IMPROVED TIMELINESS OF THUNDERSTORM DETECTION FROM MAPPING A LARGER FRACTION OF LIGHTNING FLASHES

Don MacGorman\textsuperscript{1,2}, Ivy Apostolakopoulos\textsuperscript{2}
\textsuperscript{1}NOAA/National Severe Storms Laboratory
Norman, Oklahoma, USA
\textsuperscript{2}Cooperative Institute for Mesoscale Meteorological Studies
University of Oklahoma
Norman, Oklahoma, USA

Alan Nierow
Federal Aviation Administration
Washington, D. C., USA

John Cramer, Nick Demetriades
Vaisala Thundestorm
Tucson, Arizona, USA

Paul Krehbiel
New Mexico Institute of Mining and Technology
Socorro, New Mexico, USA

1. INTRODUCTION

One application of lightning ground strike mapping systems has been thunderstorm detection. However, the climatological ratio of in-cloud flashes to cloud-to-ground flashes typically is greater than 2:1. Thus, systems that map either cloud flashes or all types of flashes will detect storms more quickly and reliably. The improvement typically is even greater than would be expected simply from the greater number of samples, because the first flashes produced by a storm usually are cloud flashes. However, the improvement obviously is affected by the fraction of flashes that a lightning mapping system detects. Because it costs substantially more to detect a larger fraction of all flashes, one would like to know how much lead time will be added by various levels of lightning detection. This information obviously is of interest to the meteorological operations of the many federal agencies that use lightning data.

The U.S. National Lightning Detection Network (NLDN) (described by Cummins et al. 1998, but subsequently upgraded) being used by the National Weather Service is now capable of detecting roughly 10-25\% of cloud flashes, in addition to a much larger fraction of cloud-to-ground flashes, over the contiguous United States. So far, this cloud flash option has been enabled only in a test region. The optical lightning mapper being planned for GOES-R is expected to detect 80-90\% of cloud flashes. Some research mapping systems can detect essentially all but the smallest flashes throughout much of their coverage region.

This paper analyzes a test cloud flash data set from the NLDN network, to see how much that system’s cloud flash detection would improve thunderstorm detection. Furthermore, data from the Oklahoma Lightning Mapping Array (OKLMA), a VHF lightning mapping system that detects all types of flashes, also are used to evaluate how much the timeliness of thunderstorm detection can be improved over what is now achieved with ground strike mapping systems. The data presented in this paper were acquired May – August 2005, a period in which Vaisala enabled the cloud flash detection capability of the NLDN over the region of coverage of the OKLMA for this evaluation.

2. INSTRUMENTATION AND ANALYSIS PROCEDURE

The region of coverage of the OKLMA is shown in Fig. 1. This system was developed by the New Mexico Institute of Mining and Technology (NMIMT) and delivered to the University of Oklahoma in
August 2002. The University of Oklahoma installed the system in central Oklahoma in fall 2002, with considerable assistance from the National Severe Storms Laboratory and NMIMT and funding from the Office of Naval Research. Regular operation began in December. The innermost shaded circle in Fig. 1 indicates the approximate region over which the OKLMA maps lightning with good accuracy in three dimensions. At larger ranges, errors in mapped height become too large, but the horizontal location of lightning is determined reasonably well out to a range of roughly 200 km.

The OKLMA receives VHF signals in the channel 3 television band at eleven stations and measures a signal’s time of arrival at each station. The time of radiation and the three-dimensional location of the lightning channel segment that produced the signal are then determined by a least-squares technique. Time at the stations is synchronized by using signals from the satellite constellation of the Global Positioning System. More detailed characteristics of the Lightning Mapping Array, including an analysis of errors, is provided by Rison et al. (1999) and by Thomas et al. (2004). The OKLMA produces a reduced data set in real time, but the data used in this study were from the full archived data set.

Cummins et al. (1998) describe the general characteristics of the NLDN, as it was operated from 1993–2002. Much about the system remains the same, but in 2002-2004, the station spacing was made somewhat denser and station sensitivity was improved. Furthermore, a capability for mapping cloud flashes was added to the original capability for detecting cloud-to-ground flashes. Because cloud flashes tend to radiate weaker signals than ground flashes do in the frequency band at which the NLDN

---

**Figure 1.** Coverage of the Oklahoma Lightning Mapping Array. The inner circle having a radius of 75 km indicates roughly where lightning can be mapped in three dimensions. The outer 200-km radius circle is the nominal region over which the plan location of lightning can be mapped.
operates, the detection efficiency for cloud flashes was expected to be significantly less than that for ground flashes and depends more sensitively on station spacing. With the present configuration of the network, typical cloud flash detection efficiency is expected to be 10-25% over the contiguous United States. It was expected to be toward the upper end of this range over Oklahoma in summer 2005, because of somewhat smaller-than-usual NLDN station spacing there.

The procedure for this study was to peruse data from the OKLMA to identify periods of lightning activity. These periods were then examined in detail to identify when storms produced their first lightning flash, their first cloud flash, and their first cloud-to-ground flash. Furthermore, because there was some question of the reliability of identification of ground flashes with small estimated peak return stroke currents, flashes identified by the NLDN as ground flashes having peak currents <10 kA were considered separately from ground flashes having larger peak currents. To try to insure that the OKLMA detected the first flash, the range for storms in this analysis was constrained to be within roughly 200–225 km of the center of the OKLMA network. Storms whose lightning activity began outside this range were ignored. The lightning activity of each storm was tracked manually to insure that, once a storm had produced lightning, later lightning would not be considered a first flash. To be considered a new storm, the storm’s lightning had to be well away from both all previous lightning activity and the extrapolated position of all previous lightning activity.

For each storm, the time lag was determined from the first flash detected by the OKLMA to the first flash of various categories of flashes detected by the NLDN. In the unusual case in which the first flash of a storm near the outer range of our analysis was not detected by the OKLMA, the storm was omitted from our analysis. The first category of NLDN flashes consisted of all ground flashes with peak currents of at least 10 kA. The second category consisted of the first category plus all negative ground flashes with peak currents of <10 kA. The third consisted of the first two plus all positive ground flashes with peak currents of <10 kA. And the fourth category consisted of the first three categories plus all cloud flashes detected by the NLDN. Note that, because the categories were cumulative, the time lags for higher categories were always less than or equal to the time lags for lower categories.

Besides looking at the time lag from the first flash to the first flash in each category, it was also thought worthwhile to analyze the lag until the first period in which the storms produced at least 2 flashes per 5 min and at least 5 flashes per 5 min in the various categories of flashes. Some storms never reached these thresholds of flash rate. Because the initial flash rate obviously influences the time lag, we also tabulated the total flash rate for the first three 5-min periods following the first flash and then sorted storms by the flash rate and by the month of occurrence. The categorization of a storm’s flash rates was based on the average total flash rate for the first 5 minutes of lightning activity: “low” for storms producing <1 flash min⁻¹, “medium” for storms producing 1-3 flashes min⁻¹, and “high” for storms producing at least 3 flashes min⁻¹.

Last, because a preliminary analysis had shown that cloud and ground flash rates of storms in Kansas and Colorado behave much differently than those in Oklahoma, the analysis of time lags using LMA data and NDLN data was repeated for storms that occurred during STEPS, though NLDN cloud flash data were unavailable for these storms. The configuration of the Lightning Mapping Array in STEPS is described by Lang et al. (2004).

3. RESULTS

The results shown in this paper are preliminary results, which will be corrected by the time of the conference presentation. However, changes are expected to be slight. The main changes are expected to be a slight reduction in the fraction of storms detected by the NLDN data sets within 1-2 minutes and a slight reduction in the number of storms in each plot, as a few storms too distant for the OKLMA to detect the first flash are being eliminated in subsequent checking of the data. Furthermore, the categorization of some storms as having “low,” “medium,” or “high” flash rates will be revised.

Figure 2 shows the time to first detection of the various categories of NLDN flashes for May, June, and July. Note that both the fraction of storms that was eventually detected and the increase in the fraction with elapsed time varied considerably from month to month. One reason for this variability may be systematic differences in the flash rate produced by storms from month to month.

To examine the influence of flash rate, the flash rate of each storm was categorized as “low,” “medium,” or “high,” as described in the previous section, and the cumulative probabilities as a function of elapsed time were recomputed. The
results are shown in Fig. 3. Note that the “low” distribution is most like the “May” distribution, as one might expect because most storms in May had low flash rates. The “July” distribution, however, is more like the medium flash rate distribution.

Note also that the distributions in Fig. 3 change systematically as the initial flash rate progresses from low to high. Both the maximum fraction of
storms detected and the rapidity with which the larger fractions were reached tend to increase as one progresses from “low” to “high.”

However, there is one apparent anomaly. During the first few minutes, the fraction of storms detected actually decreases as the initial flash rate categories increase from low through high. We suggest that the reason for this is related to the observation by MacGorman et al. (1989) that ground flash activity tends to be delayed in severe storms, which tend to have very strong updrafts. Several studies, including the modeling study by Kuhlman et al. (2006), have shown a strong correlation between total flash rates and updraft mass flux through the mixed phase region. Also, several studies (e.g., MacGorman et al. 1989) have shown that ground flash rates tend to increase as precipitation forms at the middle levels of storms and descends. Larger updrafts can increase the time required for precipitation to form and descend to the lower altitudes at which charge is needed to initiate ground flashes.

NLDN-detected cloud flashes made the biggest difference in storm detection for low-flash-rate storms, as one might expect. In operational data, +CG flashes with peak current of less than 10 kA are now classified as cloud flashes. With these flashes combined with those identified originally as cloud flashes, an additional 10% of low-flash-rate storms were detected at most elapsed times. Small-peak-current negative ground flashes also contribute roughly 10% of storm detections beyond 10 minutes of elapsed time. Analyses of OKLMA data have recently shown that some small-peak-current negative ground flashes probably are cloud flashes in Oklahoma, but the conditions under which this occurs have not yet been determined.

As mentioned previously, results of an earlier similar study of storms in northern Kansas and northeastern Colorado (the region of the Severe Thunderstorm Electrification and Precipitation Study, STEPS) were much different. Results of a similar analysis of data from the NLDN and from the STEPS Lightning Mapping Array are shown in Fig. 4. No storm had a ground flash detected by the NLDN within the first minute, and it was 30 minutes before 50% of the storms produced a ground flash. Approximately 20% of storms failed to produce a ground flash detected by the NLDN within an hour.

Another issue is how fast storms begin producing larger flash rates. To examine this, the period from the time a storm produced its first detected flash to the time it reached a threshold of 2 flashes per 5 minutes and a threshold of 5 flashes per 5 minutes (not shown) was tabulated for each storm. In operations, if one needed to make sure that occasional outliers or errors were not identified incorrectly as storms, one might want to use a threshold of 2 flashes per 5 min for storm detection, but this would be a conservative threshold. The distribution of elapsed time required for a storm to meet the 2-flashes-per-5-minute threshold is shown in Fig. 5 for storms stratified by their initial flash-rate category.

Even for low flash rate storms, at least 80% of the storms produced 2 flashes per 5 min within five minutes of the first flash, when one considers all flashes. This threshold was reached even faster by storms in the other two flash-rate categories, and all storms in those two categories reached the threshold within 10-16 minutes.

If one considers only cloud-to-ground flash rates, the time to reach 2 flashes per 5 minutes tended to be significantly longer. Very few storms in any flash-rate category reached this threshold for ground flashes within the first minute. Ground flashes never reached this threshold in 40% of storms initially having low flash rates and in almost 20% of storms initially having medium flash rates.

Similarly, Fig. 6 shows the time required for storms that occurred during June 2000 in the STEPS field program to reach the 2 flashes per 5 minutes threshold with all flashes and with ground flashes alone. The behavior of rates for all flashes is similar to the behavior for all flashes in storms initially having low flash rates in Oklahoma. Only 46% of storms in STEPS produced 2 ground flashes per 5 minutes within 60 minutes of the first flash, less even than the low-flash rate storms in Oklahoma.
4. SUMMARY

In north Texas and Oklahoma, 50% of storms produced a cloud-to-ground flash within 5-10 minutes of the storm’s first cloud flash, but in roughly 10% of storms, no cloud-to-ground flash occurred within an hour of the first cloud flash. Cloud flash detection improved storm detection most (adding an additional 10% of storms) for low-flash rate storms. Behavior was much different in storms over the High Plains of northwest Kansas and northeast Colorado. There it required 30 minutes after the first cloud flash for 50% of storms to produce a cloud-to-ground flash, and 20% of storms produced no cloud-to-ground flash within their first hour of lightning activity. One might expect such a result on the basis of climatological studies showing that cloud flashes comprise at least 90% of all lightning over much of the High Plains.

Acknowledgments

This study was supported by the National Science Foundation, grant ATM-0233268, by the Office of Naval Research, grant N00014-00-1-0525, and by a grant from the NOAA/Office of Atmospheric Research. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation, the Office of Naval Research, or NOAA. Additional support was provided by the National Severe Storms Laboratory and the Cooperative Institute for Mesoscale Meteorological Studies. Vaisala provided

Figure 5. Fraction of storms that have produced 2 flashes per 5 minutes in each flash category as a function of the time elapsed from the first flash detected in the storm. Results are shown separately for storms having different initial flash rates (low, medium or high).

Figure 6. Fraction of storms that have produced at least 2 flashes per 5 minutes for all flashes and for ground flashes only as a function of the time elapsed since the first flash in each storm. Data are from 26 storms that occurred in June 2000 during the STEPS field program.
the NLDN data, including the special cloud flash data set.

REFERENCES


