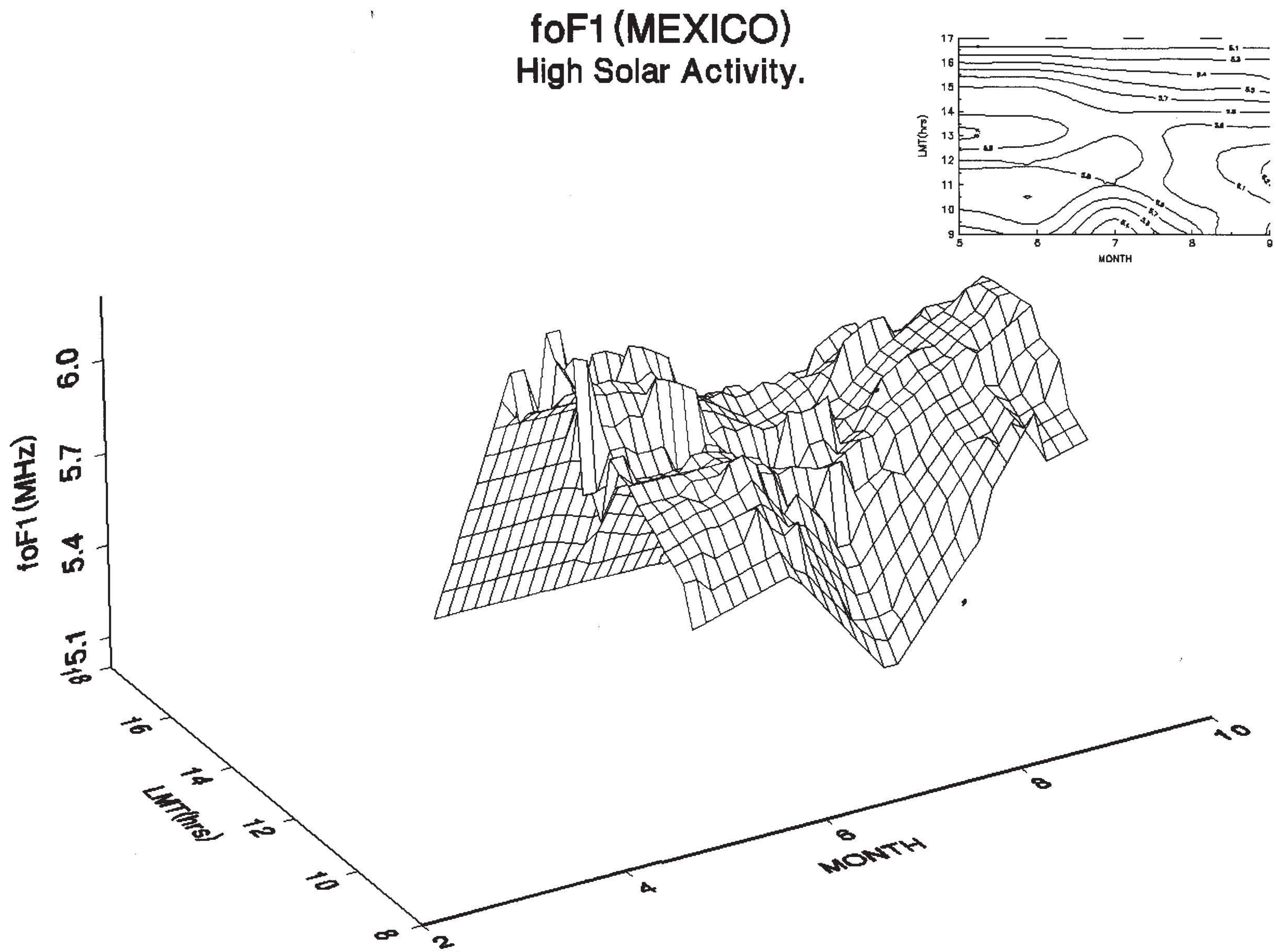

Fig. 2. foF1 seasonal behavior during high solar activity.

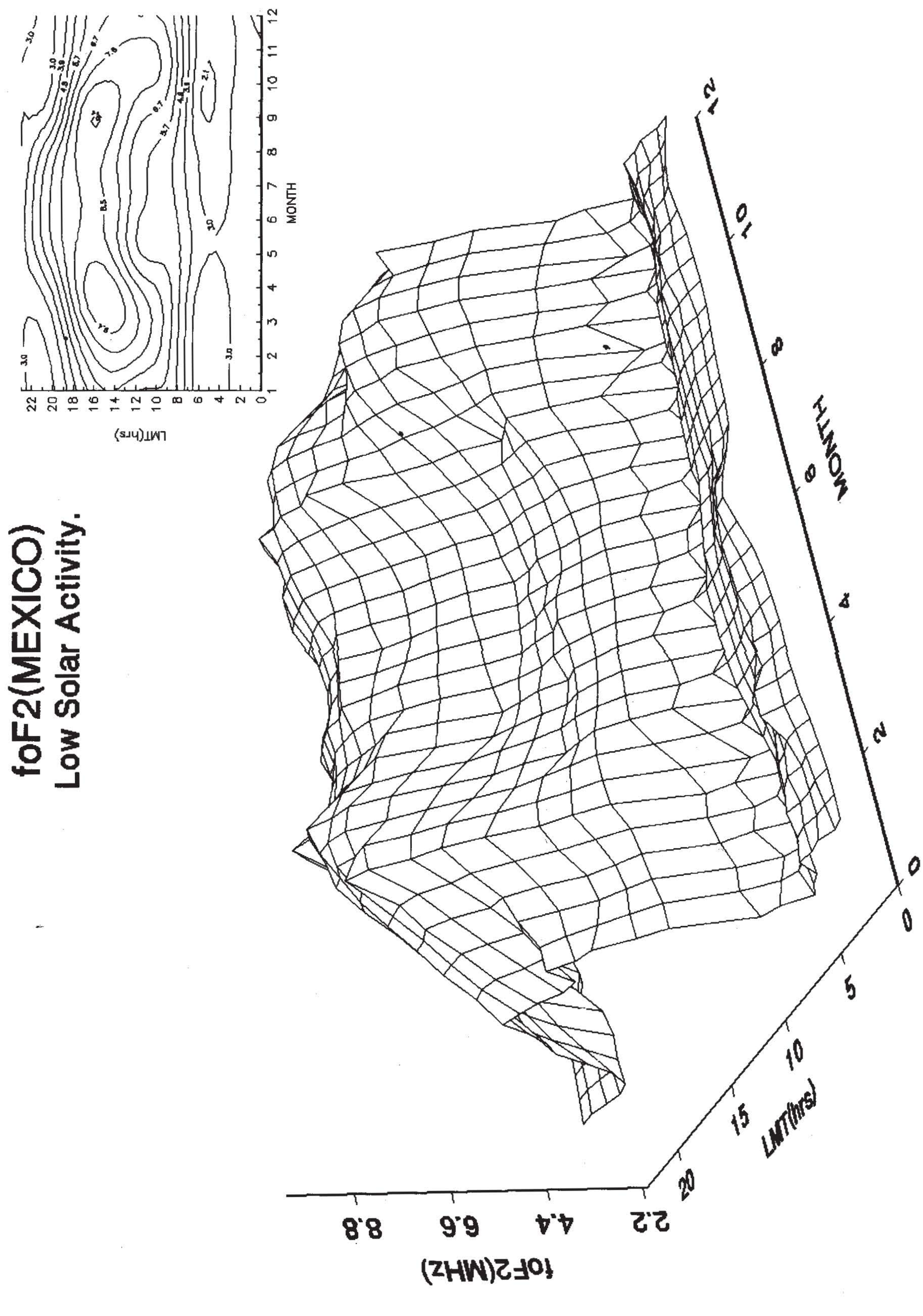

Fig. 3. foF2 seasonal behavior during low solar activity.

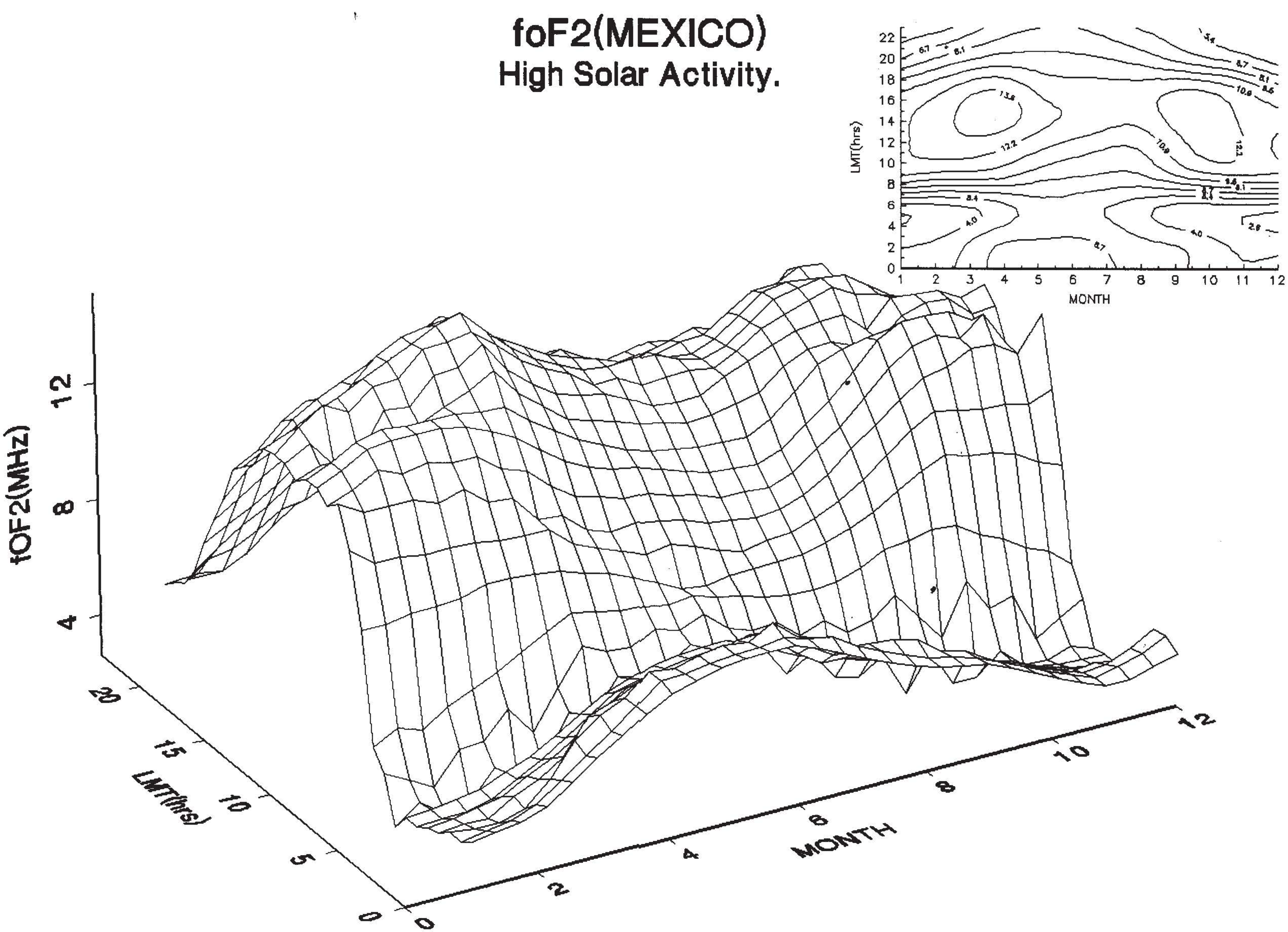

Fig. 4. foF2 seasonal behavior during high solar activity.

Seasonal variations of atomic (O) and molecular (O_2, N_2) concentrations in the thermosphere (Rishbeth and Setty, 1961) have been supported by several studies. For mid and low latitudes, maximum ratios of $[O]/[O_2]$ and $[O]/[N_2]$ at the equinoxes and during winter are at least twice as high as in summer (Stubbe, 1975). Alcayde *et al.* (1974) found winter - summer rates of O_2 of 1.5 and 4.0, respectively. Such changes will affect the rates of production and loss which provoke these anomalies.

The absence of a seasonal anomaly during low solar activity may be due to the fact that the southern winds in winter are much stronger, almost twice during the day, than the winds in summer. The direction of the north - south component of the wind speed is towards the pole during the day; therefore the downward movement of the ionization is more intense and there is a greater accumulation of charged particles at lower heights in winter.

However, this is not consistent with observational results. Numerical solutions of the continuity equation show that NmF2 should be reduced more intensely in winter than in summer; the decay of the ionization in lower heights due to the higher loss rate overcomes the increase due to the downward transport of plasma. This fact, plus the control that the ion drag exerts on the magnitude of the winds, allows us to understand why the seasonal anomaly does not exist during low solar activity.

4. CONCLUSIONS

The F1 layer behaves like the normal E layer, principally during periods of low solar activity. They differ in that the F1 layer is observed more frequently during the summer, in daytime hours and at lower levels of solar activity, while the E layer is permanent though with very low nocturnal values. The F1 layer is formed near the limit between linear and quadratic mechanisms of recombination, one of which causes irregularities not explained by other factors. During high solar activity, the maxima appear near the equinoxes and the minima during solstices.

Transport processes play a fundamental role, generating typical "anomalies" in F2 layer (Hoang *et al.*,1984; Lois Menéndez *et al.*, 1992). The depression at 0500 LMT, the seasonal anomaly (during high solar activity) and the semiannual variation are clearly observed.

Comparing Figures 1 and 2, corresponding to the F1 layer, with Figures 3 and 4 for the F2 layer, we find that transport processes are predominant in the F2 layer , while at similar heights of the F1 layer there are no dominant mechanisms of this behavior. In conclusion, the influence of the photochemical phenomena is altered by transport processes, which causes a less regular behavior with respect to the F2 layer and the E layer.

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