Two-Point Observations of Electric Property of Snow-Shower Clouds

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Abstract

In the winters of 1960 and 1961 respectively, two kinds of simultaneous observations and measurements were carried out in order to get some data as to the main factors such as the surface electric potential gradient, the charge on snow particles, the falling rate of snow and the forms of snow particles.

First, these four factors were measured at two stations installed about 1.2 km separated each other along a line on which a shower-cloud often passes. Enough satisfactory data, however, could not be obtained at these two stations, so the surface electric potential gradient and the charge on snow particles were simultaneously measured at another two stations at different altitude, that is, at the Cloud Physics Observatory on the top of Mt. Teine (1023.7 m M.S.L.) and the Paradise Hut about 500 m lower than the top.

Through these observations, the following points were noted :

- (1) the origin of the inverse relation between the sign of the surface electric potential gradient and that of the charge on precipitations
- (2) the space charge effect of the charge on precipitations on the surface electric potential gradient
- (3) the difference of electrification of shower- and thunderclouds
- (4) the existence of the difference between the conclusions obtained at the lower and the higher part of the mountain

From these observations some interesting results were obtained.

1. Introduction

In the previous report, Magono and Orikasa (1966) pointed out a lot of interesting phenomena which could not be explained by Wilson's induction theory on the electrification of precipitation particles. But these were easily explained by the "charge transportation theory" (If a small group of charge of positive sign on snow particles falls from a cloud, a narrow negative space charge in the cloud layer will be left, and this negative space charge may be formed of negative ions or negative small snow crystals of low falling velocity. Under this situation, positive snow particle will be observed under negative electric field due to the negative space charge. Thus the inverse relation is established between sign of charge and sign of electric

field.) proposed by the authors in the report. The authors also presented some models of charge distribution as regards the stratocumulus cloud and the shower-cloud by introducing the mechanism of friction between non-rimmed snow crystals and graupels. But almost all the clouds observed, moved at a velocity of about 10 m/sec, therefore some typical states of clouds expected from the charge distribution model (four states were proposed in the previous paper) could not be confirmed by the observation carried out at only one point. From the above-mentioned point of view it was decided that the same kind of observation as had hitherto been made at one station should be carried out at many other points which were separated at suitable intervals on the line which a shower-cloud might move along. To meet this requirement, another station was established in a corner of an agricultural experimental station about 1.2 km away from the existing point.

*) This work was done when the author was in Hokkaido University.

At these two observation points, exactly the same kind of observation was carried out simultaneously. Because the new point was windward of the existing point, the shower-cloud which passed over the former also passed over the latter. From this method many interesting results were obtained.

Furthermore, in order to make sure whether or not the conclusions obtained up to that time on the flat ground near the sea-level hold true in the mountains nearly as high as the cloud base, two more stations were installed at the Cloud Physics Observatory on the top of Mt. Teine (1023.7 m M.S.L.) and at the Paradise Hut about 500 m lower than the top respectively. The conclusions obtained from the simultaneous measurements of surface electric potential gradient and the charge on snow particles corresponded with those from the previous measurements. The measuring apparatus and its arrangements were not mentioned in this paper because they were exactly the same as those mentioned in the previous paper.

2. The examination of the rapid increase of potential gradient in accordance with the rapid increase of the rate of snowfall

If the electrification of snow particles occurs mainly in the cloud high up in the sky, the signs of the charge on snow particles and that on potential gradient should, at least when the snow begins to fall onto the ground, be the same because of the effect of the charge on snow particles. But in almost all cases approximately inverse relations were found between them. This may be due to the fact that snowfall rarely began when the cloud came just above the station but, in practically all the cases, it had already begun before the cloud came right above the station. However, we can obtain some information about this phenomena in such a case as is shown in Fig. 1. The rapid increase in potential gradient indicated by an arrow in the figure may correspond to the starting time of snow- or rain-fall, or to the rapid increase in the falling rate of snow or rain. For example, Fig. 1(a) corresponds to the beginning of the fall of positive snow, and Fig. 1(d) corresponds to the rapid increase of the falling rate of positive snow. We could not

Fig. 1. Rapid increase of surface electric potential gradient which was caused by snow- and rain-shower.

Fig. 2. The location of the observational stations.

Fig. 3. Rapid increase of surface electric potential gradient caused by space charge of a small group of falling snow and hail.

(a)

(b) The spots of graupels

(c) Snow gauge

(d) Graupel collector

(e) A.E.S. Station

(f) D.S. Station

Fig. 4.

make clear the meteorological conditions in the case of Fig. 1(b) and Fig. 3(c) because the observer was absent. However, the conditions were considered to be the same as those in Fig. 3(a), that is, they corresponded to those at the beginning of the fall of positive rain. It is very difficult to catch the condition of snowfall at its initial stage, but because all the phenomena in Fig. 3 are fundamentally the same as those in the initial stage, we can grasp the initial condition by examining the phenomena seen in the rapid increase in the potential gradient in accordance with the rapid increase in the falling rate of snow.

In the previous work it was found that positive heavy snow- or graupel-fall occurs just after positive potential gradient reaches its peak. This phenomenon suggests that the rapid increase in potential gradient is caused by the fact that the local rapid increases of both the falling rate of snow and the space charge are in proportion to each other. If we observe an active showery cloud simultaneously at two suitable stations above which the cloud passes, we may find the difference between the values of potential gradient and the falling rate of snow determined at the two stations. D.S. and A.E.S. in Fig. 2 show the locations of the old Fig. 4f and the new Fig. 4e station respectively. These stations are situated on a line nearly parallel to the course of the monsoon from Ishikari Bay to the Ishikari Plains, and the showery cloud moved along from A.E.S. station to D.S. station. But we could not get sufficient data of factors, because it was very difficult to know beforehand the time at which the shower would arrive just above the station and the time the shower-cloud spent in passing above the station was short enough. Therefore, some records were obtained as to potential gradient alone at first, and these results were illustrated in Fig. 3 and Fig. 5. In the upper part in the figure is shown the record obtained at A.E.S. station, while in the lower part the one obtained at D.S. station. The falling rate of snowfall is divided into five stages, namely, 0, I, II, III, IV and V, and is shown in the top column of the figure. In this, 0 shows that the falling snow is so small that it cannot be detected by the snow gauge. I shows the falling rate of about 0.1 mm/hr, V

Fig. 5. Rapid increase of surface electric potential gradient caused by space charge of a small group of falling snow and hail.

Table 1. The symbols of snow crystal type.

✱	dendrites or steller crystals
✱	snowflake made of dendrites or steller crystals
✱	rimed dendritic or steller crystal
⊗	spatial dendrite
⊗	graupel-like crystal
⊗	snowflake made of spatial dendrites
○	graupel
▨	rimed irregular thick plate
✚	drifting snow
✚	snowstorm
○	snow particles which have positive charge
●	snow particles which have negative charge

shows the falling rate of about 5–10 mm/hr. The rough falling rate was also determined visually. The second column in the figure indicates the forms of snow particles which are illustrated in Table 1. And the sizes of snow particles are shown roughly by the indexes of 'large', 'middle' and 'small'. 'Large' denotes more than 10 mm in diameter, 'middle' 5–10 mm, and 'small' less than 5 mm. The indexes of + and - in the third column are the signs of the charge on snow particles. The directions and velocities of the surface wind obtained by the Sapporo Meteorological Observatory are shown in the lowest column of the figure. Since it is a matter of course that the wind direction does not always agree with the path of the cloud, it was shown only as information. However, as for the examples of Fig. 3

and Fig. 5 and other examples which will be referred to later, we confirmed that the path of the cloud was parallel to the line connecting the two stations. A positive sharp peak of potential gradient, as is shown in Fig. 3, occurred at A.E.S. station simultaneously with the fall of positive snow at 20 : 25, but there occurred no peak at D.S. station, and such phenomena were seen also at 22 : 20 and 23 : 06. Thus it was found that these rapid increases of potential gradient were localized in an area far narrower than expected. It is seen in Fig. 5 that a heavy graupelfall with a large peak of potential gradient occurred during the period from 13 : 00 to 13 : 02, and that the graupel, when measured, had a large charge of about $+1 \times 10^{-1}$ e.s.u. This result clearly suggests that the peak of positive potential gradient is caused by the space charge effect of the positive charge on the graupel. It may safely be considered that graupels fall for such a short time that they will end before the shower-cloud reaches D.S. station. Consequently, the peak of potential gradient does not always occur at D.S. station.

Here, we shall examine the mechanism of the occurrence of the peak of potential gradient with a value of about 1000 v/m for only 2 or 3 minutes.

Suppose a point charge of Q coulomb is moving horizontally along the straight line at the height of 1000 m above the ground surface, and that when it comes just above a station, it gives the maximum potential gradient of 1000 v/m to the station. Now we get the following relation from the method of images :

$$F = 2HQ / 4\pi\epsilon_0 (H^2 + R^2)^{3/2}$$

where F is the potential gradient at the station, H is the height of a point charge Q from the ground surface, R is the horizontal distance between the point charge Q and an observation point, and ϵ_0 is the dielectric constant of the atmosphere. From this formula, the charge Q of 1/18 coulomb gives the maximum value of F (1000 v/m) to the station. When the point charge of 1/18 coulomb reaches a point which is separated by 4.6 km, it gives the potential gradient of 10 v/m to the station. The employed electrometer was adjusted so that it could have the maximum sensitivity at 10 v/m, so the potential gradient at the

station began to increase sensibly when the point charge came to the above-mentioned point. When this point charge of 1/18 coulomb is moving to the station at a velocity of 10 m/sec, the increase of potential gradient takes 7.7 minutes to reach the maximum value of 1000 v/m, so this assumption cannot explain the peak of potential gradient with a short duration of about two minutes, and this is indicated in Fig. 6 by a solid line. However,

Fig. 6. A theoretical example of the rapid change of surface electric potential gradient calculated by the method of images assuming a point charge horizontally moving at the height of H m just above the station at a velocity of 10 m/sec.

if the point charge is falling vertically from a point just above the station at a velocity of 1.6 m/sec (this value is quoted from Magono's result (1954)) and the space charge has a spherical extent of about 200 m in radius, then the charge gives the maximum potential gradient when the center of the group of charged particles reaches the point about 200 m high above the station. The point charge which gives the maximum potential gradient of 1000 v/m to the station when it comes to the point of 200 m high just above the station is calculated at 2.2×10^{-3} coulomb, and this gives 10 v/m when it comes to a point of 2000 m just above the station. So the increase of potential gradient takes 19 minutes to reach the maximum value of 1000 v/m. Therefore, the snow-flake may take longer time because the falling velocity of the snow-flake is much smaller than that of the graupel. Even a rain-drop which has a falling velocity of 5 m/sec takes more than 6 minutes.

If a point charge of $2/9 \times 10^{-2}$ coulomb is horizontally moving at the height of 200 m just above the station at a velocity of 10 m/sec, the potential gradient at the station begins to increase when the point charge reaches just above the point which is horizontally separated by 906 m, and after 1.5 minutes it gives the maximum potential gradient of 1000 v/m to the station. This is indicated in Fig. 6 by

a dotted line. All the discussions given above have been followed by assuming the point charge, and we get the following conclusion: the peak of potential gradient must be caused by a group of charged particles, which, with small concentration and large space charge density, fall at their terminal velocity and pass above the station at a horizontal velocity of about 10 m/sec at a level of several hundred

Fig. 7. The records produced by snow-shower clouds successively passed over the station. (An arrow point out the time (7:19) at which the largest space number density of graupel was observed with a sharp peak of potential gradient.)

meters above the ground.

The synoptic meteorological conditions which satisfy the above-mentioned conditions may be confined to the snow- and rain-shower caused by the shower-cloud accompanied by a fast-moving cold front. All the examples illustrated in this paper were, of course, obtained from the rain- or snow-shower of this kind. In the example of Fig. 7, the space number density of the graupel was observed by the collectors Fig. 4d at 4:59, 5:58, 7:19, 7:31 and 7:37, while the largest space number density was observed at 7:19 Fig. 4b, when only a sharp peak of potential gradient occurred. In other 10 examples of observations, it was not certain whether both the peak of potential gradient and the space number density of the graupel in all the examples were smaller than those in the example at 7:19 in Fig. 7. It was expected from most of these examples that the peak of potential gradient would be about several thousand v/m as was derived from the simultaneous observations of the charge on, and the space number density of, the graupel. Contrary to our expectation, however, we could not confirm this except in only one example of Fig. 7. It seems that this fact suggests the difficulty in observing the peak of potential gradient just at the station. Then it may be concluded that this is a strictly local phenomenon which occurs in a small area and ends in a very short time.

3. On the change of the electric property of the snow-shower cloud while passing above the two stations which are 1.2 km separated from each other

The two stations mentioned in this chapter are the same as the two ones in chapter 2. During the observation in this chapter, however, no observer was installed at one of the stations, so we saw to it that there was at least one observer at each station in order to get some data, compare them with one another and discuss the results. Then, simultaneous observations were made at either station as to four factors, *i.e.*, potential gradient, the charge on snow particles, the falling rate of snow particles, and forms of snow particles. Fig. 8 shows an example of them, and as in chapter 2, the upper record in the figure

was obtained at A.E.S. station and the lower one at D.S. station. Both potential gradient and the falling rate of snow are indicated by a solid and a dotted line respectively. The snow gauge Fig. 4c has an error due to evaporation from the surface of the heated funnel of the snow gauge, so the falling rate of snow was recorded by adding a corrective value of 0.5 mm/h. The mark of WIND in the figure shows the time when the wind was particularly strong, and BLANK shows the blank part of the measuring factors except potential gradient, which could not be confirmed because the observer was absent at the station. In the lowest part of the figure are shown the velocities of the wind and its directions at some levels from the ground to the height of 3000 m (this was obtained by radiosondes of the Sapporo Meteorological Observatory indicated in Fig. 2 as M.O.). The result in Fig. 8 was obtained when several shower-clouds successively passed above the station. The most interesting phenomena occurred during the period from 6:40 to 8:00, that is, a clear inverse relation between potential gradient and the charge on snow particles was found during this period at A.E.S. station, while at D.S. station both signs were the same. To put it concretely, the signs of the charge on snow particles are negative at both stations, whereas the signs of potential gradient at both stations were different. Then, the examination of the falling rate of snow rapidly increased at D.S. station and reaches a value of about twice as large as the one at A.E.S. station. Therefore, it must be considered that the relation of the same signs between potential gradient and snow particles was produced by the rapid increase of the intensity of snowfall, and this may be a strong proof of the "charge transportation theory", from which this phenomenon was predicted.

Fig. 9 is the result brought about by the passage of four single shower-clouds, and the lowest diagram is the manifestation of the two upper records of potential gradient at A.E.S. (dotted line) and D.S. (solid line) station. In this example very interesting phenomena are noted during the period from 9:00 to 9:30. When the first half of a snow-shower cell passed above A.E.S. station, the cell produced negative light snow and positive

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ALTITUDE (M.S.L.)	GROUND	500	1000	1500	2000	2500	3000 M
WIND DIRECTION	3 hr NE 2.5	307° 4.0	301 10.0	304 11.0	296 9.0	307 8.0	294 8.0
& VELOCITY	9 hr N 3.3	305° 10.0	309 13.0	311 13.0	300 14.0	285 12.0	301 11.0

Fig. 8. The records produced by snow-shower clouds successively passed over the station with continuous heavy snow and hailfall.

Fig. 9. The records produced by intermittent passage of four single shower-cloud. The records marked C and D were produced by shower-clouds which were developed near the station.

potential gradient increased to the maximum value. When the latter half of a snow-shower cell passed, potential gradient rapidly decreased to the half of the maximum value the moment negative snow changed into positive light snow, and then potential gradient gradually decreased. On the other hand, when the first half of a cell passed above D.S. station, similar kinds of phenomena occurred except that potential gradient became larger than at A.E.S. station. But when the latter half passed, the sign of potential gradient became negative in spite of the positive charge on snow.

These phenomena suggest that the relation between the same signs of the latter half of positive potential gradient and the positive charge on snow at A.E.S. station was caused by the excess of the space charge of falling positive snow particles over the upper negative charge, because the positive snowfall began just above the station. And when the cell reached D.S. station, a large number of positive snow particles fell onto the ground. Consequently, the upper negative space charge became predominant and this produced an inverse relation. The sign of the charge on snow and that of potential gradient were the

same in both Fig. 8 (obtained at D.S. station) and in Fig. 9 (obtained at A.E.S. station), and this is perhaps due to the same cause, that is, the former was produced by the fact that the rapid increase of the space charge density and the rapid increase of the falling rate of snow are in proportion to each other, and the latter was produced in the beginning of snowfall. Furthermore, it is very important that the sign of potential gradient changed from positive to negative after positive snow began to fall, in other words, the change of the sign of charge precedes that of the sign of potential gradient. From these facts, it was confirmed that the "charge transportation theory" was supported by the results of the observation, while "Wilson's induction theory" was not. Because the mean value of the wind directions (331°) at various levels between the ground surface and the height of 2000 m agrees well with the direction of the line (331°) connecting the two stations, it may be certain that the shower-clouds which we observed passed just above the two stations. As indicated in the lower part of Fig. 9, the records of potential gradient at the two stations were compared with one another, and it was found that the periods during which the homologous disturbances of potential gradient were kept were nearly equal each other and they have phase differences of about 3 minutes. Consequently, the moving velocity of the cell is calculated at about 7 m/sec, and the showery cloud was considered to be electrified to negative value in only 3 minutes just after positive snow began to fall. There is a more interesting phenomenon, that is, in Fig. 9 the snow-shower cells noted as C and D gave only the positive type of potential gradient to A.E.S. station, and the positive-negative type to D.S. station. Therefore, it is considered that the former type is a momentary phenomenon which appears in the developing stage of a snow-shower cell.

Fig. 10 shows an example of a thunder-cloud which developed at 3 O'clock on the same day as in Fig. 9. Therefore, this may be considered as the typical type of snow-shower cloud which is developed most electrically and has positive polarity. The majority of shower-clouds belong to this type, and heavy graupel and snow-fall occurred

Fig. 10. The records produced by a single thunder-cloud.

when most intensive negative potential gradient occurred. But at 7:30 on the same day, a shower of negative polarity which has heavy negative graupel- and snow-fall occurred (the cell noted as A in Fig. 9), and this phenomenon also occurred in the cases of Fig. 7 (at 5 o'clock at A.E.S. station) and Fig. 8 (at 7 and 8 o'clock at A.E.S. station). This suggests the existence of the two charge separation mechanisms either of which has polarity inverse to each other.

Recently this suggestion was examined by making laboratory experiments (Magono & Takahashi, 1963) and analyzing by the author of the observational results of the charge on natural graupels (Orikasa, 1962), and the obtained results supported the suggestion. More interesting phenomena in Fig. 10 are that the different kinds of positive peak of potential gradient occurred at each station at different times, and that while the smooth positive pattern of potential gradient was nearly equal at both stations, the negative pattern of potential gradient at D.S. station decreased to less than the half of the value obtained at

A.E.S. station.

Furthermore, it must be noted that a thunder was heard when the snow fell with maximum intensity, and when the second peak of positive potential gradient occurred at A.E.S. station.

So long as it was observed by the author, thunder occurred at the same time with, or just after, the beginning of heavy graupel- or rain-fall. From these facts it is supposed that the charge separation of thunderclouds considerably depends on the concentrated heavy graupel or snow-fall, since the role of precipitation is to transport the charge from the cloud to the ground.

The fact that the values of positive potential gradients at the two stations were nearly equal and that they were much smaller than the value of negative potential gradient, suggests that the positive charge concentration occupies higher part of the cloud, that this concentration may consist of smaller and lighter particles than the negatively charged particles, and that the light particles must be blown up by strong up-drift of the air. From these considerations it was made clear that precipitation and strong up-drift of the air may be important factors in the generation of charge, and it is easily understood that negative potential gradient is much larger than positive potential gradient when a shower

cloud with positive polarity comes up. From the discussion in this chapter, two kinds typical charge separation models of shower clouds were proposed, and these were schematically illustrated in Fig. 11.

4. Two-point observations at Mt. Teine

The electrical conditions of various types of precipitating clouds have been observed at one point on the ground nearly equal to

Fig. 12. The location of the observational stations at Mt. Teine.

Fig. 11. Two kinds typical charge separation models of snow-shower cloud.

Fig. 13. The records produced by successive passage of snow-shower clouds.

the sea level. Therefore, it is very necessary and interesting to obtain information about various factors at different altitudes. Now the following are the results of simultaneous observations carried out at the top of Mt. Teine (1023.7 m, M.S.L.) and halfway up the mountain (500 m, M.S.L.) in January, 1960. The arrangement of the two stations were indicated in Fig. 12. On these observations two factors, *i.e.*, potential gradient and the charge on snow particles were measured simultaneously. The first example produced by a big showery cloud with strong snow-shower was illustrated in Fig. 13. The upper and lower part of the figure show the records obtained at M.T. station situated on the top of Mt. Teine and at P.H. station situated at the Paradise Hut halfway up the mountain respectively. Because the reduction coefficient was not obtained, the unit of the value of potential gradient (solid line) was shown in the value of fine weather (broken line). The signs of the charge on snow particles were

written as + and - in the upper part, corresponding to each of the times when the snow particles were observed.

From these results the following conclusions were obtained:

- 1) the inverse relation between potential gradient and the charge on snow particles generally holds true.
- 2) positive snow particles appears with the remarkable depression of the pattern of positive potential gradient.
- 3) the following interesting relations were found by comparing the amplitudes of potential gradient observed at both M.T. and P.H. station:

positive potential gradient:

at M.T. > at P.H.

negative potential gradient:

at M.T. < at P.H.

at M.T.: positive potential gradient >

negative potential gradient

at P.H.: positive potential gradient <

negative potential gradient

Fig. 14. Wave patterns of electric potential gradient which oscillates from the fine weather level without no change in sign.

In Fig. 14 it is also seen that the distinct inverse relation indicates not only the projection of the curve of potential gradient with the excess of negative charged snow particles but also the depression of the curve of potential gradient with the excess of positive charged snow particles. It is very interesting that the periodic occurrences of the projection and the depression in potential gradient form the waved pattern which oscillates from the fine

weather level at M.T. station during the period from 9:10 to 10:10. Fig. 15 shows the record of potential gradient produced by a single shower-cloud, and this indicates the tendency of the conclusion (3) more distinctly, that is, the value of positive potential gradient at M.T. station is twice as great as that at P.H. station, while the value of negative potential gradient at P.H. station is twice as great as that at M.T. station.

Fig. 15. The distinct inversion of intensity of positive and negative electric potential gradient caused by the difference of altitude of the observational stations.

From these results the following conclusion was reached: positive charge and negative charge concentrate at a higher and lower level of a showery cloud respectively. The direction of this positive polarization does not always occur, of course, but it was found more frequently than the other direction. The fact that the direction of polarization agreed with the result of Simpson's observation (1937) made by using altielectrograph in thunderclouds, may arouse our interest when we discuss the charge separation mechanism of thunderclouds.

From the fact mentioned in this chapter, it was found that the conclusions obtained from the observations on the ground near the sea level also held good near the cloud base.

5. Conclusions

From the discussion of the observational results in the previous chapters, the following conclusions were derived: the inverse relation between the signs of the charge on snow particles and of potential gradient can be explained by the charge transportation theory. However, the inverse relation does not always occur, for example, in the beginning of snow-

fall, and when the falling rate of snow increase rapidly, the signs of potential gradient and the charge on snow are always the same. The effect of space charge on the falling snow particles is so large that it is very difficult to try to clarify the charge distribution in clouds by observing on the ground. It is not too much to say that Wilson's induction theory does little to clarify the electrification of snow particles except, as mentioned in the previous paper, on light and steady snowfall from non-active stratus. But even in this case we cannot say definitely that friction mechanism has nothing to do with electrification, because the inner state of a cloud of this kind has not yet been fully made clear. Therefore, other mechanisms must be introduced, and to take an example, the friction mechanism mentioned in the previous paper may be one of the most probable. Of course, friction is caused not only by the collision between snow particles but also by many other relating phenomena which are controlled by environmental meteorological conditions, such, for example, as are mentioned by Reynolds and Brook (1957) or Latham and Mason (1961a, 1961b and 1961c). More important is the mechanism of the melting of snow particles mentioned by Magono and Kikuchi (1963 and 1965) and Kikuchi (1965a and 1965b).

The electrification of the non-convective nimbostratus cloud depends mostly on the charge transportation by snow particles, whereas the electrification of the convective showery cloud fairly depends on the charge transportation by both up- and down-drift of the air and snowfall. There were no differences between the type of surface electric field patterns produced by common snow-shower clouds and thunderclouds. Then it will be concluded that, the study of charge generation of thunder-cloud should satisfactory be made by examining the electric property of common snow-shower clouds and rain-shower clouds.

The conclusions obtained from the observations on the ground near the sea level also held good near the cloud base. Then this results suggest that the electrification of precipitation particles below the cloud base is not effective in discussion of the inverse relation between the sign of the charge on pre-

precipitation particles and that of the surface electric field.

The examinations which have been mentioned in this paper should be developed further by increasing the number of observation points and getting full information about the changes in the state of electrification of a cloud and many other factors connected with it. Because the falling rate of snow particles is a factor essential to the discussion of the problems of the electrification of a cloud, it may also be interesting to carry out examinations of the same kind on the continuous rain, the showery rain and the thunderstorm, since the accurate measurement of the rainfall rate is much easier than that of the snowfall rate.

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しゅう雪をともなう積乱雲の電気的特性の2地点による観測

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1960年及び1961年の冬期間に、地表電場、降雪の電荷、降雪強度及び雪の結晶形などについての二つの種類の同時観測がなされた。

一つは、これらの4つの要素は積乱雲がしばしば通過する線上に沿って互に1.2 km離れた地点に設置された二

つの観測所に於て同時に測定された。しかし乍ら之だけでは不充分なので、互に異った高度の位置に設置された他の二つの観測点、すなわち海拔 1,023.7 m のティネ山頂の雲物理観測所と、これより 500 m 高度が低いパラダイスシュッテにおいて、地表電場と降雪電荷の同時測定を行った。

これらの観測を通して、次の様な 4 つの点に注意がはらわれた。(1) 地表電場と降雪の電荷の符号の間の逆関係の主な原因は何であるか、(2) 降雪のもつ空間電荷の地表電場への影響、(3) 普通積乱雲と雷雲の帯電状態の比較、(4) 低地で得た結論と雲底附近で得た結論に相違があるかどうか。

第(1)の点については著者等が前の報告で述べた降水の電荷輸送の理論(降水物体が雲の中で帯電して或符号の電荷を地表に運ぶためにその符号と反対符号の電荷が上空に残ってこれと同符号の電場が地表に於て観測される)が主因となることがほぼ確実となった。第(2)の点については、上述の降水の電荷輸送の理論が実際に成立している場合、降水の初期又は降水強度が急激に増加した場合、降水のもつ空間電荷の影響により必ず降水の電荷符号と地表電場の符号が一致する筈であるが、実際にこの様な現象が数多く確認され、又早い速度で移動して来る積乱雲からの集中的な降雪時には 2~3 分の非常に短い周期の降雪の電荷と同符号の地表電場の鋭いピークが発生することが確認された。第(3)の点については、普通の積乱雲の通過の際に与える地表電場の型と雷雲が通過した場合のそれとは全く同様で、電場の強さも特に雷雲の方が大きいという傾向はみられず、電荷分離発生の基礎研究を行うには普通の積乱雲の性質を調べることで充分であることが判明した。第(4)の点については、地表附近で得られた結論と雲底附近で得られた結論との間には何等の相違も見られず、特に正、負の降雪の周期的な発生に対応して雲底附近の電場が正の符号のままで晴天時の電場の値を中心にして周期的に減少及び増大する **Wave pattern** を生ずることが確認され、このような現象は **Wilson** の誘導説では説明出来ない。従って降水の電荷輸送の理論が定常状態に於ける地表電場と降水電荷の符号の間の逆関係及び降水の初期に於ける複雑な現象その他の説明に有利であることが確認された。