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Ionospheric Changes Observed Over Waltair (Dip 20° N) During the Total Solar Eclipse of 24th October 1995

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ABSTRACT

The ionosonde measurements made at Waltair (20° N dip) during the solar eclipse of 24th October 1995 showed significant decreases in both the critical frequency and the height of the F-layer during the eclipse. Also, significant oscillatory variations were observed in h'F and f_oF_2 during the course of the eclipse. When compared with the control days, f_oF_2 and f_oF_1 fell by about 15% and as much as 50%, respectively, on the eclipse day. The spectral components derived from the quasi-periodic variations observed in f_oF_2 and h'F over Waltair (81% obscuration) clearly showed the presence of an additional 30-minute component on the eclipse day, which was not present on the control days, indicating that the waves are observed away from the totality path.

(Key words: Solar eclipse, Electron density, Critical frequency, Virtual height, Quasi periodic variations)

1. INTRODUCTION

Ionospheric eclipse observations make a worthwhile contribution in the study of the transient phenomena of the ionosphere. It is known that the solar eclipse decreases the electron density in the E, F_1 and F_2 layers. However, a slight increase in electron density as well as a significant decrease in the height of the F-layer (h'F) are also reported (Anastassiades, 1970). The salient features observed in the ionosonde measurements made at Waltair, a low latitude station, during the total solar eclipse of 24th October 1995, are presented in this paper.

Present eclipse observed in India is also a unique event since it occurred in the morning hours when the degree of ionisation begins to increase. In addition, the period under study is a low sunspot activity period (R_z = 25) and is also free from magnetic disturbances (Ap = 10). The study aims to investigate the behaviour of the various parameters of the ionosphere during and after the total solar eclipse, with particular reference to the dynamics and chemistry of the ionosphere.

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2. DATA

The digital ionosonde system (KEL-IPS 42) situated at Nagarampalem field station (11 km from Waltair) was operated continuously from 23rd to 26th October 1995, covering the eclipse day and three control days. The first contact of the solar eclipse was observed at 0733 hrs IST (IST = UT + 0530 hrs), the maximum obscuration at 0844 hrs IST and the last contact at 1008 hrs IST over Waltair. Measurements were taken at 5-minute intervals on 24th and 25th, and at 15 - minute intervals on 26th October 1995. This data has been used to study the changes in the ionospheric parameters, namely f_oF_2, f_oF_1 and h'F scaled from the ionograms.

3. RESULTS

3.1 Minimum Virtual Height of F-layer (h'F)

The variation of h'F over Waltair as a function of local time from 0600 hrs to 1800 hrs IST (IST ≡ LT) on 24th, 25th and 26th October 1995 are presented in Figure 1a. On the eclipse day, after a time-lag of about 30 minutes from the first contact, sudden and significant oscillatory type fluctuation in h'F is observed. The oscillations in h'F are found to have a time-period which is similar in duration to that of the eclipse event. Subsequently, the height shows a gradual decrease up to 1600 hrs IST followed by a sudden increase, from where it joins the regular variation trend.

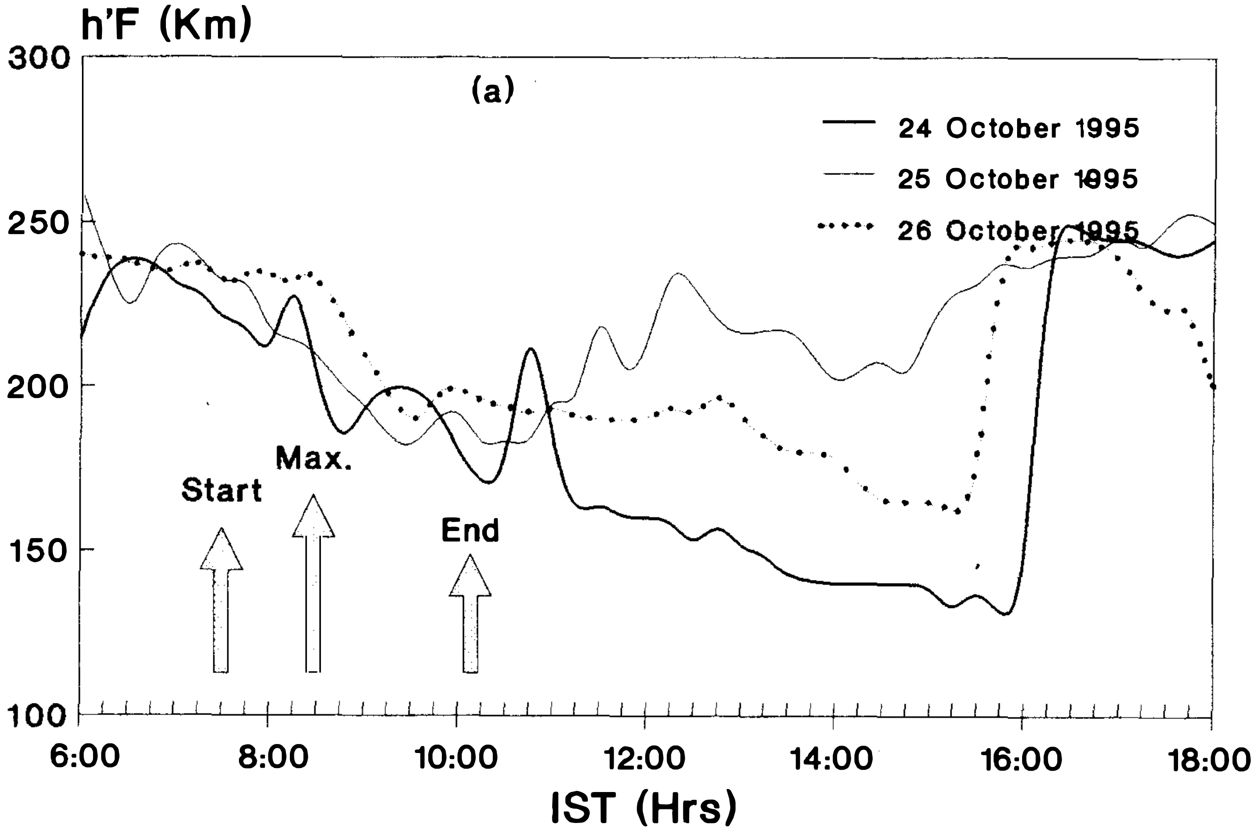

Fig. 1a. h'F variation on eclipse (24th) and control (25th and 26th) days over Waltair.

The rate of change of h'F (dh'F/dt), which represents the rate at which the F-layer moves up and down , during the eclipse day and on control days over Waltair is computed and presented in Figure 1b. This figure also clearly shows the oscillatory type variation occurring for the duration of the eclipse, with the average value of dh'F/dt as ± 45 m/s compared to ± 22 m/s on the control days. The oscillations are quite significant, particularly after the first and final contacts of the eclipse.

Furthermore, the h'F and h'F_2 variations on the eclipse and control days (Figure 2) show that h'F_2 initially decreased during the eclipse period, and attained the same regular variation trend as that of the control day from 1130 hrs IST onwards, while h'F continued to decrease on the eclipse day till 1600 hrs IST.

3.2 Critical Frequency of the F_1 layer (f_oF_1)

It is known from earlier studies, that the lower regions of the ionosphere (E and F1) are observed to be affected more than the higher regions (F_2 region and above) during a solar eclipse (Rishbeth & Garriott, 1969). To examine this feature, the f_oF_1 variation over Waltair during the eclipse and on the control days is presented in Figure 3a. From this figure it is seen that the values of f_oF_1 around the time of the start of the eclipse are found to be nearly the same (around 4.5 MHz), both on the eclipse day as well as on the control days, Later, on the eclipse

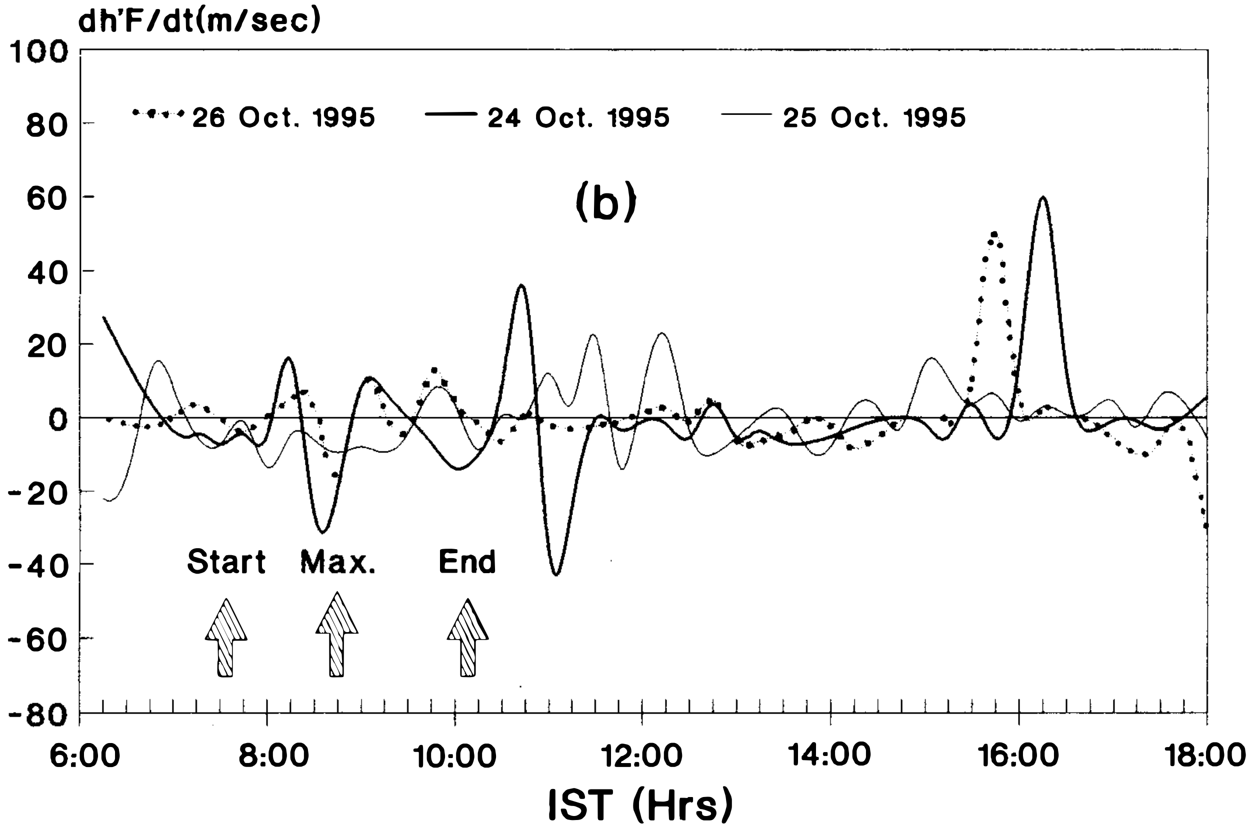

Fig. 1b. Vertical drift velocity of F-layer (dh'F/dt) during the solar eclipse day (24th) and control days (25th and 26th) over Waltair.

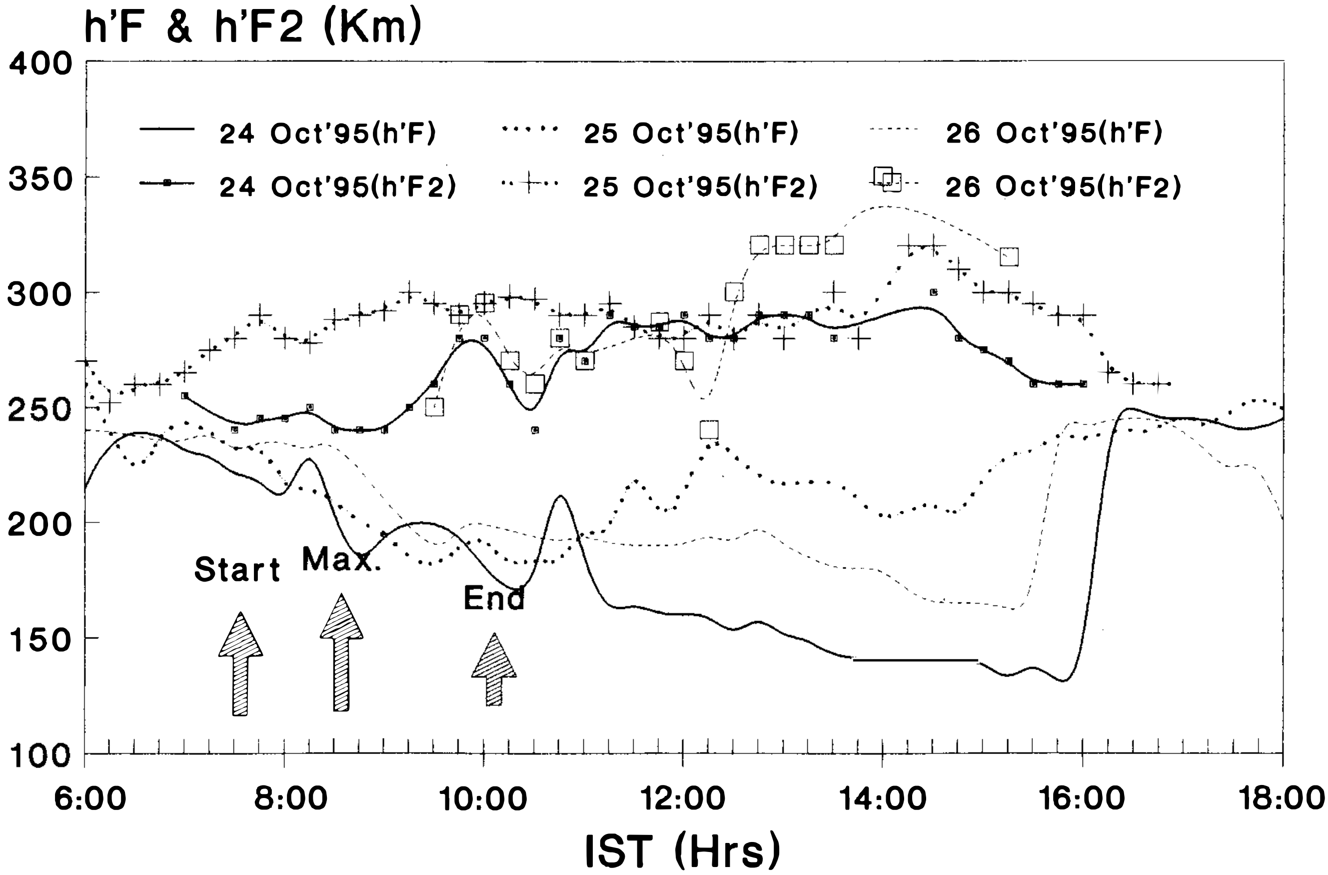

Fig. 2. h'F and h'F_2 variations on eclipse (24th) and control days (25th and 26th) over Waltair.

day, the value of foF_1 decreased to nearly 3 MHz during the maximum phase of the eclipse, while on the control days, the values of f_oF_1 remained at 4.8 MHz during the local time when the eclipse has occurred. Thus it is clear from this figure that there is a distinct depletion in f_oF_1 (by about 50%) during the maximum phase of the solar eclipse.

3.3 Critical Frequency of the F_2 layer (f_oF_2)

Another important parameter, namely the critical frequency of the F_2 layer, for the above three days (24th, 25th and 26th) is presented in Figure 3b. It can be seen that f_oF_2 on all three days showed a similar variation trend, reaching a value of about 9 MHz by about 0815 hrs IST. But, on the eclipse day, the f_oF_2 started decreasing from 0815 hrs IST, i.e. about 45 minutes after the first contact (0733 hrs IST) of the eclipse. The decrease in f_oF_2 is at a maximum at 0915 hrs IST, i.e. 30 minutes after the maximum obscuration. Again, it started increasing gradually and joined the regular diurnal trend of variation from 1300 hrs IST. The maximum decrease in f_oF_2 on the eclipse day is found to be about 15% as compared to the corresponding to the control day variations.

The cumulative distribution function (CDF) of f_oF_2 ($\sum \Delta F_2$) for 15-minute intervals on the eclipse day (24th October 1995) as well as on the control days (25th and 26th October 1995) are presented in Figure 4. On all three days, the CDF of f_oF_2 shows a faster increase up

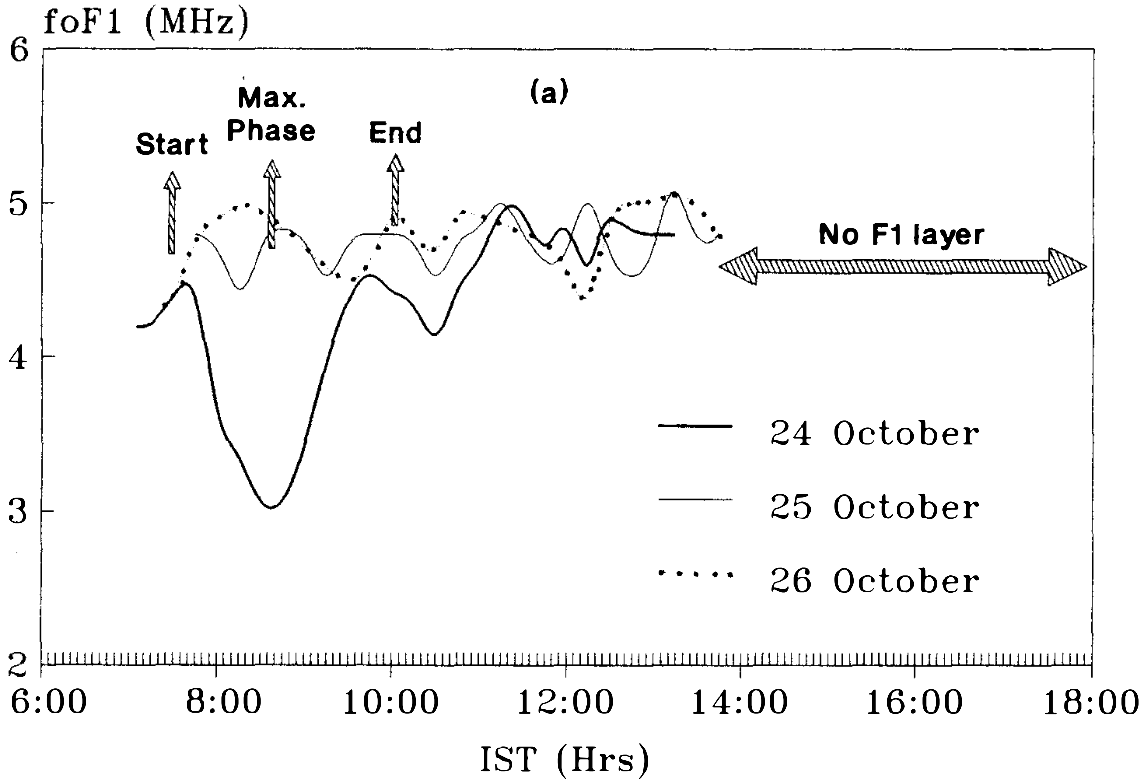

Fig. 3a. f_oF_1 variation on eclipse day (24th) and control days (25th and 26th) over Waltair.

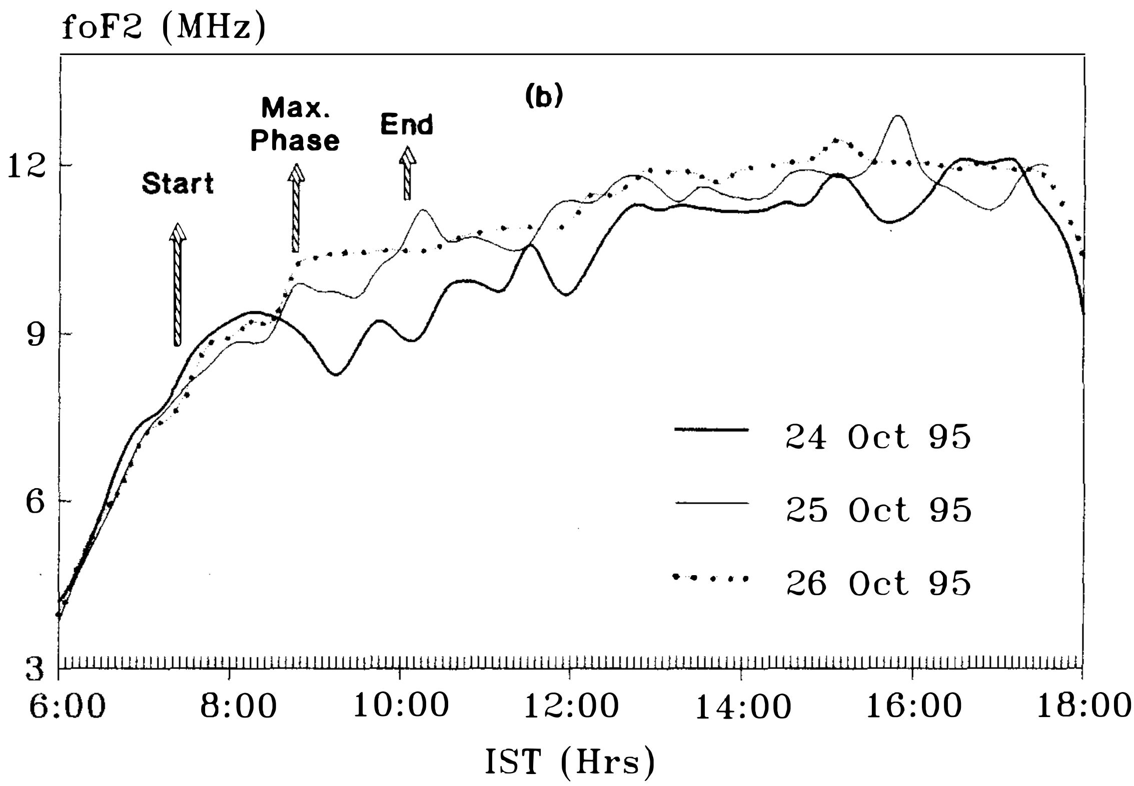

Fig. 3b. f_oF_2 variation on eclipse day (24th) and control days (25th and 26th) over Waltair.

to 0800 hrs IST. Whereas on the eclipse day, a small gradual increase in CDF is observed up to 0800 hrs IST (i.e. up to 30 minutes after the start of the eclipse), followed by a decrease which attains it's lowest value by 1200 hrs IST. However, on the control days (25th and 26th) the CDF continued to show an increasing trend, as expected during the day.

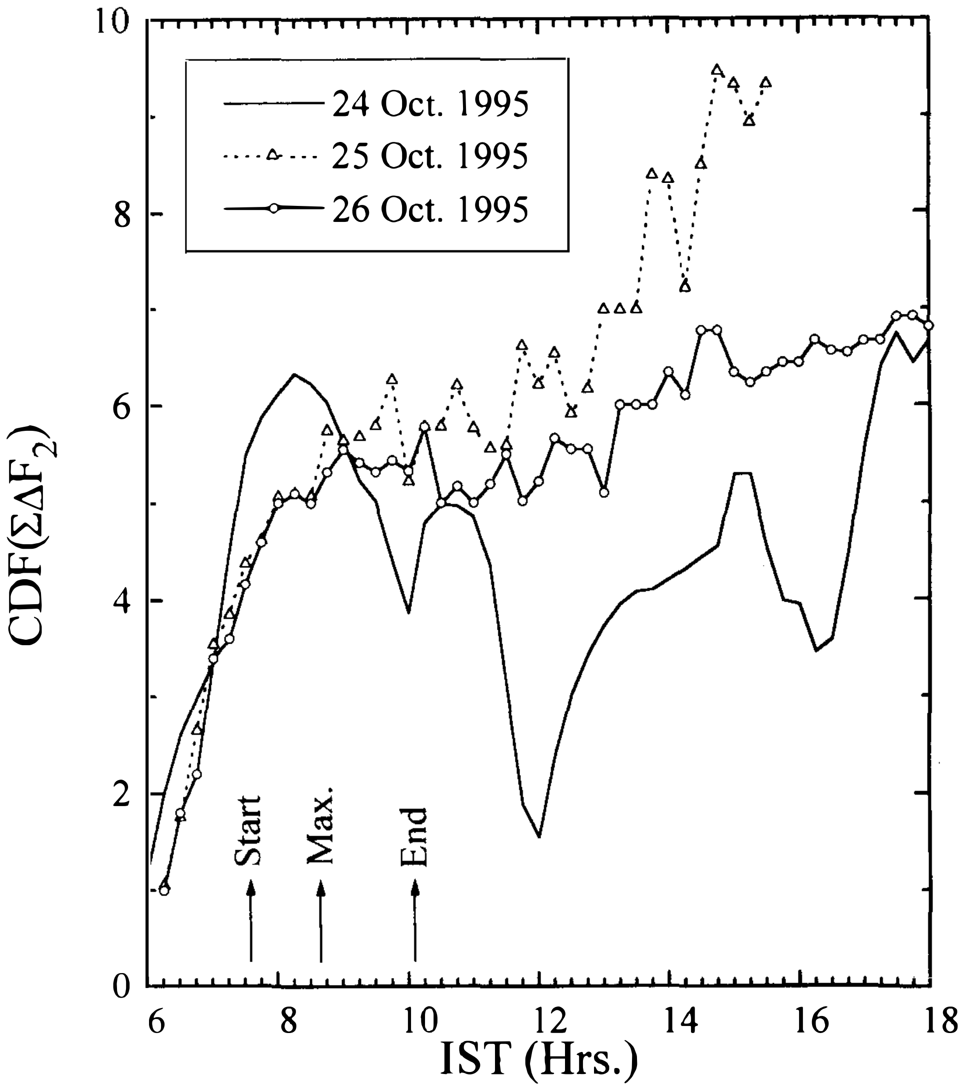

Fig. 4. Cumulative distribution of f_oF_2 on eclipse day (24th) and control days (25th and 26th) over Waltair.

3.4 Typical Electron Density Profiles During the Eclipse

The three typical electron density profiles (N-h profiles) deduced by using SPOLAN (Titheridge, 1985), under zero valley and no E-layer conditions, before the start of the eclipse (0730 hrs IST), at the maximum obscuration (0845 hrs IST) and after the eclipse (1130 hrs IST) are presented in Figure 5. From this figure, it is seen that the electron density profile at 0845 hrs IST showed a marked stratification of the F_1 and F_2 layers with a great semi-thickness in the F_1 layer when compared to the other two N-h profiles corresponding to the timings before and after the eclipse. The semi-thickness of the profile, corresponding to 0845 hrs IST,

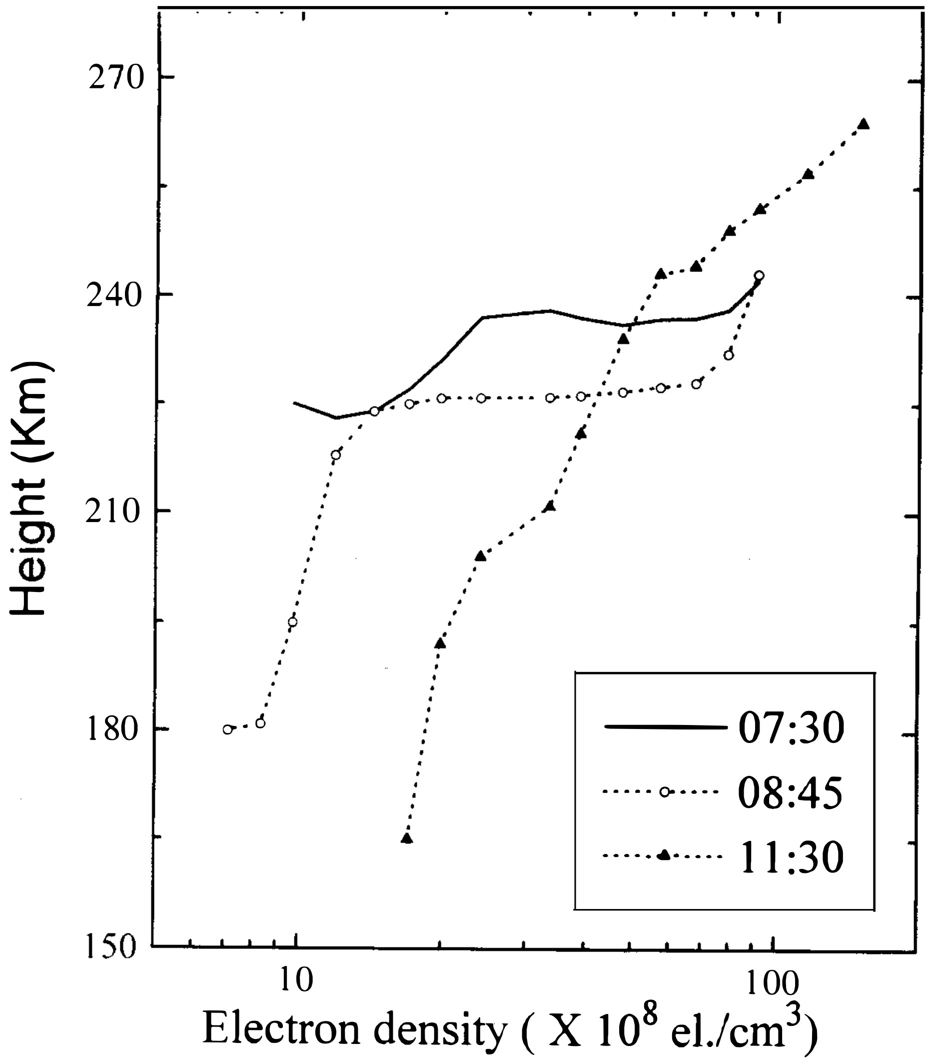

Fig. 5. N-h profiles at 07:30 hrs (before eclipse), 0845 hrs (at maximum obscuration) and 1130 hrs (after eclipse) on elipse day (24th) over Waltair.

is found to increase from 15 km at 0730 hrs IST to 100 km at 1130 hrs IST, indicating that the increase could be due to the variation in the neutral temperature at F-region heights (Titheridge, 1973).

3.5 Quasi Periodic Variations in f_oF_2 and h'F

Significant wave-like variations are observed in h'F and f_oF_2 throughout the day, both on the eclipse day and on the control days. The 15- minute values of h'F and f_oF_2 from 0600 to 1800 hrs IST of all three days are subjected to dynamic Maximum Entropy Method (MEM), and their resulting spectra are presented in Figures 6a and 6b respectively. It is seen from the figures that on the eclipse day (24th October), significant periodic components of 30 and 60 minutes are seen in both parameters. While on the control days (25th and 26th October), only the 60-minute component is present. The possible mechanisms responsible for the presence of the additional 30- minute component on the eclipse day are discussed in detail in the following section.

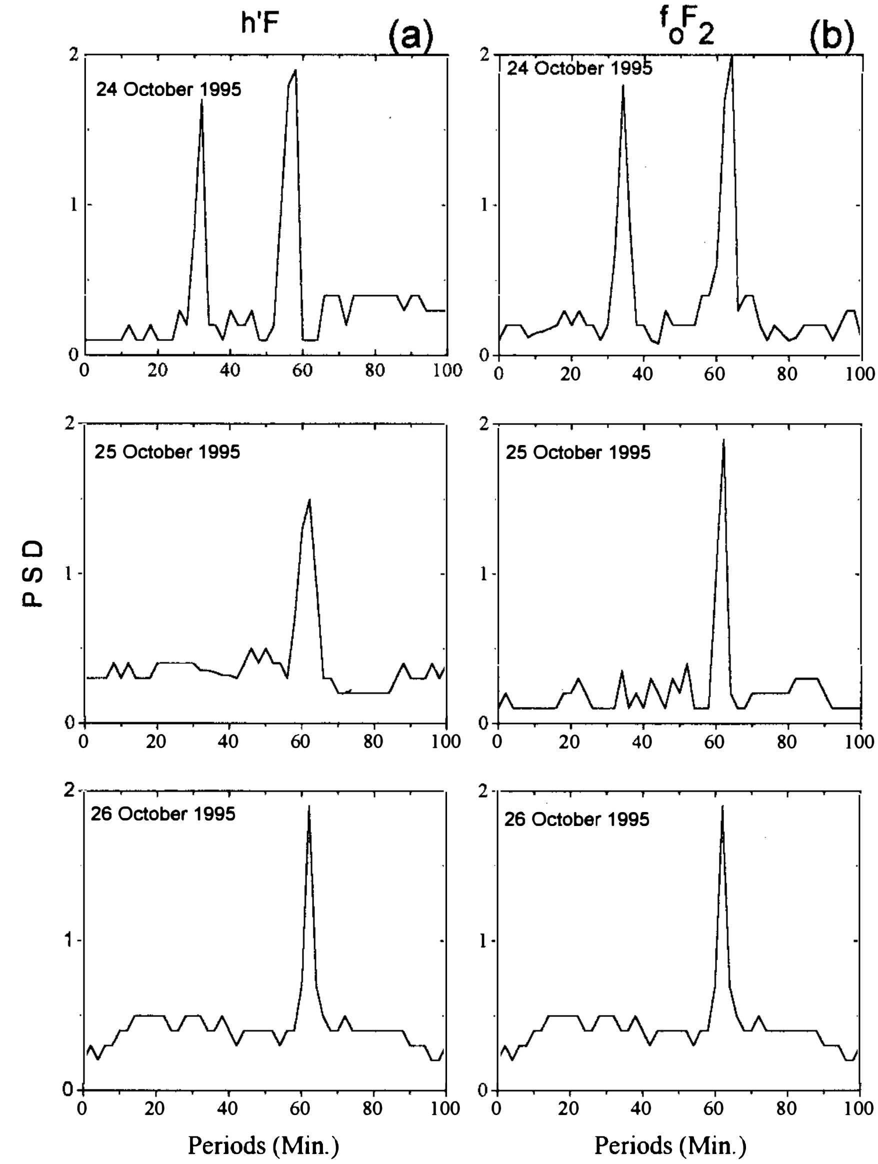

Fig. 6a. Dynamic MEM spectrum of oscillations in h'F on eclipse day (24th) and control days (25th and 26th) over Waltai. *6b.* Dynamic MEM spectrum of oscillations in foF2 on eclipse day (24th) and control days (25th and 26th) over Waltair.

4. DISCUSSION

As the solar flux in each wavelength region is progressively reduced during a solar eclipse, the chemical equilibrium in the ionospheric layers is disturbed. The loss rate of ionisation at different altitudes depends on the composition of the ionosphere. In the altitude range of 140 to 170 km, NO^+ and O_2^+ are the dominant ions and their loss rates are higher than that of O^+. O^+, which has a slower loss rate (Banks and Kockarts, 1973), becomes the dominant ion above 170 km. Accordingly, the decrease in the electron density in the F1 region (in which NO^+ and O_2^+ are dominant) is seen on the eclipse day, without any time-delay, right from the onset of the eclipse (Figure 3b), due to the higher loss rate of NO^+ and O_2^+. However, the decrease in the electron density in the F_2 region (in which $O^+$is dominant) is found to show a time-delay in the decrease of ionisation from the onset of the eclipse (Figure 3a) due to the slower loss rate of O^+. Holt *et al.,* (1984) have shown that the formation of an electron density trough in the eclipse zone is due to an increase in the charge transfer ($O^+ + N_2 \rightarrow NO^+ + N$; $O^+ + O_2 \rightarrow O_2^+ + O$) processes, in which the O^+ ions (which are dominant in the F_2 region) will be driven through the neutral atmosphere producing NO^+ and O_2^+ (which are dominant in F_1 region). Thus, the above processes are responsible for the faster recovery of f_oF_1, and the delayed recovery of f_oF_2, after the end of the eclipse and before returning to the control day values (Figures 3a and 3b).

The totality of the present eclipse occurred on the northern side of Waltair, with the magnetic equator being due south. The slight increase observed in the values of f_oF_2 on the eclipse day at Waltair after the first contact (at 0815 hrs IST in Figure 4) may be due to the temperature gradient created by the eclipse (Holt *et al.*, 1984), which might have caused an increase in ionisation (over Waltair) due to its transport from the equator to the eclipse-induced trough-region. Later, when the ionospheric region over Waltair came under the path of the shadow of the eclipse, the f_oF_2 started decreasing. It has been reported that during a total solar eclipse, electron temperatures drop by roughly 1000° K at all heights, while ion temperatures decrease by only 100 ° K at 350 km and 350 ° K at 650 km (Holt *et al.*, 1984 and the references therein) in the path of the totality. Thus the formation of the cooler region on the northern side of Waltair might have created conditions favourable for the onset of transequatorial winds (Bertin *et al.*,1977) blowing from the southern to the northern hemisphere. These winds may be responsible for the transport of ionisation from the equator to the trough region created by the eclipse shadow.

Furthermore, the stratification of the F-layer into F_1 and F_2 layers is observed to be more significant (as seen from the large difference between h'F and h'F_2 presented in Figure 2) during the eclipse period. Huang (1974) proposed that a large upward drift is a necessary condition for the stratification of the F-layer into F_1 and F_2 regions, which is clearly seen in the vertical drift velocities (Δh'F/Δt) observed over Waltair (Figure 1b). Vertical transport is likely to be important if it moves the plasma through one scale height during its lifetime, which is around one minute in the E-region and about an hour or more in the F_2 region (Rishbeth & Garriott, 1969). Therefore, the larger drift of the F-layer (40 to 60 km within 5 minutes of time) observed during the eclipse also favours the stratification of the F-layer (Huang., 1974). Furthermore, the raising of the F-layer to higher altitudes during the solar eclipse over Waltair may also slow down the diffusion and hence reduce the ionisation of the F_2 region and increase the accumulation of ionisation in the F_1 region, making the stratification more prominent. In addition to the above two reasons, factor G, which is proportional to $\beta^2 / \alpha \mathbf{q}$ (where β = linear loss coefficient, α = recombination coefficient and q = rate of production of ions and electrons), quantifies the stratification of the F_1 and F_2 regions (Rishbeth & Garriott, 1969). During a solar eclipse, q decreases as the solar disc is obscured and a also decrease as the temperature decreases due to the eclipse shadow region. Hence the value of G may become larger around the eclipse time, which is attributed to increased stratification of the F-layer.

The 30- minute component observed in the quasi-periodic variations of h'F and f_oF_2 is also seen in the phase height variations of the F-region over Waltair (Rao & Anjaneyulu, 1996). Bertin *et al.* (1977) have proposed a model in which they assumed that, if a wave is generated at the totality path and travels towards the observing station at a velocity of about 300 m/s (close to the velocity of sound) then the presence of a wave, whose component gives a wavelength comparable to the size of the umbral region of the eclipse, may be attributed to the eclipse generated wave. Huang *et al.* (1996) have reported that the quasi-periodic oscillations observed in the electron density during the present solar eclipse (24th October 1995) are propagating with a horizontal velocity of 296 m/s, which is similar to the acoustic velocity assumed in the model proposed by Bertin *et al.* (1977). In the present observations at Waltair, the 30-minute component seen in h'F and f_oF_2 variations (Figures 6a & 6b) on the eclipse day, may be due to the eclipse generated wave, since its (30-minute component) wavelength, which comes out to be 470 km, is comparable to the distance of 500 km between Waltair and the totality path. Thus it may be concluded that the quasi-periodic variations of the 30-minute component observed in h'F and f_oF_2 are attributable to the eclipse induced wave.

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