Observation of Vertical Distribution of Atmospheric Electric Potential Gradient, Point Discharge Current and Antenna-Earth Current in Winter Fog and Snowfall

(Electrical Properties of Winter Fog: Part II)

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Abstract

Various electrical properties of winter fog were measured at Asahikawa in 1968, following the previous observation as reported in Part I (Endoh, Iwabuchi and Magono 1972).

From the results of measurement of the vertical distribution of the potential gradient in a fog layer, it was found that the electric potential gradient in a fog layer was greater than that above the layer. This was considered to be caused by the smaller conductivity of the air in the fog layer.

When a snow cloud passed overhead during the fog, a high negative point discharge current was observed. This was explained by the negative potential gradient at the point due to the negative space charge of the snow cloud.

Peculiar changes were noticed in the antenna-earth current, and they were explained by the effect of the smoke from steam locomotives, flapping of crows' wings, falling off of frost pieces from the antenna line, and the sheathing-layer-like phenomenon on the upper surface of the fog layer.

1. Introduction

In the previous article, Part I, (Endoh, Iwabuchi and Magono, 1972) the results of observation of the surface potential gradient in a winter fog and snowfall were reported. Other electrical quantities were measured simultaneously: vertical distribution of the electrical potential gradient, point discharge current and antenna-earth current. This paper describes the results of the simultaneous observation, although those data are somehow tentative and fragmentary.

2. Observation methods

2.1 . Vertical distribution of potential gradient

The change of the potential gradient with height in a fog layer was measured with an "Atmospheric Electricity Sonde", suspended from a captive balloon (kitoon) with a volume of 20 m³

as shown in Fig. 1(a). The sonde used had two equalizers with Po 210. The vertical distance between them was 50 cm. The potentials of these two equalizers were introduced to a grid and the anode of an electron tube of 5886, type respectively. Although the amplification of the first stage was relatively stable, the input of potential difference was periodically connected to the earth by a motor-driven cam-wheel in order to check the drift of the zero point. The signal of output of the airborne sonde was connected with a two axial wire to a recorder at the ground surface.

The sonde was set at a site 300 m below the kitoon, in order to avoid the distortion of atmospheric potential caused by the static charge on the kitoon. The kitoon was moored to the ground surface with a nylon rope.

The measurement of the potential gradient with height was performed during the ascending course. The height was determined from the length of the nylon rope of the kitoon.

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Fig. 1. Observation methods for (a) vertical distribution of potential gradient, (b) point discharge current at a height of 130 m and (c) antenna-earth current.

2.2. Point discharge current

As shown in Fig. 1(b), a platinum needle with Po 210 equalizer was set instead of the above-mentioned sonde and connected to the earth through a suitable shunt with a steel wire, and the potential difference between the input and output of the shunt was measured with another recorder. The height of the needle was fixed at 130 m above the surface, and the time change of the point discharge current was measured simultaneously with that of the surface potential gradient. The nylon rope was good for the insulators against the point discharge current.

2.3. Antenna-earth current

As shown in Fig. 1 (c), a steel wire was stretched horizontally at a height of 10 m between two iron poles 40 m apart. A Po 210 equalizer was added to the system of the horizontal wire for the purpose of confirming equalization of the antenna. The antenna-earth current was measured with an electrometer, utilizing a suitable shunt.

Fig. 2. Vertical distribution of potential gradient through fog layers.

3. Results and consideration

3.1. Vertical distribution of potential gradient

The vertical distribution of the potential gradient in a fog layer was obtained on two occasions: 11th and 12th Feb. 1968. The results obtained are shown in Fig. 2(a) and (b). Because

the height of the top of the fog layers was from 30 m to 60 m, it is considered that the potential gradient shows the normal fair weather values above the top of the fog layers. The values of the potential gradient in the fog layers measured were three or four times the fair weather ones. Because the air-earth conducting current was considered to be constantly uniform from the wide horizontal extension of the fog layer, it is considered that the potential gradient in the fog layer was larger than that above it since the electric conductivity of foggy air is less than that in the free air above the fog layer.

The vertical distribution of space charge was deduced from the vertical distribution of the potential gradient as shown in Fig. 2. It is seen in Fig. 2 (a) that the sign of space charge was negative in the lower part up to 57 m, and positive in the upper part from 57 m to 65 m.

In case of Fig. 2 (b), a lower negative charge and an upper positive charge were in a layer from the surface to 38 m and from 38 m to 57 m, respectively. In both cases, the fog layer was electrified in the positive polarity, and in those cases, ice crystals were visible to the naked eye at the ground surface. And in Tazawa's observation by the use of the snow crystal sonde (see Magono and Tazawa, 1966) at this time, ice crystals were detected only in a lower part of those fog layers.

Considering the vertical distribution of charge and the existence of ice crystals near the surface, it may be expected that the carriers of the negative and the positive electric charge were the ice crystals and the liquid fog respectively.

3.2. Point discharge current

The time changes of the point discharge current and of the surface potential gradient are shown in Fig. 3.

In the figure, the broken and the solid curve indicate the change of the surface potential gradient and the point discharge current respectively. And the number of black dots shows the grade of concentrations of liquid fog. Although liquid fog was observed in the periods 06^h 05^m–06^h 28^m, 0532–0658 and 0710–0740, the potential gradient did not increase but decreased during the fog, contrary to the result described in Part I.

It is noted that in the period from 0601 to 0650 a snowfall occurred, which contained stellar and dendritic snow crystals with diameter of about 3 mm. The intensity of the snowfall was the greatest around 0620, when the point discharge current increased abnormally in the negative. The maximum value of this increase was -6×10^{-6} ampere.

According to those results, the mechanism of the large negative current was considered as follows. Because a negatively electrified snow trail approached and passed over the observation point, the surface potential gradient decreased and became negative values, so that high negative point discharge current occurred in spite of the presence of liquid phase fog.

3.3. Antenna-earth current

The investigation of the antenna-earth current was reported by Noto (1933) and Misaki (1951).

Fig. 3. Time change of point discharge current and potential gradient during snowfall and fog.

16 FEB. '68

Fig. 4. Disturbances of antenna-earth current caused by steam locomotive.

According to the results of their studies, the antenna-earth current i is

$$i = C \frac{dV}{dt} + V \frac{dC}{dt} + A(F - M) + B \frac{dq}{dt}$$

where V , C and F are the potential, electric capacity of the system and environmental potential gradient respectively, q is the electric charge which was transferred from precipitations, and A , B and M are constants.

In the equation, the first term in the right-hand represents the current induced by the time change of the potential of the antenna, the second term the current caused by the time change of electric capacity of the system, the third term the point discharge current, and the fourth term the current endowed with charged precipitation elements.

In Fig. 4, the time change of the potential gradient and the antenna-earth current early in the morning of 16th are shown in the common time axis.

It is seen that, corresponding to the two peaks in the potential gradient change, the antenna-earth current was disturbed positively and then negatively. It is considered that these disturbances in the current are caused by the effect of the first term of the induction.

At 0305 and 0318, the whistle of a steam locomotive was heard to the windward of the observation point, and then the potential gradient

Fig. 5. Disturbances of antenna-earth current caused by (a) (b) flapping of crows' wings and (c) falling of frost pieces.

was observed to rise suddenly to positive values. Such a phenomenon was also pointed out by Mühleisen (1958).

Figs. 5 (a) and (b) show the oscillations in the current on the morning of 21st and 22nd. It was noticed that a group of crows came over and flapped their wings above and around the observation point at this moment. The mechanism of the oscillation is considered to be related to the movement of these crows.

In case of Fig. 5 (a), a crow passed closely above the antenna line and there was occurred one oscillation of the line by the downdraft due to the flapping.

In case of Fig. 5 (b), by the flapping of some 40 crows, most of the frost attached to the line fell off and then the antenna oscillated vertically. Thus the oscillation in the current occurred as shown in the figure.

These changes in Figs. 5 (a) and (b) seem to

be caused by the effect of the second term, because the stray capacitance between antenna line and earth changes with the variation in height of the antenna line.

Fig. 5 (c) shows the records in the morning of 17th. In this case, frost of the sheath type with a diameter of about 2 cm had been formed on the antenna. It began to fall from the antenna when it was warmed by the morning sunlight. It was observed that when a piece of the frost dropped from the line, a pulse of the positive antenna-earth current occurred. It is supposed that the positive pulse current was caused by the effect of the second term of the equation, because the height of the antenna line above the surface would increase and the volume of the antenna system would decrease quickly as bending was remedied by the falling off of the frost pieces and as a result the electric capacitance would quickly decrease.

Fig. 6 Antenna-earth current caused by sheathing-layer-like phenomena (a) in ice crystal fog and (b) in liquid fog.

Phenomena which seemed to have to do with the screening layer were observed on 15th and 21st. The results are shown in Fig. 6. In this figure, pulsations are seen in the antenna-earth current. They occurred when the top of the fog layer touched the antenna line. In the case of (a) on 15th, the fog consisted of ice crystals, and positive pulsations occurred, while in the case of (b) on 21st, the fog consisted of liquid droplets and the pulsation was all negative. In the figure, ice crystals and liquid fog droplets are indicated schematically by white triangles and black dots respectively.

If the ice crystals on 15th carry negative electric charges as considered from the result reported in Part I, the electric charge of the opposite sign, namely positive charge, may be concentrated on the top of the fog layer by the electrode effect, as shown in the center of Fig. 6 (a). It seems that the positive pulsation currents were produced by the effect of the fourth term in the equation, when the antenna line was touched with the positive charge layer near the top of the ice crystal fog of negative charge.

On the other hand, in case of 21st, negative charge may be concentrated on the top of the fog layer, as shown in Fig. 6 (b), and negative pulsations were produced when the line was touched with the negative charge layer around the positive space charge which included fog droplets.

The authors suppose that the occurrence of the pulsation was caused by a kind of sheathing-layer, as named by Eden and Vonnegut (1965), although the outer electric field was weak.

4. Concluding remarks

It was observed that the potential gradient was positive through a fog layer, and the gradient in a fog layer was larger than above it. It is considered that the greater gradient in the fog layer was caused by the larger resistance of air in the fog layer, because the air-earth conducting current was considered to be uniform through a wide horizontal extension of the fog layer. From the vertical distribution of the potential gradient, it was deduced that the upper half of the layer carried positive charge and the lower half negative charge.

It was observed that the point discharge

current suddenly decreased to an abnormally great negative value when a snow cloud covered the observation point and a fog layer was formed under the cloud. The formation mechanism of the great negative point discharge is to be explained as follows. Since the point of the needle was situated between the upper negative snow cloud and the lower positive space charge in the fog layer, a high negative potential gradient was applied to the point.

The effects of the smoke from steam locomotives, the downdraft due to the flapping of the crows' wings, the falling of frost pieces from the antenna, and a kind of sheathing-layer phenomena were observed in the antenna-earth current.

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冬霧と降雪における電位傾度の鉛直分布, 尖端放電々流 及びアンテナ・アース電流の観測

(冬霧の電氣的性質, その 2)

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冬霧の種々の電氣的性質が(その1)の観測と同時に測定された。

霧層を通る電位傾度の鉛直分布の測定結果から霧層内の電位傾度は霧層より上方の値より大きいことがわかった。これは霧層内の大気の電気伝導度が霧層より上方の値より小さいことによるものと考えられた。

霧時に降雪雲が上空を通過したことがあり高い負の尖端放電々流がみられた。これは雪雲の負電荷により尖端での電場が強い負になったためと考えられる。

アンテナ・アース電流について特異な変化がみられた。それらは蒸気機関車の煙とカラスの羽ばたき、アンテナ線についた霜の落下及び霧層上面のスクリーニング層に似た現象等として説明された。

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