The Electrical Soundings in the Decay Stage of a Thunderstorm in Pingliang Region

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ABSTRACT: An electric field (E-field) sounding system, based on corona discharge, was designed to measure the vertical component of the electric fields in thunderstorm. The experiment of electrical soundings in thunderstorm was conducted in Pingliang region by (E 106.59°, N 35.57°, 1620 m, above sea level, asl) in the summer of 2012.One case of thunderstorm occurred in the night of August 20th have been investigated by two balloon-borne electrical soundings in the decay stage. The result of the first sounding showed that the thunderstorm have a simple tripole charge structure in stratiform precipitation regions, a lower positive charge center (2.0-4.0 km, asl),a middle negative charge region (4.5-5.3 km, asl) and an upper positive charge region (5.3-6.3 km, asl). The charge density of middle negative charge is larger than that of lower and upper positive charge region. Influenced by downdraft of precipitation, each charge region moved down to a lower altitude region. The result of second sounding showed that the lower positive charge center totally disappeared and only middle negative charge region (3.7-4.2 km, asl) and upper positive charge region (4.2-4.7 km, asl) existed in stratiform precipitation regions. We can conclude that the downdraft with precipitation induced the dissipation of lower positive charge region. Compared with the first sounding result, we found that the charge density increased and the depth decreased for both of charge region.

INTRODUCTION

This document can be used as a template for preparing your paper for inclusion in the extended abstract volume that will be distributed electronically at ICAE2014. Main sections are labelled in boldface, all capitals, without section numbers. The charge structure of thunderstorm in mature stage has been extensively studied by using various detection methods, and a series of important progress has been achieved [Simpson and Scrase, 1937; Simpson and Robinson, 1941; Winn et al., 1981; Weber and Few, 1983; Byme et al., 1989; Williams, 1989; Marshall et al., 1991, 1995; Stolzenburg et al., 1998, 2001]. However, the observation about charge structure of thunderstorm in disappearing stage is still limited. Usually, a fluctuation (EOSO, End of Storm Oscillation) of surface electric field can be observed in late

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stage of thunderstorm, and cloud charge also began to change until the decline and fall [Marshall et al., 1992, 2009]. Marshall et al [1992] studied two cases of thunderstorm in disappearing stage and found that the cloud charge structure was comprised of a negative charge kernel and two positive shielding charge region of upper and lower boundary. Marshall et al [2009] found the charge structure of thunderstorm changed sequentially during the period of EOSO, i.e., the earlier charge region sequentially fell to the ground and new charge region has been generated in the higher part of cloud. Start from the late mature stage, a regular quadrupole charge structure evolved into a reversed polarity quadrupole charge structure. Stolzenburg et al [2010] observed once process of multicell thunderstorms in disappearing stage by using a series of electric field sounding and found that the external of main cloud anvil was negative shielding charge layer with a positive charge region inside.

Chinese scholars found, for most of thunderstorm in Chinese inland plateau, a larger-than-usual positive charge region exists at lower portion of thunderstorm and a large proportion of intracloud discharge occurs between the middle negative charge region and the lower positive charge region [Liu et al., 1987; Qie et al., 2005]. The charge structure retrieved by multi-station synchronous observation of electric field change indicated that the thunderstorm over inland plateau regions has a triple charge structure [Qie et al., 1998; Zhang et al., 2008; Cui et al., 2009]. By using corona probe radiosonde, Zhao et al [2009] found four charge regions, alternating in polarity, existed in thunderstorm with a negative screen layer at the lower boundary.

Because nearly no lightning occurred in the disappearing stage, the charge region distribution could not be obtained by the surface multistation observation. In order to study the profile of E-field in the decay stage of thunderstorm in Chinese inland plateau, the experiment of E-field soundings was carried out in Pingling region in the summer of 2012.

INSTRUMENTS

The experiment of E-field sounding was conducted in Pingliang station of lightning and hail research Chinese academy of sciences (E 106.59°, N 35.57°, 1620 m, asl), a X-band Doppler radar in the station was employed to monitor the activity of thunderstorm, and the balloon launching site was about 200m away from the radar. The electric field sounding system, based on corona discharge, was designed to measure the vertical component of the electric fields in thunderstorm. The measurement range of corona current is ± 16 μA. The SEFM was calibrated in lab and field experiments [Zhao et al., 2008]. The relation between the E-field intensity (E) and the corona current (I) is derived as:

$$I = 4.48 \times 10^{-3} E(\mathrm{E} - \mathrm{E}_0) \quad (1)$$

$$\rho = \varepsilon \left| \frac{\Delta E_z}{\Delta z} \right| \quad (2)$$

Where E is in kV/m, E_0 is the threshold of E-field for corona current in kV/m, and I is in μA. The charge polarity and density along the sounding path is calculated by the vertical component profile of the E-field and the one-dimensional approximation to Gauss law, the charge density ρ can be expressed as expression (2), in which ε is the permittivity of air (8.86×10^{-12} F/m). In this paper, the E-field is deduced from corona current whose direction is same with the direction of the E line of force. If the downward current is defined as positive, and the associated E-field is also defined as positive.

The data, including corona current, GPS and temperature with a sample rate of 1Hz, are all transmitted to ground receiver by a digital transmitter with a center frequency of 2.4G Hz. an automatic tracking antenna is designed to receive the signals from E-field sounding, which is controlled by a computer via GPS information of soundings.

RESULTS

On August 20th, one case of thunderstorm occurred in the east about 45km away from radar at 19:20, and moved slowly to the station. At 21:30, the thunderstorm divided into several convective cells and they were distributed in the southeast about 20km away. These thunderstorm group entered mature stage at 22:00 and arrived at station about half an hour late. As the production of precipitation the maximum value of reflectivity decreased. About at 23:00, the thunderstorms joined together and the echo intensity further weakened. The convective region moved out of station with a large scale of stratiform region overhead. At 3:00 of August 20th, the thunderstorm moved away from station and finally dissipated about 20 km away in the west. Two E-field soundings were released at 23:51 of August 20th and 02:09 of August 21st, both of them successfully traversed the stratiform region of the thunderstorm in the decay stage, and we defined them as T-1 and T-2 in accordance with time sequence.

Sounding of T-1

The T-1 balloon-borne sounding was launched at 23:51, about 23 minutes after the final lightning flash. The total duration was about 20 minutes and then went through the cloud top at 00:10 of August 21st. Fig 1a-b showed the composite reflectivity (CR) with scanning time of 23:58 and 00:21, the radius was 75 km. Fig 1c was the ground projections of sounding path. During the period of sounding, the thunderstorm began to dissipate, so the value of CR was ranged from 20 to 40 dBZ, and the station was covered by stratiform region of thunderstorm. The total horizontal migration of balloon-borne radiosonde was about 3.3km away from launch site. Compare with the radar echo, we can conclude that the radiosonde traversed the stratiform region completely.

Fig 2 was the sounding result of T-1. Because the temperature sensor broke down, the temperature profile was given by the routine meteorological sounding at 19:30. The ascending velocity of T-1 kept in a steady value of 4m/s, which indicated that the airflow in stratiform region was stable as expected. The profile of E-field showed that the maximum negative value of E was -45kV/m and existed between 4-4.4km above sea level, and the maximum value of positive E was 40kV/m and located in a low altitude from 2km to 5.2km. According to one dimensional approximation to Gauss law, the charge density has been figured out. The lowest charge layer was found in the first 400 meters above the surface and probable was caused by point discharge from object on the ground, and its mean charge density was -0.79 nC/m^3.The lower positive charge center (LPCC) existed between 2.0-4.0 km asl; the main negative charge area was present between 4.5-5.3 km asl; the upper positive charge layer was between 5.3-6.3 km asl. Their charge densities were $0.3nC/m^3$, $-0.75nC/m^3$ and $0.18nC/m^3$, respectively. On the whole, the charge structure of the thunderstorm conformed to the tripole model, while the LPCC existed in the region warmer than 0℃. Zhao et al [2009] found a larger-than-usual LPCC existed in the region colder than 0℃ in mature stage for a thunderstorm in the same study region. In this study case, thunderstorm developed into decay stage, the downdraft was predominant in the thunderstorm and persistent precipitation may drag the charge layer move to the ground as a result. The product term of charge density ρ and thickness h was used to estimate the intensity of each charge region, and the horizontal distribution of charge density was regarded as uniform [Marshall et al., 1991]. The values of ρ h for the four charge regions from surface to cloud top were -316 nC/m^2, 600 nC/m^2,-600 nC/m^2 and 180 nC/m^2, respectively. The results indicated that the intensity of LPCC and negative charge region were equal, and both of them were larger than that of upper positive charge region.

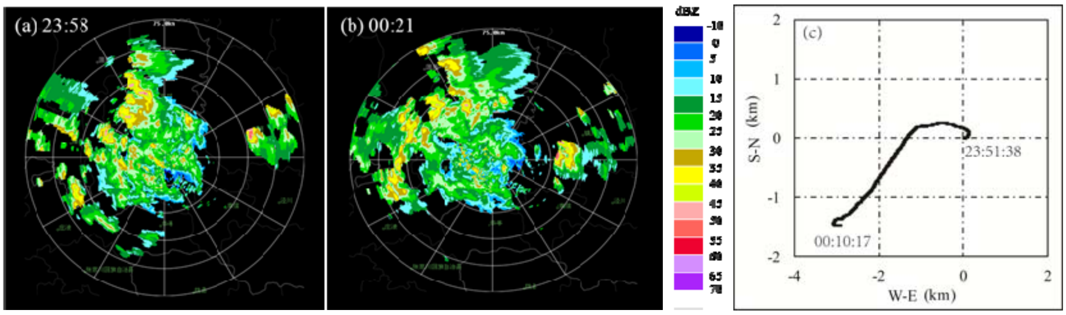

Fig 1. The radar composite reflectivity at 23:58 (a)and 00:21 (b)， and ground projections of sounding path (c)

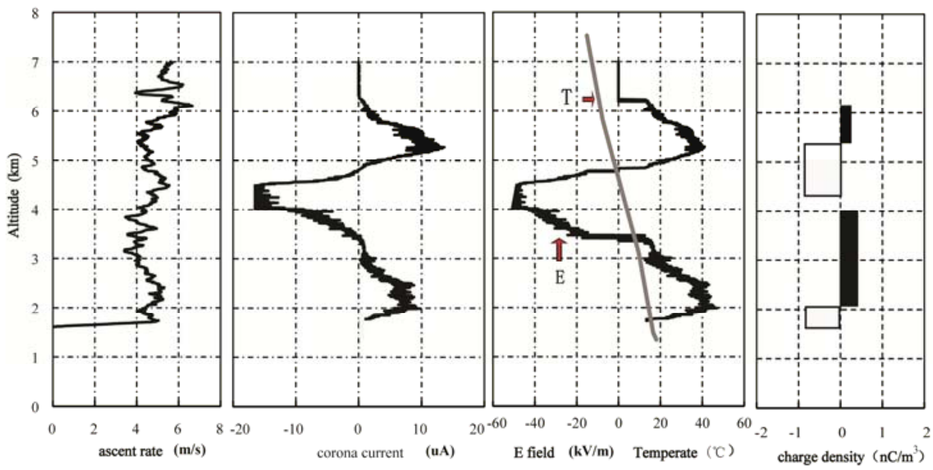

Fig 2. The sounding result of T-1

Sounding of T-2

The T-2 balloon-borne sounding was released at 02:09 of August 21st and passed through cloud top about at 02:20am。 Compared with the first sounding, we can find the value of CR further decreased, as shown in the Fig 3a-b. The total horizontal migration of balloon-borne sounding was about 2.9 km from launch site, and the large scale of stratiform region over the station ensured that the sounding kept flying in the cloud before passing through cloud upper boundary.

According to the E-field, we found the peak values of E-field were still high, and the maximum positive and negative values were 50kV/m and -25kV/m. A uniform E field about -25kV/m ranged from

2km to 3.7km. The charge density showed that the LPCC observed in the T-1 has been disappeared, and a positive charge region existed near the surface which may be the result of corona ions. In the cloud, a positive charge region upon a negative charge region has been observed, and the charge densities for both of charge region were -1.17 nC/m^3 and 0.73 nC/m^3. Compared with the result of T-1, we found that the height of the upper positive charge region declined by about 1.1km and thickness decreased by 0.5km. For the negative charge region, the height also declined by 0.8km and thickness reduced 0.3km. However, the charge densities of the two charge region were all increased. The ρh also has been calculated for each charge region, the value of negative charge region was -585 nC/m^2 and 365 nC/m^2 for positive charge region.

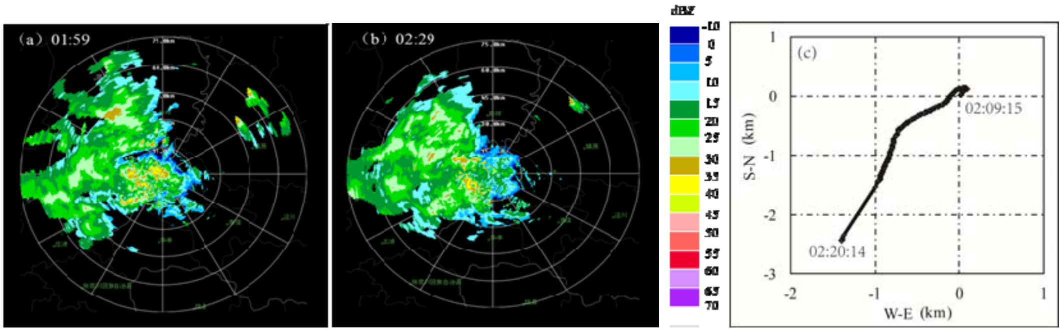

Fig 3. The radar composite reflectivity at 01:59（a）and 02:29（b），and ground projections of sounding path（c）

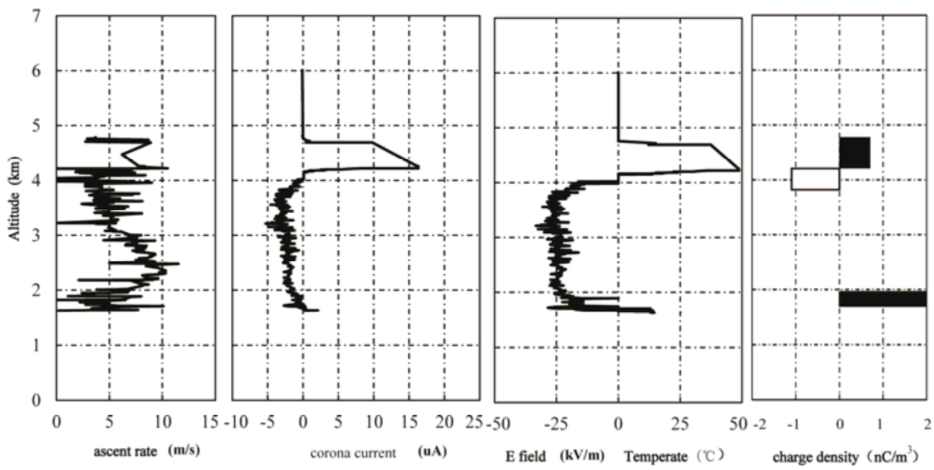

Fig 4. The sounding result of T-2

CONCLUSIONS

Two balloon-borne E-field soundings were successfully passed through a case of thunderstorm in decay stage which occurred in the Pingliang region, and the charge structure has been discussed in this paper.

The study thunderstorm was composed of several isolated convective cells in mature stage and combined together in the later stage. The station was covered by a large scale of stratiform region, and the sounding of T-1 was released about 23 minutes after the last lightning flash. The observation results showed that three charge regions existed in cloud and the negative charge region stayed in middle part of cloud. An obvious feature of charge structure was that each charge region located at a lower altitude compared with those observed in mature stage. On the one hand, the cloud upper boundary was limited below 6.3km, on the other hand, the predominant airflow was downdraft in this stage; the charge region has been dragged downward and the LPCC move to the region warmer than 0℃, and the low boundary of cloud. The charge density of LPCC was less than that of negative charge region, while the thickness of LPCC was the largest among three charge regions.

Marshall and Lin [1992] considered that the upper and lower positive charge region were screen layers of middle negative charge region for New Mexico thunderstorm in decay stage. Theoretically, complete screening should make the electric field just outside the cloud zero and the summation of ρ h of each charge region should be zero if the distribution of charge density is regarded as uniform in horizontal plane. The summation of ρ h calculated from T-1 was larger than the theoretical value, just like the result from Marshall and Lin [1992]. If the positive charge region at upper and lower boundary were screen layers, the gross ions captured by the E field of negative charge region should keep nearly equal at upper and lower boundary. However, the value of ρ h for LPCC was about 3.3 times larger than that of upper positive charge region. In addition, screen layers should be a shallow region at boundary. So, more works are needed to be done to confirm the inherent mechanism.

The result from T-2 further confirmed that the precipitation had a great influence on charge region, the LPCC disappeared and only two charge regions existed. Moreover, the thickness and height for both of charge region were all decreased, while the charge densities increased. There were two possible reasons related to the increase of charge density. Firstly, the attenuation effect of precipitation on the LPCC was greater than that on the other two upper charge regions, and the charge was compressed to a smaller range with the decrease of the cloud top height. Secondly, the charging process was not ceased completely and no lightning flash occurred to consume the charge in the cloud.

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