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# Evaluation of systematic location error of GHMLLS based on observation of Canton Tower stroke

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***Abstract*—In this paper, locations reported by Guangdong-Hongkong-Macau Lightning Location System (GHMLLS) for 140 lightning strokes occurring on the Canton Tower were compared with the ground-truth location of Canton Tower. The location error analysis shows a systematic bias toward south (68 m) and west (118 m). Using the simple cell count method and the smoothing method based on confidence ellipse, GHMLLS records were analyzed at resolution of 100 m. After the systematic bias correction, it was found that the regions with high values of stroke density and average peak current are co-located better with the location of the tall structures up to 4 km away from the Canton Tower. The results indicate that the tower lightning observation can be used to re-calibrate the lightning location error in a local area.**

***Keywords*—LLS; Canton Tower-stroke; Systematic Location Error***

## I. INTRODUCTION

Lightning location systems (LLSs) have been widely applied in many countries and regions to mainly provide lightning information by accurately detecting and locating cloud-to-ground lightning strikes. Due to the propagation and terrain effects, systematic location errors of LLS may occur in some region. Lafkovici et al. (2008) reported that the NALDN stroke location error seems to have a bias towards the north and east of the CN Tower, based on the CN Tower lightning data acquired in 2005. Recently, Kazazi et al. (2015) found that the NALDN stroke location error have a bias towards the north and west of the CN Tower, based on the data acquired in 2014.

Several LLSs have been set up in Guangdong Province, China, among which, the Guangdong-Hongkong-Macau Lightning Location System (GHMLLS) was jointly established by the Guangdong Meteorological Bureau, the Hong Kong Observatory and the Macao Meteorological and Geophysical Bureau since 2005. After the upgrade in 2012, the GHMLLS has become one of the most important LLSs in South China. The 600 m-tall Canton Tower, which experiences frequent lightning strokes during the thunder storm season, is located at the center of the network of GHMLLS. In this paper, the GHMLLS-reported lightning locations of the strokes terminated on Canton Tower will be compared with the lightning data acquired at the Tall-Object Lightning Observatory in Guangzhou (TOLOG, Lu et al., 2012, 2013) to reveal the possible systematic location error bias.

## II. EXPERIMENT

The GHMLLS was originally built in 2005 with the setup of 5 IMPACT sensors. Then, in 2007, one more IMPACT sensor was added. In 2012, 11 LS-7000 sensors were also integrated into the lightning location network, with 10 of them being set up in Jan 2012 and 1 being set up in Sep 2012. The combined MDF/TOA technology is used to retrieve CG lightning stroke information such as longitude and latitude, GPS time, peak current, polarity, reporting sensors, confidence ellipse, etc (Zhang et al., 2016). Fig. 1 shows the distribution of the sensors of GHMLLS.

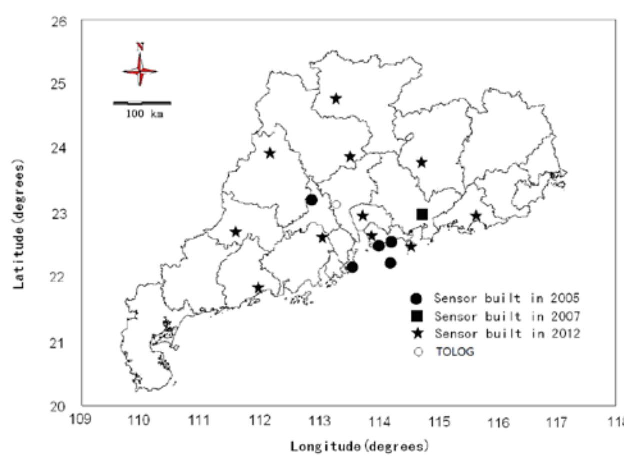


Fig.1 Distribution of sensors of GHMLLS and the position of TOLOG.

Since 2009, a field experiment mainly focusing on lightning flashes striking Canton Tower and the surrounding tall structures has been conducted in Guangzhou, Guangdong

Province, China (Lu et al., 2012, 2013). The observation data include the high-speed camera records and the simultaneously measured electromagnetic fields, which could provide ground-truth location of lightning for comparison with LLS data (Chen et al., 2012).

## III. RESULTS

### A. Location Error

In this paper, GHMLLS records corresponding to 140 lightning strokes striking the Canton Tower during 2016-2017, were selected for the analysis. Based on high-speed camera records, all the 140 strokes were confirmed to terminate on Canton Tower. 29 of them belong to 12 downward negative flashes, and the remaining 111 belong to 22 upward negative flashes. The GHMLLS-reported locations are compared to ground-truth location of the Canton Tower (113.319082°E, 23.109027°N). The absolute location error is found to vary between 8 m and 4965 m with a median of 180 m and an average of 372 m. Fig 2 shows the location errors for the 140 GHMLLS records. The horizontal and vertical axes correspond to the east-west (with east being positive) and north-south (with north being positive) error components, respectively. In addition, the average stroke location error is found to be 68 m toward south and 118 m toward west. If we shift all the 140 GHMLLS-reported locations uniformly according to the bias, i.e., shift to north by 68 m and to east by 118 m, the average (median) value of the absolute location errors were reduced to be 300 (77) m.

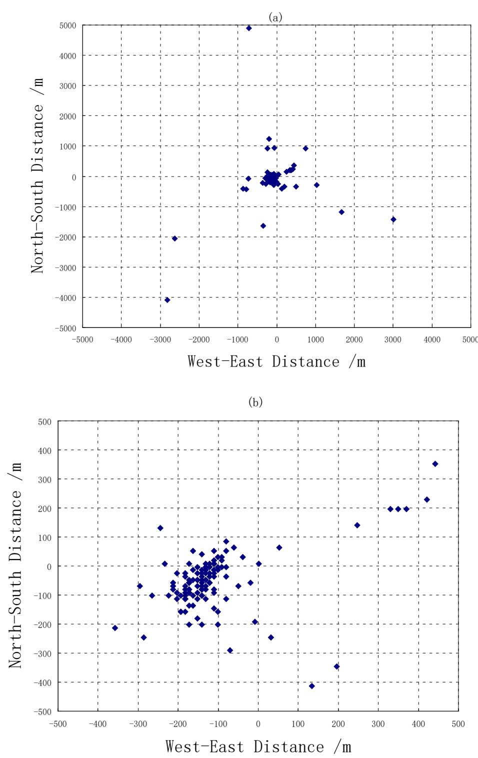


Fig.2 Plots of the GHMLLS-reported locations for 140 strokes terminated on Canton Tower. The origin corresponds to the position of Canton Tower. (a) area of 10×10 km (b) zoom-in of panel of (a) for the area of 1×1 km

The semi-major (semi-minor) axes of the 50% confidence ellipses of the 140 GHMLLS records are found to be in the range of 183-2000 (100-400) m, with an average and median value of 336 (176) m and 200 (200) m. It was found that about 52% (73 out of 140) of the detected strokes were enclosed by the 50% confidence ellipse, while 85% and 91% of the detected strokes were enclosed by the 90% and 99% confidence ellipse, respectively.

The absolute location error was also projected on the orientations of semi-major axis and semi-minor axis. The ratio of the projected location error to the length of semi-major axis (semi-minor axis), denoted as $r_a$ ($r_b$), was analyzed. The results show that the $r_a$ is in the range of 0-8.3 with the average and median values being 0.7 and 0.6, while the $r_b$ is in the range of 0-16.0 with an average and median value of 1.3 and 0.9. It seems that the random location error on the orientations of semi-minor axis tend to be underestimated compared to those on the orientations of semi-minor axis.

### B. Distribution of GHMLLS Records around Canton Tower

Several tall structures over 300 m are located within the area of 10×10 km centered at the Canton Tower, as shown in Fig 3. The symbol 'A' denotes the position of the Canton Tower. The symbol 'B'~'D' indicate three tall structures with height of 530 m, 440 m and 390 m respectively, while the triangle symbols indicate the rest 6 tall structures with height ranging from 300-360 m.

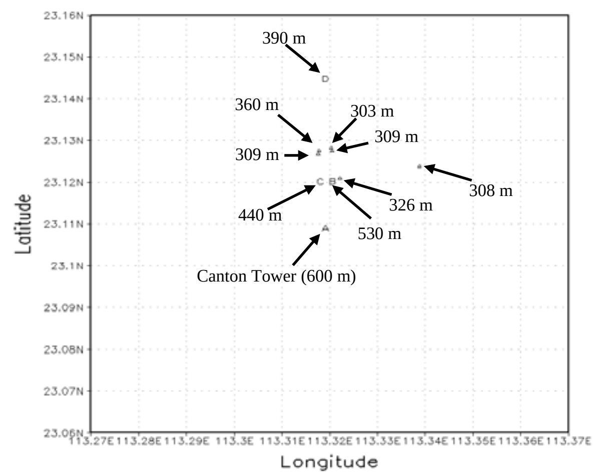


Fig.3 Positions of the 10 tall structures with height over 300 m around the Canton Tower.

Fig 4 shows the stroke density and the average absolute peak current distributions round the Canton Tower based on the GHMLLS records during 2014-2017. Note that all the positive strokes with peak current smaller than 10 kA were removed for the data because they are likely to be misclassified cloud discharges. The absolute values of peak current were used for negative strokes. The map is created using a simple cell count method with the spatial resolution of 0.01°×0.01°(about 1 km × 1 km for each grid) centered at the Canton Tower. It could be found from Fig 3 that the area showing both highest stroke density and highest peak current is located near the Canton Tower, while the secondary highest area is located near a tall structure (marked with 'D') which is about 4 km north to the Canton Tower.

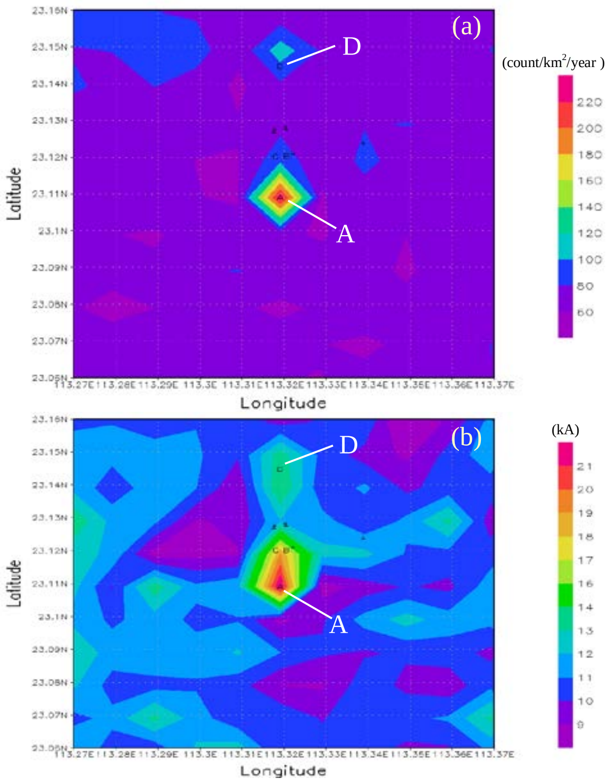


Fig.4 Stroke density distribution(a) and average absolute peak current(b) around the Canton Tower using cell count method at resolution of 1 km.

Fig 5 shows distribution of the average semi-major axis of confidence ellipse round the Canton Tower. The value near the Canton Tower is smaller than 500 m, apparently smaller than that for the outer area.

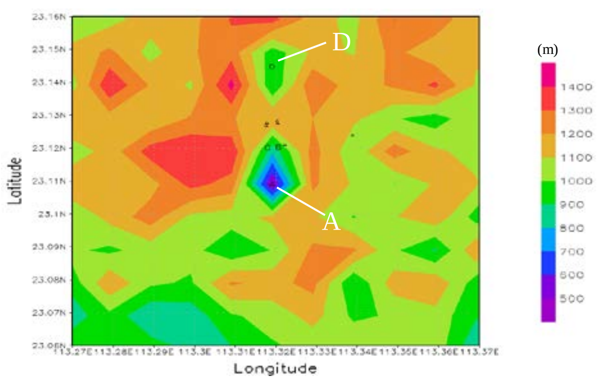


Fig.5 Average semi-major axes distribution round the Canton Tower at resolution of 1 km.

### *C. Systematic Location Error Correction*

It is hard to discriminate the possible systematic bias at an order of hundred meters from the map using a resolution of 1 km. Due to that limitation, we created the map at a resolution of 0.001°×0.001° (about 100 m×100 m) in two ways: One is to use the simple cell count method, and the other one is to use a smoothing method similar to that called Gaussian kernel based on confidence ellipses (GKBCE) and proposed by Bourscheidt et al (2013). For smoothing the stroke density, the probability of a stroke occurring within a cell will be numerical calculated according to the Bivariate Gaussian distribution function provided by the information of confidence ellipse, and then the stroke density will be accumulated for each cell. Similarly, the probability will be multiplied by the corresponding peak current for smoothing the peak current. The result is shown in Fig 6.

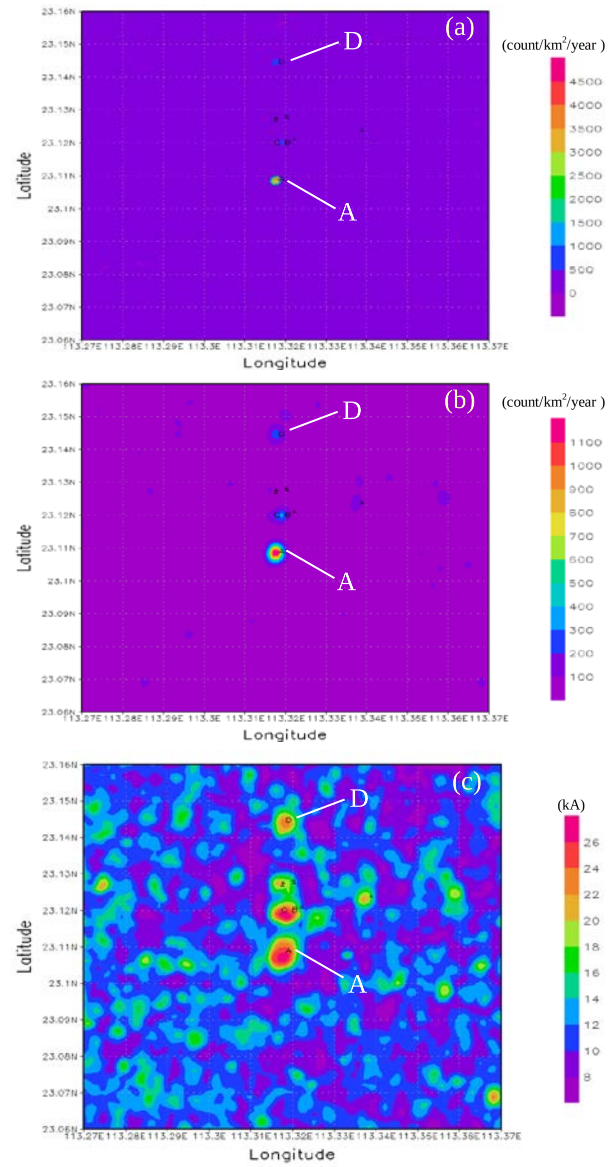


Fig.6 Stroke density and average peak current distribution round the Canton Tower at resolution of 100 m. (a) stroke density via cell count method (b) stroke density via smoothing method. (c) average peak current via smoothing method.

It can be found that the shape of the high stroke density areas seems to become more uniform after smoothing by comparing Fig 6a and Fig 6b, which help to determine the fine centers. It is shown in Fig 5 that the centers of the regions with high lightning density and average peak current do have a small systematic bias from the position of tall structures.

All the GHMLLS-reported locations were shifted uniformly 118 m eastward and 68 m northward, and the corresponding result is shown in Fig 7. It can be found that the regions of high stroke density and high peak current are co-located better with the position of these tall structures above 300 m after the systematic bias correction.

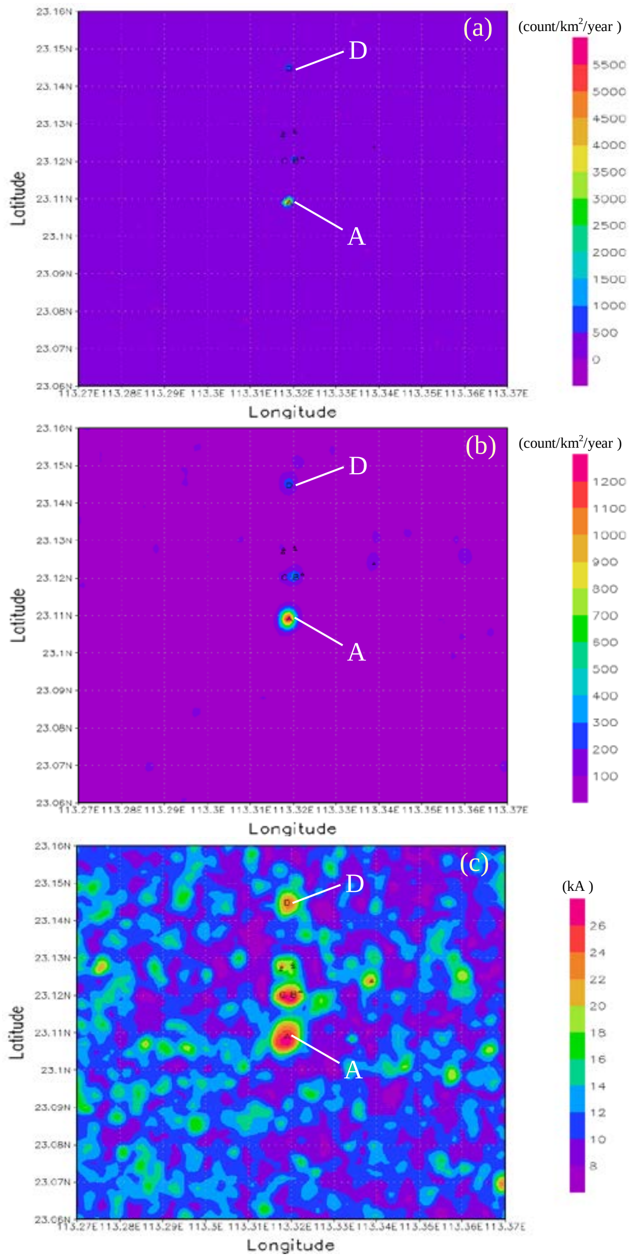


Fig.7 Stroke density and average peak current distribution round the Canton Tower at resolution of 100 m after systematic bias correction. (a) stroke density via cell count method (b) stroke density via smoothing method. (c) average peak current via smoothing method.

## IV. SUMMARY AND DISCUSSION

In this paper, GHMLLS-reported locations of 140 lightning strokes occurring on the Canton Tower during 2016-2017 were compared with the ground-truth location of Canton Tower. The analysis of location error shows a systematic bias of toward south (68 m) and toward west (118 m).

GHMLLS records during 2014-2017 within the area of 10×10 km centered at the Canton Tower were analyzed at resolution of 1 km. The results show that the area of high stroke density, high peak current, and small confidence ellipse are close to the Canton Tower and other tall structures, which may be due to the facts that 1) a tall structure are more frequent to be struck by lightning , 2) transient processes for lightning striking tower produce enhanced electromagnetic fields, and 3) the tower acts like a perfect vertical conductor instead of tortuous lightning channel at the lower several hundred meters, which might help to achieve a better location accuracy.

Using the simple cell count method and the smoothing method based on confidence ellipse, GHMLLS records were also analyzed at resolution of 100 m. After the systematic bias (based on the observation of Canton Tower strokes) correction, it was found that the regions with high stroke density and high peak current are co-located better with the position of the tall structures up to 4 km away from the Canton Tower. It seems that the tower lightning observation can be use to re-calibrate the lightning location error in a local area.

## ACKNOWLEDGMENT


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