NOTES AND CORRESPONDENCE

An Observation of the Inverse Relation between the Polarities of Electric Field and Precipitation Charge Near the Ground, as Revealed by a Tethered Balloon

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1. Introduction

The formation mechanism of 'mirror image relation' or 'inverse relation' between the polarities of electric field and precipitation charge observed at the ground surface is not fully explained. In other words, it is not yet determined whether the change in the polarity of electric charge on precipitation is brought by the selective ion capture process (Whipple and Chalmers, 1944 and Chalmers, 1956) or the change in the polarity of surface electric field is caused by the removal of space charge by the fall of charged precipitation particles (Magono, 1980).

In the present paper, the inverse relation means a relation in which the polarity of electric field is opposite to that of precipitation charge, and the mirror image relation calls a special case of the inverse relation in which the polarity of electric field alternatively changes corresponding to the alternative change in the polarity of precipitation charge.

During the observation period of electrical properties of ice fog in Asahikawa (Endoh *et al.*, 1972), the time variations of electric field and charge on falling snow crystals were measured in lower air layers a few hundred meters above the ground surface, by the use of a tethered balloon, simultaneously with the observation on the ground. Numerous data about the inverse or mirror image relation observed on the ground were accumulated, however we have scarcely

available data aloft near the ground. It is, therefore considered that the balloon observation will give us some information about the formation mechanism of these relations, in other words, about a question whether these relations are already formed aloft near the cloud base or formed immediately near the ground surface.

2. Measuring method

A tethered balloon observation was made up to 300 meters above ground surface on a flat river bed of Ishikari River at Asahikawa, Hokkaido in February in 1968. The river bed was already covered by snow in the observation period.

The relative value of vertical electric field aloft was measured by the difference between the potentials of the top and bottom of a short vertical antenna which was mounted to the tethered balloon. A Po^{210} ion collector was attached to the two ends of the vertical antenna. The electrical charge on falling snow crystals or small snowflakes aloft was measured by the use of an electric charge meter which was mounted to the tethered balloon. The charge meter showed an impulse according to the polarity and magnitude of individual charged snow crystals when they fell into a Faraday cage in the charge meter. The field meter and charge meter were connected to a recorder on the ground by thin wires.

Simultaneously with the balloon measurement, the surface electric field was measured by a Benndorf field meter, and the polarity of charge on individual snow crystals was read by the use of another charge meter on the ground. The magnitude of the charge was not recorded.

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3. Result

Light snowfalls were observed in the daytime on Feb. 3 and 7. It was so windless that the launching of spherical balloon was able. The results obtained on the two days are shown in Figs. 1 and 2 respectively. The vertical and horizontal axes in the figures indicate the height above ground surface and the time after the launching time of the balloon. Data aloft are shown on an oblique axis which corresponds to the height and the elapsed time. Data obtained on the ground are shown along the horizontal axis.

Fig. 1 gives the result of measurement on Feb. 3. A waved curve in the oblique axis shows the relative value of time variation in the electric field during the ascent of the balloon, and short lines along the axis show the polarity and magnitude of charge on snow crystals aloft. It may be seen that the magnitude of field changed but the polarity was always positive during the observation time. It may be also seen that when or where the positive field increased, the negatively charged snow crystals were predominant.

Similarly to the pattern of electric field aloft, the electric field on the ground was waved but always positive. And corresponding to the peaks

of positive electric field, groups of negative charge on snow crystals were observed on the ground.

As a result of the measurement, it is said that the inverse relation between the signs of electric field and precipitation charge was observed both aloft and on the ground. Comparing the patterns aloft to those on the ground, it may be seen that positive peaks in electric field *A*, *B* and *C* aloft well correspond to positive peaks *A'*, *B'* and *C'* on the ground, and that negative peaks *a*, *b* and *c* in the charge on snow crystals aloft well correspond to negative charge groups *a'*, *b'* and *c'* on the ground.

The inclination of chain lines which connect the minimums of field and charge aloft with those on the ground gives the falling velocity of snow crystals, that is, $36 \text{ cm} \cdot \text{sec}^{-1}$, because it was windless. This value of falling velocity is reasonable, considering the terminal falling velocity of unrimed snow crystals (Nakaya, 1954 and Magono, 1964). Accordingly the observed results described above may be summarized as follows. The patterns of electric field and precipitation charge aloft (inverse relation) was transported by the fall of charged snow crystals to the ground without any remarkable change.

The meteorological situation on Feb. 7 was

Fig. 1 Time variations of electric field and snow crystal charge aloft and on the ground, Feb. 3, 1968.

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Fig. 2 Time variations of electric field and snow crystal charge aloft and on the ground, Feb. 7, 1968.

nearly the same as that on Feb. 3. Fig. 2 shows the result on Feb. 7. In the case of the figure, the precipitation charges are indicated in a form of histogram of mean value in 3 minute intervals. As seen in the figure, the peak of positive field aloft (B) corresponds to the maximum of negative precipitation charge (b), and the bottom of positive field at 200 m height, to the maximum of positive charge. These tendencies are very similar to those in Fig. 1, although not exactly called the inverse relation. Corresponding to the pattern of electric field aloft, the field on the ground showed a similar positive pattern, however snow crystals observed on the ground were charged positively against the predominant negative charge aloft. The result on Feb. 7 may be summarized as follows. The field pattern aloft was transported, as it was, at a rate of fall velocity of $40 \text{ cm} \cdot \text{sec}^{-1}$, but the correlation between the precipitation charges aloft and on the ground was not always good.

4. Discussion

It is a well known fact that during a light and steady snowfall, negatively charged snow crystals predominantly fall under a weak positive field on the ground (Nakaya, 1954; Magono and Orikasa, 1966). In those snowfalls, snow crys-

tals are almost unrimed in general. Therefore the inverse relation as observed on Feb. 3 is considered to correspond to one of usual light and steady snowfalls.

It was observed that the inverse relation as frequently formed on the ground was established at levels of heights of 100–300 m above ground surface, and that the pattern of electric field was lowered to the ground at the rate of falling speed of snow crystals. It may be easily understood that the pattern of precipitation charge distribution is downward transported by the fall of charged snow crystals. However some considerations are required in order to understand how the field pattern was lowered to the ground in the same speed as the fall of snow crystals, because it is difficult to imagine that the pattern of net space charge which determine the field pattern is lowered with the same speed.

4.1 Electrification mechanism of predominant negative snow crystals

The maximum value of surface electric fields was about $300 \text{ V} \cdot \text{m}^{-1}$. This value is considerably small, compared with the threshold value of point discharge e.g. $600 \text{ V} \cdot \text{m}^{-1}$ which was given by Chalmers (1957). In addition, the snow surface of the river bed was flat, and there were no trees nearby. Therefore no point discharge is

considered to occur. Accordingly it is considered that the negative electrification of snow crystals was made already within a cloud or below the cloud base by some mechanisms, not by capturing point-discharged ions.

4.2 Formation of electric fields below cloud base by gravitational charge separation

When negatively charged snow crystals begin to fall at a level, a positive field will be formed at the level by the removal of negative space charge from above. Thus an inverse relation will be formed at the level if the snowfall continues. This consideration for the formation mechanism of positive electric field aloft is supported by the result of the present observation of patterns of field and charge aloft.

In the case of electric field on the ground also, positive fields will be formed in steady state of snowfall except for a short period until the first snowfall arrives at the ground, as Magono and Orikasa (1961) theoretically showed by the use of a space charge model of finite dimension.

4.3 Downward transportation of electric field pattern

Two mechanisms are considered for the downward transportation of field pattern. Once a positive field is formed at a level, snow crystals which fall through the level are considered to be negatively charged by selectively capturing negative ions under the static induction (Wilson, 1979), but not capturing point-discharged ions. Thus the positive field will be magnified by the fall of negative snow crystals, then the inverse relation will be kept. And as Magono *et al.* (1982) theoretically showed, the inverse relation produced by the gravitational charge separation will be intensified as the separation progresses, although the pattern of the relation is deformed.

Because those two mechanisms described above are accompanied by the fall of snow crystals, it will be reasonable that the field pattern is downward transported nearly at the rate of falling speed of snow crystals.

About the exceptional observation fact that the sign of charged snow crystals observed on the ground on Feb. 7 was positive against the expectation from the inverse relation. We can not talk about the electrification mechanism which added a positive charge to snow crystals during their fall from the balloon height to the ground surface. However it is sure that the mechanism was not the ion capture process, because the

direction of electrification is opposite to that expected from the process.

Recently, Rust and Moore (1974) made a tethered observation for the electric field and raindrop charge in New Mexico under thunderclouds. The balloon was flown up to 1000 meter height above a mountain top where they made the observation. The results they obtained may be summarized as follows. The mirror image relation was observed on the mountain top, but no noticeable relation was observed aloft by the balloon, rather the positive relation was predominant. About the result they considered that the mirror image relation on the ground was formed by the selective ion capture process immediately near the ground surface of the mountain top. Their consideration is reasonable, because the field intensity on the ground was as large as $10 \text{ kV} \cdot \text{m}^{-1}$. However the surface field in our observation was very weak below the threshold value of point discharge.

5. Conclusion

A simultaneous observation of electric field and snow crystal charge was made aloft and on the ground, and it was found that the inverse relation was already formed aloft at air layers 300 m above the ground surface and that the relation was transported to the ground by the fall of charged snow crystals without any noticeable change. Because the strength of electric field was far below the threshold value of point discharge, it was concluded that the inverse relation occurred not by capturing ions discharged from points on the ground, but snow crystals were negatively charged by some mechanism in a cloud or below the cloud base, and positive electric field aloft was formed by the removal of space charge by the fall of negatively charged snow crystals.

Because the measurement of absolute values of electric properties required were not completely made both aloft and on the ground, it was impossible to discuss about the development of the inverse relation. More complete measurements are hoped to be made.

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繫留気球による地表近くの電場と降水電荷の逆相関関係の観測

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