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Characteristics of lightning activities in the hailstorm using the data from two types of lightning detection network

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ABSTRACT

The region of Beijing, Tianjin and Hebei province is covered by two different lightning detection network like SAFIR to detect total lightning(IC+CG), and ADTD network of China to detect CG flashes. A total of 14 hail-bearing thunderstorms from this region were examined in this study. From these isolate hailstorms by using the data from SAFIR and ADTD, it was found that the peak of lightning frequency was often observed in advance of the occurrence of severe weather at the ground, there existed trend of rapid increase before the hail reports, and the relationship of total lightning and hail is more stable than that of CG lightning of ADTD. The average lead time of jump occurrence to the hail events were obtained (Total: 26.2min, CG: 19.6min) through the 2σ lightning jump algorithm. In the meantime, it was demonstrated that when the high ratio of PCG flashes appeared, the diameter of hail was larger and duration of hail was longer, while the NCG dominated, the diameter of hail was relatively smaller. The overall goal of this study is to obtain the characters of total and CG lightning occurrence trends in hailstorms, which might contribute to forecast the time and size of hail storm occurrence by using lightning detection data.

Key Words: total lightning, Cloud to ground (CG) lightning, 2σ lightning jump algorithm

1. INTRODUCTION

In hail cloud, there exist not only strong updrafts but also complicated micro-physical processes involving ice particles, which consequently make the electrification process more intense and the discharge phenomena more active. In recent years, a large amount of observations have revealed that during strong thunderstorms like hail, the characteristics of lightning activities are different from general thunderstorms. There exist high rates of intracloud (IC) flashes, some strong storms lead to very low frequency of cloud-to-ground (CG) flashes. Xue Qiufang showed that it exist a correlation between diurnal variation of lightning frequency and strong convective weather in summer in Beijing area. The change of lightning intensity and frequency was 0.5 ~ 1 h ahead of ratio of echo intensity changes. Cai Xiaoyun and other studies also believe that the changes of lightning activities were prior to radar in the hailstorm. In the meantime, rapid increases in total lightning activity are often observed tens of minutes in advance of the occurrence of severe weather at the ground, which have been termed ‘‘lightning jumps’’ . Gatlin (2006)

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and Gatlin and Goodman (2010) described numerous lightning jumps that occurred prior to the onset of severe thunderstorms in the Tennessee Valley, and these studies utilized the time rate of change of the total flash rate as a predictor for defining a jump in the total amount of lightning. Schultz et al chose 107 severe thunderstorm to test six lightning jump algorithm configurations (Gatlin, Gatlin 45, 2s, 3s, Threshold 10, and Threshold 8),and yield encouraging results to document a positive correlation between lightning jumps and the manifestation of severe weather in thunderstorms occurring across the Tennessee Valley and Washington D.C. These features of lightning activities are worthy of discuss further with more types of thunderstorms in different regions. The trends in the lightning flash rate should perform as a tool for severe weather warning decision support.

This paper present a detailed study of 14 hailstorms occurred over Beijing and Tianjin. The region of Beijing, Tianjin and Hebei province is covered by two different lightning detection network like SAFIR to detect total lightning(IC+CG), and ADTD network of China to detect CG flashes. Thus, the observations can allow a comparison to discuss the characteristics of the lightning activity of hailstorms.

2 DATA AND METHODS

2.1 TWO DIFFERENT LIGHTNING DECTECTION NETWORKS

SAFIR (Systeme d'Alerte Fondre par Interferometrie Radioelectrique) is a multi-sites location VHF (very high frequency) lightning detection system. Compared with the general low frequency lightning location system, SAFIR can detect more IC flashes and have advantages and characteristics in detection efficiency and accuracy. SAFIR system has high time resolution, and can provide spatial distributions of lightning location (2 dimensional and 3 dimensional), as well as time distribution of lightning frequency. This can provide important information source for the description and surveillance of thunder storm areas. The network of Beijing-Tianjin-Hebei region was composed by three VHF interferometers of SAFIR type (Yongqing, Fengrun, Huairou) and a center station (Beijing). The expected flash detection efficiency is 90 % with maximum location accuracy of 2 km within 200km.

ADTD is a lightning detection network of China meteorological administration. There are about 301 sensors in our country. It covers by the combined technique of magnetic direction finding (DF) and time of arrival (TOA), the efficiency in the network is up to 90%. Combined with a robust data dissemination infrastructure, this network can provide nearly instantaneous CG lightning flash location, count, and polarity information to a wide variety of end users. In Beijing-Tianjin-Hebei region, there consists of 11 sensors and provides real-time CG lightning locations.

2.2 DATA AND METHODS

In this section we describe the method used to directly compare total (IC+CG) from SAFIR and CG lightning information from ADTD in order to test the lightning information as an aid for predicting the manifestation of severe weather at the surface.

a. Case selection

Hailstorm cases were primarily chosen from Beijing-Tianjin-Hebei region, where are covered by Doppler radar, SAFIR and ADTD lightning detection systems. The period of study was from 2004 to 2011 for severe thunderstorms. The cases were chosen based on the criteria, which were: 1) To eliminate spurious noise lightning points, the

hailstorm should happen in situations where severe convection were isolated, 2) The locations, magnitudes, and timing of hail events reported were obtained from the China meteorological administration, and these data were all in detail. Despite the doubt of accuracy time of hail occurrence, the dataset provided by CMA is still the most accessible and accurate in determining what exactly occurs during hail events. After selection，We chose 14 cases from the total of 98 hail reports.

b. Total and CG Lightning

Several VHF sources were obtained by SAFIR, in order 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 lightning discharge is a maximum of 500 ms.

2) The horizontal motion distance of a lightning discharge is the distance between adjacent covered points and does not exceed 25 km.

3) In order to have an accurate study, several positive flashes reported by the LF 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.

Ground flash counts were determined from the ADTD, The network occasionally misclassifies small in-cloud positive flashes as positive CG flashes; therefore, a +10kA peak current threshold is applied to accurately estimate cloud-to-ground lightning activity.

c. Radar data

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

The data of S band Doppler weather radar located in Daxing District, Beijing City, (Location: E116.47°, N39.81°) and Tanggu of Tianjing(Location:E117.73°,N39.04°) were used to analyzed these cases, For the convenience of analysis, the reflectivity of the original polar scan data were converted to 21 layers in the vertical direction by bilinear interpolation methods, in which,0.5-5.5km were divided into 11 layers, with 0.5km interval; 6-10km were divided into 5 layers, with 1km interval; 11-20km were divided into 5 layers, with 2km interval, and its Horizontal resolution was 0.01 x 0.01 degrees.

The cells were primarily identified from radar maximum reflectivity plots and lightning activity images. The radar image frequency of 6 minutes allows describing correctly the lifetime of cells. For the lightning activity, the locations of the strokes associated with the CG flashes were superimposed in the radar images, by distinguishing the positive and negative ones.

d. Lightning jump algorithm selection

Schultz et al. (2009) tested six lightning jump algorithm configurations on both nonsevere and severe thunderstorms and determined statistically that the ‘‘2σ’’ configuration held the most promise for an operational algorithm. A lightning jump was determined to occur when the value of the flash rate exceeded the trigger threshold and DFRDT exceeded 2σ of the mean DFRDT of the previous 10 min. A jump ends when the DFRDT value is less than or equal to 0, unless two jumps are separated by 6 min or fewer. Based on the performance of the 2σ algorithm, we also used this method to analyze the characteristics of lightning jump in a hailstorm.

3 RESULT

a. Case examples

According the systematic studies of

the selected hail cases in Beijing and Tianjin area using the lightning monitoring data, In most cases the time when the peak of lightning rate was the 0-37 minutes leading time before the hail occurrence. The ratio of positive cloud-to-ground lightning flashes to cloud-to-ground flashes was higher than that of normal thunderstorms. And by using 2σ algorithm, we also compared the lightning jump through the data from two different lightning detection networks, the purpose was to learn the application in our country.

1) 10 JULY 2007,HAIL IN BEIJING

From 21:00 to 23:00 BT, Hail report was issued in Shunyi county of Beijing, the duration of hail was 30 minutes and the diameter was 6cm. In this hailstorm, From SAFIR system there were 3358 total lightning flashes observed, including 3261 IC flashes, accounting for 97.1%, and 97 CG lightning(PCG: 75 flashes,NCG:22 flashes), accounting for 2.9%.

Figure 1 show the moving path of thunderstorms and Hail occurring position at 21:00-23:00 BT. and Figure 2 provided the hail location in the detection efficiency of SAFIR system.

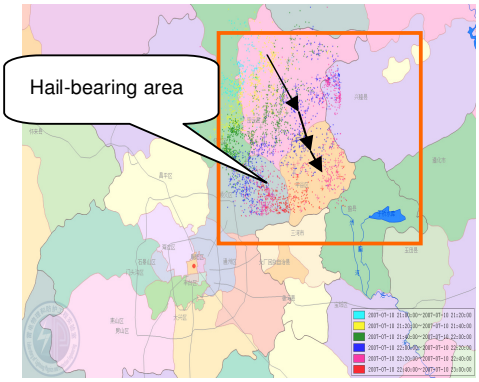

FIG1. Moving path of thunderstorms and Hail occurring position at 21:00-23:00 BT

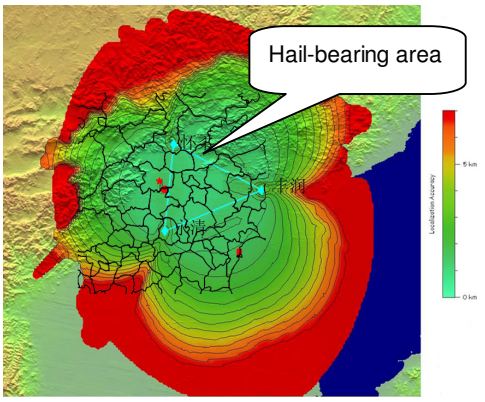

FIG 2. Detection efficiency of SAFIR system (blue diamond denote the sensors of SAFIR)

In view of total lightning rate, before the hail appeared at ground level, the total lightning rate increased continuously up to 276/6min at 21:48 BT. Then hail occurred between 22:00 and 22:30 BT, total lightning frequency appear decreasing, from 276 flashes /6min to 164 flashes /6min, which showed that the peak of frequency was advanced to the hail. Maybe this leading time is the time when the hail dropping from the cloud to the ground. The lightning rate decreasing was the result from the decrease of ice phase particles. After the end of hail (22:30 BT), the total lightning frequency reduced from 113 flashes / 6min to 32 flashes / 6min.

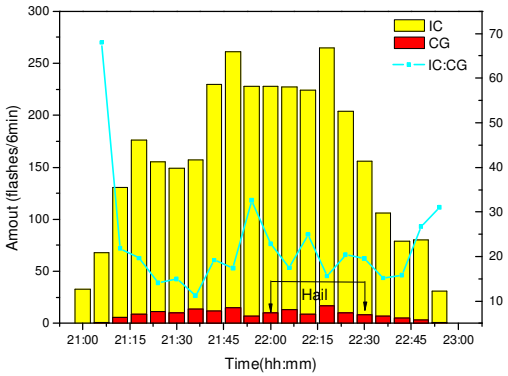

FIG3. Time-amount plot of lightning rate

From FIG 3, the studied cell exhibited low CG rate during their whole lifetime. CG remained lower than 1 min^{-1} during 2h. The change of CG flashes was consistent with

the IC flashes; it also had a peak just before the hail occurrence, and then followed by a rapid decrease. In view of IC flashes, initially, IC flashes began increased rapidly, with the first peak of IC flashes frequency at t1 (21:48) up to 261/6min. The ratio of IC flashes to CG flashes was an important thunder storm parameter. The value was about 3 in general thunder storm, but the value of this hailstorm kept above 10, the average value was 50. It could be concluded that high IC:CG value was one of the important lightning characteristics during this hail storm.

As for CG from SAFIR system, The PCG accounted for 77.3% of the total CG flashes, while the NCG accounted for 22.7%. The high ratio of PCG flashes appeared in this case, the ratios were almost excess 70% in the statistic time span of six minutes, which were also higher than usual thunderstorm.

Using the 2σ lightning jump algorithm based on the total lightning (FIG 4), there are four lightning jumps in the whole lifetime. That is at 21:07 (16 flashes/min), 21:17(31 flashes /min), 21:18(30 flashes/min) and 21:44(53 flashes/min). Because the time span of jumps at 21:17 and 21:18 were separated less than 6 minutes, we handled these two jumps as one jump. Then, the three lightning jumps that we obtained were all ahead of hail occurrence. Six centimeters hail was observed fifty-three minutes after the time of the first jump.

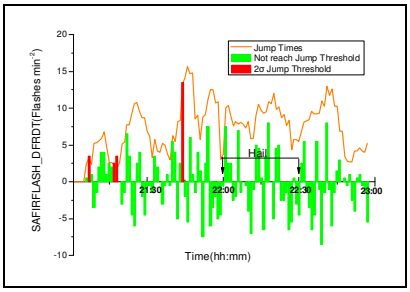

Fig 4. Time–DFRDT plot of the hailstorm using the total lightning information of SAFIR

We also analyzed the trend of CG lightning provided by ADTD network. 39 CG flashes happened in this case, there were all positive. It was mentioned that the duration of hail was 30 minutes and the diameter was 6cm.

Using the 2σ lightning jump algorithm based on the CG lightning from ADTD(FIG 5.), A lightning jump was determined to occur when the value of the flash rate above 2 flashes/min, so only one CG lightning jump was observed during the storm's entire lifetime, that was at 21:39. At that moment the CG rate was 2 flashes min^{-1}.The leading time before the hail onset was 21 minutes without any false alarm. In this case, the 2σ algorithm exhibited a good performance.

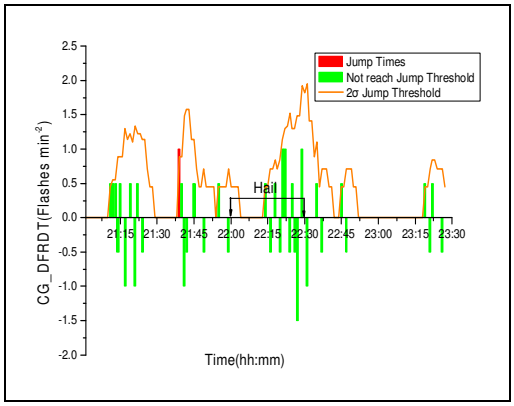

Fig 5. Time–DFRDT plot of the hailstorm using the CG lightning information of ADTD

In this case, the total lightning information provided an average of 37.3 min and the CG lightning trend information provided nearly 20 min of lead time.

2) 6 JUNE 2011,HAIL IN TIANJIN

This storm occurred in Jinghai county of Tianjin, the report of hail was at 18:40 BT on 6 June 2011, the diameter of hail was 0.8cm, hail density was 100 /$meter^2$, and the hail duration was 10 minutes. (FIG 6)

The hail happened at the region where the IC flashes were considerably larger, while the CG component was virtually

nonexistent. From the lightning information provided by SAFIR network, we found that there were 456 IC flashes and 19 CG flashes. This thunderstorm did not produce many CG flashes.

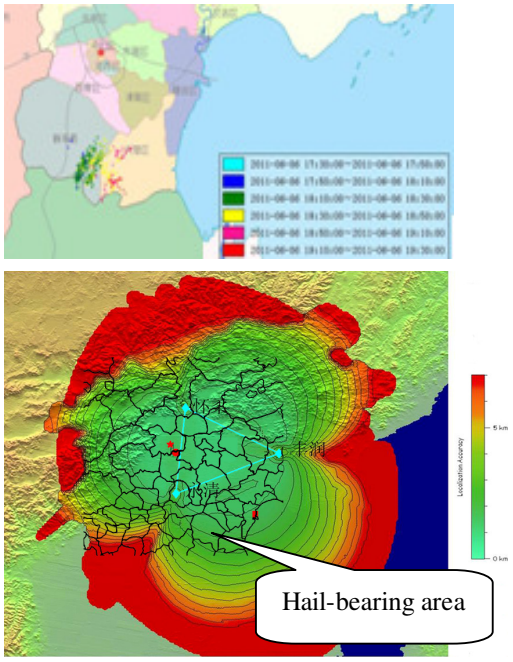

FIG 6. Lightning detection and Hail occurring position at 17:00-19:00 BT on 6 June 2011

The study cell also exhibit high IC rate and low CG rate. Initially, total flash rates were below 10 flashes /6min with no CG lightning. The maximum height of 30dBZ was 3km, as the system developed, between 17:54 and 18:18 BT, the height rose to 13km, the strong echo center happened which the maximum reflectivity was higher than 55dBZ, Corresponding to the vertical development, the total flash rate was jumping from 5 to 58 flashes /6min. the total lightning frequency increased up to the peak at 18:18 BT, 22 minutes ahead of hail onset. The height of 30dBZ was gradually down to 8km. And the behavior observed of peak time was also occurred before hail in this case. (FIG 7)

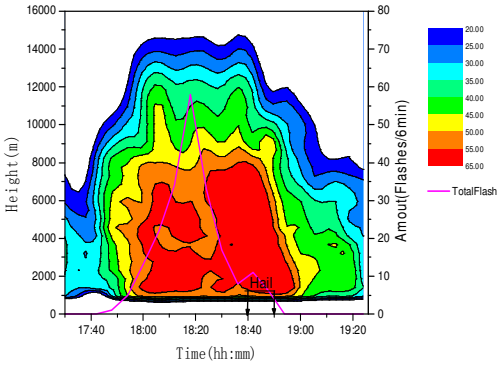

FIG 7 Time–height plots of (top) maximum reflectivity (dBZ) and total lightning values

Using the 2σ lightning jump algorithm based on the total lightning(Fig 8), there are two lightning jumps in the whole lifetime. That is at 18:18 (14 flashes/min) and 19:11(12 flashes/min). At 18:18 total lightning jump occurred as the flash rate from 6 to 14 flashes min^{-1}, Twenty-two minutes after it, 0.8 cm hail was observed. But one false alarm (19:11) was recorded, there was no evident to show the severe weather event happen.

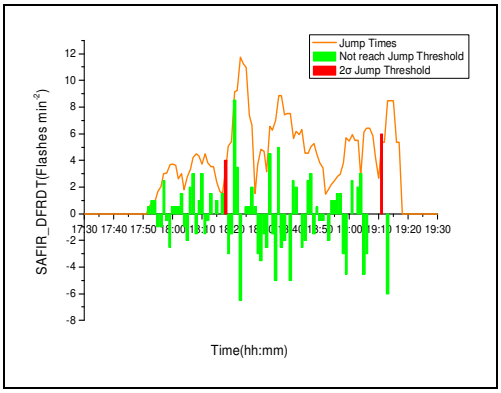

Fig 8. Time–DFRDT plot of the hailstorm using the total lightning information of SAFIR

Consider the CG flashes provided by ADTD network, there existed 32 flashes in the whole lifetime, and PCG were 3 flashes，NCG were 29 flashes. The CG flash rate was merely 0.27 flashes min^{-1}.Initially, CG flash rates were 2 flashes /6min, they were all PCG lightning. As the system developed, there appeared polarity reversal, the polarity

of CG was from positive to negative, CG flash rate was jumping from 2 flashes / 6min at 17: 54 to 7 flashes / 6min at 18:18. Then, the CG flash rate was also down to 5 / 6min.(FIG 9)

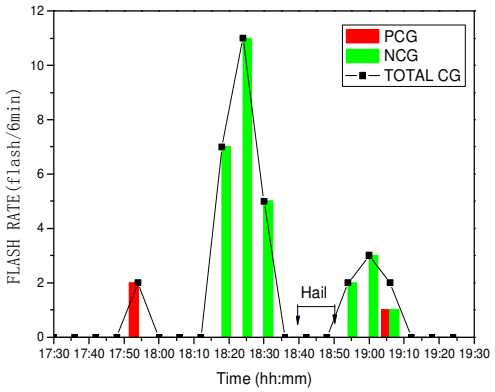

FIG 9. Time-amount plot of CG lightning rate

Using the 2σ lightning jump algorithm based on the CG lightning from ADTD, A lightning jump was determined to occur when the value of the flash rate above 2flash/min, so only one CG lightning jump was observed, that was at 18:20. At that moment the CG rate was 6 flashes min^{-1}.The leading time before the hail onset was 20 minutes without any false alarm. In this case, the 2σ algorithm exhibited a good performance.

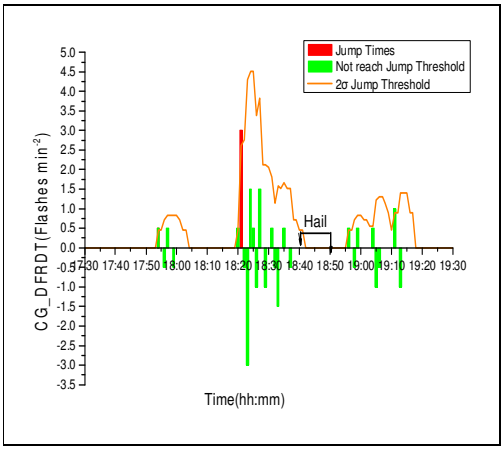

Fig 10. Time–DFRDT plot of the hailstorm using the CG lightning information of ADTD

b. Summary of trend of Lightning activities of hailstorm

Through the study of 14 cases by using the data from SAFIR and ADTD, the analysis of the lightning activity in a hail-bearing thunderstorm was presented. The most important characteristics were summarized as follows:

1) The studied cells in the hailstorm exhibited low CG rate. CG remained lower than 2 min^{-1} during their whole lifetime. This is a common characteristic in some severe storms characterized by hail.

2) Based on the lightning information of SAFIR, The value of IC: CG flashes was higher than general thunderstorm, In those 14 cases, the maximum value of IC: CG was 68, the mean value was 12.12, which was higher than the value of 3 in the general thunder storm, It could be concluded that high value of IC: CG was one of the important lightning characteristics.

3) Using the 2σ lightning jump algorithm, it could be proposed that the peak of total lightning and CG flashes were all happened before hail occurrence. The total lightning information provides lead times on 13 of 14 hail events, The lead time prior to the onset of hail was 9-37 minutes, the average lead times was 26.2 min while the CG lightning information provided lead times on 6 of 14 hail events, the average lead times was 19.6min.

4) it was found that when the hailstorm was dominated by PCG flashes, the diameter of hail was larger and duration of hail was longer(> 15min), for example case 1,while the high ratio of NCG occurred, the diameter of hail was relatively smaller (< 2cm),like case 2.

4. CONCLUSIONS

The two main goals of this study were to, first, obtain the characters of total and CG lightning occurrence trends in hailstorms. And, second, to confirm the utility of the 2σ

lightning jump algorithm in hail events. Through the systematic analyses by using the data from SAFIR and ADTD, we demonstrated that the relationship of total lightning and hail is more stable than that of CG lightning of ADTD. The average lead time of jump occurrence to the hail events (Total: 26.2min, CG: 19.6min) is a useful alarm index, which might contribute to forecast the time of hail storm occurrence by using lightning detection data. And statistical analysis also found that when the high ratio of PCG flashes appeared ,the diameter of hail was larger and duration of hail was longer, while the NCG dominated, the diameter of hail was relatively smaller. This might contribute to the prediction of hail storm disasters by using lightning detection data.

5. ACKNOWLEDGEMENTS

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