WAVEFORM STUDIES OF ELECTRIC FIELD-CHANGES DURING CLOUD-TO-CLOUD LIGHTNING DISCHARGES

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Introduction

It is well known from the work of Simpson and his colleagues (1937–1942) that usually in a cloud-mass, there is a distribution of negative electrical charge with some positive concentration at the top. Based on the bi-polar nature of charge distribution in a cloud, Appleton, Watson-Watt and Herd (1926) showed that when there was positive charge above and negative charge below, the discharge between the two opposite charges would give rise to a positive net field-change at near distances and a negative net field-change at relatively large distances, there being a critical distance for zero field-change. These conclusions were later confirmed by Schonland and Craib (1927). The oscillographic records of the field-changes due to cloud-to-cloud discharges were perhaps for the first time obtained by Schonland, Hodges and Collens (1938), and they clearly mentioned that there was no evidence of return strokes in these waveforms. Lutkin (1939) described some cloud-to-cloud discharges. He pointed out that in the waveforms of his group 3, the sets of small isolated pulses of three half-cycles which were separated by very short quiet intervals were just what would be expected from discharges within the cloud, each discharge having a discontinuity in the current pulse. Some waveforms in Lutkin's group 2 were also attributed to discharges within the cloud. It was later pointed out by Schonland, Elder, Hodges, Phillips and van Wyk (1940) that Lutkin's waveforms of group 2 were to be identified with discharges of the stepped-leader type having no return stroke. They also suggested that Lutkin's waveforms of group 3 were very likely due to successive dart discharges within the cloud. They were also able to record the waveforms of Lutkin's group 2 and group 3. Pierce (1955) has mentioned that cloud-to-cloud discharges do not produce return stroke pulses.

Out of thousands of waveforms of atmospherics recorded during the course of our investigations, we have been able to find a large number of oscillograms which we can attribute to cloud-to-cloud discharges. The main considerations which have helped in deciding whether a particular oscillogram of the waveform is to be associated with a cloud-to-cloud discharge are as follows:

(i) In a discharge within a bi-polar cloud with a negative charge below and a positive charge above, the net electric field-change at some distance greater than the critical distance must be negative. For a cloud-to-ground discharge the net field-change at all distances is always positive.*

(ii) In the case of multiple strokes, the time-interval between successive strokes for discharges within the cloud is relatively much smaller than that for cloud-to-ground discharges. The time-interval between the

* A positive field-change is defined as the one which causes a positive charge to pass from the aerial to the earth or which, when an amplifier is employed, results in the appearance of a positive potential at the grid of the first valve due to the lightning discharge. The positive field-change can be indicated on the fluorescent screen of any particular oscillograph-unit.

successive strokes in cloud-to-ground discharges, as observed by various workers, lies in the range of about 30–200 milliseconds. The moving-camera observations of McCann (1944) revealed that the cloud-to-cloud discharges were sometimes multiple in character with shorter time-intervals between the successive components and with shorter total duration of flash than in the case of cloud-to-ground discharges.

It has been concluded that a cloud-to-cloud discharge has got all the features which are known to be associated with a cloud-to-ground discharge. These features are:

(i) Multiple strokes.
(ii) Return-stroke pulses with or without successive reflections from the ionosphere.
(iii) 'Predischarges' preceding the return-stroke pulse.
(iv) Slow field-changes and the 'hook'-components following the return-stroke pulse.
(v) Junction field-changes between the successive strokes.

In the case of a cloud-to-ground discharge, it is already established that the most rapid destruction of thunder cloud moment takes place during the return stroke, giving rise to an extremely rapid electric field-change in the form of an aperiodic or a *quasi*-periodic pulse. Such pulses have been termed return-stroke pulses. It appears therefore that the term 'return stroke' has a definite connotation and refers only to discharges to the ground. Since we have observed similar pulses appearing in successive multiple strokes in many oscillograms which we ascribe to cloud-to-cloud discharges from considerations of the sign of field-change and the time-interval between successive strokes, we have used the same nomenclature for such pulses in cloud-to-cloud discharges. We have also retained the same terms for the 'pre-discharges' originating in a leader stroke preceding the return stroke, for the *c*-field change and 'hook'-components and also for the junction field-change in the case of cloud-to-cloud discharges.

Experimental Results on the Waveforms due to Cloud-to-cloud Discharges

The waveforms of various atmospherics were recorded at Banaras during 1952–1955 both during the day and the night with the help of the Automatic Atmospherics Recorder, a brief preliminary account of which has already been reported (Tantry, 1952). The details of the Atmospherics Recorder, with a description of the different parts and of the special electronic circuit arrangements for the automatic recording of full and precise waveforms without overlappings, will be published elsewhere. The various waveforms observed in cloud-to-cloud discharges have been classified. Some details are given below:

(*a*) *Simple multiple strokes between cloud and cloud*

The waveforms showed a succession of simple multiple strokes from 2 to 7 in number separated by a quiet interval which varied from 0·5 to 2·5 milliseconds. A good similarity of the different strokes indicates that they must have originated in the same channel. The peak amplitudes of the strokes varied from 50 mV./m. to 0·7 V./m. and in most cases the waveforms showed an initial rapid negative field-change. As the distance of the source of atmospherics was always greater than the critical distance for the zero field-change, the negative sign of the field-change indicated that the discharge must be between a positive charge above and a negative charge below in a bi-polar cloud. The small time-interval of the successive strokes lent support to the conclusion that the strokes were of cloud-to-cloud origin.

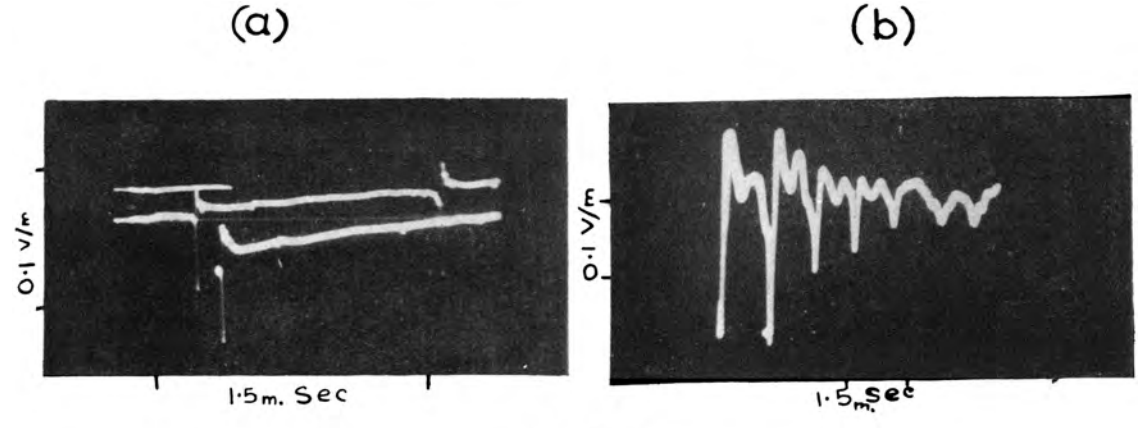


FIG. 1

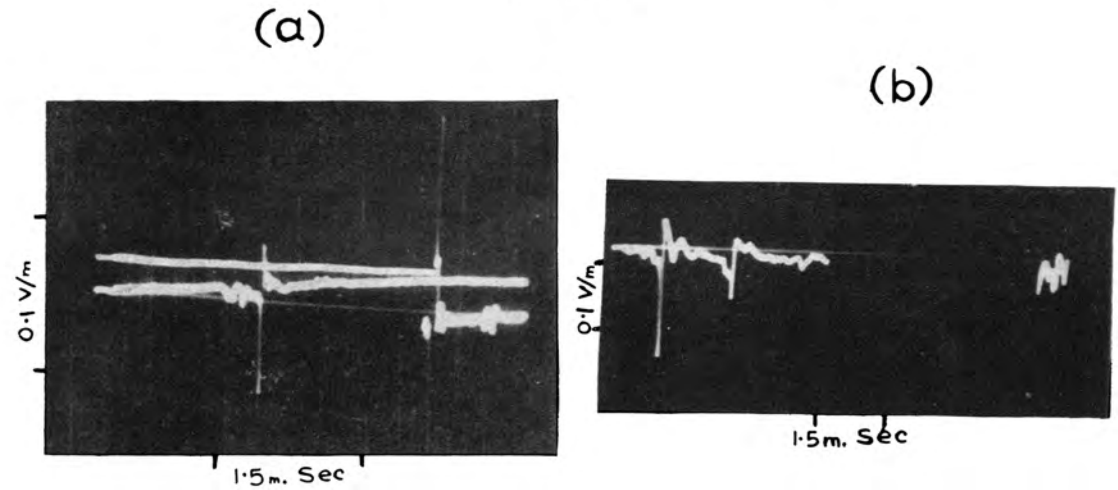


FIG. 2

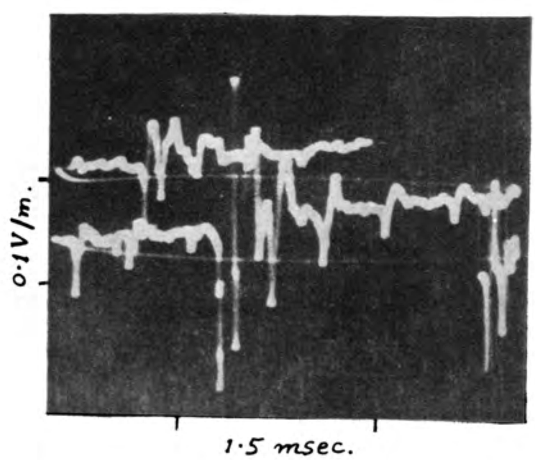


FIG. 3

Fig. 1. Simple multiple strokes between cloud and cloud. (a) 9-9-55, 11-20 p.m. (b) 11-8-52, 6-30 p.m.
Fig. 2. Cloud-to-cloud multiple strokes with 'predischarges'. (a) 9-9-55, 11-30 p.m. (b) 24-8-52, 11-30 p.m.
Fig. 3. Cloud-to-cloud multiple strokes with ionospheric reflections. 22-8-54, 11-15 p.m.

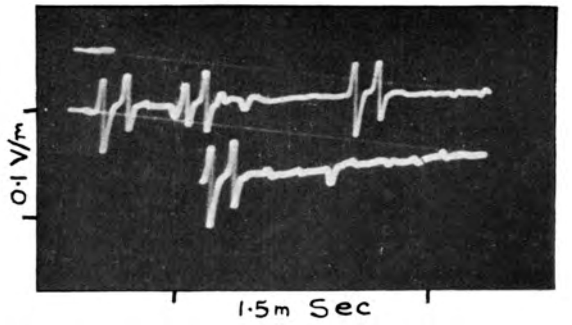


FIG. 4

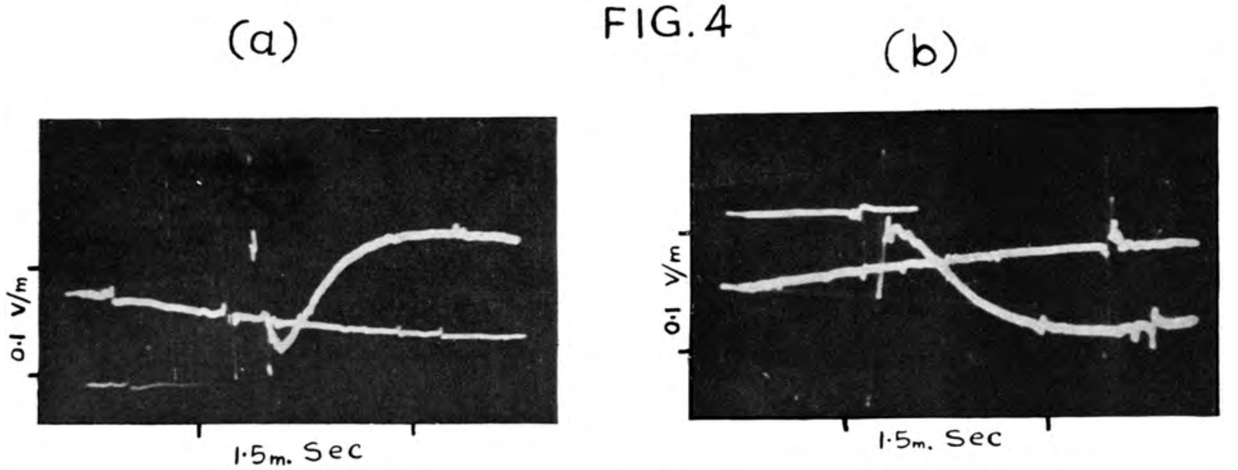


FIG. 5

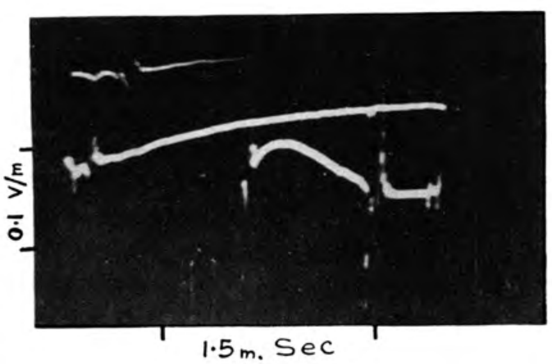


FIG. 6

FIG. 4. Cloud-to-cloud multiple strokes with twin pulses. 22-8-54, night.

FIG. 5. Cloud-to-cloud multiple strokes with c-field change and 'hook'-components. (*a*) 30-6-55, 9-50 p.m. (*b*) 14-8-55, 7-45 p.m.

FIG. 6. Cloud-to-cloud multiple strokes with junction field-changes. 30-6-55, 9-55 p.m.

Occasionally the initial pulse showed a positive field-change and this was considered as due to the discharge between the positive charge, occasionally observed at the base of the cloud and the negative charge in the cloud (Simpson and Scrase, 1937). The typical oscillograms showing simple multiple strokes between cloud and cloud are shown in Fig. 1.

(b) Cloud-to-cloud multiple strokes with 'predischarges'

Two representative oscillograms showing multiple strokes, each stroke having 'predischarges' followed by an aperiodic return-stroke pulse, are shown in Fig. 2. The observed negative pulses were characteristic of the discharges between the upper positive and the lower negative charges in a cloud. The amplitude of the aperiodic pulses varied from 50 mV/m. to 0·2 V/m. The 'predischarges' were irregular high-frequency pulses of much smaller amplitude. The 'predischarges' observed in cloud-to-cloud strokes must be associated with the stepped-leaders or with the branchings in the leader much in the same way as the 'predischarges' in the cloud-to-ground discharges.

(c) Cloud-to-cloud multiple strokes with ionospheric reflections

The oscillograms showing multiple strokes with successive reflections between the ionosphere and the earth were usually observed at night. Fig. 3 which represents one such oscillogram shows three successive strokes. It can be seen that, corresponding to each stroke, the aperiodic or *quasi*-periodic pulse associated with the return streamer is followed by a series of ionospheric reflections. The distance of the atmospherics as determined from the observed time-interval between successive reflections was about 430 Kms. The characteristic negative sign of the pulses and the small time-interval between the successive strokes indicated that the waveforms must be due to discharges in a bi-polar cloud with the positive charge above and the negative charge below.

(d) Cloud-to-cloud multiple strokes with twin pulses

These waveforms showed groups of pulses, usually two in number, each group being separated from the next one by a quiet period lying between 0·5 and 2·5 milliseconds. Usually there was an initial positive field-change. This suggested that the discharges were between the positive charge occasionally found at the base of the cloud and the negative charge above. Each group of the twin pulses appeared to be associated with each of the successive strokes. A typical oscillogram showing groups of twin pulses recorded in this laboratory is shown in Fig. 4. These waveforms are similar to those recorded by Lutkin (1939) in his group 3 and by Rivault (1945) in his type II.

(e) Cloud-to-cloud multiple strokes with c-field change and 'hook'-components

Typical oscillograms showing multiple strokes with the *c*-field change and the 'hook'-components are shown in Fig. 5. These oscillograms start with initial negative field-change indicating discharges in a bi-polar cloud with the positive charge above and the negative charge below. The subsidiary field-changes of small amplitude during the *c*-field change and even afterwards were called 'hook'-components by Malan and Schonland (1947). The amplitude-ratio of the return stroke pulse to the 'hook'-components was found to vary from 0·1 to 0·02 in all such oscillograms.

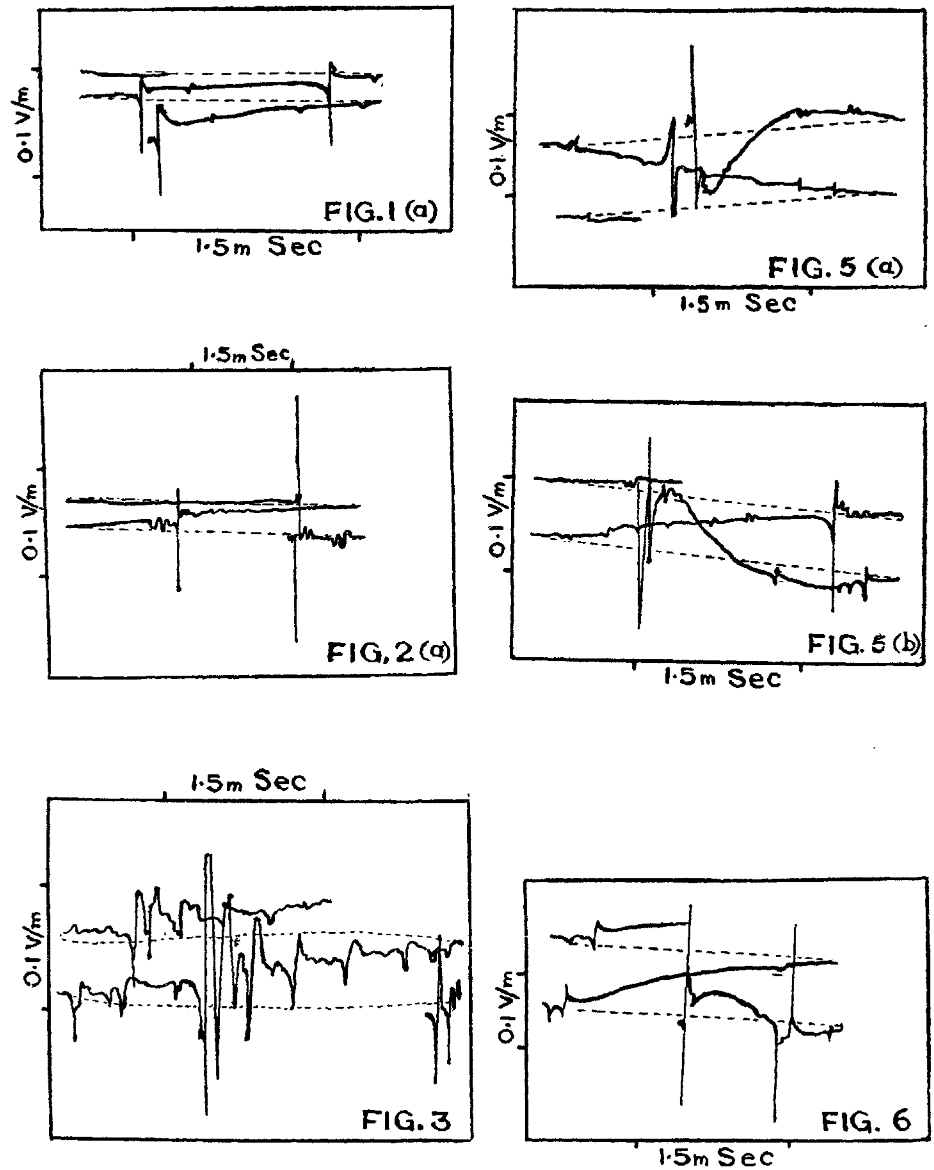
(f) Cloud-to-cloud multiple strokes showing junction field-changes

These oscillograms showed the presence of a very slow field-change, called the junction field-change, between the successive strokes of a cloud-to-cloud discharge.

A typical oscillogram is shown in Fig. 6. The initial negative field-change and the small time-interval between the successive strokes indicated that these oscillograms were caused by discharges in a cloud with positive charge above and the negative charge below.

The j-field changes in multiple strokes between the cloud and the ground were reported by Malan and Schonland (1951) and also by Pierce (1955).

As some of the oscillograms in Figs. 1–6 are not very clear in the prints, the traces of such oscillograms are shown in Text-fig. 1.



TEXT-FIG. 1. Tracings of the oscillograms shown in Figs. 1(*a*), 2(*a*), 3, 5(*a*), 5(*b*) and 6.

Conclusions

From the oscillograms of waveforms shown in Figs. 1–6 it can be said with some certainty that cloud-to-cloud discharges are similar to the cloud-to-ground discharges in respect of (i) multiple strokes, (ii) 'predischarges', (iii) return-stroke pulses with or without ionospheric reflections, (iv) *c*-field changes and 'hook'-components, and (v) junction field-changes. As has already been mentioned, the identification of an oscillogram caused by a cloud-to-cloud discharge is possible in many cases from (i) the sign of the field-change and (ii) the small time-interval between the successive strokes.

With regard to the *c*-field changes and the 'hook'-components, it is not possible to say whether the processes suggested by Malan and Schonland (1947) leading to these field-changes are the same in a cloud-to-cloud discharge as in a cloud-to-ground discharge. The junction-process in a cloud-to-ground discharge has been explained by Malan and Schonland (1951). It is premature to say whether a similar process would also explain the *j*-field change in a cloud-to-cloud discharge.

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Abstract

The sign of the electric field-changes during the lightning discharge and the relatively small time-interval (0·5 to 2·5 milliseconds) between the successive discharges in multiple strokes have enabled identification of the oscillograms showing waveforms originating from cloud-to-cloud discharges. A large number of oscillographic records taken at Banaras during 1952–1955 with the help of the Automatic Atmospherics Recorder constructed in the laboratory has revealed that the waveforms due to cloud-to-cloud discharges have features similar to those due to cloud-to-ground discharges in respect of (i) multiple strokes, (ii) 'predischarges', (iii) return-stroke pulses with or without ionospheric reflections, (iv) c-field changes and 'hook'-components and (v) junction field-changes. The relevant experimental results have been discussed and typical oscillograms showing waveforms due to cloud-to-cloud discharges are shown.

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