Classification Study on the Relationship between Lightning Activity and Precipitation in Beijing

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Abstract—This paper chose a total of 28 thunderstorms occurring in Beijing area from 2006 to 2008. It aimed to investigate the relationship between the total lightning (obtained by SAFIR3000) and convective precipitation (inverted from radar). These cases were classified according to the parameters of the local atmospheric stratification and the reflectivity of radar. Rainstorm and hailstorm were further chosen for the comparison of their lightning activities and the relationship between lightning and precipitation. The analysis result showed that the general relationship between the lightning and convective precipitation, on the whole, the average convective rain-yield per flash (RPF) is $1.92 \times 10^7$ kg/fl, while the linear correlation coefficient between the total flash rates and RPF is 0.584.

These 28 thunderstorms are classified according to the Convective Available Potential Energy (CAPE) and Lifting index (LI) of the atmospheric stratification where they are generated. It is explored that strong instability of atmospheric stratification tends to be associated with smaller RPF$_{TL}$ (TL: total lightning) and more pronounced correlation between total lightning and precipitation. Of which, the classification of CAPE $\geq 1600$ J/kg has the correlation coefficient of 0.837, while the classification of LI $\geq 4$ K has the correlation coefficient of 0.853. At the meantime, these thunderstorms are classified according to the following parameters of the radar reflectivity, maximum height of 20-dBZ reflectivity ($H_{20dBZ}$) and volume ratio of the reflectivity larger than 30 dBZ above $0 \, ^\circ C$ to the reflectivity larger than 40 dBZ above $0 \, ^\circ C$ ($VR_{40/30}$), in term of their radar volume scans. The most pronounced relationships between lightning and precipitation occur in the classification of $H_{20dBZ} < 11.5$ km, and $VR_{40/30} < 0.39$, while the correlation coefficients are 0.804 and 0.750, respectively.

Keywords—Precipitation; Lightning; Correlation; Contrastive Analysis
INTRODUCTION

The relationship of lightning and precipitation is a scientific problem concerned in recent years. The relationship is complex, which is dependent on the dynamic and microphysical processes to some extent. On the one hand, in the thunderstorms with strong convection, the intensity of lightning activity and convective motion is close with the ice phase process in the cloud; on the other hand, convection is also the key reason for the heavy rainfall produced by strong thunderstorms. So there is an intrinsic link between lightning and precipitation, meanwhile, lightning and rainfall are important objects of weather detecting, warning and nowcasting. With the development of lightning location technology, the role of lightning data in convective weather monitoring is prominent increasingly. Precipitation estimation based on lightning data, can provide a complement to the tools of rainfall warning, and it has also an important reference for assimilation of numerical weather model.

In recent years, a large number of observations have revealed that the change of lightning intensity and frequency was ahead of the peak of rainfall. Williams et al. (1999) found that the peak of total lightning frequency was 5-20 minutes ahead of the strong weather phenomena on the ground in Florida. Piepgrass et al. also found that rainfall peak occurred in 10 minutes before or after the peak time of total lightning. Some studies have also noted that the spatial relationship between lightning and precipitation. Reap and MacGorman, Orville and Silver found that the region produced strong lightning also appeared the strongest regional precipitation. In addition, It also found that the distribution of positive and negative ground flashes in some thunderstorms was often different, which may corresponded to the region of different precipitation.

Rain-yield per flash (RPF) is an important parameter reflects the relationship between lightning and rainfall. The RPF has differences in different regions. Pineda et al. analyzes 9 thunderstorm cases occurred in the northwestern Mediterranean region, the average value of RPF was $38.9 \times 10^3$ kg/fl, range from $10.8-87.2 \times 10^3$ kg/fl. Petersen and Rutledge calculated the relationship between Precipitation and lightning in the number of places, the research period of time was 1 month, and the space range was $10^4 - 10^5$ km$^2$, they found that RPF was about $10^5$ kg/fl in the middle continent of USA., and $6 \times 10^7$ kg/fl in the southwestern; $4 \times 10^6$ kg/fl in the tropical mainland; the value of RPF was $10^5$ kg/fl in the tropical western Pacific. Zheng Dong et al. analyzed the relationship of lightning and rainfall using the total lightning data of Beijing, the value of RPF was in the range of $0.86-6.57 \times 10^7$ kg/fl, the average value was $2.65 \times 10^7$ kg/fl.

The relationship between lightning and rainfall also changed varies with climate, Petersen and Rutledge found that the correlation coefficient of ground lightning and convective rainfall was 0.71, 0.45, 0.87, and 0.90 in the southeast, northeast, central and southwest of USA respectively. Research showed that RPF had a great change, even several magnitude orders, in different regions, but Petersen ,Rutled and Ziper pointed that the relationship of lightning and rainfall id stable relatively in a certain area.

It has a certain degree of consistency in the development of strong convective precipitation and the trend change of the lightning activity. But the relation is complex with the difference of thunderstorms intensity, area and climatic zone, and the atmosphere environment. So it is necessary to study the relationships of lightning and rainfall according to the change of lightning activity and rainfall intensity, and obtain the quantitative analysis result, provide the parametric relationship of lightning and precipitation.

DATA AND METHOD

A. Lightning data

SAFIR (Systeme d’Alerte Fondre par Interferometrie Radioelecetrique) is a multiple site VHF (very high frequency) lightning detection system. The network of the Beijing-Tianjin-Hebei region is composed of three VHF interferometers of the SAFIR type (Yongqing, Fengrun, Huairou) and a center station (Beijing). The expected flash detection efficiency is 90%, with a maximum location accuracy of 2 km within 200 km. Several VHF sources were determined by SAFIR. To automatically determine whether each covered point belongs to the same lightning.
discharge, the following criteria are used in identifying a given "flash".

1) The continuous time for one IC lightning discharge is the maximum of 100ms; the continuous time for one CG lightning discharge is the maximum of 500ms.

2) The horizontal motion distance of a lightning discharge is the distance between adjacent covered points and does not exceed 7 km.

3) To provide an accurate study, several positive flashes reported by the SAFIR network were eliminated from the original dataset. The criterion to validate a positive CG flash was based on a threshold minimum for the peak current value fixed to 10 kA.

B. Radar Data

Radar data are extensively used in this study for cell identification and comparison with lightning data.

The data from S-band Doppler weather radars located in Daxing District, Beijing City, (Location: E116.47°, N39.81°) was used to analyze these cases. For convenience of analysis, the reflectivity of the original polar scan data were converted to Cartesian coordinates, with 21 layers in the vertical direction by bilinear interpolation methods, in which 0.5-5.5 km were divided into 11 layers with a 0.5 km interval; 6-10 km were divided into 5 layers with 1 km interval; 11-20 km were divided into 5 layers with 2 km interval, and its horizontal resolution was 0.01 x 0.01 degrees.

The scope were primarily identified from radar reflectivity plots and the lightning activity images, the region of 20 dBZ radar reflectivity should be selected, and no continuous lightning activity near the cell edge.

C. Convective precipitation calculation method

This research focus on the precipitation in thunderstorms convection area. It was using the methods of Steiner to identify convective or stratus area, then select reflectivity factor of 3 km height to calculate the precipitation rate. The classic convective precipitation formula was adopt, that was $Z=300 \times R^{1.4}$, in which, $Z$(mm$^3$/m$^3$) is the reflectivity factor of 3 km height, R (mm/h) denote the rainfall rate. The RPF was calculated through convective precipitation divided by lightning frequency of the corresponding time period (6min in general).

RESULT

A. Relationship between lightning and rainfall in Beijing

The selected thunderstorm cases in Beijing region were studied systematically, based on the lightning monitoring data from SAFIR. Through the study of 28 cases, the analysis of the lightning activity and precipitation was presented.

RPF in Beijing was range from $1.84 \times 10^5$ kg/fl to $7.91 \times 10^7$ kg/fl, the average value was $1.92 \times 10^7$ kg/fl. The RPF of cumulative distribution 5 % and 95% respectively was $2.69 \times 10^6$ kg/fl and $6.05 \times 10^7$ kg/fl. From Fig.1, it showed that log(RPF) distributed in 6.5-7. that is the RPF ranged from $3.16 \times 10^6$ kg/fl to $3.16 \times 10^7$ kg/fl.

Fig.2 was the scatter plot of lightning frequency and convective precipitation, from the result of linear fit, the linear correlation coefficient is 0.584, the linear regression equation is $R = (2.813 \times 10^8) + (4.570 \times 10^6)F$, where R denoted convective precipitation(kg/6 min), F is lightning frequency of Total lightning from SAFIR.
B. Relationship between lightning and rainfall in different classification criteria of stratification parameters

Instability parameters of 28 cases were analyzed in the text, such as CAPE and Lifted Index. The study classified the CAPE into three categories: CAPE < 1000 J/kg, 1000 J/kg ≤ CAPE < 1600 J/kg and CAPE ≥ 1600 J/kg. The statistics of RPF based on CAPE was obtained in table.1. The RPF corresponding to a large CAPE was relative small. We also had a statistic result base on the LI, similarly to the CAPE, Large LI (LI ≥ 4K) also correspond to a smaller RPF.

Through the analysis of stratification parameters, it got that with the increase of atmospheric stratification instability, RPF has a decreasing trend.

Table 1. The statistics of RPF based on CAPE

<table>
<thead>
<tr>
<th>CAPE (J/kg)</th>
<th>&lt;1000</th>
<th>1000–1600</th>
<th>≥1600</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (%)</td>
<td>156(45%)</td>
<td>123(35%)</td>
<td>68(20%)</td>
</tr>
<tr>
<td>Min (×10^7 kg/fl)</td>
<td>1.84</td>
<td>6.80</td>
<td>5.00</td>
</tr>
<tr>
<td>Max (×10^7 kg/fl)</td>
<td>6.81</td>
<td>11.50</td>
<td>5.37</td>
</tr>
<tr>
<td>AM *(×10^7) kg/fl</td>
<td>1.98</td>
<td>2.02</td>
<td>1.50</td>
</tr>
<tr>
<td>GM *(×10^7) kg/fl</td>
<td>1.30</td>
<td>1.22</td>
<td>1.13</td>
</tr>
<tr>
<td>Mid* (×10^7 kg/fl)</td>
<td>1.55</td>
<td>1.25</td>
<td>1.08</td>
</tr>
</tbody>
</table>

AM* : Arithmetic Mean; GM*: Geometric Mean; Mid*: Median Value.

C. Relationship between lightning and rainfall in different radar parameters

The height of 20dBZ of radar reflectivity as cloud top can reflect the strength of convective activity to a certain extent. Through the linear fit results, we got that it is obvious between lightning and convective precipitation in H_20dBz<11.5km. The smaller H_20dBz may be corresponding to the development or extinction of thunderstorm, when the lightning and precipitation had the characteristic of increase and reduction together, the relationship is more apparent. The linear correlation coefficient was 0.853. But when the lightning and the rainfall were all active, the thunderstorm was in the vigorous stage, the relationship may be more complicated and had relative weak correlation. The linear correlation coefficient was 0.663.

Volume ratios of the reflectivity larger than 30 dBZ above 0 °C to the reflectivity larger than 40 dBZ above 0 °C (VR_40/30) can reflect the ratio of core discharge area in the whole electrification. The value of VR_40/30 is larger when the thunderstorm in the development stage. We studied the RPF distribution in the criteria of VR_40/30 < 0.39, 0.39 ≤ VR_40/30 < 0.48, and VR_40/30 ≥ 0.48. From the results, it was known that VR_40/30 ≥ 0.48 corresponds to the large RPF and 0.39 ≤ VR_40/30 <0.48 corresponds to the small RPF. Consider the extent level of thunderstorm, small ice-phase particles were not transported to distant area that is it was in the development of thunderstorm, at this time the RPF was large, and this conclusion is also consistent with the conclusion of result A and B. The Stronger convection thunderstorms is (or stronger convective thunderstorm stages), the relatively smaller RPF is.

CONCLUSION

28 thunderstorm cases in Beijing were selected to study the relationship between the total lightning and convective precipitation. The analysis was based on atmospheric stratification and the reflectivity characters of radar. It is found that:
1) The average convective rain-yield per flash (RPF) is $1.92 \times 10^7$ kg/fl, while the linear correlation coefficient between the total flash rates and RPF is 0.584.

2) According to analysis of the Convective Available Potential Energy (CAPE) and Lifting index (LI) of the atmospheric stratification, it found that with the enhancement of instability, RPF has a decreasing trend.

3) From the characteristics of radar, it showed that the stronger convection thunderstorms are (or stronger convective thunderstorm stages), the relatively smaller RPF is. The most pronounced relationships between lightning and precipitation occur in the classification of $H_{20dBZ} < 11.5$ km and $V_{R40/30} < 0.39$, while the correlation coefficients are 0.804, 0.609 and 0.750, respectively.

REFERENCES


