# 7.1 ASSESSMENT OF CLOUD LIGHTNING DETECTION BY THE U.S. NATIONAL LIGHTNING DETECTION NETWORK USING VIDEO AND LIGHTNING MAPPING ARRAY OBSERVATIONS

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## 1. INTRODUCTION

The U.S. National Lightning Detection Network™ (NLDN), historically viewed as a cloud-to-ground (CG) detection network, underwent an upgrade aimed at increasing the detection efficiency (DE) for intra-cloud (IC) lightning flashes starting in early 2013 (Nag et al., 2014). In order to evaluate this upgrade, we employed observations obtained during field programs carried out near a wind farm in Kansas (central U.S.) during the summers of 2012 before the upgrade and 2013 after the upgrade (Cummins et al, 2014a). A previous study (Cummins et al, 2014b) has shown an unexpectedly low DE (32.9%) for IC flashes during late May through early June 2013, due to a network-wide NLDN communication problem. In this analysis, NLDN data during an extended period after the problematic duration is examined. The NLDN performance summary for 2012 and 2013 is also given.

For flashes identified as IC discharges we have examined the possible relationship between their temporal and spatial behaviors represented by Very High Frequency (VHF) sources reported by a Lightning Mapping Array (LMA, see Rison et al., 2000) and low frequency IC pulses reported by the NLDN. Additionally, we have explored correlations between storm characteristics and the NLDN IC flash DE including flash rate, IC/CG ratio and percent positive CG.

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## 2. DATA AND METHODS

The observations in this analysis include optical measurements that were obtained using two standard-speed automatically-triggered video cameras employed during the 2012 and 2013 storm seasons, and VHF lightning mapping data provided by a short-baseline LMA available during the 2013 storm season (see Cummins 2014a for details). Generally, lightning flash type (IC versus CG) was identified by using the video observation based on any distinguishable channel. The LMA data were used to classify flashes for cases where the video data provided ambiguous flash type identification, since the LMA data provide a description of the spatial and temporal evolution of a flash.

Time and location information of CG strokes and IC pulses from nearby NLDN sensors are also used in our analysis. It should be noted that this analysis excludes the problematic period during late May through early June mentioned above, when a network-wide communication problem lowered the DE for IC flashes.

## 3. RESULTS AND DISCUSSION

### *3.1. NLDN Performance Summary of 2012 and 2013*

The NLDN performance summary for 2012 and 2013 is shown in Table 1 below. The CG flash DE in 2013 was 97% (149/154), which is slightly higher than the 96% (183/190) DE in 2012. The IC flash DEs in 2012 and 2013 were 29% (28/98) and 41% (134/329), which shows an improvement after the upgrade. The supplemented 2013 data referred to in the table includes the original data in 2013 (problematic period excluded) and 278 additional flashes (including 51 CGs and 100 ICs) over extra days in July. The slightly higher IC detection efficiency of the supplemented data compared to that of previous 2013 data indicates that the NLDN communication problem was resolved during the new analysis period.

As for the flash type classification, our previous study (Cummins et al. 2014b) showed a 92% (98/107) correct type classification for cloud flashes by the NLDN. For individual NLDN-report cloud pulses, 78% (46/59) of negative and 100% (108/108) of positive pulses were classified correctly. Overall, 92% (154/167) of the IC pulses reported by the NLDN were properly classified. Qualitatively, storms with high percentages of positive CG flashes seem to have a larger number of misclassified negative IC pulses.

*Table 1 The NLDN Performance Summary of 2012 and 2013 (* May 29$^{th}$ through June 4$^{th}$ removed)*

| **Flash Type** | **Detection Efficiency % (counts)** | | |
|---|---|---|---|
| | *2012* | *2013* | *Supplemented 2013* |
| CG | 96 (183/190) | 96 (99/103) | 97 (149/154) |
| IC | 29 (28/98) | 40 (89/229) * | 41 (134/329) * |

## 3.2. Correlation between LMA Features and NLDN-reported Flashes

In order to study possible relationships between LMA source patterns and the NLDN-reported IC pulses, four types of LMA temporal features were identified in LMA time:height plots. As shown in Fig. 1, an IC flash will typically have an upward breakdown between a mid-level charge region (typically negative) and an upper level charge region (typically positive) during the initial 10-50 ms, which is identified here as a Type 1 feature. Many occurrences of this feature have an associated NLDN report. Type 2 is defined as the pattern where multiple charge layers become clear in the time:height plot (Fig. 1). Type 3 is defined as the occurrence of vertical development between any two charge layers (Fig. 2). In addition to these three types, the NLDN has reported several IC pulses that do not have a visually distinct pattern on the time:height representation, which we define as Type 4.

A total of 47 flashes were analyzed, including 21 reported and 26 non-reported. A reported flash can have one or more pulses that are reported by the NLDN. Preliminary results indicate that IC pulses associated with either an LMA Type 1 or Type 3 feature are more likely to be reported by the NLDN. On a flash basis, 12 out of 21 (57%) had Type 1 features, and 8 (38%) had Type 3 features. On a pulse basis, 41% (13/32) and 25% (8/32) of them were associated with Type 1 and Type 3, respectively. Only two NLDN reports were associated with LMA Type 2 feature. This is consistent with earlier findings that the NLDN tends to detect the vertical breakdown during the initiation of the flashes or between two charge regions. In addition, there were 9 (28%) reported pulses that were related to Type 4 features. Given this large number of Type 4 reports (which do not show a clear LMA time:height representation), we can say that the time height feature alone is not sufficient to predict detection by the NLDN. It should be noted that some of the flashes could have more than one report for each type. However, it is still not clear what determines the number of the NLDN reports and the IC pulses during a flash.

IC flash behavior during the initial breakdown and early leader propagation may also be associated with the likelihood of an NLDN report. Preliminary findings indicate that for an NLDN report to be associated with a Type 1 feature of an IC flash, the LMA initial upward velocity is of importance. Among 21 reported flashes, 17 (81%) of them had an initial upward velocity larger than $2 \times 10^5$ m/s. Additionally, 22 out of 26 (85%) non-reported flashes had an initial upward velocity less than $2x10^5$ m/s. Though more data are needed to reach a definitive conclusion, the initial (within 10 ms) upward velocity may reflect flash energetics that help determine whether it will have an associated NLDN report. Future work will explore this and other LMA-derived flash characteristics.

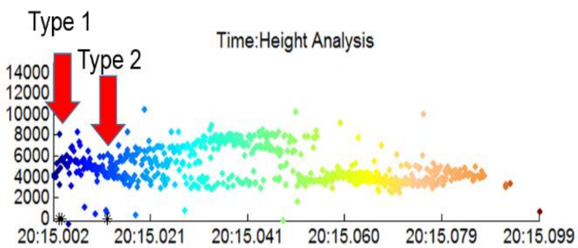


*Fig. 1 Sample of LMA Type 1 and 2 source patterns in Height-time distribution of the LMA sources. Black stars represent the NLDN reports*

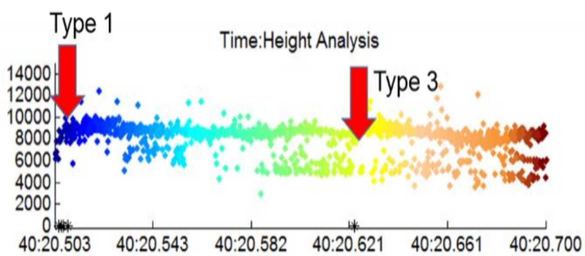


*Fig. 2 Same as Fig. 1, but for Types 1 and 3*

### 3.3. Correlation between Storm Type and NLDN-reported Flashes

To examine the variation of IC flash DE for different storm types, one-hour periods from each of two storms, including a squall line (June 25th, 2013) and a multi-cell storm (July 3rd, 2013) were analyzed. 10-minute total lightning (IC+CG) flash counts were determined from a visual analysis of LMA data within the field-of-view of the camera. IC/CG ratios and percentage of positive CG flashes were determined using NLDN CG stroke data (see Table 2 and 3). The 10-minute LMA source height distributions for the two storms during the one-hour periods are shown in Fig.3 and Fig.4. Both of the storms have a dominant source density region at lower levels early in the hours, implying negative breakdown in a low-altitude positive charge region. Both storms appear to develop an upper positive charge layer later on, indicating two highly dynamic storms with variable charge distributions. The hourly-averaged IC/CG ratios for the squall line and the multi-cell storm are 6.4 and 8.2 respectively. This is much higher than the climatological average number over the U.S., though it is not uncommon in this particular region (Boccippio et al, 2001, Carey and Rutledge, 2003).

*Table 2 The 10-minute LMA and video statistics summary for the squall line during 6:00-7:00 am on June 25th*

| | LMA | | | Video | | |
|---|---|---|---|---|---|---|
| | | | | | CLD DE | |
| June 25th | Flash Count | IC/CG | +CG/CG | Classified Flash Count | 10 min | 30 min |
| 6:00-6:10 | 221 | 7.8 | 0.4 (9/25) | 35 | 43.8% | 44.4% (12/27) |
| 6:10-6:20 | 252 | 7.7 | 0.5 (15/29) | 35 | 50.0% | |
| 6:20-6:30 | 389 | 12.4 | 0.5 (14/29) | 42 | 40.0% | |
| 6:30-6:40 | 291 | 5.9 | 0.2 (10/42) | 61 | 42.9% | 65.1% (28/43) |
| 6:40-6:50 | 383 | 4.5 | 0.2 (17/70) | 100 | 83.3% | |
| 6:50-7:00 | 421 | 5.0 | 0.1 (5/70) | 122 | 55.6% | |
| Total | 1947 | 6.4 | 0.3 | 395 | 57.1% | |

*Table 3 Same as Table 2, but for the multi-cell storm during 9:00-10:00 am on July 3rd*

| July 3rd | LMA | | | Video | | |
|---|---|---|---|---|---|---|
| | Flash Count | IC/CG | +CG/CG | Classified Flash Count | CLD DE 10 min | CLD DE 30 min |
| 9:00-9:10 | 114 | 18.0 | 0.7 (4/6) | 15 | 28.6% | 42.4% (14/33) |
| 9:10-9:20 | 124 | 40.3 | 0.3 (1/3) | 19 | 50.0% | |
| 9:20-9:30 | 69 | 16.3 | 0.3 (1/4) | 26 | 44.4% | |
| 9:30-9:40 | 75 | 8.4 | 0.1 (1/8) | 54 | 30.0% | 32.1% (18/56) |
| 9:40-9:50 | 42 | 1.6 | 0.1 (3/16) | 42 | 42.9% | |
| 9:50-10:00 | 38 | 1.9 | 0.2 (2/13) | 33 | 25.0% | |
| Total | 462 | 8.2 | 0.2 | 89 | 36.0% | |

The strong lower positive charge regions at the beginning of the hours in both storms are associated with higher percent positive CG (see Table 2). Both storms have higher percent positive CG during the first 30 minutes when compared to the second 30 minutes. The IC/CG ratios display the same 30 minute trend as well. However, the 30-minute-averaged IC flash detection efficiencies do not follow the IC/CG ratio or CG polarity trends. The detection efficiency for the line storm is lower when the IC/CG ratio and percent positive CG are higher, and higher when the IC/CG ratio and percent positive CG are lower. For the multi-cell storm, however, the detection efficiency is higher when the IC/CG ratio and percent positive CG are higher, and vice versa.

Although the 30-minute DEs may not be statistically meaningful due to the small datasets, the overall DE is statistically higher for the line storm than for the multi-cell storm. This fact is demonstrated using a Monte-Carlo simulation. For this simulation, the computed detection efficiency (ratio of “hits” to the total number of observations) was assumed to be the expected value of a Binomial distribution. The “p” values were taken as the observed DE (as a fraction), and the ‘n” values were the number of observations. Thus the expected (mean) values (n*p) were the number of “hits.” Using these parameters, 10,000 random samples of “hits” were drawn from these Binomial distributions, and then plotted in histogram form as a function of computed detection efficiency in Figure 5.

This results indicate that the detection efficiencies for the two storms are significantly different (the overlapping region of the two storm DEs is less than 5% of the whole regions), which points out that the IC/CG ratio and percent positive CG did not determine the NLDN IC flash detection efficiency in this case. There was also no evidence that the NLDN IC flash detection efficiency was associated with flash rate or LMA-derived charge structure. Since the DEs are primarily based on the video-defined IC flashes, it is possible that the measured DE is associated with the storm visibility from the camera site, which depends on intervening moisture and cloud depth.

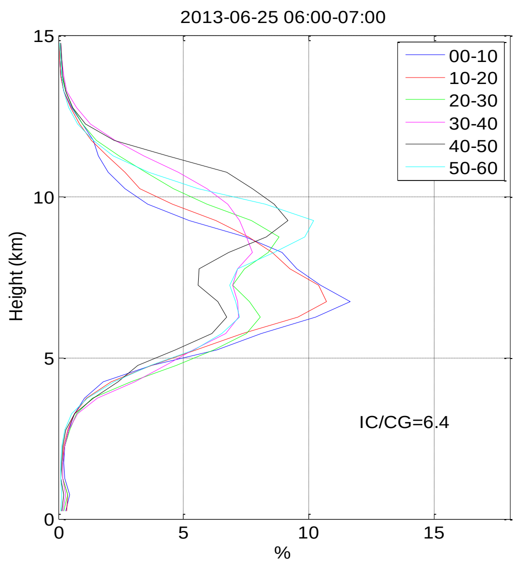


Fig. 3 Height distribution of the squall line storm during 6:00-7:00 am on June 25th. Each curves represent each 10-minute duration in the hour

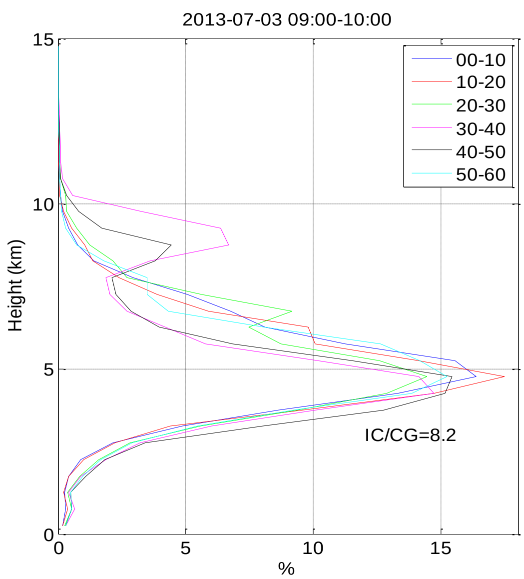


Fig. 4 Same as Fig. 3, but for the multi-cell storm during 9:00-10:00 am on July 3rd

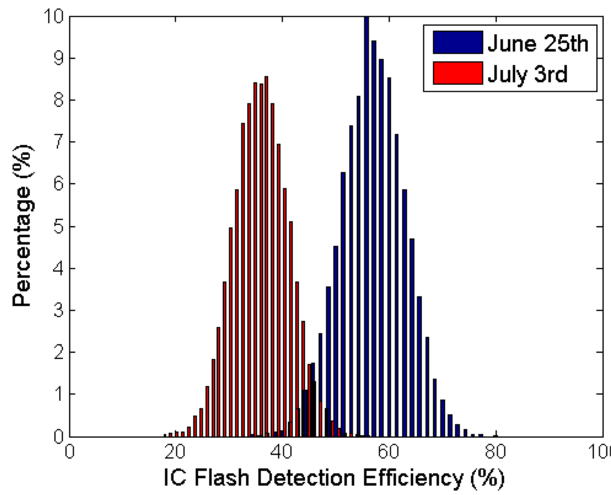


Fig. 5 Monte-Carlos simulation of the overall IC flash detection efficiencies of the two storms

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