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LARGE CURRENT LIGHTNING FLASHES IN CANADA: 1999-2006

B. Kochtubajda[1], WR. Burrows[1,2] and BE. Power[3]

Environment Canada
[1]Hydrometeorology and Arctic Lab, MSC Operations - Prairie and Northern
Edmonton AB Canada
[2]Cloud Physics and Severe Weather Research Section
Downsview ON Canada
[3]MSC Internship Training, Prairie and Northern
Edmonton AB Canada

1 Introduction

Cloud-to-ground (CG) lightning is a major cause of severe weather-related fatalities and injuries (Mills et al. 2007; Curran et al. 2000), property and infrastructure damage (Holle et al. 1996), forest fires (Stocks et al. 2002), and interruptions in or damage to electric power transmission and distribution systems (Cummins et al. 1998a). Lightning flash discharges associated with thunderstorms can vary from low current intra-cloud occurrences to large CG events with peak currents of several hundred kA. Knowledge of lightning characteristics is important for various applications, including weather forecasting, conducting lightning risk assessments for site selection of telecommunication or electric power infrastructure, and for the prediction of the severity of the transient voltages generated across power lines or equipment (Lightning and Insulator Subcommittee, 2005). While many of lightning climatologies (Burrows et al. 2002; Schulz et al. 2005; Sonnadara et al. 2006) have characterized median peak currents, few have examined the very large cloud-to-ground events. Orville et al. (1987) reported that some peak currents analyzed in the Northeastern United States reached 300-400 kA. Lyons et al. (1998) found that of the 60 million flashes examined during 14 summer months in the United States, 2.3% had peak currents >75 kA; the largest negative CG reaching 960 kA and the largest positive CG reaching 580 kA.

The objective of this study is to advance our understanding of the occurrence of Large Current Lightning Flashes (LCLFs) over Canada through an examination of their spatial, temporal and diurnal distributions.

2 Data

Eight years (1999-2006) of lightning data, obtained from the Canadian Lightning Detection Network (CLDN), were examined for LCLFs. In this study, LCLFs are defined as ground flashes with peak currents ≥ 100 kA for the first return stroke detected. The CLDN, established in 1998 as the first ever national lightning network in Canada, is a hybrid configuration of 83 IMPACT (Improved Accuracy from Combined Technology, ES version) and LPATS-IV (Lightning Positioning and Tracking, Series 4) sensors. The CLDN is fully integrated with the United States National Lightning Detection Network (Orville et al. 2002) and provides continuous lightning coverage over most of Canada and offshore to about 300 km. Sensor characteristics and detection methods are discussed in Holle and Lopez (1993), Cummins et al. (1998b) and Burrows et al. 2002). The LCLF statistics characterized in this study include their time and date of occurrence, location, amplitude, polarity, and multiplicity (number of strokes).

The Canadian landscape is broad and diverse and its climates range from arid to moist and from maritime to continental. These climates are influenced by several factors including latitude, amount of insolation, topography, and the character of migratory weather systems (Phillips, 1990). Eco-climatic regions as defined by the Ecological Stratification Working Group (1995) are typically broad areas integrating vegetation composition and landform physiography and characterized by distinctive ecological responses to climates. Thus, the Cordilleran eco-climatic region of the Pacific, the Grasslands region of the prairies, the Boreal, Sub-Arctic and Arctic regions that span much of the country, and the Temperate region of eastern Canada (Figure1) were used to describe the geographical characteristics of LCLFs.

3 Characteristics of large current lightning flashes

The total number of CG flashes and LCLFs detected by the CLDN, for 1999-2006, over Canada's landmass is summarized in Table 1. An average of approximately 2.13 million flashes was detected each year, varying from 1.82 million in 2004 to 2.64 million in 2005. LCLFs are rare occurrences, comprising 0.7% of the annual CG flashes detected over the Canadian landmass. The detection efficiency of the CLDN over much of the Arctic eco-zone is <50%, therefore the LCLF occurrence in this region is likely to be underestimated. The polarity characteristics of LCLFs differ markedly from the total CG flashes. Burrows et al (2002) reported that about 10% of all C-G flashes in Canada were positive. An examination of the polarity of LCLFs shows that a significantly higher fraction is positive (about 52%).

Seasonal maximum LCLF strength characteristics in each eco-climatic region were determined by combining the top 10 positive and 10 negative flashes from each of the 8 years. Median statistics for these flashes are summarized in Table 2 by eco-climatic region and by season. Seasonally, the strongest positive currents are detected during summer in all regions except the temperate eco-climate region where the strongest positive flashes occur during spring. The strongest negative flashes occur during the summer season in all regions. Regionally, the strongest LCLFs occur over the boreal eco-climate region in all seasons except winter. A latitudinal dependence on LCLF strength is also noted; LCLFs decrease in their peak currents, for both polarities, as latitude increases.

3.1 LCLF peak current

Where are the strongest LCLFs detected in Canada? The seasonal and spatial distribution of the strongest 10 positive and 10 negative LCLFs for each of the years during the study period is illustrated in Figure 2.

During spring, the spatial pattern (Figure 2a) shows that strong LCLFs are detected across all regions. However, a large fraction of the strongest LCLFs are located in western Canada, primarily in the boreal, grassland and southern interior of the Cordillera. The region from central Alberta through southern Saskatchewan and into south-western Manitoba is dominated by positive LCLFs while negative LCLFs are more concentrated in the north-eastern part of BC and Northern Alberta. The timing of snowmelt on the land cover influences thunderstorm development during spring as more flashes are initially detected over the grasslands and boreal zones in the early spring months and over the sub-arctic in the late spring. The strongest LCLFs during the spring were detected in the grassland region; reaching +574 kA (lat49.85N/long107.89W) located near Shaunavon, SK and -598 kA (lat50.00N/long108.99W) located near Maple Creek, SK.

A different pattern is evident during the summer (Figure 2b). The majority of the strongest LCLFs are detected in western Canada, in an area extending from the Yukon Territory to southern Alberta, associated with convective weather. A secondary cluster is noted in the boreal region extending from central Saskatchewan to northern Manitoba. Summer peak current strengths of +596.1 KA (lat58.63N/long96.52W) and -529.1kA (lat55.61N/long103.12W) were detected in north-western Alberta and west central Manitoba, respectively. LCLFs have been detected as far north near Old Man Lake located about 60km southeast of Tuktoyuktuk, Northwest Territories.

Although the spatial pattern during fall (Figure 2c) shows some similarity to the spring pattern, distinct differences are also noted. The southward passage of the Arctic front diminishes convective activity over the arctic and northern boreal zones. Strong LCLFs are not detected in the northern cordilleran zone, and a greater fraction of the strongest LCLFs occur in the eastern boreal and temperate zones. The strongest positive and negative LCLFs during this season were detected in the temperate region of eastern Canada; reaching +370.4 kA near Lac Saint Jean, PQ (lat48.86N/long72.41W) and -455.9 kA over Northern Quebec (lat52.14N/long70.83W) of the boreal region.

The spatial pattern of maximum strength locations during winter (Figure 2d) is markedly different from the other seasonal patterns. LCLFs detected along the Pacific coast in the cordilleran region and over the Maritime Provinces in the temperate region are primarily of positive polarity. Lewis (2000) previously identified the Martimes as an area of greater winter lightning occurrence. The thermal gradient between the sea surface and the cold short waves and upper lows destabilizes the atmosphere leading to winter convection and significant electrical activity. Some LCLFs also occur over the eastern boreal region of central Quebec and southern Ontario and are primarily of negative polarity. This region commonly experiences freezing rain, ice pellets and wet snow during winter (Cortinas et al. 2004), and some lightning has been associated with these types of events (King and Stewart, 1990; Henson et al. 2006). The strongest LCLFs detected during the winter reached +349.4 kA (lat51.76N/long121.12W) located near 100 mile house, BC in the central interior of the Cordilleran region and -301.7 kA (lat45.7N/long73.52W) located near Terrebonne, Quebec in the eastern boreal region.

3.2 LCLF Multiplicity

Analyses of the stroke multiplicity (number of strokes per flash) in the summer (Figure 3) indicate that nearly 80% of positive LCLFs and about 30% of negative LCLFs are single-stroke flashes in most ecozones except the Arctic. LCLFs in the Arctic are mostly single-stroke flashes irrespective of polarity. It is possible that shallow convective cloud depths in the Arctic may influence the stroke multiplicity.

LCLFs with stroke multiplicity ≥ 10 are associated with negative CG flashes, and are detected in all seasons except winter over several areas of the country. The majority of these flashes occurs during summer season and is observed over the grasslands and western boreal eco-regions (Table 3).

3.3 LCLF Diurnal distributions

LCLFs of both polarities for each eco-climate region were accumulated on an hourly basis for the entire summer data record (Figure 4) to examine their diurnal variations and determine whether there were regional differences. In general, LCLF activity across Canada occurs throughout the day reflecting the regional nature of thunderstorms and convection, however, several interesting characteristics emerge.

A weak diurnal signature in the arctic eco-climatic region (Figure 4a) is evident for both polarities. More negative LCLFs are detected than positive LCLFs for the majority of the hours. On the other hand, the diurnal distribution in the sub-arctic eco-climatic region (Figure 4b) shows an increase from 1300 UTC to a maximum at 2100 UTC followed by a slow decrease. Negative polarity LCLFs in the sub-arctic region exceed or are equal with positive polarity LCLFs at all hours. This pattern is typically linked initially to the heating of the boundary layer and the development of shallow convection. Once storms have developed, further activity may be caused by the interactions with other existing storms or other processes.

A strong diurnal signature is evident in the cordilleran region (Figure 4c) reaching a peak between 2100 and 2300 UTC. However, positive polarity LCLFs surpass negative LCLFs from 2300 to 1200 UTC. A similarly strong diurnal signature is observed over the boreal eco-region (Figure 4d). An increase in LCLF activity occurs from 1500 UTC to a maximum at about 2100 UTC followed by a slow decrease. Negative LCLFs outnumber positive LCLFs from 1100 to 0200 UTC, but positive LCLFs exceed negative LCLFs between 0300 and 0900 UTC.

The grassland eco-region (Figure 4e) reflects a unique LCLF characteristic. A strong diurnal signature dominated by positive polarity LCLFs is observed. Positive LCLFs greatly exceed negative LCLFs between 2000 and 1000 UTC, peaking at 0400 UTC. This region often experiences advection of moist unstable air from the south, and the nocturnal signature also reflects the incursion of High Plains mesoscale convective systems. A pattern of positive LCLFs exceeding negative LCLFs between 2300 and 0600 UTC is also observed in the temperate eco-region (Figure 4f).

4 Concluding Remarks

The occurrence of large current cloud-to-ground lightning flashes (LCLF) across Canada's landmass is rare, comprising 0.7% of the total annual lightning activity. Their spatial, temporal and polarity characteristics reveal distinct seasonal and geographic differences.

During winter months, the majority of LCLFs, associated with mild and moist maritime air masses, are detected along the Pacific coast of the cordilleran zone and temperate zone of eastern Canada. The timing of snowmelt on the land cover influences the distribution during spring as more flashes are initially detected over the grasslands and boreal zones in the early spring months and over the sub-arctic in the late spring. The greater part of annual LCLFs, associated with convective activity, occurs during the summer. Some LCLFs have been detected close to Tuktoyuktuk, NWT. The southward passage of the Arctic front in early fall diminishes LCLF occurrence over the arctic and boreal zones.

Positive LCLFs are generally single-stoke flashes while negative LCLFs are typically multiple-stoke flashes in all eco-climatic regions except the Arctic. LCLFs in the Arctic are mostly single stroke flashes irrespective of polarity. Most LCLFs with multiplicity $\geq$ 10 are associated with negative CG flashes detected during all seasons except winter over several areas of the country.

The diurnal variations of LCLF activity reflect the regional nature of thunderstorms and convection. Negative LCLF activity over the sub-arctic, cordillera, and boreal eco-regions reflected a diurnal cycle with maximum frequencies in the afternoon to early evening. Positive LCLF activity over the cordilleran, grassland and temperate eco-regions showed a diurnal cycle with significant nocturnal activity.

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TABLE 1: Cloud-to-ground (CG) and large current lightning flash (LCLF) data and polarity characteristics.

Year	Total CG	Total LCLF	LCLF Positive %	Tot LCLF/Tot CG %
1999	2,213,485	13,938	48.5	0.6
2000	2,214,625	14,335	45.1	0.7
2001	2,159,572	13,457	52.8	0.6
2002	2,013,304	9,945	57.2	0.5
2003	1,829,334	9,112	57.7	0.5
2004	1,818,178	14,846	51.5	0.8
2005	2,642,484	24,698	51.9	0.9
2006	2,146,134	21,067	51.7	1.0
Total	**17,037,116**	**121,398**		
Average	**2,129,640**	**15,175**	**52.1**	**0.7**

TABLE 2: Median LCLF peak currents based on combined top-10 LCLFs from each year from 1999-2006, and stratified by eco-climatic region, polarity and season.

	Positive				**Negative**			
Ecoclimatic region	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Cordillera	141.0	208.6	281.8	197.4	134.4	219.4	274.7	187.3
Boreal	113.1	259.7	305.4	241.7	126.2	230.8	294.0	195.9
Grassland	*	232.3	264.3	190.8	ND	154.1	210.7	140.7
Sub-arctic	*	174.0	252.3	189.6	*	152.0	220.2	143.0
Arctic	ND	118.6	132.9	127.3	ND	114.4	139.3	133.4
Temperate	154.3	206.1	191.3	204.7	105.3	141.1	184.6	156.8

ND indicates that LCLF were not detected. * Few LCLFs detected

TABLE 3: LCLF's with multiplicity ≥ 10 stratified by ecoclimatic region (1999-2006)

Ecoclimatic region	Spring Negative	Summer Negative	Fall Negative
Cordillera	5	51	1
Boreal	4	265	20
Grassland	4	136	9
Sub-arctic	-	37	1
Arctic	-	1	-
Temperate	4	50	5

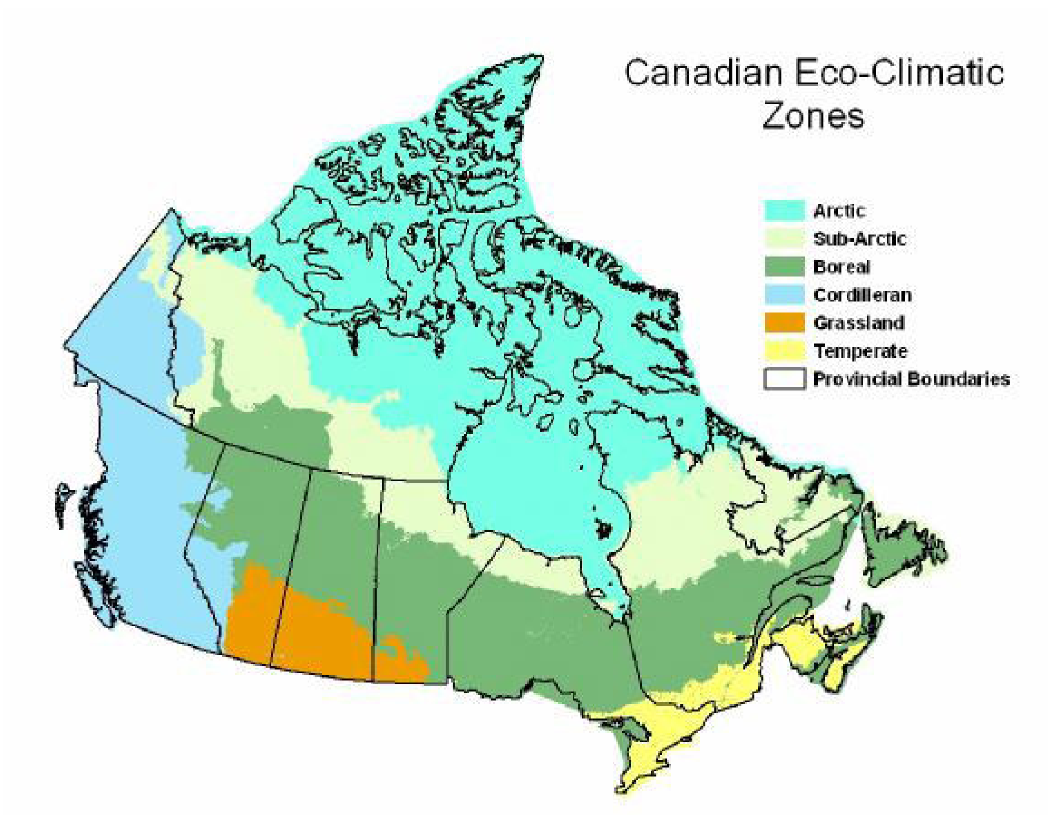

Figure 1: The eco-climatic regions of Canada.

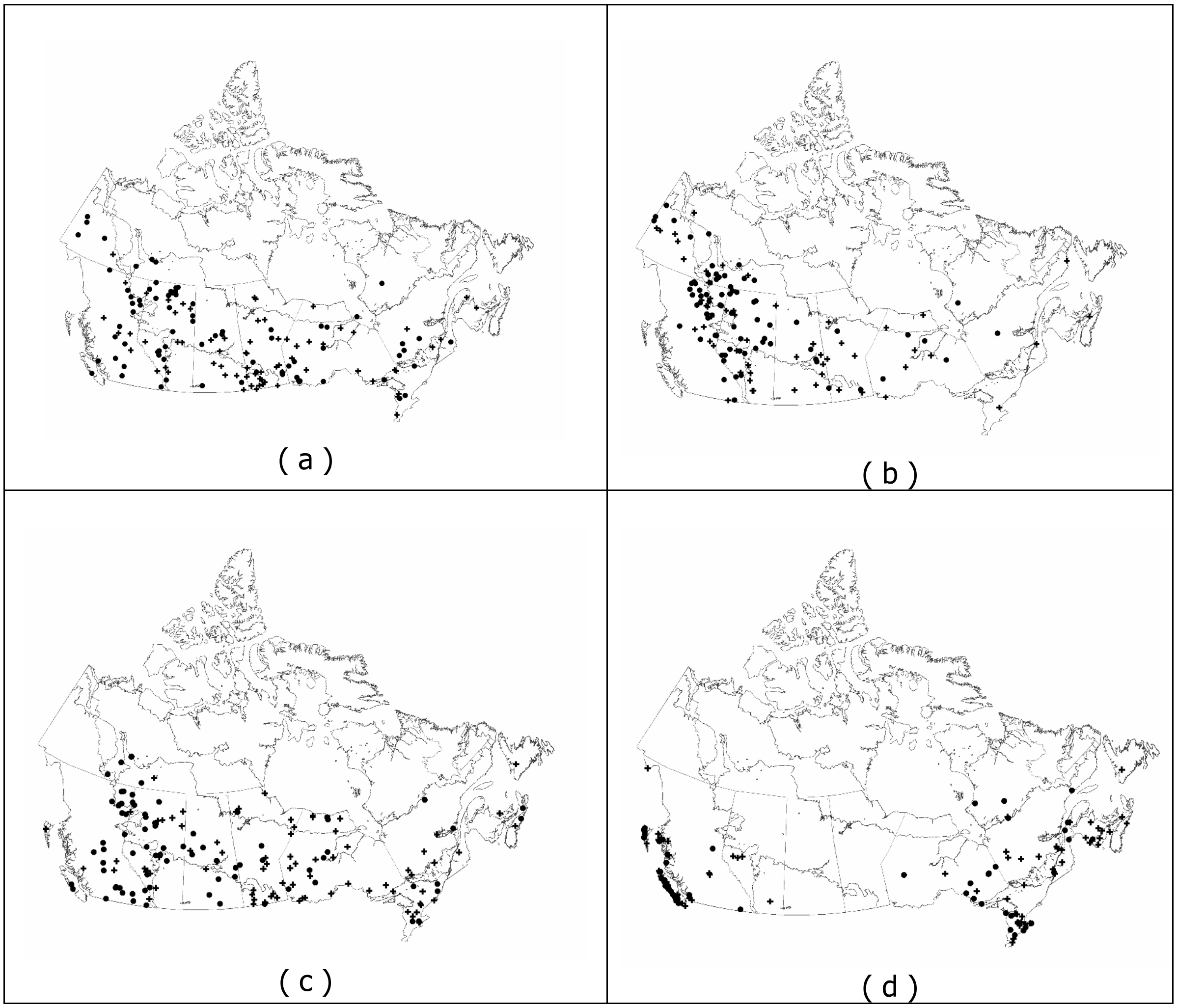

Figure 2. The seasonal distribution of the strongest 10 positive (dots) and 10 negative (crosses) LCLFs for each of the years during the study period during (a) spring, (b) summer, (c) fall, and (d) winter.

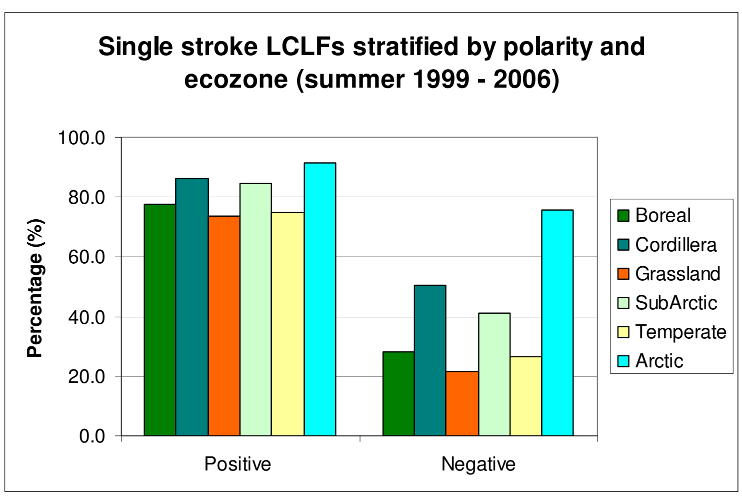

Figure 3. Single-stroke LCLFs stratified by polarity and ecozone (summers 1999-2006)

Figure 4. Diurnal distributions of summer positive and negative LCLFs for each eco-climate region including, a) arctic, b) sub-arctic, c) cordillera, d) boreal, e) grassland and f) temperate. Positive and negative polarity LCLFs are represented by the solid lines and bars, respectively.