P1.18 Analysis of Cloud and Cloud-to-Ground Lightning with Winter Precipitation

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1. INTRODUCTION

Lightning characteristics in weather events across the continental United States has been studied extensively in the last decade using Vaisala's National Lightning Detection Network (NLDN: Orville 1991, 1994, Zajac and Rutledge 2001, Carey and Rutledge 2003) and the North America Lightning Detection Network (NALDN: Orville et al. 2002). Most of these studies, however, either focus on the climatological aspect of lightning characteristics over a number of years or by specific weather type (Carey and Rutledge 2003). Orville (1994) identified a latitudinal dependence on the polarity of lightning showing that the percent of positive flashes increases with increasing latitude. He also indicated diurnal tendencies in flash rate, but attributed them to dissipating mesoscale convective systems over the central plains.

Recent research in thundersnow has aroused new interest in lightning characteristics in a specific weather event. Previous studies of this phenomenon include Holle et al. (1998) who examined surface observations at or below freezing in the presence of thunder and lightning. Market et al. (2002) extended this work by creating a 30-year climatology of thundersnow, and dividing it down spatially and temporally over the U.S. during the winter season, which is defined as October through April.

Vaisala, Inc. performed recent upgrades (Cummins et al. 2006) to adjust the threshold frequency in order to minimize the number of false positive cloud-to-ground strokes and flashes and identify them instead as cloud flashes. A collaboration between Vaisala, Inc. and the University of Missouri was started in order to use the cloud lightning data in order to analyze not only the feasibility of the product but also to analyze the storm characteristics of convective snowfall via lightning data.

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Previous research on lightning in winter precipitation has been done primarily on the mountainous coasts of Japan (Taniguchi et al. 1982, Brook et al. 1982, Michimoto 1993) while few studies of lightning with winter precipitation have been done over the central U.S. (e.g., Trapp et al. 2001; Holle and Watson 1996). Part of the difficulty with *in situ* studies in this region has been the flat terrain and strong winds creating blizzard conditions, with cloud particles and precipitation particles blowing around significantly (MacGorman and Rust 1998). The current work seeks to gain an understanding of the thundersnow environment using lightning data along with assessing the value of cloud lightning detection in the NLDN in storms involving winter precipitation.

2. DATA AND METHODOLOGY

Lightning stroke data was taken from local archives of Vaisala's NLDN data feed. According to Cummins et al. (1998), the NLDN has a median location reporting error of about 500 m. Biagi et al. (2007) reports a detection efficiency of ~71% for cloud-to-ground (CG) strokes and >90% for CG flashes. The detection efficiency of the cloud lightning in the NLDN varies between 10 and 20%. In previous studies (Orville et al. 2002), low amplitude (<10 kA) positive CG flashes were eliminated from datasets and deemed cloud flashes. This is not necessary for this study since the upgrade of the NLDN sensors to detect cloud flashes (Cummins et al. 2006). It should be noted that the latitude and longitude data represented in the NLDN for CG strokes indicates the point where the lightning strikes the ground and not where it originates in the cloud. The detection of cloud flashes is more complicated since there is no contact with ground.

Three cases were analyzed for the winter season (October through April). These cases were all significant storms producing heavy precipitation both in the warm sector of the cyclone and in the subfreezing air, where winter precipitation fell. The dates for these include 29 November through 02 December 2006, 29-31 December 2006, and 28 February through 02 March 2007.

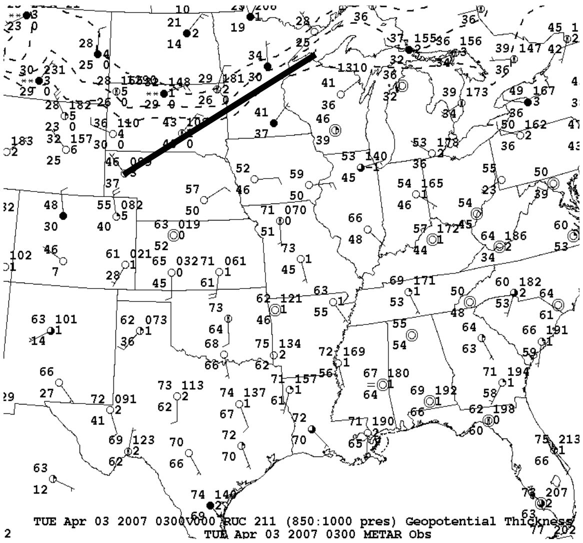


Figure 1. Map encompassing central U.S. representing domain from which lightning data was queried along with surface METAR observations. Dashed lines are 850-1000-mb thickness from 1290 gpm to 1310 gpm. Line represents rain-to-snow transition line.

For each of the three cases, lightning data were queried for a region encompassing the central U.S. (longitude 114 W to longitude 79 W: Figure 1) and separated into cloud and CG events. Using the surface METAR reports and 40-km Rapid Update Cycle (RUC2) analysis of 850-1000-mb thickness, a rain-snow transition line was determined. The standard rain-to-snow transition line in this partial thickness regime is 1290 geopotential meters (gpm).

However, mixed-phase precipitation such as sleet, ice pellets, and freezing rain can occur at thicknesses greater than 1290 gpm. For this reason, thickness was plotted out to 1310 gpm at a 10 gpm interval and plotted with surface METAR reports at matching times every 4 hours. From this approach, a line is fixed with two endpoints, each having a longitude and latitude point, indicating a transition line representative of the 4-hour period. The slope of the line was calculated given the coordinates for these endpoints. We employed a simple linear equation of the classic form:

$$y = mx + b$$

Where m is the slope, x is a point in the x direction, which is represented by a change in the longitude between the western endpoint and the longitude of any given lightning event detected, and b is the y-intercept given by the latitude on the western endpoint of the line. Solving for y gives the latitude of the line at any given longitude of a detected lightning event, thus by comparing the latitude of the line to the latitude of the detected lightning, those that occur in cold air as opposed to warm air can be separated.

Lightning trends were determined in each case based on both the total lightning from the storm and from lightning determined to be associated with frozen precipitation. A percent occurrence of each type of lightning (e.g. negative CG, positive CG, and cloud) was also calculated in each case. This will help not only to gain knowledge of lightning characteristics in storms with frozen precipitation but also serve as a determination of the value of cloud lightning detection by Vaisala's NLDN.

3. RESULTS AND DISCUSSION

3.1 *Individual Storm Analysis*

3.1.1 December 01, 2006

The first storm analyzed began during the day of 29 November 2006 and lasted through 01 December 2006. Significant lightning from this storm began at 1900 UTC on 29 November and was sampled until the last thundersnow event was observed around 1200 UTC on 01 December. Throughout this duration of the storm, the NLDN observed 98108 total lightning events. Of the total lightning events, 33% were observed as cloud flashes and 67% were CG strokes. Of the CG strokes, 95% were negative while the remaining 5% were positive. For the total storm, positive strokes made up 3.5% of all the strokes. According to Uman (1986), however, there is, on average, about 10 cloud flashes for every 1 CG flash, although recent studies are indicating a ratio closer to 5:1. The breakdown of total lightning counts can be seen in Table 1.

When separated, 7230 total lightning events, or 7.4 percent, of the original 98,108 were found to occur in surface temperatures at or below freezing and associated with some sort of winter precipitation. Of those, 40% were detected cloud flashes and 60% were CG strokes, in which 91% of the CG strokes were negative CG strokes and 9% were positive. Positive CG strokes made up 5.5% of the total detected events with winter precipitation. On average, this storm displayed lightning event rates of 39 min^{-1} with a rate of 3 min^{-1} in the winter precipitation.

Table 1. Total lightning stroke counts for each storm for the entire storm and those that occurred only in winter precipitation.

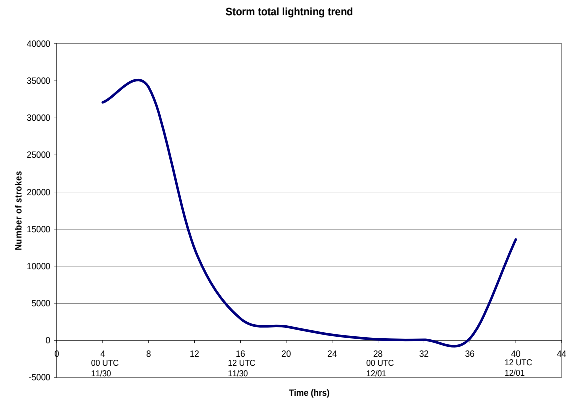
Event	Total Lgt.	IC Total	CG Total	Winter Lgt.	Winter IC	Winter CG
01 Dec. 2006	98108	32229	65868	7230	2909	4292
30 Dec. 2006	497546	199706	297840	1801	511	1290
02 Mar. 20007	334847	101230	233617	6552	2568	3944

The peak lightning times for this storm occurred between 0000 UTC and 0400 UTC on 30 November 2006 with a total of 34126 total events, of which 2030 events were associated with winter precipitation. Of this total, 58% were CG strokes along with 42% cloud flashes. The event rate at this time was 142 min^{-1} for the total storm and 8.5 min^{-1} for those in winter precipitation. The peak for lightning associated with winter precipitation was between 0800 UTC and 1200 UTC on 30 November with a total of 2497 events, of which 58% again were CG strokes and 42% were cloud flashes, resulting in an event rate of 10 min^{-1}. Figure 2 shows the lightning trend both for the total storm and for lightning events associated with winter precipitation. Notice the diurnal trend in the winter lightning with peaks near dusk and dawn. Figure 3 shows the dominance of negative CG strokes in the winter lightning, which contrasts with the findings of Hobbs (1974), Brook et al. (1982) and MacGorman and Rust (1998) where they found a bias towards positive polarity in winter lightning, albeit off the coast of Japan. The bulk of the negative however was <10 kA, where Biagi et al. (2007) found that up to 80% of low amplitude negative strokes in the NLDN were most likely CG strokes.

3.1.2 December 29, 2006

The second storm occurred between 0000 UTC on 29 December 2006 and lasted through 2200 UTC on 31 December 2006. This cyclone event lasted for 72 hrs accumulating 497,546 detected lightning events. Of this total, 40% were cloud flashes and 60% were CG strokes. Only 6% of the CG strokes had positive polarity and a positive to total ratio of 3.5%. A total of 1801 lightning events (0.4% of total) were associated with winter precipitation in this storm, of which 28% were cloud flashes and 72% were CG. Positive strokes made up 9.4% of lightning events in subfreezing temperatures. The total average event rate for this event was 115 min^{-1} with the event rate in winter precipitation only at 0.5 min^{-1}.

The peak time of lightning occurrence for the entire storm and winter lightning happened between 2000 UTC 29 December and 0000 UTC 30 December where 155,769 total events were detected at a rate of 649 min^{-1} and 1392, or 0.9% of the total, were associated with winter precipitation at a rate of 6 min^{-1}. Of this total, only 27% were cloud flashes and 73% were CG. Figure 4 shows the trend for this storm. A slight diurnal peak appears in the storm total trend, while only one peak occurs in the winter lightning trend, but matches a time of day associated with diurnal trends in the previous storm's analysis. A storm total histogram of the winter lightning



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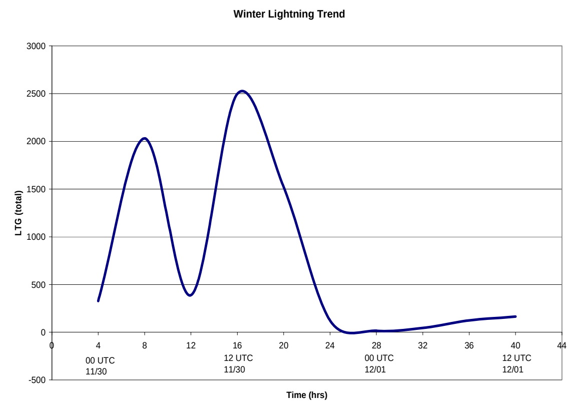


b)

Figure 2. Storm total lightning trend for both *a*) the total storm and *b*) the lightning associated with winter precipitation for 29 November 2006 through 01 December 2006. Time given in hours from the onset of lightning detected in winter precipitation. Date labeled every 12 hrs. in UTC.

reflects the results shown in Figure 3 indicating a strong tendency towards the occurrence of negatively polarized lightning to dominate the environment.

3.1.3 March 01, 2006

The third storm began around 1800 UTC 28 February 2007 and ended by 0400 UTC 02 March 2007. This system produced severe blizzard conditions in much of Iowa, Minnesota and Wisconsin. The duration of this storm was much shorter than in late December; it lasted for 44 hrs across the central U.S. and produced a storm total of 334,847 detected lightning events, with an average event rate of 127 min^{-1}. The total consisted of 30% cloud flashes and 70% CG strokes. Positive CG strokes made up 4.5% of all CG strokes and 3.2% of the total lightning. Lightning events in winter precipitation made up only 2%, or 6552 events, of the total. The event

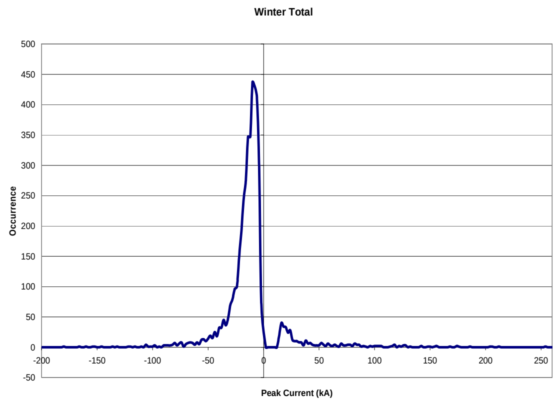


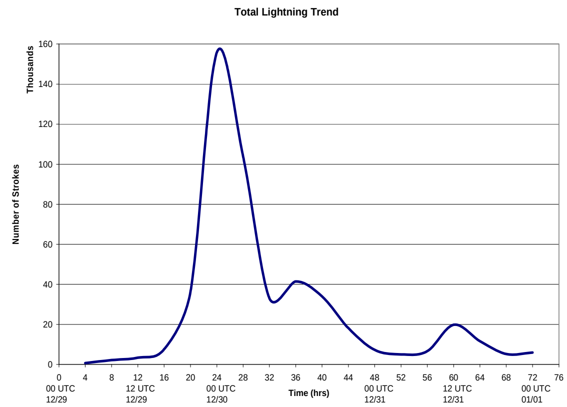
Figure 3. Histogram showing the dominant occurrence of low amplitude negative CG strokes for lightning occurring in winter precipitation for thundersnow event on 01 December 2006. The x-axis is peak current in kA and the y-axis is the number of times a stroke of a given amplitude occurred.

rate in winter precipitation was 2.5 min^{-1}. cloud flashes in winter precipitation made up 39% of the winter total and the 61% were CG strokes. Positive strokes made up 14% of the CG total associated with winter precipitation, but only 5% of the winter lightning (CG and cloud) total. The peak in lightning activity for the entire storm occurred between 0800 UTC and 1200 UTC on 01 March with 75,706 events at a rate of 315 min^{-1} while the peak for lightning in winter precipitation occurred between 0400 UTC and 0800 UTC on 01 March with a total of 2733 events at a rate of 11 min^{-1}. A secondary peak in winter lightning occurred between 2000 UTC 01 March and 0000 UTC 02 March (Figure 5). Again, this storm showed a tendency to be dominated by negatively polarized lightning strokes in winter precipitation, similar to that of the previous two storms (Fig. 3).

3.2. *Combined Analysis for the Three Cases*

The values for the three individual storms were combined by matching the lightning data for each 4-hr segment to the times of the day. Thus, all lightning occurring between 0000 UTC and 0400 UTC for a given storm was matched with lightning from the other storms for the same diurnal periods. The three-storm total lightning event count was 930,501 with 36% detected as cloud flashes and 64% detected as CG strokes. Only 2%, 15,583 events, of these three storms' total count occurred in regions containing winter precipitation, of which 38% were cloud flashes and 62% CG strokes. When the data are matched up with the individual times of day, a more coherent trend appears for wintertime cyclone events. Figure 6 shows diurnal lightning trends for the three storms for the total lightning event count and the event count in winter precipitation.

The storm total lightning trend for these three storms for a 24-hr period shows a decrease in detection of all lightning types during the overnight to early morning hours (0400 UTC to 0800 UTC) with a slight increase during the late morning to early afternoon hours (1400 UTC to 1800 UTC) and then peaking by the late afternoon (after 2000 UTC). Orville (1994) identified overall diurnal trends in the high plains for yearly climatologies of the overall network, partly due to the increase in mesoscale convective system (MCS) activity during the summer months. The 24-hr trend of lightning associated with winter precipitation shows a distinct diurnal trend with a peak at dawn (1200 UTC) trending towards little activity in the afternoon and peaking again by 0000 UTC. No conclusion has been drawn to the specific reason of the diurnal



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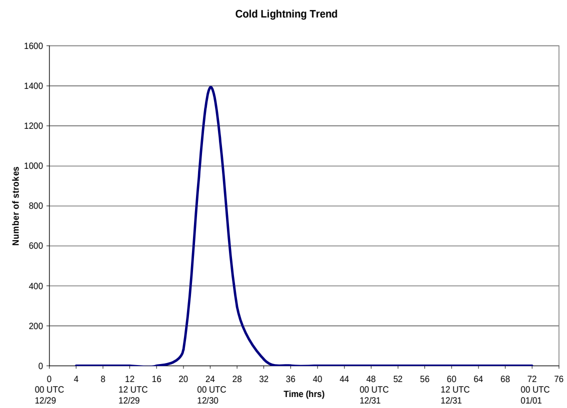

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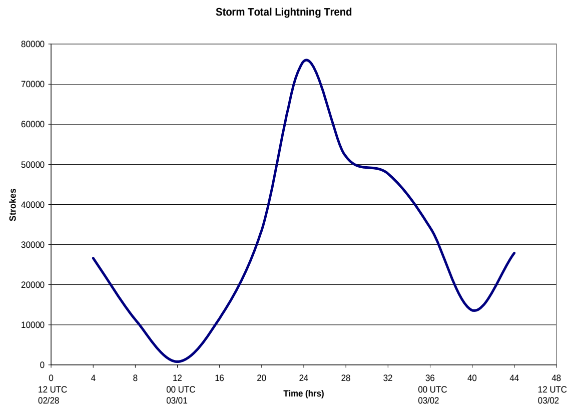
Figure 4. Storm total lightning trend for both *a*) the total storm and *b*) the lightning associated with winter precipitation for 29 December 2006 through 31 December 2006. Time given in hours from the onset of lightning detected in winter precipitation. Date labeled every 12 hrs. in UTC.



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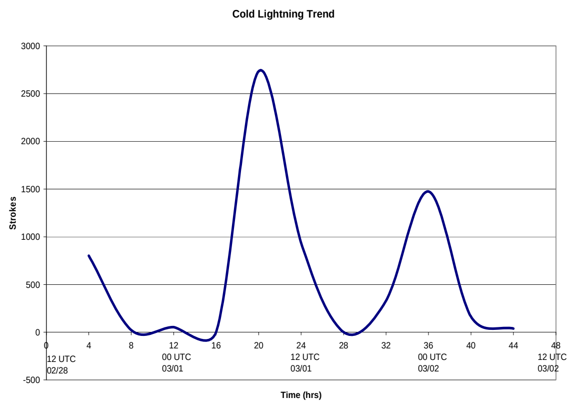

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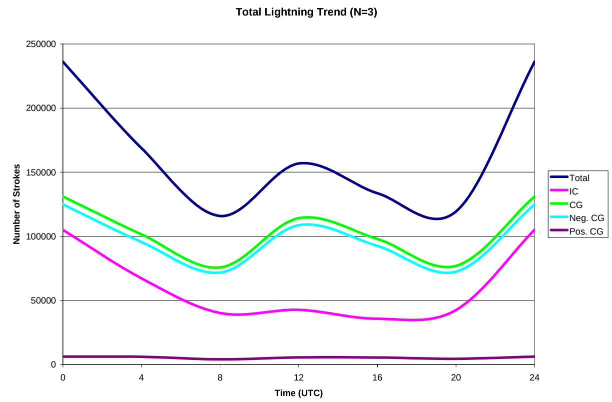
Figure 5. Storm total lightning trend for both *a*) the total storm and *b*) the lightning associated with winter precipitation for 28 February 2007 through 02 March 2007. Time given in hours from the onset of lightning detected in winter precipitation. Date labeled every 12 hrs. in UTC.



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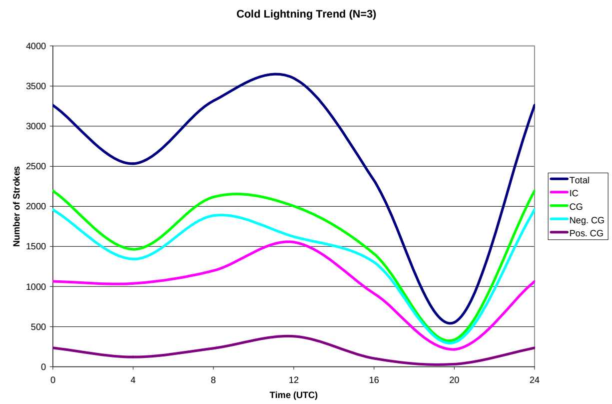

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Figure 6. Season (N=3) total lightning trend for both *a*) storm total and *b*) total lightning associated with winter precipitation for a 24-hr period. Time is in hours (UTC). Local Standard Time is 5 hrs behind UTC.

variation in lightning associated with winter precipitation due to the small number of storms examined (N=3).

6. SUMMARY

Three storms were analyzed for the winter season of 2006-2007 for lightning characteristics. The two earlier storms both occurred in the month of December while the third storm was a deep cyclone producing blizzard conditions through much of the central U.S. Each storm exhibited a different lightning trend throughout its lifetime, but when matched together, it suggested a more coherent trend in total lightning in a 24-hr period for a wintertime cyclone than had been inferred earlier (e.g., Market et al. 2002). Moreover, lightning associated with winter precipitation separated out of the dataset made up only 2% of the total lightning and showed a distinct diurnal trend peaking at 1200 UTC and 0000 UTC. Of the winter lightning total, 38% were detected as cloud flashes and 62% as CG strokes. On an individual storm basis, the diurnal trend appeared at the height of the lightning activity showing similar peaks in total lightning activity associated with peaks in lightning with winter precipitation.

Previous research (Reap and MacGorman 1989) has only identified diurnal patterns in lightning associated with the development and decay MCS activity in late summer and with winter season elevated thunderstorms, not associated with winter precipitation. It can be inferred, however, that when looking at convective snow, similar conditions may exist providing a peak in lightning activity both at dusk and at dawn.

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