St. John's Climate Profile

(2020)

Summary

Historical Observations

The City of St. John's has seen an increase in average **temperatures** of approximately +0.8 °C since 1942. The warming has been an increased tendency to break high temperature records (warmest parts of the day became much warmer), and a relatively smaller shift in our low temperatures (coldest parts of the day became a little warmer). Similarly, the **hottest temperatures** in the year have increased by approximately 1.0 °C, while the **coldest temperatures** in each year have increased by 0.5 °C. St. John's may have seen a very slight decreasing trend in the number of days per year that experience **freeze-thaw** since 1950.

Precipitation (rainfall and snowfall) trends show that St. John's may have seen a very small reduction in the amount of precipitation every year since 1942. However, the intensity and duration of **storms** is likely to have increased since 1949 (particularly with durations over 30 minutes). Observations show slightly more precipitation falls as **rain or freezing rain**, with about 23-24% of average yearly precipitation falling as **snow**. Consistent with this shift, data shows that it is possible that the total annual **snowfal**l in St. John's may have decreased slightly since 1942. Satellite imagery suggests that Eastern Canada has seen a decrease in **snow cover** (-5% to -10%) duration in the months between October-January since 1981. Data for annual **maximum snow on the ground** shows no significant change, however, it is possible that there has been an increase of 4 cm over the last 66 years.

St. John's coast has seen a long-term trend of rising **sea levels**, with relative sea-level changing by +1.9mm/year since the 1940's. Observations show a warming in the **sea surface temperature** of 0.13 °C per decade (at the ocean surface), and a warming of 0.02 °C per decade was observed below the surface (0-175m).

The analysis of St. John's observed **wind** speeds shows a possible decrease in hourly wind speeds. However, St. John's is in the region with the most frequent **wind gusts** in the country and data shows that it experiences approximately 1,424 hours per year with wind gusts above or equal to 40 km/hr, 151 hours above or equal to 70 km/hr, and 24 hours with winds above or equal to 90 km/hr.

Projections

Climate models (under scenarios RCP 8.5 and RCP4.5) estimate that St. John's will continue to see increases in **temperatures**, both average daily temperatures as well as extreme temperatures (+2.8 by 2050s, +4.8 by 2080s). Extreme maximum temperatures are projected to increase (+1.5 by 2050s, +2.4-3.5 by 2080s) and minimum temperatures are also projected to increase (+2.5-2.8 by 2050s, +4.0-5.8 by 2080s). Along with these changes, the number of days with **frost** and/or **freeze-thaw cycles** per year are projected to decrease.

The amount of **precipitation** is projected to increase overall (+7% by 2050s, +9% by 2080s). However, this is not uniform across seasons and does not speak to all storm sizes. For example, winter is expected to see less precipitation but events with greater intensity. St. John's is projected to see a decrease in the percentage of precipitation that is **snowfall**, this means it is likely that more winter precipitation will be **freezing rain or rain**. Consequently, **snow cover** and **maximum snow on the ground** are projected to decrease. Most **storm** events are projected to increase in frequency and intensity, specifically events with durations over 30 minutes.

The rise in **sea level** is projected to continue, reaching 75 to 100 cm by the year 2100. The **sea surface temperatures** are projected to see further warming, resulting in further reductions in **sea ice cover**. There is significant uncertainty around projections of wind. However, existing research suggests that St. John's will see an increase in **wind** speeds and **wind gusts**, particularly in winter.

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Introduction to the Climate Profile

In municipal operations, decisions often require consideration of climate and/or weather conditions. These decisions often influence best management of natural resources and essential operations (e.g., water, snow clearing, land use planning, infrastructure design). Information about current or approached weather conditions is often necessary for operational decision-making over periods of hours to a week, and may include monitoring/anticipating changes in temperature, precipitation and wind (among other factors).

When weather data covering longer periods (e.g. decades) is examined collectively, it provides important information about the climate of our municipality and guidance for long-term planning. For example, by looking at many years of weather data we can see how prone the region is to a variety of environmental hazards including storms, heat waves, or cold spells. This information also can be analyzed to try to understand climate trends, like whether our municipality is getting warmer or cooler, drier or wetter over long periods of time. This information, combined with information about impacts (e.g., flooding, insurance claims) are key in supporting planning, especially when climate trends show changes. This report outlines how the City of St. John's can expect climate change to materialize.

What are Climate Trends and Climate Change?

Climate change is a term used to describe various changes in long-term weather patterns (for example the difference in the general weather conditions experienced in the mid-20th century and the early 21st century). Discussion of climate change often begins with a look at temperature, which has (as a global average) been rising noticeably over recent decades. Consequently, 'climate change' is often referred to as 'global warming'. Since the 1880s, the average global mean surface temperature has risen by a bit more than 1 degree Celsius. This is a significant change: for reference, the last Ice Age was about 5.5 degrees Celsius colder than pre-industrial temperatures. Figure 1 shows global surface temperatures relative to the average between 1951-1980.

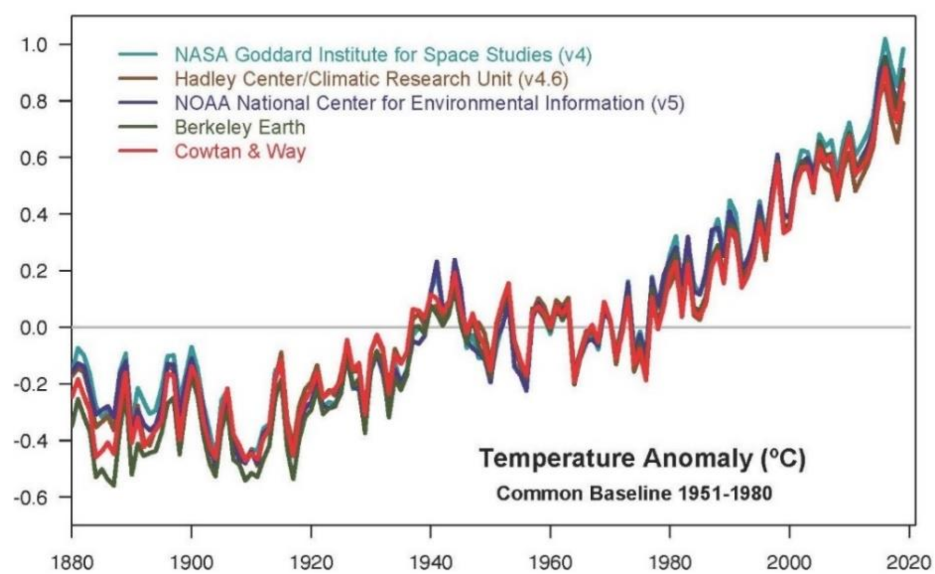

Figure 1 Global surface temperatures relative to 1951-1980 as recorded by NASA, NOAA, the Berkeley Earth research group, the Met Office Hadley Centre (UK), and the Cowtan and Way analysis. Though there are minor variations from year to year, all five temperature records show peaks and valleys in sync with each other. All show rapid warming in the past few decades, and all show the past decade has been the warmest. (Source: https://www.giss.nasa.gov/research/news/20200115/).

This does not mean that temperatures have increased to the same degree everywhere, risen consistently every year, impacted every season equally. A particular city can still see days, months, or even seasons that are colder than average, and we continue to see new record setting cold temperatures; however, this is now happening rarely, even as the number of record warm observations has increased steadily. This reflects the natural variability inherent in climate which (on local or regional scales) is often as large or larger than the influence of climate change to date.

Regardless of what is happening in a given year and particular location, collectively temperature data from across the planet confirms that the world as a whole is warming. This has in turn influenced other aspects of climate, including precipitation patterns, snow and ice cover, ocean temperatures, sea level, and more. Figure 2 shows just some of the indicators of change measured globally in recent decades that show the Earth's climate is warming. White arrows indicate increasing trends, and black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are, in fact, increasing, and all those expected to decrease in a warming world are decreasing. (Source: http://nca2014.globalchange.gov/report/our-changingclimate/observed-change#tab2-images)

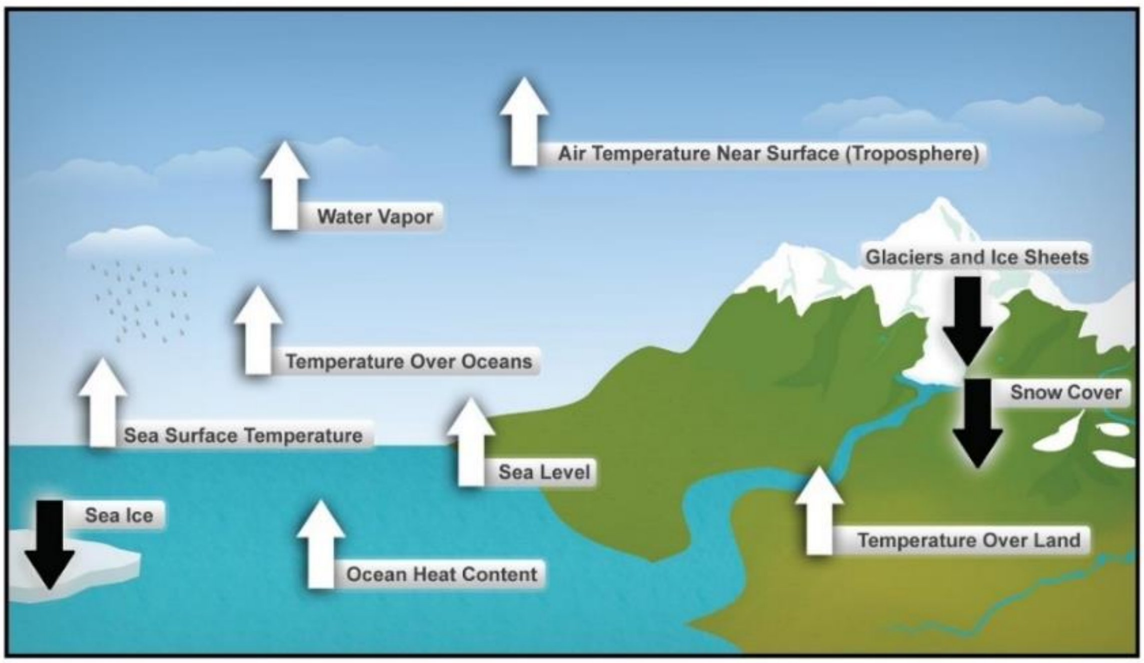

Figure 2 Observed indicators of a warming world. White arrows indicate increasing trends. Black arrows indicate decreasing trends. Source: http://nca2014.globalchange.gov/report/our-changingclimate/observed-change#tab2-images

Canada is a large country with three coasts and various climatic regions. In Canada, temperatures have been observed to increase between 1948 to 2016 (Figure 4) at a much faster rate than the global average. The North West of Canada has seen the largest change in temperature in this time period (2-3°C), and winter is changing faster than any other season (up to 5°C in some areas). Other climate change impacts are also distributed unevenly across the country and between seasons.

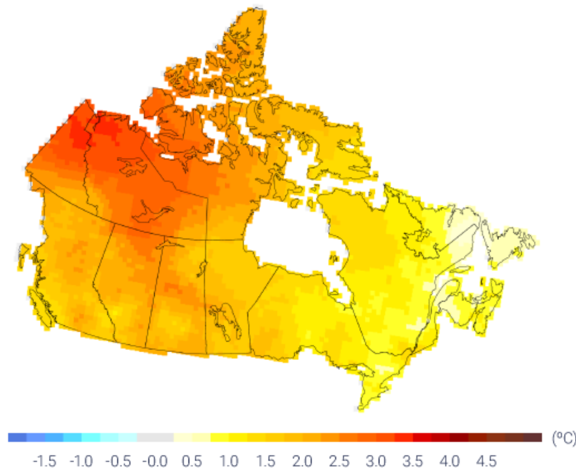

Figure 3 Observed Changes in Annual Temperatures 1948 to 2016. Atlantic Canada +0.7C (Bush and Lemmen, 2019).

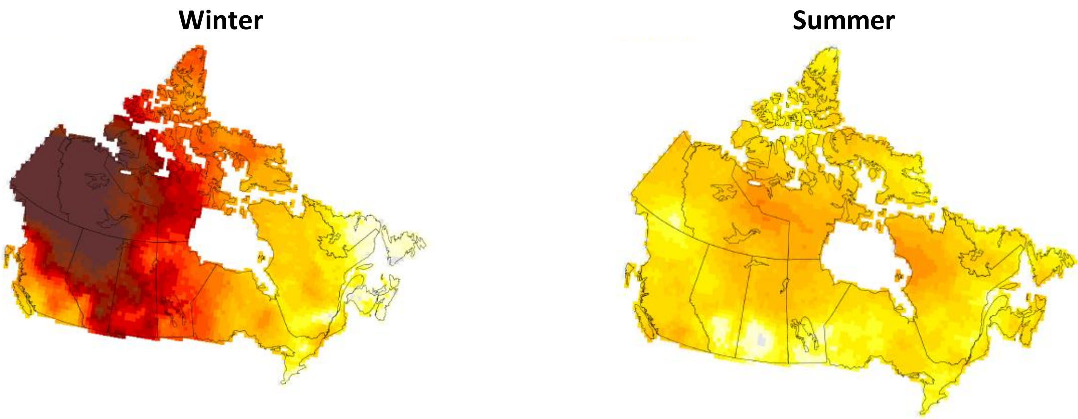

Figure 4 Observed Changes in Seasonal Temperatures 1948 to 2016. Atlantic Canada +0.7C (Bush and Lemmen, 2019).

Why is the Climate Changing?

Science academies, scientific societies, and intergovernmental bodies all agree that Climate Change is real, as well as that the role of humans in causing this is clear and mostly linked to the emissions of greenhouse gases (GHGs) from human activities (e.g., burning fossil fuel, deforestation, waste, etc). The amount of carbon dioxide (CO_2) between the atmosphere, the ocean or the land in the past 10,000 years was roughly balanced. However, since the start of the Industrial Era it has risen by 240 Pg[1]. Human activities in the last 100 years, like burning of fossil fuels and significant changes in land use, have increased CO_2 (and other GHGs) in the air. Humans have emitted 550 Pg of CO_2, therefore it can be understood nature has been a carbon sink.

The contribution from human activity has been studied through the use of isotopes (C13/C12) ratios to understand how much of the CO_2 came from combustion vs other natural processes and estimates of the reduction of oxygen in the atmosphere (which is consumed by combustion) (Bush and Lemmen, 2019). Current GHG levels are the highest in millions of years and the highest levels in human history (Our species, *Homo sapiens*, evolved around 300,000 years ago) (Figure 5). In May 2019, global levels of CO_2 reached a 3 million-year record high.

[1] Petagram: 1 petagram = 1 billion metric tonnes.

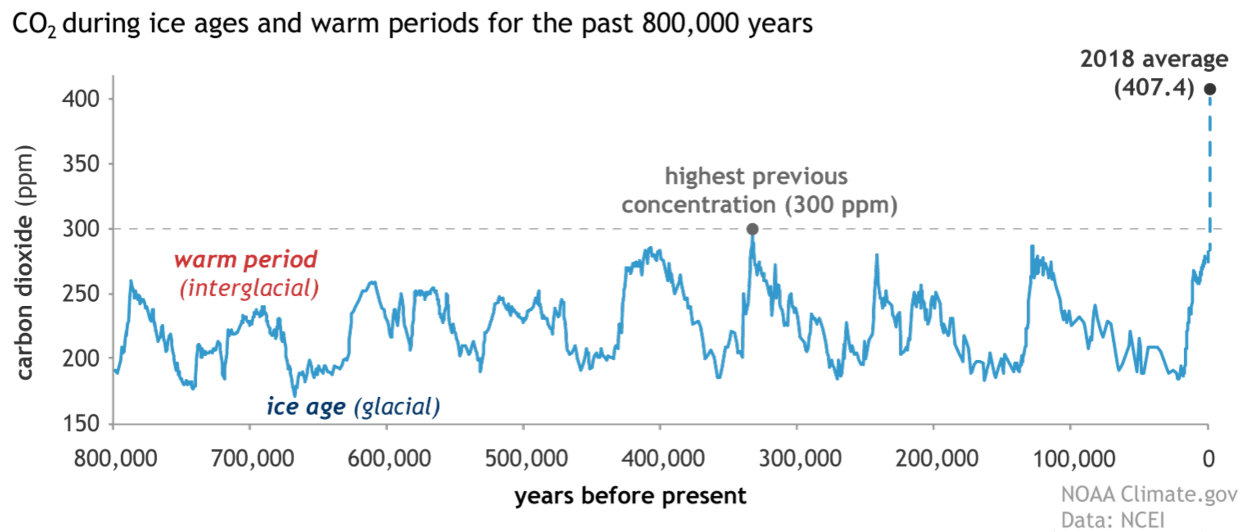

Figure 5 Atmospheric carbon dioxide concentrations in parts per million (ppm) for the past 800,000 years, based on EPICA (ice core) data. The peaks and valleys in carbon dioxide levels track the coming and going of ice ages (low carbon dioxide) and warmer interglacials (higher levels). Throughout these cycles, atmospheric carbon dioxide was never higher than 300 ppm; in 2018, it reached 407.4 ppm (black dot). Source: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.

This rise in atmospheric GHG levels, predominantly CO_2, has been the main driver of climate warming during the Industrial Era (mid-18th century to today). The ability of GHGs in the Earth's atmosphere to absorb heat energy radiated from the Earth is well understood, as are many ensuing climate impacts. This increase in GHGs limits the ability of the planet's surface to lose heat it receives from the sun. This energy circulates in our systems (air, ocean, land, ice, etc.) and we see it as increases in temperature of the air and ocean, melting of icecaps, strengthening of hurricanes, changes in flows of air (e.g., polar vortex), etc.

Measurements show that we have reached CO_2 concentrations of 400 ppm at this time. The last time the planet had these concentrations (mid-Pliocene), the Antarctic was largely ice-free, sea levels were 10 to 20 meters higher, and global temperatures were an average of 2 to 3 ^{o}C warmer[2]. In the Arctic, summer temperatures were approximately 14 degrees higher. If CO_2 continues to rise, we could reach levels unseen in over 34 million years.

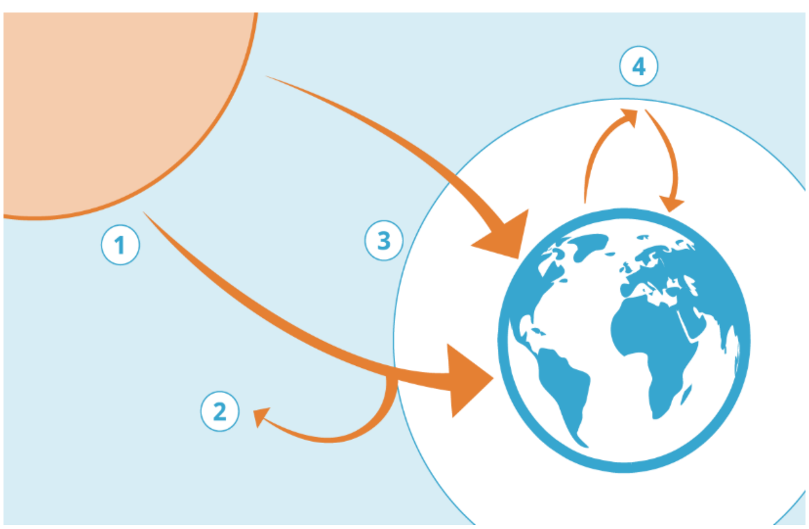

Figure 6 The Greenhouse Gas Effect. 1) Solar energy from the sun passes through the Earth's atmosphere; 2) Some energy is reflected back into space; 3) The surface of the Earth is heated by the sun and radiates the heat back into space; 4) Greenhouse gases in the atmosphere trap some of the heat, warming the Earth. Source: https://www.turnbackthetide.ca/about-climate-change-and-energy-efficiency/what-is-climate-change.shtml.

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[2] https://e360.yale.edu/features/how-the-world-passed-a-carbon-threshold-400ppm-and-why-it-matters

Other factors, beyond increases in CO_2, that contribute to changes in climate in smaller amounts are:

- Sun brightness variation during the Industrial Era (10x smaller than human emissions effect).
- Volcanic eruptions (Cooling effect that can last several years but cannot explain the observed long-term change in global temperature).

Increasing concentrations of GHGs will not only impact climate change, but also presents adverse effects on physical and mental health due to hazards that accompany extreme weather events, heatwaves, lower ambient air quality, and increasing range of vector-borne pathogens[3]. Not all regions of the world are affected in the same way, and the scientific community studies these changes to help communities understand what can be expected for the near, medium, and long-term future.

The Irreversibility of Climate Change

Earth system model simulations of the response to CO_2 emissions show that surface temperatures remain approximately constant for many centuries following a hypothetical stop of emissions. Vegetation, ice sheet volume, deep ocean temperature, ocean acidity, and sea level are projected to change for centuries after stabilization of surface temperatures (NRCAN, 2017).

Climate Change Adaptation Planning

The climate change adaptation planning process has been taken up by municipalities across Canada to anticipate and adjust to new or changing environments in ways that take advantage of the beneficial opportunities and reduce negative effects. This process is similar to other resource management planning processes and generally include:

- Identifying past and future trends
- Identifying risks and vulnerabilities
- Assessing and selecting options
- Implementing strategies
- Monitoring and evaluating the outcomes of each strategy
- Revising strategies and the plan in response to evaluation outcomes

The steps in adaptation planning processes are being undertaken by the City of St. John's as part of its Sustainability Planning framework and as part of the commitment to the Global Covenant of Mayors for Climate and Energy.

Confidence Indicators

There are various levels of confidence in the past and future trends in our region. In part this is due to the length of the record, the method of collecting data, or generally the research to date in the particular hazard. To ensure there is a level of transparency we have assigned a confidence indicator to the trends presented under each section. You will see these in the report to help guide you in the level of confidence you can place on the trends shown.

[3] https://www.who.int/news-room/facts-in-pictures/detail/health-and-climate-change; https://www.cpha.ca/climate-change-and-human-health

St. John’s Historical Climate

The instrumental record from an Environment & Climate Change Canada climate station operating at St. John’s International Airport (YYT) was used for this analysis. Climatologists refer to the period from 1895 to the present as the “instrumental record” period. The earliest instrumental record at this site dates back to 1942. The St. John’s station 8403500 and 8403501 cover a record between 1874 and 1975, however, these datasets have significant gaps in measurements and data quality. So, for the purpose of illustrating recent climate trends, this report will focus the analysis on the YYT station.

Temperature

The City of St. John’s has observed an increase in average temperatures of approximately +0.7 to +0.8 °C since 1942. This is in line with what other Atlantic provinces have experienced in a similar time period (1948-2006) (Bush and Lemmen, 2019). Rather than looking at simple daily average, temperatures have been assessed in terms of the i) average daily maximum, ii) average daily minimum, and iii) overall daily average; this can be useful in identifying the character of any trends experienced, and potentially highlight important patterns.

- **Maximum annual average** is the average of all the warmest daily temperatures.
- **Minimum annual average** is the average of the lowest temperature readings each day of the year.
- The **overall average** is the average of both maximum and minimum temperatures for the location.

Results for the YYT station daily maximum, minimum and mean are shown in Figure 7, and emphasize that maximum temperatures have been rising faster than minimum temperatures. This pattern suggests the warming trend is best summarized by an increased tendency to break high temperature records (warmest parts of the day became much warmer), but a relatively small shift in our low temperatures (coldest parts of the day became a little warmer).

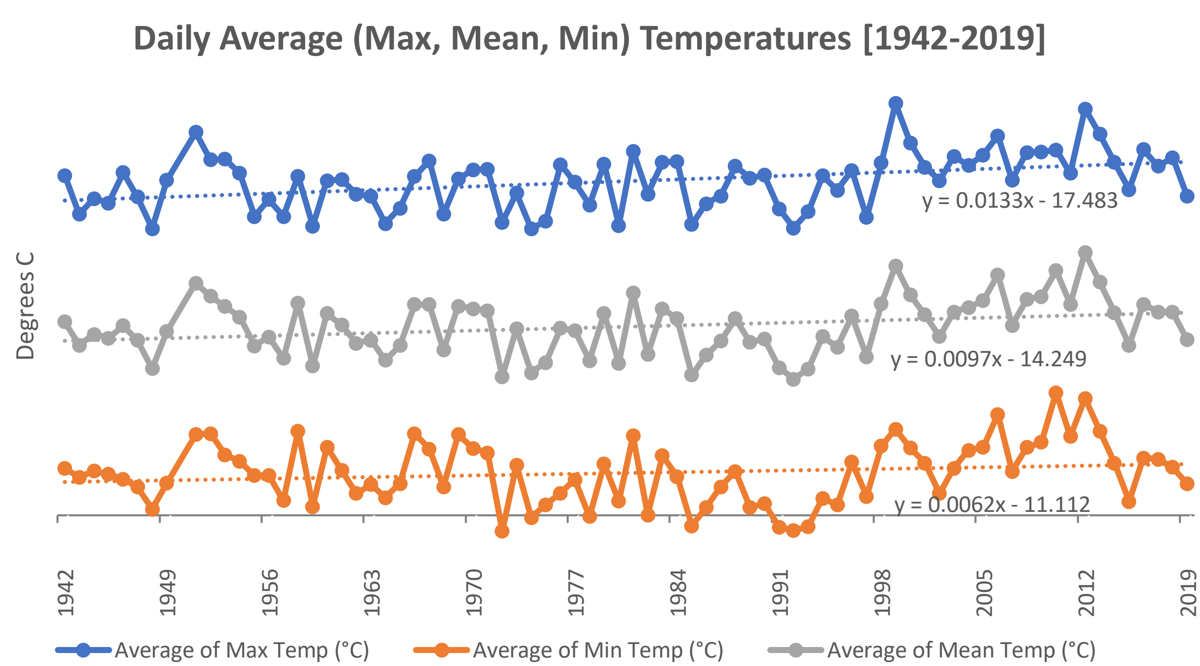

Figure 7 Changes to average, minimum, and maximum temperatures at the St. John’s International Airport Station.

Table 1 Estimated changes in yearly average, minimum and maximum temperatures at St. John's Int. Airport (1942-2019).

Change in Average Maximum Temperatures	Approx. +1.0 °C
Change in Average Temperatures	Approx. +0.8 °C
Change in Average Minimum Temperatures	Approx. +0.5 °C

The previous section tells us a lot about the "average day", however, we are also interested in how the extreme temperatures in the year (coldest and hottest days of each year) have changed over time. This is important since these days pose different hazards than seasonal or gradual changes. The change in the most extreme temperatures can be examined by looking at yearly maximum records (highest temperature recorded in the year) and minimum (lowest temperature recorded in the year) temperatures. These extreme temperatures have changed more significantly, and the greatest change is in the year's coldest temperature, which has increased by about 2.3 °C, while the highest temperature in the year has increased by approximately 1.0 °C.

Table 2 Estimated changes in yearly average, minimum and maximum temperatures at St. John's Int. Airport (1942-2019).

Change in Extreme Minimum Temperature	Approx. +2.3 °C
Change in Extreme Maximum Temperature	Approx. +1.0 °C

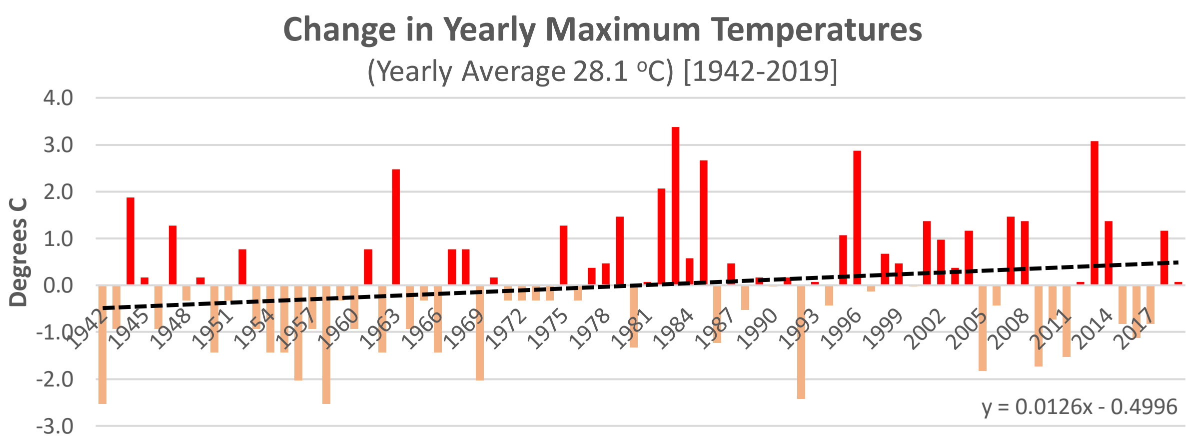

Figure 8 Estimated change in yearly maximum temperatures at St. John's International Airport. Orange years are below average, while Red years are warmer than average.

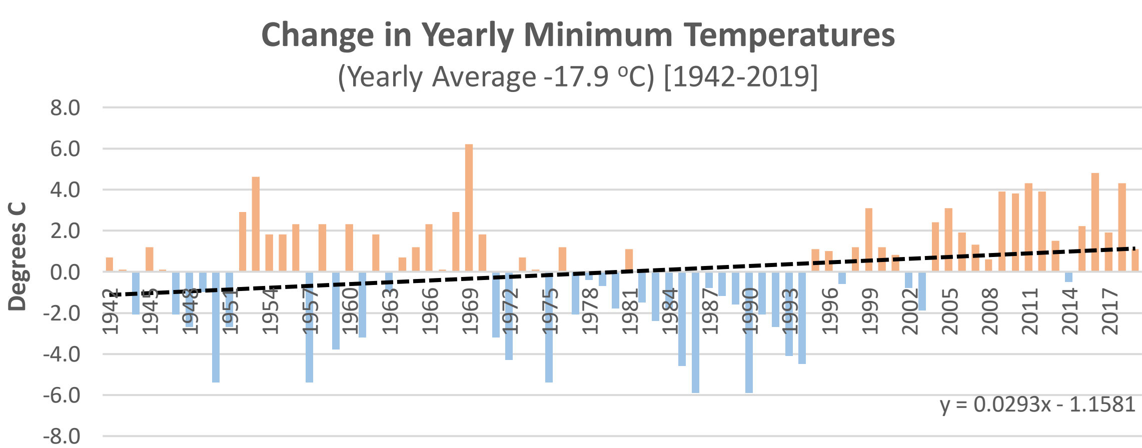

Figure 9 Estimated change in yearly minimum temperatures at St. John's International Airport. Blue years are below average, while Orange years are warmer than average.

We looked at how many days per year exceeded a comfortable heat threshold of 25 °C. While there are warmer temperatures in other parts of Canada, we chose to rely on a threshold suggested by St. John's residents as these thresholds often pose hazards to vulnerable populations. Since 1942, St. John's has seen an increase of 8.5 days per year above 25 °C.

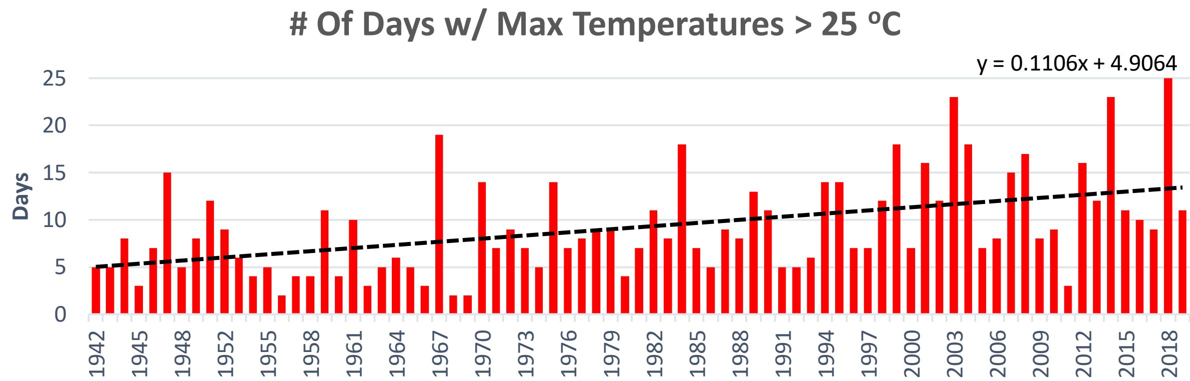

Figure 10 Yearly number of days with maximum temperatures greater than 25 C.

Similarly, we looked at cold temperatures. This was done by looking at the number of days with temperatures below -15 °C. Since 1942, St. John's has seen a small decrease (about 1 day per year) in the number of days below -15 °C.

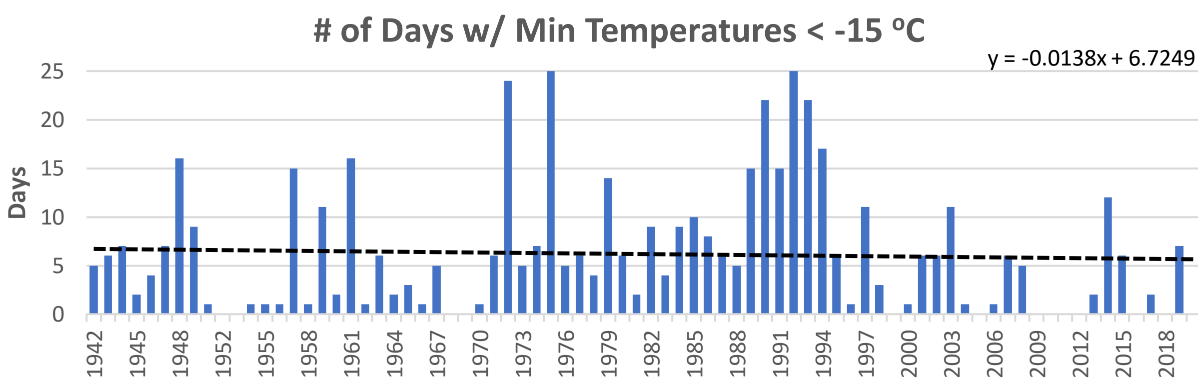

Figure 11 Yearly number of days with minimum temperatures lower than -15 C.

Natural Variability

St. John's temperatures are heavily influenced by its proximity to open ocean, particularly during the winter (Banfield and Jacobs, 1998). Finnis and Bell (2015) found that our region is heavily influenced by decadal-scale variability (a change every approximately 10-years). This natural variability comes mostly from synoptic systems like North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO), to a lesser extent for St. John's the El Nino- Southern Oscillation (ENSO).

This explains the unusually cool conditions from the 1980s through the late 1990s, and then a shift to warmer conditions in the late 1990s to approximately 2011 seen in the temperature data. When the influence of these systems is removed (Finnis and Bell, 2015), the yearly overall change is reduced somewhat. However, a sign of overall warming is still evident, and the temperature increases in winter and spring are more pronounced. These results showed that after accounting for natural variability within the observations, climate change in the region has been obscured by other shorter-term natural variability in this region for some periods of time. However, it is clear that it has impacted the climate of the region.

A freeze-Thaw cycle is a simple way to count the days per year when the air temperatures cross the freezing point ($0^{o}C$) at some point (coldest temperature in the day is lower or equal to $0^{o}C$, and the hottest part of the day is above $0^{o}C$). St. John's sees approximately 86.8 freeze-thaw cycles in an average year. These temperature cycles, along with the precipitation and snowmelt, have a significant impact on infrastructure. The impact comes from the fact that water expands when frozen and can cause damage to roads and sidewalks, as well as other infrastructure. The number of cycles may have decreased slightly since 1950, by about 2.5 days.

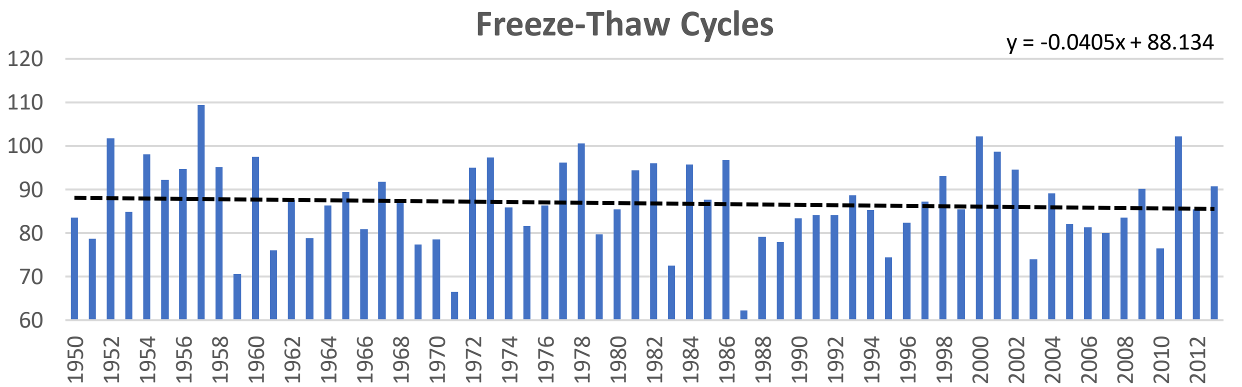

Figure 12 Freeze-Thaw Cycles in St. John's based on historical data from Natural Resources Canada (1950-2013) (NRCan; McKenney et al., 2011).

Precipitation

Precipitation data from YYT show that St. John's may have seen a reduction in the amount of average yearly precipitation of about -58 mm (between 1942 and 2019). However, this doesn't speak to the frequency and intensity of storm events. Precipitation includes both rainfall and snowfall during the year (January to December).

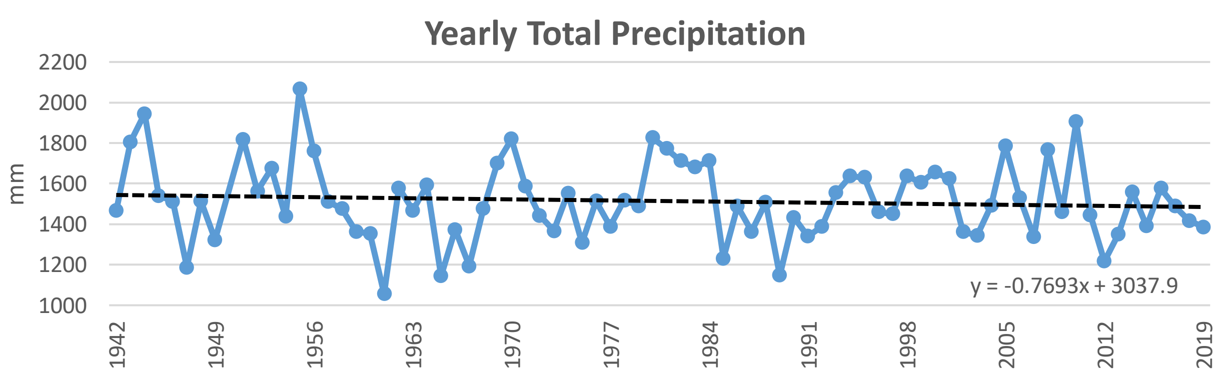

Figure 13 Yearly total precipitation from 1942 to 2019 at St. John's International Airport.

Environment and Climate Change Canada (ECCC) analyzed the rainfall storm events at YYT from 1949-1996[4]. This analysis shows that most storm events have increased in intensity and frequency. Later, the province of Newfoundland and Labrador commissioned a study that incorporated more recent data from YYT (1949-2014)[5]. This study found trends consistent with ECCC YYT estimates. Subsequently, the Rennies River Catchment Stormwater Management Plan[6] incorporated data from Windsor Lake rain gauge, which brought better estimates of rainfall for Tropical Storm Chantal and Hurricane Igor into the analysis. The estimates found consistent trends with previous studies, which showed an increase in the

[4] https://climate.weather.gc.ca/prods_servs/engineering_e.html
[5] https://www.exec.gov.nl.ca/exec/occ/climate-data/index.html
[6] http://www.stjohns.ca/publications/rennies-river-catchment-stormwater-management-plan

intensity and frequency of storms with durations over 30 minutes (e.g., 30 min, 1 hr, 2 hr, 6 hr, 12 hr, 24 hr).

Table 3 Summary of Observed Trends for Storm Events at YYT.

Duration	Estimated Trend[7]
5m	Small Decrease
10m	Small Increase
15m	Increase
30m	Increase
1hr	Significant Increase*
2hr	Significant Increase*
6hr	Significant Increase*
12hr	Increase
24hr	Increase

*indicates statistically significant trends

Yearly total snowfall (Jan-Dec) has been observed to decrease slightly. Observations show slightly more precipitation falls as rain or freezing rain, with about 23-24% of average yearly precipitation falling as snow.

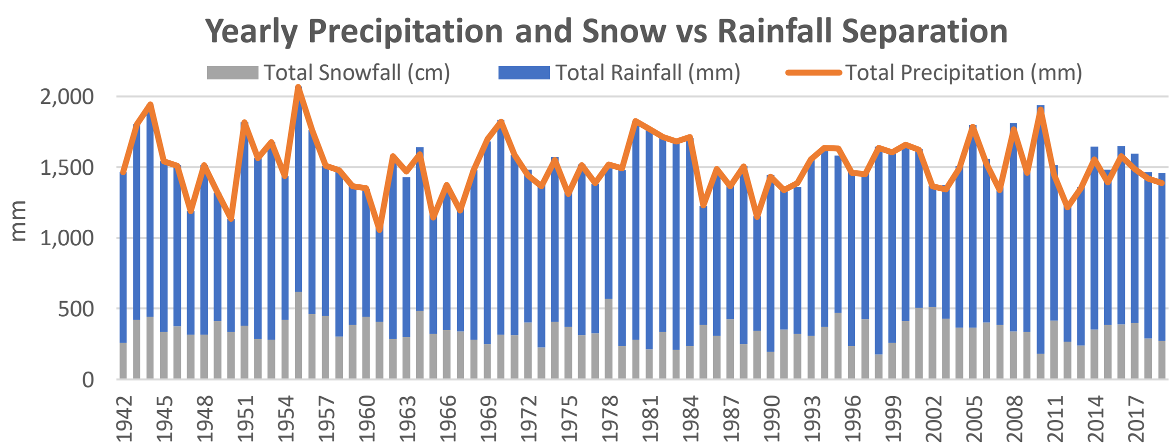

Figure 14 Yearly total precipitation from 1942 to 2019 at St. John's International Airport. Bar graph shows which portion fell as rainfall vs snowfall.

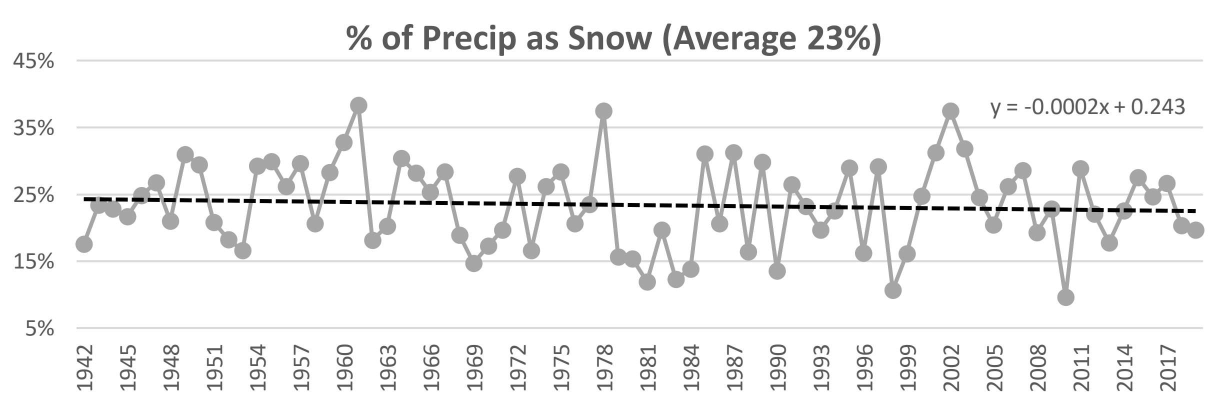

Figure 15 Percentage of precipitation falling as snow at St. John's International Airport (1942-2019).

[7] https://www.exec.gov.nl.ca/exec/occ/climate-data/index.html

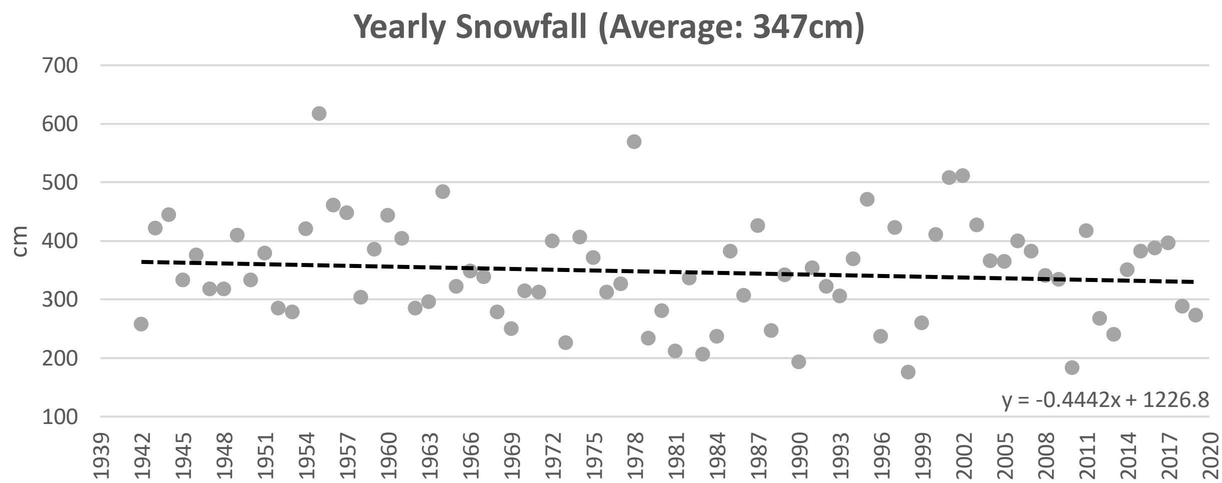

Figure 16 Yearly snowfall at St. John's International Airport (1942-2019).

Satellite imagery suggests that Eastern Canada and St. John's has seen a decrease in snow cover of approximately 5% to 10% in the months between October-January between 1981-2015 (Bush and Lemmen, 2019). To provide an idea of the changes in the depth of snow cover, YYT station provides observations of daily maximum snow on the ground. The available data (1954-present) shows a nearly flat trend, with a possible increase of 4 cm over the last 66 years. However, this is heavily influenced by both snowfall trends and temperatures, among other things. A 10-year average of the maximum snow on the ground better shows the fluctuations of cold and warm periods.

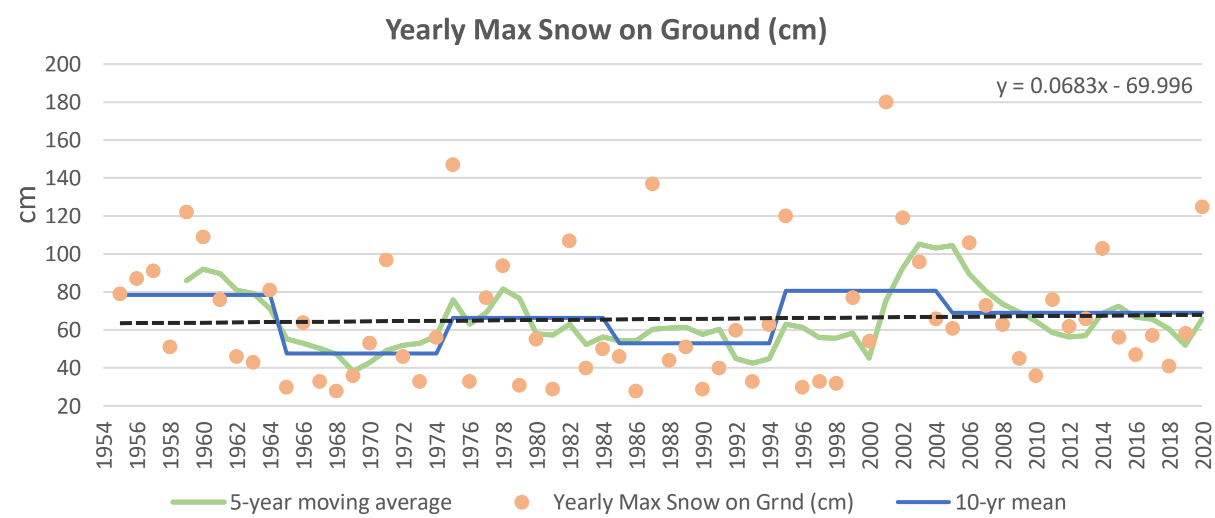

Figure 17 Maximum snow on the ground at St. John's International Airport (1998- February 2020).

Not all precipitation in St. John's falls as rainfall or snowfall. Cheng et al., 2011 studied freezing rain in Canada. The results showed that St. John's is in the region that experiences the most days with freezing rain for the three durations that were studied. St. John's experiences over 12.5 days per year (within November-April) experiencing freezing rain for 1 hour or longer.

Table 4 Regional seasonal mean number of days with freezing rain from November to April (Cheng et al., 2011).

Duration	**≥1h**	**≥4h**	**≥6h**
Number of Days per year	12.5	3.5	1.7

Sea Level and Temperature

Relative sea level has been observed to rise over the past century in much of Canada, if at significantly different rates in different regions; these differences are due to the combination of sea level rise with local changes in the land surface (e.g. local uplift or subsidence). St. John's is in an area where the land is subsiding, and it has seen a long-term trend of relative sea-level changing by +1.9mm/year since the 1940's.

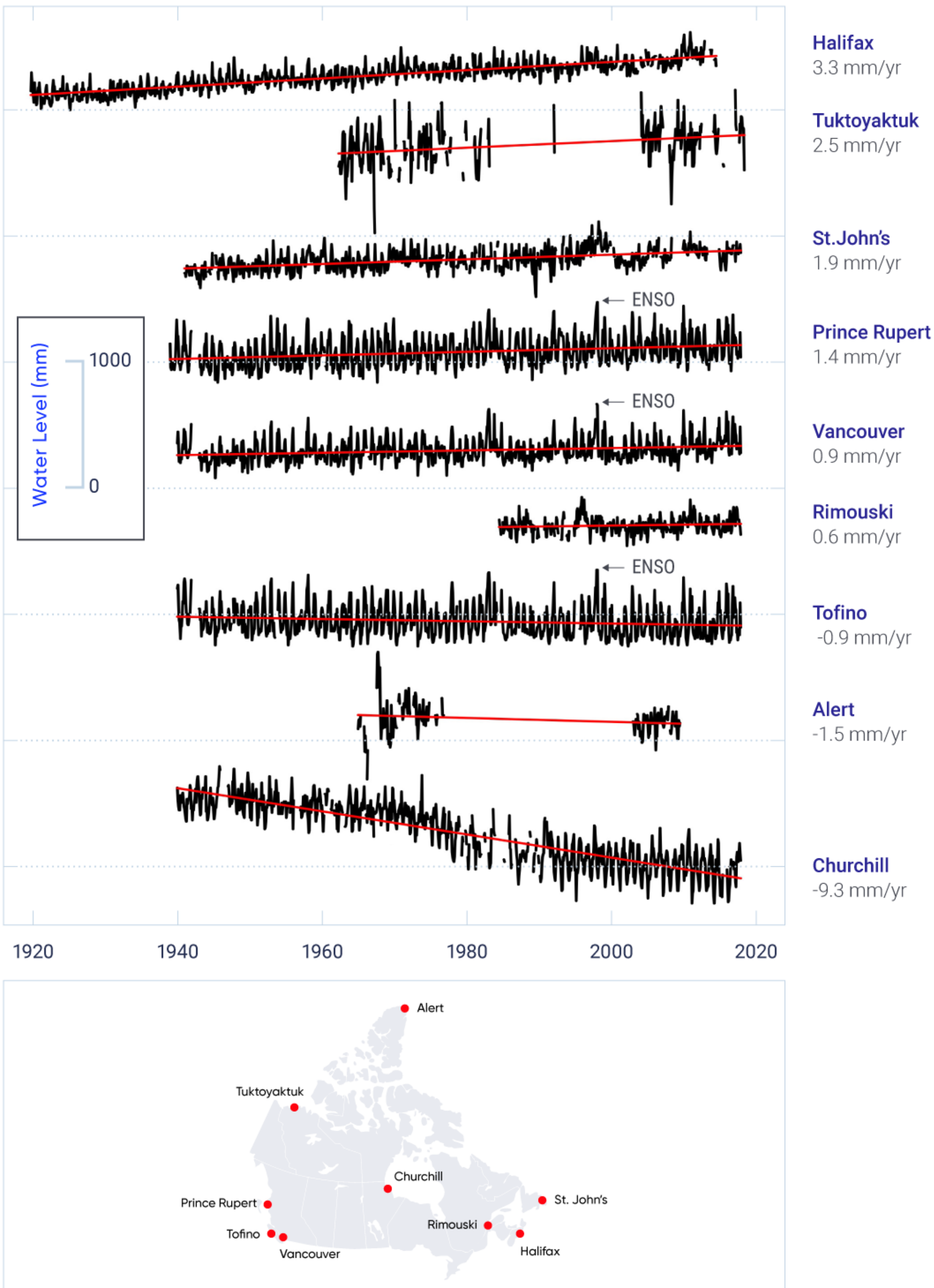

Figure 18 Long-term trends of relative sea-level change at representative sites across Canada (Bush and Lemmen, 2019)

Atlantic Zone Monitoring Program (AZMP) Station 27, located near St. John's, has observed a sea surface temperature warming trend of 0.13 °C per decade at the ocean surface. A somewhat lower warming of 0.02 °C per decade was observed below the surface (0-175m). A long-term comparison of the average surface (land and ocean) temperature between 1951 and 1980 to the past year (2019) also shows a warming in most of the ocean regions near St. John's.

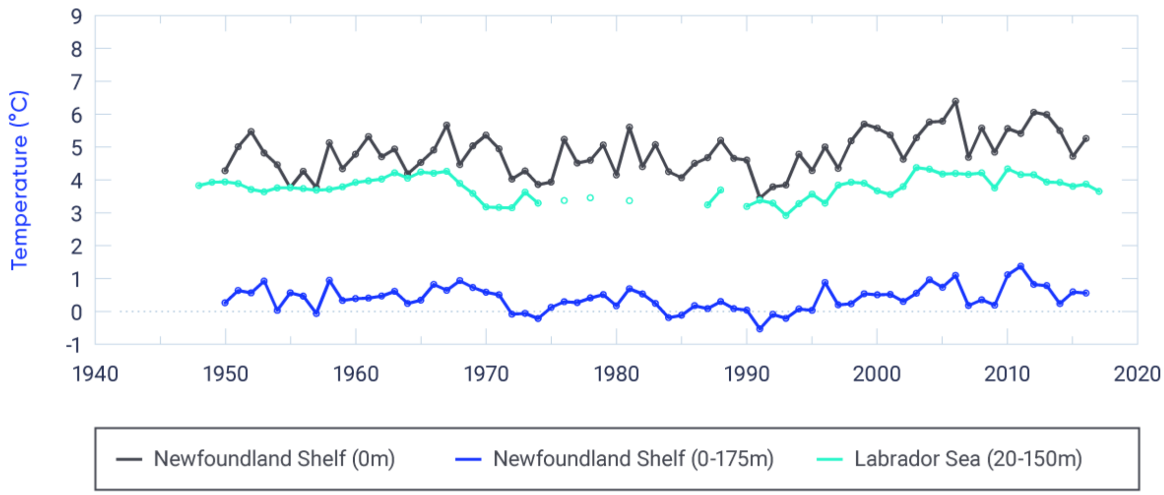

Figure 19 Ocean temperature time series in the Newfoundland Shelf and Labrador Sea collected by DFO monitoring programs. Sea surface temperature (0 m) on the Newfoundland Shelf at AZMP Station 27 near St. John's (1950–2016) and depth-averaged ocean temperature (0–175 m) from that site (1950–2016). Upper-ocean temperature (20–150 m) of the central Labrador Sea basin (OWS Bravo) does not demonstrate long-term warming (1948–2016) (Bush and Lemmen, 2019).

Wind

There is a limitation in the analysis of wind due to available observations and the limited research on the mechanisms that cause observed and projected changes in Canada. However, since there is a strong interest in better understanding what the wind historical and future conditions may be, we present the available information. Any insight in this section should be taken with caution.

The YYT station is part of ECCC's Adjusted and Homogenized Canadian Climate Data (AHCCD), which are climate station datasets that incorporate adjustments (derived from statistical procedures) to the original historical station data to account for discontinuities from non-climatic factors, such as instrument changes or station relocation. This data shows decreasing trends at YYT station for hourly wind speeds for every season, ranging between 7.2 and 8.9 km/hr. Winter appears to be the least impacted by this decreasing trend.

Table 5 Summary of Trends at the YYT Station (1953-2014)[8]

Time Period	Km/hr
Annual	-8.0
Winter	-7.2
Spring	-8.9
Summer	-8.1
Fall	-8.1

[8] https://climate-viewer.canada.ca/climate-maps.html#/?t=annual&v=sfcwind&d=ahccd&cp=-62.67291171604404,46.99654881950912&z=5

A more detailed analysis including extreme wind and frequency of a particular wind speed is available from the MSC50 hindcast dataset (C-CORE, 2017a; C-CORE, 2017b). The dataset contains hourly wind values for 10 m above mean sea level wind speeds from 1954 to 2015. The MSC50 database is the most comprehensive, long-term, widely used model hindcast, it models the Canadian East Coast at significant high resolution and incorporates shallow-water physics and ice pack. The wind fields used in the model are based on careful re-analysis of three-hourly wind fields. This provides a sense of 1-hour wind speed and direction at for the region where St. John's is located. The MSC50 dataset is broadly used in coastal risk assessment processes, and offshore environmental risk assessments in the region.

In St. John's the winter months have the strongest average sustained winds (11.3-11.6 m/s) and most of the strongest sustained winds as well (17.1-16.6 m/s). Summer (Jun, July, August) is usually the least windy, with average sustained winds of 6.3-6.8 m/s. The maximum sustained winds can take place in August (up to 28.3 m/s), September (up to 31.9 m/s), and during the winter (26.8-29.3) (Table 7 and Table 8). However, August and September are less likely to reach speeds over 22-24 m/s (Table 6).
In the winter, wind comes primarily from the North West and West. During spring, wind direction is a lot more distributed than in Winter, ranging mostly Between North West and South West. During the summer winds come from mostly from the South West. During the fall, wind direction is a lot more distributed than in winter, ranging mostly Between North West and South West.

Table 6 Summary of Probability of Exceedance by Month (1-hr wind speeds)

Cell: 370 47.46°N 52.44°W		Wind Speed - Probability of Exceedance by Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (m/s)	2	1	1	1	0.999	0.996	0.995	0.993	0.997	0.998	1	1	1
	4	0.998	0.996	0.987	0.969	0.914	0.885	0.874	0.919	0.956	0.985	0.994	0.997
	6	0.964	0.956	0.919	0.854	0.734	0.684	0.652	0.72	0.813	0.896	0.937	0.956
	8	0.873	0.848	0.783	0.666	0.506	0.431	0.392	0.453	0.593	0.726	0.79	0.847
	10	0.716	0.674	0.6	0.457	0.3	0.21	0.169	0.216	0.366	0.517	0.601	0.687
	12	0.523	0.487	0.401	0.28	0.144	0.079	0.047	0.08	0.187	0.312	0.399	0.5
	14	0.345	0.311	0.24	0.147	0.054	0.026	0.01	0.025	0.079	0.16	0.233	0.323
	16	0.202	0.178	0.126	0.064	0.016	0.006	0.002	0.007	0.032	0.072	0.12	0.184
	18	0.104	0.09	0.055	0.021	0.005	0.001	0.001	0.002	0.013	0.029	0.05	0.087
	20	0.047	0.04	0.02	0.005	0.002	0.001	0	0.001	0.005	0.012	0.017	0.036
	22	0.018	0.016	0.005	0.001	0	0	0	0	0.003	0.004	0.006	0.013
	24	0.005	0.006	0.001	0	0	0	0	0	0.001	0.001	0.002	0.004
	26	0.001	0.002	0	0	0	0	0	0	0	0	0	0.001
	28	0	0	0	0	0	0	0	0	0	0	0	0
	30	0	0	0	0	0	0	0	0	0	0	0	0
	32	0	0	0	0	0	0	0	0	0	0	0	0

Table 7 Summary Wind Speed Tables (1-hr winds)

Cell: 370 47.46°N 52.44°W		Summary Table - Wind Speed												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Wind Speed (m/s)	Mean	11.6	11.2	10.3	8.9	7.3	6.6	6.3	6.8	8.1	9.4	10.3	11.3	9
	St. Dev.	4.1	4.1	3.9	3.7	3.3	3	2.8	2.9	3.4	3.6	3.8	4	4
	Median	11.3	10.9	10	8.6	7.1	6.5	6.2	6.6	7.8	9.2	10	11	8.6
	P90	17.1	16.7	15.6	14	11.8	10.5	9.9	10.6	12.5	14.2	15.4	16.6	14.5
	Max.	27.9	29.3	27.1	24.7	22.3	23.5	20.8	28.3	31.9	25.7	26.5	26.8	31.9
	Dom. Dir.	285	285	285	225	225	215	215	225	225	235	285	275	225

Table 8 Extreme Return Periods (1-hr winds)

Cell: 370 47.46°N 52.44°W		Wind Speed Extremes by Return Period												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
WS (m/s)	10 Year	25.9	27	23.7	21.2	19.4	17.5	16.4	19.3	23.8	23.6	23.6	25.1	28.2
	25 Year	27.8	29	24.9	22.5	20.8	18.9	17.9	21.7	26.8	25.6	25.3	26.3	29.4
	50 Year	29.2	30.4	25.7	23.6	21.8	20	19.1	23.5	29.2	27.1	26.5	27.2	30.4
	100 Yr.	30.7	31.9	26.6	24.7	22.7	21.1	20.3	25.4	31.6	28.6	27.8	28	31.3

Although high-speed (over 90km/hr or 25 m/s) sustained winds are rare, St. John's more often experiences destructive wind gusts. Wind Gusts are the sudden increases of wind speed that lasts no more than 20 seconds, these are the portion of wind that usually reach the highest speeds and can increase damage to infrastructure. Cheng et al. (2014) studied the patterns of hourly and daily wind gusts[9] in Canada and found that St. John's is in the region with the most frequent wind gusts in the country, where the least frequently occur in the summer months. The results showed that the City may experience approximately 1,424 hours per year with wind gusts above or equal to 40 km/hr, 151 hours above or equal to 70 km/hr, and 24hrs with winds above or equal to 90 km/hr.

Table 9 Regional annual-average number of hours and days observed with wind gust events greater or equal to the thresholds. Hourly gusts (1994-2009), Daily gusts (1976-2009), and projected change by 2050s and 2080s (Cheng et al., 2014)

Region	**Hourly wind gust (km/hr)**				**Daily wind gust (km/hr)**			
	≥28	**≥40**	**≥70**	**≥90**	**≥28**	**≥40**	**≥70**	**≥90**
Historical	2505	1424	151	24	238	188	40	10

The Environment & Climate Change Canada YYT stations reports daily speed of maximum 3-5 second wind gusts. The maximum values per year and season were analyzed and are presented below.

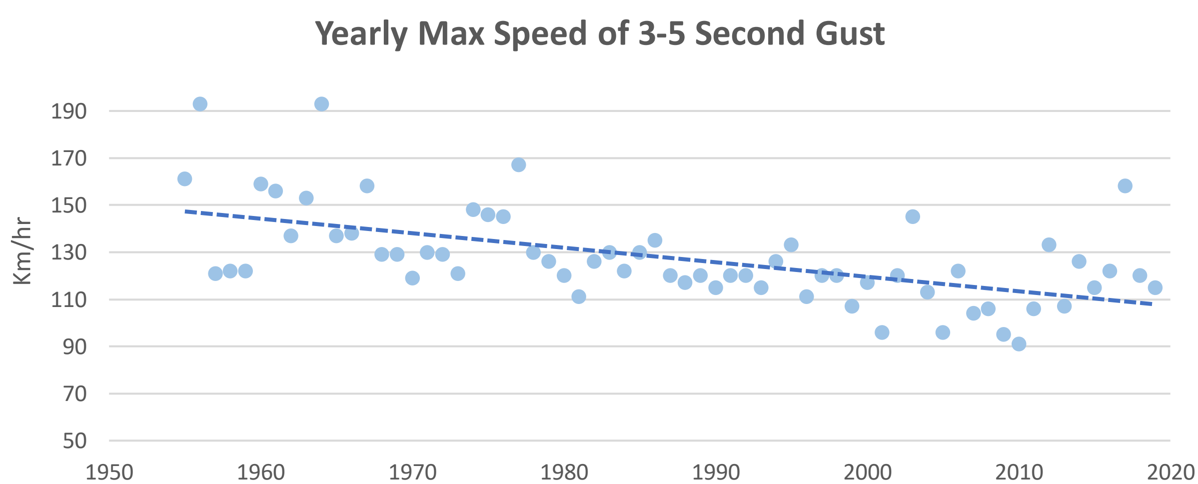

Figure 20 Yearly maximum speed of 3-5 second gusts at St. John's International Airport (1953-2019).

[9] An hourly wind gust was defined as a sudden increase in wind speed during the 10-min period prior to the observation with a ≥28 km/hr speed and measured at 9km/hr greater than the 2-min-average wind speed prior to the observation. A daily wind gust was defined as a daily peak wind that is ≥28 km/hr measured during the entire 24-h period of a day.

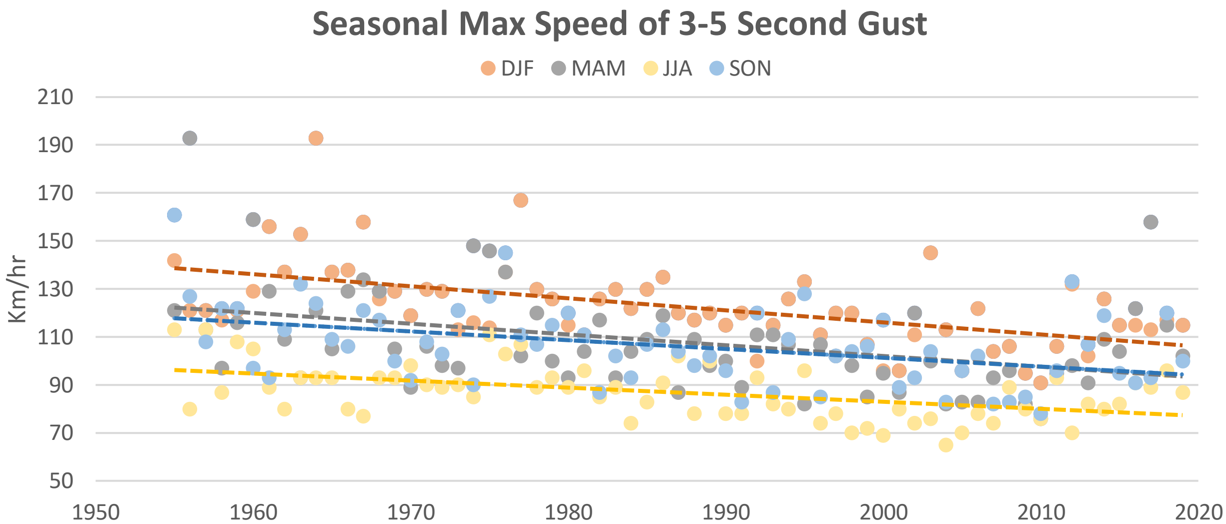

Figure 21 Seasonal maximum speed of 3-5 second gusts at St. John's International Airport (1953-2019).

The decrease in maximum speed of gusts annually and in every season shown by the data should be taken with caution and further research is needed to really estimate changes in wind in St. John's. This type of recent trends in decreasing wind speeds in areas of Eastern Canada have been seen elsewhere, but do not stand out in the context of other longer-term studies. However, they are consistent with a global stilling process (a decrease in wind over the last three decades) and may be partially because of large-scale climate dynamics. More information is needed to confidently say what the past trend of winds have been locally at the YYT station.

St. John's Future Climate

Environment and Climate Change Canada (ECCC) determines the climate of a region and how it changes over time using various statistical tools, and often communicates these in terms of Climate Normals. These are estimates based on 30-year periods (as per the World Meteorological Organization). Long-term climate change predictions are communicated in terms of changes to the Climate Normal, frequently named for the central decade. For example, the 2050's usually refers to what would be possible between 2041-2070, while 2080's refers to what would be possible between 2071-2100. This is to make sure that these estimates incorporate the impact of various slow-changing phenomena like the NAO, AMO, to a lesser extent for St. John's ENSO. The projections are estimated using global and subsequently regional climate models, which are state-of-the-art mathematical representations of the major climate system components (atmosphere, land surface, ocean, and sea ice), their interactions, and a range of future emission scenarios.

It is unknown what the total greenhouse gas emissions (GHG) emissions will be in the future. To develop climate projections and account for multiple possible future emissions scenarios, the Inter-Governmental Panel on Climate Change (IPCC) developed four Representative Concentration Pathways (RCP) (Taylor et al., 2012). Each RCP (RCP 2.6, 4.5, 6.0 and 8.5) reflects on various assumptions like levels of energy uses and greenhouse gas mitigation efforts. To account for uncertainties in sources of GHGs, land use and short-lived aerosols, the RCP scenarios reflect the outcome of the scenario assumptions in the form of numbers corresponding to potential radiative forcing levels reached by 2100. Radiative forcing is a measure of the combined effect of greenhouse gases, aerosols, and other factors that can influence climate to trap additional heat. For example, RCP2.6 results in an increase in radiative forcing to the global climate system reaching only 2.6 W/m^2 in 2100, while the no-policy or intervention GHG emissions RCP8.5 would be expected to lead to an increase reaching 8.5 W/m^2 in 2100.

Peters et al. (2013) and Smith and Myers (2018) found that RCP8.5 most closely resembles emissions from recent years. As such, some studies only focus on RCP8.5 and in some cases include RCP4.5. Raferty et al. (2017) suggested that RCP8.5 may be on the outside of the range of plausible emissions scenarios. However, he also showed that even without reaching RCP8.5 scenario emissions, significant impacts can come from RCP6.0 and RCP4.5. This report and its sources attempt to incorporate the uncertainty in GHG emissions by providing estimates and develop a conservative approach by focusing on RCP8.5 but incorporating RCP4.5 where possible.

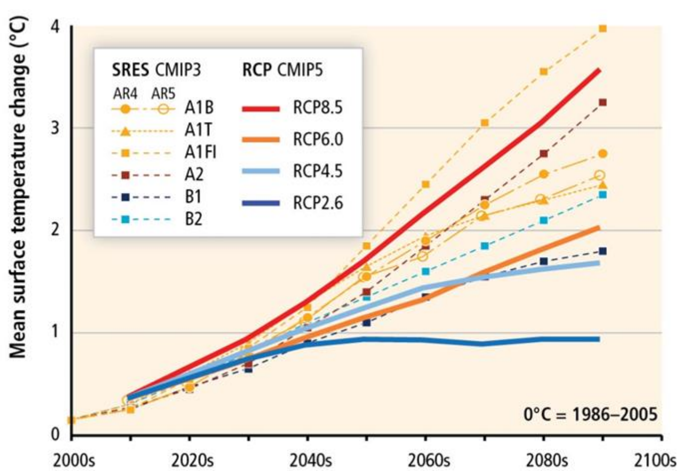

Figure 22 Global Mean Surface Temperature Change (°C) over the 21st Century Using the Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathway (RCP) Scenarios

Temperature

Average yearly temperatures are expected to increase in St. John's by about 2.5-2.8 °C by the 2050s and 4.4-4.8 °C by the 2080s. Similarly, average maximum and minimum temperatures are projected to increase. The projected warming trend of average temperatures is best summarized by an increased tendency to break high temperature records (warmest parts of the day will become much warmer), and a shift in our low temperatures (coldest parts of the day will become warmer).

Table 10 Summary of temperature related projected changes for St. John's.

Variable	20th Century	2050s (2041-2070)	2080s (2071-2100)
Average Temperature	5.1 °C	7.7 °C (+/- 1.2) **+ 2.7 °C**	9.7 °C (+/- 1.6) **+4.6 °C**
Average Maximum Temperature	8.8 °C	11.3 °C (+/-1.3) **+2.5 °C**	13.2 °C (+/- 1.7) **+4.4 °C**
Average Minimum Temperature	1.4 °C	4.2 °C (+/- 1.2) **+2.8 °C**	6.2 °C (+/- 1.6) **+4.8 °C**

Seasonally, changes in temperature are anticipated to be more intense during the Fall and Winter. The change in temperature is projected to bring a significant reduction in days with frost (days with minimum temperatures reaching below freezing), particularly in winter and spring months, with a reduction between -18 and -19 days for each season by the 2050's, and -33 to -36 days by 2080s.

Table 11 Summary of projected seasonal temperature changes for St. John's.

Variable	Season	20th Century	2050s (2041-2070)	2080s (2071-2100)
Average Temperature	Winter (DJF)	-3.2 °C	0.2 °C (+/- 1.5) **+3.4**	2.1 °C (+/- 1.8) **+5.3**
	Spring (MAM)	1.8 °C	3.4 °C (+/- 0.9) **+1.6**	5.3 °C (+/- 1.1) **+3.5**
	Summer (JJA)	14.1 °C	16.5 °C (+/- 1.2) **+2.4**	18.3 °C (+/- 1.8) **+4.2**
	Fall (SON)	7.6 °C	10.9 °C (+/- 1.3) **+3.3**	13.0 °C (+/- 1.7) **+5.4**
Average Maximum Temperature	Winter (DJF)	0.0 °C	3.1 °C (+/-1.4) **+3.2**	4.9 °C (+/-1.7) **+4.9**
	Spring (MAM)	5.4 °C	6.6 °C (+/-1.1) **+1.2**	8.4 °C (+/-1.4) **+3.0**
	Summer (JJA)	18.6 °C	21.0 °C (+/-1.2) **+2.4**	22.8 °C (+/-1.8) **+4.2**
	Fall (SON)	11.1 °C	14.5 °C (+/- 1.4) **+3.4**	16.5 °C (+/- 1.7) **+5.5**
Average Minimum Temperature	Winter (DJF)	-6.5 °C	-2.8 °C (+/-1.6) **+3.6**	-0.7 °C (+/-2.0) **+5.7**
	Spring (MAM)	-1.9 °C	0.1 °C (+/-0.7) **+2.0**	2.1 °C (+/-1.1) **+4**
	Summer (JJA)	9.6 °C	12.0 °C (+/-1.2) **+2.3**	13.9 °C (+/-1.8) **+4.2**
	Fall (SON)	4.2 °C	7.3 °C (+/- 1.3) **+3.2**	9.5 °C (+/- 1.7) **+5.3**
Number of Days with Frost	Year	160.4	109.9 (+/-22.0) **-31%**	75.2 (+/-27.8) **-53%**

Average temperatures are important; however, we are most often concerned with extremely hot or cold days. To examine trends on these kinds of days we looked at the highest and lowest temperatures throughout the year and how they are expected to change. The Climate Atlas of Canada (2019) shows that the maximum temperature is projected to change by +1.5 °C (to approximately 28.4 °C) by the 2050s (2021-2050), and up to 2.4-3.5 °C (about 30.4 °C) by the 2080s (2051-2080). Minimum temperatures are projected to increase by 2.5-2.8 °C by 2050s (2021-2050) and 4.0-5.8 °C by the 2080s (2051-2080). Similarly, the number of days when temperatures will not go above freezing temperatures (Icing days) are projected to decrease significantly (27-30% by 2050s and 42-59% by the 2080s). Freeze-thaw cycle days are also projected to decrease by the 2050s and the 2080s.

Table 12 Climate Atlas of Canada Summary of temperature related projected changes for St. John's.

Variable	20th Century	2050s (2041-2070)	2080s (2071-2100)
Maximum Temperature	26.9 °C	+1.5 °C	+2.4 to 3.5 °C
Minimum Temperature	-17.8 °C	+2.5 to 2.8 °C	+4.0 to 5.8 °C
Icing Days	58.4	-16.3 to -17.8	-24.6 to -34.6
Freeze-Thaw Cycle Days	82.1	-7.0 to –8.4	-13.3 to -20.9

Energy use in building and facilities is heavily impacted by weather and changes in climate. Cooling requirements are expected to increase for the summer and spring months. Summer cooling requirement is expected to increase by 82% by the 2050s and 164% by the 2080s. Spring is expected to also see an increase in instances of days when cooling may be needed. Heating needs for winter are expected to decrease by approximately -18%, spring and fall are also projected to decrease -20% and -30% respectively by the 2050s. Further decreases are projected for the 2080's, -28% during winter, -25% and -50% for spring and fall respectively.

Table 13 Summary of projected temperature changes as they relate to indoor cooling and heating needs for St. John's.

Variable		20th Century	2050s (2041-2070)	2080s (2071-2100)
Cooling Degree Days	JJA	133.2	243.1 (+/-51.0) **+82%**	351.3 (+/-96.7) **+164%**
	Annual	157	310.0 (+/- 81.3) **+97%**	477.7 (+/- 151) **+204%**
Heating Degree Days	Annual	4,135.8	3,311.1 (+/-369.9) **-20%**	2772.6 (+/-453.8) **-33%**
	Winter (DJF)	1,736.0	1427.0 (+/-132.9) **-18%**	1252.4 (+/-165.9) **-28%**
	Spring (MAM)	1,314.4	1162.1 (+/-77.9) **-12%**	992.8 (+/-100.1) **-24%**
	Summer (JJA)	303.9	197.5 (+/-63.2) **-35%**	137.7 (+/-78.9) **-55%**
	Fall (SON)	781.6	524.5 (+/-96.1) **-33%**	389.6 (+/-108.9) **-50%**

Precipitation

Average daily precipitation is expected to increase by approximately 7% by the 2050s and 9% by the 2080s. The biggest increase is expected to take place in the summer months, while the winter months are expected to see a decrease by the 2050s, but then bounce back to near-20th century levels by the

2080s. These changes in daily precipitation appear small but are significant when taken over a full season. For example, 0.5 mm/day change for a 90-day season amounts to 45mm or roughly 10% change in total seasonal precipitation.

The distribution of precipitation between seasons is also important. Seasonally, winter is projected to remain the season with the most days with heavy (+10mm) precipitation, and the highest average precipitation. Summer and fall are projected to get wetter by the 2050s, and by the 2080s summer and spring will continue to see that increased wetness.

Table 14 Summary of Precipitation volume changes for St. John's (Canada Climate Atlas, 2019).

Variable		20th Century	2050s (2021-2050)	2080s (2051-2080)
Total Precipitation	Annual	1,400 mm	1,474 mm **+5.3**	1,523 mm **+8.8%**
	Winter (DJF)	408 mm	440 mm **+7.8%**	462 mm **+13.2%**
	Spring (MAM)	327 mm	352 mm **+7.6%**	365 mm **+11.6%**
	Summer (JJA)	267 mm	274 mm **+2.6%**	277 mm **+3.7%**
	Fall (SON)	398 mm	410 mm **+3%**	418 mm **+5%**

Table 15 Summary of Precipitation changes for St. John's (Finnis and Daraio, 2018).

Variable		20th Century	2050s (2041-2070)	2080s (2071-2100)
Average Daily Precipitation	Annual	5.1 mm	5.5 mm (+/- 0.5) **+7%**	5.6 mm (+/- 0.5) **+9%**
	Winter (DJF)	7.2 mm	6.6 mm (+/- 0.5) **-7%**	7.1 mm (+/- 0.6) **-1%**
	Spring (MAM)	4.8 mm	5.0 mm (+/- 0.3) **+5%**	5.4 mm (+/- 0.4) **+13%**
	Summer (JJA)	3.4 mm	4.3 mm (+/- 0.6) **+27%**	4.2 mm (+/- 0.6) **+23%**
	Fall (SON)	5.1 mm	6.0 mm (+/- 0.4) **+16%**	5.8 mm (+/- 0.5) **+12%**
Days with +10 mm	Annual	59.9	62.5 (+/-5.1) **+2.6**	62.2 (+/- 5.6) **+2.3**
	Winter (DJF)	21.9	19.6 (+/- 1.5) **-2.3**	20.3 (+/- 1.5) **-1.6**
	Spring (MAM)	14.0	14.9 (+/- 1.1) **+1.0**	15.6 (+/- 1.2) **+1.6**
	Summer (JJA)	9.6	11.8 (+/- 1.4) **+2.2**	11.1 (+/- 1.4) **+1.5**
	Fall (SON)	14.4	16.2 (+/- 1.1) **+1.8**	15.2 (+/- 1.5) **+0.7**

The intensity and frequency of most storms are projected to increase by the 2050s and by the 2080s. The increasing trend for St. John's has been reported in various studies (Finnis, 2013, Finnis and Daraio 2018), which have used various datasets (NARCCAP and CORDEX-NA). These studies both incorporated high-resolution climate models to estimate the projections for the City of St. John's. The latest projections show for example, two design storms (one with a 4% probability of taking place every year, also referred to as the 25-year storm; and one with a 1% probability, also referred to as the 100-year storm) may increase by approximately 17% by mid-century and 25% by the end of the century.

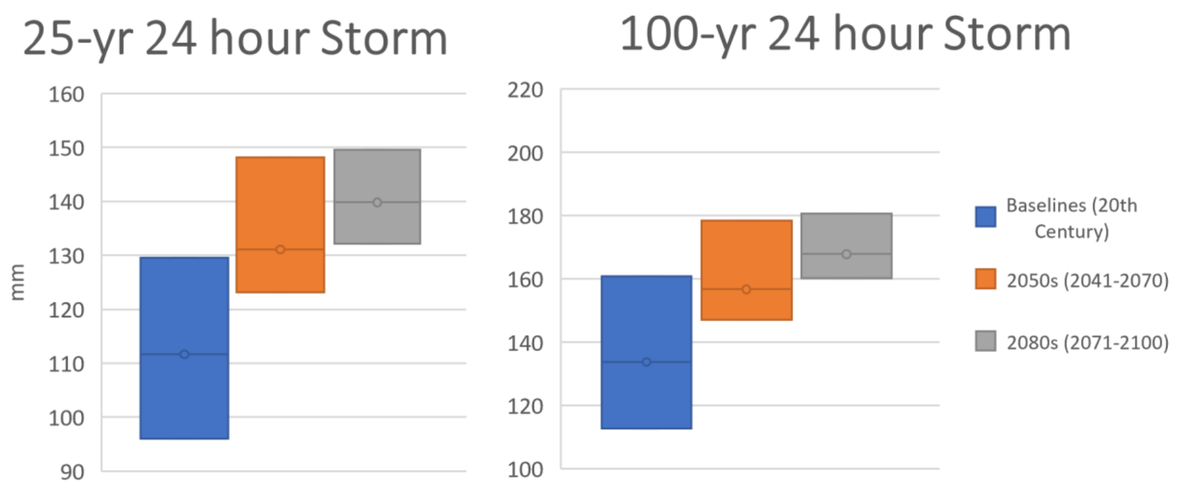

Figure 23 Example of change to volume of two storms of frequency and duration (Finnis and Daraio, 2018). The baseline box plots show the 5th percentile, median, and 95th percentile. Projections show 10th, median, and 90th percentiles due to data availability.

An alternative way to interpret these projected changes is that the 100-year, 24-hour event for St. John's is projected to increase its frequency to become the 25-year 24-hour event by the 2050s, and it will proceed to become more frequent as we approach the end of century. This means that St. John's will be almost four times more likely to see a storm with approximately 133 mm of rainfall over 24 hours by mid-century.

Freezing rain events are projected to increase (Cheng et al., 2011) with December-February projected to see the greatest increase in freezing rain, while March may see a moderate/small increase, and November and April may experience no change.

Table 16 Approximation of annual average number of days with freezing rain (Cheng et al., 2011).

Months	Dec, Jan, Feb			March			Nov, April		
Duration	≥1h	≥4h	≥6h	≥1h	≥4h	≥6h	≥1h	≥4h	≥6h
Number of Days	6.5	1.8	1	3	1	0.5	3	1	<1
Change 2050s (2046-2065)	+20%	+18%	+30%	+2%	+10%	+10%	-	-	-
Change 2080s (2081-2100)	+35%	+30%	+55%	+5%	+15%	+20%	-	-	-7%

The detailed impact of temperature and precipitation changes on snowfall can be more complex than temperature and precipitation projections. However, an expectation exists that snowfall will continue to decrease by the 2030s and the 2050s. This is based on the projected decrease in winter precipitation (-7%) by the 2030's and (-1%) by the 2080s. Historically, approximately 25% of the annual precipitation falls as snowfall, this percentage is expected to continue to decrease. Another indication that snowfall is projected to decrease is that climate models project that snow depth (the amount of snow on the ground) is predicted to decrease by approximately 60% by the 2050s and closer to 80-90% by the 2080's.

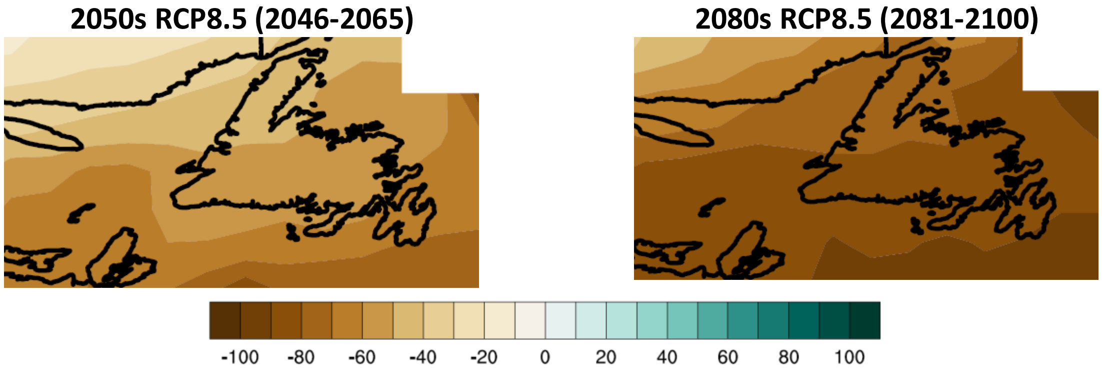

Figure 24 Projected Percent Change of Winter (DJF) Snow Depth for 2050s and 2080s RCP8.5 (Source: http://climate-scenarios.canada.ca/?page=download-cmip5)

Sea Level and Temperature

Sea level has been rising near the City of St. John's at about +1.9 mm/year since the 1940s. Projections show this will continue and will result in a rise of 75 to 100 cm by the year 2100. This does not include the influence of storm surges, which if timed with high tide can create a significant increase in water level.

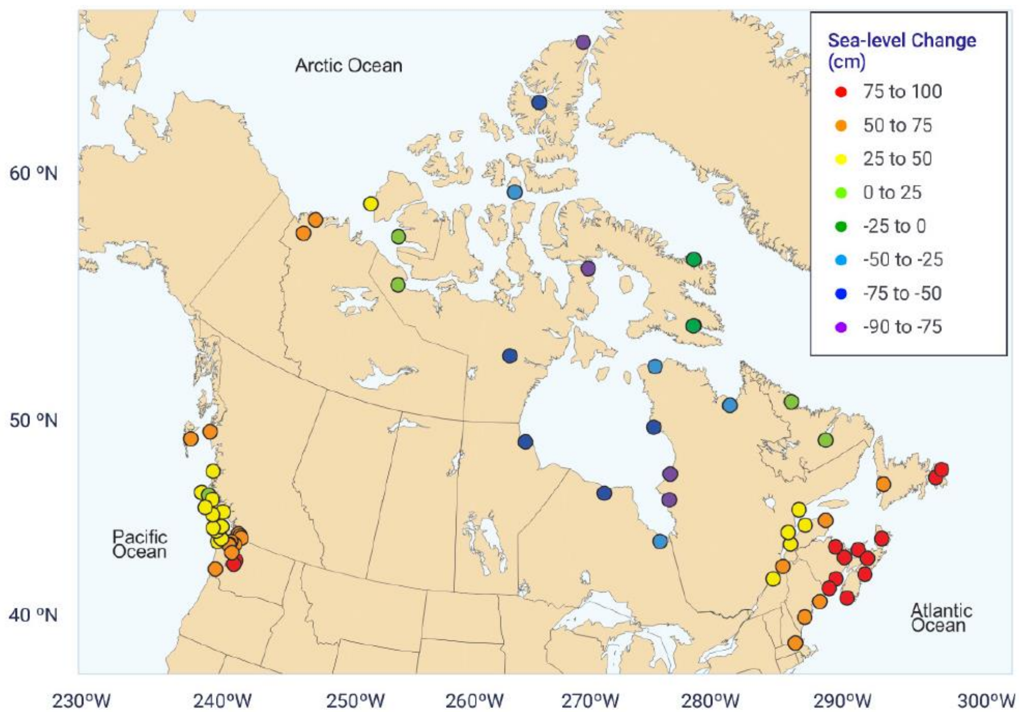

Figure 25 Projected relative sea-level changes shown at 2100 for the median of a high emission scenario (RCP8.5) at representative sites across Canada (Bush and Lemmen, 2019).

Sea surface temperatures have been higher during the past three decades than any other time since reliable data collection began in 1880. The ocean near St. John's has seen a rise in temperatures of 0.13 ^{o}C per decade and is projected to see further warming. Sea ice has seen a decrease of 1.53% per year between 1998-2013. Warmer winters and a warmer ocean are projected to result in further reductions in ice cover, as well as shorter duration of the ice season and decreases in ice thickness. The Gulf of St. Lawrence, for example, is projected to experience ice-free winters by the year 2100.

Wind

There is significantly more uncertainty in wind and extreme wind projections than in projections of temperature, sea level, or even precipitation. However, we present here estimates relevant to the City of St. John's for consideration in the assessment of risk. These projections should be used with caution as there is a significant amount of uncertainty within these.

Jeong and Sushama (2019) studied average wind speeds in North America. The study found that projections mostly show increases in future yearly average wind speeds and the 50-year return period wind speed for Eastern Canada (approximately +4%). Seasonally, the increase in future sustained wind speed (3-hr winds) are larger in winter than in summer and intensify in more intense emission scenarios (RCP8.5 vs RCP4.5). Increases were also projected for spring in Eastern Canada, while the fall shows no significant change.

Wind Gusts are the sudden increases of wind speed that lasts no more than 20 seconds, these are the portion of wind that usually reach the highest speeds and can increase damage to infrastructure. Cheng et al. (2014) studied hourly and daily wind gusts[10] across Canada and attempted to developed projections for the 2050s and 2080s. Wind gust differences are experienced seasonally. Changes in the number of days with wind gusts greater or equal to 70 km/hr are projected to increase by 30-50%.

Table 17 Regional annual-average number of hours and days observed with wind gust events greater or equal to the thresholds. Hourly gusts (1994-2009), Daily gusts (1976-2009), and projected change by 2050s and 2080s (Cheng et al., 2014)

	Hourly Wind Gusts				Daily Wind Gusts			
	≥28 km/hr	≥40 km/hr	≥70 km/hr	≥90 km/hr	≥28 km/hr	≥40 km/hr	≥70 km/hr	≥90 km/hr
Historical	2505	1,424	151	24	238	188	40	10
Change 2050s (2046-2065)	+10%	+14%	+20%	+100%	+9%	+13%	+24%	+30%
Change 2080s (2081-2100)	+15%	+22%	+30%	+100%	+12%	+19%	+37%	+60%

Table 18 Regional seasonal-average number of days observed with wind gust events greater or equal to 70 km/hr (1976-2009) and projected change by 2080s (Cheng et al., 2014)

	Daily Wind Gusts ≥70 km/hr			
	Winter	Spring	Summer	Fall
Historical	19	9	2	10
Change 2080s (2081-2100)	+10-30%	+30-50%	+50%	+30-50%

[10] An hourly wind gust was defined as a sudden increase in wind speed during the 10-min period prior to the observation with a ≥28 km/hr speed and measured at 9km/hr greater than the 2-min-average wind speed prior to the observation. A daily wind gust was defined as a daily peak wind that is ≥28 km/hr measured during the entire 24-h period of a day.

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