2016 24th International Lightning Detection Conference &
6th International Lightning Meteorology Conference
18 - 21 April | San Diego, California, USA

Update to the U.S. National Lightning Detection Network

Amitabh Nag[1], Martin J. Murphy[1], and John A. Cramer[2]
[1]Vaisala Inc., Louisville, Colorado, USA
[2]Vaisala Inc., Tucson, Arizona, USA

***Abstract*— Updates were made to the NLDN central processor (CP) on August 18, 2015. In this study, we examine the effect of the latest updates by comparing lightning data reported by the new and old NLDN central processors in the interior of the network. About 13.1 million lightning events (CG strokes and cloud pulses) were reported by the NLDN during the chosen period (August 20 and December 10, 2015). Of these, the majority, about 63%, were cloud flashes. On average, 2.3 pulses were reported per cloud flash. The average multiplicity (number of strokes per flash) for negative and positive cloud-to-ground flashes was 2.7 and 1.4, respectively. Overall, the new CP reported 30% more cloud pulses and 8.5% more cloud flashes relative to the old CP. There is no major change in the number of reported negative first and subsequent strokes. The 15 kA peak current limit below which all positive lightning events were classified as cloud has been removed in the new NLDN CP. This has resulted in a significant change in the classification of positive polarity events. Further investigation is necessary to examine the characteristics of positive events, especially those in the 2-10 kA range, being reported by the new CP as cloud-to-ground strokes.**

Keywords*— *U.S. NLDN; performance characteristics; cloud lightning; cloud-to-ground lightning; detection efficiency; location accuracy; peak current

I. Introduction

In 2013, LS7002 sensors were deployed in the U.S. National Lightning Detection Network (NLDN) replacing the older generation LS7001 and IMPACT sensors [Nag et al., 2014]. The new sensor technology improved the sensitivity of the network to low amplitude lightning-generated signals and led to enhanced detection of cloud and cloud-to-ground lightning. In addition to a cloud-to-ground flash detection efficiency of greater than 95%, the cloud lightning flash detection efficiency of the network is about 50% [e.g., Murphy and Nag, 2015; Zhang et al., 2015]. Most studies [e.g., Mallick et al., 2014; Zhang et al., 2015] have reported the NLDN's lightning type classification accuracy to range from 80% to more than 90% for different known lightning types. However, in special storm types (such as inverted polarity storms), the NLDN might misclassify a larger proportion of lightning events. The performance characteristics of the NLDN continue to be validated by triggered lightning, tower strikes, network inter-comparison, and camera studies [e.g., Mallick et al., 2014a, b; Cramer and Cummins, 2014; Murphy and Nag, 2015; Zhang et al., 2015].

The performance characteristics of a lightning detection network depend upon the characteristics of its sensors and the techniques used in the network's central processor (CP) to geolocate lightning. After the 2013 upgrade, which consisted of deploying the latest sensor technology in the NLDN, further improvements have been made to the NLDN. On August 18, 2015, a new sensor data format, transmitted by the NLDN's LS7002 sensors and containing more information about each lightning event and flash, was adopted. Additionally, the NLDN CP was updated to include a new location algorithm, a "burst processing" algorithm for geolocation of multiple pulses in lightning pulse trains, a new technique for classifying lightning using multiple waveform parameters, and improved handling of electromagnetic wave propagation resulting in smaller arrival-time errors.

In this study, we examine the effect of these latest changes to the NLDN on the reported lightning data. Lightning discharges reported by the new NLDN CP between August 20 and December 10, 2015 within the interior (latitude and longitude boundaries of 33, -116 and 41, -80) of the contiguous United States are analyzed. We compare this dataset with data from the same time period reprocessed using the old (now obsolete) NLDN CP.

II. Data and Analysis

About 13.1 million lightning events (CG strokes and cloud pulses) were reported by the NLDN within the interior of the network during the chosen period. Of these, the majority, about 71%, were cloud pulses as classified by the NLDN. These lightning events can be grouped into flashes using the flash grouping algorithm described by Murphy and Nag [2015]. Any flash containing a cloud-to-ground return stroke is a cloud-to-ground flash, whereas cloud flashes consist of cloud pulses only. A cloud-to-ground flash is called negative or positive depending upon the polarity of the first stroke. The new NLDN CP reported 4.1 million flashes, of which about 63% (2.56 million) were cloud flashes. On average, 2.3 pulses were reported per cloud flash.

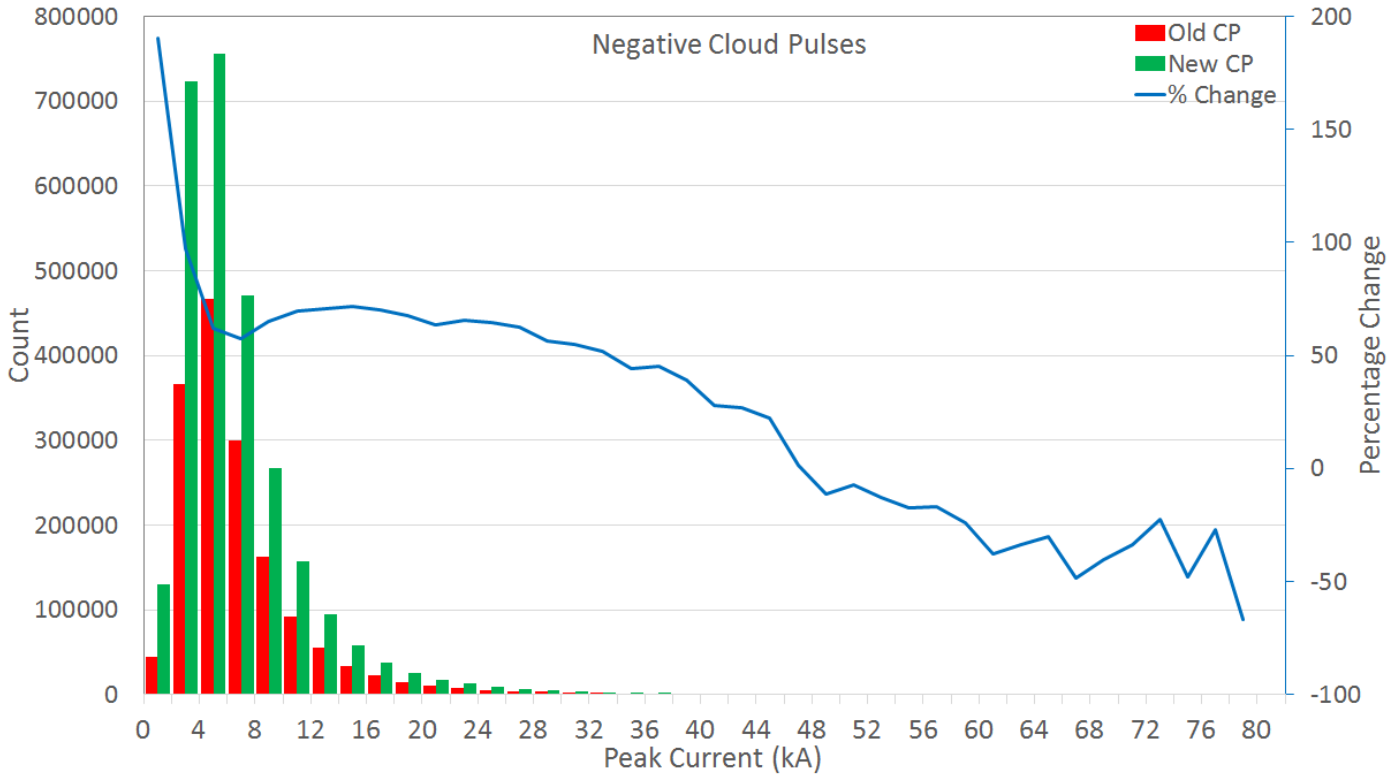

Fig. 1. Histograms showing the absolute value of peak current of negative cloud pulses in 2 kA bins reported by the old (red bars) and new (green bars) NLDN central processors. The blue line indicates the percentage change (100 x [$NLDN_{new}$ – $NLDN_{old}$]/$NLDN_{old}$, shown on the right vertical axis) in the number of negative cloud lightning pulses reported in each 2 kA peak current bin.

A. Cloud Lightning

Figure 1 shows the histograms of absolute value of peak current for negative cloud lightning pulses reported by the new CP (green bars) and the old CP (red bars). The peak currents reported by the new CP ranged from 1 kA to 269 kA, and the arithmetic mean and median peak currents were 7 kA and 6 kA, respectively. Note that the horizontal axis in Figure 1 was truncated at 80 kA as the proportion of cloud pulses having peak current magnitudes greater than this limit was less than 0.05%. A total of about 2.79 million pulses were reported. By comparison, the old CP reported about 1.60 million pulses, indicating a 74% increase in the number of cloud pulses in the new CP. The blue line in Figure 1 indicates the percentage change (100 x [$NLDN_{new}$ – $NLDN_{old}$]/$NLDN_{old}$, scale shown on the right vertical axis) in the number of cloud lightning pulses reported in each 2 kA peak current bin. The largest increase in detection was for negative cloud pulses with peak currents less than 4 kA, but at least 50% more cloud pulses were reported in every 2 kA bin up to about 30 kA. For peak currents above 50 kA, the new NLDN CP reported fewer events as cloud pulses than the old CP. This is a result of the new classification algorithm that takes into account multiple waveform features, including peak current, in order to classify an event as cloud or cloud-to-ground. Events having peak currents greater than few tens of kiloamperes are much more likely to be cloud-to-ground strokes than cloud pulses, and it is likely that some of these events were misclassified by the old NLDN CP as cloud pulses (see further discussion in Section II B).

Figure 2 shows the histograms of peak current for positive cloud lightning pulses reported by the new CP (green bars) and the old CP (red bars). The minimum and maximum peak currents reported by the new CP were 1 kA and 366 kA, respectively, and the arithmetic mean and median peak currents were both 6 kA. Note that the horizontal axis in Figure 2 was truncated at 100 kA as the proportion of cloud pulses having peak current magnitudes greater than this limit was less than 0.005%. A total of about 6.49 million pulses were reported. By comparison, the old CP reported about 5.52 million pulses, indicating an 18% increase in the number of positive cloud pulses in the new CP. The blue line in Figure 1 indicates the percentage change (scale shown on the right vertical axis) in the number of cloud lightning pulses reported in each 2 kA peak current bin. The largest increase in detection was for positive cloud pulses with peak currents less than 10 kA. For peak currents above 20 kA, the new NLDN CP reported fewer events as cloud pulses than the old CP. As with the negative cloud pulses, this change likely reflects the fact that the old NLDN CP misclassified some cloud-to-ground strokes as cloud pulses.

Overall, the new CP reported 9.28 million cloud pulses, versus 7.12 million reported by the old CP (an increase of about 30%). The new CP reported 2.56 million cloud flashes versus 2.36 million reported by the old CP, indicating an 8.5% increase in the number of cloud flashes reported by the new CP. Note that the cloud pulses considered in Figures 1 and 2 may belong to cloud or cloud-to-ground flashes. Only a subset of these pulses belong to the cloud flashes discussed above and the rest are associated with cloud-to-ground flashes.

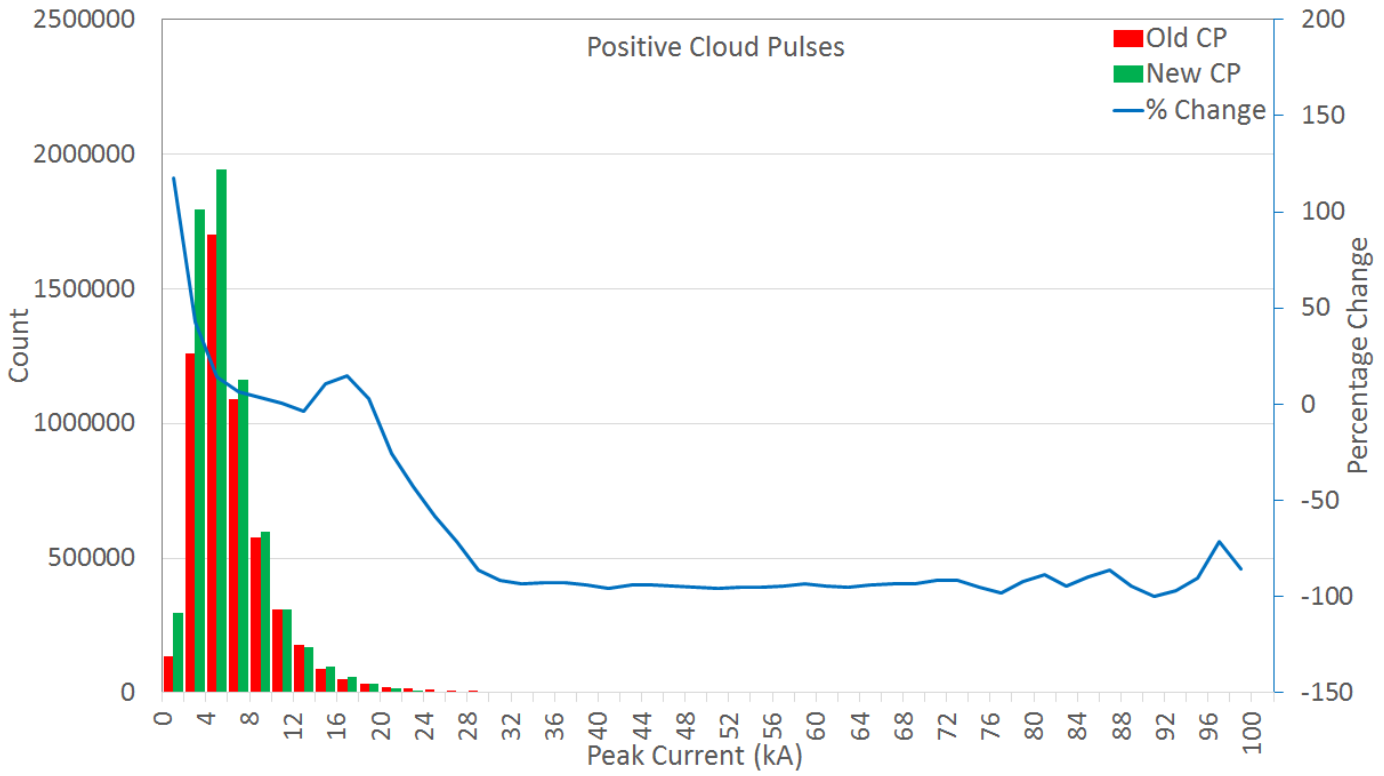

Fig. 2. Histograms showing the peak current of positive cloud pulses in 2 kA bins reported by the old (red bars) and new (green bars) NLDN central processors. The blue line indicates the percentage change (100 x [$NLDN_{new}$ – $NLDN_{old}$]/$NLDN_{old}$, shown on the right vertical axis) in the number of positive cloud lightning pulses reported in each 2 kA peak current bin.

B. Negative Cloud-to-Ground Lightning

About 83% of the cloud-to-ground flashes and 91% of cloud-to-ground strokes reported by the new CP were negative. Figure 3 shows the histograms of peak current for first (blue bars) and subsequent (brown bars) strokes in negative cloud-to-ground lightning. The minimum and maximum negative first stroke peak currents were 1 kA and 451 kA, respectively. The arithmetic mean and median peak currents were 19 kA and 14 kA, respectively. For negative subsequent strokes, the minimum and maximum first stroke peak currents were 1 kA and 431 kA. The arithmetic mean and median peak currents were 16 kA and 13 kA, respectively. Note that the horizontal axis in Figure 3 was truncated at 100 kA as the proportion of strokes having peak current magnitudes greater than this limit was less than 0.5%. About 1.30 million first and 2.21 million subsequent strokes were reported. The average multiplicity (number of strokes per flash) for negative cloud-to-ground flashes was 2.7. It is possible that a small fraction of cloud pulses were misclassified by the NLDN as single stroke cloud-to-ground flashes and some low peak current subsequent strokes were not reported by the NLDN. Hence, the average multiplicity for negative cloud-to-ground flashes is likely an underestimate.

By comparison, the old CP reported about 1.37 million negative first and about 2.17 million negative subsequent strokes. The first stroke (and negative flash) count decreased by 3.2% in the new CP, the subsequent stroke count increased by 1.0% and the total number of events reported as strokes decreased by 0.94%. This indicates a small overall change in classification. Figures 4a and b show, for first and subsequent strokes, respectively, the histograms of peak current reported by the new CP (green bars) and the old CP (red bars). The blue line in each figure indicates the percentage change (shown on the right vertical axis) in the number of strokes reported in each 2 kA peak current bin. Events previously classified as cloud-to-ground strokes and now classified as cloud pulses mostly have peak currents less than 15 kA. On the other hand, as seen from Figure 4b, some events, mostly having peak currents greater than 20 kA, are now classified as cloud-to-ground strokes rather than cloud pulses by the new CP. This is consistent with the observed decrease in the number of high peak current negative cloud pulses reported by the new CP relative to the old one, as discussed in Section II A.

C. Positive Cloud-to-Ground Lightning

About 17% of the cloud-to-ground flashes and 9.0% of cloud-to-ground strokes reported by the new CP were positive. Figure 5 shows the histograms of peak current for first (blue bars) and subsequent (brown bars) strokes in positive cloud-to-ground lightning. The minimum and maximum positive first stroke peak currents were 1 kA and 714 kA. The arithmetic mean and median peak currents were 23 kA and 17 kA, respectively. For positive subsequent strokes, the minimum and maximum first stroke peak currents were 1 kA and 643 kA, respectively. The arithmetic mean and median peak currents were 24 kA and 18 kA, respectively. Note that the horizontal axis in Figure 5 was truncated at 150 kA as the proportion of strokes having peak current magnitudes greater than this limit was less than 0.5%. 274306 first and 74135 subsequent strokes were reported. The average multiplicity for positive cloud-to-

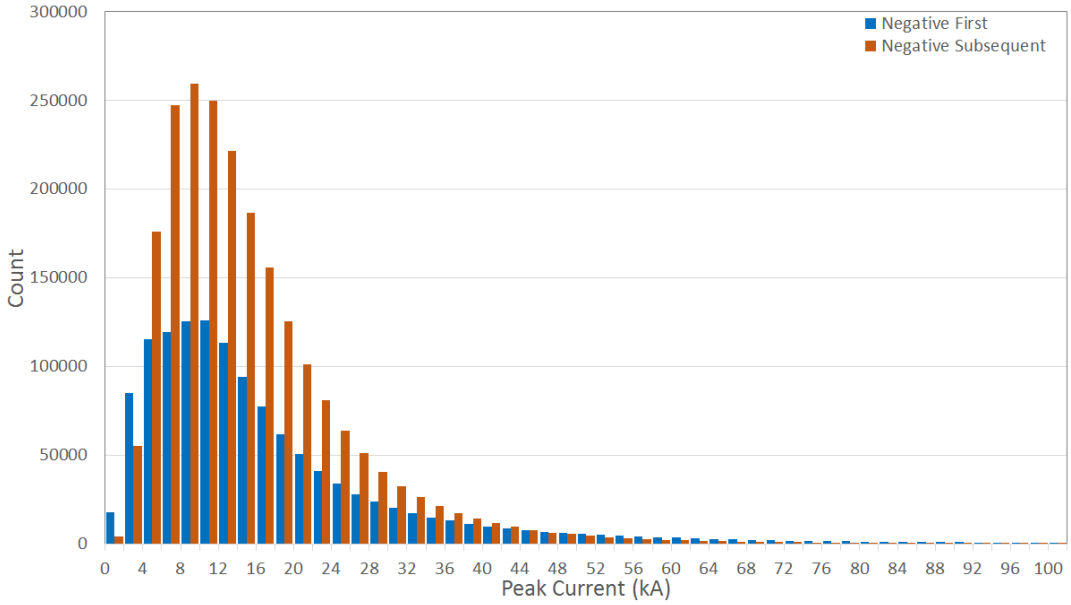

Fig. 3. Histograms showing the absolute value of peak current of negative first (blue bars) and subsequent (brown bars) strokes in 2 kA bins reported by the new NLDN central processor.

ground flashes was 1.4. Note that the old NLDN CP classified all positive lightning events having peak currents less than +15 kA as cloud pulses. The new CP removes this hard limit for peak current for positive events and classifies lightning events on the basis of their waveform characteristics (which includes their peak current). From Figure 5 we can see that both first and subsequent stroke distributions reported by the new CP have peaks in the 2-10 kA range. Additionally, there is a secondary peak in the 16-24 kA range. This is likely due to misclassification of low peak current cloud pulses as cloud-to-ground strokes by the new CP. Further studies need to be conducted to examine the characteristics of positive events in the 2-10 kA range being reported by the new CP as cloud-to-ground strokes.

Figures 6a and b show, for first and subsequent strokes, respectively, the histograms of peak current reported by the new CP (green bars) and the old CP (red bars). The old CP reported 95898 positive first and 34122 positive subsequent strokes; both counts are a factor of 2 to 3 lower compared to the new CP. This is due to the removal of the hard limit of +15 kA for classification (discussed above). Additionally, a significantly greater number of events having peak currents greater than 16 kA are being detected and classified as cloud-to-ground strokes by the new CP versus the old CP. This is consistent with the observed decrease in the number of high peak current positive cloud pulses reported by the new CP relative to the old one, as discussed in Section II A. Clearly, the new classification technique in the new CP has had a significant impact on the classification of positive polarity events and needs to be further studied. It is likely that some positive polarity cloud pulses such as preliminary breakdown and stepped leader pulses occurring prior to the first return stroke are being misclassified by the new CP as positive first strokes. However, positive strokes comprise less than 10% of all cloud-to-ground strokes and 2.9% of all events reported by the new CP, so the overall misclassification rate is still expected to be relatively small.

III. Summary

On August 18, 2015, a new sensor data format that contains more information about each lightning event and flash was adopted. Additionally, the NLDN central processor (CP) was updated to include a new location algorithm, a "burst processing" algorithm for geolocation of multiple pulses in lightning pulse trains, a new technique for classifying lightning using multiple waveform parameters, and improved handling of electromagnetic wave propagation resulting in smaller arrival-time errors.

About 13.1 million lightning events (CG strokes and cloud pulses) were reported by the NLDN during this period of which the majority (about 71%) were cloud pulses as classified by the NLDN. These events can be grouped into 4.1 million flashes, of which about 63% (2.56 million) were cloud flashes. On average, 2.3 pulses were reported per cloud flash. We compared the data from the new and old NLDN CPs. A significantly larger number of cloud pulses (74% for negative and 18% for positive) are being reported by the new NLDN CP due to improved detection. Overall, the new CP reported 30% more cloud pulses and 8.5% more cloud flashes relative to the old CP.

About 83% of the cloud-to-ground flashes and 91% of cloud-to-ground strokes reported by the new CP were negative. There is no major change in the number of reported negative first and subsequent strokes, even though, some low peak current events are now being classified as cloud pulses and high peak current events are being classified as cloud-to-ground strokes by the new CP. Positive strokes comprise less than 10% of all cloud-to-ground strokes reported by the new CP. The +15 kA peak current limit below which all positive lightning events were classified as cloud has been removed in the new NLDN CP. This has resulted in a significant change in the classification of positive polarity events. Further investigation is necessary to examine the characteristics of positive events, especially those

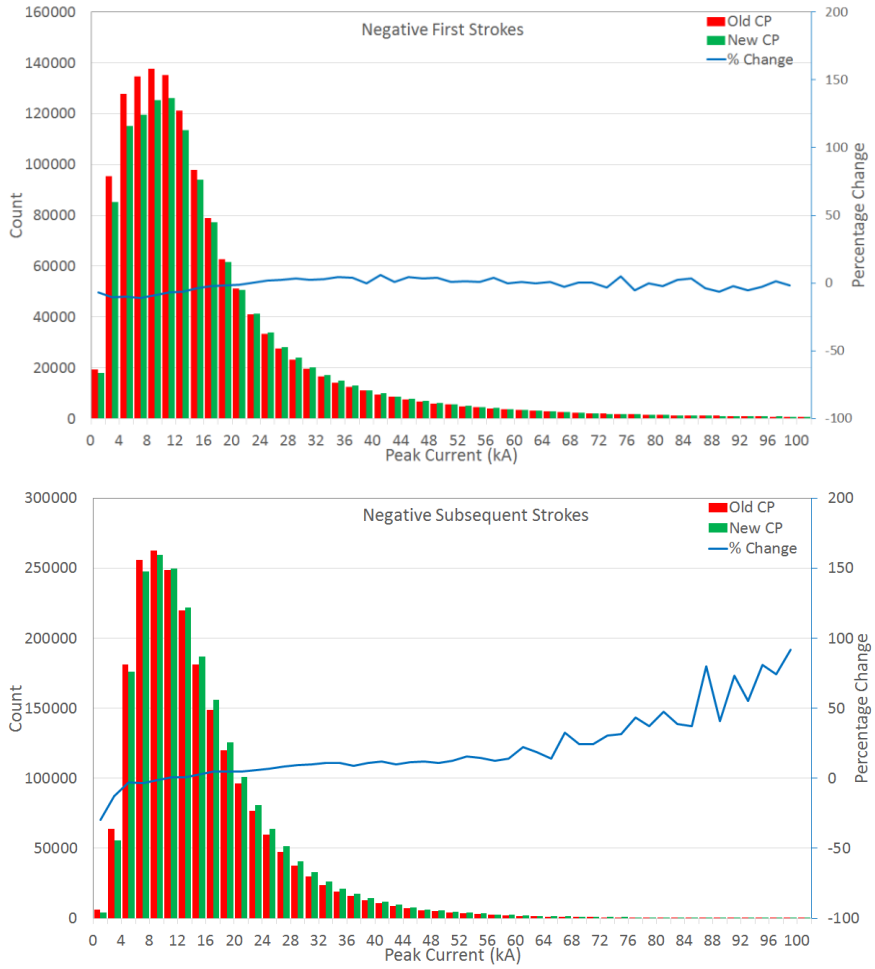

Fig. 4. Histograms showing the absolute value of peak current of negative (a) first and (b) subsequent strokes in 2 kA bins reported by the new NLDN central processor (green bars) and the old NLDN central processor (red bars).

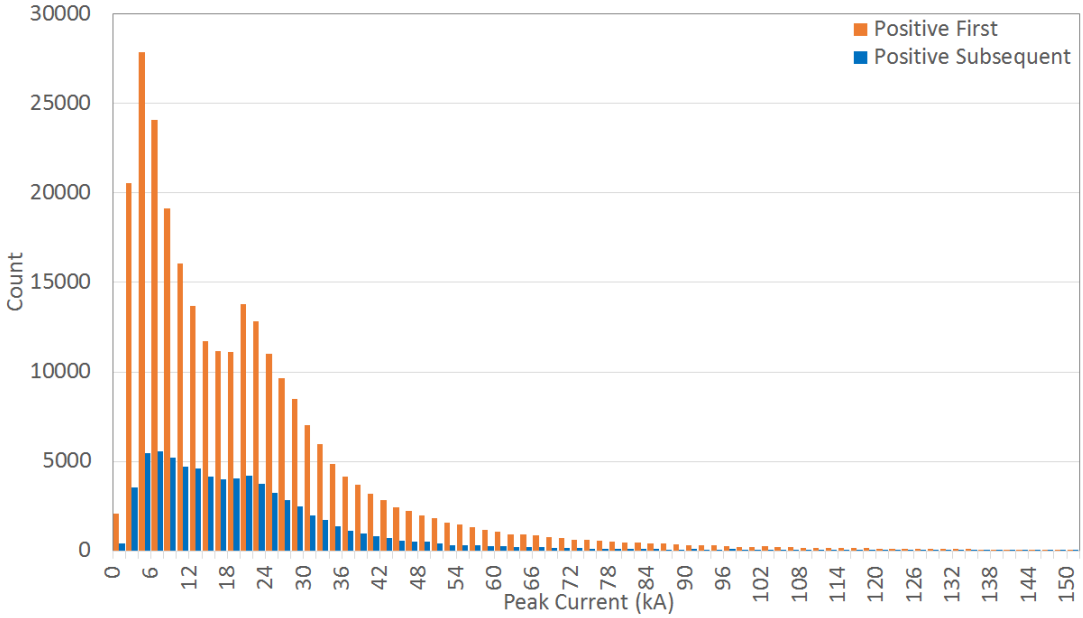

Fig. 5. Histograms showing the peak current of positive first (blue bars) and subsequent (brown bars) strokes in 2 kA bins reported by the new NLDN central processor.

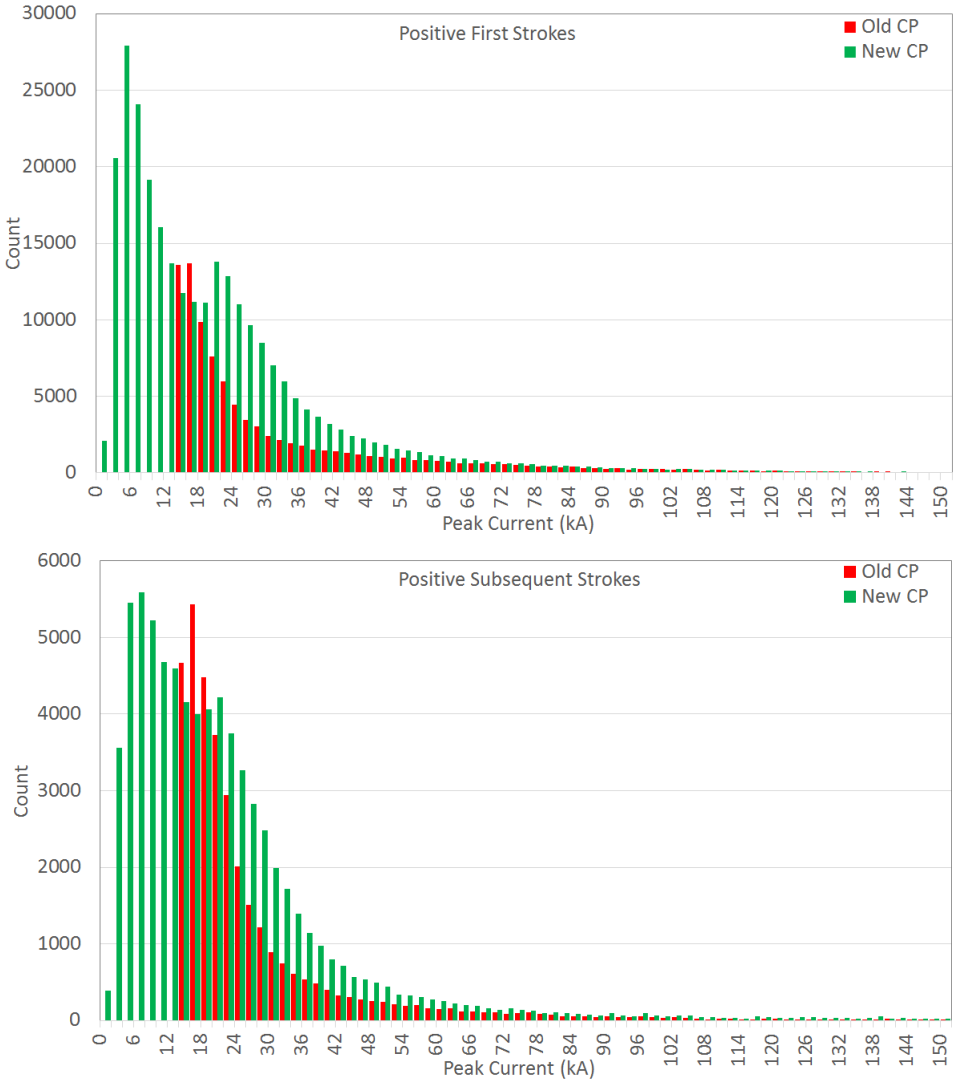

Fig. 6. Histograms showing the peak current of positive (a) first and (b) subsequent strokes in 2 kA bins reported by the new NLDN CP (green bars) and the old NLDN CP (red bars).

in the 2-10 kA range, being reported by the new CP as cloud-to-ground strokes.

In summary, the introduction of the new classification algorithm has generally moved the distributions of most events in the anticipated, and mostly likely correct, direction relative to the older classification method. That is to say, we anticipate that most cloud pulses are of relatively low amplitude, and indeed, the largest increases in cloud pulse counts in the new CP are at equivalent peak currents of about 10 kA and lower, in both polarities. CG strokes are expected, on average, to be higher in amplitude than most cloud pulses, and we find that the gains in CG stroke counts are primarily at larger peak currents. The exception is in the positive CG strokes, which also showed a sizable gain in low-current events. Although this is an important issue and will receive greater scrutiny in future studies, it is also important to note that positive CG strokes still comprise only 2.9% of all events reported by the new CP, such that the overall misclassification error of the NLDN is still expected to be very low, consistent with the results of validation studies discussed in Section I.

REFERENCES

Cramer, J. A., and K. L. Cummins (2014), Evaluating location accuracy of lightning location networks using tall towers, in 23rd International Lightning Detection Conference & 5th International Lightning Meteorology Conference, Vaisala Inc., Tucson, Ariz.

Mallick, S., et al. (2014a), Performance characteristics of the NLDN for return strokes and pulses superimposed on steady currents, based on rocket-triggered lightning data acquired in Florida in 2004–2012, J. Geophys. Res. Atmos., 119, 3825–3856, doi:10.1002/2013JD021401.

Mallick, S., V. A. Rakov, T. Ngin, W. R. Gamerota, J. T. Pilkey, J. D. Hill, M. A. Uman, D. M. Jordan, J. A. Cramer, and A. Nag (2014b), An update on the performance characteristics of the NLDN, in 23rd International Lightning Detection Conference & 5th International Lightning Meteorology Conference, Vaisala Inc., Tucson, Ariz.

Murphy, M., and A. Nag (2015), Cloud lightning performance and climatology of the U.S. based on the upgraded U.S. National Lightning Detection Network, in Seventh Conference on the Meteorological Applications of Lightning Data, paper 8.4, Am. Meteorol. Soc., Phoenix, Ariz., 4–8 Jan.

Nag, A., M. J. Murphy, K. L. Cummins, A. E. Pifer, and J. A. Cramer (2014), Recent evolution of the U.S. National Lightning Detection Network, in 23rd International Lightning Detection Conference & 5th International Lightning Meteorology Conference, Vaisala Inc., Tucson, Ariz.

Zhang, D., K. L. Cummins, and A. Nag (2015), Assessment of cloud lightning detection by the U.S. National Lightning Detection Network using video and Lightning Mapping Array observations, in Seventh Conference on the Meteorological Applications of Lightning Data, Am. Meteorol. Soc., Phoenix, 4–8 Jan.