Translated to English from paper in Japanese, originally published in: Gijutsu Houkoku, Vol.37, No.3, 4 (No.105), 58–71, 1998 with permission of authors.

Discussion of Variation Patterns of Atmospheric Electricity

by

T. TOYA and S. TSUNOMURA

1. Introduction

Along with geomagnetic and earth current observations, atmospheric electricity observations are important activities of the Kakioka magnetic observatory. However the level of interest in atmospheric electricity as an object of research and study has remained low in recent years. There are a number of reasons for this: the problem of charge retention was resolved, only gradients of electrical potential are observed, the phenomena only occur locally, there is no accessible data other than annual reports, it is cumbersome to deal with data recorded on rolls of paper, and so forth. Despite these negative aspects of atmospheric electricity research and study, we would like to point out that many aspects of atmospheric electricity still remain to be clarified. Given this background, we conducted this survey to review the contents of data so far accumulated, see if there is any data that was overlooked, and determine how we should conduct a survey if there are overlooked data.

2. Classification of Variation Patterns

Variation patterns of atmospheric electricity were classified, as shown below, like geomagnetism classifications. Note that the type names are of our own devising, and values shown in parentheses are from the data collected during the three years from 1976 to 1978.

[Geomagnetism]	[Atmospheric Electricity]	[Scale of Phenomena]
(1) Secular variation	Secular (long-term) variation	?
(2) Seasonal variation	Seasonal (yearly) variation	Global scale
(3) Daily variation	Daily variation	Global scale
(4) Sudden variation phenomenon: storm	Sudden variation: Thundercloud type (106 cases)	Mesoscale
(5) Sudden variation phenomenon: bay, sfe	Slight variation: Isolated type (96 cases)	Mesoscale
(6) Sudden variation phenomenon: –	Slight variation: Cyclic type (60 cases)	Synoptic scale
(7) Sudden variation phenomenon: pi, pc	Slight variation: Pulsating type (104 cases)	?

There are many research reports on the types of variation (1), (2) and (3) shown above. The recent report by Hasegawa (1995) summarizes these types of variation. The remained subjects in these types are, for example, investigation of the difference in secular and/or seasonal variations at Memambetsu and those at Kakioka.

There are reports that cover sudden variation phenomena (4) from various aspects. Hatakeyama (1950) studied the movement of the discharge area, but at the time results were only gained with much work. However, as technology has advanced, the discharge area can now be tracked in real time.

Sano studied the movement of the discharge area by relating it to atmospheric electricity data collected at Kakioka (personal correspondence, 1997).

Figure 1 shows the results of both older and more recent studies. The prevention of lightning disasters is an important area of study to be covered by studies of atmospheric electricity (Kuwashima: personal correspondence, 1997). Electric power companies are in the lead in lightning disaster prevention; they have already developed and brought onto practice their own systems. (Recently, the Japan Meteorological Agency deployed the Lightning Detection Network System, LIDEN for lightning disaster prevention in airports.)

For the slight variations in (5), (6) and (7), the study made by Hatakeyama (1946) is used as a textbook, but this area of study has drawn less attention from researchers than other areas, presumably since slight variation is too local a phenomenon, whereas the sudden variation phenomenon of geomagnetism occurs on a global scale. Figure 2 shows typical examples of sudden and slight variations.

This survey report described the results of the survey we conducted on (1), (5) and (6).

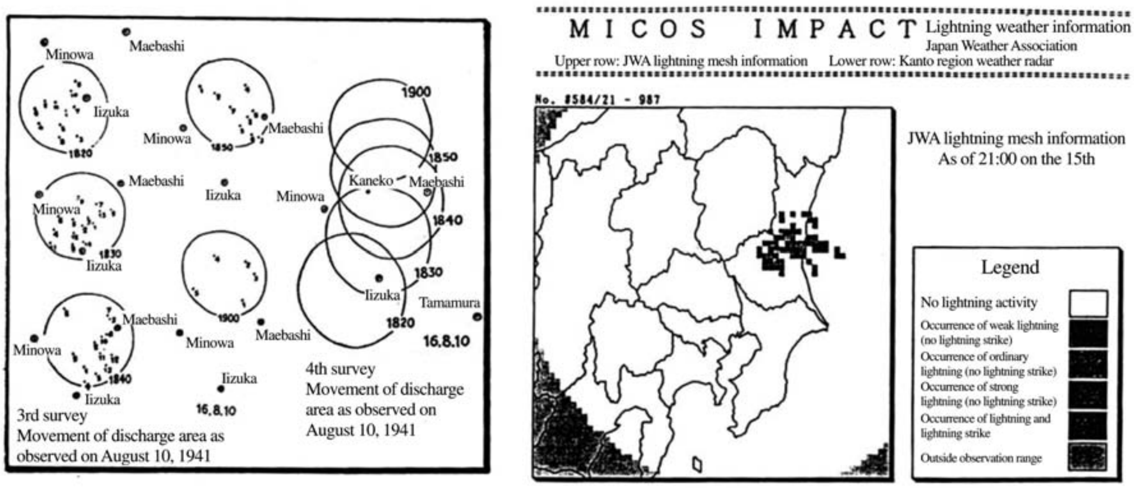


Figure 1 The results of surveys of discharge area movements (surveys conducted in 1950 by Hatakeyama are shown at left, those conducted in 1996 by the Japan Weather Association are shown at right)

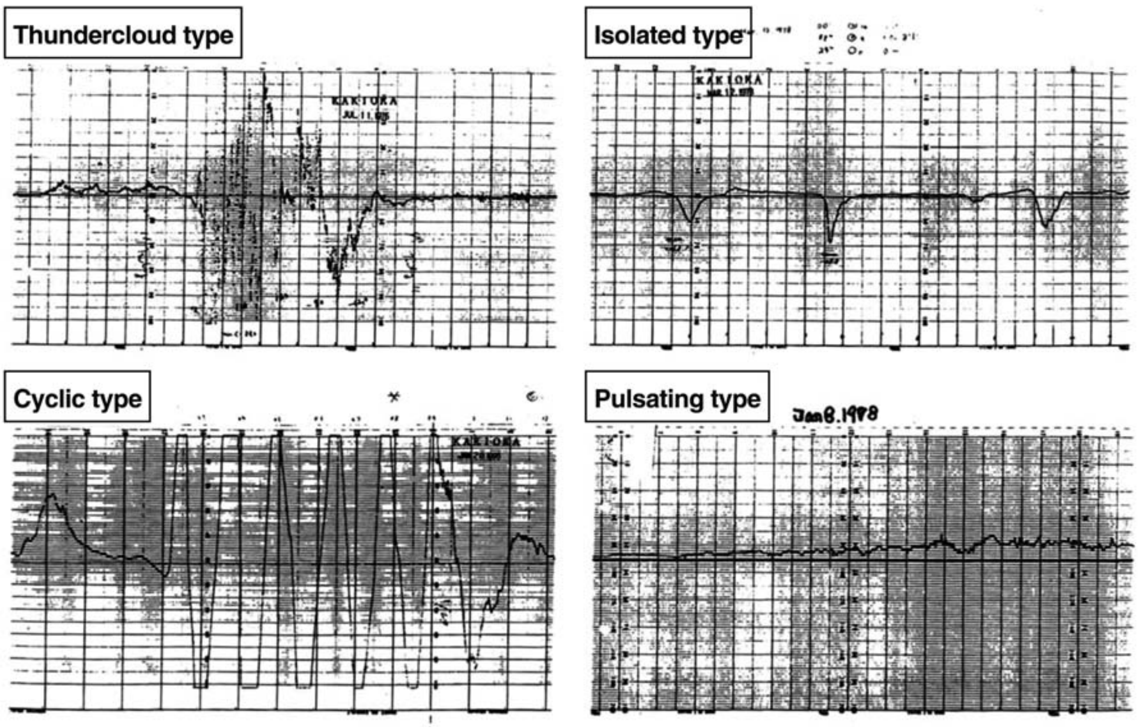


Figure 2 Examples of sudden variation phenomena (thundercloud type) and slight variation phenomena (isolated type, cyclic type and pulsating type) observed

3. Secular Variation in the Atmospheric Potential Gradient

The Swider Observatory, located about 20 km southeast of Warsaw, Poland ($\phi = 52°\ 07'$, $\lambda = 21°\ 15'$), continues to issue an annual report on atmospheric electricity observations. As far as we have checked, this observatory is the only observatory other than our own that makes regular observations of atmospheric electricity. They began observations in the International Geophysical Year of 1957. As we were missing many of their annual reports at our observatory, we requested the Swider Observatory to send as many of these back numbers of their annual reports as they could. As a result we were able to acquire most of the annual reports issued during the 24-year period from 1957 to 1994, though some are still missing.

3.1 Results of Observations Made by the Swider Observatory

At the Swider Observatory, atmospheric potential gradients are observed at a height of 2 m above the ground by using a radioactive collector. In addition, atmospheric electric conductivity observations are made, meteorological observations are made three times a day, and detailed reports on weather change are prepared. On the monthly table, average “fair weather” values and average “all days” values are shown. Average “fair weather” values correspond to the “calm day” values in the. Upper- and lower-limit values are not established for “fair weather” values. In Figure 3, data collected over a period of 24 years are shown in such a manner as to allow them to be compared at a glance. We examined the differences between the data of each year and noted the following two tendencies:

(1) Values continue to increase each year.
(2) The difference between values measured in summer (June to August) and those measured in winter (December to February) is increasing.

The above tendencies may be attributed to the effect of the direction of the wind blowing in urban areas that contains smoke or dust. According to the Swider reports, large values are measured when the direction of the wind is NW to NE. The same tendency is observed at Memambetsu (Nagamine, 1953) and Kakioka (Nakayama, 1971). Nakayama pointed out that the value reaches 1,000 V/m in the + direction due to the effect of exhaust gas. It is presumed, based on measured values given in the reports of the Swider Observatory, that the cause of these increased values may be air pollution. These observed tendencies at the Swider Observatory are interesting in that they may be linked with the recent social conditions in Eastern Europe. Thus the clarification of relations between air pollution and values of atmospheric electricity is a major research task that we should work on (Hatakeyama, 1956).

3.2 Comparison of Secular Variations

Figure 4 shows secular variations (on calm days) at Kakioka, Memambetsu, and Swider. For the reason described above, values measured in summer were used for the Swider data. Even so, the marked variation at the Swider Observatory from the middle of the 1970s should be noted. Assuming that the upper-limit value (180 V/m at Kakioka and 140 V/m at Memambetsu) used to differentiate between calm days and other days is the cause of the small variations at Kakioka and Memambetsu, we reexamined the annual reports of the Kakioka Magnetic Observatory, but could not observe any tendency for the number of days when the upper-limit value is exceeded to increase.

It was presumed, therefore, that the values of the secular variation measured at the Swider Observatory are local and may be influenced by the effect of big city, Warsaw.

The difference between values measured at Kakioka and those at Memambetsu occurs from the middle of the 1970s. Hasegawa (1995) noted and investigated this difference. The cause, however, is still unknown. According to additional data gathered during the four years from 1994 to 1997, measured values continued to increase at Memambetsu until 1995; in 1994 and 1995, values measured at Memambetsu became almost the same as those measured at Kakioka. In 1996, however, they again began to decrease. This clear difference in measurements between these two

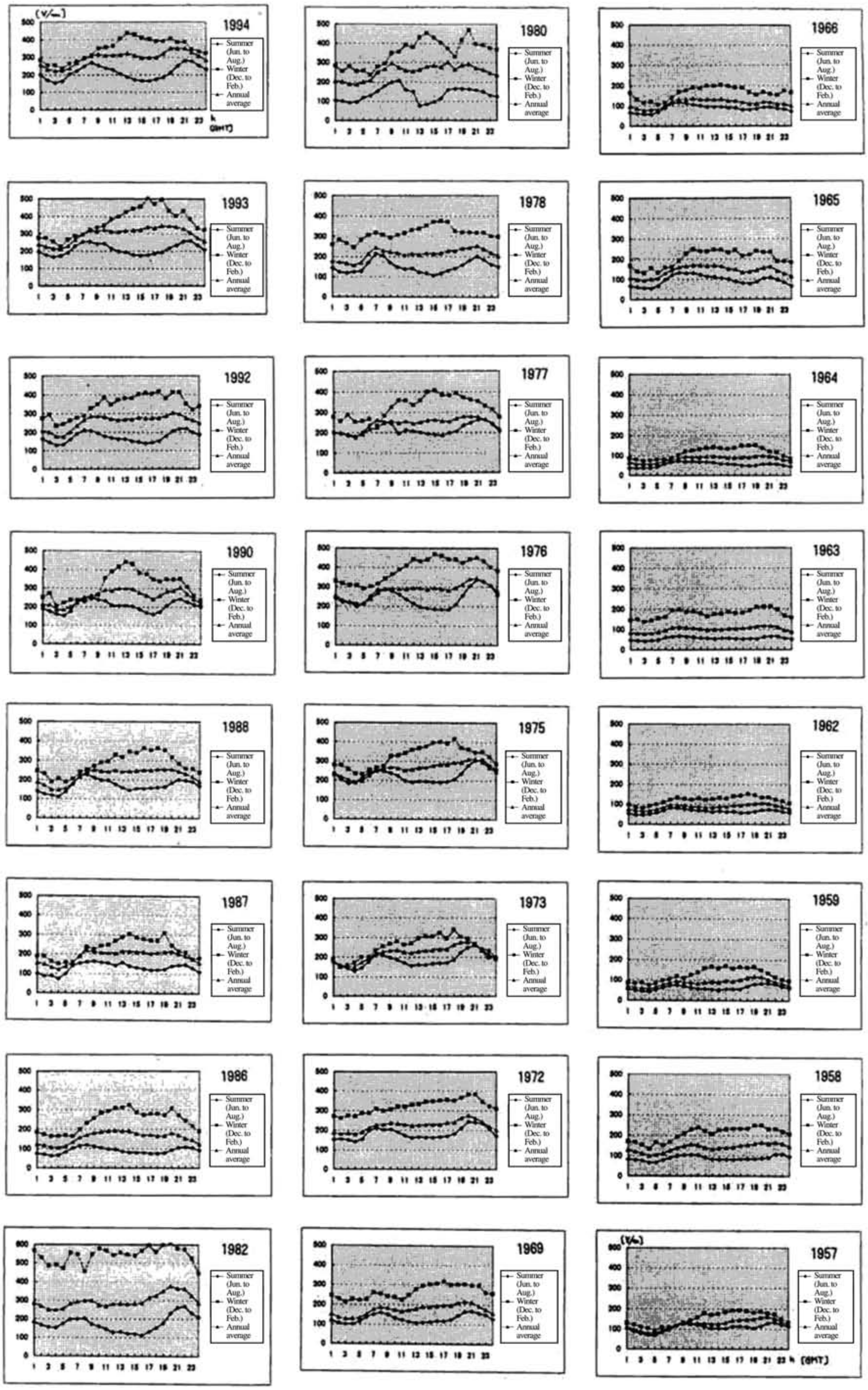


Figure 3 Variation in potential gradients at the Swider Observatory by season and year (1957 to 1994)

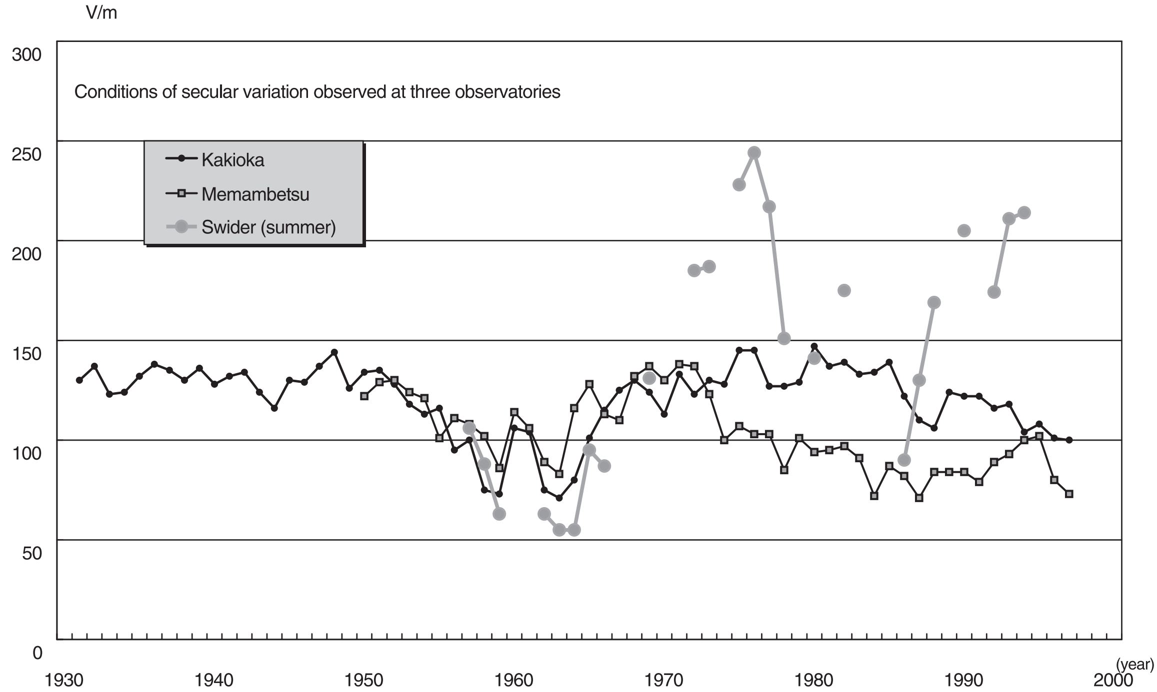


Figure 4 Secular variation (on calm days) observed at Kakioka, Memambetsu and Swider

observatories must be studied in order to explain the significance of continuing atmospheric electricity observations. In this survey, we were able to analyze data provided by the Swider Observatory and understand the conditions unique to their location. Based on this experience, we should question our longstanding perception that values measured at Memambetsu are abnormally smaller than those measured at Kakioka, and approach this matter from a different viewpoint.

A noticeable drop occurring from the late 1950s to the early 1960s is considered to be attributable to the effects of nuclear tests conducted frequently during those years. Kondo (1959) referred to similar cases reported in England and Portugal and noted the same clear drop. In our survey, we were able to demonstrate a similar variation also occurred in Eastern Europe. It is unfortunate, however, that data for two years, 1960 and 1961, when marked increases were observed at Kakioka and Memambetsu, are not available and a detailed comparison of variations cannot be made. However, the surveys that we conducted are significant in that continuous of atmospheric electricity observations can contribute to monitoring of global environmental conditions.

4. Slight Variation Phenomena

Factors responsible for causing slight variation were investigated, and isolated-type and cyclic-type slight variations were examined.

4.1 Factors Responsible for Causing Slight Variation

Sudden variation, such as the thundercloud type variation, is caused by a thundercloud overhead. The process of thundercloud formation and the way charges are distributed by upward motions due to convections were investigated in detail (Hatakeyama, 1955). However, there are less researches on the charges in types of clouds, such as cumulus, stratus, and so on. Slight variation phenomena of these clouds are only investigated in relation to mist, rain, snow, air masses, etc. It is conceivable that it is hard to generate charge separation in the clouds such as cumulus, stratus and so on, where strong convective motions of ice crystals may not occur. As we try to explain the following observed facts, we must admit that charge separation also occurs with common types of clouds and that charge separation is a factor responsible for causing slight variation.

(1) Cases of slight variation occurring in fair weather

96 cases of isolated-type slight variation were selected from records taken over three years. They were sorted according to weather conditions: 62 cases in rainy weather (65%) and 34 cases in non-rainy weather (35%). In the 34 non-rainy weather cases, 14 cases occurred in the daytime; seven of these 14 cases occurred in fine or fair weather according to records of sunshine. Figure 5 shows two cases clearly in fair weather: one on January 20, 1976 and the other on April 19, 1977. In the former case, slight variation was observed after clouds covered for 5 to 6 minutes in the sky, according to sunshine records. Since it is inappropriate to call these clouds cumulonimbuses, they are presumed to be cumulus clouds in fair weather. Specifically, it is thought that charge separation was occurring in even a single small cloud and that the bottom and top parts took positive (+) and negative (−) charges respectively. In the latter case, it is presumed that a somewhat larger cloud, or some masses of clouds, passed by and the front and back surfaces took positive (−) and negative (+) charges respectively.

(2) Cases where negative (−) charge does not occur in rainy weather

Figure 6 shows the polarity of a potential gradient measured in rainy and snowy weather for three years. The polarity is expressed as either positive (+) or negative (−). The number of cases in which a potential gradient was positive (+) without ever becoming negative (−) in rainy weather account for 20% of the total number of cases surveyed at both Kakioka and Memambetsu. This negates the perception that a potential gradient becomes negative (−) if there is rainfall. Although Kikuchi (1943) and Kawamura (1957) conducted detailed surveys of raindrop charges, they do not mention the cause-and-effect relationship between raindrop charges and the potential gradient.

Rainfall may increase atmospheric electric conductivity and thereby contribute a little to decreasing a atmospheric potential gradient. However, it is more reasonable to think that the charge separation occurring in clouds (mostly

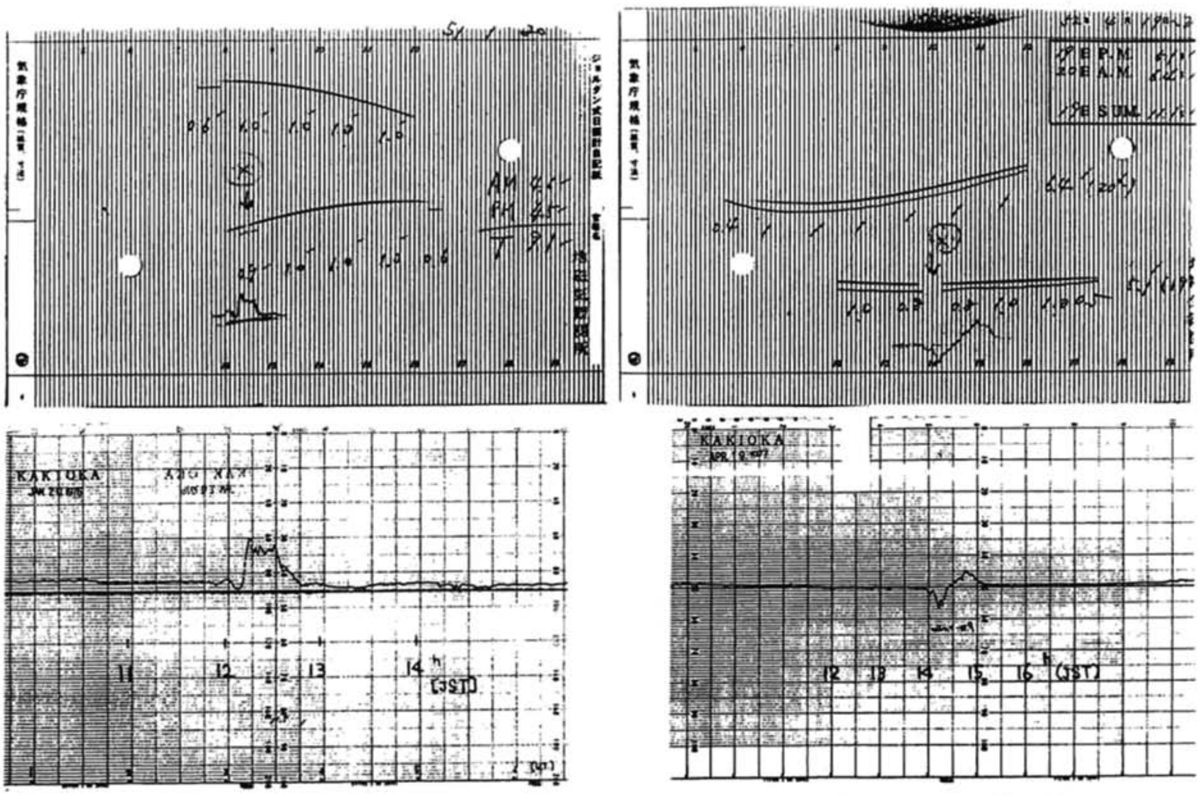
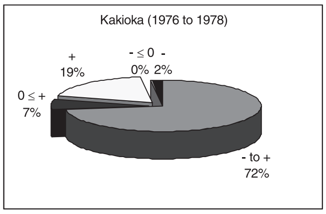


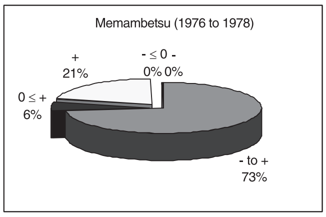
Figure 5 Cases of slight variation observed in fair weather (case at left observed on January 20, 1976, case at right observed on April 19, 1977)

nimbostrati) overhead contributes the most to decreasing a potential gradient. Based on this understanding, we performed simple model calculations to explain the observed facts as described in the following section.



Kakioka (1976 to 1978)

	Frequency	%
- to +	284	72%
0 ≤ +	26	7%
+	74	19%
- ≤ 0	1	0%
-	7	2%
Total	392	100



Memambetsu (1976 to 1978)

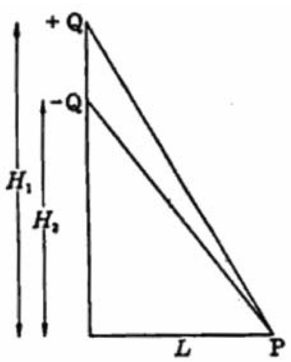
	Frequency	%
- to +	437	73%
0 ≤ +	33	6%
+	125	21%
- ≤ 0	1	0%
-	1	0%
Total	597	100

Figure 6 The frequency of potential gradient polarity in rainy weather at Kakioka and Memambetsu

4.2 Isolated-type Slight Variation

Figure 8 shows some cases of isolated-type slight variation. By appearances, the shape and cycle resemble those of the bay type variation of geomagnetism. Hatakeyama (1955) expressed an electrostatic field as bipolar charge by using the following equation, and mentioned various types of slight variation can be explained by combining some couples of bipolar charge.

To estimate the charge needed to cause isolated-type slight variation, the intensity of variation was defined as about 1,500 V/m (normal value), and cloud models were made as shown in Figure 9 by referring to cloud models made by Ishimaru (1952). As a result of calculations based on these cloud models, the charge value was found to be about 0.6 coulombs. This value is



$$F = \frac{2Q}{4\pi\varepsilon}\left\{\frac{H_1}{\left(L^2+H_1^2\right)^{3/2}} - \frac{H_2}{\left(L^2+H_2^2\right)^{3/2}}\right\}[V/m]$$

wherein

F: Electrostatic field

Q: Quantity of electricity of charge

L: Distance from an observation point to a point right under a cloud

H_1 and H_2: Height of charge

Figure 7 The Relationship between the positions of bipolar charges and the observation point

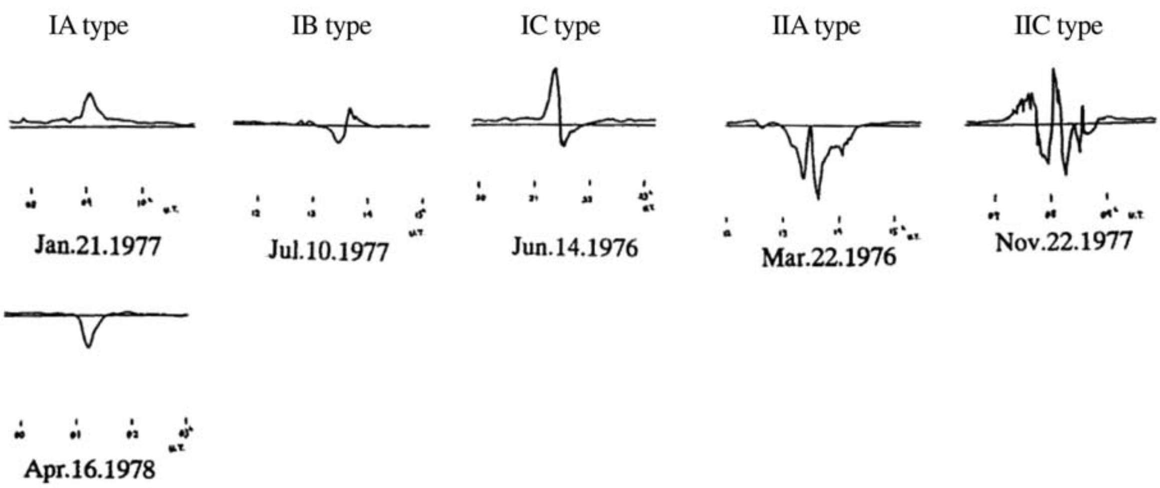


Figure 8 Cases of isolated-type slight variation observed (type symbols, IA, IB, etc., according to the classification method used by Tamura

about 2% of the normal inter-cloud discharge of 20 to 30 coulombs.

Figure 10 shows calculations made from models in which the charge was separated vertically and horizontally. A case in which charge was separated vertically corresponds to type IA (January 21, 1997) shown in Figure 8. If the polarity of charge is reversed (− at the top and + at the bottom), type IA (April 16, 1978) applies. A case in which charge was separated horizontally corresponds to type IC (June 14, 1976). If the polarity is reversed (− at the front and + at the back), type IB (July 10, 1977) applies. The observed cases IIA and IIC can be explained by combining some of these types.

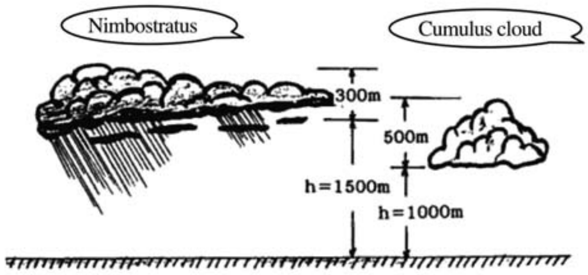


Figure 9 Nimbostratus and cumulus cloud models

If this level of charge separation is occurring in actual nimbostratus and cumulus clouds, slight variation can be explained. Since slight variation is not necessarily observed with all clouds, a clarification of under what conditions charge separation occurs in clouds, i.e., a generation mechanism, is the key to accounting for the slight variation phenomenon in the future.

It is ideal to directly measure the charge

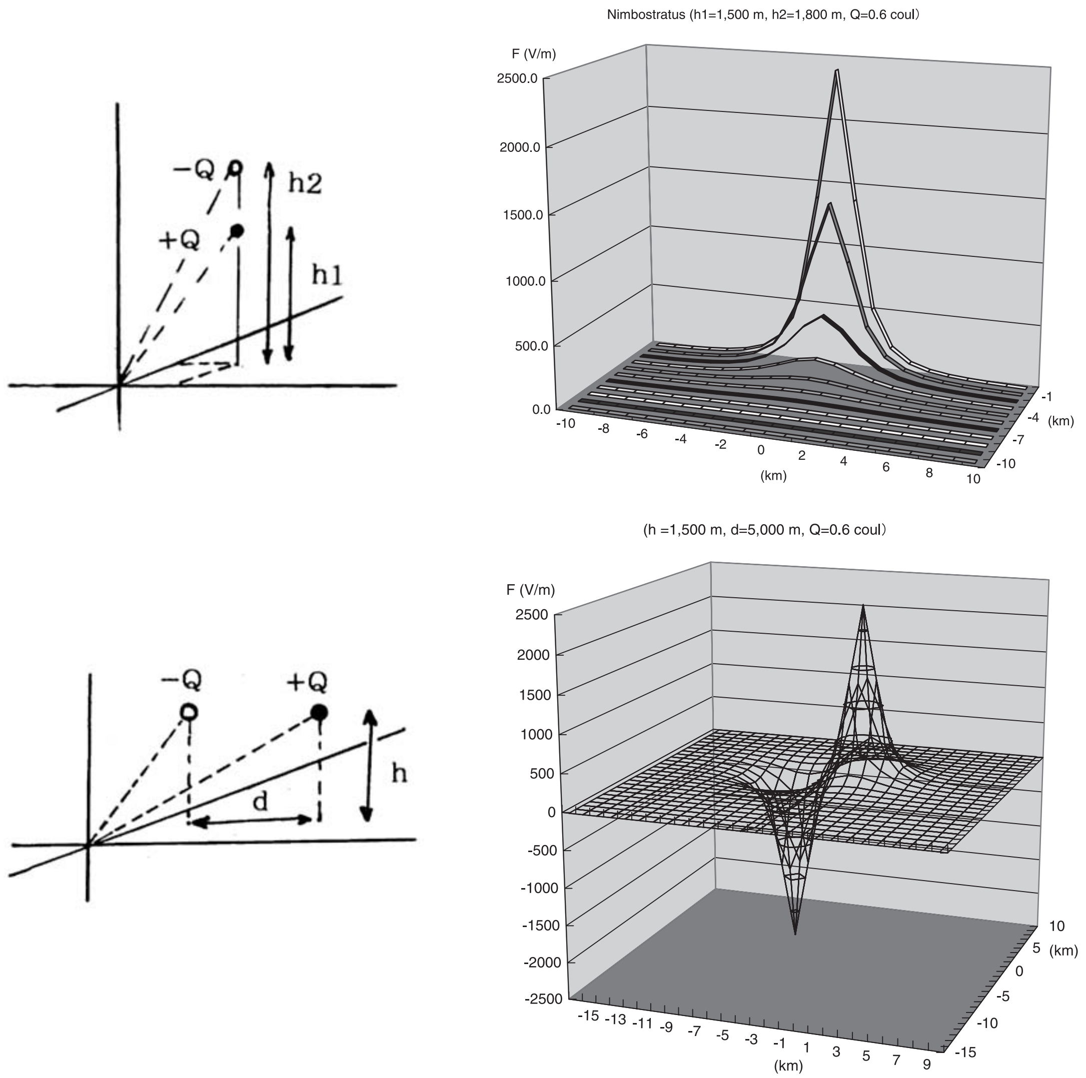


Figure 10 Example (I) of calculations made concerning isolated-type slight variation by using Hatakeyama's equation (vertical charge separation at the top, and horizontal charge separation at the bottom)

distribution inside a cloud using an airplane. Hoping that we would be able to acquire useful information from the results of multipoint observations made on the ground, we reviewed the records of observations made using a field mill at three points, Kakioka, Hayashi and Aoyagi, during the period from 1945 to 1947. Unfortunately we could not find useful information because the records were aimed for sudden variation phenomena caused by lightning and only a few days' worth of records suitable for our purpose of investigation was collected. Kitagawa (1996) made mobile observations by setting a field mill on a vehicle to survey the structure of a thundercloud. As new observation methods, mobile observations, multipoint observations, and so on are expected to develop new dimensions in the study of atmospheric electricity.

4.3 Cyclic-type Slight Variation

We surveyed 13 definite cases of 60 cases of cyclic-type slight variation observed during the period of three years. The survey results are shown in Table 1 and Figure 10. These 13 cases were compared with weather charts, and it was found out that cyclic-type slight variation was observed in seven out of 13 cases when low pressures off the southern coast of the Boso Peninsula were passing. In the remaining six cases, cyclic-type slight variation was observed when a front was passing.

However, according to weather charts for these three years, there were 103 cases of low pressures off the southern coast of the Boso Peninsula. In these 103 cases, cyclic-type slight variation was observed in 37 cases, non-cyclic slight variation was observed in 45 cases, and

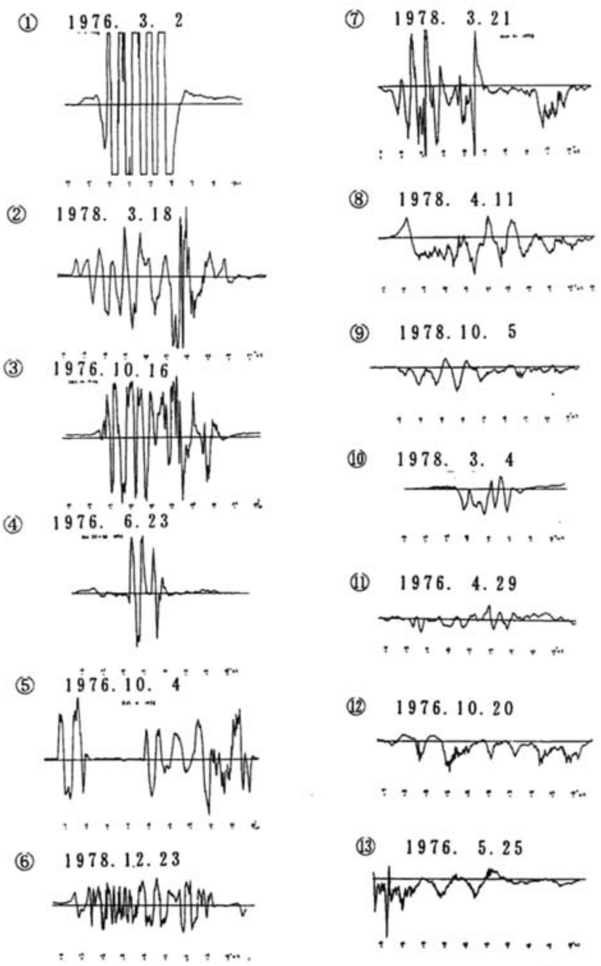


Figure 11 Observed cases of cyclic-type slight variation

Table 1 Characteristics of cyclic-type slight variation observed at Kakioka

No.	Date of Occurrence	Wave Number	Wavelength	Amplitude	Duration	Weather Chart
①	1976. 3. 2	5	35～45 min.	O. S.	4 hours	South Coast L
②	1978. 3. 18	13	25～40	120mm	8	South Coast L
③	1976. 10. 16	11	25～40	150	6	South Coast L
④	1976. 6. 23	4	25～30	120	2	Over a stationary front
⑤	1976. 10. 4	2+6	35～60	120	1. 5+5	Cold front
⑥	1978. 12. 23	12	30～40	60	7	South Coast L
		17	10	40		
⑦	1978. 3. 21	9	20～35	150	5	South Coast L
⑧	1978. 4. 11	7	65～80	60	8	South Coast L
⑨	1978. 10. 5	8	55～65	40	8	South Coast L
⑩	1978. 3. 4	5	25～30	40	3	Cold front
⑪	1976. 4. 29	17	20～35	30	8	Cold front
⑫	1976. 10. 20	8	70～80	30	10	The Sea of Japan L
⑬	1976. 5. 25	3	100～110	30	5	South of a stationary front

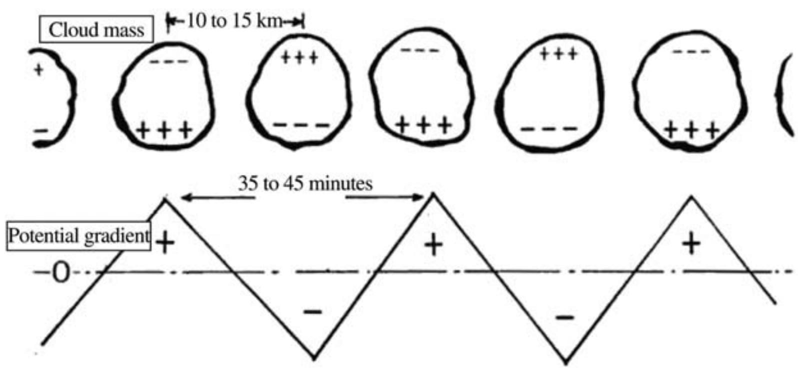


Figure 12 Charge separation model of a cloud mass to explain cyclic-type slight variation

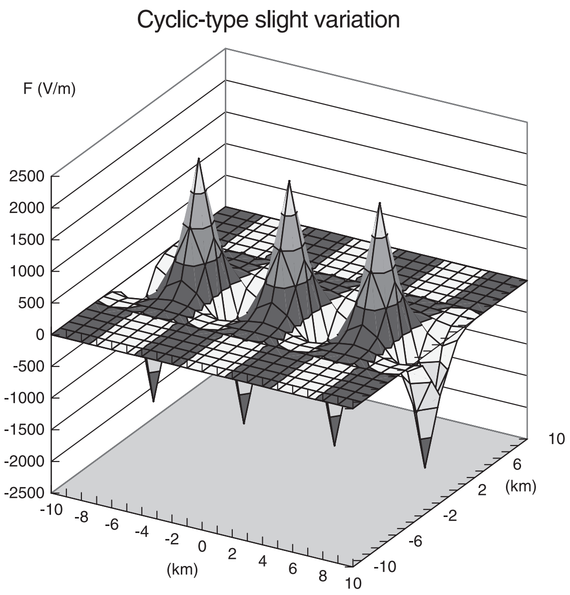


Figure 13 Example of calculations made using Hatakeyama's equation (II)

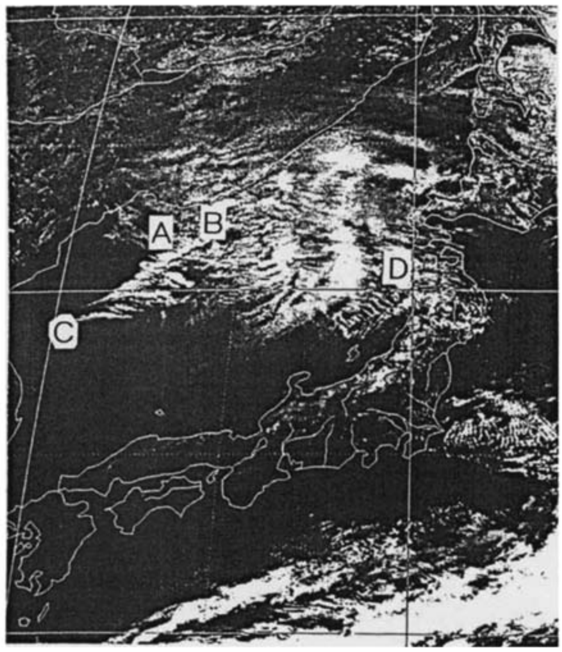


Figure 14 An example of satellite observation of cloud masses (March 7, 1981)

slight variation was not observed in 21 cases. This leads us to the conclusion that although a weather disturbance of a synoptic scale is necessary to induce cyclic-type slight variation, mesoscale meteorological elements are directly responsible for causing cyclic-type slight variation.

The amplitude reached 10 kV/m on March 2, 1976, when the weather changed from rain to snow. Similar examples occur about once every several years. The most recent one was observed on January 19, 1996, when the weather was snowy, as in the case observed on March 2, 1976.

The structure of a cloud mass that causes cyclic-type slight variation can be explained by assuming a model of a cloud mass whose base alternately takes positive (+) and negative (−) charges, as shown in Figure 12. Figure 13, which should serve to illustrate this assumption, shows the result of calculations made using Hatakeyama's equation.

To check to see if such a cloud actually exists, we examined weather satellite data and cloud images. The average period of cyclic-type slight variation is 35 to 45 minutes. Based on weather satellite data, the speed of middle-latitude clouds in early spring was set as an average of 15 m/s. Considering that cumulus clouds usually line up in NW to SE directions, the width of a cloud mass was calculated and defined as 10 to 15 km. The possibility that undulati near a front (around points B and D) shown in Figure 14 may initiate the process of cyclic-type slight variation is considered very likely.

As we examine the recording papers, we may be able to detect the presence of cyclic-type slight variation among irregular waveforms of thunderclouds and other types of clouds. If the presence of cyclic-type slight variation can be verified, the regular occurrence of charge separation will also be able to be substantiated. Since observational data have been digitized from this year, we will be able to perform period analyses, and accumulate and analyze data on cases of sudden and slight variation phenomena.

5. Summary

In this report, we described the results of our survey activities which can be summarized as follows:

(1) It was noted that secular variation of atmospheric electrical potential gradient is affected strongly by air pollution and other local atmospheric conditions; sometimes it is affected by the effect of radioactivity. We propose that environmental variations should also be observed in addition to the natural variations now being observed. It becomes possible to observe both environmental and natural variations simply by calculating statistical values without filtering them through the upper- and lower-limit values which we use to differentiate between calm days and other days.

(2) Assuming that charge separation also occurs in types of clouds other than cumulonimbuses, we analyzed observational data to investigate the possibility that nimbostratus or cumulus clouds may initiate the process of slight variation. It would be very difficult to give a reasonable explanation for this assumption since even now the theory explaining the mechanism of charge generation in a cumulonimbus is not clearly established. Such previous work as the study of charge separation in columns of smoke (Hatakeyama, 1956) and the experience that we have about static electricity occurring on chemical fiber sweaters indicates that the requirements for charge separation in common types of clouds are much less restrictive that we would expect.

(3) To contribute to the further development of atmospheric electricity research and develop new methods for preventing lightning disasters, we briefly estimated the effectiveness of mobile observations and multipoint observations.

Although the shift to a digital atmospheric electricity observation system was delayed, from this year the possibility to develop investigations has increased dramatically; records of one-second data were started and much more precise analyses will be made. On the other hand, meteorological observations at Kakioka and Memambetsu were ceased last year (April 1997). Although unavailability of weather information is a considerable setback, we can expect to be able to change our viewpoint and carry out research and study activities based on weather satellite data obtained in the form of CD-ROMs.

Lastly, the Swider Observatory in Poland has continued to release detailed reports on atmospheric electricity observations and the results of related weather observations since the IGY, and they continued geomagnetic observations even while their country was occupied during World War Two. We would like to express our greatest respect and appreciation to our colleagues on the other side of the earth who suffered through such hardships.

Acknowledgment

We would like to send best appreciations to the Swider Observatory for their kindness to send us their annual reports for our research.

References:

Hasegawa, K., 1995: "Results and discussion of atmospheric potential gradient observations made at a magnetic observatory," *Technical Report*, No. 99, pp. 30–57 (in Japanese).

Hatakeyama, H., 1950: "Quantity of electricity of lightning discharge, zones of influence, and observations of atmospheric electricity during thunderstorms in and around Maebashi," *Lightning Research*, Denki Shoin, pp. 49–54 (in Japanese).

Hatakeyama, H., 1946: "Electrical field formed by charge distribution using a lighting model," *Meteorological Technical Report*, Vol. 1, Nos. 1 and 2, pp. 23–48 (in Japanese).

Nagamine, W., 1953: "Effects of weather on atmospheric potential gradient: the effects of wind," *Memoirs of the Kakioka Magnetic Observatory*, Vol. 6, No. 2, pp. 97–100 (in Japanese).

Nakayama, T., 1971: "Effects of air pollution on atmospheric potential gradient at Kakioka," *Technical Report*, No. 44, pp. 29–42 (in Japanese).

Kondo, G., 1959: "Relationship between the present situation of secular variations in various atmospheric electricity elements and nuclear explosions," *Memoirs of the Kakioka Magnetic Observatory*, Vol. 9, No. 1, pp. 2–6 (in Japanese).

Kuboki, T., Nakayama, T., 1971: "Secular variation of atmospheric potential gradients (1)," *Technical Report*, No. 45, pp. 35–89 (in Japanese).

Kikuchi, S., 1943: "Rainwater electricity quantity (1st report)," *Memoirs of the Kakioka Magnetic Observatory*, Vol. 4, No. 2, pp. 1–10 (in Japanese).

Kawamura, T., 1957: "Relationship between precipitation phenomenon and atmospheric electricity elements (general report)," *Memoirs of the Kakioka Magnetic Observatory*, Vol. 8, No. 1, pp. 105–132 (in Japanese).

Hatakeyama, H., Kawano, M., 1955: *The Science of Meteorological Electricity*, Iwanami Zensho, Iwanami Shoten (in Japanese).

Hatakeyama, H, Kawano, M., 1956: *The Science of Meteorological Electricity*, Chijin Shokan (in Japanese).

Ishimaru, Y., 1952: *Cloud Meteorology*, Hokuryukan (in Japanese).

Kitagawa, S., 1996: *The Science of Atmospheric Electricity*, Tokai University Press (in Japanese).