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WAVE DISTURBANCES IN THE LOW LATITUDE IONOSPHERE AND EQUATORIAL IONOSPHERIC PLASMA DEPLETIONS

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ABSTRACT

An isolated nightime ionospheric wave disturbance was observed simultaneously by a meridional scanning 6300 Å photometer, a 6300 Å zenith phtometer, a 30 MHz riometer and an ionosonde over Cachoeira Paulista, a low latitude station in Brazil. From the results, we have identified at least two different scale sizes for the disturbances which could be broadly classified as: (a) a larger scale component easily identified in the riometer data and has characteristics similar to those of a large scale TID and (b) smaller scale disturbances observable in the scanning photometer data, occurring during the ascending phases of the larger scale waves. A Fourier analysis of the zenith airglow variations clearly reveals a dominant period of about 104 minutes that seems to correspond to the period of the larger scale waves and no single dominant period is present for the smaller scale waves. Whereas all these waves have a poleward velocity component, the smaller scale waves show up this feature more markedly. The equatorial source of the smaller scale disturbances and other characteristics have led us to suggest that these disturbances are perhaps the low latitude manifestations of the upward propagating field aligned plasma bubbles in the equatorial ionosphere.

INTRODUCTION

Low latitude ionosphere dynamics has assumed added importance in the light of the increasing interest by scientific groups in recent years in the studies of the dynamics and morphology of the equatorial ionospheric irregularities. Observational evidence on the latitudinal extension of the equatorial irregularity dynamics, in particular, could provide important input for verifying theories of the irregularities and related phenomena. The purpose of this work is to present and discuss an isolated event of low latitude propagating disturbance observed simultaneously by four instruments, namely, a meridional scanning 6300 Å photometer, a 6300 Å photometer looking at zenith only, a 30 MHz riometer with a vertical looking antenna and an ionosonde, all working at the same location. The large scale oscillation both on the riometer and airglow data discussed here is more sinusoidal-like and has a longer duration than anyone obtained on more than 100 (unpublished) similar experimental results from Cachoeira Paulista. The results suggest an equatorial source for the disturbances and hence seem to have implications on the possible latitudinal extension of the plasma density bubbles in the equatorial ionosphere (for recent works on the subject see Booker, 1979; Ossakow et al, 1979 and Fejer and Kelley, 1980).

OBSERVATIONS

Routine measurement of meridional profiles of 6300 Å nightglow emission is being carried out by a scanning photometer at Cachoeira Paulista (22°44'S, 45°00'W). Briefly, a mirror placed at 45° with respect to the horizontally oriented PMT axis is made to rotate back and forth around a horizontal axis such as to see the sky within zenith distances of 75° north to 75° south, in the magnetic meridional plane. A tilting filter was used such that one way scanning of the sky was carried out at the passband centered at 6300 Å and in the reverse scan a second tilt position of the filter at which the passband is centered a few Angstrom away from 6300 Å represented the sky background intensity. Each scanning irrespective of its direction required approximately 2.3 minutes. The narrow bandwidth (3 Å) of the filter and the usually high intensity of the red nightglow during events such as the one presented here permit us to discard any contamination by the OH 9-3 rotational band (Burnside et al., 1977). The angular diameter of the photometer receiving angle was 5°. A 30 MHz riometer with a vertical looking 5-element yagi antenna and an ionosonde were in operation in the immediate vicinity of the airglow observation site.

RESULTS AND DISCUSSION

A simultaneous recording by three instruments of an event that occurred on the night of 24-25 October, 1978 is presented in Figure 1. The zenith nightglow intensity as read from the scanning data shows correlated variations with time with the riometer absorption, especially in the large scale features, from around 2000 LT till around 0100 LT. Some additional features in the airglow variations, namely, (a) deepened minima at 2015, 2200 and 2340 LT (Figure 1) and (b) superimposed smaller scale structures, have important implications, as will be discussed shortly, but are absent in the absorption data due to spatial averaging by the relatively wider riometer reception angle. Owing to spread-F activity that usually accompany wavelike disturbance in the airglow over Cachoeira Paulista (Sobral et al, 1980) regular values of f_0F_2 for this case also could not be deduced from the ionograms for most part of this event. However, the contours of the virtual height of constant electron densities, shown in Figure 1, suggest an inverse relationship with the average trend of the airglow variation. It is the large scale quasi-periodic fluctuations in the airglow intensity about this mean trend that are related to the abosrption variations. Since the latter depends upon the height integrated square of the electron density ($\int N^2 dh$) near the F_2 peak (Abdu and Rai 1975) the spatial and temporal structures in the airglow or absorption profiles could, in fact, be referred to as structures in the electron density itself. The decrease in the riometer absorption at about 01 00 LT is related to a rapid decrease in the f_0F_2, (the absorption being proportional $f_0F_2{}^4$), observable after the spread-F activity had subsided at this time but not shown in the figure. On the other hand, the rising trend in the airglow intensity that was seen from about 2000 LT to 0200 LT is a clear height dependent event as could be verified from the ionosonde data. This may explain the fact that the correlated variation in the photometer and riometer record were present only until 0100 LT.

Meridional scanning airglow data show that during intervals immediately following the minima in the airglow intensity (such as the three intervals marked with an asterisk in Figure 1), namely, when the airglow intensity starts increasing, there appear smaller scale wavelike disturbances propagating in a direction away from the equator. An example of such travelling disturbances is shown in Figure 2 corresponding to one of these intervals, namely from 2200 to 2300 LT. The left and the right hand extremes of each profile correspond to the zenith angles of 75^{o}S and 75^{o}N respectively. North to south propagating disturbances are clearly seen from 2200 LT until about 2257 LT in Figure 2, whose estimated wavelength and trace speed are respectively 400 (± 40) m/s and 270 (± 30) m/s. These propagating disturbances are in fact superimposed on the larger scale quasi-periodic wave mentioned before (and which can be easily identified from the riometer record). The trace speed of this larger scale wave seems to be away from the equator as is evident in Figure 3, that presents time profiles of the airglow intensities for three fixed directions (45^{o}N, Zenith and 45^{o}S) in the meridional plane, read from the scanning data. On the basis of the most significant minima and their relative positions on those curves we have estimated the period and the southward speed of the large scale component as 150 (± 70) minutes and 600 (± 230 m/s) , respectively.

Simultaneous 6300 Å airglow data from a zenith photometer for the interval 2000 to 0100 LT was subjected to a discrete Fourier transform analysis making use of 156 data points read at two minutes interval. The scanning photometer data set was not used for this analysis since the minimum sampling period in this case would be about 4.5 minutes). The result is shown in Figure 4 in which the square of the DFT ploted along the ordinate is proportional to the power spectrum. A dominant period of 104 minutes correspond to that seen clearly in the riometer data (Figure 1). There are several smaller periodicities, some of them being around 25 minutes corresponding to those seen in the scanning data (Figure 2). The mean trend of the curve seems to indicate a linear spectrum, somewhat similar to the spectrum of the much smaller scale irregularities observed from a rocket flight in Brazil (Basu and Kelley, 1977) and similar also to the composite spectrum of plasma fluctuations as given by Booker (1979) where the spectrum linearly decreases at angular spatial frequencies greater than that corresponding to the scale height of the atmosphere.

Multiple trace type of spread F was observed (during the spread F occurrences of Figure 1) which is typically caused by the higher frequency end of the TID spectrum, where the scale of the fluctuations is of the same order of magnitude as the Fresnel zone for an ionosonde (Booker, 1979).

The parameters of the larger scale disturbances mentioned above, agree well with those of the TID's generated by auroral electrojet during magnetically disturbed periods (Chimonas and Hines, 1970; Francis, 1974; Richmond, 1978). However, magnetic indices showed that very quiet conditions prevailed for at least 3 days preceding this event, a fact, which, taken together with the poleward velocity component, seems to rule out any possible auroral source for the disturbances of both the smaller and larger scale sizes.

The poleward propagation of the airglow disturbances presented here could in fact be a manifestation of the latitudinal extension of the plasma bubbles in the equatorial ionosphere. Dynamics of these plasma depleted regions have been the subject of extensive investigation by ground based radars, in situ satellite and rocket probes and theoretical modelling (see for example, Woodman and LaHoz, 1976; McClure et al., 1977; Kelley et al., 1976 and Scannapieco and Ossakow, 1976). In particular, field aligned plasma depleted regions associated with spread-F events in the equatorial ionosphere have been observed by satellite probes (McClure et al., 1977; Heron and Dorling, 1979) and by ground based photometers (Weber et al., 1978). Owing to its field aligned nature, an upward propagation of a plasma depleted region in the equatorial ionosphere could appear, near its extremities, as a poleward propagating plasma depleted region by a ground based instrument observing at latitudes in the immediate vicinity of the magnetic equator. Thus, the poleward propagating airglow disturbances displayed in Figure 2 could in fact result from the upward propagation of a succession of field aligned plasma depleted regions over the equatorial ionosphere. The scale size of the disturbances observed by our photometer would in fact correspond, from the geometric characteristics of the geomagnetic field lines, approximately to half of these values (Heron and Dorling, 1979) for the bubble dimension in the equatorial plane.

The condition for generating plasma instabilities under collisional Rayleigh-Taylor mode as given by Ossakow et al. (1979) is that the linear growth rate γ be positive, where

$$\gamma = \left\{ \frac{1}{n_0} \frac{dn_0}{dh} \frac{g}{\nu_{in}} - \nu_R \right\},$$

where dn_0/dh is the unperturbed electron density gradient, ν_{in} is the ion to neutral collision frequency, g is the gravitational acceleration and ν_R is the recombination rate. Evaluation of this expression using the 6 MHz and 8 MHz frequency curves in Figure 1 shows that γ becomes positive around 1900 LT which is about the onset of the TID detected on riometer record plus the subsequent appearance of spread-F echoes in the ionograms.

Range type spread-F was present during this night over Fortaleza (3^oS dip) situated near the magnetic longitude of Cachoeira Paulista. However no clear relationship with the observed airglow could be established from this one event. However, a recent study (Sobral et al. 1980) has shown that almost the totality of the North-South propagating airglow disturbance observed over Cachoeira Paulista, during a 26 month period of study, was accompanied by range type spread F in the ionogram over the same location. This strengthens our suggestion that the N-S airglow disturbances presented here could indeed be manifestation of the upward propagating field aligned plasma depleted region in the equatorial ionosphere. Thus, the large scale wave (seen as a TID in the riometer data) might point out the possible role of TID's in initiating the disturbances that eventually give rise to the plasma bubbles detectable in the scanning photometer data.

CONCLUSIONS

Observations of an isolated ionospheric disturbance simultaneously by a 6300 Å scanning photometer, a 6300 Å zenith looking photometer a riometer and an ionosonde have made possible easy identification of larger and smaller scale propagating disturbances over Cachoeira Paulista. The larger scale disturbance (poleward speed of 600 ± 230 m/s, $T \cong 100$ minutes) has the characteristics of a large scale TID, but does not seem to have a high latitude source. The Fourier analysis of zenith airglow data has revealed a dominant period of oscillation of about 104 minutes which presumably corresponds to the period of the larger scale disturbance. The smaller scale disturbance (poleward speed of 270 ± 30 m/s, $T \cong 25$ minutes) also has phase velocities directed away from the equator. We have tried to interpret these poleward moving disturbances as manifestations of the upward propagation of field aligned plasma density depletions in the equatorial ionosphere.

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FIGURE CAPTION

Fig. 1 - Zenith profiles of the OI 6300 Å airglow intensity, riometer absorption and virtual heights of constant electron density. Notice the zenith arglow and riometer absorption minima of the larger scale wave at around 2015, 2200 and 2340 LT. The time intervals indicated by an asterisk denote the occurrence of intense multiple trace spread F, and the north-south propagating airglow disturbances (explained in the text).

Fig. 2 - Geomagnetic meridional profiles of the OI 6300 Å airglow intensity. A pronounced valley in the airglow profile appears at zenith at 2200 LT which clearly propagates southwards. It corresponds to a large electron density rarefaction.

Fig. 3 - OI 6300 Å intensity versus time plot for three photometer directions, 45°N, zenith and 45°S.

Fig. 4 - Square of the discrete Fourier transform (DFT) of about 156 airglow data points with a sampling period of two minutes. Notice the linear trend of this plot which is similar to the spectrum of plasma fluctuation given by Booker (1979).

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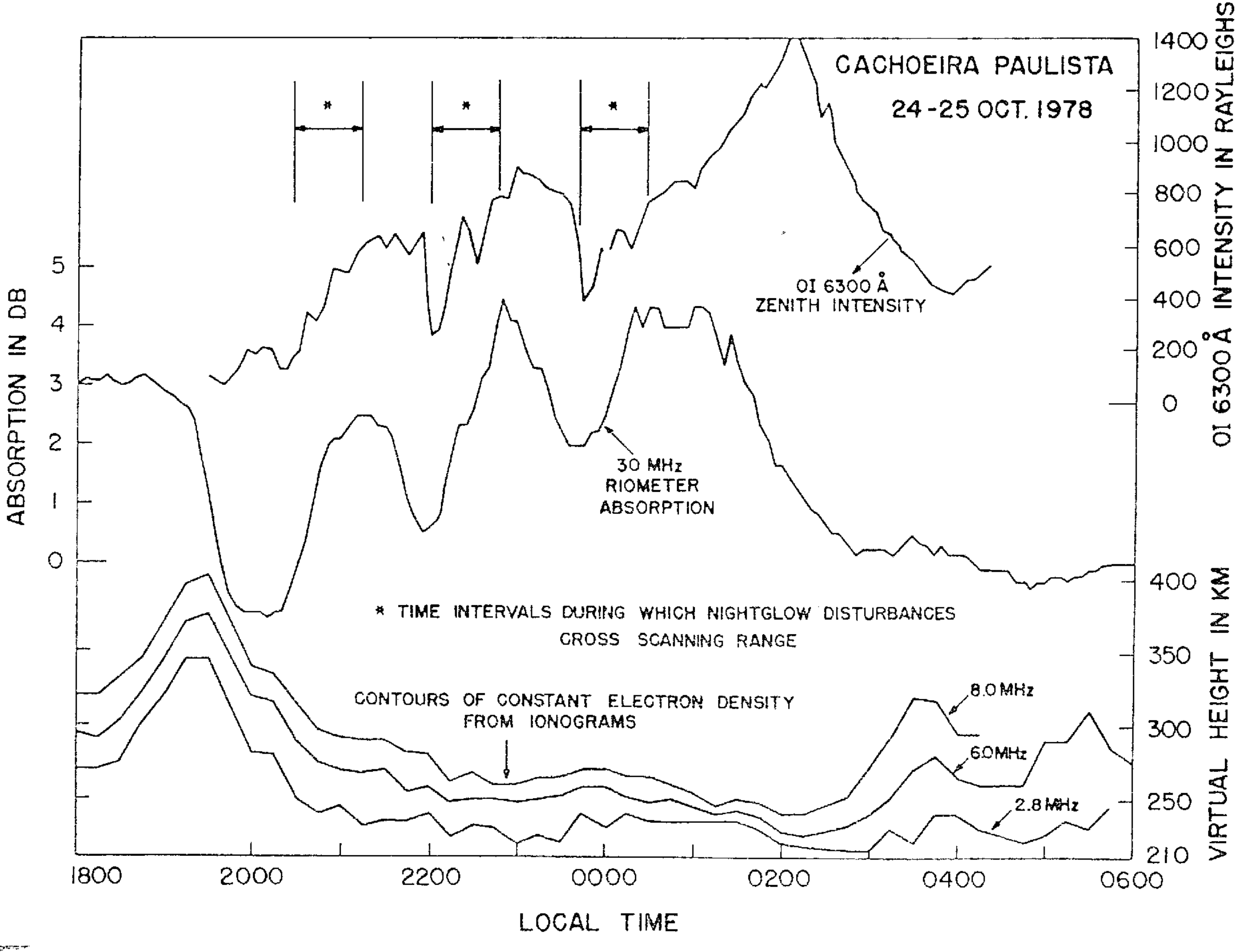
CACHOEIRA PAULISTA
24-25 OCT. 1978
OI 6300 Å ZENITH INTENSITY
30 MHz RIOMETER ABSORPTION
* TIME INTERVALS DURING WHICH NIGHTGLOW DISTURBANCES CROSS SCANNING RANGE
CONTOURS OF CONSTANT ELECTRON DENSITY FROM IONOGRAMS
8.0 MHz
6.0 MHz
2.8 MHz
*
*
*
ABSORPTION IN DB
5
4
3
2
1
0
OI 6300 Å INTENSITY IN RAYLEIGHS
1400
1200
1000
800
600
400
200
0
VIRTUAL HEIGHT IN KM
400
350
300
250
210
1800
2000
2200
0000
0200
0400
0600
LOCAL TIME

Fig. 1

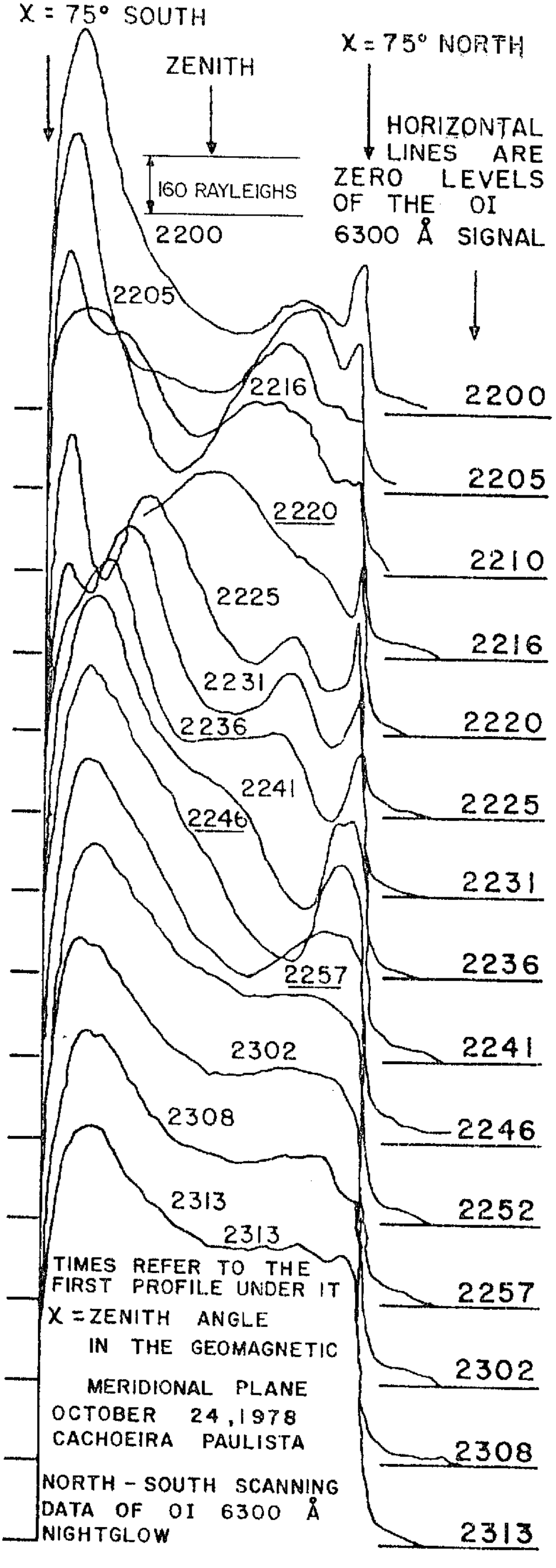
X = 75° SOUTH
ZENITH
X = 75° NORTH
HORIZONTAL LINES ARE ZERO LEVELS OF THE OI 6300 Å SIGNAL
160 RAYLEIGHS
2200
2205
2216
2220
2225
2231
2236
2241
2246
2257
2302
2308
2313
2313
2200
2205
2210
2216
2220
2225
2231
2236
2241
2246
2252
2257
2302
2308
2313
TIMES REFER TO THE FIRST PROFILE UNDER IT
X = ZENITH ANGLE IN THE GEOMAGNETIC MERIDIONAL PLANE
OCTOBER 24, 1978
CACHOEIRA PAULISTA
NORTH - SOUTH SCANNING DATA OF OI 6300 Å NIGHTGLOW

Fig. 2

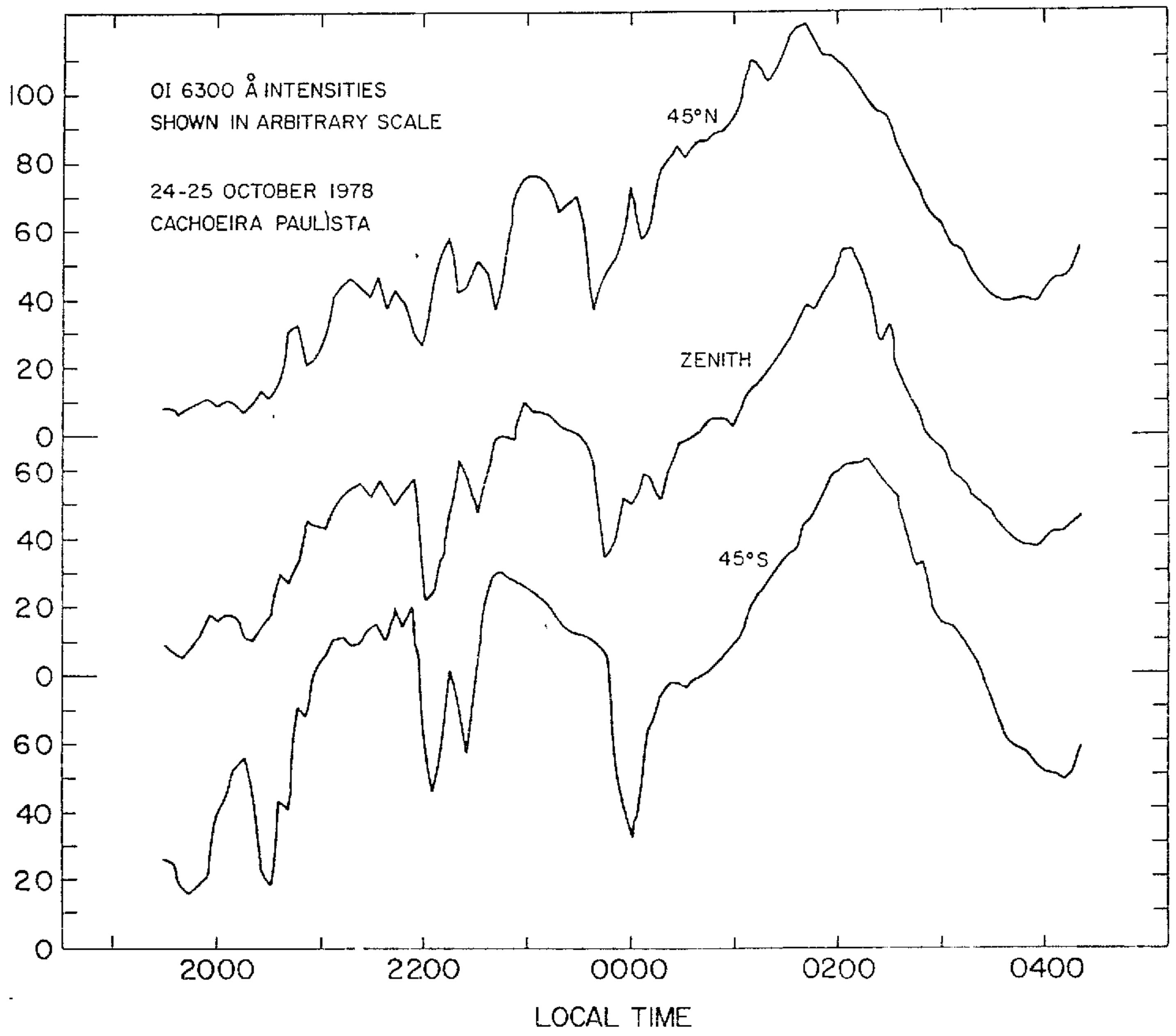
OI 6300 Å INTENSITIES
SHOWN IN ARBITRARY SCALE
24-25 OCTOBER 1978
CACHOEIRA PAULISTA
45°N
ZENITH
45°S
100
80
60
40
20
0
60
40
20
0
60
40
20
0
2000
2200
0000
0200
0400
LOCAL TIME

Fig. 3

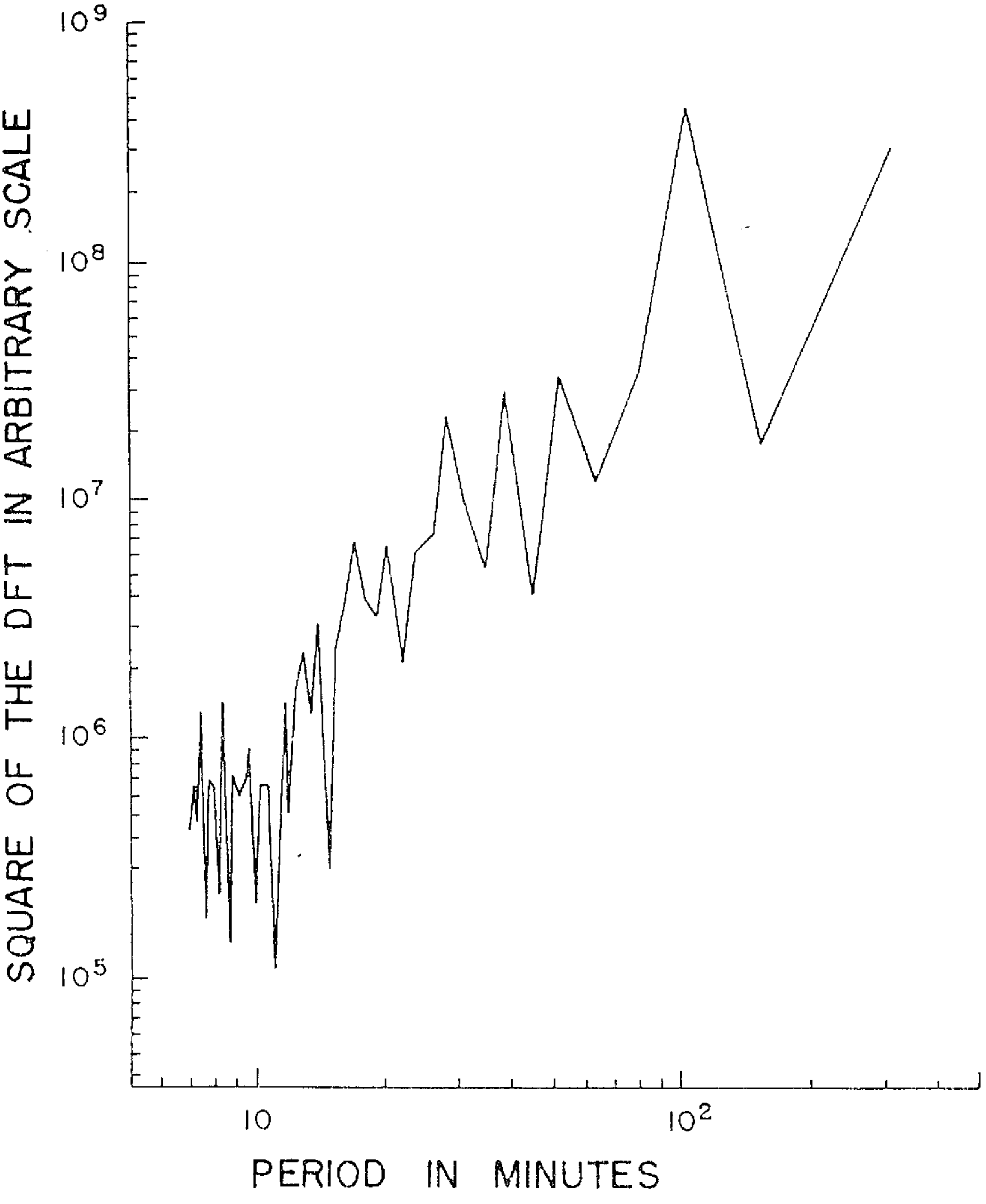
SQUARE OF THE DFT IN ARBITRARY SCALE
10^9
10^8
10^7
10^6
10^5
10
10^2
PERIOD IN MINUTES

Fig. 4