

Some characteristics of tropical lightning*

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Abstract

Some characteristics of lightning over tropical landmasses which could be deduced from studies of lightning flashes through aural and visual observations, with the use of HF lightning flash counters, and, by recording noise bursts arising from flashes on magnetic tapes, level recorders and the cathode ray oscilloscope are described and discussed. The median distance up to which thunder can be heard, the duration of thunder during the activity of a thundercloud, the number of thunders heard per hour, the duration of a lightning flash, the rate of flashing in thunderclouds, the number of cells developed during the activity of a thundercloud, the percentage of ground flashes, etc., are dealt with in numerical terms. The structure of a noise burst arising from a lightning flash and its variation with growth and decay of the activity of a thundercloud, the number of pulses in the structure of a noise burst, etc., are examined critically. Most of the physical parameters associated with lightning and lightning flashes have a log-normal distribution. Differences in the characteristics of lightning as between temperate and tropical regions are brought out.

Key words : Thunder, lightning.

1. Introduction

Storms, lightning and thunder have interested mankind from times immemorial. There are references to these phenomena in ancient literature. In the *Rig Veda* of India, believed to have been written thousands of years back, there is the following hymn :

“There clings to the Maruts (Storm-Gods), one who moves in secret like a man’s wife (Lightning), and who is like a spear carried behind, well grasped, resplendent, gold-adorned; there is also with them Vak (Voice of thunder), like unto a courtly, eloquent woman.”

Such descriptions are based on careful, systematic and extensive aural and visual observations. The latter as techniques are quite relevant and important even today.

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Modern science traces studies of lightning from the eighteenth century. D'Alibard (France) and Benjamin Franklin (USA) showed that lightning is electrical in nature. Popov (USSR) first received the electromagnetic radiations from lightning flashes at a distance. Wilson, Appleton, Schonland, and their collaborators, and several others have studied the lightning discharge and some of its features¹⁻¹⁰. Meteorologists have been collecting and maintaining a record of days on which thunder is heard at a weather office, viz., thunderstorm days¹¹⁻¹⁴. The record of thunderstorm days is a valuable world wide data and relating some of the other results to such data serves a very useful purpose. Using satellite-borne receivers operating in the HF band, global distribution of the rate of lightning flashes per 10° latitude and longitude has been mapped every six hours of local time for all the four seasons¹⁵. Power transmission engineers have studied the effect of lightning on power transmission lines and the data can be utilised to test theoretical generalisations¹⁶.

An atmospheric is what arises from the complete electromagnetic radiation of a lightning flash. When it is picked up by a receiver tuned to a certain frequency and having a defined bandwidth, the resultant output at the detector of a receiver is a band limited atmospheric or atmospheric radio noise burst, or, as conveniently described, a noise burst. In studies of atmospheric radio noise at Poona (18·31 N, 77·35 E), and at Bangalore (12·58 N, 77·35 E), short and long term amplitude and time characteristics and structure of such noise bursts were investigated at several frequencies during all hours of day in all seasons for several years¹⁷⁻¹⁹. Such studies yielded information on lightning flashes also. Hence, more direct experimental investigations were carried out²⁰⁻²³. Results obtained prompted further studies²⁴⁻²⁶. Some of the conclusions drawn have been reported²⁷⁻²⁸.

This paper furnishes an integrated and generalised account of some of the characteristics of lightning flashes as observed in the tropics. This leads to a description of tropical lightning and the way in which it differs from the similar phenomenon at higher latitudes. Some of the results incorporated in the paper have not been published. These are described in greater detail. The subject-matter of the paper is treated in the following order. After a reference to conditions conducive to lightning, the characteristics of lightning as known are furnished. There follows descriptions of aural and visual observations, counting and recording of flashes, thundercloud and isolated cloud in a clear sky and activity in them, etc. Duration and structure of a flash as revealed from its corresponding noise burst are described. Thereafter, the distributions that the random processes appear to follow are indicated. The results are discussed and a concluding section reviews the entire work.

2. Weather conditions

Heat storms, frontal storms, hurricanes, typhoons, tornados, cyclones, etc., are the usually used terms to describe disturbed weather. This terminology is avoided in this paper for reasons which become clear from the rest of the paper. What follows is a

generalised description of what was observed at Poona and Bangalore over a period of several decades.

On a cloudy day, a storm may develop. The area under disturbed conditions when idealised to a circle has a radius between 100 and 400 km. The more common value appears to be 300 km. When this large area is considered as a whole, activity commences after local noon and continues till about the hour of the following sunrise. Anywhere in such a disturbed area, a thundercloud may develop and become active. The area involved in the activity of a thundercloud appears to have a mean radius of about 20 km, when the area is idealised to a circle. In round figures, one could with justification assume the area involved in the activity of a thundercloud as 1000 sq.km. As will be seen later, the mean duration of the activity of a thundercloud or its mean lifetime is about 3 hr. In the disturbed area, a thundercloud may become active at any time between local noon and the following sunrise. Consequently it is to be expected that different thunderclouds become active in different places at different times with the additional possibility that more than one thundercloud can be active at any one time. Further, it appears that over a specific area over which one thundercloud had once become active, another thundercloud does not become active on the same day. Storms of the type described occur in bunches, the most probable number of days of such bunching being 4.

Between two successive groups of such storm days, there are quiet days. Some quiet days have clear skies. Some of these quiet clear days may be warmer than the other days, in particular having temperatures during day of the order of 35° C. There can be isolated clouds on such days. Flashing in such clouds has been observed, particularly during years of weak thunderstorm activity. Generally, in such cases, flashing commences after 14 hr LMT and is over before 22 hr LMT. This type of flashing is never accompanied by thunder.

Prior to the onset of the monsoon (seasonal storm activity), disturbed conditions develop over an area of the order of that of a single thundercloud during some afternoons or evenings. A regular thundercloud activity is witnessed for about 3 hr.

3. Lightning

As visually observed, lightning consists of a series of intermittent visible radiations described as flashes. The electrical discharges responsible for such a lightning flash radiate over almost the entire electromagnetic spectrum and the visible radiation seen is only a part of such radiation. Often, portions of the flash are hidden inside the cloud and cannot be seen. Sometimes, even portions of a flash below the cloud base are not visible during day. In such cases, and, generally in the case of all flashes, it is always possible to record an entire flash by utilising the electromagnetic radiation of the flash in a suitable radio frequency band. This is the procedure adopted for several of the studies whose results are reported in this paper and it has been continuously supplemented by aural and visual observations.

Lightning flashes are classified as follows :

- (a) Intra-cloud flashes
- (b) Air flashes
- (c) Ground flashes
- (d) Inter-cloud flashes
- (e) Clear warm day isolated cloud flashes
- (f) Ball lightning

During the activity of a properly developed thundercloud, (a), (b) and (c) are the types of flashes which are observed or recorded. The contribution of (d) and (e) which are comparatively rare to the total number of flashes recorded during a season at tropical latitudes does not exceed a few per cent. During the long and extensive studies reported in this paper, ball lightning has not been observed either at Pona or at Bangalore.

Intra-cloud or cloud flashes appear as intermittent illumination inside the cloud whenever visible. All available evidence supports the view that the electrical discharges responsible for cloud flashes are practically vertical. They constitute the largest percentage of flashes observed in the tropics.

Air flashes, when visible, can be seen to extend to the ionised or neutral air mass well below the cloud base. Part of the electrical discharges responsible for an air flash is hidden inside the cloud and this portion is similar to that of a cloud flash. Air flashes are not as frequent as cloud flashes and it is difficult to distinguish them. Perhaps, through CRO photographs of the noise bursts arising from them, it may be possible to distinguish them. There is no conclusive evidence but it is not improbable that they do occur during the early stages in the activity of a thundercloud. They merit special studies through separately designed experiments.

Ground flashes are almost invariably visible. Part of the electrical discharge in a ground flash occurs inside the cloud and this again appears to be similar to that of a cloud flash. Thunder has been heard *almost invariably* after seeing a ground flash. The more intense the flash, the more violent the thunder. This simple observation has proved quite invaluable for counting the number of ground strokes per hour, etc., as it has so far become impossible to design suitably an instrument which can record exclusively ground strokes.

There have been a few occasions when low intensity rumbling sounds were heard after an intra-cloud or air flash. But there is no recorded observation of thunder being heard after an intra-cloud or air flash.

There is flashing in isolated clouds on a clear warm quiet day as already described. These flashes exhibit a similarity to intra-cloud flashes when observed but instrumental recording indicates that the power radiated is much smaller.

Between 0800 and 1200 hr LMT, there is no record of lightning flashes of any type being logged. This indicates that there is probably no lightning activity over land masses in the tropics during these hours.

The observations so far described show clearly that most of the lightning flashes in the tropics arise from the activity of properly developed thunderclouds. All these flashes give rise to noise bursts as described earlier. In the studies currently reported, all flashes are studied together. Thereafter, the ground flashes are separately estimated. Air flashes are allowed to get lumped with cloud flashes as their numbers are small.

Inter-cloud flashes show up as long horizontal or practically horizontal intermittent illumination between clouds. Cases of thunder accompanying such flashes have not been recorded. The conditions under which they occur have not been identified. Since they do not occur frequently, they have been ignored in large scale estimations.

4. Aural and visual observation

Records were maintained of lightning seen and thunder heard at the Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore, during 1960–1972. They included time of commencement and end of thunder and lightning, time interval between the seeing of a lightning flash and the subsequent hearing of thunder, number of flashes seen and number of thunders heard and, occasionally, correlation between thunder heard and the type of flash seen. Thereafter, some systematic data were collected to evaluate distributions²⁴. These will be described in what follows.

4.1. Range of audibility of thunder

The place of observation, although located in a large city, is a comparatively quiet place at an altitude of about 0.9 km. Hence, the mean distance up to which thunder can be heard was computed by analysing the results of measurements of the time interval between lightning seen and thunder heard. The results are shown in fig. 1. The mean distance is 9 km. This is almost the same as reported earlier¹¹. What is important is the fact that the distribution is log-normal.

4.2. Duration of thundering activity

The time interval between the hearing of the first thunder and the last thunder has been recorded. The results are shown in fig. 2. The time duration recorded corresponds to the duration of the activity of a thundercloud when ground strokes are occurring. The mean value is 170 minutes. This is less than the mean value deduced from lightning flash counter studies *viz.*, 186 minutes. This is to be expected as ground strokes have actually been observed to appear sometime after the activity of a thundercloud has started and cease a little before the end of the activity. The distribution is log-normal and this is an interesting result.

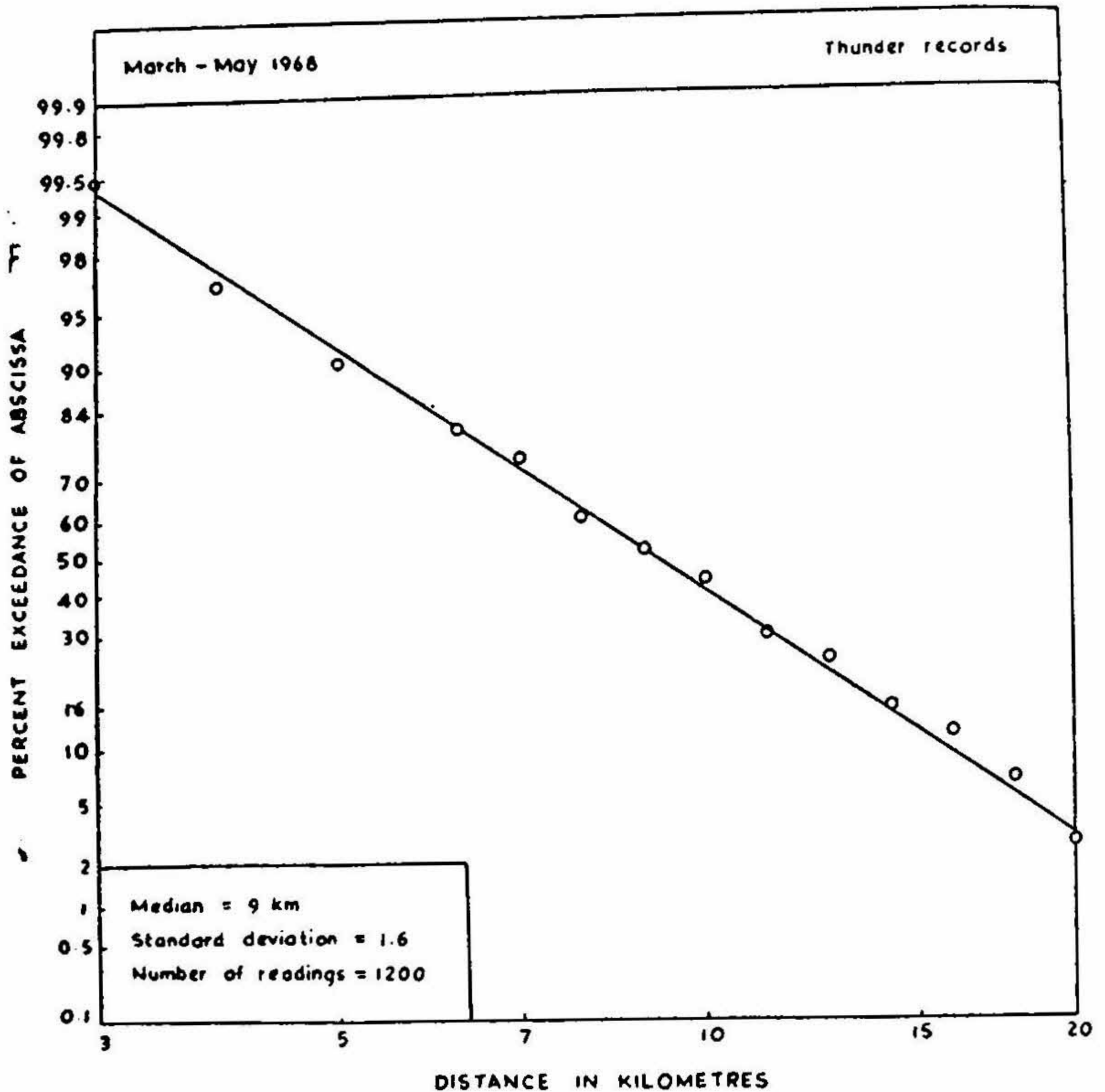


FIG. 1. Distribution of sources of thunder.

4.3. Number of thunders per hour

The number of thunders heard per hour during the activity of a thunder cloud have been recorded. The results are shown in fig. 3. The distribution is log-normal. The median value is 18.5 per hour. This corresponds, as explained earlier, to the number of ground strokes per hour. This method of recording ground strokes is, perhaps, the cheapest and most reliable. Since the activity of a thundercloud is spread over about 1000 sq.m., one could say that there are about 18 ground strokes per hour per 1000 sq. km. Ground strokes are more during the peak activity of a thundercloud. This and other details will be discussed in a later section.

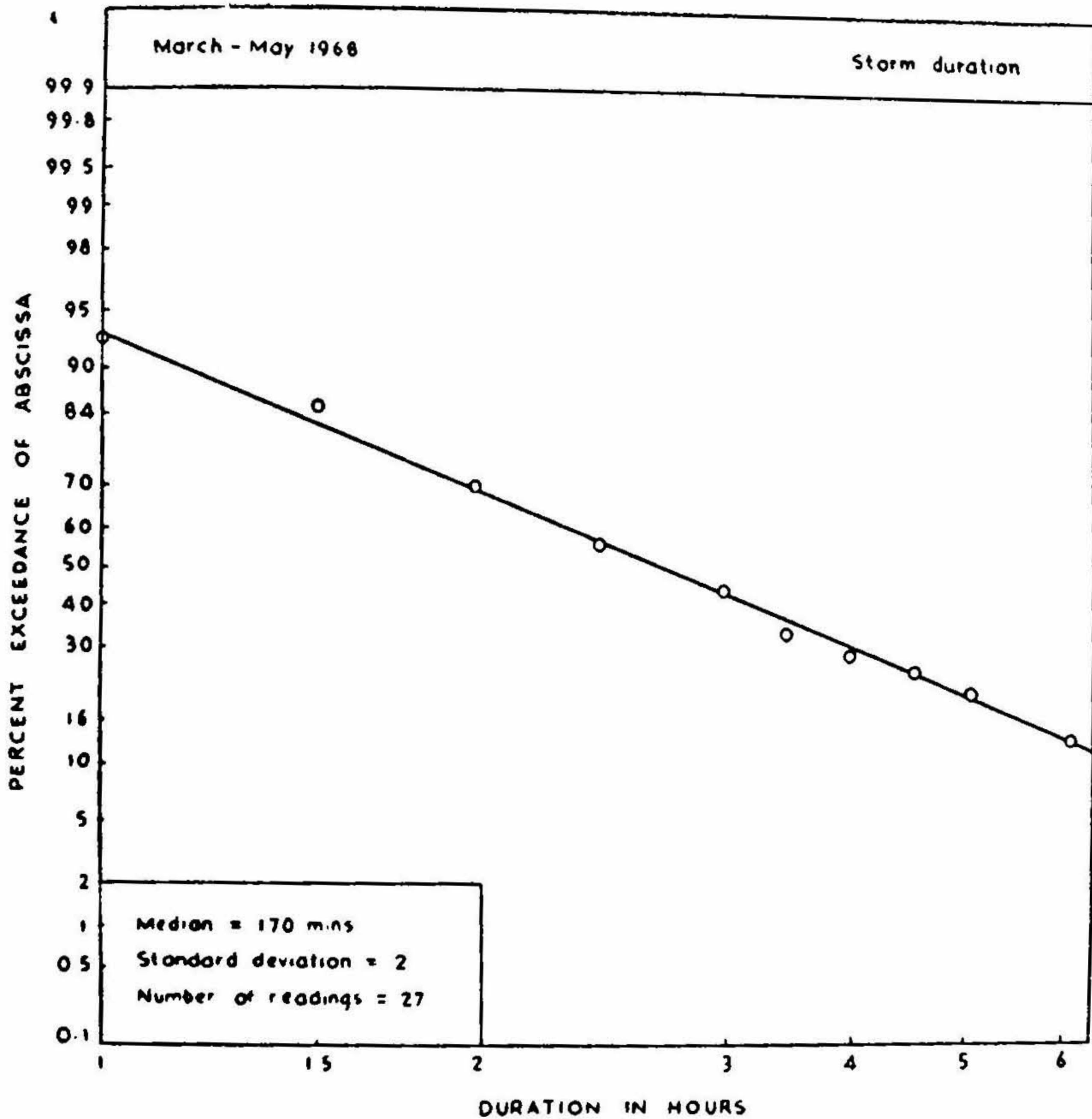


FIG. 2. Distribution of thundercloud activity duration.

5. Counting of flashes

Several lightning flashes are hidden inside the cloud. Most of them cannot be seen even during night. Quite a number of flashes which would be visible during night cannot be seen during day. Under the circumstances, resort to instruments to count flashes is a must. There is need, firstly, for an instrument which can record all types of flashes. Such an instrument must have a defined range stipulated in terms of median value of the field strength of the radiation from the flash. It must have a proper resolving power. Thus, it should not record a long duration flash as two and it should also be able to distinguish two flashes of short duration and small time interval between

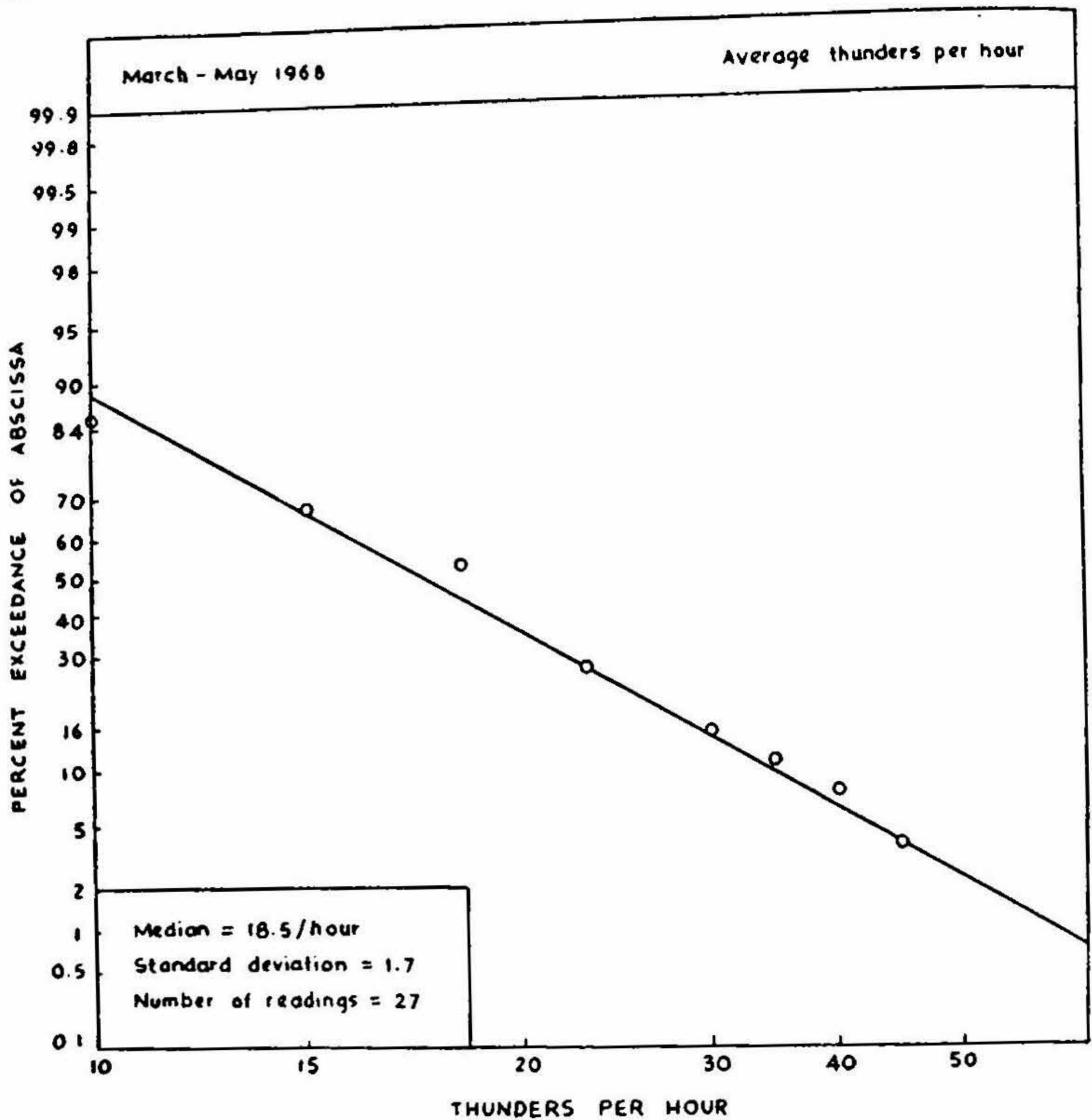


FIG. 3. Distribution of average number of thunders per hour.

them. There was adequate data on these points from noise burst measurements. These were supplemented by separate field experiments. Sonde²⁹ has given thought to these considerations and designed HF and MF lightning flash counters. They were also extensively tested and found to be satisfactory. Basically, they count noise bursts and, as explained earlier, each noise burst corresponds to a single lightning flash. The following are the specifications of the lightning flash counter most extensively used in counting lightning flashes :

Frequency : 3 MHz
Bandwidth : 10 kHz/6 dB

Resolving power :	1.5 sec.
Sensitivity :	200 $\mu\text{V}/\text{m}$
Range :	20 km.

Lightning flash counters with sensitivities of 100 and 400 $\mu\text{V}/\text{m}$ have also been operated at the same frequency and bandwidth. Similarly, there were lightning flash counters operating at 1.6 MHz with the same bandwidth but with sensitivities of 200 and 400 $\mu\text{V}/\text{m}$. The basic idea behind having such a large number of counters was to operate several of them simultaneously for checks and cross-checks.

The high frequency radiation arises almost entirely from the electrical discharges inside the cloud. In the tropics, the cloud base is over 3 km above mean sea level. Hence, the radiation is received as a space wave and inverse distance variation of field strength can be assumed and has been found to be correct. Further, the field strength varies inversely as frequency. There can be interference from stations. In order to avoid this, the operating frequency of a lightning flash counter may have to be changed slightly. For such a purpose, the facts stated are useful.

The results obtained using the lightning flash counters are described and discussed in later sections.

6. Recording of flashes

Two important parameters of a lightning flash are its duration and its structure. For data on both, flashes have to be recorded. Since a flash duration has been found to be the same as that of its corresponding noise burst³⁰, this parameter can be recorded by recording noise bursts. Three methods have been adopted for this purpose. They are : (a) recording the noise burst on a magnetic tape, (b) recording the same on a level recorder, and (c) recording it on a cathode ray oscilloscope and photographing the wave form. The latter method is the only one which is convenient for the study of the structure of a noise burst. The tape recorder is the most convenient for duration measurements and cheapest of the three. After recording the flashes on the tape, it is played back and the time interval between the commencement of the audibility of a flash and its subsequent just ceasing to be audible as a noise burst is measured.

The procedure adopted with the cathode ray oscilloscope is as follows. The main sweep circuits are adjusted to perform a single sweep and be unresponsive to any further triggers. The first pulse in a noise burst that exceeds a pre-set amplitude triggers the main sweep and the wave form of the noise burst gets displayed on the screen. Ordinarily, the sweep is set to correspond to 1000 msec, but other values have also been adopted to suit specific requirements. The displayed wave form is recorded on a photographic film using a camera. After recording one flash, the film is moved manually to make it ready to record another flash and the sweep is reset for a fresh trigger to

actuate the sweep again. As the CRO operates on the single sweep mode, there is no possibility of the same length of the film getting exposed to two successive flashes.

7. Thundercloud activity

The activity of several thunderclouds have been individually investigated using lightning flash counters described earlier. Some of the results have also been reported²⁰⁻²². After the flash counter begins to record counts, the thundercloud is assumed to have started activity when the rate of flashing exceeds one in five minutes. It is regarded as having ceased to be active when the rate of flashing falls back to the same value. The flash counter is read every five minutes because it had been found that there is no significant change during a five-minute interval. The rate of flashing is plotted against time to display the activity of a thundercloud. Figures 4 and 5 give typical curves as recorded. The two separate thunderclouds on April 9, 1962, could be distinguished by the fact that lightning was seen and thunder heard from a different direction for the second case. In fig. 4, it is seen that the rate of flashing increases to a peak value, falls and then increases again. In the first part of fig. 5 (A), the rate of flashing increases and then falls rapidly towards the end of the activity, viz., abc. In the second part of fig. 5, it is seen that the flashing activity as a whole is low. The three typical varieties commonly observed have been displayed in the figures for illustration.

The flashing rate-time curves can be smoothed by the method of moving averages. After this is done, the time interval between crests and the time interval between troughs can be measured. Such a time interval gives the lifetime of a thundercloud cell. This is found to be about 30 min. This is the same value as that observed at higher latitudes. But, at higher latitudes, the number of cells involved is hardly one or two and the lifetime of a thundercloud is about an hour. At tropical latitudes, the number of cells involved has 5 as median value and the mean duration of the lifetime of a thundercloud is about 3 hr. Similarly there are differences in the rates of flashing. In the tropics,

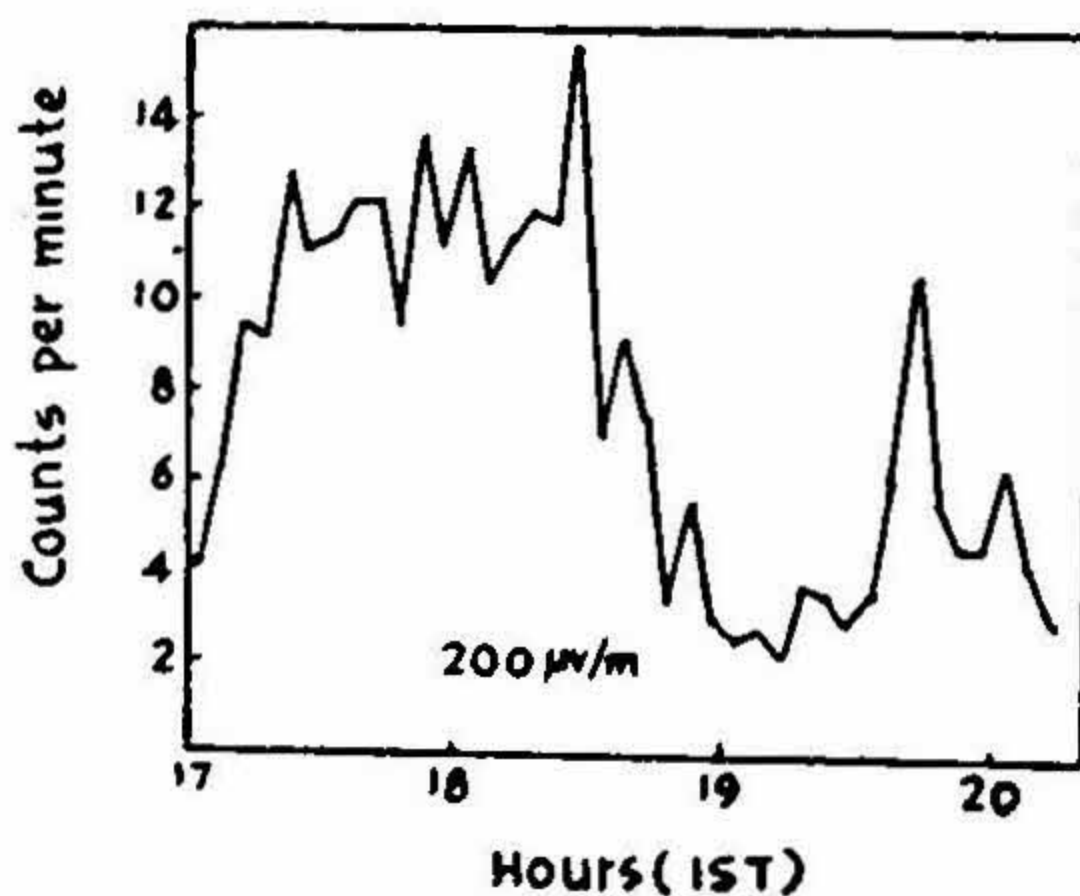


FIG. 4. Variation of flashing rate with time for a thundercloud on April 14, 1962.

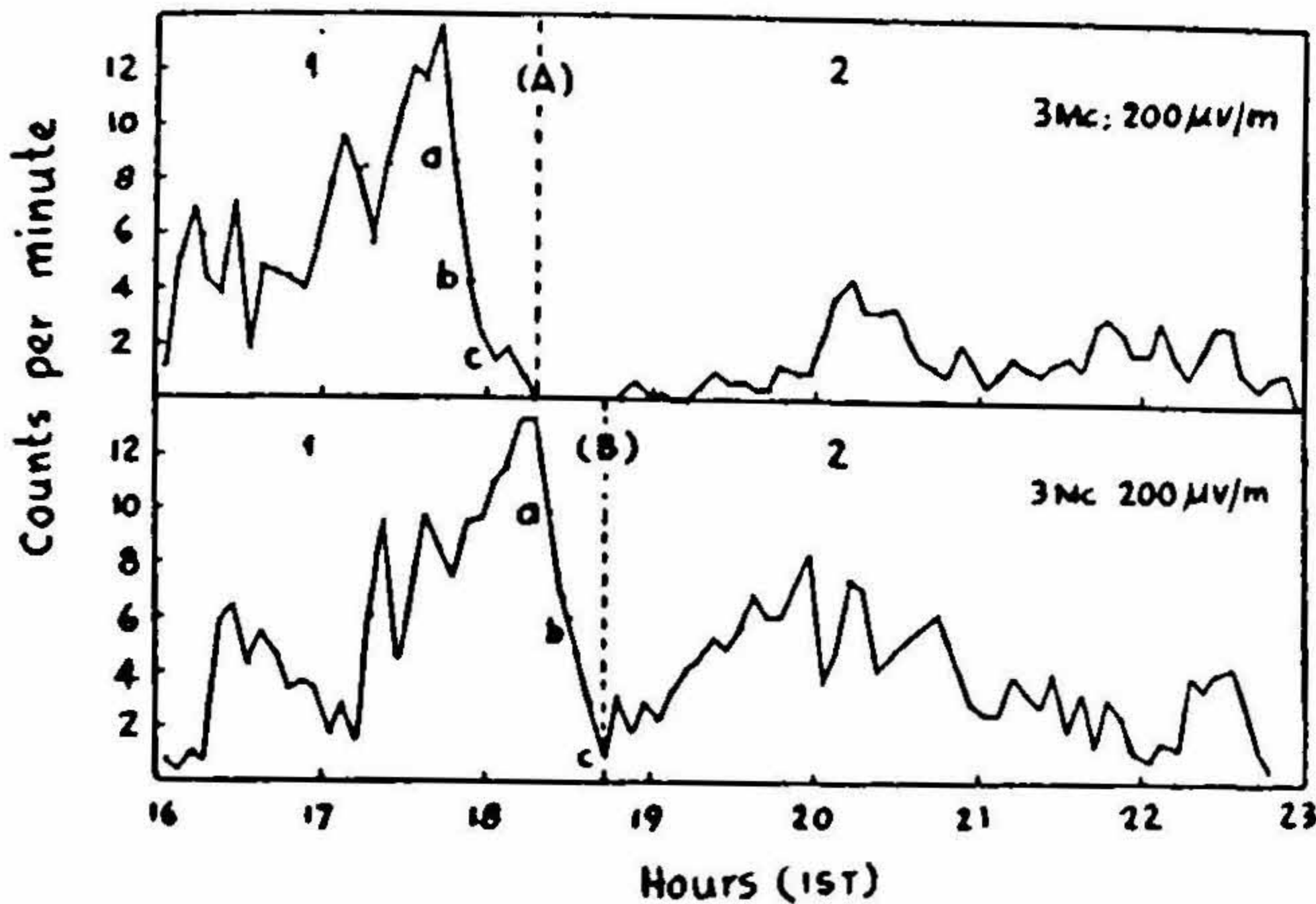


FIG. 5. Flashing rate characteristics of two thunderclouds on one calendar day : (A) Distinguishable—May 4, 1962. (B) Indistinguishable—April 9, 1962.

the average and peak rates of flashing are 3 and 8 per min respectively. The results of the analysis of the data of several thunderclouds are given in Table I.

The typical flashing characteristics of thunderclouds are given in Table II. In view of the possibility of more than one thundercloud becoming active during a calendar day and covering in each case, a part of an area of 1000 sq. km around a point of observation, the number of flashes recorded per calendar day of thunder heard is important. This has been separately computed and has a median value of about 1000, a higher decile value of about 3000 and a lower decile value of about 100. Hence, one could assume

Table I
Data of thundercloud parameters

Parameter	Distribution	Mean value	Standard deviation in log units
Lifetime of a thundercloud	log-normal	186 min	0.25
Lifetime of an active cell	log-normal	35	0.22
Number of cells developed during the lifetime of a thundercloud	log-normal	5	0.23
Peak rate of flashing	log-normal	8	0.30

Table II**Flashing characteristics of thunderclouds during March-May, 1962**

Parameter	No. of observations	Median value	H. D. value	L.D. value
Duration in minutes of flashing	41	186	400	87
Growth in minutes (commencement to peak activity)	41	107	220	31
Decay in minutes (Peak activity to end)	41	81	200	27
Average rate of flashing	40	3	8	1
Total number of flashes during the lifetime of a single thundercloud	40	700	2000	100

that, on a thunderstorm day, there would be one flash per sq.m. This is an extremely simple but most useful result.

7.1. *Some anomalies*

During March-May, 1962, 47 thunderclouds were logged by the HF counter which had a range of 20 km. By the hearing of thunder, only 38 were logged. Since the median distance up to which thunder can be heard is 9 km, it has to be concluded that 9 thunderclouds were active at distances beyond 9 km. Rainfall was observed in only 26 of these cases. This poses the question that there may possibly be no rain accompanying the activity of a thundercloud in some cases. Whenever rain accompanied thundercloud activity, data shows that the median, higher decile and lower decile values of the duration of rain are 28, 73 and 8 min.

7.2. *Ground flashes*

During 1962, on several groups of days, a British Electrical Research Association (ERA) lightning flash counter meant to record ground flashes only was operated simultaneously with the 3 MHz 200 μ V/m sensitivity HF counter. The ERA counter is claimed to have a nominal range of 40 km against the 20 km range of the 3 MHz counter mentioned. In the hilly terrain around Bangalore, the ERA counter appears to have a much smaller range but this has not been estimated and is really difficult to do so. Further, the ERA counter does register cloud flashes too. The results have been published². The percentage of ground flashes in all the flashes recorded varied from 1.1 to 9.8. All that could be said then was that ground flashes are probably less than 10 per cent of all the flashes,

Later, as mentioned earlier, a definite conclusion could be drawn that ground strokes could be recorded by counting the number of thunders heard and by this method, the median value of the number of thunders heard, *i.e.* ground flashes, were found to be 18.5 per hour. From Table II, it can be seen that the total number of all types of flashes per hour is 180 as the mean rate of flashing is 3. This leads to the conclusion that the percentage of ground flashes can be taken as 10, a conclusion which had previously been drawn from periodic aural and visual observations.

While the percentage of ground flashes in tropical latitudes is thus only 10, in temperate latitudes, it can be as high as 40. This difference may be due, among other factors, to the higher height of the tropopause at tropical latitudes.

7.3. General observations

A very common experience of observation has been that the number of ground flashes increases towards the peak activity of a thundercloud and then falls off. Around the period of peak activity, *i.e.* the time during which the rate of flashing exceeds half the peak rate of flashing, it is estimated that the number of ground flashes could be of the order of even 50 per cent. This peak activity extends generally to about half the lifetime of a thundercloud cell.

The highest rate of flashing in a thundercloud has exceeded 40 per minute.

The peak activity of a thundercloud can occur at any time between 1400 and 0400 hr LMT. Its occurrence outside these hours is very rare. The most probable hour of this peak activity is 1630 LMT during March-May. The hours during which this peak activity can be most frequently observed varies with the seasons and they are given below:

Season	Hours of peak activity (Frequent)
March-May	16-18, 19-21, 22-01
June-August	20-24
September-November	16-18, 02-04

8. Flashing in cloud patches

Flashing in isolated cloud patches on warm quiet days intervening days of actual storm activity has been referred to in Section 3. Figure 6 gives a record of such flashing. It is seen that there are no sharp rises and falls in the rate of flashing as in the case of thunderclouds. The radiated power per flash also appears to be much smaller²². The activity duration varied from 195 to 530 min. The maximum and average rates of flashing ranged from 2 to 8 and 1 to 3 respectively. The total number of flashes recorded per day of such activity varied from 165 to 1623. The activity was mostly observed between 1500 and 2200 hr LMT.

This phenomenon was observed during March-May for 2 days in 1961 and 1962 and for 10 days in 1963. The phenomenon was not studied during other seasons and in subsequent years.

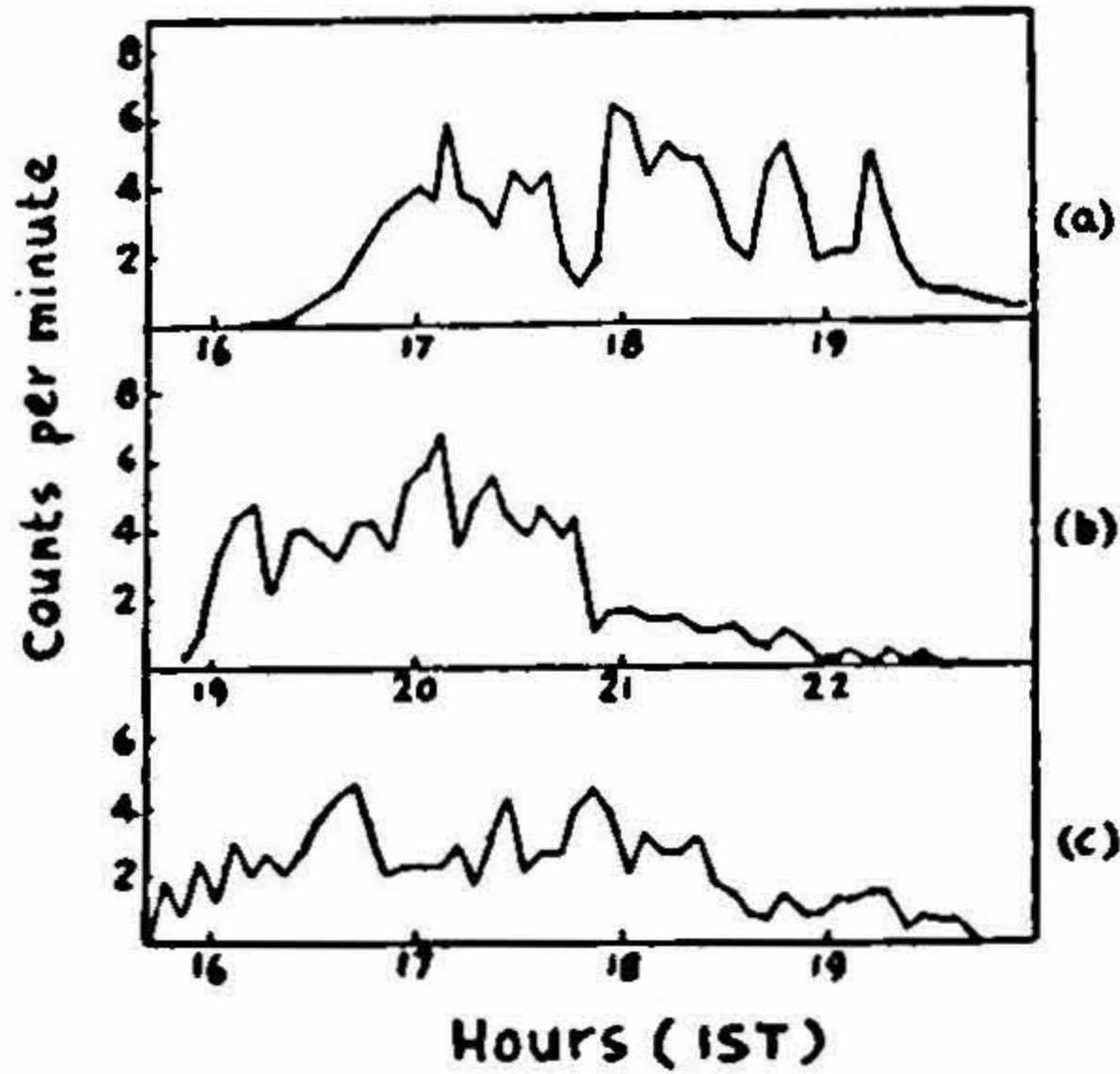


FIG. 6. Flashing characteristics of isolated clouds (March-May, 1963), (a) March 26, (b) April 15 and (c) May 25.

9. Duration of a lightning flash

The duration for a lightning flash has been measured by the use of a Boys' camera, by the recording of atmospherics and by noise burst studies using a magnetic tape recorder, a level recorder and a CRO. Measurements have been carried out in the USA, South Africa, USSR, UK, Japan and India. All the results have been re-examined³⁰. It is found that in all cases in which the raw data is available, the distribution is found to be log-normal. The mean value, however, is not the same in all cases. This value varies from 200 msec as given by Schonland *et al* to 525 msec as given by Japanese workers. Even in studies at Bangalore and Poona, the mean value has varied from occasion to occasion. However, the mean value of the duration of a noise burst as deduced from extensive experiments while measuring noise was found to be 500 msec. In order to obtain a solution to the problem, it was decided to evaluate the mean value of the duration of a flash (*i.e.* noise burst) during different stages of the activity of a thundercloud. From the typical result (fig. 7), it will be seen that the mean value for the duration of a flash decreases with the growth of activity of a thundercloud and then increases as the thundercloud activity decays. The mean value of the duration of a flash is minimum when the thundercloud is at its peak activity.

The above result can explain all the observed differences as arising from the stage or stages of the activity of a thundercloud covered by the investigators during their experi-

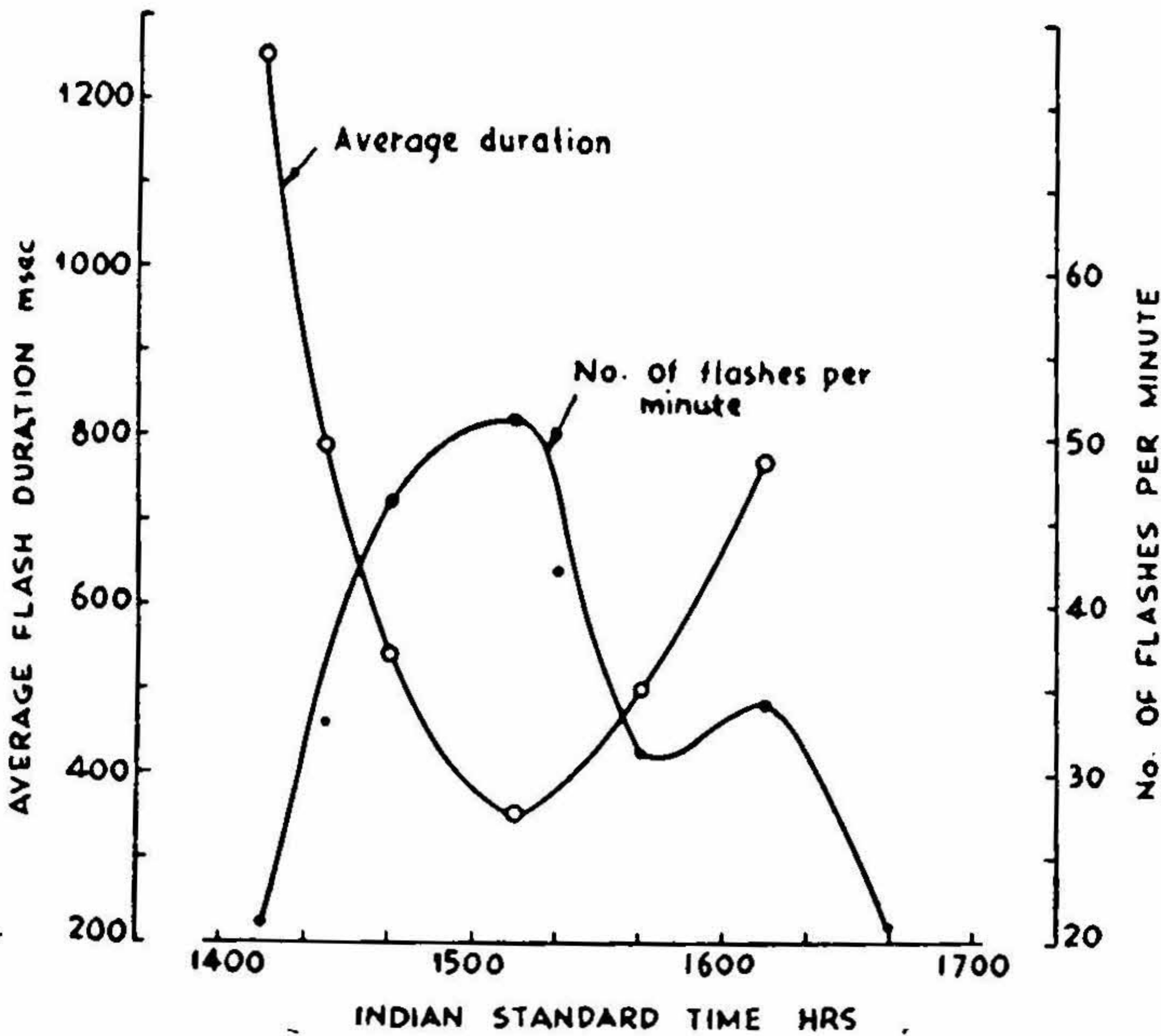


FIG. 7. Variation of the parameters of a lightning flash with the growth and decay of the activity of a thundercloud. Thundercloud activity on May 1, 1969.

ments. Further, this variation of the duration of a lightning flash with the growth and decay of a thundercloud poses important scientific problems in the physics of the lightning discharge.

Whenever the time interval between flashes is measured, the distribution is found to be log-normal. This is another interesting result.

10. Structure of a flash

A lightning flash radiates practically over the entire electromagnetic spectrum. It is not possible to obtain on any single direct record this entire radiation. Hence, photographs are taken of 'band-limited' atmospherics of close lightning. Ramaswamy³¹, Shivaprasad³², Bhat²⁴, and Sastri²⁵ have recorded HF noise bursts on a CRO and photographed the wave forms. The structure of a noise burst was found to depend largely on the frequency at which it was studied, the bandwidth employed, etc. In addition, for the same frequency and bandwidth, the photographs were occasionally showing some differences. Oetzel and Pierce³³ have observed that the number of pulses in a noise burst increases with frequency of observation up to 100 MHz and then falls off rapidly.

They also found that the pulse amplitudes are log-normally distributed, the standard deviation at 11 MHz being 4.5 dB. The pulse spacing at HF corresponds to that of the K processes or K-type discharge as described by lightning discharge investigators. This statement is limited to pulses lying within 6 dB of the peak amplitude pulse.

Actual radiation from lightning probably contains primary pulses of very much less than a micro-second duration. Some of these probably bunch together for periods of the order of a millisecond, etc. It is such bunching which corresponds to the K-type discharges, stepped leaders, etc. When such pulsive radiation is received as a noise burst, there is the limitation imposed by the frequency of tuning and the bandwidth of the receiver. Consequently, these bunched pulses appear as millisecond pulses in the HF noise burst.

The above statements are valid for the majority of lightning flashes, *i.e.*, noise bursts, as recorded at MF and HF. A typical photograph taken at 3 MHz is reproduced in fig. 8. It is self-explanatory. It has, however, been mentioned in the previous section that the duration of a noise burst and, hence, the corresponding flash, varies with the growth and decay of thundercloud activity. Therefore, photographs of noise bursts were taken as the thunderstorm was growing, during peak activity, and as the thunderstorm was decaying. Figure 9 gives the photographs, which are self-explanatory. The long duration flash during growth has a similarity to the normal flash as shown in fig. 8. During the decay, the number of pulses appear to be extremely large. During peak activity, the pulses are so very close that they almost give the impression of continuity. Studies of this type need to be conducted more extensively if they are to be utilised for understanding the mechanisms of discharge.

Figure 10 gives three photographs of noise bursts taken at 62 MHz. There are a very large number of distinct pulses above the continuous background in the first two photographs but, in the third, there are fewer pulses and they appear well separated. Since the amplitude of the pulses is not very much above the background, one could assume, in any first approximation, that the noise in the noise burst is continuous. But, the pulses merit being taken note of for scientific purposes.

11. Distributions

As mentioned in the previous sections, several parameters appear to follow the log-normal distribution. The distances up to which thunder can be heard, the number of thunders per hour, the duration of thundering, the duration of a flash, the time interval between flashes, the peak rate of flashing, the duration of the flashing activity of a thundercloud, the number of cells developed during the lifetime of a thundercloud and the number of msec pulses in a noise burst are some of the parameters.

In view of this, typical samples of available data on the effect of lightning on power transmission lines, *viz.*, surge currents in transmission lines, discharge currents in

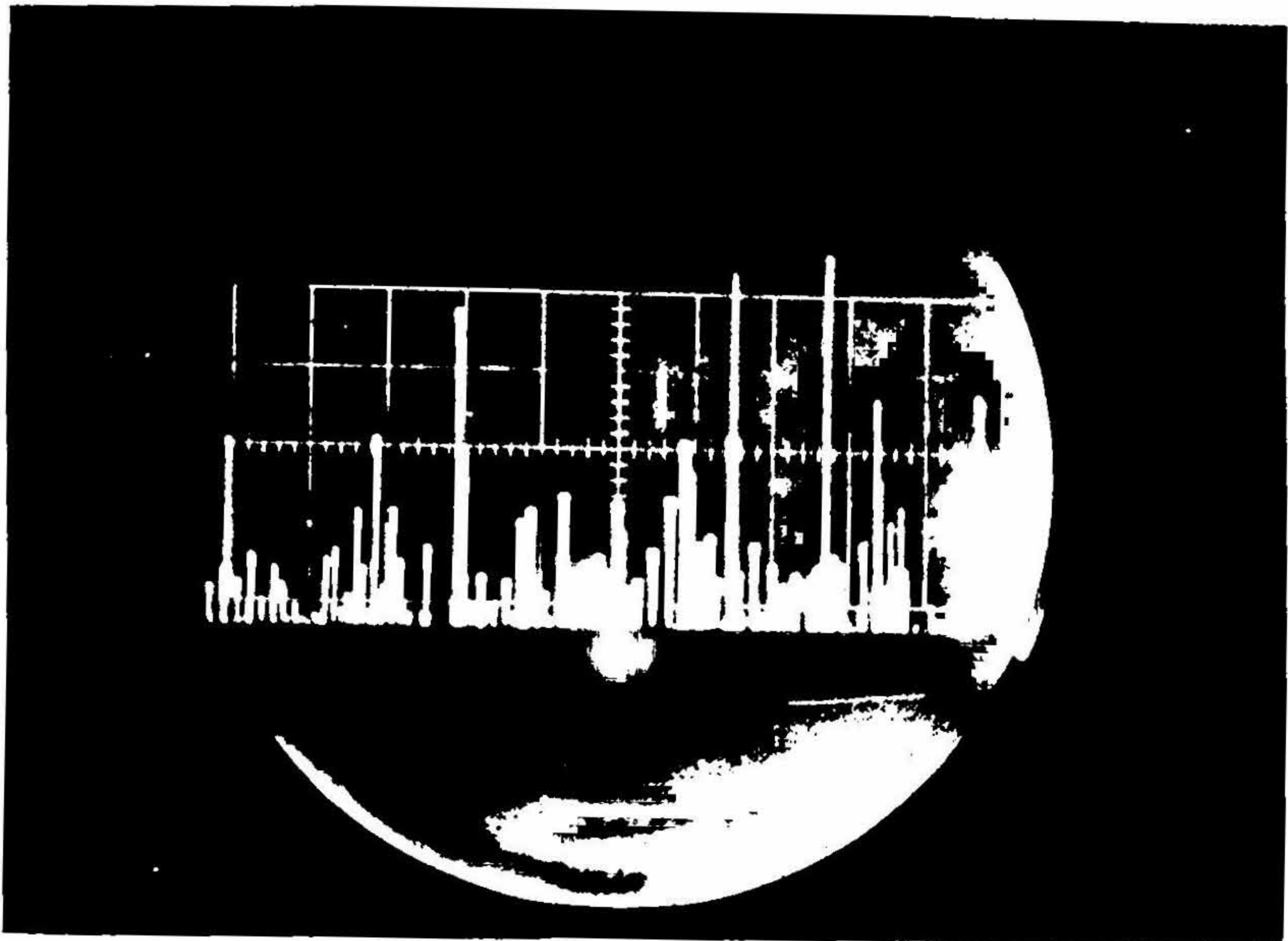


FIG. 8. Typical CRO photographic record of a noise burst (Frequency—3 MHz; Bandwidth—3.2 kHz; Duration—500 msec).

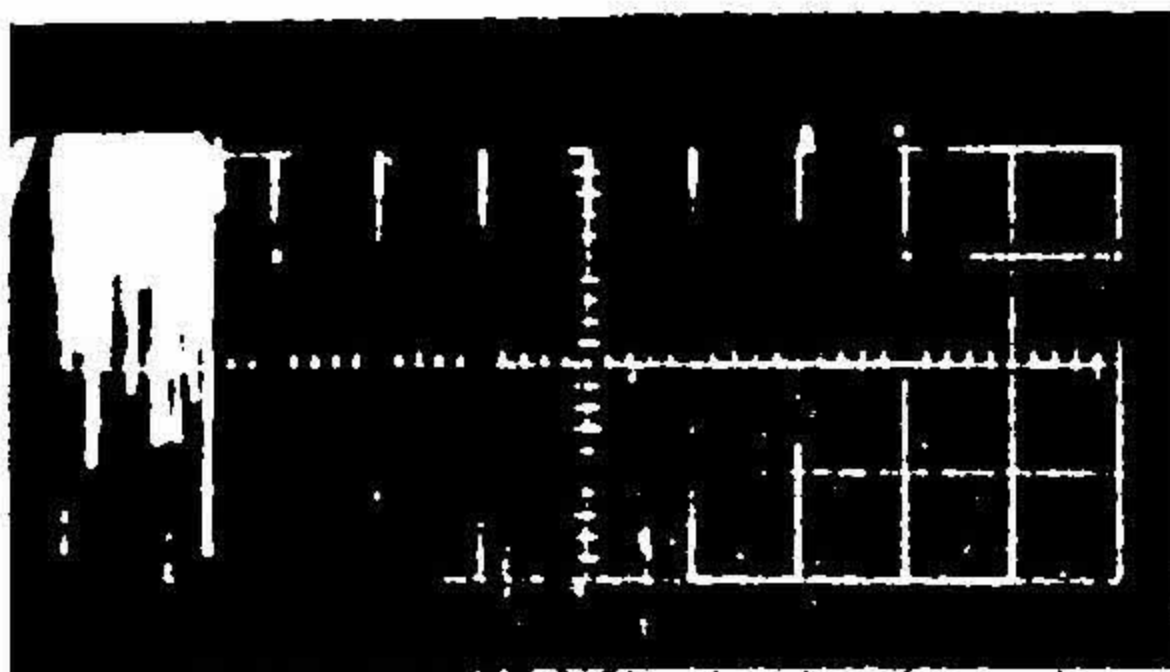
lightning arresters, crest currents in transmission line towers, half-value periods of surgecurrents, etc., were analysed¹⁶. It was found that, in every case, the distribution law is log-normal.

For getting a log-normal distribution for a physical parameter, it must be the result of several random processes, each independent of the other. Several such random processes responsible for a typical case, viz., vertical component of the current in a step of stepped leader or a return stroke, have been identified³¹. Similar attempts for several other parameters of lightning having a log-normal distribution may ultimately lead to a better understanding of the phenomenon.

Conclusions about the distribution law for a physical parameter associated with lightning could be drawn here because the investigations were carried out in the tropics. Thus information on the distribution of the number of cells developed during the activity of a thundercloud cannot possibly be obtained in temperate regions as the number of cells involved is mostly one or two.



(a)



(b)



(c)

FIG. 9. Typical CRO records of a noise burst during (a) growth, (b) peak and (c) decay of activity of a thundercloud (Frequency—3 MHz; Bandwidth—3 kHz).

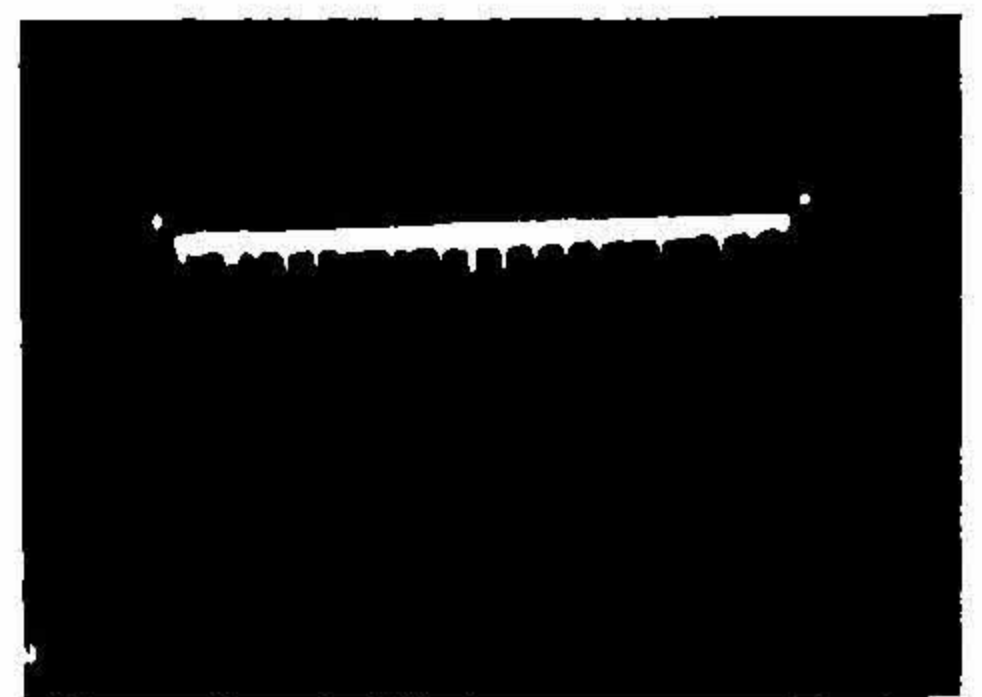
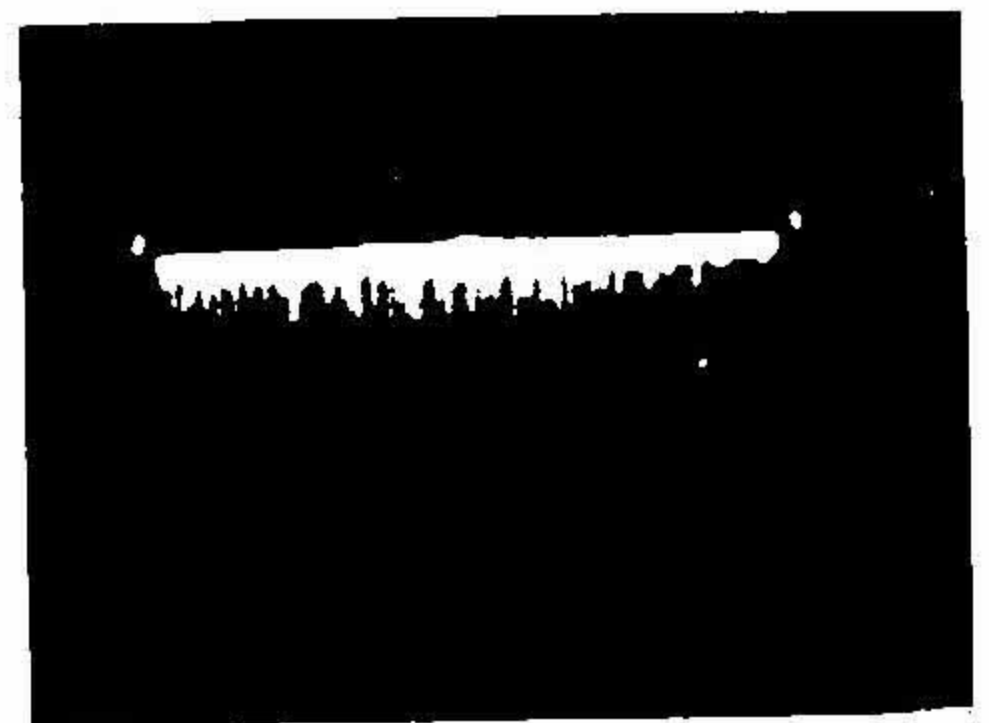
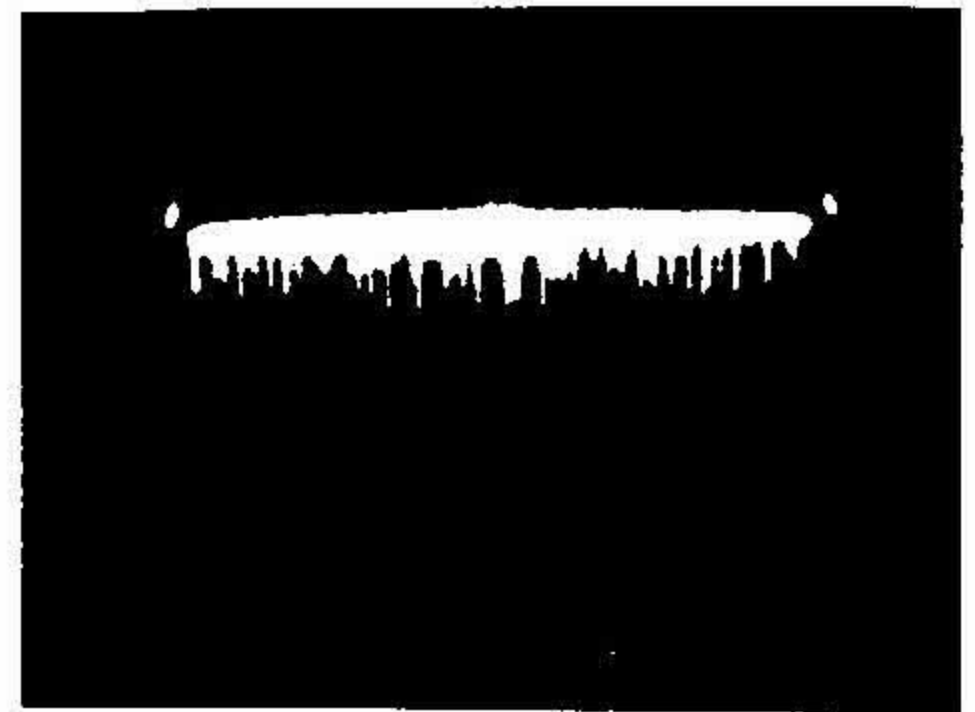


FIG. 10. Typical CRO photographic record of noise bursts (Frequency—62.5 MHz; Bandwidth—10 kHz; Duration of trace—500 msec).

12. Conclusion

Over tropical land masses, lightning flashes can be observed under disturbed weather conditions and on clear and quiet warm days, in isolated cloud patches. Extensive studies have shown that mere aural and visual observations can yield valuable information on lightning. Analysis of data collected with HF lightning flash counters has yielded valuable information on the characteristics of a tropical thundercloud. Recording of noise bursts on the magnetic tape, level recorder and the cathode array oscilloscope has furnished information on the duration of a lightning flash and its variation, and on the structure of a lightning flash under defined conditions of resolution. Most of the parameters associated with lightning and lightning flashes have a log-normal distribution. Significant differences between lightning as observed in tropical and in temperate regions have been brought out. It has been emphasised that, as observed, thunder is associated with ground flashes only and this provides the simplest and cheapest method of recording ground strokes. The value and importance of the preliminary results on the variation of the duration of a flash and its structure with the growth and decay of the activity of a thundercloud are indicated.

Throughout the paper, an attempt has been made to highlight the remarkable simplicity of the essential features of a tropical thundercloud and the simple laws it obeys. Wherever possible, indications have been furnished of the need for further investigations. In this connection, special mention may be made of the need for detailed studies of flashes in isolated cloud patches on clear warm days and of air flashes in active thunderclouds. Rain has not been observed to accompany the activity of a thundercloud in all cases. This needs a closer and more extensive examination.

It should be possible to design more refined and more sophisticated electronic instruments. The question that arises then is whether such instruments can yield better and more reliable results. Consequently, this item is kept out of the purview of this paper. The limiting factor, in many cases, is electromagnetic interference.

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