Charge separation in non-riming conditions

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INTRODUCTION

Extensive evidence from aircraft observations in thunderstorms have shown that substantial electric charge is to be found on millimeter-sized hydrometeors; indicating that the ice phase play an important role in the process of charge separation inside the clouds. Electric charge is separated during the contact time between graupel and ice crystals and then particles with opposite charge could be carried away at different regions of the clouds due to gravitational force and convective currents. This process could develop the different charged regions in clouds.

Laboratory measurements have shown that the magnitude and sign of the charge transfer to graupel particles during interactions with ice crystals is a function of the cloud microphysical conditions. In fact, it depends on: the cloud temperature, supercooled water concentration, cloud droplet size distribution, ice crystal size and impact velocity.

Few experiments were conducted under non riming conditions and under zero liquid water content because the low magnitude of the charging current but ice particles with significant charge is observed in stratiform cloud regions where the ambient is subsaturated respect to liquid water.

New laboratory measurements of the charge transfer in collisions between vapor-grown ice crystals and a graupel particle (2 mm diameter) in non-riming conditions are presented in this work. The experiments were all performed for a supersaturated-atmosphere with respect to ice and subsaturated with respect to liquid water; which ensures the environment free of supercooled liquid water droplet. The relative humidity of the air inside the chamber was controlled and measured during the measurements. The experiments were conducted for ambient temperatures between –7°C and –20°C and air velocity around 3 m/s. The results show that the charging acquired by the graupel depends on the temperature and supersaturation.

EXPERIMENTS

The cloud chamber used in this study consists of a single chamber with a height of 1.8m and side dimensions of 0.6 x 0.9m^2, located inside a cold room.

The principle for increasing the relative humidity (RH) in the cloud chamber was based on the adiabatic

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isobaric mixing of two air masses with different temperatures and RH (Curry and Webster, 1999). Because of the nonlinearity of the Clausius-Clapeyron equation, this kind of mixing may result in an increase in RH. Thus, the relative humidity of the cloud chamber was raised by injecting controlled volumes of humid air. Humid air was forced to flow into the cloud chamber from the exterior (ambient temperature) by means of a pump located through one of the tubes connected to the chamber.

Ice crystals were nucleated in supersaturated-atmosphere with respect to ice, and subsaturated with respect to liquid water. The ice nucleation was performed by cooling a local volume of the air, inside the cloud chamber, with a rapid expansion of air from compressed air inside a syringe after which the ice crystals grew at the expense of the vapor present.

A vertical wind tunnel with a section of 10 cm in diameter connected to an air pump placed outside the cold room was used. The speed of the air (V) inside the tunnel was controlled by adjusting the power to the air pump and measured by an anemometer with an accuracy of ±0.1ms. The measurements were conducted at 3 m s^{-1} velocity. According to Locatelli and Hobbs [1974], the velocity used in this work is representative of the fall velocity of a graupel particle with a maximum dimension of 4 mm.

A network constituted by brass wires of 2 mm in diameter was used as a target [Avila et al., 2013], which was placed across the wind tunnel and connected to a sensitive current amplifier whose output current (I) was a measure of ice crystal charging events associated with collision and separation from the target. The area of the gap between the wires is approximately 15 x 15mm^2; this area is large enough in order to consider that the flow pattern around the target is mainly produced by the wire diameter. The network-type collector was used instead of the typical single rod target used in the previous works (Takahashi, 1978; Jayaratne et al., 1983; Saunders et al., 1991, 2004, 2006; Pereyra and Ávila, 2002; among others) due to the low-magnitude charging current produced in these kinds of experiments as a consequence of the low-speed collisions and the absence of cloud droplets. Thus, with this device, it was possible to increase sufficiently the ice crystals impacting area on the target in order to get detectable charging currents

Previous to the experiments, the target was covered with ice by impacting supercooled water drops over the target to simulate the typical rimed surface of the graupel.

The ambient temperature (T) was determined by two thermistors located in the lower part of the wind tunnel and in the cloud chamber. Both temperatures were sensed as a function of time during the whole run. The variation of both temperatures and its difference during the measurement was typically ~2°C.

The relative humidity over ice (RHi) was determined as a function of time by using the hygrometer EE31 Series Model D (E+E Elektronik) which has a remote sensing probe for RH measurements in the temperature range [–40,180]°C. The variation of RHi during the experiments was typically ~ 3%.

A sample of the particles inside the cloud chamber was collected on 2mm wide glass strips, previously covered with a thin layer of a 5% wt/wt Formvar solution in chloroform [Schaefer, 1956]. The collection was made at -8°C, -13°C, and -21°C and for two different times, immediately after the nucleation and 2 minutes after nucleation. Based on the samples collected, the sizes of the ice crystals were measured. Figure 1 shows the box charts for the ice crystal size distribution. The squares and horizontal bars inside the boxes give the mean and median droplet diameters, respectively. The boxes indicate the standard deviation, and the small dashes give the minimum and maximum droplet diameters. The sizes extend to 340 µm, and the median sizes are between 7 and 20 µm at the initial sample and between 10 and 25 µm in samples at 2 minutes. On each temperature, the ice crystal size increase in time showing that the ice crystals are growing on a supersaturated-atmosphere.

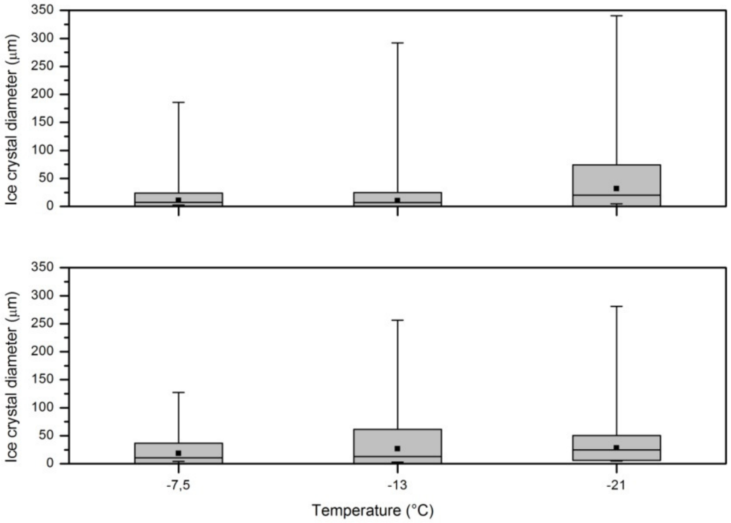

Figure 1. Statistical analyses as box charts for the ice crystal sizes for T = -7.5°C, -13°C, and -21°C. The squares and horizontal bars inside the boxes indicate the mean and median ice crystal diameters, respectively. The boxes indicate the standard deviation, and the small dashes indicate the minimum and maximum ice crystal diameters.

The following steps were followed to run an experiment:

1. The cold chamber was adjusted to the desired temperature.
2. The target was rimed.
2. Warm and moisture air was introduced into the cloud chamber and the RH was sensed.
3. When the RH overpasses the saturation over ice, the ice crystals were nucleated.
4. The power to the air pump was switched on and the graupel charging current was measured for a lapse of time between 90 and 210s.

RESULTS AND DISCUSSION

The charging current (CC) of the target was measured during collisions with ice crystals. The experiments were carried out at temperature ambient between -7 and -21°C and at RHi between 105 and 113%.

Figure 2 shows the time evolution of the charging current of the target (Figure 2, top), as well as the ambient temperature (T) and supersaturation (RHi) (Figure 2, bottom) during a typical run at ambient temperature around -20°C. The abrupt decay to zero of CC are due to the air pump was switched off in order to check the correct operation of the charge amplifier. This run lasts 3 min and a positive charging current is observed during the whole run, which decreases with time because the ice crystals concentration diminishes with time as well. Both the ambient temperature and supersaturation increased during this experiment as a consequence of the continuous input of warm and humid air from outside. The temperature and RHi varied from -21°C to -19°C and 106% to 110%, respectively.

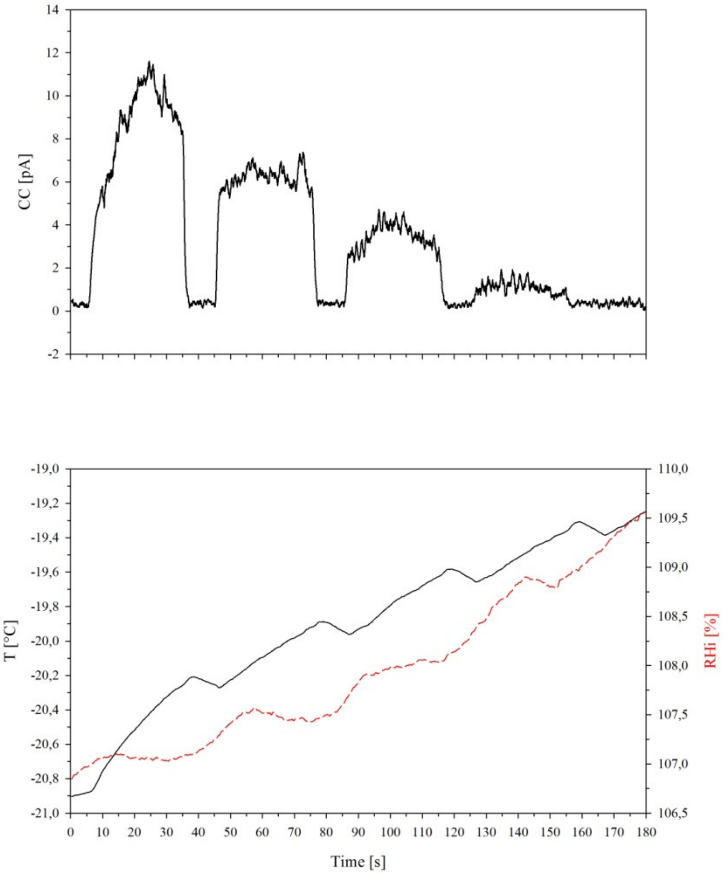

Figure 2. (top) Charging current to the target and (bottom) ambient temperatures and supersaturation for an experiment at ~ -20°C.

In general, the results were affected by chamber and laboratory temperature and the relative humidity of the laboratory; however, they followed the general trend: the graupel acquired mainly negative charge for low RHi values and it was predominantly positive for high RHi.

Saunders et al. [2001] performed similar experiments to those here described, but they did not determine the RH. They found that an ice crystal cloud growing in an environment supersaturated with respect to ice, but in the absence of water droplets charges the target negatively when the input of external air was moderate or low. The sign reversed to positive if the input of external air was incremented. They also observed that when the input of air was turned off, the charge can be reversed from negative to positive then fell to zero when the crystals had completely fallen out.

The past and present studies suggest that the sign of charging when ice crystals rebound from an ice target representing a falling graupel pellet may be influenced by the local supersaturation controlling the growth of the interacting cloud particles. More experiments are in progress.

ACKNOWLEDGMENTS

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