Chapter V

Lightning discharge as origin of atmospherics

1. Introduction

Atmospherics are the pulsive electromagnetic waves having mostly originated from lightning discharges and propagated long distances along the earth's surface. An aggregation of strong electromagnetic pulses emitted by a lightning discharge will propagate round the earth's surface through the atmospherical space limited between the ionosphere and the earth by the distance at least roughly a hundred kilometers, by the process of which some of the pulses involved in the original electromagnetic waves will be attenuated completely and others will be subjected to considerable deformations according to the electromagnetic structure of the space concerned and the intensity-frequency, as well as the phase-frequency characteristics of each of the original electromagnetic pulses. This may be the principal procedure by which the so called atmospherics will be constructed.

Concerning the origin of atmospherics, it is well known that lightning discharges generally can be divided into the two classes, i.e., the ground discharge and the cloud discharge. Corresponding to this, the atmospherics originating from lightning discharges must be attributed some times to ground discharges and some times to cloud discharges according to circumstances. Further, the observational results we have hitherto obtained by measureing the continuous records of electromagnetic field changes due to nearby lightning discharges, clearly has shown the fact that the greater part of the lightning discharges investigated by us could be classified into the category of a cloud discharge, therefore it is very expected that majority of atmospherics having propagated long distances also must come from cloud discharges, if the nature of the atmospherics sources observed by us in Maebasi district of our country are very comprehensive, and applicable to the lightning sources in other part of the world.

2. Occurrence frequencies of ground discharges and cloud discharges.

One of the most convenient way to distinguish a ground discharge from a cloud discharge is to investigate the electromagnetic field changes _____ short range atmospheric waveforms ______ due to lightning discharges, by the method of which we can easily discriminate the two sorts of the discharges appearing in the range of distances from less than 5 km up to about 400 km. However, to know the occurrence frequencies of ground discharges and cloud discharges in the source area of atmospherics, it is necessary to investigate the percentages of the two sorts of the discharges on the records of atmospheric waveforms having propagated the distances less than 60 km from their origins. This will limit an appreciable deformations of the waveforms caused by the influence of ionosphere, and therefore the possible ambiguity may be avoided to arise in the discrimination of the two sorts of the discharges Following this idea we have investigated the waveforms of atmospherics which have been recorded respectively with the resultant gains -20 ~ +20 db of the waveform recorder, and represent remarkable variations resulting from the electrostatic component of the field changes due to a lightning discharge. In this way we may be able to limit the distances of the recorded lightning discharges within 60 km from the observation station (1). The result of this investigation is represented in Table 1, according to which the percentages of ground discharges recorded by us, give the values extending 11.5 % ~ 30 % in the annual statistics, and the mean of the three years occupies 23.7 %

Table 1.

Year / Sort of discharge	1956	1958	1959	1956 - 1959
Ground discharge	11.5 %	30 %	23.1 %	23.7 %
Cloud discharge	88.5 %	70 %	74.0 %	74.1 %
Unclassifiable	0 %	0 %	2.9 %	2.2 %
Number of recorded Waveforms	87	247	968	1293

3. Polarities of atmospheric pulses produced by lightning discharges.

Generally speaking, a lightning discharge usually involves an appreciable number of fast streamer processes which may develop each at a very high speed larger than 10^9 cm/sec (2) according to circumstances. So that strong electromagnetic pulses may be expected to radiate from these fast streamers processes*, and to propagate long distances along the earth's surface so as to get a considerable deformations and finally to take the form of the atmospheric waves. According to the measurement of the pulse widths of the main discharge type atmospheric waveforms** (quasi sinusoidal type waveforms), the principal portion of the pulse widths hystogram were found to exist in the frequency range 6 - 9 kc, (3) which indicates a remarkable capacity of the electromagnetic radiation pulse, whose energy is concentrated at frequencies round 10 kc, to propagate long distances. Hence, it will be reasonable to consider that a radiation pulse produced by a fast streamer has a capacity to propagating a long distance, if the pulse width of it being recorded in the neighborhood of its origin has the value roughly comparable with 100 μs.
Regarding these points, we have investigated the polarities of the radiation pulses which possess remarkable amplitudes and pulse widths roughly distributing 40 - 100 μs*** in median values, on the records of atmospheric waveforms due to lightning discharges occurring within the distance less than 60 km from the observation station. The polarity characteristics

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*** According to our statistical investigations, the radiation pulses coresponding to return ground strokes have the pulse widths giving the median value 100 μs, and the remarkable radiation pulses corresponding to fast streamer processes involved in a cloud discharge have the pulse width giving the median value 40 μs or 90 μs, in accordance with the nature of the streamer processes.

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* According to the measurement of atmospheric waveforms due to lightning discharges occurring at short distances, a cloud discharge usually emitts groups of a few remarkable radiation pulses intermittently through the process of a lightning discharge. As the number of radiation pulse groups emitted by a cloud discharge, and the number of radiation pulses involved in a group are respectively 21 and 2 in the median values, so that the total number of fast streamers each emitting strong radiation pulse will be 42.

** The atmospheric waveforms probably coming from individual return strokes composing a ground discharge.

of individual pulses involved in the waveforms due to a lightning discharge are, of course, not alway identical with each other, nevertheless it is possible to determine the average polarity of radiation pulses relating to a lightning discharge, because in most cases, the polarities of the individual pulses are held roughly unchanged throughout the period of a lightning discharge, Table 2 represents the result of the investigations of pulse polarities relating to return ground strokes which were recorded at the distances roughly less than 60 km from themselves. Following the table about 98 % of the 265 ground discharges examined are of positive polarity. This indicate that the return strokes mostly bring about negative discharges which neutralize the negative electricity distributing in the lower portion of a thundercloud, with the positive electricity induced on the earth's surface located just beneath the negative electricity, while the positive cases

Table 2

Year of observations		1958, 1959
Polarity of return ground stroke	+	98.1 %
	−	0.8 %
	complicated	1.1 %
Number of ground discharges examined		265

occupy only 1 % of all the investigated ground discharges. For the sake of a comparison, the case of cloud discharges is represented in Table 3. The distances of the cloud discharges concerned are similar to the case of ground discharges. The table indicates that 63.8 % of the examined cloud discharges radiate principally negative pulses, while the case of positive polarity occupies only 8 %. Therefore it is evident that most of the cloud discharges principally radiate negative pulses. If we ignore the lightning discharges falling into the complicated case given in Table 2 and 3, the percentages of the discharges which produce respectively positive or negative radiation pulses will take the values represented in Table 4.

Following what Table 4 indicates, it is clear that positive radiation pulses principally break out on the waveforms of ground discharges and negative pulses principally break out on the waveforms of cloud discharges, so long as the lightning discharges are observed at distances roughly less than 60 km from the discharges. This will result in the production of

Table 3

Year of the observation	1956	
Polarity of differential pulses involved in cloud discharge waveform	+	7.9 %
	−	63.8 %
	complicated	28.3 %
Number of examined discharges	177	

Table 4

Sort of discharge		Ground discharge (Return Stroke)	Cloud discharge (Fast streamer)
Pulse Polarity	+	99.2 %	11.0 %
	—	0.8 %	89.0 %
Number of examind discharges*		262	127

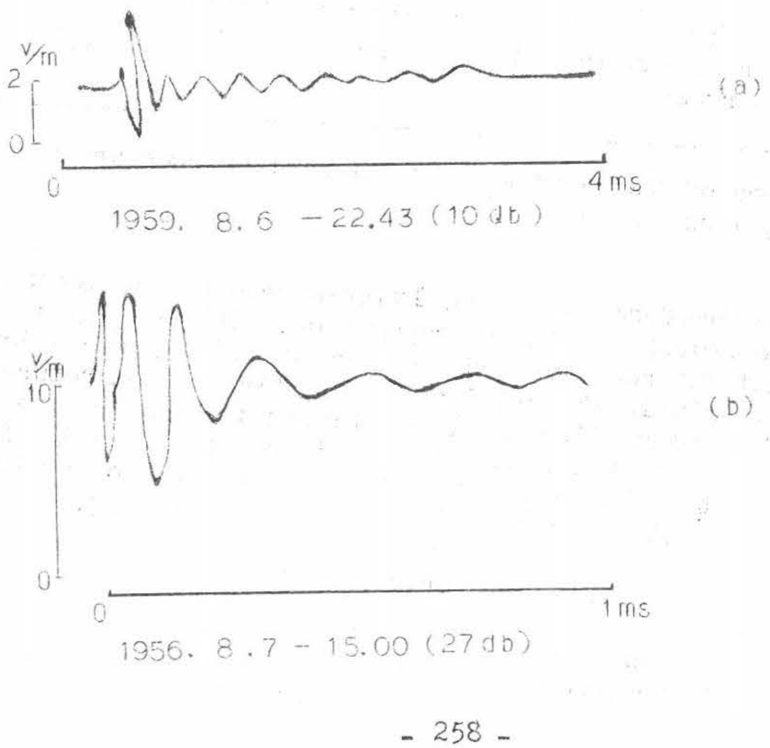
* Distances of the recorded lightning discharges are all roughly less than 60 km.

atmospheric waveforms not severely influenced by the ionosphere through the process of their propagation. The meaning of this is that the positive and the negative strong radiation pulses must principally originate respectively from return strokes of a ground discharge, developing upwards from the earth's surface to the cloud base, and from the negative fast streamers of the character of a dart leader, developing in the direction extending from the cloud base upwards.

4. Waveforms of atmospherics

We have investigated in the previous section the polarities of strong electromagnetic pulses which radiated from individual fast streamer processes involved in a lightning discharge that appeared in the near distance from the station, and arrived at the conclusion that the positive and the negative strong radiation pulses must mainly be attributed respectively to the ground and the cloud discharges. However, how these polarities of the individual radiation pulses observed at their origins will vary with the increase in the propagation distances? One of the convenient way to see this point is to investigate statistically the polarities of individual atmospheric radiation pulses having propagated appropriatly long distances. An atmospheric propagated a long distance more than roughly 300 km along the earth's surface generally has a complicated and diverse waveform, hence it is difficult to interpret all the observed atmospheric waveforms of this sort by one or two simple but comprehensive propagation mechanisms. However, it is also not so infrequent that many of the atmospheric waveforms having recorded at a certain occasion really had the relatively regular structures according to circumstances. One of the most typical case of this sort of atmospherics is the regular peaked type waveform which is constructed from the successive multiple reflections, between earth's surface and the E innospheric layer, of the original electromagnetic pulse radiated from a fast streamer involved in a lightning discharge. An example of this type waveforms is illustrated in Fig. 1 (a).

Fig 1



It is well known that the regular peaked type atmospherics generally are recorded during the night-time, when the D layer having existed in the day-time in the atmospherical space bounded by earth's surface and E layer vanishes rapidly. Another remarkable type of the atmospheric waveforms which have a regularity is the quasi sinusoidal type waveform representing a quasi sinusoidal damped oscillation, as illustrated in Fig. 1(b). This type of waveforms usually are recorded under the day-time condition, in which the activity of the D layer is generally remarkable. In this type of the waveform the first pulse and the succeeding pulses may be interpreted respectively by a ground wave, and by mode waves which are built up when the original pulse with an appropriate frequency spectrum travel through the two dimensional waveguide corstructed from the earth's surface and the D layer. In this case, D layer must absorb the energy of an atmospheric wave more strongly than E layer will do it at night.

(A) Regular peaked type atmospherics

In this paragraph we shall investigate the regular peaked type atmospherics which were recorded with the waveform recorder gain 10 or 20 db. This limits the waveforms with the amplitudes respectively less than 2.1 or 0.7 v/m being measured on the records of waveforms. Lutkin and his colleagues reported in their paper (4) that the mean field intensity of the individual atmospheric pulses, each probably corresponding to a return ground stroke or to a fast streamer process involved in a cloud discharge, amounted roughly to 3 v/m, when the atmospherics were recorded at distances roughly 10^3 km apart from the discharge. Following these observational facts, it will be probable to infer that the records we have investigated were due to the lightning discharges having occurred statistically within the distances respectively less than about 10^3 or 3×10^3 km from the observation station. Further, the measurement of individual regular peaked type waveforms has shown that the peak am litudes of the waveforms really distributed roughly from 0.7 v/m to 5 v/m. This fact also seems to indicate the point that the waveforms we have investigated really came from lighthing discharges having appeared mostly in the range of distances roughly given by $4 \times 10^2 \sim 3 \times 10^3$ km. Concerning this point the estimation of the propagation distances of the recorded atmospherics has been made on an appreciable number of the regular peaked type waveforms by assuming the E layer altitude to be 85 km (5). The results of this examination also has shown that the propagation distances of the atmospherics investigated really distributed from 3×10^2 km to 10^3 km. On the other hand, the sunset line on the earth's surface will be moved from Maebashi roughly as far as 3×10^3 km to the westward in $2^h 30^m$ after the sunset in August, hence it is evident that partical area of the earth's surface within the distance 3×10^3 km from Maebashi, which may include the origins of all measurable atmospherics will completely enter the night time region, if we record the atmospherics at a certain time later than $2^h 30^m$ after the sunset at this place in August. Under this condition, the measured atmospherics are all expected to have propagated the spaces completely lying under the night time condition independent of their arival directions. The result of the pulse polarity measurement under the above limitations of the atmospheric waveforms, is represented in Table 5, in which + + - -, etc have the meanings as follows. As the atmospherics corresponding to a lightning discharge must generally be composed of, at least, a few pulsive waves, like those illustrated in Fig. 1, appearing in succession with appropriate time intervals. Hence if the first pulses of the greater part of the individual pulsive waves composing a wave train have a positive or a negative

Table 5

Polarity variation type of an atmospheric wave train	+ +, − −	87.8 %
	+ −, − +	12.2 %
Number of examined atmospheric wave train		559

polarity, then we designate it respectively as + + or − −. And if the first pulses of the individual pulsive wave change their polarity from + to − or from − to + on half way of a wave train, we designate it by + − or − + respectively. Then, the pulse polarity variation type + −, and − + indicated in the Table 5 must be attributed to the statistical change in the polarity, or in the direction by the angle 180^0 of the fast streamers in the course of a lightning discharge. Since these two polarity variation types occupy only 12.2 % of all the examined waveforms, the ignorance of these two may not result in any erroneous conclusion concerning the general postulation of the polarities of lightning streamers as origins of atmospherics. Table 6 represent the results which have been obtained by

Table 6

Polarity variation type of an atmospheric wave trains	+ +	37.8 %
	− −	62.2 %
Number of examined atmospheric wave trains		491

neglecting the pulse polarity variation types + − and − + of the atmospheric wave trains. Concerning this point, the statistical polarity characteristics of the pulses involved in the electromagnetic field changes respectively due to a ground discharge and to a cloud discharge, have already been given in the respective Tables 2 and 3 in regard to the lightning discharges having appeared within the distances roughly less than 60 km from the observation station. Further the occurrence frequencis of the ground discharges and the cloud discharges, both recorded at distances less than 60 km from the station, on the other hand, have been given in Table 1. Hence we can get the statistical knowledges about the pulse polarity characteristics concerning all lightning discharges which will be produced at distances less than 60 km from the observation station, through the simple calculation using the values represented in the above three tables. In this calculation the waveforms falling into the unclassifiable case in Table 1 have been regarded as to appertain to the positive polarity variation type + +, as the greater part of them have been composed statistically of the pulsive wave each with a pos tive polarity. The result of this calculation is represented in Table 7, from which the Table 8 and 9 respectively corresponding to Table 5 and 6 can be easily obtained.

Table 7

Pulse polarity / Discharge sort	Pulse polarity variation type of the waveforms*	+ +	— —	complicated
Sort of discharges	Ground discharge	23.2 %	0.24 %	0.26 %
	Cloud discharge	5.9 %	47.0 %	21.0 %
	Un-classifiable	2.2 %	0	0
		31.3 %	47.44%	21.26 %

Table 8

Polarity variation type of the waveforms*	+ + — —	79.7 %
	complicated	21.3 %

Table 9

Polarity variation type of the waveforms*	+ +	39.7 %
	— —	60.3 %

* Waveforms due to lightning discharges appearing at distances less than roughly 60 km from the observation station.

The comparison of Table 5 with Table 8 shows that the percentage of the wave trains which represent more or less pulse polarity variations in the course of each train, is increased appreciably as the distances of the original discharges becomes remarkably short. The reason of this may be as follows: the data giving the result of Table 5 are the regular peaked type waveforms which propagated mostly the distances distributing roughly from 3×10^2 to 10^3 km, therefore the reversal of the first pulse polarity of each waveform composing an atmospheric wave train ______ probably correspond to a lightning discharge _______ from positive to negative or from negative to positive in the course of a wave train may be attributed to the polarity reversal of the ground pulse each originating from a remarkable fast streamer process involved in an original lightning discharge. Concerning this point, the thoretical investigation of the propagation of VLF continuous radio waves made by J.R. Wait and his collegue(7) clealy indicated that the phase of a VLF ground wave can not be expected to vary nearly as much as 180° during the course of propagation of the ground wave through a distances roughly less than 2×10^3 km along the earth's surface, even through the electric conductivity of the earth's surface is varied from the value corresponding to dry earth to the value corresponding to sea water. Further a simple theory of continuous electromagnetic radiation from a diple antenna (7) shows the point that the vertical component of a radiated electromagnetic wave is composed of the two parts, i.e., the part contributed from the vertical component of the dipole, and the part contributed from the horizontal component of it, however, the contribution from the horizontal component of the dipole is at least 10^{-2} times (7) smaller than the contribution from the vertical component of it, provided that the electromagnetic wave has propagated a sufficiently long distance along the earth's surface possessing an ordinarily plausible values of the refractive coefficient. Therefore the vertical componant of an atmospheric radiation having propagated a long distance will be determined by the vertical componant of the original dipole discharge that represents a fast streamer process involved in a lightning discharge. Following these two theoretical expectations, we may deduce the conclusion that the polarity reversal of the first pulse of an atmospheric wave that propagated a long distance, must generally be attributed to the reversal of direction of the vertical component or to the polarity reversal of a fast streamer involved in a lightning discharge.

In contrast to this, when a lightning discharge breaks out at a distance roughly less than 60 km from the observation the field reversal circle corresponding to a local discharge* will have a large diameter comparable with 60 km, if the lightning discharge, accordingly the local discharge,

are inclined to the horizontal direction considerably, for the example, if a lightning channel in a thunder cloud extends horizontally 3 km and vertically 1 km as reported by Workman and his colleagues (8). In this case, the field reversal circles each corresponding to a local discharge will come to a location so as to include, or to exclude, the observation station respectively, inside, or outside, of the circle in accordance with the aximuth and the altitude of a local discharge. Concerning this point, as the directions of the local discharges involved in a lightning discharge will probably fluctuate, and altitude of them will progressively vary, from a local discharge to another through the process of the lightning discharge, so the probability that the polarity of a radiation pulse due to a local discharge will be changed from a local discharge to another may be increased appreciably, if the observation distances are decreased to the values roughly comparable with the field reversal distances corresponding to individual local discharges. Hence, it is very expected that the atmospheric wave train recorded at a short distance from a lightning discharge will represent more frequent polarity variations in the first pulses of the component waves than the atmospheric wave train recorded at a long distance will do it. The comparison of Table 5 with Table 8 also clearly indicates the tendency which supports the above expectation, namely, that Table 8 which corresponds to the records obtained at short distances actually indicates more frequent polarity variations in the first pulses of the component waves than Table 5 that corresponds to the records obtained at long distance really indicates it. In contrast to the above fact, it is remarkable that the result represented in Table 6 fairly well coincides with that represented in Table 9. From these statistical facts we have obtained, the following conclusion may be deduced: if the regular peaked type atmospheric waves each have a positive first pulse, the majority of the wave must come from ground discharges, on the contrary, if the same type waves each have a negative first pulse the greater part of them must be attributed to cloud discharges. To see the point how large part of the positive or the negative regular peaked type atmospheric waves will come respectively from ground discharges or cloud discharges, we have rearranged the results represented in Table 7 that represent the case of short distant sources, and have obtained the following Table 10.
The statistical tendency that has been indicated in Table 7 can also be inferred from the pulse polarity investigation of the regular peaked type atmospheric waveforms.
The magnitudes of the fast electrostatic field changes and

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* A lightning discharge involves statistically 21 local discharges, from each of which about 2 radiation pulses will be emitted.

Table 10

Sort of discharges \ Pulse Polarity	Polarity Variation type of the Waveforms*	
	+ +	— —
Ground discharge	74.1 %	0.6 %
Cloud discharge	18.8 %	99.4 %
Unclassificable	7.1 %	0.0 %
Total	100.0 %	100.0 %

* Waveforms due to lightning discharges apprearing at distances roughly less 60 km from the observation station.

the amplitudes of the radiation pulses appearing on the short range atmospheric waveforms have been compared between the records of ground discharges and those of cloud discharges. The result of this investigation clearly indicates the point that a return ground stroke generally has a larger peak electric current and a larger time rate of increase in the electric current than a fast streamer process involved in a cloud discharge. Therefore it is statistically expected that the regular peaked type atmospherics, when they have large amplitudes, must chiefly come from ground discharges, and when they have small amplitude, they must chiefly come from cloud discharges. Hence if we classify the regular peaked type atmospherics into the two categories in accordance with their amplitudes, the large amplitude group must mostly correspond to ground discharges, and the small amplitude group must mostly correspond to cloud discharges. Following to this idea we have classified the regular peaked type atmospherics with regard to their amplitudes, the result of which is represented in Table 11.
As the large and the small amplitude groups represented in the table mainly relate respectively to ground discharges and to cloud discharges, the results represented in Table 11 should statistically coincide with those represented in Table 4. The comparison of the two tables acutually indicates the expectation having been satisfied. Rather a trivial disagreement of the percentage values in the corresponding space of the two tables must come from the fact that the classification of the regular peaked type waveforms has been

Table 11

		Amplitude of regular peaked type atmospherics	
		Large **	Small **
Pulse polarity variation type of an atmospheric wave train	+ +	61 %	29.7 %
	− −	39 %	70.3 %
Number of examined waveform train*		123	366

* Regular peaked type atmospherics

** Atmospherics have been classified into the large or the small category according as their amplitude being roughly larger or smaller than 1 v/m, respectively.

made with respect to their amplitude, so that an appreciable number of ground discharges are divided into the small amplitude group, and, on the contray, an appreciable number of cloud discharges are divided into the large amplitude group. For this reason the percentage values represented in Table 11 are all more or less balanced and approach nearer to 50 % value than the values represented in Table 4.

(B) Quasi sinusoidal type atmospherics

We shall next investigate statistically the polarities of quasi sinusoidal type atmospherics, as illustrated in Fig. 1(b), which may be recorded usually under the daytime condition. This type of atmospherics will be constructed when the original electromagnetic pulse radiating from a fast streamer process involved in a lightning discharge will propagate a long distance through the two dimensional wave-guide space limited by the earth's surface and the D ionospheric layer, so the process of the atmospheric wave formation is rather complicated in this case, and the type is not suited for the estimation of propagation distances of the individual atmospherics from the measurement of their waveforms. So that it is necessary, in this case, to measure directly the propagation distance of the individual atmospheric through an appropriate procedure. On the basis of his coincident observation of the atmospheric waveforms and the direction finding of their origins, F.E. I utkin (4) gave the observational result represented in Table 12 concerning his statistical investigation of the first pulse polarity of each of the quasi sinusoidal type atmospheric waveforms having propagated the distances ranging from 8×10^2 to 4×10^3 km. The comparison of Tables 11 and 12 clearly indicates that the result represented in latter table roughly coincide with what is indicated in the former table concerning the regular peaked type atmospherics of large amplitudes. Following F.E. Lutkin, the amplitudes and the propagation distances of the quasi sinusoidal type atmospherics giving the result of Table 12

Table 12

Quasi sinusoidal atmospheric waveform*		
Polarity of the first pulse	+	67.7 %
	−	32.3 %
Number of examined waveforms		288

* Propagation distance $8 \times 10^2 \sim 4 \times 10^3$ km

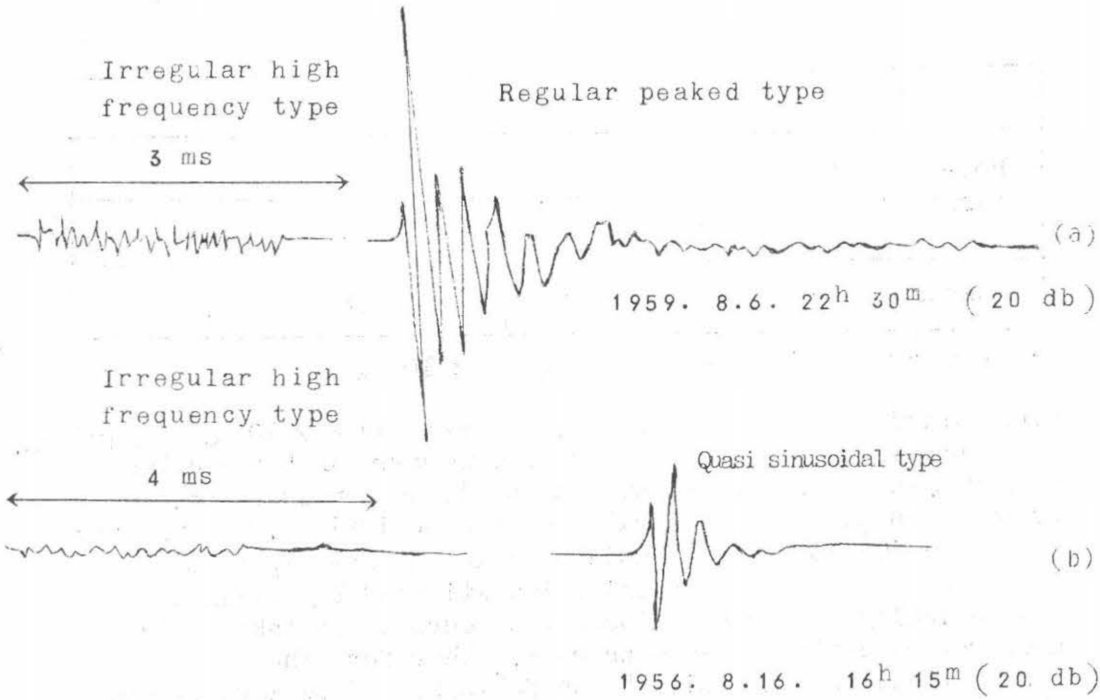
were distributed respectively $0.2 \sim 6$ v/m and $8 \times 10^2 \sim 4 \times 10^3$ km.

Concerning this point, our measurement of the regular peaked type atmospherics gave the amplitudes values and the propagation distances distributing respectively $0.7 \sim 5$ v/m and $3 \times 10^2 \sim 10^3$ km, on the basis of which we may expect the deduction that the atmospherics investigated by Lutkin had statistically larger amplitudes than ours if we take their propagation distances into account. Therefore the observational results will be as follows: If we investigate the first pulse polarities of the atmospheric waveforms, which have propagated the distances roughly given by 10^3 km along the earth's surface and possess large amplitudes, then $60 \sim 70$ % of the investigated atmospherics will have the positive polarity, regardless of the atmospherics being the regular peaked type or the quasi sinusoidal type. This is also the point which seems to support the inference that majority of the large amplitude atmospherics must originate from ground discharges, and majority of the small amplitudes atmospherics must originate from cloud discharges.

(C) Regular peaked type and quasi sinusoidal type atmospherics originating from return groundstrokes

Some of the regular peaked type atmospherics having propagated the distances roughly ranging $3 \times 10^2 \sim 10^3$ km, and some of the quasi sinusoidal type atmospherics presumably having propagated the distances comparable with the former type were observed to have been preceded each by a small amplitude irregular high frequency type atmospheric, from which we inferred that the atmospherics concerned actually originated from ground discharges. Fig. 2, illustrates the Typical

Fig. 2



examples of these two types of atmospherics preceded each by a irregular high frequency type atmospheric, in which (a) represents the regular peaked type, and (b) the quasi sinusoidal type. The first pulse polarity has been investigated on the atmospheric waveforms like those illustrated in the Fig 2, whose result is represented in the second and the third columns of Table 13. According to what we have already described, the polarity of a ground pulse* will not be changed during the course of its propagation along the earth's surface, so long as the propagation distance does not exceed at least 2×10^3 km. Hence, if the first pulse of an atmospheric really corresponds to a ground pulse, the polarity of the first pulse

* Electromagnetic pulse propagating along the earth's surface.

discussed here must directly be connected with the polarity of a ground return stroke independent of the atmospheric waveform type. Following this idea, let us compare the results obtained from the measurement of atmopheric waveforms having propagated long distances with those of other estimation methods of occurrence frequencies of positive and negative electromagnetic field changes respectively due to negative and positive ground discharges. The result is summarized in Table 13, which indicate the fact that the occurrence percentages of the positive and the negative electromagnetic field changes are not influenced considarably by the method of measurement, i.e., they must roughly represent the occurrence frequencies respectively of the negative and the positive return ground strokes constituting the origins of the concerning electromagnetic field changes.

Table 13

Method of recording / Polarity		Long range waveform recorder		Short range waveform recorder	Electrostatic field meter
		Regular peaked type **	Quasi sinu-soidal type *		
Polarity of electro-magnetic field changes	+	84.3 %	100 %	99.2 %	96.6 %
	—	15.7 %	0 %	0.8 %	3.4 %
Distance from ground discharge		$3 \times 10^2 \sim 10^3$ km		0~6 x 10 km	0~1.5 x 10 km
Number of examined records		19	11	262	176

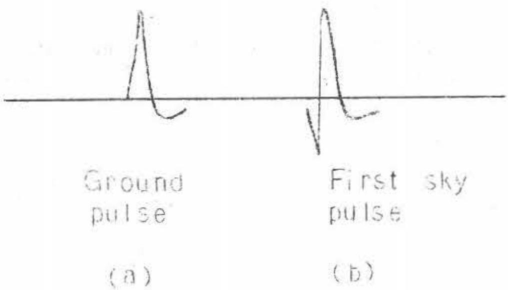
* Atmospherics recorded under day-time conditions.
** Atmospherics recorded under night-time conditions.

However, the investigate of detailes of Table 13 will show the point that a small but by no means negligible discrepancy exist at least, between the case of the regular peaked type and the other three cases. Concerning this points, it may be possible that the discrepancy partly comes from the shortage of data of the regular peaked type waveforms, however, the greater part of it seems to be attributed to the effect of propagation of an atmospheric radiation pulse. If we consider the discrepancy between the regular peaked type and the quasi sinusoidal type, i.e., the case depending on small number of data, and the fairly well coincidence between the quasi sinusoidal type and the other two recording methods, i.e., the case depending respectively on small and large number of data, we may presume that the discrepancy rather chiefly comes from the pulse polarity reversion due to a certain propagation mechanism of the regular peaked type atmospherics. If this latter factor had predominated over the former factor, at least 15.7 - 3.4 = 12.3 % of the investigated regular peaked type atmospherics would have been subjected to the pulse polarity reversal. Further, for example, if the region of propagation distances, inside which the polarity of the first pulse of a regular peaked type atmospheric is reversed, is sufficiently narrow compared with the range of the propagation distances $3 \times 10^2 \sim 10^3$ km, then the occurrence frequency of the regular peaked type atmospherics subjected to a polarity reversal will be limited to rather a small value.

In the next place we shall investigate the probable cause of the polarity reversal of a regular peaked type atmospheric.

Because the first pulse of an atmospheric waveform, as a ground pulse, will propagate along the earth's surface by a long distance, it will be subjected to a strong attenution , while the succeeding pulses, as sky pulses, will not propagate along the earth's surface in any section of their propagation distance, so long as the distance does not exceed roughly 2×10^3 km, hence they will not be subjected to an appreciable attenuation. The regular peaked type wave form illustrated in Fig. 2(a), indicates the case in which the first pulse is appreciably smaller than the suceeding pulse. This tendency is also discernible on the records of quasi sinusoidal waveforms, as illustrated in Fig. 2(b). To see this point statistically, the amplitudes E_1 and E_2 of the first and the second pulses were measured on each record of a regular peaked type atmospheric waveform preceded by a irregular high frequency type atmospheric, and then the ratio E_1/E_2 was derived for each waveform. Table 15 represents the result of the statistical investigation of the ratio values. Following the table, it is evident that the amplitude of a ground pulse generally becomes smaller than that of the succeeding first sky pulse, when the concerning regular peaked type atmospheric propagates the distance exceeding roughly 400 km. Further the table includes six waveforms whose propagation distances are roughly 800 km. These six cases are seen all satisfying the relation $E_1 \ll E_2$, therefore it is very probable that a ground pulse will be attenutaed faster than the succeeding sky pulse so as to attain the magnitude much less than 1/10 of the latter pulse, if the propagation distance of the atmospheric pulses becomes sufficiently larger than the above value. In this case it will be very difficult to detect the existence of a ground pulse on the waveform of a regular peaked type atmospheric. According to our measurement of the electromagnetic field changes due to a cloud discharge, a ground pulse radiated from a fast streamer process involved in the discharge has generally the pulse width of about 50 μs in the median value. This will make the lowest measurable value of the time separation between two successive radiation pulses comparable with 25 μs. Hence it becomes difficult to measure the time separation between the ground pulse and the first sky pulse on the record of a regular peaked type atmospheric having propagated the distance larger than 2×10^3 km. For these two reasons, the propagation distance within which the ground pulse is discernible on the record of regular peaked type atmospheric waveform, will roughly be limited to less than 2×10^3 km. The theoretical estimation of the individual pulse waveforms which compose a regular peaked type atmospheric with the propagation distance 10^3 km, recently has been made in our Institude[9] by assuming the current waveform of a ground stroke given by R.B. Morrison (1), and the altitude 85 km of the E ionospheric layer. Fig. 3 illustrates the rough waveforms of the ground pulse and the first sky pulse obtained from these theoretical calculations.

Fig. 3



It is remarkable that the first sky pulse takes the $\mp$ type waveform, while the ground pulses simply + type waveform Since the negative deflection of the first sky pulse is comparable with the positive deflection of it, the composite regular peaked type waveform will come to have the negative first pulse, if the ground pulse is subjected to an abnormally stronger attenuation than the first sky pulse in the course of a propagation process through the distances roughly given by $3 \times 10^2 \sim 10^3$ km along the earth's surface. Concerning this point, we have already discussed the possibility that a ground pulse generally attenuates faster than the suceeding first sky pulse. To confirm this point we have measured on the waveform of negative regular peaked type atmospherics the amplitude E_1 of the first negative deflection, and the amplitude E_2 of the immediately following positive deflection. So that the value E_1/E_2 represented in the Table 15 for the case of negative regular peaked type atmospherics, may be inferred to correspond to the ratio of the negative deflection relative to the positive deflection of the first sky pulse that has the waveform as illustrated in Fig. 3(b), if the polarity of the first pulse of a regular peaked type atmospheric will be reversed by the process that has already been described in the above discussion. Therefore it is expected that $|E_1/E_2|$ values corresponding to the negative regular peaked type atmospherics are statistically larger than those corresponding to the positive atmospherics, so long as we take only the atmospherics propagated sufficiently long distances into account. The comparison of the $|E_1/E_2|$ value, indicated in Table 15, between the positive and the negative regular peaked type atmospherics propagated the distances $5 \times 10^2 \sim 8 \times 10^2$ km, seems to indicate the tendency to support the above point in spite of the small number of the data. Therefore, if we attach a large importance to this point, it will be probable that some of the regular peaked type atmospherics having propagated the distances $3 \times 10^2 \sim 10^3$ km, actually have their ground pulses completely attenuated through a certain process of an abnormal propagation and come to have each a negative first pulse. This will be a probable mechanism of the polarity reversal of a regular peaked type atmospheric.

5 Conclusion

We have investigated statistically the pulse polarities of the atmospherics having propagated long distances along the earth's surfaces, from which the following conclusions have been obtained.

(A) According to the statistical investigation made on the records of electromagnetic field changes, the occurrence frequencies of the ground discharges and the cloud discharges are given roughly by 24 % and 76 % respectively.

(B) The atmospheric waveform chiefly composed of a number of positive radiation pulses and those chiefly composed of number of negative radiation pulses can be attributed to the ground and the cloud discharges respectively so long as the waveforms are recorded within the range of distances roughly less than 60 km. Concerning this point the atmospherics (the regular peaked type and the quasi sinusoidal type) recorded at long distances roughly ranging $3 \times 10^2 \sim 2 \times 10^3$ km also represent the analogous tendency with respect to their polarities, hence it is coucluded that the positive and negative atmospherics must chiefly originate from the ground and the cloud discharges respectively even after they have propagated long distances. The polarity investigation of the regular peaked type atmospherics really has shown that the occurrence frequencies of the positive and the negative polarities are respectively 38 % and 62 %.

(C) The occurrence frequencies of the ground and the cloud discharges respectively given by 24 % and 76 % (see Item (A)), do not exactly coincide with the occurrence frequencies of the positive and the negative regular peaked type atmospherics respectively given by 38 % and 62 % (see Item (B)). These small but by no means neglibible discrepancies may be attributed to the fact that not negligibly small number of the positive regular peaked type atmospherics really originate from the cloud discharges.

(D) It has been made statistically clear that the large and the small amplitude atmospherics correspond, in most cases, to the ground and the cloud discharges, respectively, and this is not influenced by the fact whether the atmospherics are the regular peaked type or the quasi sinusoidal type.

(E) In a small number of cases, it is expected that the regular peaked type atmospherics may really be subjected to the reversal of their pulse polarities while they are propagating the distances roughly ranging $10^2 \sim 10^3$ km. In contrast to this, we could not find this kind of rather an abnormal process of propagation on the records of the quasi sihusoidal type atmospherics.

(THE END)

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