AN INTENSE WINTER LIGHTNING EVENT OVER NOVA SCOTIA AND SURROUNDING WATERS JANUARY 11TH/12TH 2000

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1. INTRODUCTION

The Canadian Lightning Detection Network (CLDN) became fully operational in November 1998. The CLDN consists of 26 IMPACT and 55 LPATS sensors and is fully integrated with the US National Lightning Detection Network (NLDN). The CLDN is capable of delivering 500 metre accuracy with a 90% probability of detection south of 60° N (Fournier and Pyle 1998). The system was installed and is operated by Vaisala-GAI under contract to the Meteorological Service of Canada.

At the 2000 International Lightning Detection Conference the author presented a paper called Winter Lightning in the Maritime Provinces of Canada (Lewis 2000). From this analysis for two winter seasons of CLDN data it was evident that winter lightning in the Maritime Provinces (Nova Scotia, New Brunswick and Prince Edward Island) is far more prevalent than historical "thunderstorm day" climatologies would suggest. During this study one particular storm, which occurred in January 2000, stood out as an exceptionally intense lightning event; both in duration and in terms of the total number of cloud to ground (C-G) flashes. This paper provides a preliminary investigation into the meteorological dynamics, and an analysis of the C-G lightning flashes, that were associated with this event.

2. ANATOMY OF THE STORM

Between 20 and 21 UTC (Z) in the late afternoon of January 11th 2000 a line of thunderstorms developed off the U.S. eastern seaboard . At 21Z the line extended from just east of Cape Cod southwestwards for about 440 km. By 00Z on the 12th the line had moved east-northeastward at about 30 knots and had also developed further northward. At this time a thunderstorm was reported at Yarmouth Airport (YQI) on the southwestern tip of Nova Scotia. A second area of thunderstorms had also developed about 330 km to the east of the line and about mid-way along its length.

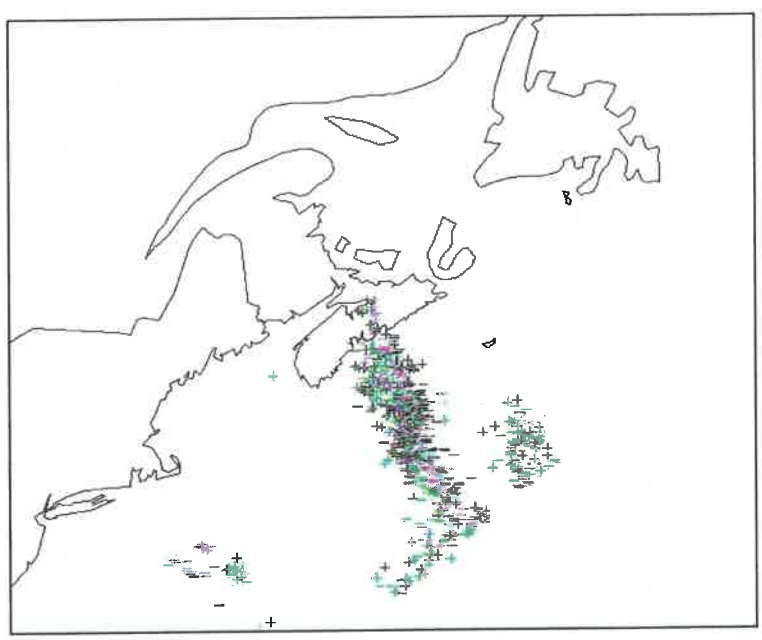

Fig 2-1. C-G Lightning flashes between 04-05Z 12th Jan 2000

The hourly flash rate increased as the system progressed east-northeastward and reached a peak between 04 and 05Z (Figure 2-1)when a total of 1776 C-G flashes was recorded. Of these, 1581 were attributed to the squall line, with the remainder located in the cell cluster to the east and also in newly developed cells in the cold air outflow to the west of the squall line (see Fig 2-1). The northern extent of the lightning paralleled the Nova Scotia coast, reaching about 50 km inland.

The flash rate began to decline slowly over the next 8 hours and the squall-line continued east-northeastward. By 09Z the line had caught up with and absorbed the cell cluster to the east, and by this time "only" 458 C-G flashes had been recorded in the preceding hour . Activity in the cold outflow to the west was continuing but was an order of magnitude smaller.

By 13Z on the 12th the squall line had dissipated with no flashes recorded east of longitude 53 W. Sporadic flashes continued through the day over the relatively warm waters to the north of the Gulf Stream...a not uncommon occurrence for this time of year (e.g., Burrows et al, 2002, Orville 1990).

The lightning attributed to the squall line and to cell cluster to the east of the line, persisted for a period of 17 hours and extended from longitude 71W to 54W. The areal coverage of the storm is shown in Figure 2 but it should be understood that the southernmost extent of the storm was likely well beyond the limit of the lightning detection network, as illustrated by the "apparent" cut off to the southeast in Figure 2-2 (see also Figure 3 in Lewis 2000).

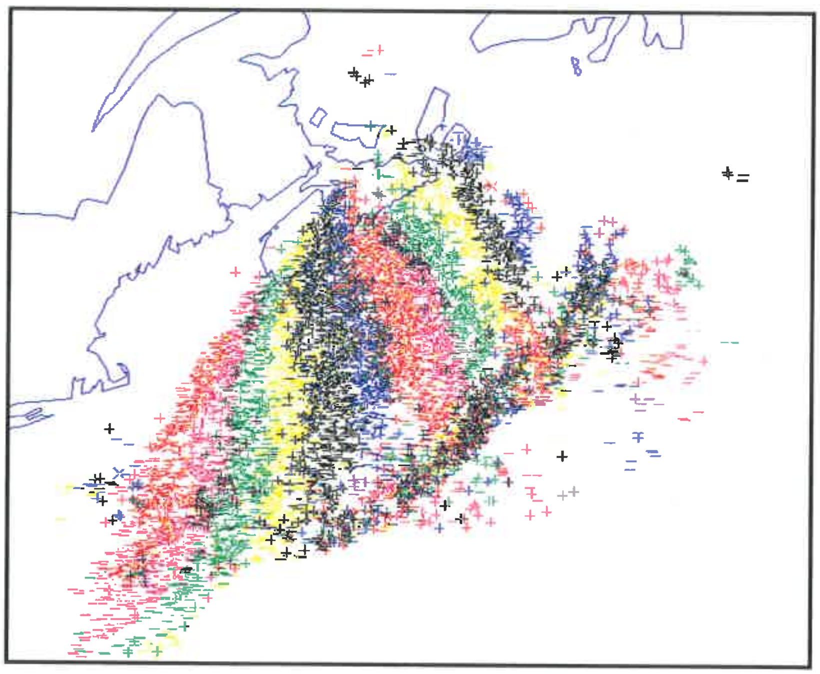

Fig 2-2. Total C-G Lightning flashes 20Z 11th - 13Z 12th Jan 2000 (displayed in hourly colour bins).

3. METEOROLOGICAL DISCUSSION

3.1 Synoptic Situation

The synoptic pattern was not unusual for the time of year. At 00Z on the 12th January, a 500 millibar (mb) low over the Quebec/Labrador border (~ 55° N) was reflected almost vertically at the surface by a 982 mb low. A short wave trough extended southward from the upper low over the New England states. Over the next 12 hours this trough sharpened and moved eastward to lie over Nova Scotia (12Z on the 12th) . The axis of the associated surface trough surface was about 370 km east of the upper trough. The hand analysis produced by the Maritimes Weather Centre (MWC) for 00Z on the 12th indicates that cylcogenesis was beginning to take place in the trough, with a new 989 mb low analysed close to Bangor, Maine. The 00 hr 12th Jan U.S. Eta model run for 00Z on the 12th did not show this low. The 06Z hand analysis depicted the deepening surface low at 988 mb close to the Nova Scotia/New Brunswick border. The 6hr Eta model forecast for 06Z on the 12th (Figure 3-1) indicated a 991 mb low centre about 110 km east of the hand analysis position. The intense lightning activity took place within the warm sector of this developing secondary low pressure system, in advance of the surface cold front. The following analysis will show that this activity was likely associated with a cold front aloft (CFA).

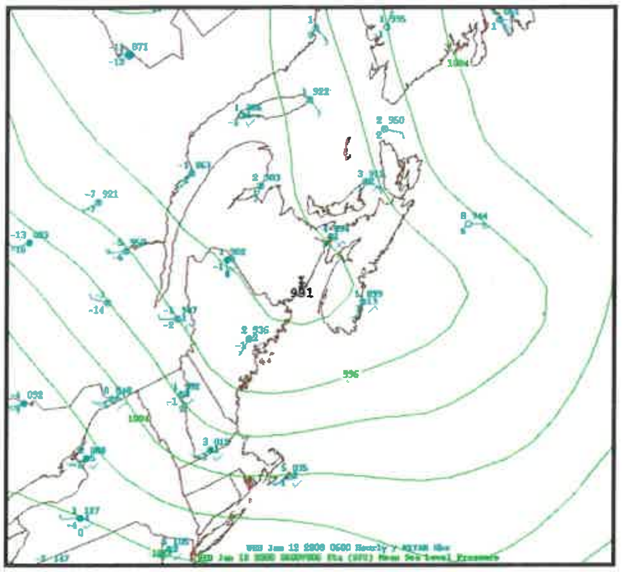

Fig 3-1. 6hr Eta model surface prog valid 06Z 12th Jan

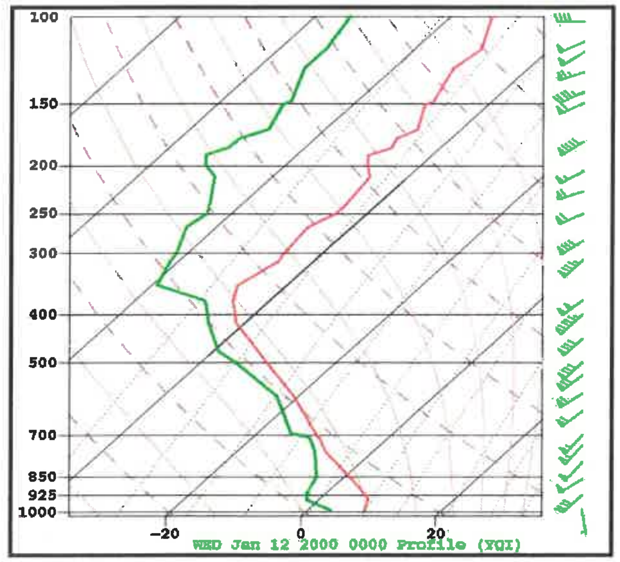

Fig 3-2. Upper air sounding for Yarmouth 00Z 12th Jan

3.2 Storm Analysis

Figure 3-2 shows the upper air sounding for Yarmouth, NS (YQI). At the time of the sounding, the first observation of a thunderstorm was being reported at the station. The sounding shows a nearly saturated, conditionally unstable air mass from the mid-levels to near the tropopause. Also of note, is the lack of any significant directional wind shear and the gradual increase in wind speed from 50 knots at 925 mb to 100 knots at 400 mb.

Figure 3-3 aids in understanding the dynamic processes taking place. The figure shows the GOES 8 satellite, water vapour channel image for 0615Z on the 12th. Superimposed on this, are the pressure levels of the 290 K theta (potential temperature) surface and the system relative wind vectors at these levels. The ascending warm moist air, with a long southerly oceanic fetch (warm conveyer belt), is clearly indicated. The descending dry air (dry conveyer belt) to the west, is also evident.

A cross-section showing vertical velocity (omega) and relative humidity though the system at 06Z on the 12th, using the 6 hr forecast Eta model data, is displayed in Figure 3-4. This indicates significant uplift (with a maximum greater than 14 microbars/sec near the 700 mb level) in the warm moist air from near the surface to the tropopause together with high humidity values. The descending and undercutting colder and drier air to the west is also evident (leading to further destabilisation).

The 06Z MWC hand analysis indicated a surface cold front approximately 110 to 150 km to the west of the core of lightning activity. The existence of the surface front and its position were based mainly on change in wind direction. Neither the surface observations of temperatures or dew points (though there were few observations available) nor the model surface fields showed much evidence of a strong surface front. Figure 3-5 shows the 6 hr Eta model forecast of 600 mb heights and theta e (equivalent potential temperature). A strong contrast in air masses is indicated at this level, providing evidence that the core of

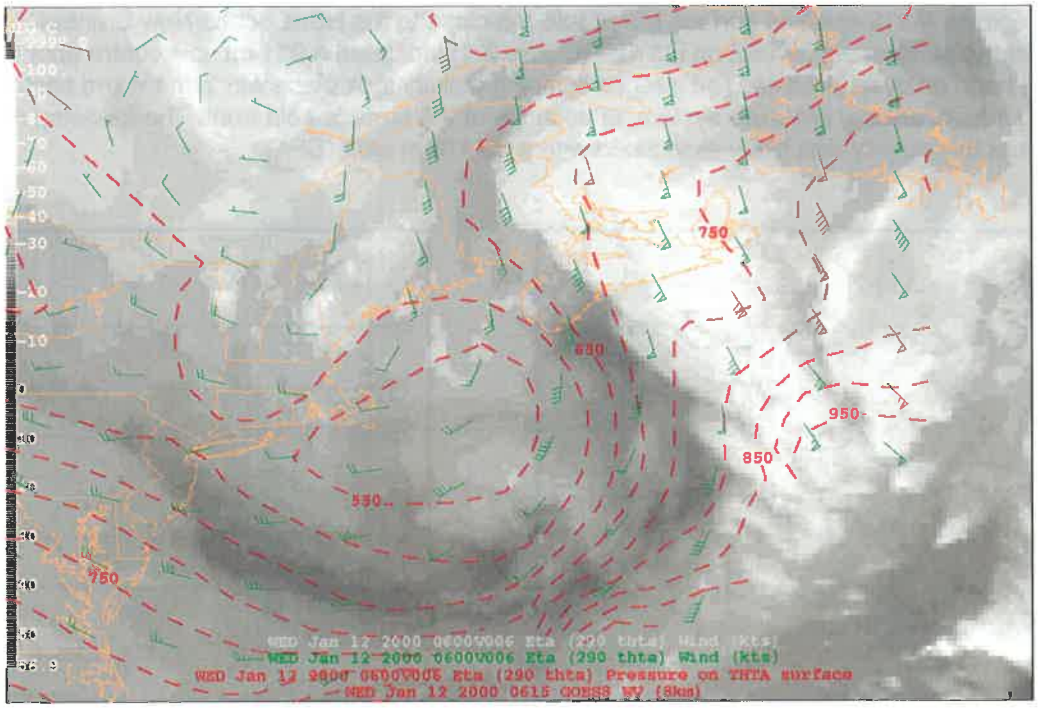

Fig 3-3 Goes 8 water vapour image for 0615Z 12th Jan with the pressures on the 290 K theta surface (red) and the system relative wind vectors (green)1. A-B is line of cross- section used in Fig 3-4 (below)

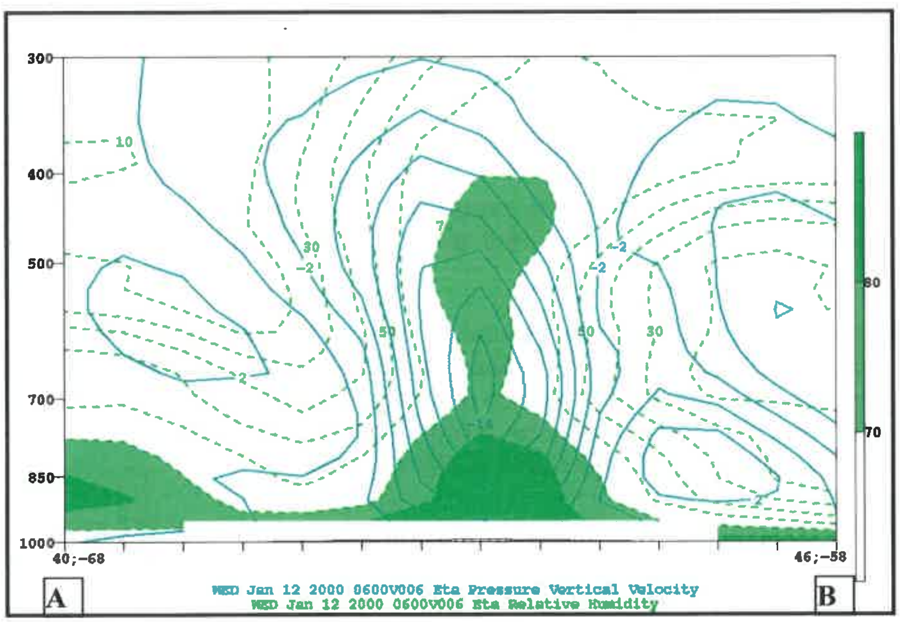

Fig 3-4. Vertical cross section following line A-B in Fig 3-3 of Eta model 06hr prog. vertical velocity "omega" (millibars/sec) blue, relative humidity (%) green

lightning activity was associated with an upper cold front. This system appears to be an example a "kata" cold front. A conceptual model describing this situation is well illustrated in Browning 1986 (his figure 5). The leading edge of the dryer colder air is advancing ahead of the surface cold front as a CFA . Ahead of the CFA the depth of the warm moist air increases abruptly leading to an organised band of convection.

It is clearly evident that there were strong dynamics to support a significant convective event. The squall line lightning activity provides evidence of this event. Further investigation is needed to determine the significance of the season and the roles the various meteorological ingredients played in producing this rare lightning event.

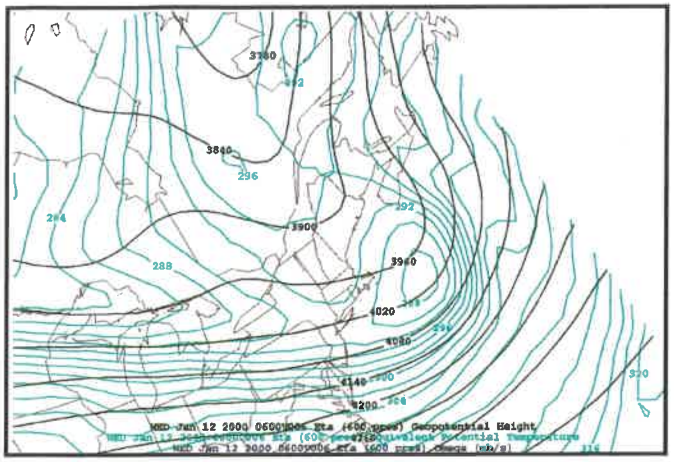

Fig 3-5. Eta model 6 hr prog valid 06Z 12th Jan - 600mb heights (green) and equivalent potential temperature (blue)

4. LIGHTNING ANALYSIS

4.1.Temporal Analysis

Table 4-1 shows the temporal breakdown of the entire lightning event on an hourly basis from 20Z on the11th until 13Z on the 12th January. The storm has been sub-divided into three sub-events which had differing meteorological dynamics these are: the squall line, the convective cell cluster which developed to the east of the squall line and the cold air convection which developed behind the squall line. The table also gives a breakdown of the ratio of +ve to -ve flashes for the total event and the three sub-events. As is evident from Figure 2-2, it is important to understand that that this storm extended well beyond the limits of the detection network. Hence the actual number of C-G flashes associated with storm would have been much greater. Also since the detection efficiency decreases towards the network limits many "weaker" C-G flashes were likely undetected.

	TOTAL C-G FLASHES			SQUALL LINE			EASTERN CONVECTION			COLD AIR CONVECTION		
Time Z	Total	+ve	%+ve	Total	+ve	%+ve	Total	+ve	%+ve	Total	+ve	%+ve
20-21	220	13	5.91	211	13	6.16	9	0	0.00			
21-22	331	68	20.54	322	65	20.19	19	3	15.79			
22-23	730	62	8.49	684	53	7.75	46	9	19.57			
23-00	935	132	14.12	878	119	13.55	57	13	22.81			
00-01	997	169	16.95	859	121	14.09	138	48	34.78	7	0	0.00
01-02	1247	257	20.61	1108	213	19.22	129	44	34.11	10	0	0.00
02-03	1673	352	21.04	1460	307	21.03	191	39	20.42	22	6	27.27
03-04	1495	267	17.86	1326	215	16.21	137	39	28.47	32	13	40.63
04-05	1776	312	17.57	1581	245	15.50	151	49	32.45	44	18	40.91
05-06	1089	257	23.60	945	199	21.06	85	30	35.29	59	28	47.46
06-07	772	309	40.03	656	233	35.52	53	29	54.72	63	47	74.60
07-08	512	263	51.37	431	209	48.49	41	24	58.54	40	30	75.00
08-09	458	209	45.63	398	173	43.47	21	12	57.14	39	24	61.54
09-10	305	180	59.02	280	164	58.57				25	16	64.00
10-11	155	63	40.65	123	47	38.21				32	16	50.00
11-12	95	35	36.84	44	13	29.55				51	22	43.14
12-13	90	34	37.78	39	4	10.26				51	27	52.94
Total	12880	2982	23.15	11345	2393	21.09	1077	339	31.48	475	247	52.00

Table 4-1 Hourly distribution from 20Z 11th Jan through 13Z 12th Jan of C-G flashes and +ve/-ve flash ratios for the "total" event and the 3 "sub-events"

4.1.1 The Squall Line

The number of C-G flashes produced by the squall line was an order of magnitude higher than those in the other two "sub-events". The lightning produced by this feature was not typical of "cold outflow" lightning more commonly associated with winter lightning in this region (e.g. Burrows et al 2002, Orville 1990). It has been illustrated in Section 3 that this feature was associated with synoptic scale meteorological forcing. Cloud top temperatures associated with the intense lightning were below minus 40° C indicating overshooting of the tropopause which from the Yarmouth upper air sounding for 00Z 12th was near 8 km. Radar echo tops from the Halifax Radar also indicated maximum tops at around the 8 km level. Figure 4-1 shows a steady intensification of the flash rate from an initial 220 flashes in the first hour to a peak of 1581 between 04 and 05Z then a steady decline. The +ve/-ve ratio shows some interesting features which could give some insight into the electrification processes. After 23Z the +ve/-ve ratio remains between 14 and 21 percent up until the hour of peak flash rate ,(04-05Z), the ratio then increases, reaching a maximum of 59% between 09-10Z before declining again as the activity tapers off - though values in the last three hours may be relatively too small to draw useful statistical conclusions.

4-1-2 The Eastern Convective Cluster

Figure 4-2 shows the temporal distribution of flashes for the convective cluster which formed to the east of the main squall line and remained as a separate entity until it was overtaken and absorbed by the squall line between 08 and 09Z .A separate meteorological analysis of this feature has not been performed. It is likely of too small a scale to be resolved by the Eta model. Cloud top temperatures in this cell were similar to those in the squall line. The hourly flash rate peaked at close to 200 between 02-03Z - two hours earlier than the squall line peak. The +ve/-ve charge ratio built to ~ 20% after the first two hours then remained between 20 to 35% for 7 hours before, increasing to above 50% as the flash rate declined (this was similar to the squall line).

4.1.3 Western Cold Air Convection

As colder air moved in behind the squall line smaller, lower topped convective cells began to develop, a more common winter lightning scenario for this region. Lewis (2000) found a +ve/-ve charge ratio of 46% for the region for the two winters (December -April) of his study. Others (e.g. Orville 1990) also report a high ratio for "cold outflow" lightning. This is also supported here. Apart from the first three hours (when there were very low flashes rates) the ratio remained well above 40% and reached as high as 75%. This cold air convection lightning may fit the "tilted dipole" model of Brooke et al 1982.

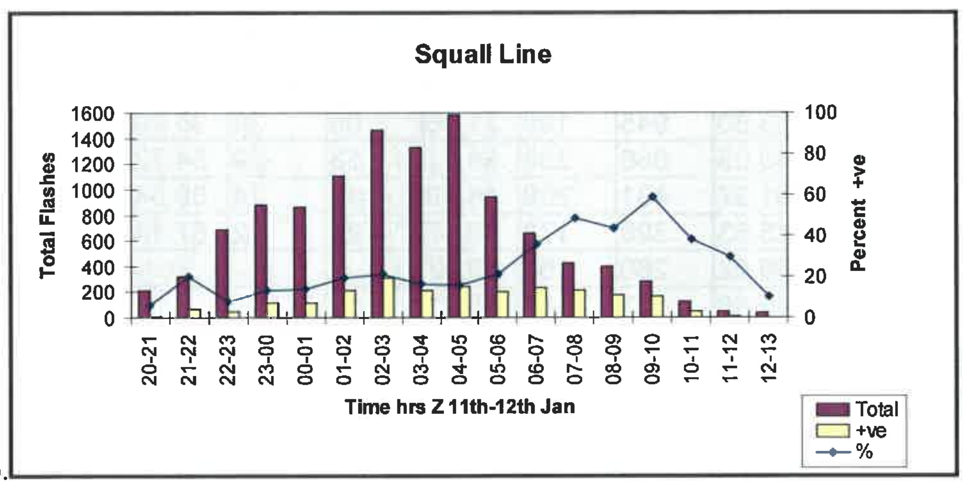

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Figure 4-1 Hourly C-G total flash rate, +ve flash rate and percent +ve for the squall line

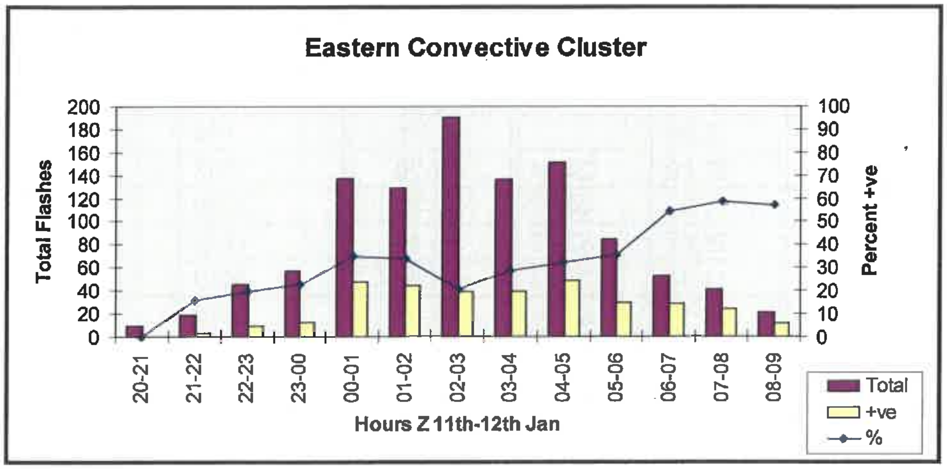

Fig 4-2 As Fig 4-1 for the eastern convective cell

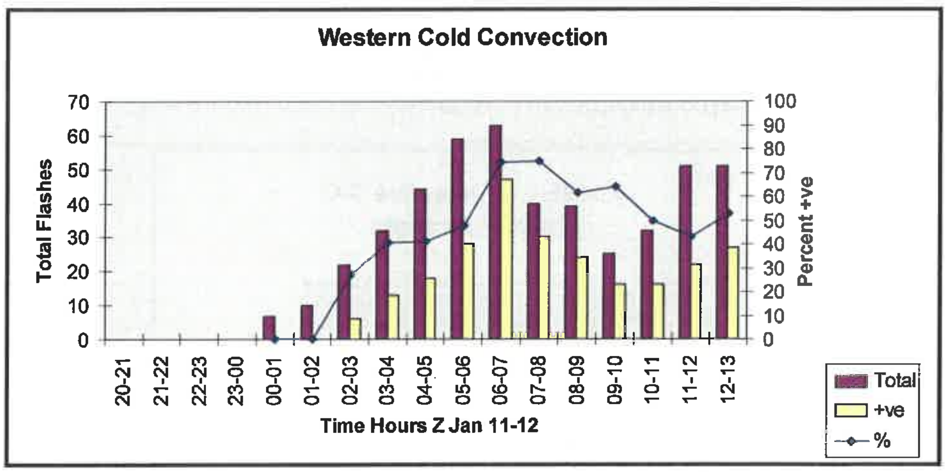

Fig 4-3 As Fig 4-1 for the western cold air convection

4.2 Analysis of Current Strengths

It has been reported in the literature (Uman, 1987) that +ve cloud to ground flashes are typically characterized by higher current strengths and fewer return strokes. Analysis of the relative distributions of current strengths for this extensive event with a relatively large number of +ve strokes would seem to support this. It should again be emphasized that this event extended beyond the limits of the detection network and it is likely that some lower current value flashes near the limits of the network may not have been detected. However, this may also have "filtered out" in-cloud +ve flashes which Cummins 1998 and Orville and Huffines (2001) report can be falsely detected as low current (0-10 K amp) cloud to ground flashes.

Table 4-2 shows a cumulative frequency analysis for +ve and -ve cloud to ground flashes for the entire event.

Positive Current Kamps	Total Flashes	% Total	Cumul-ative %	Negative Current Kamps	Total Flashes	% Total	Cumul-ative %
0-10	64	2.04		0-10	148	1.49	
10-20	710	22.60	24.64	10-20	2568	25.82	27.31
20-30	689	21.93	46.57	20-30	2786	28.02	55.33
30-40	499	15.88	62.45	30-40	1892	19.03	74.36
40-50	357	11.36	73.81	40-50	1069	10.75	85.11
50-60	238	7.57	81.38	50-60	612	6.15	91.26
60-70	159	5.06	86.44	60-70	373	3.75	95.01
70-80	119	3.79	90.23	70-80	222	2.23	97.24
80-90	87	2.77	93.00	80-90	116	1.17	98.41
90-100	59	1.88	94.88	90-100	77	0.77	99.18
>100	161	5.12	100.00	>100	110	0.82	100.00

Table 4.2 Cumulative frequency analysis of current strength for +ve and -ve C-G flashes for the entire event

For +ve flashes 74% reported had values below 50 K amps compared to 85% of -ve flashes. At the upper end almost 10% (9. 77) for +ve flashes had values above 80 k amps compared to only 2.76% for -ve flashes. These results are displayed as cumulative frequency curves in Figure 4-4).

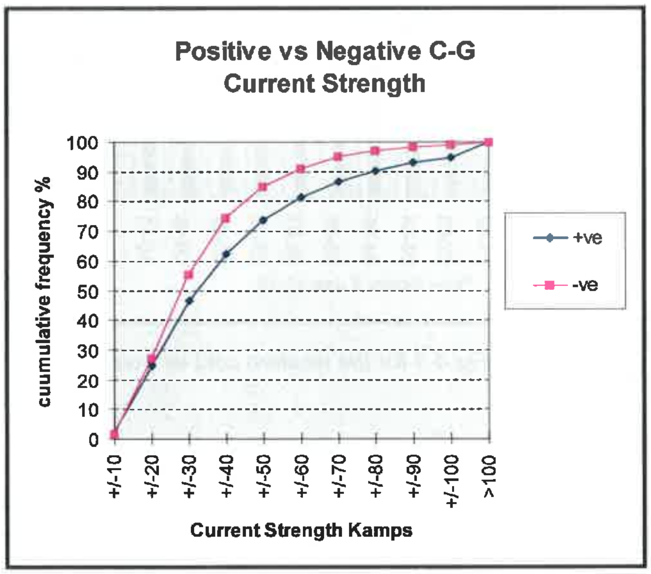

Fig 4-4. Cumulative frequency curves of current strength for +ve and -ve C-G flashes

5. SUMMARY AND CONCLUSIONS

This preliminary study provides an outline of an exceptional lightning event which occurred over Nova Scotia, Canada and the surrounding waters in January 2000. In terms of intensity of lightning this event would have been remarkable for this region at any time of the year. The benefits of CLDN data for providing more realistic lightning climatologies have already been demonstrated (e.g. Lewis 2000, Burrows et al 2002) Here, it has been shown that intense lightning events are possible in this region during the winter months. Prior to the installation of the CLDN the storm would have likely only have been detected at three synoptic observing stations and its full extent and areal coverage would never have been realised. This study has demonstrated that differing meteorological forcing mechanisms can produce differing lightning characteristics , such as differing +ve/-ve charge ratios. Further investigation into how and why the meteorological ingredients came together to produce such a remarkable event is certainly warranted. Further analysis of the lightning data in conjunction with the meteorology could provide useful insights into the electrification processes which took place to produce such intense lightning.

6 ACKNOWLEDGMENTS

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