2.2 WARNINGS OF CLOUD-TO-GROUND LIGHTNING HAZARD BASED ON TOTAL LIGHTNING AND RADAR INFORMATION

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1. INTRODUCTION

In a previous study (Murphy and Holle, 2005), total lightning mapping data were combined with radar composite reflectivity information to provide warnings for cloud-to-ground (CG) lightning in the particularly difficult situation of mesoscale convective systems (MCS) with extensive stratiform regions. These stratiform regions often produce CG flashes that are widely separated in space and time, and they constitute the most difficult situation for an automated CG lightning warning system. In the prior study, we demonstrated that we could reduce the number of failures-to-warn (FTW) for CG lightning occurrence in MCS cases by about a factor of 4 by improving the continuity of the lightning warnings. The vast majority of the benefit was due to the use of total lightning mapping information. The increased continuity came with a relatively smaller penalty in terms of a 19% increase in the total duration of warnings. The primary contribution of the radar data was to keep the warning duration from increasing even further.

At the conclusion of Murphy and Holle (2005), we asserted that the method should provide some benefit, or at least do no harm, in non-MCS storm situations. Our primary objective for this paper is to demonstrate the performance of the same method in a variety of other storm types, including a few additional cases of MCSs. We particularly focus on air-mass convection, the most common variety of storm.

2. DATA AND METHODS

As in Murphy and Holle (2005), the CG flash data for this analysis are taken from the U.S. National Lightning Detection Network (NLDN). All positive-polarity events with an estimated peak current less than 10 kA are automatically removed from the analysis because of the high likelihood that they are mis-classified cloud discharges. Cloud lightning information is provided by the LDAR II network (Demetriades *et al.* 2002) operated by Vaisala in the vicinity of Dallas-Fort Worth, Texas (DFW). The LDAR II source data are processed into "flash extent density" grids according to the method described by Lojou and Cummins (2005). Radar composite reflectivity information comes from the NWS WSR-88D radar south of Ft. Worth. Radar data processing uses the NEXRAD ORPG software as described by Reed *et al.* (2002).

The analysis methods and terminology are identical to those used by Murphy and Holle (2005). A particular location where warning information is needed is referred to as a point of interest, and each point of interest is surrounded by a small region called the Area of Concern (AOC). In this study, the point of interest in almost all cases is the DFW International Airport, although for a couple of cases where lightning was observed in the area but not at the airport, we moved the point to a nearby location. In this study, we have expanded the number of storm cases significantly from the original set of 3 MCSs analyzed in the first study. Table 1 summarizes the dates, times, and storm types analyzed in this paper. These analysis periods were selected to start prior to the first flash of any type in order to assess the CG warning value of cloud lightning data. For several of the air-mass convection cases, storms developed in several widely-separated locations at various times during the analyzed time period. For these cases, we used several different points of interest, taking care not to allow the AOCs to overlap. The purpose for doing this was to expand the sampling of storms at their earliest development in order to explore the relationship between first cloud lightning and first CG lightning.

Two methods involving total lightning were described by Murphy and Holle (2005). The "five-level" method combines composite reflectivity and total lightning information to define five levels of alert. These five levels are as follows: (1) reflectivity above 10 dBZ but without any lightning, (2) cloud lightning only with no reflectivity above 10 dBZ, (3) cloud lightning only with reflectivity above 10 dBZ but below a second (variable) threshold, (4) cloud lightning only with reflectivity above the second threshold, and (5) CG lightning in progress, regardless of reflectivity. Reflectivity values

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below 10 dBZ are not considered. There is also a “two-level” method that excludes the radar information. In this method, “level 1” corresponds to cloud lightning only, and as soon as CG lightning appears, it jumps to “level 2”.

Table 1. List of cases analyzed in this study (all are from 2005 in the DFW area)

Date	Time (Z)	Storm description
3-4	12:00-18:00	scattered showers/ thundershowers
4-10/11	21:00-07:00	marginal svr. supercells
4-25	12:30-24:00	severe supercells
5-14	03:30-11:00	nascent MCS
5-25	16:30-21:30	developing cells merging into SW end of MCS
5-28	12:00-19:30	on-end MCS stratiform region
6-1	03:30-10:00	line of storms breaking up
6-5	07:30-14:00	air-mass convection
6-14	02:00-09:00	broken MCS/MCC
7-1	14:30-20:30	broken line to MCS
7-12/13	17:00-01:00	air-mass convection
7-13	17:00-22:30	air-mass convection
7-14/15	20:30-03:30	air-mass convection
7-15	09:00-14:30	air-mass/broken line
7-15/16	19:00-01:30	air-mass convection
8-6	18:00-24:00	air-mass convection
8-7	16:00-23:00	air-mass convection
8-14/15	17:00-02:00	air-mass/broken line
8-15/16	20:00-05:00	air-mass/broken line
9-28/29	21:00-05:00	marginal svr. supercells

Each of these methods involves three parameters: (1) the size of the AOC, (2) the second reflectivity threshold mentioned above, and (3) the “dwell time”, or how long any warning state persists. Unlike in the 2005 study, with few exceptions, we hold these three parameters constant in the present analysis. Based on the Murphy and Holle (2005) results, we used a fixed composite reflectivity threshold of 20 dBZ throughout this analysis. The dwell time was also kept constant at 15 min. For much of the analysis, the half-width of the AOC was set to 10 km, although we also performed a sensitivity analysis using a half-width of 5 km.

In order to quantify the benefit of the total lightning/radar methods, we have also compared their results with the CG-only warning method discussed by Murphy *et al.* (2002a). In order to provide some advance notice of the onset of CG flashes in the AOC, the CG-only method requires looking at flashes in a “Warning Area” (WA) that surrounds the AOC. In the analysis presented here, the half-width of the WA is always 20 km.

As in all of our previous warning studies, the metrics for quantifying performance are (1) the probability that the start of a warning preceded the onset of CG within the AOC by at least 10 minutes; this is referred to here as “POD10”, (2) the false alarm ratio (FAR), (3) the fraction of cases with a failure to warn (FTW), and (4) the total warning duration.

3. RESULTS

Figure 1 shows a comparison between the CG-only, two-level, and five-level methods for the sample of cases listed in Table 1. Fig. 1 simply compares, in the form of a bar chart, the values of POD10, FAR, FTW and total duration of warnings across the three methods. The method parameter values were as follows: 10 km half-width of the AOC, 20 dBZ reflectivity threshold to define the level-4 alert, 15-min dwell time, and in the case of the CG-only method, the half-width of the WA was 20 km. In Fig. 1, the “total duration” is defined as the sum of all warning durations over all cases, and its value is shown in units of weeks to make the magnitudes of the values fall between 0-1. The bars with diagonal hatching show the five-level method, the solid bars show the two-level method, and the stippled bars show the CG-only method. This comparison shows that both the two- and five-level methods produced significant improvements in both FAR and FTW relative to CG-only warnings. The two-level method involves only total lightning information, without the addition of composite reflectivity. The fact that this method and the five-level method,

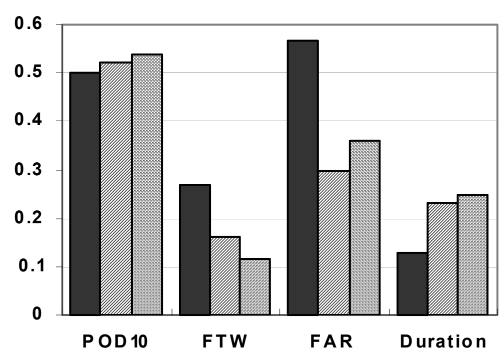

Fig. 1. Comparison of performance metrics for CG-only (solid), five-level (diagonal hatching), and two-level (stippled) warning methods for storms in the DFW area.

which does involve composite reflectivity, produce similar improvements in FAR and FTW means that the improvements in those two quantities are due to the total lightning data.

The other result we note in Fig. 1 is the rise in warning duration as a result of both the five-level and two-level warning methods. In the case of the two-level method, the total duration is almost double what it was for the CG-only case. Underneath this analysis, however, is a question about how we measure the total duration in the CG-only case. Historically, we have only considered the total time when CG flashes were present inside the AOC because operational users of such methods typically only act on that condition. That original measure of warning duration is what we have represented in Fig. 1. This analysis then says that what operational users would experience by adding total lightning information is nearly double the total amount of warning time that they currently have.

In order to try to address the issue of increased warning duration, we have tried out a modification to the scheme that places a threshold on the flash extent density required to go to a warning state in the two-level method. In the nominal two-level method, we require that only one flash detected by the LDAR II passes through any grid square before we go into a warning state. In the modified method, we require three. The results are shown in Fig. 2, which compares the two-level method results from Fig. 1 with the results using the 3-discharge threshold. Little change is detected, but the changes move in the right direction in terms of the total duration. As we would expect, the FAR is lower, because we no longer allow cases where a portion of a single flash touches the AOC to trigger a warning. The FTW is a bit higher because we have a more stringent requirement for turning on a warning.

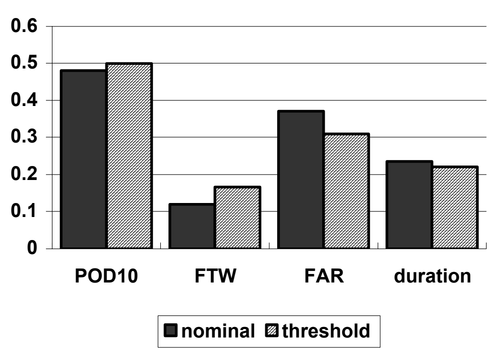

Fig. 2. Comparison of 2-level method results with nominal (solid) and 3-discharge threshold (diagonal) for cloud lightning.

Although based on the operational definition of a CG-only warning, the “standard” measure of warning duration in that situation necessarily eliminates all lead time, which might be very important for certain applications. In those cases, it might be advisable for users to act when flashes are detected within the WA, not just when they occur within the AOC. Therefore, the better measure of total warning duration would be the amount of time when CG flashes are present either within the WA or the AOC. In this study, that total time amounts to 0.28 weeks, meaning that our total lightning-based warning methods actually reduce the total warning duration by 10-20% depending on the method.

In Murphy et al. (2002b), we speculated that total lightning information should probably be applied only in a small zone directly overhead. The reason for that assertion was that most storms are already actively producing CG flashes before they move into an area and that the main purpose of total lightning, therefore, is to pick up the first cloud flashes in storms that develop overhead. In Murphy et al. (2002b), when we used total lightning information in a WA that extended outside the AOC, we increased the FAR significantly. Therefore, in Murphy et al. (2005) and in this study, we have taken out the WA when total lightning is involved, and we have considered only the AOC. Now, however, we wish to look into what happens if we make the AOC smaller. Can we further reduce the FAR by concentrating on a smaller area that is more directly overhead? To answer this question, we have run the five-level method on all of the storms in Table 1 but with an AOC half-width of 5 km instead of 10. We have already seen that the two-level method has a higher FAR than the five-level method (Fig. 1), so we have chosen to do this analysis with the five-level method only. Figure 3 shows the comparison between the two AOC sizes for the five-level method only. Contrary to expectations, we see the FAR going up when we reduce the AOC size. This occurs because the area covered by cloud flashes is almost always greater than the area covered by CG lightning within any given storm. As we make the AOC smaller, there is a greater chance that a storm will pass by the AOC and produce one or more cloud flashes that reach over into the AOC but no CG flashes fall into the AOC. There is a reduction in total warning duration by going to a 5-km AOC, but because of the higher FAR, the reduction still leaves us with more warning time (0.19 weeks) than we had under the standard definition of warning duration for the CG-only method (0.13 weeks).

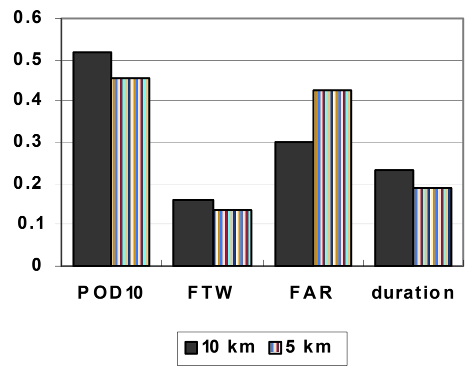

Fig. 3. Comparison of performance metrics using the five-level method with a 10-km AOC half-width vs. 5 km.

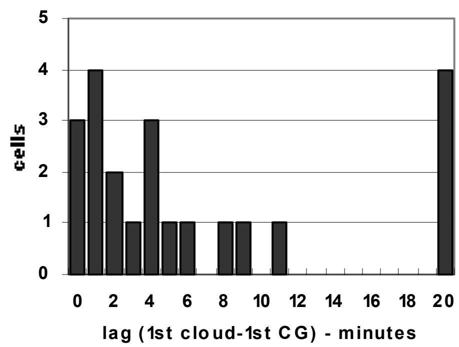

Fig. 4. Distribution of the time between the 1st cloud flash and 1st CG flash in 22 newly developing cells in the DFW area in 2005.

Finally, the summer of 2005 offered a number of cases of air-mass convection that ran over into what is normally a fairly dry season in northern Texas (July-August). On many of these days, isolated storms developed in widely separated locations over a number of hours. This offered us the chance to do an analysis of how frequently the first flash in a storm is a CG, as opposed to the more normal situation where the first flash is a cloud flash. For many of the air-mass cases in Table 1, we were able to use multiple AOCs in order to pick up the first flashes in different widely separated cells. For this analysis, we have a total of 9 storm days with a total of 22 separate cells that were observed at their initial development. Figure 4 shows the distribution of times from onset of cloud lightning to onset of CG lightning in these storms. The first bar corresponds to those cases where the first flash is a CG, of which there are 3 (14% of the sample). Thirteen of these cells had a 1st cloud-to-1st CG lag time of less than 5 minutes (59% of the sample), and 17 had a lag time less than 10 minutes (77%). Only 4 lag times are 20 minutes or longer (18%). A larger sample of Dallas-Fort Worth storms has recently been analyzed by D. MacGorman (2005, personal communication). He finds that 14% of storms have a CG flash within 1 minute of the first cloud flash, which is quite consistent with our results. At longer lag times, our results diverge from MacGorman's. For example, whereas about 3/4 of our storms have a lag of less than 10 minutes, MacGorman finds that only slightly over 50% of storms have that small a lag. The inconsistencies at longer lag times are probably due mostly to our small sample size. Our sample is also somewhat biased because we specifically selected cases where there were CG flashes somewhere in the vicinity of DFW, whereas MacGorman looked at a larger sample without regard for whether CGs were produced in the area.

5. CONCLUSIONS

In this paper, we have taken a warning method that was previously designed for use in MCSs and applied it to a larger sample of storms from across the spectrum of storm types that affect the Dallas-Fort Worth region. The results are mixed, in that we can demonstrate notable improvements in both FAR and FTW by using the newer method, but with a heavy penalty in terms of increased warning time, even when we apply a threshold to the total lightning data. In the future, we will attempt to reduce the warning time by making better use of the radar information and/or using a different strategy for employing the total lightning data. Future analysis should also look in more detail at whether warnings based on CG lightning information alone are satisfactory if no action is taken until lightning actually occurs within the AOC.

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