

UPWARD MOVING IONOSPHERIC IRREGULARITIES OVER KODAIKANAL

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ABSTRACT

The occurrence of upward moving kinks first found on ionograms at Thumba (Rastogi, 1970) has been confirmed to occur at another equatorial station, Kodaikanal. These kinks have been found in many records and they occur mostly during local summer months. The occurrence of the kink is shown to be closely associated with horizontal F-region drifts, occurrence of intermediate cusp between F_1 and F_2 layers, bite-out effects of f_0F_2 and rise of h_pF_2 , all being most pronounced around 10 hr. The upward movement of the kink is due to $\vec{E} \times \vec{B}$ drift, while its initiation is probably due to a sudden change in the electrostatic field of the equatorial electrojet.

The study of the upward moving kink gives a direct measure of the height variation of the vertical upward drift of ionization over the magnetic equator.

INTRODUCTION

THE critical frequency f_0F_2 , at low latitude stations, shows anomalous behaviour both in its diurnal as well as in its latitudinal variations; the values of f_0F_2 at an equatorial station being lower during midday than during forenoon or afternoon hours. Moreover, the values of f_0F_2 around midday hours are lower near the magnetic equator than at latitudes around 20° north or south of it.

The first attempts to explain the equatorial bite-out of f_0F_2 were in terms of thermal expansion of the ionosphere (Appleton *et al.*, 1935) but this idea was later shown to be untenable by Martyn and Pulley (1936). Norton and VanZandt (1964) have tried to explain the daytime equatorial ionospheric $N(h)-t$ variation in terms of photo-ionization and recombination

in a time-varying neutral atmosphere whose temperature increases rapidly in the morning hours, and is roughly constant during the afternoon.

S. K. Mitra (1946) suggested that the ionization formed in the equatorial ionosphere above h_{\max} diffuses polewards and downwards along the magnetic lines of force and gives rise to enhanced critical frequencies at lower heights to the north and south of the equator. However, it was pointed out that there would not be enough ionization above the equatorial F_2 region to produce the observed increase of ionization at about 20° north or south of the magnetic equator.

Martyn (1947) showed that the electron density distribution with height at any station would be greatly modified by the vertical transport of ionization with velocity varying with height and time. The vertical forces in the F-region were suggested to arise from the interaction of the horizontal geomagnetic field with the horizontal (eastward) polarization electric field of the dynamo region (Martyn, 1949). The equatorial F_2 region is thus lifted upward due to electro-dynamic forces and the increased ionization could diffuse horizontally north and south along the magnetic lines of forces (Martyn, 1955).

Rastogi (1959) studied the diurnal development of the equatorial anomaly and showed that the mid-latitude maximum in $f_0 F_2$ first develops at low-latitudes and shifts poleward with the progress of the day. Further, the two maxima in the daily variation of $f_0 F_2$ at low-latitude stations are less separated with increasing latitude, finally converging into a single maximum at 25° dip. He suggested that these two anomalies in $f_0 F_2$ are due to vertical drift of ionization over the magnetic equator together with its motion towards the poles along the magnetic lines of forces, causing $f_0 F_2$ peaks around 20° latitude. This suggestion explained the variation with solar cycle of the latitude of maximum $f_0 F_2$ as well as the differences in the latitudes of maximum $f_0 F_2$ and $f_0 F_1$ during years of high solar activity. The same suggestion was given later by Duncan (1960) comparing the daily variation of the critical frequencies at an equatorial station Chimbote and the tropical latitude station, Panama. Quantitative calculations of electron density distribution with height and latitude using the above suggestion, generally called the "fountain effect", were made by Moffett and Hanson (1965) as well as by Bramley and Peart (1965). Further detailed calculations, using time-dependent electro-dynamic term, have been computed by Baxter and Kendall (1968).

All these calculations can be made to fit the observed $N(h)$ profiles only by a proper adjustment of the vertical drift velocity. Evidence for vertical drift motions over the magnetic equator has come from the back-scatter experiments at Jicamarca (Balsley and Woodman, 1969). No direct evidence of vertical movements have been reported from any ionospheric stations which have been operating near the magnetic equator for nearly two decades.

Recently, Rastogi (1970) reported a new type of ionospheric discontinuity (kink) observed at the equatorial station, Thumba (dip 0.6° S). A sharp discontinuity in the ionogram was observed at about 120 km range, which moved upward through the virtual height and frequency record in a period of about 3 to 4 hours. In each of the ionograms the discontinuities were clearly visible on both the ordinary and extraordinary components, the heights of the first and second order echoes did not show any evidence of oblique echoes. Computing the true height of such a discontinuity with time, he estimated the vertical velocity of the disturbances to be about 15 metres per second. He suggested this to be due to $\vec{E} \times \vec{B}$ electro-dynamic lift over the equator during the daytime. It is undoubtedly of utmost importance to study the occurrence of such an event at other equatorial ionospheric stations.

The present paper describes similar vertically upward moving disturbances in the ionosphere for another equatorial station Kodaikanal and some of the properties observed therefrom.

A sequence of ionograms showing an example of upward moving kink similar to that reported for Thumba (Rastogi, 1970) is illustrated in Fig. 1. At 06.30, both the O and X critical frequencies of the F_2 and E_2 layers with no E_s are clearly seen. At 07.00, the frequency at 120 km range has suddenly increased and the equatorial E_s layer has developed. At 07.30 the E_2 ionization is not seen, but a discontinuity appears both in O and X traces of the F_1 layer. At 08.00, the kinks have crossed the F_1 critical frequencies and continue to progress up the ionogram trace with progress of time.

The F_2 critical frequencies at an equatorial station is known to increase very rapidly after sunrise followed by a maximum with a bite-out around the midday hours. The occurrence of multiple stratifications have been reported to occur during the bite-out hours at equatorial stations (Skinner *et al.*, 1954). The ionograms at Kodaikanal have indicated frequent

occurrence of an intermediate stratification between the F_1 and F_2 critical frequencies during the bite-out period. It may be noted that these cusps are not the lunar stratifications reported by Gautier *et al.* (1951). A sequence of ionograms showing simultaneous occurrence of $F_{1.5}$ layer as well as

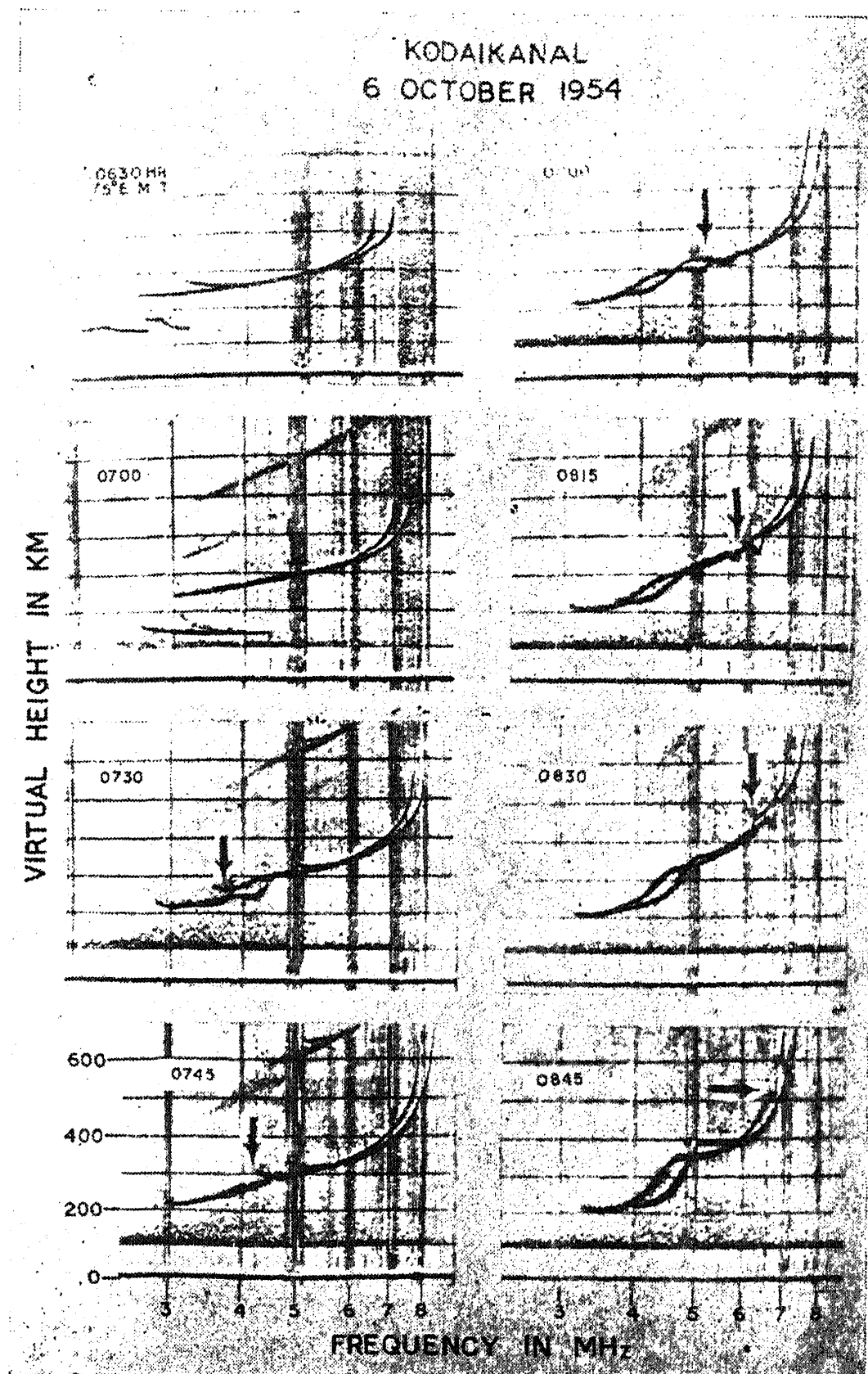


FIG. 1. Sequence of ionograms showing a sudden increase of fE_2 (0700 hr.) followed by sharp discontinuities (0730 hr.) which move up the height as well as frequency scales with the progress of time. The arrows point to the kink, in the ordinary and extraordinary traces of F_1 .

the sharp kinks is illustrated in Fig. 2. The record at 0900 hr shows a shallow ($F_{1.5}$) cusp between the F_1 and F_2 critical frequencies. At 0915 hr. the $F_{1.5}$ cusp is quite distinct and a sharp kink appears close to $F_0 F_1$ and $f_x F_1$. With the progress of time both the cusps as well as the kink move up the frequency scale till the cusps cross the height of the peak F_2 ioniza-

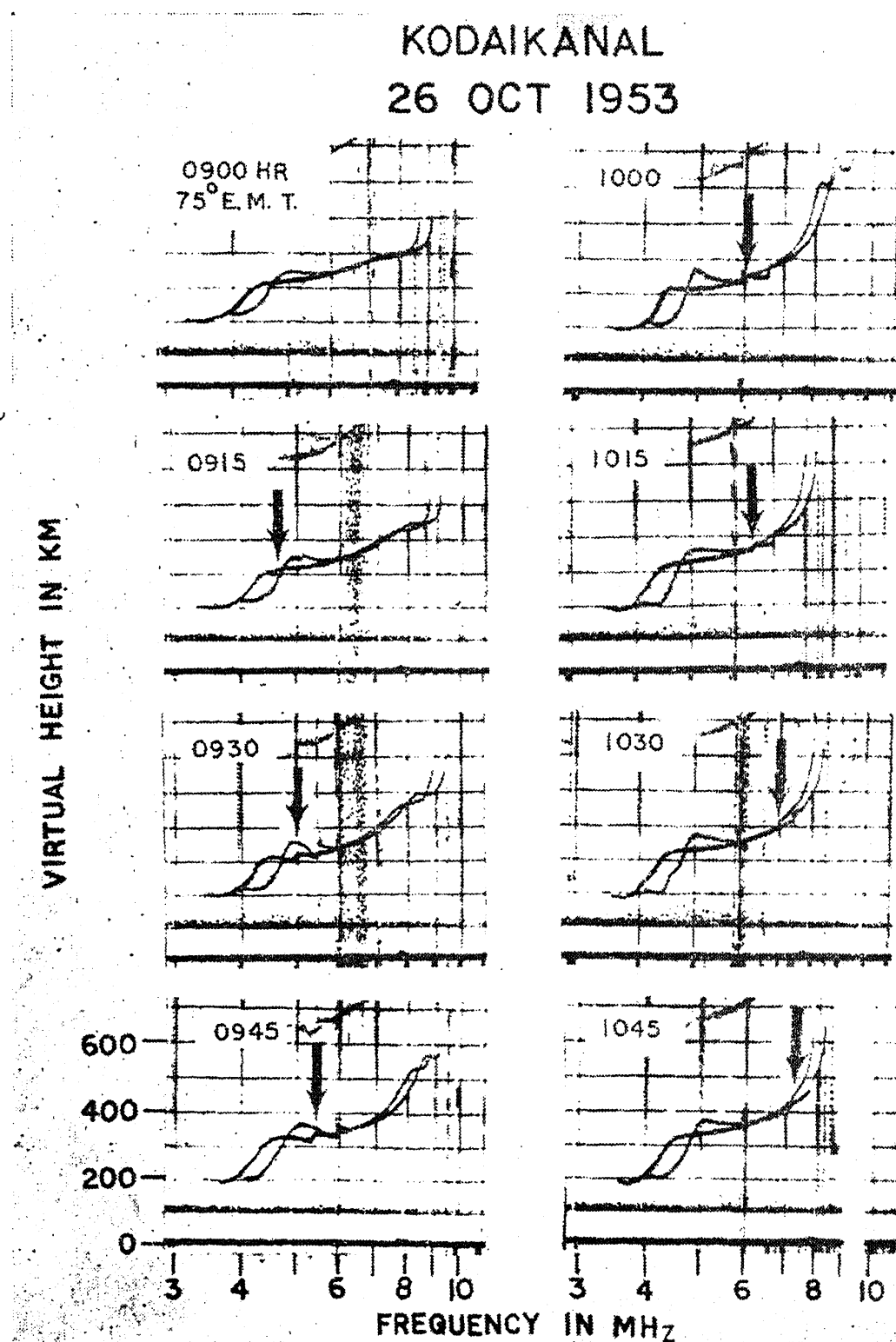


FIG. 2. Sequence of ionograms showing the movement of intermediate cusp in F_2 trace and the kink towards higher frequency with time.

tion at about 1015 hr. while the kink is seen upto 1045 hr. Whenever the kinks and $F_{1.5}$ are observed simultaneously, the kinks are found to follow the intermediate cusps.

Figure 3 shows the occurrence of these kinks on 21 April 1961, a moderately active epoch of the solar cycle, while Fig. 4 shows the occurrence of the kink on 7 May 1958 during the maximum solar activity period. The kink originates at the very base of the F_1 layer and progressively moves up the virtual height upto about $h_m F_2$. It may be noted that the depth

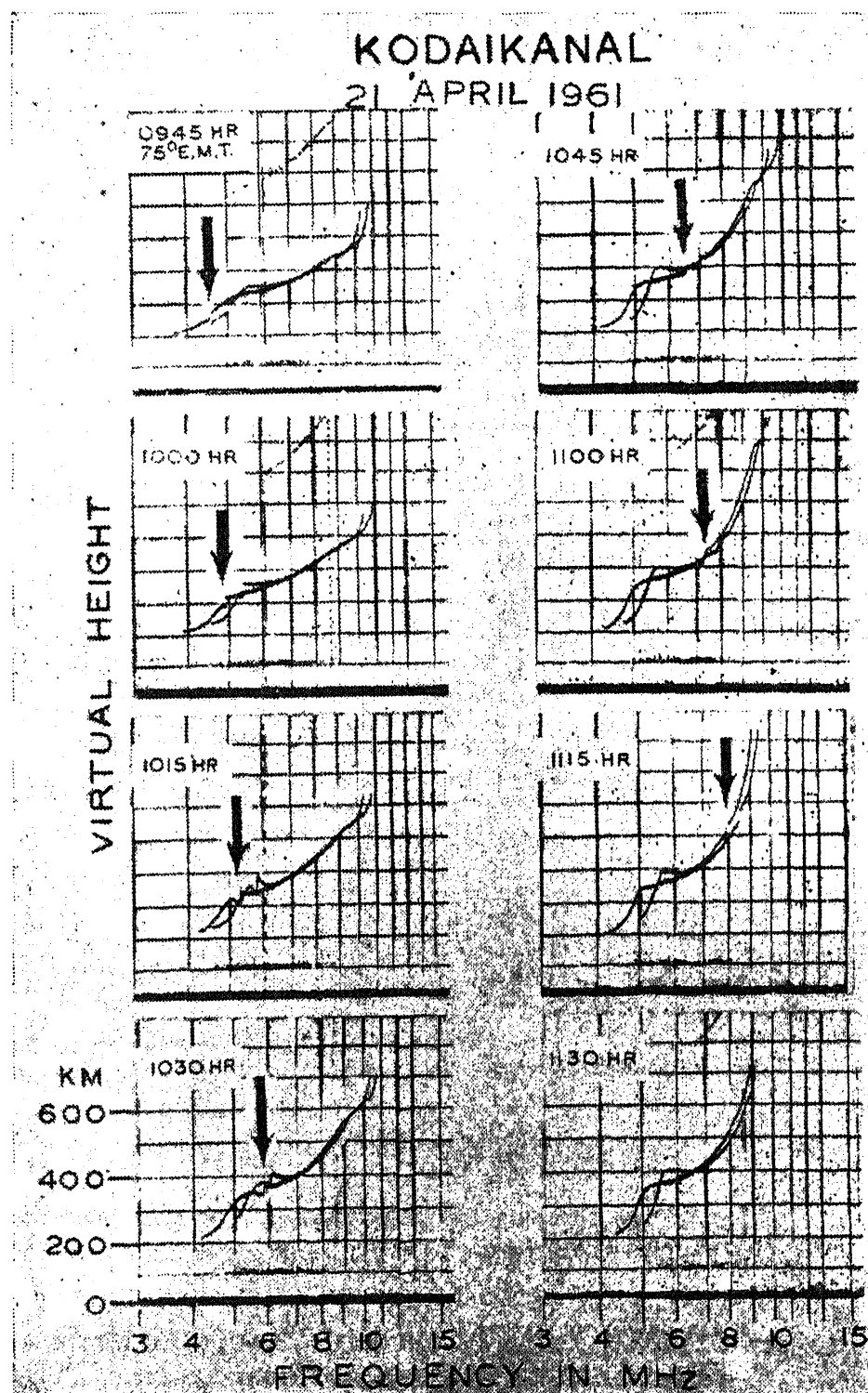


FIG. 3. Sequence of ionograms showing the movement of the kink from the F_1 region to the height of peak F_2 ionization during a moderately active solar cycle epoch.

of the discontinuity on the ionograms was comparatively smaller during high sunspot years.

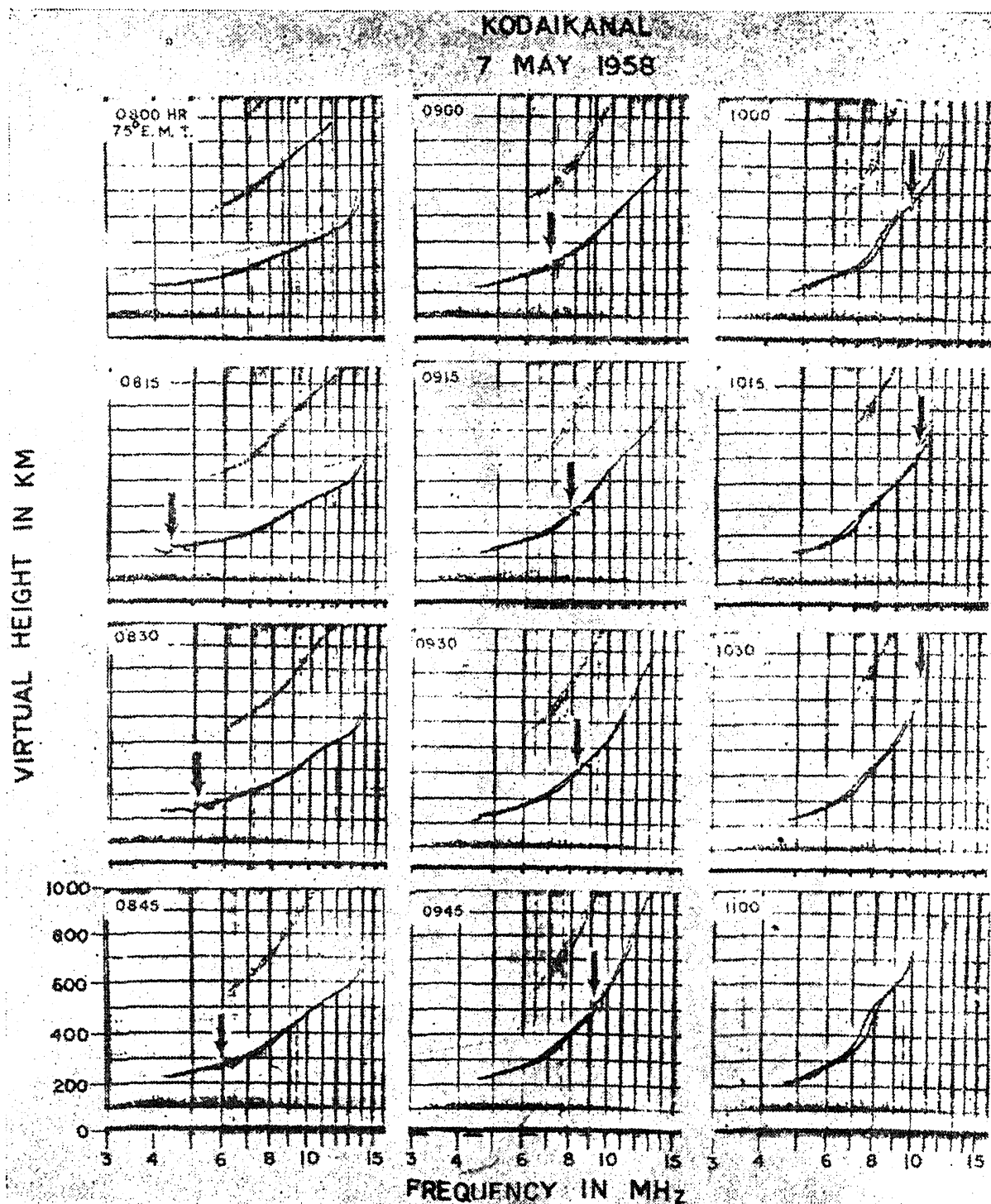


FIG. 4. Sequence of ionograms showing the movement of the kink from the virtual height of about 200 km at 0815 hr. to about 800 km at 1030 hr. during a maximum solar activity period.

The true heights of these kinks in each of these ionograms were calculated using Budden's (1955) matrix method. The variation of the height of these kinks with time for a few selected events at Kodaikanal during the period 1952-64 are shown in Fig. 5. The kinks seem to rise slowly

in the beginning between 120 to about 180 km after which their heights seem to increase linearly with time. The mean velocities of the kink between two consecutive ionograms have been calculated and a mass plot of the velocity *versus* height of the kink during these events are shown in Fig. 6. A gradual increase of the vertical drift velocity with height is indicated, being about 10 m/sec around 120 km and 40 m/sec around 300 km.

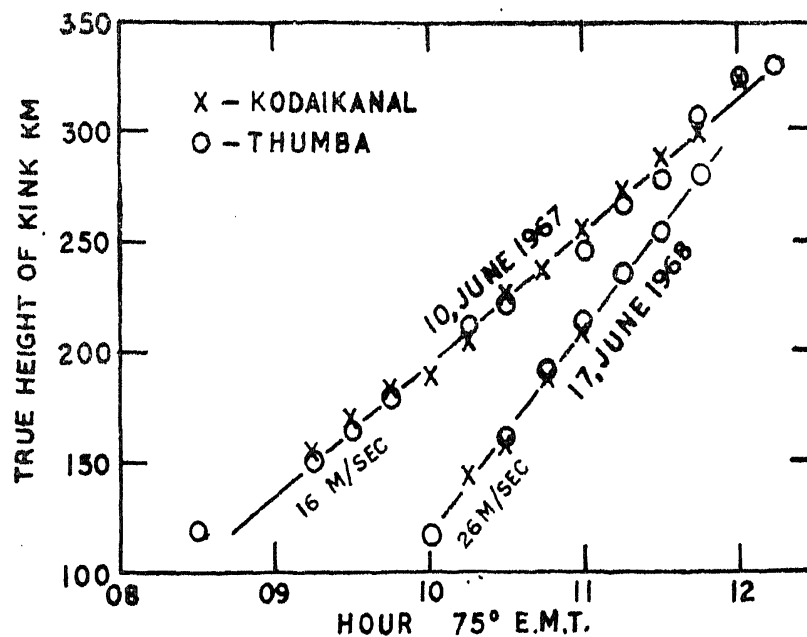


FIG. 5. The variation of true height of the kink with time for some of the events recorded at Kodaikanal.

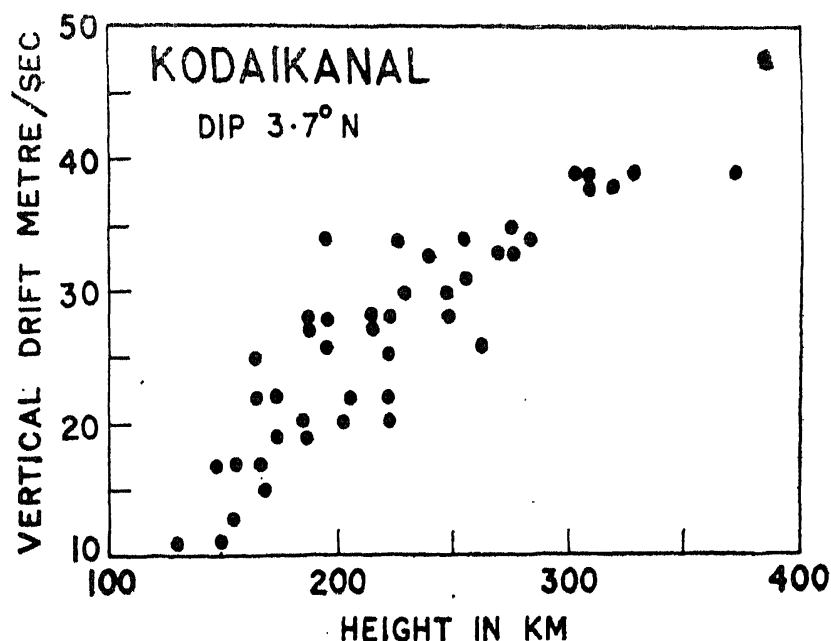


FIG. 6. The mass plot of the mean velocity and height of the kink between two adjacent observations of an event derived from the curves in Fig. 5.

Figure 7 shows the occurrence of these kinks in different months of the year 1964. The largest number of days with kinks (about 30%) occur during local summer months. A study of these events in other years also suggested a maximum occurrence during summer and minimum during winter.

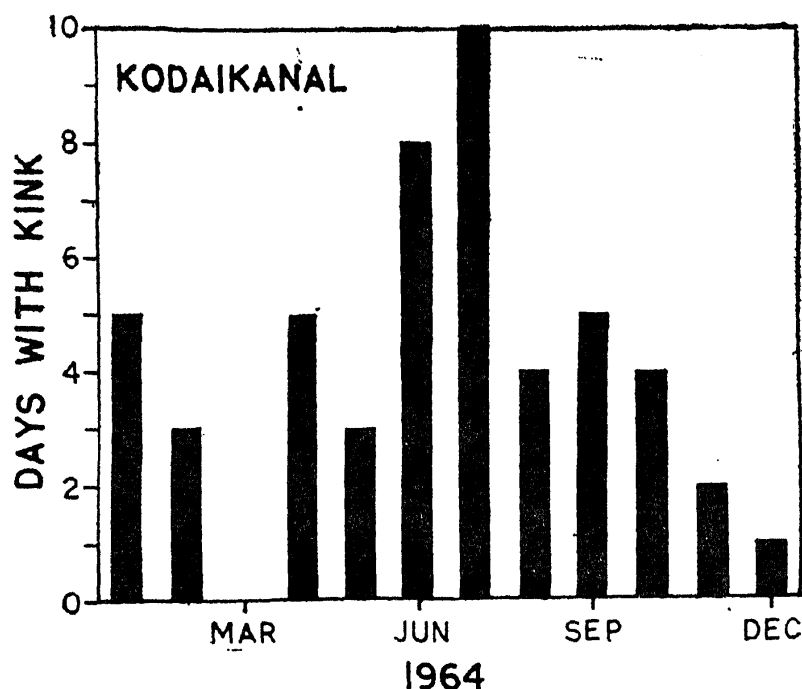


FIG. 7. Seasonal variation of the occurrence of the days with upward moving kinks in the ionosphere.

Figure 8 shows the daily variations of some of the geomagnetic and ionospheric parameters near the magnetic equator, viz., the occurrence of kink, horizontal component of the geomagnetic field (H), horizontal drift velocities in the E and F regions, critical frequency ($f_o F_2$) and the height of maximum ionization ($h_p F_2$) of the F_2 layer. As is well known, the H -component at low latitudes remains fairly constant during the night, starts increasing immediately after sunrise, reaching a maximum at about 11 hr, and then decreases to its night value by about sunset. This large increase of H has been shown to be due to a belt of intense eastward electric currents flowing over the magnetic equator. The electron drifts measured at Thumba have indicated the direction to be predominantly towards west during the daytime hours (Deshpande and Rastogi, 1966). The latitudinal, seasonal and other variations of the horizontal drifts at the equator have indicated the horizontal drifts to be very intimately associated with the electrojet currents (Rastogi *et al.*, 1970). The maximum drift speed is seen to be around 09 hour for the E-region and 10 hour for the F-region. The minimum value of $f_o F_2$ as well as the maximum value of $h_p F_2$ are seen to

occur simultaneously at the time of maximum horizontal F-region drift. It is thus suggested that maximum horizontal drift would occur at the time of maximum upward vertical drift, which causes the bite-out in the daily variation of $f_0 F_2$. It is seen that the maximum number of kinks occur around 10·00 hour. The kinks are thus undoubtedly associated with the vertical drift produced with the coupling effect of northward horizontal magnetic field and the eastward horizontal electric field of the equatorial electrojet.

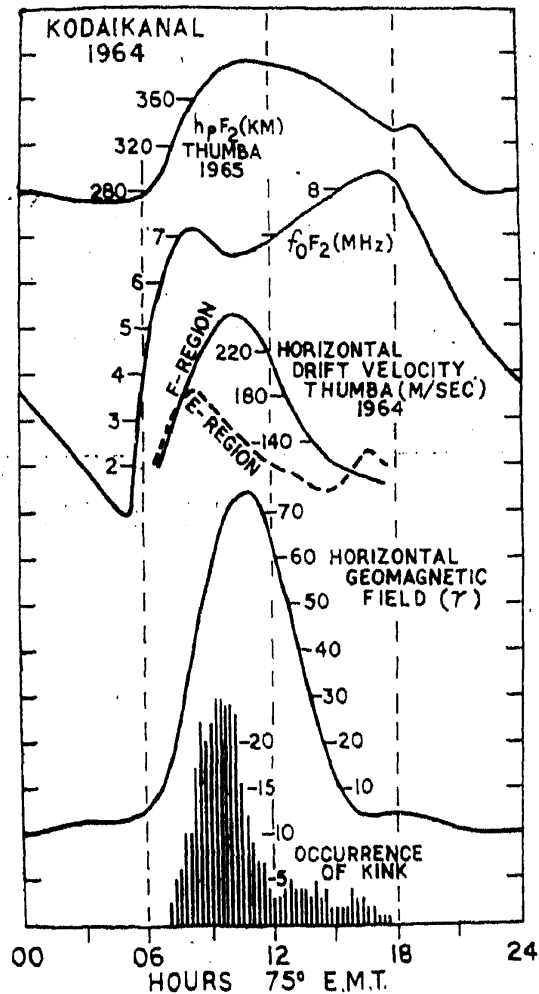


FIG. 8. Solar daily variations of the occurrence of upward moving kinks together with those of horizontal geomagnetic field, horizontal drift velocities in the E and F regions, $f_0 F_2$ and $h_p F_2$ over the magnetic equator.

Regarding the extent of the region over which the kinks are observed simultaneously, the kinks were clearly seen in Kodaikanal ionograms for June 10, 1967, the same day as the reported event at Thumba (Rastogi, 1970). A few other events have been recorded simultaneously at the two stations differing by about 4° magnetic dip. Figure 9 shows two examples of the height variations of the kinks observed on the same day at Thumba and Kodaikanal. It is seen that on a particular day the true height of the kink is practically the same at both the stations, indicating that they are caused by the same mechanism which extends over a distance which exceeds

the distance between these two stations. The most likely cause of generating the kink seems to be a sudden change in the horizontal electric field. This is later followed by upward movement due to $\vec{E} \times \vec{B}$ drift.

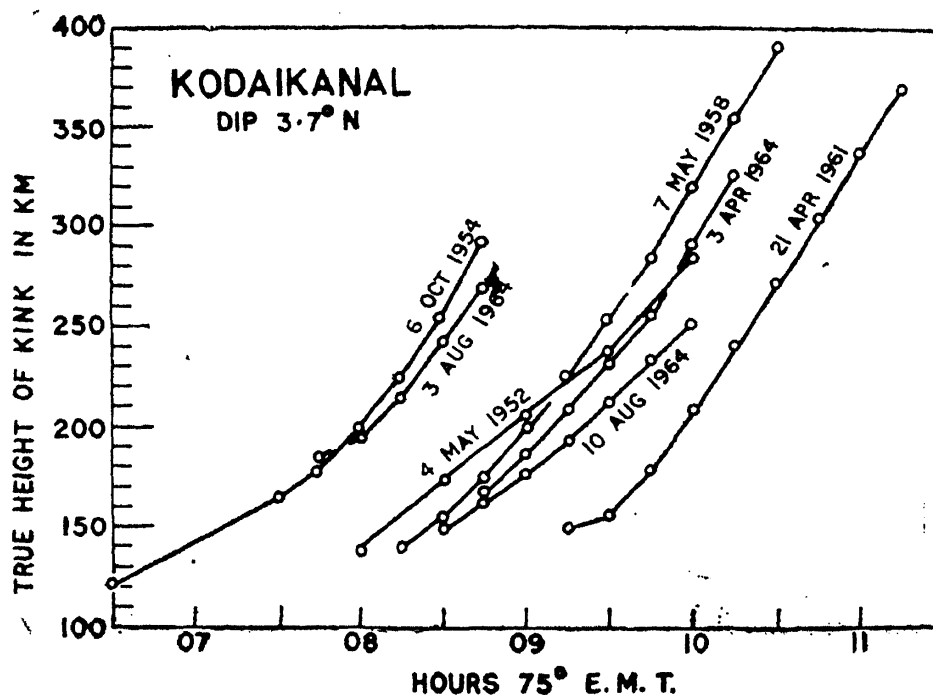


FIG. 9. The variation of the true height of the kinks simultaneously recorded at two close equatorial stations Kodaikanal and Thumba.

These sharp kinks are not produced by events like meteors, local gravity waves, any atmospheric disturbances or thunderstorms.

SUMMARY

(1) Vertically upward moving kinks first observed at Thumba are seen to occur fairly regularly at Kodaikanal at all epochs of solar activity, the occurrence being more frequent during local summer months.

(2) The vertical drift velocity derived from time variation of the true height of the kink indicates a gradual increase with height, being 10 m/sec at 120 km and about 40 m/sec at about 300 km.

(3) The kinks occur most frequently at the time of maximum bite-out in the daily variation of $f_0 F_2$ or the maximum westward drift speed in the F-region, and are thus associated with the equatorial electrojet currents.

(4) The kinks are observed simultaneously at Thumba and Kodaikanal suggesting an extensive area over which they occur at any time.

(5) The upward movement of the kink is due to the normal $\vec{E} \times \vec{B}$ effect in the F-region and its velocity corresponds to the vertical drift in the F-region.

(6) The first production of the discontinuity in the E₂ or the F₁ region is suggested to be due to sudden changes in the horizontal electric field of the electrojet.

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