The Impact of Non-convective Cloud-to-Ground Lightning and the Primary Application of Convective Cloud-to-Ground Lightning Data on Hail Warning in a Strong Squall Line

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ABSTRACT: The radar data and the cloud-to-ground lightning data in a strong squall line with disaster surface hail are collected. The convective regions of the squall line are partitioned based on the radar reflectivity. The cloud-to-ground lighting flashes occurring in every radar scanning time are also classified into the convective cloud-to-ground lightning flashes and the non-convective cloud-to-ground lightning flashes according to which region their return strokes are located in. Some reflectivity characteristics above different kinds of the cloud-to-ground lightning flashes are given respectively. Further analysis indicates that the convective cloud-to-ground lightning flashes have a good correlation with the non-convective cloud-to-ground lightning flashes within 30 km from the convective regions and they have the similar changing trend. On the contrary, the convective cloud-to-ground lightning flashes seem to have no relationship with the non-convective cloud-to-ground lightning flashes 30 far away from the convective regions. Additionally, the whole cloud-to-ground lightning data and the partitioned convective cloud-to-ground lightning data are respectively used in the 3σ lighting jump algorithm to warning the surface hail. The comparison shows that the application of the convective lighting data improves the efficiency of surface hail warning.

INTRODUCTION

Lightning is one of productions of strong convection in a thunderstorm. It always accompanies with strong surface wind, hail and rain gush. Many researches have confirmed the connection between lightning activity and severe weathers, for example, the rapid increase of total lightning rate before the occurrence of severe weathers [Williams et al., 1999; Buechler et al., 2000; Goodman et al., 2005; Steiger et al., 2007; Gatlin et al., 2010; Darden et al., 2010; Schultz et al., 2011]. But for many countries, total lightning detection is still impossible. Cloud-to-ground lightning data is the only lightning data which can be easily obtained in these countries. Although some observations have found that cloud-to-ground lightning flashes don't have good correlation with severe weathers like total lightning flashes [Perez et al., 1997; Carey and Rutledge, 1998; Bluestein and MacGorman, 1998; Knupp and Goodman, 2003; Carey et al., 2003], some other researches give evidences to prove that some characteristics of cloud-to-ground

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lightning flashes can indicate the emergence of some kinds of severe weathers such as tornado signal and surface hail [Rutledge and MacGorman, 1988; Yao et al., 2013]. For example, Yao et al. [2013] examined the cloud-to-ground lightning data in some hailstorms and warned the surface hail effectively using cloud-to-ground lightning data by the lightning jump algorithm proposed by Schultz et al. [2009].

Some researchers find that lightning can initiate in stratiform regions of thunderstorm [Lang et al., 2004; Kuhlman et al., 2009]. This kind of lightning has different charge structure with the lightning initiating in convective regions. The sources of these charges in two regions might be different because of dynamic and microphysical conditions in these two regions. However, severe weathers, such as surface hail, are produced by strong convection and they should be more coincident with lightning activity initiating in convective regions theoretically. Lightning occurring in stratiform regions might confuse the signal from convective lightning for severe weather warning.

The cloud-to-ground lightning location data and the radar data in a strong squall line are used here to examine the impact of lightning flashes striking the ground in stratiform regions, some of which should not initiate in convective regions, and the efficiency of convective cloud-to-ground lightning data for surface hail warning.

DATA AND METHOD

A strong squall line occurred in Shangqiu, Henan province, China, on 3 June 2009 with disaster hail. The cloud-to-ground lightning data in this squall line is provided by the Chinese National Lightning Detection Network (CNLDN) which receives the Low Frequency (LF) signal produced by the return stroke of cloud-to-ground lightning and locates its location using the Improved Performance through Combined Technology (IMPACT) method. Only cloud-to-ground lightning can be detected by the network. The average detection range of a detector is about 300 km. the detection efficiency of the network can reach 80-90%. The radar data is from an S-band Doppler radar installed in Shangqiu, Henan province.

For participating the cloud-to-ground lightning striking in different regions, the radar data is used to classify the convective regions from the stratiform regions. The classification algorithm used here combines the algorithm proposed by Steiner et al. [1995] and the algorithm improved by Biggerstaff and Listemaa [2000]. For avoiding the misclassification, the classification and the analysis are only made when most of the front convective line of the squall line comes into the range of 140 km away from the radar station. Simultaneously, the return stroke position located by the network will be treated as the position of cloud-to-ground lightning position for further analysis. Only cloud-to-ground lightning located by at least 4 detectors is adopted and positive cloud-to-ground lightning with return stroke current less than 10 kA is excluded.

For surface hail warning, a 3σ lightning jump algorithm proposed by Schultz et al. [2009] is employed and the warning length is set to 45 minutes. The total cloud-to-ground lightning flashes located in the squall line and the cloud-to-ground lightning only located in the convective regions are respectively used for the lightning jump algorithm and the results are compared to determine which has the better efficiency for surface hail warning.

RESULTS

1) Reflectivity Characteristics

The cloud-to-ground lightning flashes, which are located in the convective region in the same period as the radar scanning time (convective cloud-to-ground lightning), are separated from those located in the non-convective region (non-convective cloud-to-ground lightning) based on the radar reflectivity.

In the total analysis time for the squall line, most of the cloud-to-ground lightning flashes occur in convective regions. About 94.7% of convective cloud-to-ground lightning flashes are positive; the proportion of positive cloud-to-ground lightning in non-convective regions is about 81%. The maximum reflectivity in the volumes above convective cloud-to-ground return stroke positions assemble from 30 to 65 dBZ; the maximum reflectivity in the volumes above the return strokes of cloud-to-ground lightning flashes within 30 km and 30 km further away from convective regions all distribute from 10 dBZ to 55 dBZ. The center range for cloud-to-ground lightning flashes within 30 km from convective regions is from 20 dBZ to 25 dBZ. The center range for cloud-to-ground lightning flashes 30 km far away from convective regions is from 40 dBZ to 45 dBZ, which is bigger because of the impact of the bright band. The center range for the convective cloud-to-ground lightning flashes is from 50 dBZ to 55 dBZ.

From the time series, the first cloud-to-ground lightning flash appears in the convective region, and then the first non-convective cloud-to-ground lightning flash occurs in the range of 30 km far from the convective region. The occurrence of the first non-convective cloud-to-ground lightning flash within 30 km from the convective region is the last. The evolutions of convective cloud-to-ground lightning flashes and non-convective cloud-to-ground lightning flashes within 30 km from convective regions are similar (Figure 1): in the first half of the study period, cloud-to-ground lightning flashes in the two regions are all sparse; most of positive and negative cloud-to-ground lightning flashes in the two regions all densely emerge after half of the period. The maximum reflectivity in the volumes above the return strokes of convective cloud-to-ground lightning flashes and non-convective cloud-to-ground lightning flashes within 30 km from convective regions gradually increase and all reach their max values after half of the period. But for cloud-to-ground lightning flashes 30 km far from convective regions, it is contrary that the maximum reflectivity in the volumes above their return strokes reaches the max in first half of the period then decreases gently. Negative non-convective cloud-to-ground lightning flashes 30 km far from convective regions occur in the initial stage and the final stage.

Additionally, with the minimum distances from non-convective cloud-to-ground lightning flashes to convective regions increasing, maximum reflectivity in the volumes above non-convective cloud-to-ground lightning return strokes within 30 km from convective regions show a descent trend, but the trend for the maximum reflectivity in the volumes above non-convective cloud-to-ground lightning flash return strokes 30 km far from convective regions is ascent.

Also, the analysis demonstrates that more than 99% and 89.7% of the maximum reflectivity in the volumes above convective cloud-to-ground lightning return strokes exceed 30 dBZ and 40 dBZ respectively. It is consistent with many previous observations. But for non-convective cloud-to-ground lightning flashes within 30 km and 30 km far from convective regions, 37.4% and 75.6% of maximum reflectivity in the volumes above their return strokes beyond 30 dBZ. The proportion with reflectivity greater than 40 dBZ in these two regions even decrease to 8.2% and 41.9%. It indicates that 40 dBZ is not suitable for describing radar characteristics above non-convective cloud-to-ground lightning return strokes any more. Moreover, more than 98% and 95% of the volumes above non-convective cloud-to-ground lightning return strokes within 30 km and 30 km far from convective regions respectively have the maximum reflectivity exceeding 15 dBZ.

Simultaneously, the analysis between the frequencies of convective cloud-to-ground lightning flashes and non-convective cloud-to-ground lightning flashes indicates that the non-convective cloud-to-ground lightning frequency doesn't have a significant correlation with the convective cloud-to-ground lightning frequency. Especially for the non-convective cloud-to-ground lightning flashes, which locations are 30 km far from convective region, the correlation between them is very low. Additionally, the proportion of non-convective cloud-to-ground lightning flashes in every radar scanning time has a large undulation from less than 5% to more than 80%.

The analysis on the evolution of 15 dBZ echo tops above non-convective cloud-to-ground lightning return strokes shows that more than 94.7% of the 15 dBZ tops above non-convective cloud-to-ground lightning return strokes within 30 km from convective regions are over 5 km, and even about 92.4% exceed 6 km. 92.5% of the 15 dBZ echo tops above non-convective cloud-to-ground lightning return strokes 30 km far from convective regions are higher than 6 km. Comparing with non-convective cloud-to-ground lightning flashes within 30 km from convective regions, non-convective cloud-to-ground lightning flashes 30 km far from convective regions tend to occur in the regions with higher 15 dBZ top. In addition, 15 dBZ/6km might be a more suitable factor combination for non-convective cloud-to-ground lightning warning than 40dBZ/7km. But it still needs more evidences to assess its performance.

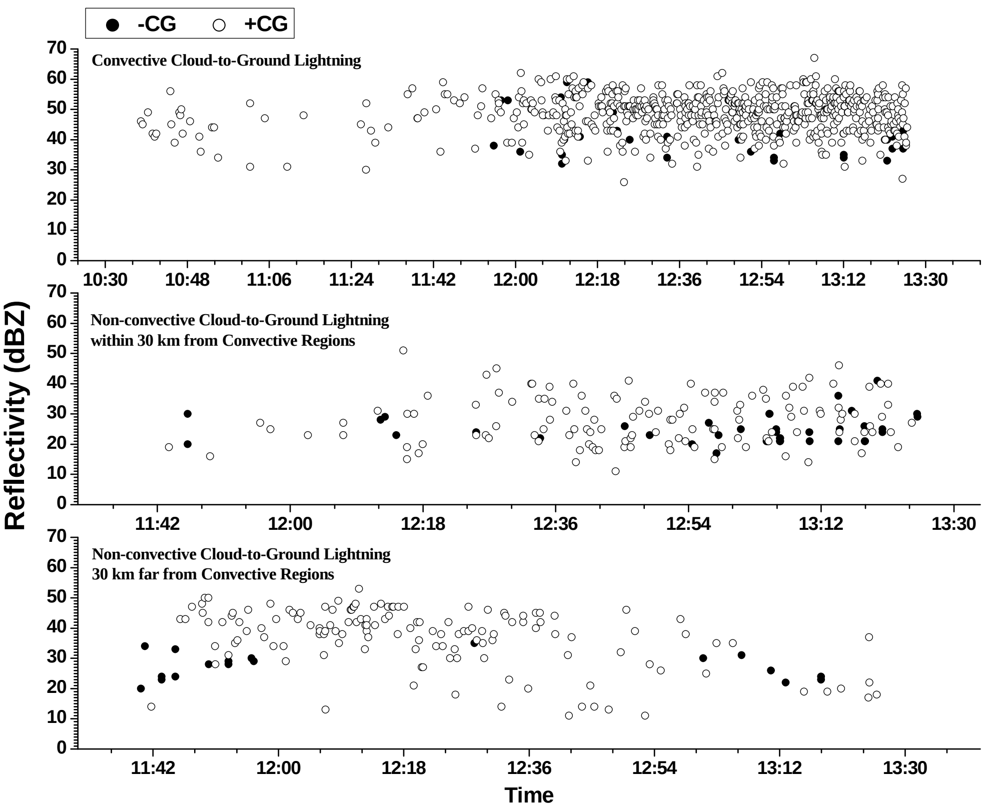

Figure 1 evolutions of maximum reflectivity above cloud-to-ground lightning flashes

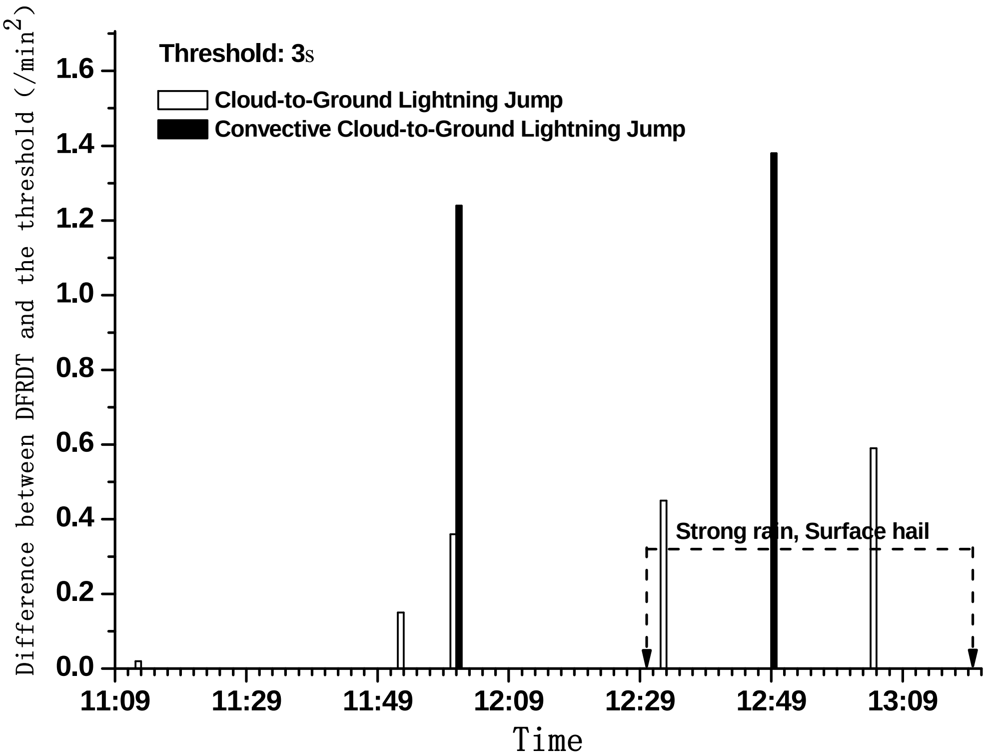

Figure 2 Cloud-to-ground lightning jumps calculated by the whole cloud-to-ground lightning flashes in the squall line and the convective cloud-to-ground lightning flashes.

2) Application in Lightning Jump Algorithm

The whole cloud-to-ground lightning data in the squall line and the convective cloud-to-ground lightning data are respectively used to warn the surface hail in the lifetime of the squall line based on the 3 σ lightning jump algorithm with the warning length of 45 minutes (Figure 2). Before the surface hail occurs, only one convective cloud-to-ground lightning jump is calculated but there are two whole cloud-to-ground lightning jumps in the same valid warning length. Furthermore, one whole cloud-to-ground lightning jump appears before the valid warning length and it is treated as an invalid warning; another two occur during the surface hail and they are also invalid. For the convective cloud-to-ground lightning jump, there is only one during the surface hail. It seems that convective cloud-to-ground lightning activity shows a closer link with the surface hail. It is reasonable because surface hail and convective cloud-to-ground lightning are all the productions of strong convection in thunderstorm and have the same background of dynamics and microphysics. Presumably, convective cloud-to-ground lightning data could provide more valid information for other severe weather warning.

CONCLUSION AND DISCUSSION

The correlation between non-convective cloud-to-ground lightning flashes and convective cloud-to-ground lightning flashes is low. Non-convective cloud-to-ground lightning flashes within 30 km from convective regions have relatively similar trend with convective cloud-to-ground lightning flashes. It implies that there should be something shared by these two regions relating the lightning activities in two regions. We guess it is the charges generated in convective regions and transported into non-convective regions. The charges mainly affect the non-convective region close to convective regions.

On the other hand, lightning flashes further away from convective regions have no correlation with convective lightning flashes. It might be caused by the charge structure which is very different with the charge structure in convective regions. The in situ charging mechanism in non-convective regions would generate new charges without relationship with the charges from convective regions. Different dynamic, temperature and humidity conditions would produce a different charge structure. It can lead lightning flashes in the regions far from convective regions to have little relationship with convective lightning flashes. Non-convective lightning flashes may occupy a large proportion if the statistical time span is small enough.

As we know, disaster weathers, such as hail, are the productions of strong convection. The existence of non-convective lightning flashes, which have no relationship with the strong convection leading to disaster weathers, will reduce the forecast results if whole lightning flashes are used to warn disaster weathers. Our experiment using whole lightning data and convective lightning data demonstrates that using the convective lightning data can improve the efficiency of surface hail warning. Categorized lightning data has potential power for further research and warning application in the future.

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REFERENCES

Biggerstaff, M. I., and S. A. Listemaa, 2000: An Improved Scheme for Convective/Stratiform Echo Classification Using Radar Reflectivity. *J. Appl. Meteor.*, 39, 2129-2150.

Bluestein, H. B., and D. R. MacGorman, 1998: Evolution of cloud-to-ground lightning characteristics and storm structure in the Spearman, Texas, tornadic supercells of 31 May 1990. *Mon. Wea. Rev.*, 126, 1451-1467.

Buechler, D. E., K. T. Driscoll, S. J. Goodman, et al., 2000: Lightning activity within a tornadic thunderstorm observed by the Potical Transient Detector (OTD). *Geophys. Res. Lett.*, 27, 2253-2256.

Carey, L. D., and S. A. Rutledge, 1998: Electrical and multiparameter radar observations of a severe hailstorm. *J. Geophys. Res.*, 103, 13979-14000.

Carey, L. D., W. A. Petersen, and S. A. Rutledge, 2003: Evolution of cloud-to-ground lightning and storm structure in the Spencer, South Dakota, tornadic supercell of 30 May 1998. *Mon. Wea. Rev.*, 131, 1811-1831.

Darden, C. B., D. J. Nadler, B. C. Carcione, et al., 2010: Utilizing total lightning information to diagnose convective trends. *Bull. Amer. Meteor. Soc*., 91, 167-175.

Gatlin, P. N., and S. J. Goodman, 2010: A total lightning trending algorithm to identify severe thunderstorms. *J. Atmos. Oceanic Technol*., 27, 3-22.

Goodman, S. J., and Coauthors, 2005: The North Alabama Lightning Mapping Array: Recent severe storm observations and future prospects. *Atmos. Res*., 76, 423-437.

Knupp, K. R., S. Paech, and S. Goodman, 2003: Variations in cloud-to-ground lightning characteristics among three adjacent tornadic supercell storms over the Tennessee Valley region. *Mon. Wea. Rev.*, 131, 172-188.

Kuhlman, K. M., D. R. MacGorman, M. I. Biggerstaff, et al., 2009: Lightning initiation in the anvils of two supercell storms, *Geophys. Res. Lett.*, 36, L07802, doi:10.1029/2008GL036650.

Lang, T. J., Steven A. Rutledge, and Kyle C. Wiens, 2004: Origins of positive cloud-to-ground lightning flashes in the stratiform region of a mesoscale convective system. *Geophys. Res. Lett.*, 31, L10105, doi: 10.1029/2004GL019823.

Perez, A. H., L. J. Wicher, and R. E. Orville, 1997: Characteristics of cloud-to-ground lightning associated with violent tornadoes. *Wea. Forecasting*, 12, 428-437.

Rutledge, S. A., and D. R. MacGorman, 1988: Cloud-to-ground lightning activity in the 10-11 June 1985 mesoscale convective system observed during the Oklahoma-Kansas PRE-STORM project. *Mon. Wea. Rev.*, 116, 1393-1408.

Schultz, C. J., W. A. Peterson, and L. D. Carey, 2009: Preliminary development and evaluation of lightning jump algorithms for the real-time detection of severe weather. *J. Appl. Meteor. Climatol.*, 48, 2543-2563.

Schultz, C. J., W. A. Petersen, L. D. Carey, 2011: Lightning and severe weather: A comparison between total and cloud-to-ground lightning trends. *Wea. Forecasting*, 26, 744-755.

Steiger, S. M., R. E. Orville, and L. D. Carey, 2007: Total lightning signatures of thunderstorm intensity over north Texas. Part I: Supercells. *Mon. Wea. Rev*., 135, 3281-3302.

Steiner, M., R. A. Houze Jr., and S. E. Yuter, 1995: Climatological characterization of three-dimensional storm structure from operational radar and rain gauge data. *J. Appl. Meteor.*, 34, 1978–2007.

Williams, E. R. and Coauthors, 1999: The behavior of total lightning activity in severe Florida thunderstorms. *Atmos. Res*., 51, 245-265.

Yao Wen, Zhang Yijun, Meng Qing, et al., 2013: A Comparison of the characteristics of total and cloud-to-ground lightning activities in hailstorms. *Acta Meteor. Sinica*, 27(2), 282-293.