An Update on Testing the Performance Characteristics of the ENTLN

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ABSTRACT: We have estimated the ENTLN performance characteristics using data for 62 negative return strokes in 12 flashes triggered during 2013 at Camp Blanding, Florida. The flash and stroke detection efficiencies were 100% and 94%, respectively. The ENTLN misclassified 53% of detected return strokes as cloud discharges. The median location error was 603 m and the median absolute current estimation error was 20%. The 2013 results are compared to those for 2009–2012, both corresponding to the same processor, implemented in November of 2012.

INTRODUCTION

The Earth Networks Total Lightning Network (ENTLN), formerly Weatherbug Total Lightning Network (WTLN), is a multiple-station lightning locating systems (LLS) which operates in the United States and in a number of other countries. The ENTLN employs wideband sensors (1 Hz to 12 MHz) to detect both cloud (IC) and cloud-to-ground (CG) lightning discharges [Heckman and Liu, 2010]. The time-of-arrival method is used to obtain lightning locations. Besides locations, polarity of charge lowered to ground by CGs and peak current estimates for both CGs and ICs are reported.

Mallick et al. [2013] evaluated the performance characteristics of the ENTLN using rocket-triggered lightning data from Camp Blanding (CB), Florida, for June of 2009 to August of 2012. During this period, 55 flashes containing 245 return strokes were triggered at Camp Blanding. The resultant flash and stroke detection efficiencies of the ENTLN were 80% and 49%, respectively. The median location error was 621 m and the median absolute peak current estimation error was 51%. The sample size for evaluation of errors in peak current estimates was 105. As many as 60% of negative return strokes detected by the ENTLN were incorrectly identified as +CGs or ICs. In November of 2012, the Earth Networks upgraded their data processor and in 2013, the same 2009–2012 triggered-lightning data were reprocessed using the new algorithm. After the reprocessing, the flash and stroke detection efficiencies became 89% and 67%, respectively. The median location error became 687 m and the median absolute peak current estimation error became 17%. The sample size for evaluation of errors in peak current estimates was 148. After the

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reprocessing, 52% of negative return strokes detected by the ENTLN were still incorrectly identified as +CGs or ICs. Table 1 gives a summary of results presented by Mallick et al. [2013].

In this paper, we will extend the study of Mallick et al. [2013] to additionally examine 62 strokes in 12 flashes triggered at Camp Blanding in 2013. We will make comparison between the performance characteristics for 2013 and for 2009–2012, the latter corresponding to the same processor as that operating in 2013 ("New Processor" in Table 1). This is the first evaluation of the new processor when it was actually in service.

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

Table 1 Summary of Performance Characteristics of the ENTLN Evaluated Using Rocket-Triggered Lightning Data Acquired at Camp Blanding in 2009–2012 (adapted from Mallick et al., 2013)

	Old Processor	New Processor
Flash Detection Efficiency	80% (N = 55)	89% (N = 55)
Stroke Detection Efficiency	49% (N = 245)	67% (N = 245)
Percentage of Misclassified Events	60% (N = 119)	52% (N = 165)
Median Location Error	621 m (N = 119)	687 m (N = 165)
Median Absolute Current Estimation Error	51% (N = 105)	17% (N = 148)

The old processor was in service when the 2009–2012 data were acquired. The new processor results can be viewed as prediction of future performance.

DATA AND METHODOLOGY

In 2013, a total of 12 flashes with 62 negative return strokes were triggered at Camp Blanding. The position of the launcher is known to within a few meters. The channel-base current was measured by resistive shunts with a bandwidth of 0 to 8 MHz. Fiber optic links were used to transmit signals from the sensors to digitizing oscilloscopes. The current measuring system is described in detail by Ngin et al. [2013]. The directly-measured current peaks may contain errors up to 10% [Jerauld et al., 2005], but for the purpose of this study they are assumed to be the absolute ground-truth.

Similar to the approach of Mallick et al. [2013], the following ENTLN performance characteristics were determined: (a) flash and stroke detection efficiencies, (b) percentage of misclassified strokes, (c) location error, and (d) peak current estimation error. Camp Blanding and ENTLN events were correlated using GPS time stamps. The detection efficiency values were computed as the ratios of the numbers of ENTLN-detected events and all triggered-lightning events recorded at Camp Blanding. Since all the triggered-lightning strokes examined here were negative strokes to ground (–CGs), the percentage of misclassified strokes is the number of ENTLN-detected strokes that were reported as not –CGs, expressed in percent of the total number of ENTLN-detected strokes. For a given event, the distance between the location of rocket launcher (or, in one case, the lightning attachment point on the ground) and the location

reported by the ENTLN is defined as the location error. The errors in ENTLN-reported peak currents were computed using the equation $\Delta I = I_{ENTLN} - I_{CB}$, where I_{ENTLN} is the ENTLN-reported peak current and I_{CB} is the peak value of current waveform directly measured at Camp Blanding. The current estimation error is expressed in percent of I_{CB}. Note that the detection efficiency values, location errors, and peak current estimation errors were computed regardless of how the stroke was classified (–CG, +CG, or IC) by the ENTLN, although different plot symbols and/or colors were used, where appropriate, to identify ENTLN classification.

Of the 62 strokes recorded at Camp Blanding, directly measured currents were available for 61 strokes. Figure 1a shows the peak current histogram for all return strokes (N = 61) recorded at Camp Blanding, regardless of whether they were detected by the ENTLN. For all the 61 directly measured peak currents, the geometric mean (GM) is 12.9 kA, median is 12.5 kA, maximum is 38.1 kA, and minimum is 5.5 kA. The statistics of return-stroke peak currents in 2013 are similar to those in 2009–2012 (see Figure 1b).

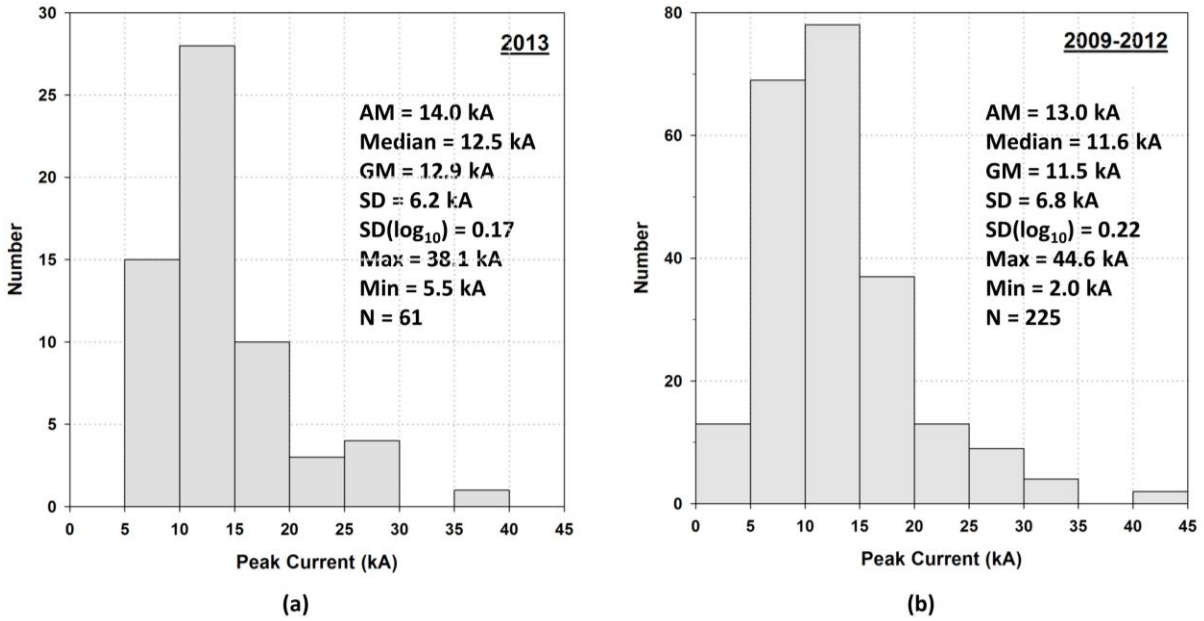


Figure 1. Histograms of peak currents directly measured at Camp Blanding for return strokes, both detected and not detected by the ENTLN in (a) 2013 and (b) 2009–2012. Statistics given are the arithmetic mean (AM), median, geometric mean (GM), standard deviation (SD), standard deviation of the $\log_{10}$ of the parameter ($SD(\log_{10}I)$), maximum value (Max), and minimum value (Min). N is the sample size.

RESULTS

Flash and Stroke Detection Efficiencies

The ENTLN detected 58 strokes in 12 flashes (out of 62 strokes in 12 flashes) in 2013. The ENTLN flash detection efficiency in 2013 was 100% and the stroke detection efficiency was 94%. Figure 2a shows histogram of the ENTLN stroke detection efficiency as a function of peak current directly measured at Camp Blanding. As expected, the stroke detection efficiency decreases with decreasing the peak current. For 2013, the stroke detection efficiency was 100% for peak current >10 kA. However, ENTLN missed one stroke with peak current of 38.1 kA, the reasons of which are presently unknown. Note that some of the strokes were detected by the ENTLN, but not correctly identified as –CGs.

Percentage of Misclassified Strokes

The ENTLN misclassified 31 strokes (out of 58 detected strokes, all –CGs) as ICs in 2013. None of the strokes was misclassified as +CGs. Hence, the percentage of misclassified strokes is 53%. Table 2 gives the number and percentage of strokes misclassified by the ENTLN as a function of peak current directly measured at Camp Blanding in 2013. The percentage of misclassified events monotonically decreases as the peak current increases.

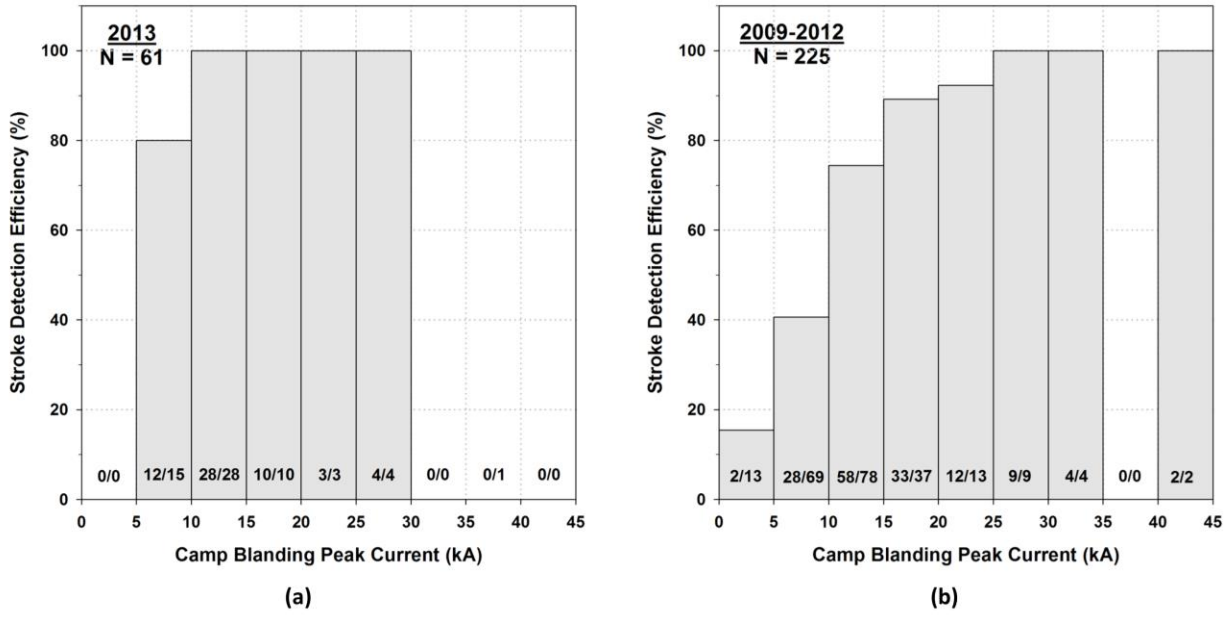


Figure 2. ENTLN stroke detection efficiency as a function of peak current directly measured at Camp Blanding for (a) 2013 and (b) 2009–2012. For each peak current range (bin size of 5 kA), the ratio given inside the column indicates the number of strokes detected by the ENTLN (numerator) and the number of strokes recorded at Camp Blanding (denominator) for that peak current range. Some of the strokes detected by the ENTLN were not correctly identified as –CGs. N is the sample size.

Table 2 Number and Percentage (in Parentheses) of Strokes Correctly Reported and Misclassified by the ENTLN in Different Ranges of Peak Current Directly Measured at Camp Blanding in 2013

Peak Current (kA)	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	0–40
Correctly Reported as -CGs	–	1 (8%)	12 (43%)	6 (60%)	3 (100%)	4 (100%)	–	–	26 (46%)
Misclassified as +CGs	–	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	–	–	0 (0%)
Misclassified as ICs	–	11 (92%)	16 (57%)	4 (40%)	0 (0%)	0 (0%)	–	–	31 (54%)
Total	0	12	28	10	3	4	0	0	57

The current record for one stroke is unavailable since the stroke did not terminate on the instrumented facility at CB. Hence, the percentage of correctly classified strokes is 47% (27 out of 58) and the percentage of misclassified strokes is 53% (31 out of 58).

Location Error

Figure 3 shows spatial distributions of locations for ENTLN-detected 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. Different plot symbols are used to identify triggered-lightning strokes (all negative) that were reported by the ENTLN as –CGs (blue circles), +CGs (red triangles), and ICs (green squares). In 2013, the AM and median north-south location errors are 951 m and 214 m, respectively, while the AM and median east-west location errors are -355 m and -132 m, respectively.

Figure 4 shows histograms of ENTLN location errors. Different colors are used to distinguish between the strokes reported by the ENTLN as –CGs (blue), +CGs (red), and ICs (green). In 2013, the median location error was 603 m, with the largest error being 31.7 km. About 67% (39 out of 58) of strokes had location errors ≤1 km. Table 3 gives the statistics of location errors for 2013 and 2009–2012.

Peak Current Estimation Error

Figure 5a shows scatter plots of the ENTLN-reported peak current versus peak current directly measured at Camp Blanding. The slanted broken line (slope = 1) in this figure is the locus of the points for which the ENTLN-reported peak currents and the directly-measured peak currents are equal. Different plot symbols are used to identify triggered-lightning strokes (all negative) that were reported by the ENTLN as –CGs (blue circles), +CGs (red triangles), and ICs (green squares). In 2013, for all 57 ENTLN-reported strokes with directly measured currents, the GM of Camp Blanding peak current was 13.1 kA versus 12.3 kA for ENTLN-reported peak currents. The AM value of the ratio I_{CB}/I_{ENTLN} was 1.1 (the ENTLN overestimates the peak current by about 10%, on average).

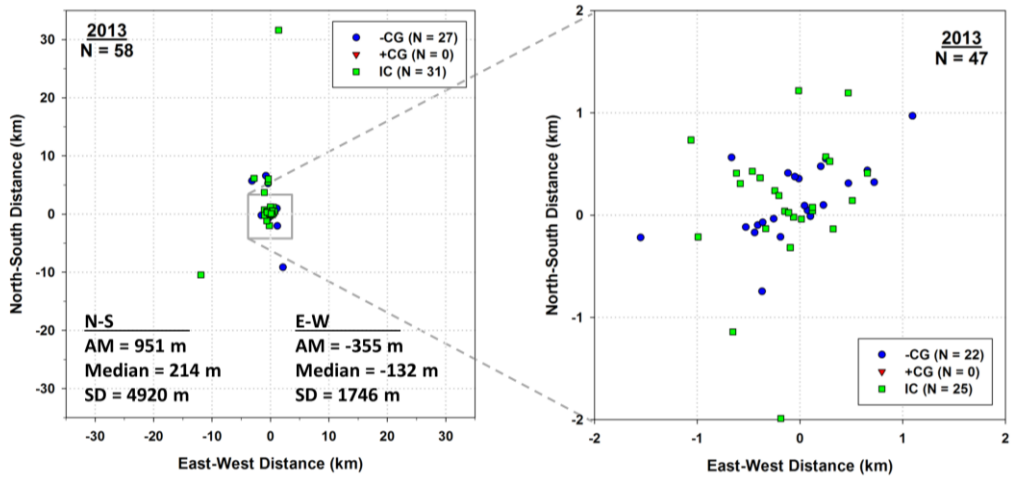


Figure 3. Plots of ENTLN-reported stroke locations for triggered-lightning strokes in 2013. The origin of coordinates corresponds to the actual stroke location. The horizontal axis corresponds to the east-west component of the location error, with positive values corresponding to east. The vertical axis corresponds to the north-south component of the location error, with positive values corresponding to north. Different plot symbols are used to identify triggered-lightning strokes (all negative) that were reported by the ENTLN as –CGs (blue circles), +CGs (red triangles), and ICs (green squares). Statistics given are arithmetic mean (AM), median, and standard deviation (SD), computed, for each location error component, regardless of how the stroke was classified by the ENTLN. N is the sample size.

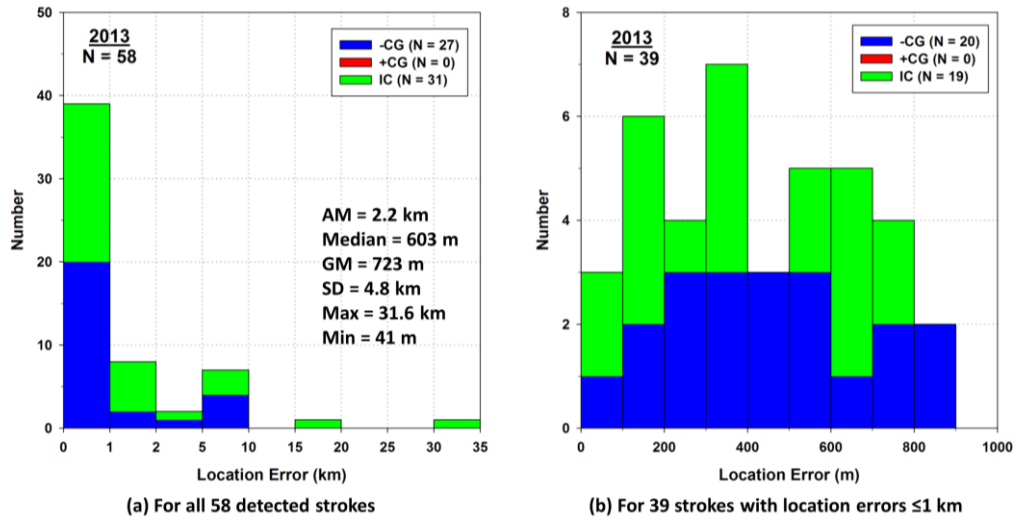


Figure 4. Histograms of the location error for (a) all ENTLN-detected strokes and (b) ENTLN-detected strokes with location error ≤1 km. Different colors are used to distinguish between the strokes reported by the ENTLN as –CGs (blue), +CGs (red), and ICs (green). Statistics given are the arithmetic mean (AM), median, geometric mean (GM), standard deviation (SD), maximum value (Max), and minimum value (Min), computed regardless of how the stroke was classified by the ENTLN. N is the sample size.

Table 3 Statistics of Location Errors

	2013	2009–2012
Arithmetic Mean (AM)	2.2 km	1.5 km
Median	603 m	687 m
Geometric Mean (GM)	723 m	725 m
Standard Deviation (SD)	4.8 km	3.0 km
Maximum (Max)	31.6 km	18.6 km
Minimum (Min)	41 m	66 m
Sample Seize (N)	58	165

Figure 6a shows histogram of signed values of ENTLN peak current estimation error as a percentage of Camp Blanding peak current ($\Delta I\% = 100\Delta I/I_{CB}$, where $\Delta I = I_{ENTLN} - I_{CB}$). The AM and median values of $\Delta I\%$ were −2.6% and −1.6%, respectively. Figure 6b shows histogram of the unsigned (absolute) values of ENTLN peak current estimation error as a percentage of Camp Blanding peak current. The AM and median values for absolute values of $\Delta I\%$ were 21% and 20%, respectively. Table 4 gives statistics of signed peak current estimation errors in 2013 and 2009–2012. Table 5 gives a similar summary for unsigned (absolute) peak current estimation errors.

Table 4 Statistics of Signed Peak Current Estimation Error

	2013	2009–2012
Arithmetic Mean (AM)	-2.6%	-5.5%
Median	-1.6%	-8.0%
Standard Deviation (SD)	24%	25%
Maximum (Max)	39%	71%
Minimum (Min)	-44%	-58%
Sample Seize (N)	57	148

Table 5 Statistics of Unsigned (Absolute) Peak Current Estimation Error

	2013	2009–2012
Arithmetic Mean (AM)	21%	20%
Median	20%	17%
Geometric Mean (GM)	17%	13%
Standard Deviation (SD)	11%	15%
Maximum (Max)	44%	71%
Minimum (Min)	1.6%	0.4%
Sample Seize (N)	57	148

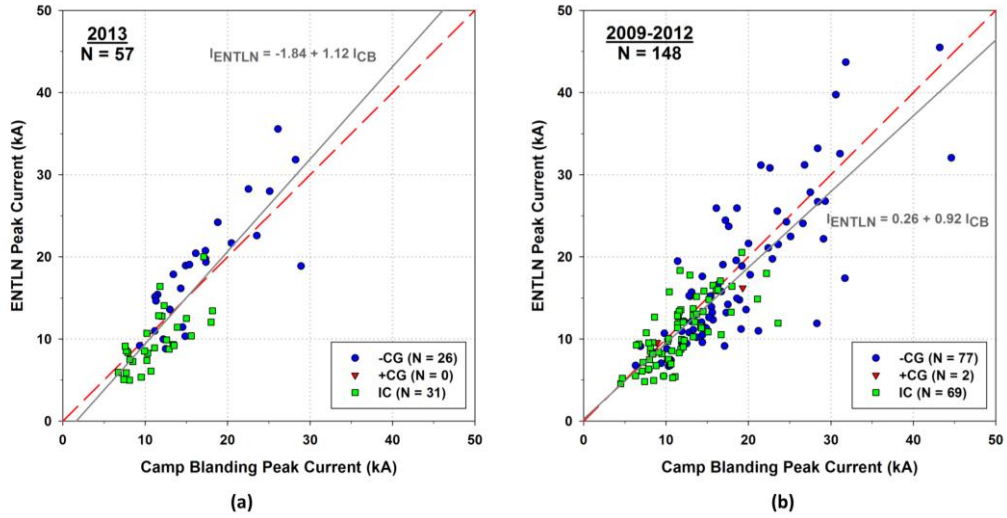


Figure 5. ENTLN-reported peak current versus peak current directly measured at Camp Blanding for (a) 2013 and (b) 2009–2012. The slanted broken line (slope = 1) is the locus of the points for which the ENTLN-reported peak currents and the directly-measured peak currents are equal. Different plot symbols are used to identify triggered-lightning strokes (all negative) that were reported by the ENTLN as –CGs (blue circles), +CGs (red triangles), and ICs (green squares). N is the sample size.

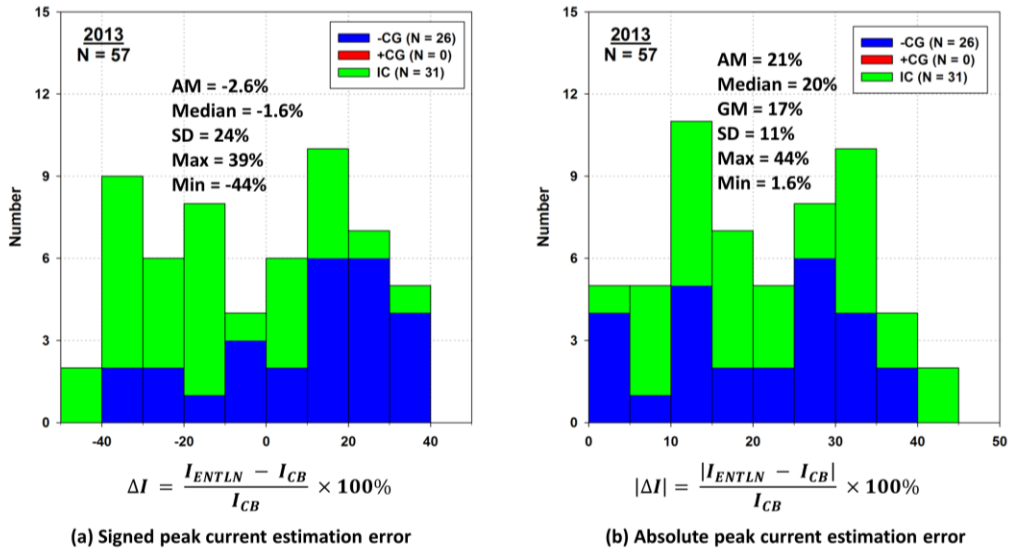


Figure 6. Histograms of ENTLN peak current estimation error, in percent of the directly measured Camp Blanding current ($\Delta I\% = 100\Delta I/I_{CB}$, where $\Delta I = I_{ENTLN} - I_{CB}$), for (a) signed values, and (b) unsigned or absolute values. Different colors are used to distinguish between the number of strokes reported by the ENTLN as –CGs (blue), +CGs (red), and ICs (green). Statistics given are the arithmetic mean (AM), median, geometric mean (GM), standard deviation (SD), maximum value (Max), and minimum value (Min), computed regardless of how the stroke was classified by the ENTLN. N is the sample size.

DISCUSSION

Table 6 gives a summary of performance characteristics of ENTLN for 2009–2012 and 2013. It follows from Table 6 that the flash and stroke detection efficiencies have increased (particularly for strokes), while other characteristics remain more or less the same.

It is important to note that more than half of negative return strokes detected by the ENTLN are still not correctly classified. Recall that the results presented here apply only to subsequent strokes and may be different for first strokes which the ENTLN classification algorithm is presumably tuned to.

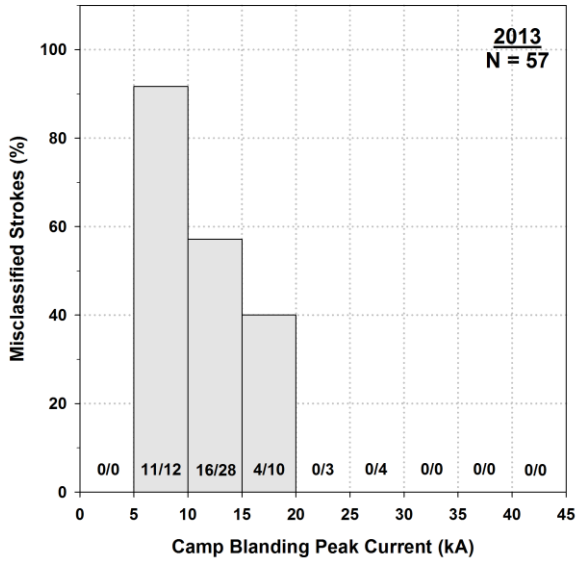
Figure 7 shows the percentage of –CG strokes misclassified by the ENTLN as a function of current peak, 10-to-90% risetime, and half-peak width. For all the 61 directly measured peak currents, the GM is 12.9 kA, median is 12.5 kA, maximum is 38.1 kA, and minimum is 5.5 kA. For 10-to-90% risetimes, the GM is 0.33 μs, median is 0.27 μs, maximum is 1.78 μs, and minimum is 0.16 μs. For half-peak widths, the GM is 18.9 μs, median is 23.8 μs, maximum is 70.7 μs, and minimum is 3.5 μs. It appears that the chances of misclassification of a stroke is relatively low for current peaks above 15 kA, risetimes in the range of 0.2 to 0.6 μs, and half-peak widths greater than 30 μs. Analysis of ENTLN field waveforms, which should shed some light on this issue, is presently in progress.

SUMMARY

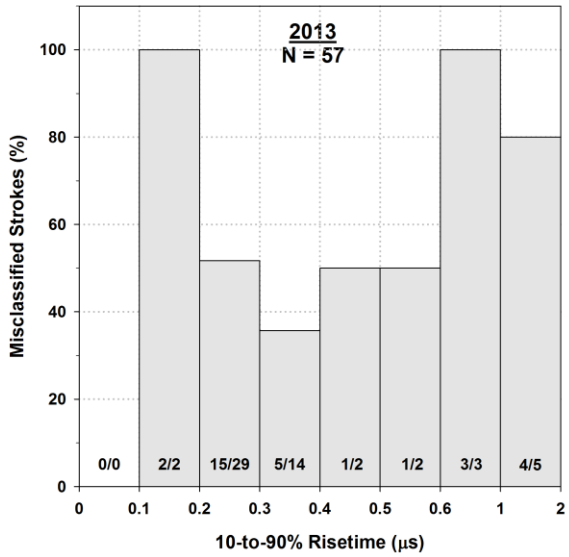
We have estimated the ENTLN performance characteristics using data for 62 negative return strokes in 12 flashes triggered during 2013 at Camp Blanding, Florida. The flash and stroke detection efficiencies were 100% and 94%, respectively. The ENTLN misclassified 53% of detected return strokes as cloud discharges. The median location error was 603 m and the median absolute current estimation error was 20%. The 2013 results are compared to those for 2009–2012, both corresponding to the same processor, implemented in November of 2012.

Table 6 Summary of ENTLN Performance Characteristics in 2009–2012 and 2013

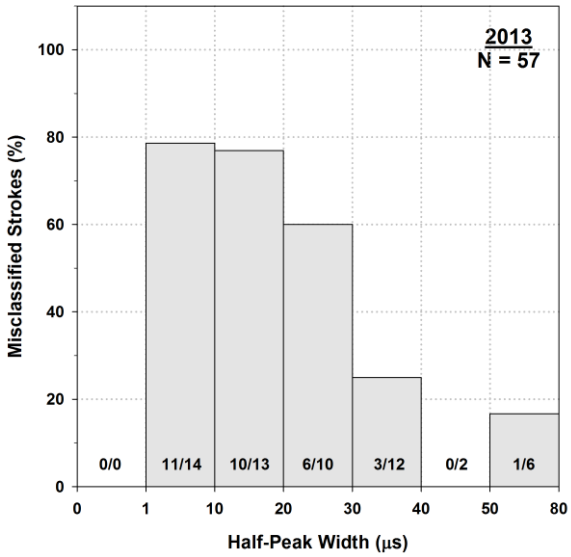
	2009–2012	2013
Flash Detection Efficiency	89% (N = 55)	100% (N = 12)
Stroke Detection Efficiency	67% (N = 245)	94% (N = 62)
Percentage of Misclassified Events	52% (N = 165)	53% (N = 58)
Median Location Error	687 m (N = 165)	603 m (N = 58)
Median Absolute Current Estimation Error	17% (N = 148)	20% (N = 57)



(a) Current Peak



(b) 10-to-90% Risetime



(c) Half-Peak Width

Figure 7. Percentage of –CG strokes misclassified by the ENTLN as a function of (a) current peak, (b) current 10-to-90% risetime, and (c) current half-peak width. For each histogram bin, the ratio given inside the column indicates the number of strokes misclassified by the ENTLN as ICs (numerator) and the number of strokes detected by the ENTLN (denominator). N is the sample size.

ACKNOWLEDGMENTS

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