ATMOSPHERICS RADIATION FROM LIGHTNING DISCHARGES

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Abstract.

To see the mechanism of radiation from a lightning flash, we observed atmospherics in the frequency range of 0.1 to 500 Mc/s under thunderstorm conditions. Within the distance of 30 km from the origins, the intensity of atmospherics from a discharge is of the order of 0.1 v/m at 100 kc/s in case of band width 10 kc/s. With the increase of receiving frequency, the intensity decreases roughly in inverse proportion to the frequency, but in the range higher than about 3 Mc/s it seems to decrease more rapidly and show comparatively larger fluctuations than in the lower range. The radiation from a discharge is usually composed of many intermittent pulses individually associated with electrostatic pulses, though it sometimes includes some long radiations such as continuing over 0.1 s especially in the close vicinity of origins. The first leader of a ground discharge is one of the most powerful radiation origins in any frequency, but the return process does not always show a large intensity in the range higher than 10 Mc/s.

1. Introduction.

The nature of atmospherics radiated from nearby origins is a very interesting subject to investigate in the study of the mechanism of lightning discharges as well as it is important to analyze atmospheric disturbances on radio communication systems. Up to this time the atmospheric noise due to lightning flashes in sight has often been observed by many workers in receiving at HF and VHF band and even at radar operations. However, atmospherics in such a high frequency range have not always been measured systematically under thunderstorm conditions except for Malan's qualitative investigation[1] in the range from 3 kc/s to 12 Mc/s.

We have continued for about ten years observations of several kinds concerning thunderstorm phenomena, such as photographic and photoelectric measurements of lightning flashes, measurements of electrostatic and electromagnetic field variations up to LF band. Last summer we started on the systematic observation of atmospherics at the frequency ranging from LF to VHF band. In the present paper some general results will be described. The detailed relation between the atmospherics intensity and the lightning discharge process is now being examined and will be presented in our next report.

2. Observation method.

The construction of the apparatus is schematically shown in Fig. 1. To observe electric disturbances accompanying lightning discharges, four systems of antenna and amplifier are utilized in accordance with the respective frequency ranges. Two vertical antennas are for taking the so-called slow and fast antenna oscillograms, which are detected by the resistance and condenser method with time constants of 10 s and 1 ms. They cover the ranges respectively from 0.1 to 1000 c/s and from 1 to 100 kc/s. These two observations have long been carried out, and consequently we now have considerable knowledge about the correspondence between the waveform of electric field changes and the lightning mechanism. The details of the two recorders have already been published, [2][3] and Fig. 1 shows only a part directly related to the present report.

The intensity of individual atmospherics is measured with two receivers, which cover the frequency ranges respectively from 0.1 to 28 Mc/s and from 27 to 500 Mc/s. The respective amplifiers have different band widths of 10 and 80 kc/s, and the quasi-peak detectors also have different response times : the chage time constants are 1 and 0.12 ms, though the discharge time constants are the same, 600 ms, in both. The differences must be taken into account at the time of comparing results of the two receivers. The antenna used in the lower frequency receiver is of a vertical whip type of 2 m length, while in the higher frequency receiver a vertical dipole of half wave length is used. Both are undirectional in the horizontal plane.

We use at the same time two recording systems : a 6-element pen-writing oscillograph and a dual beam cathode ray oscillograph. The former gives us an individual quasi-peak value of atmospherics in reply to every lightning flash. Flashes usually take

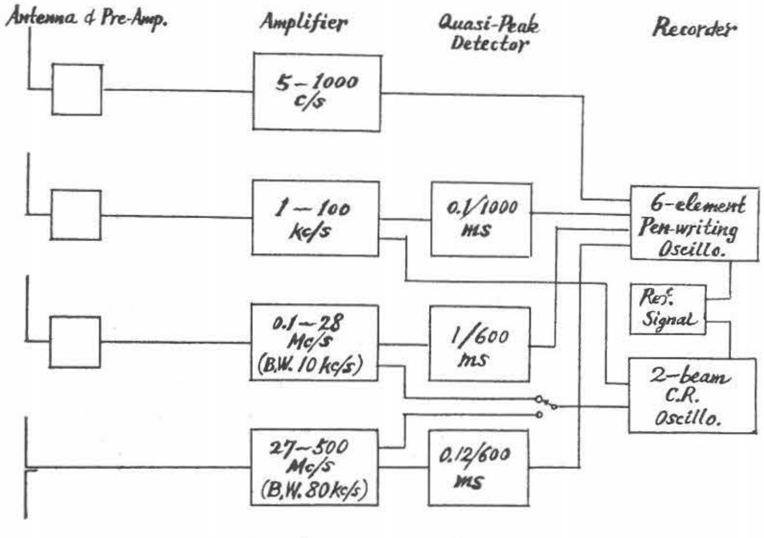

Fig. 1. Construction of apparatus

place with time intervals of at least several seconds, and so the response of the pen of 20 c/s and the moving velocity of the recording paper of 1 mm/s are adequate to separate one by one all the deflections of atmospheric intensitise. Fig. 2 is an example of pen oscillogram. The latter system is used to record the detailed structures of high frequency atmospherics and to treat them in connection with the discharge mechanism. Two bright spots on a dual beam C. R. T. screen simultaneously draw, side by side, the appearance of high frequency atmospherics and the fast antenna oscillogram by which we can find the situations of discharge processes. Examples of the records are shown in Figs. 7 and 8.

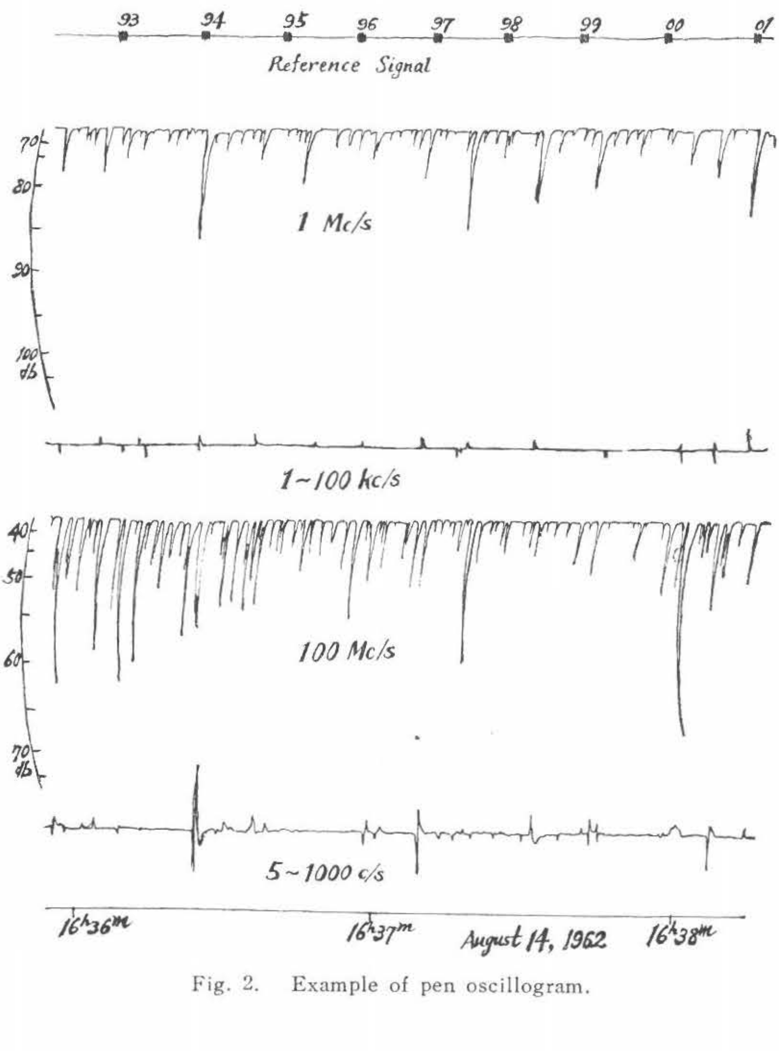

Fig. 2. Example of pen oscillogram.

3. Intensity of high frequency atmospherics.

Fig. 3 shows a statistical result on the intensity of atmospherics received within the listance of 30 km from thunderstorms. We equip only two receivers in these frequency :anges. To obtain such a curve in Fig. 3 as to show the relation of intensity to frequency, therefore, we must change many times the tuning frequency of receiver in the :ourse of a thunderstorm. The activity of storm itself and the distance from station to storm should of course vary with the lapse of time and affect the intensity of individual atmospherics recorded by us. Curves in Fig. 3 may possibly be obtained by connecting ntensities of atmospherics received under somewhat different conditions. If possible, it s desirable to measure a discharge simultaneously at many points of frequency with nany receivers. As will be shown below, however, the relation of radiation energy to requency is so complicated and altered according to the conditions of discharge that such a curve is available in a statistical meaning only.

The data given in Fig. 3 were obtained under three thunderstorms, which were not so active which fact accounted for the low percentage of the occurrence of ground lischarges — only several percents of all discharges. The curves are shown divided into he earlier half (three connecting black circles) and the later half (three connecting white :ircles) of the storms, but the difference associated with the storm development seems 1ot to be found. The three storms we observed continued their activities for about hree or four hours, and so several stormcells should have come into existence by turns n the course of a storm development. However, it is difficult to resolve a storm activity nto several individual cells and to find the situation of high frequency radiation in

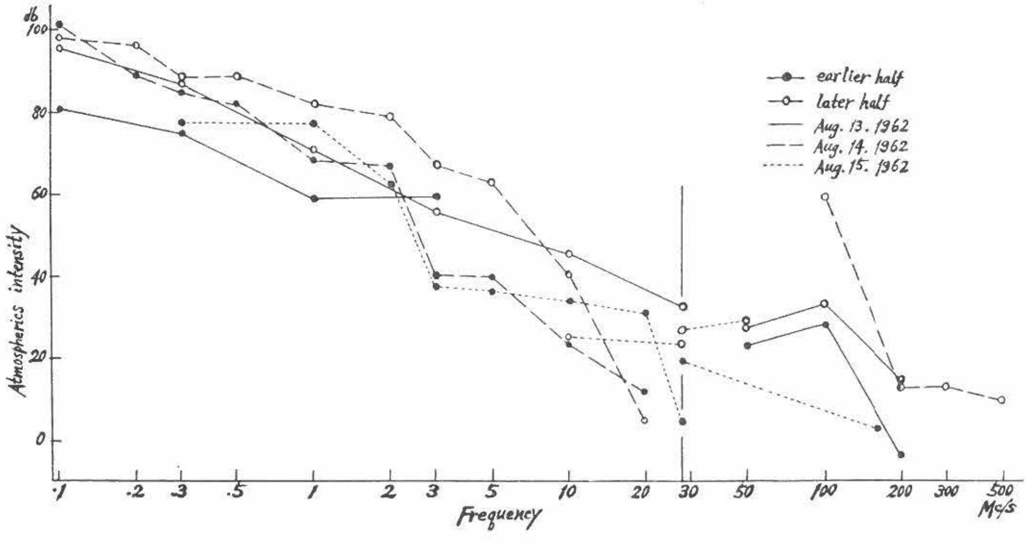

Fig. 3. Relation of atmospherics intensity to frequency.
(O $db=10^{-8}vm^{-1}(c/s)^{-\frac{1}{2}}$)

reference to the cell development, because we have no available means for locating exactly each discharge point under the present condition. The abscissa in Fig. 3 shows receiving frequencies and the ordinate shows quasi-peak values of atmospherics which are converted into a unit receiving band width. Within a certain narrow frequency band width the radiation from a lightning flash may be thought to have the characteristics of random noise, the energy of which is proportional to the band width. Each value is given as the mean of all the two largest deflections recorded in each minute of the respective half period of a storm.

The characters of curves shown in Fig. 3 are as follows. The field intensity of atmospherics at 100 kc/s reaches the order of about 0.1 v/m in case of the band width 10 kc/s. The intensity decreases monotonously with the increase of frequency : it is roughly in inverse proportion to the frequency, but often decreases more rapidly in the range higher than about 3 Mc/s. The tendency of the rapid decrease is not always expected through the attenuation to result from the dielectric characters of the earth surface,(4) because the origin of radiation should have the height of several kilometers, which is by no means so much smaller than the horizontal distance, at most 30 km, between the origin and the receiver in the present case. It seems to be nothing other than the nature of lightning discharge itself. In connection with this there is found another tendency that the intensity at frequencies higher than 10 Mc/s shows much larger fluctuations than in lower frequencies. These may be connected with the following assumption : if the lightning spark channel acting as a sending aerial is effectively shorter in length in higher frequencies than in lower frequencies, the direction of the effective spark channel in space as well as the polarization of electromagnetic wave received on the earth surface will become more arbitrary with the increase of frequencies. In the range higher than 200 Mc/s we sometimes could not detect any radiation based on lightning discharges because of the comparatively high internal noise level of the receiver, which point is not shown in the figure. It must be noted that the intensities in the frequency range higher than 100 Mc/s shown in Fig. 3 are not always applicable to all the thunderstorms.

At 28 Mc/s, the boundary between the covering ranges of the two receivers, the curves on both sides are somewhat in discord with each other. The reason is of course in the difference between the respective time responses of detectors. If the atmospherics in these frequencies are appreciably contributed by many local discharge processes in a cloud, which cause individually electrostatic pulses or K changes, the response time 1 ms of the lower frequency receiver will rather be too large to compare with the duration of each local process of about 0.2 to 0.5 ms.(5)

Now it is known by referring to C. R. oscillograms what sort of lightning discharge really gave a deflection on a recording-paper. Fig. 4 shows examples of the correlation between the atmospherics intensities coincidently measured with two receivers at respective frequencies. Each point corresponds to a lightning discharge. The correlation is not good in spite of the fact that all points in a figure are based on the data recorded for only about five minutes, during which the activity of a storm seems not to be

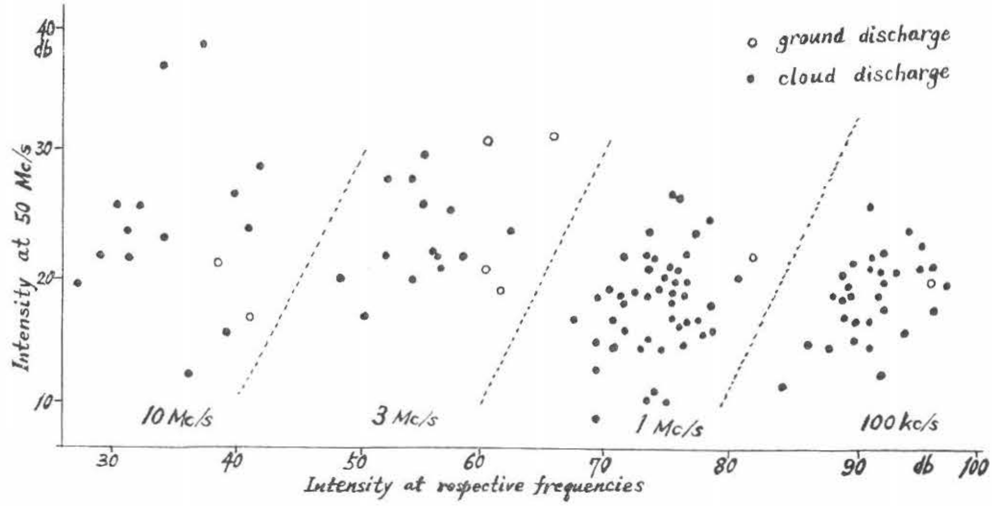

Fig 4. Correlation between atmospherics intensities measured at 50 Mc/s and at respective lower frequencies. (O db $=10^{-8}vm^{-1}(c/s)^{-\frac{1}{2}}$)

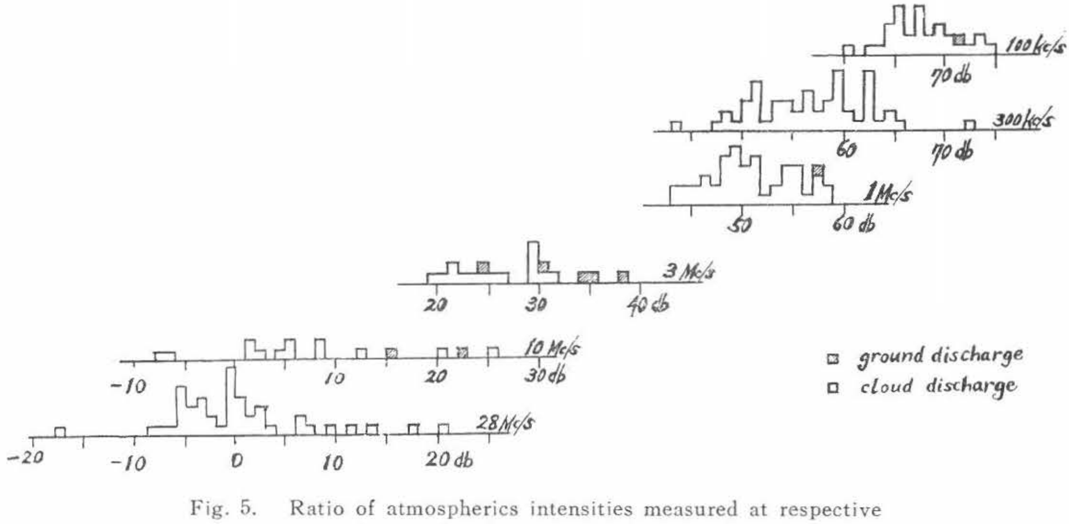

Fig. 5. Ratio of atmospherics intensities measured at respective lower frequencies shown in the figure and at 50 Mc/s.

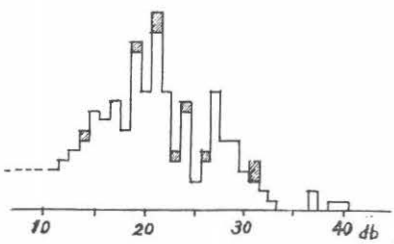

Fig. 6. Atmospherics intensity at 50 Mc/s. (O db $=10^{-8}vm^{-1}(c/s)^{-\frac{1}{2}}$)

appreciably altered. It is inferred that the relation of radiation field intensity to frequency is considerably altered according to the condition of individual discharge. Fig. 5 shows the distributions of the ratio of atmospherics intensity recorded at the respective frequency shown in the figure to that recorded coincidently at 50 Mc/s. We find also in Fig. 5, as well as in Fig. 3, that the decrease of field intensity of atmospherics with the increase of frequency is larger in the higher frequencies than in the lower. Fig. 6 shows the distribution of field intensity at 50 Mc/s, which we adopt as a standard to compare the intensities at the respective frequencies in Fig. 5. The area shown with hatching in Figs. 5 and 6 corresponds to ground discharges. Although the occurrence of ground discharges is not so frequent, we clearly see in Fig. 5 that ground discharges in the range of lower frequency radiate the larger energy than in the case of cloud discharges. In other words, ground discharges are distributed in the larger intensity range than cloud discharges up to 10 Mc/s, but the difference of distribution ranges becomes smaller with the increase of receiving frequency, and at 50 Mc/s, as shown in Fig. 6, both have almost the same distribution.

4. Atmospherics radiation and discharge process.

Figs. 7 and 8 are respectively examples of ground discharges and cloud discharges recorded with a dual beam C. R. oscillograph. Each gives a set consiting of records of high frequency radiation on the left side and waveform of electric field change caught with a fast antenna on the right side. The frequency used in receiving is given below each record in the figures. The high frequency radiation is detected with a short time constant before it is supplied into the C. R. oscillograph. Therefore, the intensity of radiation field is not absolutely decided corresponding to individual short electrostatic changes included in a lightning flash, but relative intensities between every stage of a discharge process are estimated to some degrees. As the duration of extremely short impulsive radiation is not correctly measured, it is difficult to see, as an instance, which part of an electrostatic pulse particularly contributes to the radiation. In spite of these defects, the qualitative natures of radiation may generally be summarized as follows.

1) The radiation from a leader process of ground discharge is remarkble in any frequency. It is always marked even at the time when the waveform of electric field does not show any change because of an insufficient recorder gain. Three stages found on the first leader field change, B, I and L,[6] are also recognized on the record of high frequency radiation. Usually the intensities of them are the largest in L stage, and evidently weak in I stage. The radiation of dart leaders guiding subsequent strokes to ground is not essentially distinguished from that of J process filling up an interstroke period especially at higher frequencies.

2) A return stroke seems to cause rather more intensive radiation fields than its preceding leader stroke at the frequency lower than 1 Mc/s. But the duration of a return stroke is very short, and so it is difficult to pick out the return stage on radiation records only. In the range higher than 10 Mc/s, the radiation of a return stroke is usually indistinguishable from that of the preceding leader.

3) After the completion of a return stroke, the radiation often takes a rest for about 5 to 20 ms, as Malan[1] found in his records. No correlation is found between the order of strokes to ground and the duration of the rest time. The J process seems to

start its progress after waiting for the regeneration of electric field dissipated by the preceding return stroke. However, this fact of the rest time does not always mean that an interstroke period is wholly occupied by continuous radiation noises except for this rest time. It is often occupied especially at lower frequencies by several intermittent short pulses which actually correspond to small electrostatic pulses or K changes.

4) We formerly confirmed that the process of an intracloud discharge has a likeness to J process developing between strokes of a ground discharge and that it is generally composed of a slow J-like streamer and many rapid local streamers.[5] In case of receiving at high frequencies, continuous radiations which seem not to depend upon any process like a stepped leader are observed as well as intermittent radiations. When a lightning flash takes place within the distance of about 5 km from the station, the continuous radiation with the duration exceeding 0.1 s is often recorded, and the electric field usually shows complicated variations for a long time. But it is not infrequent that a continuous radiation is not accompanied with any appreciable field change. (Refer to Fig. 8—2) If we could photoelectrically observe the flash luminosity together with the high frequency radiation, we might find a good correlation between the continuous luminosity and the continuous radiation.

5) An impulsive radiation always happens whenever any electrostatic pulse is recognized on the field change waveform. The beginning time of such a radiation accords with that of an electrostatic pulse, though this is not exact. Impulsive radiations, furthermore, often happen when we find no appreciable change on the electric field. Intensities of impulsive radiations accompanied with electrostatic pulses are not always larger than those not accompanied with pulses : we do not see in this case either a good correlation between the intensities of radiation and the magnitude of electric field change. In the earlier stage of a complete discharge process many impulsive radiations are observed without being accompanied with any electric change, but in the later stage the mutual relation of both occurrences becomes better than the earlier, since radiations gradually come to happen more scatteredly.

6) With increasing frequencies, the intermittent impulsive radiations come gradually to sink into the continuing radiations. However, we can still see them often associated with electrostatic pulses at the frequency higher than 100 Mc/s.

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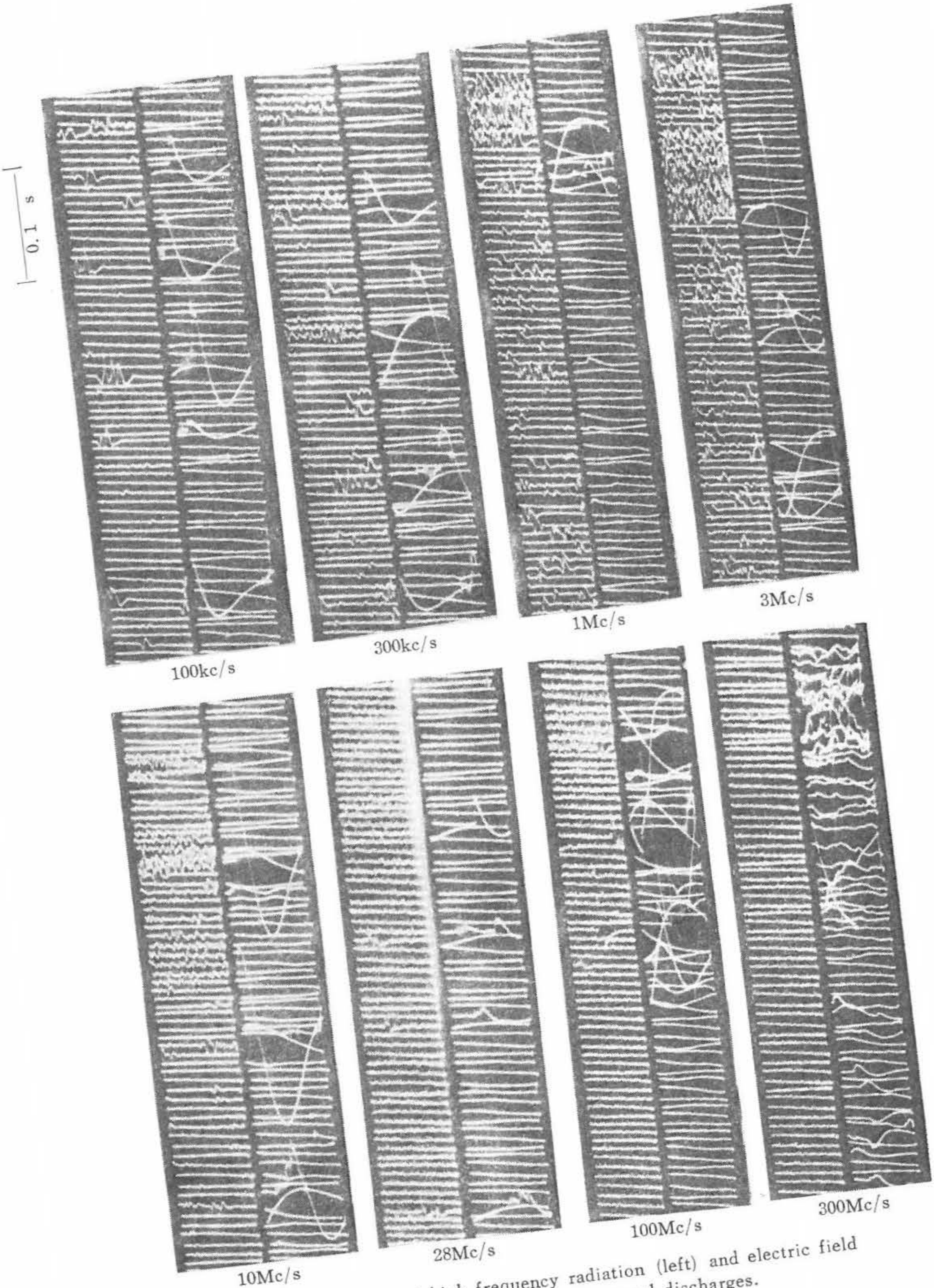

Fig. 7. Records of high frequency radiation (left) and electric field change (right) accompanying ground discharges.

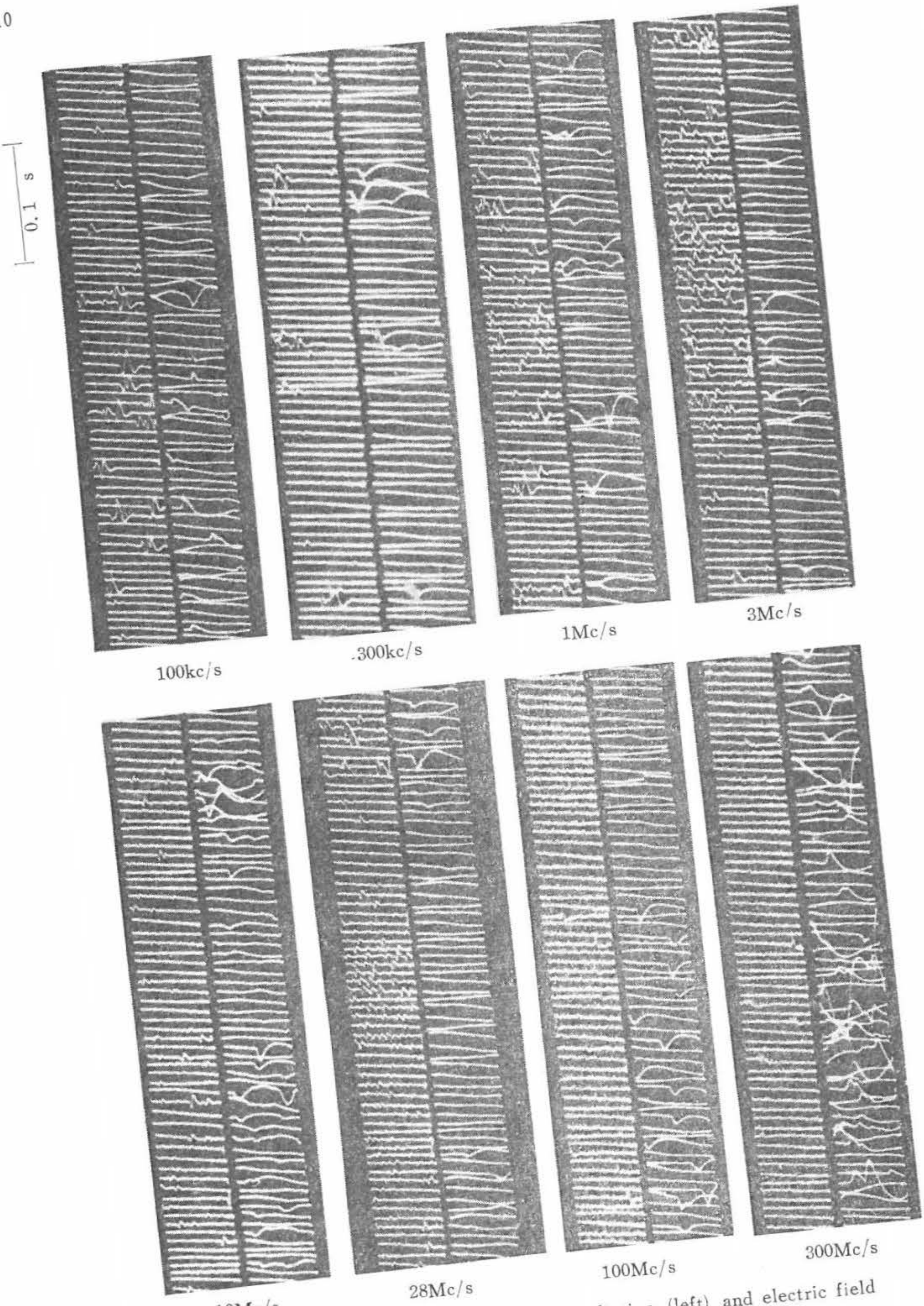

Fig. 8-1. Records of high frequency radiation (left) and electric field change (right) accompanying cloud discharges. (Examples of intermittent radiation)

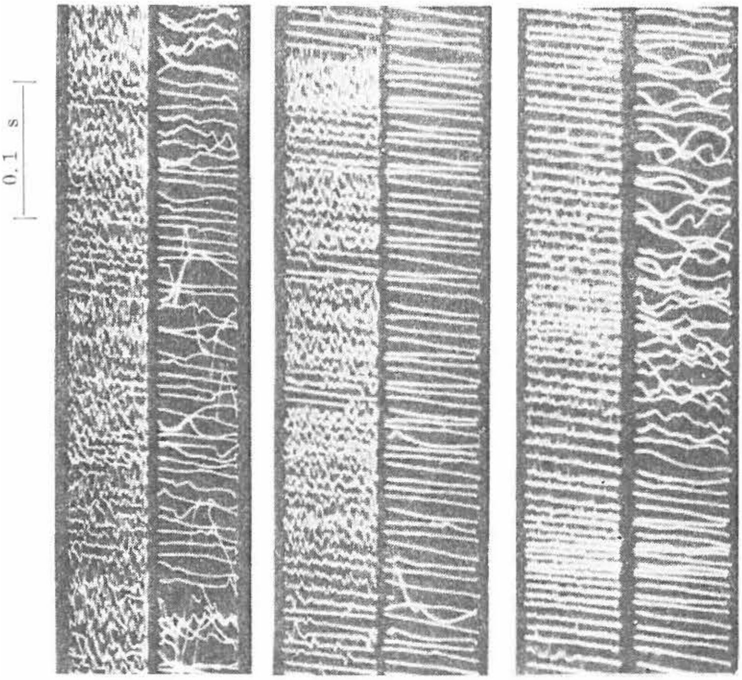

Fig. 8-2. Records of high frequency radiation (left) and electric field change (right) accompanying cloud discharges.
(Examples of continuous radiation)

References.

(1) Malan, D. J.: Recent Advances in Atmospheric Electricity, 557 (1958).

(2) Takagi, M. and Ishikawa, H.: Proc. Res. Inst. Atmospherics, Nagoya Univ. **4**, 48 (1956).

(3) Takeuti, T.: Proc. Res. Inst. Atmospherics, Nagoya Univ. **9**, 1 (1962).

(4) Namba, S. and Maeda, K.: Propagation of Electric Wave, 203 (1940). (in Japanese)

(5) Takagi, M.: Proc. Res. Inst. Atmospherics, Nagoya Univ. **8B**, 1 (1961).

(6) Clearance, N. D. and Malan, D.J.: Quart. J. R. Met. Soc. **83**, 161 (1957).