ON THE ATMOSPHERICS FROM A SUMMER CUMULO-NIMBUS

PART II. THE NATURE OF THE DISCHARGES IN THE CLOUD COMPUTED FORM THE WAVE FORM ANALYSIS

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Synopsis—The study on the amtospherics wave forms from the developing cumulo-nimbus in the stages prior to a thunderstorm indicates that the stepped-leader type discharges in the cloud have fairly the same characteristics as that of the cloud to earth discharges reported by several workers[1)2)3)] except the step period, and that the dart-leader or partial type discharges are of different characteristics from the main discharges in several respects.[4)5)]

1. Introduction

It has been studied in Part I of this paper the activity variations of the three fundamental discharge types in the course of the cloud lives, and has been shown that the activity of these three types implies the characteristic course of the cloud development. It is the purposes of Part II of this paper to make a statistical analyses of the wave forms of these special atmospherics radiated from the cumulo-nimbus and to investigate the mechanism of the cloud discharges which radiate the special atmospherics of the summer cumulo-nimbus.

2. Stepped-Leader Type Discharges

In Part I of this paper it has been described that the atmospherics radiated from the cumulo-nimbus developed to the state, on step preceding a thunderstorm, have the characteristic wave form, which can be composed by repeating the simple pulses at certain intervals and that these pulses have the characteristics of discontinuity obtainable through the single differentiation of a smooth but sharp pulse wave, *i.e.*, inductive wave form as shown in Fig. 1.

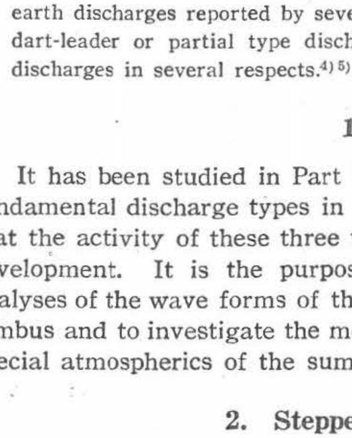


FIG. 1. The schematical wave form of the fundamental pulse and the differentiated pulses, *i.e.*, inductive and radiative type pulses.

The comparison of the wave forms of Figs. 4 *A* and *B*, in Part I with the wave forms of the "a" portion of a lightning flash reported by Appleton and Chapman[1)] (see for example Fig. 5 in their paper) and with those of the stepped-leader portion of a cloud to earth lightning flash represented by Malan and Schonland[2)] (see Fig. 1 of their paper) indicates that the observed wave forms from the cloud are identical to the stepped-leader wave forms of cloud to earth lightning discharges in every respect except the step intervals and sign of the component pulses, the latter of which may be determined by the sign of discharge currents, the direction of discharge channels and the distance from the station. Hence it can be concluded that the discharges in the cloud at the stage under considerations were chiefly constructed from stepped-leader type discharges.

Meek's theory of lightning discharges[6] interpreted the mechanism of the stepped-leader development by the volume recombination of ions in the lightning discharge channel. According to his theory the leader streamer of every step appears at the upper cloud end of the discharge channel every time when the potential gradient along the channel at the cloud end reaches to a critical value for sparking resulting from the increase in electric resistances of the discharging channel through the reduction of ion densities by volume recombination processes. Hence it may be reasonable to interpret that each discontinuous pulses of the stepped-leader type waves are caused either by the formation of the leader streamer of each step at the cloud end of the discharging channel or by the processes through which each stepped-leader streamer catches up the preceding pilot streamer. Small pulsations between the large successive pulses may be interpreted as to be produced at the head of continuously advancing pilot streamer and at the progressing tip of each leader-streamer. Fig. 2 shows the distribution of step intervals, which was obtained by measuring these pulse intervals. The curves I, II, III were obtained from the measurements of intervals between small, medium, and large amplitude pulses respectively. The train of large pulses is reproduced in Fig. 4 *A* of Part I and the appearances in which the medium and small amplitude pulses are held between the large amplitude pulses is reproduced in Fig. 4 *B* of Part I. In the case of cloud to earth lightning discharges it is reported by Schonland and his collaborators,[3] that the step intervals are ranged from 20 to 100 micro-seconds with most frequent values 30–50 micro-seconds. This corresponds roughly to the curve II in our observations, which, however, represents the pulse intervals of medium amplitudes. Hence there is a distinct discrepancies between the values of the step intervals reported by Schonland of the order 30–50 micro-seconds and those of the curve III in the case of our observations, of which the most frequent values are roughly 250 micro-seconds. This seems to indicate that the stepped-leader streamers would have longer step intervals in the case when the discharges take place in the electric field within the thundercloud, than in the case when the discharges occur in the electric field outside the cloud.

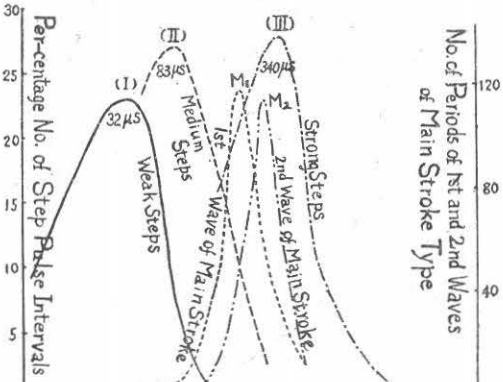
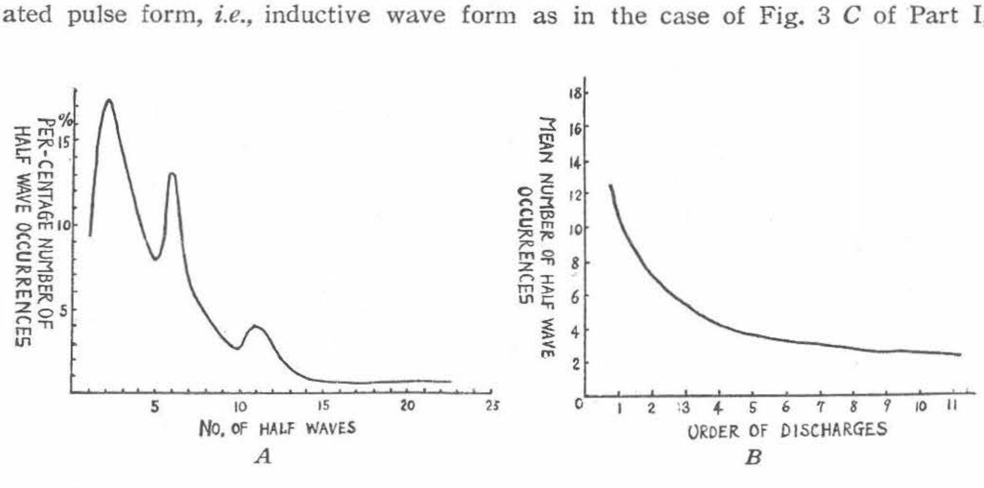


FIG. 2. The step interval distribution curves of the stepped-leader type atmospherics.

As to the smaller pulsation intervals it may be possible to obtain another distribution curve to the smaller side of the distribution curves reproduced in Fig. 2, if the time scale of the wave figure photograph of the order smaller than 100 microseconds can be obtained using the instrument with appropriate frequency characteristics of amplifier. Accordingly it may be said that frequency range of the stepped-leader pulse intervals is considerably so wide that it covers even the frequency range of the main stroke type atmospherics, which is shown by the curves for comparison M_1 and M_2 in Fig. 2, *i.e.*, the distribution curves of the first and the second waves of them respectively.[5] It can therefore be concluded that the frequency distribution of the stepped-leader stroke pulse intervals can be radically altered according to the method of selecting the step pulse intervals.

3. Partial Discharge Type Discharges

This type present itself most actively in the early stage of the cloud development, and is caused by small discharges in the cloud. In these cases the oscillations of smaller periods and shorter durations than the main stroke type are often repeated between time intervals, which are ranged in the intermediate region between the intervals of the multiple main strokes and those of the pulses of the stepped-leader strokes. The component wave forms of the partial discharge type has the quasi periodic damped oscillation or doubly differentiated pulse form, *i.e.*, radiative wave form as in the case of Fig. 3 *A* of Part I, and the singly differentiated pulse form, *i.e.*, inductive wave form as in the case of Fig. 3 *C* of Part I,



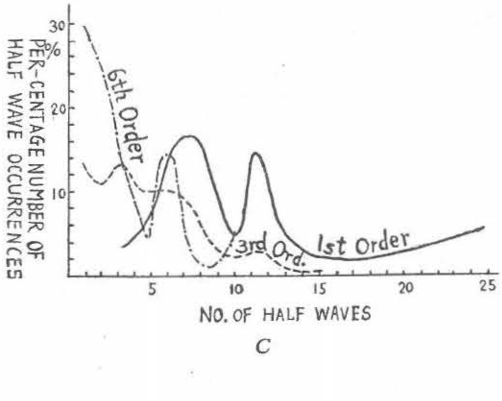


FIG. 3. *A*: The percentage number distribution of half waves of component partial discharges. *B*: The relation between number of half waves and order of the component of partial discharges. *C*: The distribution of the number of half waves in each order of multiple partial discharges.

which are represented as the two extreme cases (see Fig. 1). This type seems to include the partial discharges after the main discharge[7] as well as the dart-leader discharge,[8] both of which are interpreted as to be produced inside the thunder-clouds.

Figs. 3 *A*, *B* and *C* represent the distribution of the number of half waves of the component partial discharges, the change of the number of half waves with the order of the component partial discharges, and the distributions of the number of half waves in each order of the multiple partial discharges respectively. Fig. 3 *A* shows that the case of two half waves, *i.e.*, the case of inductive pulses shown in Fig. 3 *C* of Part I, is most frequent and the quasi periodic damped oscillations with three cycles are also frequent. Hereafter the distribution decreases with the increase of the number of half waves. Thus it may be supposed that one simple weak dart-leader discharge with no appreciable pulsation current and no after glow radiates the single inductive wave form, but more strong single dart-leader discharges radiating the wave-form with several cycles may be considered to have more complex discharge structures. Figs. 3 *B* and *C* represent that the number of half waves decreases with the order of the discharges, which is contrary to the results reported by Schonland and others[9] in the case of the cloud to earth discharges. In the case of the dart-leader type cloud discharges the electric charge available for the processes is not much enough that the component dart-leader like discharges decrease their violences rapidly from stroke to stroke of the discharges, and the discharge mechanism becomes more simple in the course of them.

Figs. 4 A_1, A_2, *B* and *C* represent the distribution of multiple partial discharge intervals, the distribution of multiple cloud to earth discharge intervals, the variation of multiple partial discharge intervals with their order, and the distribution of multipe partial discharge intervals in different orders. The discharge interval distribution curves show that the most frequent values of multiple partial cloud discharge intervals of the order of 1 milli-second are much smaller than that of multiple cloud to earth discharge intervals but larger than those of stepped-leader intervals, hence the partial discharge seems to have different discharge structures from the other two. If the discharge intervals of the partial discharge are caused through the same mechanism as in the case of the cloud to earth discharge, the

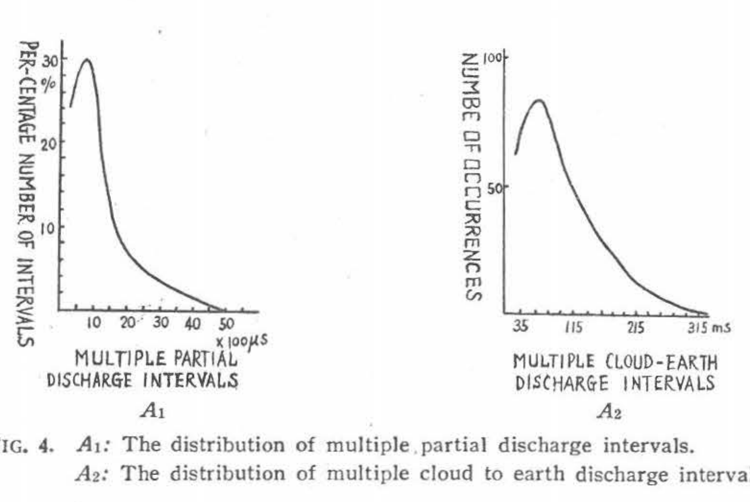


FIG. 4. A_1: The distribution of multiple partial discharge intervals.
A_2: The distribution of multiple cloud to earth discharge intervals.

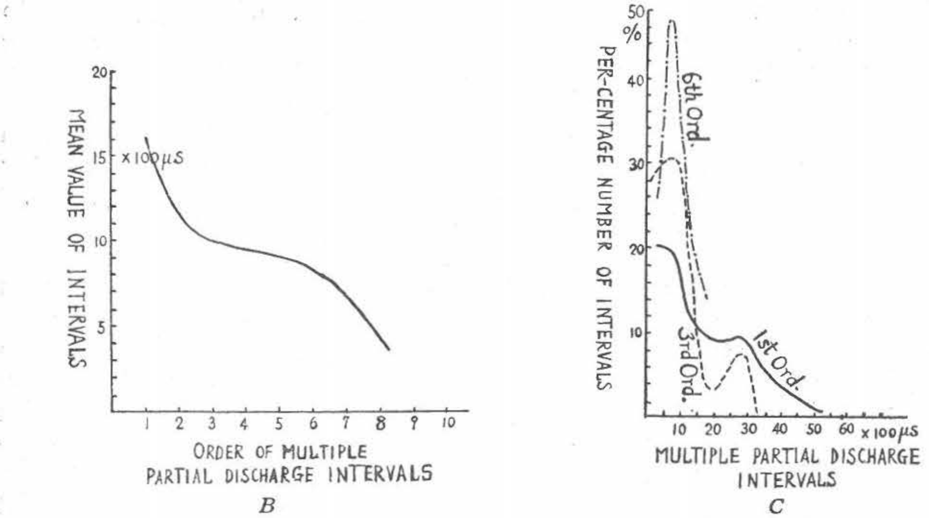


FIG. 4. *B:* The variation of multiple partial discharge intervals with the order of discharge strokes. *C:* The distribution of multiple partial discharge intervals at different orders.

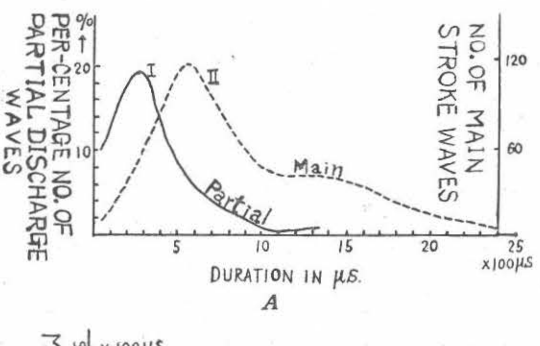
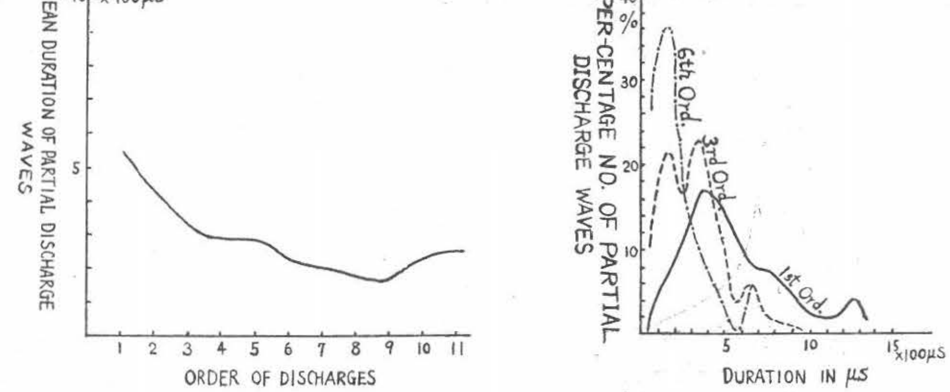


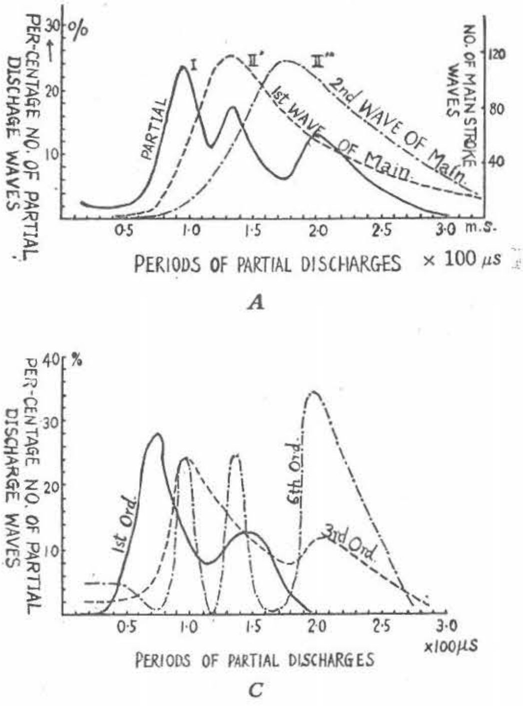
FIG. 5. *A:* The distribution curves of the durations of partial and main stroke discharges. *B:* The variation of mean duration with the order of multiple partial discharges. *C:* The distribution of multiple partial discharge durations in different orders.



small peak values of the distribution curve of multiple partial discharge intervals indicates that the electric charges contributing to a partial discharge are very little in this case compared to the case of the cloud to earth discharges. Figs. 4 *B* and *C* both represent that the length of the multiple partial discharge intervals decreases from component to component of the partial discharges, which also can be interpreted through the decrease of the intensity of the partial discharges with their order as already described in the case of Fig. 3 *B*.

Figs. 5 *A*, *B* and *C* represent the distribution of partial and main stroke discharge durations, the variation of mean duration with the order of multiple partial discharges, the distributions of multiple partial discharge durations in different orders respectively. In Fig. 5 *A* the curve II is reproduced for comparison from the data of the reference (5) and represents the case of main stroke duration, and the curve I represents the distribution of partial discharges. It may be concluded from these curves that the partial discharges in the thunder-clouds have much shorter durations than that of main stroke discharges, hence the former has much smaller and simpler discharge mechanism than the latter. The most frequent value of the duration is nearly 300 micro-seconds, which is a characteristics of the partial discharge wave forms, compared to 600 micro-seconds in the case of main discharge waves. Strictly speaking, however, it is difficult to classify all the resembling wave forms difinitely into these two groups. In practice there are a few cases in which the durations have the intermediate values, therefore it may be reasonable to consider that the main stroke type wave forms may include the partial discharges of longer durations and *vice versa* the partial discharge type waves may include the main stroke discharges of shorter durations. Never-the-less it can be discussed in the gross the nature of the partial and the main discharges from these distribution curves, because it consists only a small portion of the whole wave forms, which causes such a confusion. Figs. 5 *B* and *C* indicate that the duration of the component of the multiple partial discharges decreases from component to component, which may correspond to the decrease of the energies dissipated at each component discharges and to the simplfication of the discharge mechanism from one component to another. This is another point, which is contrary to the results obtained in the case of cloud to earth discharges by Schonland.[9]

Figs. 6 *A*, *B* and *C* represent the distribution of the periods of the multiple partial discharges, the mean period variations with the order of multiple partial discharges, the distribution of the periods of multiple partial discharge type wave forms. In Fig. 6 *A* the curve I represents the distribution in the case of multiple partial discharges and the curves II′ and II″ are reproduced for comparison from the data of the reference (5) and represent the periods of first and second waves of the main stroke type. It was observed also in the case of the partial discharge type waves that the periods are prolonged from cycle to cycle in a component oscillation, *i.e.*, the wave form is quasi-periodic. However, the quantitative determination of the variation of periods with the progress of the cycles could not be carried out, because the large time scale of the observed wave forms enabled us not to determine the small differences between them. Therefore the value of the period was obtained as the ratio of the duration to the number of cycles in a component partial discharge. It might be said from Fig. 6 *A* that partial discharge type waves have shorter periods than those of the main stroke type wave forms, which might indicate the shorter discharge channels in the case of partial discharges than in the case of main stroke discharges. It is not accurate whether there may be small peaks in the distribution curve I on the larger side of periods.



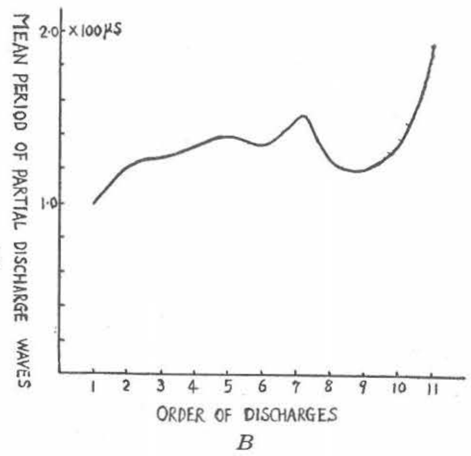


FIG. 6. *A:* The distribution of discharge periods. *B:* The mean period variation with the order of multiple partial discharges. *C:* The distribution of multiple partial discharge periods in different orders.

But the maximum at about 90 micro-seconds which appears 40∼90 micro-seconds to the left side from these main stroke curves evidently indicates that the partial discharge type wave forms have statistically shorter periods than those of main stroke type wave forms. Figs. 6 *B* and *C* show clearly that the periods of the waves of the multiple partial discharge type increase from component discharge to component discharge. This may be interpreted as to indicate the increase in the discharge channel length with the repetition of the small dart-leader like discharges or the increase of electrical resistances within the discharge channel, which may be caused from the decrease of the discharge energy from component to component in multiple partial discharges. It is not clear, however, whether the component wave forms of the partial discharge with typical quasi-periodic damped oscillations are produced by the dart-leader like discharges with pulsating currents accompanied by the gradual increase of the channel resistances as in the case of cloud to earth discharges indicated by Lutkin.[10] It seems rather probable to surmise that the initial portion of the quasi-periodic damped wave of the partial discharge component is produced from the dart-leader streamer and the succeeding tail portion of it is produced from the faint after discharge in the cloud that follows directly the leader streamer. The latter therefore be ascribed to the probable small discharges at the head or tail portion of the leader channels, which are produced just after the strong dart-leader streamer has grown up. This may probably be the same processes as those described by Schonland and his collaborators.[9] Hence the weak dart-leader streamer with no appreciable after-discharge would produce the wave form of the partialdischarge type with single inductive pulses.

4. Main Stroke Type Discharges

This type of wave forms was ordinarily not observed during the developing periods of the cloud, and therefore the mention will be made only briefly on these points. As already described in Part I of this paper the main stroke type have a smooth quasi-periodic damped oscillation wave form without any superposed small pulsations in the case of calm periods often in the morning. The typical wave forms in such cases have relatively large amplitudes and the durations, which are ordinarily larger than 1,000 micro-seconds in our observations as shown already in Fig. 2 *A* of Part I. Therefore it will be probably reasonable to consider that the waves of this type have come from the main stroke like discharge channels at fairly distant regions. On the occasions of thunderstorms the main strokes of the cloud to earth discharges radiate fairly the same wave forms as those of the typical distant main stroke type wave forms, if the small pulsations are neglected in the case of thunderstorms. The length of the quasi-periods is distinctly longer in the case of near thunderstorm wave forms than in the case of typical distant main stroke wave forms, which may be attributed to the propagation of atmospherics as reported by Norinder.[11] In these cases the typical wave forms of main stroke discharges are superposed by small pulsations as already illustrated in Fig. 2 *C* of Part I of this series, which might be produced for example from the small streaks at every folding point along the discharge channel in Boys' camera photographs of the lightning flashes.

There have been made no sufficient observations at present on these points just described, therefore the detailed discussions on these points shall be made in our furture report on the atmospherics wave forms from near thunderstorms.

5. Conclusion

It has been made clear from the above discussions that the stepped-leader discharge in the summer cumulo-nimbus has longer main step intervals than in the case of cloud to earth or air discharges, but otherwise there was observed no fundamental differences between these two cases. The intervals of the pulsations of the stepped-leader type wave forms, *i.e.*, the frequencies of the leader stroke wave forms spread out so wide range that one can not speak at least of the frequency distribution for them unless the characteristics of the pulses to be considered are designated.

The partial discharges in the cloud can be distinguished from the main stroke discharges in many respects, which indicate alike the littlenesses of these discharge energies. There remains, however, a little intermediate wave forms which may produce the confusions, therefore it may be reasonable to surmise that the main stroke type wave forms have the possibility to include dart leader like discharges in the cloud of relatively longer durations and *vice versa* the partial discharge type wave forms have also the possibility of including the weak main stroke like discharges of rather short duration as a typical main type. Never-the-less these confusing cases are not so often that it may be possible to discuss from the distribution curves the nature of the discharges produced within the thunderclouds.

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