

## Enhancement of Atmospheric in relation to pre-monsoon and monsoon Thunderstorms

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**ABSTRACT.** Enhancements of atmospheric associated with local thunderstorms occurring in a tropical station, Calcutta, were studied on 30 kc/s. The various stages of an enhancement were correlated with the different stages of development of thunderclouds occurring in the rainy seasons. The results show an association of a sudden increase and sudden decrease of atmospheric in the pre-monsoon and monsoon seasons respectively, with precipitation. Atmospheric activity noticed early in the process of development of clouds before any precipitation occurs and even before the cloud has, perhaps, developed upto the ice-forming level, is indicated. The potential meteorological importance of the enhancements, in forecasting the thunderstorms and also in providing with a new insight into the mechanism of charge separation in thunderclouds, is discussed. The studies also indicate the significance of cloud discharges as a source of atmospheric radio noise.

### 1. Introduction

It is now well known that atmospheric originate from natural electrical disturbances in the atmosphere such as lightning flashes. Location of the sources of atmospheric by direction finding methods have shown that the great majority are situated in regions of 'definite meteorological disturbances' where thunderstorms would be expected and very frequently where thunderstorms are reported (Thomas and Burgess 1947, Sen 1965 b). Within the past few years there have been numerous reports of the close association of thunderstorms of different types with atmospheric (Schonland *et al.* 1940, Sashoff and Roberts 1942, Wanta 1951, Kimpara 1955, Jones 1958). In fact, systems for fixing sources of atmospheric have been in routine operation in several countries for some years (Pierce 1956, Alpert and Borodina 1956, Skeib 1956, Malkowski 1957). During the International Geophysical Year, observational programmes directed solely towards the location and tracking of thunderstorms by recording atmospheric at a distance, were undertaken in several countries. Samson and Linfield (1962) observed that spheric\* variation rate was indicative of the rate of movement and degree of development of severe thunderstorm and tornado outbreak. Even a single thunderstorm of nearby origin may give rise to quite large increases of atmospheric radio noise (Yabsley 1960, Aiya 1962). We have observed in Calcutta

large enhancements of atmospheric associated with severe local thunderstorms occurring in the pre-monsoon and monsoon seasons (Das Gupta and Sen 1963, 1965, Sen 1965 a). A detailed analysis of these enhancements, together with an analysis of the delay between various stages of an enhancement as also that between an enhancement and the thundersquall and its associated precipitation are presented in this paper.

### 2. Equipment

For the last few years, we have been recording the integrated field intensity of atmospheric at Calcutta (Lat. 22°34'N, Long. 88°24'E) on 30 kc/s. The receiver used for the observations was based upon designs supplied by Mr. J. A. Ratcliffe and his colleagues of the Radio Section of the Cavendish Laboratory with slight modifications and was constructed during the International Geophysical Year primarily for the purpose of solar flare patrol by the S.E.A. (Sudden Enhancement of Atmospheric subsequent to solar flares) technique (Ellison 1955). The overall time constant of the equipment is 8 seconds for a sudden increase of input level, while it is 1 minute for a decrease.

### 3. Observations

The author was prompted to examine the daily records of the integrated field intensity of atmospheric (abbreviated IFIA) for the period March to September 1962. This is because every year during this period the eastern part of India, particularly West Bengal, experiences severe

\*A special nomenclature for atmospheric originating in, and being propagated through the space between the earth and the ionosphere

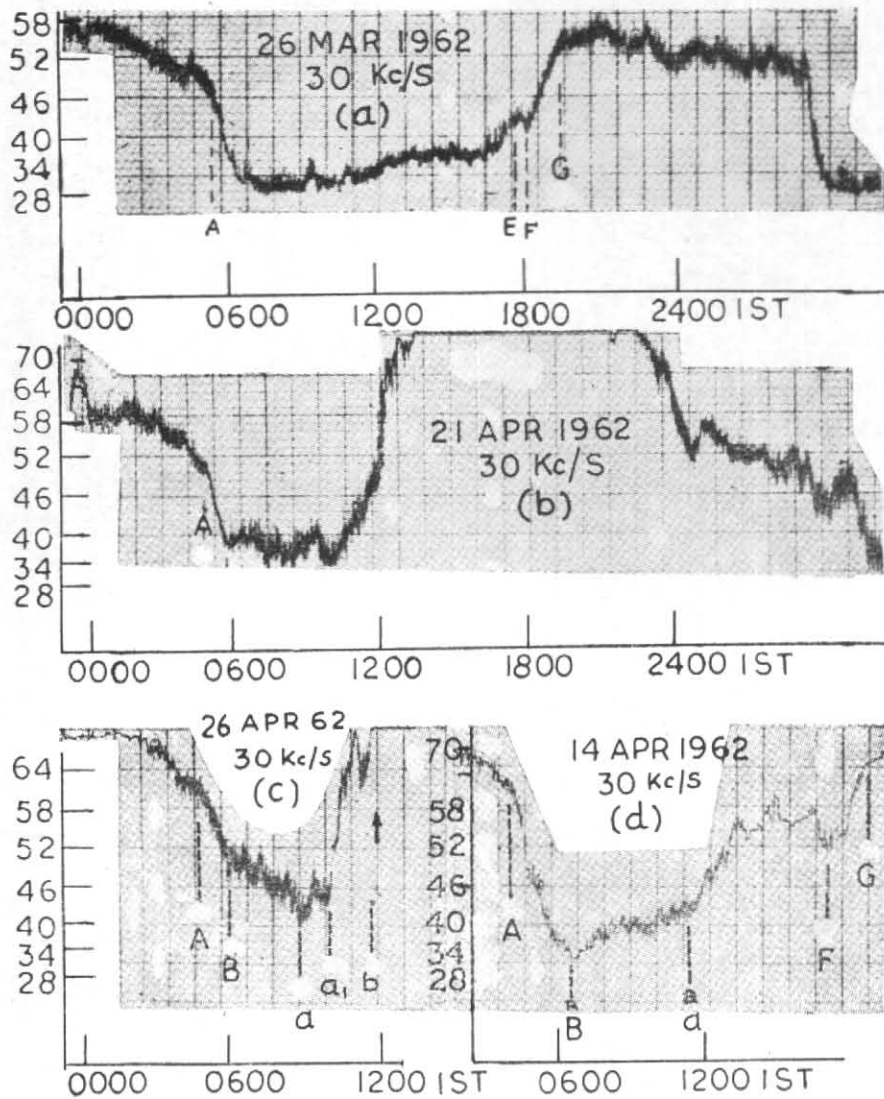


Fig. 1

(a) The usual diurnal variations in the integrated field intensity of atmospheric (IFIA) on a normal per-monsoon day

(b) IFIA on a day when a severe Nor'wester was experienced in Calcutta

a—IFIA starts rising gradually; a<sub>1</sub>—first sudden commencement; b—second sudden commencement; c—decay of IFIA starts; d—IFIA regains normal value

(c) Second sudden enhancement of IFIA associated with local precipitation

The arrow indicates the time of onset of the precipitation

(d) Gradual enhancement of IFIA having no association with Nor'wester

(The ordinate shows the r.m.s. field strength for a 1 kc/s band-width in decibels above 1  $\mu$ V/m)

thunderstorms. Of these, those occurring in the pre-monsoon months, March–May, in association with hail, in general, comes from northwest and are, therefore, called Nor'westers. A Nor'wester is characterized by its association with

a sudden onset of high wind speed varying from about 40 mph to that of hurricane winds (above 73 mph), a sudden drop in temperature, an abrupt change in humidity and a cumulonimbus type of cloud formation. Thunderstorms occurring in

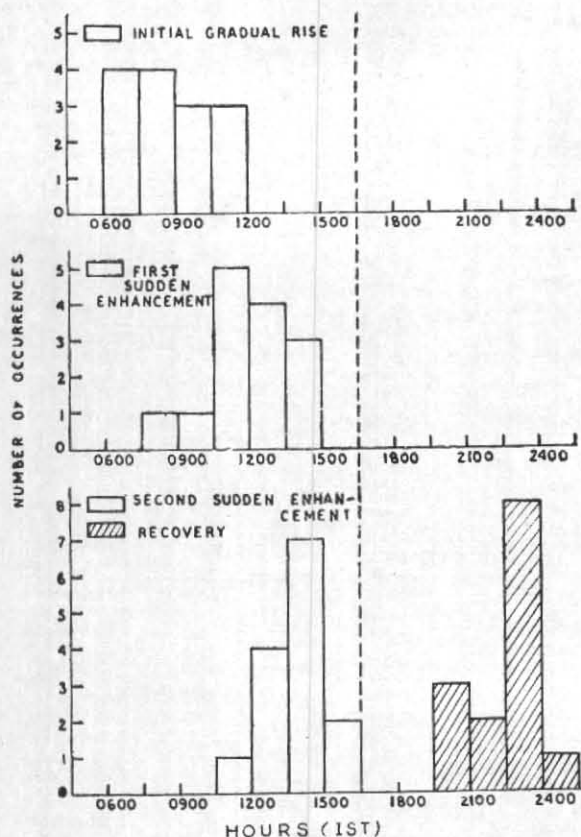


Fig. 2. Histograms of the diurnal variation of the occurrence of the various stages of an enhancement of IFIA associated with a Nor'wester

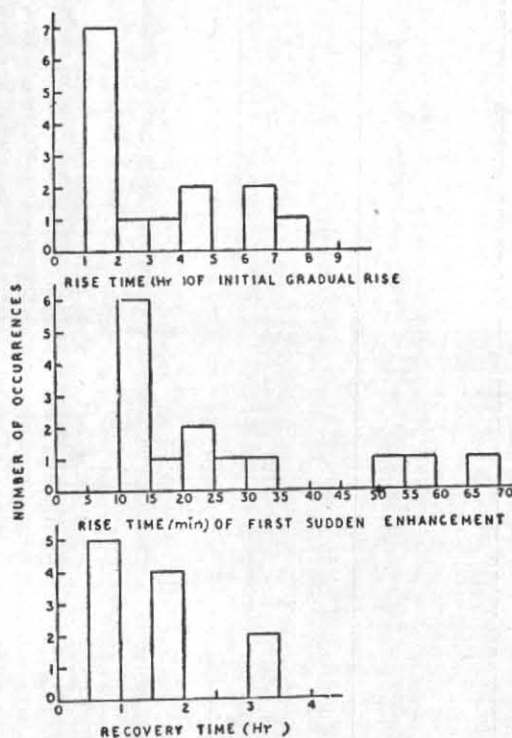


Fig. 3. Histograms of the rise and recovery times of an enhancement of atmospherics associated with a Nor'wester

the monsoon months, June-September, however, comes from southeast and have got certain distinctive features. During the period under consideration there were twelve Nor'westers occurring in March-May while eleven cases occurring in June-September were monsoon thunderstorms. Besides these, three more cases of Nor'westers occurring in June are also included in the analysis.

4. Enhancements associated with pre-monsoon thunderstorms or Nor'westers

(i) *Typical records*—Two typical records are shown in Fig. 1, the upper one showing the usual diurnal variations (WMO 1957), viz., the sunrise effect (A), morning minimum (D), afternoon maximum (E), late minimum (F) and night maximum (G), while the lower one (b), besides the sunrise effect also shows the recovery effect (C). However, the predominant feature of the records on the disturbed day is the unusually large enhancement of IFIA starting at 1002 IST, rendering the recorder off-scale and obscuring E, F and G. The Nor'wester associated with the enhancement occurred at 2112 IST.

(ii) *Detailed features*—A close examination of the typical record presented in Fig. 1(b) re-

veals that the enhancement occurs in three distinct stages of which the first one is slow and steady rise starting at 1002 IST. In the second stage, IFIA exhibits a sudden increase within a period of about 10 min starting at 1202 IST, followed by a period of minor changes of field intensity, while in the third stage, a second sudden enhancement appears at 1330 IST. The IFIA started decreasing near midnight at 2330 IST regaining the normal night level within about 105 minutes. During the period under consideration there were altogether fourteen Nor'westers. Each of these were associated with enhancements quite similar to those reproduced in Fig. 1(b).

(iii) *Occurrence*—The diurnal variation of the occurrence of the various stages of enhancements are shown in Fig. 2, which shows that the initial gradual rise, first and second sudden enhancements start at 0600-1200, 0730-1500 and 1030-1630 IST respectively with the respective maxima occurring in the ranges 0600-0900, 1030-1200 and 1330-1500 IST, while the recovery starts at 1930-0130 IST, the maximum number occurring around midnight between 2230 and 2400 IST.



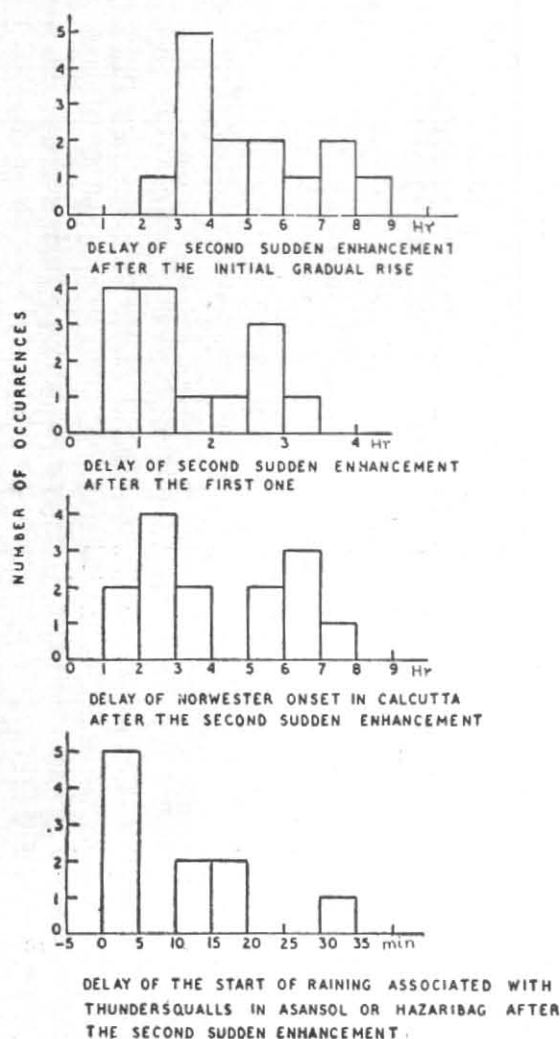


Fig. 4. Histograms of the delay between the various stages of an enhancement and that between an enhancement and the onset of the associated thundersquall or raining in Calcutta, Asansol or Hazaribag

(iv) *Statistical characteristics of the enhancements*—Histograms of the rise and recovery times of the various stages of the enhancements are shown in Fig. 3, which shows that the rise time of the initial gradual rise and the first sudden enhancement varies from about 1-8 hours and 10-70 minutes respectively with the respective maxima occurring in the ranges 1-2 hours and 10-15 minutes, while the recovery of IFIA to the normal night level occurs within  $3\frac{1}{2}$  hours of the time of start of the decrease, the maximum number of recovery times occurring in the range  $\frac{1}{2}$ -1 hour.

(v) *Delay between the various stages of enhancement*—Histograms of the time advance of the initial gradual rise and the first sudden enhancement before the second sudden enhancement are shown in Fig. 4, which shows that the time advance is 2-9 and  $\frac{1}{2}$ - $3\frac{1}{2}$  hours for the initial

gradual rise and the first sudden enhancements respectively with the respective maxima occurring in the ranges 3-4 and  $\frac{1}{2}$ - $1\frac{1}{2}$  hours.

(vi) *Delay between an enhancement and the associated thundersquall*—The initial gradual rise, the first and second sudden enhancement start about 4-13, 2-9 and 1-8 hours in advance respectively before the onset of the associated Nor'wester over the station. A histogram of the time advance of the second sudden enhancement before the thundersquall onset in Calcutta is shown in Fig. 4, which shows that the time advance has a tendency to cluster around 2-3 and 6-7 hours.

(vii) *Discussion*—The Nor'westers, in general originate in the hills of Chota Nagpur and neighbouring areas particularly, in Hazaribag (Lat.  $23^{\circ}59'N$ , Long.  $85^{\circ}25'E$ ) and Asansol (Lat.  $23^{\circ}42'N$ , Long.  $87^{\circ}01'E$ ), where incursion of moist air from the Bay of Bengal under favourable synoptic conditions produces a primary or parent thunderstorm (Rao and Boothalingam 1957). The uplift provided by the cold downdraught outflowing from the parent thunderstorm generally spreads in some southeasterly direction and provides the requisite vertical displacement for another thunderstorm further to the southeast. Thus a whole series of thunderstorms—secondary, tertiary, quaternary, etc.—is generated propagating the thunderstorm activity against the direction of inflow of moist air at lower levels. The mechanism is known as Regenerative Drift Process (Desai and Mull 1938, Byers and Braham 1949).

The unusually large enhancements of IFIA associated with a Nor'wester could not be explained in terms of a better propagation condition for distant atmospherics induced by lightning flashes occurring in the parent thunderstorm, although there are indications that sporadic increases of ionization in the *E*-layer are often produced by a lightning discharge originating in thunderclouds (Ratcliffe and White 1933, Appleton and Nasimuth 1933, Bhar and Syam 1937, Mitra and Kundu 1954, Isted 1955, Rastogi 1957). For, at 30 kc/s, the ionospheric propagation, particularly in daytime (when the thunderclouds are most active), would be governed mainly by reflection from the *D*-region and the ionization of this region is not likely to be affected by Nor'westers because of a high collision frequency at the height involved. The abnormal increase should, therefore, be attributed mainly to the electromagnetic radiations from the intense electrical activity in the thunderclouds responsible for the onset of Nor'westers. In fact,

a detailed examination appeared to indicate a close association of the rising and decaying portions of the enhancements with different stages of development of the thunderclouds.

It has been generally accepted that Nor'westers are associated with a high level (1.5 to 2 km a.s.l.) surface of discontinuity with warm and dry air above cold and moist air (Desai and Mull 1938, Mull *et al.* 1963). At the initial stage convection currents are set up irregularly due to insolation. With the advance of the day the currents are enhanced and cumulus clouds are formed when they reach the condensation level. Radar observations show that the cumulus clouds gradually develop vertically into towering cumulus due to the increase of convection currents, until it reaches the surface of discontinuity where a marked instability is set up due to the downdraught of the warm and dry upper air coming in contact with the cold moist air below, and the cumulus head shoots up with explosive violence producing dense cumulonimbus cloud, the vertical growth at this stage being very rapid. Finally with the onset of precipitation the height of the cumulonimbus cloud is decreased (Mull *et al.* 1963) while about the same time the electrical activity of the thundercloud increases (Workman and Reynolds 1949) presumably due to a vigorous separation of charge occurring at such times (Keuthner 1950, Byers and Braham 1953).

The basic process by which a thunderstorm acquires its charge remains obscure. A vast literature is available on charging mechanisms as demonstrated in the laboratory, but there has been much less attempt to investigate the role of each mechanism under actual thundercloud conditions and no general agreement on the subject has yet been reached (Pierce 1960). However, a direct relationship between vertical convection and electric fields has been widely demonstrated (Reynolds and Brook 1956, Brook 1957, Moore *et al.* 1958) and a vigorous convection appears to be a major requirement for cloud electrification (Workman and Holzer 1942, Holzer and Saxon 1952, Moore *et al.* 1960). An increased convection associated with precipitation can, therefore, be expected to produce an increase of electrical activity at such times.

The first sudden enhancement of IFIA after the initial gradual rise might be associated with onset of marked instability when the top level of the towering cumulus reaches the surface of discontinuity. The cloud then suddenly increases in height probably giving rise to a sudden increase of electrical activity, which manifests itself

as the sudden increase of IFIA. In fact, a calculation based on the relation between the diameter of a hailstone and the ascending current (Weikmann 1953) indicated that a typical cumulonimbus thundercloud might grow suddenly upto about 12 km within a period of 7-30 minutes while the growth upto 18 km might occur within about 11-43 minutes (Mull *et al.* 1962). These figures are comparable to the rise times of the first sudden enhancement, 10-70 minutes as can be expected if a close connection exists between the explosive build-up of the thundercloud and the first sudden enhancement.

The second sudden enhancement of IFIA might be related to an increased convection associated with the onset of precipitation. In fact, on few special occasions, when the development of the thundercloud was local, it was observed that the second sudden enhancement occurred about the time of onset of visible precipitation—a fact, which appears to indicate that this enhancement is intimately connected with precipitation. A typical record obtained when the development of the thundercloud was local is reproduced in Fig. 1(c). The figure shows that the second sudden enhancement and visible precipitation occur about the same time. It is interesting to note here that on certain occasions when the initial gradual rise of IFIA was not succeeded by marked sudden enhancements, no Nor'wester was reported from nearby regions. There is, however, nothing surprising in it, for, if the first and second sudden enhancements of IFIA be assumed to be due to the sudden growth of cumulus head on reaching the surface of discontinuity and to the subsequent precipitation after the growth of the cumulonimbus cloud formed respectively, absence of these sudden enhancements would indicate that the cumulus head has probably not developed sufficiently to reach the surface of discontinuity. A typical record showing the absence of sudden enhancements after the initial gradual rise is reproduced in Fig. 1(d). No Nor'wester was reported on that date.

The delay between the onset of Nor'westers in Calcutta and the start of the second sudden enhancement, which presumably indicates the rain-stage of the thunderclouds, is understandable as it would depend upon the rate of travel of the active thunderstorm centre from the place of origin to Calcutta. The rate of travel is of the order of 30 and 40 mph from Asansol and Hazaribag respectively towards Calcutta and a thunderstorm sequence starting from Hazaribag would travel to Calcutta within a period of about

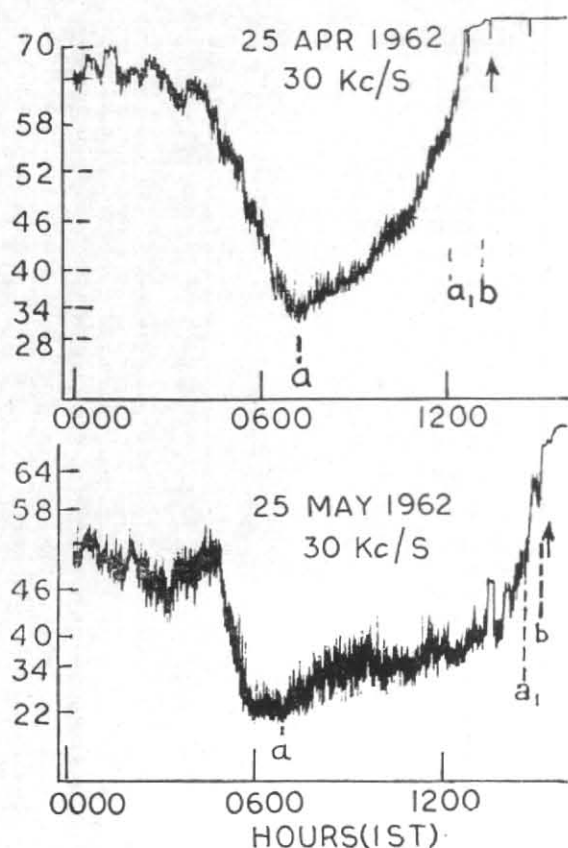


Fig. 5. Second sudden enhancement of IFIA associated with a thundersquall occurring in (a) Hazaribag and (b) in Asansol occurring 0630 and 0312 hours in advance respectively of the onset of a severe Nor'wester in Calcutta

a, a<sub>1</sub> and b indicate the same as in Fig. 1(b). The arrow marks indicate the times of onset of precipitation associated with thundersqualls occurring in Hazaribag and Asansol at 1315 and 1520 IST respectively. The ordinate show the r.m.s. field strength for a 1 kc/s bandwidth in decibels above 1 $\mu$ V/m

7 hours while that starting from Asansol would arrive at Calcutta within about 3 hours (Rao and Boothalingam 1957). It is interesting to note here that the delay between the second sudden enhancement of IFIA, and the onset of Nor'westers around Calcutta—as has been mentioned earlier—has a tendency to cluster around 6–7 and 2–3 hours which are comparable to the travel times, 7 and 3 hours, of parent thunderstorms originating in Hazaribag and Asansol respectively. This fact appears to indicate that most of the enhancements were produced by thunderstorms originating in Hazaribag or Asansol. In fact, an analysis made with thundersquall data from Hazaribag and Asansol appears to substantiate our suspicion in a great majority of the cases considered. The results show that a second sudden enhancement occurring about 5–8 hours in advance of the onset of Nor'westers in Calcutta was followed within 3–18 min by

the onset of precipitation associated with a thundersquall occurring in Hazaribag while those occurring 1–4 hours in advance of a Nor'wester onset in Calcutta were followed within 3–34 min by precipitation associated with thundersqualls occurring in Asansol. Two typical records exhibiting the association of second sudden enhancements with thundersqualls occurring in Hazaribag and Asansol are reproduced in Figs. 5(a) and 5(b) respectively. A histogram of the time delay of the onset of precipitation from parent thunderclouds occurring in Hazaribag and Asansol after the second sudden enhancement of IFIA is shown in Fig. 4, which shows that the delay varies between 3–34 min, with a maximum number occurring in the range 0–5 min. This delay is indicative of a finite time of fall of precipitation from the cloud height to ground.

##### 5. Enhancements associated with monsoon thunderstorms

(i) *Typical records*—In Fig. 6 typical records are shown. The upper one (a) shows the IFIA recorded on a normal pre-monsoon day while the middle two (b) and (c) show IFIA when severe thundersqualls were experienced in and around Calcutta on two different dates. The record on the normal day shows the usual diurnal variations in the IFIA (WMO 1957), while that on the disturbed day shows unusually large enhancement of IFIA starting at 1320 IST—Fig. 6(b). Similarly on another occasion shown in Fig. 6(c), the gradual increase of IFIA is quite marked. However, the predominant feature of these records appears to be a sudden decrease of IFIA starting about the time of onset of heavy raining associated with the thundersquall as obtained from meteorological data. Figure in the left (Fig. 6 b) shows that IFIA starts decreasing at 1800 IST, while local raining started at 1720 IST and for the other one (Fig. 6 c) these occurred at 1505 and 1520 IST respectively. Out of a total of eleven cases considered, ten cases showed a sudden decrease, while in the remaining one case no such decrease was evident. Of the ten cases showing a sudden decrease, however, one case exhibited a double sudden decrease, thus making a total of eleven cases of sudden decrease of IFIA, all of which were associated with the onset of raining.

(ii) *Detailed features*—On close examination of the records on the disturbed days, it was revealed that an enhancement occurs in distinct stages. For instance, the record on the middle left (Fig. 6 b) shows that the initial gradual rise of level is followed by two distinct stages of sudden enhancements of which the first one starts at 1325 IST, while the second at 1455 IST. The record on another disturbed day (Fig. 6 c), however, shows a single sudden enhancement starting at 1310 IST after the



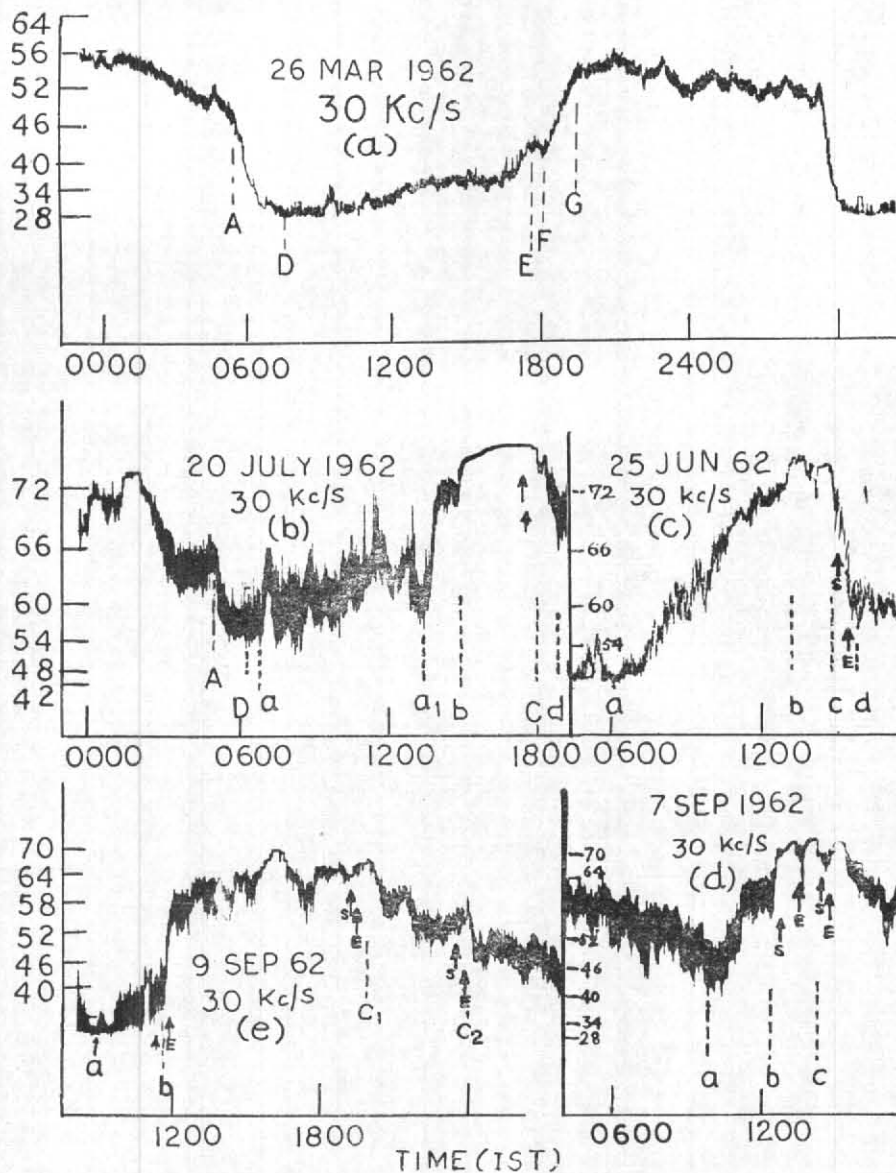


Fig. 6. Enhancement of IFIA associated with thundersqualls occurring in Calcutta in the monsoon season

- (a) The usual diurnal variations [A, D, E, F and G indicate the same as in Fig. 1(a)]
- (b) IFIA on a day when a severe thundersquall was experienced in Calcutta [a, a<sub>1</sub>, b, c and d indicate the same as in Fig.1(b)]
- (c) IFIA on another disturbed day when a severe thundersquall was experienced in Calcutta
- (d) IFIA on a disturbed day exhibiting the association of a sudden increase occurring at the initial stage of thundercloud development and that of a sudden decrease occurring in the final stage, with precipitation
- (e) IFIA on another disturbed day exhibiting the association of a sudden enhancement and that of a multiple sudden decrease occurring at the initial and final stages respectively of the thunderclouds development, with precipitation

c<sub>1</sub> and c<sub>2</sub> indicate the times of start of sudden decreases during the multiple sudden decrease of IFIA. The arrow marks indicate the times of start (S) and end (E) of precipitation. The ordinates show the r.m.s. field strength for a 1 kc/s bandwidth in db above 1.2V/m

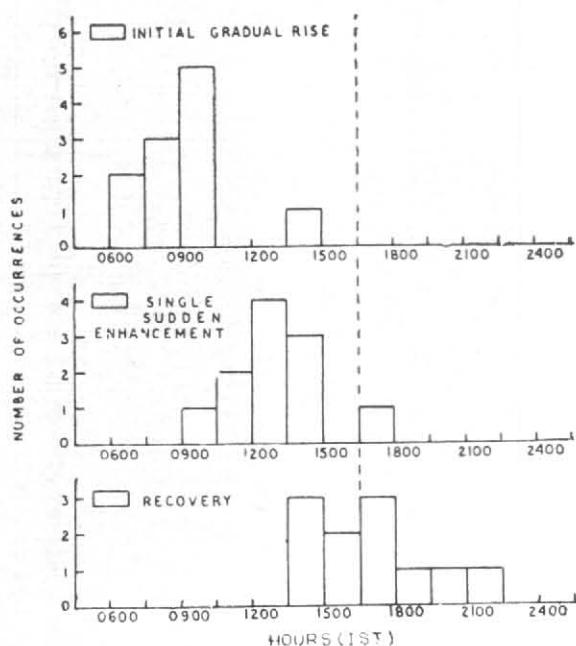


Fig. 7. Histograms of the diurnal variation of the occurrence of the various stages of an enhancement of IFIA associated with a monsoon thundersquall

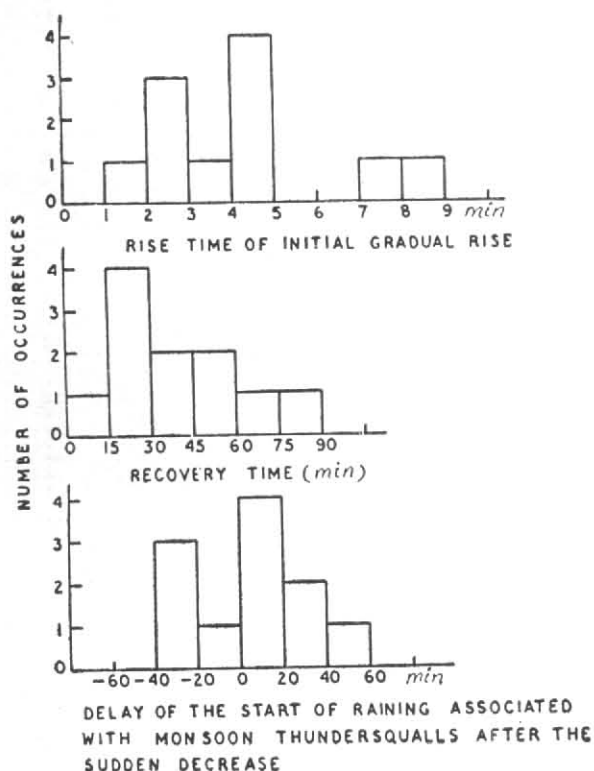


Fig. 8. Histograms of the rise and recovery times of an enhancement of IFIA and that of the delay between a sudden decrease and the onset of the associated precipitation in Calcutta

initial gradual rise. Out of a total of eleven cases considered, ten cases showed a single sudden enhancement while the remaining only one, shown in Fig. 6 (b), exhibited a double enhancement after the initial gradual rise.

(iii) *Occurrence*—The diurnal variation of the occurrence of the various stages of an enhancement is shown in Fig. 7, which shows that the initial gradual rise, the single sudden enhancement and the sudden decrease of IFIA occur at 0600–1500, 0900–1800, and 1330–2230 IST respectively, the respective maxima occurring in the ranges 0900–1030, 1200–1330, and 1330–1800 IST.

(iv) *Statistical characteristics of the enhancements*—Histograms of the rise and recovery times of the various stages of the enhancements are shown in Fig. 8, which shows that the rise time of the initial gradual rise varies between 1–9 hours with a maximum number occurring in the range 4–5 hours, while the recovery of IFIA to the normal night level occurs within  $1\frac{1}{2}$  hours of the start of the sudden decrease, the maximum number of recovery times occurring in the range  $\frac{1}{4}$ – $\frac{1}{2}$  hour.

(v) *Delay between an enhancement and the associated thundersquall*—The initial gradual rise and the single sudden enhancement start about 4–11 and 2–6 hours in advance respectively before the onset of the associated thundersquall in Calcutta.

(vi) *Delay between a sudden decrease of IFIA and the raining associated with the thundersquall*—A histogram of the delay between precipitation and sudden decrease of IFIA is shown in Fig. 8, which shows that the heavy raining associated with a monsoon thundersquall occurred within  $\pm 40$  minutes of the start of a sudden decrease, with a maximum number occurring within 20 minutes after the start of the decrease.

(vii) *Discussion*—The thunderstorms occurring in the monsoon season are, in general, associated with the passage of upper (400–200 mb level) easterly trough line passing over the station with an appreciable number occurring ahead of the trough line (Srinivasan 1960). The thunderstorms, in fact, generally coincide with the transit of the coldest portion of the trough line. The wavelength of the easterly waves is of the order of 20 degrees of longitude (2000 km) at 300-mb level and their speed of travel is about 10–15 knots. The thundersquall, in fact, originates from the eastern sea level depressions in the Bay of Bengal. With the westnorthwestward movement of these depressions, the thunderclouds gradually develop under the combined influence of the southwest monsoon current at 1.5-km (a.s.l.) level and the upper easterly trough line at about 10 km until it culminates in a thundersquall, most of which



occurs in and around Calcutta because of its location near the thermal equator for the season. The initial gradual rise of IFIA may have relation to the gradual development of the thundercloud and also partly to its gradual approach to the station with a speed controlled by that of the easterly wave trough line. If it be so, knowing the speed of travel of the easterly waves the location of the origin of the thundercloud can be calculated and is found to be on the longitude 40–165 km east of Calcutta for the delay of 4–11 hours between the initial gradual rise of IFIA and the onset of the thundersquall, as quoted earlier.

The single sudden enhancement observed in the great majority of cases might be associated with the onset of precipitation in the thundercloud, in a manner similar to that occurring in case of second sudden enhancement during a pre-monsoon thunderstorm or Nor'wester (Sen 1965a). In fact, on a few occasions precipitation about the time of start of the single sudden enhancement was detectable from ground. Such an example is shown in Fig. 6(d). Within the next few tens of minutes, however, this precipitation stops altogether, as indicated in the figure, until finally a sudden decrease of IFIA occurs accompanied by the onset of a sharp heavy shower. The close association of the sudden decrease with the raining appears to be something peculiar to the monsoon thunderclouds.

The double sudden enhancement observed on one occasion shown in Fig. 6(b) may have relation to a sudden growth of the thundercloud associated with the first of the enhancement and to a subsequent precipitation associated with the second enhancement, in a manner, quite similar to that occurring in case of pre-monsoon thunderclouds producing a Nor'wester (Sen 1965 a). In fact, debriefing reports from aircraft (cruising level 10,000 to 20,000 ft) flying across the trough line indicate a very rough weather with heavy thunderstorms, turbulence, icing and even clear air turbulence (Srinivasan 1960). In the upper levels there is divergence ahead of the trough line and convergence to the rear, while at the lower levels convergence ahead of the trough line and divergence to the rear are prevalent. The low level convergence and high level divergence ahead of the trough line may create a very favourable condition for the formation and often, perhaps, for a sudden growth of the thunderclouds.

It is now generally accepted that in a thundercloud, there are two processes of charge separation, one in the region above the freezing point level and the other below (Chalmers 1956, Sivaramakrishnan 1962). Chalmers (1956) suggested that in a cumulo-

nimbus thundercloud the upper process is more important while in a nimbostratus rain cloud the two processes operate more nearly equally. From the present observations, it appears likely that the process occurring above the freezing point level is predominant at the initial stage of cloud development leading to the observed sudden enhancement of IFIA associated with precipitation (Sen 1965a) while in the final stage, the process occurring below the freezing level is more significant, giving rise to a sudden decrease of IFIA associated with precipitation (Das Gupta and Sen 1965). It may be that the difference in behaviour of the thundercloud between the initial and final stages arises from a change over of the cloud from a cumulonimbus to a nimbostratus type at such times. Indeed, a recent observation of atmospherics from monsoon type of clouds revealed that a sudden decrease of atmospherics is closely associated with precipitation from a nimbostratus rain cloud (Sen 1966). It might be that the Dinger and Gunn (1946) process of melting ice is at work in the final stage. According to them ice particles contain entrapped air. On melting, the entrapped air becomes charged negatively while the water drops receive positive charge. It thus appears that when the drops begin to fall as rain the bipolar structure of the cloud layer vanishes leading to a sudden decrease of lightning activity within the cloud as indicated by the observed sudden decrease of IFIA with raining. Association of the decrease with raining also lends support to the view that the process of charge separation above the freezing point level characterised by its association of a marked sudden increase of IFIA with raining (Sen 1965a), is insignificant in the final stage of cloud development. An interesting record exhibiting the occurrence of a sudden increase associated with precipitation in the initial stage and that of a multiple sudden decrease associated with precipitation in the final stage of a thundercloud development in the monsoon season is shown in Fig. 6(e). A recent evidence obtained from the measurement of time lag between electric field change at ground and the onset of rain in the final stage of thundercloud development also supports the view that rain occurs from a height below the freezing level in cases of thunderstorms occurring in the monsoon season (Sivaramakrishnan 1960), while "bright band" a phenomenon observed during the dissipating stages of a monsoon thunderstorm, indicates the presence of melting ice just below the freezing level at such times (Gupta *et al.* 1955, De 1962).

A comparative study of the enhancements of IFIA observed in the pre-monsoon and monsoon seasons can be made from Table 1 giving their dominant features.

TABLE 1

Comparison between enhancements of IFIA associated with pre-monsoon and monsoon thunderstorms

Dominant features	Pre-monsoon season	Monsoon season
Time advance of the occurrence of the initial gradual rise before the onset of the associated thundersquall in Calcutta	4-13 hr	4-11 hr
Number of sudden enhancements after the initial gradual rise	Two in all the fourteen cases observed	One in ten cases, two in the remaining one case
Time of occurrence of decrease	1930-0150 IST, maximum number in the range 2230-2400 IST	1330-2230 IST, maximum number in the range 1330-1800 IST
Recovery time	0-3½ hrs; maximum number in the range ½-1-hr	0-1½ hrs; maximum number in the range ¼-½ hr
Association with precipitation	Precipitation occurring at the place of origin (Asansol or Hazaribag) of the thundercloud within 0-35 min (with maximum number in the range 0-5 min) after the second sudden enhancement	Precipitation occurring in Calcutta within ± 40 min (with a maximum number, in the range 0-20 min) of the start of sudden decrease

From Table 1 it appears that the most significant distinctive feature is obtained from the nature of association of precipitation with IFIA, which suddenly increases in the pre-monsoon season, while it decreases suddenly in the monsoon season about the time of onset of precipitation from the respective thunderclouds. Another distinctive feature is the predominance of single or double sudden enhancement in the two seasons. Time of occurrence of the decrease of IFIA is also distinctive for the two seasons. The time, for the pre-monsoon season, is around midnight while that for the monsoon season is between midday to sunset, for the great majority of the cases. Time advance of the initial gradual rise is, however, of the same order for the two seasons, while the recovery time is half as large in the monsoon season as it is in the pre-monsoon season.

## 6. Conclusion

Unusually large enhancements of IFIA occurring in day-time are, no doubt, an indication of a developing thundercloud in and around the observing

station, within a distance of a few hundred kilometres, probably beyond the line of sight range of a typical meteorological radar installation. Even in the case of a purely local development of thunderclouds advanced information could be gained from the appearance of the initial gradual rise and the first sudden enhancement before the onset of precipitation and culmination into a thunderstorm. Recent observations of summer thunderstorms, in particular, developing over mountainous region have, in fact, shown that electrification begins early in cloud's development (Moore *et al.* 1958). Measurements within and above the cloud show that electric charge accumulations similar in polarity to those of the mature storm begin to form before any echo can be seen with an X-band radar. It appears that the enhancement of IFIA if supplemented by directional observations might prove to be an effective aid to forecasting violent thunderstorms occurring in the pre-monsoon and monsoon seasons for the security of aerial navigation particularly for the Dum Dum Airport, one of the busiest international airports of the world. The initial gradual rise as also the first sudden enhancement is indicative of the existence of electrical activity within the cloud before the onset of precipitation and even before the cloud has developed upto the freezing level — facts, which are contrary to the popular notions, that charge separation in thunderclouds is intimately connected with precipitation (Chalmers 1957), and that ice plays an important part (Mason 1957). It is not certain whether some of these discrepancies arise from the precipitation occurring in clouds evaporating before reaching the ground. Nor it is clear whether some special type of discharge could occur significantly in clouds before precipitation. A recent measurement of a correlated increase of atmospheric radio noise from individual cells of thunderstorm activity preceding the first lightning stroke by 10-15 min have, however, indicated the significance of minor streamer processes in the cloud presumably due to charge density fluctuations (Zonge and Evans 1966), while observations of lightning within a warm cumulus cloud, in recent years, indicate either that ice is not required for cloud electrification or that there are two or more processes that may operate at different stages in the development of the cloud (Moore *et al.* 1960, Pietrowski 1960, Michnowski 1963, Rossby 1966). Evidences appear to indicate that the electrical generating mechanism depends critically on the cloud size and its convective movements. In tropics and subtropics, where the cloud base is low and the freezing level is high, convective clouds may attain the critical size necessary to produce lightning flash even before they have grown to the freezing level (Moore *et al.* 1960). As regards the charge separation

apparently associated with precipitation, the present studies with atmospherics suggest a predominance of processes occurring above and below the freezing point level at the initial and final stages respectively of a thundercloud development. In the upper process, the degree of electrical activity after precipitation appears to be significantly larger compared to that occurring before any precipitation, with its associated increase of convective activity, is evident, while in the lower one, the electrical activity appears to decrease suddenly with the onset of precipitation.

It may be mentioned here that the Central Radio Propagation Laboratory (NBS 1948), the International Consultative Committee on Radio Communication (ITU 1957) as also Aiya (1954, 1955) divided a day into six 4-hour time blocks for the purpose of giving radio noise data on a worldwide basis. It, however, appears from the above studies that a division into smaller time blocks such as a 1-hour block would become necessary at least for certain parts of the day, for which the diurnal variation is most pronounced and abrupt, produced by nearby sources of thunderstorm activity. Such abnormal increases of atmospheric radio noise cannot be ignored as the number of thunderstorm days, particularly in the tropical belt, is significant. Increase of dynamic range of the receiver used for the observations in order to accommodate the unusually large increase of atmospherics (often exceeding 70 db above  $1 \mu \text{V/m}$  for a 1 kc/s band width) associated with local thunderstorms

might reveal important features of the thundercloud development subsequent to the sudden enhancements. The large increase of atmospherics also indicates that cloud discharges are important as generators of atmospheric radio noise, particularly in the tropics, where less than 10 per cent of the discharges go to ground (Pierce 1956). Evidences obtained from a study of wave forms in a tropical station, also indicate a major role of cloud discharges as a source of atmospherics (Khastgir *et al.* 1957). Simultaneous observations of atmospherics and of radar echoes from the thunderclouds might bring out more clearly the relationship between IFIA and different stages of development of the thunderclouds and provide us with a better understanding of the process of charge separation in thunderclouds.

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