12.4 ANOMALOUS LIGHTNING BEHAVIOUR IN NORTHERN PLAINS TORNADIC SUPERCELLS

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1. INTRODUCTION

In 1989, the U.S. National Lightning Detection Network (NLDN) was established providing a dense data collection network. Since then, numerous attempts have been made to associate lightning activity with severe weather events.

In 1998, Canada established a similar lightning detection network. The Canadian Prairies are part of the North American Northern Plains and is the location of the majority of Canada's tornado occurrences. The new Canadian Lightning Detection Network (CLDN), in combination with the American network, now provides a comprehensive coverage of the Northern Plains. Unusual lighting activity with tornadic supercells in this region has been occasionally noted by Canadian forecasters.

On August 21, 1999, one of the more notable anomalous lightning events was detected by the new CLDN. A tornadic supercell near the town of Whitewood, Saskatchewan exhibited unusual lightning activity. This storm was part of a north-to-south line of discrete thunderstorms. All produced typical lightning behaviour, except for the Whitewood storm. Virtually all detectable lightning ceased early in its lifecycle, when a large F2 tornado developed. After the tornado lifted, normal lightning activity resumed. The remaining thunderstorms in this convective line produced much higher flash activity, during their lifespan.

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Lightning patterns and lightning rates, and their relationship to severe storms have been the subject of numerous studies and investigations for some time, often revealing conflicting results in the relationship and utility of lightning data and severe storms. A rigorous assessment of any relationship between lightning activity and supercell tornadoes had never been fully attempted.

The Meteorological Service of Canada's Prairie and Arctic Storm Prediction Centre and Hydrometeorological and Arctic Lab are attempting to track cell-based lightning activity and to correlate it with tornado reports.

2. METHODOLOGY

Canada's Storm Prediction Centres use a radar system that can track automatically individual cells. Each tracked cell is then correlated with CLDN data. This allows for the automatic and continuous assessment of all storms within the radar space. Information collected could then be compared with both Canadian and American near-border tornado reports to assess potential lightning/tornado correlations.

Canadian radar data is obtained from 5 cm radars operating on a 10-minute scan cycle. The first five minutes of the cycle is used to obtain a volume scan of reflectivity comprising 24 different elevation angle sweeps of reflectivity data. The last five minutes of the cycle is used to acquire four elevation angle sweeps of Doppler velocity and reflectivity data. The valid time associated with the cycle is arbitrarily assigned as the mid-point in the 10 minute period. The radar beam width generally varies between 0.6 degrees and 1.1 degrees, depending on the radar.

The data is analyzed by the Unified Radar Processor (URP) software, developed and maintained by the Meteorological Service of Canada. URP identifies and tracks thunderstorm cells using the TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) technique (Dixon and Wiener, 1993). The Maximum Reflectivity (MaxR) field from the volume scan is projected onto a horizontal plane. An echo is identified as a cell if its MaxR field meets a reflectivity threshold over a sufficiently large area. The thresholds are configurable and are currently set to 45 dBZ over at least 4 radar bins (> ~4km^2). According to the TITAN technique, URP calculates a best-fit ellipse for the shape of the cell.

Lightning data is obtained from the CLDN. The data include flash time, latitude, longitude, amperage, polarity, cloud-to-ground flag, stroke count, and quality flag. The lightning flashes that occur in the proximity of a cell within 5 minutes before and after the valid time of the radar data are deemed to be associated with that cell. In order to handle "proximity" lightning data, two sizes of ellipses were used. Lightning flashes occurring inside the ellipse area calculated by URP were analyzed. This can be considered to be cell core lightning. A second larger ellipse was constructed, such that the major and minor axes of the ellipse were extended by 10 km. Lightning flashes inside this larger ellipse were analyzed as well, and can be considered to be total cell lightning.

Additional information is collected for each cell, including detailed ellipse data (e.g. orientation, diameter, etc.), and URP cell /algorithm information (e.g. MESO, HAIL, etc.).

3. RESULTS

The technique was tested on a small number of pre-2006 tornado events. For this paper, two tornadic storms that occurred near the Manitoba and U.S. borders on July 2, 2005 will be highlighted.

Figure 1 shows the lightning activity being tracked for various TITAN-derived ellipses from July 3 0000-0059Z. In this view, the ellipses and lighting strikes are colour-coded for each 10-minute interval. The first storm investigated was the one denoted with an "A", north of the town of Pilot Mound Manitoba. A large tornado was observed from 0120-0145Z. Figure 2 gives a close-up view of the data captured for the Pilot Mound storm during the early phase of the storm's evolution.

Lightning information (Figure 3) for this storm showed a gradual increase in lightning activity with a sudden drop occurring roughly the same time as the tornado formation. There also appeared to be an anomalously high proportion of positive lightning flashes during the tornado occurrence.

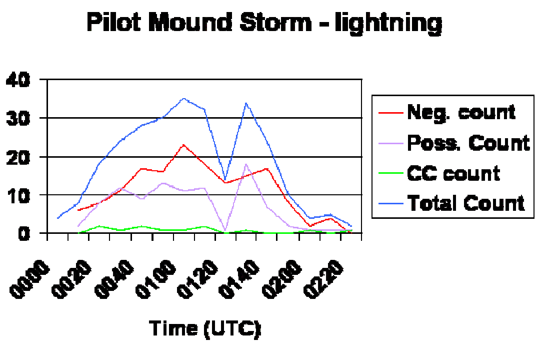

Figure 3. Lightning activity associated with the Pilot Mound, MB cell. Negative (neg.), positive (pos.) cloud-to-cloud (CC), combined (Total) strikes are displayed for each 10-minute interval.

The TITAN algorithm tracked 98 separate cells from between 2300Z and 0300Z. Of those cells, only 9 lasted 1 hour or more in duration. All but two of these cells went through a simple cycle of lightning activity, where the rate gradually peaked then gradually diminished. The Pilot Mound cell, on the other hand, had a notable drop during its lifetime. The other cell that had a notable drop was a supercell in Kittson County just across the border in Minnesota.

Figure 4 shows the lightning activity for the Kittson County cell. The lightning count gradually increased early in its lifetime then fell dramatically in the 0040Z to 0050Z period. The flash rate returned to its pre-drop rate by 0100Z, and increased afterwards.

Local Storm Reports from the Storm Prediction Centre indicate that 15-minute tornado occurred during at part of this period of low activity.

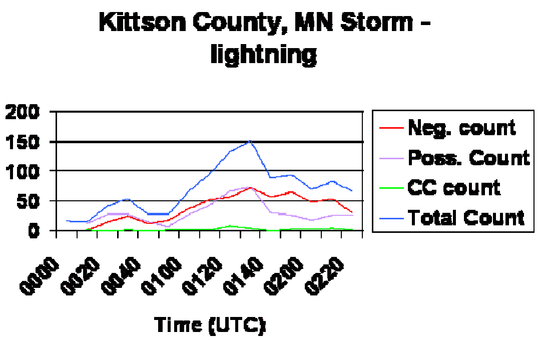

Figure 4. Lightning activity for the Kittson County, MN cell.

4. DISCUSSION

Anomalous lightning activity associated with supercells including tornadic thunderstorms has been examined by a number of authors (e.g. MacGorman et al, 1991; Branick et al, 1992; Seimon, 1993; Bluestein et al, 1998; McCaul et al, 2002; Knupp, 2003).

There are numerous theories on why lightning is almost non-existent in some tornadic storms. MacGorman et al. (1989) suggested that the reason cloud to ground lightning flashes in the mesocyclone region of a tornadic storm were infrequent, when the mesocyclone was strongest, was that the lower boundary of negative charge was higher than is normally observed in non-severe storms. Very strong updrafts that exist in some mesocyclones would cause electrical charges to be displaced higher in the storm than usual, likely leading to a sharp increase in intra-cloud flashes rather than cloud to ground strikes. As the mesocyclone decays the charge region retreats back to lower levels leading to a more favourable environment for increased cloud to ground flashes.

Davies-Jones (1986) also suggests that a strong vortex reduces entrainment of particles into its core thus reducing potential for electrification at low levels in the core. Buechler et al. (1996) suggest that the scarcity of CG flashes is often influenced by the impingement of cirrus clouds from anvils of nearby storms. In the Whitewood case there was not much cirrus impingement from nearby storms that would provide an additional contribution of electrification in the cirrus anvil in this storm.

Numerous studies have also been done on anomalous cloud to ground lightning relating the periods of peak lightning flash rates to tornadic events and polarity shifts of positive charge to negative charge in relation to tornadic activity. Kane (1991) found the lag time between the local peak flash rates and tornado formation to be 10-15 minutes.

A few studies have looked at set of tornado cases, rather than one or two specific events. MacGorman and Burgess (1994) studied the lightning characteristics of 15 severe storms. In their dataset, the majority of storms dominated by positive CG flashes produced tornadoes. They noted that the storm's tornadoes began after the positive CG flash rates decreased from their peak value.

Another study by Perez et al (1997) showed that 31 of the 42 (74%) tornadic storms analyzed had a similar pattern and the average lag time for these cases was 17 minutes. Following the peak there is a general decrease in CG activity until the tornado touches down. Perez noted that 20 of the 42 (48%) storms exhibited a local minimum flash rate coincident or near the time of tornado formation. A possible explanation for this behavior may come from our current understanding of updraft dynamics associated with tornadogenesis.

A common characteristic of these studies has been the limited datasets used. It is unclear as to what the climatology of lightning anomalies may be. It is also unclear as to the robustness of the correlation of these anomalies and severe weather occurrence.

The preliminary work presented here demonstrates some of these observations are present over the Canadian Prairies. The approach used also has the potential to determine the climatology of lightning anomalies. The cell-based system can automatically track lightning information for all cells in Canadian radar space. The technique can also build databases that could be used to determine how strongly these anomalies correlate to types of severe convective weather.

For the summer of 2006, the authors will be cataloguing and assessing these anomalies for the Canadian portion of the Northern Plains.

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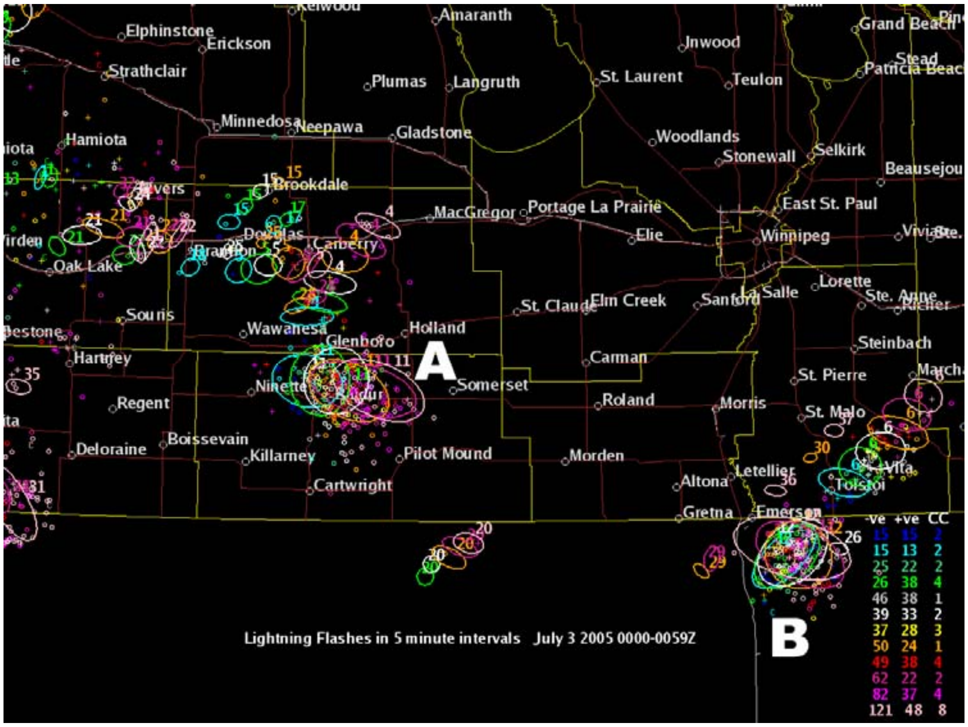

Figure 1. View of cell ellipses and lightning activity for some of the cells tracked between 0000-0059Z. Cell A is the Pilot Mound cell. Cell B is the Kittson County cell.

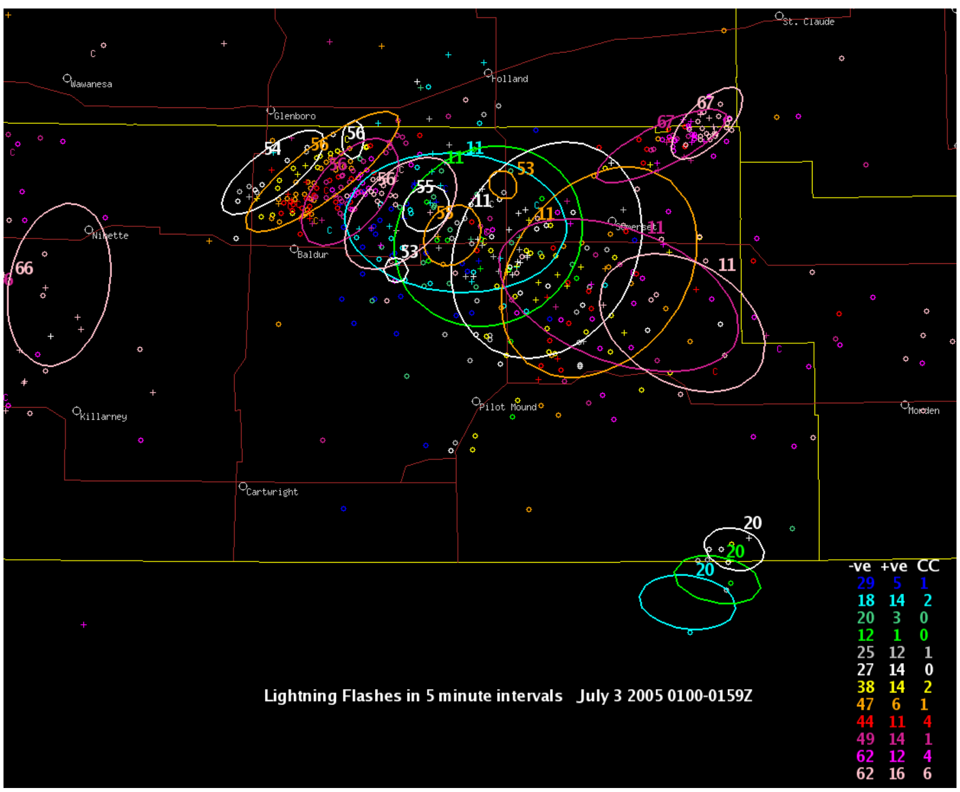

Figure 2. Close-up view of Pilot Mound cell ellipses and lightning strikes.