A Study of Radar Echoes and their Relation to Lightning Discharge of Thunderclouds in the Hokuriku District Part I: Observation and Analysis of Thunderclouds in Summer and Winter

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Abstract

The ascent rates of individual radar echoes of thunderclouds in the Hokuriku district were investigated in relation to lightning activity. Both CAPPI radar and the sferics direction-finding system were used for this investigation. Multicell-type thunderstorms containing several moderate to strong precipitating domains were observed by means of a conventional 5.7 cm weather radar and 100.5 MHz sferics direction-finding system installed at Komatsu Airport and its periphery. The results are briefly summarized as follows:

- 1) The first lightning discharge appears about five minutes after the 30 dBZ reflectivity echo exceeds the -20°C temperature level.
- 2) The mean ascending velocity of echoes just before the initial reception of sferics from them is about the same both in summer and winter. By contrast, in cases without lightning activity, the 20-to-45 dBZ echoes have nearly the same ascending velocity as those with lightning activity in winter, but, in summer, the 20 and 25 dBZ echoes have a higher ascending velocity and the 30 and 35 dBZ echoes have equal or lower velocity than those with lightning activity.
- 3) In cases of very intense lightning activity, the 20-to-35 dBZ echoes ascend much faster than the 40 and 45 dBZ echoes in summer, while in winter, the 20-to-35 dBZ echoes ascend slowly or remain stationary and the 40 and 45 dBZ echoes ascend very fast.
- 4) In both summer and winter, the peak of lightning activity is observed when several strong echoes of 45 or 50 dBZ are formed at the -10°C temperature level and descend toward the 0°C temperature level. Takahashi (1984) established a rational thundercloud model through numerical calculation and clarified the characteristic convective and electrical activity of cloud cells in correlation with their life cycle. The present observational results can be interpreted as evidence that Takahashi's model corresponds well with actual thunderclouds observed in the Hokuriku district.

1. Introduction

Air temperature at the top of radar echo is frequently used for determining whether convective clouds are accompanied by lightning activities or not. Investigating the critical temperature from RHI radar echoes for lightning activities in summer in the Kanto district, Tohsha and Ichimura (1961) showed that, with a 90 percent probability, echo tops exceeding the -15.6°C isothermal level belong to the thunderstorm type, and those not exceeding this level, to the shower type. On the other hand, for the beginning of lightning activity in summer, Larsen and Stansbury (1974) indicated that the crit-

ical height for the 43 dBZ echo in thunderstorms near Montreal, Canada, is 7 km (-30°C), and Tomine *et al.* (1986) pointed out that the critical temperature of the echo top in winter thunderstorms in the Hokuriku district is -20°C .

Since ice crystals play an important role in the mechanism of charge generation in thunderstorms (*e.g.*, Takahashi, 1984), it may be termed natural to refer to the critical air temperature in this connection. MacGorman *et al.* (1989) suggested that this mechanism operates at the 7- to 9-km level, where the environmental temperature ranges from -25 to -40°C and there are ice crystals in sufficient quantities.

Most of the air temperatures observed at the echo

Fig. 1. Distribution of radar echo top temperatures in the three winter seasons of 1983, 1983/1984 and 1984/1985 in the vicinity of Komatsu Airport. Open circles indicate those of convective clouds without lightning activity in February and March; crosses, those of convective clouds with lightning activity; and black circles, those of convective clouds without lightning activity. A broken line indicates -20°C temperature.

top both in summer and winter are lower than the critical one. As shown in Fig. 1, however, many cases of convective cloud without lightning activities were observed in the winter from December to March of 1983 to 1985 (with the exception of January of 1983) in the area surrounding Komatsu Airport (Tomine *et al.*, 1986). It can be noted that, although the corresponding echo top temperatures were lower than -20°C , no lightning activity was observed in February and March in each winter season.

Takahashi (1984) pointed out that charge accumulation process appears to act most effectively to intensify the negative space charge and that the positive charging process below -10°C plays an important role in the acceleration of the negative space charge. On the basis of the numerical results of Takahashi (1984), Michimoto (1989) investigated the altitude of the -10°C isothermal level of winter thunderstorms and found that the altitude which forms the threshold between strong and weak or no lightning activity is 1.8 km (see Fig. 2). But it is difficult to distinguish weak lightning activities or IPPATSURAI from a lack of lightning discharges from convective echo cells in spite of the fact that the temperatures of the echo tops may be sufficiently low.

Part I of this article presents an analysis, based on radar observation, of the ascent and descent of echo cells on CAPPI in summer and winter thunderstorms with reference to sferics data. A corresponding analysis of echo cells of IPPATSURAI thunderstorms and storms with no lightning discharge is presented in Part II.

Fig. 2. Lightning activity classified by the altitude of the -10°C level in three winter seasons in the vicinity of Komatsu Airport. Temperature at the top of echoes is indicated on the abscissa. When the altitude of the -10°C level is below 1.8 km (dashed-and-dotted line), convective clouds exhibit no lightning activity (open circles) or only very weak lightning activity (black triangles). Black circles, crosses and the broken line indicate the same as Fig. 1. (after Michimoto (1989b))

2. Observational instruments

A thundercloud detection system consisting of weather radar and three sets of sferics direction finders was installed and operated at Komatsu Airport and its vicinity. This system was used to observe summer thunderstorms over the Chubu mountains in August, 1988 and winter thunderstorms along the coast of the Sea of Japan in December, 1987 and in January to March, 1988 to 1990. The details of this system have already been described in the papers by Tomine *et al.* (1986) and Michimoto (1988b); only a brief description is provided here. The sites of the weather radar and the three direction finders are shown in Fig. 3.

The specifications of the weather radar are shown in Table 1. Horizontal and vertical resolutions of the stepped PPI echo are about 1 km at a distance of 50 km from the radar site. Stepped PPI data are recorded every 100 sec on magnetic tape. On the basis of radar echo data obtained by the stepped PPI technique, CAPPI are delineated from the surface (0 km) to altitudes up to 15 km for summer thunderstorms and up to 7 km for winter ones at every 1 km interval.

Operation of the sferics direction finders is as follows. Each antenna receives 100.5 MHz frequency

Fig. 3. Observation sites in the Hokuriku district. Included are the weather radar site at Komatsu, the sferics direction finder sites at Komatsu, Shishiku and Kariyasu, and the Aerological Observatory at Wajima.

sferics with an azimuth angle accuracy of about 2 degrees within a radius of about 100 km. The individual lightning discharge points are determined on the plane map by intersections of three direction finding records.

Upper air temperatures at a given altitude and time were interpolated from the rawinsonde observations at 0900 and 2100 JST at Wajima Aerological Observatory, which is 120 km distant from Komatsu Airport.

3. Observational results

Kitagawa (1989) has classified summer and winter thunderstorms into several types. The types over a mountainous region in summer and those over the Sea of Japan coast are analyzed here in accordance with this classification.

The nine storm cases with or without lightning activity, *i.e.*, the 1st to 6th cases in summer and 7th to 9th cases in winter, are illustrated in Figs. 4 to 12, respectively. Figures. 4 and 10, which present

typical examples for summer and winter, respectively, consist of three sections ((a), (b) and (c)), while Figs. 5 to 9 in summer and Figs. 11 and 12 in winter consist only of one, (b). In (a), the CAPPI image delineated by radar reflectivity contours is shown from the outermost 20 dBZ to 50 dBZ at 5 dBZ intervals at the 7 or 2 km altitudes. In (b), the temporal variation of the height of radar reflectivity contours based on radar data is obtained at 100 second intervals. In (c), the radar reflectivity pattern at 5 dBZ intervals at the 4 to 12 km altitudes and at the 0 to 4 km altitudes is presented for summer and winter thunderclouds.

The main observational results described below are summarized in Table 2.

3.1 Thunderstorms in summer season

Case 1: 6 August 1988 (Fig. 4)

A late afternoon thunderstorm hovered over the Chubu mountainous region at an altitude of from 1000 to 2000 m above MSL as shown in Fig. 4a. Figure 4b shows that the first sferics of a series of lightning discharges (hereinafter referred to as FLD) was received at 1614 JST. The peak of lightning activity (hereinafter referred to as PLA) occurred at 1637 JST and the last lightning activity at 1706 JST. As shown in Fig. 4c-1, the FLD occurred about 5 minutes after the 30 dBZ echo reached the -20°C level (8 km). About 5 to 10 minutes before the PLA, the 20-to-35 dBZ echoes ascended very rapidly and the PLA (10 flashes per minute around 1637 JST) occurred 5 minutes after the 45 dBZ echo reached the -20°C level (8 km). As can be seen in Fig. 4c-2, the PLA occurred between 1634 JST, when several cells of 45 dBZ appeared at the -10°C level (6 km), and 1640 JST, when they descended to the 0°C level (4 km). This descent is shown in this figure by the three thick arrows.

Case 2: 7 August 1988 (Fig. 5)

This thunderstorm was also located over the Chubu mountainous region at an altitude of from 1500 to 2000 m above MSL. As shown in Fig. 5, the FLD occurred at 1512 JST, about 5 minutes after the 30 dBZ echo reached the -20°C level (8 km) and just when the 35 dBZ echo reached the -20°C level. This thunderstorm had very weak lightning activity. Subsequent sferics were received at 1514, 1515 and

Table 1. Specifications of the weather radar at Komatsu Airport.

Frequency	5 300 MHz
Repetition rate	260 Hz
Pulse length	2 μs
Peak power	250 kw
Antenna beam width	1.3 degree
The minimum detectable signal	105 dBm below the peak power

Fig. 4. Observation on 6 August 1988. Sheet (a) shows CAPPI at 7 km, at 1633 JST obtained by the 5.7 cm wavelength weather radar. An echo cell pattern with intense lightning activity is indicated by an arrow. Sheet (b) shows temporal change of the 20-to-45 dBZ reflectivity echoes altitude. The number of sferics is shown in the histogram. The first sferics of a series of lightning discharges (FLD) was received at 1614 JST. The peak of lightning activity (PLA) occurred at 1637 JST. (c) The radar reflectivity pattern is shown by the contours of 30, 35, 40, and 45 dBZ at the selected altitudes. The FLD occurred between 1608 and 1620 JST, and the PLA, between 1628 and 1640 JST. Black regions indicate areas with a reflectivity over 45 dBZ.

Fig. 5. Observation on 7 August 1988. Same as Fig. 4(b), with FLD at 1512 JST.

1516 JST, occurring at one minute intervals. Afterward, between 1520 and 1530 JST, sferics were also received at about the same frequency. This storm contained only one strong cell, with a maximum reflectivity of 45 dBZ.

Case 3: 7 August 1988 (Fig. 6)*

This thunderstorm over the Chubu mountainous region consisted of two strong cells (cell A with lightning activity and cell B without lightning activity). Each echo top height in cells A and B changed over time as shown in the figure. Around 1520 JST, cell A temporarily diminished as cell B in turn developed. Thereafter, cell A redeveloped, and the FLD was received at 1542 JST. In this example, the FLD

*Asterisk indicates another thunderstorm on the same day.

Table 2. List of thunderclouds in 1988 summer and in 1987 winter.

Case	Figure	Date	Location	FLD (JST)	After 30 dBZ reached -20°C (min)
1	4	6 Aug. 1988	Chubu Mountainous Region	1614	5
2	5	7 Aug. 1988	ditto	1512	5
3	6	7 Aug. 1988	ditto	1542	10
4	7	8 Aug. 1988	ditto	1424	5
5	8	9 Aug. 1988	ditto	1422	5
6	9	9 Aug. 1988	ditto	1500	5
7	10	22 Dec. 1987	Sea of Japan	2047	5
8	11	25 Dec. 1987	ditto	2224	5

Fig. 6. Observation on 7 August 1988. Same as Fig. 4(b), with FLD at 1542 JST. Solid lines indicate the echo cell with lightning activity (cell A), and dashed lines, the echo cell without lightning activity (cell B).

also occurred about 5 minutes after the 35 dBZ echo of cell A reached the -20°C level (8 km). On the other hand, the 30 and 35 dBZ echo of cell B did not exceed the -20°C level (8 km), and no lightning activity was detected.

Case 4: 8 August 1988 (Fig. 7)

This thunderstorm was located over the Chubu mountainous region. Figure 7 shows that the FLD occurred at 1424 JST, also about 5 minutes after the 30 dBZ echo reached the -20°C level (8 km). But in this case, the FLD occurred 2 or 3 minutes before the 35 dBZ echo reached the -20°C level.

Case 5: 9 August 1988 (Fig. 8)

This thunderstorm was located over the Chubu mountainous region. The dashed reflectivity contour lines in this figure indicate echo cells without lightning activity, while solid reflectivity contour lines indicate echo cells with lightning activity. The FLD occurred at 1422 JST, about 5 minutes after the 30 dBZ echo reached the -20°C level (8 km), but 5 minutes before the 35 dBZ echo reached the -20°C level.

Fig. 7. Observation on 8 August 1988. Same as Fig. 4(b), with FLD at 1424 JST.

Case 6: 9 August 1988 (Fig. 9)*

The FLD was observed at 1500 JST from a thunderstorm located over the Chubu mountainous region, as shown in the figure, about 5 minutes after the 30 dBZ echo reached the -20°C level (8 km) and just when the 35 dBZ echo reached the same level.

3.2 Thunderstorms and a showerstorm in the winter season

Case 7: 22 December 1987 (Fig. 10)

Figure 10a shows a thunderstorm located over the Sea of Japan whose surface temperature remained about 10°C . The FLD was received at 2047 JST and the PLA occurred at 2103 JST. The last lightning discharge occurred at 2108 JST (see Fig. 10b).

The FLD occurred about 5 minutes after the 30 dBZ echo reached the -20°C level (4 km), while the PLA (4 flashes per minute around 2103 JST) occurred just after the 40 dBZ echo reached the 4 km level (-20°C). The PLA was found between 2102 JST, when the several cells of 45 dBZ appeared at the 3 km level (-10°C), and 2104 JST, when they descended to the 1 km level (0°C). This descent is shown in Fig. 10c by the three thick arrows. These

* Asterisk indicates another thunderstorm on the same day.

Fig. 8. Observation on 9 August 1988. Same as Fig. 4b, with FLD at 1422 JST. Solid lines indicate the echo cell with lightning activity, and dashed lines, the echo cell without lightning activity.

Fig. 9. Observation on 9 August 1988. Same as Fig. 4b, with FLD at 1500 JST.

results are similar to those for the summer season thunderstorms (Case 1 on 6 August 1988), except for the large difference in the altitude of each temperature level from -10°C to -60°C .

Case 8: 25 December 1987 (Fig. 11)

This thunderstorm was also located over the Sea of Japan region. As shown in Fig. 11, the FLD was received at 2224 JST. This thunderstorm consisted of three strong cells (cells A and B without lightning activity and C with lightning activity). The FLD occurred about 5 minutes after the 30 dBZ echo of cell C reached the -20°C level (5 km) at 2219 JST. The 30 dBZ echoes of cells A and B did not reach the -20°C level and no lightning discharge occurred.

Case 9: 26 December 1987 (Fig. 12)

This storm was located over the Sea of Japan and produced no lightning discharge during the observational period. It was observed that the 20 and 25 dBZ echoes ascended rapidly, but the 30 dBZ echo did not reach the -20°C level (5 km). This storm dissipated without lightning activity.

Fig. 10. Observation on 22 December 1987.

(a) Same as Fig. 4a. An arrow indicates CAPPI pattern at 2 km, 2100 JST. (b) Same as Fig. 4b, with FLD at 2047 JST and PLA at 2103 JST. (c) Same as Fig. 4c, with PLA between 2100 and 2110 JST. In this case, the radar reflectivity pattern is shown by the contours of 35, 40, 45, and 50 dBZ. Black and white regions indicate areas with a reflectivity over 45 and 50 dBZ, respectively.

Fig. 11. Observation on 25 December 1987. Same as Fig. 4b, with FLD at 2224 JST. Solid lines indicate cell C with lightning activity, and dashed lines, the 30 dBZ echo of cell A and cell B which were not accompanied by lightning activity.

Fig. 12. Observation on 26 December 1987. Same as Fig. 4b. No lightning activity (NLA) appeared during the observation period.

4. Analyses

In certain earlier studies (Workman and Reynolds, 1949, and Jacobson and Krider, 1976), electrical activity was investigated in relation to the life cycle of thunderstorm cells. According to these observational results in the United States, after the radar echo top reached an altitude with a temperature of -28 or -30°C , it started to descend. This occurred just after the first flashes began within the cloud. In the Thunderstorm Project (Byers and Braham, 1949), it was found that a temperature of -21°C is required for the initiation of lightning, and that the maximum altitude of cells, consequently, the minimum temperature at the cloud top and the maximum lightning frequency occurred together. The results of the present observations summarized in Table 2 are almost perfectly consistent with those of these earlier ones in the United States. But, detailed analysis reveals the following differences:

- 1) The FLD was received during the ascending period of radar echoes.
- 2) A temperature of -21°C is required for the outbreak of the FLD, but the temperature is not that of the cloud top but that of the 30 dBZ echo top.
- 3) The PLA and minimum temperature at the cloud top did not occur together, and occurred after all radar echo tops started to descend.

According to Michimoto (1988a, 1989b), the critical temperature for the 30 dBZ echo which distinguishes thunderclouds from showerclouds is -20°C in both summer and winter, with the exception of the midwinter season. However, these results were obtained only in one case in summer and winter, respectively, while the earlier results in the United States were obtained from numerous observational examples.

Based on the findings of his numerical model of winter thunderstorms, Takahashi (1984) pointed out that the FLD was caused by intracloud flashes near the cloud top (-30°C) in the developing stage. In the model, the FLD occurs several minutes after the 30 dBZ echo reaches the -20°C level. Since the formation of graupel particles becomes intense at temperatures of -15 to -20°C , this suggests that the FLD is associated with the growth of a vast number of graupel particles which causes the 30 dBZ reflectivity in the cloud at a temperature of near -20°C . This effect occurs in both the winter and summer seasons. In the mature stage of Takahashi's model, the negative space charge is high at this level because the downward flux of negative graupel particles from the cloud's upper levels is combined with the upward one of the negative snow crystals from lower levels.

Thus, the positive charging process of graupel particles below -10°C plays another important role in accumulating the negative space charge in the cloud. In the present observations of summer storms, the temperature of the cloud base was 15°C or higher even over the mountainous region. In winter, for clouds of relatively intense lightning activity, the temperature of the cloud base was about 10°C for storms over the Sea of Japan and along the Hokuriku coast. Graupel particles can be substantially changed in charge from negative to positive at such warm temperatures. Hence, riming electrification may be more effective in the temperature range between -10°C and 0°C . It can be pointed out, therefore, that intense lightning activity is associated with ascent and descent of the 40-to-50 dBZ echo cells between -10°C and 0°C , as shown in the summer example (Fig. 4c-2) and the winter example (Fig. 10c). The PLA occurs when several cells of the 45 dBZ first appear at the -10°C level and then descend to the 0°C level (Figs. 4c-2 and 10c). In addition, the lower part of the 30 dBZ echo reaches the sea or the ground surface in both summer and

winter. These results may be regarded as verifying the intense electrical activity of thunderclouds in the mature stage of the Takahashi's model (1984).

A comparison of the results of these summer and winter observations reveals some differences between summer and winter thunderstorms as follows:

- 1) Both the echo altitude and the altitude of the -20°C level for winter storms are only about half as great as those for summer.
- 2) The total number of the sferics in one winter thunderstorm is less than half as great as those in a summer thunderstorm.

From these observational results, it may be generalized that the number of lightning discharges in one winter storm is less than half as great as those in one summer storm. According to Sakakibara *et al.* (1988), the maximum upward air velocity in convective snowbands over the Sea of Japan observed by means of single Doppler radar attains 4 m/s in and above the reflectivity region higher than 25 dBZ. Winter storms with much lightning activity are, therefore, inferred to have stronger upward motions. At the same time, as mentioned in the previous studies of summer storms in the Kanto plain (Ishihara *et al.*, 1987; Tabata *et al.*, 1989), the upward air velocity was 15 m/s in the cases with lightning activity and 7 m/s in the cases without lightning activity. From these observational data, it may be generalized that the upward air velocity in winter thunderclouds is about half as great as that in summer ones.

As shown in Table 2, almost all FLD were received about 5 minutes after the 30 dBZ echo reached the -20°C level on the way to a higher altitude. But in case 3, the FLD was received about 10 minutes after the 30 dBZ echo reached the -20° level and about 5 minutes after the 35 dBZ echo reached the -20°C level on the way to a higher altitude (see Fig. 6). It may be inferred that the difference in summer and winter storms may be due to the degree of convective activity in thunderclouds.

Table 3 shows the average ascending velocity of each echo reflectivity in the 14 cases in summer and the 8 cases in winter which contain the FLD (Cases 1 to 9) for 5 minutes before the occurrence of the FLD. Table 4 shows the average ascending velocity of each echo reflectivity for 5 minutes during no lightning activity (hereinafter referred to as NLA). In these NLA cases, the maximum ascending velocity of each echo reflectivity has been adopted to indicated the average of each maximum value. The average ascending velocity for the 10 summer cases is generally higher than in the 10 winter cases. It can be seen from Table 3 that the velocity before the FLD increases along with the echo intensity. On the other hand, the velocity values during the NLA decrease along with the increase of echo intensity in summer and are nearly equal in winter. It is supposed

Table 3. The average radar echo ascending velocity before FLD.

dBZ	Summer (m/s)	Winter (m/s)
20	3.0	2.4
25	3.4	2.6
30	4.8	2.8
35	4.9	3.6

Table 4. The average radar echo ascending velocity during NLA.

dBZ	Summer (m/s)	Winter (m/s)
20	8.7	2.3
25	6.9	2.7
30	4.6	2.2
35	2.3	2.9

that, in summer, the 20 and 25 dBZ echoes ascend rapidly due to intense updraft, but in winter, those echoes may be nearly stationary due to weak updraft. Reynolds and Brook (1956) pointed out that the presence of radar detectable precipitation did not lead to thunderstorm electrification, unless the precipitation echo developed rapidly in the vertical direction. In winter storms, because of slow vertical development of radar echoes, the charge separation process sometimes may not be effective enough to cause lightning discharges.

Table 5 indicates a typical example of ascending velocity of each echo reflectivity in 5 minutes before the FLD and during the PLA in cases 1 and 5 in summer and winter, respectively. In the FLD, the velocity of the 30 and 35 dBZ echoes of summer clouds is about twice faster than that of winter. On the other hand, during the PLA, the velocity of the 30 and 35 dBZ echoes of summer clouds is extremely fast. During the PLA of winter clouds, the velocity of the 40 and 45 dBZ echoes is faster than that of the 20-to-35 dBZ echoes.

5. Conclusions

The ascent and descent of echo cells in summer and winter thunderclouds in the Hokuriku district were investigated by means of weather radar. It has been ascertained that the life cycle of echo cells has a certain relationship with lightning activity. The following conclusions were obtained:

- 1) In both summer and winter, the FLD (the break-out of the first lightning discharge) occurs about 5 minutes after the 30 dBZ echo reaches the -20°C level. In such situations, the lower part of the 30 dBZ echo also reaches the sea or the ground surface, and the echo core of 35 dBZ or higher reflectivity is observed at a lower altitude. It is inferred that the FLD is caused by the interaction of graupel parti-

Table 5. The radar echo ascending velocity before FLD and PLA. A summer case (Case 1 on 6 August 1988) and a winter case (Case 7 on 22 December 1987) are presented.

dBZ	FLD (m/s)		PLA (m/s)	
	Summer	Winter	Summer	Winter
20	2.2	2.2	6.9	0.8
25	2.5	2.2	8.7	0.1
30	4.7	2.0	8.7	0.4
35	4.7	3.0	6.2	0.8
40	2.9	—	5.0	4.8
45	1.1	—	3.3	4.8

cles with ice crystals during the ascent of the 30 dBZ echo near the -20° level in both summer and winter thunderclouds.

2) When relatively intense lightning activity is associated with thunderstorms both in summer and winter, these storms contain several moderate to strong radar echo cells of 40-to-50 dBZ which ascend and descend one after another. It is deduced that the ascent and descent of each echo cell may be associated, in certain ways, with the electrical activity of the thunderstorm.

3) When the 30 dBZ echo does not reach the -20°C level, no lightning discharge occurs.

4) During the PLA (the peak lightning activity), the 20-to-35 dBZ echoes ascend fast in summer thunderstorms, while, in winter thunderstorms, the ascent of 40-to-45 dBZ echoes is faster than that of 20-to-35 dBZ echoes during the PLA. The PLA occurs as several cells of 45 dBZ descend from the -10°C level to the 0°C level. These observational results can be interpreted as verifying the convective and electrical activity characterized by Takahashi's thundercloud model (1984).

In part I of this article, the life cycle of echo cells was investigated in relation to lightning activity both in summer and winter. In midwinter, thunderstorms with very weak lightning activity have echo cells with an interesting life cycle. A detailed study of such thunderstorms will be introduced in Part II.

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北陸地方における雷雲の発雷に関連するレーダエコーの研究

Part I: 夏および冬季の雷雲に関する観測および解析結果

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北陸地方において、発雷に関連するレーダエコーの上昇・下降を夏・冬の両季節について、CAPPI (定高度 PPI 画面) から得られるエコーパタンと空電方向探知機によって得られる空電 (雷放電電波) のデータをもとに解析して調べた。並から強い降水域のエコーセルを数個含むマルチセル型の雷雲を、小松空港およびその周辺に設置されている波長 5.7 cm の通常型気象レーダと受信周波数 100.5 MHz の VHF 波空電方向探知システムを用いて観測し、次の結果を得た。

- 1) 一連の雷放電の最初の発雷は、雷雲中の反射強度が 30 dBZ のエコーが -20°C 高度を越えてさらに上昇して、数分後 (5 分後程度が最も多い) に観測される。
- 2) 初回発雷直前のエコーの平均上昇速度は、夏冬ともに同様な傾向を示した。しかし、発雷しない対流雲の平均上昇速度はかなり異なった様相を呈した。すなわち、冬は各エコー強度とも発雷雲と同様な上昇速度であったが、夏の場合には 20 および 25 dBZ のエコーは非常に大きな速度で上昇するが、30 および 35 dBZ のエコーの上昇速度は発雷雲と比べると、同じかまたは小さい値であることがわかった。
- 3) 非常に強い放電活動をもたらした雷雲では、夏の場合 20 から 35 dBZ のエコーが非常に大きな上昇速度を有し、40 と 45 dBZ のエコーはさほど大きい上昇速度を示さないことがわかった。一方、冬の場合は夏とは逆で、弱いエコーはほとんど上昇せず、並〜強のエコーが急激な上昇をすることがわかった。
- 4) 夏・冬ともに雷放電活動のピークは、45 もしくは 50 dBZ のエコーセルが先ず -10°C 高度に数個形成されて、その後 0°C 高度へ下降しながらやはり強いエコーセル群として出現する間に起きていることが確認された。Takahashi (1984) は数値計算によって合理的な雷雲のモデルを樹立し、雷雲セルのライフサイクルに対応する対流活動、電氣的活動の推移を明確にした。レーダ観測と空電受信による今回の観測結果は、Takahashi のモデルが大筋に於て、北陸地方の雷雲にあてはまることを示すと考えられる。