THE CLIMATOLOGY OF FREEZING RAIN IN THE MONTREAL AREA

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ABSTRACT Using data from the winter seasons 1953-54 to 1970-71 from Dorval, Ste. Agathe des Monts, Quebec City, Ottawa and Maniwaki a freezing-rain climatology for the Montreal area was developed. The monthly, seasonal and hourly distributions, and the dependence of freezing rain events on temperature and wind direction were investigated. The monthly and seasonal distributions, the average duration and areal extent of long-duration freezing rain storms (events with durations of 4 or more hours) were determined. Preferred tracks for cyclones associated with these storms were constructed.

1. Introduction

According to the Glossary of Meteorology (Huschke 1959), freezing rain may be defined as: "rain that falls in liquid form but freezes upon impact to form a coating of glaze upon the ground and on exposed objects. While the temperature of the ground surface and glazed objects initially must be near or below freezing, it is necessary that the water drops be supercooled before striking. Freezing rain frequently occurs, therefore, as a transient condition between the occurrence of rain and ice pellets."

To date, many studies have been done on particular synoptic situations involving freezing rain, and on the resulting ice; especially on those severe storms which damaged transmission lines or struck heavily populated areas(eg Brooks (1914), Ackley and Itagaki(1970), McQueen and Keith(1956), Ferland(1974), Mahaffy(1961), Thomas(1960), Chagnon(1969)). Typically, freezing rain is associated with a warm frontal situation. Warm air (with temperatures above $0^{\circ}C$) overruns underlying colder air (with temperatures below $0^{\circ}C$) in a narrow band ahead of the surface warm front. These conditions are conducive to the occurrence of ice pellets and/or freezing rain. Quite often, snow will be the first precipitation to fall, followed by ice pellets, freezing rain and finally rain as the surface warm front approaches and then goes through the area. The type of precipitation, and the duration of each type are dependent upon the thicknesses of the warm and cold layers.

Also quite common are occluding frontal systems. In these cases, the warm air may be trapped aloft, above the surface of the occlusion, and the colder air is near the surface. With these conditions, it is less likely that there will be rain after the freezing rain.

Studies dealing with the climatology of freezing rain and/or icing have also been undertaken (eg McKay and Thompson(1969), Thomas(1955), Wilson(1973), Chainé(1973), (1974), Powe(1969), Boyd(1970)).

Because it occurs as a transition stage between frozen (solid) and non-freezing liquid precipitation types, freezing rain is difficult to forecast accurately. The transitions between the various precipitation types depend upon the thicknesses of the warm and cold layers of air and thus are difficult to predict. However, they are important. If the freezing rain is of short-duration, or followed by rain, the ice accumulations will be less severe, and consequently less damage is likely to result. Attempts at improving forecast techniques for the transition from one type of precipitation to another have been made by various investigators (eg Koolwine(1975), Jarvis(1961), Tyner(1972), Moeller(1967), Glahn and Bocchieri(1975), Cott(1966)).

Utilities companies have been particularly interested in the problem of ice accretion.

Preferred regions, ice load climatologies (leading to design load statistics), and studies of individual storms have been undertaken (eg Leech and Renaud(1976), Leech and Low(1977), Richmond and Boomer(1974), (1975), Félin(1976)).

Also, research has been done on the physical processes of ice accretion, and icing models have been developed (eg Kuroiwa(1965), Chainé and Skeates(1974), Leech and Low(1977), Richmond and Boomer(1974)). The type and amount of ice which accumulates on a particular collector depends on the air temperature, humidity, drop size, rainfall rate, wind speed and direction, and on the temperature, shape, size and surface characteristics of the collector. The rate of ice accumulation determines how much damage will be done.

The purpose of this paper is to present a climatology of freezing rain in the Montreal area, more detailed than any in the literature. Hourly- and long-duration (4 or more hours of freezing rain) freezing-rain events will be studied.

2. Climatology of 1-Hour Freezing Rain Events

The data that were used in the preparation of this climatology consisted of hourly weather observations at Montreal International Airport (Dorval), Quebec City Airport, Ottawa International Airport, and Ste. Agathe des Monts; and 6- or 3-hourly reports from Maniwaki. (The data from Maniwaki were not used in all of the analyses as they were not available hourly.) The periods of data are given in Table 2.1. From these data, the surface observations for all occurrences of freezing rain were extracted.

Table 2.1 Climatology Data

Type of Data	Station	Period of Data
Hourly	Montreal (Dorval)	Jan '53 - Dec '70
Hourly	Quebec City	Jan '53 - Dec '70
Hourly	Ottawa	Jan '53 - Dec '70
Hourly	Ste. Agathe	Dec '65 - Dec '71
6-Hourly	Maniwaki	Dec '53 - Dec '54
3-Hourly	Maniwaki	Jan '55 - Apr '70

The annual average number of hours of freezing precipitation (freezing rain and freezing drizzle) occurring in the Montreal area has been determined by several investigators using different periods of data (eg McKay and Thompson(1969), Powe(1969), Wilson(1973)). Their results indicate annual averages of approximately 50 hours of freezing precipitation, of which 12 - 30 hours are in the form of freezing rain.

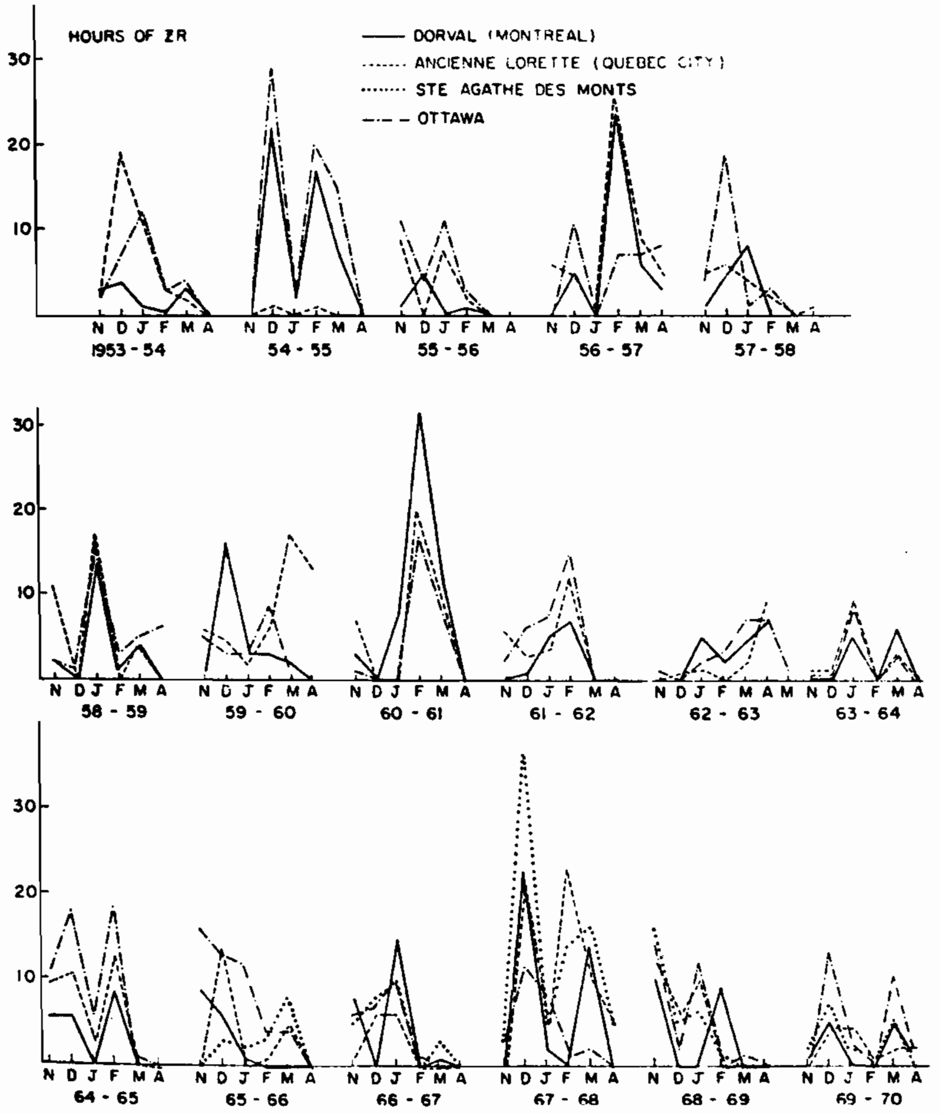
Table 2.2 Means and Standard Deviations of Seasonal Hours of Freezing Rain

Station	Mean (hours)	Standard Deviation
Montreal (Dorval)	22.9	13.2
Quebec City	27.8	16.1
Ottawa	31.6	13.0
Ste. Agathe	30.3	22.3

Table 2.2 gives the seasonal (November - April inclusive) means and standard deviations for the data used in the present study. (No observations of freezing rain in October were reported, and only one hour in May was reported, this was at Ottawa.) According to these values, there are fewer hours of freezing rain annually at Dorval (23) than at the other locations, and the maximum is at Ottawa (32). Fig. 2.1 indicates the number of hours of freezing rain by month throughout the period studied. The seasonal values are shown in Fig. 2.2. It can be seen that the variability from one month or season to the next may be large, and no pattern is apparent. Two (or more) stations having corresponding peaks in the same month, is usually due to one storm affecting both (or all). However, in other cases, a particular storm may bring several hours of freezing rain to one location, whereas at the others the precipitation may all have been in other forms. The high standard deviations in Table 2.2 reflect the large variabilities seen in Figs. 2.1 and 2.2. (At Ste. Agathe the standard deviation is especially large, but the period of data is shorter.)

The mean number of hours of freezing rain in each month are given in Table 2.3, and the monthly frequencies are shown in the histogram of Fig. 2.3. In all locations except Ste. Agathe, the maximum frequencies occur during the mid-winter months, with lower frequencies during the transition seasons(November, March-April). The absolute maximum in December at

Fig. 2.1 Number of hours of Freezing Rain per Month, 1953-54 to 1969-70



Ste. Agathe is the result of a particularly severe month, December 1967, (36 hours of freezing rain), and a shorter data period. From McKay and Thompson(1969), at Toronto the pattern is basically the same; while at Calgary, Alberta and Churchill, Manitoba bi-modal distributions occur. The winters are colder there and the maxima correspond to the onsets of the winter and spring seasons (see Fig. 2.4). (Note that there is very little freezing rain in Calgary.) At St. John's Newfoundland, the freezing rain season extends into May, and the maximum frequency occurs in March.

The distributions of freezing rain occurrences with respect to time of day were determined. Whereas the monthly frequencies at Ste. Agathe were biased due to the shorter record and an extreme event, the hourly frequencies may be considered unbiased. The most likely time for Montreal is in the early morning hours with the peak at 4-5 AM; and the least likely time from 5-6PM. The patterns at the other locations are somewhat different. At. Ste. Agathe, there is a very marked peak at midnight, and two minima, one in the early morning (4-5 AM) and the second at 1 PM. At Quebec City, the nighttime hours are favoured, and the maximum is at 11 PM. At Ottawa, however, the peak is during the midmorning hours (9 AM) and the minima are in the late afternoon-early evening period, and in the early

Fig. 2.2 Number of Hours of Freezing Rain per Season, 1953-54 to 1970-71

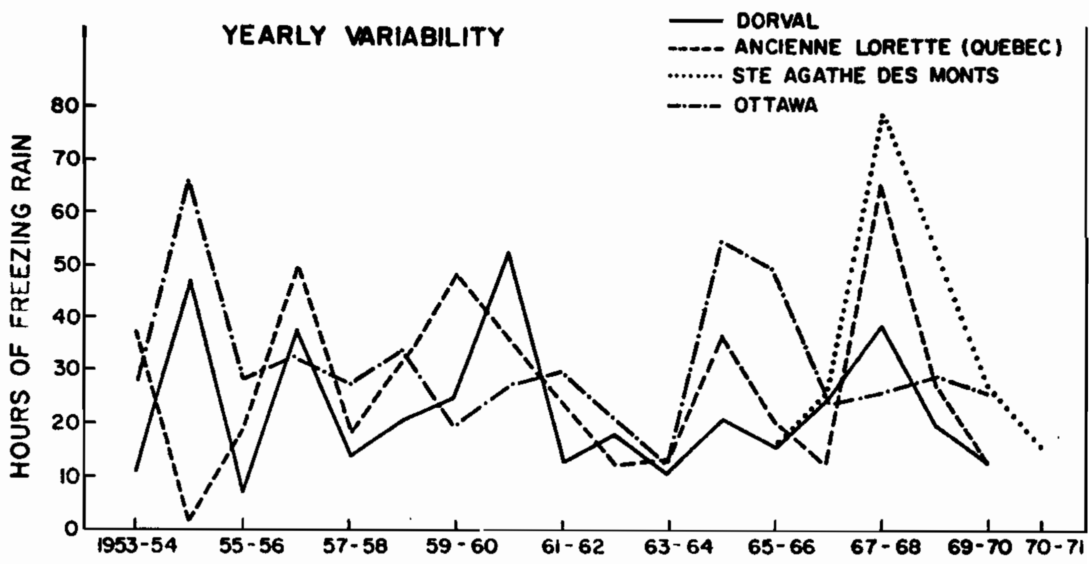


Table 2.3 Monthly Means

	Nov	Dec	Jan	Feb	Mar	Apr	May
Montreal	2.7	5.8	4.5	5.8	3.7	0.6	-
Quebec City	4.3	6.1	6.1	6.4	3.9	1.9	-
Ste. Agathe	4.3	10.7	5.0	3.2	5.3	1.5	-
Ottawa	4.5	8.1	7.1	6.0	4.3	1.3	0.1

Fig. 2.3 Monthly Frequency Distribution of Freezing Rain Events

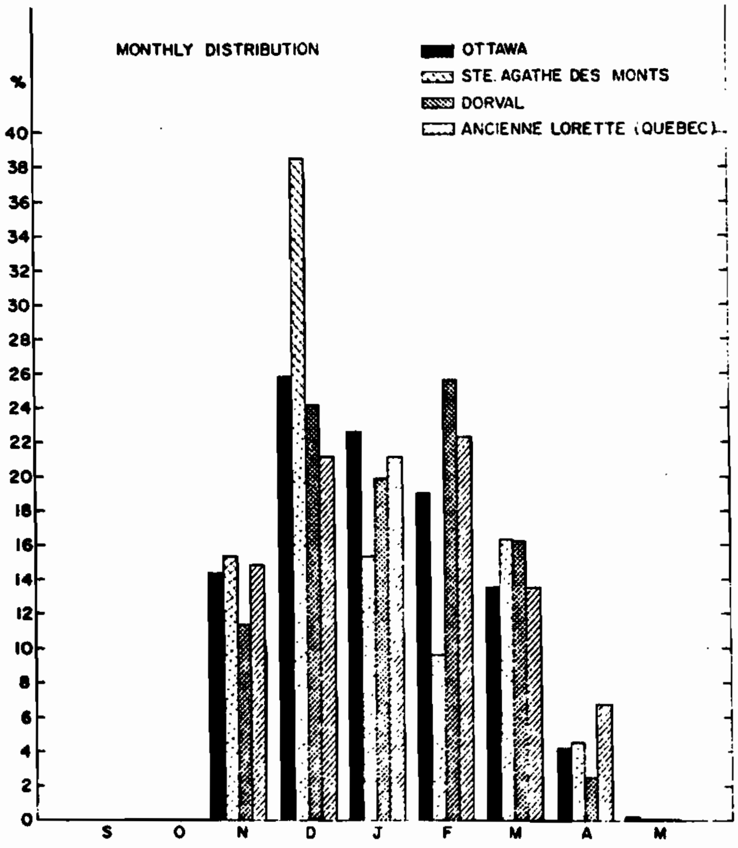
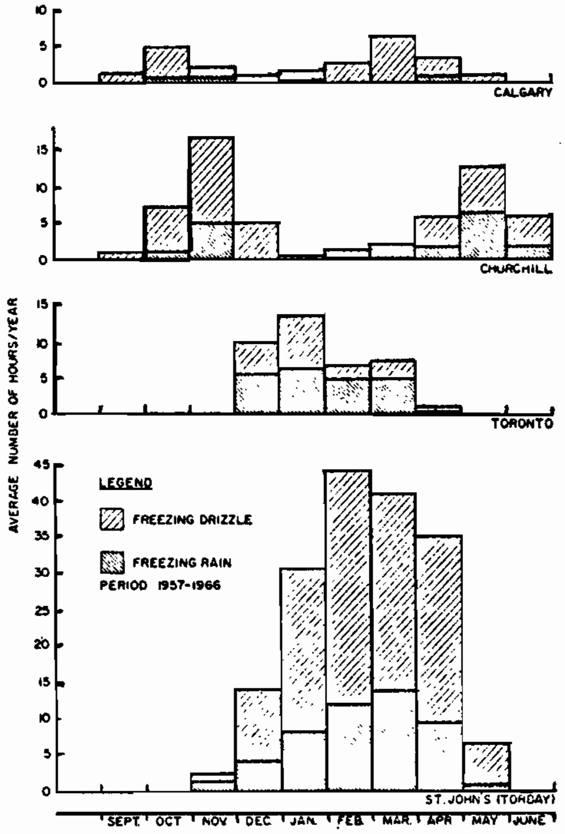


Fig. 2.4 Average Number of Hours of Freezing Precipitation (McKay and Thompson, 1969)



Average number of hours of freezing precipitation.

morning (4 AM). In summary, with the exception of the 9 AM maximum at Ottawa, the least likely hours for freezing rain in the area seem to be the daylight hours. Powe (1969) in his analysis of Montreal data (1957-66) found that the most likely time for freezing rain was in the evening with a peak about midnight; the least likely time was from 6-9 AM.

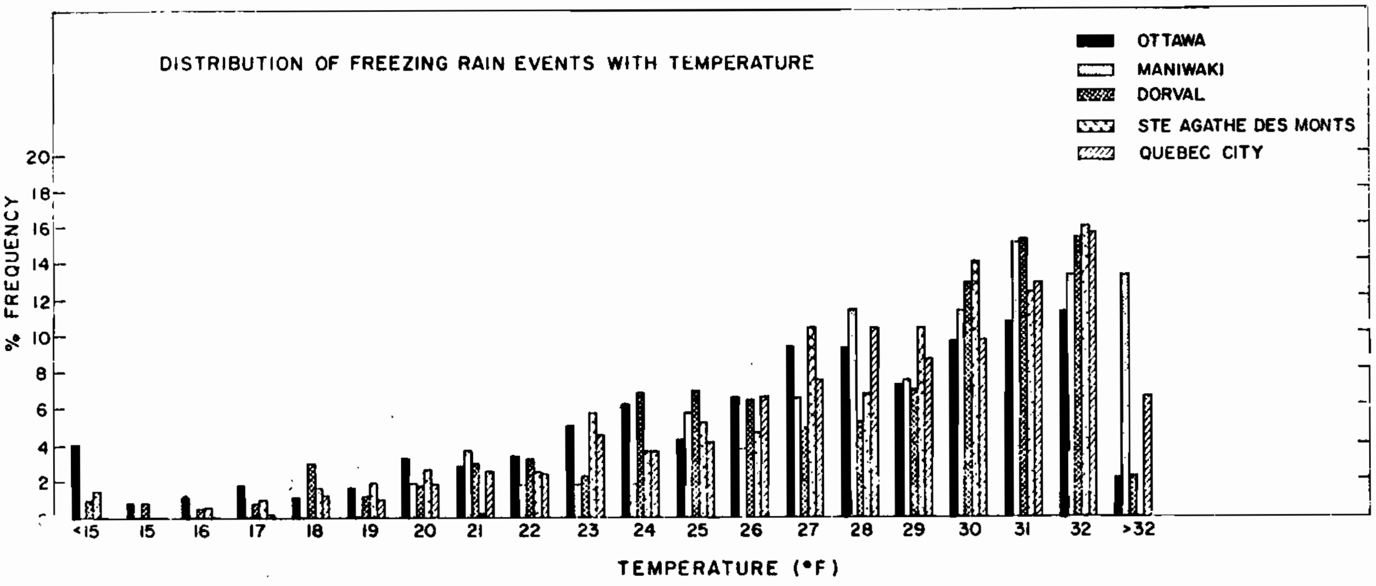
A histogram of the distribution of freezing rain events with temperature is given in Fig. 2.5. The temperature used is the screen temperature (1.6 m above ground) read sometime during the hours in which freezing rain was reported. For all locations, the pattern is basically the same: the %-frequency of events increases with increasing temperature up to the melting temperature (32°F), and then drops sharply. (Fahrenheit rather than Celsius temperatures were used since the data were in that form. A change from $^{\circ}$F to $^{\circ}$C would have resulted in a loss of precision.) There is no abrupt decrease in frequency of occurrence for temperatures greater than 32°F at Maniwaki, but there observations were taken only every 3 or 6 hours (depending on the year), and the temperature that was recorded may not have been the actual temperature during the freezing rain. Since freezing rain occurs most frequently ahead of an approaching warm front, it is quite likely that the temperature may have risen above 32°F during the 3- or 6-hour period, but been at or below freezing during the freezing rain event. This could explain the pattern at Maniwaki.

At the lower end of the temperature scale, there are very low frequencies for temperatures below about 18°F. There are two possible explanations for this cut-off:

(i) that it is unlikely that the necessary synoptic conditions will occur when the surface temperature is below about 18°F, or

(ii) that freezing rain does not occur when the surface temperature is below about 18°F because the drops have refrozen during their fall through the sub-freezing layer and the precipitation at the surface is therefore in the form of ice pellets or sleet.

Fig. 2.5 Distribution of Freezing Rain Events with Temperature



According to the Glossary of Meteorology (Huschke 1959), sleet is defined as: "generally transparent globular, solid grains of ice which have formed from the freezing of raindrops or the re-freezing of largely melted snowflakes when falling through a below freezing layer of air near the earth's surface." Also, McQueen and Keith (1956) state that the greater the thickness of the below-freezing layer, the greater is the chance that the supercooled raindrop will fall as sleet. However, according to Vali (1964), the freezing of drops of melted snow water would not occur until much colder temperatures. (see Fig. 2.6. The filtered sample was once-filtered snow water. The filtering removed the nuclei which were activated at the warmest temperatures.) Considering the unfiltered sample which experienced nucleation at warmer temperatures, it can be seen that it is not until temperatures significantly colder than 18°F that any appreciable frequency of nucleation events takes place. Therefore, the second of the explanations mentioned above seems unsuitable. Vali's results also suggest that McQueen and Keith's statement concerning the thickness of the subfreezing layer and the probability of sleet is also inappropriate (except perhaps for much colder surface temperatures). A more critical factor is the thickness of the layer warmer than freezing which determines whether or not the snowflakes melt completely or only partially. The thicker this layer, the greater is the likelihood that the precipitation particles emerge from it in the liquid state. Particles emerging from a thinner layer, and which still contain some ice, ie partially-melted snowflakes, will refreeze more quickly than liquid drops since they contain more quickly-activated nuclei, ie ice crystals.

Thus, it would seem that the occurrence of sleet at temperatures comparable to those of the freezing rain observations is due to the refreezing of partially-, not wholly-melted snowflakes, and not, as had been suggested earlier, to the refreezing of supercooled drops. This implies that the synoptic explanation must be the correct one: that freezing rain occurs infrequently when the surface temperature is below about 18°F because the necessary synoptic conditions are not likely to occur. That is, if the surface temperature is too cold, the required warm layer probably does not exist, or it is not warm enough, or thick enough, to completely melt the snowflakes falling through it and yield liquid drops, which would then be supercooled in a sub-freezing layer near the surface, resulting in freezing rain.

The distributions of wind directions at Montreal, Ottawa and Quebec City airports for the months of the freezing rain season, ie November to April, are shown in Fig. 2.7. It can easily be seen that the frequency of wind by direction has a bi-modal distribution at these locations; this is largely due to the influence of the St. Lawrence and the Ottawa River valleys. The differences in the location of the peaks are due to the differences in the orientation of the valleys at these stations, and to other topographic features in the

Fig. 2.6 Smoothed Distributions of Freezing Events for Filtered and Unfiltered Melted Snow Water (from Vali 1964)

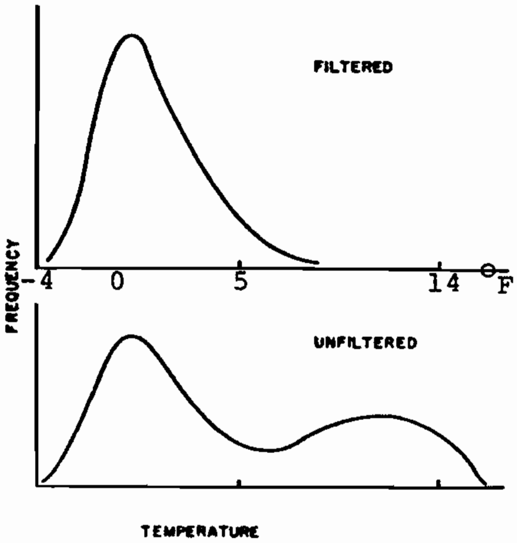
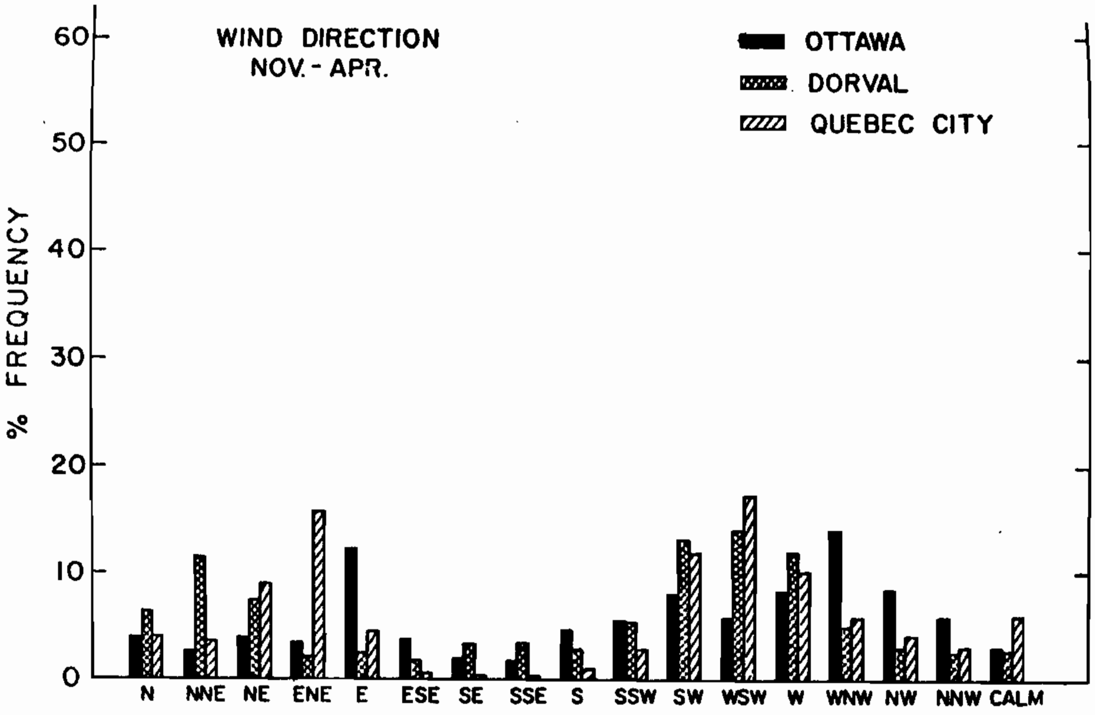
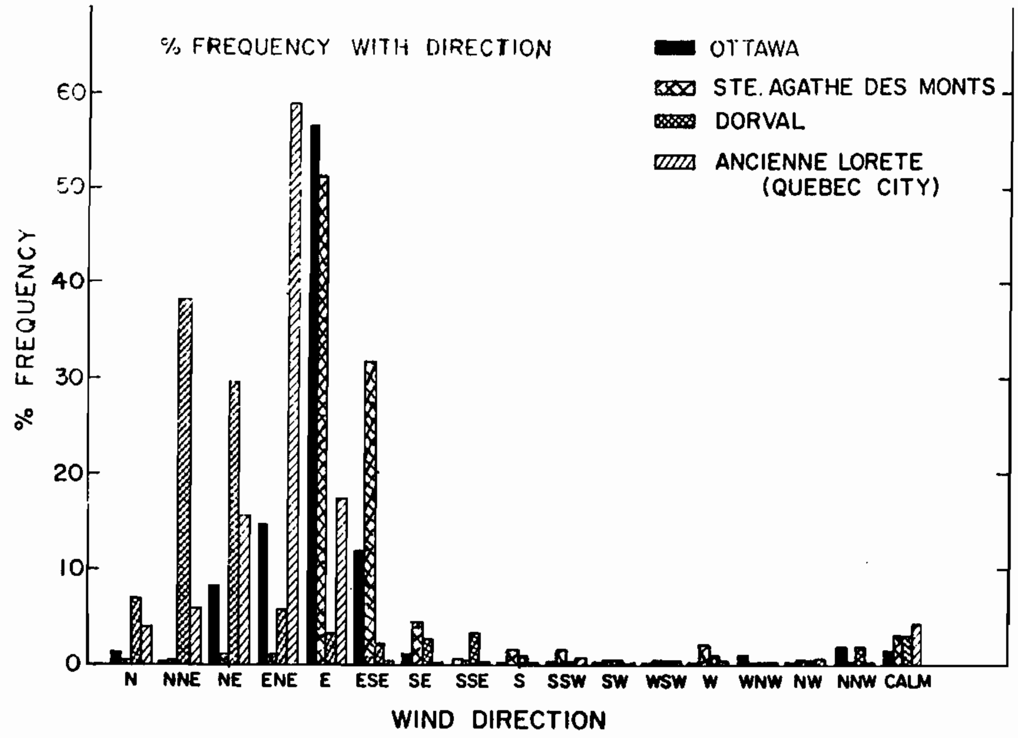


Fig. 2.7 Distributions of Wind Directions at Montreal, Quebec City, and Ottawa Airports November - April



area (Powe 1968). As described by Powe, the valleys have two effects on the winds at these locations: the first is to funnel or deflect the winds and cause them to follow the valley; and the second may be described as a tunnel effect. In situations where there is a low pressure system approaching this area from further west and/or south on the continent, the pressure at sites down-river will be higher than that at sites up-river. The pressure gradient along the valley results in a surface flow from high to low pressure along the valley, ie from down-river. This results in NNE-NE winds at Montreal, NE-ENE-E winds at Quebec City and ENE-E-ESE winds at Ottawa. In such cases, the upper flow is generally bringing warmer air from the southwest, and a very stable situation is created. Warm air is pumped in aloft, and colder, denser air from the Gulf of the St. Lawrence is brought in at the surface. The warmer air may be considered a lid and the colder air tunnels up the valley below it. This situation will often delay the passage of the warm front at the surface. If the air aloft is sufficiently warm to melt any snow that may be falling, an ideal situation for freezing rain is created. The snow melts as it falls through the layer of warm air, and then becomes supercooled as it falls through the colder air near the surface.

Fig. 2.8 Distribution of Freezing Rain Events with Respect to Wind Direction



The distribution of freezing rain occurrences with respect to wind direction is presented in Fig. 2.8, and shows the effect of the valley. Not only would pre-warm frontal winds have a tendency to be turned by the valley to NE, but the additional influence of the pressure gradient flow results in maximum frequencies for winds blowing up-river. The stability of this situation, and delaying of the surface warm front can lead to prolonged freezing rain events. It the warm air is not sufficiently warm to melt the snow, the result is that snow will continue to fall longer than it would have otherwise, and that rain will fall less often. A comparison of the precipitation records of these locations with others just to the south of the valley reflects this (Powe 1968).

3. Analysis of Freezing Rain Storms

3.1 Introduction

The climatology of the previous section was based on hourly freezing rain events without regard to their duration or how they were grouped together as synoptic events. In this section, a freezing rain event is classified as a long-duration storm if there were four or more hours of freezing rain at one or more of the sites considered: Ste. Agathe, Montreal, Quebec City, and Ottawa. A total of 98 such storms were identified.

3.2 Climatiology of Long-Duration Storms

In order to determine whether part of the area is more prone to long-duration storms that the rest, the number of storms at each station, throughout the period studied, was determined (see Table 3.1). The seasonal average numbers of storms indicate that Ste. Agathe has about one more long-duration storm per season than do Montreal or Quebec City. The value at Ottawa falls between those of Ste. Agathe and Montreal-Quebec City. (Although Ste. Agathe had the least total number of storms, recall that the period of data was shorter.)

Table 3.1 Number of Long-Duration Freezing Rain Storms at Each Station

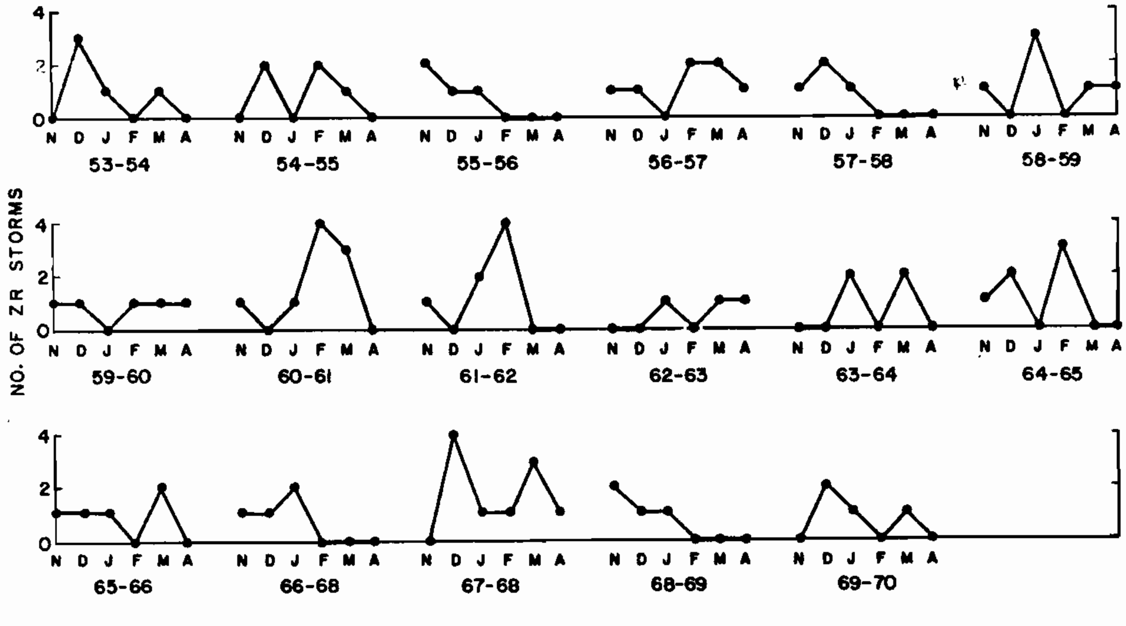
Station	No. of Storms	Seasonal Average
Ottawa	57	3.35
Quebec City	44	2.59
Montreal	46	2.71
Ste. Agathe	19	3.80

Table 3.2 Areal Extent of Long-Duration Freezing Rain Storms (96 Storms)
(ZR Freezing Rain)

# Sites	Storm %	ZR %
3	12.5	32.3
2	28.1	41.7
1	59.4	26.0

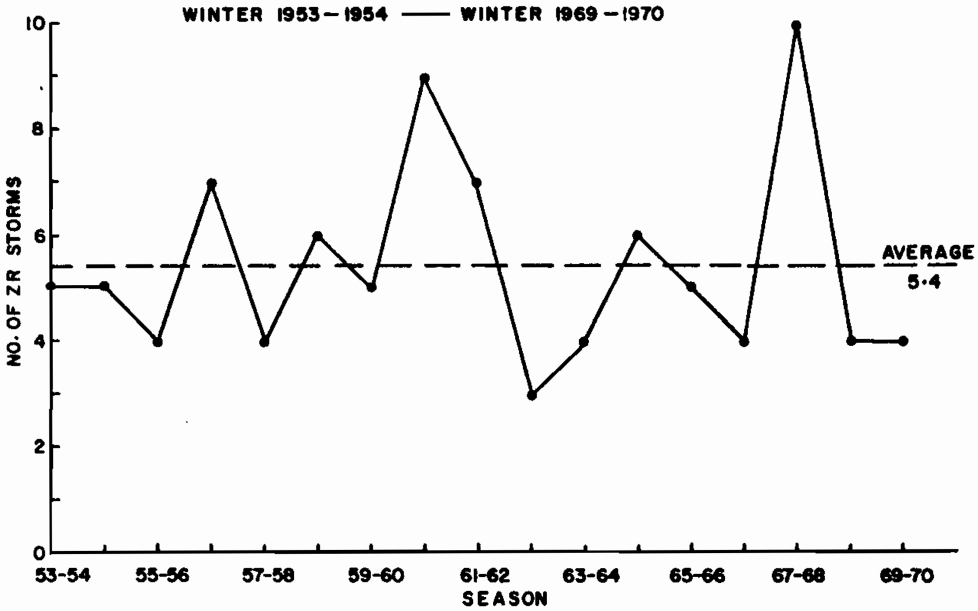
The areal extent of the long-duration storms studied was examined. Only Ottawa, Quebec City and Montreal were included in this analysis since the Ste. Agathe data were not available for the whole period, making interpretation of the results difficult. Each storm was classified according to whether it had been categorized as a storm at 1, 2, or 3 of the stations. Also, since there may have been a long-duration storm at one location, and freezing rain, but not enough to be classified as a long-duration storm at another location, the areal extent of freezing rain with a long-duration storm at one or mare stations was also calculated. The results are presented in Table 3.2. The column labelled "Storm %" gives the percentage of storms which were classified as such at the indicated number of sites; the column labelled "ZR %" gives the percentage of storms which were classified as such at at least 1 station and produced freezing rain at 1, 2, or 3 stations. It can be seen that the majority of long-duration storms (59.4%) qualified as such at only one location, although a significant portion (12.5%) were so classified at all three locations simultaneously. Approximately one-quarter of the long-duration storms produced freezing rain at only one location (ie the location where it was a long-duration storm), the rest yielding freezing rain at two or more of the sites.

Fig. 3.1 Number of Long-Duration Freezing Rain Storms per Month 1953-54 to 1969-70



In Fig. 3.1, the number of long-duration freezing rain storms affecting the area during each month of the period under study is plotted. (The month is determined by the first date on which the storm brought freezing rain to the Montreal area.) Just as there was a large variability in the number of hours of freezing rain per month, so is there a variability in the number of long-duration storms. The total number of storms in each season is presented in Fig. 3.2, and again the lack of pattern is apparent. There seems to be no relationship between the number of storms one month (or season) and the next. However, for the seasons studied here, there was never a positive deviation from the mean for more than two consecutive seasons, although a negative deviation of at least three seasons occurred at the beginning of the period. Since negative deviations from the mean occur more frequently than do positive ones, their average magnitude is smaller. Thus, we may quite often experience winters with fewer than the average number of long-duration storms, but winters with more than the average, although occurring less frequently, are likely to be relatively severe (with respect to long-duration freezing rain storms). It is to be noted, that in no season did fewer than three, or more than ten long-duration storms affect this area. The average was 5.4 storms per season.

Fig. 3.2 Number of Long-Duration Freezing Rain Storms per Season, 1953-54 to 1969-70



Both Koolwine (1975) and Chagnon(1969) in their analyses of freezing rain storms in southern Ontario and Illinois, respectively, found no repetitive cycle in the number of storms per season. For the winter seasons from 1957-58 to 1973-74, for southern Ontario, the minimum number of freezing rain storms in one season was 0, the maximum was 6, and the average was 3.1.

Table 3.3 Monthly Distribution of Long-Duration ZR Storms and of One-Hour ZR Events

	Total No.	Average	Storms %	1-Hr Events %
Nov.	13	0.72	13.4	13.9
Dec.	22	1.22	22.6	25.4
Jan.	20	1.11	20.6	20.7
Feb.	18	1.00	18.6	20.7
Mar.	19	1.06	19.6	14.6
Apr.	5	0.28	5.2	4.6
Season	92	5.41	100.	99.9

In Table 3.3, the total number, the average, and the percentage of long-duration storms occurring in each month of the freezing rain season, are given. Table 3.3 also indicates the average monthly frequencies of one-hour freezing rain events (averaged over all data from Ste. Agathe, Quebec City, Montreal and Ottawa). The months December through March each account for approximately the same number of storms (20%), while the months of November, and especially April account for considerably fewer. A comparison with the one-hour events indicates that, in general, the months with the most hours of freezing rain are also the months with the most long-duration storms. However, some differences may be seen, for instance, in March. The number of storms in March is approximately the same as that in December, January of February, but the number of hours of freezing rain is less. This can be explained using the data in Table 3.4, which gives the numbers of storms and the average storm durations (defined as the number of hours of freezing rain in the storm) by month and location. The grand average storm duration in March is shorter than those of December and February which explains why there can be about the same number of long-duration storms, but fewer hours of freezing rain. However, the grand average duration in January is also shorter than those of December and February, and this implies that in January there must be more freezing rain events not associated with long-duration storms (ie of less than 4 hours duration) than in the other months. This results in about the same number of long-duration storms, and of hours, but with storms of shorter average duration.

Table 3.4 Number of ZR Storms and Average ZR storm Duration by Month and Location (the figure in parentheses is the number of storms)

Location Month	Montreal	Ottawa	Quebec City	Ste.Agathe	Average
Nov.	5.4 (5)	6.6 (9)	6.0 (8)	6.7 (3)	6.2 (25)
Dec.	7.4 (12)	7.9 (14)	7.1 (8)	9.4 (5)	7.8 (39)
Jan.	6.3 (9)	7.4 (11)	7.7 (9)	5.2 (4)	6.9 (33)
Feb.	7.5 (11)	7.0 (12)	10.3 (9)	14.0 (1)	8.3 (33)
Mar.	4.8 (8)	4.9 (8)	13.0 (6)	5.0 (5)	6.7 (27)
Apr.	7.0 (1)	6.7 (3)	6.2 (4)	5.0 (1)	6.3 (9)
Average	6.5 (46)	6.9 (57)	8.4 (44)	6.9 (19)	7.2 (166)

The figures in Table 3.4 on average storm duration for individual months and locations are difficult to compare since they represent different numbers of long-duration storms (from 1 to 14 storms occurred in some location in one of the months of the freezing rain season). It can be seen, however, that storms on the average have a longer duration at Quebec City than elsewhere; and, that storms in November and April are generally shorter, while those in December and February are longer, than the others. The average of all storm surations is 7.2 hours, and the range is from a minimum of 4 hours (according to the definition of a long-duration storm) to a maximum of 46 hours.

3.3 Analysis of Long Duration Storm Tracks

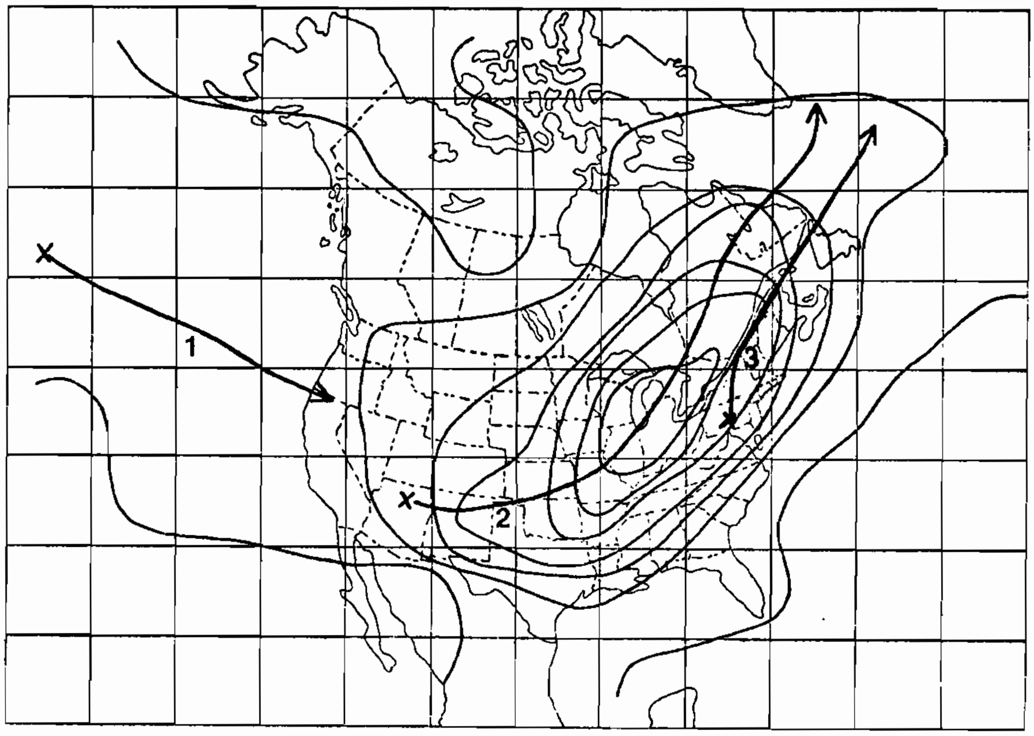
In order to determine whether long-duration freezing rain storms follow certain preferred tracks, the track of the low-pressure system associated with each of the storms was studied. In a similar analysis, Koolwine(1975) established that two 'average' tracks accounted for 86% of all the freezing rain storms he studied in southern Ontario. Using the method of Reitan (1974), as Koolwine had done, it was hoped that preferred tracks could be identified for the long-duration freezing rain storms of the Montreal area. These tracks might prove useful in predicting freezing rain, and would give utilities companies a valuable classification scheme for freezing rain and icing storms.

Using 12-hourly surface maps, National Weather Service (NWS) weekly summaries, and the NWS Climatological Data National Summary, the track of each long-duration storm was identified and plotted. The method then consisted of marking a grid on a base map, and determining the frequencies of cyclogenesis and of cyclonic events for each grid square. This involved following each track, individually, across the map, and noting, first, in which square it originated (cyclogenesis), and secondly, all of the squares through which it passed (cyclonic event). Contours were then drawn and the areas of maximum frequency of cyclogenesis and cyclonic passage (or events) identified.

The most probable tracks were then constructed as follows: starting from each of the centres of maximum frequency of cyclogenesis, an arrow was drawn through the axes and centres of maximum frequency of cyclonic events. These lines then represent the 'most-likely' paths taken by cyclones which produce long-duration freezing rain storms in the Montreal area. The results of this first analysis were rather arbitrary since the paths were not clearly defined. (see Fig. 3.3. The ' X ' s denote the locations of the maxima of cyclogenesis.)

The difficulty in obtaining conclusive results from this first analysis, led to a second in which, instead of studying all of the storms together, the storms were divided into categories depending on their region of cyclogenesis. These regions were not chosen arbitrarily, but with synoptic reasoning with regard to the formation of the cyclone. These regions, and the percentage of storms fitting into each are listed below:

Fig. 3.3 Most Probable Tracks for Long-Duration ZR Storms

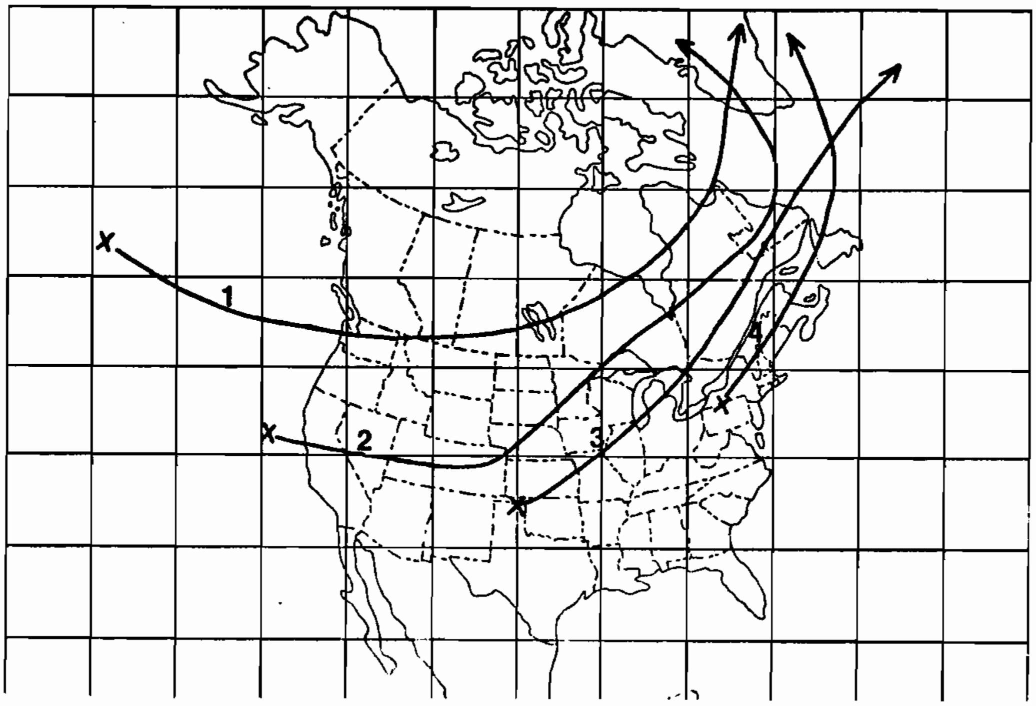


I. Gulf of Alaska (4.6%): cyclones originating in the northwestern Pacific and coming out of a low in the Gulf of Alaska or Bering Sea
II. West Coast and Pacific (9.2%): cyclones originating along the west coast of North America or in the Pacific Ocean
III. Lee of the Mountains (45.0%): (lee cyclogenesis) cyclones originating to the east of the mountains
IV. Central Continent (29.4%): cyclones which could be traced westward only to the central area of the continent
V. East Coast (11.9%): east coast cyclones which brought freezing rain to the Montreal area
For each of these categories, the long-duration storms were reanalysed, and the areas of maximum frequency of cyclogenesis and cyclonic events were determined. 'Preferred' paths were constructed for each area of origin, Some were very similar to each other; the only difference was that some storms could be traced further westward than others and so were included in a different category. Fig. 3.4 indicates the final tracks that were chosen to represent the long-duration freezing rain storms.

With the exception of the storms classified as East Coast cyclogenesis, the preferred paths of long-duration storms are all to the north of the St. Lawrence valley. (Recall that these represent the paths of the centres of low pressure.) This implies that, in general, the Montreal area was in the warm sector of the cyclones, unless the cyclones were well-occluded and there was no warm sector at the surface or it was much further south. Usually the warm sector passage would occur after the freezing rain event, which is generally associated with the approaching of the warm front. For the East Coast storms, the warm sector, in general, did not cross this area.

Whether or not temperatures rise above freezing after a freezing rain event can be crucial in terms of the damage and inconvenience caused by the event. If melting occurs shortly after the freezing rain, the hazard to transportation, communication, and transmission line networks will be short-lived and perhaps less severe, depending on the thickness of the ice accumulated. On the other hand, if below freezing temperatures persist, the situation may well be worse (this also depends on the wind velocity). Of course, the passage of the warm front does not ensure the occurrence of above-freezing temperatures, but it makes it very likely. For occluded systems, the warm air may never reach the ground but remain trapped above the surface of the occlusion. Recall also the effect of the river valley on wind direction, and that this may delay or prevent the arrival of warm air at the surface for stations in the valley.

Fig. 3.4 Final Choice for Most-Probable Tracks for Long-Duration Freezing Rain Storms



Even after dividing the long-duration storms into several categories, and reanalysing them, there was still much ambiguity in drawing the preferred tracks. An attempt was made to classify each individual storm track as being one of these types (as had been done by Koolwine for southern Ontario), but it was not possible. There was too much uncertainty in the paths, and the only classification that could be made was that based on the region of cyclogenesis.

In his analysis, Reitan had studied all cyclones during the months of January, April, June, July and October for the 20-year period 1951-70. The paths he constructed for January, which should be representative of the freezing rain season, are presented in Fig. 3.5. In general, these paths are further to the east when they curve northward than are the paths for the long-duration freezing rain storms. This would seem to suggest that the long-duration freezing rain storm tracks are slightly different from what might be called the 'average' winter storm tracks, in that they are further west when they cross the latitude of this area. Being further east, the average storms of Reitan would, in general, bring colder weather, since their warm sectors would never reach this area. On the other hand, those which are further west would tend to bring milder weather to the Montreal area.

According to Powe(1969), the most common source region for low pressure systems which affect Montreal weather in the winter, is the south-central United States. These systems move north-eastward, pushing warm air ahead of them aloft, which may result in quite mild winter weather in southern Quebec, and the occurrence of snow, freezing rain and/or rain. Fig. 3.6 shows the winter storm tracks which he determined to be important for the Montreal area. Powe's track marked with an asterisk, is quite similar to the long-duration freezing rain storm tracks (#2 and #3) developed in the present study.

Fig. 3.5 Preferred Storm Tracks for January (from Reitan 1974)

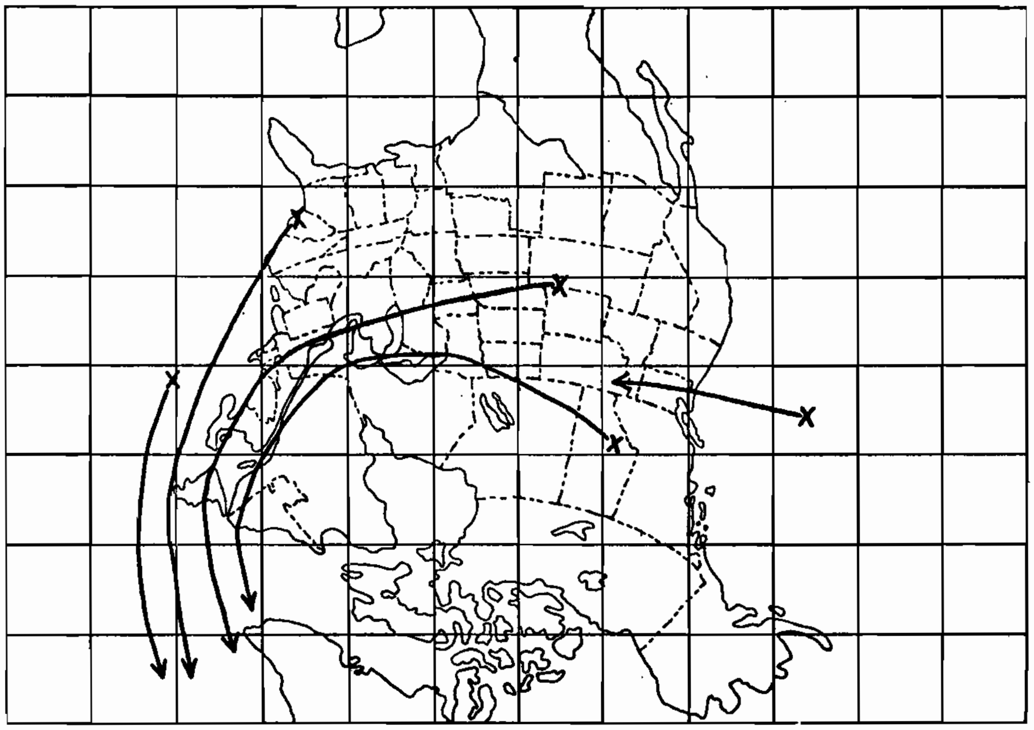
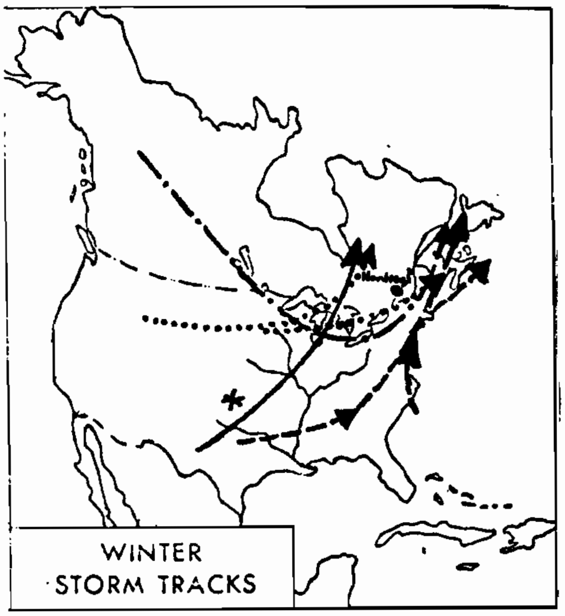


Fig. 3.6 Winter Storm Tracks (Powe 1969)



Perhaps the most that can be derived from this analysis is a sort of negative result. The tracks obviously cannot be used to predict which storms will produce freezing rain in the Montreal area because many storms following similar tracks do not do so. Also, because of the ambiguity in the construction of these preferred paths, little confidence can be placed in their accuracy. However, cyclones following paths much different from these would be relatively unlikely to be associated with freezing rain in the Montreal area.

4. Summary and Conclusions

Using data from the winter seasons 1953-54 to 1970-71, a climatology of freezing rain in the Montreal was developed. An average of approximately 25 hours of freezing rain occurs each season (November - April), although the variability from season to season is large. There is an increase in the frequency of occurrence of freezing rain as the temperature rises from about 18°F to 32°F. As discussed, it is unlikely that the necessary synoptic conditions exist when the surface air temperature is below about 18°F; and when the air temperature is much above 32°F, it is unlikely that the drops will be supercooled. The orientation of the river valley was found to have an effect on the wind direction during freezing rain events, such that the maximum frequency of events occurred with winds blowing from down-river.

A long-duration freezing rain storm was defined as one having 4 or more hours of freezing rain associated with it. An average of approximately 3 such storms affect this area each season; and 32% of these storms produce freezing rain at all 3 of the locations used in the analysis (Quebec City, Dorval, Ottawa). The average storm duration is 7.2 hours; those is December and February are generally longer, and those in Novermber and April shorter than the average.

The track of the low pressure system associated with each long-duration storm was analysed, and certain average or preferred tracks were determined. However, there was a considerable amount of ambiguity involved in the construction of these tracks. They did seem to differ slightly from the average winter storm tracks, and they certainly differed from the preferred tracks of storms bringing freezing rain to southern Ontario. They would seem to be useful in determining which storms would not be likely to produce freezing rain in the Montreal area, and not which storms would (ie storms with much different tracks would be relatively unlikely to be associated with long-duration freezing rain storms, but those with similar tracks may or may not be so associated).

An extension of the period of data used for the climatology and storm study would determine the applicability of the results. Also, with a longer period, patterns in the number of storms per season may exist. It would be interesting to compare the results of similar detailed climatologies of other areas with those found in this study.

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