International Conference on Lightning Protection
33rd International Conference on Lightning Protection
25 - 30 September 2016
Estoril, Portugal

On the relationship between the cloud-to-ground lightning characteristics and the air quality over Guangzhou megacity, South China

Yu Wang, Shanqiang Gu, Haitao Wang, Wanxing Feng, Hantao Tao, Han Zhang
The State Grid Electric Power Research Institute
Wuhan, China
wangyu16@sgepri.sgcc.com.cn

***Abstract*—The relationship between the cloud-to-ground lightning characteristics and the air quality data over Guangzhou megacity, South China was investigated in this report. A simple method was proposed to cluster lightning location data into two types of thunderstorms: the traverse thunderstorms and the local ones. It was found that the AQI (air quality index), PM10 concentration, PM2.5 concentration, NO_2 concentration and O_3 concentration were positively correlated to the number of cloud-to-ground lightning flashes for the local thunderstorms. It was also found that the ratio of the positive cloud-to-ground flashes showed decreasing trend and the duration of the local thunderstorm showed increasing trend as the PM10 concentration increased. No obvious correlation was observed for the cloud-to-ground lightning count and the SO_2 concentration.**

Keywords- Cloud-to-Ground lightning; Aerosol; Air quality

I. INTRODUCTION

Lightning occurs in the convective thunderstorms, thus could be affected by many factors. In recent years, the lightning enhancement has been observed in urban areas by many authors and the correlation with the meteorological conditions and environmental factors have been investigated. Westcott et al. studied the summertime cloud-to-ground lightning activity around 16 major cities in Midwest U.S., and found that the lightning frequency increased on the order of 40%~85% over the downwind of many of these cities [1]. Six years of cloud-to-ground lightning data in the metropolitan region of São Paulo, Brazil presented a significant increase in the number of negative cloud-to-ground (CG) lightning and a decrease in the percentage of positive CG flashes [2]. By analyzing the total lightning, Aerosol Optical Depth (AOD) and rainfall data over two inland and two coastal metropolitan cities of India, Lal and pawar indicated that thermodynamic effect and aerosol played a major role in enhancement of lightning activity [3]. Ashley et al. compared the location of warm-season convection in a range of cities in the southeastern U.S. with the adjacent control regions, and considered that the demographic and land-use changes affected the local atmospheric process, hence had an impact on the thunderstorms [4]. Liu et al. developed similar method to investigate the lightning characteristics over Pearl River Delta region of South China, and found considerable variations of lightning activities for different micro environmental areas [5].

However, some researchers reported relative decrease in thunderstorm activities. Yang et al. analyzed the time series data of temperature, surface winds, visibility, thunderstorm days, etc. in Xian, China, and found intense aerosol loading suppressed summer thunderstorms in the area [6]. Recently, Tan et al. investigated the impact of aerosols on lightning flash density in Nanjing, China, and attributed the decrease of the lightning flash density and the increase of percentage of positive cloud-to-ground flashes to the radiative effect and microphysical effect of aerosol, respectively [7]. Thunderstorm days are recorded by meteorological observers. Since the thunder is audible in the range of 20 km, the thunderstorm day probably is underestimated. For the lightning location data acquired by LLS (Lightning Location System), they are inevitable to be influenced by the upgrade of the LLS itself. So it is important to make sure the lightning and thunderstorm observation data represent the actual situation.

Guangzhou city is one of the four megacities in China (the other three are Beijing, Shanghai and Shenzhen), which occupies an area over 7400 km^2 and has a residential population of over 12 million, of which over 85% are urbanized (https://en.wikipedia.org/wiki/Guangzhou). Guangzhou is under the control of the subtropical monsoon climate, and is one of the most frequently flash-striking areas in China. In this report, we retrieved the cloud-to-ground lightning data in Guangzhou megacity for the observation period from 2013 to 2015, and developed a method to cluster the lightning flashes to thunderstorms, then studied the relationship between the thunderstorm-level lightning characteristics and the corresponding air quality data.

II. DATA DESCRIPTION

The lightning location data were collected using the lightning location system (LLS) operated by China Southern power grid (referred as GD LLS). The GD LLS, including the sensors and the central processor, were developed by the State Grid Electric Power Research Institute in Wuhan, China [8]. Figure 1. presents the topographic map of Guangdong Province along with the sensor locations of the system. More than 20 lightning detection stations for the location network ensured the high precision and continuous lightning locating in this region. As with many similar ground-based lightning location systems, the GD LLS had underwent several upgrades. The last upgrade was conducted before the thunderstorm season of 2013. So the lightning data were collected under the same detection efficiency level since 2013. It was reported that the flash detection efficiency was greater than 90% and the location accuracy was between 500 m ~ 1 km [9]. The artificially triggered lightning was used to evaluate the detection efficiency and location accuracy of GD LLS, which were 92% and 760 m, respectively, for the triggered flashes [10].

The air quality data were downloaded from the website at http://www.stateair.net/web/post/1/1.html and the website at http://beijingair.sinaapp.com/, which were originally acquired by the U.S. embassy in Guangzhou and the ministry of environmental protection of China (MEPC), respectively. Note that only PM2.5 concentration is available for the U.S. embassy data and the AQI (air quality index), PM2.5, PM10, SO_2, NO_2, CO, O_3 are included in the MEPC data from May 13, 2014.

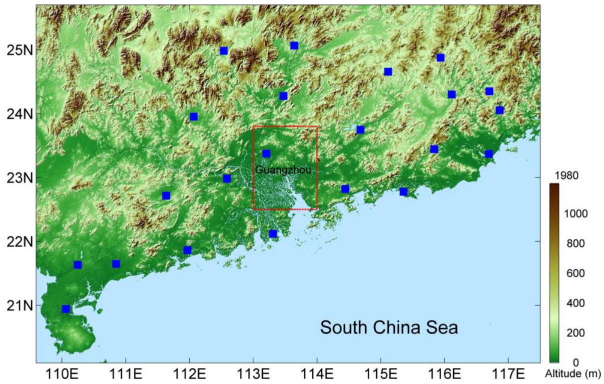

Figure 1. Topographic map of Guangdong Province. The blue squares indicate the lightning location stations and the red rectangle markes out Guangzhou city.

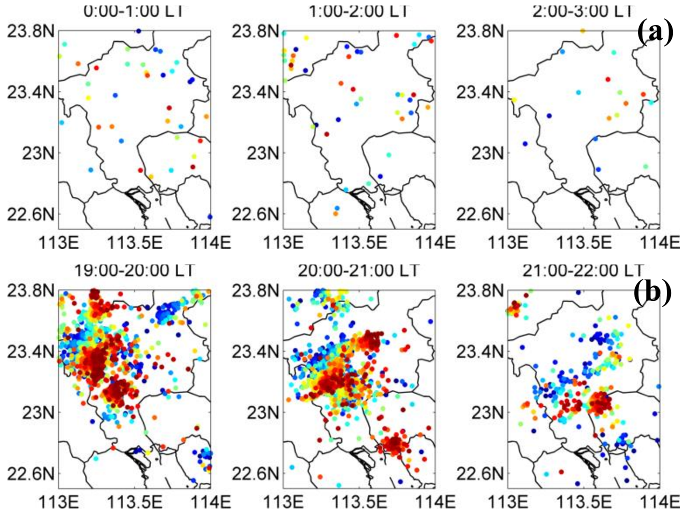

Figure 2. Three consecutive hours of cloud-to-ground lightning location results in Guangzhou city. All lightning data are divided into hourly subset according to their occurrence time. (a) is for the thunderstorm occurred in 2014-8-7 and (b) for 2013-6-3. Whereas the thunderstorm in (a) seems to generate locally, the thunderstorm that passed over Guangzhou city from northwest is clearly recognized in (b).

III. METHODOLOGY

We selected the Guangzhou lightning location data within the domain (113°E ~ 114°E, 22.5°N ~ 23.8°N) from the GD LLS database. Hundreds of thunderstorm days were identified, but only the data of the thunderstorm day with more than 100 flashes were kept down for analysis. A simple method was proposed to cluster the lightning flashes into different thunderstorms. First, all lightning data were visualized according to the position and the occurrence time. Figure. 2 depicts two thunderstorms occurred in Guangzhou. For each thunderstorm only three consecutive hours of the CG data were presented here. In each one-hour subfigure, the dots were color coded to indicate the time sequence. The blue dots were prior to the red ones. Then, we checked all the visualized one-hour data to cluster them into different thunderstorms. Lastly, the thunderstorms were divided into two groups according to their temporal-spatial distribution. The thunderstorms that exhibited obvious moving direction were classified as traverse thunderstorms and the remaining ones were classified as local thunderstorms. Figure. 2 (a) displays a local thunderstorm and Figure. 2 (b) displays a traverse one. Since the time resolution of the air quality data measurement was one hour, the method proposed here enabled the comparison of the lightning data to the air quality data on the hour level. Note that this method is only effective for the situation where the analysis area is relatively small (like one city).

IV. RESULTS AND DISCUSSION

During the period 2013~2015, there were 293 thunderstorm days with more than 100 lightning flashes. We conducted the analysis for all these major thunderstorm days at first. The hourly average lightning flash count and the hourly average air quality concentration were calculated for each major thunderstorm day. No obvious correlation was found for any of the pollutants with the flash count. However, when the attention was payed on the summertime (June, July and August) thunderstorm days, some of the pollutants increased the correlation with the flash count. Figure 3. shows the scatterplot of the CG flash count and the air quality data. We can see that the association with the AQI, PM10 concentration, PM2.5 concentration, NO_2 concentration was stronger than that with the SO_2 concentration, O_3 concentration and CO concentration. Naccarato et al. (2003) also found the positive linear correlation between the CG flash number and the PM10 concentration [11]. Soriano et al. (2002) considered that the large population and the high SO_2 concentration contribute to the increase in the number of CG flashes in urban areas of Spain [12], which was contrast to the finding in our analysis. Besides, we find that the dots in the Figure 3 (c) are more disperse than that in the Figure 3 (d). This may be because the PM2.5 data from US embassy was collected at one site, whereas the air quality data (including the PM2.5 data) from MEPC were the average values of many monitoring stations deployed in Guangzhou city.

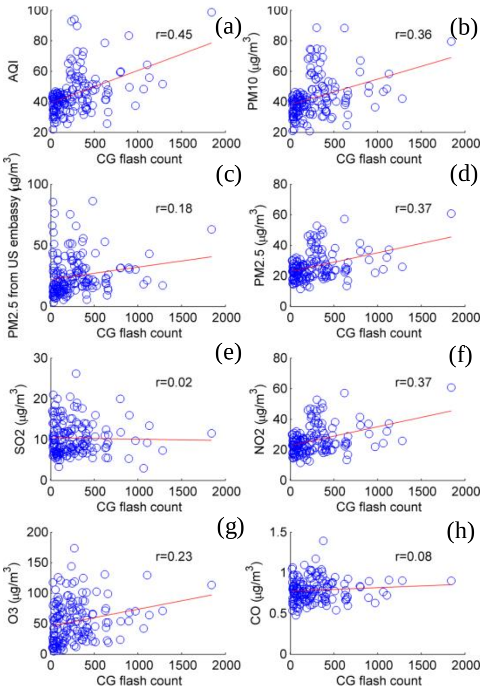

Figure 3. Scatterplot of the hourly average CG flash count and the hourly average air quality data for the summertime thunderdays, with the linear best fit (red line) and the correlation coefficient (r).

Considering that the convective thunderstorms are affected by many factors, particularly the meteorological conditions, we casted a light on the local thunderstorms, discarding the traverse thunderstorms that may be controlled by large scale processes. There were 67 local thunderstorms occurred in Guangzhou city according to our clustering method during May 13, 2014 ~ Dec 31, 2015. For each thunderstorm (noting that not for each thunderstorm day), the hourly average CG flash count, ratio of positive CG flash and the pollutant concentrations were calculated. In Figure 4. we can see the AQI, PM10 concentration, PM2.5 concentration, NO_2 concentration, O_3 concentration are more correlated to the CG flash count, which means the influence of the meteorological factors were reduced to a certain extent. Lal and Pawar. (2011) analyzed the relationship between lightning and aerosol over four metropolitan cities of India, and found that the coastal cities did not show any increasing trend in rainfall and lightning activity with the aerosol. The authors also considered that the weather conditions overwhelmed the effect of aerosol in the coastal cities [3].

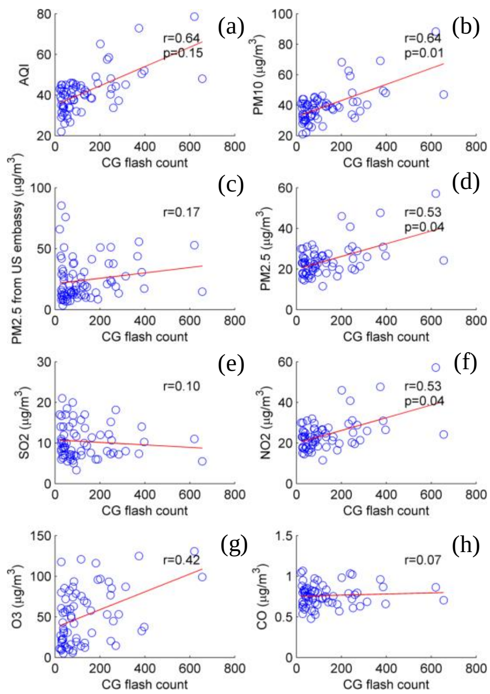

Figure 4. Scatterplot of the hourly average CG flash count and the hourly average air quality data for the local thunderstorms during 2014-2015, with the linear best fit (red line) , the correlation coefficient (r) and the p value.

In addition, we found that the ratio of the positive CG flash showed a relatively obvious decreasing trend with the PM10 concentration (see Figure 5.), which was consistent with the result of Naccarato et al. in Brazil [11] and Kar et al. in South Korea [13]. It was thought that the contaminants in the air affected the charge structure in the thundercloud, thus facilitating the production of negative CG flashes. Besides, a positive correlation between the duration of the local thunderstorms and the PM10 concentration was observed (see Figure 6.). Similar result was found by Farias et al. (2009) [2].

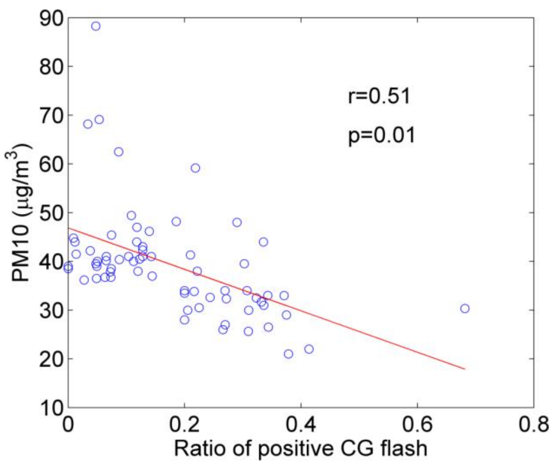

Figure 5. Scatterplot of the hourly average positive CG flash ratio and the hourly average PM10 concentration for the local thunderdays during 2014-2015, with the linear best fit (red line) , the correlation coefficient (r) and the p value.

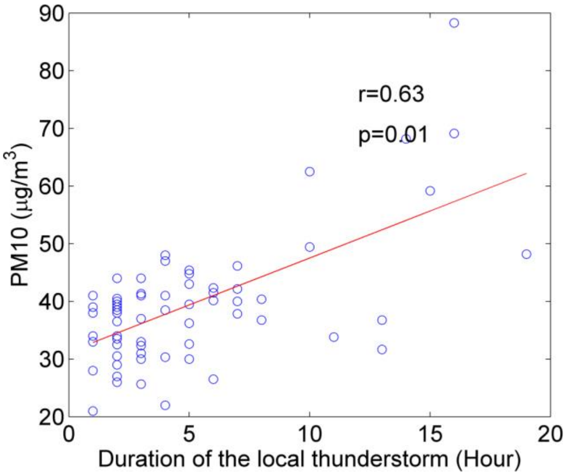

Figure 6. Scatterplot of the duration and the hourly average PM10 concentration for the local thunderdays during 2014-2015, with the linear best fit (red line) , the correlation coefficient (r) and the p value.

In conclusion, we found positive linear correlation between the lightning activity and the concentration of PM10, PM2.5, NO_2 and O_3. The correlations became stronger when the data were limited to the local thunderstorms. We believe that for the local thunderstorms, the air quality played a more important role in the lightning activity. The correlations were also observed by other researchers, though the correlation coefficients were relatively low in this study. We considered that the complex terrain (see Figure 1.) and the close distance to the sea for Guangzhou city made it more difficult to resolve a significant linear relationship between lightning and aerosol. Besides, we found the percentage of positive CG flash decreased with the PM10 concentration, which may implied that the pollutant could change the distribution of positive and negative charge in thundercloud. The storm lifetime seemed to increase as the air pollution was more serious. It is worth mentioning that some researchers have reported that heavy air pollution could suppress the lightning activity [6,14]. Since the number of heavily polluted day was not enough for the study period in this report, it was hard for us to draw the same conclusion.

ACKNOWLEDGMENT

The authors would like to thank U.S. embassy in Guangzhou and the owner of the website (http://beijingair.sinaapp.com/) for sharing the air quality data.

REFERENCES

[1] N. E. Westcott, ñSummertime Cloud-to-Ground Lightning Activity around Major Midwestern Urban Areas,ò *Journal of Applied Meteorology*, vol. 34. pp. 1633ï 1642, 1995.

[2] W. R. G. Farias, O. Pinto, K. P. Naccarato, and I. R. C. . Pinto, ñAnomalous lightning activity over the Metropolitan Region of São Paulo due to urban effects,ò *Atmos. Res.*, vol. 91, no. 2ï 4, pp. 485ï 490, 2009.

[3] D. M. Lal and S. D. Pawar, ñEffect of urbanization on lightning over four metropolitan cities of India,ò *Atmos. Environ.*, vol. 45, no. 1, pp. 191ï 196, 2011.

[4] W. S. Ashley, M. L. Bentley, and J. A. Stallins, ñUrban-induced thunderstorm modification in the Southeast United States,ò *Clim. Change*, vol. 113, no. 2, pp. 481ï 498, 2011.

[5] Y. Liu, L. Y. Chan, Q. Lin, W. Feng, X. Bi, J. Chen, H. Tao, X. Wang, D. Chen, G. Sheng, and J. Fu, ñPhysical and observable characteristics of cloud-to-ground lightning over the Pearl River Delta region of South China,ò pp. 5986ï 5999, 2014.

[6] X. Yang, Z. Yao, Z. Li, and T. Fan, ñHeavy air pollution suppresses summer thunderstorms in central China,ò *J. Atmos. Solar-Terrestrial Phys.*, vol. 95ï 96, pp. 28ï 40, 2013.

[7] Y. B. Tan, L. Peng, Z. Shi, and H. R. Chen, ñLightning flash density in relation to aerosol over Nanjing (China),ò *Atmos. Res.*, 2016.

[8] J. Chen, Y. Wu, and Z. Zhao, ñThe new lightning detection system in China: Its method and performance,ò *2010 Asia-Pacific Symp. Electromagn. Compat. APEMC 2010*, pp. 1138ï 1141, 2010.

[9] S. M. Chen, Y. Du, L. M. Fan, H. M. He, and D. Z. Zhong, ñEvaluation of the Guang Dong lightning location system with transmission line fault data,ò in *Science, Measurement and Technology, IEE Proceedings-*, 2002, vol. 149, no. 1, pp. 9ï 16.

[10] Y. Zhang, S. Yang, W. Lu, D. Zheng, W. Dong, B. Li, S. Chen, Y. Zhang, and L. Chen, ñExperiments of arti fi cially triggered lightning and its application,ò *Atmos. Res.*, vol. 135ï 136, pp. 330ï 343, 2014.

[11] K. P. Naccarato, ñEvidence of thermal and aerosol effects on the cloud-to-ground lightning density and polarity over large urban areas of Southeastern Brazil,ò *Geophys. Res. Lett.*, vol. 30, no. 13, pp. 1ï 4, 2003.

[12] L. R. Soriano and F. De Pablo, ñEffect of small urban areas in central Spain on the enhancement of cloud-to-ground lightning activity,ò *Atmos. Environ.*, vol. 36, pp. 2809ï 2816, 2002.

[13] S. K. Kar, Y. Liou, and K. Ha, ñAerosol effects on the enhancement of cloud-to-ground lightning over major urban areas of South Korea,ò *Atmos. Res.*, vol. 92, no. 1, pp. 80ï 87, 2009.

[14] W. R. G. Farias, O. Pinto, I. R. C. A. Pinto, and K. P. Naccarato, ñThe influence of urban effect on lightning activity: Evidence of weekly cycle,ò *Atmos. Res.*, vol. 135ï 136, pp. 370ï 373, 2014.