Charge Distribution in the Average Thunderstorm Cloud

By Akira Huzita

Earth Science Laboratory, Konan University, Kobe 658

and Toshio Ogawa

Geophysical Institute, Kyoto University, Kyoto 606

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Abstract

Ninety nine examples of electric field variations were chosen from the continuously observed data in Kyoto with a field mill during three summer seasons from 1965 to 1967, and were classified into 12 types of field variation patterns. A composite of the field variations which appear frequently has the following representative features: the negative field appears first in time, the time scale is about 1 hour and the field intensity is about ± 5000 V/m. A thunderstorm charge distribution model which gives the observed field patterns is presented, in which the charges are +120 Coul at the height of 8.5 km, -120 Coul at 6.0 km and +24 Coul at 3.0 km where the negative main charge locates 0.2-0.6 km ahead the other charges in the storm moving direction.

1. Introduction

The charge distribution in the thunderstorm cloud has long been worked out by many investigators with various methods at many places in the world, but the results do not seem to converge at a conclusion. The cloud charge magnitudes and their locations seem to depend on the method of investigation and the place where the observation was made. In this paper is described one approach to this problem from a statistical examination of the electric field variations observed in Kyoto.

2. Electric field variation patterns

The composite electric field variations due to thunderstorm clouds were deduced statistically from the data obtained with a continuously operating field mill mounted on the roof of the building of the Geophysical Institute, Kyoto University in the north-eastern part of Kyoto City during three summer seasons from 1965 to 1967. Ninety-nine examples of field variations were chosen from the observed data, and were classified into 12 types of field variation patterns following a scheme similar to the one used by Tamura (1940). The 12 classifications from type *a* to type *k* including type *d'* are shown in Fig. 1,

Table 1. Number of field variations of 12 types observed during three summer seasons from 1965 to 1967 in Kyoto.

Type	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i> and <i>d'</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>	<i>j</i>	<i>k</i>	Total
Number	3	14	4	14	7	13	6	9	6	16	7	99

and the number of each type is tabulated in Table 1. Type *d'* differs from type *d* only in its time scale. Field variations which appear frequently are: negative first and then positive (type *b*); negative first, then positive and negative (types *d* and *d'*); negative first, then positive, then negative and finally positive (type *f*). Type *j* is a variation which appears most often, but this type may be due to the successive appearance of simpler types *b*, *d* and *d'*, and *f*. The seven types, *a*, *b*, *d* and *d'*, *f*, *h* and *j* constitute 70% of all the field variations measured during the course of this work. A composite of the field variations of these types has the following representative features; the negative field appears first in time, the time scale is about 1 hour, and the field intensity is about ± 5000 V/m. (The thunderstorm clouds which had the electric field intensity from ± 4000 V/m to ± 6000 V/m occupied 41% of all the clouds.)

Simpson and Robinson (1940) described a typical thunderstorm cloud, in which the charges

Fig. 1 Classification of field variations due to thunderstorm clouds observed during three summer seasons from 1965 to 1967 in Kyoto.

were located vertically with +24 Coul at 6 km, -20 Coul at 3 km and +4 Coul at 1.5 km from the ground surface respectively. Malan (1952) presented a model in which the charges distribute vertically with +40 Coul at 10 km, -40 Coul at 5 km and +10 Coul at 2 km.

It was suggested by Simpson and Robinson (1940) and Kuettner (1950), that the levels at which charges occur in thunderstorm clouds depend on the atmospheric temperature. Simpson and Robinson showed that the upper positive charge was, on the average, at a temperature 15°C colder than the negative charge which was found at an average temperature of -7°C. The lower positive charge was located at a temperature warmer than freezing. In Kuettner's model of a thunderstorm cell, the negative charge appears at a temperature of -8°C and the positive pocket of charge at the freezing level. The possible altitudes for those temperature regions were examined from the aerological data at Yonago meteorological station, 230 km west of Kyoto and the results are shown in Fig. 2, in which the -22°C level is located at 8.0-9.0 km for the upper positive charge, the -7°C level at 6.0-6.5 km for the lower negative charge and the 0°C level at 5.0 km respectively.

A modified electrical model of Simpson and Robinson's thunderstorm cloud, in which the charges are +24 Coul at 8.0-9.0 km, -20 Coul

Fig. 2 Number of occurrences of the levels -22°C, -7°C and 0°C with respect to the altitude.

at 6.0-6.5 km and +4 Coul at 3.0-5.0 km does not reveal the field on the ground as strong as ± 5000 V/m as observed in this work. An examination of this modified Simpson and Robinson's model suggests that the cloud charges must be larger than in the model considering the observed results described above. Further it is suggested that the lower negative charge deviates a

little toward the moving direction because the composite of field variations reveals an asymmetry with the first negative field. An examination of Malan's model in the same way also gives the same suggestion.

3. Charge distribution

Based on the above described suggestions, the electric field variations on the ground surface due to thunderstorm clouds were calculated with various charge distributions assuming that a thunderstorm cloud which has two positive and one negative point charges, passes along a straight line some distance away from the observing station keeping its charge distribution constant. In these calculations the following was assumed; the positive main charge is located at 8.0-9.0 km, the negative charge center at 6.0-6.5 km and the lower positive charge center at 3.0-5.0 km. It was also assumed based on the average feature of the actual storm passages in the northern part of Kyoto that the storm passes 2 km away from the observing station. The calculations were made every 0.5 km height for the respective charge locations.

In Fig. 3 are shown the calculated results of the electric field variations which best fit for the types *b*, and *d* and *d'* which appeared most often in the observation (cf. Table 1). These space variations can be converted to the time variations which has a time scale of 1 hour if assuming the wind velocity be 10 m/sec. The charge distribution which produces these field variations of about ± 5000 V/m is +120 Coul at 8.5 km, -120 Coul at 6.0 km and +24 Coul at 3.0 km as shown in the top of Fig. 3, in which the negative charge center deviates 0.2-0.6 km horizontally ahead the other charges in the moving direction. It is reasonable to assume the model of charge distribution shown in Fig. 3 for the average thunderstorm cloud which appears in Kyoto.

It is interesting to note that the charge magnitude derived above is about 6 times larger than that in the Simpson and Robinson's model and about 3 times larger than that in the Malan's model, but the charge proportions between the upper positive, the negative and the lower positive charges are similar in all the models.

The estimated values of charges obviously depend on the assumed distance between the storm passing line and the observing station. In order to check this variability we calculated the case in which the storm passes 1.5 km away from the observing station keeping the same charge heights

Fig. 3 The calculated electric field variations (bottom) for the average thunderstorm cloud model (top). The storm is assumed to pass along a straight line 2 km away from the observing station.

and the magnitude proportion of respective charges as the derived above. In this case the charge magnitudes which best fit the observation are ± 100 Coul and +20 Coul for the upper positive, the negative and the lower positive charges respectively. The electric field intensity due to cloud charges assumed in this paper is given by

$$E = \frac{1}{4\pi\epsilon_0} \sum_{i=1}^3 \frac{2Q_i H_i}{(H_i^2 + D_i^2)^{3/2}}$$

where Q_i is the assumed point charge, H_i the charge height, D_i the horizontal distance from the charges to the observer, and ϵ_0 the permittivity of free space. It is clear from examination of this equation that the observed maximum fields are mainly determined by the lower positive charge for the positive maximum field and by the negative charge for the negative maximum field. As these charge heights (H_i) are 6.0 km and 3.0 km in average respectively, dependency of the field intensity on the distance (D_i) is greater for the positive field than for the negative field. The relatively large magnitudes of charges derived in the present work are not much altered by

assuming 1.5 km for the storm distance. This results essentially from the relatively high positions of the negative and the lower positive charges. The lower positive charge, its position and magnitude, play a critical role in calculating the field variation patterns.

Based on a study of electric field changes from lightning flashes measured at two stations near Socorro, Ogawa and Brook (1969) showed direct evidence that the storm motion is shaping the charge distribution in the cloud. Other dynamical environments such as wind distribution, up-and-downdraught and precipitation will also influence the displacement of the negative charge described in this paper. The magnitude of the displacement may be related to activity of such dynamical features of the storm cloud, but will be as large as 0.6 km if assuming that the charges distribute as points in the cloud.

In future simultaneous observations of electrical and dynamical features of the thunderstorm cloud are desirable to investigate the mechanism of the charge distribution, and a dynamical thunderstorm-cloud model should be considered including the growing and dissipating phases of the cloud.

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平均的雷雲内の電荷分布

藤 田 晃

(甲南大学理学部)

小 川 俊 雄

(京都大学理学部)

1965年から1967年に至る3年間の夏期に、京都市北東部において、回転集電器を用いて連続的に観測したデータから、雷雲による電場変化99例を選んで、それらを12の変化型に分類した。

最も頻繁に現れる電場変化の特性は、負の電場が最初に現れ、時間スケールは約1時間で、電場の値は約 $\pm 5000\text{V/m}$ である。このような観測された電場変化を与える電荷分布のモデルは、 $+120$ クーロンが 8.5 km の高さに、 -120 クーロンが 6.0 km の高さに、 $+24$ クーロンが 3.0 km の高さに存在し、負の電荷は雷雲の移動方向に他の電荷より $0.2\text{--}0.6\text{ km}$ 先方に突き出している。