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14. Abstract/Notes

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GRAVITY WAVE INDUCED IONIZATION LAYERS IN THE NIGHT F REGION OVER CACHOEIRA PAULISTA

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ABSTRACT

Ionosonde observations over Cachoeira Paulista (22^{o}S, 45^{o}W), a low latitude station, show distorted h'(f) traces in the ionograms due to passage of TID's. The distortions of the traces, at times, take the form of an F-region bifurcated into two distinct layers. These effects are observed mostly during presunrise hours. One specific event is studied in greater detail using true height analysis of the quarter hourly ionograms. The characteristics of the electron density and height oscillations for this case are compared with the results obtained, from the simulation of the same, based on linear theory of gravity wave induced ionization perturbations. The results show that gravity wave winds of unrealistically large magnitudes are required to explain the observation. The results suggest further that the inclusion of a source of ion production in the presunrise period, perhaps, produced by precipitation of low energy (< 10 KeV) electrons in the South Atlantic anomaly, together with the ionization loss process, might lead to a better agreement between the observation and the theory.

INTRODUCTION

Experimental studies of travelling ionospheric disturbances (TID's) have been carried out using ionosondes, incoherent scatter radars, HF Doppler techniques and Faraday rotation polarimeters (Munro, 1950; Bowman, 1968; Thome, 196B; Georges, 1968; Testud and Vasseur, 1969; Davies, 1974). These and several other studies have been mostly confined to middle latitude, where two distinct categories of TID's have been identified, namely, the large scale and the medium scale TID's. The former class of TID's is believed to be driven by high latitude sources (such as auroral electrojet current) during magnetic storms, whereas the medium scale TID's could have sources also elsewhere than in the polar region. A detailed review on the theory of acoustic gravity waves, the source of the TID's, has been given by Yeh and Liu (1974), and a review on the global propagation characteristics of these waves has been presented by Francis (1975).

Observations of TID's in low latitudes, (which have been relatively sparse) are needed to provide important inputs for verifying theories on the long distance propagation of internal atmospheric gravity waves responsible for the TID's. Recent observations over some Brazilian low latitude stations indicate that TID's frequently occur over this region. Some limited results on TID's from riometer and polarimeter observations have already been published (Abdu and Rai, 1975; Kaushika and de Mendonça, 1974). This paper presents and discusses a few TID's (mostly large scale) over Cachoeira Paulista (22^{o}S, 45^{o}W) observed by an ionosonde. Some of these do seem to have high latitude sources, based on the values of the magnetic disturbance indices. An interesting point about these TID's is that their characteristic signatures on the F-region electron density profile appear to be unique for this region.

RESULTS

The occurrence of multiple (or satellite) F-layer traces in the ionogram, especially at sunset hours, is a regular feature with a seasonal dependence, over Cachoeira Paulista. Such satellite traces are usually followed by range spreading echoes, resembling the sequences regularly observed over an equatorial station. Multiple F-layer traces are observed also during day as well as night hours following geomagnetic storms. This latter type of multiple traces is easily identifiable with the characteristics of the TID's described for middle latitude (see for instance, Chan and Villard, 1962; King, 1967; Bowman, 1968; Georges, 1968). The TID signatures being present and discussed in this paper are, however, quite different and in a way unique from those reported so far. Some examples of ionograms displaying distorted h'(f) traces characterizing the TID signatures are presented in Figure 1 (a) and (b). Figure 1(a) presents a sequence of ionograms taken on 28 June 1978, wherein the h'(f) profile most significantly distorted is the one at 0430 LT when the F layer is seen bifurcated into two well defined layers having h'F values 220 km and 390 km. A few more ionograms illustrating h'(f) traces distorted by passages of TID's, are presented in Figure 1(b), for different days, observed in the one year period of June 1978 - June 1979. We may note that bifurcation of the F layer trace into more than one layer is evident in most of these ionograms. Some of them, which do not exhibit such well defined features show, instead, presence of low lying ionization, as seen in the records of 0515 LT on 4 June and 0430 LT on 20 June, 0345 LT on 28 June 1978 and 0500 LT on 14 December 1979. The forking trace in the ionogram at 0400 LT on 27 June indicates strong ionization gradients. One interesting point to be observed in all these ionograms is that these events invariably occur in the presunrise period.

An example of a long period oscillation in the virtual heights of iso-ionic density contours, caused by the passage of a TID on 25 April 1979, is presented in Figure 2. (One ionogram showing distorted F-traces taken at 0330 LT during the passage of this TID has been presented in Figure 1 b). The period of oscillation suggests that it was a large scale TID, and it was preceded by an SSC of a severe storm at 2100 LT (0000 UT) on the same night. However, from an examination of such events, selected on the basis of events that showed significant h'(f) curve distortion, during the one year period of study, we could not establish a clear association of many of them with SSC's and magnetic activity. Perhaps the auroral electrojet activity index, as suggested by Francis (1975), might have been a better parameter, although they are not available for the southern hemisphere.

In the following we will discuss in some detail the event of 28 June 1978, as this seems to be a typical case. The quarter hourly f_0F_2 and h_pF_2 values for the morning hours of 28 June 1978 are plotted as a function of local time in Figure 3 together with the values for three adjacent days, 26, 27 and 29 June. A severe storm with SSC occurred on the morning of 25 June, and the first distorted h'(f) trace was observed on 27 June (presented in Figure 1 b). In Figure 3, the oscillations in f_0F_2 and h_pF_2 on 28 June are particularly interesting since they show their quasi-periods increasing with time, in a way that resemble some of the ionosonde results of TID's presented by Klostermeyer (1969) for mid-latitude. This increase of quasi-periods with time shows good similarity with theoretical results of Chimonas and Hines (1970) for the gravity wave oscillations expected at F-region heights due to a distant auroral electrojet source. True height analysis based on Howe and McKinnis (1967) formulation of Paul's method (1967) was carried out on the quarter hourly ionograms for a two hour interval during the 28 June event. The resulting true height curves are presented in Figure 4. It should be pointed out here that the true height analysis of ionograms in the presence of horizontal gradients such as those that occur during the passage of an atmospheric wave might lead to some error. The error could be significant if strong layer tilts are present as would be manifested by presence of satellite traces. In the example that we consider here no satellite trace was present and some of the ionograms show second order trace at nearly twice the h'(f) for the first order trace suggesting that the tilts are not very significant. The horizontal wave length of the TID is also very large (as will be shown presently). The error expected from the true height analysis in the present case, would be a certain degree of horizontal dislocation of some of the profiles relative to the vertical over the ionosonde (see also Klostermeyer, 1969, who has studied TID's on the basis of true height analysis of ionograms).

The electron density profile at 0430 LT corresponding to the bifurcated F-layer trace in the ionogram of Figure 1a clearly shows that the ionization underwent significant redistribution with much of the ionization having been lifted up from below during the 15 minutes that elapsed since the previous profile. However, all of the ionization in the upper layer does not seem to be explained by this process alone. (We will come back to this point a little later). Figure 5a presents true height-time cross section of the iso-electron density values, based on Figure 4, in which the downward phase propagation characteristic of an internal atmospheric gravity wave is clearly seen. Unfortunately, we do not have spaced observation of these events to determine the velocity vector of the propagating disturbances. As indirect estimation of the velocity of propagation however, can be obtained as follows. The vertical wavelength (λ_z), from Figure 5a comes out to be approximately 200 km (as will be shown presently from a simulation of these results). The corresponding horizontal wavelength, λ_x, could be determined using a relationship between them given by Hines (1960), namely, $\omega^2\lambda_x^2 \simeq (\omega_g^2 - \omega^2)\,\lambda_z^2$, where ω_g is the Brunt-Väisälä frequency (which we have taken as $2\pi/14\ \text{min}^{-1}$) and ω is the wave frequency. The horizontal wavelength comes out to be $\simeq$ 850 km. Taking the wave period to be 60 minutes, the velocity of propagation turns out to be 240 m/s.These values fall within the limits atributed to medium scale TID (Francis, 1975). The direction of propagation, however, is not known. (The event in the Figure 2, on the other hand, seems to have large scale characteristics). The total electron content below the F-layer peak (N_t) resulting from the true height calculation, is presented in Figure 6a. We may observe in this figure that the N_t undergoes oscillation in phase with the height variations, in particular with h_m. This behaviour is apparent in Figure 2 also.

INTERPRETATION OF THE RESULTS

It looks almost certain that the oscillations in the total ionization such as that shown in Figure 6a cannot be explained as due to ionization descending from the topside ionosphere as could be verified from an examination of the electron density profiles at 0415, 0430 and 0445 LT in Figure 4. We shall examine below if the oscillations in the iso-ionic contours and in the columnar ionization content, in Figure 5a and 6a, could be explained, partly or fully, by the ionization perturbation induced by the gravity wave winds of reasonable magnitudes.

The gravity wave associated dynamic effect on the ionosphere has been studied by several authors (Hook, 1968, 1970; Georges, 1968; Davies, 1973; Yeh et al., 1976, see also the review by Yeh and Liu, 1974). For small perturbation amplitude the expression for the perturbation electron density (N') derived from its linearised equations (see Hook, 1968) is given by:

$$N' = (1/\omega)\ U \cdot I_b \left[(k \cdot I_b) + i\ I_b \cdot I_z \left(\frac{\partial}{\partial z}\right) \right] N_0 \qquad (1)$$

Where, ω is the angular frequency of the gravity wave whose wave number is k. N_0 is the ambient electron density. z is the height, and I_b and I_z are the unit vectors directed parallel to the geomagnetic field and in the z direction respectively. The properties of (1) have been discussed in detail by Hook (1970). This expression does not, however, include the effect of ambipolar diffusion which could be significant at the F_2 region heights. Results of numerical solution of the full continuity equation including the effect of ambipolar diffusion velocity by Clark et al. (1971) has shown significant difference in the phase and amplitude of the perturbation as compared to the solutions that do not include the diffusion. We will use below a modified form of the equation (1) given by Yeh and Liu (1974) that approximately includes the effect of diffusion (with coefficient D_a), given by:

$$N' = \frac{U \cdot I_b \left[(k \cdot I_b) + i\, I_b \cdot I_z\left(\frac{\partial}{\partial z}\right) \right] N_o}{\omega + i\, D_a (k \cdot I_b)^2} \qquad (2)$$

Subtituting $U \cdot I_b = u_b$, $k \cdot I_b = k_b = k_{br} + i\, k_{zi} \sin I$, where, I is the dip angle, and only the vertical component k_z of k is complex, we can rewrite the Equation (2) as follows.

$$N'/N_o = \frac{u_b \sin I}{C} (A + i\,B) \qquad (3)$$

Where

$$A = a\, k_{br}/\sin I + b\left(k_{zi} + \frac{1}{N_o}\frac{\partial N}{\partial z}\right),$$

$$B = a\left(k_{zi} + \frac{1}{N_o}\frac{\partial N_o}{\partial z}\right) - b\, k_{br}/\sin I,$$

and

$$C = a^2 + b^2$$

Also

$$a = \omega - 2\, D_a\, k_{br}\, k_{zi} \sin I, \text{ and}$$

$$b = D_a(k_{br}^2 - k_{zi}^2 \sin^2 I)$$

Computation of N'/N_0 as a function of time and distances along the x, y and z axes can be carried out conveniently using the following form of this equation, namely,

$$N'(x,y,z,t)/N_0 = \frac{U_b(z_0)\ \sin I}{C}\ \exp(k_{zi}(z - z_0)) \cdot (A^2 + B^2)^{1/2}$$

$$\cdot\ \exp\{i(\omega t - k_x x - k_y y - k_{zr} z - \tan^{-1} B/A)\} \quad (4)$$

Where z_0 is a reference height, and

$$u_b = U_b(z_0)\ \exp\left[(k_{zi}(z - z_0)) + i(\omega t - k_x x - k_y y - k_{zr} z)\right]$$

When the ambipolar diffusion coefficient is ignored, the Equation (4) is the same as the Equation (51) of Hook (1968). The Equations (2)-(4) show that the electron density perturbation will be zero when the gravity wave vector is exactly in the magnetic meridional plane while at low dip angles the perturbation will be small also for the wave vector orientation in the direction perpendicular to the magnetic meridional plane.

Using standard values for the diffusion coefficient at F-region heights we performed calculations of the height-time cross section of iso-ionic contours for different combinations of the reference electron density profiles, wind velocities $U_b(z_0)$ and wave lengths of the gravity waves having a period of 60 minutes (the observed period) until the best possible agreement was obtained with the observed iso-ionic contours of the Figure 5a. Figure 5b shows the results of calculation for two wind velocity amplitudes, namely 100 ms^{-1} and 200 ms^{-1}, z_0 being taken as 300 km. The vertical wave length used for this case was 200 km and the reference electron density profile is shown as R1 in the Figure 4. It is clear that, of the two sets of contours in the Figure 5b, the ones corresponding to 200 ms^{-1} resemble better the observed ones especially in the later half of the event, around 0430 LT. However, there is significant disagreement between the calculated and observed F_2 peak height oscillations. On the basis of the available measurements of the gravity wave induced wind speeds (see for example the results of incoherent radar measurements by Testud and Vasseur, 1969, and Roble et al., 1978) the 200 ms^{-1} used to obtain the results in the Figure 5b seems to be unrealistically large. Calculations with different N(h) profiles showed that there is no unique electron density profile that could give rise to the observed magnitude of the iso-ionic density height oscillations without requiring unrealistically large wind velocities. In fact,a reverse calculation was performed in order to determine the winds (namely, u_b from the Equation (4)) that would be required to obtain each of the observed N(h) profile in the Figure 4 from a reference profile shown as R2 in the same figure. The resulting equatorward winds (u_b) at the F-region peak heights are presented in Figure 6b. The magnitude of these winds are inadmissably large. Further the corresponding airparcel velocity would approach the sound speed and in fact,the linear theory used here will not be suitable to derive such large wind velocities. In Figure 6a we have plotted the subpeak electron content values obtained from observation, corresponding to the Figure 5a, and that resulted from the simulation, corresponding to the Figure 5b, and they also present large differences between them; namely, the amplitude of the observed N_T oscillation is much larger than can be accounted for by the winds considered here.

It seems, therefore, that wind induced ionization perturbation could explain only partly the observed variations in the iso-ionic contours. It is very likely that the ambient electron density profile (or the reference profile) has undergone significant modification during the course of this event owing to factors other than wind induced motion. The degree of the possible change in the ambient profile for this event could be determined from a solution of the full continuity equation that should include also ionization production and loss terms, in a way, perhaps, similar to the treatment of Clark et al. (1971). In our case, however, the ion production by solar radiation considered by Clark et al. (1971) should be ignored and instead an unknown source of ion production possibly with certain variability with time, which is also unknown, will have to be included in a full numerical solution of the continuity equation. In the present work, which discusses in detail only one example of the gravity wave induced true height-time cross section, we do not attempt such a detailed analysis. However, the possible effect of including ion production and loss processes on the results obtained using the Equation (4) could be visualised as follows.

The ambient electron density distribution in the F-region (namely, the distribution unperturbed by winds) is determined by the processes of ion production, chemical loss and diffusion. Analytical solutions of continuity equations representing the steady state balance of these processes have been carried out by several authors in the past (see for example, Bowhill, 1962; Yonezawa, 1966). The results show that though the electron density is a complicated function of these different processes it is, nevertheless, proportional to the ratio, Q/β, of ion production rate to the linear loss rate. This dependence on Q/β should be valid even if we consider variations with time of the ambient ionization profile. β is expected to decrease exponentially with height. Q may be considered, for the time being, to be height independent in the height region of the present interest, although for our nighttime case the nature of its height and time distribution is unknown. Thus if ionization is raised up due to winds (u_b) from lower heights of relatively higher β to higher regions of lower β, it would contribute to an enhancement of the ionization at the higher levels and also would result in a net build up of the columnar electron content. In a similar way the ionization transport to lower heights could cause a net decrease in the columnar content. Therefore the amplitudes of the oscillations in the columnar content obtained from simulations based on gravity wave induced ionization perturbations might get enhanced if the ion production and loss processes were included in the calculation. This would be true, however, only if the ionospheric response time due to chemical processes is small compared to the period of the gravity wave, a condition that is satisfied in the example considered here. The inphase oscillations in the columnar content in Figure 6a, in the h_mF_2 in Figure 5a (or h_pF_2 in Figure 3a) and in the f_0F_2 in Figure 3b seem to suggest that the process explained above was indeed operative during this event. If the order of magnitudes of the winds are known, then it should be possible to deduce an ion production source function that would be required to obtain agreement between the calculation and observation. While the above arguments indirectly suggest the presence of a significant ion production source during the passage of the TID, direct evidence to this effect seems to be present in certain characteristics of the h'F traces registered during these events. Presence of low lying ionization, such as that are clearly observable in the form of group retardation at the low frequency end of the F-layer trace in the ionograms of 0515 LT on 4 June, 0430 LT on 20 June, 0345 LT on 28 June 1978 and 0500 LT on 14 December 1979, seem to indicate a source of ionization at these hours (sunrise effects over Cachoeira Paulista starts usually around 0615 in winter and 0545 in summer months). The source of ion production operative at night at these heights could be precipitation of low energy (< 10 KeV) electrons due to the South Atlantic magnetic anomaly that covers the region of this observation. Presence of enhanced fluxes of charged particles in the 0.5 - 10 KeV range arising from the anomaly region has been reported from rocket measurement over Natal, Brazil by Kelley et al. (1977). Topside sounder studies by King et al. (1967) and satellite total electron content measurements by Mendonça (1965) and Massambani (1978) have suggested particle precipitation effect during quiet as well as disturbed period in the F-region over the South Atlantic. Precipitation of high energy electron (> 20 KeV) during magnetically quiet as well as disturbed periods has been deduced from observations of blanketing and a-type sporadic E-layers by Abdu and Batista (1977) and Batista and Abdu (1977) (see also Abdu et al., 1979) over Cachoeira Paulista. In fact during the disturbed period that characterizes the present event, E_s layers typical of magnetic storm associated particle precipitation effects were present, although not exactly coincident in time with the passage of the gravity wave detected on the F-layer trace.

Spatial resonance effect originally suggested by Whitehead (1971) has been involked by several authors to explain the growth of gravity wave induced ionization irregularities in the ionosphere. In particular, its aplication to the problem of the generation of spread F irregularies and plasma depleted regions ("bubbles") in the equatorial ionosphere has been investigated for example, by Klostermeyer

(1978), Beer (1973), Koster and Beer (1972), and Rottger (1973, 1978). When the phase trace speed in a gravity wave induced ion density oscillation becomes equal in magnitude to the component of the ambient ionization drift speed in the same direction, the irregularities associated with the gravity wave tend to grow in amplitude by the spatial resonance, the growth being limited by the balance of other factors such as recombination, diffusion and production of the ionization. However, from considerations of the recombination of the ionization Whitehead (1971) has pointed out that the spatial resonance could have only little effect for wave periods greater than 30 minutes in the F-region. The period of oscillation in the example presented here is around 1 hr and in some others it is still higher (see for example the figure 2 where the period is more than 2 hrs). Moreover the phase propagation is downward in the iso-ionic contours in the figure 5a whereas the mean trend of the h_pF_2 oscillations in the Figure 3 suggests that the overall F-layer drift was upward at these times. Therefore it does not seem likely that spatial resonance has played a recognizable role in the ionospheric gravity wave response characteristics presented here.

CONCLUSIONS

F layer traces in the nighttime ionograms over Cachoeira Paulista undergo drastic distortions due to passage of ionospheric disturbances induced by atmospheric gravity waves. In extreme cases the regular night F-layer bifurcates into two distinct layers. From true height analysis of one specific event, it was possible to determine some relevant parameters of the propagating gravity wave using a true height-time cross section of iso-ionic contours. Calculations of the electron density perturbations on the basis of linearised perturbation equations showed that gravity wave wind induced ion motion alone could not explain the magnitude of the oscillations observed in the iso-ionic contours and in the subpeak ionization content. Possible contribution to the observed characteristics from the spatial resonance effect has been ruled out based on considerations on the period and phase velocity of the wave and the F-layer mean drift. The results, thus, suggested that the ambient electron density has, most likely, undergone variations during the course of the event due to the factors other than winds, namely, ion production and loss processes, that might have been important in determining the ambient electron density. If this indeed be the case then the gravity wave induced F-region response such as is presented here may be used for detecting low energy particle precipitation in the South Atlantic magnetic anomaly which is otherwise difficult to detect from regular F-region behaviour registered in the ionogram. It should be pointed out, however, that the application of the linearised perturbation equations to the present event is not, perhaps, sufficiently rigorous since the perturbed electron density for some of the profiles used here represents a large percentage of the ambient reference density. A more rigorous analysis involving more number of events and numerical solution of the full continuity equations including ion production and loss terms is planned as an extension of this work.

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FIGURE CAPTIONS

Figure 1 - (a) Ionograms taken during the passage of a TID on 28 June 1978. The most pronounced effect due to the TID is observed in the ionogram taken at 0430 LT when the F-layer is seen bifurcated into two well defined layers. Distortion of the trace to a lesser degree is present in the ionogram at 0330 LT.

(b) Some examples of distorted F-traces due to passages of TID's observed during the one year period from June 1978 - June 1979.

Figure 2 - An example of the oscillations in virtual heights of reflection at fixed frequences during the passage of a TID. This event was observed on 25 April 1979. An ionogram taken during this event, at 0330 LT, is shown in Figure 1b.

Figure 3 - Time plots of (a) h_pF_2 and (b) f_0F_2 during the TID event of 28 June 1978, together with similar plots for three adjacent days, 26, 27 and 29 June. Note the in-phase oscillations in h_pF_2 and f_0F_2 during the passage of the TID, from 0140 to 0600 LT.

Figure 4 - The true height profiles calculated for quarter hourly ionograms for a 2-hour interval during the passage of the TID on 28 June 1978. The profile at 0430 LT shows two reasonably well defined layers, resembling the F_1 and F_2 bifurcation of the regular day time ionosphere. The reference profile marked R1 was used to obtain the iso-ionic density contours plotted in Figure 5(b), and the reference profile R2 was used to deduce the winds velocity component (u_b) plotted in Figure 6(b).

Figure 5 - (a) True height-time cross section of the electron iso-density contours corresponding to the profiles shown in Figure 4. The height of layer peak, h_m, is represented by the curve, ---▲---.

(b) Height-time cross section of the electron iso-density contours calculated from Equation (4) using the reference electron density profile marked R1 in the Figure 4. The gravity wave parameters used are: U_b(300 km) = 100 ms^{-1} (---) and 200 ms^{-1} (——), λ_z = 200 km, k_{zi} = 10^{-5} m^{-1} $\omega = 1.74 \times 10^{-3}$ sec^{-1} and I = 28^0, Da = 2×10^{19}/n cm^2 sec^{-1} (where n is mostly atomic oxygen density).

Figure 6 - (a) The subpeak electron conten (N_t) (—o—) that resulted from the true height calculations corresponding to the contours in the Figure 5(a) and that resulted from the simulation (—●—) corresponding to the Figure 5(b) (for u_b=200ms^{-1})

(b) The equatorward wind u_b determined from the Equation 4 using the reference electron denisty profile R2 in the Figure. Other parameters used in this calculation are the same as that used to obtain the results of the Figure 5(b).

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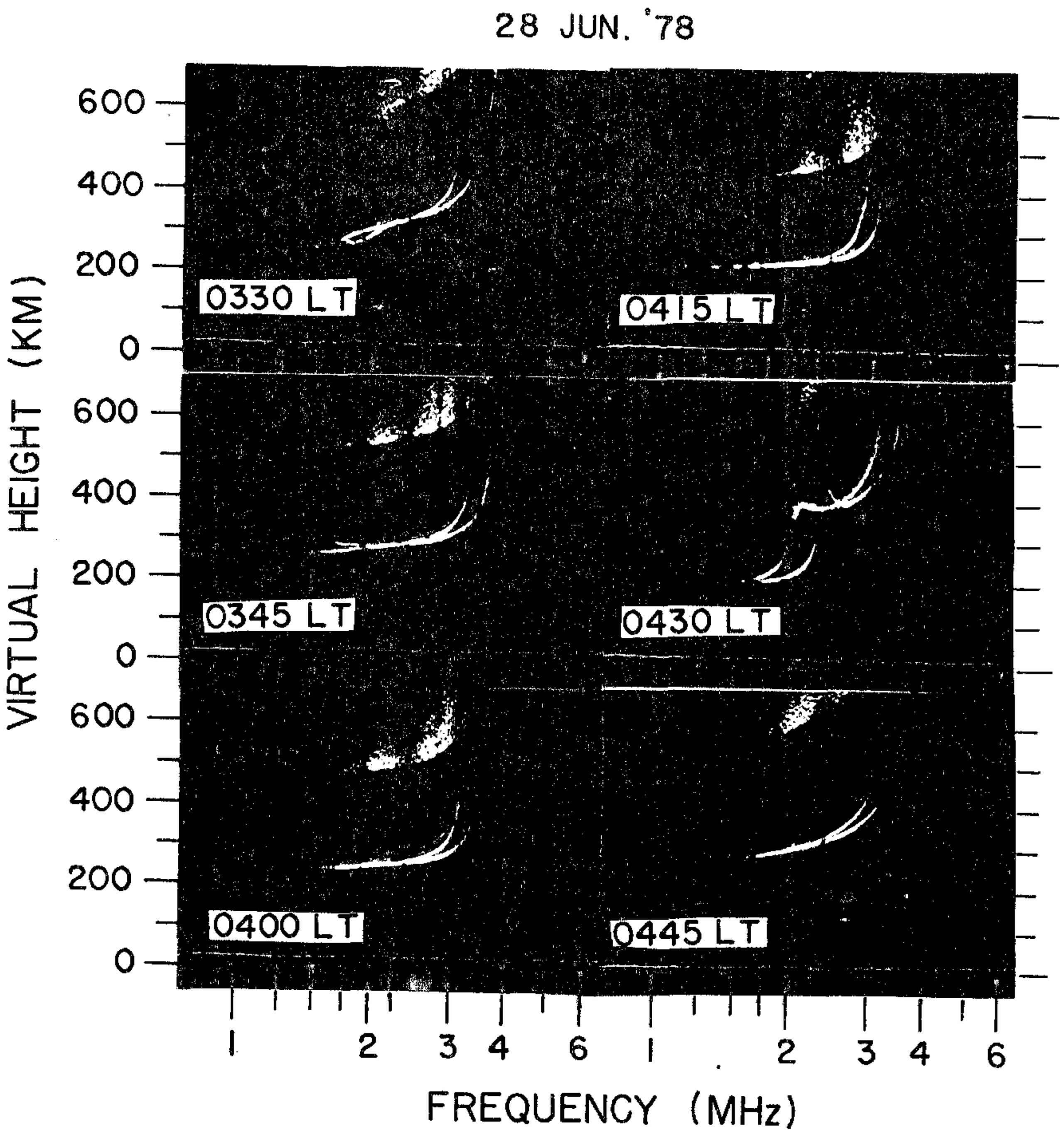
28 JUN. '78
VIRTUAL HEIGHT (KM)
600
400
200
0
0330 LT
0415 LT
0345 LT
0430 LT
0400 LT
0445 LT
1
2
3
4
6
FREQUENCY (MHz)

Fig. 1a

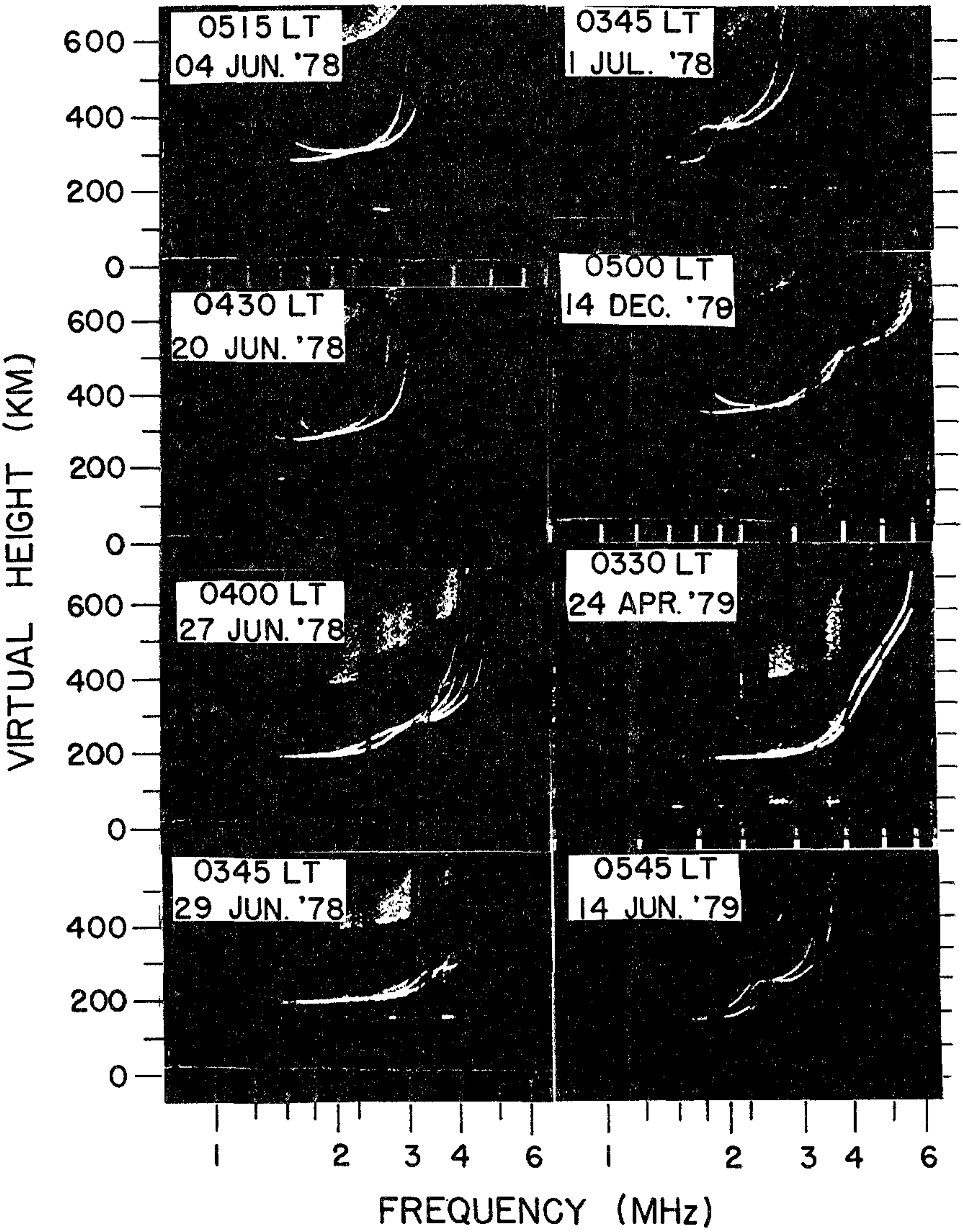
0515 LT
04 JUN. '78
0345 LT
1 JUL. '78
0430 LT
20 JUN. '78
0500 LT
14 DEC. '78
0400 LT
27 JUN. '78
0330 LT
24 APR. '79
0345 LT
29 JUN. '78
0545 LT
14 JUN. '79
VIRTUAL HEIGHT (KM)
600
400
200
0
FREQUENCY (MHz)
1
2
3
4
6

Fig. 1b

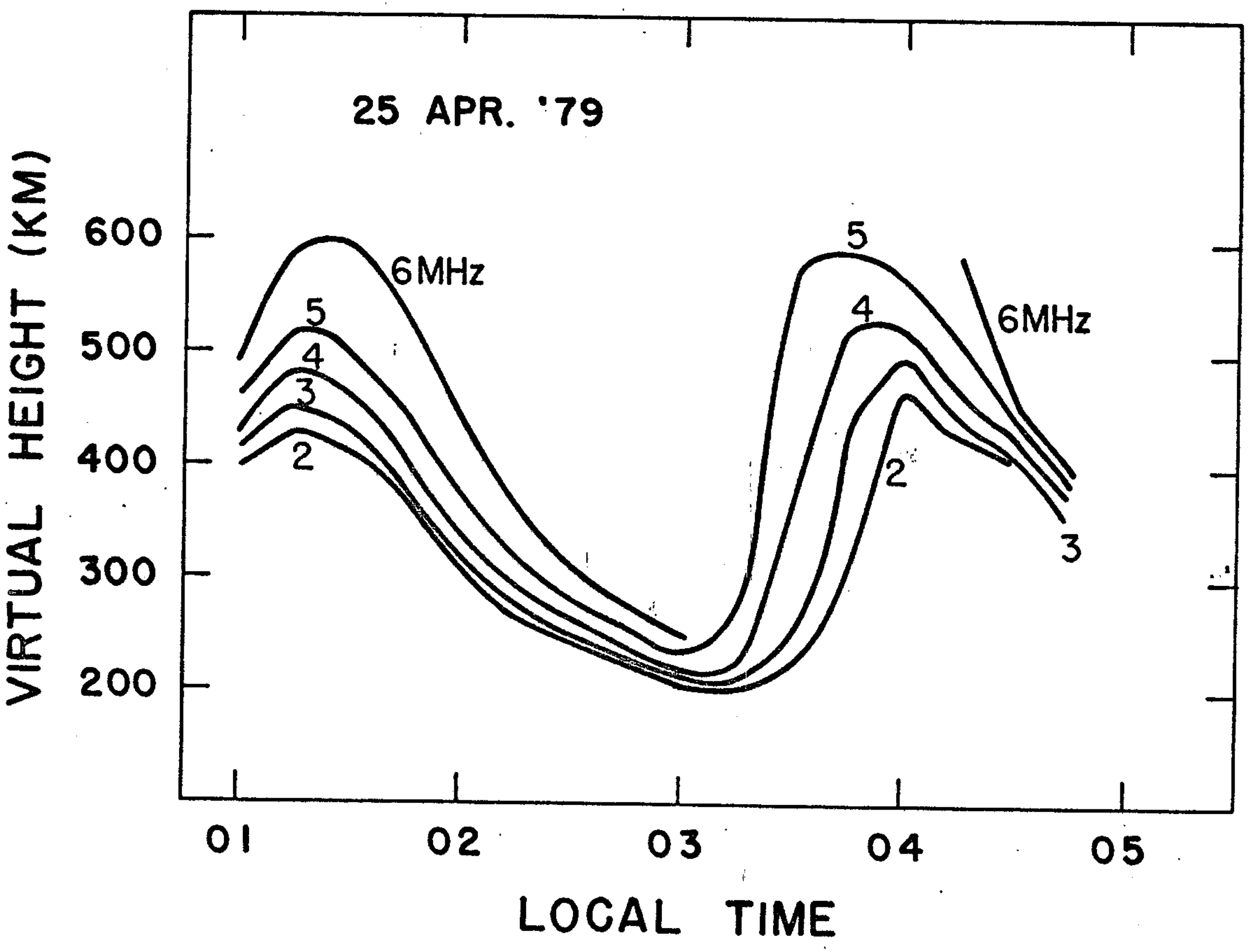
25 APR. '79
VIRTUAL HEIGHT (KM)
600
500
400
300
200
6MHz
5
4
3
2
5
4
6MHz
2
3
01
02
03
04
05
LOCAL TIME

Fig. 2

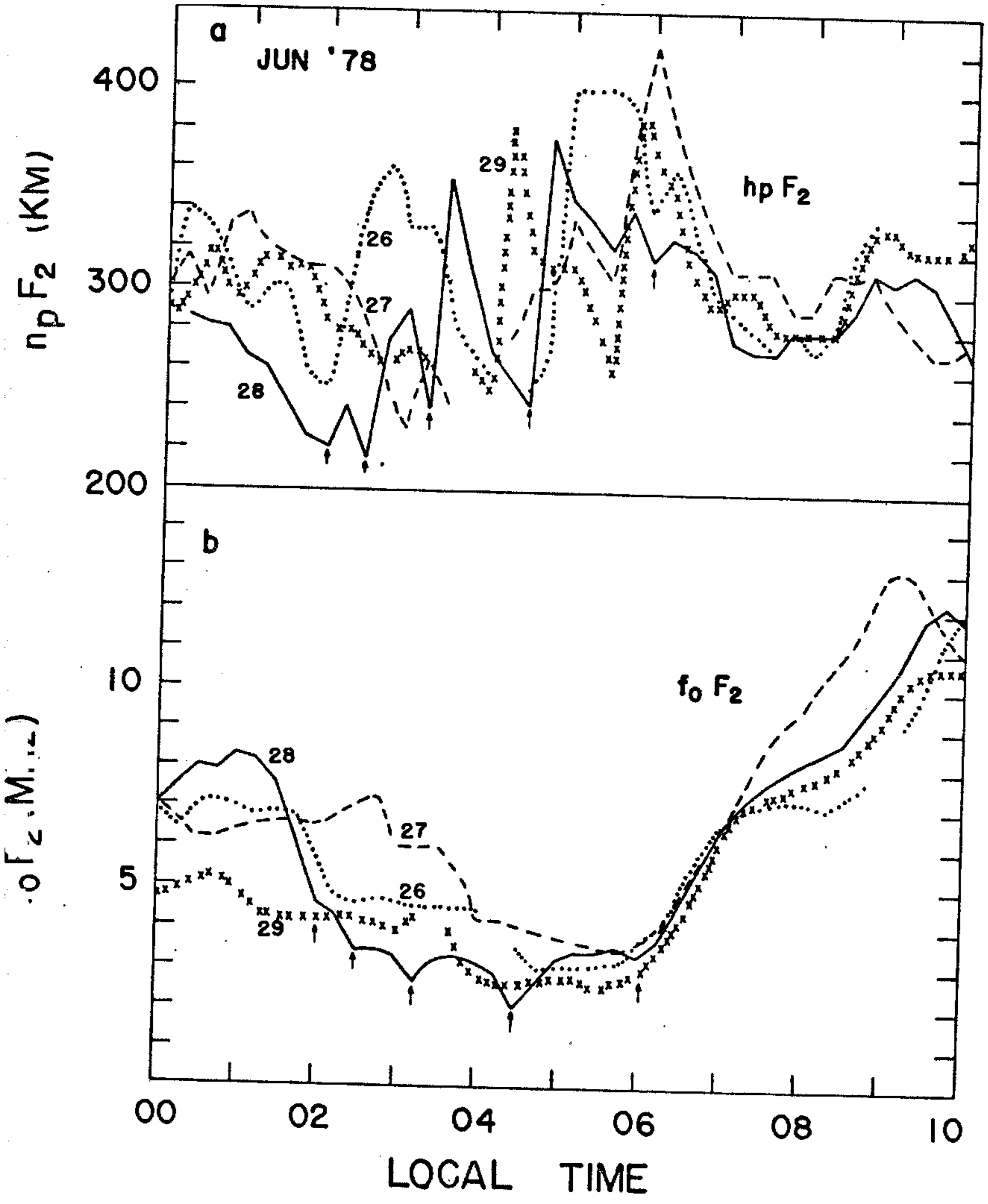
a
JUN '78
400
300
200
hp F2 (KM)
29
26
27
28
hp F2
b
10
5
fo F2 (MHz)
fo F2
28
27
26
29
00
02
04
06
08
10
LOCAL TIME

Fig. 3

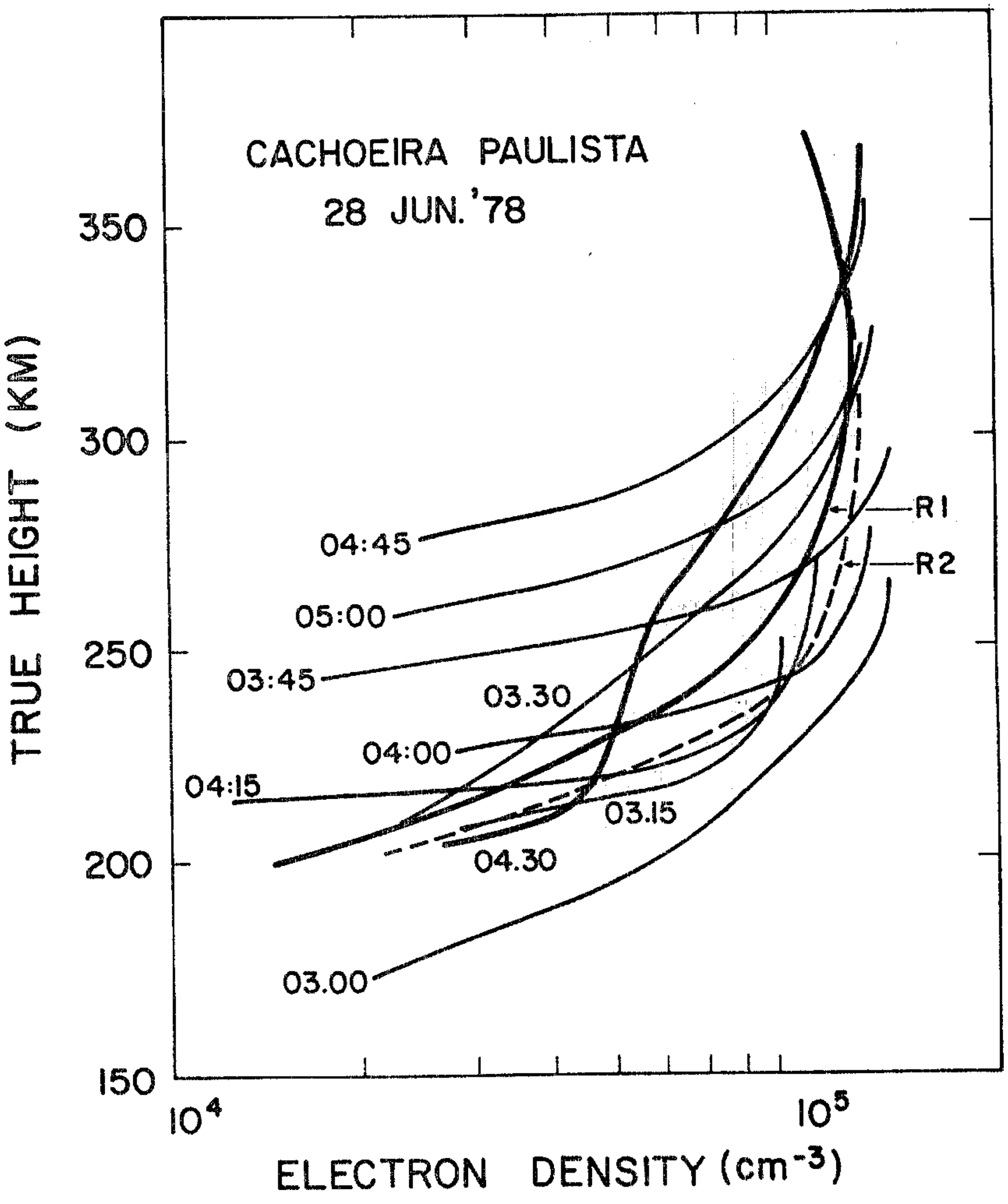
CACHOEIRA PAULISTA
28 JUN.'78
TRUE HEIGHT (KM)
350
300
250
200
150
ELECTRON DENSITY (cm-3)
10^4
10^5
04:45
05:00
03:45
03.30
04:00
04:15
03.15
04.30
03.00
R1
R2

Fig. 4

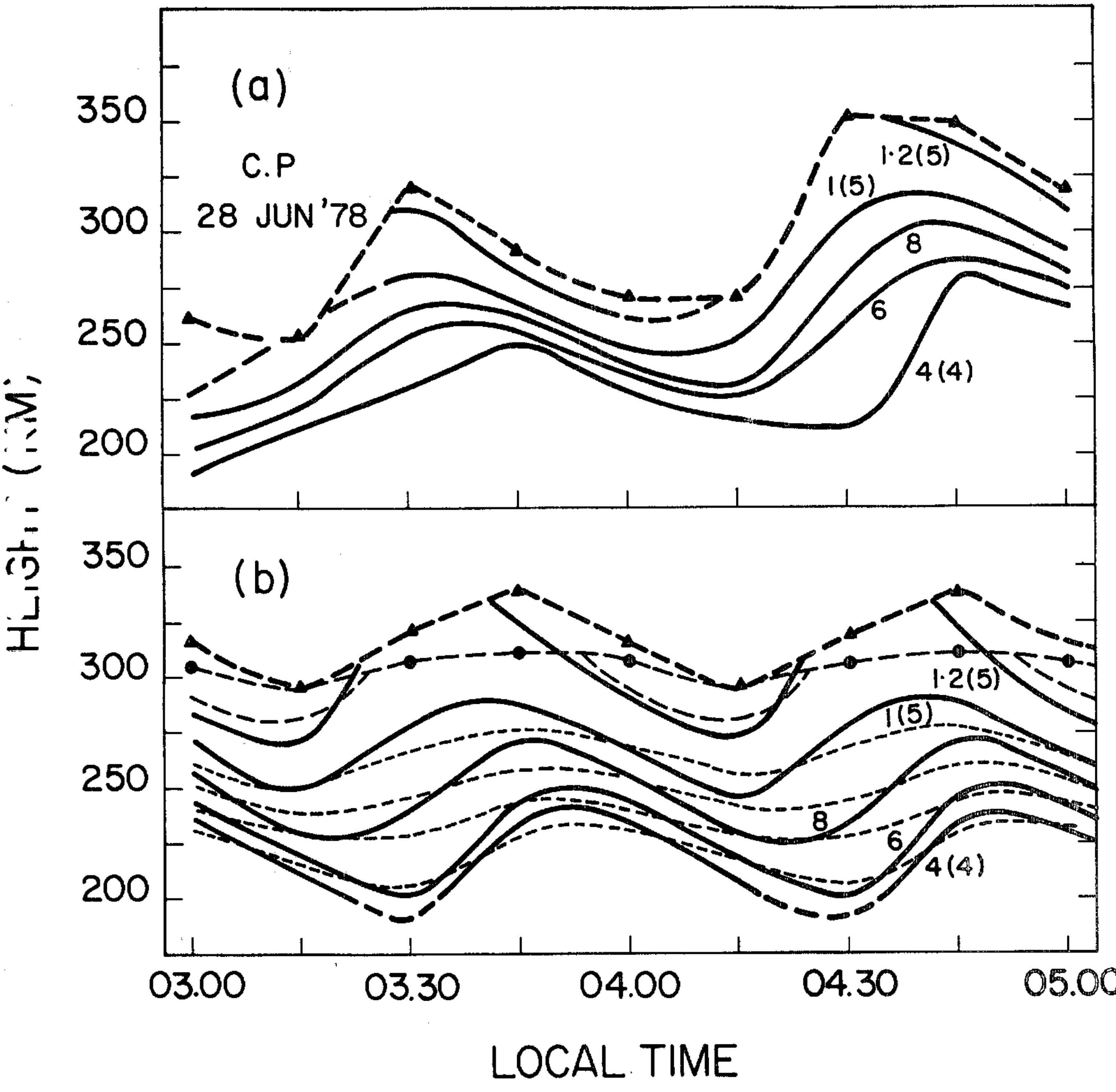
(a)
C.P
28 JUN '78
1·2(5)
1(5)
8
6
4(4)
(b)
1·2(5)
1(5)
8
6
4(4)
350
300
250
200
HEIGHT (KM)
03.00
03.30
04.00
04.30
05.00
LOCAL TIME

Fig. 5

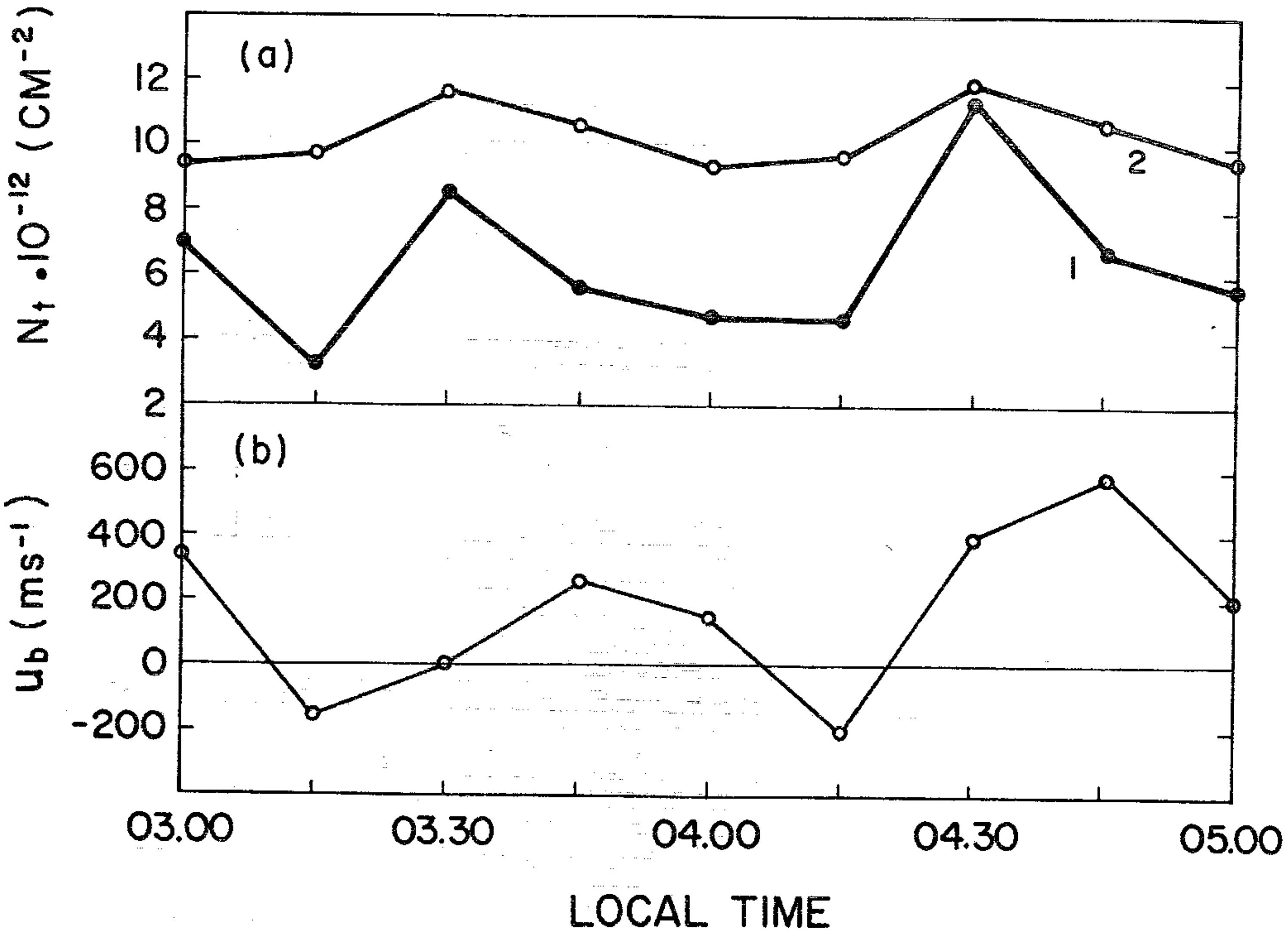
(a)
(b)
$N_t \cdot 10^{-12}$ (CM^{-2})
12
10
8
6
4
2
1
2
u_b (ms^{-1})
600
400
200
0
-200
03.00
03.30
04.00
04.30
05.00
LOCAL TIME

Fig. 6