[Journal of the Faculty of Science, Hokkaido University, Ser. VII (Geophysics), Vol. VI, No. 1, 1979]

Atmospheric Electrical Observations of Precipitation Particles in the Winter Monsoon at Hokuriku District, Japan

Part I. Results at Unoke Town

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(Received Oct. 5, 1979)

Abstract

Atmospheric electrical observations of precipitation particles, electric field, shape, charge and constitution of precipitation particles and melted diameter of the particles and so on, were carried out in the winter monsoon season at Hokuriku district, Japan in 1978. Careful attention was paid on the surface condition of the particles, that is to say, whether they were rain or sleet or snow and rime or not, and whether they were graupel particles (soft hail) or small hail. Further, whether the mirror image relation between the polarity of electric charge on precipitation particles and the polarity of the atmospheric electric field was present or not in the Hokuriku district.

As a result, it was found that graupel particles (soft hail) were positively charged predominantly under the negative electric field and vice versa in the case of small snowflakes and snow crystals. Therefore, the mirror image relation between electric charges on graupel particles and small snowflakes, and electric field was present. Furthermore, it was noted that when the positive charged relatively large snowflakes and graupel particles were predominant under the negative electric field, a number of small snow particles coexisted with them. The results obtained in the observations carried out at Hokkaido previously, coincided well with the results obtained at this time at Unoke Town in Hokuriku district, Honshu Island. In the case of rain, sleet and small hail, however, the mirror image relation between the electric charges and electric field during their falling was not clear. It was thought that the degree of melting strongly affected the complexity of charge generation.

1. Introduction

A limited number of observations of electric charges on snow crystals comparable to that on rain drops have been carried out till the present as summarized in the publications by Chalmers[1], Mason[2] and Takahashi[3]. Moreover, the results reported were different. It is thought that the divergence

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between the different results was probably due to differences in the conditions of precipitation particles and crystal shapes when the observations were made. Electric charges, especially, polarity of precipitation particles is changeable with the stage of clouds, namely, as in the case of developing and dissipating stages in warm rain at Hawaii[4),5)]. Also, the electric polarity of snow crystals changes with their shapes[6)]. Further the amount of riming changes, negative dendritic crystals into positive graupel particles[7)-11)]. It is well known that precipitation particles change their electric polarity in their melting process from negative snow crystals to positive sleet and rain drops[12)-18)].

In general, in the sub-tropical regions the precipitations from convective clouds, regardless of whether they are rain or snow give some disturbances such as wave patterns to the atmospheric electric field. Under such conditions, it is known that there are a "mirror image relation" between the polarity of electric charge (or current) on precipitation particles and the polarity of the electric field[7)-11),19)-23)].

On the other hand, however, there is an opinion that there is no mirror image relation between them at Honshu district. Therefore, careful observations are required of precipitation particles, especially, the surface condition of the particles, that is to say, whether they are rain or sleet or snow and rime or not, and graupel particles (soft hail) or small hail, under the conditions of below and above freezing temperature on the earth surface. This paper describes the atmospheric electrical properties of precipitation particles in the winter monsoon season at Unoke, Ishikawa Prefecture in Hokuriku district, based on the simultaneous observations of atmospheric electric field, shape, charge and constitution of precipitation particles and melted diameter of the particles.

2. Observation sites and equipments

Almost all observations carried out hitherto on Hokkaido were at the Hokkaido University campus,[7),8),21),22)] Sapporo and the seashore of Ishikari[9),11)] approximately 20 km to the north of Sapporo. To the precipitation particles in the winter monsoon season on Hokkaido, the former site is thought for precipitation from the dissipating stages and the latter is for the developing stages of the precipitating clouds invading from northwest. As a result, atmospheric electrical properties of precipitation particles did not change at both sites, especially, polarity of precipitation particles and the mirror image relation between the polarity of electric charge on precipitation particles and of electric field did not change. However, there is an opinion that the mirror image relation does not hold on Honshu Island, the Kahoku-gata inlet area, Ishikawa Prefecture, Hokuriku district, Honshu Island was selected as the observation area (Fig. 1). When the monsoon wind prevails in the winter season, the direction of the prevailing wind is from west-southwest to northwest. Thus, four observation sites were set up in a triangle form. Observations at Unoke site were carried out at the Sand Dune Agricultural Experimental Station, Ishikawa Prefecture.

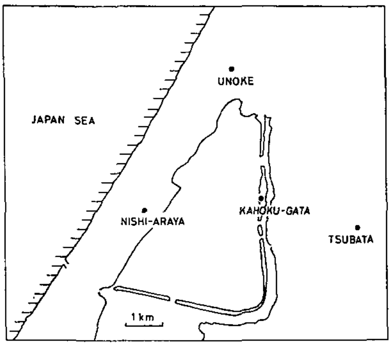

Fig. 1 Observation sites at Kahoku-gata inlet, Ishikawa Prefecture.

The charge on precipitation particles was measured by an induction ring method[11] and electric field was measured by an inverted field mill. The melted diameters of precipitation particles were recorded on filter papers. The surface condition and constitution of the particles was observed by naked eyes, carefully. The records of the charge and electric field were taken continuously during the observation period. On the other hand, the filter paper method was carried out at approximately 5 to 10 minute intervals during precipitation. The observation was carried out from 11 to 22 January 1978.

3. Observation results

3.1 Periods of disturbances of electric field by precipitation

It is well known that the electric field is affected by precipitation particles and electrified clouds, and changes its sign from positive to negative and vice versa depending on the precipitation intensity and so on. Especially, in the case of precipitations in the winter monsoon season, the frequency of change of electric field is more frequent compared with that of continuous precipitations.

And, it is thought that each period of positive and negative electric field corresponds to a precipitation cell. Then periods of disturbance of electric field by precipitating clouds were considered. During the observation period, 86 disturbances of electric field by precipitating clouds were recorded at Unoke. And, it was found that the duration of precipitation was divided into two types, that is to say, one is shorter than 1 hour (short period), another is longer than 1 hour (long period). Fig. 2 shows the cases of short (a) and long (b) periods. As seen in the figure, however, the period of disturbance of electric field predominated within 5 minutes in the positive and negative fields in both cases. Relatively frequent number around at 20 minutes in

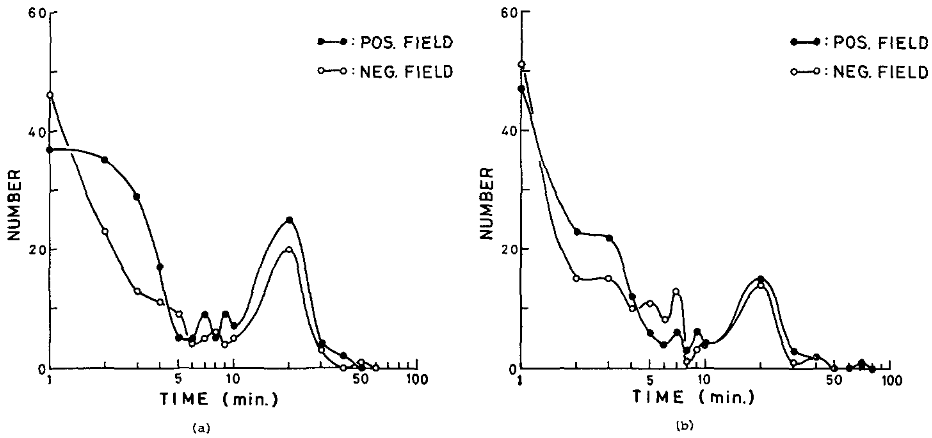

Fig. 2 Periods of disturbances of atmospheric electric field.
(a): Short period, (b): Long period.

cases of short period means that unit cell of positive or negative electric field with precipitation passed over the observation site. On the average, the duration of disturbances in the cases of the short period is 25 minutes, and the disturbances consisted of 5 minute each of three positive and two negative electric fields alternatively. On the other hand, in the case where the long period is 130 minutes, the disturbances consisted of 5 minute each of positive and negative field, alternatively in the same manner. Accordingly, it was found that the duration of positive or negative electric field is not longer than the other, selectively. Furthermore, it was concluded that it was similar electrically, and not the length of the duration in the case of a long period.

3.2 Examples of mirror image relation

Fig. 3 shows an example of the time change of atmospheric electric field and electric charge on precipitation particles. The ordinate shows the electric field in KV·m^{-1} on the left side and the amount of electric charge in esu on the right side. The sign of electric field is positive at the upper part of the axis of the abscissa of time, the same as the sign of electric charge and vice versa. As the gate time, controlled by a time controller was 2 seconds in this case, each amount of charge shows the maximum absolute charge of precipitation particles passing through the induction ring during 2 seconds[11]. Although the measuring range of the charge adopted was between 1×10^{-4} and 1×10^{-1} esu the charge of 10×10^{-2} esu around at 05:31 shows a charge above 1×10^{-1} esu. In this analysis, the amount of charge below 5×10^{-4} esu is excluded as their small values. In this case, especially, the mirror image relation between polarities of electric field and electric charge is remarkable. That is to say, positive charge of graupel particles prevails under negative electric field before 05:31, and after that time, negative charge of snowflakes under positive electric field prevails.

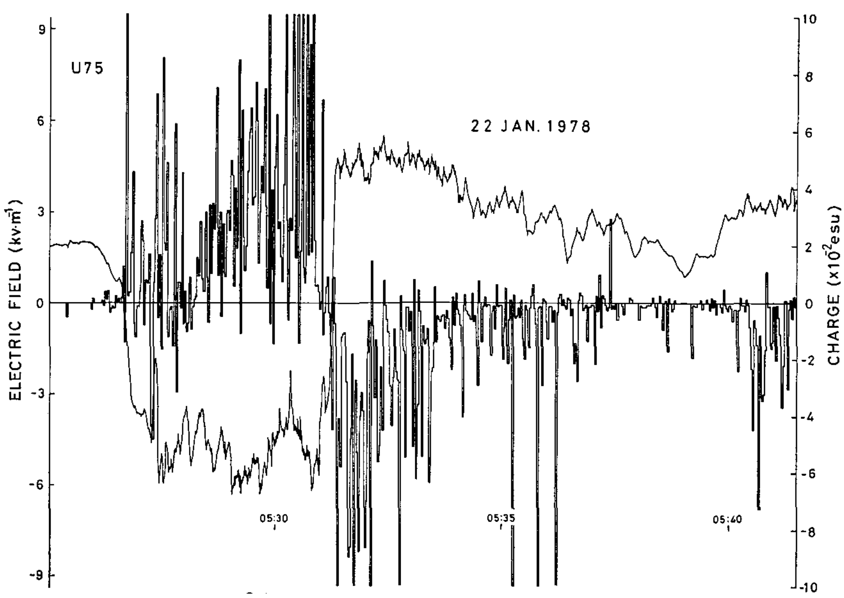

Fig. 3 A time change of atmospheric electric field and electric charge on precipitation particles.

During the observation period, a number of data of the mirror image relation were obtained. Fig. 4 shows the charge versus field plot in the cases of negative charge under positive field. Precipitation particles of the case of U22 at a gate time of 2 seconds were mixed with sleet and snowflakes consisting of dendrites. It is thought generally that the electric polarity of snowflakes depends on the size, that is to say, the large snowflakes have a positive charge and the small ones have a negative charge. Negative polarity of small snowflakes is the same as in single dendritic crystals. On the other hand, the electric polarity of sleet depends on the degree of melting, that is to say, relatively small snowflakes have a negative charge and melted snowflakes

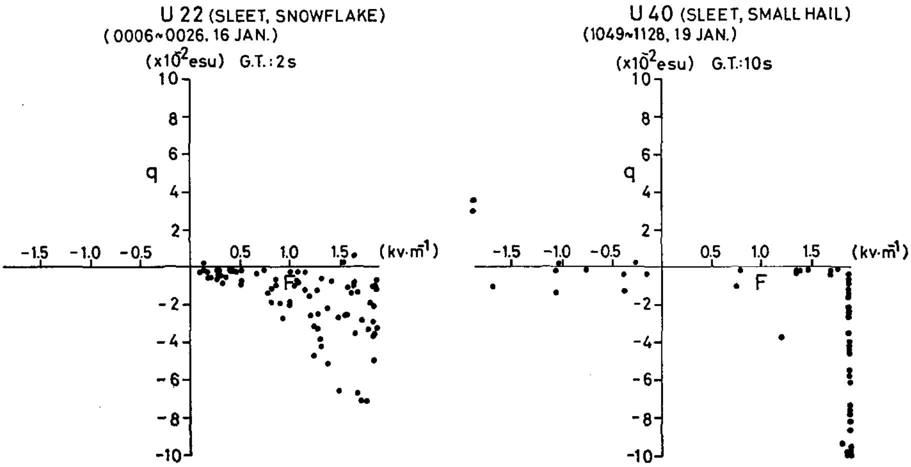

Fig. 4 Charge (q) versus field (F) plots in the case of negative charge under positive field.

(sheet) have a positive charge. Precipitation particles in the case of U40 at a gate time of 10 seconds were sleet and small hail. The surface condition of small hail particles is wet and covered by a thin liquid layer, therefore, the electric polarity of small hail depends on the degree of melting. In this case, the strength of electric field showed, off-scale values above 2 $KV \cdot m^{-1}$ many times. Fig. 5 shows the cases of positive charge under negative field. Precipitation particles in both cases of U23 and U62b were graupel particles (soft hail), therefore, positive charge prevails predominantly as reported by Kikuchi and Inatsu[11].

Fig. 6 shows the cases of positive and negative charges under negative

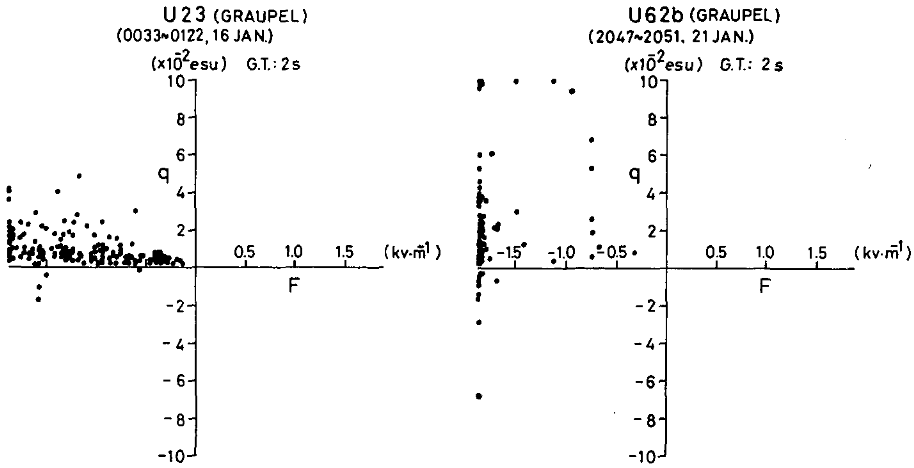

Fig. 5 Charge (q) versus field (F) plots in the case of positive charge under negative field.

and positive fields. It means, therefore, that electric field shows a wave pattern change. Although the case of U24 was a relatively small charge under a weak field, while the other three cases of U42, U44 and U46 showed a large charge under a strong field, especially in the case of U46, the electric charge on considerable number of particles were more than 1×10^{-1} esu and the electric field was higher, over 3 $KV\cdot m^{-1}$. Although it is accepted that positive charge of graupel particles under negative field and negative charge of snowflakes under positive field prevails under the condition of wave pattern of electric field, it is not understood why the conditions of electric charge and field prevails under the existence of graupel particles and rain drops.

Fig. 7 shows similar results to Fig. 6. In the cases of U47, U62a and U64a, they showed a positive charge of graupel particles under a negative field and a negative charge of snowflakes under a positive field. The case of U51 showed positive and negative charges under negative and positive fields, however, the precipitation particles were sleet, rain and graupel, and electric field was weaker than the cases of U47 and U62 at the same gate time of 10 seconds.

All cases selected up in Fig. 8 are graupel particles and snowflakes. Consequently, the mirror image relation is remarkable, especially, in the case of U72 because the gate time of 30 seconds.

3.3 *Examples of no mirror image relation*

Fig. 9 shows an example of time change of atmospheric electric field and

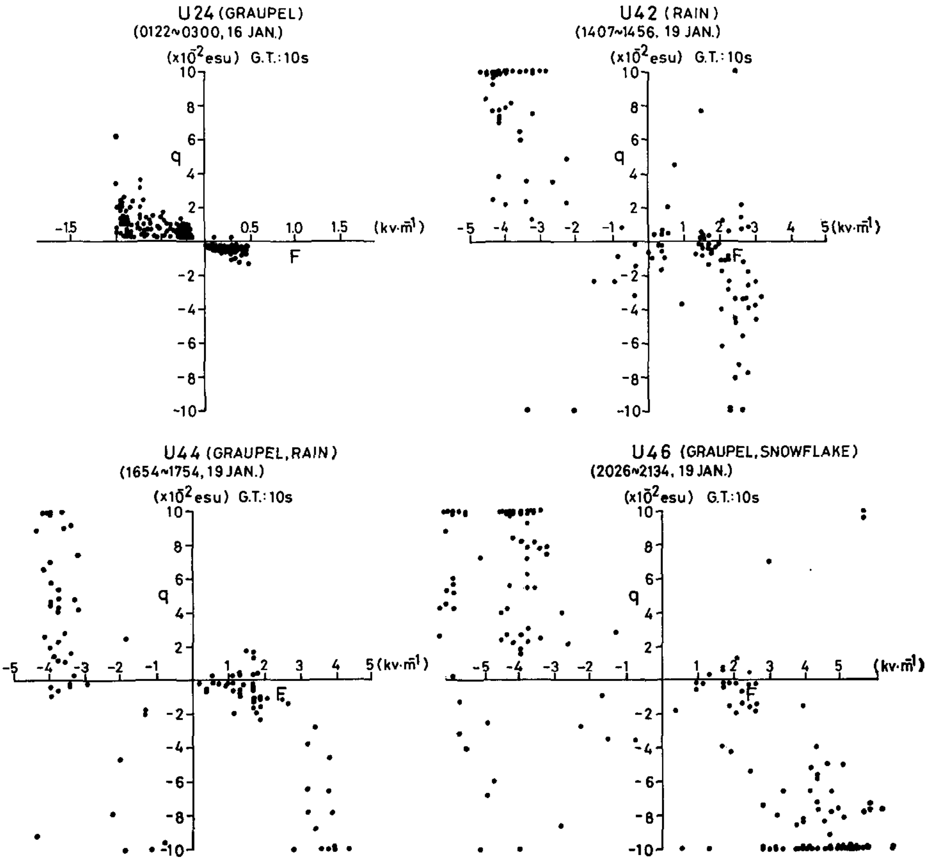

Fig. 6 Change (q) versus field (F) plots in the case where wave patterns prevailed.

electric charge on precipitation particles the same as in Fig. 3. As seen in the figure at a cursory glance, there is a no mirror image relation, especially, the same signs of the electric charge and electric field were seen from 07:55 to 08:02. Precipitation particles are sleet predominantly. As described in the above section, the electric polarity of sleet particles depends on the degree of melting. Therefore, it is thought that this is due to the difference in degree of melting according to their sizes during the observation period.

Fig. 10 shows the charge versus field plots in the cases of no mirror image relation. Dots showing the charge versus field strength scatters widely in all quadrants, however, it seems the dots are more dense in the second and forth quadrants than other ones in the case of U32. Precipitation particles during

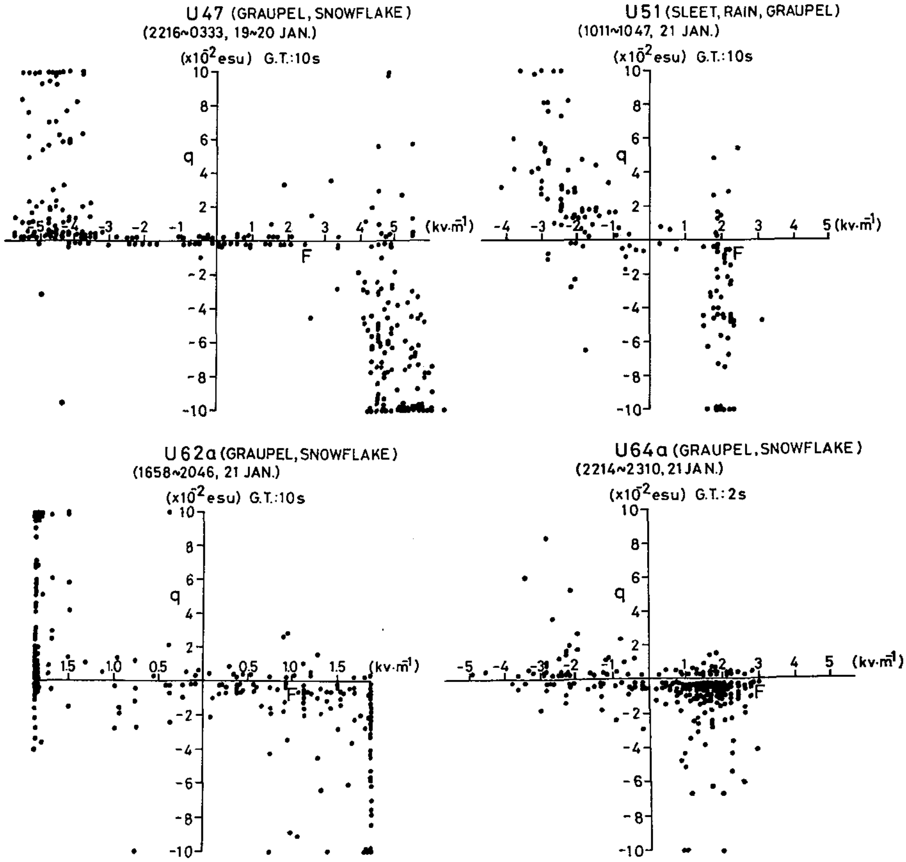

Fig. 7 Charge (q) versus field (F) plots in the case where wave patterns prevailed.

this observation period of about 4.5 hours are rain, sleet and small hail. In the case of U54 in Fig. 10, there is no mirror image relation and precipitation particles are small hail and rain. There is every indication, therefore, that precipitation particles such as rain, sleet and small hail accompanying the melting process in the winter season do not show a distinct polarity coming from their melting.

3.4 *Time change of precipitation particles*

An example of U50 in the Fig. 11 shows a precipitation system during 07:12 to 09:39 JST January 21, 1978. According to the analysis of the time

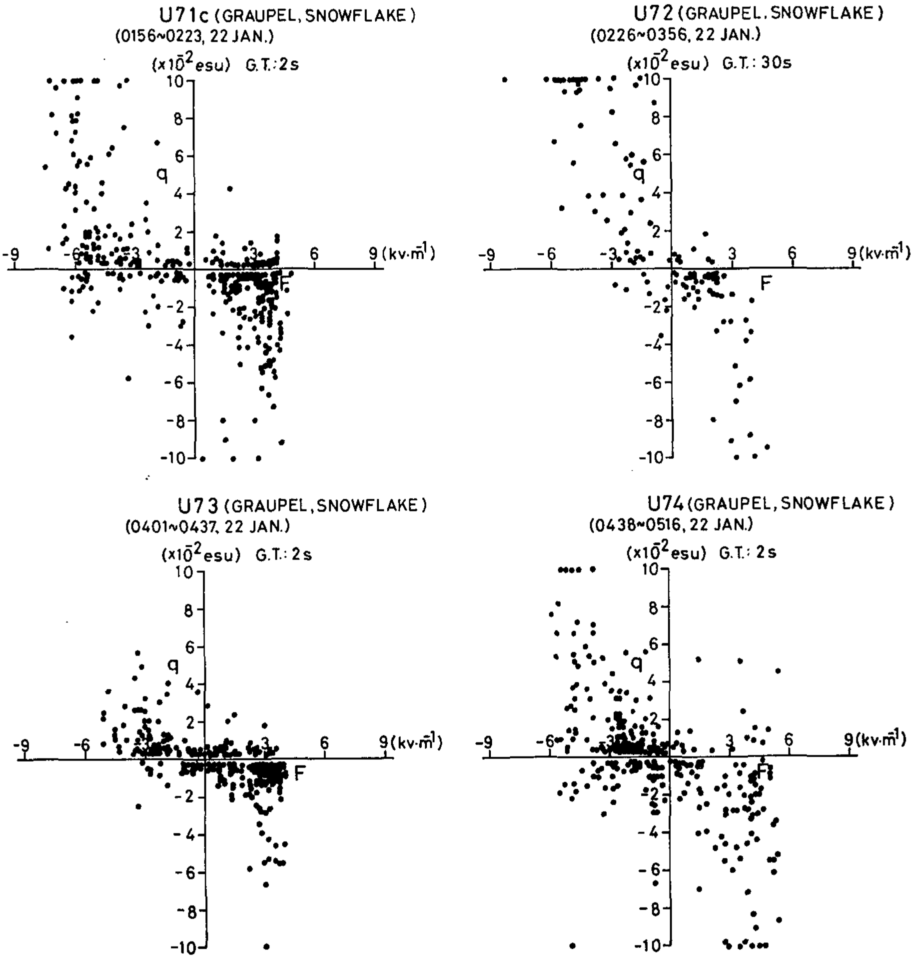

Fig. 8 Charge (q) versus field (F) plots in the case of graupel particles and snowflakes.

change of electric charge versus electric field, there is no systematic tendency in the gate time of 30 seconds, namely, dots scatter widely in all quadrants. Precipitation particles during this time are rain, sleet, graupel and snowflakes. A sampling of the gate time of 2 seconds, during 10 minutes from 07:55 to 08:05 in rain and sleet shows no mirror image relation as seen in the case of U50a in Fig. 11. However, a sampling of the same gate time of 2 seconds, during 10 minutes from 08:47 to 08:57 in graupel particles and snowflakes shows the mirror image relation as seen in the case of U50b. In these

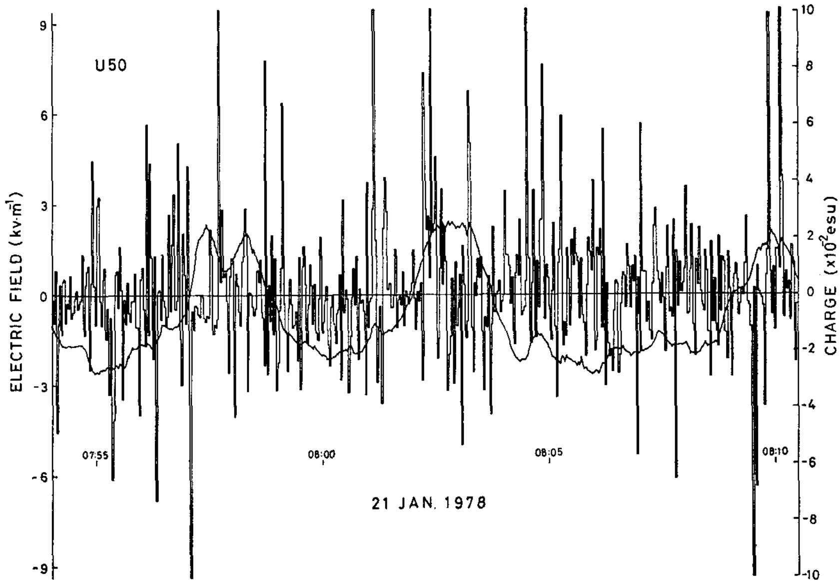

Fig. 9 A time change of atmospheric electric field and electric charge on precipitation particles.

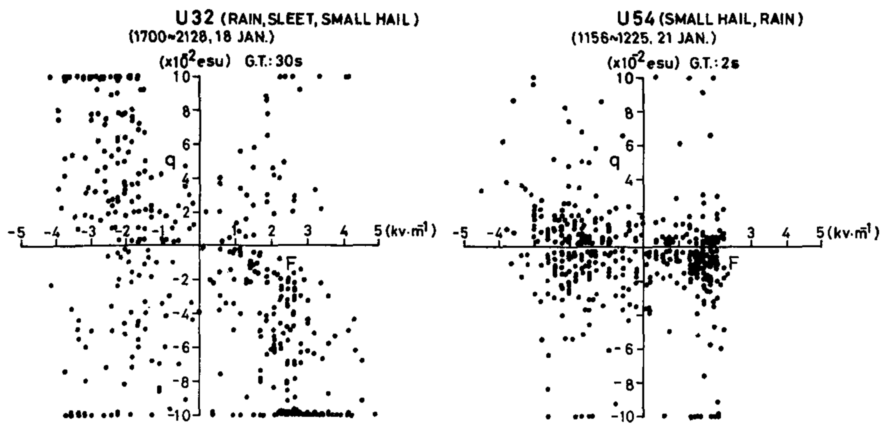

Fig. 10 Charge (q) versus field (F) plots in the case of no mirror image relation.

examples, therefore, the precipitation particles such as rain and sleet did not shows a distinct polarity.

An example of U72 in the Fig. 12 shows a precipitation system during 02:26 to 03:56 JST January 22, 1978. As a result of the analysis of the

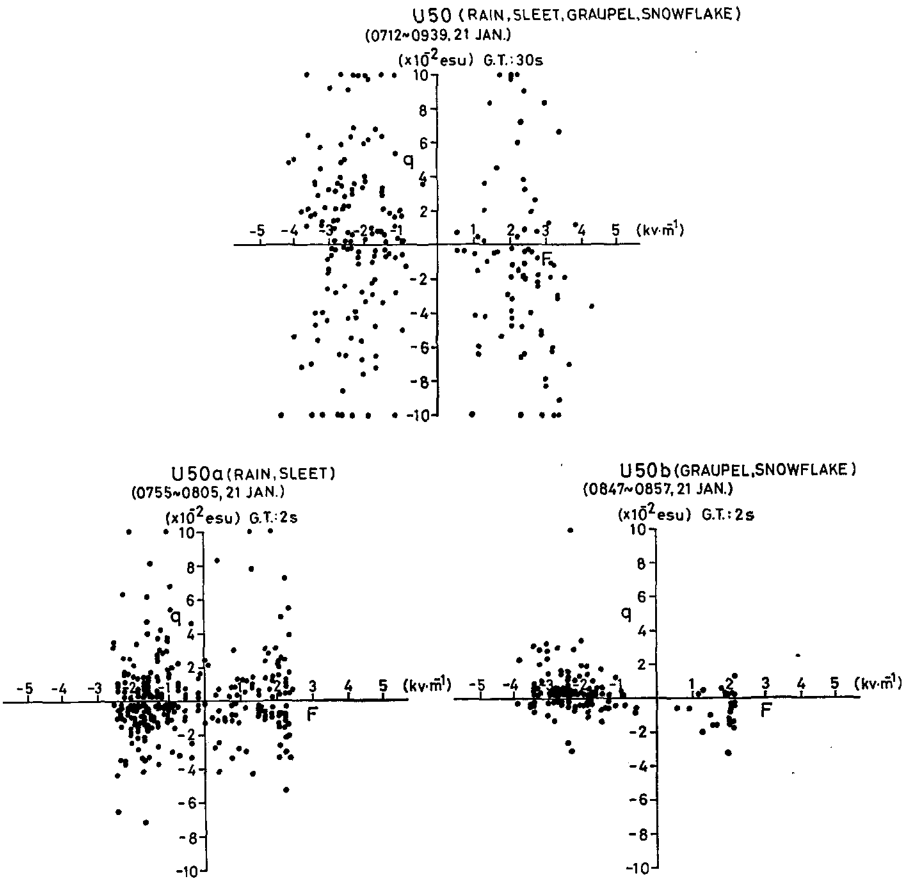

Fig. 11 Charge (q) versus field (F) plots in the case of time change of precipitation particles.

time change of electric charge versus electric field, there is a good mirror image relation in the gate time of 30 seconds. In this time, precipitation particles are graupel particles and snowflakes throughout the period. Now, dividing the precipitation condition into 4 groups namely from U72a to U72d, it was found that there is a good mirror image relation in all groups. That is to say, in the case of U72a, positive charged graupel particles prevail under a negative field and in the case of U72b, negative charged snowflakes prevail under positive field. U72c and U72d show positive charged graupel particles and negative charged snowflakes under the conditions of opposite

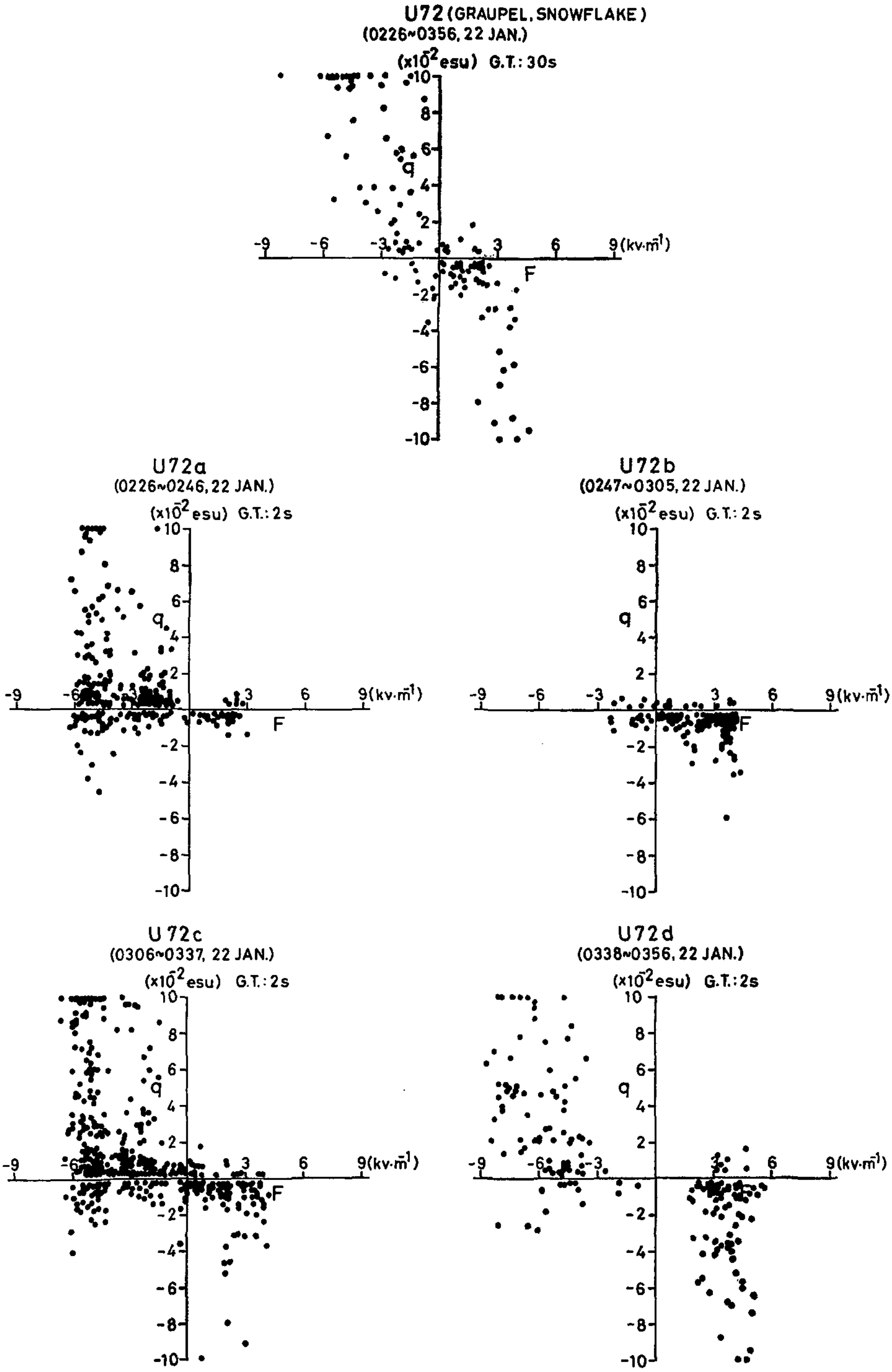

Fig. 12 Charge (q) versus field (F) plots in the case of time change of precipitation particles.

electric field, respectively. Therefore, it was found that a good mirror image relation holds in the case of graupel particles or snowflakes.

3.5 Charge versus field plots by the difference of gate time

Fig. 13 shows another example of graupel particles and snowflakes. Both figures show the same data in the case of graupel particles and snowflakes from 05:20 to 06:27 JST January 22, 1978. The figure in the right side shows all values to the charge versus field plots of the gate time of 2 seconds. At first glance, it may be seen that there is a remarkable mirror image relation between both factors. However, it is recognized that there are a number of precipitation particles with small charges located at the neighbouring sides of the axis of the electric field. The figure in the left side shows the results counted at each 30 seconds for the same data. As a matter of course, the mirror image relation was emphasized by the disappearing of the data of small charges.

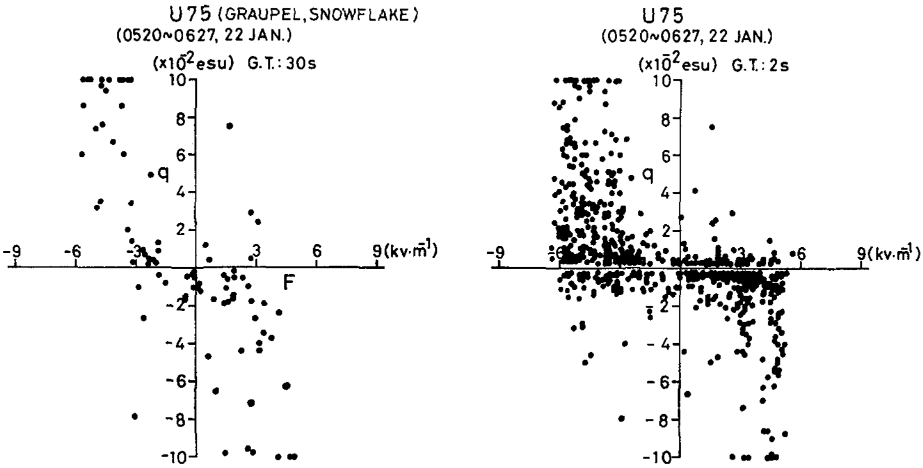

Fig. 13 Charge (q) versus field (F) plots by the difference of gate time.

3.6 Size distribution of precipitation particles

Previously, Kikuchi[9] and Kikuchi and Inatsu[11] observed that relatively large dendritic snowflakes, densely rimed crystals and graupel particles were positively charged under a negative electric field. Further, they pointed out that when positive snowflakes and graupel particles fell, the mode value of the size distribution of melted diameter shifted to smaller sizes as compared with that when negative snow crystals fell alone.

Based on these results, they concluded that relatively large snowflakes, densely rimed crystals and graupel particles were charged positively by collision and friction with small snow particles which were charged with smaller values than the margin of the measurement or by disintegration of small particles or fragments from fragile snowflakes and graupel particles. Then, the size distributions of precipitation particles were noted in the case of U64 on January 21, 1978 as shown in Fig. 14. The main precipitation particles of F 230 (22:57 JST) and F 231 (23:10) were small snowflakes charged

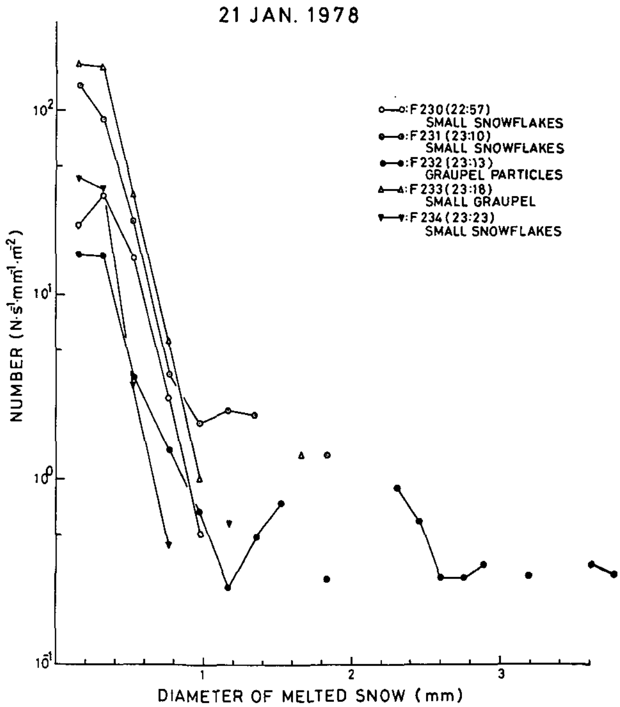

Fig. 14 Size distributions of melted precipitation particles.

negatively under a positive field. After 3 minutes, the precipitation particles of F 232 (23:13) changed to graupel particles charged positively under a negative field of 3 mm to 5 mm in diameter in a non-melted state and further the particles of F 233 (23:18) changed to small graupel particles of 1 mm to 2 mm in diameter in a non-melted state. Further, after 5 minutes, the particles of F 234 (23:23) changed to negative small snowflakes under a positive electric field. As seen in the size distribution curves of melted precipitation particles, it was found in all filter papers that a distribution tendency in the melted diameter smaller than 1 mm showed nearly the same gradient. When the graupel particles prevailed(F 232), however, the particles having melted diameter larger than 2 mm increased as shown by solid circles, and yet, there were considerable smaller precipitation particles. This is the same result in that when positive charged graupel particles prevail under a negative electric field in the observations at seashore of Ishikari, a number of small snow particles coexisted with them[9),11)].

4. Conclusions

As a result of the careful observations between the electric charge of precipitation particles and electric field with the conditions of precipitation particles taken into consideration, it was found that there was the mirror image relation between both factors. As expected, however, there was no mirror image relation between both factors in the cases of rain, sleet and small hail. In the cases described above, the electric field changed frequently. Therefore, it is thought that the degree of melting strongly affects the complexity of charge generation. In the case of long periods of precipitation, even though there was no mirror image relation between the electric charge on precipitation particles and electric field partially, when viewed in its entirety with a longer time scale the relation between them holds. Furthermore, when the positive charged relatively large snowflakes and graupel particles were predominant under a negative electric field, a number of small snow particles coexisted with them. Therefore, the results concluded in the observations carried out at Hokkaido previously, coincided well with the results obtained in the present work at Unoke in Hokuriku district, Honshu Island.

Acknowledgments: The authors wish to express their hearty thanks to Dr. I. Wakisaka, Head of the Sand Dune Agricultural Experimental Station, for his help in carring out the observations. This work was made as a part of the Project No. 046001 of "Experimental and Observational Studies on the Mirror Image Relation Between the Polarities of Precipitation Particles and Atmospheric Electric Field" in 1975 and 1976, and the Project No. 246033 of "Studies on the Atmospheric Electrical Properties of Precipitation Particles" in 1977 and 1978 under the Grant-in-Aid for Scientific Research (B), the Ministry of Education, Science and Culture of Japan.

It is authors' pleasure to dedicate this paper to Prof. Choji Magono on the occasion of his retirement from the Hokkaido University.

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