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Technical Note

Charging Effect on the 80–200 nm Size Atmospheric Aerosols during a Lightning Event

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ABSTRACT

Atmospheric aerosol charging is caused mainly by cosmic rays and/or natural radioactive material decay. Because the ionization process generates well-balanced ion pairs, positive and negative ions in the air are at almost the same concentrations. The atmospheric aerosol electrical charge is therefore usually neutral. We measured the particle charge polarity distribution in the atmosphere during a lightning event at ground level. We found that the 80–200 nm particle charge balance during a lightning event was skewed either to the positive or the negative. Furthermore, the particle charge polarity changed very rapidly (within a few minutes) from negative to positive or vice versa. There was also a two-fold higher charged particle fraction during a lightning period than a normal day. This increased charged particle fraction may decrease the total particle concentration in the atmosphere by deposition on raindrop surfaces.

Keywords: Atmospheric particle charging; Charging polarity reversal; Lightning effect; Charged cloud.

INTRODUCTION

There have been numerous research reports on atmospheric aerosol effect on climate, visibility, human health and so on (Pöschl, 2005). The atmospheric aerosol plays a very important role in cloud formation and the radiative energy budget of the Earth (IPCC, 2007; Andreae and Rosenfeld, 2008). Usually, particles in the air are in an electrically neutral state. If particles are charged, the charged particles can scavenge aerosols by coagulation and their rate of deposition on surfaces may be increased and also enhance ice particle formation in a cloud (Tinsley *et al.*, 2000). Atmospheric particles are usually charged by galactic cosmic rays (GCRs) and/or radioactive material decay from soil (Reist, 1993). Because GCRs and/or radiation generate an almost equal number of positive and negative ions in the air, atmospheric particles are usually in a neutrally charged state. Charged atmospheric particles may also affect human health because the deposition of charged particles in human lungs is enhanced compared to that of uncharged particles (Fews *et al.*, 1999). Some researchers have reported that the atmospheric aerosol can enhance lightning activity (Yuan *et al.*, 2001; Naccarato *et al.*, 2003; Kar *et al.*, 2009). However, no report on atmospheric aerosol charge phenomena related with a lightning has been published.

Laakso *et al.* (2007) developed an instrument incorporating a differential mobility analyzer (DMA) (Winklmayr *et al.*, 1991) to classify the charged ultra-fine particles and a condensation particle counter (CPC) (Stolzenburg and McMurry, 1991) to measure new particles formed by ion-induced nucleation. However, this instrument is not suitable for measuring rapidly changing aerosol charging states because of the electrical scanning time of the DMA.

In this research, we monitored the charging state of the atmospheric aerosol and its particle charging characteristic during a lightning event on the ground. To monitor the charging characteristics of the atmospheric aerosol, we used the aerosol electrical mobility spectrum analyzer (AEMSA) devised by Ahn and Chung (2010). The AEMSA can detect the electrical mobility spectrum of charged single particles in the nano-meter size range, regardless of their polarity, without electrical scanning.

METHODS

Measurements were performed at Hanyang University, Ansan, R. of Korea and the aerosol sampling system was housed in the 4th floor laboratory of the 5th Engineering Building. The sampling site, marked as the concentric circle in Fig. 1 is located near the west coast of the Korean Peninsula. Precipitation was measured every 30 minutes using AWS (Davis Instruments, Vantage pro2) at the

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Fig. 1. The sampling location, Ansan, is located south-west of Seoul and near the Yellow Sea.

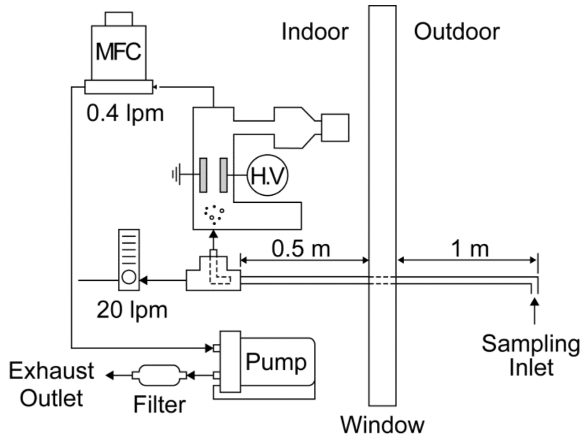

Fig. 2. Schematic of atmospheric particle sampling and measurement system.

sampling site. The lightning event was measured with polarity, magnitude, type (cloud-to-ground:CG, cloud-to-cloud:CC) and location (Krider *et al.*, 1980). The lightning event and cloud coverage data were provided by the Korea Meteorological Administration (KMA). The lightning events recored only within the broken line circle with a radius of 10 km shown in Fig. 1 were used in this study.

We built the sampling system shown in Fig. 2 to measure the charging state of atmospheric particles. Atmospheric particles are sampled through an OD 12.5 mm and a 1.5 m long copper tube. To minimize particle loss in the sampling tube, the sampling air is pumped at a flow rate of 20 L min^{-1} with a vacuum pump and a small portion of sampling air (0.4 L min^{-1}) is extracted and introduced into the AEMSA for particle charge analysis. To prevent the charged particle loss inside the sampling tube, an electrically conductive copper tube is used. The main sampling flow (20 L min^{-1}) is monitored with a rotameter, and the AEMSA flow (0.4 L min^{-1}) is controlled with a mass flow controller (MFC). We applied an analyzing voltage of 1,500 V to the AEMSA. This electrical potential allows the detection of particles with an electrical mobility ranging from 3.945×10^{-8} $cm^2 V^{-1} s^{-1}$ to 1.027×10^{-8} $cm^2 V^{-1} s^{-1}$. Assuming that a particle is singly charged, this corresponds to particles with a diameter of from 80 nm to 200 nm. The AEMSA was installed inside the laboratory window and the sampling probe was projected outside of the window. The total length of the sampling probe was l.5 m and the end of probe was 1 m away from the window. AEMSA measures particle charge and size distribution every second. However, when the particle concentration is not high enough like a clean day, 1 second data does not give statistically meaningful results. To overcome this problem we accumulated the data for 5 minutes to reduce statistical error. The raw AMESA data are shown in Fig. 3. A positively charged particle in the AEMSA yields a corresponding count on the left side of the graph. Smaller charged particles are detected further away from the center pixel. Non-charged particles are detected at the center pixel. However, the finite dimensions of a particle-introducing nozzle, the spread of signals in the AEMSA for the same electrical mobility particle is inevitable. To find a relationship between the particle electrical mobility and the AEMSA detection pixel position a calibration process is needed. The AEMSA system was calibrated with known size particles generated by the DMA. The detected position of particles with a single charge is labeled on the upper x-axis in Fig. 3 (Ahn and Chung, 2010).

RESULTS AND DISCUSSION

Some of the measurement results obtained on October 15th, 2011 are shown in Fig. 3 and there was a very severe thunder storm as shown in Fig. 4(a). A typical atmospheric aerosol charge distribution is shown in Fig. 3(a) and it shows that the number of positively and negatively charged atmospheric particles are fairly well balanced. However, when the thunderstorm passes over the sampling site, the atmospheric aerosol charge balance shifted and the populations of negatively charged particles increased, as shown in Fig. 3(b). About four minutes later, the positively charged particle count increased dramatically (Fig. 3(c)). This polarity reversal phenomenon continued until the thunderstorm had moved away from the sampling site. This may imply that a strong electric field was formed between the cloud and ground to break the particle charge balance and the particle charge reversal phenomena may cause by the electrical field formation between the cloud and the ground. This atmospheric aerosol charge polarity reversal phenomena is very similar to the observation of atmospheric electric field change reported by Moore and Vonnegut in 1977. They took measurements on the ground beneath a thunderstorm. Based on their report and our measurement, it is believed that the atmospheric aerosol charging during lightning is strongly related with the electric field between the thunder cloud and the ground. The charged particle polarity ratio (N_+/N_-), precipitation, and two types

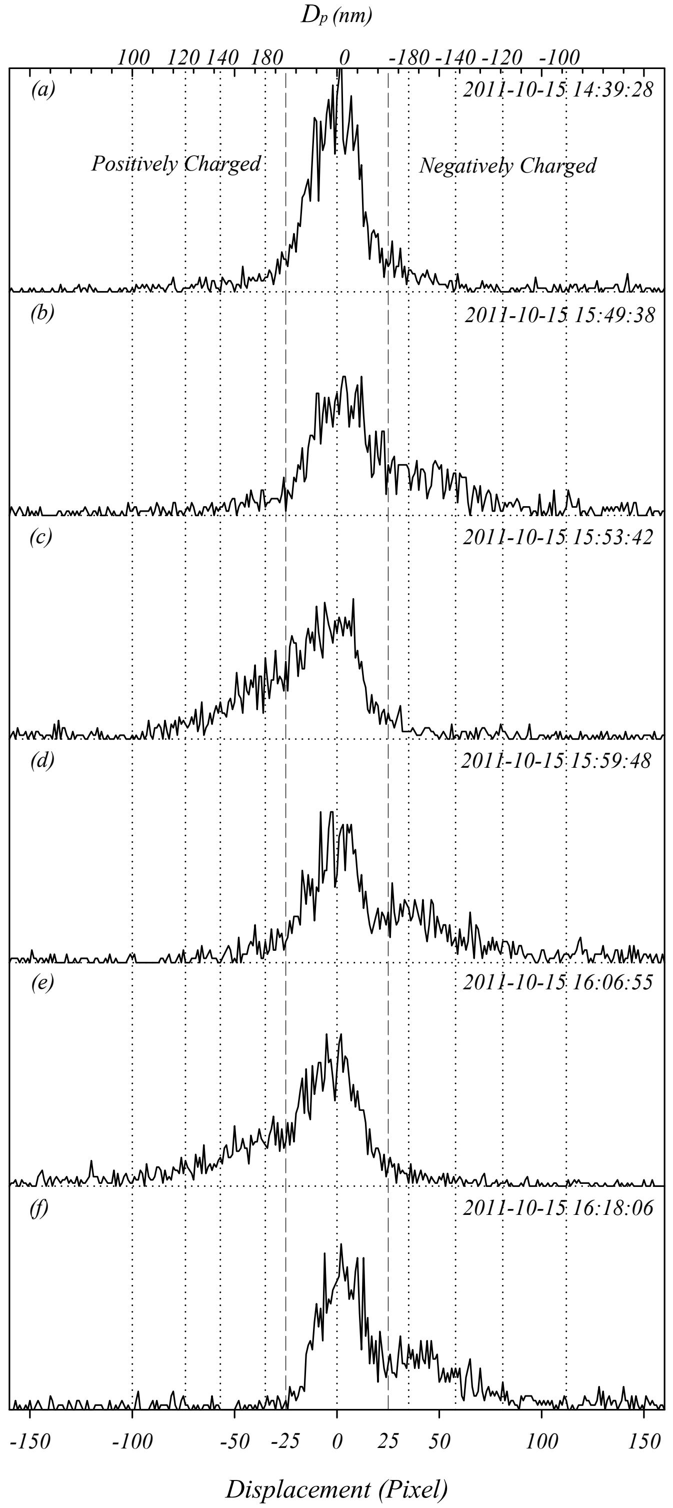

Fig. 3. Series of data measured by AEMSA. (a) Long before the rain accompanied by lightning. (b), (c), (d), (e), (f) data are listed according to the lapses of time during lightning event.

of lightning events from October 15th to 16th, 2011 are shown in Fig. 4(a). Precipitation was plotted by simple bar graph along with right y-axis. The types of lightning were distinguished by cross (CC: cloud to cloud) and star (CG: cloud to ground) symbols. Polarity and magnitude of lightning were plotted along with offset y-axis on the right side of the graph.

On the stormy days of Figs. 4(a), 5(a) and 5(b), a strong charged particle polarity ratio fluctuation was observed. The fluctuation was almost coincident with the lightning event. However, on clear days, the atmospheric particle charge balance is close to 1, as shown in Fig. 4(b). This

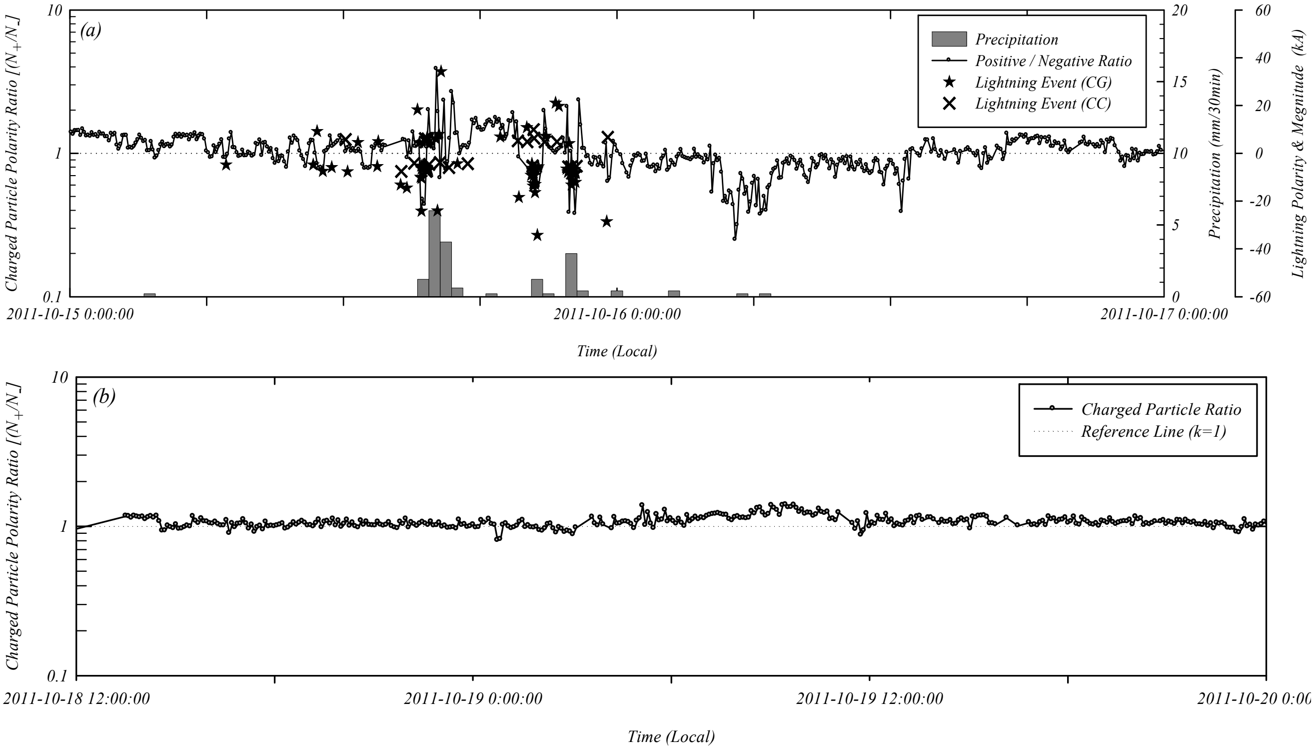

Fig. 4. The charged particle polarity ratio (N_+/N_-) during (a) a lightning event and (b) clear days; (a) Oct. 15–16th, 2011, (b) Oct. 18–19th, 2011.

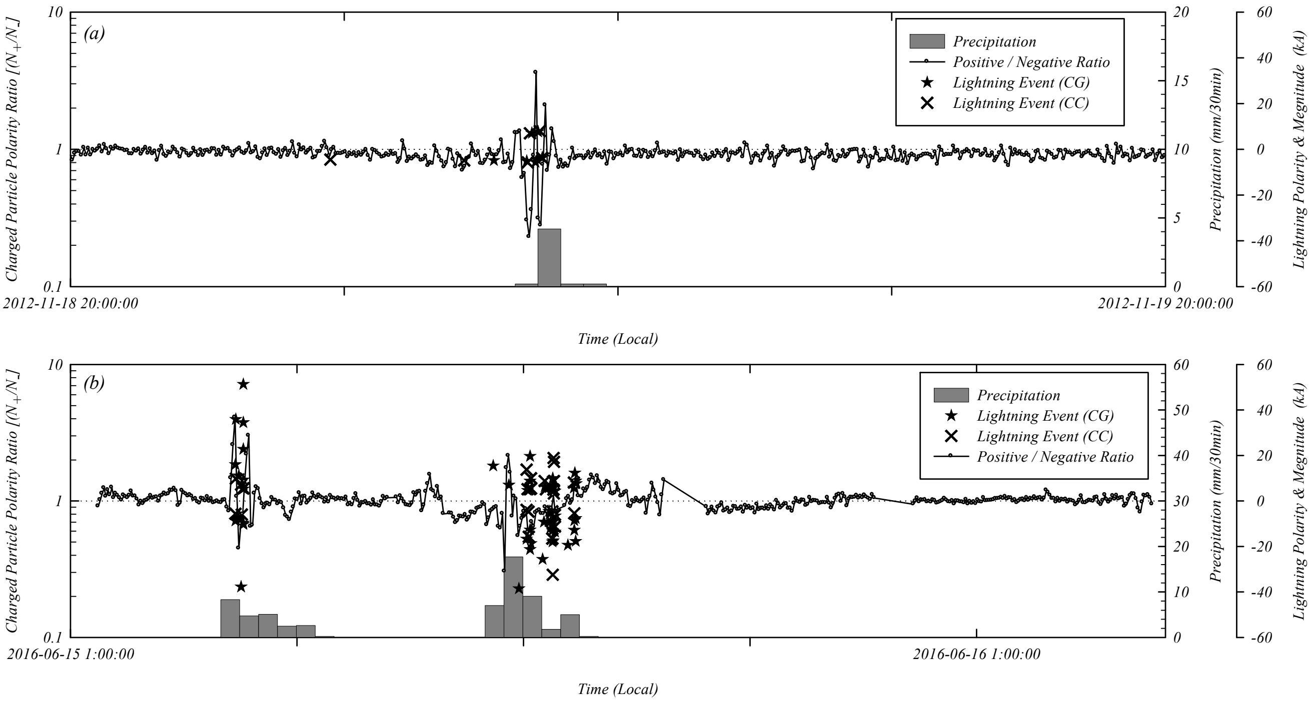

Fig. 5. The charged particle polarity ratio (N_+/N_-) during lightning event; (a) Nov. 18–19th, 2012 (winter season), (b) Jun. 15–16th, 2016 (summer season).

phenomenon also has been observed from 2011 to 2016 on clear days. Figs. 5(a) and 5(b) are one of the representative measurements in summer and winter season. From these measurements, we can deduce that the thunderstorm has a strong effect on atmospheric particle charge balance regardless of seasonal variation.

Lightning generates vast numbers of ion pairs, some of which will be separated in the strong electric field and increases the electrical conductivity of cloud temporarily. Then, on a stormy day, the charge distribution of thunder cloud can be changed easily. The ratio of charged particles, $N_+ + N_-$, to total detected particles, $N_t = N_0 + N_+ + N_-$, was calculated and the curve that was plotted is shown in Fig. 6. The charged particle ratio ranged from 13.7% to about 66.9% on the stormy days, such as Oct. 15–16th, 2011 (Fig. 6(a)). However, on the clear days of Oct. 18–19th, 2011, the charged particle population was very stable and ranged from 19.3% to 36%, as shown in Fig. 6(b). The mean value and standard deviation of charged particle ratio in Fig. 6(a) were 39.42% and 9.3%. In Fig. 6(b), they were 27.36% and 4.2%. These two graphs clearly show that thunderstorms can enhance the charged particle population in the atmosphere near the ground.

The interior of thunder cloud contains a bipolar charge distribution consisting of positive charge in the upper part of the cloud and negative charge below the positive (National Research Council *et al.*, 1986). Usually, lower negative charge causes CG lightning with negative polarity (–CG) and upper positive charge cloud causes CG lightning with positive polarity (+CG). Generally, when the thunder cloud causes +CG lightning comes near, the ground is polarized as negative and positively charged particles are concentrated near the ground. Then, the charged particle polarity ratio (N_+/N_-) increases larger than 1 and vice versa. Fig. 7 shows correlation with CG lightning events polarized by same polarity for more than 5 minutes and its charged particle polarity ratio from 2011 to 2016. In Fig. 7, most of the charged particle polarity ratio corresponding to positive lightning shows the charged particle polarity ratio value greater than 1 and vice versa except a few cases. From this plot, we may deduce that when the ground is polarized by thunder cloud, the number of particle charged by opposite polarity increases near the ground.

Fig. 8 illustrates the mechanism of charged particle imbalance phenomenon near the ground. Charged particle imbalance is mainly caused by the electrical field induced by the thunder cloud and the cloud nearby that may carry induced charges too. As a result, the charged particle polarity ratio is changing by the polarity of thunder clouds and by the following clouds passing over the test site. These moving clouds by the wind will give the charged particle polarity oscillation phenomena for the fixed ground monitoring station. Therefore, on a stormy day, a substantial charge imbalance may often be observed without a lightning, as shown in Fig. 4(a).

CONCLUSIONS

For the first time, we successfully monitored the charge of atmospheric particles during thunderstorm events. We found that the atmospheric particles were usually in the neutral state on clear days. However, when a thunderstorm occurred, the aerosol charge balance was strongly disturbed, and, as a result, a rapid fluctuation in particle charge polarity was observed. Under thunderstorm conditions, the charged particle population in the air was two- to three-fold higher than observed on clear days. We also found that thunderstorm clouds could strongly influence atmospheric aerosol charging and the particle charge polarity near the ground.

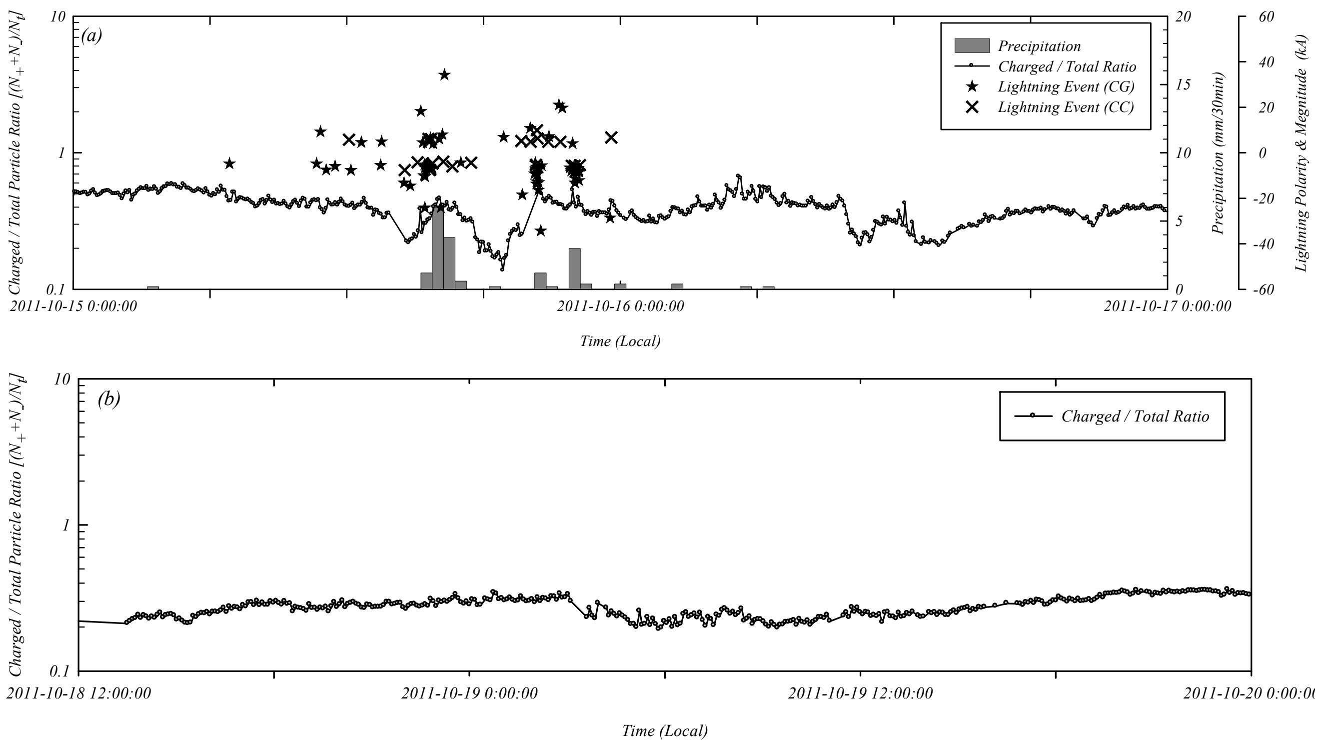

Fig. 6. The charged particle ($N_+ + N_-$) to total particle ($N_t = N_+ + N_- + N_0$) ratio during (a) lightning event and (b) clear days; (a) Oct. 15–16th, 2011, (b) Oct. 18 (cloud coverage: 0)–19th (cloud coverage: 1.1), 2011.

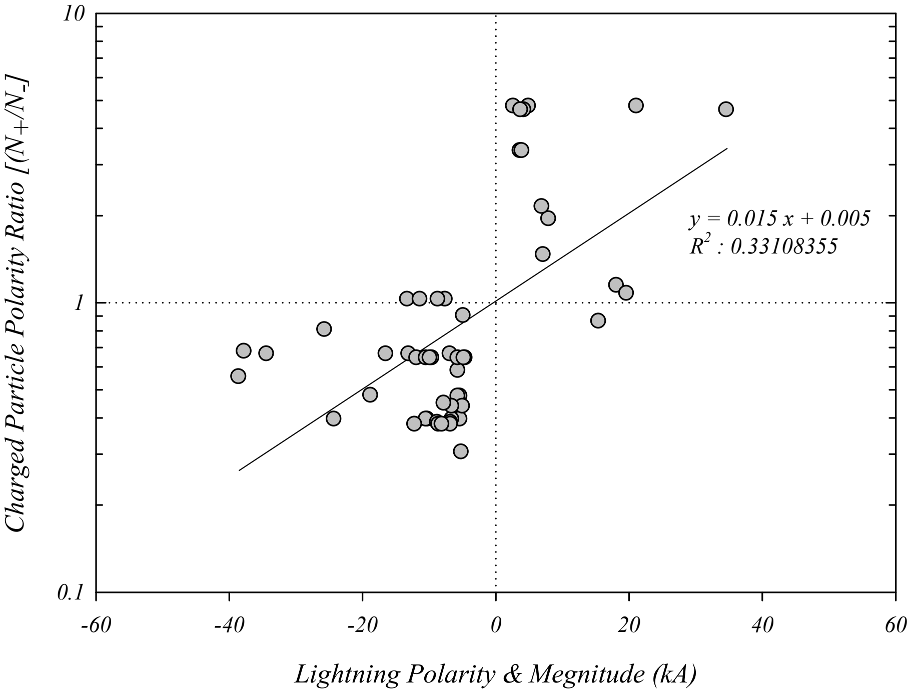

Fig. 7. The charged particles polarity ratio according to lightning intensity during the CG lightning event measured from 2011 to 2016.

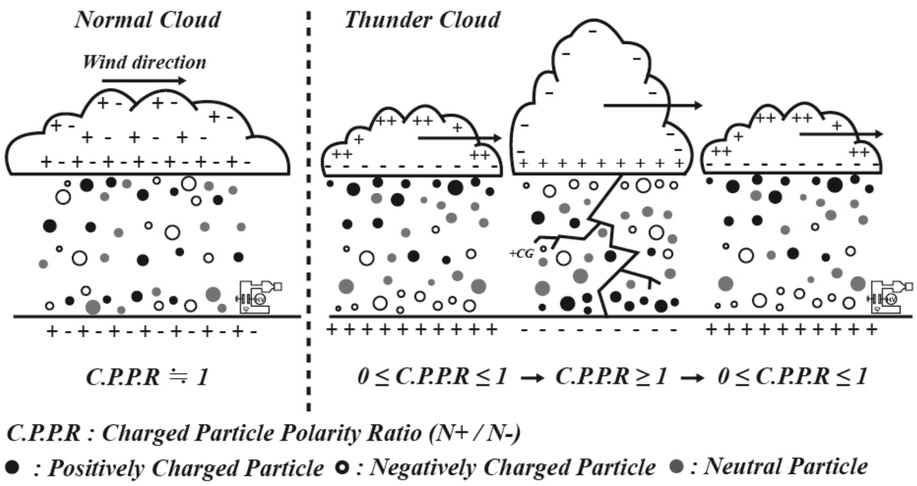

Fig. 8. The mechanism of charged particle imbalance phenomenon.

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