Climate Warming and Extreme Weather in Canada (Updated)

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Image credit: The Globe and Mail

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Climate Warming and Extreme Weather in Canada

1. Background

A number of scientific reports have outlined the extent of climate warming in Canada, including the *Canada Climate Change Report* of March 2019. This report identified the rate of temperature changes in Canada across all regions of the country, and noted that the warming was greatest in the Arctic and least in Atlantic Canada.

"Annual and seasonal mean temperatures across Canada have increased, with the greatest warming occurring in winter. Between 1948 and 2016, the best estimate of mean annual temperature increase is 1.7ºC for Canada as a whole and 2.3ºC for northern Canada." [1]

According to the CCCR report, temperatures have increased everywhere in Canada, but most in the northwest and least in the southeast. [2]

A separate study of temperatures since 1953 up to 2019 at ten stations in Canada showed that mean annual temperatures at St. John's NL and Halifax, NS increased at a rate of 1.21 Deg. C per 100 years at St. John's and 1.99 Deg. C per 100 years at Halifax. Montreal's mean temperature for the same period increased at a rate of 2.07 Deg. C per 100 years and Toronto's mean temperature increased at a rate of 3.11 Deg. C. Similar values were recorded at other stations across Canada. However, mean annual temperatures in the central and western Arctic rose at a faster rate. The mean temperature at Cambridge Bay increased at a rate of 4.5 Deg. C per 100 years. The rate of change in the eastern Arctic was similar to points further south, as the rate of change at Iqaluit was 2.08 Deg. C per 100 years.

When only the 30 years since 1987 to 2017 were taken into account, all stations except Victoria, BC had higher rates of temperature increases, in some cases double that of the longer period since 1953.

The question addressed in this study is to what extent do increases in annual mean temperatures affect extreme weather events. Archived weather data makes it possible to readily assess wind speed and precipitation extremes. Climate scientists hypothesize that climate warming is impacting the frequency and intensity of extreme weather events. Most reports on the subject project such impacts but express low confidence in any projections.

"There has been an increase in costly extreme weather and climate events worldwide (WMO, 2014) and across Canada (Kovacs and Thistleworth, 2014; OAGC, 2016; OPBO, 2016). Much of this rise is due to greater exposure to the effects of such extreme events, as Canada's population and the value of its supporting infrastructure have both increased considerably. Changes in the intensity and frequency of damaging extreme weather and climate events due to climate change (IPCC, 2013) may also be playing a role."[3]

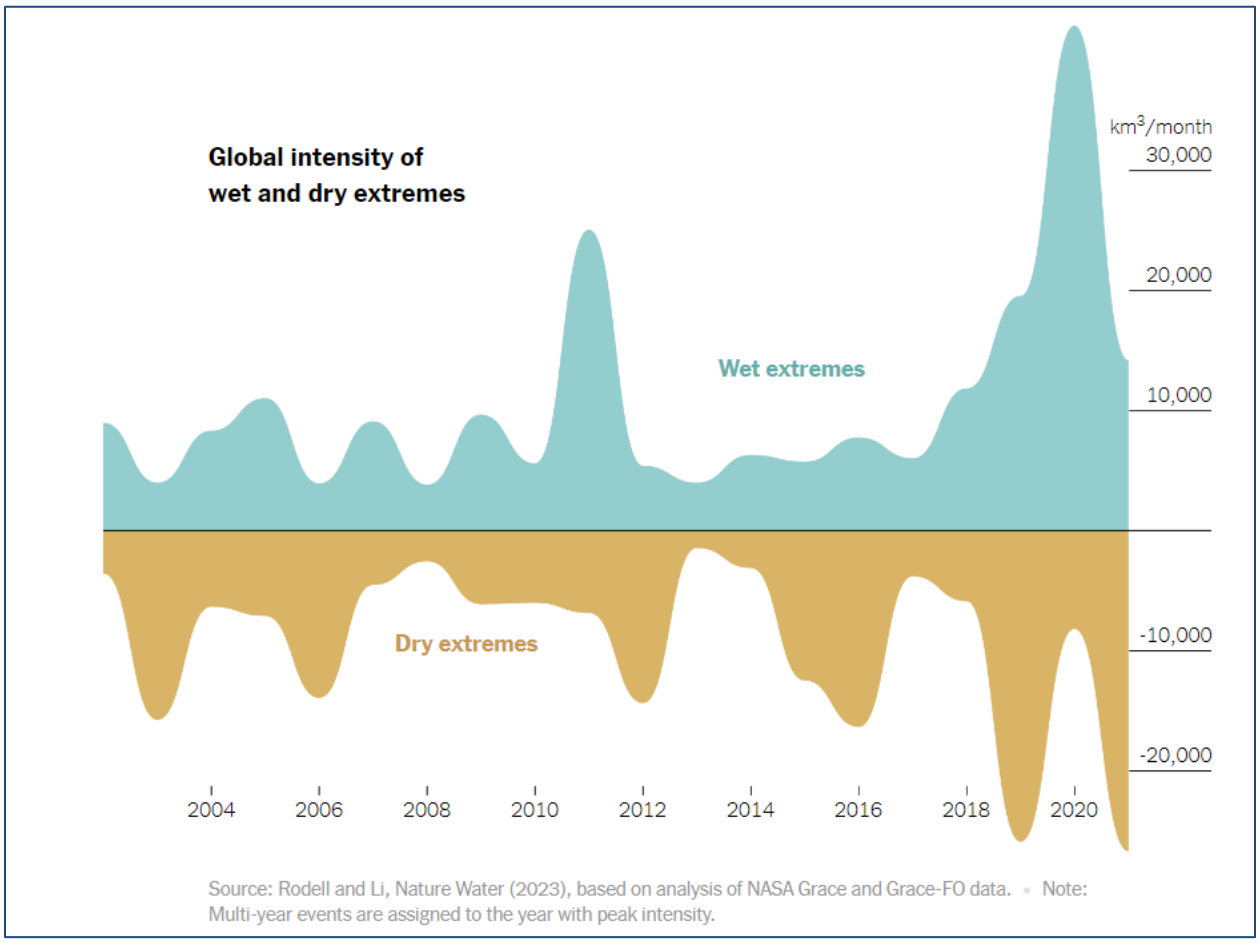
[1] Canada Climate Change Report, Government of Canada, March 2019. p.121.
[2] Ibid., p. 125
[3] Ibid., p. 174

Since climate warming is occurring at a significant rate, then if climate warming is related to weather extremes, the data should show the impact of climate warming on the frequency and/or intensity of such events. The following analysis of extreme wind speeds and precipitation at twelve locations across Canada investigates whether the trend towards more frequent and/or more intense weather events is apparent from the data. If it is not apparent, that does not mean that the trend towards more extreme events is not happening; only that a sample of data from twelve stations is insufficient to form a conclusion.

A recent study using groundwater data from satellite imagery was published in Nature Water[4]. The authors of the study analyzed water cycle extremes 2002-2021. Of course, groundwater data would not likely reflect all extreme incidents, but intense precipitation periods over shorter periods of time would likely be reflected in groundwater measurements. The chart from the study (Figure 1) shows a clear link between climate warming and more intense groundwater cycles.

[4] M. Rodell and B. Li, Nature Water, March 2023

Figure 1 Extremes in Groundwater Cycles 2002-2021



2. Extreme Wind Speeds

Wind speeds are measured at many stations in Canada as part of hourly weather reports. The mean wind speed is the average wind speed over the previous 2 minutes at the time of the observation. The gust speed is recorded as the peak wind observed over the ten minutes prior to the observation. These values used to be recorded from a U2A anemometer and a Munro wind recorder. The responsiveness of the wind recorder was estimated to be 1 or 2 seconds. Since the 1980's, digital wind recorders have averaged wind speed over 5 second intervals, and the gust and peak wind speed became the highest five second average recorded. There is likely an impact on the change in measurements of wind speed, but little has been documented.

A warming atmosphere may be responsible for stronger wind gusts in certain situations, particularly in the case of squalls, thunderstorms and hurricanes. However, if baroclinicity is weakening between the poles and the equator as the Arctic warms more than latitudes further south, that may result in less energy being available for synoptic scale storms. Theoretically, then, average wind speeds should be declining.

It has been documented that land winds speeds around the globe are decreasing, a process scientists call "stilling". https://www.abc.net.au/news/2018-10-27/land-wind-speeds-slowing-down-over-land-the-stilling/10392980

Wind data is often missing in the archives available. For the online records available from Environment and Climate Change Canada, the peak wind speed is recorded in daily data. The following table lists the twelve stations. Where daily peak wind data was missing, the peak winds were determined from hourly data archived by third party U.S. agencies.

Table 1 Table of Station Data Used in Wind Analysis

City, Province	Years Analyzed	Missing Data	Notes
St John's NL	1955-2022		St. John's International Airport
Halifax, NS	1960-2022	2004-2005	Halifax International Airport
Montreal, QC	1960-2022	1995-2001	Trudeau International Airport
Bagotville, QC	1955-2022		Bagotville Airport
Toronto, ON	1955-2022		Pearson International Airport
Winnipeg, MB	1955-2022		Winnipeg International Airport
Regina, SK	1955-2022		Regina International Airport
Cold Lake A, AB	1955-2022		CFB Cold Lake Airport
Victoria, BC	1964-2022		Victoria International Airport
Churchill, MB	1960-2022	1994	Churchill Airport
Iqaluit, NU	1960-2022		Iqaluit International Airport
Cambridge Bay, NU	1961-2022	1996-1998	Cambridge Bay Airport

To assess whether extreme winds are becoming more frequent or more intense, daily data from twelve stations were examined to identify the frequency of daily peak winds at or above the 80th and 50th percentile of the yearly peak winds at that station.

Table 2 lists the extreme winds by 80th and 50th percentile of the peak winds determined on an annual basis for each station.

Table 2 Extreme Winds by Percentile of Annual Peak Winds

Station	80th Percentile (Kmh)	50th Percentile (Kmh)
St. John's NL	139.4	122
Halifax, NS	116.8	106.5
Montreal, QC	106	93
Bagotville, QC	96	85
Toronto, ON	106	97.5
Winnipeg, MB	106	97
Regina, SK	121.2	102.5
Cold Lake, AB	97	80
Victoria, BC	94	84
Iqaluit, NU	124.4	105
Churchill, MB	108	95
Cambridge Bay, NU	104	91

Figures 1-24 outline the analyses of extreme winds for each of the twelve stations.

Generally, the results showed a long term trend towards less frequent extreme winds. However, more recent trends show a slight uptick at some stations. The extreme winds of the 1960's and early 1970's did not appear to be repeated in recent decades at any location.

In terms of the frequency of extreme winds, and the intensity of extreme winds, it appears that climate warming in Canada is generally leading to fewer occasions of extreme winds, and when they occur, they are weaker than in earlier decades. It is not known what the impact of changing wind speed instrumentation and measurement is on the results. It also may be that the trend towards less frequent and less violent winds is due to causes other than climate warming.

This analysis of wind data at 12 stations was not exhaustive. The nature of extreme winds may be that they are local rather than synoptic scale. If that is the case, then a much finer resolution of data would be required.

a. Wind Analysis – St. John's, NL

Figure 2 – Peak Winds By Year St. John's, NL 1955-2022

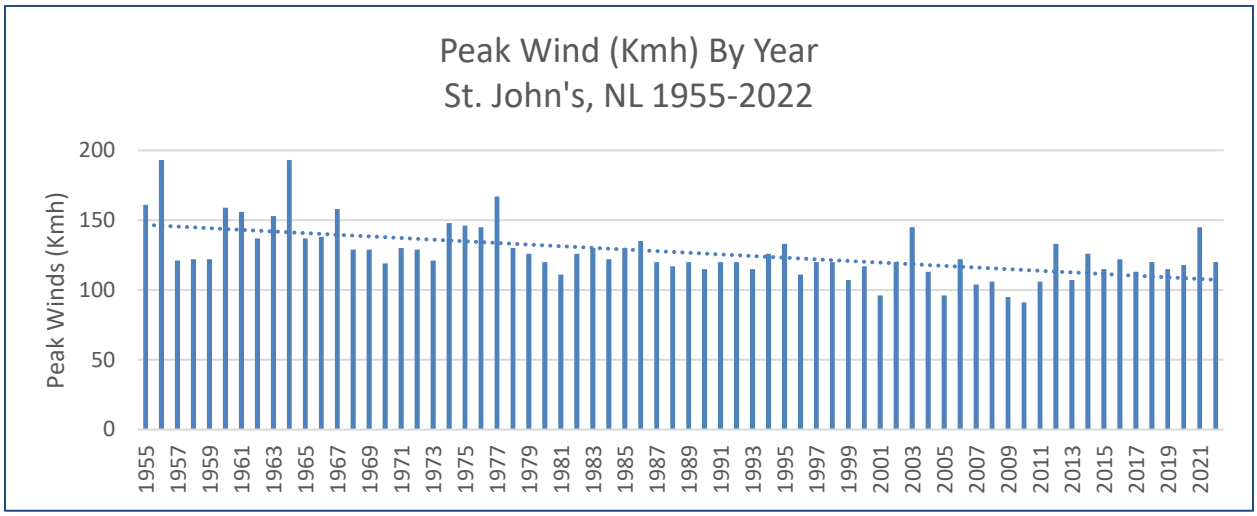
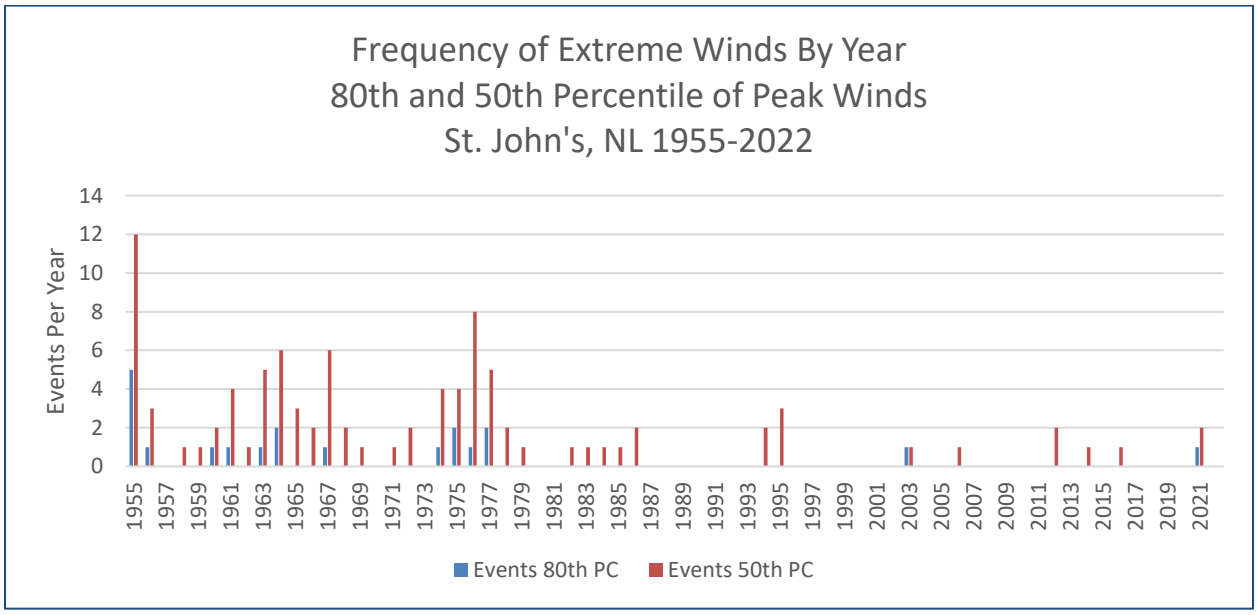


Figure 3 Frequency of Extreme Winds - St. John's, NL 1955-2022



b. Wind Analysis – Halifax, NS

Figure 4 Peak Winds by Year Halifax, NS 1960-2022

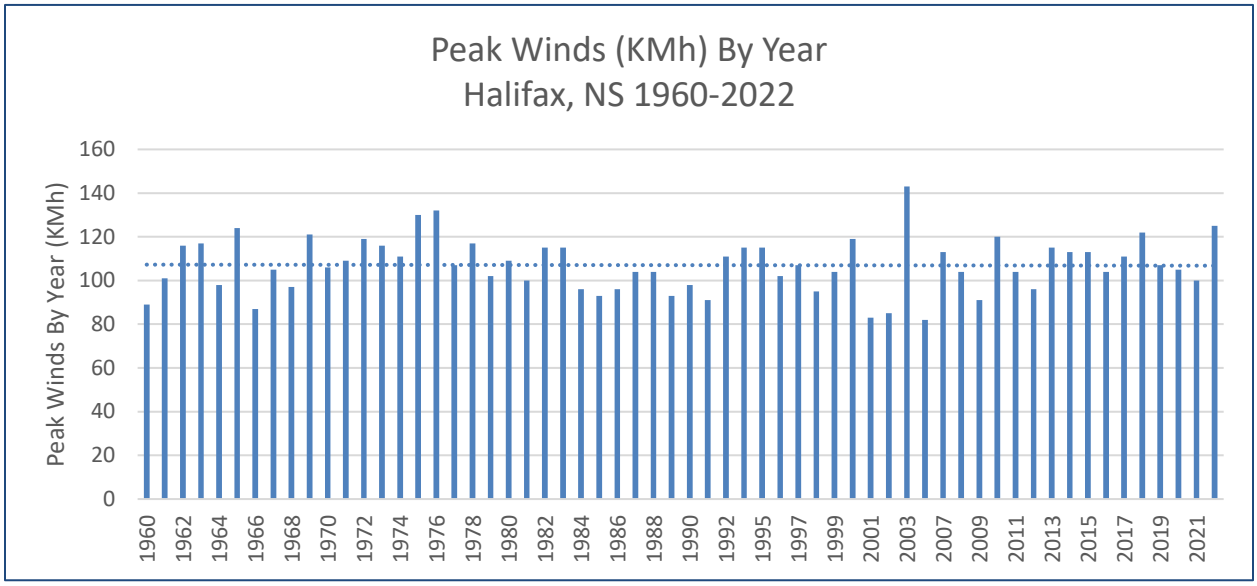
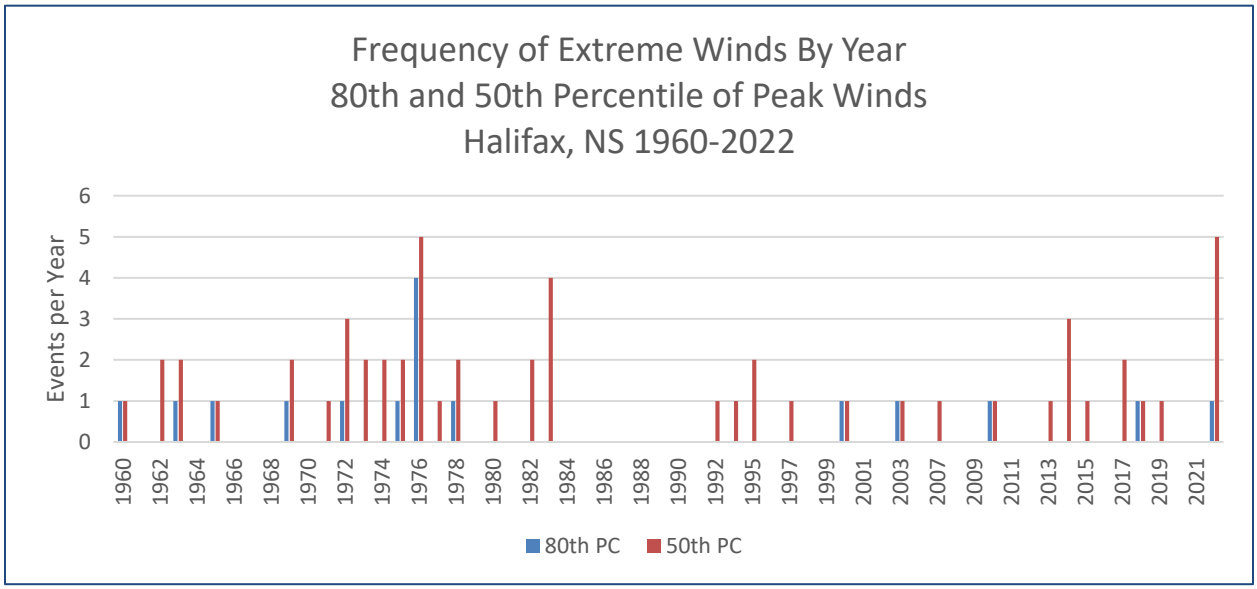


Figure 5 Frequency of Extreme Winds Halifax, NS 1960-2022



c. Wind Analysis – Montreal, QC

Figure 6 Peak Winds By Year Montreal, QC 1960-2022

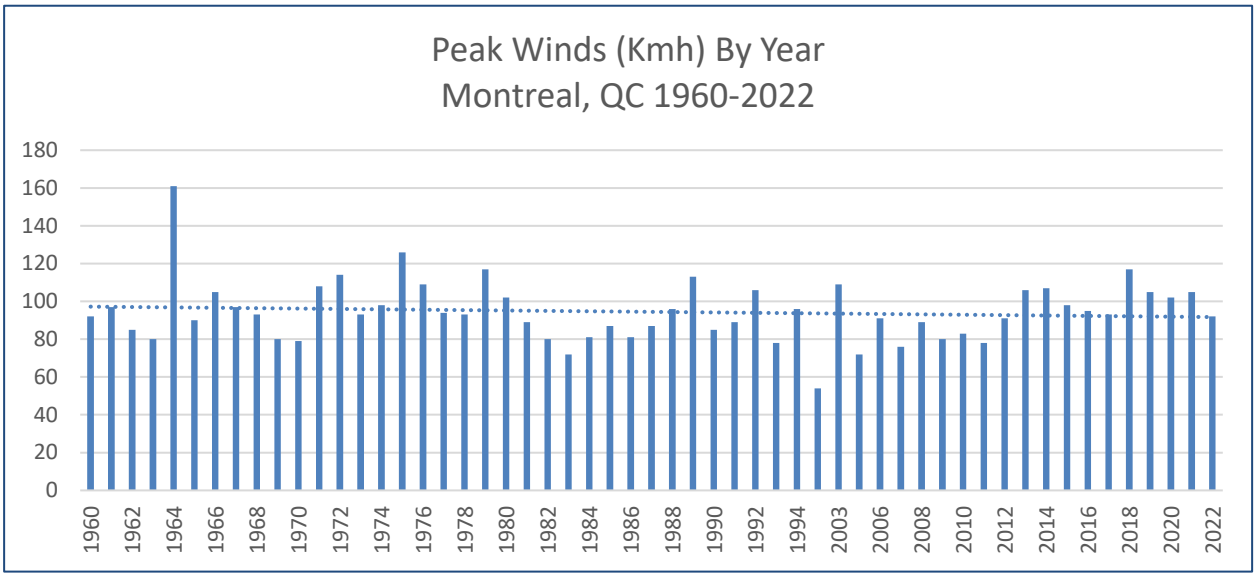
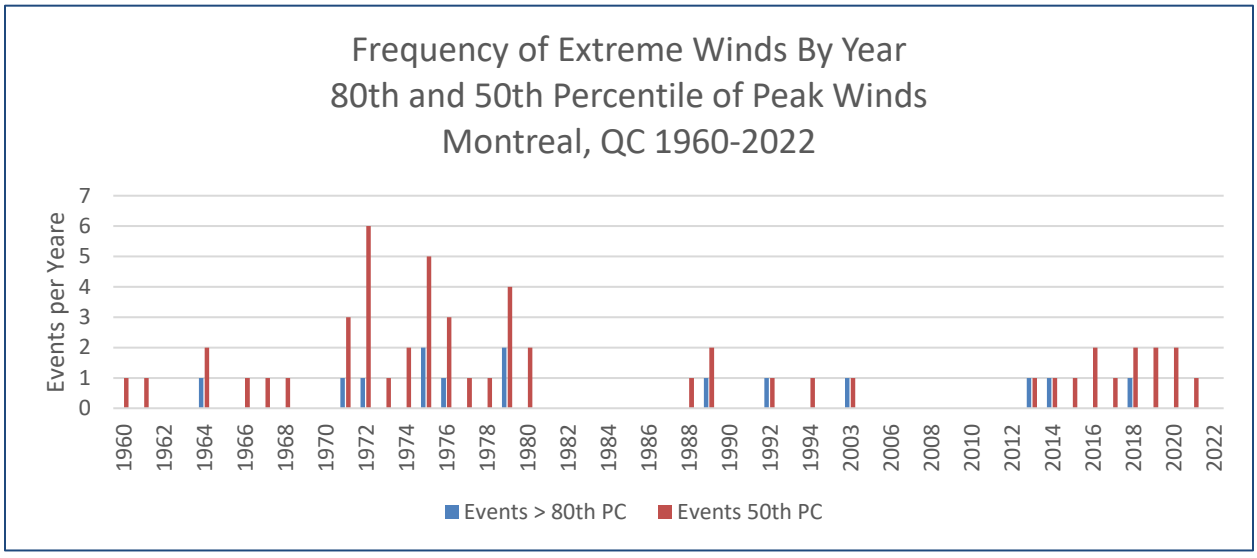


Figure 7 Frequency of Extreme Winds By Year Montreal, QC 1960-2022



d. Wind Analysis - Bagotville

Figure 8 Peak Winds By Year Bagotville, QC 1955-2022

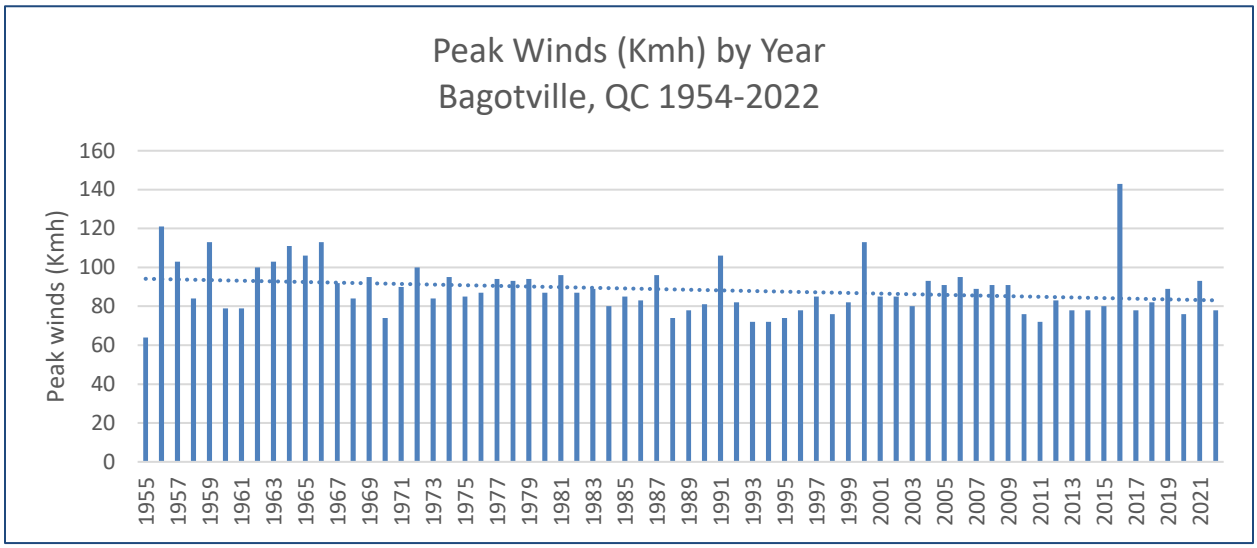
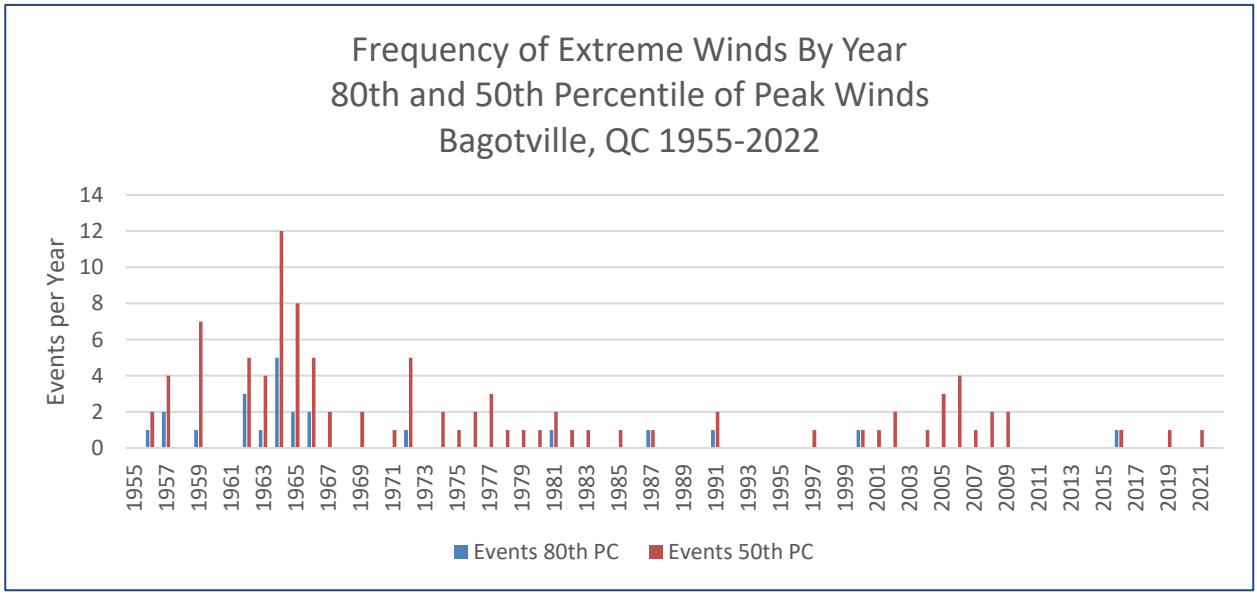


Figure 9 Frequency of Extreme Winds Bagotville, QC 1955-2022



e. Wind Analysis - Toronto

Figure 10 Peak Winds By Year Toronto Pearson Airport, ON 1955-2022

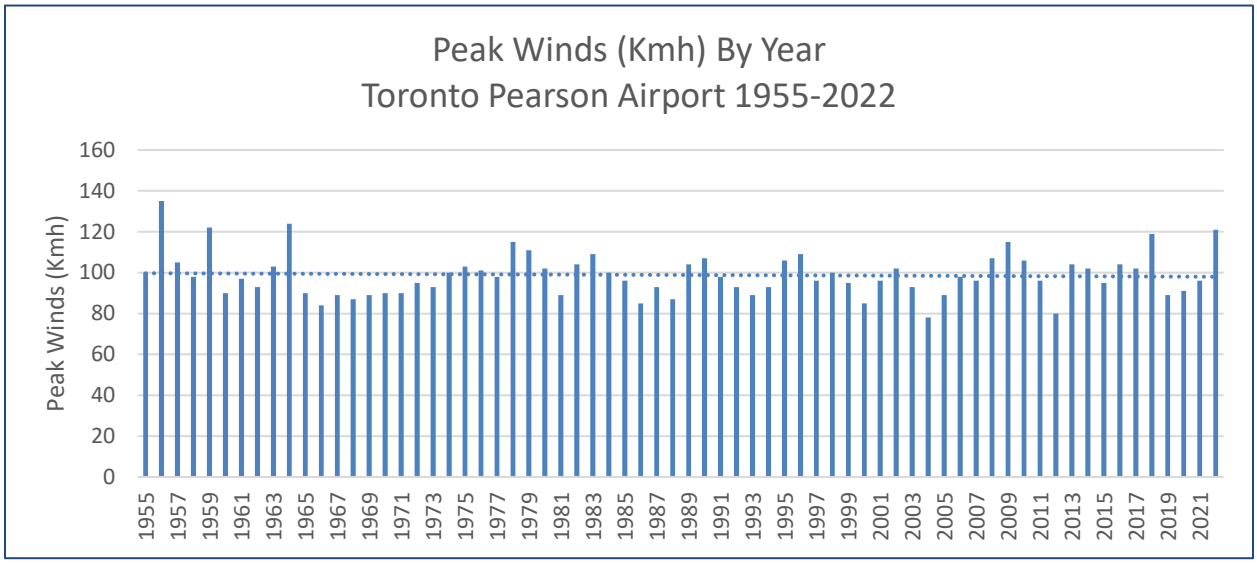
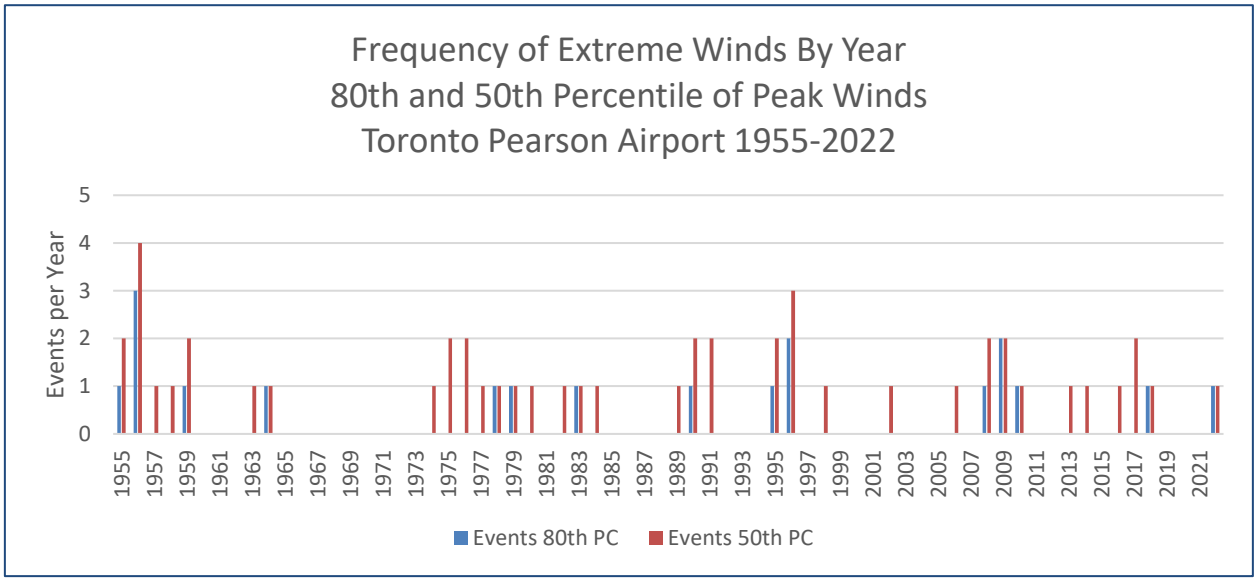


Figure 11 Frequency of Extreme Winds Toronto Pearson Airport, ON 1955-2022



f. Wind Analysis – Winnipeg

Figure 13 Peak Winds By Year Winnipeg, MB 1955-2022

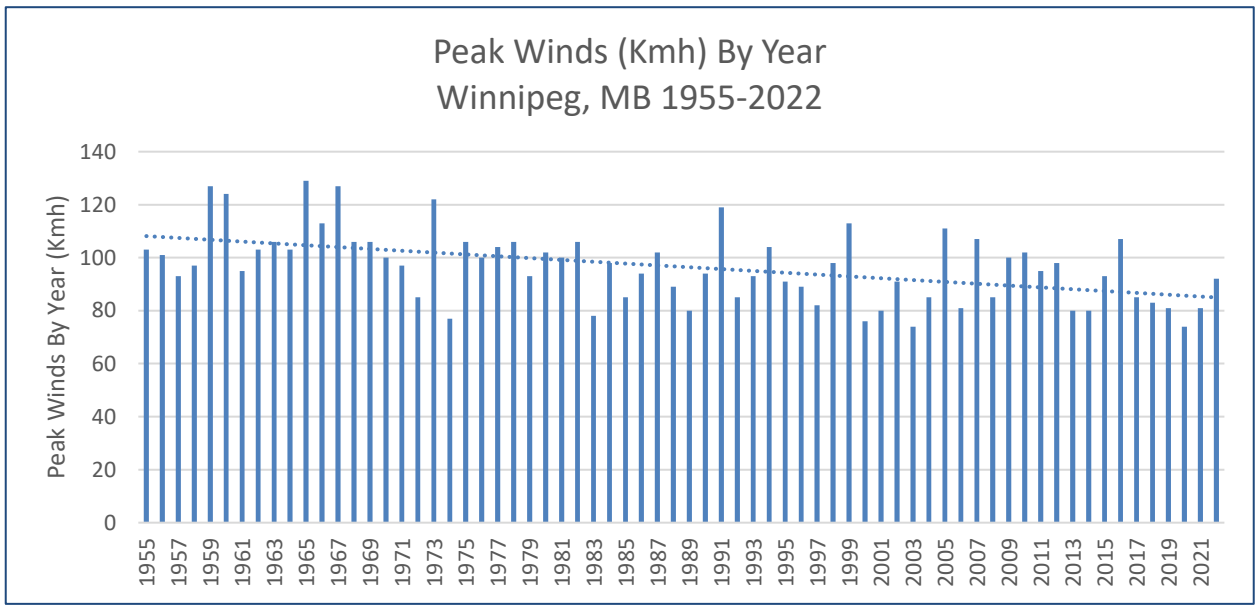
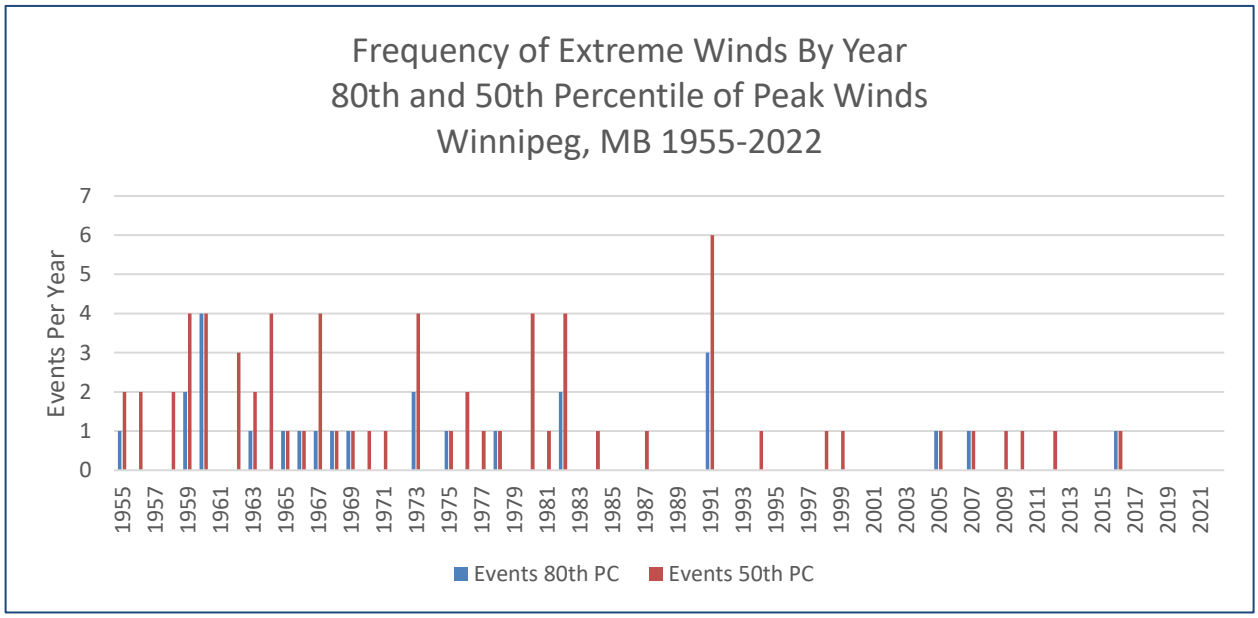


Figure 12 Frequency of Extreme Winds Winnipeg, MB 1955-2022



g. Wind Analysis - Regina

Figure 14 Peak Winds By Year Regina, SK 1955-2022

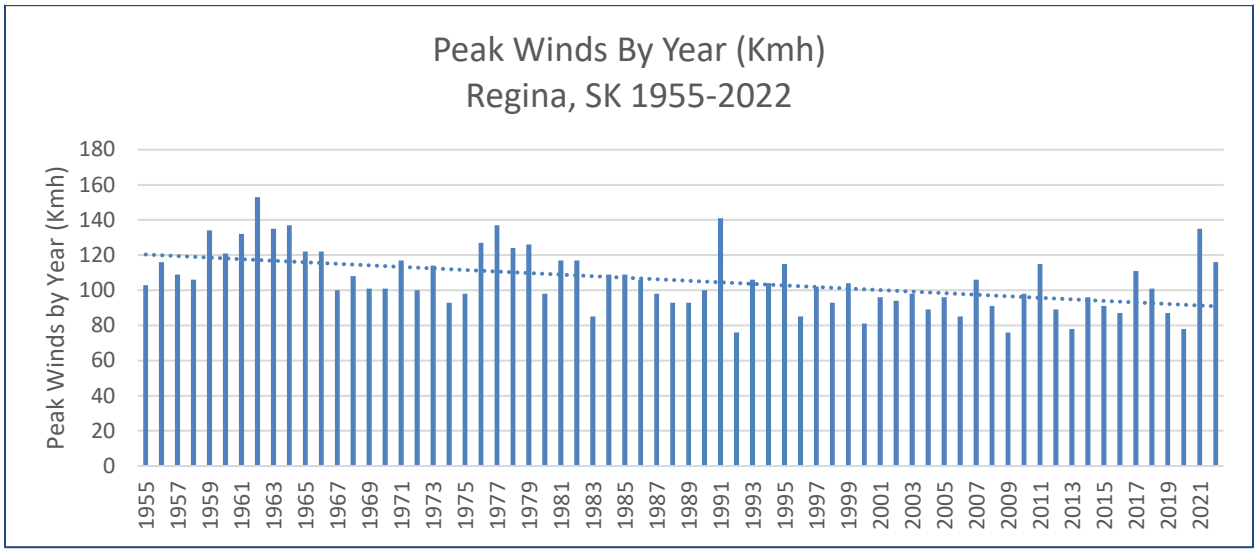
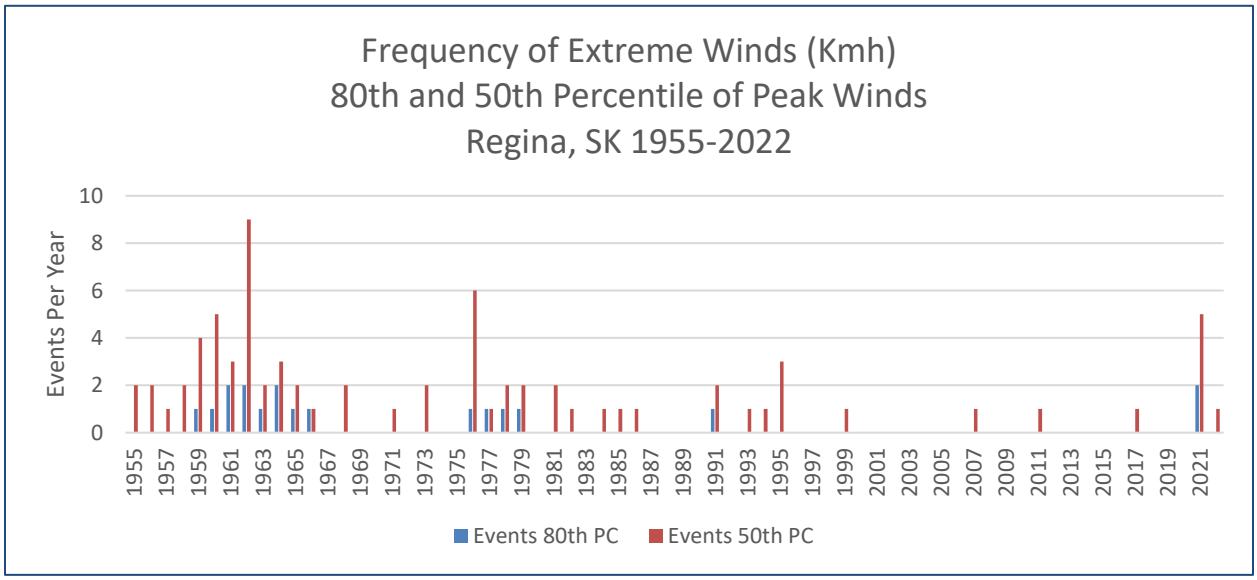


Figure 15 Frequency of Extreme Winds Regina, SK 1955-2022



h. Wind Analysis – Cold Lake

Figure 16 Peak Winds by Year Cold Lake, AB 1960-2022

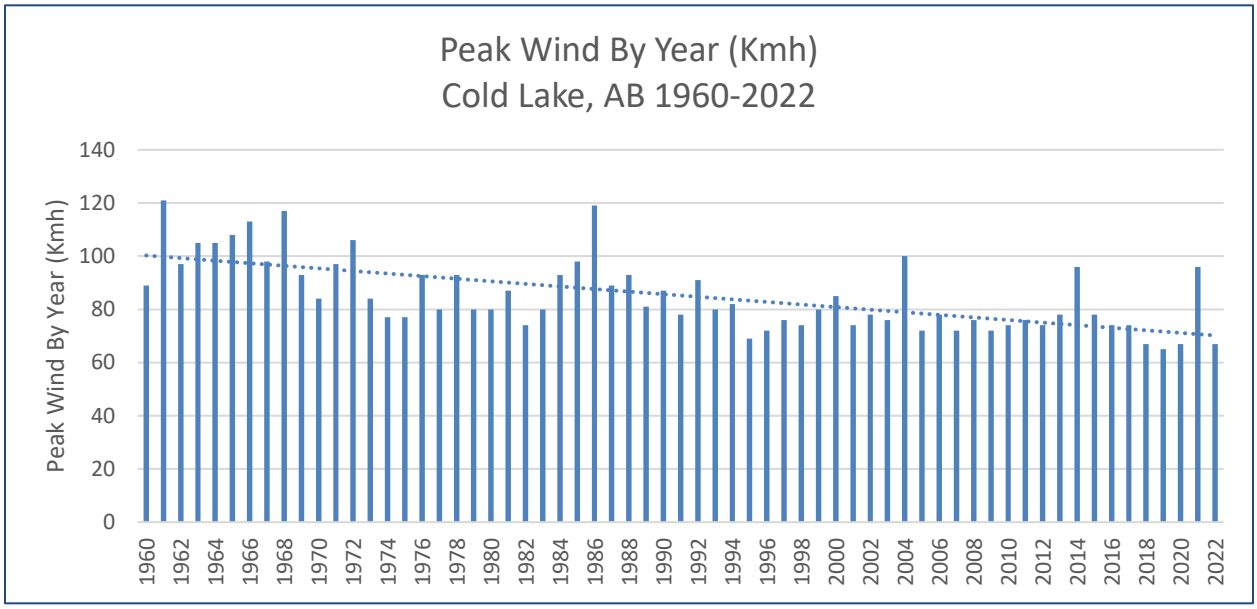
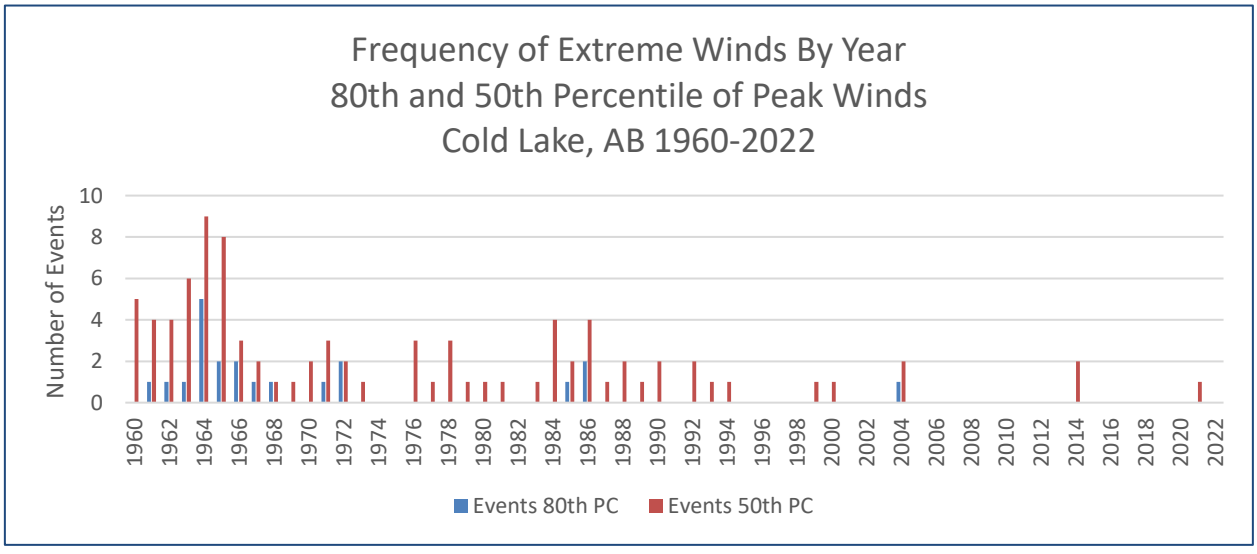


Figure 17 Frequency of Extreme Winds by Year Cold Lake, AB 1960-2022



i. Wind Analysis - Victoria

Figure 18 Peak Winds By Year Victoria, BC 1964-2022

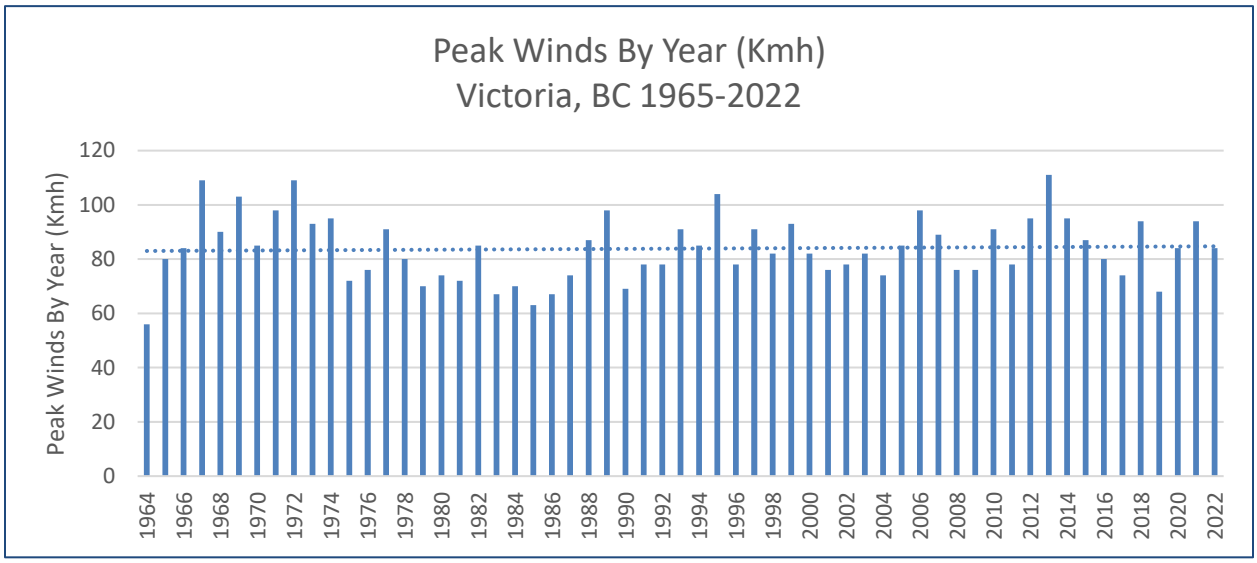
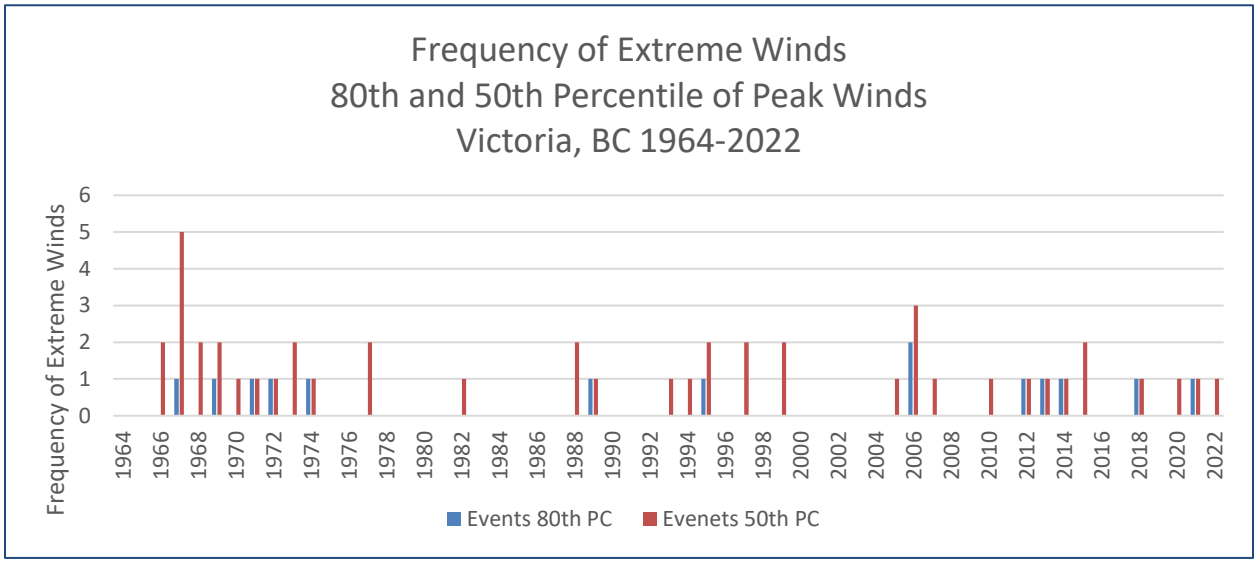


Figure 19 Frequency of Peak Winds Victoria, BC 1964-2022



j. Wind Analysis - Iqaluit

Figure 20 Peak Winds by Year Iqaluit, NU 1960-2022

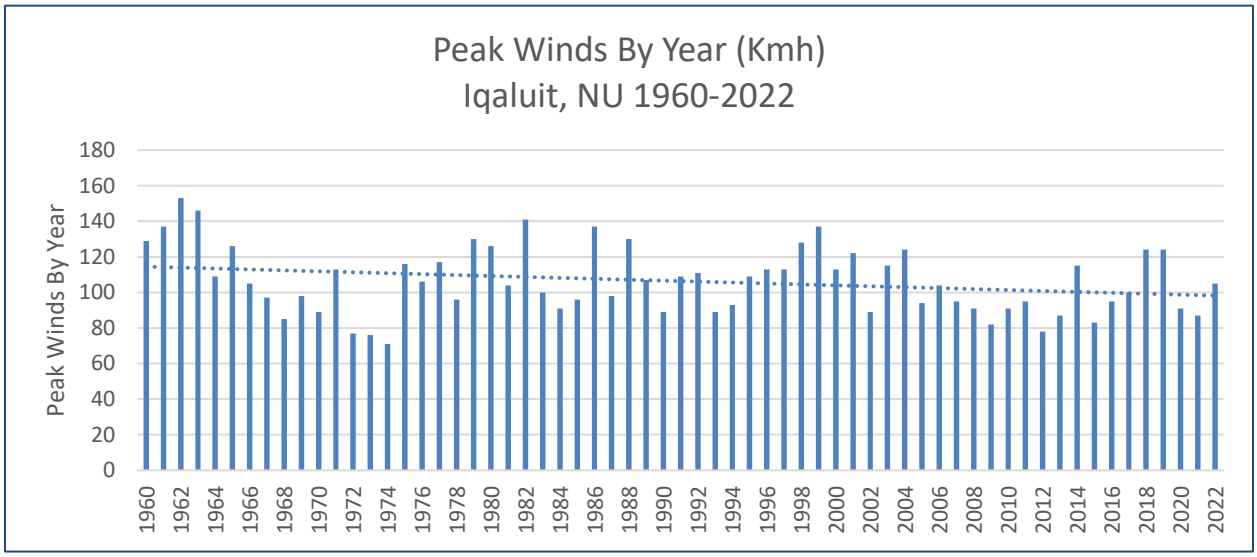
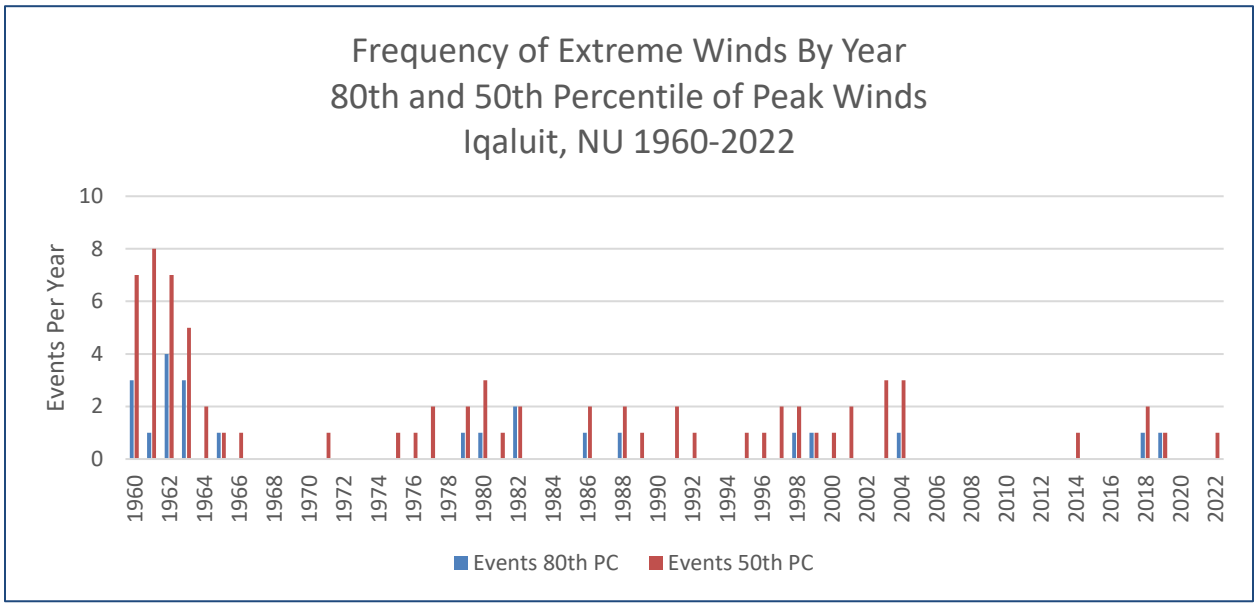


Figure 21 Frequency of Extreme Winds by Year Iqaluit, NU 1960-2022



k. Wind Analysis - Churchill

Figure 22 Peak Winds By Year Churchill, MB 1960-2022

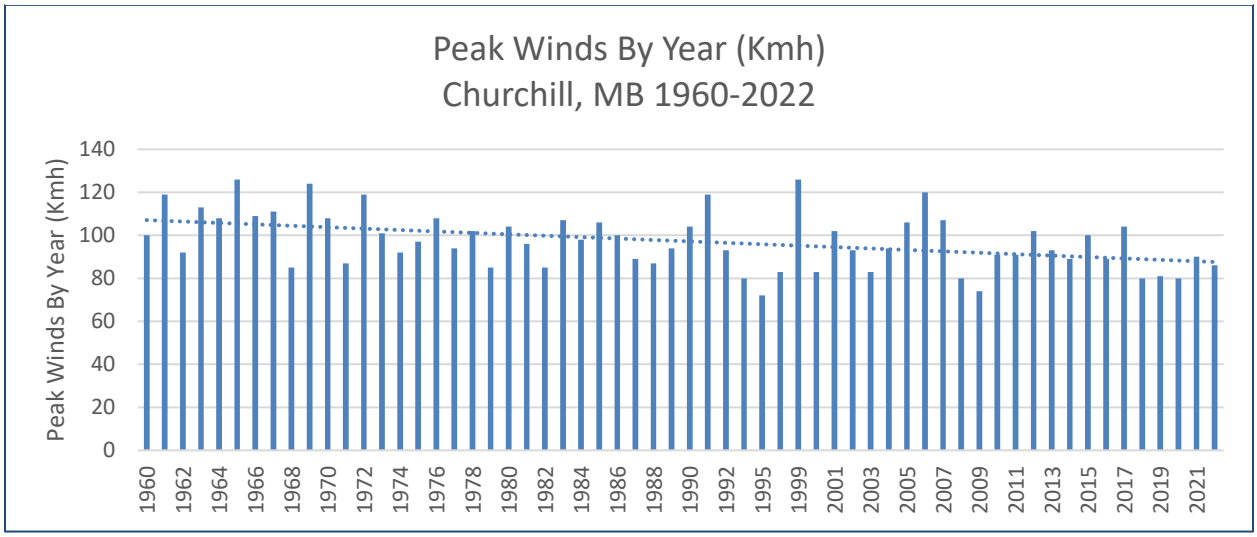
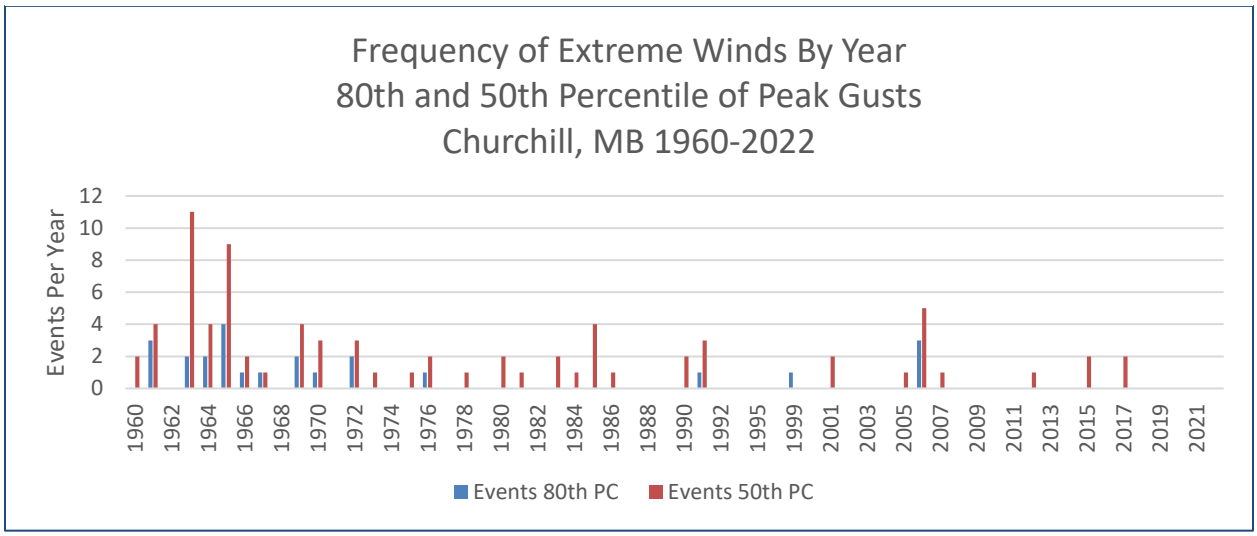


Figure 23 Frequency of Extreme Winds Churchill, MB 1960-2022



l. Wind Analysis – Cambridge Bay

Figure 24 Peak Gusts by Year Cambridge Bay, NU 1960-2022

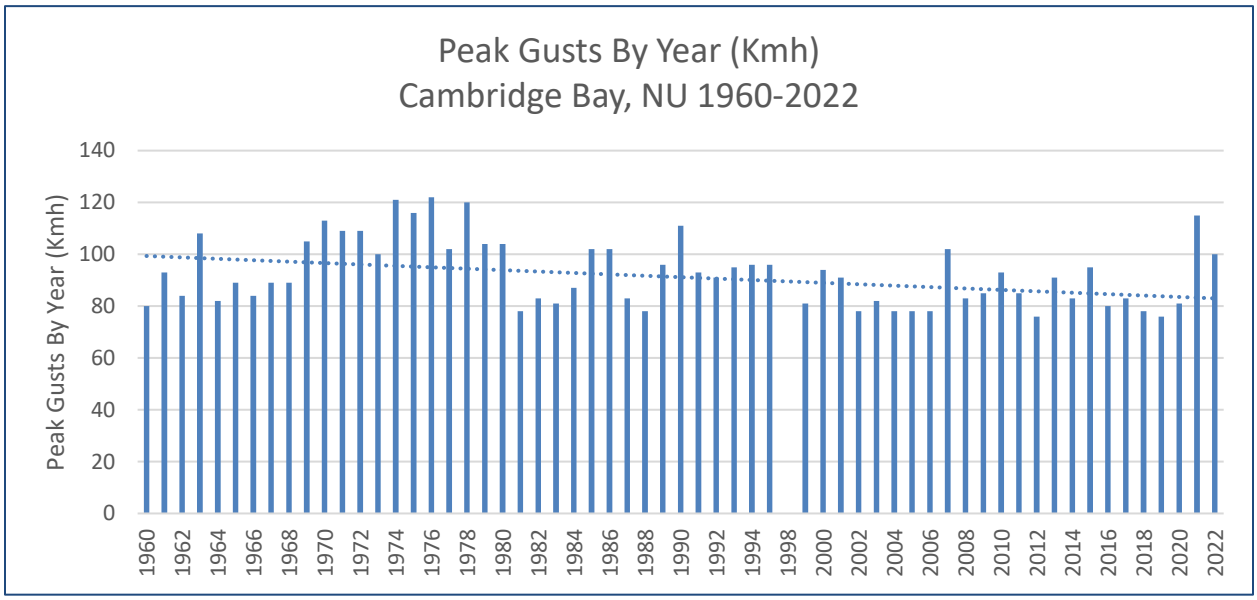
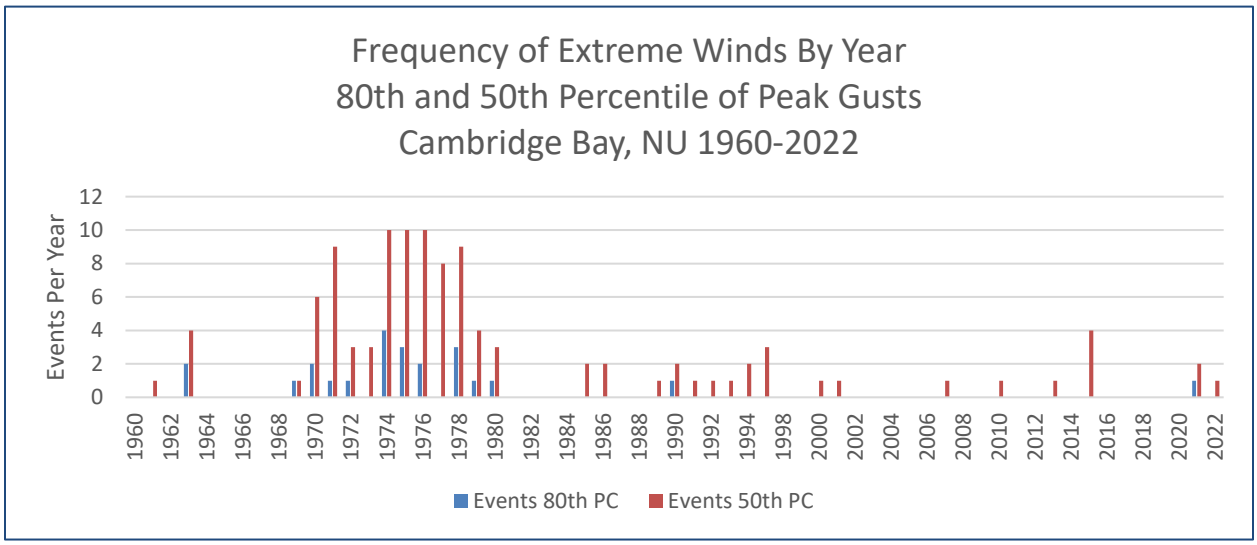


Figure 25 Frequency of Extreme Winds by Year Cambridge Bay, NU 1960-2022



In terms of the frequency and intensity of extreme winds, it appears that climate warming in Canada is generally leading to fewer occasions of extreme winds, and when they occur, they are weaker than in earlier decades. It is not known what the impact of changing wind speed instrumentation and measurement is on the results, nor of missing data which has become more common in recent years than in earlier periods. It also may be that the trend towards less frequent and less violent winds is due to causes other than climate warming.

3. Extreme Precipitation

In order to assess whether extreme precipitation events were becoming more frequent or more intense, an analysis of daily precipitation data was undertaken for the same 12 stations in Canada. The list of stations and data assessed is presented as Table 3.

It was not possible to identify a single threshold value for what defines extreme precipitation at all sixteen stations. Rather, it was determined that an extreme precipitation event would be the value of the maximum precipitation that occurs at the 80th and 50th percentile.

Extreme precipitation events could occur over multiple days. For example, a 50 mm rainfall on one day may be insignificant if it was preceded by and followed by dry weather. However, if the 50 mm event was followed by another 50 mm rainfall on the following day, the accumulated precipitation would be very significant. In many cases, continuous precipitation is spread over two calendar days. For this reason, the accumulated precipitation over two days was also analyzed.

Five charts for each station are presented as the results of the analysis, somewhat similar to the presentation of the extreme wind analysis. The first chart is to display the accumulated annual precipitation. The second chart shows the Maximum Daily Precipitation for each year. The third chart shows the Frequency of Extreme Precipitation Events defined as the 80th and 50th percentiles of the maximum daily precipitation over the 1953-2022 period. The fourth and fifth charts display the Maximum Accumulated Two-day Precipitation, as well as the frequency of the 80th and 50th percentiles of the maximum two-day precipitation.

Table 3 - 80th and 50th Percentiles of Maximum Daily Precipitation

Station	80th Percentile (mm)	50th Percentile (mm)
St. John's NL	73	63
Halifax, NS	84	64
Montreal, QC	58	43
Bagotville, QC	49	37
Toronto, ON	57	40
Winnipeg, MB	59	44.5
Regina, SK	48.6	32.5
Cold Lake, AB	45.6	36
Victoria, BC	54.8	47
Iqaluit, NU	34	24
Churchill, MB	40	32
Cambridge Bay, NU	20.8	13

Table 4 Listing of Stations and Data in Precipitation Analysis

City, Province	Years Analyzed	Missing Data	Notes
St John's NL	1953-2022		St. John's International Airport
Halifax, NS	1960-2022		Halifax International Airport
Montreal, QC	1960-2022		Montreal Trudeau Airport
Bagotville, QC	1953-2022	1993	CF60Bagotville Airport
Toronto, ON	1953-2022		Pearson International Airport
Winnipeg, MB	1953-2022	2008	Winnipeg International Airport
Churchill, MB	1960-2022	1993, 2009	Churchill Airport
Cold Lake A, AB	1960-2022	1993	CFB Cold Lake Airport
Victoria, BC	1953-2022		Victoria International Airport
Iqaluit, NU	1960-2022	1997-98	Iqaluit International Airport
Cambridge Bay, NU	1953-2022		Cambridge Bay Airport

a. Precipitation Analysis – St. John's

Figure 26 Annual Precipitation St John's, NL 1953-2022

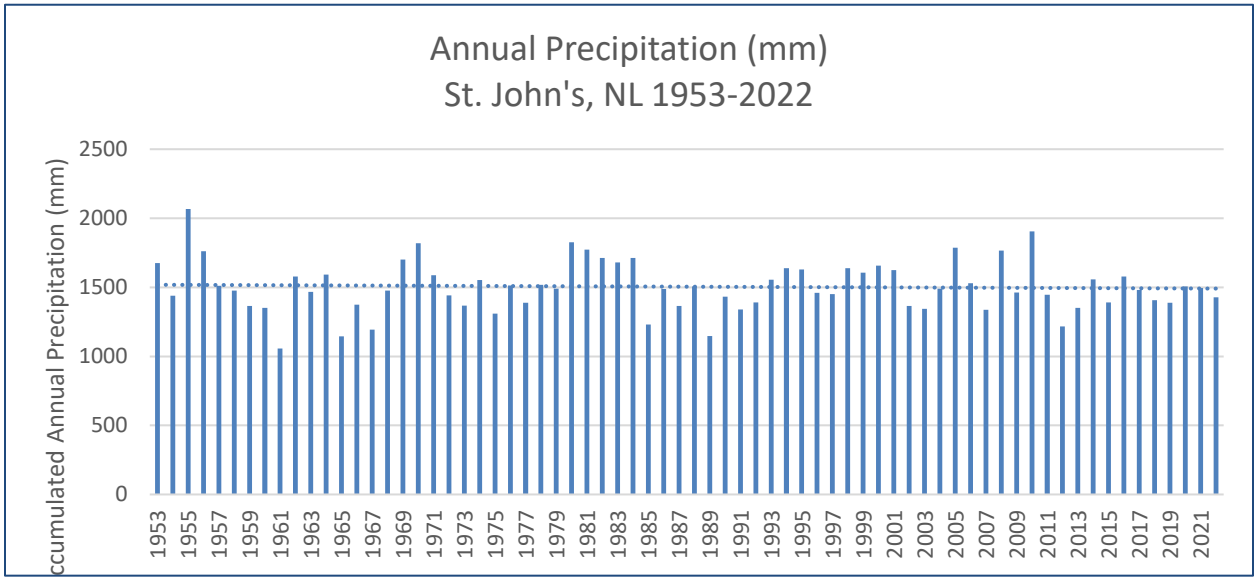


Figure 27 Maximum Daily Precipitation By Year St. John's, NL 1953-2022

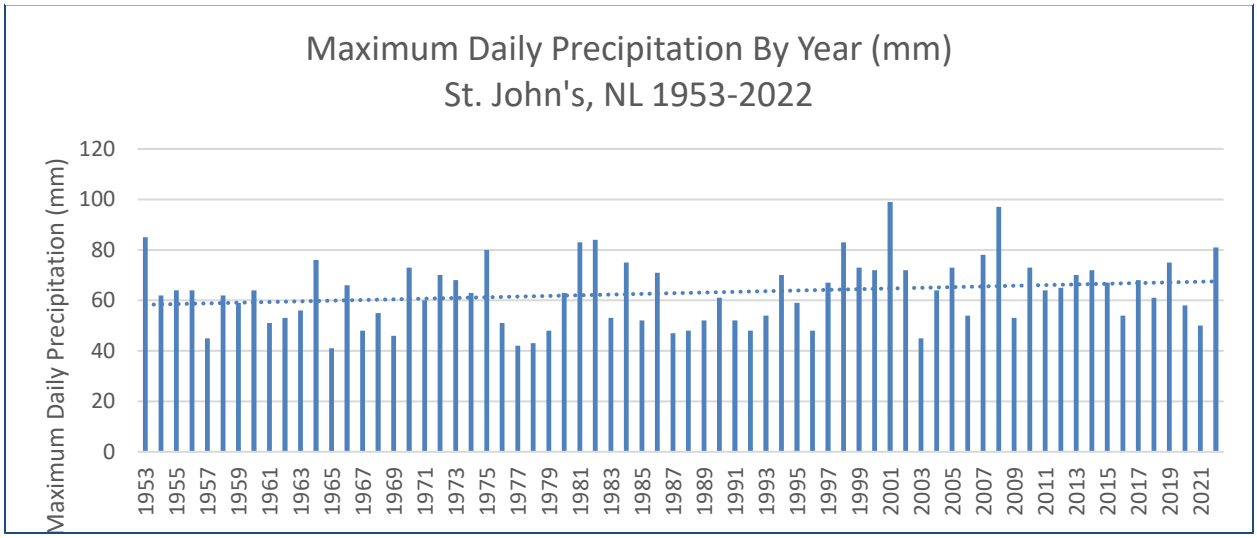


Figure 28 Frequency of Extreme Precipitation Events St John's, NL 1953-2022

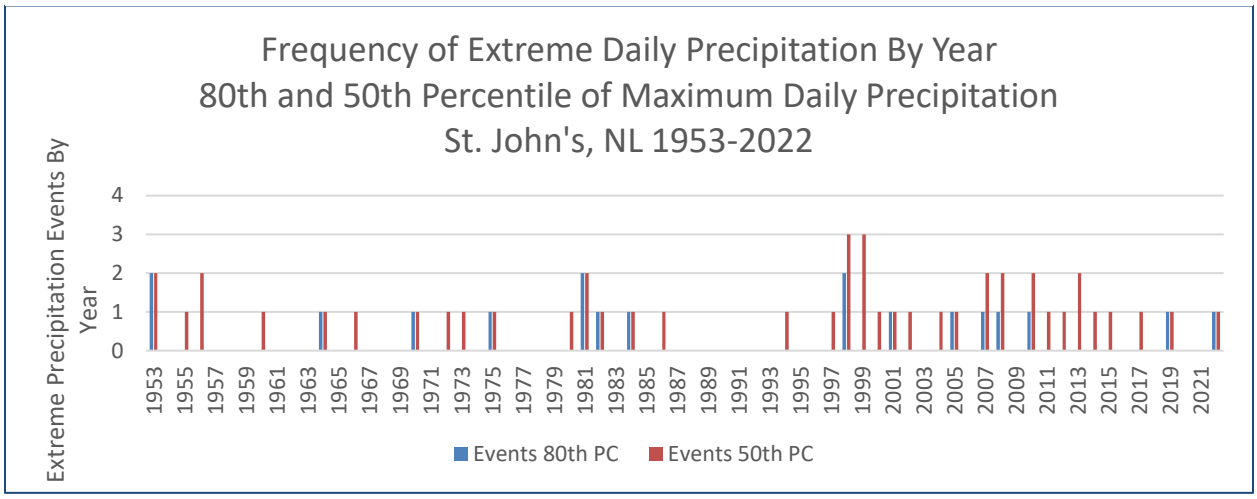


Figure 29 Maximum 2 Day Precipitation St. John's, NL 1953-2022

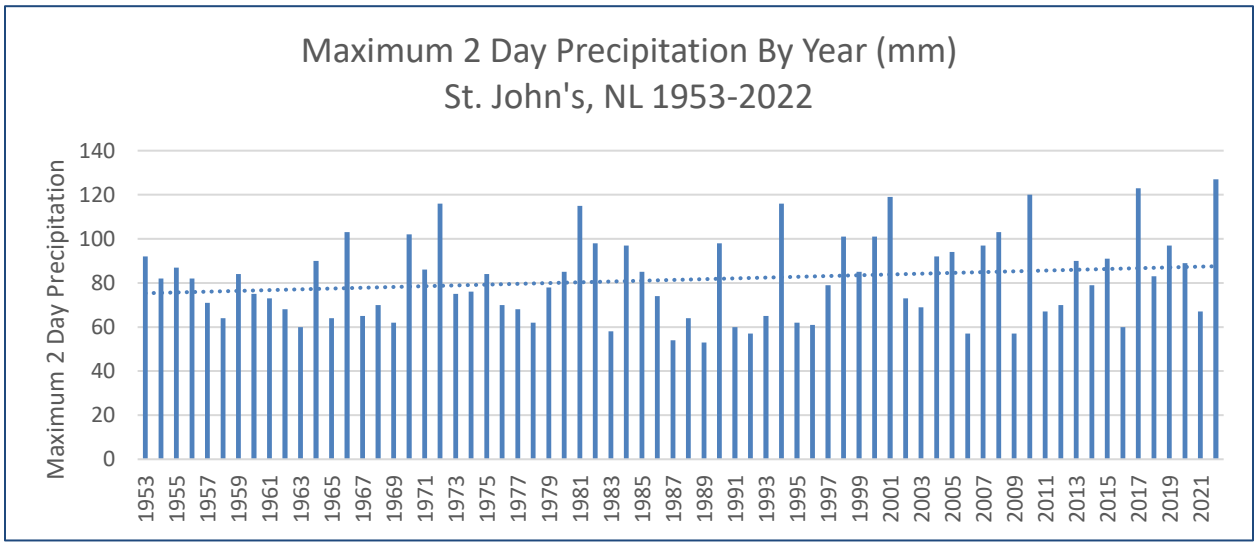
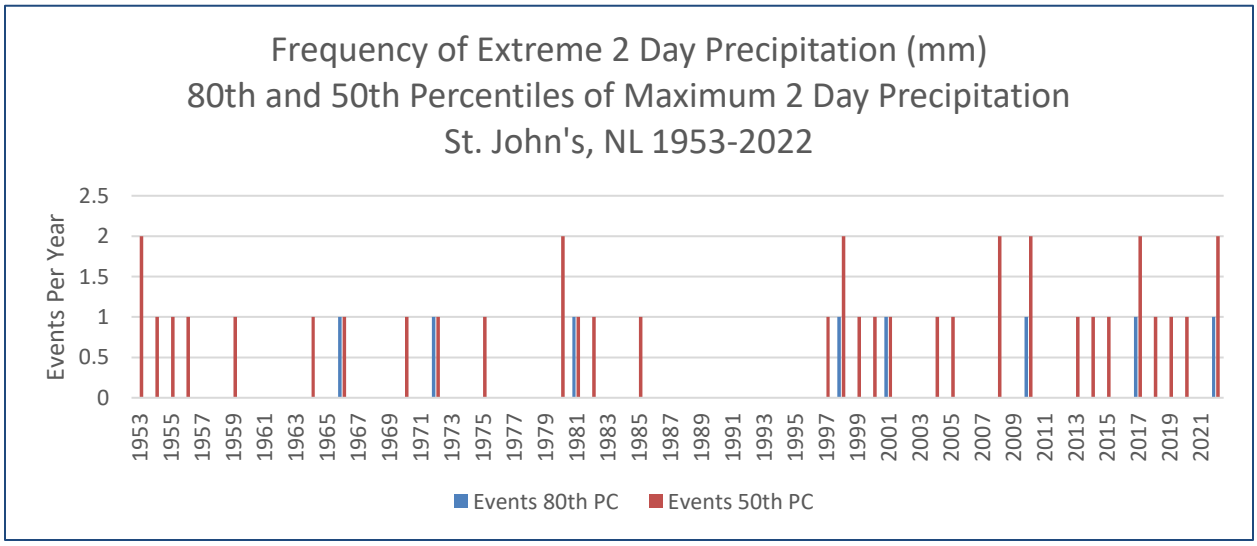


Figure 30 Frequency of Extreme 2 Day Precipitation St. John's, NL 1953-2022



Both the intensity and frequency of extreme precipitation show an increasing trend at St. John's. This is true for both daily precipitation and 2-day precipitation totals.

b. Precipitation Analysis - Halifax

Figure 31 Annual Precipitation Halifax, NS 1960-2022

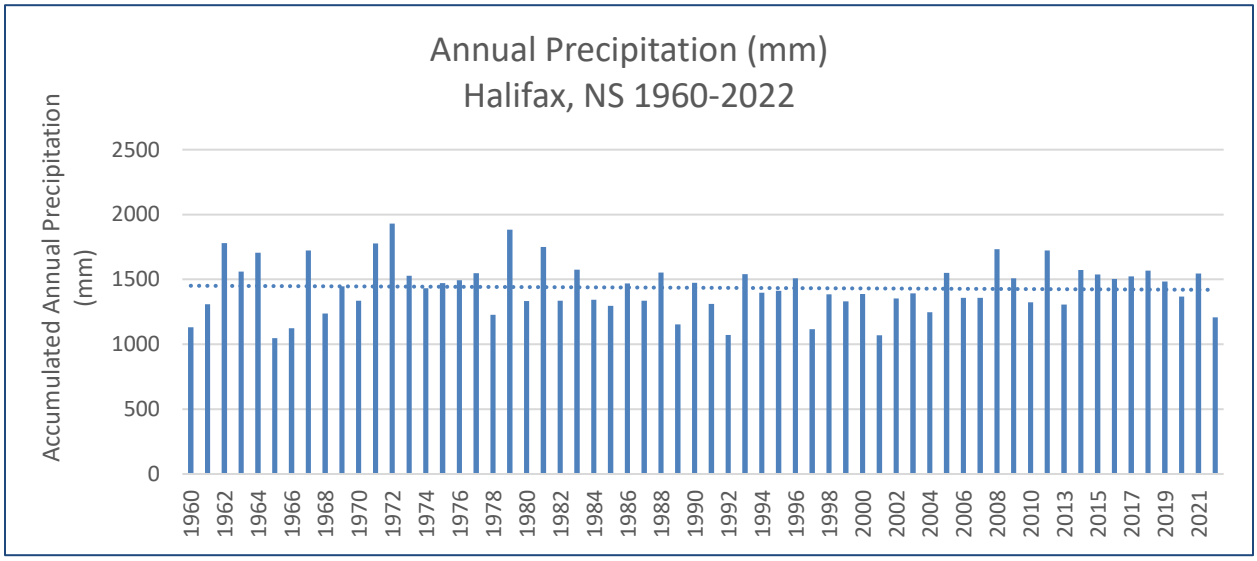


Figure 32 Maximum Daily Precipitation By Year Halifax, NS 1960-2022

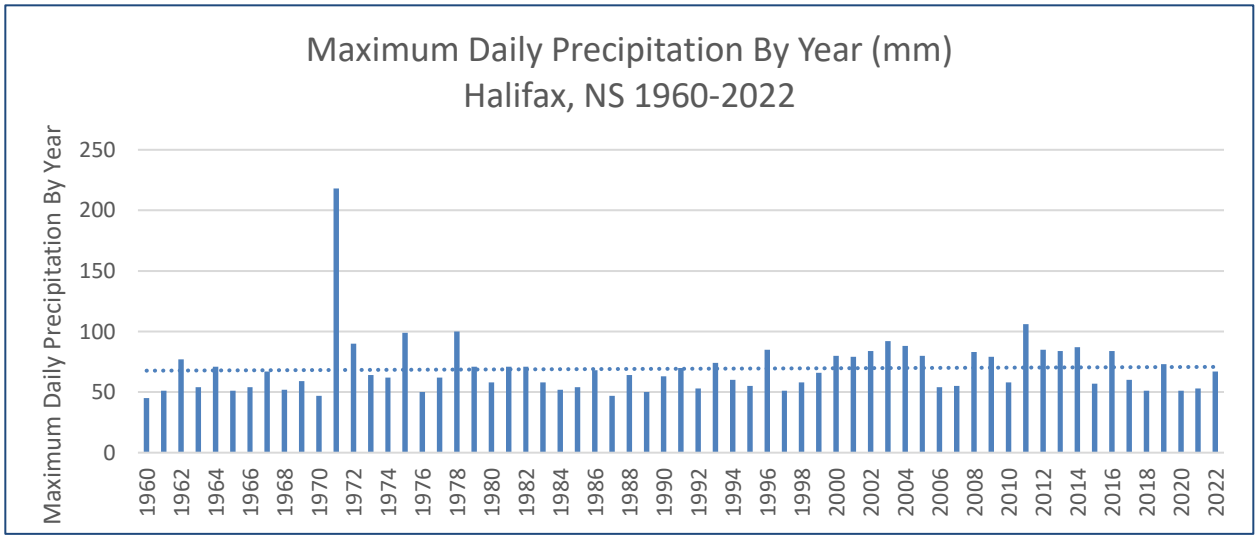


Figure 33 Frequency of Extreme Daily Precipitation Events Halifax, NS 1960-2022

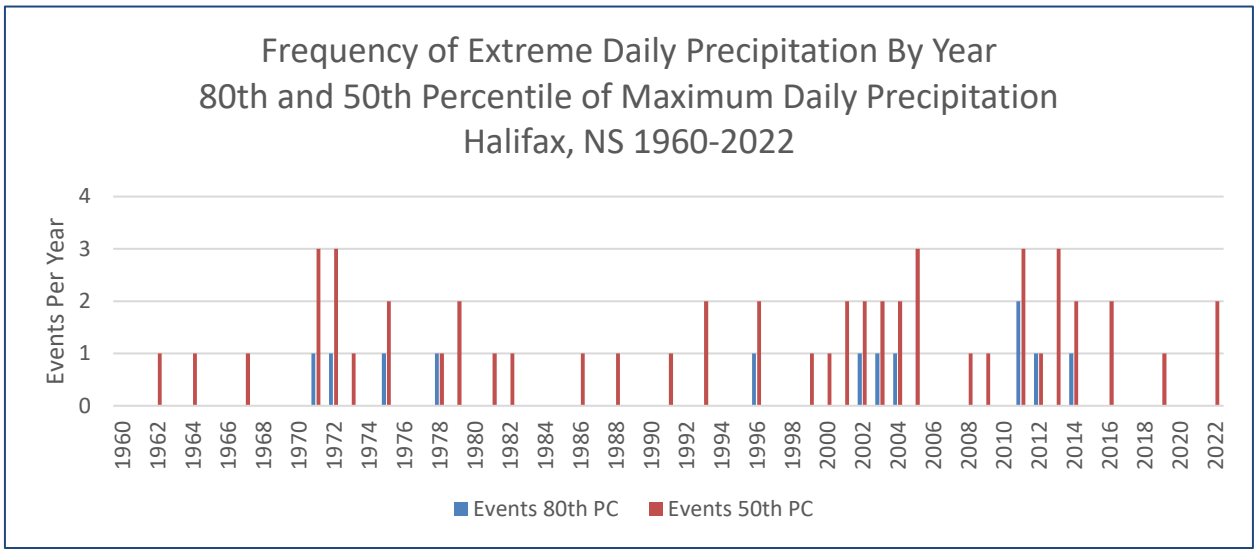


Figure 34 Maximum 2 Day Precipitation Halifax, NS 1960-2022

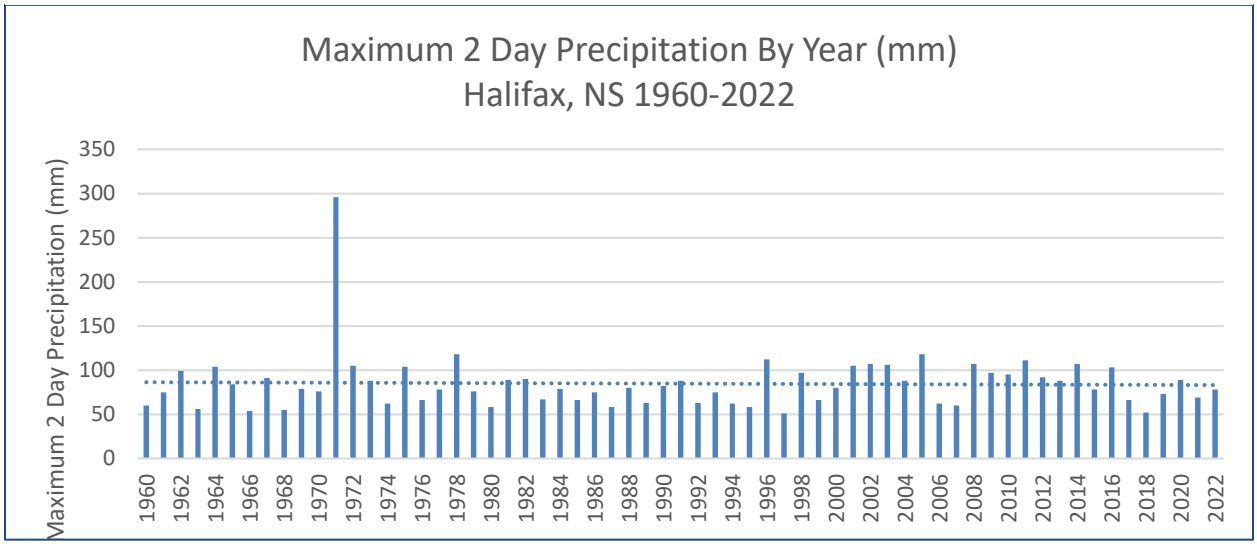
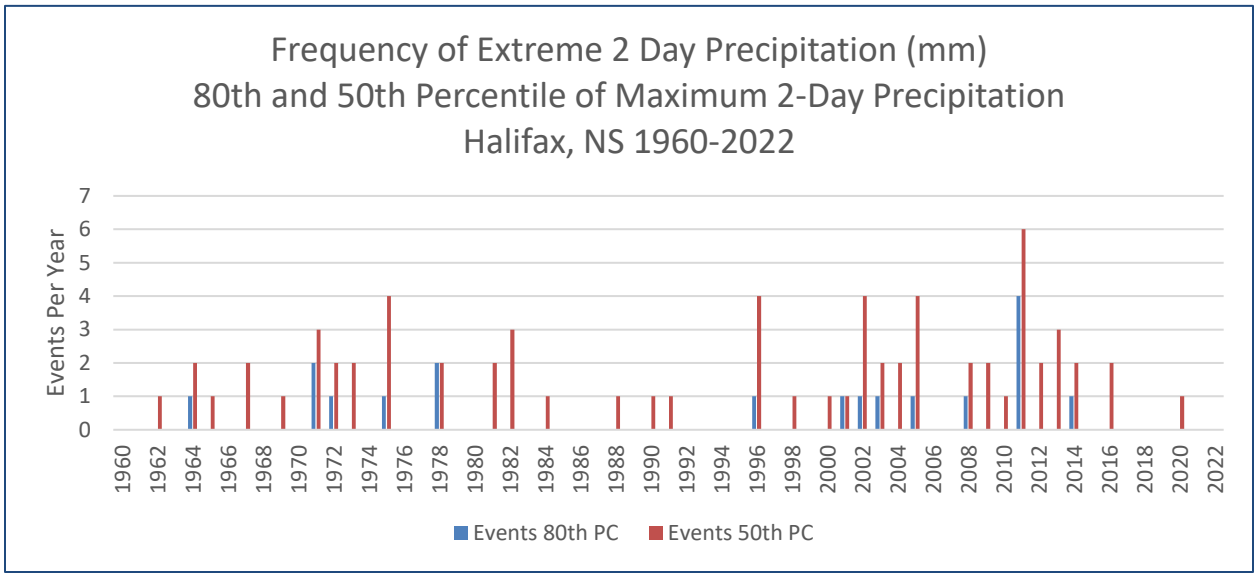


Figure 35 Frequency of Extreme 2 Day Precipitation Events Halifax, NS 1960-2022



c. Precipitation Analysis - Montreal

Figure 36 Annual Precipitation Montreal, QC 1960-2022

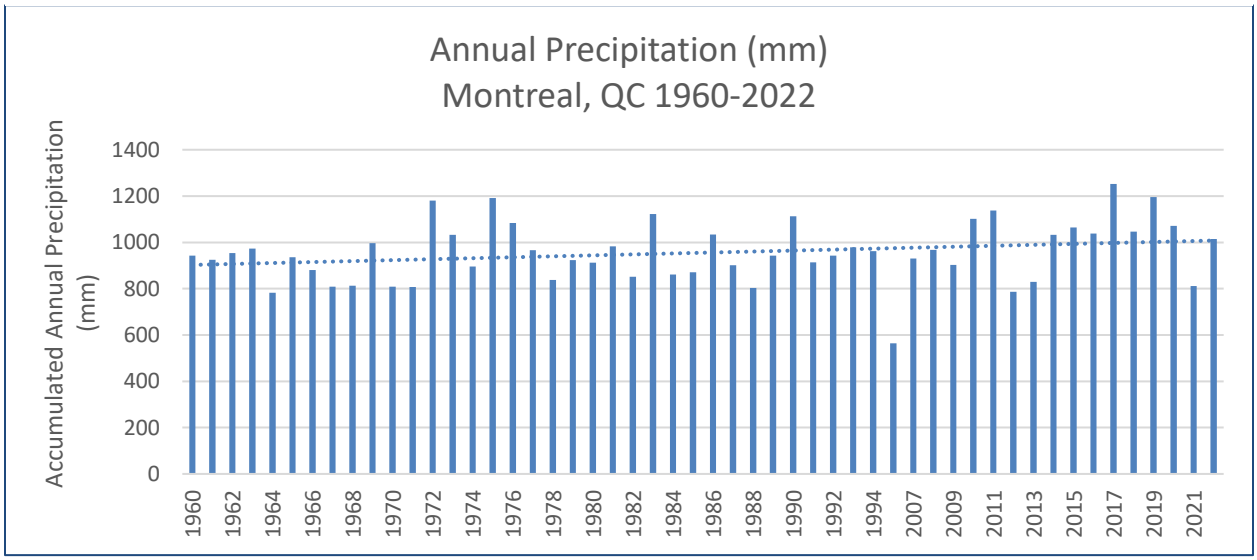


Figure 37 Maximum Daily Precipitation By Year Montreal, QC 1960-2022

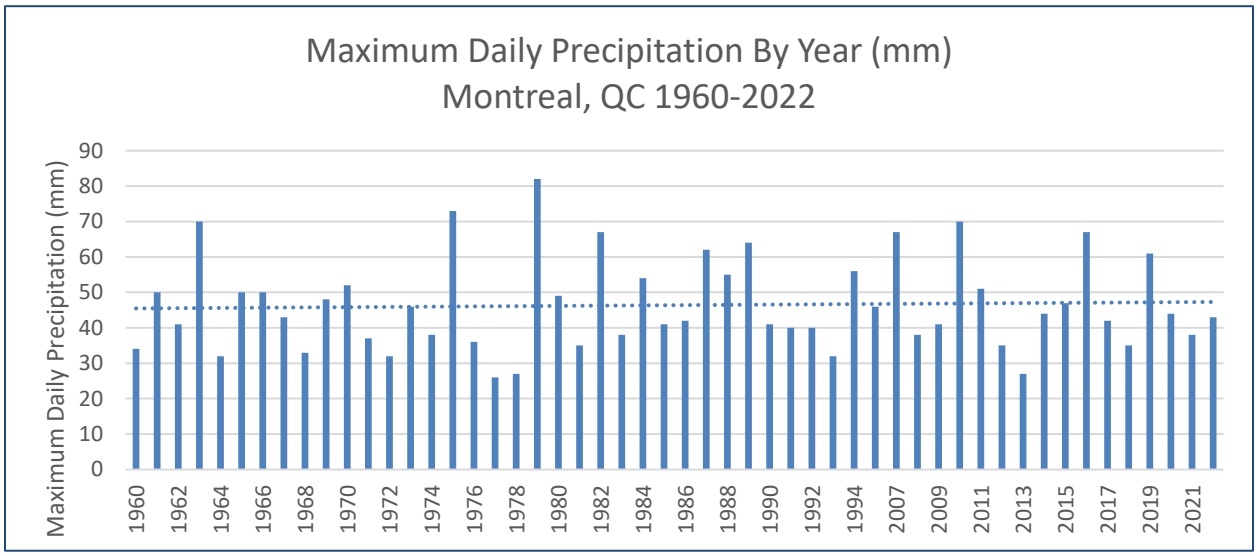


Figure 38 Frequency of Extreme Precipitation Montreal, QC 1960-2022

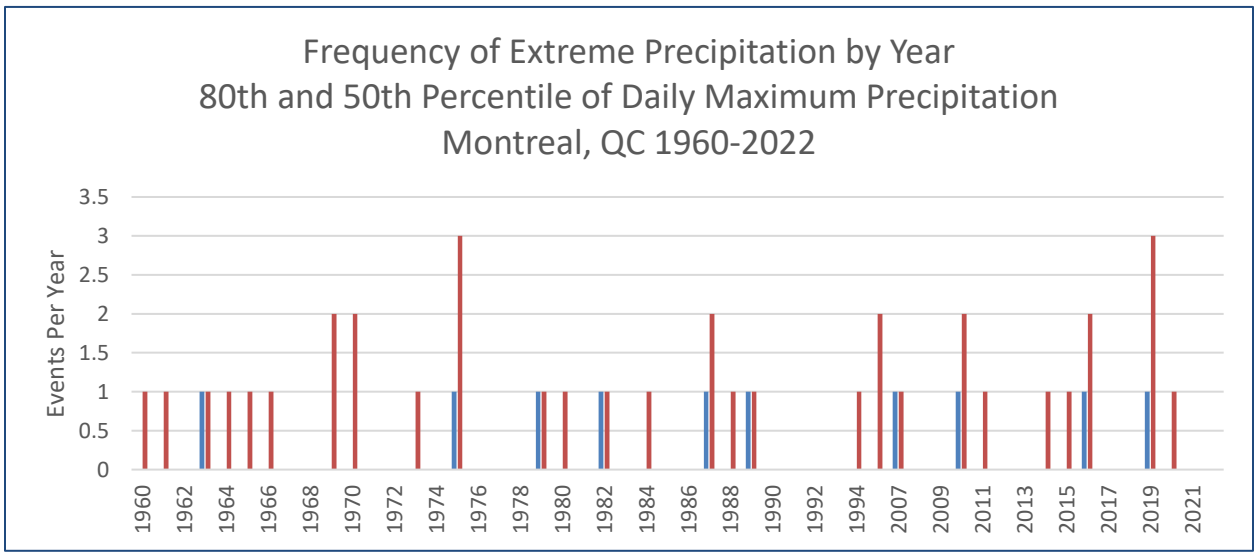


Figure 39 Maximum 2 Day Precipitation Montreal, QC 1960-2022

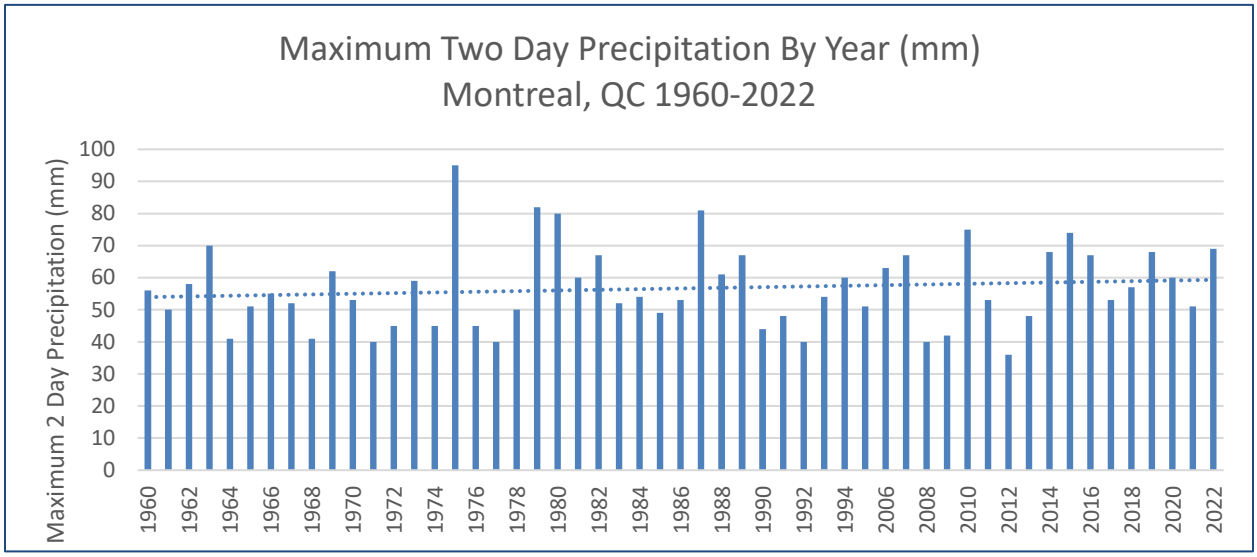
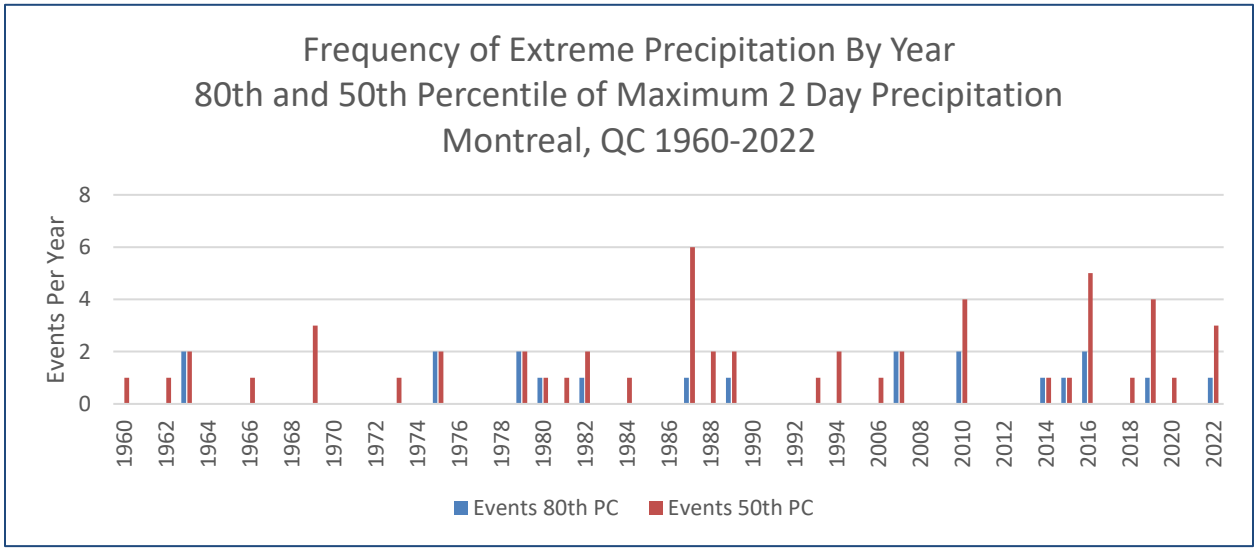


Figure 40 Frequency of Extreme 2 Day Precipitation Montreal, QC 1960-2022



d. Precipitation Analysis – Bagotville, QC

Figure 41 Annual Precipitation Bagotville, QC 1953-2022

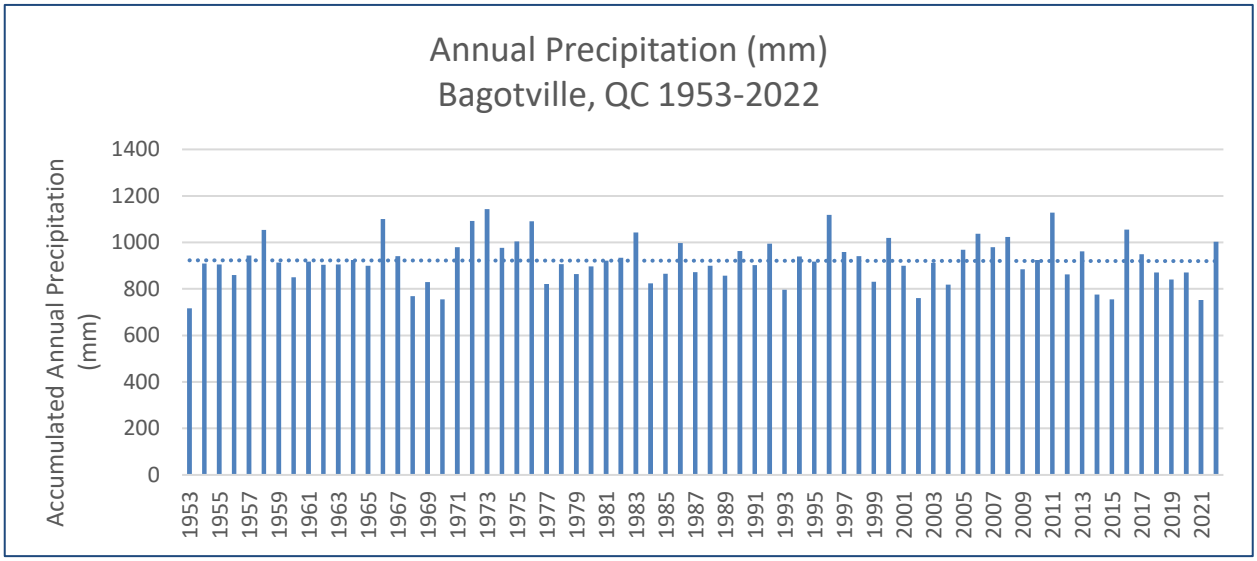


Figure 42 Maximum Daily Precipitation Bagotville, QC 1953-2022

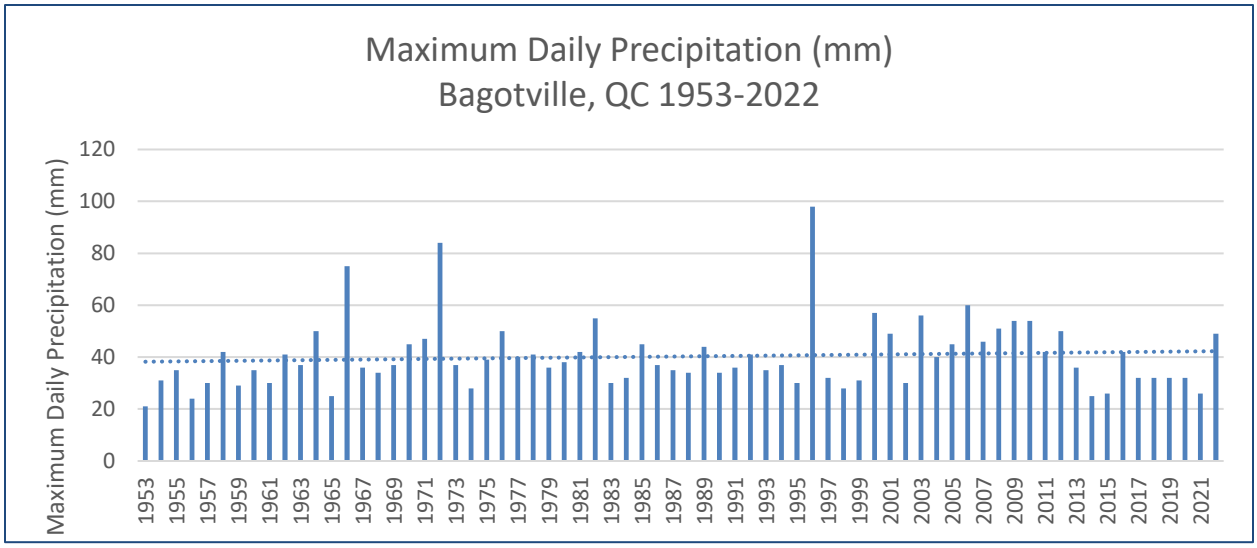


Figure 43 Frequency of Extreme Precipitation Bagotville, QC 1953-2022

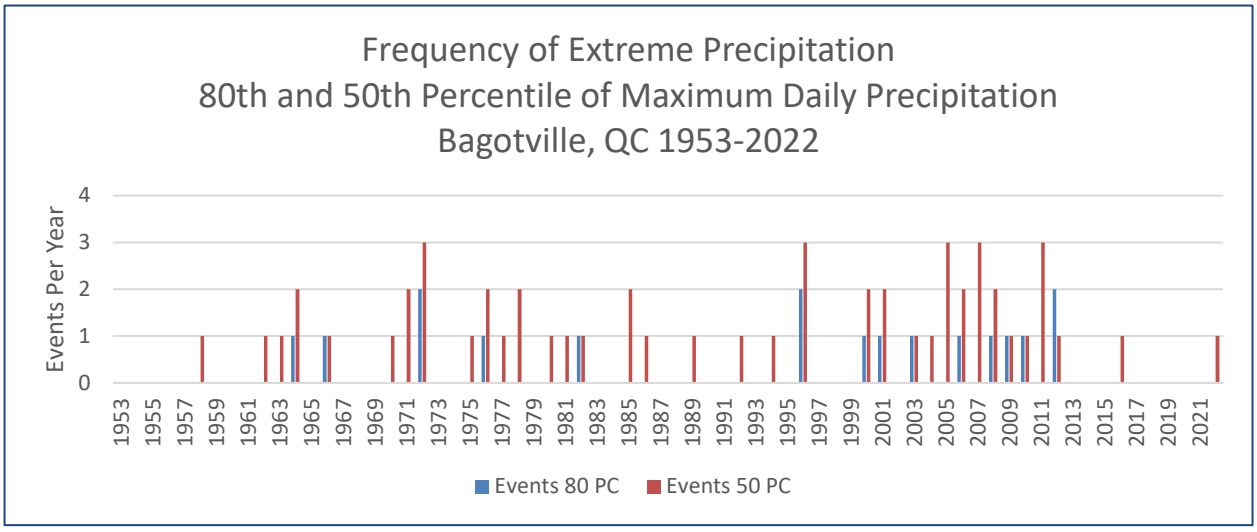


Figure 44 Maximum 2 Day Precipitation By Year Bagotville, QC 1953-2022

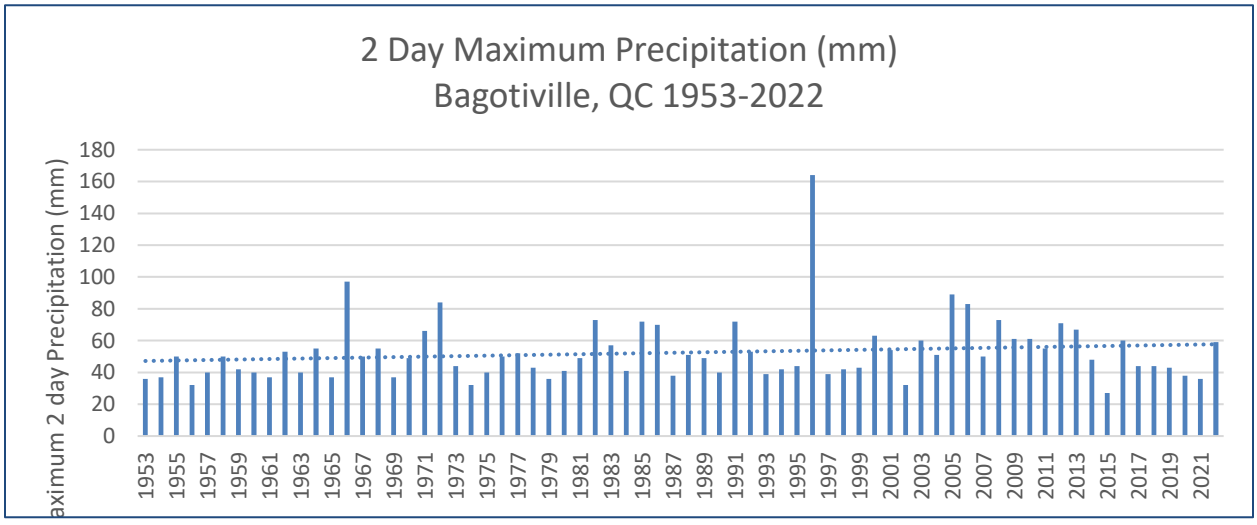
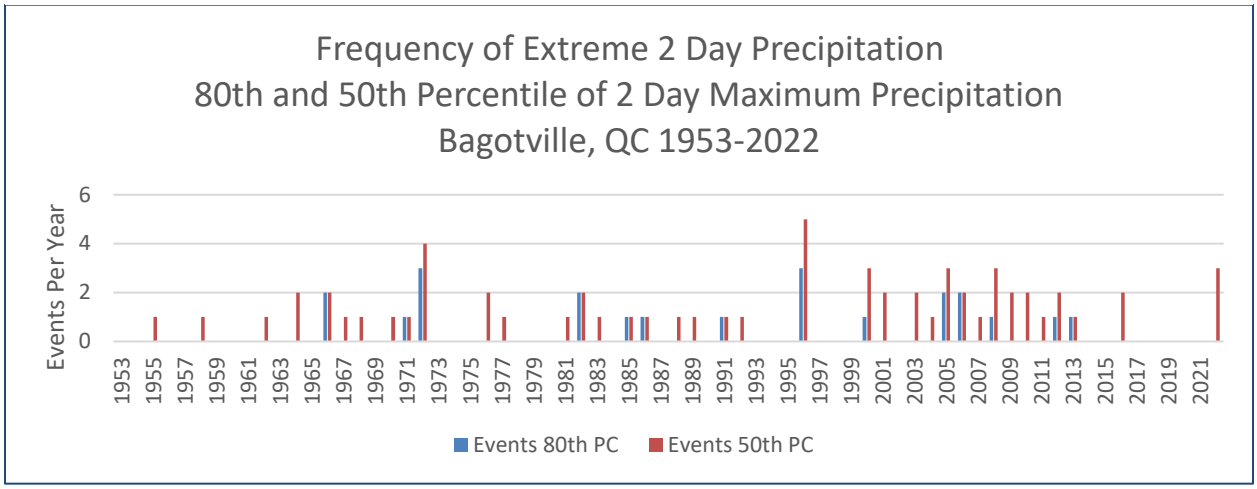


Figure 45 Frequency of Extreme 2 Day Precipitation Bagotville, QC 1953-2022



e. Precipitation Analysis - Toronto

Figure 46 Annual Precipitation Toronto Pearson, ON 1953-2022

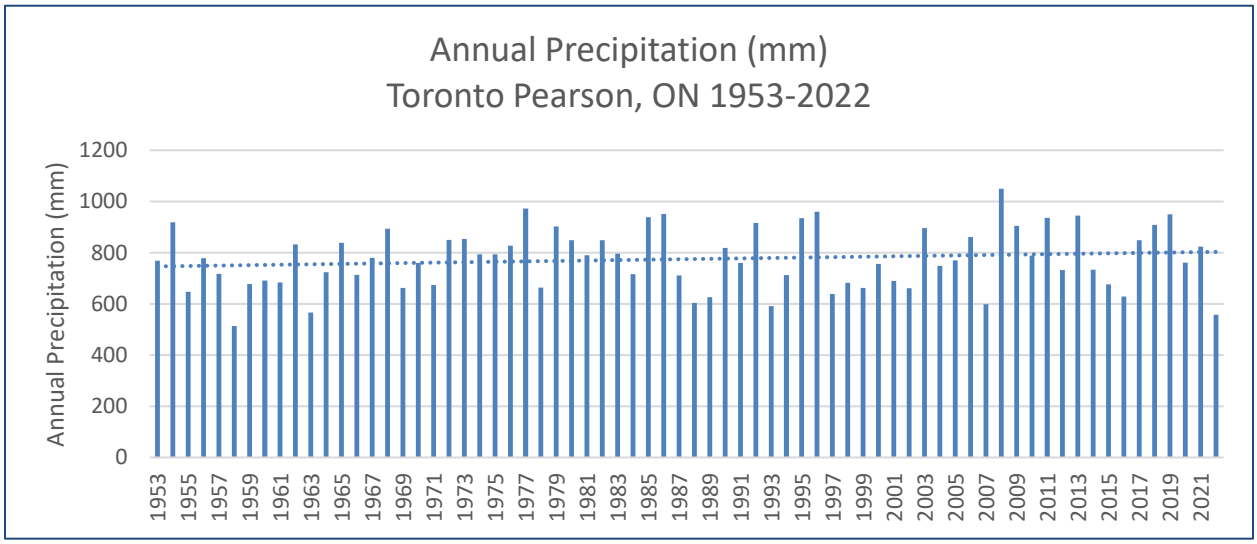


Figure 47 Daily Maximum Precipitation Toronto, ON 1953-2022

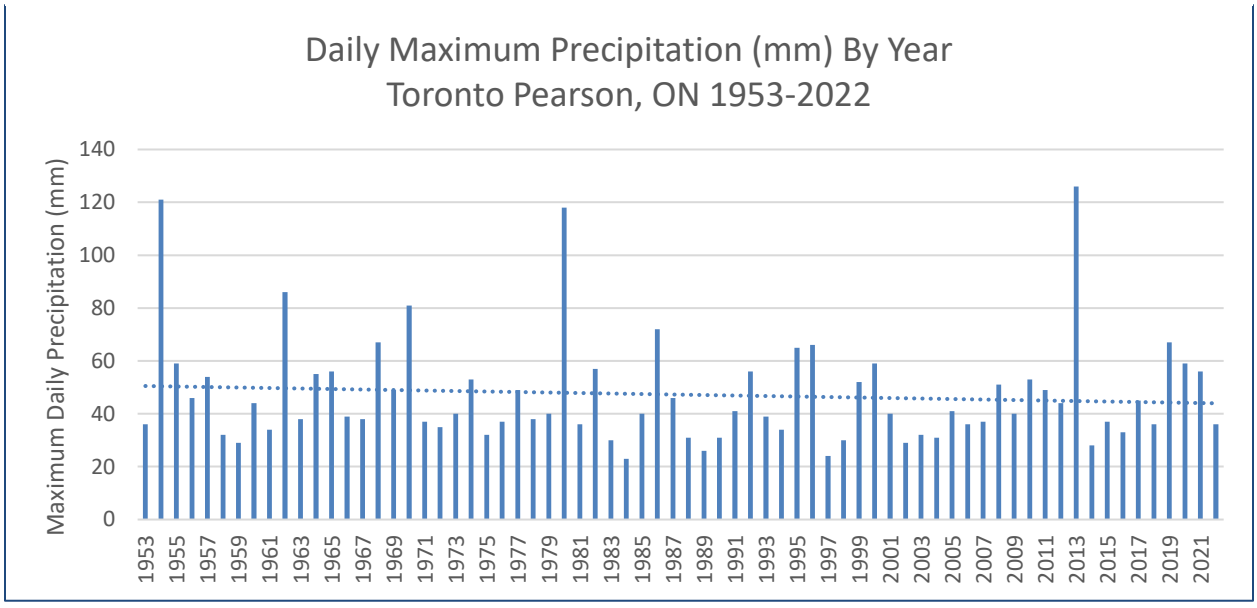


Figure 48 Frequency of Extreme Daily Precipitation Toronto Pearson, ON 1953-2022

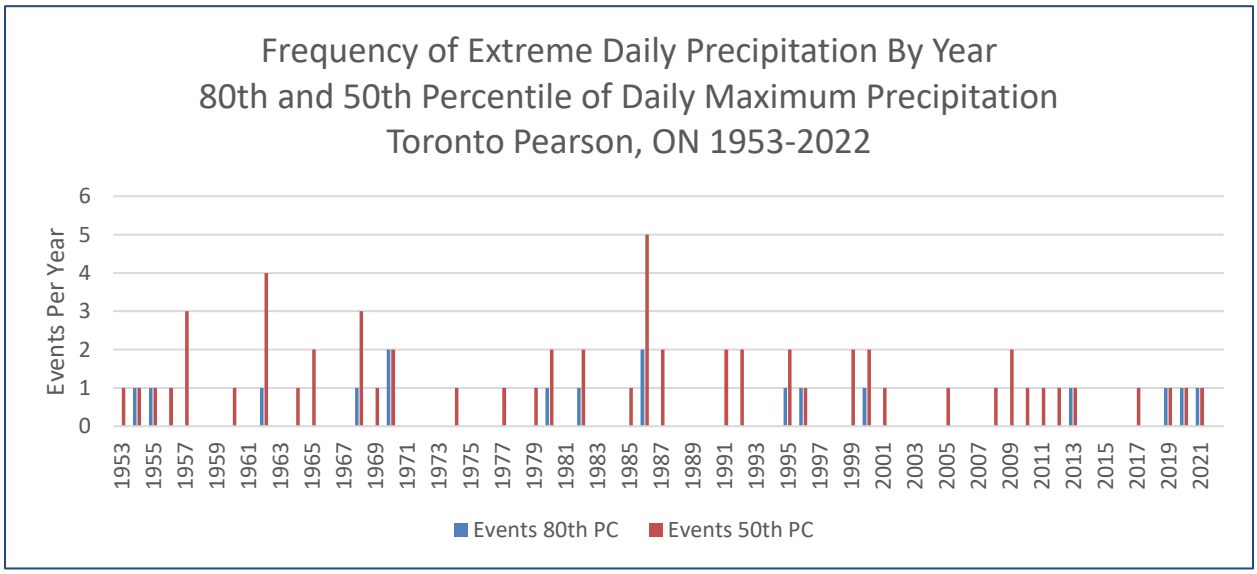


Figure 49 Maximum 2 Day Precipitation Toronto Pearson, ON 1953-2022

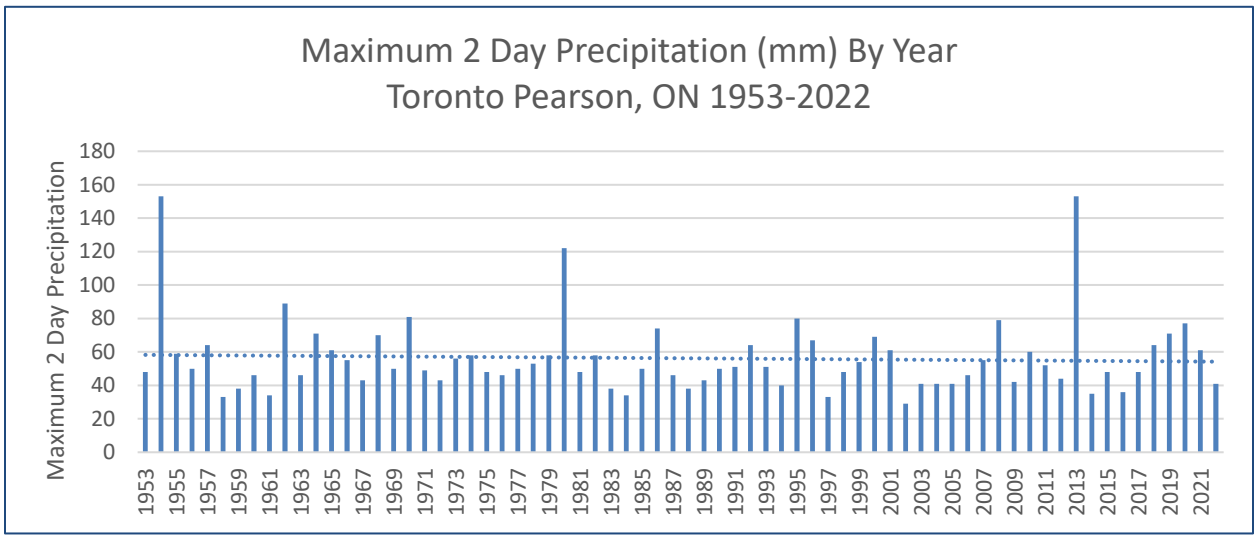
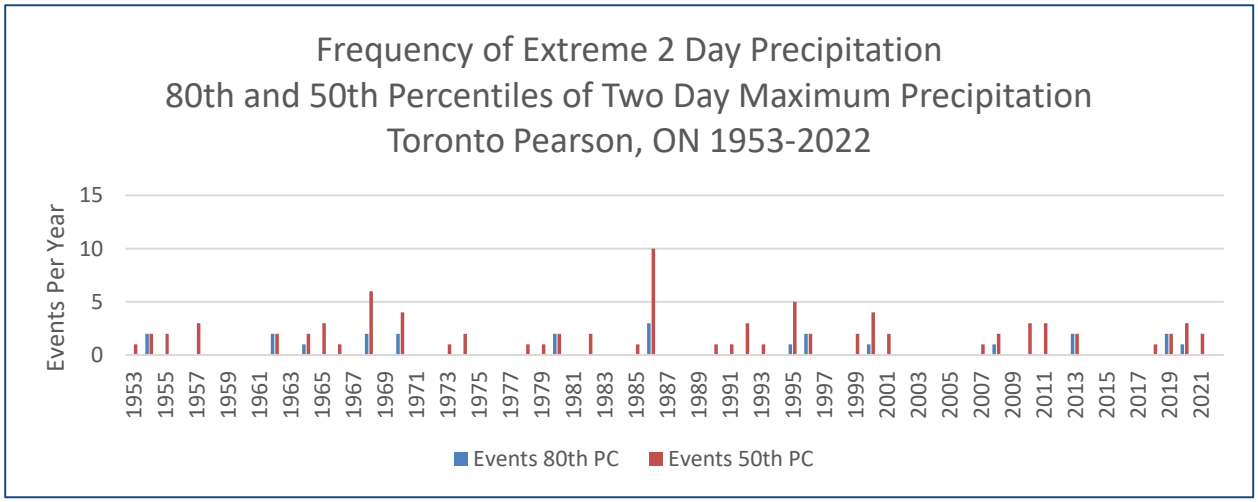


Figure 50 Frequency of Extreme 2 Day Precipitation Toronto Pearson, ON 1953-2022



f. Precipitation Analysis - Winnipeg

Figure 51 Annual Precipitation Winnipeg A, MB 1953-2022

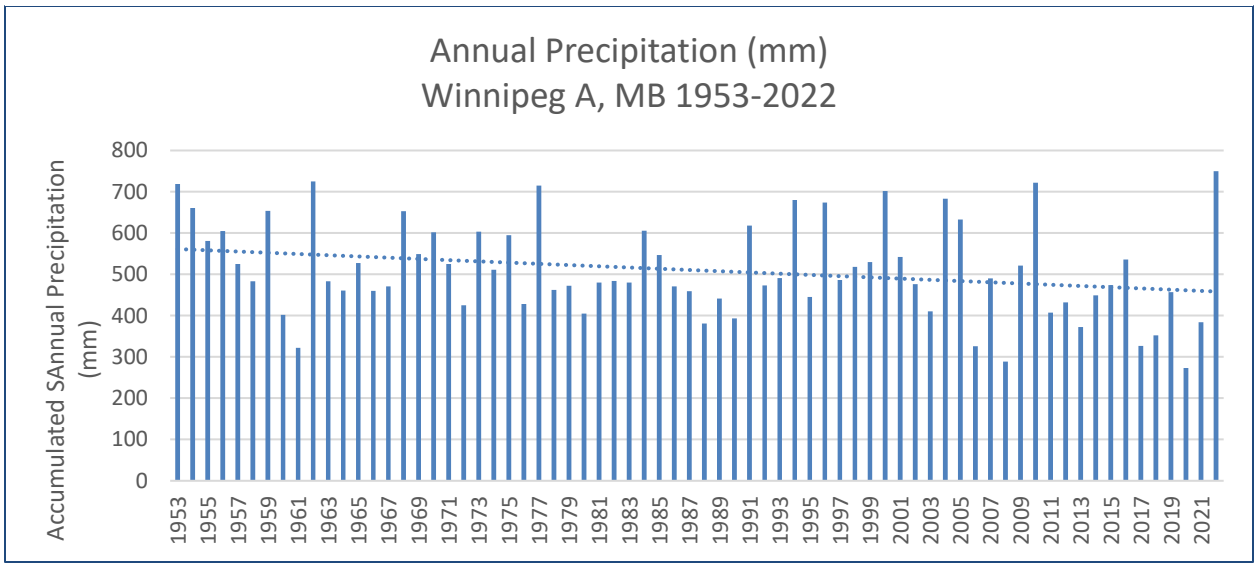


Figure 52 Maximum Daily Precipitation Winnipeg A, MB 1953-202

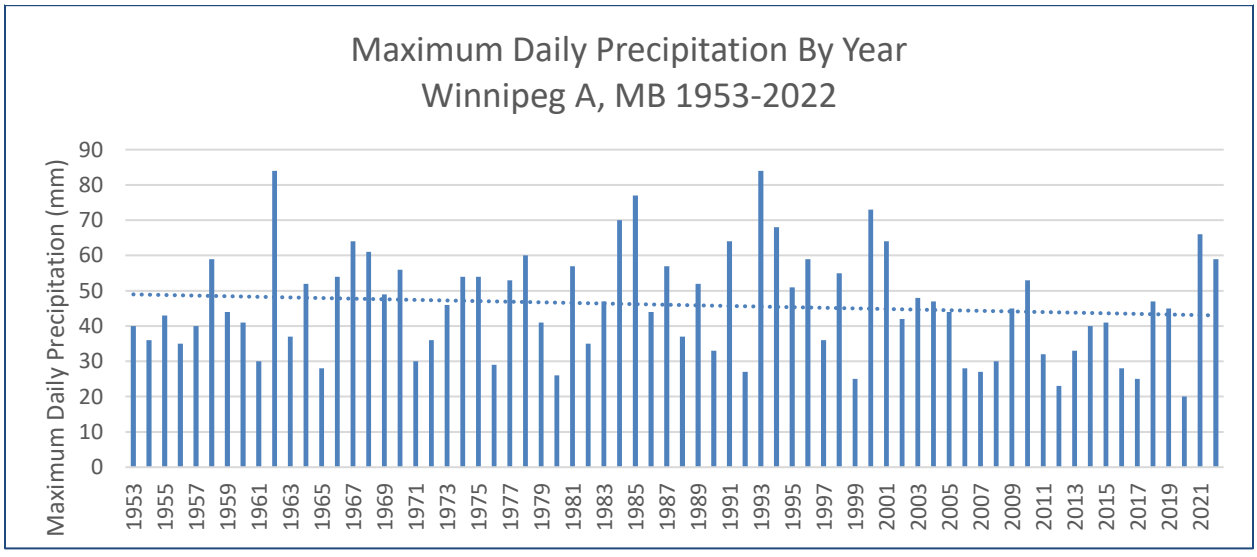


Figure 53 Frequency of Extreme Precipitation Winnipeg A, MB 1953-2022

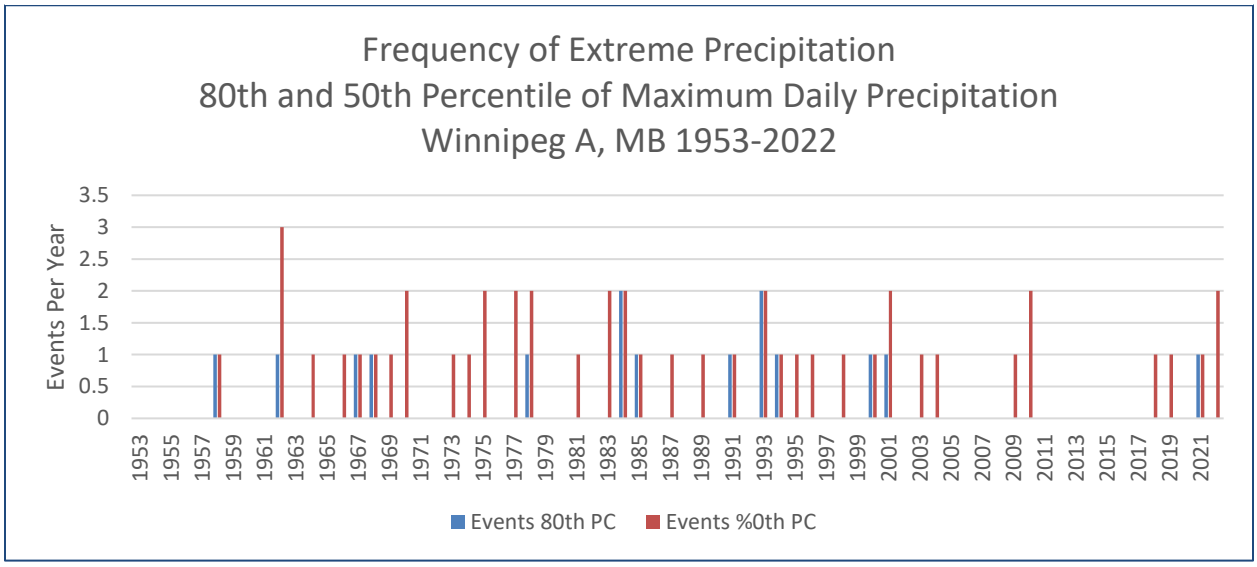


Figure 54 Maximum 2 Day Precipitation Winnipeg A, MB 1953-2022

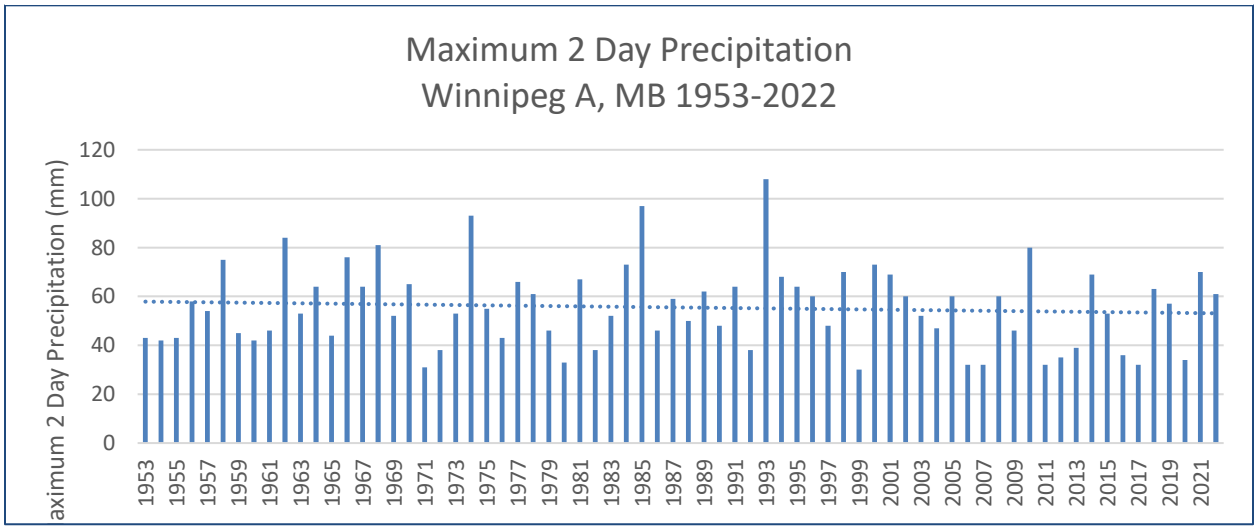
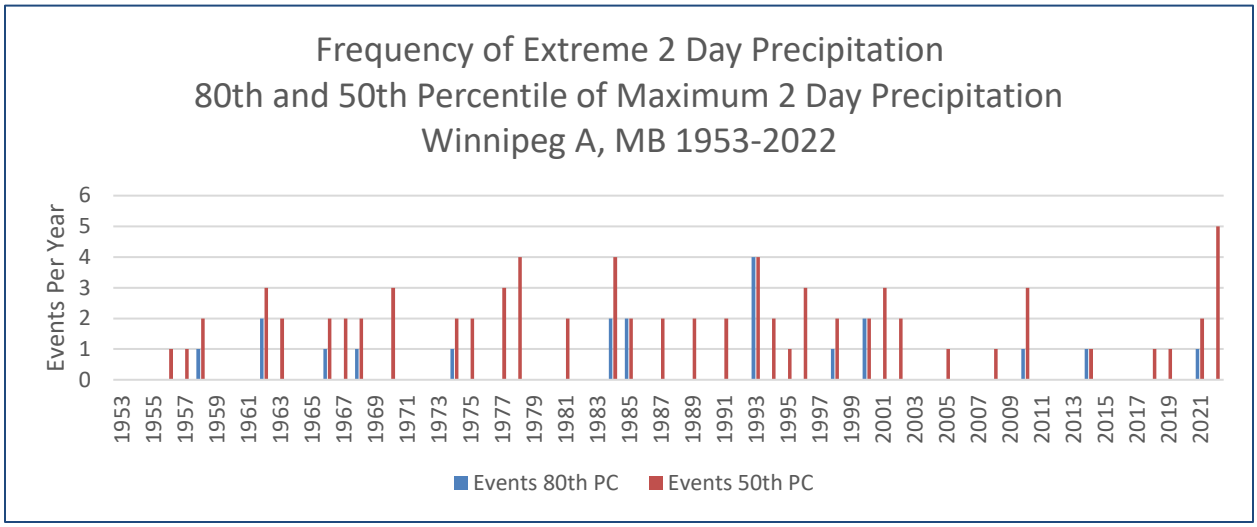


Figure 55 Frequency of Extreme 2 Day Precipitation (mm) Winnipeg A, MB 1953-2022



g. Precipitation Analysis - Regina

Figure 56 Annual Precipitation Regina A, SK 1953-2022

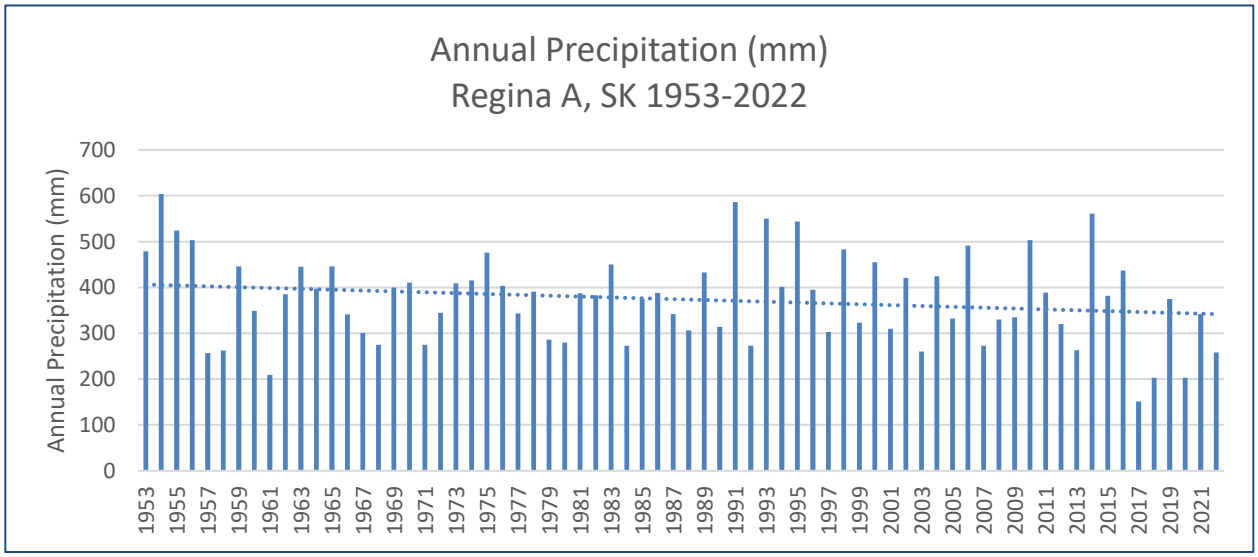


Figure 57 Maximum Daily Precipitation (mm) Regina A, SK 1953-2022

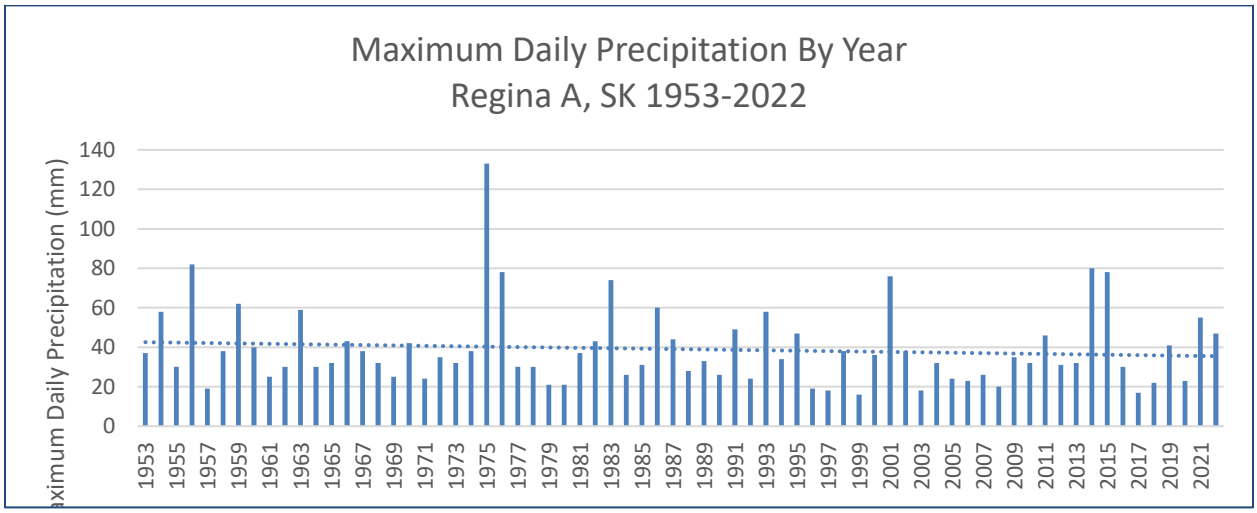


Figure 58 Frequency of Extreme Precipitation Regina A, SK 1953-2022

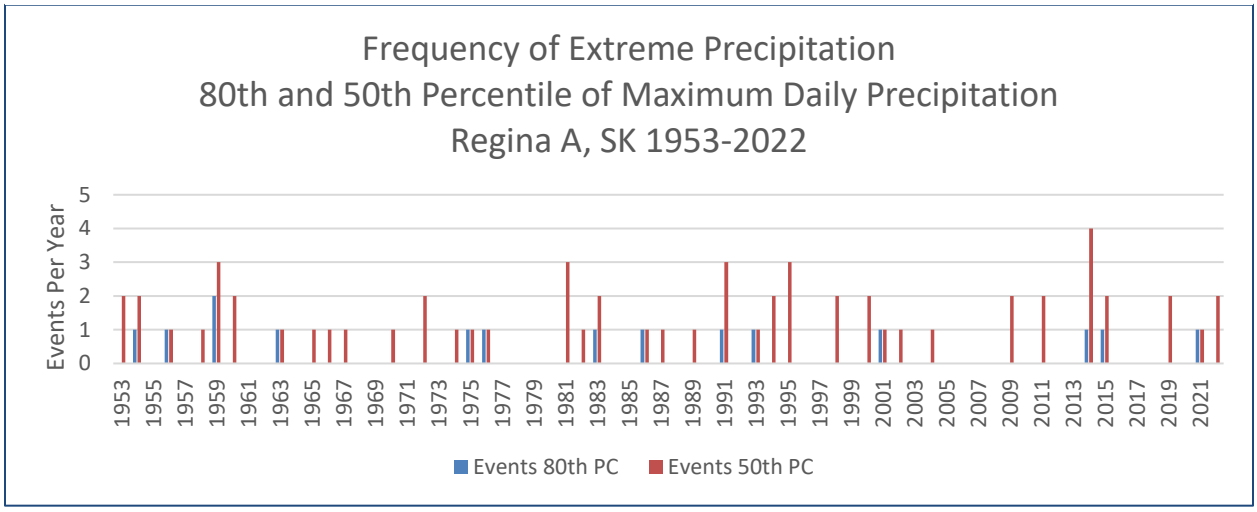


Figure 59 Maximum 2 Day Precipitation Regina A, SK 1953-2022

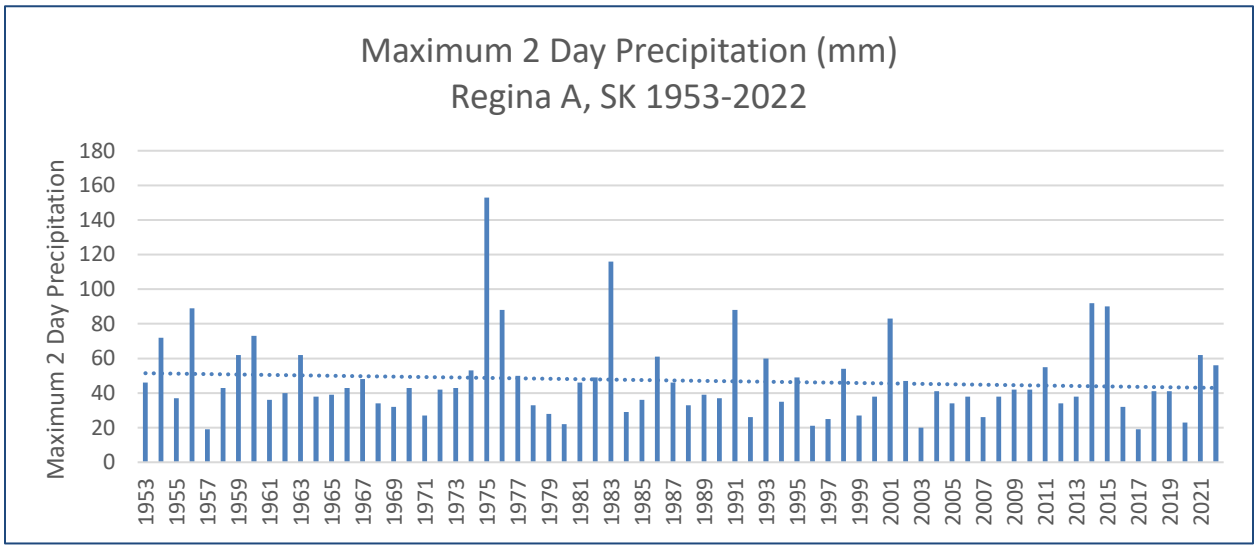
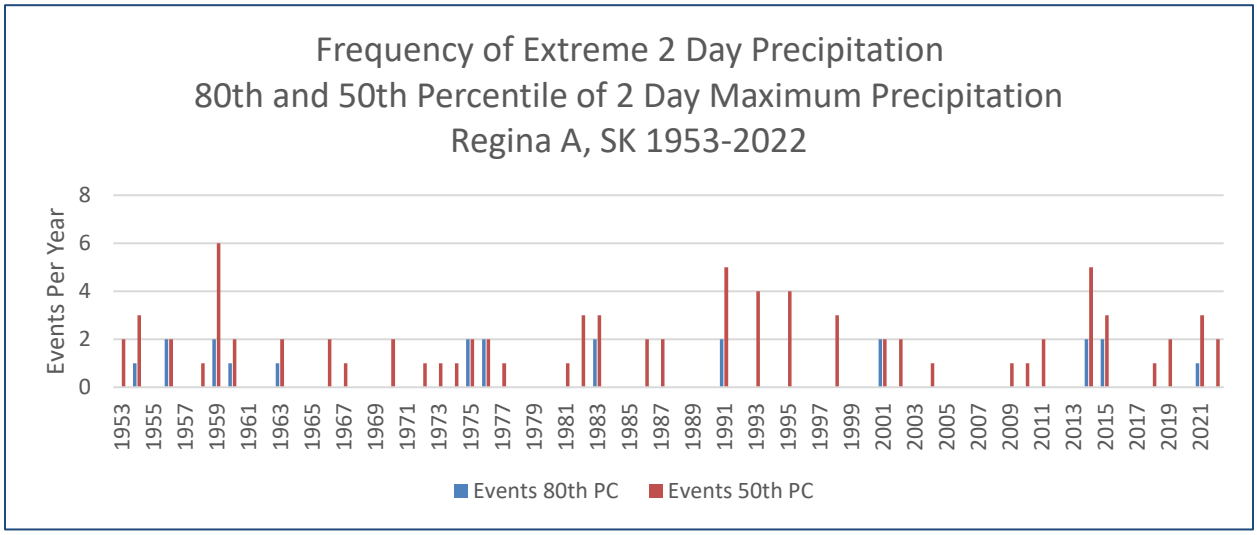


Figure 60 Frequency of Extreme 2 Day Precipitation Regina, SK 1953-2022



h. Precipitation Analysis – Cold Lake

Figure 61 Annual Precipitation Cold Lake, AB 1960-2022

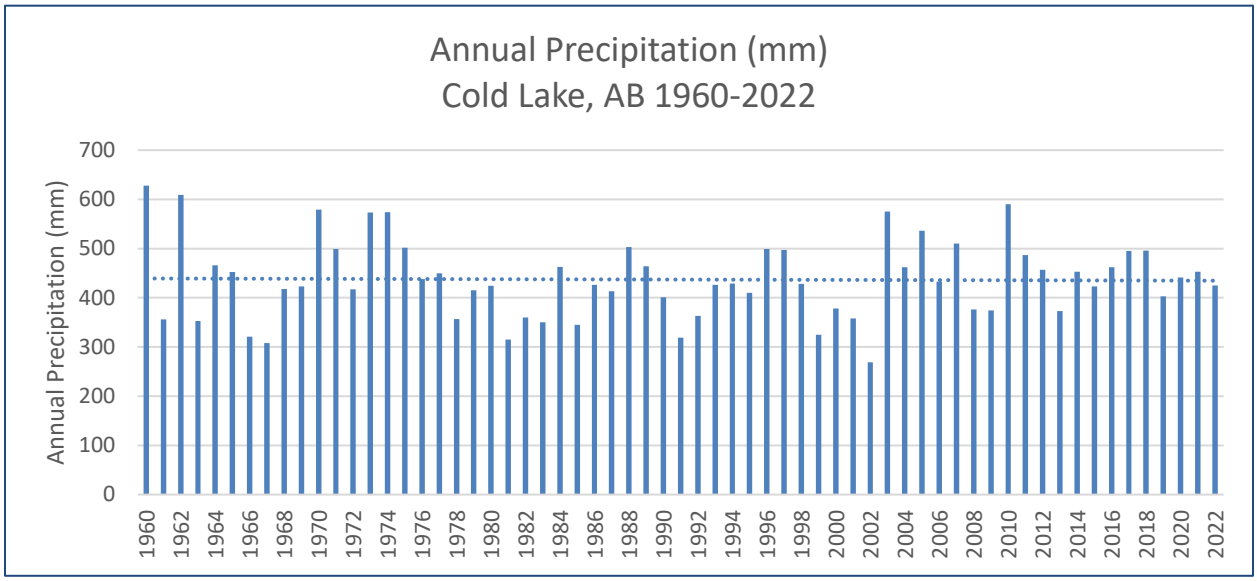


Figure 62 Daily Maximum Precipitation By Year Cold Lake, AB 1960-2022

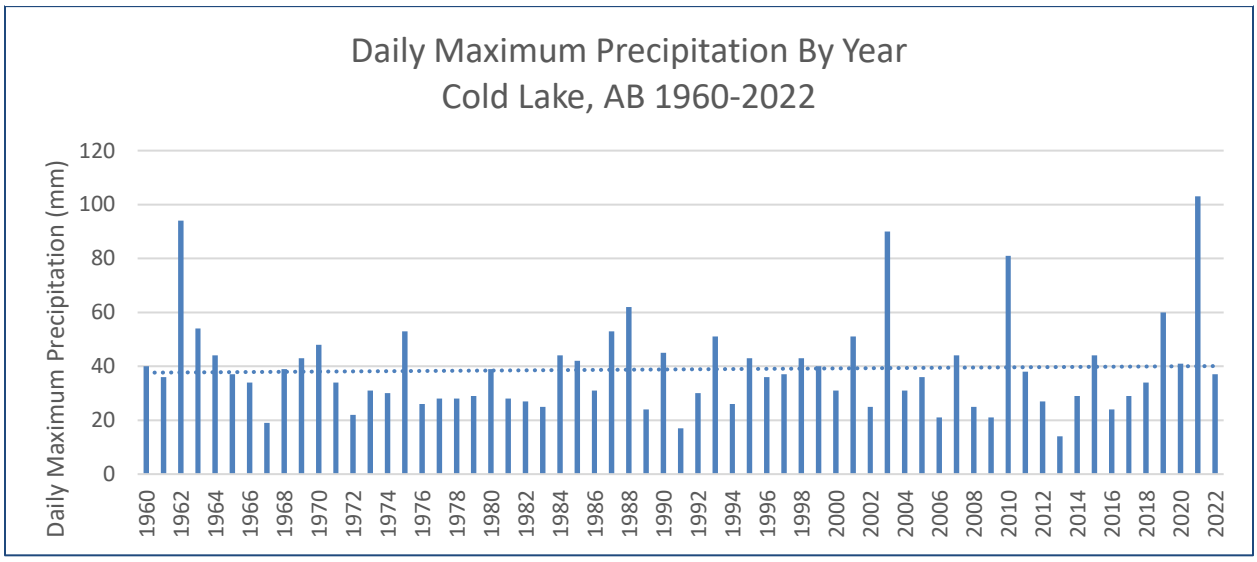


Figure 63 Frequency of Extreme Daily Precipitation Cold Lake, AB 1960-2022

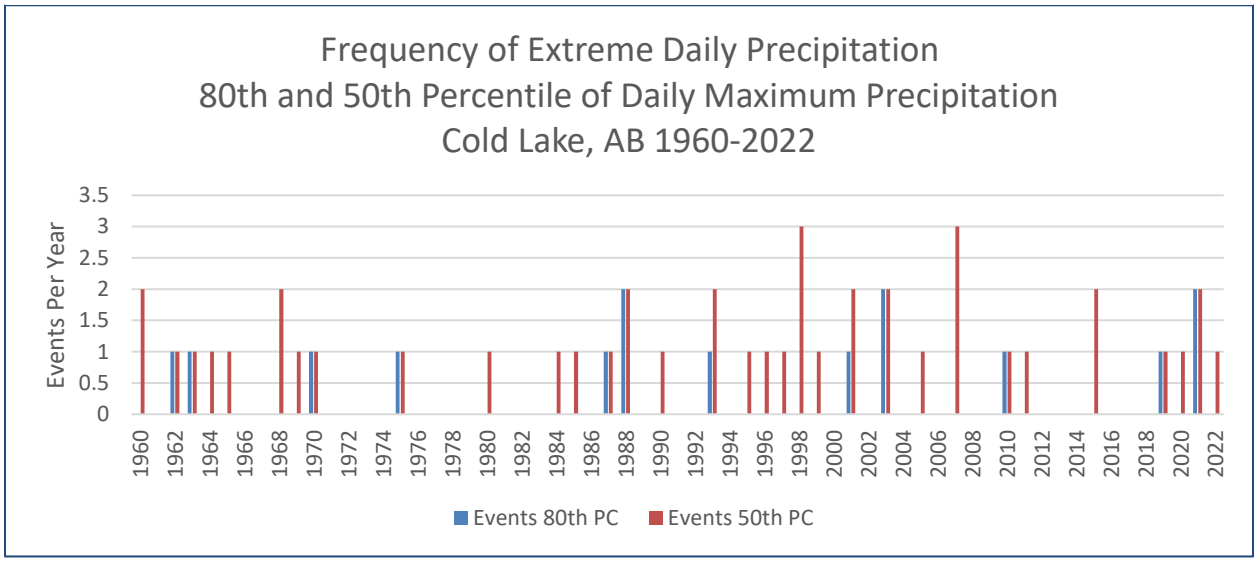


Figure 64 Maximum 2 Day Precipitation By Year Cold Lake, AB 1960-2022

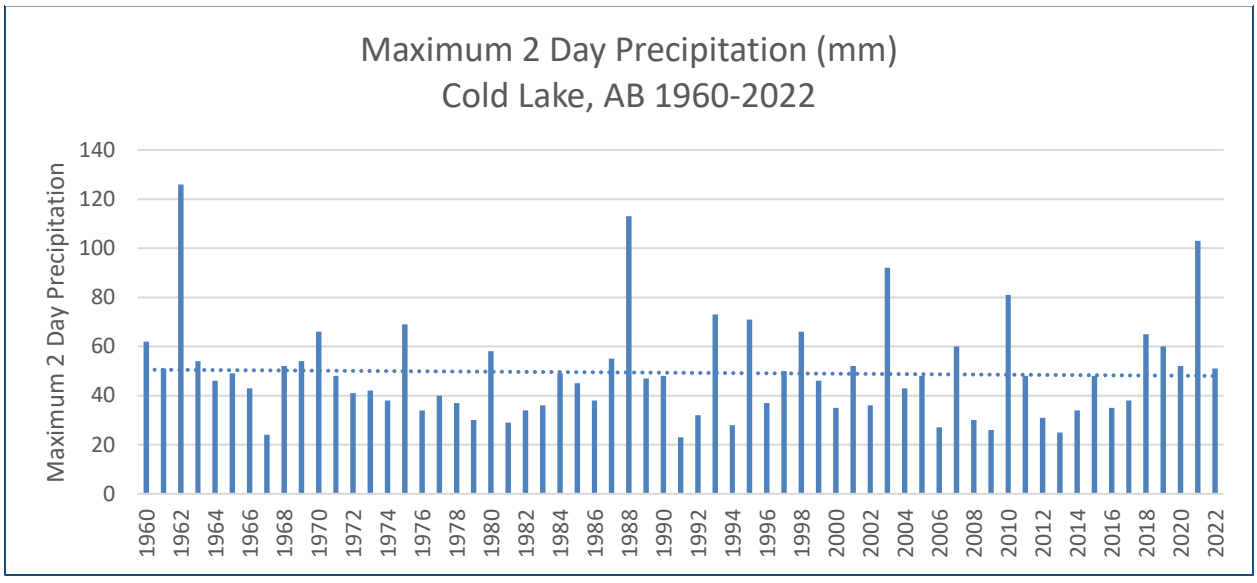
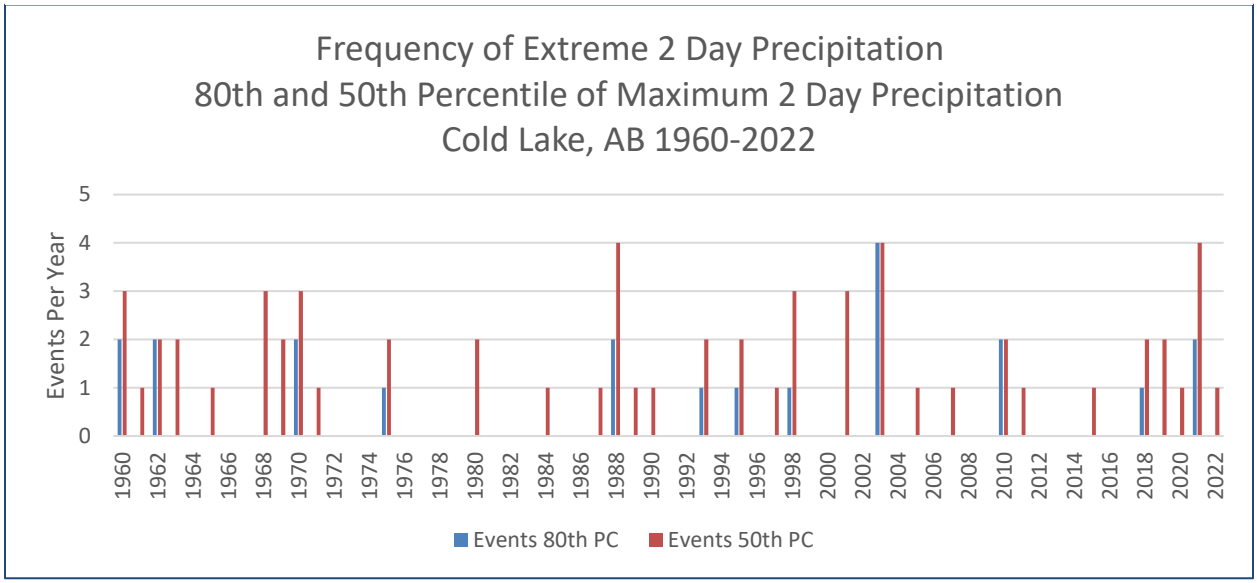


Figure 65 Frequency of 2 Day Maximum Precipitation Cold Lake, AB 1960-2022



i. Precipitation Analysis - Victoria

Figure 66 Annual Precipitation (mm) Victoria, BC 1953-2022

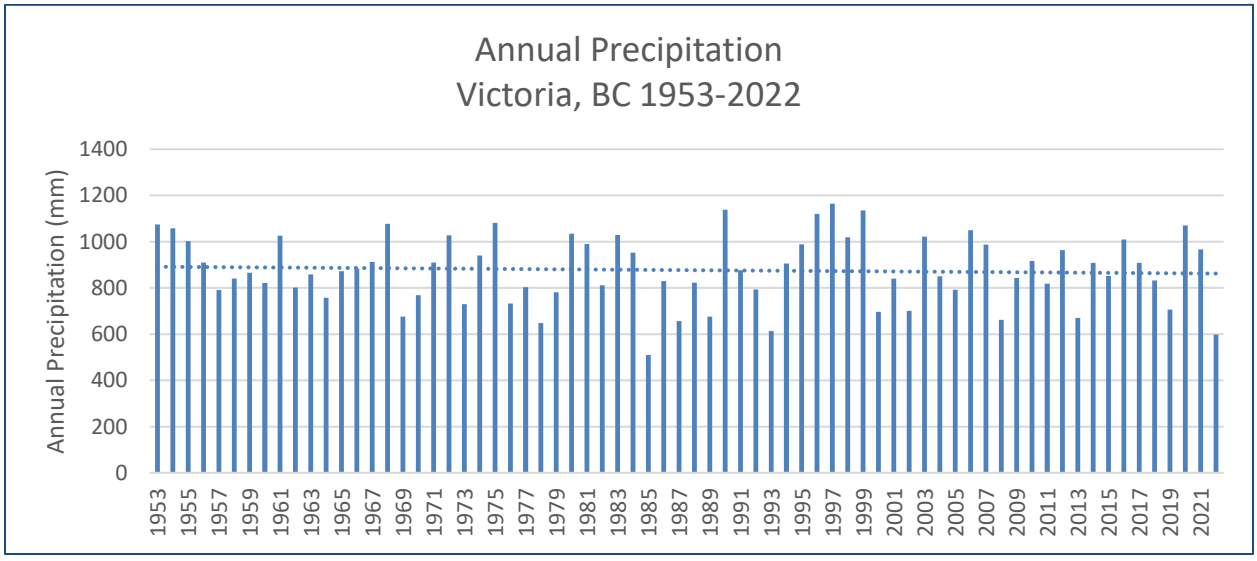


Figure 67 Maximum Daily Precipitation By Year Victoria, BC 1953-2022

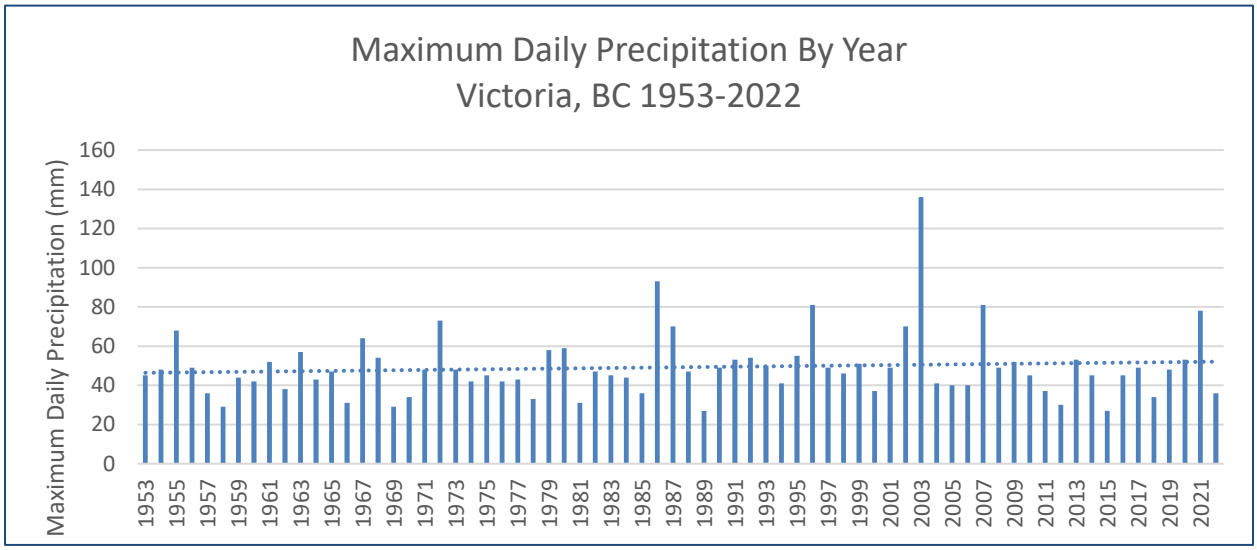


Figure 68 Frequency of Extreme Daily Precipitation Victoria, BC 1953-2022

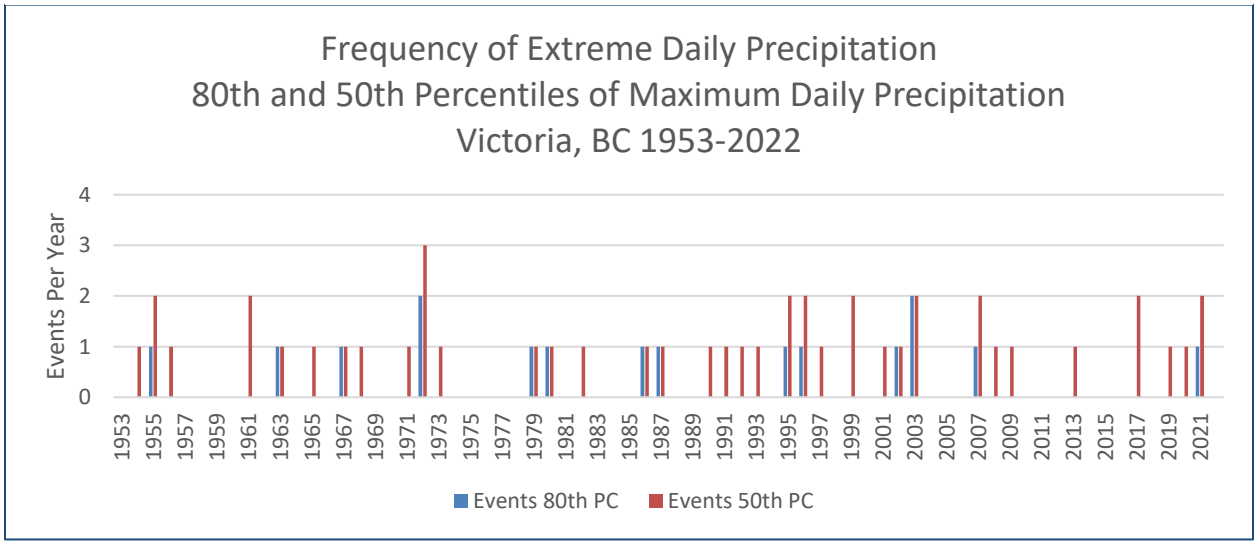


Figure 69 Maximum 2 Day Precipitation Victoria, BC 1953-2022

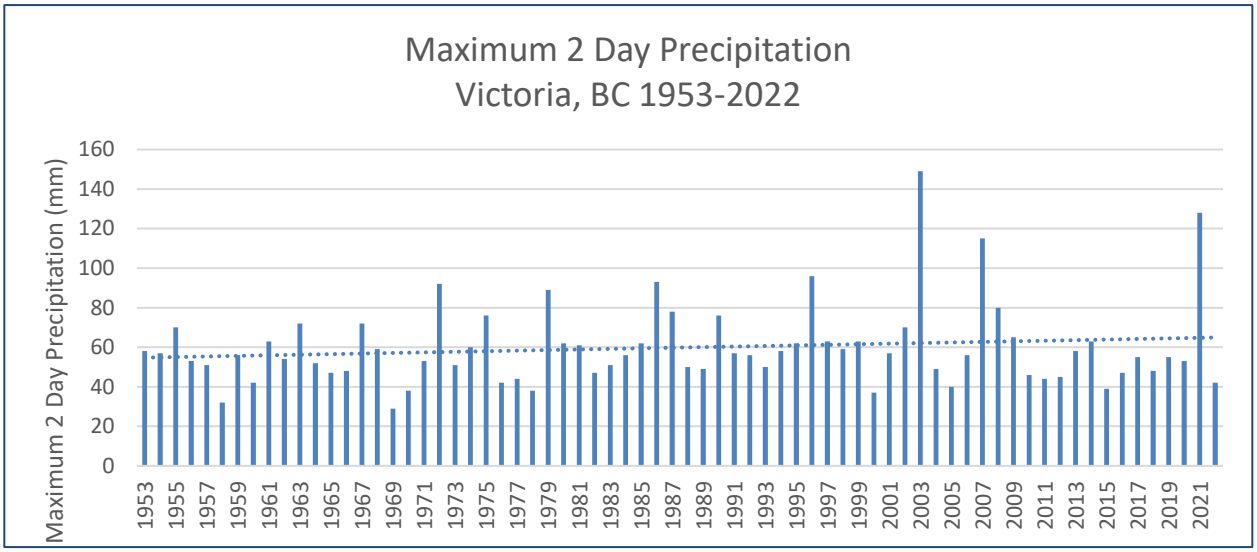
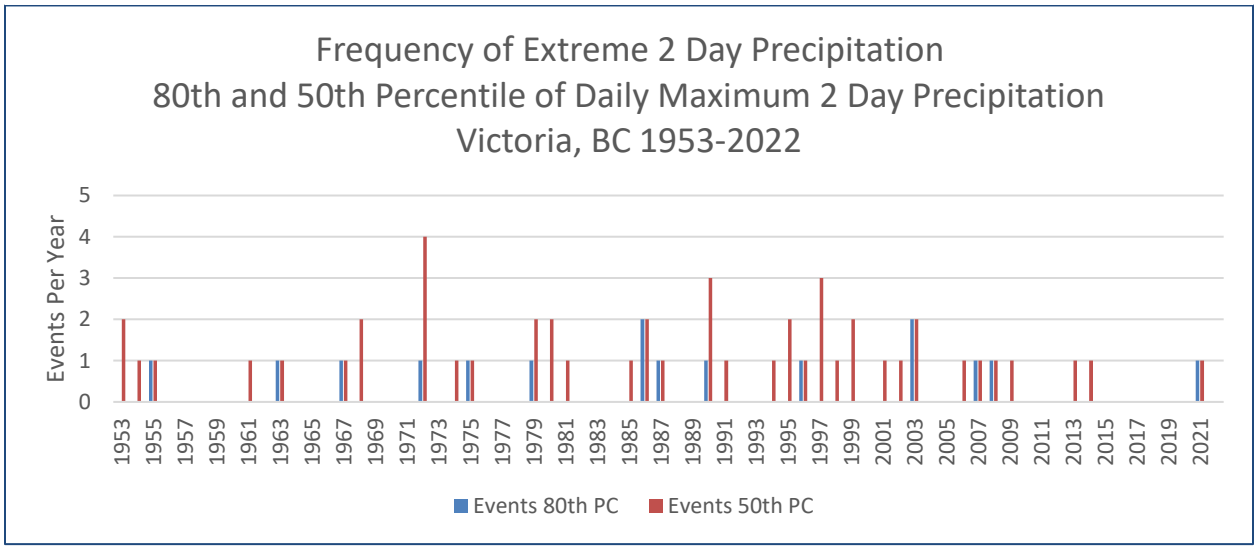


Figure 70 Frequency of Extreme 2 Day Precipitation Victoria, BC 1953-2022



j. Precipitation Analysis – Churchill

Figure 71 Annual Precipitation Churchill, MB 1960-2022

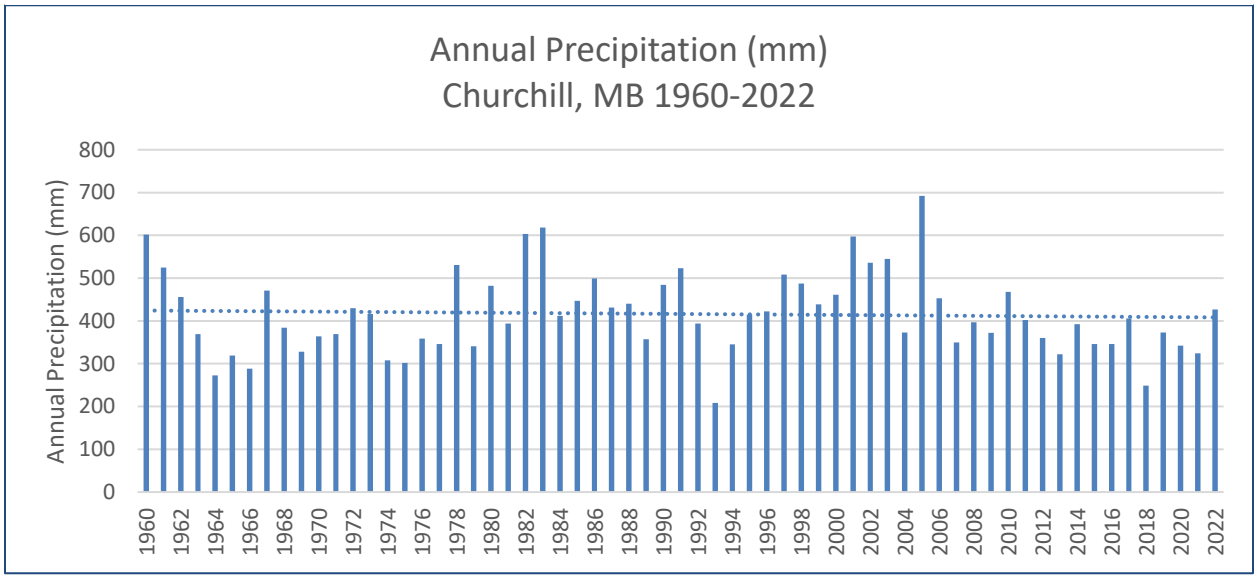


Figure 72 Maximum Daily Precipitation Churchill, MB 1960-2022

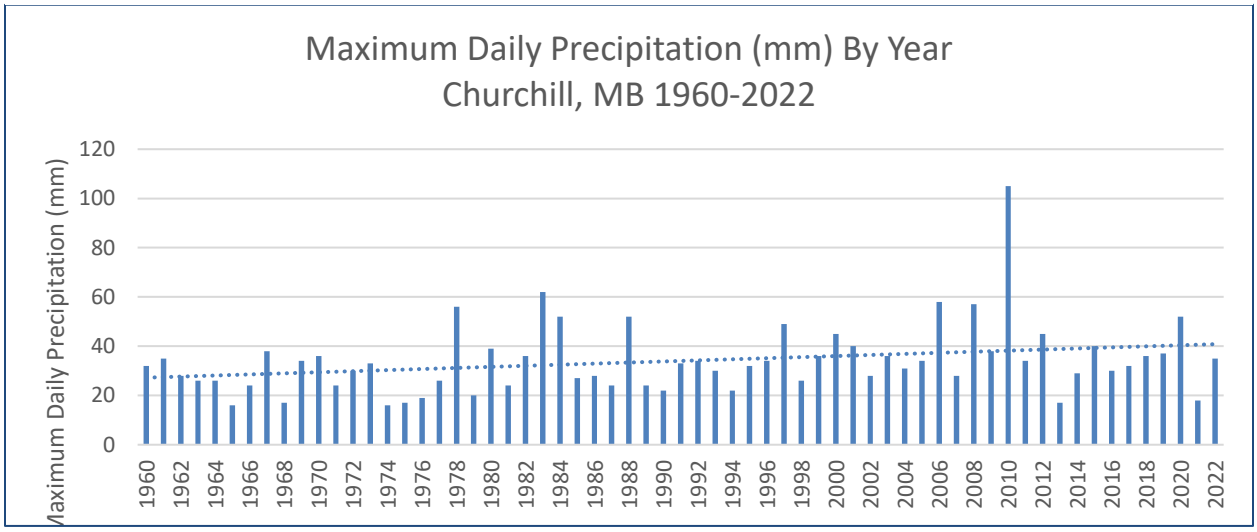


Figure 73 Frequency of Extreme Daily Precipitation Churchill, MB 1960-2022

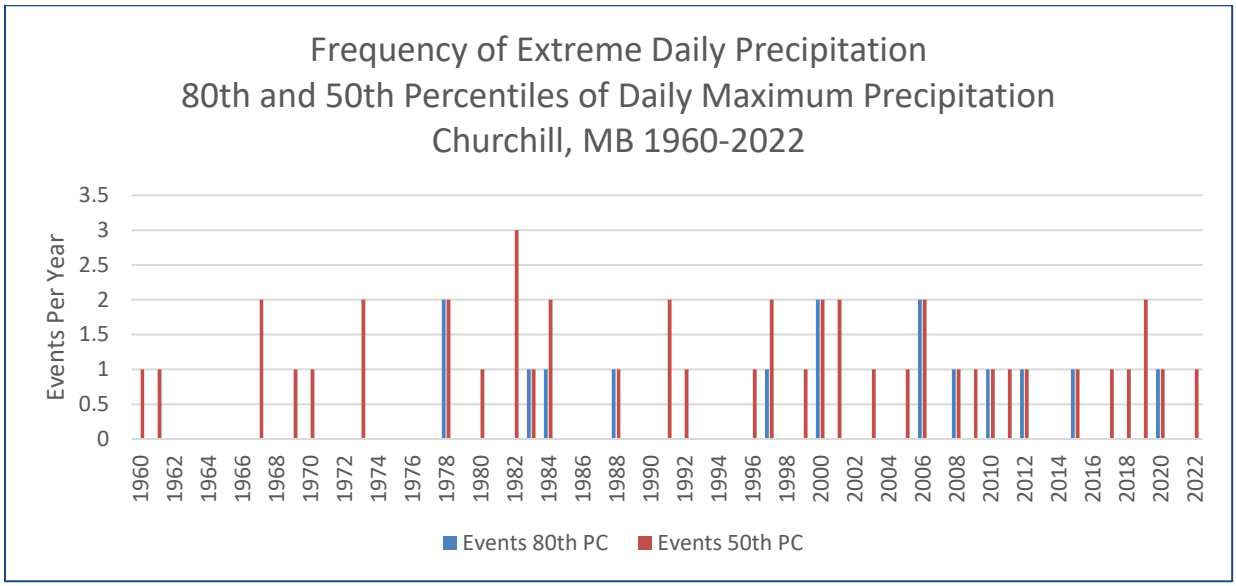


Figure 74 Maximum 2 Day Precipitation Churchill, MB 1960-2022

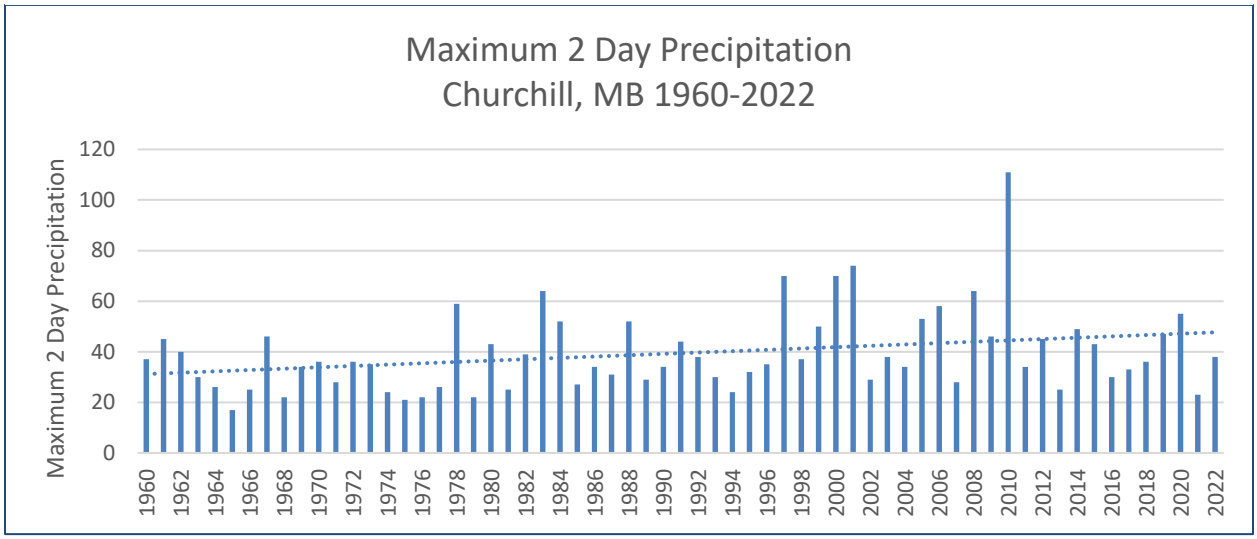
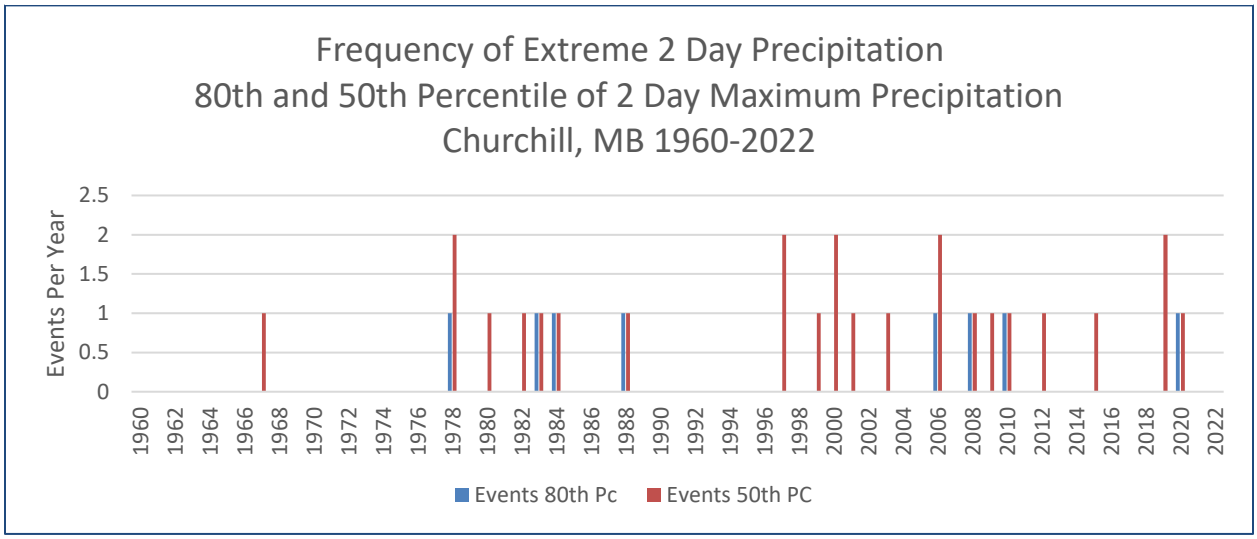


Figure 75 Frequency of Extreme 2 Day Precipitation Churchill, MB 1960-2022



k. Precipitation Analysis – Iqaluit

Figure 76 Annual Precipitation Iqaluit, NU 1960-2022

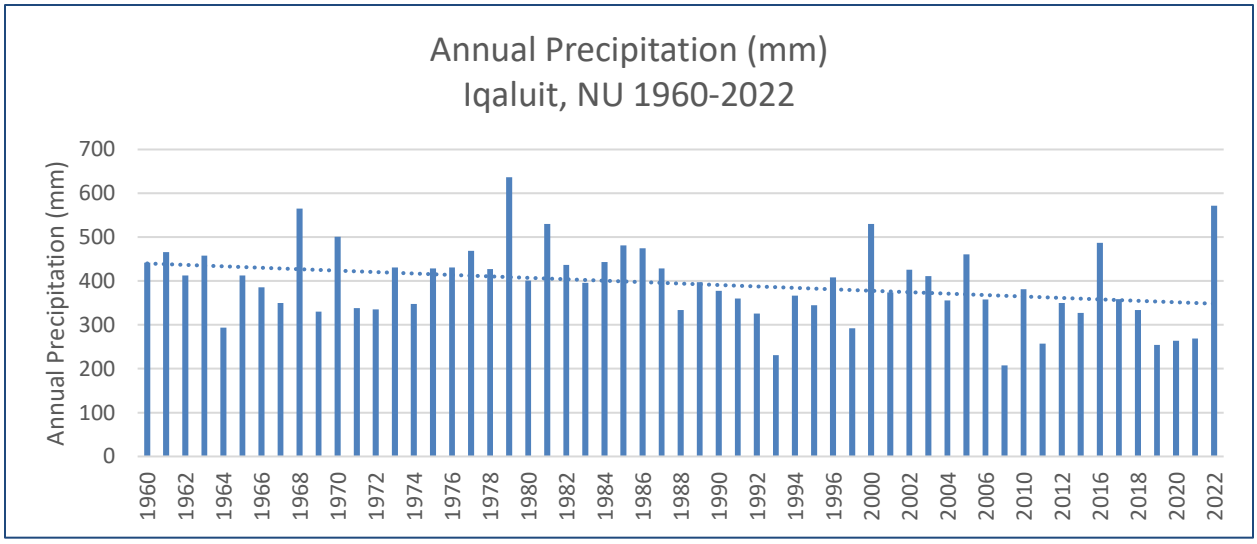


Figure 77 Maximum Daily Precipitation Iqaluit, NU 1960-2022

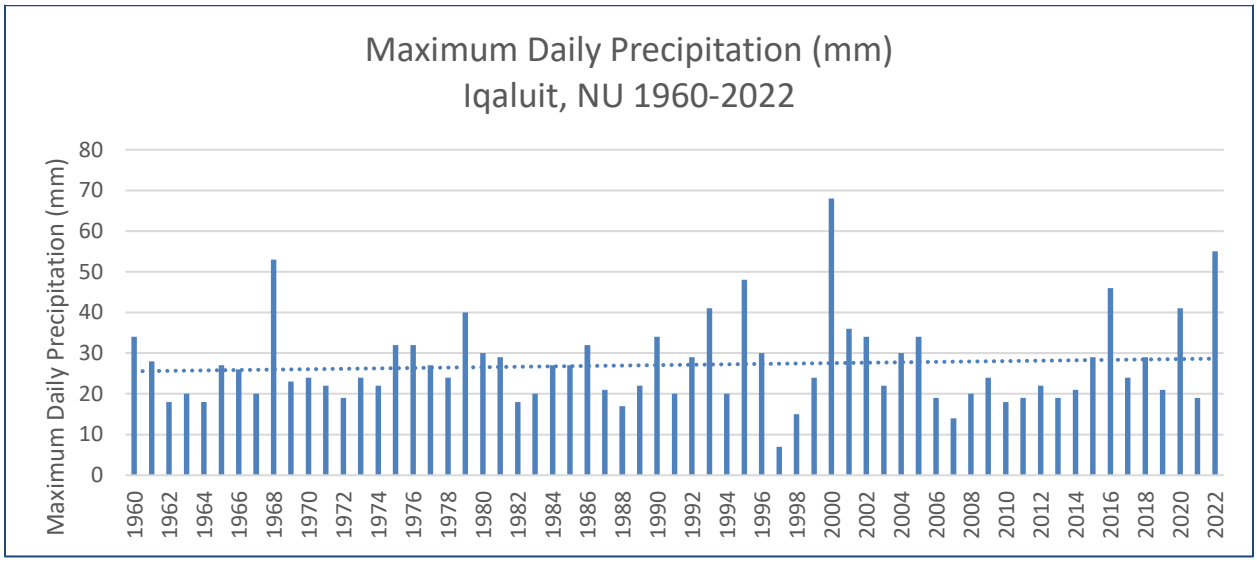


Figure 78 Frequency of Extreme Precipitation Iqaluit, NU 1960-2022

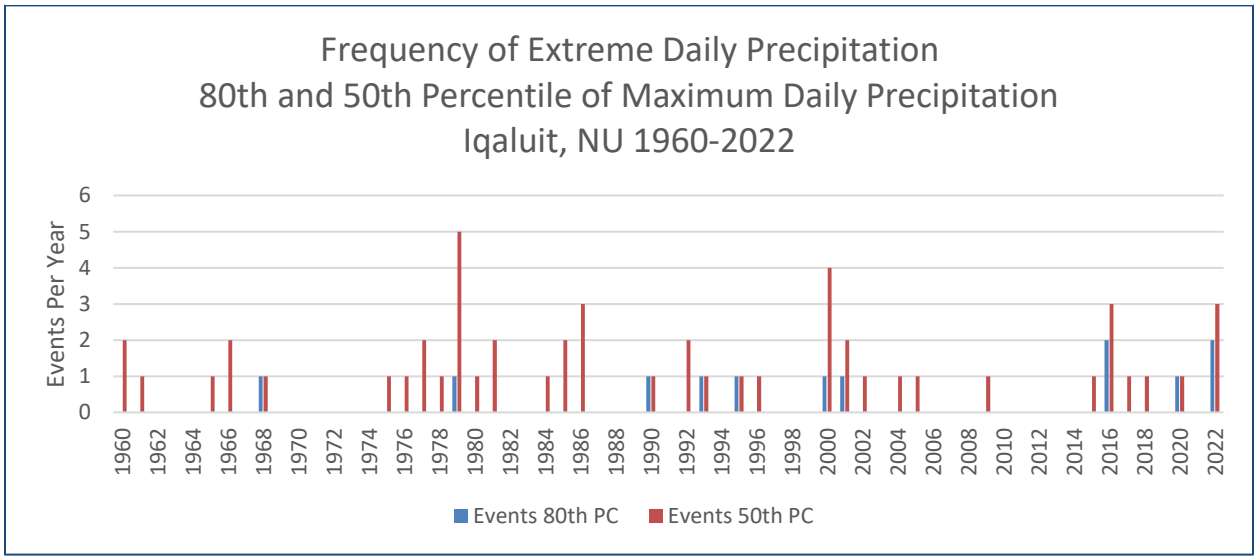


Figure 79 Maximum 2 Day Precipitation Iqaluit, NU 1960-2022

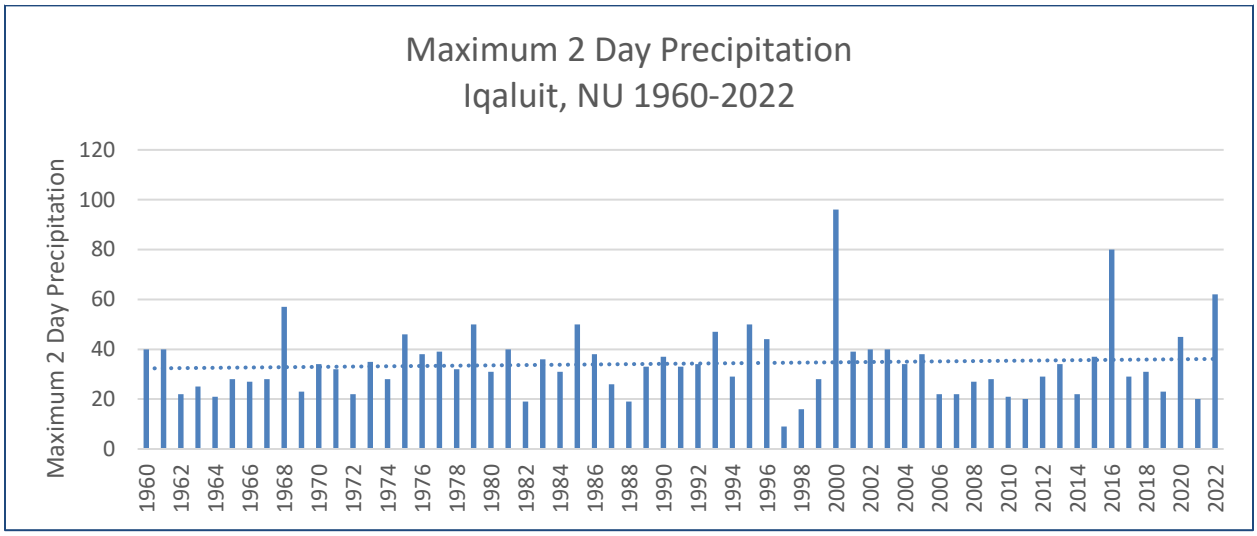
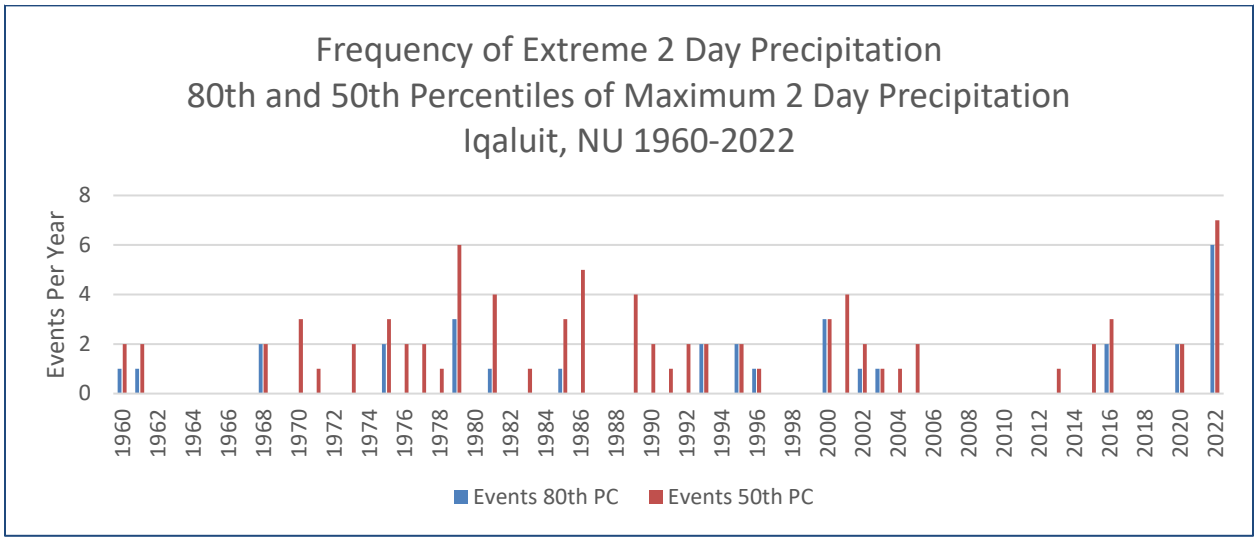


Figure 80 Frequency of Extreme 2 Day Precipitation Iqaluit, NU 1960-2022



l. Precipitation Analysis – Cambridge Bay

Figure 81 Annual Precipitation Cambridge Bay, NU 1953-2022

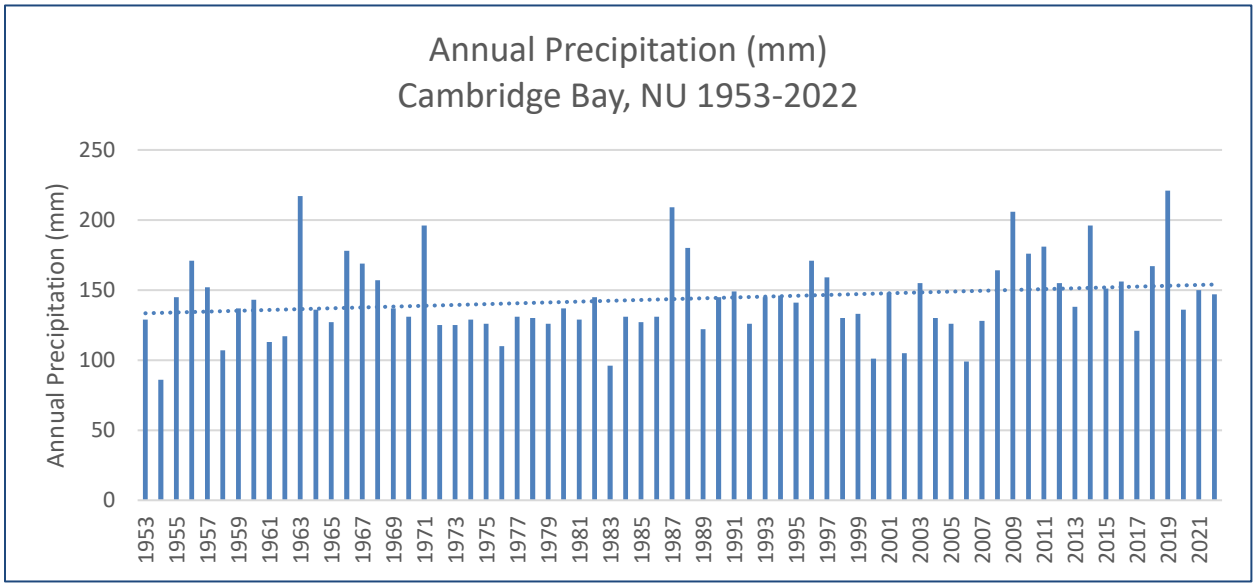


Figure 82 Maximum Daily Precipitation Cambridge Bay, NU 1953-2022

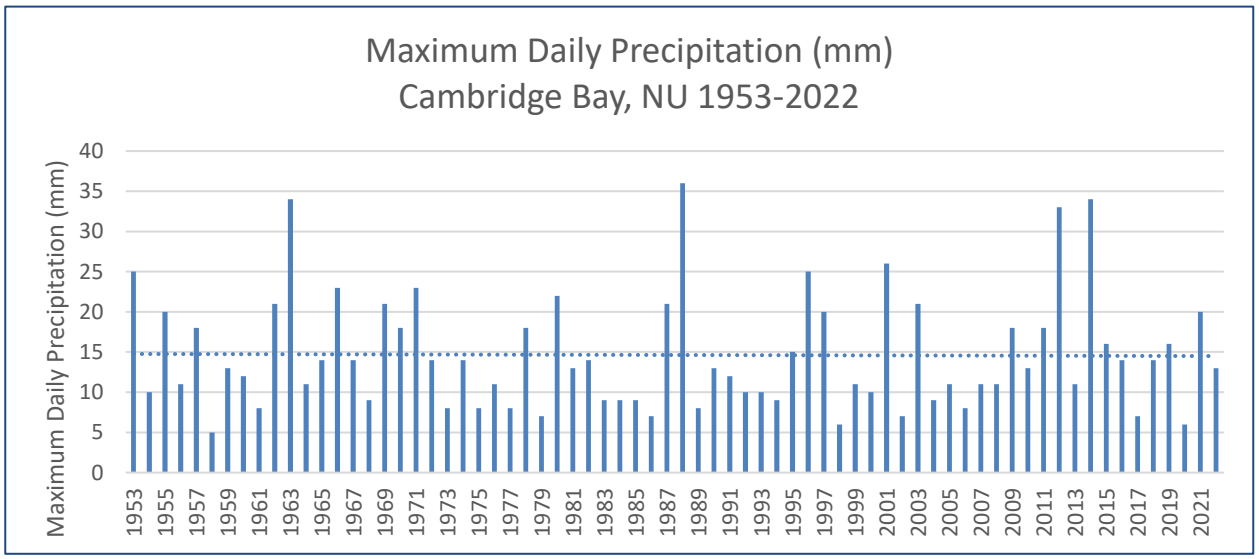


Figure 84 Frequency of Extreme Daily Precipitation Cambridge Bay, NU 1953-2022

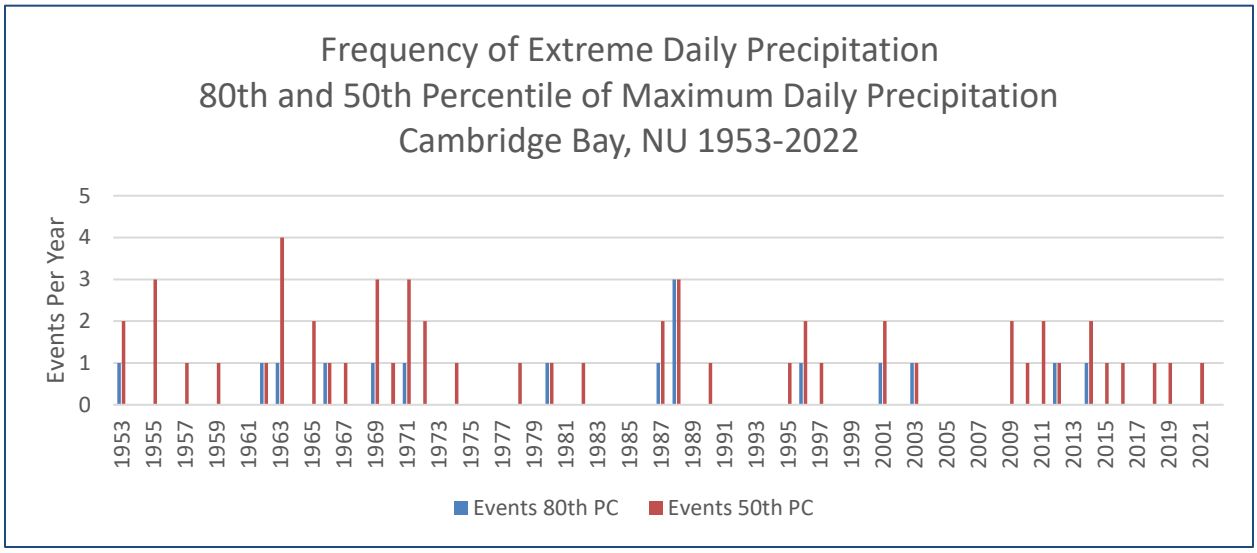


Figure 83 Maximum 2 Day Precipitation Cambridge Bay, NU 1953-2022

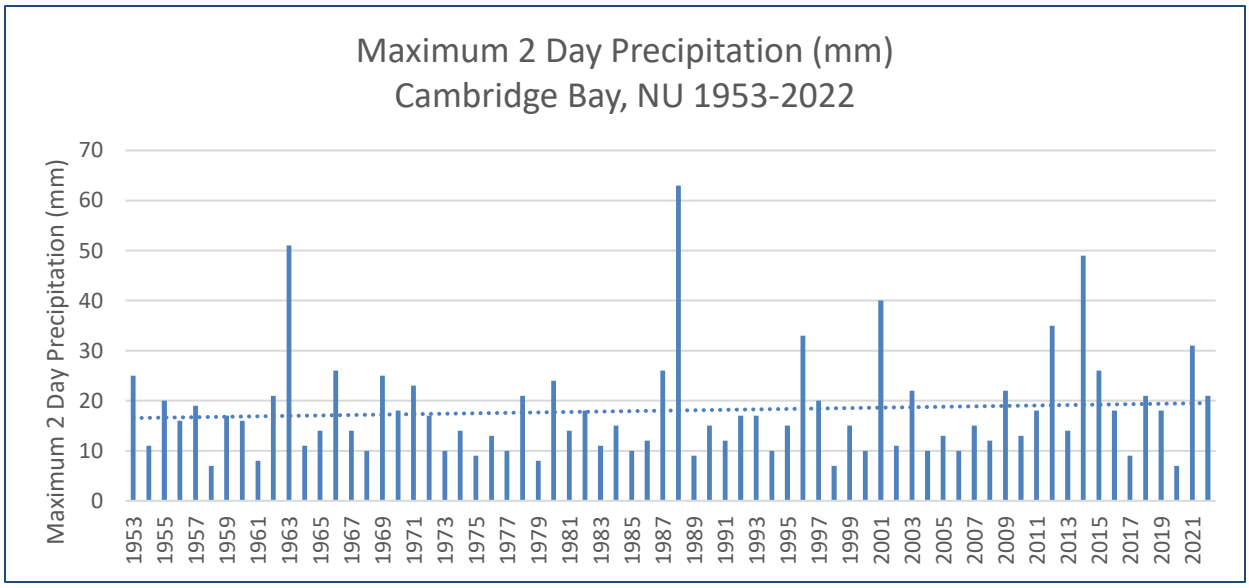
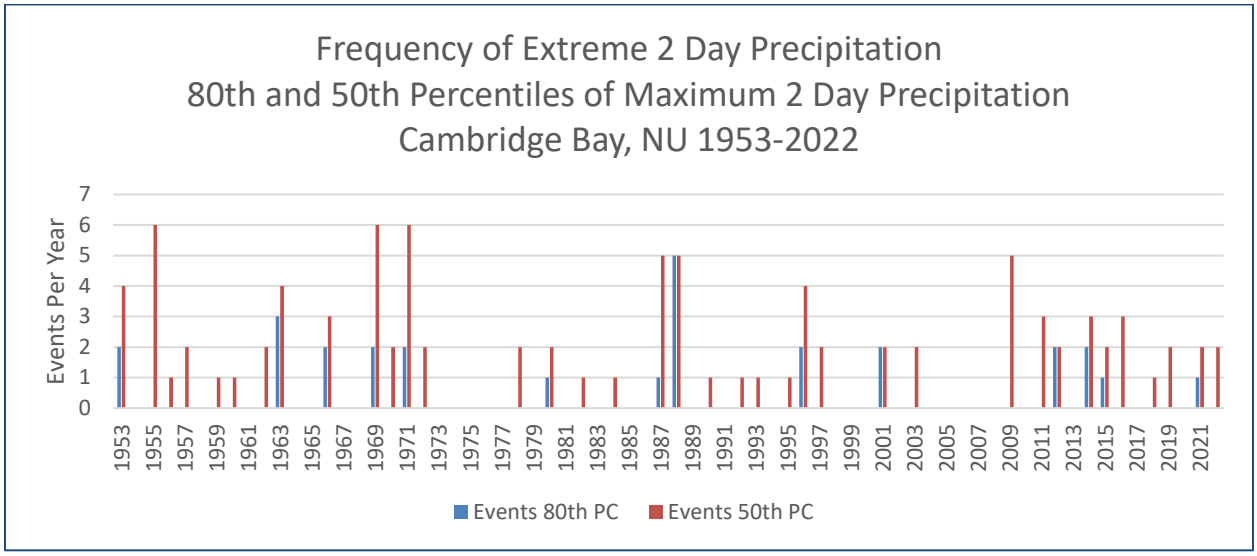


Figure 85 Frequency of Extreme 2 Day Precipitation Cambridge Bay, NU 1953-2022



Conclusions

Although an analysis of ten stations across Canada showed a significant trend towards increases in climate warming, an analysis of wind data for twelve stations across Canada did not show a significant link between climate warming and an increase in extreme events. On the contrary, the strongest and most frequent extreme winds generally occurred in decades past. That is, the overall trend was towards decreasing frequency and intensity of extreme winds. There could be an uptick at some stations in recent years, but there is insufficient data to reach any conclusions in that regard.

Extreme precipitation events show a general increase in frequency and intensity in Eastern Canada from Montreal and east, especially on the Atlantic coast. However, there appears to be a decline in the frequency of extreme precipitation events in Western Canada and the Arctic, with little change elsewhere.

While the climate warming appears to be accelerating, there is no similar trend evident in an analysis of extreme wind speeds and extreme precipitation at the 12 stations in Canada that were analyzed.

The Canada's Climate Change Report (2019) had similar conclusions.

"Only about 8.5% of all stations over global land areas with more than 30 years of data show an increase in extreme precipitation at the 5% significance level, which is slightly higher than the rate of stations showing and increase (5%) that could be expected from chance (Westra et al., 2013). …On the regional scale, there is much less information, which is the case for Canada, where long term observations are very limited, and detection becomes more difficult."[5]

It could be that extreme wind and precipitation events are local in scale, such as the flooding in Abbotsford, or the extreme winds associated with Hurricane Fiona. Extremes of wind and precipitation may also be more regionally oriented; that is, some regions of Canada may have more extremes and other regions less. If that is the case, then a much finer scale analysis would be required. In the meantime, the trend towards more extreme weather still requires validation.

Notwithstanding these conclusions, the recent study on groundwater from satellite data referred to in the background does show an increase in extreme precipitation where it would impact groundwater. It may be necessary to examine remote-sensed precipitation data to identify extreme episodes, much like research on tornadoes now considers satellite data over more remote areas rather than simply depending upon human observations.

[5] CCCR 2019, p169.