

LOCATION OF CHARGES ASSOCIATED WITH POSITIVE C-G FLASHES IN WINTER

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ABSTRACT: Cloud-to-ground lightning flashes in winter have been observed by a network of 8 VHF receivers, 8 slow antennas and 5 fast antennas on the coast of the Sea of Japan. VHF radiation sources are located by the TOA method. 68 VHF pictures of lightning flashes in winter are analyzed, and charges associated with 9 positive C-G strokes are located by using data from slow antennas. Distribution of positive charge layers observed by VHF radiation is bimodal in height having peaks at -30°C and -10°C in temperature, respectively. Nevertheless, none of the located charges associated with the 9 positive C-G strokes belong to the cluster at higher altitudes.

INTRODUCTION

Location of positive charges associated with eight positive C-G flashes of Japanese winter thunderstorms was reported by *Brook et al.* [1982], who located the positive lightning charge in a colder region than the corresponding negative charge of the same storm, and concluded that the winter thunderstorms were similar to the summer storms exhibiting a positive dipolar structure. No charge location data for this type of thunderstorms have been reported since then. *Kitagawa and Michimoto* [1994], on the other hand, speculated evolution of the charge structure of winter thunderstorms based on radar data and time variation of electric field observed on ground. New data on charge location on this type of thunderstorms, which are different from those obtained by *Brook et al.* [1982], are added in this report.

OBSERVATION

Figure 1 shows the location of 8 slow antennas, 8 VHF receivers and 5 fast antennas on the Fukui Plain. Slow and fast antennas are placed at elevated positions several meters above ground, so that their sensitivities are hardly affected by accumulated snow. Their sensitivities are calibrated by using an LF broadcast signal, and the authors estimate the uncertainty of the sensitivities to be 15%. The center frequency of VHF receivers is 62 MHz, and envelope-detected waveforms were digitized every 179 ns for the data in this report. Sources of VHF and LF pulses are located by the time-of-arrival (TOA) method using the GPS-timed waveform data from the VHF and fast antenna networks. The 3-D location and the charge amount associated with a C-G stroke are estimated from data of the slow antenna network postulating the point-charge model.

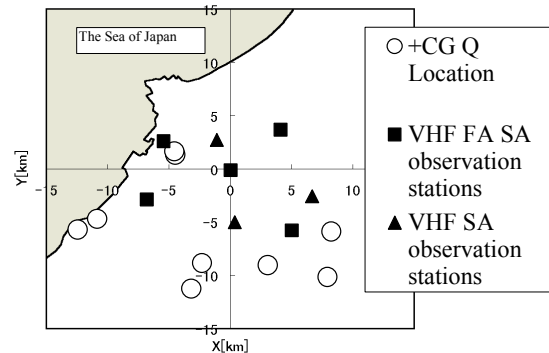


Fig. 1 Location of observation stations on Fukui Plain, and plan view of the charge locations of +C-G strokes in Table 3.

VERIFICATION OF OBSERVATION SYSTEM

A negative five-stroke C-G flash observed by the Fukui network in summer is analyzed to evaluate the performance of the network. Table 1 shows the location and magnitude of charges of a negative flash in summer,

Table 1 Located charges associated with a negative 5-stroke flash on Sept. 9, 2000.

Stroke	Leader Type	Duration	I _{peak} [kA]	X[km]	Y[km]	Z[km]	Q [C]	v
R1	Stepped	0.30	55	-5.3	3.1	4 ~ 5	-5 ~ -16	2
R2	Dart	0.35	23	-4.9	3.0	4 ~ 5	-2 ~ -4	2
R3	Dart	0.45	23	-4.8	2.6	5 ~ 6	-2 ~ -4	2
R4	Stepped	1.50	11	-4.4	3.5	5 ~ 6	-4 ~ -11	2
R5	Dart Stepped	1.00	12	-4.8	2.6	6 ~ 7	-3 ~ -11	2

located by the slow antenna network. ν is the degree of freedom in point-charge location, and $\nu=2$ means that 4+2 stations participated in the optimization of location. The peak currents of return strokes are estimated from the location of return strokes and electric field peaks observed by the fast antenna network. Figure 2 shows the location of return strokes and plan view of the VHF sources and location of charges. According to the VHF picture not shown here, the discharge was initiated at the height of 5 km (-3°C), and extended horizontally for about 8 ms before started to descend. There were horizontal extensions of discharges at the same height before R2 and R3. The leader preceding R2 formed a new grounding point, possibly branched from the old channel at a height lower than about 1.5 km. R4 was preceded by a stepped leader forming an entirely new channel. R4 and R5 were followed by continuing currents, and estimated magnitudes of charges are large although estimated peak currents are small.

It is inferred that there was a positive charge layer at the height of about 5 km, and negative charge layer was located above that layer. The relationship between the located VHF sources and charges is reasonable, and the estimated location of charges, horizontally placed at about the same height around -10°C , is in agreement with the observation in the North America in summer [Krehbiel *et al.*, 1979]. Thus, it is concluded that the performance of the observation network is satisfactory.

LIGHTNING DISCHARGES IN WINTER OBSERVED BY VHF RADIO PICTURES

Table 2 summarizes the types in initiation of lightning flashes in winter observed by VHF radiation. The total 68 flashes were observed during December 2000, January 2001, December 2001 and January 2002. Type A is initiated by discharges below a charge layer at around -30°C , and VHF sources goes up to the upper layer. At type B, VHF sources are located at around -10°C , and this type of flashes are subdivided into types B1 and B2, where type B1 flash is initiated above the charge layer, and type B2 is initiated below that layer. At type C flash, a downward negative leader starts from about -15°C .

The polarity of the charge layer is estimated from the polarity and the relative height of the bipolar pulses observed by fast antenna at the initial breakdown, and from the magnitude of VHF radiation located in the charge layer. At 12 out of 13 type-A flashes, the charge layers at around -30°C are identified as positive layers. At 24 out of 49 type-B flashes, the charge layers at around -10°C are identified as positive layers. Figure 3 shows the height distribution of positively charged layers observed by VHF radiation. It shows bimodal distribution having peaks at about -30°C and -10°C in temperature.

Table 2 Types in initiation of lightning flashes in winter observed by VHF radiation.

Type	Total	IC	+CG	-CG
A	13	7	3	3
B1	29	16	11	2
B2	20	12	6	2
C	6	4		2
Total	68	39	20	9

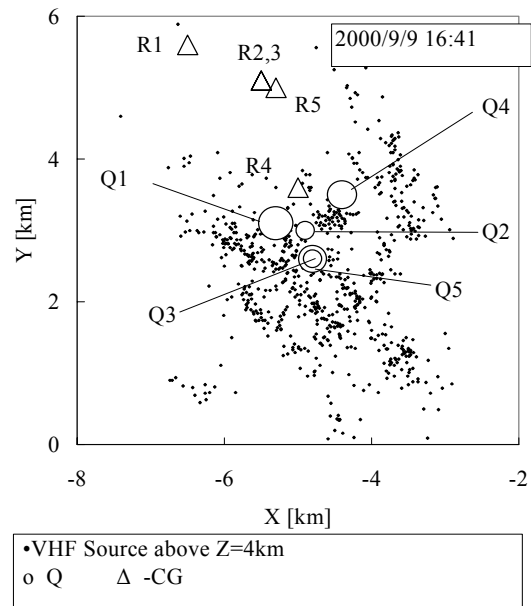


Fig. 2. Location of return strokes (Δ) and plan view of VHF sources (\bullet) and charges (O) associated with negative 5-stroke C-G flash in summer.

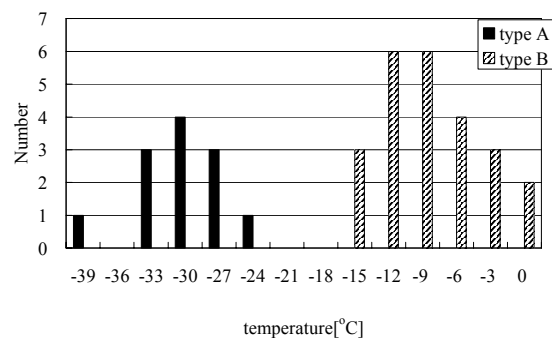


Fig. 3. Distribution of temperature heights of positively charged layers.

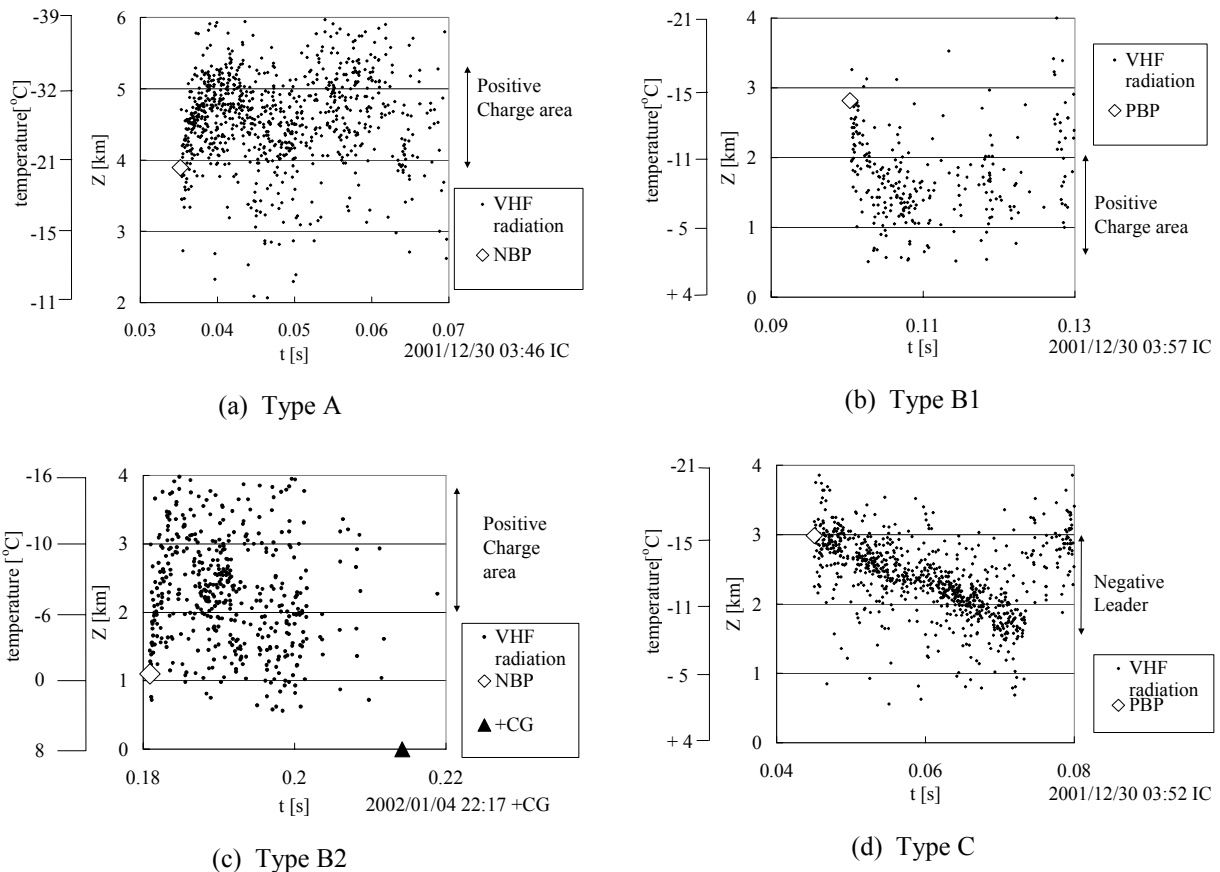


Fig. 4. Located VHF radiation sources of each type of lightning flash in winter.

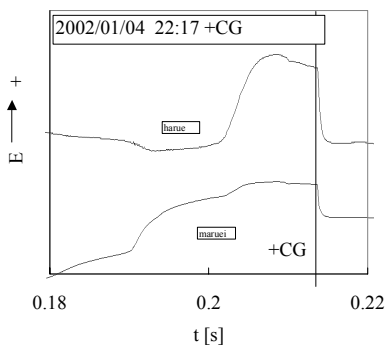


Fig. 5. Electric field changes associated with a +C-G flash (same flash as Fig. 4 (c)) observed by slow antennas.

associated with the activity of a downward positive leader like the example of Fig. 5, which shows the field change associated with a positive return stroke of initiation type B2, observed by slow antennas. Therefore, different from the analysis for negative C-G flashes in summer, the magnitudes of field change employed for location of positive charge in winter thunderstorms do not include changes associated with downward leaders. Calculated height of a model point charge is affected by the charge in the downward positive leader, and is lower than the charge center in the cloud removed by the return stroke.

Table 3 shows the located positive charges associated with 9 positive return strokes. The meaning of each column is similar to Table 1. Z_V is the height of positive charge layers identified from VHF pictures. Data of temperature height are also added. Evaluated magnitudes of positive charge tend to be larger for similar magnitudes of peak currents in summer, because continuing currents usually follow positive return strokes and contribute to the magnitudes of field change. Plan view of the charge location is superposed on the map of Fig. 1.

For the case of the only type-A flash, the height of the positive charge layer identified by the VHF picture does not agree to the charge height located by the slow-antenna network.

Figure 4 shows examples of VHF pictures for each type of flash, where polarities of the charge layers or of a leader are identified. NBP or PBP indicates the location of a first bipolar pulse observed by the fast antenna network, and the first letter indicates the polarity of the first half cycle of a bipolar pulse. Downward electric field is defined positive in this report.

CHARGE LOCATION ON POSITIVE C-G FLASH

Location and magnitudes of positive charge associated with 9 positive C-G return strokes in winter are analyzed by using data from the slow antenna network, postulating a point charge model. In most of the cases, it is hard to identify the electric field change

Table 3 Located positive charges associated with positive return strokes in winter.

date	time	Duration [ms]	Ipeak [kA]	Zv [km]	Zv [°C]	X [km]	Y [km]	Z [km]	Z [°C]	Q [C]	v	Initiation Type
2000/12/24	20:33	0.85	27	4.3	-27	-4.6	1.5	1 ~ 2	-4 ~ -10	5 ~ 35	2	A
2000/12/24	20:33	1.30	34	4.3	-27	-4.6	1.8	1 ~ 2	-4 ~ -10	15 ~ 40	2	
2000/12/24	3:21	0.35	19	-	-	7.9	-10.1	2 ~ 3	-11 ~ -17	10 ~ 20	3	B1
2001/1/28	17:06	0.30	71	2.2	-14	-12.6	-5.6	2 ~ 3	-12 ~ -19	5 ~ 20	3	B1
2001/1/28	17:04	0.35	35	1.6	-9	-10.9	-4.6	1 ~ 2	-5 ~ -12	10 ~ 30	3	B1
2002/1/4	22:17	0.80	35	2.3	-7	8.3	-5.8	3 ~ 4	-11 ~ -17	10 ~ 40	2	B2
2002/1/5	1:07	0.35	88	-	-	-3.2	-11.2	2 ~ 3	-10 ~ -15	25 ~ 75	3	B1
2002/1/4	17:44	0.35	19	1.2	-1	-2.3	-8.8	1 ~ 3	0 ~ -11	5 ~ 40	2	B1
2002/1/5	1:09	1.00	19	1.4	-3	3.1	-9.0	1	-4	2 ~ 30	3	B1

The ranges of the estimated charge location are determined postulating that each slow antenna had 15% random error in its sensitivity. Solutions for the height being less than 1 km are disregarded, and this is the reason why the lower limit of the charge height in Table 3 is 1 km. The ranges of solutions are wider than those of a summer flash in Table 1, which are evaluated in a similar way. A possible reason is that the shape of analyzed charge in winter is not well represented by a point charge model, and the effect of this misfitting is amplified when the charge height is low and close to the slow antenna network. The postulation of existence of 15% random error in the sensitivity of a slow antenna may be overestimation, because the nature of the error may not be random.

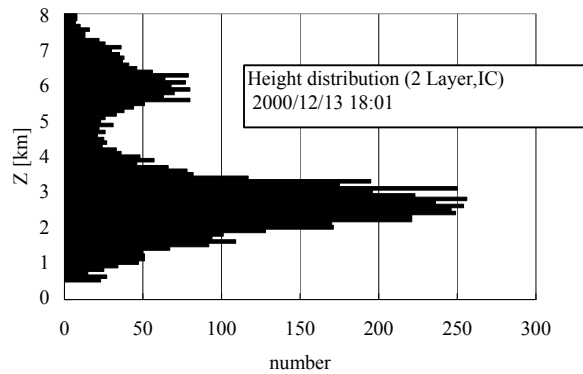


Fig. 6. Two-layer distribution of VHF sources in a cloud flash in winter.

DISCUSSION

Table 3 shows that positive charges associated with positive return strokes in winter are all located in warmer regions than -20°C . This is in contrast to the observation by *Brook et al.* [1982], who located the positive lightning charge in a colder region than -17°C for 6 positive C-G flashes out of 8. One of the reasons why the located charge heights in Table 3 are low is the influence of charge in the positive leader. Nevertheless, the influence of the leader charge cannot fully account for the difference between the two observations.

Kitagawa and Michimoto [1994] presented a hypothesis that a decaying thunderstorm in winter loses negative charge, and left positive charge is the predominant source of positive C-G flashes. In the VHF picture, more than 70% of type A flashes show VHF activity in two layers like the example of Fig. 6. At type B flashes, however, the proportion is less than 50%, and all the type B +C-G flashes in Table 3 show single-layer VHF activity. Therefore, observed results in this report do not oppose the hypothesis of monopole charge structure.

Positive charges in -30°C regions observed by *Brook et al.* [1982] were above the sea or on the coastline, whereas majority of the positive charges in Table 3 are observed more than 10 km inland from the coastline. Winter thunderstorms are short-lived [*Kitagawa and Michimoto*, 1994] and travel eastward. These features might be related to the difference between the observations of *Brook et al.* [1982] and of this report.

CONCLUSION

Positive charges associated with positive C-G strokes in winter in Japan are located by using the charge-location technique. In combination with the VHF pictures of the flashes, it is concluded that the positive charges associated with all the analyzed 9 positive C-G flashes existed in regions warmer than about -20°C .

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