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Cusps and Distortions in Ionospheric *F*1-layer observed over Kodaikanal

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ABSTRACT. A special study of cusps and distortions in *F*1-layer traces has been made from ionograms obtained at Kodaikanal during a period of about half a solar cycle. Two different types of disturbance have been noticed. The first one is a stationary type occurring near the low frequency end of the *F*1-layer trace. It is suggested that these ridges found in the course of a disturbance are connected with the *E*2-layer. In the second type, the cusp appears to move along the virtual height curve and these are ascribed to travelling wave-type disturbance. It is also found that these disturbances are associated with the disappearance of equatorial E_s on magnetically disturbed days. An explanation of the phenomenon is attempted in terms of internal gravity waves proposed by Hines (1960).

1. Introduction

Cusps and ridges are known to occur in equatorial ionograms quite frequently (Skinner, Brown and Wright 1954). A special study of ionograms obtained at Kodaikanal (Geomagnetic latitude : 0°·6 N; Dip: 3°·5N) has been made during a period of more than half a solar cycle. Two different types of distortion in *F*1–layer trace could be distinguished; one being cusps of a stationary type occurring at the low frequency end of *F*1–layer trace, while the other type which is found to move along the virtual height curves, could be ascribed to travelling wave disturbances, as advocated by Munro (1950).

Two different sets of analysis are presented in this paper. One comprises the variation of the frequency of occurrence of ridge type disturbance with season, solar cycle and also with magnetic activity. The other analysis concerns distortions in ionogram due to travelling wave-type disturbance and is based on a detailed study of day-time ionograms through a year.

2. Frequency of occurrence of the cusps or ridges in *F*1-layer traces

Ionograms obtained at Kodaikanal with a C-3 ionosonde were scrutinized for detecting the presence of ridges in *F*1-layer (virtual height traces) from March 1953 through February 1958 for day-light hours between 0700 and 1800 IST (82°·5 EMT). The frequency of occurrence at each half hour of the day was calculated and expressed in percentage. Ledges, obviously due to *E*2-layer or sequential E_s, have been omitted from this analysis. The criterion taken for this elimination was whether a discontinuity was present between *E*2-layer and *F*1-layer traces. As far as possible, cusps suspected to be due to travelling wave-type disturbances were also eliminated (see Sec. 3).

(*a*) *Seasonal and sunspot cycle variations*—The frequency of occurrence of ridges has been calculated for four different seasons (Equinox I—March and April; Summer—May to August; Equinox II—September and October; and Winter—November to February). Two illustrations are given in Figs. 1(a) and 1(b). In sunspot minimum, maximum incidence of ridges, irrespective of season, is observed between 0930 and 1000 IST in the morning and between 1430 and 1530 IST in the afternoon. In summer, the frequency is more in the afternoon than in the morning, whereas in winter the case is the reverse. Equinox I and Equinox II conditions appear to be similar to summer and winter respectively.

During sunspot maximum, the frequency of occurrence is maximum around 1300 to 1400 IST. The percentage of occurrence,

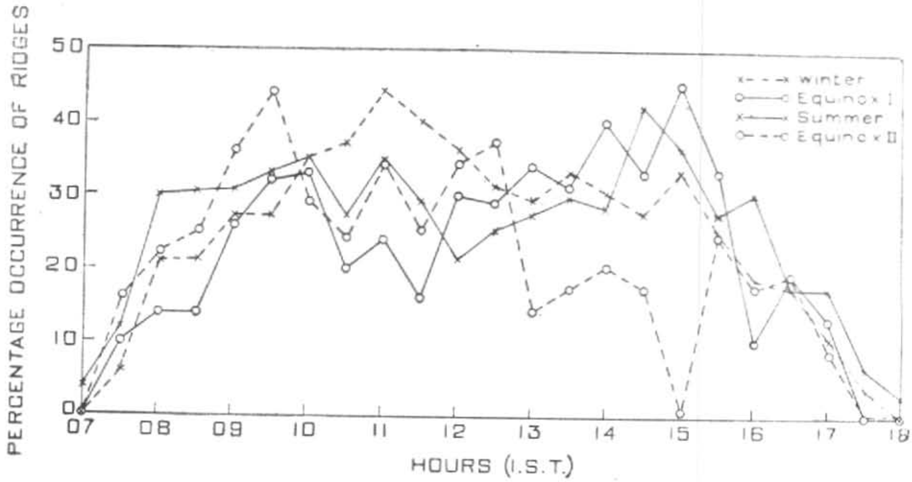


Fig. 1(a). Diurnal variation of occurrence of ridges for different seasons for a year (1954) representing sunspot minimum

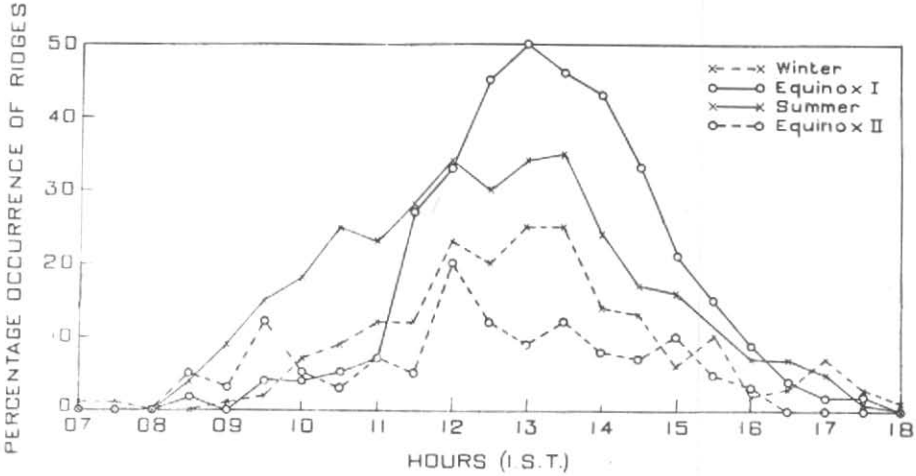


Fig. 1(b). Diurnal variation of occurrence of ridges for different seasons for a year (1957) representing sunspot maximum

irrespective of the season, increases from 0900 IST with a peak between 1300 and 1400 IST and then falls gradually towards sunset. In Fig. 2, curves showing the annual mean variation for the two years 1954 (a year of sunspot minimum) and 1957 (a year of sunspot maximum) are shown to bring out the solar cycle dependence of the occurrences. It appears that the percentage of occurrence is somewhat less for sunspot maximum than for sunspot minimum.

(*b*) *Relation with magnetic activity*—In order to find out whether the occurrence of ridges in $F1$-layer are dependent on the magnetic activity, the frequency of occurrence in percentage was calculated separately for five international quiet and five disturbed days for each month of the years 1954 and 1957 representing periods of low and high solar activity respectively.

The mean diurnal variation curves for the two years are shown separately for quiet and

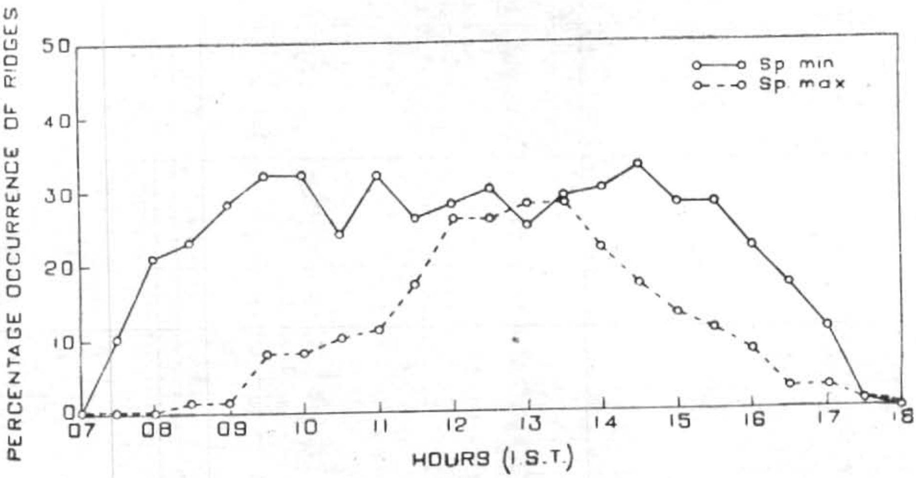


Fig. 2. Diurnal variation of annual mean percentage of occurrence of ridges representing a year (1954) of low sunspot activity and a year (1957) of high sunspot activity

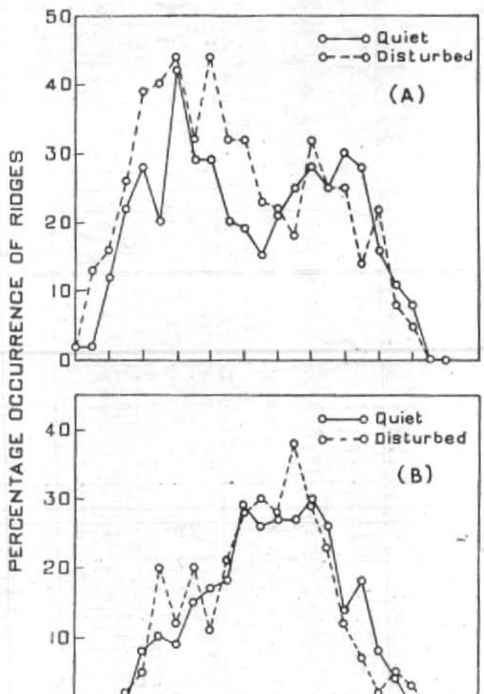


Fig. 3. Diurnal variation of annual mean percentage of ridge occurrence for five international quiet and disturbed days—(A) for a year of sunspot minimum (1954), (B) for a year of sunspot maximum (1957)

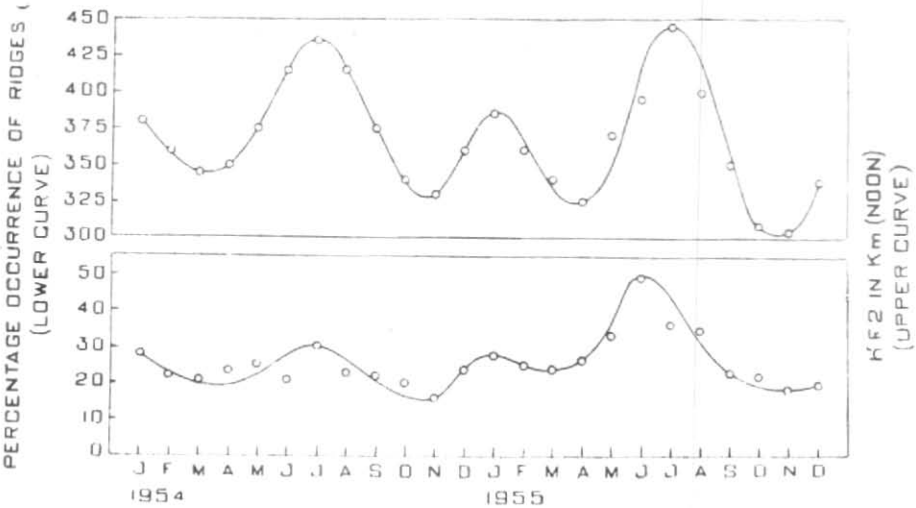


Fig. 4. Seasonal variation of occurrence of ridges in $F1$-layer (lower curve) compared with seasonal variation of noon $h'F2$ (upper curve)

disturbed days in Figs. 3(a) and 3(b). In sunspot minimum, the frequency of occurrence on disturbed days is somewhat greater than on quiet days, the diurnal variation, in both cases, showing two peaks, one in the morning and the other in the afternoon. During sunspot maximum, however, no perceptible change is noticed in the pattern for the quiet and the disturbed days.

(c) *Relation with $h'F2$ and lunar phases*—An attempt was made to find out whether the frequency of occurrence of the ridges was a function of the thickness of the $F1$-layer. As the variation of $h'F1$ at this latitude is found to be much less than that for $h'F2$, $h'F2$ could be considered as a good indication of the thickness of the $F1$-layer. Fig. 4 gives a comparison of the percentage of occurrence of the ridges and the noon $h'F2$ for the years 1954 and 1955. A fairly good correspondence is seen to exist during low solar activity period (for years of high solar activity, normally L condition prevails preventing reliable estimate of $h'F2$). No association of occurrence of ridge was found with phases of the moon.

3. Travelling disturbances observed in $F1$-layer trace

In Sec. 2, an analysis has been given of the cusp type disturbances observed in $F1$-layer traces. These cusps are found to be rather stationary in height as well as in frequency, occurring mostly near the low frequency end of the $F1$-layer trace. However, disturbances were noticed on many days and these appear to move along the virtual height curves. These could be identified with the travelling wave disturbances described by Munro and others (Munro 1950). Travelling wave disturbance may manifest itself in a particular ionogram in the form of a cusp (Munro and Heisler 1956). These might have contaminated to some extent the analysis described in Sec. 2, although every effort was made to eliminate them.

The travelling wave disturbances and their occurrences were also studied separately. In middle latitude stations they are found to be quite frequent (Heisler and Whitehead 1960) and these appear all over $F1$ and $F2$-layer traces. In lower latitudes they are, however, found to be confined mainly to the $F1$-layer trace. They seem to get dissipated when they appear in the $F2$-layer trace (Fig. 5).

The results of analysis carried out over a period of one year are shown in Tables 1(a) and 1(b).

The occurrence of travelling disturbances was studied with reference to magnetic disturbance index and also with the behaviour

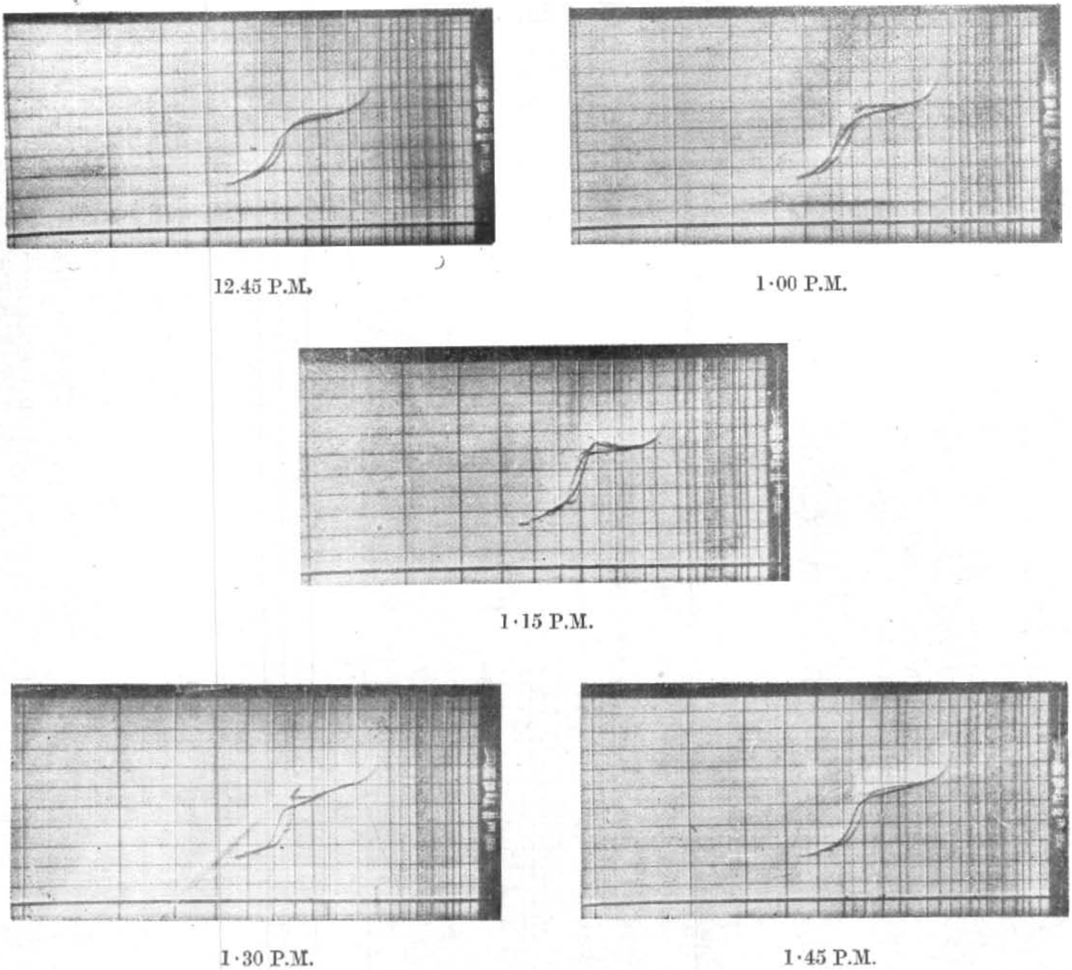


Fig. 5. A sequence of ionograms illustrating the presence of travelling wave-type disturbance observed in $F1$-layer

of equatorial type E_s. On quiet days, the travelling disturbances were in no case found to be associated with E_s disappearance, whereas during disturbed days, these were associated with E_s disappearance in less than half of the cases. As a criterion for disturbed days, a particular K (sum) ($\Sigma Kp > 30$) limit was taken instead of the five disturbed days in each month.

Table 2 shows the results of the association of travelling disturbances with geomagnetic storm recorded at Kodaikanal and also with the disappearance of equatorial E_s. It is seen that more than half of the cases of $E_s - q$ disappearances were associated with the occurrences of travelling disturbances. The association is clearly evident when we take Kodaikanal magnetic storm data, as the criterion for the disturbed days.

4. Discussion

From an examination of ionograms over an extended period it appears that there are two distinct types of disturbance appearing on $F1$-layer traces. The type of disturbance described in Section 2, *viz.*, the cusp type, is presumably the same as described by

TABLE 1 (a)

Occurrence of travelling disturbances during 1956 International Quiet Days

	(a)	(b)	(c)
1956			
January	5	3	..
February	5	1	..
March	5	2	..
April	5	1	..
May	5	2	..
June	5	2	..
July	5	4	..
August	5	1	..
September	5	1	..
October	5	..	..
November	5	1	..
December	5	1	..
Total	60	19	..

(a) Number of quiet days

(b) Number of days on which travelling disturbances associated with presence of E_s—q

(c) Number of days on which travelling disturbances associated with disappearance of E_s—q

TABLE 1 (b)

Disturbed days (K_p>30)

	(a)	(b)	(c)	(d)
1956				
January	5	..	3	3
February	2	1	..	2
March	5	2	..	2
April	6	2	..	3
May	7	1	1	4
June	3	2	..	1
July	..	..	..	..
August	5	..	2	2
September	5	1	1	1
October	5	1	1	1
November	6	1	..	2
December	..	..	..	..
Total	49	11	8	21

(a) Total number of disturbed days

(b) Number of days when travelling disturbances occurred when E_s—q is present

(c) Number of days when travelling disturbances were associated with absence of E_s—q

(d) Total number of days with disappearance of E_s—q

TABLE 2

Occurrence of travelling disturbances during 1956—Days with geomagnetic storm at Kodaikanal

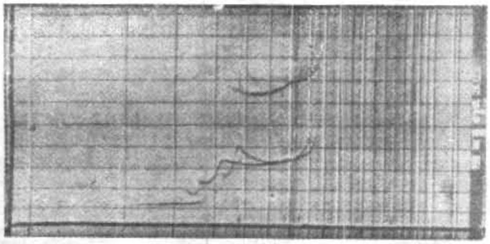
	(a)	(b)	(c)	(d)		(a)	(b)	(c)	(d)
1956					1956 (contd)				
January	4	1	3	3	July	1	1	..	..
February	5	1	..	2	August	3	2	1	1
March	2	..	1	2	September	2	1	..	..
April	2	1	..	1	October	2	2	..	..
May	4	1	1	1	November	2	..	..	2
June	1	1	..	..	December	1	..	1	1
					Total	29	11	7	13

(a) Number of geomagnetic storms

(b) Number of cases when travelling disturbances occurred when E_s—q is present

(c) Number of cases when travelling disturbances are associated with absence of E_s—q

(d) Total number of cases with disappearance of E_s—q



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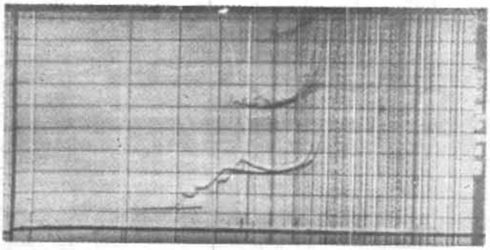

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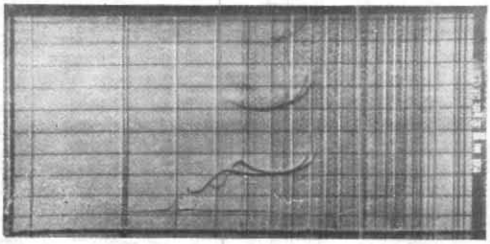

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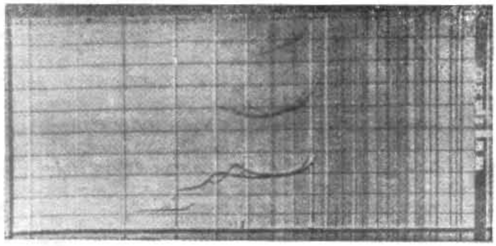

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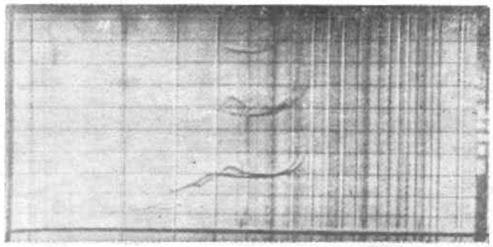

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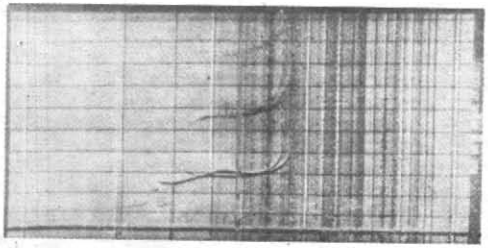

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Fig. 6. A sequence of ionograms illustrating the downward movement of the ridge in $F1$-layer and its subsequent development as $E2$ cusp

Skinner, Brown and Wright (1954) as ridges in $F1$-layer. They seem to be somewhat associated with the phenomenon of $E2$-layer. On certain days when the E_s blanketing is not very severe, the $E2$-layer trace can be seen to rise in the morning hours and ultimately form a cusp in $F1$-layer trace around 0900 IST. Similarly, in the afternoon at about 1600 IST the ridge or cusp attached to the low frequency end of $F1$-layer trace can be seen to detach itself and come down as $E2$ and ultimately develop into sequential E_s (Saha and Ray 1955). An illustration of this phenomenon is given by the set of ionograms in Fig. 6.

No definite inference can be drawn from the analysis in Section 2 of the frequency of occurrence of ridges, except that they seem to be a function of the thickness of $F1$-layer. If it is assumed that the average thickness of $F1$-layer remains about the same, then, for periods in which the heights for the composite F-layer (indicated by $h'F2$) are higher, a cusp associated with the $E2$-layer phenomena should have a better chance of being observed. If the $F1$-layer height is lower, the cusp would merge (and hence would be masked) into $F1$-layer.

We are inclined to believe that these cusps are due to genuine inflexions in the electron density profile rather than any oblique effects. The regular nature of their occurrence and their constancy in frequency and height in consecutive ionograms support this suggestion. The other type of disturbances described in Section 3 are rather erratic and distort the $h'F$ curves in an irregular way. They also seem to move all along the $F1$-layer trace and should be interpreted in terms of distortion in the isoionic contours around the observing stations (Munro and Heisler 1956). It is, however, found that they rarely move beyond the cusp between $F1$ and $F2$.

The classical interpretation of travelling wave type disturbance is due to Martyn (1950) and is in terms of cellular atmospheric waves. Recently the theory has been revived by Hines (1960). According to him, the travelling waves originate as internal gravity waves, either in the tidal region between 80 and 100 km or in the troposphere itself. King (1961) has recently described how these travelling disturbances or 'internal gravity' waves would be dissipated near the limit of diffusive equilibrium around the height of $F1$-layer maximum.

According to Martyn (1959) movement of disturbances from region E to F should be reduced in equatorial region where strong electrojet is present. It is known that during certain magnetic storms (the main phase) equatorial E_s is found to be reduced or absent (Bhargava and Subrahmanyan 1961). In these cases, there should be greater chances of occurrence of travelling wave type disturbance. This may, indeed, be an effect of the inhibition of travelling disturbance by the electrojet, considering the fact that they are not observed so often in equatorial region. It is found in Section 3 that some of the cases of equatorial E_s disappearance on magnetically disturbed days are definitely associated with travelling disturbances. However, it may be noted from Table 1 that many cases of travelling wave-type disturbance are found on quiet as well as disturbed days around which no weakening or disappearance of $E_s - q$ is observed. This may be due to the fact that short duration conditions favourable for the transmission of the disturbance could exist. According to the analysis of equatorial magnetograms by Onwumechilli (1959) short duration conditions not favourable for complete inhibition of Hall currents do occur. These may not be reflected in disappearance of $E_s - q$, but may affect the retarding influence on travelling wave disturbances going upwards.

5. Acknowledgements

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