The Characteristics of Ground Flashes in Beijing and Lanzhou Regions

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ABSTRACT

Over twenty thousand lightning location data obtained by using Lightning Location System(LLS) from Lanzhou and Beijing regions have been analysed to ascertain the characteristics of ground flashes in both regions. The strength of positive flashes is 5 times higher in Lanzhou than in Beijing. The strength of positive flashes is 3 times and 2.2 times as large as negative flashes in Beijing and in Lanzhou respectively. It has been found that the strength of positive and negative flashes is submitted to the normal distribution, and is independent of the characteristics of thunderstorm. So the lightning strength obtained by DF may be used to forecast the coming of thunderstorm. Although the stroke number in both regions decreases as exponent regulation, the maximum number of return stroke for one lightning in Beijing is more than that in Lanzhou. The peak flash rate occurs in late afternoon for both regions, but the maximum and minimum flash rate appeared an hour earlier in Beijing than in Lanzhou.

The relationship between DF display and lightning radiation electric field, discharge current is obtained.

I. INTRODUCTION

In recent years, the development of commercially available Lightning Location System (LLS) with wide–band magnetic antenna has opened the door for a variety of operational and research applications for its unique advantages, such as the higher detection efficiency, the lower false detection rate and the smaller direction error. At present, lightning location data obtained by using LLS has many potential applications. For example, LLS can be used to monitor the presence, intensity and motion of the convective storms. It can also be used to determine the large–scale climatological characteristics in combination with radar and satellite (Reap, 1986), and it is possible to nowcast the thunderstorm with severe lightning by using this system. Here is a preliminary study by using some limited LLS data.

We conducted simultaneous multi–station measurements on electric field and electric field variation of thunderstorm on the ground for 2 years in Lanzhou. It has been found that the charge distribution of Lanzhou thunderstorm is different from that found by researchers abroad (Liu et al., 1987; Ye et al., 1987 and Wang et al., 1987), i.e. the positive charge at the base of thundercloud is much larger in magnitude and much wider in extent. The different charge distribution will result in the difference of discharge process and lightning characteristics. Comparing the lightning data obtained in Lanzhou during summers of 1986–1987 with those in Beijing during August, 1988, we get the distribution of first return stroke strength, the distribution of return stroke number, the ratio of positive to negative ground flashes and the diurnal variation. These results are significant in weather forecasting, lightning protection design in engineering.

In addition, the peak current can be estimated from lightning strength indicated by LLS. This is more convenient and also more data can be obtained by using this method than that by using magnetic link and measurement meter put on the tower top.

II. DATA COLLECTION AND EXPERIMENT

The lightning location data were obtained from a network which contained 2 Direction Finders (DFs) being 50 km apart and a Position Analyser (PA) in Lanzhou and from a network of 3 DFs and a PA, with a mean distance of 35 km in Beijing, respectively. The information from the DFs, including lightning direction, strength and return stroke number, was transmitted to PA where the location of each flash is computed by triangulation, and the location data are printed and displayed in real time. According to Krider et al. (1980), less than 2% of cloud flashes are falsely accepted and 98% of noise is rejected because the noise signals rarely have waveforms similar to those of the return strokes.

During operation, LLS was operated continuously throughout the 24–hour. 1221 lightning location data were obtained during two summers of 1986–1987 in Lanzhou, while 10552 lightning location data were obtained during August, 1988 in Beijing. In addition, 4 simultaneous measurement stations were set up to interprete the unique phenomenon quantitatively in Lanzhou, and each of these stations was equipped with field mill and slow antenna, while only one station was set up in Beijing to interprete some phenomena qualitatively.

It should be noted that the specified area covered by LLS may be different in two regions due to the different DF allocation, so the detection efficiency is also different. In addition, one of the DFs in Beijing didn't have "positive flash" card, so the positive flash number tends to be low. Though the site error of location data has not been corrected, the result is in good agreement with that in 1989 which has been corrected by using parameter method.

The first return stroke strength displayed by PA is a relative value and it is different from the normal strength of lightning. In order to obtain the absolute radiation field and peak discharge current and to compare the result with that measured by using fast antenna, we have derived the relationship between DF display and the peak electric field radiated from first return stroke by actual measurement.

LLS is constituted of DFs and PA, each DF has a set of antenna system (including 2 orthogonal magnetic antennae and a plate electric antenna), an ADF and a DF digital processing and display system. In order to obtain the relationship between DF display and electric field, we measured the gain K_i of ADF and K_D of DF display. The relationship between display and electric field E_{rm} is as follows:

$$E_{rm} = 0.078 \cdot Display \qquad V/m \tag{1}$$

During analysis, the "Transmission Line Model (TLM)" is assumed for the radiation field and discharge current (Qie et al., 1988; Uman and Mclain., 1983). The current in the channel $I(t)$ and radiation field $E(t)$ is related as follows:

$$I(t) = (\ 2\pi\varepsilon_0 C^2 R / V) \cdot E(t + R / V)\ , \tag{2}$$

where R is the lightning distance from the station, V is the velocity of return stroke, ε_0 is the permittivity, C is the light speed.

If we assume that $V = 1.2 \times 10^8$ m / s (Idone, et al., 1982) the relationship between PA display (normalized to 100km) and peak current I_m is

$$I_m = 0.325 \cdot \text{Display} \qquad kA\ .$$

If the magnetic antenna is not placed on the smooth terrain, the relationship should be corrected. During observation in Lanzhou, DF1 antenna was put on the ground surface, DF2 antenna was put on the top of a high building. The strength received by DF2 was 1.08 times higher than that received by DF1. So the strength from PA is not heavily affected by the height where the DF antenna is located. We therefore use the real PA display instead of that on the ground.

The accuracy of TLM and the effect of the height where the antenna is located on the result need to be tested further. In addition, neglect of propagation effect and the orientation of channel will cauce error in the result. Especially, the assumed value of return stroke velocity would cause great error. However we have not measured the return stroke velocity by ourself, so we have to refer the results measured from abroad. Above relationship is only an approximate estimation of peak return stroke current due to the uncertainty of various factors just mentioned.

On the same background conditions, the simultaneous measurements of fast antenna and LLS are made to get the relative error of (1) and (2). It has been found that the farther the distance of lightning from the station, the higher the accuracy of (1) and (2). The error would higher than 50% when the distance is less than 15 km, and sometimes it is as high as 100%. This suggests that when lightning is near to the station, the strength accuracy is very low. The relative errors for (1) and (2) in various ranges are listed in Table 1.

Table 1. The Relative Errors for Formulas (1) and (2) in Various Ranges

Lightning range(Km)	<15	15—30	30—50	>50
Relative error(%)	62.2	10.2	8.1	5.2
Lightning number	10	8	6	2

III. DIURNAL VARIATION OF LIGHTNING

The diurnal variation of lightning within the LLS detection network is shown by the histogram in Fig.1. In Beijing the minimum lightning activity is found between 07:00–09:00 (local time the same below) with a rapid increase of activity to a peak between 16:00–17:00. In most cases, the lightning activities in the afternoon are more severe, the nocturnal lightning activities are the continuation of the afternoon thunderstorm. Sometimes, the lightning lasted to next early morning. In Lanzhou, the minimum lightning activity is found between 09:00–11:00, while the maximum lightning activity is found between 17:00–18:00. Another smaller peak is found between 03:00–04:00 in Lanzhou (this is caused by the nocturnal thunderstorm in Wushaoling located in the northwest). The lightning activities in Lanzhou are about an hour later than in Beijing. In fact, most of the Beijing lightning located in the north and the west. This indicates that the Yanshan Mountain in the north and the Taihang Mountain in the west exerts a strong local influence on the Beijing lightning activities. In Lanzhou, in addition to Wushaoling which belongs to Qilian Mountain located at nor thwest 150 km from the network center, most areas there are loess and hills. And the climate there is dry, so the convective thunderstorm is not easy to form as in Beijing. Only more than 1000 lightning flashes were detected during 4 months of 2 yeras in Lanzhou, while more than 10000 lightning flashes were detected during 1 month in Beijing. The reason for that perhaps is the difference of topography and climate.

IV. THE RATIO OF THE POSITIVE TO NEGATIVE LIGHTNING

Among 1221 Lanzhou lightning location data, the mean ratio of the positive lightning to total lightning is 9.2% with a variation from 0–72%, the most possibility is 0 or 20%–30% for each storm process. Among 10548 Beijing lightning location data, the mean ratio is 1.7%

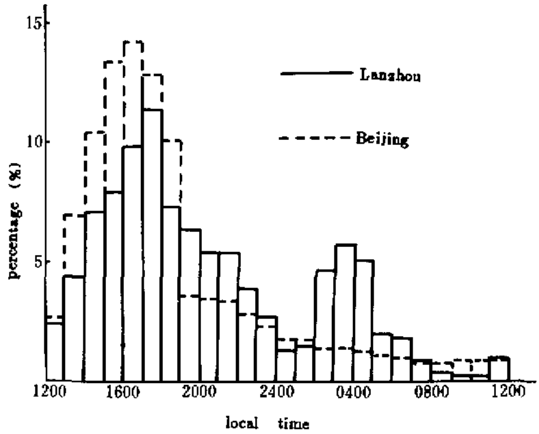

Fig. 1. The diurnal variation of cloud–to–ground lightning.

with a variation from 0–6%, the most possibility is 0–3%. The ratio in Lanzhou is much higher than that in Beijing. The ordinary results of other researchers are between 0–30% with the most possibility of 3–6% (Norinder, 1956; Fuquay, 1982). What is the reason for the high ratio in Lanzhou? From the electric field and electric field variation measured by using field mill and slow antenna, it can be inferred that when thunderstorm is over the station, the electric field on the ground is often positive (positive charge overhead by convention) for almost all the thunderstorm processes, and almost all the discharges will cause the saturation of slow antenna. It suggests that there are a large amount of positive charges in the base of thundercloud, and most positive ground flashes occur between this positive charge area and the ground. This result is verified by quantitative calculation[Wang et al., 1990).

In Beijing, although the height of the neutralized charges can not be determined without multi–station data, the positive electric field on the ground while storm is overhead is generally not found as in Lanzhou. It suggests that there are not or only a little positive charges at the base of the thundercloud. So the discharge between the positive charge at the base of thundercloud and the ground rarely occurs. The electric field on the ground is controlled by the main negative charges. The discharge between this region and the ground is easier to occur than that between the upper positive charge region and the ground. Therefore, the lower possibility of positive flash is found in Beijing. One of the Beijing DFs did not have "positive flash" card is another reason for this.

In addition, LLS data show that the ratio of positive flash to total flash strongly depends on the development stages and severe degree of thunderstorm.The ratio is higher in the weak thunderstorm than in the severe thunderstorm.In 2 severe storms with large area and long duration on 8, 9 August, 1986, the ratio of positive flash was 6.6% and 7.3%, respectively, the radar echo reflectivity was greater than 40 dBz. But in 2 weak thunderstorms on 11, 12 August the ratio was 33% and 30% respectively, the reflectivity was less than 25 dBz. In Lanzhou, most of the positive flashes originated in developing and dissipating stages, while the positive flashes originated mostly in dissipating stages in Beijing.

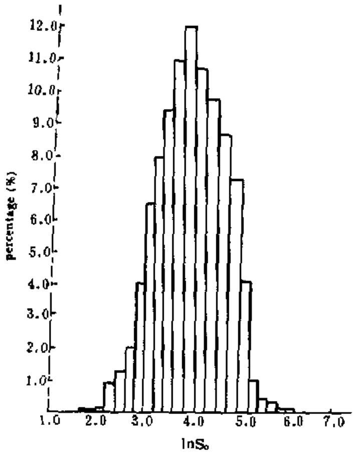

Fig.2. The relative strength distribution of negative ground flashes normalized to 100 km in Beijing.

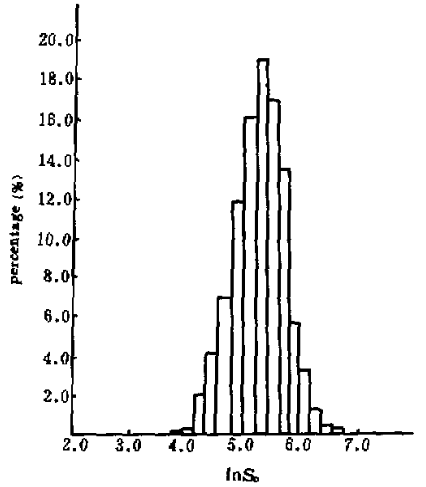

Fig.3. The relative strength distribution of positive ground flashes normalized to 100 km in Beijing.

V. STRENGTH DISTRIBUTION

Fig.2 and Fig.3 are the relative strength (from PA, normalized to 100 km) distribution of first return stroke for negative and positive flashes respectively in Beijing. The similar distribution is found in Lanzhou. The relative strength of first return strokes, for both positive and negative flashes, follows normal distribution.

In Beijing, the peak relative strength of negative flashes is between 44.7–54.6 ($\ln s_0 = 3.8$–4.0) with a percentage of 12% and a mean relative strength of 68.0. The peak electric field, normalized to 100km for the negative flashes with the distance greater than 15km, is 5.2 v / m, the peak current is 21.7 kA. In Lanzhou, the peak relative strength of negative flashes is between 50.0–60.0 with a percentage of 10.2% and a mean relative strength of 88.6. The peak electric field, normalized to 100 km, is 6.2 v / m, the peak current is 27.1 kA. The results are in good agreement with those directly measured.

The relative strength of positive flashes is much greater. In Beijing, the relative strength of positive flashes is 181.0–221.0 ($\ln s_0 = 5.2$–5.4) with a mean value of 199.2. The peak electric field is 14.8 v / m and peak current is 61.9 kA while the relative strength is 148.0–181.0 with a mean value of 190.5. The peak electric field is 14.8 v / m and the peak current is 61.9 kA in Lanzhou.

The relative strength of positive flashes is 3 times greater than that of negative flashes in Beijing, while only 2 times in Lanzhou. The strength of positive flashes in both regions is nearly the same. This indicates that the discharge strength is independent with the relative location of positive charges in thunderstorm.

Similar normal distribution is found in several different thunderstorms. So, it can be concluded that the strength of ground flashes is not related to the characteristics of thunderstorm. Most relative strength of negative flashes is concentrated in 20.0–120, while that of positive flashes is in 120.0–330.0. According to the relationship that strength inverses to distance, the strength received by individual DF can be used to estimate the distance of thunderstorm and forecast the coming of thunderstorm.

VI. DISTRIBUTION OF RETURN STROKE NUMBER

Fig.4 and Fig.5 are the distribution of negative and positive flash return stroke numbers respectively.

The return stroke numbers of positive and negative flashes decrease as exponent in both regions, and most of the flashes are with single return stroke. But the slope of decrease is slower in Beijing than in Lanzhou. The percentage of negative flash with single return stroke is 49.2% in Lanzhou, while a lower percentage 30.7% is found in Beijing. The maximum return stroke number is 14 in Beijing, and 11 in Lanzhou. The percentage of positive flash with single return stroke is 90.3% in Lanzhou and 82.9% in Beijing. The maximum return stroke number of positive flashes is 5 in Beijing and 2 in Lanzhou.

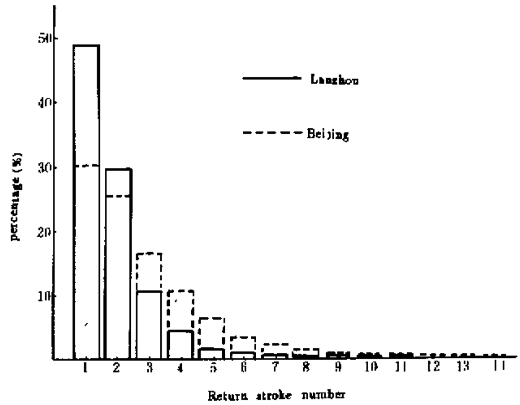

Fig. 4. The distribution of negative flash return stroke numbers.

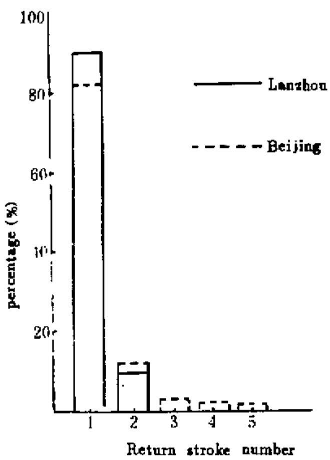

Fig.5. The distribution of positive flash return stroke numbers.

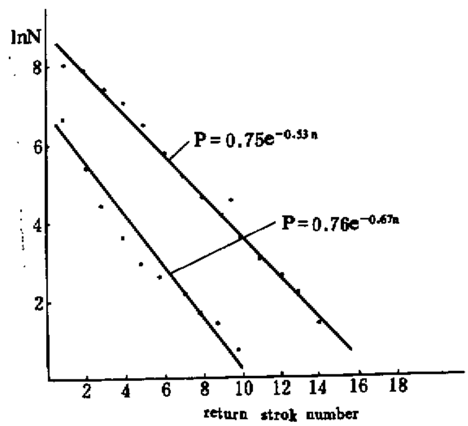

Fig.6. The logarithmic distribution of return stroke numbers versus flash numbers.

Fig. 6 is the logarithmic distribution of return stroke numbers versus flash numbers in Lanzhou and in Beijing. The probability P with return stroke number n is:

$$\text{Beijing} \quad P = 0.75e^{-0.53n}$$
$$\text{Lanzhou} \quad P = 0.76e^{-0.67n} \ .$$

The results in Beijing is very similar to Risler and Madueme (1988), while P decreases rapidly with n in Lanzhou. So it can be concluded that a large amount of positive charge at the base of thundercloud changes the discharge characteristics significantly.

VII. RESULTS AND DISCUSSION

According to the above analysis, we can get the following results:

1). In addition to lightning location, the strength data indicated by PA can be used to estimate the peak electric field and discharge current, the farther the distance, the higher the accuracy.

2). The distribution of lightning with time and lightning frequency are influenced by the different underlying topography. In Beijing region, the climate is moist and the topography is characterized by more mountains, therefore storm is easier to form than that in Lanzhou. Moreover, the lightning occurs earlier and the frequency is higher in Beijing. In different region, the storm has different electric characteristics. In Lanzhou, a great deal of positive chargesexist in the base of thunderstorm. The different electric characteristics cause different positive lightning ratio and different distribution of return stroke number. Liu et al(1987) have proposed that the lower positive charge is probably caused by a kind of electrification mechanism. This paper will not discuss it.

The multiple return stroke occurs when J–process and K–process, which occur above the top of channel between two return strokes, transmit enough charges to the channel. In Lanzhou, because of the shield effect of positive charges at the base of storm, it is more difficult to transmit enough energy to channel from the region above the main negative charge. So, the single return stroke is much more in Lanzhou than that in Beijing, and the decrease rate is faster than that in Beijing also.

Another reason for the less multiple return stroke number in Lanzhou may be due to the thunderstorm intensity. In Beijing, the thunderstorm is more severe and lasts longer than that in Lanzhou, the storm has enough electric energy to induce multiple return stroke.

3). For each storm process, the lightning strength normalized to 100km is submitted to normal distribution and concentrated in a narrow band. The strength indicated by individual DF is a function of distance. We can get the relationship of strength S_r at distance r and S_{100km} by using the regulation of strength inversely proportional to the distance, i.e.,

$$S_r = \frac{S_{100km}}{r} \times 100 \ .$$

From the Beijing data in 1988, we know that more than 70% negative lightning strength normalized to 100 km, were concentrated between 24.5–81.5, so the storm distance can be estimated from the S_r indicated by individual DF.

4). Lightning discharge is a very complicated physical process, different electric process will cause different charge distribution, and cause different discharge characteristics. This analysis attempts to give some preliminary study for further understanding lightning discharge, the relationship between charge distribution and lightning. Further studies are needed to get satisfactory results.

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