ON THE ATMOSPHERICS FROM A SUMMER CUMULO-NIMBUS

PART I. THE CHANGE OF DISCHARGE TYPES IN THE LIFE OF A SUMMER CUMULO-NIMBUS

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Synopsis—It has been made clear in this paper that the prominent wave forms of atmospherics radiated from a summer cumulo-nimbus changed its characteristics as the growth of the cloud, and the conclusion has been deduced from these observed facts that: the weak discharges in the cloud produce atmospherics of dart-leader or partial discharge type, when the electric charge accumulation reaches to a certain minimal energy level to produce them in accordance with the growth of the cloud, and further development of the cloud produces the moderate cloud discharges, which radiate the atmospherics of stepped-leader or predischarge type, then the strong discharges, which may be recognized as to form a thunderstorm under appropriate conditions, therefore must be considered to include both discharge types, *i.e.*, the strong dart-leader type cloud discharges and the cloud to earth discharges in a thunderstorm. The atmospherics at this stages can be recognized as the main-stroke type.

1. Introduction

A mass of lower warm and wet air is brought into upper cold and dry region of the atmosphere by a rising air stream along a kind of discontinuity surface caused by some disturbances in the atmosphere, there will be produced fragments of cloud, and the continuation of these processes will bring the cloud to grow up to a cumulo-nimbus scale. During the formation of the cloud the physical processes to which the water drops may be subjected as constituting elements of the cloud, *i.e.*, drop breaking and freezing processes,[1][2] produce the separation of static electricities and the energies of the separated charges are accumulated gradually in the cloud as its growth proceeds. If this electric energy reachs a certain level that is enough to discharge through a certain mechanism, the small discharges may appear and hence there may be the weak emission of electromagnetic-waves, *i.e.*, atmospherics. As the energy accumulation through the charge separation processes proceeds, the discharge intensity may also become stronger, accordingly the atmospherics intensity, *i.e.*, radiation energy per unit time from the cloud. Then the energy accumulation through charge separation processes and the energy dissipation through discharge processes may become to balance, which may be recognized as a steady stage of a thunderstorm, if the level attained is high enough, but one may observe only a group of cumulo-nimbi grown up to a certain dgree, if the level is not high enough. In these stages the atmospherics radiations become most prominent and the wave form indicates to have the characteristics of the thunderstorm. Then finally the energy accumulation ceases gradually by the stopping of the ascending air stream and the discharge indensity also decreases accordingly, which may result in the emission of the atmospherics chararcteristic of the end period of a thunderstorm.

As to the problem, whether the cumulo-nimbus in growth radiates a special wave form of atmospherics that precedes the summer thunderstorms, there have been made only a little studies to the present time. Recently Norinder reproted the wave form of snow-squalls that accompanied thunderstorms[3] and concluded that the cumulo-nimbus constituting snow-squalls radiate a special type of wave forms, which can characterize them. Hence we might be able to predict the development of a snow-squall that accompanies thunderstorm. In this respect it is a interesting problem to analyse the wave forms of the atmospherics from summer cumulo-nimbus in development that precedes a thunderstorm. Therefore an attempt was made to discuss in the following sections the atmospherics wave forms radiated from the definite cumulo-nimbi, which appeared on several days in seccession during the summer thunderstorm observation period and which did not develop to clear thunderstorms but to certain different stages of the development fitted for the wave form analysis.

2. Apparatus Used and Method of Observation

The atmospherics observations under thunderstorms were carried out during the last summer 1952 at the city of Maebasi—roughly one hundred kilometers northward from Tokyo—, where is known as one of the most frequent occurrence districts of thunderstorms in Japan. In the case of over-head thunderstorms the atmospherics wave forms and the corresponding thunderbolts were simultaneously photographed by a portable atmospherics wave form recording instrument and three Boys' camerae of each different types both prepared recently in our institute, and in the case of moderately distant thunderstorms the wave form and the corresponding flash light were observed by a photographing method and a visual method respectively. The portable wave form recorder has been constructed to produce the wave form directly on the fluorescent screen of a cathode-ray oscillograph, *i.e.*, so called E method, which was provided with a starting circuit and a cathode-ray spot brightness control circuit devices. Through these devices it was made possible to select the suitable amplitudes of the waves to start the cathode-ray spot on the fluorescent screen. The wave figure on it was photographed by a 35 mm camera of Leica type through the waiting method operated by eye and hand. The maximum gain of the amplifier was about 85 db., which was provided with gain dividers of 4 stages each in 10 db. step, therefore the resultant gain of the instruments could be varies from 65 db. to 25 db. in 10 db. steps. The drops of the frequency characteristics curve were compensated by a shunt peaking method and the gain was cutted off at about 350 kilocycles to the higher frequency side. Therefore the amplifier gain was sensibly flat in the frequency range of 0.1 to 100 kilocycles. Vertical antennae of the height of 6, 3 and 0.3 meters were used, so as we could record the atmospherics of amplitudes ranging from 0.01 to 100 v/m. The Boys' camerae were designed each to have different characteristics, *i.e.*, ordinary Boys' camera of low speed type, twin Boys' camera of medium speed type, and rotating mirror Boys' camera of high speed type all driven by moters. According to our experiences the medium speed twin camera was found to be the most appropriate one to the thunderbolt recording at the district as in Japan.

The thunderbolts of this summer were not so strong as those reproted by Schonland[4] in tropical Africa,[5] that they could be photographed accurately only by medium and slow speed camerae.

3. Wave Forms in the Life of a Summer Cumulo-Nimbus

During the thunderstorm observation in the last summer, there were several days, in which the atmospherics of special wave forms were observed very clearly and only a single composed, large definite cumulo-nimbus had developed in the field of vision, so that there remained no doubt about the fact that these atmospherics came from this cloud. Small cumulo-nimbi generated in succession along the ridge lines surrounding the plain of Maebasi in the forenoon, moved slowly towards the direction of the lower plain reaches of the river Tone, in the afternoon, then gathered gradually and composed to a large definite comulo-nimbus in the later afternoon floating above the lower plain reaches at distances from twenty to thirty kilometers from the observation station, which is shown in Fig. 1 and Photo. 1. At this stage there was observed visually no trace of cumulo-nimbus

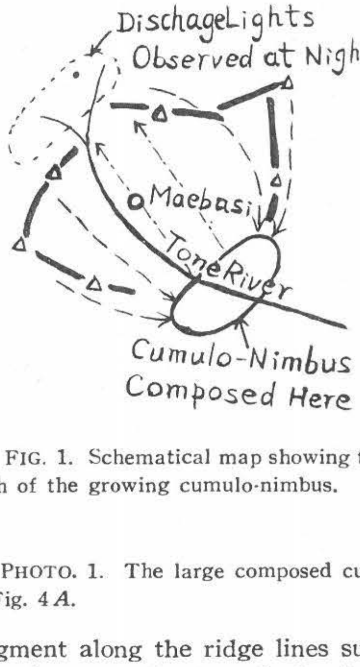


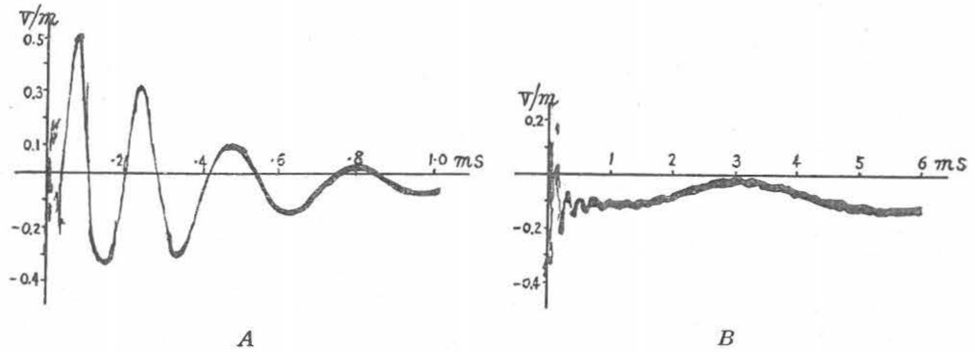
FIG. 1. Schematical map showing the path of the growing cumulo-nimbus.

PHOTO. 1. The large composed cumulo-nimbus emitting the atmospherics of the wave form in Fig. 4*A*.

fragment along the ridge lines surrounding the plain of the observation station, thus there remained no doubt about the fact that the recorded special type atmospherics at a lower gain of the instrument had come from the above large definitely isolated cumulo-nimbus.

This cloud with atmospherics emission then reversed its direction of motion flying over-head towards the upper streams of the river and covered the west-north-western ridge lines by about one hour before the sunset. Moreover in such a day when the composed cloud was large enough, the discharge lights without no audible thunder within the cloud were observed clearly after the sunset and the identification of the particular atmospherics with the definite discharge lights was established without any difficulty.

The atmospherics wave forms photographed throughout this period can be roughly classified into the following three typical types: The main stroke type[6] or Group I reported by Lutkin;[7] this has a wave form of quasi-periodic damped oscillation, and has most frequently the duration of more than 600 micro-seconds, which is longer than that of the dart-leader or partial discharge type from the statistical stand point of view. This type is said to be produced from the return stroke of a cloud-earth discharge, but it seems from our observation also to be produced from a strong dart-leader type like partial cloud discharge,[8] which radiates the atmospheric of main stroke like wave form with rather a longer duration as a partial discharge. Figs. 2*A* and *B* show the typical wave forms of main stroke type photographed at two different time scales, and Fig. 2*C* shows the case in



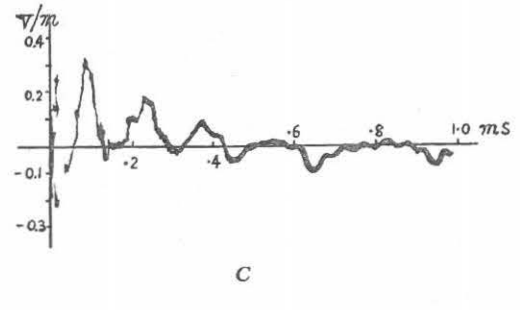
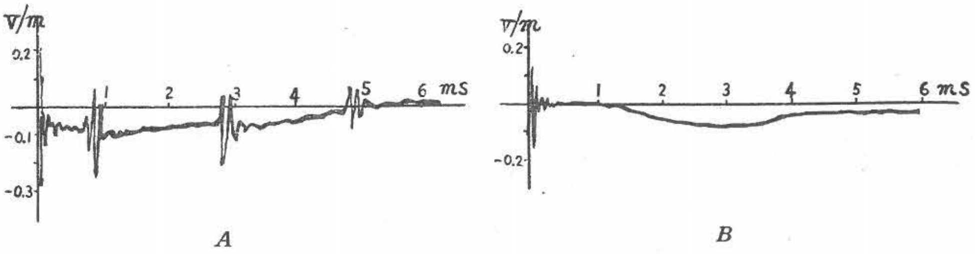


FIG. 2. *A:* The typical wave form of the main stroke type. *B:* The typical wave form of the main stroke type. *C:* The typical wave form of the main stroke type from the near discharging origin.

which the main stroke type wave is superimposed by small irregular disturbances of higher frequencies, which indicates that the discharges come out at near distances from the station. Secondly the partial discharge type,[5] dart-leader type,[8] or Group III reported by Lutkin,[7] this has also a wave form of quasi-periodic damped oscillation, but the most frequent value of its duration of about 200 micro-seconds is distinctly less than that of the main stroke type. This type occurs frequently in succession sandwitched between intervals ranging roughly from 1 to 2 milli-seconds, and may come from the weak dart-leader like discharges between or within the charged clouds. Fig. 3*A* shows the typical case of the partial discharge type wave forms, and Fig. 3*B* shows the case in which the wave is composed of a single partial discharge with appropriate intensity, finally Fig. 3*C* illustrates those case in which each partial discharge components were constructed from the single pulses, which may be obtained through single differentiation operation of a sharp half wave, in contrast to the component wave forms of Fig. 3*A*. Finally the stepped-leader type,[8][6] Group II type reported by Lutkin,[7] precursor,[9] or predischarge



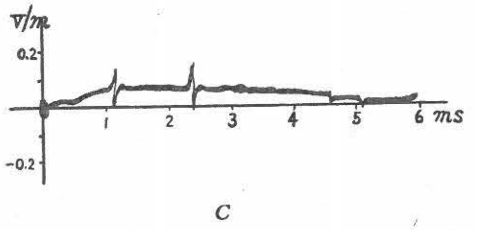


FIG. 3. *A:* The typical wave form of the partial discharge type. *B:* The partial discharge type wave with single component. *C:* The small partial discharge type wave composed from the single pulse components.

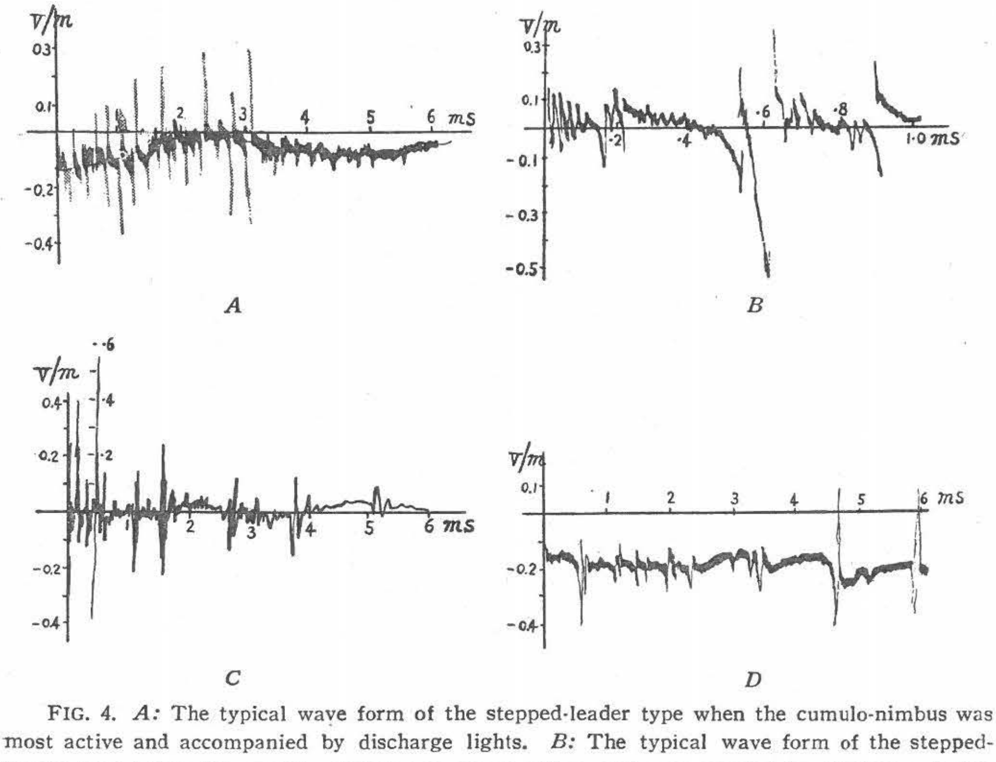


FIG. 4. *A:* The typical wave form of the stepped-leader type when the cumulo-nimbus was most active and accompanied by discharge lights. *B:* The typical wave form of the stepped-leader type when the cumulo-nimbus was most active and accompanied by discharge lights. *C:* The wave form of stepped-leader type when the cloud discharges were moderate in the cumulo-mimbus. *D:* The wave form of stepped-leader type when the cloud discharges were weak in the cumulo-nimbus.

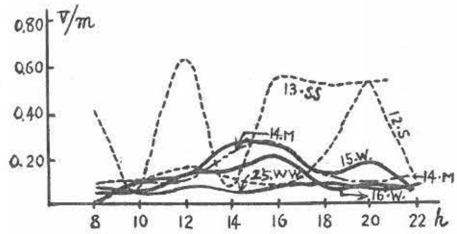
type,[3) 5)] this has a irregular wave form of higher frequencies than the fundamental frequency of a main stroke type, but shows a very distinct characteristics composed from the repetition of a wave form that can be obtained through single differentiation of a pulse, if the discharges take place at sufficiently near distances to the station.

Figs. 4 *A* and *B* show the typical wave forms of the stepped-leader type observed at two different time scales, when the cumulo-nimbus was most active to radiate the atmospherics accompanied by discharge lights in the cloud. Figs. 4 *C* and *D* show the moderate and weak cases of the stepped-leader type respectively, in the latter case the wave form varies distinctly from that of the typical case, and resembles rather to the case of the weak partial discharge type shown in Fig. 3 *C*.

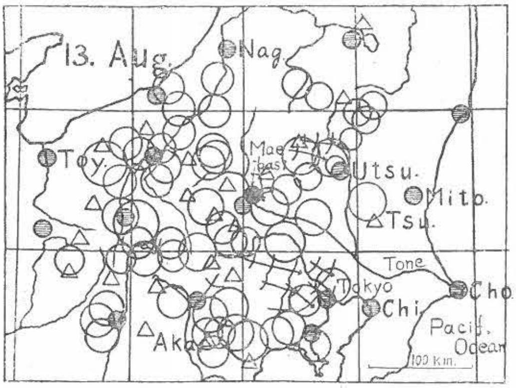
Strictly speaking one can not of course classify distinctly all the observed wave forms into such a simple category as the three types of wave forms just described. But the large portion of the observed atmospherics under consideration have appreciable characteristics, which make it possible to classify them roughly into these three typical groups and to make a statistical investigation of the problem.

Fig. 5 shows the mean amplitude distribution of the static or slow components, which have been reproduced already for example in Figs. 3 *A*, *B*, *C*, and *D*. In

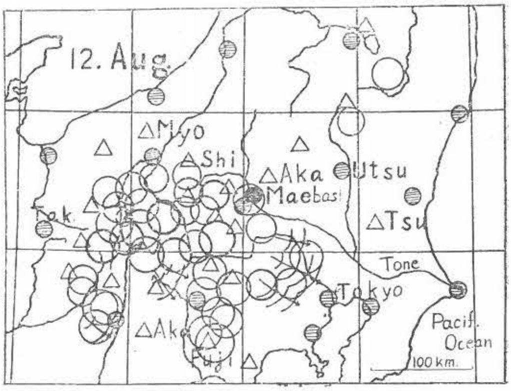
FIG. 5. The mean amplitude distribution of the slow component the numerical number attached to the curve is the date of observation, and the symbol is represent the thunder-storm intensity, *i.e.*, *ss*, very strong; *s*, strong; *w*, weak; *ww*, very weak; *m*, medium.



these figures the slow variations superposed on the typical atmospherics of higher frequencies described just in the preceding illustrations. The numeral numbers attached to the curves in the figure represent the date of the observation in August 1952, and the symbols represent the intensity of the thunderstorm on these dates. The Figs. 6 *A*, *B*, *C*, *D* and *E* represent the thunderstorm observation reports in the districts surrounding the observation station on the same dates as those corresponding to each curves in Fig. 5. Fig. 6 *A* shows the case in which the thunderstorm intensity was most strong, and the development of the composed isolated cumulo-nimbus also reached to a most progressed state, and the strong cloud discharges were observed very distinctly after the sunset, so that the corresponding slow component curve 13-*ss* in Fig. 5 due to the rapid static field changes was also most prominent. In the case of Fig. 6 *B*, the thunderstorm intensity was strong but not strong enough as in the case of Fig. 6 *A*, hence the composed cumulo-nimbus was not so large enough and radiated not so strong audible radio noises of atmospherics as in the case of Fig. 6 *A*, but one could observe clearly the cloud discharge lights to the westward after it had become dark. The corresponding curve 12-*s*, in Fig. 5 also indicates that the cloud discahrge was very strong after 18 J.M.T., therefore there remains little doubt about the fact that the atmospherics observed from 15 to 22 J.M.T. actually came out



A



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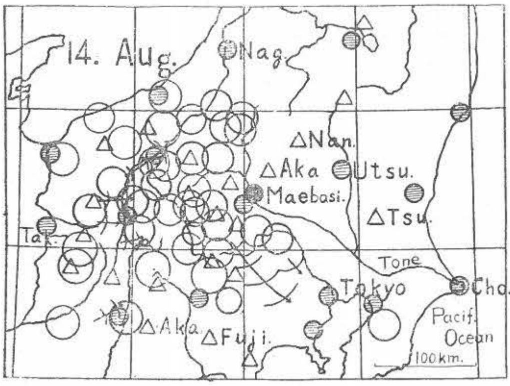

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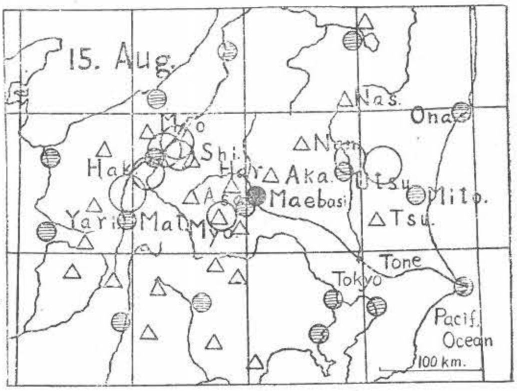

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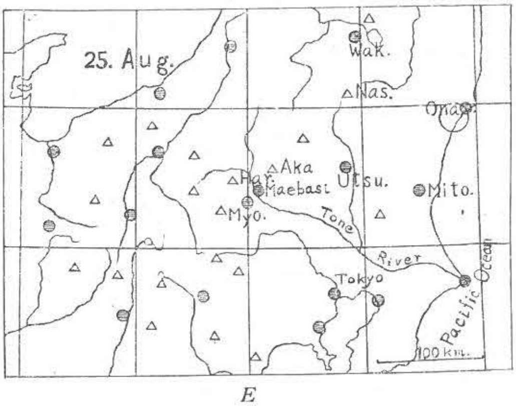

E

FIG. 6. *A:* The thunderstorm report on 13th August 1952. *B:* The thunderstorm report on 12th August 1952. *C:* The thunderstorm report on 14th August 1952. *D:* The thunderstorm report on 15th August 1952. *E:* The thunderstorm report on 25th August 1952.

from the cloud that was discussed in the preceding articles. Fig. 6*C* represents the case when the thunderstorm intensity was medium, and the composed cumulonimbus was small in this case that we could not observe the cloud discharge lights after the sunset. The corresponding mean amplitude distribution curve of the slow component 14-*m* is not prominent enough and shows roughly the same variation as the curve 15-*w*, to which the corresponding thunderstorm report, Fig.

6*D*, represents that the thunderstorm intensity on this date was weak and indeed there was observed no large cumulo-nimbus composed. Moreover in the case of Fig. 6*E*, the thunderstorm intensity was very weak, and indeed there was reported only one thunderstorm at more than 200 kilometers distant from our observation station, but the corresponding slow component distribution curve 25-*ww* represent no appreciable differences from the fore-half part of the curve 12-*s*. Hence one can deduce from the preceding discussions the fact that the amplitudes of slow components of atmospherics do not affected appreciably by the thunderstorm intensities or by the distances from the discharge channels to the observation station, provided that the amplitudes of them are not large and the thunderstorm does not take place in the over-head regions.[9] This fact seems to indicate that damping of the amplitude of the slow component is negligible so long as it has propagated the distances which may amount from 30 to 50 kilometers from the station, *i.e.*, after it has become radiative through the process under which the pure static field component has been attenuated conspicuously in these distances. Therefore one may be at least capable of concluding that the atmospherics with large slow components, if they are frequently observed in succession, can be used as the conspicuous proof that the distinctly received appropriate atmospherics had come from the particular cumulo-nimbus of sufficient scale in the field of vision, even if no discharge lights can be observable in the day time.

In Figs. 7*A*, and *B*, the curves plotted with the full line, the broken line, and the chain line represent the per centage number distributions of the main stroke type, the partial discharge type, and the stepped-leader type atmospherics. The gain of the amplifier and the height of the vertical antenna were maintained at a constant value throughout the observation periods. Hence it can be made clear from these distribution curves the course of the discharge developments in the cumulo-nimbus in summer. Fig. 7*B* shows the case when the composed cumulo-nimbus was large enough that the weak discharge lights were observed in the cloud after it had become dark. The main stroke type in this case appered most distinctly in the forenoon, and the slow component level was conspicuously low as is shown by the curve 12-*s* in Fig. 5.

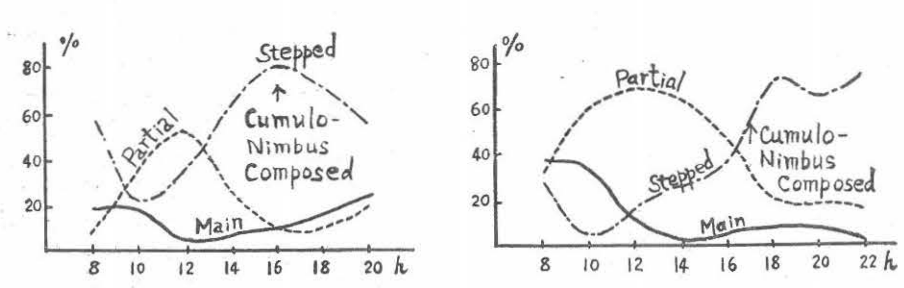

FIG. 7. *A:* The percentage number distribution curves of the three types of atmospherics wave-forms on 13th August 1952. *B:* The percentage number distribution curves of the three types of atmospherics wave-forms on 12th August 1952.

These indicate that they were really coming from the distant origins. The fall of the main stroke type distribution from afternoon towards the night may correspond to the development of the cloud to earth discharges in the thunderclouds outside the field of vision and also that of the large main stroke like partial discharges in the cumulo-nimbi in and outside the field of vision which were not strong enough to cause the cloud to earth discharges in accordance with the scale of the cloud. The level of dart-leader or partial type, which was very prominent in the forenoon, indicated that the small discharges were occuring in the fragment cumulo-nimbi floating in the extreme vicinity surrounding the observation station, which might be probably comparable to the area of the field of vision. And the curve of Fig. 6*B* shows further that the prominence of the partial discharge type was continued after the main stroke type level had fallen off, and nearly to the period, when the fragment of the cloud gathered over the lower reaches of the river Tone, here the discharge intensities were increased in accordance with development of the scale of the cumulo-nimbus. This can be clearly understood also from the curve 12-*s* of the Fig. 5, and then the level of the partial discharge type fell down in contrast to the rapid increase of that of the stepped-leader type at the stage of the development of the cloud just described in the afternoon, which was not appreciably prominent in the forenoon. The level of this type that increased rapidly with the composition of the cloud continued its prominence later to the night. This was recognized clearly throughout by the weak discharge lights in the cloud. In the case of Fig. 7*A*, the observed cumulo-nimbus was very large in scale and the strong discharge lights were observed after the sunset, although the thunder was not audible, more over the observed slow component level was also very high in this case (see curve 13-*ss* of Fig. 5). It is distinct therefore that almost whole portion of the observed atmospherics came from the cumulo-nimbus in the field of vision surrounding the observation station. The main stroke type level which was also appreciably high in the forenoon might be interpreted as to be caused by the main stroke like discharges at moderate distances, for the wave forms at these periods composed considerably of typical one represented in Fig. 2*A*. The increase in the level of this type from the noon towards the night represents the fact that the cumulo nimbi grew to the thunderclouds in the near regions but outside the field of vision, and the strong main stroke like discharges took place inside and outside the thunderclouds, because the wave forms at these stages composed mainly from the typical main stroke form from near discharging origins as represented in Fig. 2*C*. The partial disharge type level was also high enough in the forenoon and fell down as the gathering of the fragment clouds took place, and the stepped-leader type level that had been low in the forenoon, reached its maximum value at the stage when the composition of the cumulo-nimbus had completed. The rise of the stepped-leader level in the morning, as shown in Figs. 7*A*, *B*, might be caused by the moderate cloud discharges, which radiated intermediate type of atmospherics between weak stepped-leader type of Fig. 4*D* and strong multiple partial type of Fig. 3*A* from relatively wider regions surrounding the station, because the atmospherics received at this period had generally the wave form of weak irregular oscillations, which resembles to the top part of the Fig. 3*A* and hence the classification of the waves into stepped-leader and partial discharge types was not strictly evident.

4. Conclusion

It may be concluded from the preceding discussions that the summer cumulo-nimbi developed to a certain degree in the temperate zone as Japan are capable to radiate the atmospherics of the dart-leader or partial discharge type in the early period of its life. This turns into the stepped-leader type as the cloud develops, at these stages one may observe the discharge lights without the audible thunders in the clouds if it becomes dark in the evening, and finally the main stroke type will appear if the accumulated electric energy level is high enough. The comparison of the wave forms originated from the composed cumulo-nimbus with those from the cloud discharges during the violent thunderstorms has indicated no fundamental differences between them, thus it should be reasonable to conclude that developing cumulo-nimbi produce dart-leader like discharges in them in the early period of their lives, and then these change into more violent stepped-leader like discharges with the progress of accumulation of fragment clouds to the large cumulonimbus, finally there appear main stroke like discharges, which may be considered as to be a distinct proof of a thunderstorm.

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