ON THE STRUCTURES OF FLASHES AND ATMOSPHERICS ACCOMPANIED BY CLOUD DISCHARGES

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Abstract— A new equipment has been designed to record the time variation of luminosity radiated from the discharge whose stroke channel is concealed in a thundercloud. This equipment together with the atmospheric wavefrom recorder has been employed to the observation of lightning activity. It has been found that the initiation of individual cloud discharges is governed by the statistical time lag of a spark breakdown, which is altered by the conditions of the cloud activity. In the early stage of a storm activity, the interval of successive discharges is short, and the scale of each discharge is generally small, so the luminosity accompanied is too weak to be recorded. In the last stage, most of discharges have considerable scales and emit strong flashes in spite of the very weak activity of the thundercloud.

The luminosities of flashes can be classified into two groups in view of their durations, *i.e.* the weak luminosity with long duration and the pulse of strong luminosity. In the former, the luminosity continues during the greater part of the period of a cloud flash that discharges electricity in 0.2–0.8 second. In the latter, the pulses with durations of 0.8–2 ms. are repeated irregularly at time intervals less than 10 ms. and continue during the period of one discharge. The atmospheric waveform corresponding to each light pulse is an electro-static pulse when it is recorded in the vicinity of the origin or a group of differential pulses with rapid changes when it is caught in a distant place.

I. Introduction

The observation method that played the most directive role to the analysis of mechanism of lightning discharge is certainly the use of a rotating camera which can record the variation of discharge channel in time and in space. In the case of cloud discharges which occupy actually more than eighty percent of all lightning discharges observed in Japan, however, the greater part of stroke channels is usually concealed by the thundercloud from our eyes. Besides it is expected that inside the cloud, the electrical and meteorological conditions influencing the progress of a discharge are more complicated than outside the cloud. So that, the device that can record the time variation of the luminosity of a lightning flash appearing in any part of the sky is a very important means to investigate the mechanism of an invisible cloud discharge which is far more indistinct than that of a lightning to the earth. This device was first designed by Malan,[1] which was a particular kind of rotating camera. The authors attained their purposes by the use of photo-electric method and the equipment was applied together with the rotating camera, and the electro-magnetic apparatuses, to the thunderstorm observations in the last two summers.

By the use of directly correlated records of optical and electro-magnetic variations, many valuable statistical data have been obtained, which concern the storm activity and the fine structure of cloud discharges.

II. Observation Method

The electro-magnetic apparatuses that have been used in the observation of thunderstorms have already been reported in details. The atmospherics wave-form recorder[2] catches the fast disturbances of the electric field, and the static field meter[3] records the slow components of it.

The construction of the flash intensity recorder is shown in the block diagram of Fig. 1. To detect the variation of flash luminosity a photo-multiplier tube has been adopted. The photo-multiplier tube is set, the photo-sensitive side downward, and receives the flash light reflected by a convex surface mirror placed upward on the earth. Through this method the visible field of the tube can cover the upper part of the sky with the angle of elevation roughly greater than 20°, which has been chosen for the reason of preventing street lights from entering the field.

The recording system is constructed in two ways. In the first plan the image of the luminosity variation produced on the screen of a C.R.T. has the same single sweep time base synchronized with the record of the triggered atmospheric waveform, which was selected to 40 ms. in the last observation, and we can see the fine correlation between the flash luminosity and the fast disturbance of electro-magnetic field radiated from the same lightning discharge. In the second plan the luminosity variation is recorded on a magnetic tape. In this case the record can be continuously carried out over a long period without the operator's hand. This gives the knowledge about the whole features of a flash which has generally the duration of about several tenths of a second. But the resolving power of time in the second method is not so high, for the modulation of photo-electric output is necessary to record on a magnetic tape. The variation of flash luminosity is represented as the envelope of play-back output of the recorded tape and the played back image of it reproduced on a C.R.T. screen is photographed on a cine-film run continuously if necessary. The resolving time of the phenomena is limited to the order of one milli-second, for the frequency of local oscillation in the tape recording modulation circuit is chosen at 4 kc.

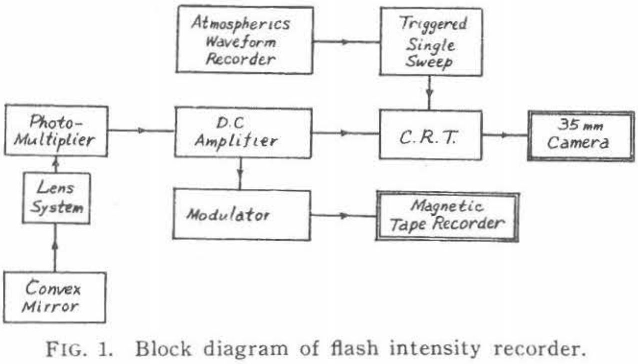


FIG. 1. Block diagram of flash intensity recorder.

By means of photo-electric recording method, the following performances can easily be obtained: the widest visible field, high sensitivity and high resolving power of time. The sensitivity of the luminosity detector is altered by the iris of lens system in front of the sensitive surface and the voltage applied to the photo-multiplier tube, whose sensitivity varies roughly in proportion to the seventh power of applied voltage. The sensitivity must be properly selected from storm to storm.

III. Frequency of Lightning Discharge

The frequency of lightning flashes comparatively fluctuates from a storm to another and it is governed by the meteorological elements, such as, for example, energy sources of the storm activity. The frequency can easily be found by playing back the magnetic tape that has recorded flash intensity. The maximum frequency of occurrence of lightning flashes which are almost all composed of cloud discharges, is generally repeated at time intervals of 10–40 minutes. The distribution of time intervals between the maximum frequency periods in 8 storms are shown in Fig. 2. It is probable that this represents the time interval of the growth of active lightning cells, for it is recognized in the observation with radar techniques that lightning flashes are the most frequent when the summit of a cell attains its maximum height.[4] The duration of the maximum frequency period is less than 10 minutes.

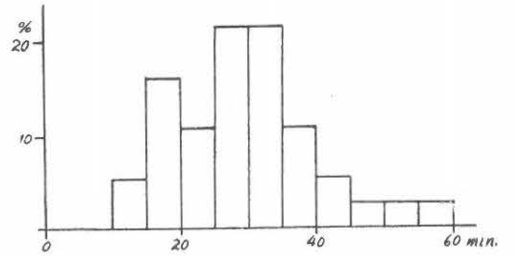


FIG. 2. Time interval between maximum frequency periods of flashes.

Fig. 3 shows the so-called probability curves[5] of flash intervals. It shows percentages, in logarithmic scale, of the numbers of such cases which have larger values than the respective time value in the abscissa. Each curve is based respectively on the data obtained in 8 storms in 1957 and 1958. The probability curves are generally linear except for two ranges. The meaning of this fact is that the initiation of lightning flashes is mainly governed by the statistical time lag so long as the linear region concerns. The non-linear range of values smaller than 3–15 seconds is perhaps affected by the time required for the reproduction of electric field to initiate the next discharge. The refraction found in the range of 25–40 seconds of some curves represents that the change of ignition conditions has occurred in the long period of a thunderstorm.

On the other hand, the continuous record of atmospherics waveforms under storm conditions provides the proof for the existence of many discharges on small scales which do not accompany any radiation of visible luminosity. Fig. 4 shows the several typical examples of the probability curves of discharge time intervals

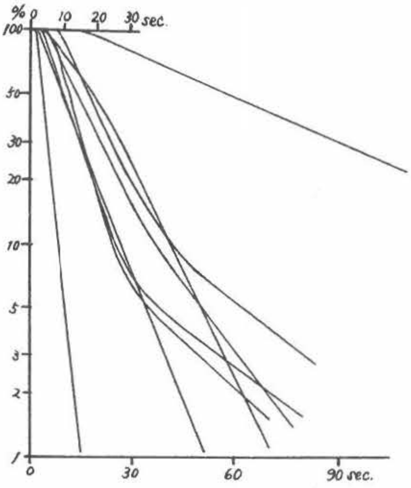


FIG. 3. Probability curves of flash intervals in each storm.

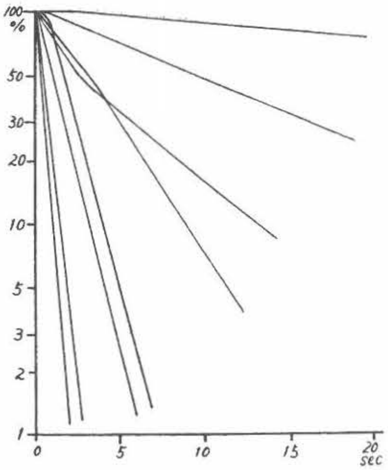


FIG. 4. Probability curves of atmospheric intervals in each period of 2–6 min. under storm condition properly selected.

measured on each continuous record of electro-magnetic disturbances. These records were obtained each in 2–6 minutes, a period properly selected during storm conditions to prevent the waste of recording photographic films. As shown in Fig. 4, the time required to restore the electric field necessary for the ignition of the next small discharge is found in such atmospherics records to be less than a second. The linearity of the curve indicates that the successive discharges on such small scales inside a cloud are not affected by the preceding ones and this may come from the fact that they do not present themselves in any fixed region within a cloud but the region varies with each small successive discharge.

The inclination of each probability curve is determined by the initiating conditions of the discharges and it is generally distributed in a wide range from case to case. Fig. 5 shows the histogram, in logarithmic intervals, of reciprocal of the inclination value, which is equal to the mean value of the statistical time lag; the value plotted is obtained by measuring the time length on abscissas in

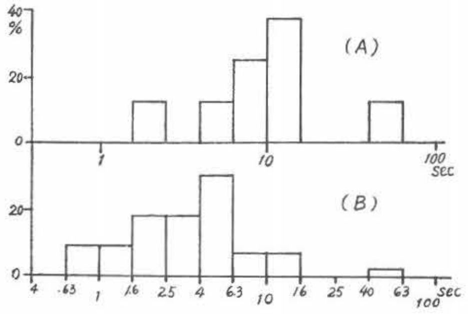


FIG. 5. Histogram, in logarithmic intervals, of mean value of stastistical time lag of lightning discharge initiation. (A) and (B) are based on the data of flashes and atmospherics records respectively.

Fig. 3, and Fig. 4, within which the probability curve drops from a certain value to $1/e$ value of it.

The reason why the statistical time lags of the lightning initiation are subjected in each case to a considerable fluctuation is that the meteorological conditions in a thundercloud are highly complex. The fact shows that the effective electric field, necessary to initiate a lightning, measured on aircrafts is only about a tenth of that of the spark breakdown obtained in a labolatory experiment.[6] This may result in the high value of statistical time lag of lightning initiation. Although the value of statistical time lag of laboratory discharges is appreciably altered by the experimental conditions such as electrode material, shape of electrode, surface condition, magnitude of irradation and overvoltage,[7] it is usually measured in the unit of microsecond. The ignition of discharges inside a thundercloud has to be controlled by the excitement occurring by chance.

TABLE 1. Comparison of Intervals of Flashes and Those of Atmospherics

Date	No. of film record	Interval (sec.)			Ratio of intervals			Sensitivity (db.)	
		Flash	Atmospherics		Flash / All atm.	Flash / Large atm.	Large / All atm.	Flash	Atmospherics
			All	Large*					
Aug. 5. 57	14	83	4.5	20	18	4.2	4.4	31	30
	15	79	11	31	7.2	2.5	2.8	42	40
	16	46	46	62	1.0	0.7	1.3	45	40
Aug. 10. 57	21	32	1.7	6.7	19	4.8	3.9	4	10
	22	22	3.4	6.8	6.5	3.2	2.0	6	20
	23	34	9.7	12	3.5	2.8	1.2	12	20
	24	21	16	22	1.3	1.0	1.3	22	20
Aug. 1. 58	10	7	1.7	9	4.1	0.8	5.3	18	10
Aug. 4. 58	11	14	7.3	19	1.9	0.7	2.6	18	10
	12	21	14	31	1.5	0.7	2.2	6	20

* The largest peak in any one of large atmospherics selected here is not smaller than 1/10 of the maximum amplitude on each film record.

The comparison of the mean time intervals between successive flashes and those of atmospherics, both recorded in the same period are shown in Table 1. The sensitivity of recording are expressed in the magnitude of attenuation from the maximum sensitivity of respective apparatuses. With the progress of thunderstorm activity, the ratio of time intervals of flashes to those of atmospherics becomes gradually smaller, while the situation is unaltered for the case of the ratio of intervals of large atmospherics to those of all atmospherics. In the last stage of a storm, most discharges have considerable scales and emit strong luminosities. On the tendency of the ratio of occurrence of large scale atmospherics, there are many data compiled in four years' observations. In Fig. 6, the abscissa shows the progress of time from the first continuous record of atmospherics in each storm. Throughout the observations in the past several summers, we had experienced the evidence on the phenomena concerning the progress of process of lightning activity just mentioned.

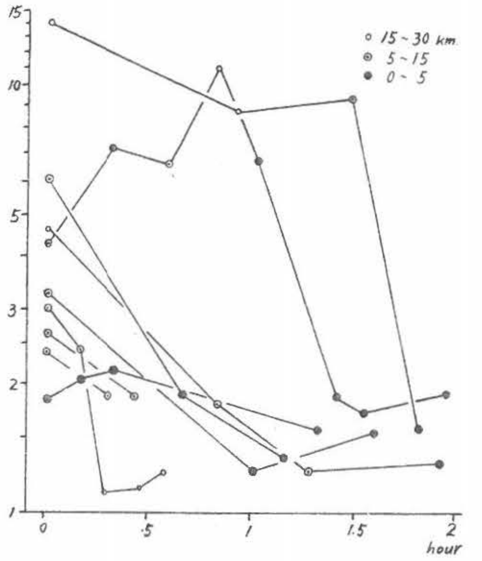


FIG. 6. Ratio of occurrence of all atmospherics measured to those of large atmospherics.

IV. Duration of a Cloud Discharge

As it will be shown in the following sections, many electric and luminous pulses are emitted successively at irregular time intervals in the course of a cloud discharge. When the activity of discharges is very violent, series of pulses in a discharge can hardly be distinguished from those of the next one. Except for such cases, however, the duration of a cloud discharge constructed from several groups of pulse series can be measured on the electro-magnetic and photo-electric records. The frequency distribution of the duration is shown in Fig. 7. Fig. (*A*) shows the case of the photo-multiplier record and the greater parts of it lie in the range of 0.2–0.5 second. Fig. (*B*), based on the record of atmospherics, shows somewhat longer duration, *i.e.* 0.3–0.8 second. The ratio of duration of a flash to that of an atmospheric, both confirmed to be emitted by

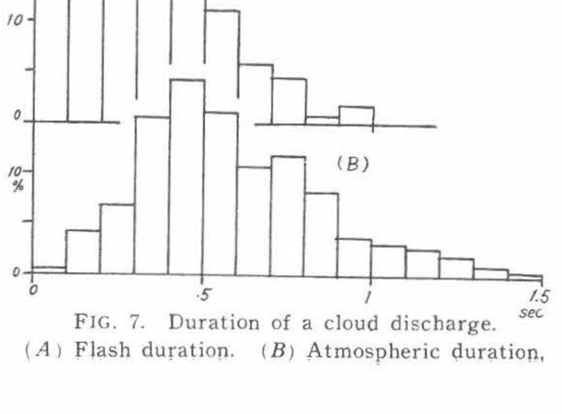


FIG. 7. Duration of a cloud discharge.
(*A*) Flash duration. (*B*) Atmospheric duration.

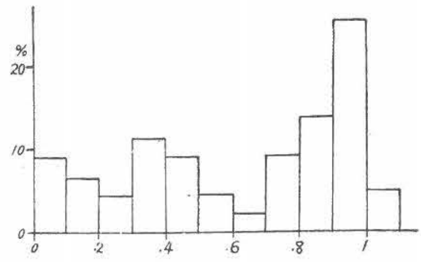


FIG. 8. Ratio of duration of flash to that of atmospheric, both emitted from the same discharge.

the same discharge, distributes as shown in the histogram, Fig. 8. In all cases the duration on the flash record is shorter than that on the atmospheric record, if the measuring error is taken into account. In 60% out of all cases, however, the flash duration is longer than half the value of the corresponding atmospheric duration. Concerning the result that the atmospheric duration is always longer than the flash duration, it must be remembered that a small electric pulse observed in the atmospheric record does not always accompany a visible luminosity.

V. Waveform of Atmospherics

The electro-static field change in the period of a cloud discharge occurrence, observed with our mill type field meter, generally forms the variation with smooth slopes, which continues several hundred milliseconds and it does not show any rapid change in any portion of it, in contrast to the moment of commencement of a lightning to the earth. However, the waveforms given by the atmospheric recorder, in which the low frequency ranges up to about 50 c/s (triggered waveform with 40 ms. sweep) or to about 1 kc. (continuous waveform) of the electric field variation are cut off through a high pass filter, indicate the characteristic series of pulses. Within the range of several kilometers from the lightning origin, the pulse series are usually composed of electro-static pulses with the shape of round or peaked hill, though their waveforms are somewhat modified in a continuous record in passing through the filter equipped in the amplifier. Electro-static pulses are always overlapped by rapidly changing inductive and radiative pulses which predominate gradually with the increase in distance from the origin. Outside of 30 km. range, electro-static pulses can hardly be found and waveforms are constructed only by intermittent groups of rapid pulses with differential shapes. Examples of the records are shown in Fig. 10, and Fig. 11. Table 2 shows the occurrence percentages of the waveforms

TABLE 2. Percentages of Atmospheric Waveforms with Electro-static Pulses and Those Without Them

Distance	With static pulse	Without static pulse	Numbers of data
0– 5 km.	64%	36%	688
5–15	28	72	700
15–30	16	84	692
Total	36%	64%	2,080

which comprise electro-static pulses and that of the waveforms which do not comprise them.

In the majority of cases of cloud discharges, the signs of electro-static pulses in a discharge are kept almost the same or are reversed once in the course of it. Table 3 shows occurrence percentages of types of polarity character for three different distances. The first column marked with + represents the cases in which almost all of the electro-static pulses are of positive polarity. The column marked with $+\rightarrow-$ represents the cases in which static pulses in the earlier stage of a discharge are mainly of the positive polarity, and in the later stage of it they become mainly negative.

TABLE 3. Polarity Character of Electro-static Pulses in a Cloud Discharge

Distance	+	−	$+\rightarrow-$	$-\rightarrow+$	±mixed	Numbers of data
0–5 km.	63	6	21	3	7%	437
5–15	41	21	10	15	13	193
15–30	27	38	1	19	15	113
Total	52	15	15	9	9%	743

The number of predominant static pulses involved in a cloud discharge is usually larger than 10, when it is measured on the record taken in the vicinity of a lightning source. Generally speaking this value is too large compared with stroke multiplicity, measured on a rotating camera concerning a cloud to cloud discharge or a cloud to air discharge. In addition, the characters of individual electro-static pulses involved in a discharge are not always the same, but they very often show conspicuous differences both in their amplitudes and in their forms. Therefore it is reasonable to consider that the static pulses must result from local movements of electric charges taking place in different regions in the cloud.

The electro-static field change on the earth's surface produced by a breakdown of a local electric dipole can be represented as follows.

$$\Delta F = 2\,Q\cdot\Delta s[(d^2 - 2\,h^2)\cos\theta + 3\,dh\sin\theta\cos\phi](h^2 + d^2)^{-5/2},$$

where $Q\cdot\Delta s$ is the dipole moment discharged, h is the height of dipole from the earth, d is the horizontal distance of the dipole from the observation point, θ is the inclination of dipole axis and ϕ is the angle between the horizontal projection of the dipole axis and that of the direction connecting the dipole to the observation point.

The reversal positions of sign of electro-static field change, which are given by the locus of $\Delta F = 0$, lie on a circle except when the dipole axis is in a horizontal position, *i.e.* $\theta = \pi/2$, though the center position and the radius of it vary with the values of θ. Within the circle an electro-static field change due to a breakdown of a dipole is of the same polarlity as that of the dipole.* Considered

* We provide that the polarity of a dipole is positive, if $0 \leqq \theta < \pi/2$ and that it is negative, if $\pi/2 < \theta \leqq \pi$,

from a statistical point of view, it will be reasonable to assume that the value of ϕ can attain any value with equal probability, if we neglect geographical factors concerning the storm activity. Then the probability that the observation point lies within the reversal circle can be represented as follows,

$$\begin{aligned} p &= 1, & \psi &\leqq -1 \\ p &= \cos^{-1}\psi/\pi, & -1 < \psi &< 1 \\ p &= 0, & \psi &\geqq 1 \end{aligned}$$

where $\psi = (d^2 - 2h^2)/3\,dh \tan\theta$. The relation between probability and distance is shown in Fig. 9, in which the curves are plotted at several values of θ. If $d = \sqrt{2}\,h$, it results in $\psi = 0$. Therefore $p = 1/2$, and p becomes independent of the value of θ. Within the distance $d = \sqrt{2}\,h$, the probability, that the polarity of any static field change is not reversed, is larger than 1/2, so that it has to be expected for the static field changes due to local dipole discharges predominantly to have the same polarity as that of the dipoles.

In Table 3, columns marked with + and − clearly indicate that each electro-static pulse can be explained by the consideration that it is produced mainly by the discharge of local positive dipole, the polarity of which coincides with that of the main dipole of a cloud discharge determined from the slow variation of electro-static field recorded with field mills. The tendency indicated in $+\rightarrow-$ and $-\rightarrow+$ columns is contrary to each other with respect to the distance. It is not explained by the vertical movement of discharge region of each small dipole with same polarity, as the sum of percentages of + and − columns, or that of $+\rightarrow-$ and $-\rightarrow+$ columns, does not change to an apreciable degree with the change of distances. The latter pair of columns may correspond, for example, to the discharges of the positive dipole in the earlier stage and the negative dipole in the later stage. Or it may correspond again to the discharges of the vertical positive dipole in the earlier stage and the horizontal dipole in the later stage.

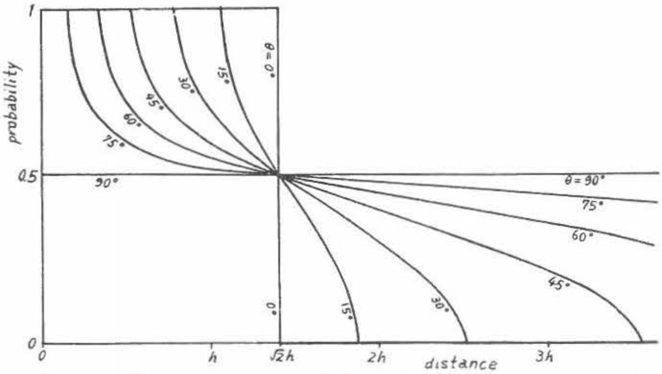


FIG. 9. Occurrence probability that the polarity of field change is equal to that of small dipole discharged at different horizontal distances.

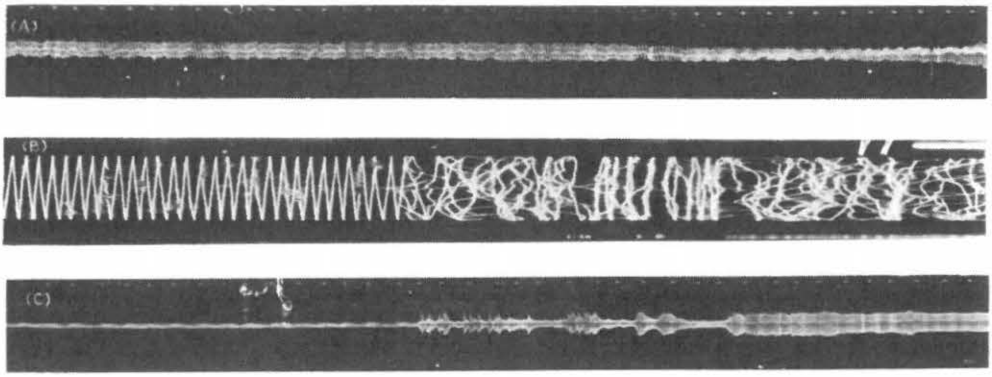


FIG. 10. An example of simultaneous
(*A*) Electro-static
(*B*) Atmospheric
(*C*) Flash lumino-

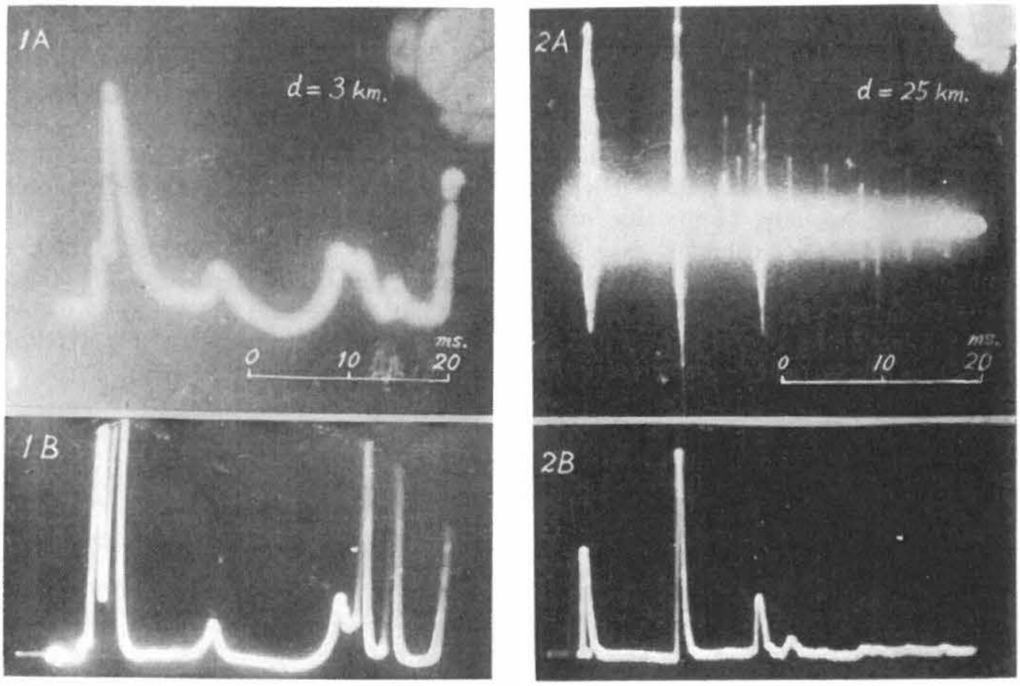
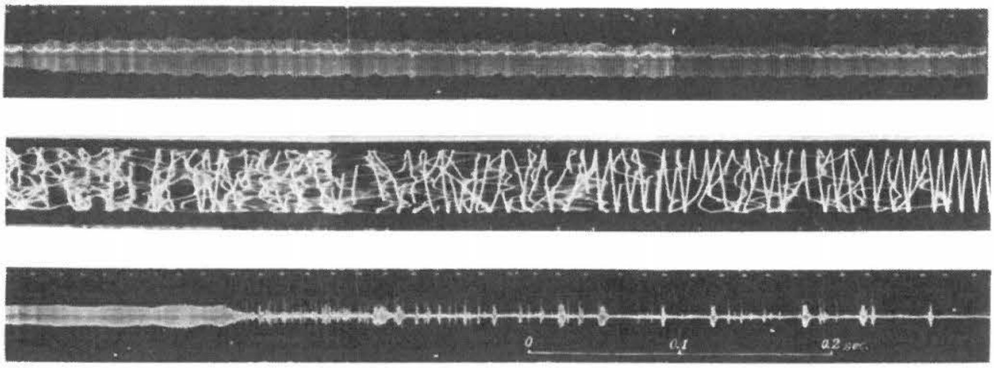


FIG. 11. Examples of simultaneous records in trigger method.
(*A*) Atmospheric waveform.
(*B*) Flash luminosity.

VI. Fine Structure of Flash Luminosity

Lightning flashes usually have very complex structures and they are composed of series of light pulses mixed with several continuous luminosities of weaker intensities. Typical examples of records are reprobuced in Fig. 10 repre-



records in continuous method.
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senting the continuous method and in Fig. 11 the trigger method. In the figures the luminosity records are illustrated together with the waveform records of electric field disturbance with equal time base. It has been found that the waveforms of light pulses do not essentially change with the distance except for the diminution of the intensity, while the atmospheric waveform is subjected to a quality change and transforms from electro-static type to radiative type.

The histogram of a number of light pulses included in a cloud discharge is shown in Fig. 12. The recorded maximum of light pulses in a discharge is more than fifty. The median value of the histogram is 13.

The frequency probability distribution of luminosity duration is shown in

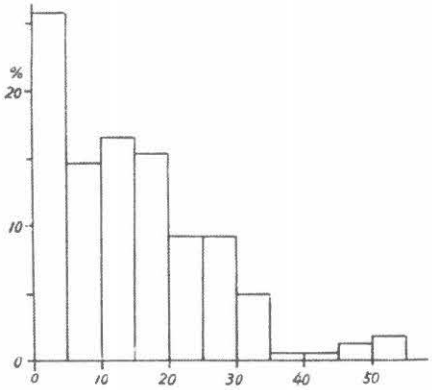

FIG. 12. Number of light pulses involved in a cloud discharge.

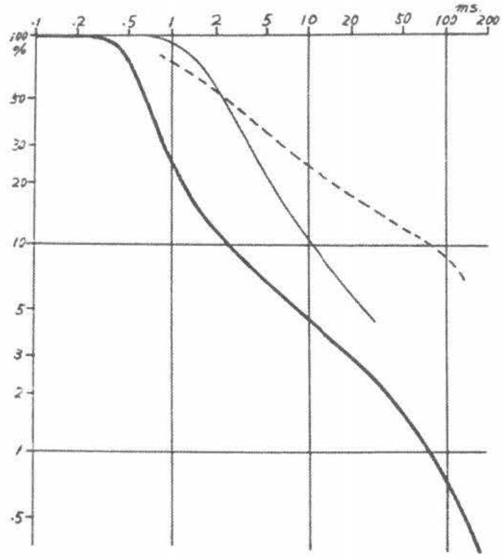

FIG. 13. Probability curve in logarithmic abscissa of luminosity duration.

Fig. 13. The ordinate, the percentage number, is plotted in logarithmic scale and it is equal to the percentage number of cases in which the duration of it is larger than the related time value on abscissa which is again graduated in logarithmic for the sake of convenience. The figure is obtained by combining the data of magnetic tape record with that of triggered record. According to what the record on magnetic tape tells, three quarters of all measurable light pulses have pulse widths less than one millisecond, which is the limit of time measurement on these records. On the triggered record, however, we can measure the true durations of light pulses, the distribution of which is shown with a fine full line in Fig. 13. We can clearly see that the curve of triggered record is more predominant in longer range of duration than that of magnetic tape record. The reason for this is that the duration measured on modulated record is the value during which duration the light intensity exceeds a certain level. If the duration, during which the light intensity exceeds the peak intensity by half, is measured on triggered record, the distribution of it roughly coincides with that of the modulated record in the range of short duration value. Generally speaking the duration measured in this way on the triggered record is roughly equal to the duration of the convex portion of a light pulse waveform. The shorter range less than 1 ms. of the distribution curve of Fig. 13, is obtained in this way.

Durations of flash luminosities may be divided into two groups with respect to the mechanism of luminosity radiation, the transition of which ranges in 1-5 ms. An idealized waveform of a light pulse is illustrated in Fig. 14 and the time values indicated in the figure are the most frequent values in millisecond. The median values of the histograms corresponding respectively to these time values are all longer than the most frequent values.

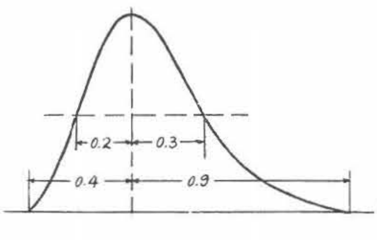

FIG. 14. Idealized waveform of a light pulse. (Time in ms.)

If a streamer in a cloud travels its whole channel with constant intensity of light and the effect of obstacles lying on the light pass on the observation point is unchanged along the whole channel, the resultant luminous intensity radiated from the whole streamer channel does not fall at least until the progress is completed. So that, the order of rise-time of a light pulse must be same as that of the period of streamer progress. The fall-time of the light pulse, on the other hand, must nearly be equal to the period of so-called afterglow.

We have now a considerable number of rotating camera photographs of inter-cloud, and air discharge strokes. The mean velocity value of the measured inter-cloud streamer —the dart leader— is 4×10^8 cm/sec. As the rise-time of an idealized light pulse is 4×10^{-4} sec., the distance advanced by a streamer must be 1.6 km, if the velocity value is applicable to the streamer inside the cloud.

Concerning the rotating camera photographs of lightning flashes, it is well known that some of the bending points on a stroke channel have much longer afterglow than the general afterglow along it, and the former takes the form of a long stripe of light in the direction of rotation. The histogram of the durations of stripe afterglow is just fitted to that of the fall-times of light pulses measured on the photo-electric record, which point is shown in Fig. 15.

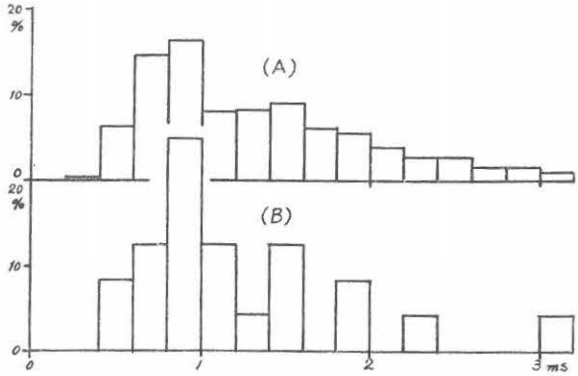

FIG. 15. Duration of afterglow.
(*A*) Photo-multiplier record, (*B*) Rotaing camera record.

The interesting fact obtained concerning the data of duration is the existence of a long luminosity lasting over several tens milliseconds. This can also be observed on the triggered record, which indicates a general elevation of the recorded level from the base line. Short light pulses freqently overlap on a long continuing luminosity. The atmospheric waveform recorded simultaneously with a long continuing luminosity generally shows a very complicated electro-static variation with large amplitude and it is very often impossible to trace such portion of the waveform. The continuing luminosity can not always be observed on every record of cloud discharge, although sometimes two or three long luminosities are involved in a cloud discharge. The light dashed line in Fig. 13 shows the distribution of the duration of the longest continuing luminosity involved in each cloud discharge. The number of cases in which the longest duration is larger than 10 ms, comprises only a quarter of all recorded cloud discharges. The position of the longest luminosity in a period of a cloud discharge is a random, as Table 4 indicates. It shows the percentage number of cases where the longest duration lies in its respective quarter of a whole period.

The number of light pulses in a discharge and the duration of them are expected to change with the sensitivity of recording equipment as well as with

TABLE 4. Position of the Longest Luminosity in a Cloud Discharge

Position / Duration	1/4	2/4	3/4	4/4	Numbers of data
3– 10 ms	14	24	38	24%	29
10–100	32	16	12	40	25
100–500	17	39	33	11	18
Total	21	25	28	26%	72

the distance between discharge point and observation station. The median values of such elements in three ranges of distance are shown in Table 5. Generally the equipment was adjusted to a low sensitivity to record flashes within a shorter range and conversely it was adjusted to a high sensitivity to record flashes in a longer range. In spite of this procedure, the numbers and durations of luminosities fell to low values with the increase in distance. Especially, a luminosity continuing longer than 100 ms. could not be found on any record of distant flashes, the distances of which had been estimated at more than 50 km from the corresponding records of atmospheric waveforms.

TABLE 5. Median Values of Several Elements Related to Light Pulses

Distance (km)	Number of light pulses	Rise-time (ms)	Fall-time (ms)	Duration (ms)	Interval (ms)
0– 5	14.0	0.68	1.46	2.19	3.51
5–15	10.5	0.63	1.25	2.00	3.52
15–30	5.0	0.50	0.92	1.49	3.48
Total	13.0	0.63	1.31	2.05	3.51

It is now evident that there is an appreciable attenuation of light intensity in the passage of light from flash source to the recording apparatus. So that the flash record taken with a higher sensitivity perhaps have the higher probability to have longer luminosities. It is reasonable to consider that a long weak luminosity continues for several tenths of a second as found on the record of electrostatic field meter. If the long continuing luminosity is related to a single streamer discharge traveling a long gap in a thundercloud, the velocity of the streamer must be extremely low and it is the order of 10^5–10^6 cm/sec., which is nearly equal to the slowest value of J-streamer velocities.[9] It is frequently observed on rotating camera photographs that both ends or some points on a streamer channel of an inter-cloud discharge are continuously luminant over several tens milliseconds before and after, or before or after, the instant of streamer breakdown. Moreover, concerning cloud discharges, Sourdillon[10] has pointed out that the long luminosity without any clear stroke channel is more frequently observed than the clear multiple stroke type; in such cases the rotating camera photographs are composed of streaks of luminosity lasting over a long period. It is evident that some of the records of a long weak continuing luminosity taken with photo-electric record, really correspond to the long streaks of light on the rotating camera photographs. One of the authors has formerly and numerically discussed in detail the possibility that the corona discharge in a thundercloud plays an important role in neutralizing two main electric charges.[11] The long continuing luminosity found on the records of rotating cameras and photo-electric equipments is perhaps due to a corona discharge occurring on a large scale in the regions of field disproportion caused by the non-uniform distribution of electric charges.

The correlation is not particularly good between the amplitude of light pulse and that of corresponding atmospheric pulse, which takes the form either of an electro-static pulse, in case a thunderstorm is nearby, or of a group of differential pulse series, when the storm is distant. As it is shown in Fig. 16, the probability curve of time intervals of light pulses is almost linear except for a short range less than 1 ms., in which case it is very difficult clearly to determine the time interval because of the existence of the afterglow of a previous light pulse, and which does not mean the time required for the restoration of the electric field necessary for the next light pulse production. Fig. 16 clearly indicates that successive light pulses are not mutually affected and so it will be reasonable to consider that the light pulses are emitted from the many local positions scattered in and around the corona region. A record of air-discharges seems conspicuously to support this point, in which as many as 14 streamers spread out from a small cloud body floating in a clear sky. Therefore the attenuation of light pulses must be very much altered in a cloud discharge by the non-uniform density distribution of cloud droplets on the way to our eyes.

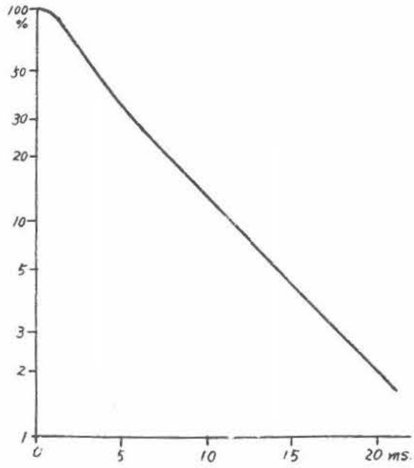

FIG. 16. Probability curve of light pulse interval.

VII. Conclusion

In the present report, the general survey of the thunderstorm activity and that of the structure of cloud discharge is described by discussing the record of observations made with the optical and electro-magnetic procedures.

In the early stage of thunderstorm activity, as a general case, majority of discharges are of small scales and the waveforms of electric field disturbances are mainly composed of the repetition of differential pulse series and generally do not accompany any visible luminosity. In the last stage, the time intervals of successive cloud discharges are very often prolonged with time, and the intensities of most of the discharges increase and emit strong luminosities.

The duration of a cloud discharge ranges from 0.2 to 0.8 second, the greater portions of which are occupied usually by a long continuing weak luminosity. In most cases many strong light pulses of the duration of 0.8–2.0 ms, which are repeated at random with time intervals less than 10 ms, superimpose a long continuing weak luminosity. The long weak continuing luminosity may be inferred to be radiated from a supposed corona discharge caused by the disproportion of the electric field and most of the strong short light pulses may be presumed to come from the local rapid discharges scattered in and around the corona regions. The atmospheric waveform corresponding to each light pulse is an electro-static pulse in the case of a nearby thunderstorm or a group of differential pulse series in the case of a distant storm.

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