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Ionospheric Storm of 4-6 December 1958 in the Indian Equatorial Region

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The characteristics of the ionospheric storm of 4-6 Dec. 1958 in the Indian sector (60-85°E) are studied using published data from ten ionospheric stations distributed from high midlatitudes to dip equator. It is shown that in the electrojet region, besides the well known positive effects in f_0F2 due to a weakening of the electrojet, negative effects in f_0 F2 with prominent increases in height of F2-layer also occurred during this particular storm. It is suggested that changes in atmospheric neutral composition (i.e. increased N_2/O and O_2/O ratios) are the basic causes of the negative effects in f_0 F2 in the electrojet region noticed for this storm.

1. Introduction

The morphology of perturbations in the ionospheric F-region that occur in response to geomagnetic storms, usually referred to as ionospheric storms, has been a topic of extensive studies over the last four decades. It is well documented in literature that ionospheric storms, at equatorial latitudes are characterized, in general, by an increase in the peak electron density of F-region, irrespective of season.[1-3] Decreases in the peak electron density of F-region, however, are also known to occur at equatorial latitudes during stormtime conditions[4-6] It has been reported that during stormtime periods, the increase in peak electron density of F-region at stations close to the dip equator (in the trough of the equatorial anomaly) occurs in association with a decrease at stations farther away from the dip equator (around the crest of the anomaly).[7] The recent total electron content (TEC) measurements in the Indian equatorial region using beacon transmissions from ATS-6, analyzed in conjunction with peak electron density data at Trivandrum, have shown that during stormtime conditions there exists a significant negative correlation (a) between equatorial electrojet strength and peak electron density for Trivandrum and (b) between changes in peak electron density for Trivandrum and changes in TEC at stations in the anomaly region with diffusion time equal to 2 hr (Ref. 8). These earlier findings suggest a prominent role of perturbations in the equatorial electrojet strength in the behaviour of ionospheric stroms at equatorial latitudes during daytime through the 'fountain effect'. It is, however, quite possible that besides the perturbations in the equatorial electrojet, several other physical processes (e.g. neutral wind effects, composition changes) might be operative at equatorial latitudes during geomagnetic storm periods[9] In this paper, we present the salient features of the ionospheric storm of 4-6 Dec. 1958 as observed in the 60-85°E longitude sector which indicate such a possibility.

2. Data and Observations

The study is based on published data of parameters f_0F2 and h_pF2 from ten ionosonde stations and ionogram data at Kodaikanal (see Table 1 for details of stations). In Fig. 1 are shown the time histories of the 3-hourly planetary K_p index and hourly equatorial *Dst* index during the interval 3-6 Dec. 1958. A glance at the evolution of the *Dst* index following the storm sudden commencement at 0030 hrs UT on 4 Dec. 1958 shows that the three characteristic phases of Sc-type geomagnetic storm, i e. initial, main and recovery phases are quite apparent for this storm. The initial phase lasted till about 0900 hrs UT on 4 December, i.e. it occurred during the forenoon period in the longitude sector under consideration. The main phase manifested till about 0000 hrs UT on 5 December, i.e. during the evening and nighttime period.

It is to be emphasized that in this paper we pay partioular attention to the behaviour of the equatorial daytime F-region and the behaviour at stations in the mid to high midlatitude regions will be consulted

Table 1 — Details of Stations Selected for Study

Station	Symbol	Geographic coordinates Lat. N	Long. E	Dip (I) °N
Salekhard	SA	66°32′	66°42′	79·4
Sverdlovsk	SV	56°44′	61°04′	73·6
Tomsk	TO	56°28′	84°56′	75·4
Alma Ata	AL	45°15′	76°55′	69·9
Delhi	DE	28°38′	77°13′	42·4
Ahmedabad	AH	23°01′	72°36′	34·0
Madras	MA	13°05′	80°17′	10·5
Tiruchirapalli	TI	10°49′	78°42′	4·8
Kodaikanal	KD	10°14′	77°29′	3·5
Trivandrum	TR	8°29′	76°57′	0·0

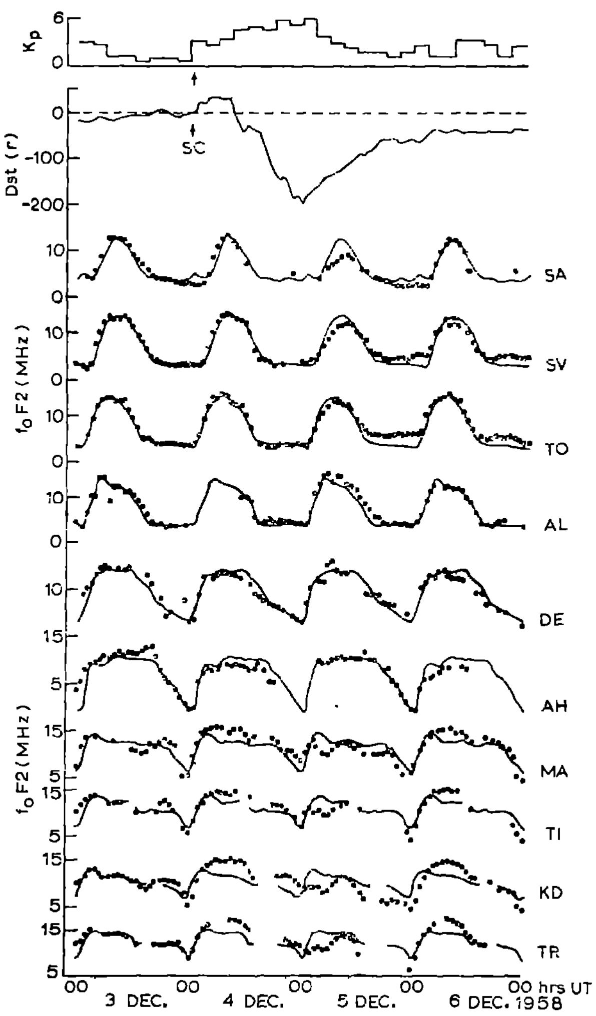

Fig. 1—Diurnal variation of f_0 F2 at stations in the Asian sector (see Table 1 for details) during the period 3-6 Dec. 1958 (The solid curves represent the monthly median diurnal pattern at the respective stations. Also shown are the time histories of the 3 hourly K_p index and hourly Dst index for the corresponding period.)

only to help in an assessment of the physical processes responsible for the equatorial F-region behaviour. In Fig. 1 is also shown the diurnal variation of f_0F2 at the various stations during the period 3-6 Dec. 1958, with the monthly median pattern of diurnal variation superimposed for reference and to provide a picture of the characteristics of the ionospheric storm at different stations. There is considerable evidence in literature to show that the equatorial electrojet governs to a major extent the behaviour of the equatorial F-region.[10-12] The parameter ΔSd_I, which is a measure of the equatorial electrojet strength, has therefore been evaluated from the H-field data at Kodaikanal (inside the electrojet region) and Alibag (outside the electrojet region) following the procedure introduced by Kane.[13] In Fig. 2 is shown the diurnal variation of ΔSd_I along with that of h_p F2 at the various stations in the equatorial region during the period 3-6 Dec. 1958. In Fig. 3 are shown true-height profiles of electron density $N(h)$ at Kodaikanal at selected times of interest during daytime on 3,4,5 and 6 Dec. 1958. The ionograms have been reduced by the single-polynominal method of Titheridge.[14] Fig. 4 shows the latitude variation of f_0F2 at specified times during daytime on 3,4,5 and 6 December to provide a picture of the behaviour of the 'equatorial anomaly'.

On 4 December, i.e. the first day of the storm, there was an increase in f_0F2 values during daytime at stations close to the dip equator and a decrease at stations farther away in the equatorial region. The increase in f_0F2 values at electrojet stations was associated with a decrease in h_p F2 values. There was a considerable distortion of the electrojet diurnal profile on this day with a noontime weakening of the electrojet strength. Considering the latitudinal profile of f_0F2 in the equatorial region, it may be seen from Fig. 4 that the equatorial anomaly showed poor developement on this day during daytime. In contrast to these significant changes in the equatorial region, f_0F2 values at stations in the mid to high midlatitude regions were more or less unaffected. The equatorial F-region exhibited an interesting behaviour during daytime on 5 December, i.e. after the end of the main phase of the geomagnetic storm. As can be seen from Fig. 1, there was a conspicuous and significant reduction of f_0F2 values during daytime at stations in the vicinity of the dip equator. In fact, the normal post-sunrise build-up of ionization was inhibited at the electrojet stations, in particular, at Kodaikanal and Trivandrum. These depressions in

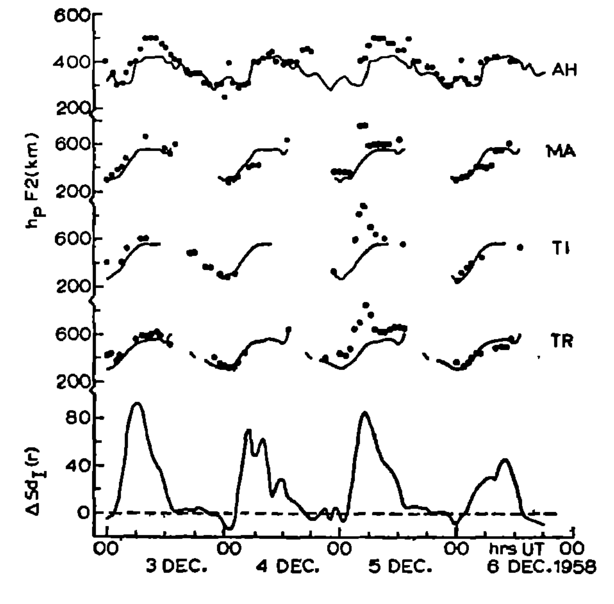

Fig. 2—Diurnal variation of h_pF2 at stations in the equatorial region during the period 3-6 Dec. 1958 (The monthly median pattern of diurnal variatron is shown as solid curves. Also shown is the diurnal variation of $\triangle Sd_I$ for the corresponding period.)

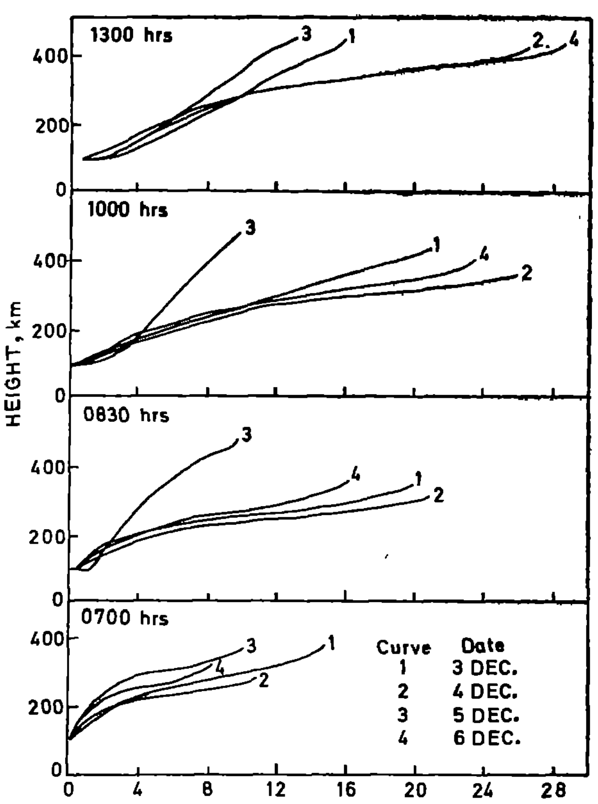

Fig. 3—Electron density $N(h)$ profiles estimated from the ionograms at Kodaikanal at specified hours (IST) during daytime on 3, 4, 5 and 6 Dec. 1958

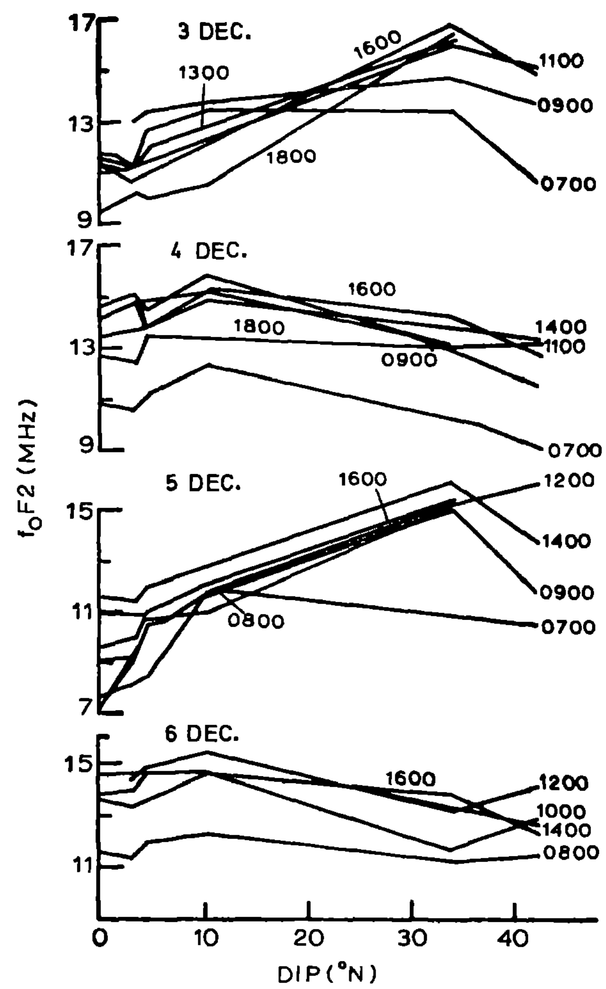

Fig. 4—Variation of f_0F2 with dip angle at specified hours during daytime on 3, 4, 5 and 6 Dec. 1958 in the equatorial region [The times indicated are in IST (UT+5½ hrs).]

F-region ionization at electrojet stations were noticed to occur in association with significant increases in the height of the F-region as may be seen from Figs. 2 and 3. There is no indication of any significant change either in the diurnal profile or strength of the equatorial electrojet on this day and equatorial anomaly showed its normal behaviour, as for example, on 3 December, a quiet day (see Figs. 2 and 4). Considering the behaviour at other stations, it may be seen that the depressions in f_0F2 are mainly confined to the electrojet and high midlatitude regions. The f_0F2 behaviour at stations in the low and midlatitude regions did not show any change except at Alma Ata where an increase is evident. It is of interest to mention here that in the Greenwich longitude sector, prominent increases in f_0F2 were noticed during daytime on 5 December (not shown) at Ibadan (7·4°N; 3·9°E) and decreases at Slough (54·5°N; 359·4°E) and Inverness (57·4°N; 355·8°E). Decreases in f_0F2 were also evident at Christchurch (43·6°S; 172·8°E), a southern hemisphere high midlatitude station in the Pacific sector. The equatorial F-region in the Indian zone remained affected on 6 December also, i.e. during the recovery phase. The behaviour on this day is similar to the one noticed on 4 December with the difference that on this day the reduction of the electrojet strength was marked compared to 4 December.

3. Discussion

As already mentioned, it is now well recognized that at least three physical mechanisms might be operative in the equatorial regions during stormtime conditions. These are : (a) perturbations in equatorial electrojet (b) neutral wind effects [15-17] and (c) neutral composition changes.[18-20] Let us now examine the characteristics of the ionospheric storm under study in the light of the above mentioned mechanisms. It is quite apparent that the weakening of the equatorial electrojet is the dominant mechanism underlying the behaviour of the equatorial F-region during daytime on 4 and 6 December. The cause of this stormtime weakening of the electrojet however is not quite obvious. As pointed out by Kane,[4] a weakening of the equatorial electrojet may be expected during the main phase of a geomagnetic storm. In this particular storm, however, weakening of the electrojet was noticed during the initial and recovery phases which is quite interesting. The marked reduction in f_0F2 at stations close to the dip equator during daytime on 5 December, which is a marked exception to the usual stormtime behaviour of f_0F2 at equatorial latitudes, is the highlight of this particular ionospheric storm. (It is to be pointed out here that decreases in f_0F2 in contrast to the normal pattern of enhancements are known to occur in the electrojet region during severe storms,[4] but detailed studies as to their probable origin are lacking.) These depressions do not fall into the category of sharp (2-3 hr duration) worldwide depletions in F-region ionization noticed during the early phases of some geomagnetic storms.[21] The possibility that the observed depressions in f_0F2 might be due to an enhancement of the electrojet (for example, as observed by Woodman *et al.*[5] for the 8 Mar. 1970 storm) may be ruled out in view of : (i) on 5 December there is no clear-cut evidence of either a significant enhancement in the electrojet strength (compared to 3 December) or a perturbation in the electrojet diurnal profile in the forenoon period and (ii) f_0F2 values at stations around the crest of the 'equatorial anomaly' were unaffected. This then leads us to the understanding that the reductions in f_0F2 are due to an increase in the loss rate caused by changes in atmospheric neutral composition (i.e. enhanced N_2/O and O_2/O ratios). Changes in neutral composition can, however, occur due to several processes, viz. (i) modifications in the global thermospheric circular pattern characterized by transport of 'molecule enriched' air from high latitudes towards the equator;[22] (ii) increase in neutral gas temperature and consequent thermal expansion of the atmosphere[23,24] and (iii) changes in local diffusive equilibrium, i e. increased mixing at the turbopause[25,26] As observed earlier, the depletions in f_0F2 observed during daytime on 5 December exhibit an interesting latitudinal variation in that they were mainly confined to the high midlatitude and electrojet regions, with the low to low midlatitude regions being unaffected. It is, therefore, quite unlikely that the depletions in the electrojet region were brought about by modifications in the thermospheric circulation although the behaviour at higher midlatitudes can be understood in those terms. This all the more appears to have been the situation as the recent work of Prolss[27] showed that in the winter hemisphere, the atmospheric disturbances responsible for the depletions in f_0F2 during disturbed periods were mainly restricted to higher latitudes. On the other hand, the marked increase in the F-region height that occurred in association with the depletions in f_0F2 clearly indicates a role of thermal expansion of the atmosphere. It is, however, difficult to account for the observed depletions entirely in terms of atmospheric heating effects. This is so because the global increases in atmospheric temperature that occur during geomagnetic disturbances are intense at higher latitudes and progressively decrease in intensity towards the equator.[28,29] This leads us to infer that the composition changes might also be due to a perturbation in the local diffusive equilibrium. The striking absence of depletions in f_0F2 at Ibadan in the Greenwich sector supports this. To conclude, it is suggested that the exceptional reductions of daytime f_0F2 in the Indian electrojet region observed during this storm are primarily due to changes in atmospheric neutral composition.

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