Effect of geomagnetic disturbances on F_2 layer of the ionosphere in low and middle latitudes

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A statistical study of F_2 layer data over a period of five years from sunspot minimum (1953) to sunspot maximum (1957) has been made to find SD and D_{st} variations of f_0F_2 in low latitudes in the eastern zone. These have been then compared with similar variations at equatorial and higher latitudes obtained by other workers. The meridional profiles of f_0F_2 from 0600 hours to midnight are drawn both for normal and disturbed days, which show on disturbed days, (i) a morning rise of f_0F_2 which is a common feature for all latitudes in the range 0°-45° magnetic dip, and (ii) a day-time rise of f_0F_2 at places with magnetic dip from 0° to 20°, as against a fall of f_0F_2 during day-time and in the early night at places with magnetic dip from 20° to 60°. This fall is particularly marked at about 35° magnetic dip. As a consequence, the intensity of equatorial trough in f_0F_2 during these hours is reduced on disturbed days. A few individual cases of severe SC type disturbances have been discussed in relation to f_0F_2 changes in the East Asiatic Zone.

The changes in f_0F_2 and in cosmic radio noise absorption on 25 Mc/s. at Ahmedabad have been correlated. A study of spread F occurrence over a period of 2 years has shown that while spread F occurrence on disturbed days is reduced to $\frac{1}{3}$ of its value on normal days at Ahmedabad, it increases at Slough to nearly $2\frac{1}{2}$ times the normal. The change-over from decrease to increase takes place at about 44° magnetic dip.

A preliminary report on the study of the effect of geomagnetic storms on the F_2 layer of the ionosphere in low latitudes was given at the CSAGI meetings held in Moscow in August 1958[1]. An extended study of the subject is presented in this paper.

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The changes in the F_2 layer associated with geomagnetic disturbances have been studied by a number of workers[2-8]. Their studies have covered a large range of latitudes and longitudes. Martyn, adopting the method of analysis introduced by Moos[9] and Chapman[10] for the study of magnetic disturbances, separated the storm time and local time variations of disturbance at several places.

The data used in this paper relate mostly to stations in the Asiatic Zone along nearly the same meridian, as it was considered desirable to separate out the local time effects and compare the variations in different latitudes as clearly as possible.

As shown in an earlier study, the values of midday f_0F_2 (1000–1400 hours) at Delhi and Ahmedabad are depressed on magnetically disturbed days, while at Tiruchirapalli and Madras they show an increase. The change-over from decrease to increase takes place at about magnetic dip 20°. For making this analysis, the superposed epoch method was followed, taking as zero epoch the day on which the noon value of f_0F_2 at Ahmedabad or Delhi was depressed by more than 10 per cent of corresponding monthly median value. The changes in f_0F_2 during a disturbance were expressed as ratios of the value on the disturbed day [or $D(f_0F_2)$] to the corresponding monthly median value at the same hour. In the present paper, a study of the D_{st} and SD variations of f_0F_2 in low latitude stations in India has been made and the results are compared with the data of some stations in middle latitudes. Disturbance variations of f_0F_2 in the East Asian Zone are compared for four SC type magnetic storms. Finally some relations between spread F, cosmic radio noise absorption on 25 Mc/s. and magnetic activity are briefly discussed. The term equator used in this paper means magnetic dip equator unless otherwise stated.

Equatorial Trough in f_0F_2. It has been known for some time that the value of day-time f_0F_2 has a peak near magnetic dip 30° and that there is a valley near the magnetic equator. The peaks get broader and the valley shallower in years of high solar activity[11]. In 1954, the peak of f_0F_2 was between Ahmedabad and Bombay[12], while in 1957 (a high sunspot year), it shifted to a position slightly to the north of Ahmedabad (magnetic dip 35°). Table 1 gives the difference $\Delta(f_0F_2)$ between f_0F_2 at Ahmedabad and Kodaikanal ($I = 3{\cdot}5°N$) at different hours of the day in 1954 and 1957. The equatorial trough is particularly pronounced in the winter months.

In 1954, the equatorial trough changed into a ridge by about 2100 hours, while in 1957 the trough continued to be pronounced even up to midnight. The earlier development of the trough in autumn and winter and its continuation until midnight in a year of high sunspot activity are respectively due to (i) the increased ionization rate and upward electrodynamic drift of

TABLE 1 — DEPTH OF EQUATORIAL TROUGH IN f_0F_2 AT DIFFERENT HOURS OF THE DAY IN 1954 AND 1957 — $\Delta(f_0F_2)$ in Mc/s. (AHMEDABAD-KODAIKANAL)

TIME	1954				1957			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
0900	0·6	0·5	0·3	0·3	2·6	−1·1	−1·2	1·0
1200	3·7	4·2	2·2	3·8	2·6	4·7	2·8	4·5
1500	4·5	4·4	2·1	4·6	5·2	5·5	3·6	5·1
1800	3·8	0·9	0·0	2·0	6·5	5·9	4·8	5·7
2100	1·0	—	—	—	7·8	5·2	0·5	7·1
2400	No data at Kodaikanal or Tiruchirapalli				1·0	2·1	−1·4	2·8

the electrons in the F region near the equator, and (ii) the lower loss rate at the increased heights of the F_2 region. The negative values at 0900 hours in April and July 1957 mean that the increase of electron production at Kodaikanal was more than sufficient to compensate for the fall in density due to upward drift in the summer of high solar activity. Appleton[13] has discussed the development and extinction of the equatorial anomaly in equinoxes of a low sunspot year.

What happens to the said anomaly during disturbed days is shown in Fig. 1 which gives the mean diurnal variation of f_0F_2 on disturbed and normal days at Ahmedabad and Kodaikanal in the year 1956 (47 days). It is seen that while f_0F_2 at Ahmedabad decreases on disturbed days between 0800 and 2300 hours, at Kodaikanal it increases. The tendency of the disturbance is to flatten out the equatorial trough. Though the midday 'bite-out' in f_0F_2 at Kodaikanal is removed, the diurnal variation on disturbed days is still not of the Chapman layer type. Another interesting feature is that on disturbed days, the normal post-sunset rise in f_0F_2 at Ahmedabad at about 2000 hours is suppressed. The reduction in the depth of the equatorial trough of f_0F_2 is shown by the shaded part in Fig. 1(b), while the curves (A′–A) and (K′–K) give the disturbance diurnal variation at Ahmedabad and Kodaikanal.

The normal and disturbed day profiles of f_0F_2 over a range of latitudes with magnetic dip 60°N–0° were obtained by taking the mean of the values on days having $\Sigma K > 25$ and the monthly median values, with due weight given to the number of disturbed days in a particular month. The analysis was made for the year 1956 at stations in the eastern zone for 0600, 0900, 1200, 1500, 1800, 2100 and zero hours. Forty-three days with $\Sigma K > 25$ were studied for which data were available at all the places. The results of this analysis given in Fig. 2 show clearly that f_0F_2 is depressed on disturbed days at all the places north of magnetic dip 20° and is enhanced at places south of it from 0900 to 2100 hours. It may also be noted that the

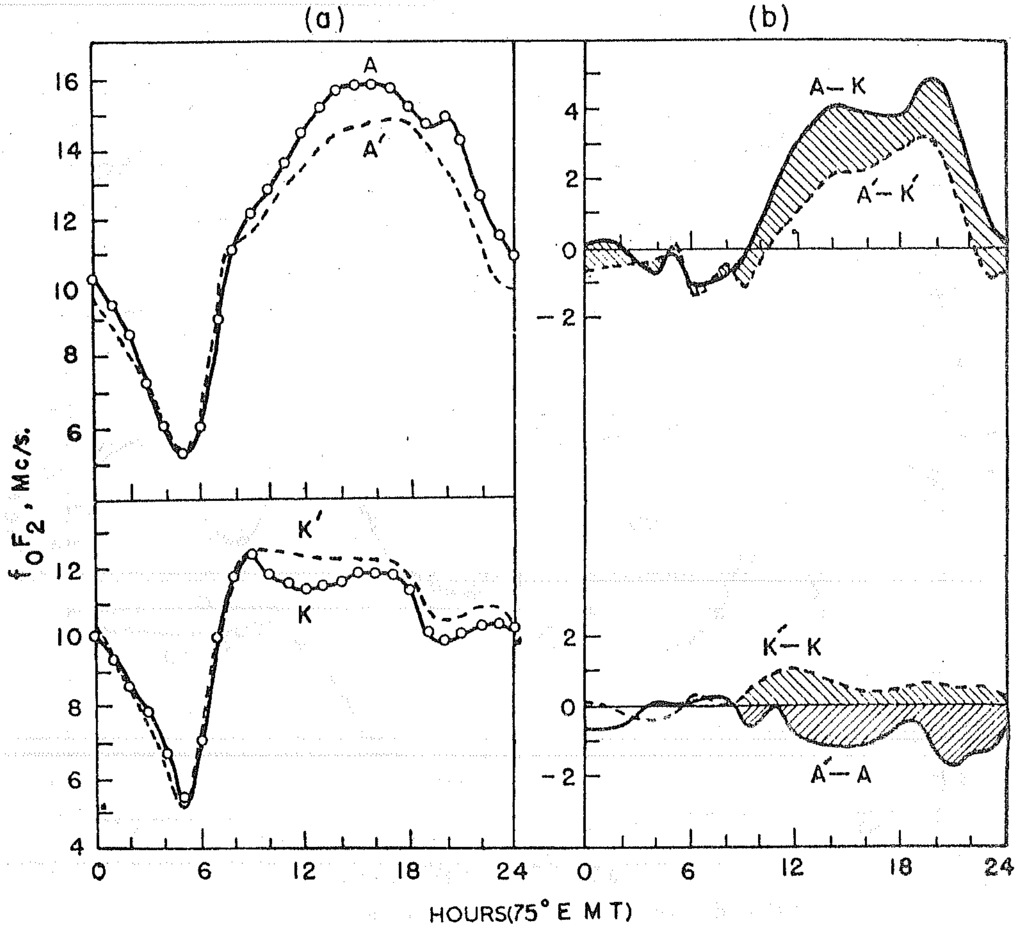

FIG. 1 — (a) MEAN DIURNAL VARIATION OF f_0F_2 AT AHMEDABAD (A AND A′) AND KODAIKANAL (K AND K′) ON NORMAL DAYS TOGETHER WITH MEAN DISTURBED DAY VARIATION (47 DAYS) IN 1956. PRIMED LETTER REFERS TO DISTURBED DAYS. (b) DIFFERENCE (A–K) AND (A′–K′) SHOWING CHANGE IN DEPTH OF EQUATORIAL TROUGH OF f_0F_2; SD VARIATION OF f_0F_2 AT AHMEDABAD AND KODAIKANAL EXPRESSED AS $\Delta(f_0F_2)$ OR DEVIATION FROM NORMAL (47 DAYS, 1956)

depression is maximum at the place of f_0F_2 peak. The morning rise of f_0F_2 on disturbed days is a feature common at all the places with magnetic dip less than 45°. The profiles bring out the reduction of the equatorial anomaly in f_0F_2 on disturbed days.

Disturbance Diurnal Variation or SD Variation of f_0F_2. To find the effect of the disturbance on the diurnal variation of f_0F_2, hourly ratios of disturbed day f_0F_2 to monthly median f_0F_2 were calculated for 47 days with $\Sigma K > 25$ during the year 1956 for Ahmedabad, Bombay and Kodaikanal [Fig. 3(a)]. At Kodaikanal 24-hourly observations were begun in August 1955 and at Bombay they were begun only in 1958. The figure shows that the changes at Ahmedabad and Kodaikanal are in opposite directions from 0800 to 2300 hours, while at Bombay the effect of the disturbance

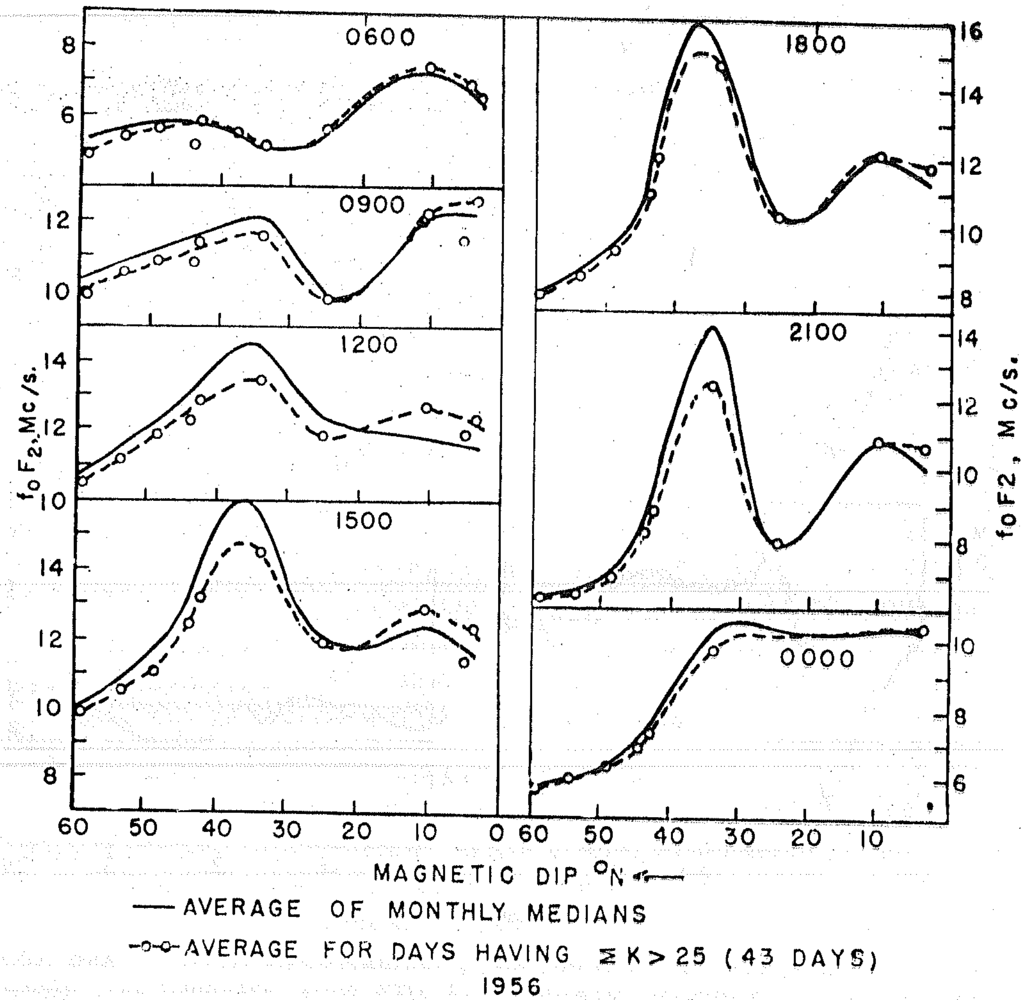

FIG. 2 — MERIDIONAL PROFILES OF f_0F_2 IN THE NORTHERN HEMISPHERE OF THE EASTERN ZONE, AT 3-HOURLY INTERVALS FROM 0600 TO 2400 HOURS IN NORMAL AND DISTURBED CONDITIONS

is small, and indicative of a transition from the equatorial zone. Sharp rises in f_0F_2 are observed in the morning both at Ahmedabad and Kodaikanal but values higher than normal continue throughout the day near the equator only.

As both Ahmedabad and Delhi had a longer series of data, the above analysis was carried out for 90 days over a period of 4 years (1953–56) with a view to finding the SD variations of f_0F_2 at these two places [Fig. 3(b)]. The curves are very similar, the only difference being that the amplitude at Ahmedabad is larger than that at Delhi. Figs. 2 and 3 prove that the phase reversal in disturbance variation of f_0F_2 during day hours takes place at about magnetic dip 20°. It is interesting to note that the lunar tidal variation of f_0F_2 also reverses in phase at about the same magnetic dip[14].

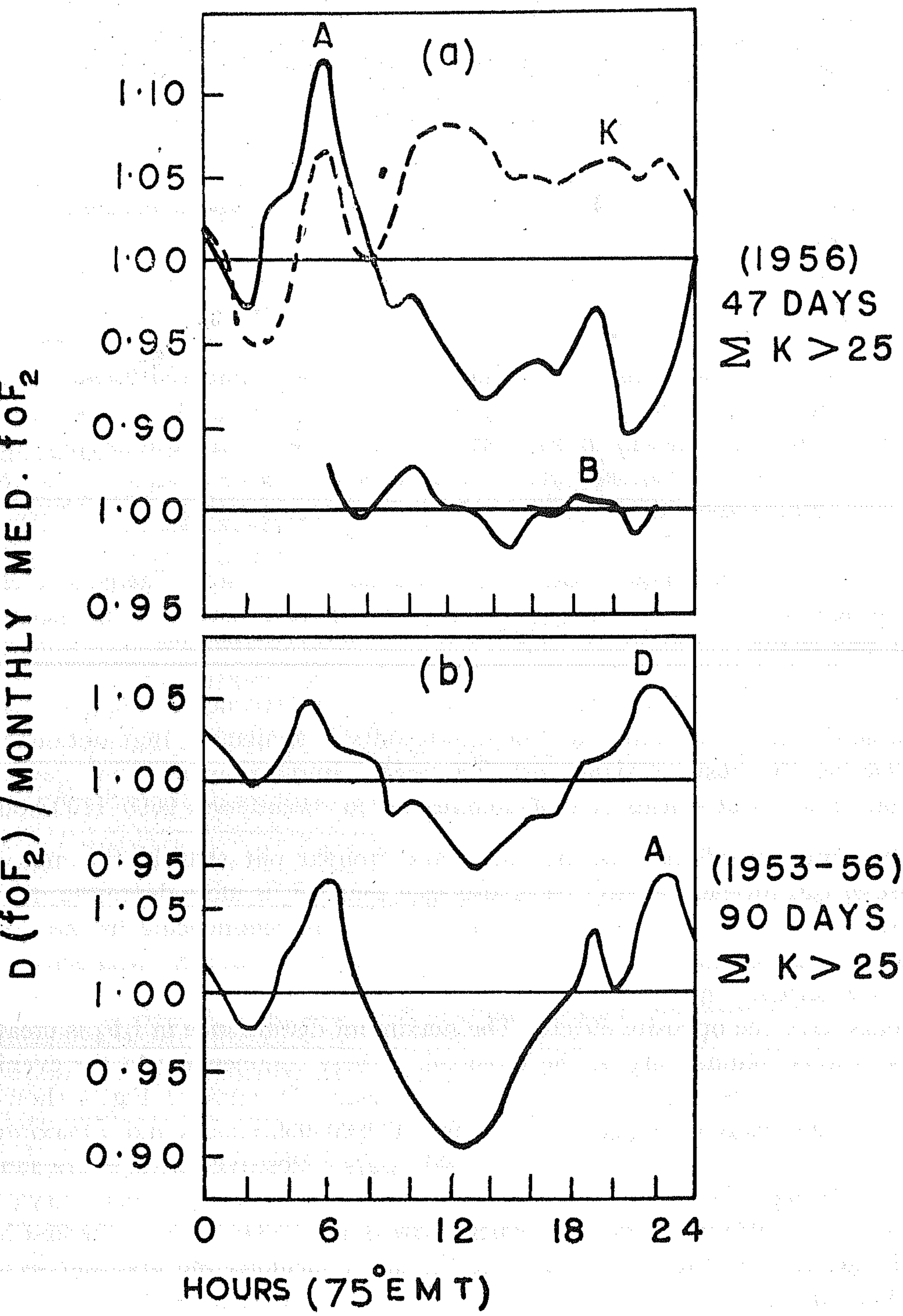

FIG. 3 — (a) SD VARIATION OF f_0F_2 AT AHMEDABAD, BOMBAY AND KODAIKANAL EXPRESSED AS RATIO $D(f_0F_2)$/MONTHLY MEDIAN f_0F_2 (1956). (b) SD VARIATION OF f_0F_2 AT AHMEDABAD AND DELHI (1953–56)

One difference in the SD variation of f_0F_2 at Ahmedabad during 1956 from that for the longer period 1953–56 may be noted. The negative phase extends well into the night in 1956, while taking the data of the whole period, it is mainly confined to day-time. This will be further considered in the next section.

Dependence of SD (f_0F_2) on Local Time of the Commencement of the Magnetic Storm at Ahmedabad. All the SC type magnetic storms were then grouped according as they commenced in each of the four quarters of the day to find the associated variations in f_0F_2 over an interval of about 50 hr after the SC. This was done for a period of five years (1953–57). Sixty-five SC type storms were found of which 16 commenced in the quarter 0000–0500 hours, 15 in the quarter 0600–1100 hours, 20 in the quarter 1200–1700 hours and 14 in the last quarter. The mean ratio $D(f_0F_2)/(\text{med. } f_0F_2)$ was then plotted separately for each of the above groups against local time. Fig. 4 gives these curves and the lowest curve gives the average SD variation on the day following the SC. The mean curve in each group starts at a time round which SCs were most frequent. There is a clear dependence of the SD variation of f_0F_2 on the local time of commencement of the storm.

It can be seen at once that the variation on the second day of the storms commencing in the interval 0600–1100 hours is similar to that obtained in 1956 on the basis of days with $\Sigma K > 25$. Further examination revealed that majority of storms in 1956 commenced in the interval 0600–1100 hours.

The arrangement of data in Fig. 4 has brought out sharply the morning rise of f_0F_2 for each group. It is also seen that f_0F_2 is more depressed during the second 24 hr of the storm, and that storms commencing in the afternoon and pre-midnight hours have the effect of initially increasing f_0F_2 above normal, whereas those commencing in the early morning and forenoon hours have the opposite effect. The maximum disturbance in f_0F_2 is created by storms commencing in the forenoon. Those commencing in the evening hours cause the least disturbance. The mean SD curve of Fig. 4 shows a maximum positive change of 7 per cent at 0500–0600 hours and a maximum negative change of 7 per cent at 1400 hours. Positive changes are found only during 5 hr in the morning. Its difference from the mean curve for 90 days in 1953–56 [Fig. 3(b)] which showed a positive phase in the first half of the night is due to the fact that the latter included the first and second 24 hr of all types of storms, many of which were weak.

Comparison of SD (f_0F_2) Variations at Middle and Low Latitudes. Martyn[15] analysed the SD variations of f_0F_2 for seven places from near the boundary of the auroral zone to the magnetic equator. There were some gaps in low latitudes, the filling up of which would elucidate the progression

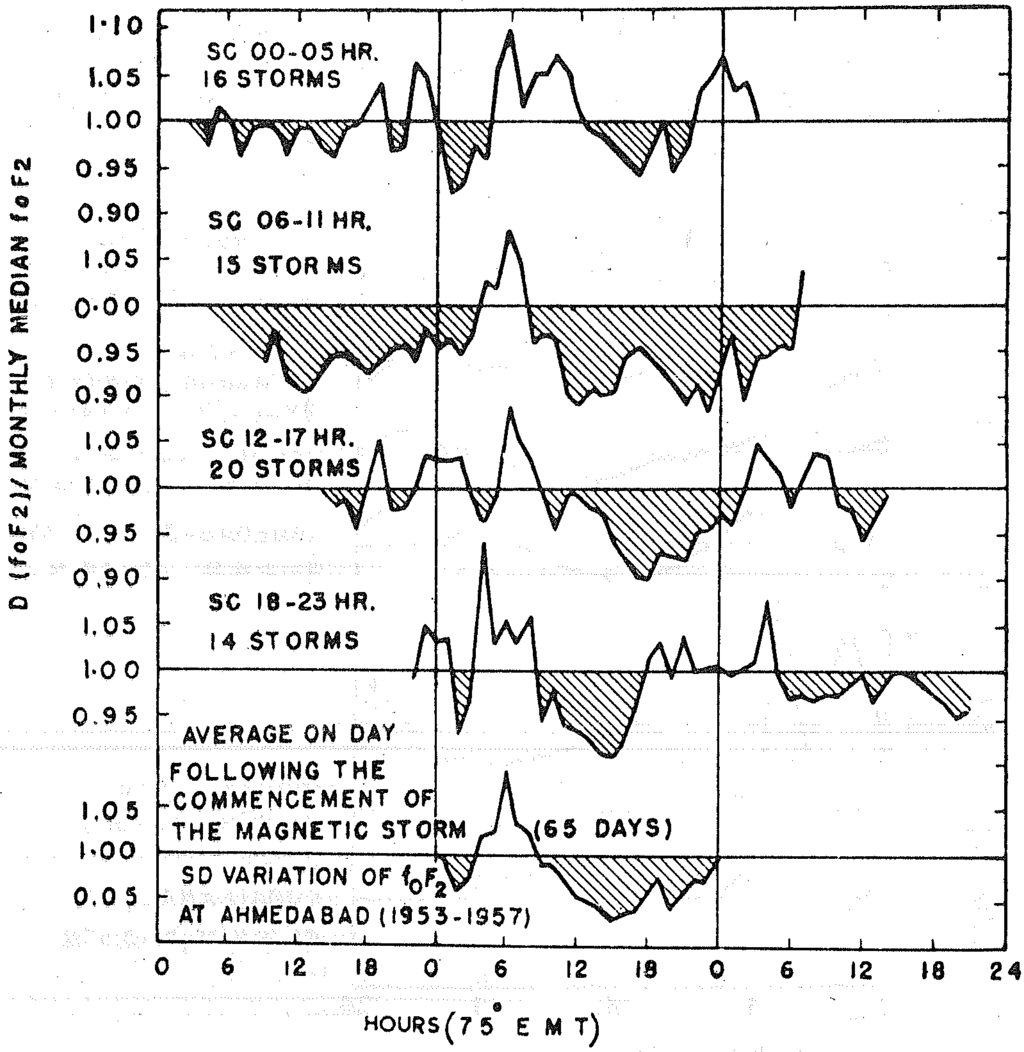

FIG. 4 — DISTURBANCE VARIATIONS OF f_0F_2 DURING MAGNETIC STORMS GROUPED ACCORDING TO THEIR TIMES OF COMMENCEMENT IN EACH QUARTER OF THE DAY. SHOWN AT THE BOTTOM IS THE MEAN SD VARIATION OF f_0F_2 AT AHMEDABAD

of changes as the equator is approached. In Fig. 5 are reproduced SD (f_0F_2) curves for Washington[16], Wakkanai[17], Yamagawa[5] and Ibadan[6]. They are compared with those at Delhi, Ahmedabad and Kodaikanal. The curves reproduced here for middle latitudes relate to winter, but they are similar to the mean for all the seasons, with only a small difference in amplitude.

The comparative study brings out the following facts:

(i) While the curves for Washington and Wakkanai are similar, an important change of phase during morning hours takes place at Yamagawa and the change involving a morning rise in f_0F_2 is continued right up to the equator.

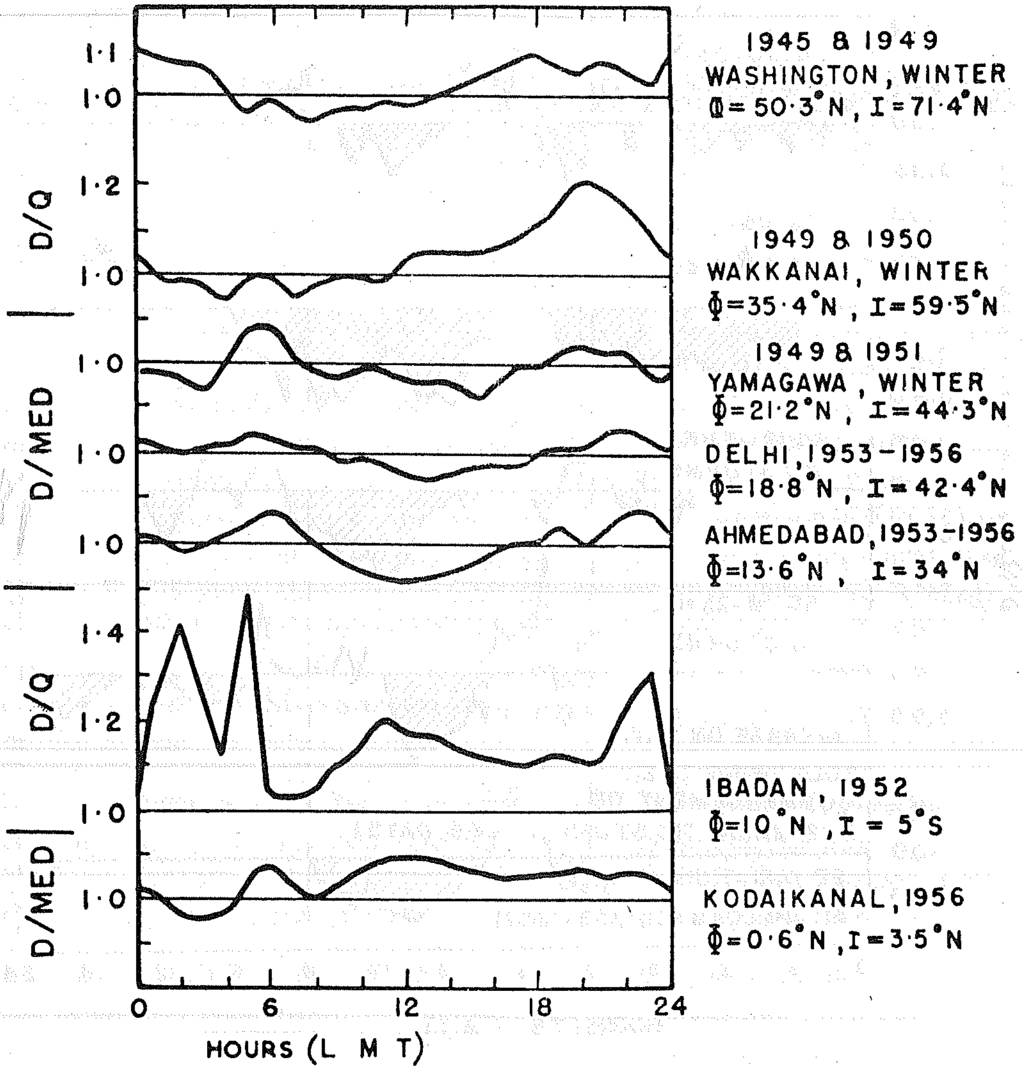

FIG. 5 — COMPARISON OF SD VARIATION OF f_0F_2 AT SOME OF THE STATIONS IN MAGNETIC DIP RANGE 0°–72°

(ii) Another change occurs during day hours on the equatorial side of Ahmedabad, viz. there is an increase of f_0F_2 near the equator corresponding to its decrease in the sub-tropics. As mentioned earlier, this change takes place at about magnetic dip 20°.

(iii) From sunset to midnight, all the stations show increased f_0F_2 during disturbance. Near the magnetic equator, $D(f_0F_2)$ is above normal throughout the day except for 2–3 hr in the night.

(iv) The difference in the amplitudes of the SD curves at Ibadan (I = 6°S) and Kodaikanal (I = 3·5°N) may be due to the fact that a smaller number of days with $\Sigma K > 30$ were considered at Ibadan. At Kodaikanal, more days with $\Sigma K > 25$ were considered.

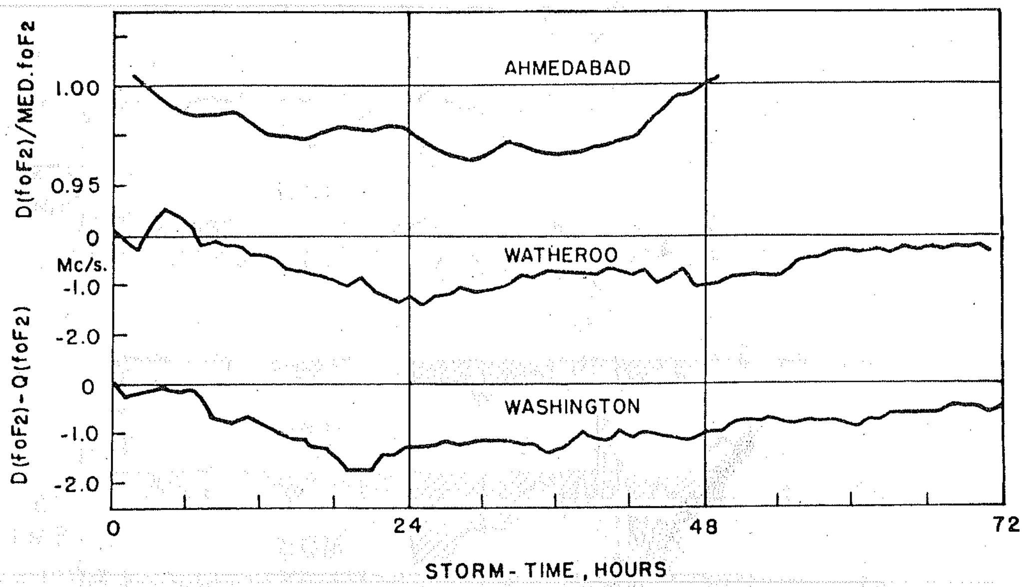

FIG. 6 — STORM TIME OR D_{st} VARIATION OF f_0F_2 AT AHMEDABAD (65 SC STORMS, 1953–57) COMPARED WITH THOSE AT WATHEROO (I = 64°S, 90 SC's, 1939–50) AND WASHINGTON (I = 71·4°N, 81 SC's, 1941–50) DUE TO MARTYN[4]

Storm Time Variation of f_0F_2 in Low and Middle Latitudes. Here, the hourly ratios $D(f_0F_2)$/med. f_0F_2 are arranged according to storm time, taking the hour nearest to the SC time as zero hour, and plotting the above ratios for 50 or more hours after the SC time. When a large number of SCs are available and their times are evenly distributed during 24 hr of the day, the superposed SD variation will be reduced to small proportions in the averaged D_{st} variation. Fig. 6 gives a smoothed curve of D_{st} variation of f_0F_2 at Ahmedabad for a duration of 50 hr after the SC, and it is compared with those at Washington and Watheroo[4] of middle latitudes.

(i) It may be noted that storm time effect is a reduction of f_0F_2 below normal at all these places. The maximum negative change at Ahmedabad is only 5 per cent as against 7 per cent in SD variation. The variations at the other two places are expressed as simple deviations, but one can see that when they are expressed as percentages, the depressions would be larger than those found at Ahmedabad.

(ii) The storm time effect on f_0F_2 attains its maximum value at a later hour in lower latitudes, e.g. it is maximum at 28 hr after SC at Ahmedabad, 24 hr at Watheroo and 20 hr at Washington. On the contrary, the recovery to normal takes place later at higher latitudes, i.e. the disturbance conditions prevail for a longer time at higher latitudes after the sudden commencement. The effect of the disturbance is more marked on the second day of the storm.

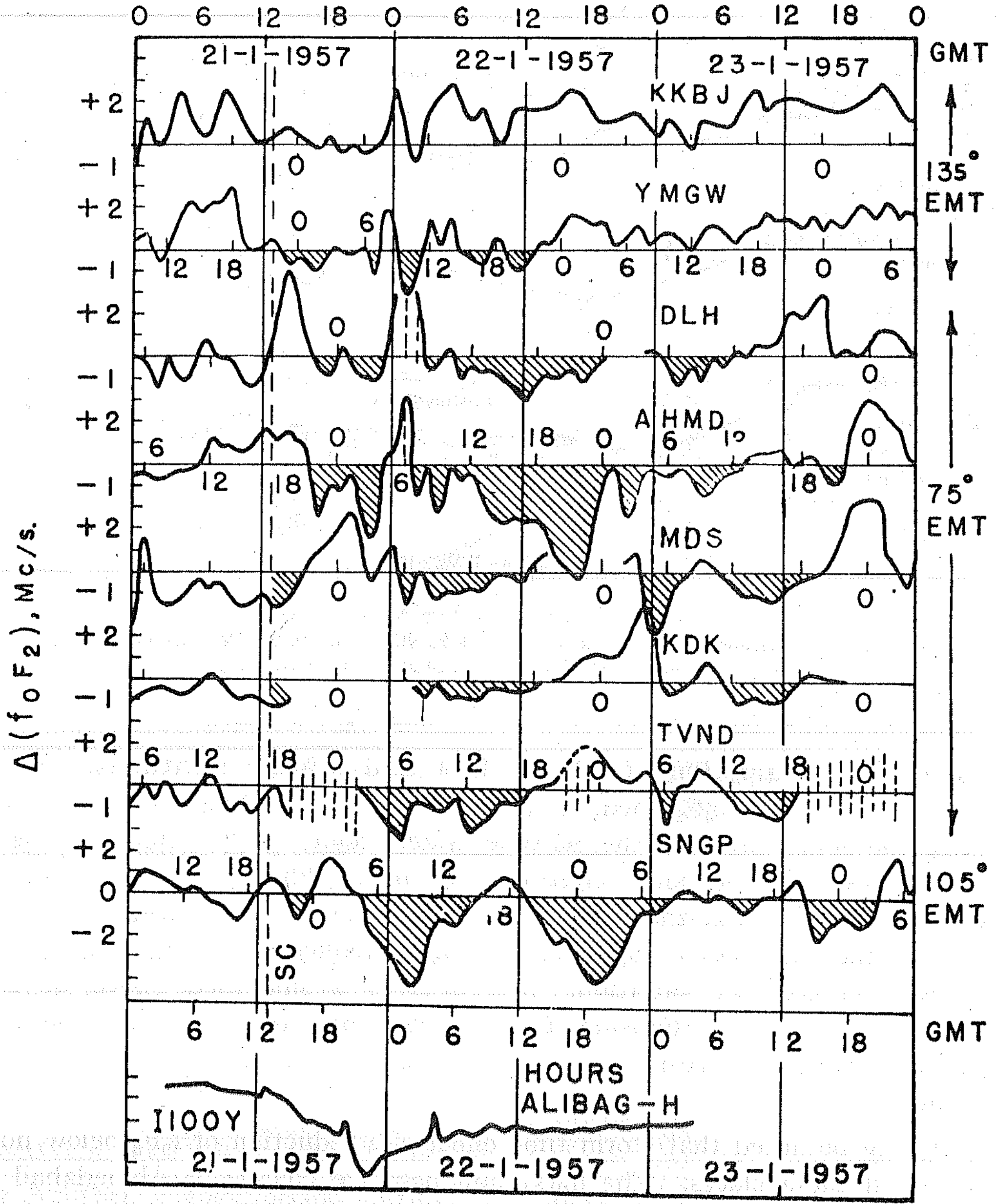

FIG. 7 — STORM TIME VARIATIONS OF f_0F_2 EXPRESSED AS SIMPLE DEVIATIONS FROM NORMAL AT VARIOUS PLACES FROM EQUATOR TO MAGNETIC DIP 49°N IN THE EAST ZONE, DURING THE SC TYPE MAGNETIC STORM OF JANUARY 21, 1957

Some Instances of f_0F_2 Variations Associated with Severe SC type Magnetic Storms. In Figs. 7–10 are shown the simultaneous changes in f_0F_2 at various places in the eastern zone. In these figures, $\Delta(f_0F_2)$, the deviation in Mc/s. of the observed f_0F_2 from the monthly median value at the same hour are plotted. At the bottom of the figure is given the smoothed magnetogram of the horizontal component of the earth's magnetic field at Alibag, which has magnetic observatory nearest to Ahmedabad.

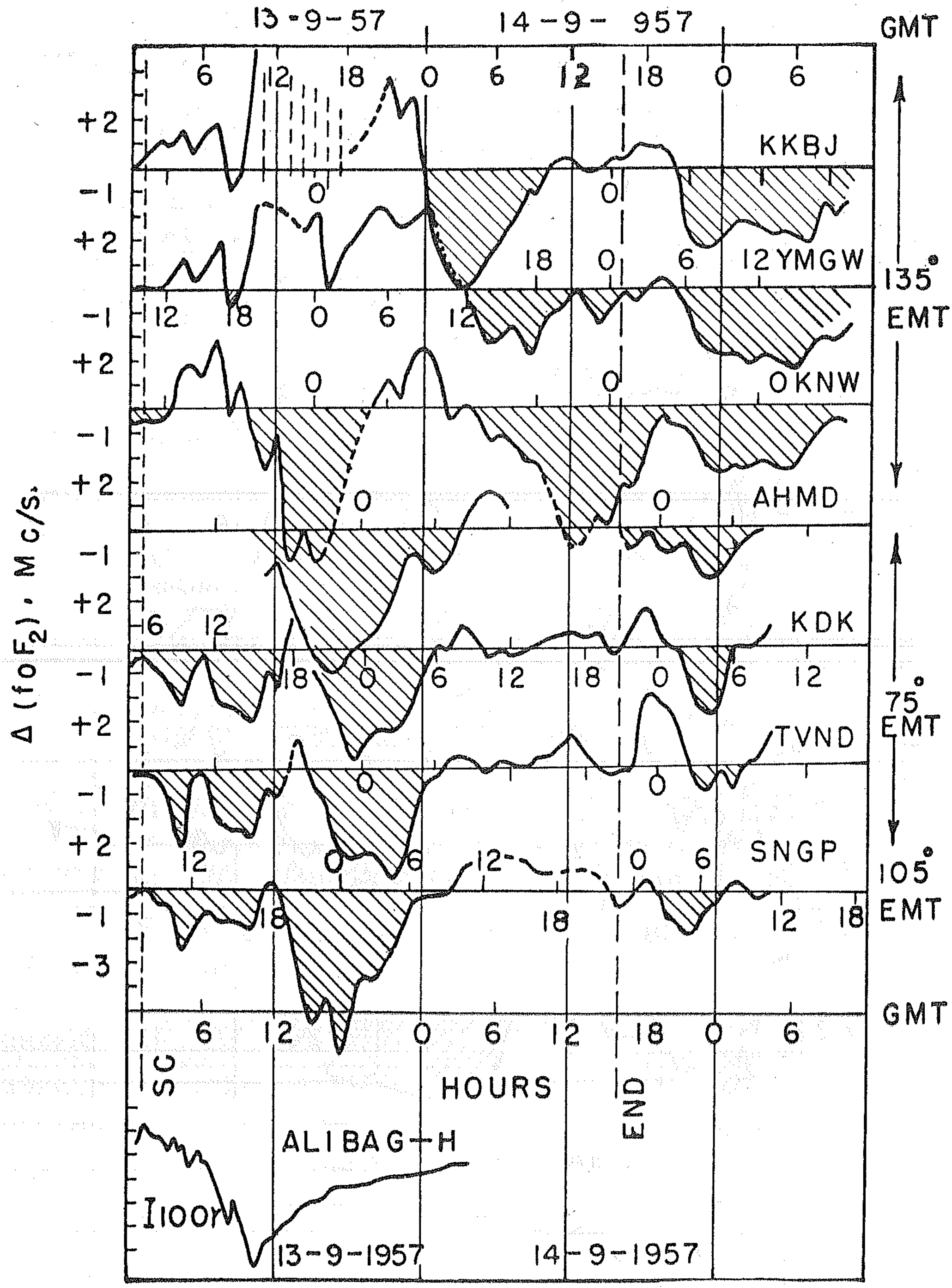

FIG. 8 — STORM TIME VARIATIONS OF f_0F_2 EXPRESSED AS SIMPLE DEVIATIONS FROM NORMAL AT VARIOUS PLACES FROM EQUATOR TO MAGNETIC DIP 49°N IN THE EAST ZONE, DURING THE SC TYPE MAGNETIC STORM OF SEPTEMBER 13, 1957

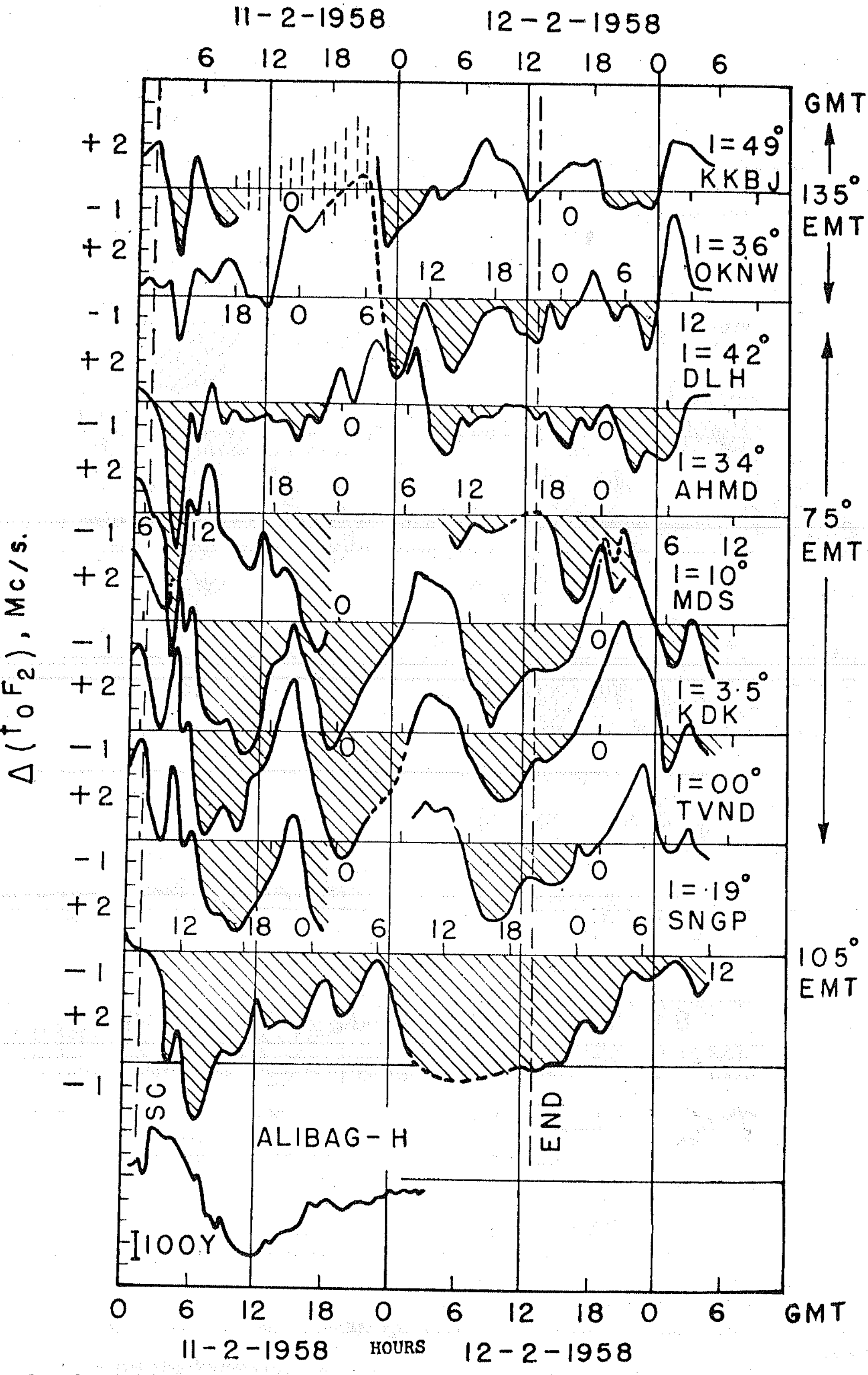

FIG. 9 — STORM TIME VARIATIONS OF f_0F_2 EXPRESSED AS SIMPLE DEVIATIONS FROM NORMAL AT VARIOUS PLACES FROM EQUATOR TO MAGNETIC DIP 49°N IN THE EAST ZONE, DURING THE SC TYPE MAGNETIC STORM OF FEBRUARY 11, 1958

TABLE 2 — SOLAR FLARE AND MAGNETIC STORM DATA

DATE AND TIME (UT) OF SC	INTENSITY OF STORM	RANGE ΔH AT KODAIKANAL *gammas*	ASSOCIATED SOLAR FLARE OR RADIO BURST
Jan. 21, 1957 1253	Severe	410	SF 2+ Jan. 20, 1957 1850
Sept. 13, 1957 0049	Severe	710	Aug. 11, 1957 Type IV burst 0300
Feb. 11, 1958 0125	Severe	813	SF 2+ Feb. 9, 1958 2053
July 8, 1958 0751	Severe	710	SF 3+ July 7, 1958 0048

Table 2 gives some details of the storms included here.

All the storms followed intense solar flares within 28 hr. In the storm of January 21, 1957, the difference between the two events was about 18 hr.

(i) The amplitude and sign of changes in f_0F_2 after the sudden commencement depend on the latitude of the place and also on the local time of commencement. Large changes begin 8–10 hr after the SC and the maximum disturbance in f_0F_2 is observed 20–24 hr later. This maximum change in f_0F_2 does not necessarily coincide with the time of maximum magnetic disturbance. There is no evidence of a sudden commencement in the ionosphere corresponding to that observed in the H field. Plots against UT give an idea of the storm time changes, but superposed on them are the SD variations. To recognize SD from D_{st}, the local times are also marked on the zero axis of each station in Figs. 7–10.

(ii) At the Japanese stations the values of f_0F_2 are higher than normal in winter, though at low latitude stations, they are below normal even in winter. A large difference has been observed between the effects at the Japanese stations of the storms on February 11, 1958 and September 13, 1957, although the SC times in both the events were nearly the same.

(iii) In all cases when the magnetic storm commenced in the morning hours, the usual midday ' bite-out ' in f_0F_2 at the equator was enhanced on the day of the SC. On the following day, however, higher values of f_0F_2 were observed during day-time. The storm of February 11, 1958 was so severe that even on the second day, abnormally low values of f_0F_2 continued near the equator. Large initial drops in f_0F_2 were recorded on a world-wide scale within 2–3 hr of SC. Because of its special features, the storm of February 11, 1958 has been studied in greater detail in a separate paper.

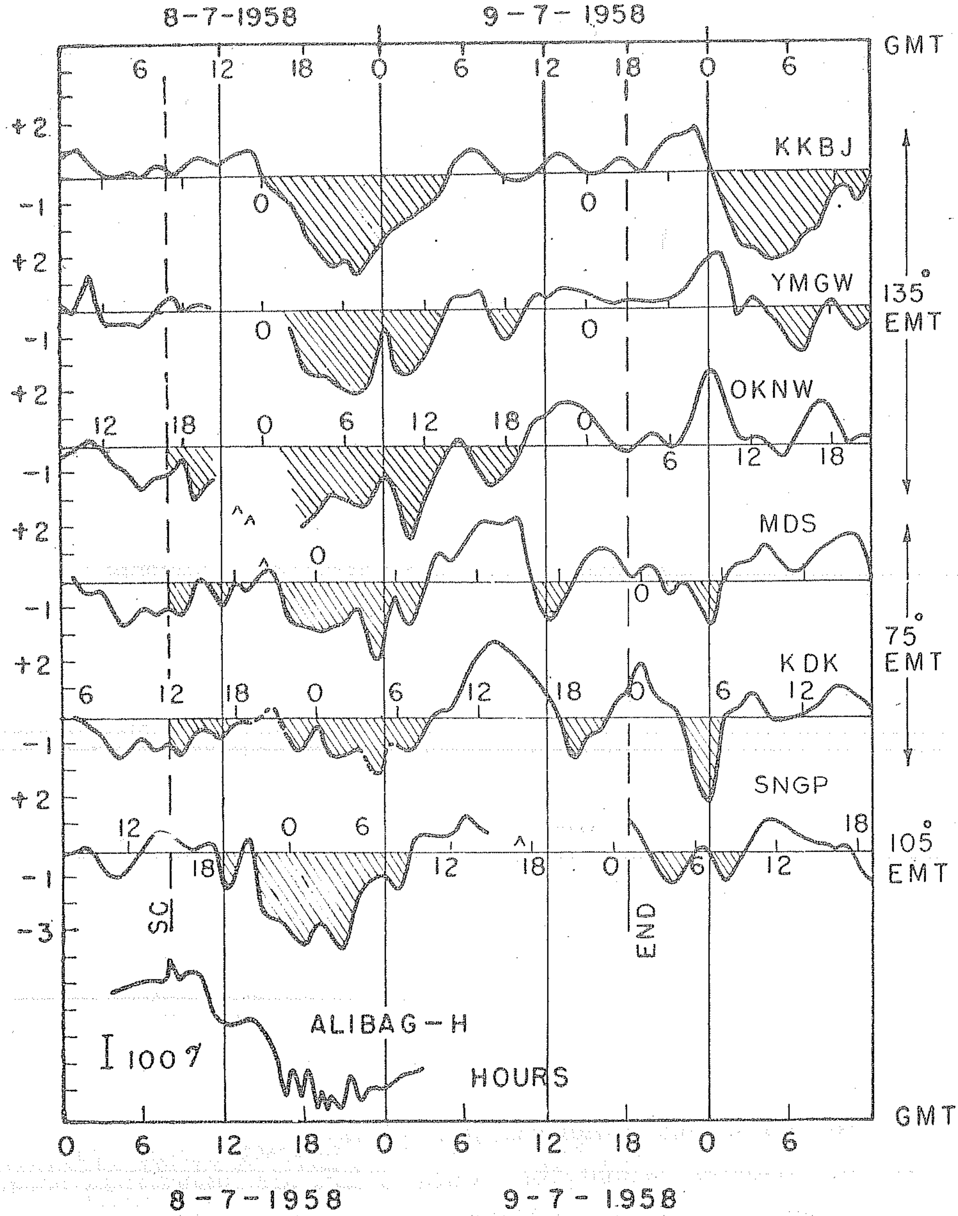

FIG. 10 — STORM TIME VARIATIONS OF f_0F_2 EXPRESSED AS SIMPLE DEVIATIONS FROM NORMAL AT VARIOUS PLACES FROM EQUATOR TO MAGNETIC DIP 49°N IN THE EAST ZONE, DURING THE SC TYPE MAGNETIC STORM OF JULY 8, 1958

(iv) A comparison of the time variations of f_0F_2 at different stations shows that Madras (I = 10°N), Kodaikanal (I = 3·5°N) and Trivandrum (I = 0°) fall in the equatorial group; while Ahmedabad (I = 34°N), Okinawa (I = 36°N) and Delhi (I = 42°N) in the sub-tropics form another group. The three Japanese stations, viz. Kokubunji (I = 49°N), Akita (I = 54°N) and Wakkanai (I = 60°N) form a third group in middle latitudes. Yamagawa (I = 44°N) stands as an intermediate station between the sub-tropics and

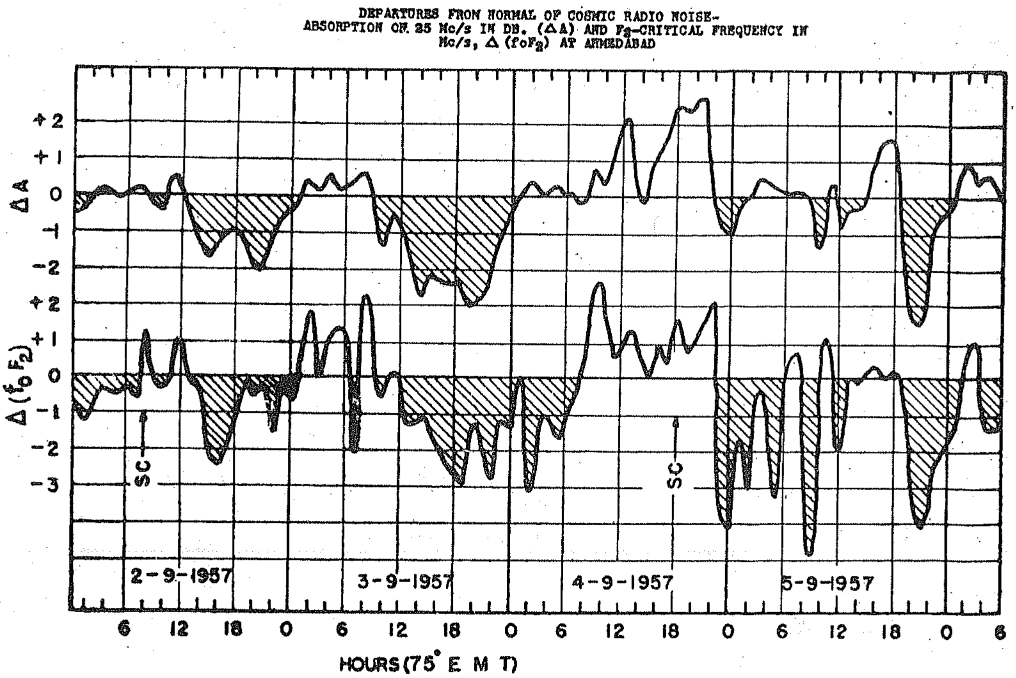

FIG. 11 — CORRELATION OF $\Delta(f_0F_2)$ AND ΔA OF COSMIC RADIO NOISE ABSORPTION DURING A MAGNETICALLY DISTURBED PERIOD, SEPTEMBER 2–5, 1957

mid-latitudes, while Baguio (I = 19°N) and Singapore (I = 18°S) are located near the transition between tropical and equatorial stations. The data show two reversals in phase of $\Delta(f_0F_2)$, one near magnetic dip 45° and the other near magnetic dip 20°.

The increased number of stations in low latitudes has helped in marking out the boundary of the zone of positive $\Delta(f_0F_2)$ near the magnetic equator with some precision.

Matsushita[7] divides the whole hemisphere into 8 zones to show the sequential changes in $D(f_0F_2)$. His analysis shows that an increase of f_0F_2 occurs at high latitudes immediately after SC.

f_0F_2 and Cosmic Radio Noise on 25 Mc/s. at Ahmedabad during a Magnetic Storm. It has been shown by Bhonsle and Ramanathan[18] that cosmic radio noise absorption (CRNA) on 25 Mc/s. at Ahmedabad is reduced on magnetically disturbed days. The cosmic radio noise as measured at ground level undergoes attenuation in its passage through the ionosphere. The absorption due to the D layer is fairly regular and is not affected much by magnetic disturbances. In the F_2 region, however, the changes in electron density are large and the layer is very much affected. On this ground, one can expect changes in CRNA (ΔA) corresponding to changes in f_0F_2. This is illustrated in Fig. 11 which shows a comparison of $\Delta(f_0F_2)$ and ΔA

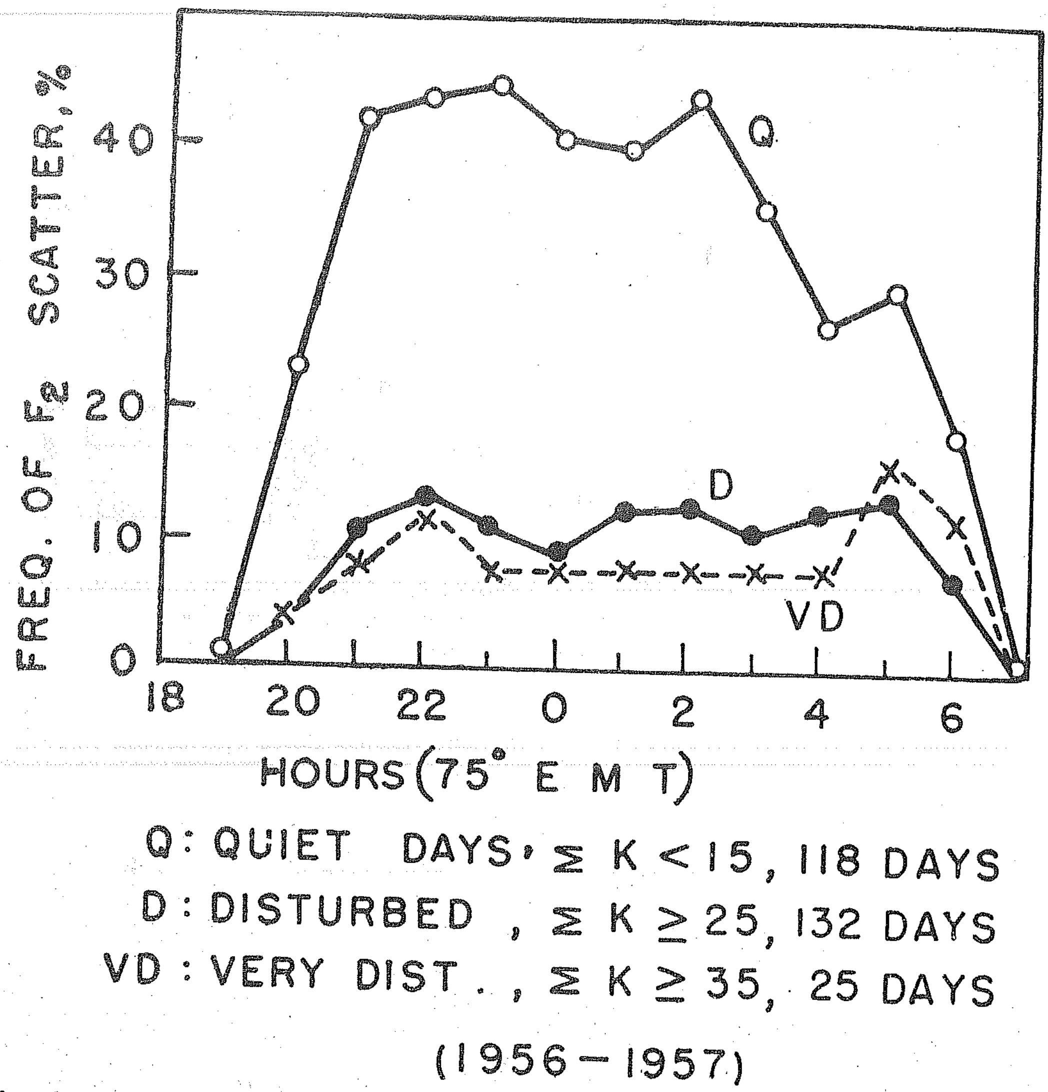

FIG. 12 — VARIATION DURING NIGHT HOURS OF THE OCCURRENCE OF SPREAD F ECHOES ON MAGNETICALLY QUIET AND DISTURBED DAYS

during a prolonged disturbed period when severe SC type magnetic storms commenced on September 2 and 4, 1957. It should be noted that on all these days spread F echoes were absent. It is clear that ΔA and $\Delta(f_0F_2)$ show good correspondence from 0900 hours till midnight, after which f_0F_2 was so low that cosmic radio noise was not influenced. It has been observed that in general electron concentrations corresponding to $f_0F_2 = 8$ Mc/s. are not effective in causing CRNA on 25 Mc/s. at Ahmedabad.

An important feature shown by ionospheric records near the magnetic equator is that f_0F_2 increases during increased magnetic activity, but spread F echoes are rare. At Ahmedabad, both f_0F_2 and spread F decrease during a disturbance. An interesting question arises as to the relative contributions

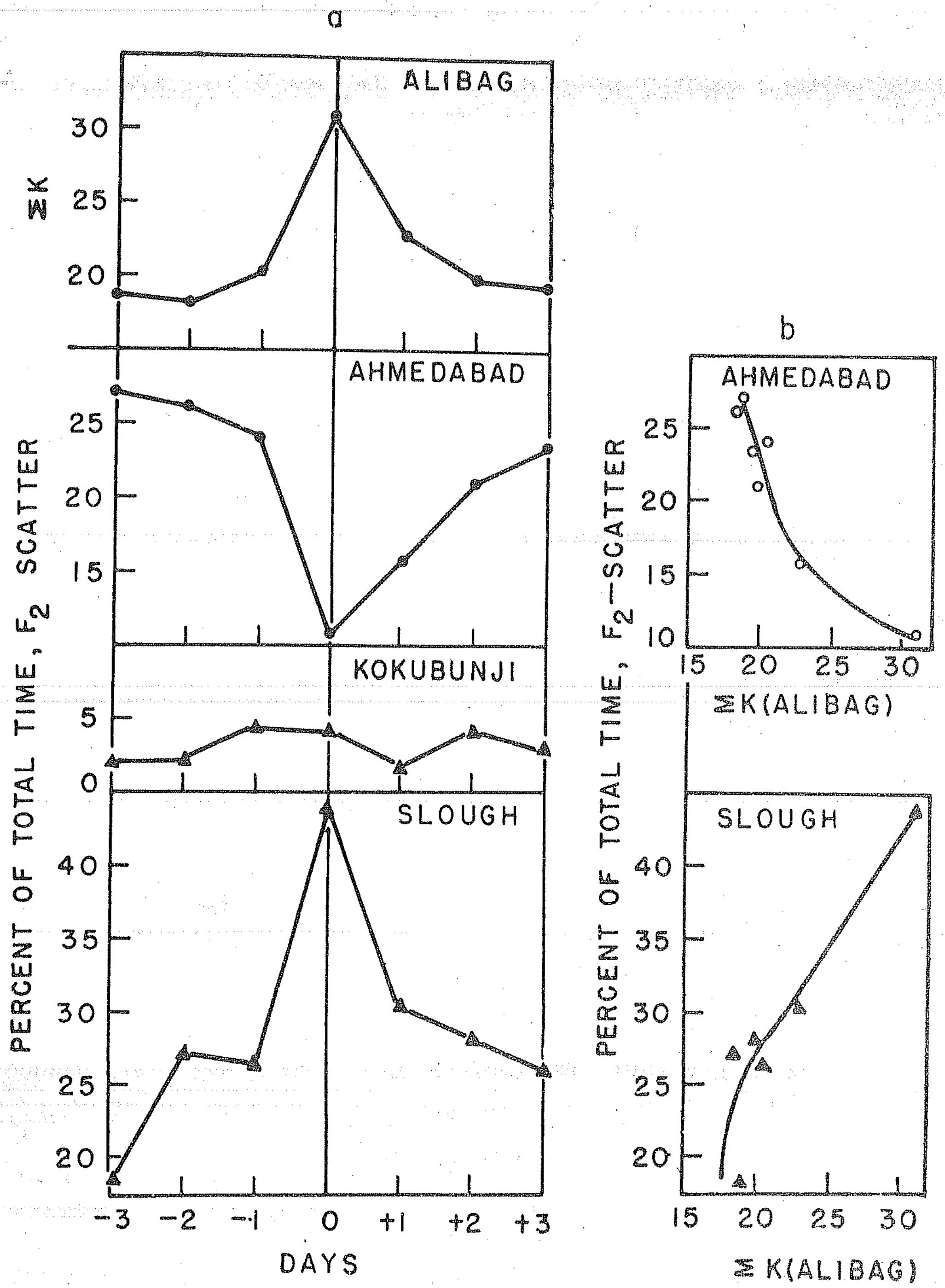

FIG. 13 — SUPERPOSED EPOCH DISTURBANCE VARIATION OF SPREAD F ACTIVITY AT AHMEDABAD, KOKUBUNJI (I = 49°N) AND SLOUGH (I = 67°N). K INDEX SUM OF MAGNETIC ACTIVITY AT ALIBAG IS ALSO SHOWN. 81 EPOCHS, 0 DAYS WITH $\Sigma K > 25$ (1956–57)

to cosmic radio noise attenuation from electron collisions in the ionosphere and F scatter. It should be possible to elucidate this by making measurements on CRNA near the magnetic equator.

Spread F and Magnetic Activity. It has been shown by one of the authors[19] that spread F was less frequent over Ahmedabad on days of increased magnetic activity and that this was also true for all stations having magnetic dip 0°–44°, though the decrease was not in the same proportion at different latitudes. The solar cycle variation of the occurrence of spread F also showed a decrease with increased magnetic character figure. In Fig. 12 are given the changes in the occurrence of spread F on (i) quiet days when $\Sigma K < 15$, (ii) disturbed days when $\Sigma K > 25$, and (iii) very disturbed days when $\Sigma K > 35$. They clearly show that spread F frequency on disturbed days is about $\frac{1}{3}$ of its value on quiet days at Ahmedabad. Days with $\Sigma K > 35$ are few in number and the percentage changes in this case cannot be given much weight. A similar reduction in spread F over Ibadan, particularly in winter, was obtained by Wright and others[20].

A further statistical analysis of spread F data was carried out by the superposed epoch method. The stations studied were Ahmedabad, Kokubunji and Slough and the zero epoch day was selected as one with $\Sigma K > 25$. When ΣK was high consecutively for 3–4 days, the day with the highest value of ΣK was taken as the zero day. The K indices of magnetic activity used in this analysis were from the Alibag Observatory. During the years 1956–57, 81 epochs could be collected and the mean percentage occurrence of spread F during the interval 2000–0600 hours on the epoch day and on 3 days before and 3 days after the epoch day were computed. The results are shown in Fig. 13a. It is found that the occurrence of spread F on a disturbed day is reduced to $\frac{1}{3}$ of its normal value at Ahmedabad for an increase of about 80 per cent in ΣK, while it increases to about $2\frac{1}{2}$ times the normal at Slough. At a place like Kokubunji, there is no appreciable change in spread F activity from quiet to disturbed period. In Fig. 13b, curves of spread F against ΣK are drawn for Ahmedabad and Slough. The change from a decrease in spread F in low latitudes to an increase in middle latitudes during magnetically disturbed periods takes place near magnetic dip 49°. Lyon and others[21] showed that in the southern hemisphere, such a change in the variation of spread F with magnetic character figure, Cp, took place at geographic latitude 20° or magnetic dip 54°. From the study of some individual storms it was found that while spread F occurrence was quite high at Kokubunji, Akita and Wakkanai after the storm commencements, it was not so at Yamagawa and other low latitude stations.

Conclusions

The following are the main conclusions on the various aspects of the disturbances in the F_2 layer of the ionosphere associated with geomagnetic storms which have been studied not only at Ahmedabad but also at other stations in lower and higher latitudes mainly in the eastern zone:

(i) The meridional profiles of f_0F_2 during quiet and disturbed periods show that in the range of latitudes with magnetic dip 0°–60°N, the maximum decrease in f_0F_2 takes place at about magnetic dip 35° on disturbed days. There is a morning rise in f_0F_2 at all the stations with magnetic dip 0°–45°. The equatorial trough of low f_0F_2 is removed to a certain extent during magnetic disturbances. The cross-over from negative to positive change in f_0F_2 takes place at about magnetic dip 20°.

(ii) Two reversals in the phase of SD(f_0F_2) variation take place, one in the morning hours near magnetic dip 45° and the other at midday hours near magnetic dip 20°. This is different from the SD variation of the horizontal component of the earth's magnetic field, which changes its phase at about magnetic dip 71° (or mag. lat. 55°).

(iii) The disturbance variations of f_0F_2 greatly depend on the local time of the commencement of the magnetic storm. Those commencing in the second quarter of the day produce maximum disturbance in F_2 at Ahmedabad, while those commencing in the evening hours cause the minimum effect.

(iv) The storm time or D_{st} variation of f_0F_2 continues for a longer period at higher latitudes. Sharp changes in f_0F_2 begin only after about 8 hr after the SC and the maximum depression of f_0F_2 occurs at later hours near the f_0F_2 peak. The maximum D_{st} variation of f_0F_2 does not occur simultaneously with that of H.

(v) Changes in cosmic radio noise absorption on 25 Mc/s. at Ahmedabad on magnetically disturbed days show correlation with changes in the maximum electron concentration in the F_2 layer.

(vi) Spread F echoes are less frequent on disturbed days at Ahmedabad. This is opposite to what is observed at Slough. The change-over from decrease to increase of spread F occurs at about magnetic dip 45°.

The disturbance effects on the F_2 layer of the ionosphere are of a complex character and for their elucidation, synoptic studies are required of true N-h profiles at a number of stations. There is reason to believe that magnetic storms disturb the whole of the ionosphere including the Van Allen belts.

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