2014 23rd International Lightning Detection Conference
18 - 19 March • Tucson, Arizona, USA
5th International Lightning Meteorology Conference
20 - 21 March • Tucson, Arizona, USA

Calibration of the GLD360 Against Rocket-Triggered Lightning Data

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***Abstract*—We have estimated the GLD360 performance characteristics using data for 201 negative return strokes in 42 flashes triggered during 2011–2013 at Camp Blanding, Florida. The flash and stroke detection efficiencies were 67% and 37%, respectively. Out of 75 detected-strokes, 1 (1.3%) was reported with incorrect polarity. The median location error was 2.1 km. The median absolute current estimation error was 27%.**

Keywords—lightning, lightning detection, lightning locating system, Global Lightning Dataset (GLD360), rocket-triggered lightning

I. INTRODUCTION

The Global Lightning Dataset (GLD360) is a long-range global lightning detection network which has been in operation since September 2009. The GLD360 employs an unspecified number of VLF sensors strategically placed around the world. The stroke locations are obtained using both time-of-arrival (TOA) and magnetic-direction-finding (MDF) methods in conjunction with a lightning waveform recognition algorithm.

All the previous evaluations of the GLD360 performance characteristics were done relative to other lightning locating systems. Using the NLDN data as ground truth, Demetriades et al. [2010] found that the CG flash detection efficiency (DE) was 86–92% and the median stroke location error (LE) was 10.8 km over the continental U.S. The study period included 21 days with lightning activity from December 1, 2009 to January 31, 2010. For the same period, but using BrasilDAT data as ground truth, Naccarato et al. [2010] found the CG flash DE was 16% and the mean stroke LE was 12.5 km over the south-east Brazil. Said et al. [2013], using NLDN data as ground truth, found that the CG flash DE was 57% and the median LE was 2.5 km over the continental U.S. for a period of one year. They also reported current estimation errors with AM and GM values of 21% and 6%, respectively, relative to the NLDN. In a similar study in Austria and using EUCLID data as ground truth, Pohjola and Makela [2013] found the CG stroke DE was 48% and the median stroke LE was 1.5 km for July 2011. They reported a strong linear correlation (correlation coefficient = 0.91) between peak currents reported by the GLD360 and by the EUCLID. Poelman et al [2013] estimated the DE and LE of the GLD360 in Belgium for 210 strokes in 57 negative CG flashes using electric field and high-speed video data. They reported the flash and stroke DE to be 96% and 70%, respectively. They also estimated the median stroke LE to be 1.4 km for 134 strokes relative to the EUCLID.

In this paper, we will evaluate the performance characteristics of the GLD360 using, as ground-truth, rocket-triggered lightning data acquired at Camp Blanding, Florida, during 2011–2013. The data set includes 201 return strokes in 42 flashes. The average number of strokes per flash was 4.8. This is the first evaluation of the GLD360 performance characteristics relative to rocket-triggered lightning data.

Results of evaluation, based on rocket-triggered lightning data, are applicable only to subsequent return strokes in natural downward lightning (or to downward lightning flashes without first strokes in the case of flash detection efficiency). In triggered lightning, the first stroke is replaced by the initial-stage processes, while the subsequent strokes are similar to those in natural lightning [Rakov and Uman, 2003].

II. DATA AND METHODOLOGY

During 2011–2013, a total of 42 flashes (containing both the initial stage and leader/return stroke sequences) were triggered at Camp Blanding (CB) using the rocket-and-wire technique. There were a total of 201 negative return strokes. Rockets were launched from two different launchers. The positions of the launchers are known to within a few meters. The channel-base current was measured by resistive shunts with a bandwidth of 0 to at least 3 MHz (typically 8 MHz). Fiber optic links were used to transmit the signals from the

NSF Grant ATM-0852869

sensors to digitizing oscilloscopes. The directly-measured current peaks may contain errors up to 10% or so [Jerauld et al., 2005], but for the purpose of this study they are assumed to be the absolute ground-truth.

The following GLD360 performance characteristics were determined: (a) flash and return-stroke detection efficiencies, (b) percentage of misclassified strokes, (c) location error, and (d) peak current estimation error. Evaluation of the GLD360 performance characteristics based on independent, ground-truth observations (particularly errors in locations and peak current estimates) can be viewed as a kind of calibration of the network.

Camp Blanding and GLD360 strokes were correlated using GPS time stamps. The detection efficiency (DE) values were computed as the ratios of the numbers of GLD360-detected strokes and all triggered-lightning strokes recorded at Camp Blanding. GLD360, at present, does not distinguish between cloud-to-ground (CG) strokes and impulsive processes in cloud (IC) flashes [Said et al., 2013]. Since all the triggered-lightning return strokes examined here were negative (–CG strokes), the percentage of misclassified strokes is the number of GLD360-detected strokes that were reported with incorrect (positive) polarity, expressed in percent of the total number of GLD360-detected strokes. For a given stroke, the distance between the location of rocket launcher or the lightning ground attachment point (used as ground-truth) and the location reported by the GLD360 is defined as the location error (LE). The errors in GLD360-reported peak currents were computed using the equation $\Delta I = I_{GLD} - I_{CB}$, where I_{GLD} is the GLD360-reported peak current and I_{CB} is the peak value of current waveform directly measured at Camp Blanding. The current error is expressed in percent of I_{CB}.

Of the 201 strokes recorded at Camp Blanding in 2011–2013, directly measured currents were available for 191 strokes. The GLD360 detected 75 strokes (directly measured currents were available for 74 of them). Fig. 1 shows the peak current histogram for return strokes recorded at Camp Blanding during 2011–2013. For return-stroke peak currents, the geometric mean (GM) was 11.5 kA, median was 11.7 kA, maximum was 38.1 kA, and minimum was 2.0 kA. According to Berger et al. [1975], the median values of peak current for first and subsequent strokes in natural negative lightning are 30 kA and 12 kA, respectively.

III. RESULTS

A. *Flash and Stroke Detection Efficiencies*

In 2011–2013, the GLD360 detected 75 strokes in 28 flashes (out of 201 strokes in 42 flashes recorded at Camp Blanding). The resultant flash detection efficiency was 67% and the stroke detection efficiency was 37%.

Fig. 2 shows the GLD360 stroke detection efficiency as a function of peak current directly measured at Camp Blanding. The total number of GLD360-reported strokes for which peak currents were measured at Camp Blanding was 74. The stroke detection efficiency was 100% for peak currents in the 25–30 kA and tends to decrease for either smaller or larger peak currents. None of the eight strokes with peak currents ≤5kA was detected by the GLD360. Note that there were only three strokes with peak currents >30 kA and only one of them was detected.

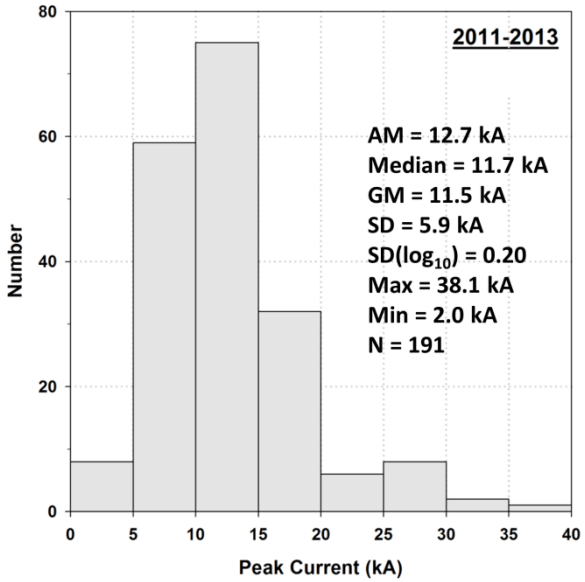

Fig. 1. Histogram of return-stroke peak currents directly measured at Camp Blanding during 2011–2013, both detected and not detected by the GLD360. Statistics given are the arithmetic mean (AM), median, geometric mean (GM), standard deviation (SD), standard deviation of the $\log_{10}$ of the parameter ($SD(\log_{10}I)$), maximum value (Max), and minimum value (Min). N is the sample size.

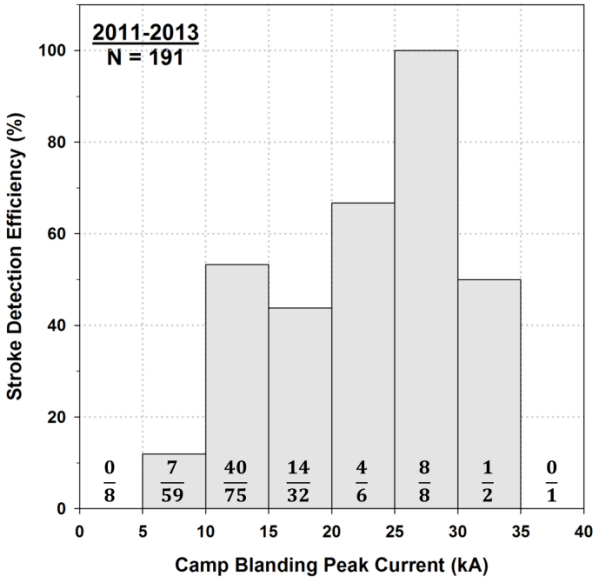

Fig. 2. GLD360 detection efficiency for 191 return strokes in flashes triggered at Camp Blanding during 2011–2013 as a function of directly-measured peak current. For each peak current range (bin size of 5 kA), the ratio given inside the column indicates the number of strokes detected by the GLD360 (numerator) and the number of strokes recorded at Camp Blanding (denominator) for that peak current range.

B. Percentage of Misclassified Strokes

In 2011–2013, 1 out of 75 return strokes detected by the GLD360 was reported with positive peak current. Hence, the percentage of misclassified strokes was 1.3%. The misclassified stroke (in a flash triggered in 2012) had a peak current of 12.8 kA.

C. Location Error

Fig. 3 shows spatial distribution of locations for the GLD360-detected return strokes. The origin of coordinates corresponds to the actual stroke location that was known to within a few meters, so that the horizontal and vertical axes correspond to the east-west (east being positive) and north-south (north being positive) location error components, respectively. The arithmetic mean (AM) and median north-south location errors were 233 m and 167 m, respectively, while the AM and median east-west location errors were 2.6 km and 293 m, respectively. From Fig. 3, we can see that the stroke locations tend to be biased towards east of the actual stroke location.

Fig. 4 shows the histogram of GLD360 location errors. The median location error was 2.1 km, with the largest error being 21.6 km. About 48% (36 out of 75) of strokes had location errors ≤2 km. The return stroke with largest location error occurred in a flash triggered in 2012 and had a peak current of 14.5 kA.

D. Peak Current Estimation Error

Fig. 5 shows a scatter plot of the GLD360-reported peak current versus peak current directly measured at Camp Blanding. The red broken line (slope = 1) in this figure is the locus of the points for which the GLD360-reported peak currents and the directly-measured peak currents are equal. For all 74 GLD360-reported strokes with directly measured currents, the GM of Camp Blanding peak current (I_{CB}) was 14.6 kA versus 15.9 kA for GLD360-reported peak currents (I_{GLD}). The AM value of the ratio I_{GLD}/I_{CB} was 1.17. A greater than 1 ratio indicates that the GLD360 tends to overestimate the peak current (by about 17%, on average), which is also evident from Fig. 5.

Fig. 6a shows a histogram of signed values of GLD360 peak current estimation error as a percentage of Camp Blanding peak current. The AM and median values of ΔI% were 17% and 7.1%, respectively.

Fig. 6b shows a histogram of the unsigned (absolute) values of GLD360 peak current estimation error as a percentage of Camp Blanding peak current. For absolute values of ΔI%, the AM and median values were 36% and 27%, respectively. The maximum current estimation error of 161% corresponded to a return stroke (in a flash triggered in 2013) with peak current of 14.9 kA. Out of 12 strokes with absolute current estimation errors >50%, 11 had peak currents ≤20 kA.

IV. Discussion

Table I gives the GLD360 performance characteristics for triggered-lightning return strokes in different years from 2011 to 2013. One can see that the flash and stroke detection efficiencies have increased from 2011 to 2013. The median location error decreased from 2011 to 2012 and in 2013 was the same as in 2012. The median absolute current estimation error varied non-monotonically consistent over the three years.

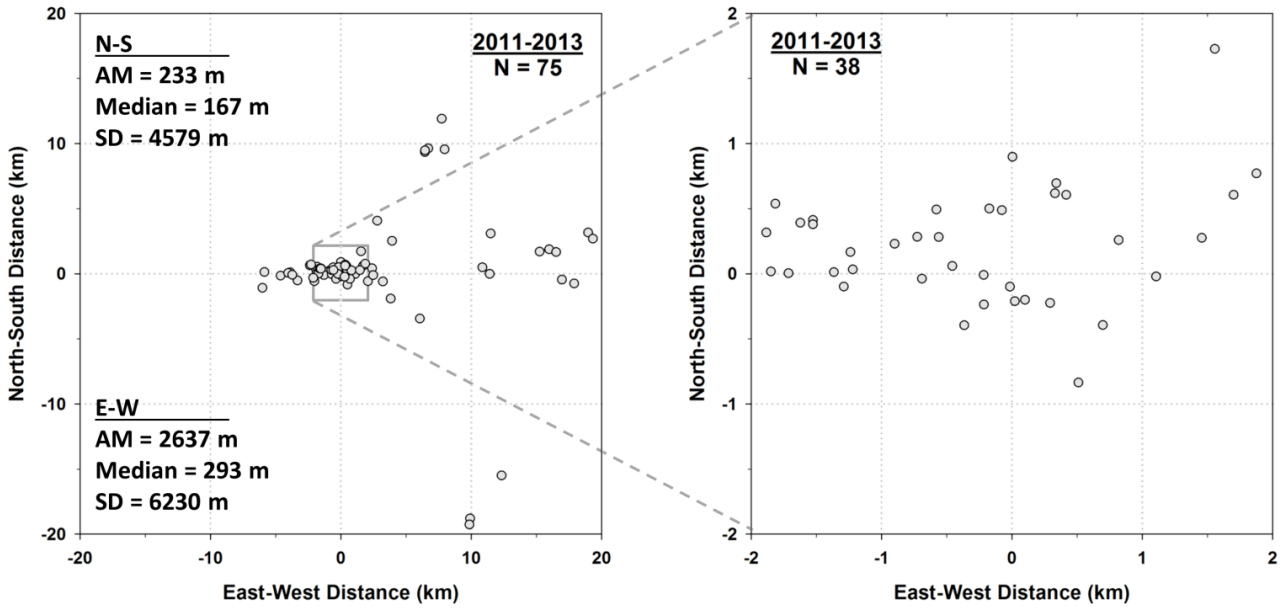

Fig. 3. Plot of GLD360-reported stroke locations during 2011–2013. The origin of coordinates corresponds to the actual stroke location. The horizontal axis corresponds to the east-west component of the location error, with positive values corresponding to east. The vertical axis corresponds to the north-south component of the location error, with positive values corresponding to north. Statistics given are arithmetic mean (AM), median, and standard deviation (SD). N is the sample size.

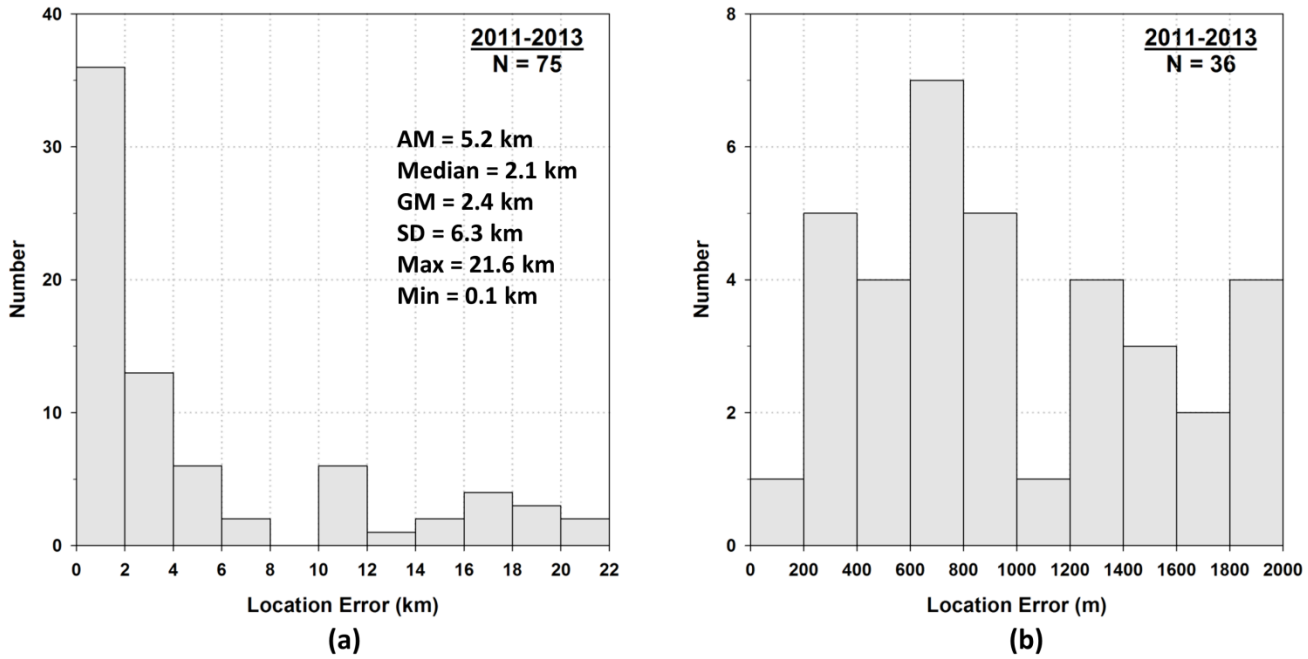

Fig. 4. Histograms of GLD360 location errors for (a) all 75 return strokes and (b) 36 return strokes with location errors ≤2 km during 2011–2013. Statistics given are the arithmetic mean (AM), median, geometric mean (GM), standard deviation (SD), maximum value (Max), and minimum value (Min). N is the sample size.

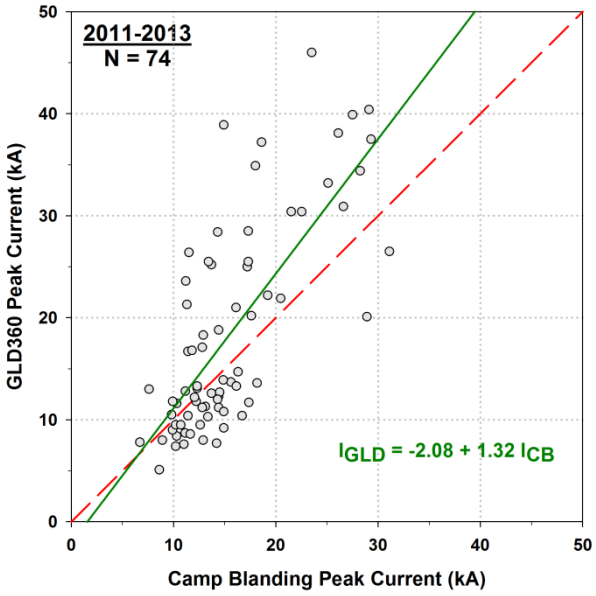

Fig. 5. GLD360-reported peak current (I_{GLD}) versus peak current directly measured at Camp Blanding (I_{CB}) for 74 return strokes in flashes triggered during 2011–2013. The green solid line, $I_{GLD} = -2.08 + 1.32 \times I_{CB}$, is the best (least squares) fit to the data, while the red broken line (the diagonal) represents the ideal situation when $I_{GLD} = I_{CB}$.

TABLE I. COMPARISON OF THE PERFORMANCE CHARACTERISTICS OF THE GLD360 FOR TRIGGERED-LIGHTNING RETURN STROKES IN DIFFERENT YEARS FROM 2011 TO 2013

	2011	2012	2013	2011–2013
Flash Detection Efficiency	55% (N = 11)	58% (N = 19)	92% (N = 12)	67% (N = 42)
Stroke Detection Efficiency	29% (N = 38)	31% (N = 101)	53% (N = 62)	37% (N = 201)
Percentage of Misclassified Strokes	0% (N = 11)	3% (N = 31)	0% (N = 33)	1.3% (N = 75)
Median Location Error	4.7 km (N = 11)	1.9 km (N = 31)	1.9 km (N = 33)	2.1 km (N = 75)
Median Absolute Current Estimation Error	41% (N = 11)	16% (N = 31)	29% (N = 32)	27% (N = 74)

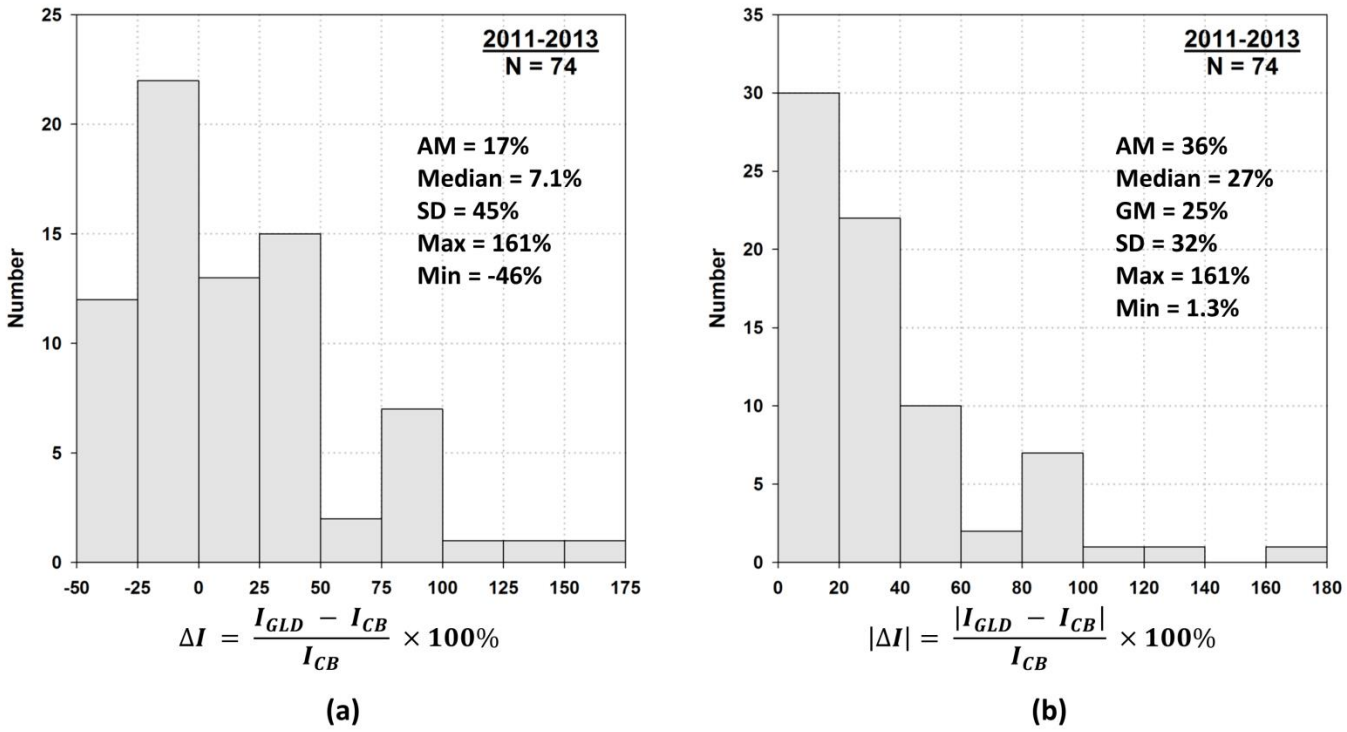

Fig. 6. Histograms of (a) signed and (b) absolute GLD360 peak current estimation errors, given as a percentage of the directly measured Camp Blanding current ($\Delta I\% = 100\Delta I/I_{CB}$, where $\Delta I = I_{GLD} - I_{CB}$) for 74 return strokes in flashes triggered during 2011–2013. Statistics given are the arithmetic mean (AM), median, geometric mean (GM), standard deviation (SD), maximum value (Max), and minimum value (Min). N is the sample size.

V. Summary

The GLD360 performance characteristics in the Florida region, estimated using 2011–2013 rocket-triggered lightning data, are as follows:

- The flash and stroke detection efficiencies were 67% and 37%, respectively.
- Out of 75 GLD360-detected strokes, 1 (1.3%) was reported with incorrect polarity.
- The median location error was 2.1 km.
- The median absolute current estimation error was 27%.

Acknowledgment

This research was supported in part by NSF Grant ATM-0852869.

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