FUTURE CLIMATE SCENARIOS PROVINCE OF NEW-BRUNSWICK

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EXECUTIVE SUMMARY

Increasing concentrations of carbon dioxide in the atmosphere, along with other greenhouse gases, modify the radiative balance of the atmosphere by reducing the amount of infrared that is emitted into space. The most visible effect is a warming of the oceans and the atmosphere, which in turn causes a multitude of related impacts, such as an increased frequency and intensity of rainfall events (IPCC, 2013).

This study presents the projected change for 29 climate indices of interest for the province of New-Brunswick. The climate projections show a substantial increase in mean temperature over all seasons for the 2020, 2050 and 2080 time horizons. Around 2080, these increases vary between +2.5 to +6.5 °C according to the seasons (higher increases in winter), scenarios (higher increases with RCP 8.5) and geographical location (higher increases in Bathurst). The consensus among models (i.e. the relative number of model showing a similar signal) is strong for all temperature based indices.

An important increase is expected for very hot days (maximum temperature higher than 30 °C) for time horizon 2080, especially for the continental cities such as Moncton (+10 to +35 hot days) as well as the most northern city of Bathurst (+10 to +35 hot days). For St-John, the projections suggest smaller increases of +5 to +20 hot days.

Changes in agricultural indices, such as growing season length, are expected for the whole province. For example, in Moncton for time horizon 2080, the expected season length varies between +29 days (RCP 4.5) to +61 days (RCP 8.5).

For precipitation, the signal is clearer for winter and spring, when accumulations of rain and snow are expected to increase. For the summer and fall seasons, projections suggest an increase but the model consensus is weaker.

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1. INTRODUCTION

Over the past 400 000 years, atmospheric carbon dioxide concentrations have varied between 180 and 300 ppm. These variations are understood to be the amplifying mechanism behind successive glaciation periods. Before the industrial revolution, CO_2 concentrations were about 280 ppm and have since increased to 400 ppm. For context, the last time the Earth had an atmosphere with 400 ppm of CO_2 was around 3.5 million years ago (Brigham-Grette et al., 2013).

The mechanism linking CO_2 to climate is radiative. The Earth receives solar energy from the Sun in the ultraviolet, visible and high infrared spectrum. This energy is either reflected, transmitted or absorbed depending on cloud cover, atmospheric transparency and surface albedo. Once it is absorbed, solar shortwave radiation is converted into heat and radiated back to space through infrared radiation at a longer wavelength. Greenhouse gases (GHG), which include water vapor, carbon dioxide, methane and many others, block a fraction of outgoing infrared emissions, thereby hindering the only process by which the Earth sheds energy back to space. Increasing atmospheric concentrations of GHG thus tips the radiative balance, more energy being absorbed than emitted, leading to a gradual warming of the oceans and atmosphere, until a new equilibrium is reached.

In the 1960s, these processes started to be simulated using climate models running on early digital computers. Although the first models were crude by today's standards, their results were roughly in line with recent values, which put the warming associated with a doubling of CO2 concentrations at around 3.5 ° C. Those first experiments were simply comparing simulations in a 280 ppm world with simulations in a 560 ppm world. Contemporary climate models have sufficiently evolved to assess the transient climate response to GHG scenarios. This allows climate scientists to estimate what climate impacts could be faced at different times within the 21st century given different hypothetical GHG emissions.

The consequence of rising GHG concentrations and the resulting radiative imbalance is a surplus of energy within the Earth system, which translates into higher ocean and atmospheric temperatures, melting glaciers and ice sheets. These temperature changes modify oceanic circulation, air pressure and wind patterns, as well as the potential for evaporation. Indeed, higher air temperatures allow larger quantities of water vapor to remain in gas phase before condensing into rain. This potential for more moisture within the air column is critical because it is associated with the extreme rainfall events that stress our infrastructures. Both observations and climate model simulations suggest that with increasing temperatures, the magnitude and frequency of extreme rainfalls would increase (IPCC, 2013).

This report describes the evolution of 29 climate indices relevant to New Brunswick Government over this century. Chapter 2 briefly presents the meteorological stations, the simulations ensemble used, as well as the climate scenario design. Chapter 3 presents the results for the climate indices for selected meteorological stations. Scatter plots of simulations dispersion for raw mean variable as well as box-plots of simulations dispersions for the climate indices are shown. The last chapter concludes and offers recommendations. Information about the stations, climate simulations and indicators' definition can be found in the appendix, as well as supplementary tables.

2. METHODOLOGY

This chapter outlines the methods used to construct the climate scenarios for the study of projected changes of climate indices. The first step of the analysis is to determine baseline conditions over the 1980−2010 period from the historical observation records. The second step is to extract from the climate model simulations change factors between the same reference period and future periods over the 21st century. These changes factors are used instead of the raw values from future simulations to work around systematic biases present in climate model simulations. These change factors are then applied to the historical observations to create synthetic "future observations" series. Climate indices are then computed on reference and future series, providing a consistent framework to assess expected changes.

2.1 Meteorological record

The meteorological stations used are shown in Figure 2.1 and are identified in Table 2.1. The daily records from these stations were obtained from Environment Canada and analysed to compute climate indices (see Table A.1).

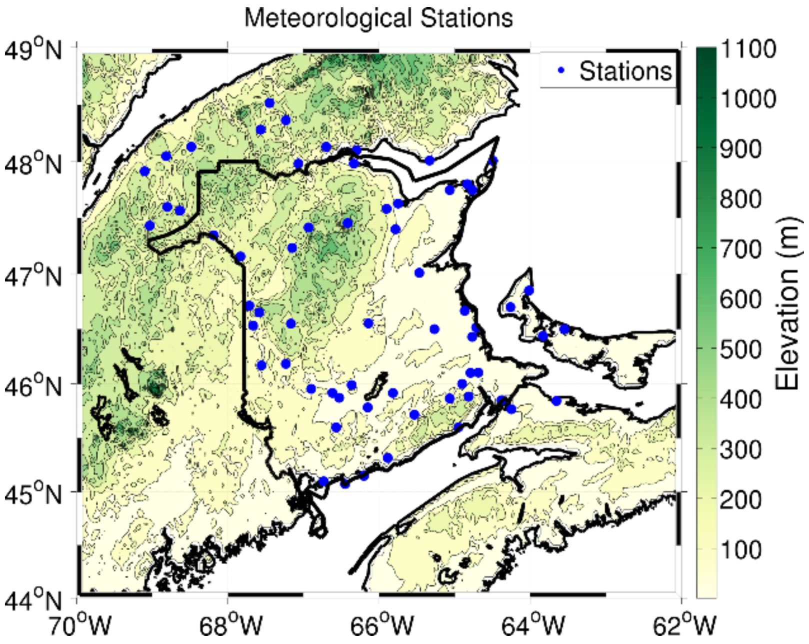

Figure 2.1 Environment Canada meteorological stations

A quality flag is defined based on the number of available years (see Table 2.2) and follows Environment Canada guidelines. This quality flag is a qualitative assessment of the uncertainty associated with the estimated climatological value for a given station. Note that this quality flag varies for each climate index because each index has different data requirements. Additional filters are applied in later steps for specific indices with more stringent data requirements (see Table A.1)

Table 2.1 Environment Canada meteorological stations. The last column indicates the percentage of missing values over the reference period (1980−2010)

ID	Name	Latitude	Longitude	Altitude (m)	Start date	End date	Missing (%)
7050140	AMQUI	48.5167	-67.45	182.9	1957-03-01	1997-10-31	44
7051200	CAUSAPSCAL	48.3667	-67.2333	168	1913-11-06	2012-05-31	6.2
7053649	LAC HUMQUI	48.2833	-67.5667	235.9	1972-12-01	2012-05-31	0.8
7053935	L'ALVERNE	48.1333	-66.7	290	1977-05-05	1999-05-07	38.9
7055422	NEW CARLISLE 1	48.0119	-65.3317	46.4	1994-01-27	2012-07-17	45
7055675	NOTRE DAME DU LAC	47.6	-68.8	320	1963-01-01	2004-04-30	34.2
7055705	NOUVELLE	48.1	-66.3	7	1969-07-01	2004-04-30	34.4
7056600	RIVIERE BLEUE	47.4333	-69.0333	213	1950-11-01	2004-04-30	44.5
7056814	ST ALEXIS DE MATAPEDIA	47.9833	-67.0667	274	1964-07-07	2004-04-30	38.7
7057024	ST CLEMENT	47.9167	-69.1	259.1	1964-07-06	2004-04-30	34.3
7057304	ST GUY	48.05	-68.8167	320	1963-01-01	2004-04-30	34.4
7057720	STE ROSE DU DEGELIS	47.5667	-68.6333	150.9	1932-11-01	2004-04-30	34.2
7058520	TRINITE DES MONTS	48.1333	-68.4833	262	1951-07-01	2004-04-30	36.6
8100100	ACADIA FOREST EXP ST	45.9903	-66.3633	54	1955-01-01	2006-02-28	16.3
8100200	ALMA	45.6	-64.95	42.7	1950-02-01	2006-02-28	16.5
8100300	AROOSTOOK	46.7122	-67.7156	80	1929-06-01	2005-02-28	28.2
8100430	BALTIMORE	45.8833	-64.8167	182.9	1982-02-01	1997-12-31	47.7
8100467	BAS CARAQUET	47.8022	-64.8333	5	1993-09-01	2012-07-17	43.1
8100503	BATHURST A	47.6292	-65.7483	58.8	1992-07-01	2012-07-17	42.2
8100512	BEECHWOOD	46.5333	-67.6667	91.4	1966-04-01	1997-04-30	47.2
8100518	BERTRAND	47.75	-65.0667	22.9	1964-02-01	2006-02-28	44
8100566	BON ACCORD	46.6508	-67.5845	450.3	1966-07-07	2005-05-31	22.3
8100590	BUCTOUCHE	46.5167	-64.7167	10.7	1965-10-15	1999-07-31	38.9
8100593	BUCTOUCHE CDA CS	46.4303	-64.7681	35.9	1991-08-01	2012-07-17	38.3
8100880	CHARLO A	47.9833	-66.3333	40.2	1966-12-01	2003-03-19	26
8101000	MIRAMICHI A	47.0095	-65.4678	32.9	1943-01-01	2005-08-31	18.2
8101151	COLESON COVE	45.15	-66.2	30.5	1972-11-01	2001-05-31	33.1
8101200	DOAKTOWN	46.5525	-66.1403	57	1952-08-01	2006-02-28	16.5
8101500	FREDERICTON A	45.8721	-66.5279	20.7	1951-04-08	2012-01-12	0
8101600	FREDERICTON CDA	45.9167	-66.6167	39.6	1913-08-01	2000-09-30	34.2
8101746	FUNDY PARK (ALMA) CS	45.6	-64.95	42.7	1993-07-01	2012-07-17	43.9
8101800	GAGETOWN 2	45.7833	-66.15	33.5	1897-04-01	2006-02-28	17.8
8102151	HARCOURT	46.5	-65.2667	39.6	1981-07-01	2004-05-31	23.7
8102206	HAUT SHIPPAGAN	47.75	-64.7667	6	1986-10-01	2006-02-28	35.3
8102234	HOYT BLISSVILLE	45.6	-66.5667	15.2	1981-06-01	2001-04-30	33.6
8102275	JUNIPER	46.55	-67.1667	259.1	1969-07-01	2004-03-31	23.2
8102536	MACTAQUAC PROV PARK	45.9544	-66.8986	110	1973-12-01	2006-01-31	18.4
8102566	MAPLETON	46.1833	-67.2333	167.6	1972-02-01	2005-05-31	21.2
8103050	MISCOU ISLAND (AUT)	48.0089	-64.4942	4	1957-11-16	2012-07-17	46.3
8103100	MONCTON	46.1014	-64.7903	12.2	1881-07-22	2006-02-28	18.4
8103200	MONCTON A	46.1039	-64.6877	70.7	1939-12-01	2012-06-10	0
8103256	MOUNT CARLETON	47.4167	-66.9333	265.1	1973-03-01	2001-08-31	31.2
8103500	NEPISIGUIT FALLS	47.4	-65.7833	106.1	1922-07-01	2006-02-28	22.4
8103700	NICTAU	47.2333	-67.15	169.7	1978-10-18	2001-05-31	32.1
8103828	PARKINDALE	45.8667	-65.0667	152.7	1983-07-03	2006-02-28	29.2
8103845	PENNFIELD	45.1	-66.7333	22.9	1976-05-04	2003-01-31	26.4

ID	Name	Latitude	Longitude	Altitude (m)	Start date	End date	Missing (%)
8104201	POINT LEPREAU CS	45.0731	-66.4492	6	1992-03-01	2012-07-17	38.6
8104400	REXTON	46.6667	-64.8667	4.6	1924-09-18	2006-02-28	16.9
8104501	SACKVILLE	45.85	-64.3833	45.7	1980-12-01	2002-03-31	29.2
8104900	SAINT JOHN A	45.3181	-65.8856	108.8	1946-11-09	2012-06-10	0
8104928	ST LEONARD A	47.1578	-67.8319	241.7	1985-04-01	2012-07-16	14.2
8105058	SOUTH TETAGOUCHE	47.5833	-65.9	182.9	1983-06-01	2000-10-31	42.5
8105200	SUSSEX	45.7167	-65.5333	21.3	1897-10-01	2006-02-28	16.1
8105520	TURTLE CREEK	46	-64.9	45.7	1980-02-01	1999-07-31	21.3
8105551	UPSALQUITCH LAKE	47.4556	-66.4153	624.8	1967-10-12	2006-02-28	20.8
8105600	WOODSTOCK	46.1703	-67.5536	153	1886-11-01	2006-02-28	19
810AL00	EDMUNDSTON	47.3464	-68.1878	163	1983-08-10	2006-02-28	27.1
810JAE0	COLES ISLAND	45.9167	-65.8167	15.2	1987-11-01	2006-01-31	42.2
8203700	NAPPAN CDA	45.7667	-64.25	19.8	1890-05-01	2005-07-31	18.9
8204525	PUGWASH	45.8433	-63.6553	4.6	1974-11-12	2006-02-28	20
8300080	ALBERTON	46.85	-64.0167	3	1969-08-16	2006-02-28	16.4
8300500	LONG RIVER	46.5	-63.55	18.004	1970-08-05	2003-06-25	25.1
8300525	O'LEARY	46.7003	-64.2617	38.1	1960-11-19	2004-03-31	22.6
8300700	SUMMERSIDE A	46.4389	-63.8317	19.5	1942-05-01	2002-06-28	47.8

Table 2.2 Quality flag description. If a climate station has less than 15 years of data, the climatological value is not calculated.

Quality flag	Number of years with complete time series required in the 1981-2010 period
A	At least 25 years
B	At least 20 years
C	At least 15 years
D	Less than 15 years

2.2 Climate simulations

The data for this climate change assessment were taken from Global Climate Model (GCM) simulations contributed to the Coupled Model Intercomparison Projet Phase 5 (CMIP5) experiments (Taylor, Stouffer, & Meehl, 2011). These simulations are used by organisations and governments around the world to study the sensitivity of the climate system to changes in GHG concentrations.

GHG concentrations modify the radiative forcing, which represents the balance between incoming and outgoing radiation (Moss et al., 2010). To study climate change induced by a modification of GHG concentrations, the evolution of the GHG needs to be provided to the climate model. However, future greenhouse gas concentrations depend on unknown future greenhouse gas emissions which themselves depend upon multiple factors that are difficult to predict (demography, public policies, economic growth, etc.). To account for this multitude of possible future greenhouse concentrations, four GHG emission scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) were developed (Moss et al., 2010) and used to drive climate models. These scenarios, called Representative Concentration Pathways (RCP) are named according to their total radiative forcing around 2100. That is, RCP 8.5 is a scenario in which GHG heat the planet at a rate of 8.5

W/m^2 in 2100. Details of the four RCPs can be found in Moss et al. (2010) and Van Vuuren et al. (2011).

These different GHG emission scenarios are used to cover a range of likely socio-economic futures. By driving models with multiple RCPs, the uncertainty associated with plausible future emissions scenarios can be estimated. While these scenarios are not necessarily comprehensive (socio-economic hypotheses have their own uncertainties), the spread of GHG forcing from current RCP still account for a wide range of future socio-economic paths.

Beyond GHG emissions, other uncertainties should be taken into account in climate change impact studies, namely climate model uncertainty and natural variability (Collins et al., 2013). Model uncertainty arises from the myriad ways climate processes can be represented within numerical climate models. That is, certain models simulate climate processes that other models don't, or the approximations used to represent these processes differ. This is in addition to differences in the spatial resolution of the grids used, the numerical algorithms used to solve fluid flow equations or the databases used to represent land use. All these differences contribute to make models more or less sensitive to GHGs, so that for a given emission scenario, there is a range of plausible climate responses. To encompass such uncertainty, the multi-model approach is usually taken whereby conclusions are drawn not from the results of a single model, but from the mean or median of a multi-model ensemble.

Finally, natural climate variability arises from the chaotic nature of the climate system. The non-linearity of the climate system means that a given model will produce different results if they are initialized by slightly different conditions. To estimate natural climate variability, modelling centers usually run multiple simulations of a given model with the same RCP scenario. Since the GHG emissions and the physics is the same in all simulations, differences can be attributed to random natural climate variability, an irreducible source of uncertainty.

The ensemble used in this study addresses the model uncertainty and the natural climate variability by selecting a large number of simulations from different models, and the GHG emissions uncertainty by looking at two RCPs at the lower and upper end of the plausible range. The projected change for the climate indices are calculated for three future time horizons (2020, 2050 and 2080). For each future time horizons, two different RCPs are used, namely RCP 4.5 and RCP 8.5. The choice of RCP is based on CMIP5 priority described in Taylor et al. (2011), which suggests RCP 4.5 and 8.5 as the core RCPs for modelling centers for their long-term experiments (i.e. years 2006-2100). Other GHG forcing scenarios are RCP 2.6, which would require immediate, aggressive, emission mitigation actions and carbon storage, and RCP 6.0, which lies between RCP 4.5 and 8.5.

All simulations currently available at Ouranos have been used. Due to data availability and to ensure a maximum number of simulations, the choice of CMIP5 models varies according to the raw variable needed in the calculation of a given climate index. A complete listing of GCM used is given in Table B.1.

2.3 Computation of climate indices

Simulations from the CMIP5 ensemble are statistically adjusted using the observed record from meteorological stations defined in Section 2.1. Statistically adjusted simulated time series are used for the calculation of the 29 climate indices.

The projected changes are calculated and presented on a station basis. For each station, the closest grid point of each CMIP5 simulations is extracted. The simulation is used to calculate a monthly delta value describing the differences between the future (2020, 2050 and 2080) and the reference (1981-2010) periods. This monthly delta value is then applied to the stations daily time series to create the “future observations” series.

In summary, the schematic algorithm used is described below.

For a given station M_i:

1. Extract the raw variables from the nearest grid point from simulation S_i;
2. Adjust M_i daily time series by applying the monthly delta value from simulation S_i between time horizon T and the reference period;
3. Calculate all climate indices for the adjusted M_i daily time series.

Once all of the simulations are extracted and used to correct the station time series, for a given climate index, time horizon, RCP and station location, the following statistics are calculated:

- Ensemble mean climatological values;
- Ensemble 10th, 25th, 75th and 90th percentile climatological values.

We also provide a “quality” flag which represent the number of available years for the calculation of the future horizons. These quality flag are relevant for the future time horizons because the delta method, applied here for the construction of scenarios, reproduces the missing values of the historical period.

3. RESULTS

3.1 Missing value analysis

The available daily values of mean temperature and precipitation are shown for 3 meteorological stations: Bathurst, Moncton and St John. As shown in Figure 3.1, the availability of the raw data is not constant through these 3 stations and through the historical time window. Bathurst presents a high percentage of missing data (42.2%). This translate into a lower level of confidence and the results for Bathurst should be analyzed with this caveat in mind. However, we are looking at climatological values for each climate index and as such, this level of missing value represent a quality flag of “C” per Environment Canada standard. While Moncton and Saint John have a very low fraction of missing value, Bathurst have complete years without data (e.g. between January 1st 1981 to June 30th 1992, as well as between September 11th 2001 to November 12th 2002).

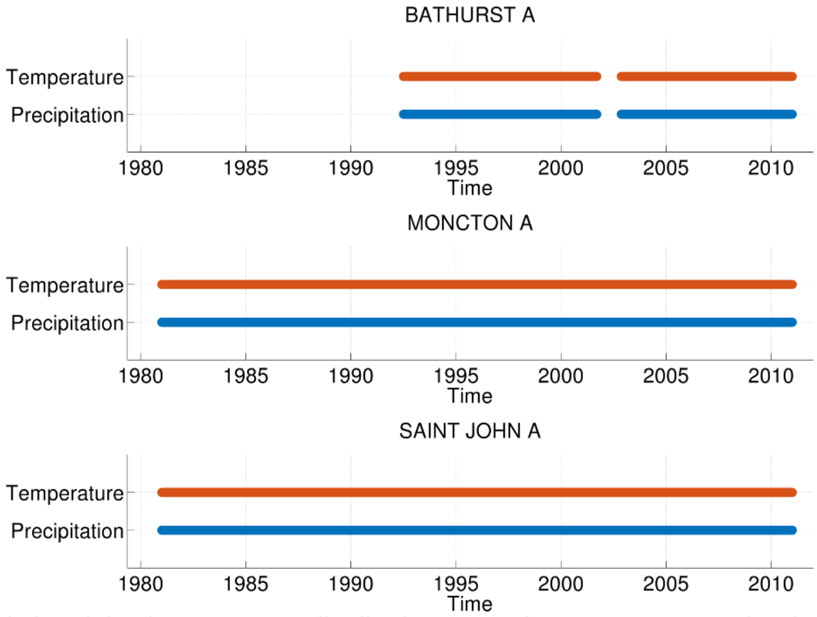

Figure 3.1 Available daily data temporal distribution for Bathurst, Moncton and Saint John for daily precipitation and mean temperature

3.2 Climate change signal for climate indices

The ensemble mean is often used as the best estimate for climate change signal. The following tables (Table 3.1 to Table 3.3) show the magnitude of the climate change signal in “delta” values, either in absolute value (temperature based climate indices) or relative (precipitation based climate indices) changes for the entire set of climate indices. For brevity, results are shown for 3 meteorological stations: Bathurst, Moncton and Saint John.

For temperature based climate indices, the difference between RCP 4.5 and 8.5 begins at time horizon 2050 and becomes significant for time horizon 2080. For precipitation based indices, the difference between RCPs is also seen mostly for time horizon 2080, except for summer and fall precipitation where the climate change signal is weaker, and thus is the difference between RCPs.

Table 3.1 Climate change signal for Bathurst

Index	2020		2050		2080	
	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85
AnnTemp (Celsius)	1.19	1.3	2.32	3.25	2.97	5.51
DJFTemp (Celsius)	1.51	1.63	2.88	3.96	3.67	6.47
MAMTemp (Celsius)	1.01	1.1	2.1	2.95	2.75	5.16
JJATemp (Celsius)	1.15	1.24	2.23	3.09	2.78	5.31
SONTemp (Celsius)	1.08	1.23	2.1	3.03	2.68	5.14
GDB10 (degree days)	156.83	174.54	321.48	461.84	412.15	855.85
GDB5 (degree days)	212.81	237.22	436.06	626.25	562.42	1148
CoolDegDays (degree days)	66.26	72.79	145.12	216.68	190.15	437.27
HeatDegDays (degree days)	-366.72	-401.28	-703.29	-970.69	-892.78	-1575.44
AnnTxFr25 (Days)	11.21	12.25	22.16	30.49	27.46	52.24
AnnTxFr30 (Days)	5.71	6.24	13.55	20.42	17.82	40.99
AnnTxFr35 (Days)	0.85	0.9	2.19	3.86	3.27	12.49
AnnTxFrLT0 (Days)	-11.67	-12.44	-21.54	-29.06	-26.77	-44.42
AnnTxFrLTM10 (Days)	-4.71	-4.95	-7.49	-9.23	-8.73	-12.25
AnnTxFrLTM20 (Days)	-0.41	-0.43	-0.53	-0.62	-0.59	-0.68
AnnPrec (%)	4.04	4.97	6.74	10.06	9.61	13.99
DJFPrec (%)	7.15	8.44	10.5	17.8	15.07	25.35
MAMPrec (%)	4.69	5.51	8.27	11.3	10.98	19.52
JJAPrec (%)	3.08	5.38	5.15	7.49	7.88	9.3
SONPrec (%)	1.91	1.35	3.9	5.12	5.63	4.13
CHU (degree days)	158	174.23	311	438.23	395.6	727.84
AnnFT (Days)	-6.1	-7.32	-13.39	-18.34	-17.21	-28.22
DJFFT (Days)	4.01	4.34	7.91	10.77	9.78	15.05
MAMFT (Days)	-4.93	-5.59	-11.31	-15.72	-14.81	-24.23
SONFT (Days)	-4.25	-5	-8.24	-11.08	-10.06	-16.43
GSL (Days)	12.68	13.06	23.3	35.25	31.94	71.31
AnnRD (Days)	-4.02	-3.44	-3.04	-2.57	-2.66	-2.5
AnnSD (Days)	-9999	-9999	-9999	-9999	-9999	-9999
FFD (Days)	17.77	19.75	34.95	47.42	44	72.66

Table 3.2 Climate change signal for Moncton

Index	**2020**		**2050**		**2080**	
	RCP45	**RCP85**	**RCP45**	**RCP85**	**RCP45**	**RCP85**
AnnTemp (Celsius)	1.16	1.25	2.23	3.09	2.82	5.22
DJFTemp (Celsius)	1.5	1.57	2.72	3.69	3.43	5.98
MAMTemp (Celsius)	1	1.06	2.01	2.77	2.57	4.78
JJATemp (Celsius)	1.14	1.25	2.2	3.01	2.72	5.17
SONTemp (Celsius)	1.05	1.2	2.06	2.96	2.62	5.01
GDB10 (degree days)	161.58	181.74	326.09	464.42	415.04	851.22
GDB5 (degree days)	216.34	241.96	436.04	620.69	557.6	1125.25
CoolDegDays (degree days)	64.75	72.14	140.19	208.59	183.86	423.81
HeatDegDays (degree days)	-357.26	-385.33	-673.15	-920.22	-844.46	-1480.95
AnnTxFr25 (Days)	13.02	14.59	25.15	34.01	30.87	56.43
AnnTxFr30 (Days)	4.96	5.53	11.65	18.06	15.94	38.94
AnnTxFr35 (Days)	0.17	0.21	0.75	1.59	1.31	7.48
AnnTxFrLT0 (Days)	-13.08	-13.29	-21.82	-28.46	-26.37	-41.99
AnnTxFrLTM10 (Days)	-3.43	-3.43	-5.51	-7.07	-6.6	-9.56
AnnTxFrLTM20 (Days)	-0.18	-0.19	-0.23	-0.24	-0.24	-0.26
AnnPrec (%)	4.22	4.58	6.76	8.36	8.21	11.89
DJFPrec (%)	7.61	8.16	10.02	15.57	13.05	21.16
MAMPrec (%)	4.52	6.38	9.11	10.14	9.51	16.82
JJAPrec (%)	2.64	3.89	4	5.23	6.72	7.72
SONPrec (%)	3.24	1.18	4.99	3.6	4.89	3.01
CHU (Corn Units)	161.25	179.58	323.52	449.96	409.66	750.32
AnnFT (Days)	-3.76	-4.98	-11.28	-17.09	-15.43	-28.52
DJFFT (Days)	4.94	5.01	6.94	8.61	8.06	11.61
MAMFT (Days)	-4.11	-4.74	-9.29	-13.14	-12.28	-20.98
SONFT (Days)	-4.22	-4.88	-8.45	-12.08	-10.72	-18.69
GSL (Days)	7.56	8.13	20.41	32.71	28.88	60.67
AnnRD (Days)	-5.36	-5.16	-4.28	-3.67	-3.69	-3.55
AnnSD (Days)	-6.79	-7.32	-10.65	-15.14	-14.49	-26.38
FFD (Days)	16.84	18.27	33.11	45.54	41.8	70.53

Table 3.3 Climate change signal for Saint John

	2020		2050		2080	
	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85
AnnTemp (Celsius)	1.15	1.24	2.19	3.05	2.77	5.13
DJFTemp (Celsius)	1.39	1.44	2.51	3.49	3.22	5.71
MAMTemp (Celsius)	1	1.06	1.97	2.75	2.55	4.7
JJATemp (Celsius)	1.16	1.25	2.2	3.01	2.73	5.13
SONTemp (Celsius)	1.07	1.21	2.08	2.97	2.62	5.01
GDB10 (degree days)	160.48	179.12	323.24	461.53	412.73	846.33
GDB5 (degree days)	223.16	247.37	445.99	635.87	571.91	1147.64
CoolDegDays (degree days)	40.98	45.45	97.26	154.21	133.8	343.68
HeatDegDays (degree days)	-378.24	-405.86	-700.9	-959.63	-877.98	-1529.8
AnnTxFr25 (Days)	11.15	12.33	22.91	32.92	29.42	59.6
AnnTxFr30 (Days)	1.33	1.44	4.02	7.28	6.18	21.63
AnnTxFr35 (Days)	0.01	0.01	0.12	0.26	0.22	1.91
AnnTxFrLT0 (Days)	-10.24	-10.56	-17.9	-24.1	-22.18	-35.5
AnnTxFrLTM10 (Days)	-2.8	-2.79	-4.55	-5.89	-5.5	-7.89
AnnTxFrLTM20 (Days)	-0.07	-0.06	-0.11	-0.13	-0.12	-0.13
AnnPrec (%)	3.83	4.11	6.77	7.9	8.3	11.74
DJFPrec (%)	7.28	7.44	9.51	14.39	12.23	20.6
MAMPrec (%)	3.78	5.17	8.69	9.38	8.8	16.46
JJAPrec (%)	2.24	4.04	4.84	5.16	8.28	7.14
SONPrec (%)	2.55	0.87	4.84	3.35	5.03	3.57
CHU (Corn Units)	202.11	222.25	392.98	540.78	493.74	899.02
AnnFT (Days)	-8.16	-9.08	-15.45	-21.51	-19.85	-33.22
DJFFT (Days)	2.42	2.54	4.09	5.07	4.82	6.71
MAMFT (Days)	-5.62	-6.06	-10.48	-14.35	-13.5	-21.99
SONFT (Days)	-4.74	-5.32	-8.72	-11.83	-10.76	-17.22
GSL (Days)	14.61	15.31	30.12	43.15	39.61	73.87
AnnRD (Days)	-3.23	-3.05	-2.52	-2.2	-2.32	-2.26
AnnSD (Days)	-4.93	-5.29	-8.18	-11.63	-11.4	-20.99
FFD (Days)	18.4	19.64	33.35	45.61	42.03	68.73

3.3 Ensemble spread

The spread of the ensemble informs us on the robustness of the climate change signal. Figure 3.2 to Figure 3.4 show the ensemble spread for mean temperature and precipitation for the three time horizons of the study; highlighting the magnitude of uncertainty of the simulations ensemble. Because all simulations are split according to their RCP scenario, the spread is due to the climate sensitivity and natural climate variability. Model sensitivity arises from the different behaviour of climate models to increased GHG (i.e. climate sensitivity) because they are differences in their numerical formulations and well as their physical approximations. Natural climate variability arises out of the chaotic nature of the system and is expected to decrease with the averaging time scale; that is, natural flucttutations of 30 year averages are smaller than fluctuations of 10 year averages. It is a relatively safe approximation to assume that natural variability is constant over the 21st century, and that the increase in the spread seen in those figures is due to the models sensitivity to rising GHG concentrations.

3.3.1 Temperature and precipitation

The following figures show the ensemble spread for the climate change signal of temperature and precipitations at Bathurst, Moncton and Saint John.

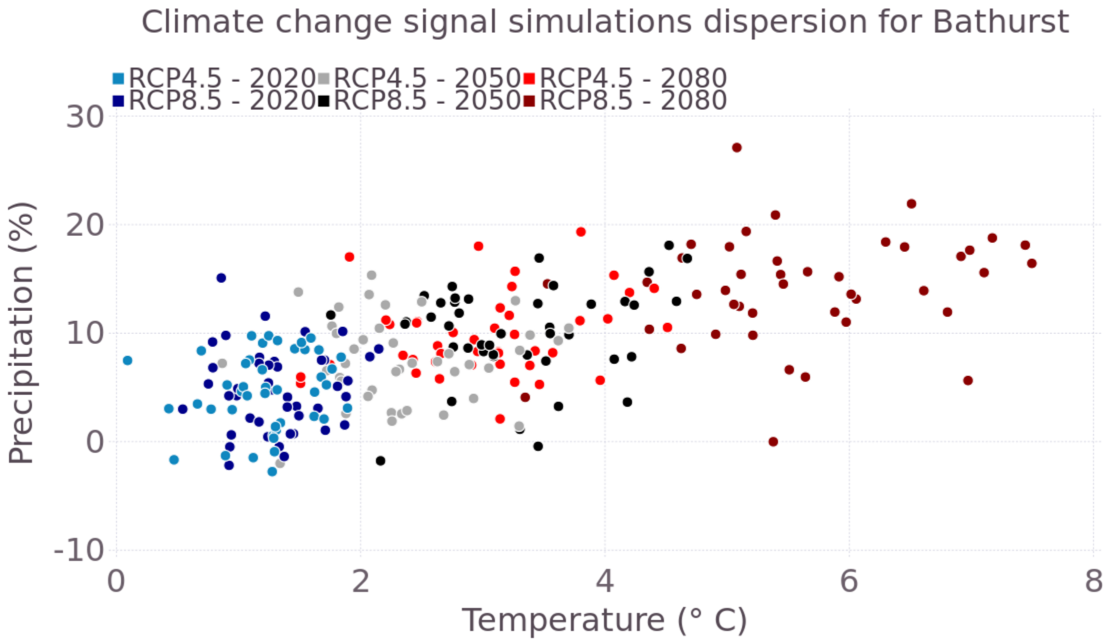

Figure 3.2 Simulations dispersion for mean temperature and precipitation changes for Horizons 2020, 2050 and 2080 with respect to the 1981-2010 period for Bathurst

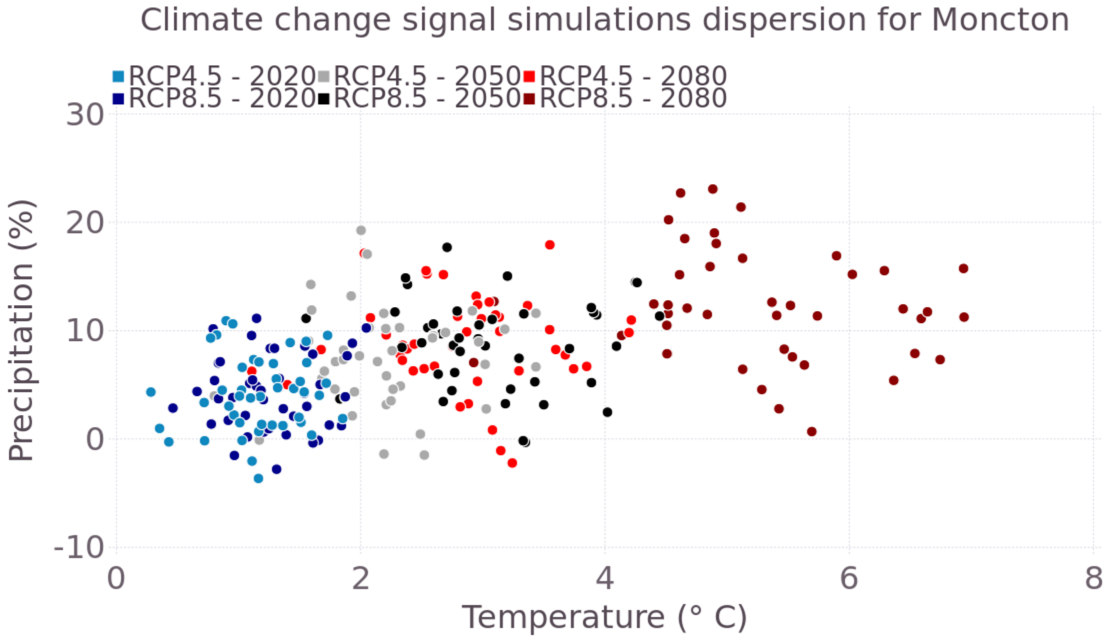

Figure 3.3 Simulations dispersion for mean temperature and precipitation changes for Horizons 2020, 2050 and 2080 with respect to the 1981-2010 period for Moncton

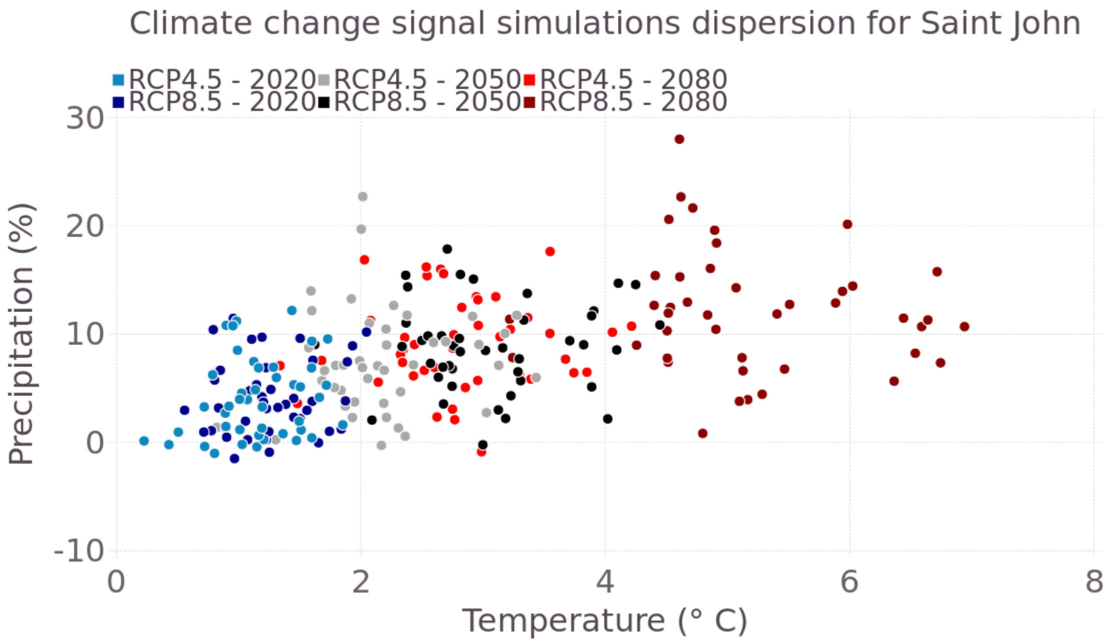

Figure 3.4 Simulations dispersion for mean temperature and precipitation changes for Horizons 2020, 2050 and 2080 with respect to the 1981-2010 period for Saint John

3.3.2 Climate change signal dispersion for climate indices

Figure 3.5 to Figure 3.91 display the ensemble spread for the 2020, 2050 and 2080 horizons, for both RCP (4.5 and 8.5) and all 29 climate indices for each meteorological station. The first column of each figure show the historic baseline for each climate index and each station, and the three rightmost columns show box plots of future indicators for RCP 4.5 and RCP 8.5 over each horizon according to the simulations in the ensemble. The red line in the center represent the median value, the box represent the Inter-Quartile Range (IQR) of the distribution (i.e. 25th and 75th percentiles), the whiskers encompass about 99.3% of the distribution, and red dots are considered outliers (with respect to the statistical proprety of the distribution, not necessarily/automatically outliers in physical terms).

The climate change signal is rather strong for temperature based climate indices, with increases for all seasons and meteorological stations. Generally speaking, the projected increases for temperature based climate indices are stronger than for precipitation, with the enveloppe of projected change being over and distinct from the historical values. These increases in temperature based indices are directly caused by the general mean temperature increase.

For precipitation, part of the enveloppe goes lower than the historical values. This means that the probability to have lower precipitation values than during the reference period is not zero, in particular for summer and fall precipitation. For winter and spring precipitation amount, the increase signal is slightly stronger. The annual precipitation accumulation sits in-between, encompassing the stronger signal from the winter and spring seasons and the weaker signal from summer and fall seasons.

3.3.3 Bathurst

Simulations dispersions for temperature based climate indices.

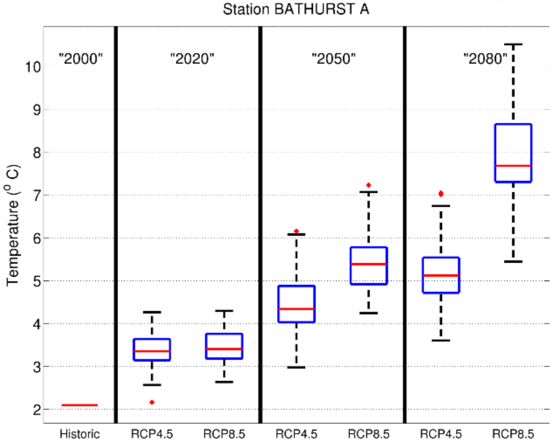

Figure 3.5 Simulations dispersion for mean annual temperature for Bathurst

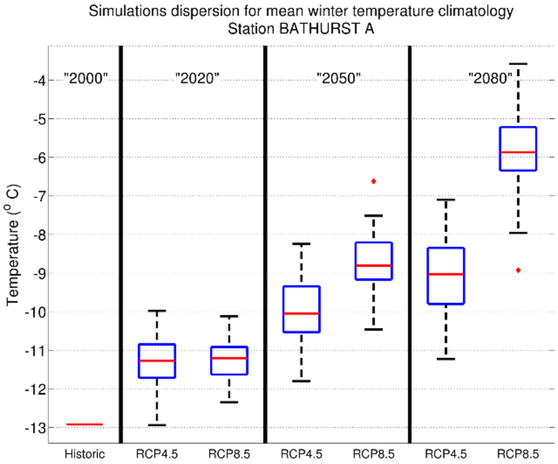

Figure 3.6 Simulations dispersion for mean winter temperature for Bathurst

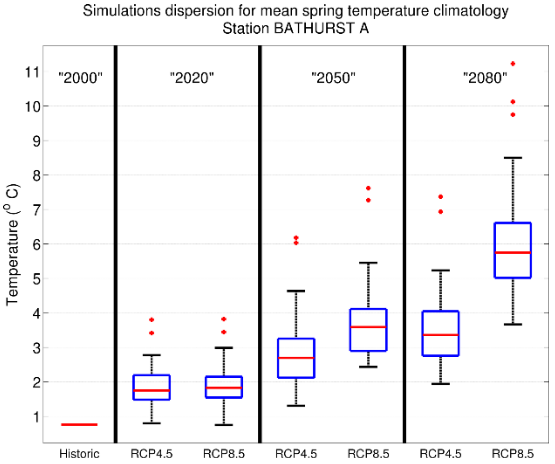

Figure 3.7 Simulations dispersion for mean spring temperature for Bathurst

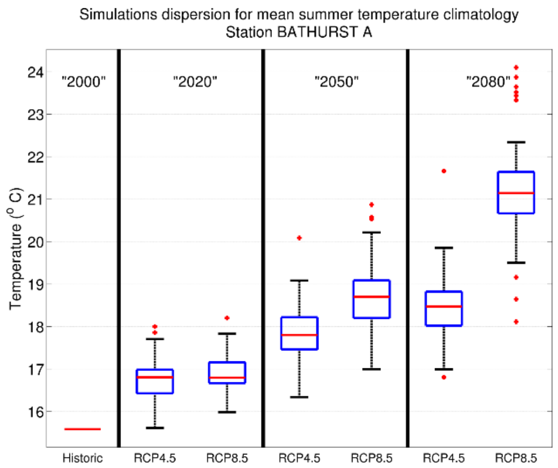
Simulations dispersion for mean summer temperature climatology
Station BATHURST A

Figure 3.8 Simulations dispersion for mean summer temperature for Bathurst

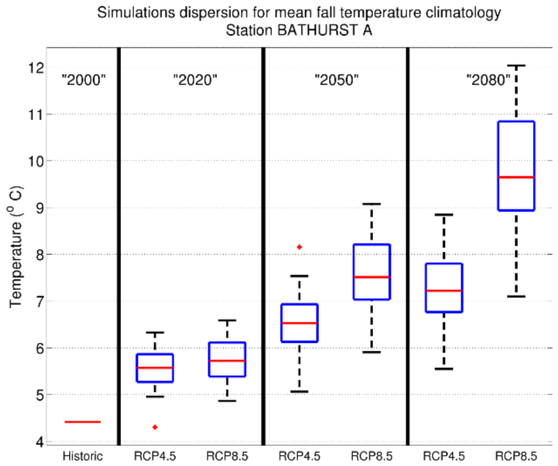
Simulations dispersion for mean fall temperature climatology
Station BATHURST A

Figure 3.9 Simulations dispersion for mean fall temperature for Bathurst

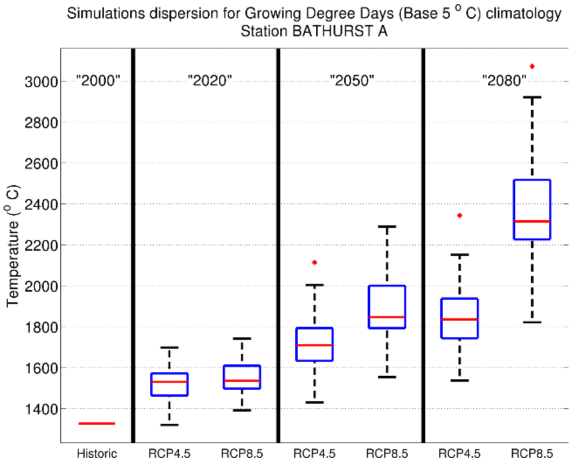
Simulations dispersion for Growing Degree Days (Base 5 ° C) climatology
Station BATHURST A

Figure 3.10 Simulations dispersion for Growing Degree Days (Base 5 ° C) for Bathurst

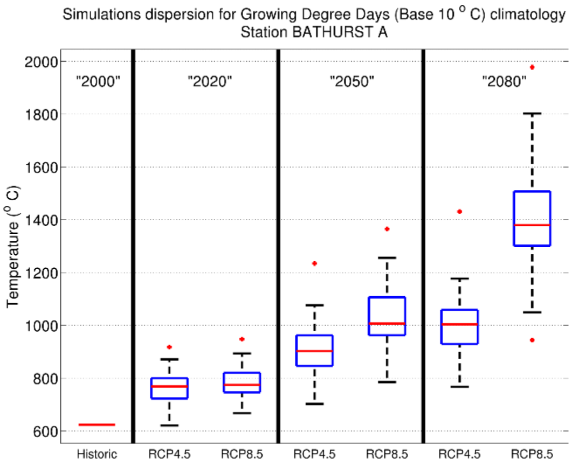

Figure 3.11 Simulations dispersion for Growing Degree Days (Base 10 °C) for Bathurst

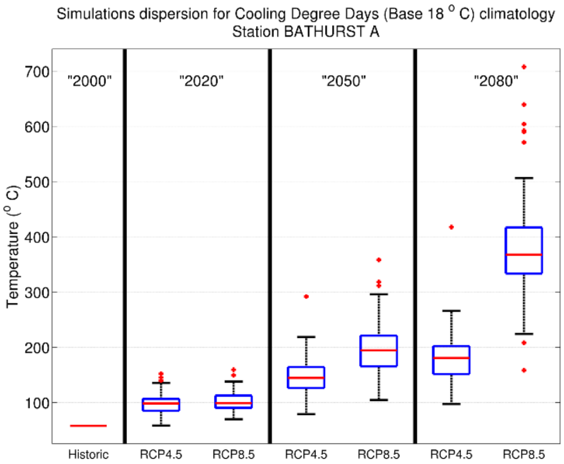

Figure 3.12 Simulations dispersion for Cooling Degree Days (Base 18 °C) for Bathurst

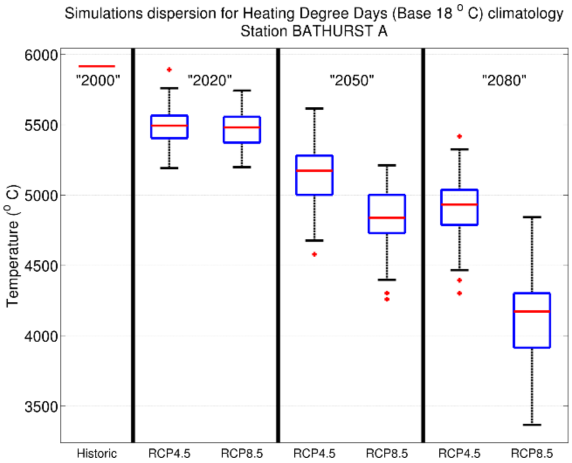

Figure 3.13 Simulations dispersion for Heating Degree Days (Base 18 °C) for Bathurst

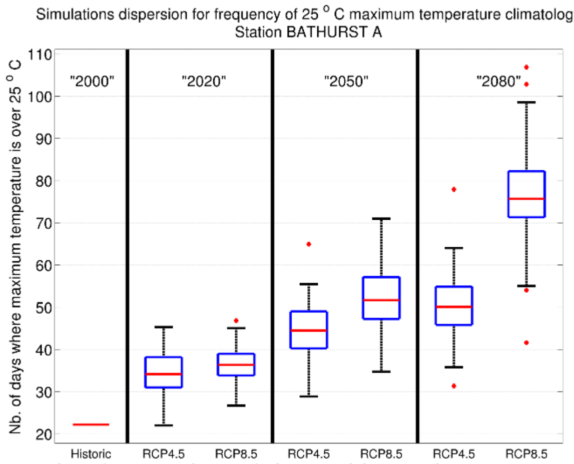

Figure 3.14 Simulations dispersion for number of days with maximum temperature higher than 25 °C for Bathurst

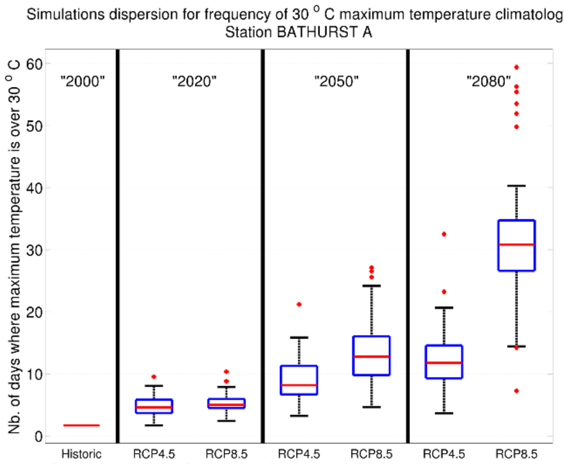

Figure 3.15 Simulations dispersion for number of days with maximum temperature higher than 30 °C for Bathurst

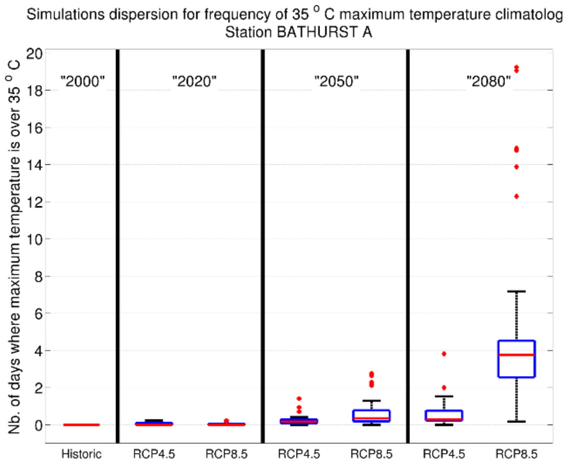

Figure 3.16 Simulations dispersion for number of days with maximum temperature higher than 35 °C for Bathurst

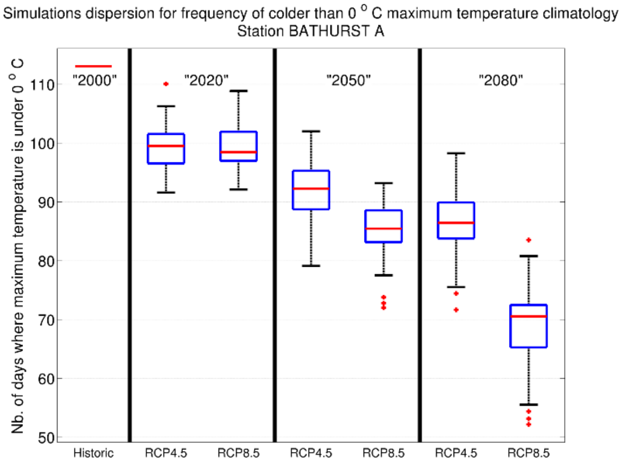

Figure 3.17 Simulations dispersion for number of days with maximum temperature lower than 0 °C for Bathurst

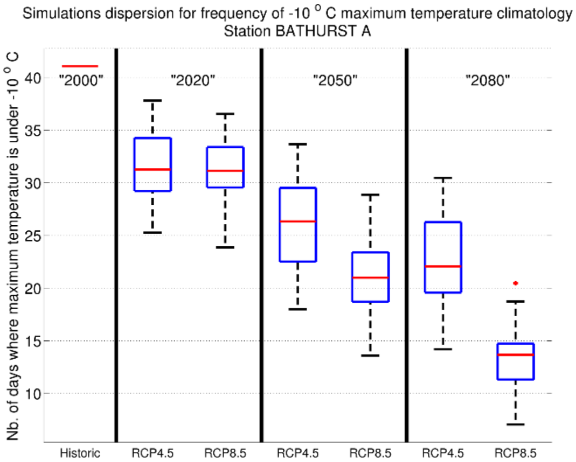

Figure 3.18 Simulations dispersion for number of days with maximum temperature lower than -10 °C for Bathurst

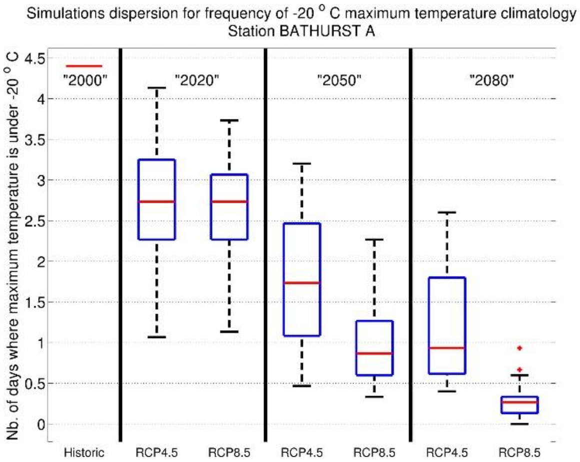

Figure 3.19 Simulations dispersion for number of days with maximum temperature lower than -20 °C for Bathurst

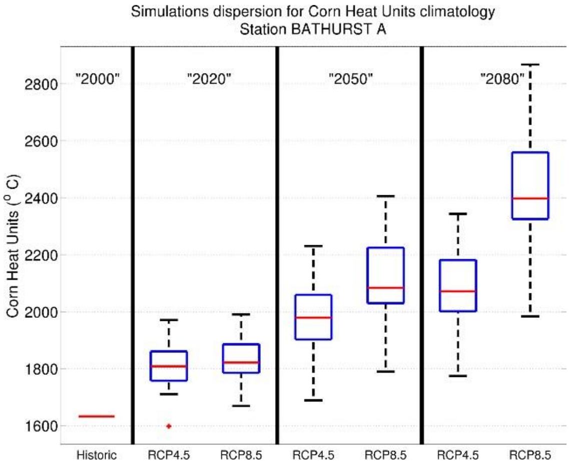

Figure 3.20 Simulations dispersion for Corn Heat Units (see description in Appendix A) for Bathurst

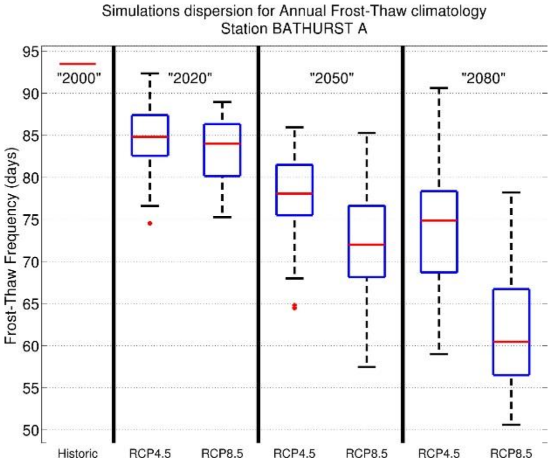

Figure 3.21 Simulations dispersion for the annual occurrence of frost-thaw cycle for Bathurst

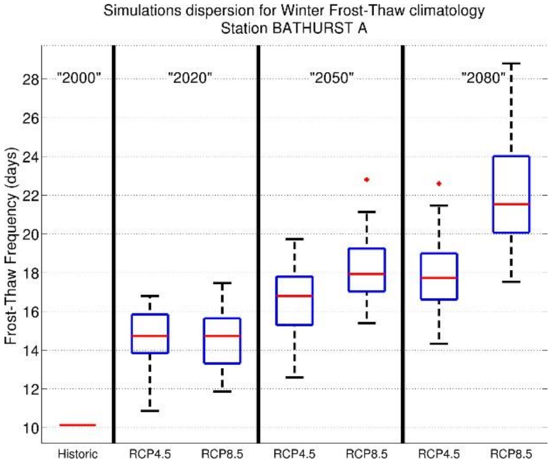

Figure 3.22 Simulations dispersion for the winter occurrence of frost-thaw cycle for Bathurst

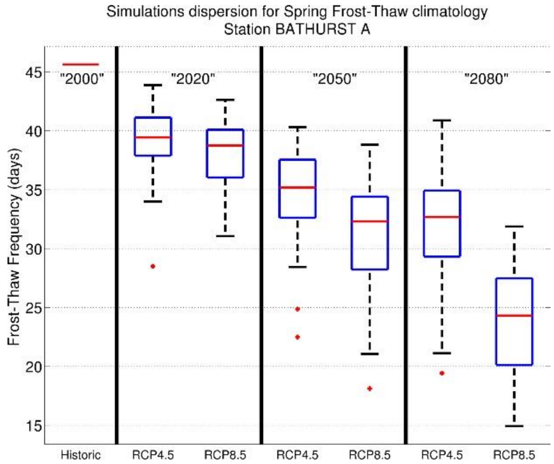

Figure 3.23 Simulations dispersion for spring occurrence of frost-thaw cycle for Bathurst

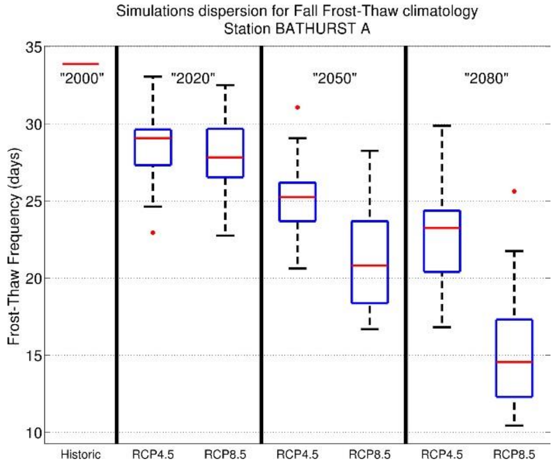

Figure 3.24 Simulations dispersion for fall frost-thaw cycle for Bathurst

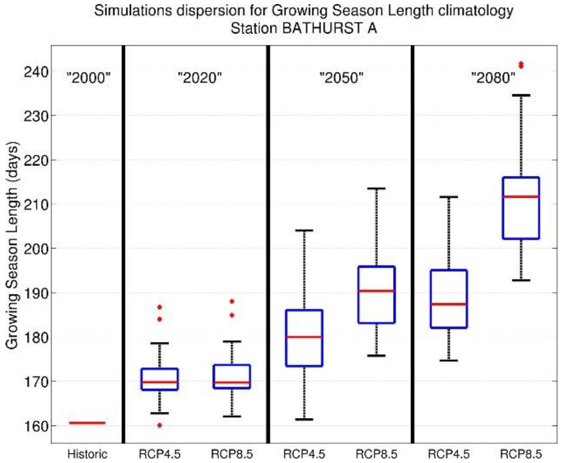

Figure 3.25 Simulations dispersion for Growing Season Length for Bathurst

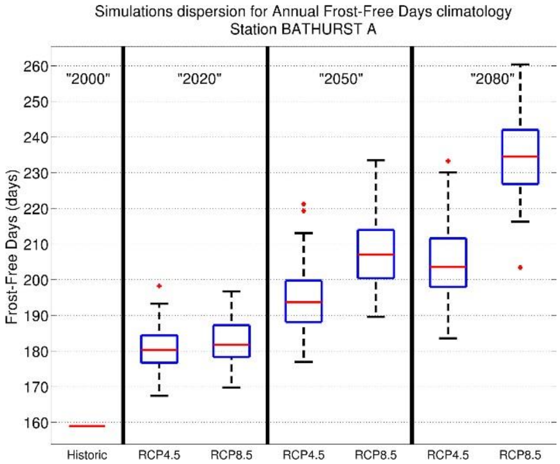

Figure 3.26 Simulations dispersion for annual number of frost-free days for Bathurst

Simulations dispersion for precipitation based climate indices

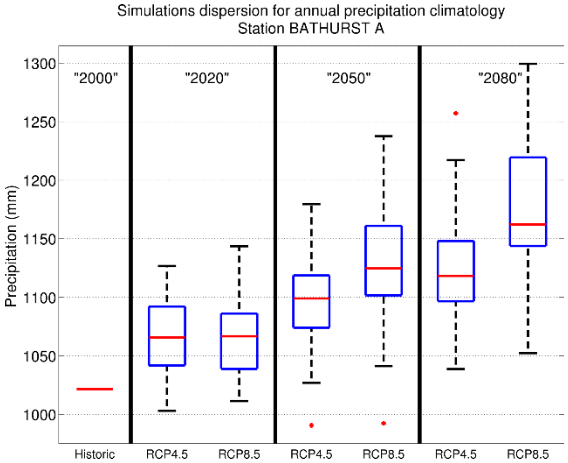

Figure 3.27 Simulations dispersion for annual precipitation accumulation for Bathurst

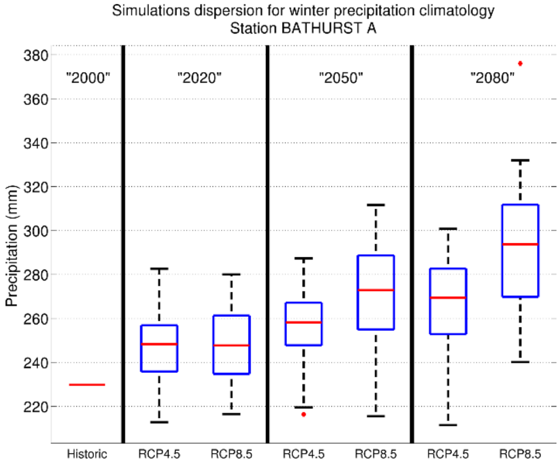

Figure 3.28 Simulations dispersion for winter precipitation accumulation for Bathurst

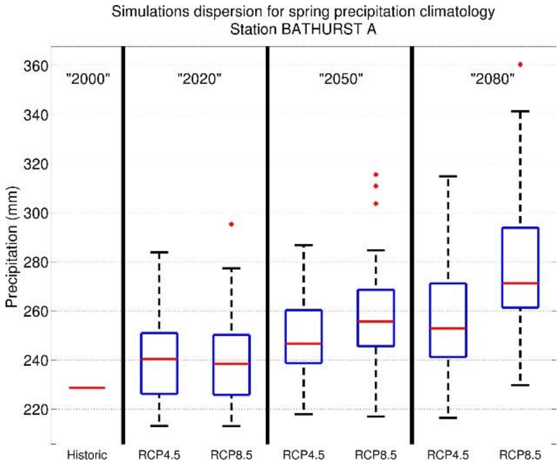

Figure 3.29 Simulations dispersion for spring precipitation accumulation for Bathurst

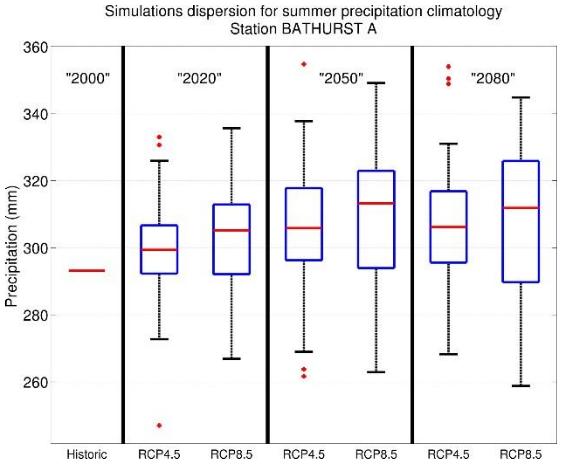

Figure 3.30 Simulations dispersion for summer precipitation accumulation for Bathurst

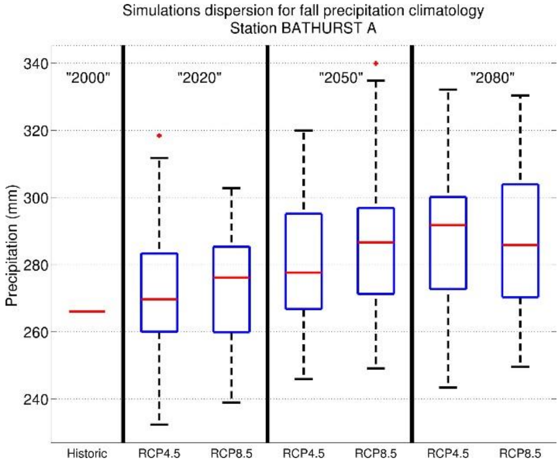

Figure 3.31 Simulations dispersion for fall precipitation accumulation for Bathurst

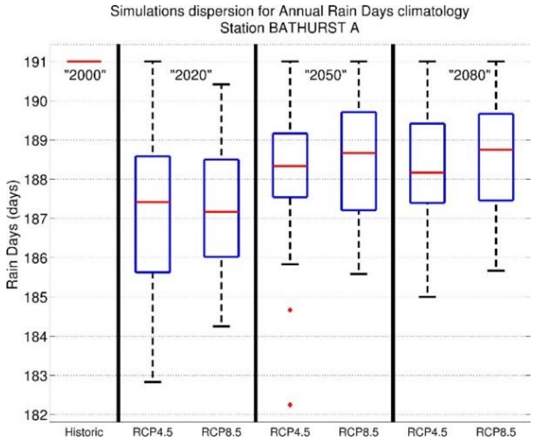

Figure 3.32 Simulations dispersion for annual number of rain days for Bathurst

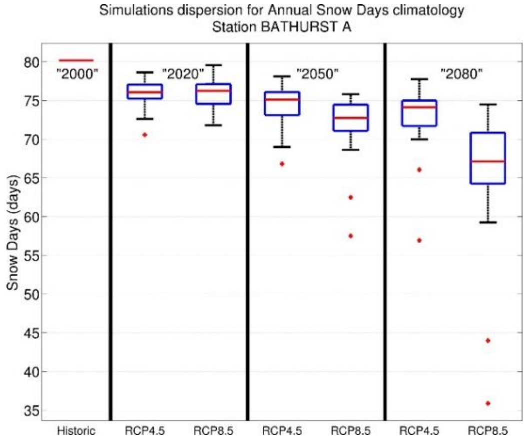

Figure 3.33 Simulations dispersion for annual number of snow days for Bathurst

3.3.4 Moncton

<u>Simulations dispersions for temperature based climate indices</u>

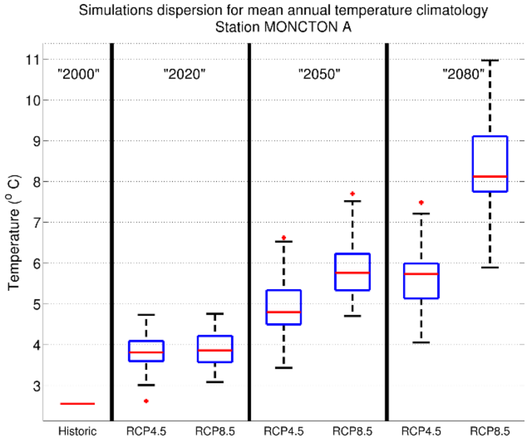

Figure 3.34 Simulations dispersion for mean annual temperature for Moncton

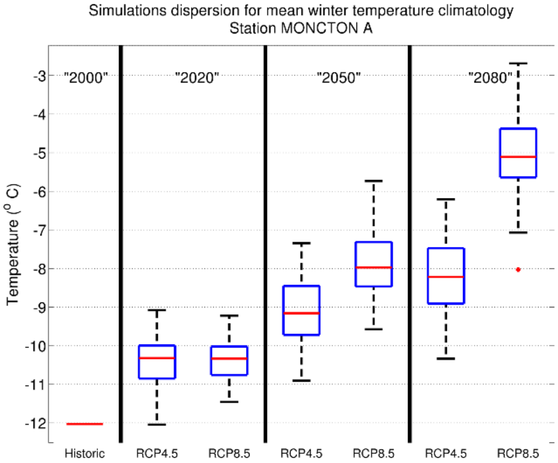

Figure 3.35 Simulations dispersion for mean winter temperature for Moncton

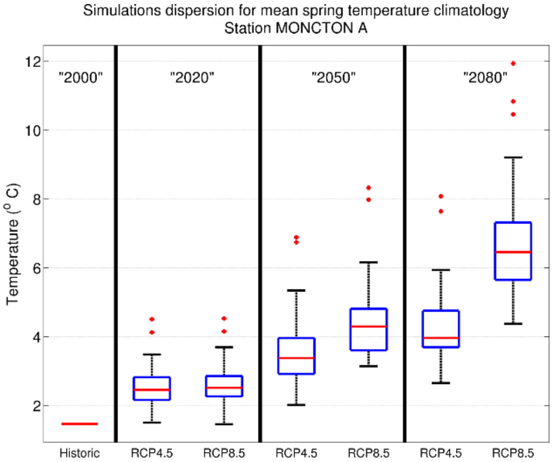

Figure 3.36 Simulations dispersion for mean spring temperature for Moncton

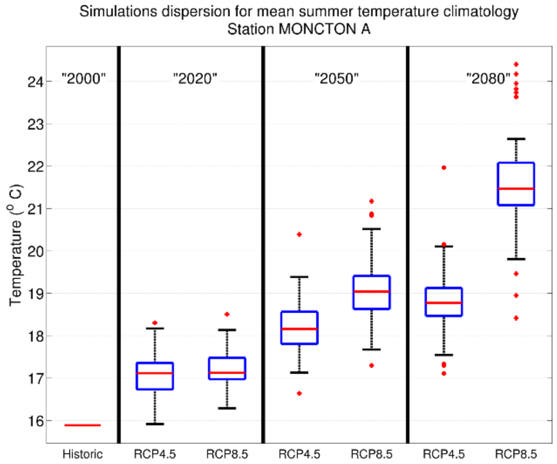

Figure 3.37 Simulations dispersion for mean summer temperature for Moncton

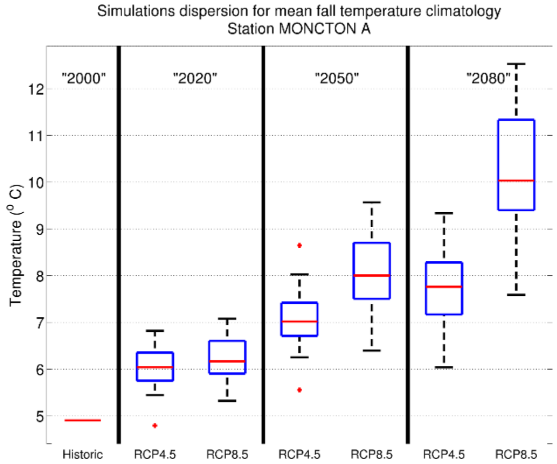

Figure 3.38 Simulations dispersion for mean fall temperature for Moncton

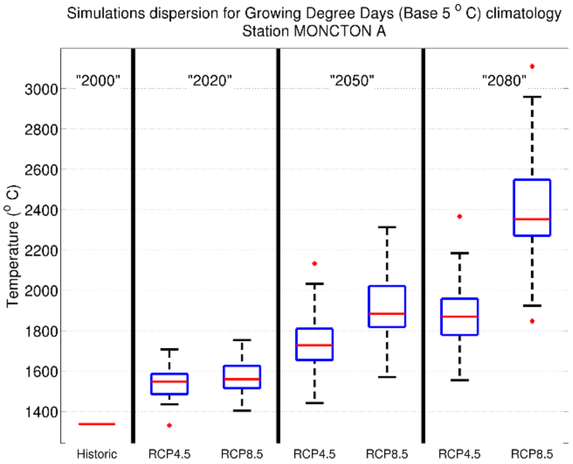

Figure 3.39 Simulations dispersion for Growing Degree Days (Base 5 ° C) for Moncton

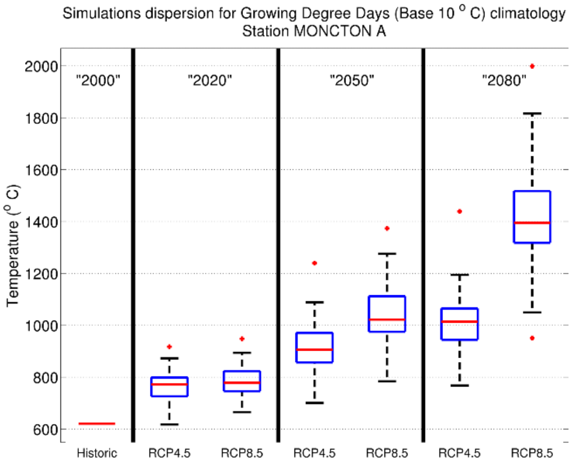

Figure 3.40 Simulations dispersion for Growing Degree Days (Base 10 °C) for Moncton

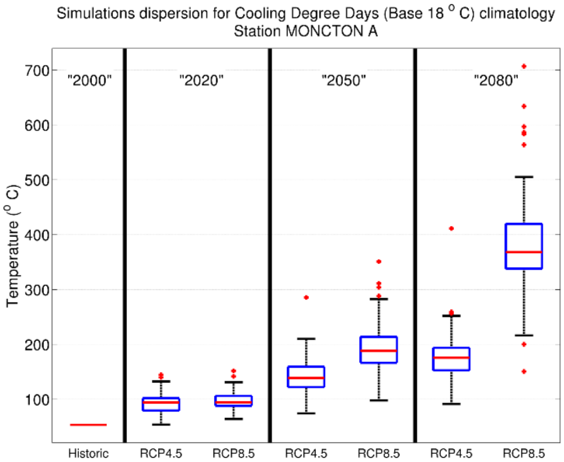

Figure 3.41 Simulations dispersion for Cooling Degree Days (Base 18 °C) for Moncton

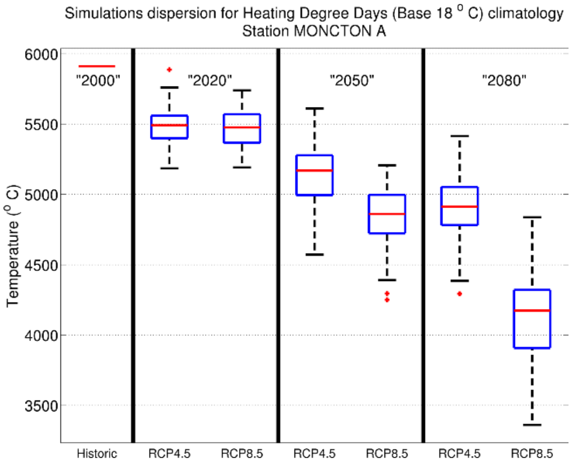

Figure 3.42 Simulations dispersion for Heating Degree Days (Base 18 °C) for Moncton

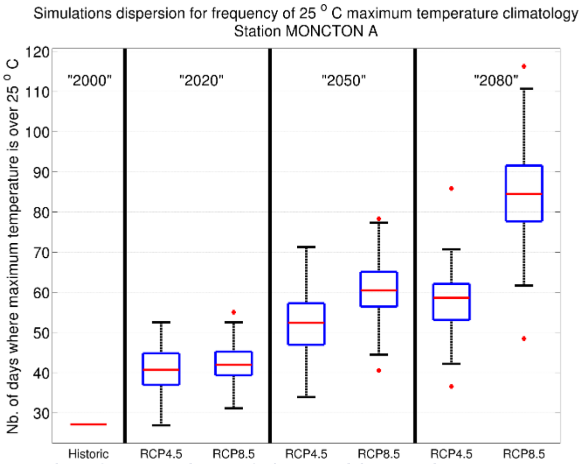

Figure 3.43 Simulations dispersion for number of days with maximum temperature higher than 25 °C for Moncton

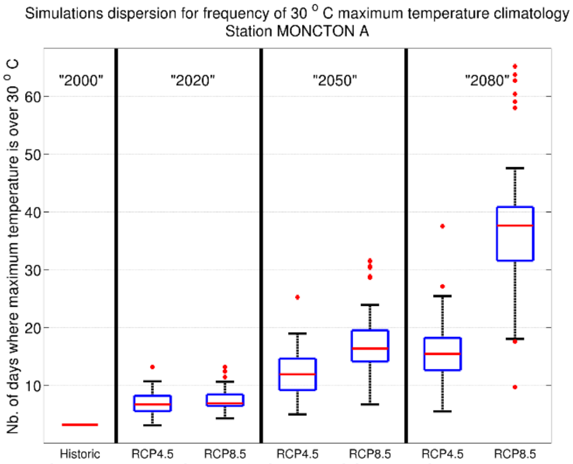

Figure 3.44 Simulations dispersion for number of days with maximum temperature higher than 30 °C for Moncton

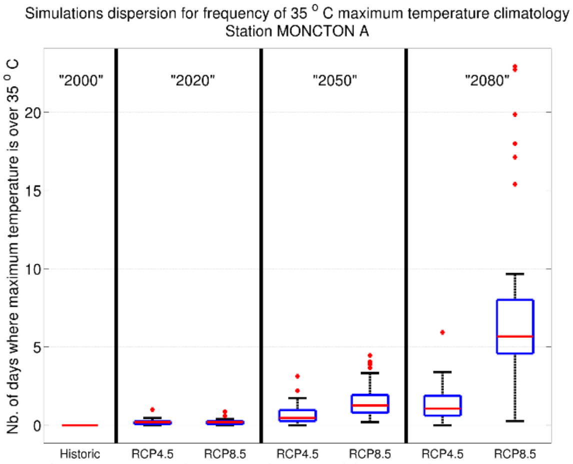

Figure 3.45 Simulations dispersion for number of days with maximum temperature higher than 35 °C for Moncton

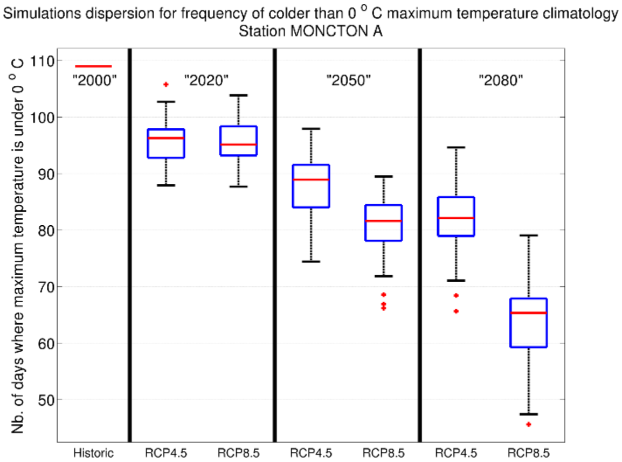

Figure 3.46 Simulations dispersion for number of days with maximum temperature lower than 0 °C for Moncton

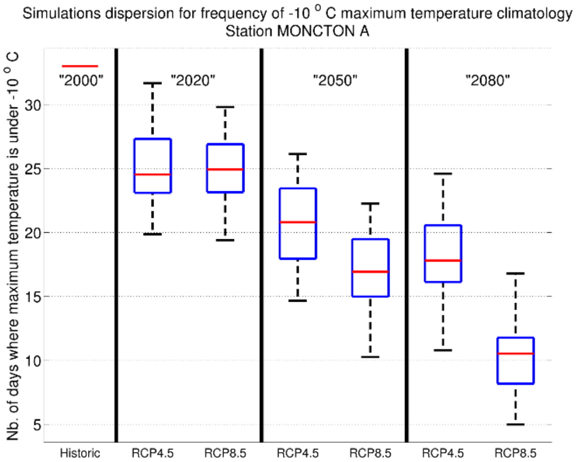

Figure 3.47 Simulations dispersion for number of days with maximum temperature lower than -10 °C for Moncton

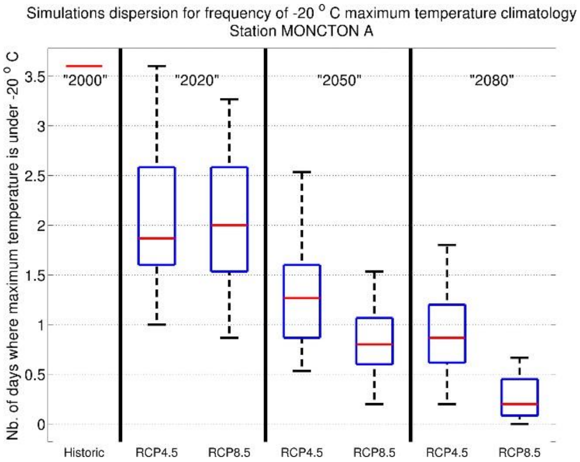

Figure 3.48 Simulations dispersion for number of days with maximum temperature lower than -20 °C for Moncton

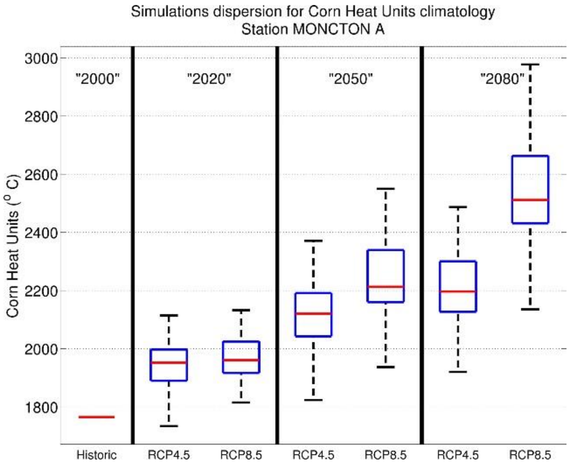

Figure 3.49 Simulations dispersion for Corn Heat Units (see description in Appendix A) for Moncton

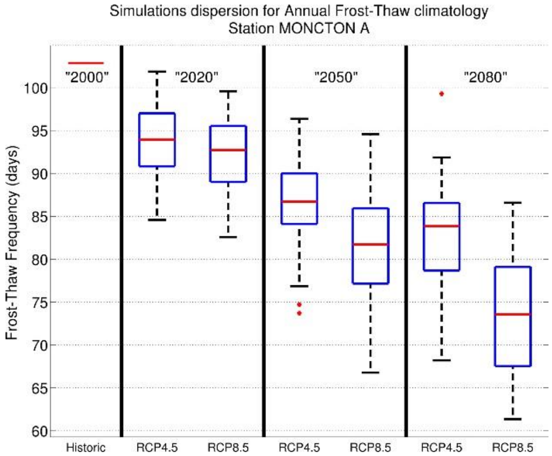

Figure 3.50 Simulations dispersion for the annual occurrence of frost-thaw cycle for Moncton

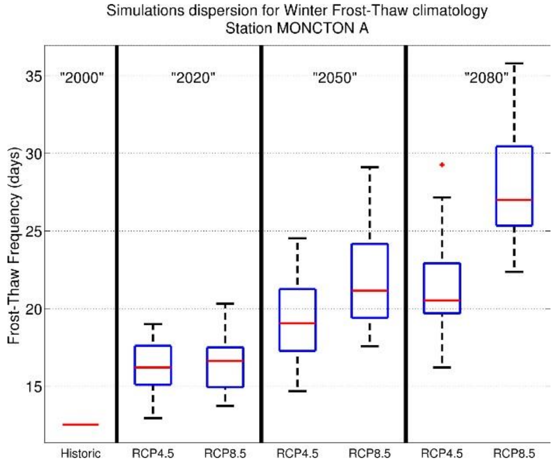

Figure 3.51 Simulations dispersion for the winter occurrence of frost-thaw cycle for Moncton

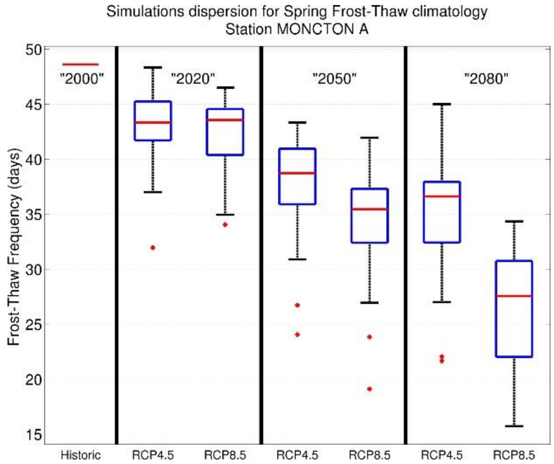

Figure 3.52 Simulations dispersion for spring occurrence of frost-thaw cycle for Moncton

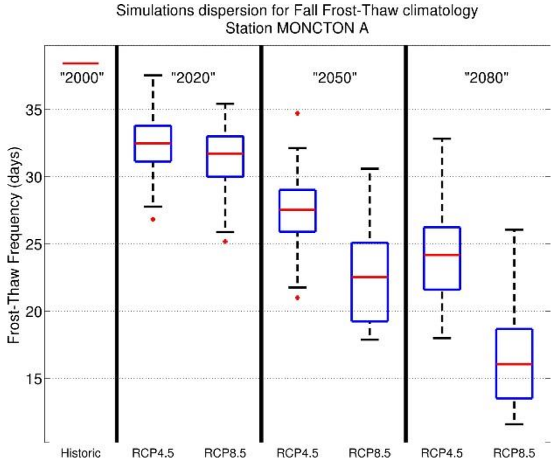

Figure 3.53 Simulations dispersion for fall frost-thaw cycle for Moncton

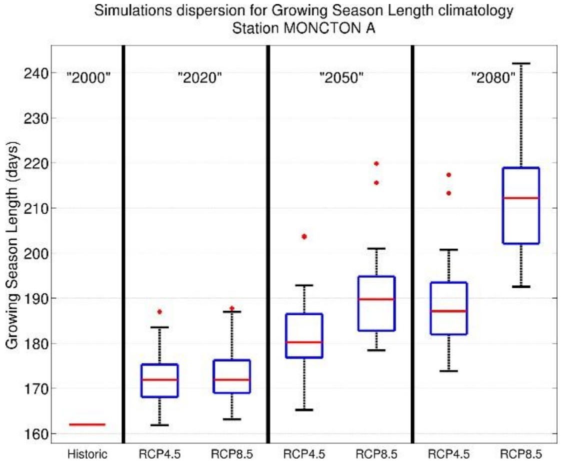

Figure 3.54 Simulations dispersion for Growing Season Length for Moncton

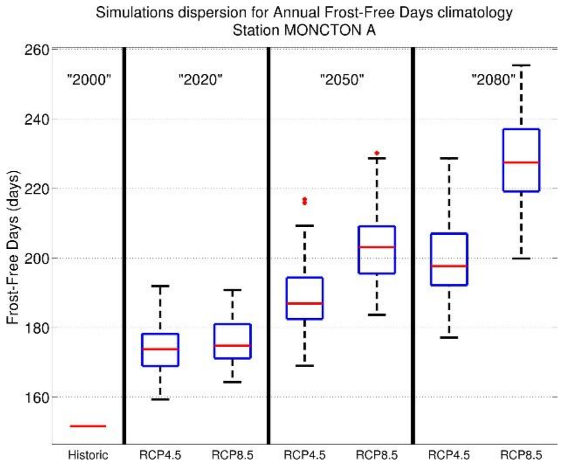

Figure 3.55 Simulations dispersion for annual number of frost-free days for Moncton

Simulations dispersion for precipitation based climate indices

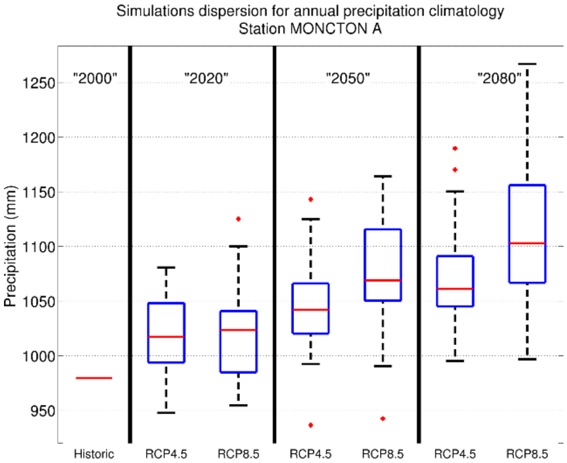

Figure 3.56 Simulations dispersion for annual precipitation accumulation for Moncton

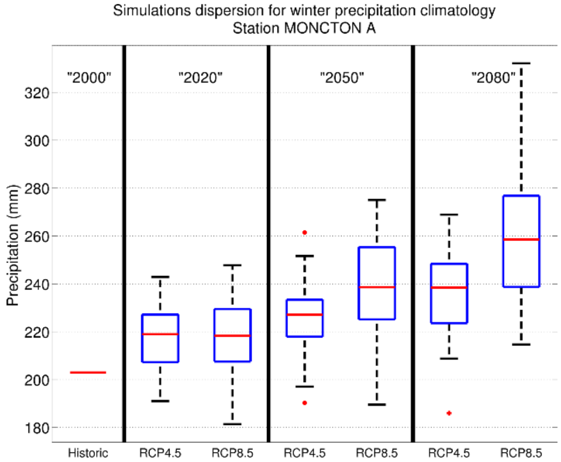

Figure 3.57 Simulations dispersion for winter precipitation accumulation for Moncton

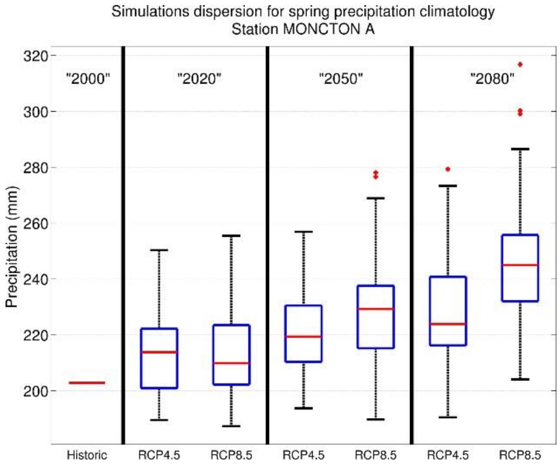

Figure 3.58 Simulations dispersion for spring precipitation accumulation for Moncton

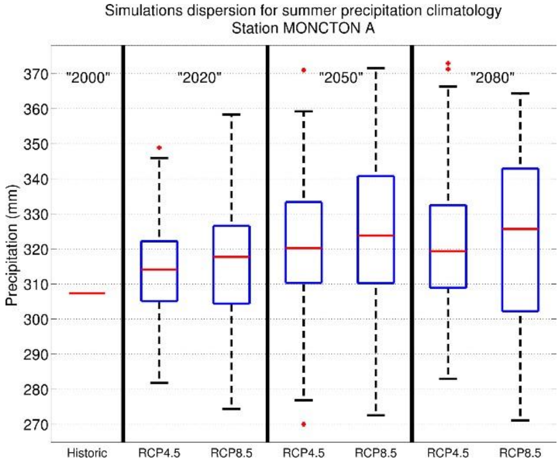

Figure 3.59 Simulations dispersion for summer precipitation accumulation for Moncton

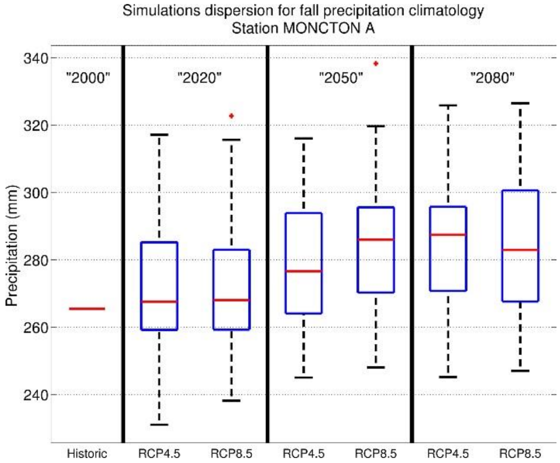

Figure 3.60 Simulations dispersion for fall precipitation accumulation for Moncton

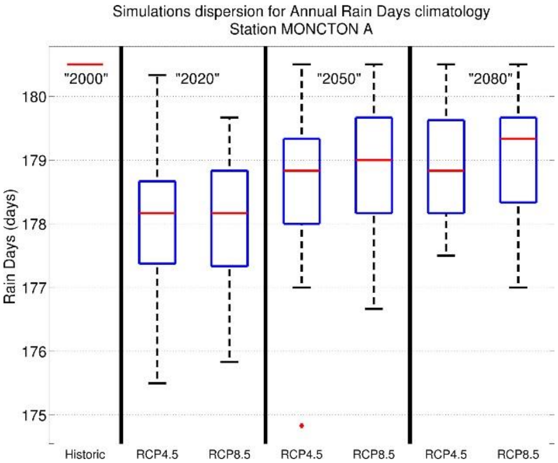

Figure 3.61 Simulations dispersion for annual number of rain days for Moncton

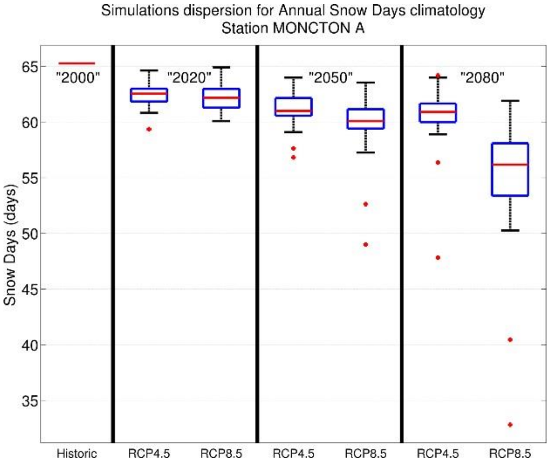

Figure 3.62 Simulations dispersion for annual number of snow days for Moncton

3.3.5 Saint-John

Simulations dispersions for temperature based climate indices

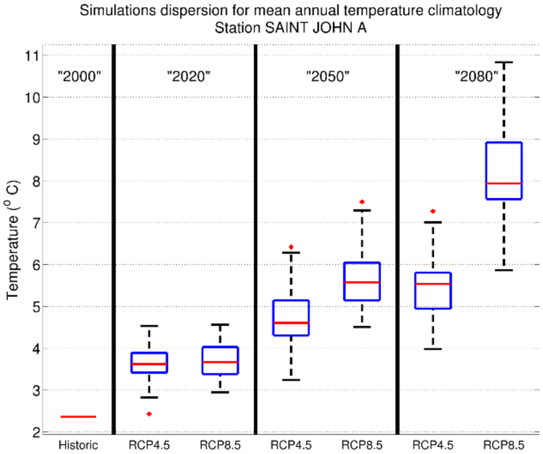

Figure 3.63 Simulations dispersion for mean annual temperature for Saint John

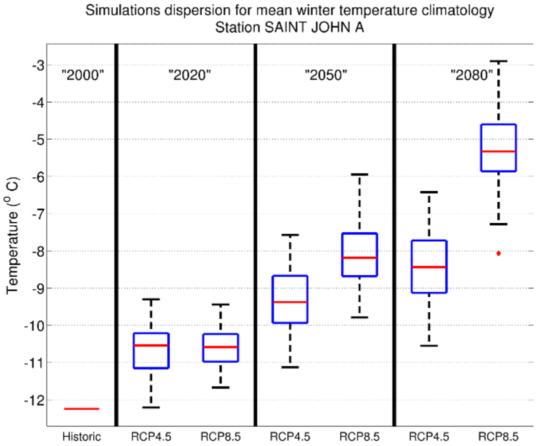

Figure 3.64 Simulations dispersion for mean winter temperature for Saint John

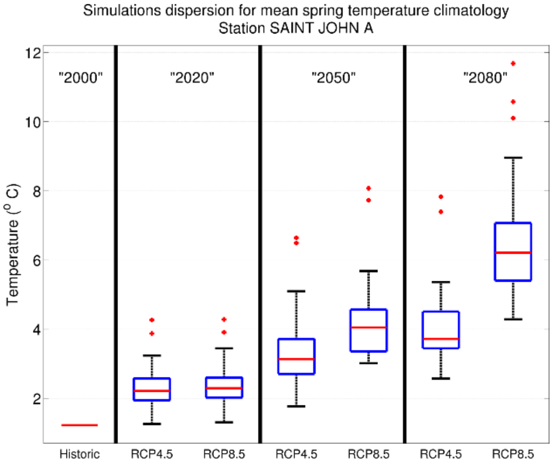

Figure 3.65 Simulations dispersion for mean spring temperature for Saint John

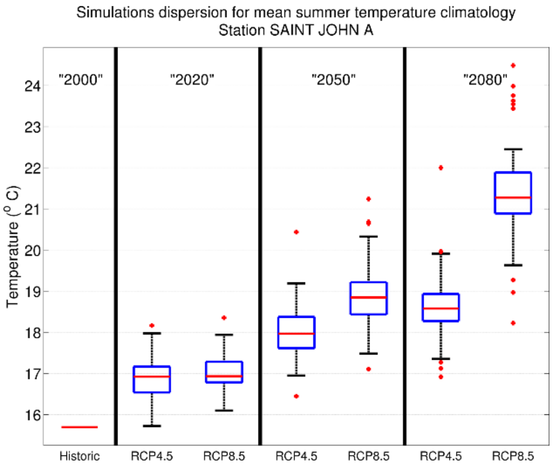

Figure 3.66 Simulations dispersion for mean summer temperature for Saint John

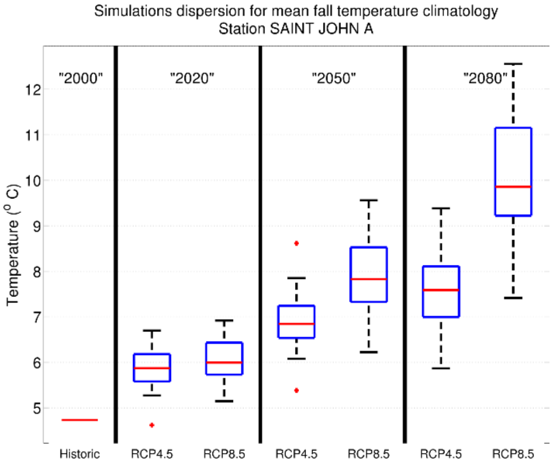

Figure 3.67 Simulations dispersion for mean fall temperature for Saint John

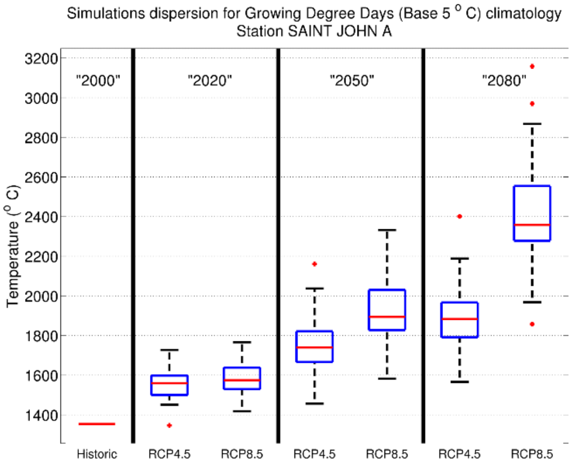

Figure 3.68 Simulations dispersion for Growing Degree Days (Base 5 ° C) for Saint John

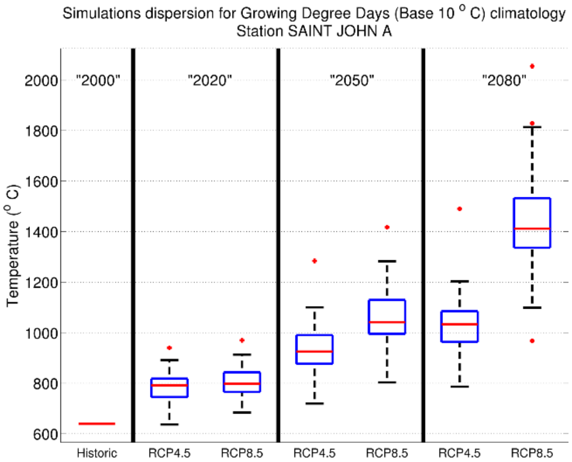

Figure 3.69 Simulations dispersion for Growing Degree Days (Base 10 °C) for Saint John

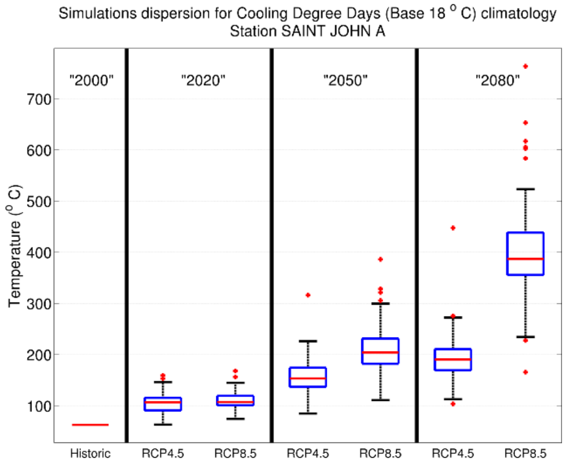

Figure 3.70 Simulations dispersion for Cooling Degree Days (Base 18 °C) for Saint John

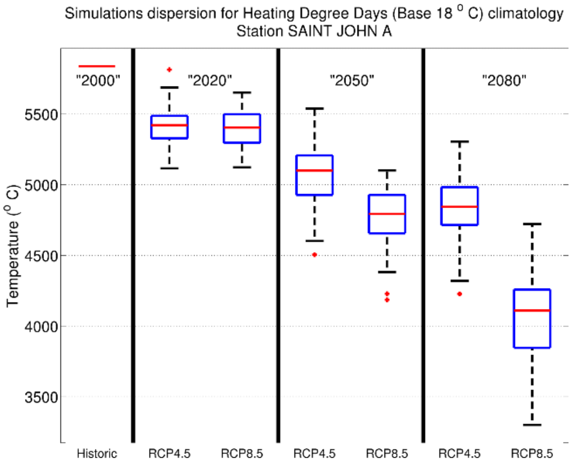

Figure 3.71 Simulations dispersion for Heating Degree Days (Base 18 °C) for Saint John

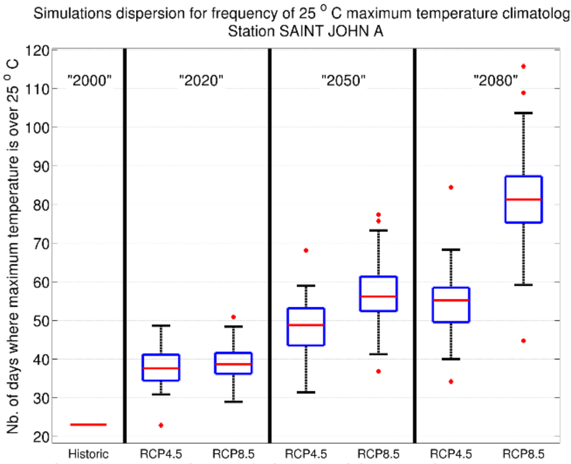

Figure 3.72 Simulations dispersion for number of days with maximum temperature higher than 25 °C for Saint John

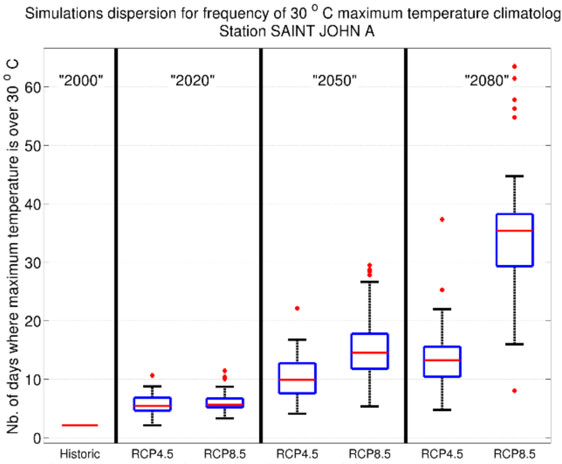

Figure 3.73 Simulations dispersion for number of days with maximum temperature higher than 30 °C for Saint John

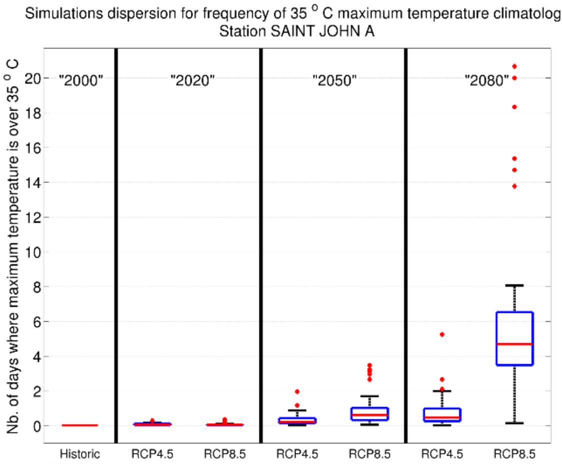

Figure 3.74 Simulations dispersion for number of days with maximum temperature higher than 35 °C for Saint John

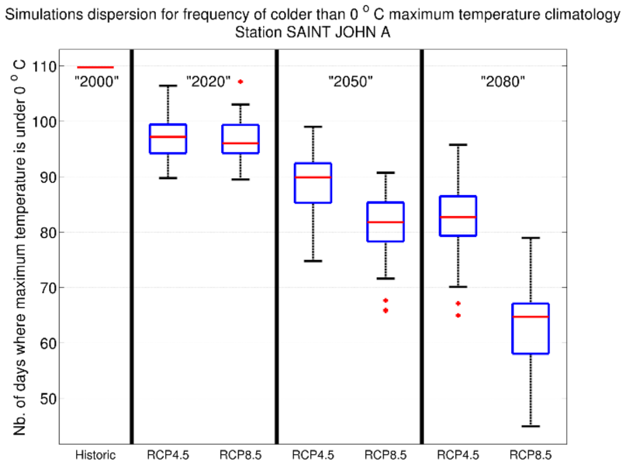

Figure 3.75 Simulations dispersion for number of days with maximum temperature lower than 0 °C for Saint John

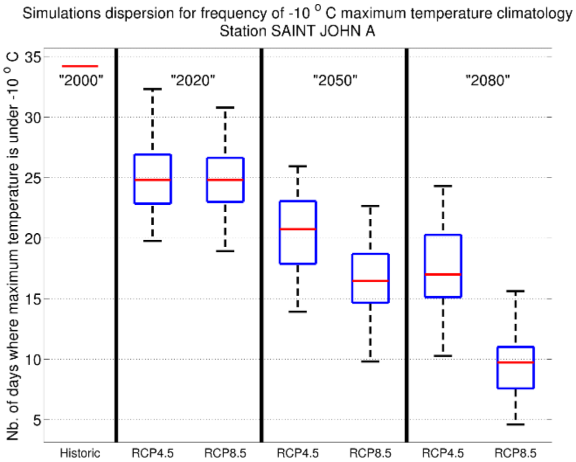

Figure 3.76 Simulations dispersion for number of days with maximum temperature lower than -10 °C for Saint John

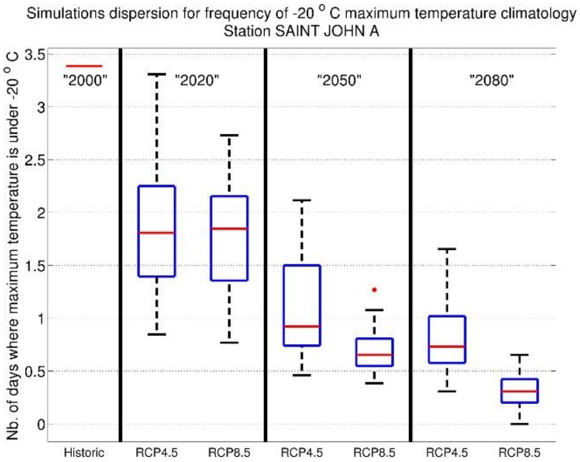

Figure 3.77 Simulations dispersion for number of days with maximum temperature lower than -20 °C for Saint John

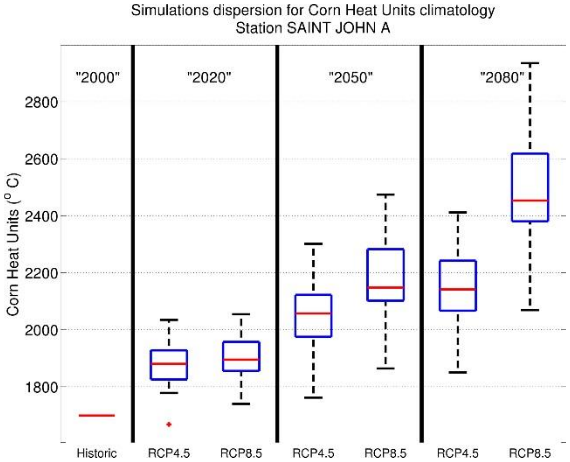

Figure 3.78 Simulations dispersion for Corn Heat Units (see description in Appendix A) for Saint John

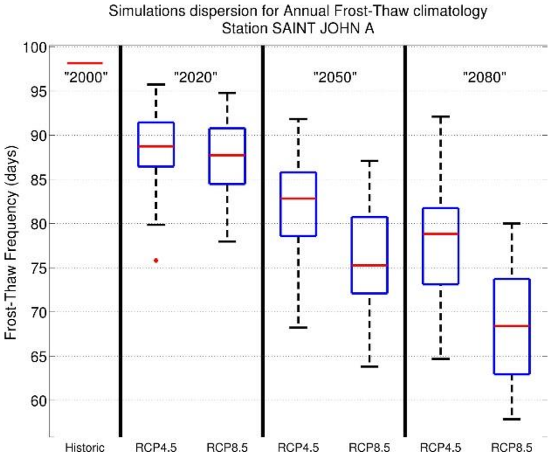

Figure 3.79 Simulations dispersion for the annual occurrence of frost-thaw cycle for Saint John

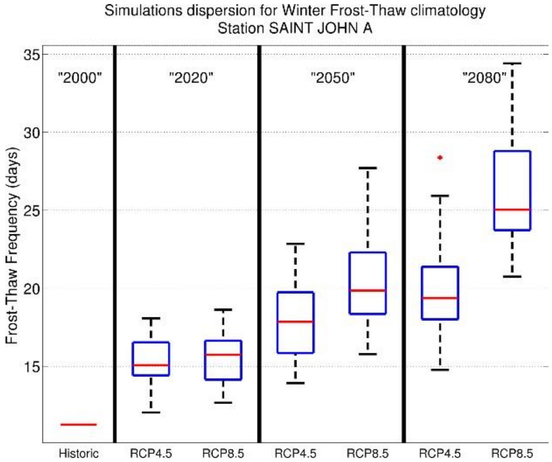

Figure 3.80 Simulations dispersion for the winter occurrence of frost-thaw cycle for Saint John

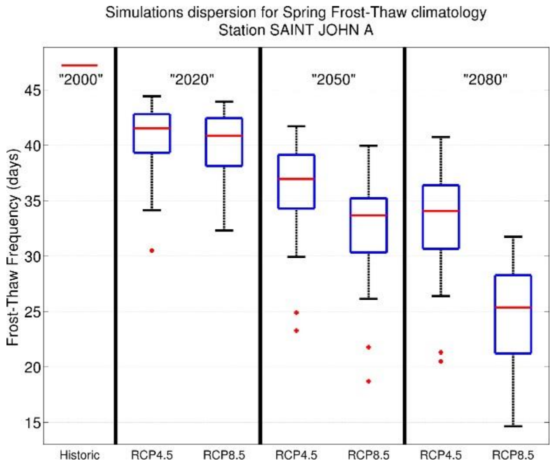

Figure 3.81 Simulations dispersion for spring occurrence of frost-thaw cycle for Saint John

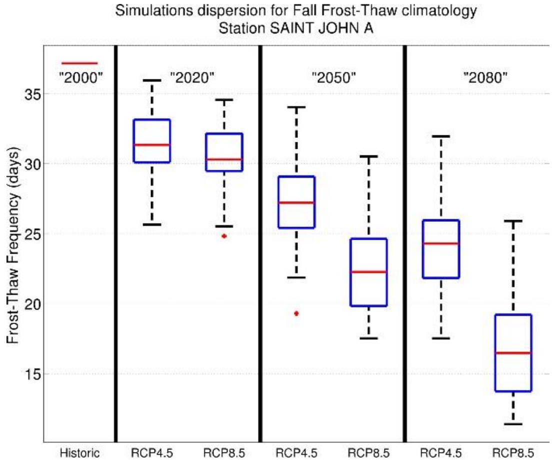

Figure 3.82 Simulations dispersion for fall frost-thaw cycle for Saint John

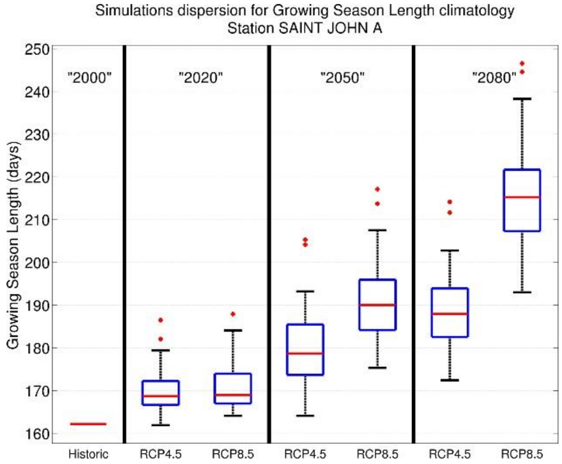

Figure 3.83 Simulations dispersion for Growing Season Length for Saint John

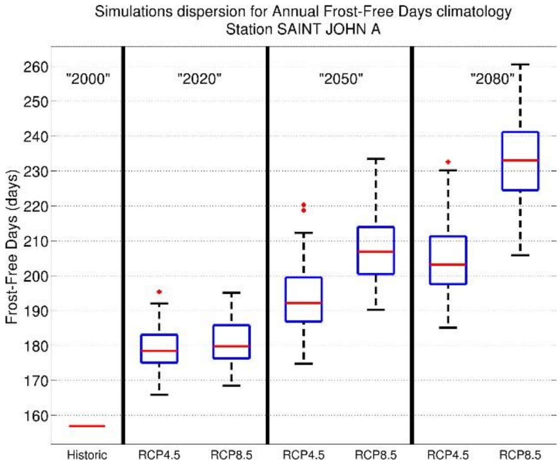

Figure 3.84 Simulations dispersion for annual number of frost-free days for Saint John

Simulations dispersion for precipitation based climate indices

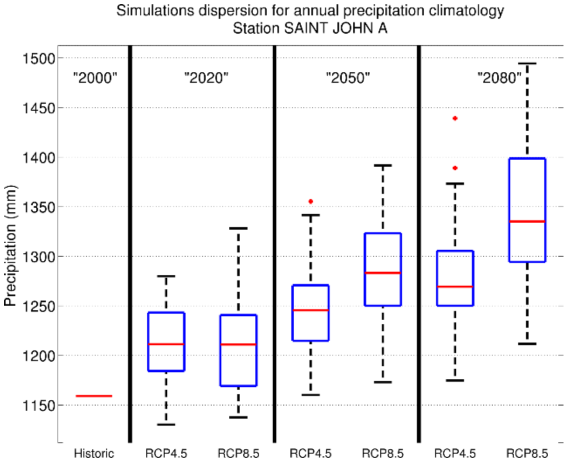

Figure 3.85 Simulations dispersion for annual precipitation accumulation for Saint John

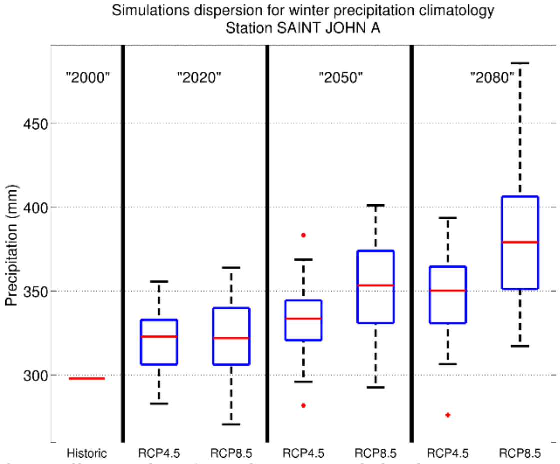

Figure 3.86 Simulations dispersion for winter precipitation accumulation for Saint John

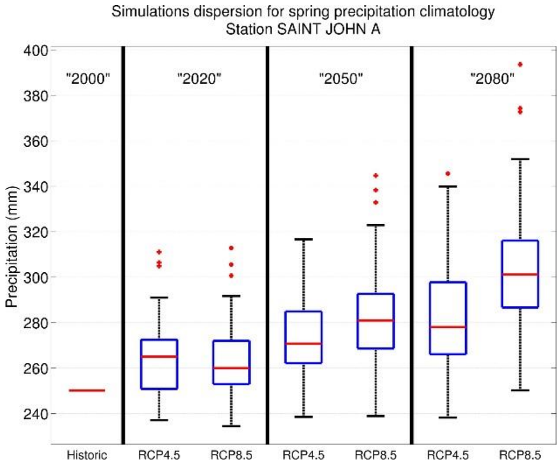

Figure 3.87 Simulations dispersion for spring precipitation accumulation for Saint John

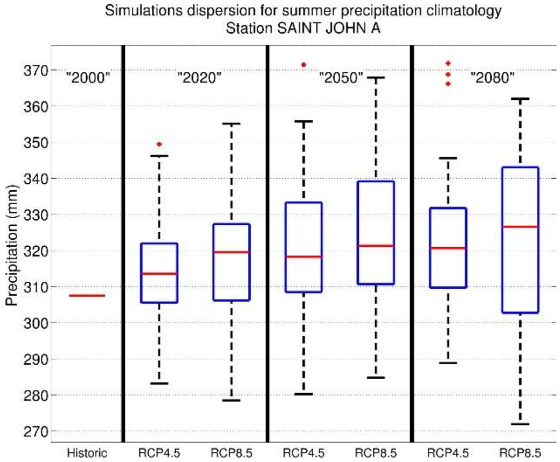

Figure 3.88 Simulations dispersion for summer precipitation accumulation for Saint John

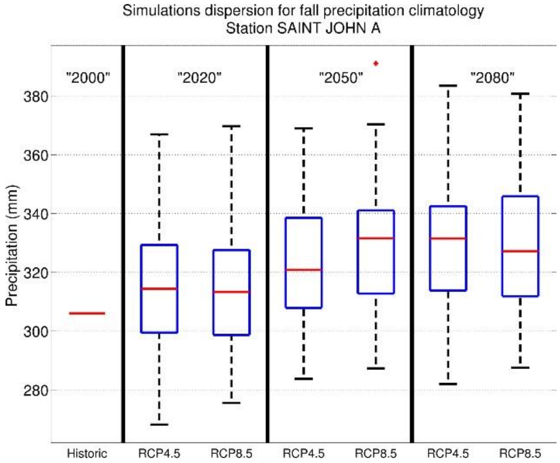

Figure 3.89 Simulations dispersion for fall precipitation accumulation for Saint John

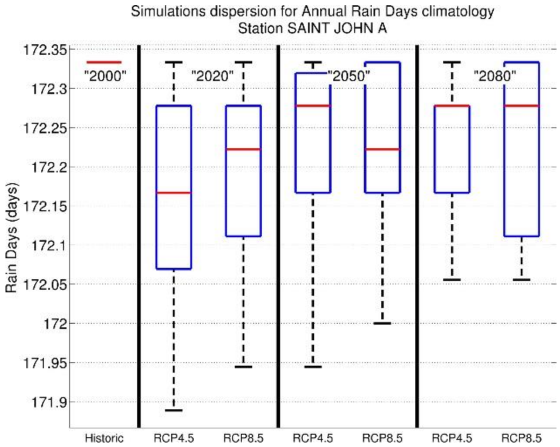

Figure 3.90 Simulations dispersion for annual number of rain days for Saint John

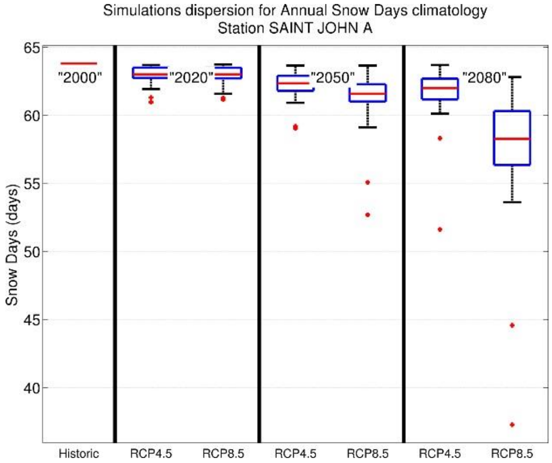

Figure 3.91 Simulations dispersion for annual number of snow days for Saint John

3.4 Analysis and discussion

The results from this study show clear temperature increases over the 21st century. Changes in temperature grow with time and with GHG emissions. In 2020, GHG scenarios RCP 4.5 and RCP 8.5 are essentially identical and yield indistinguishable climate impacts. Differences between GHG emission scenarios grow with time, as does the difference between their respective climate impacts. These temperature changes affect all stations within New Brunswick and all seasons. In Fredericton for example, days with daily maximum temperatures below -20 °C become extremely rare at the end of the century, while days with temperatures above 30 °C go from 8 per year over the historical period, to between 25 and 55 at the end of the century.

Although the warming signal is unambiguous and no climate simulations project long-term cooling trends, year to year conditions are the combination of a long term climate state and unpredictable natural variability. This natural variability component fluctuates around the mean state, bringing colder or warmer periods that sometimes span multiple years. Hence colder than average temperatures do not invalidate conclusions from climate projections, just as warmer than average temperature is not proof of climate change. Only long term changes in the mean state over at least three decades carry significant weight. In Moncton, simulations for the mean annual temperature increase around 2080 span a wide range going from 1 °C to 7 °C. This range reflects both the uncertainty in GHG emissions and the model uncertainty.

For precipitation based indices, conclusions are less robust. For one, there is greater natural variability in precipitation, weakening the signal over noise ratio. Secondly, accurate simulations of rainfall hinges on adequately capturing many complex phenomena, from soil processes influencing evapotranspiration to cloud physics and the formation of water droplets, all mediated by the circulation of air masses over the world. Due to this complexity, differences between models are larger for precipitation projections than for temperature projections, and the model consensus is weaker.

Nevertheless, the interquartile range of climate projections for annual precipitations lies above historical values, and in 2080, all simulations show increases in mean annual precipitations, as well as winter and spring precipitations. There is no reliable climate change signal for summer and fall precipitation using this ensemble of CMIP5 simulations.

4. CONCLUSION

While it is difficult to predict the amount of GHGs that will be emitted in the atmosphere over the current century, their climate effects can be estimated by climate models. The CMIP5 global climate model ensemble used in this study is an international effort to describe the anticipated climate impacts of GHG emissions. The emission scenarios used by the climate modeling community span a range of hypotheses from aggressive mitigation and storage (RCP2.6) to acceleration in GHG emissions (RCP8.5).

In this study aiming at evaluating the evolution of climate indices relevant to NB Government operations, simulations driven by GHG scenarios RCP4.5 and RCP8.5 were analyzed to bracket the potential climate impacts of GHG over the coming years. Since the climate sensitivity to GHG is the results of a number of complex feedback processes, different models come to different conclusions for the same GHG scenario. For this reason, large model ensembles such as the CMIP5 ensemble used in this report are analyzed to evaluate the consensus among models and the robustness of results, an indirect estimation of the uncertainty.

Results indicate a substantial increase in temperatures over time for all seasons and both GHG emission scenarios. For 2080 and RCP 8.5, the ensemble mean increase is similar amongst seasons. Winter season show a slightly highest increase, varying between +5.71 °C (Saint John) to 6.47 °C (Bathurst). The weakest increases are expected in the spring season, with temperature increases between +4.7 °C (Saint John) to 5.16 °C (Bathurst). For summer and fall, the increases are mostly similar, varying between +5.01 °C to 5.31 °C. This increase in mean temperature support the increase of all temperature based climate indices.

Agricultural climate indices such as Growing Degree Days, Corn Heat Units (CHU) and Growing Season Length show a substantial increase. For example, in Moncton for time horizon 2080, the CHU index show an increase of about +410 to +750 CHU, the GSL index show an increase between 29 days (RCP 4.5) and 61 days (RCP 8.5) and the Growing Degree Days an increase between 415 degree-days (RCP 4.5) and 851 degree days (RCP 8.5).

Perhaps one of the most impressive results is the number of projected hot days (daily maximum temperature higher than 30 °C). For 2080 with RCP 8.5, the expected increase is a staggering +40.99 days in Bathurst, +38.94 days in Moncton and +21.63 days in Saint John. On the other hand, cold days (i.e. days with maximum temperature lower than -20 °C) disappear for all stations across New Brunswick. However, it is important to note that the mean annual frequency of cold days is rare even for the historical period.

In terms of energy demand, projections show an increase of cooling degree days and a decrease of heating degree days. For example, in Moncton for 2080, the cooling degree days increase varies between 184 degree days (RCP 4.5) and 424 degree days (RCP 8.5) while the heating degree days decrease varies between -844 degree days (RCP 4.5) and -1481 degree days (RCP 8.5).

While results for precipitations are less robust due in part to larger natural variability, at the end of the century most simulations suggest an increase in annual precipitations, especially during winter and spring. The ensemble mean increases for 2080 with RCP 8.5 for annual precipitation accumulation is between +12.06% (Saint John) to +13.42% (Bathurst). On a seasonal basis for 2080 and RCP 8.5, the highest increases are for winter (+20.25% for Saint John to +23.19% for Bathurst) and spring (+16.34% for Saint John to +18.78% for Bathurst), while summer (+7.48% for Saint John to +8.93% for Bathurst) and fall (+4.77% for Bathurst to +6.23% for Fredericton) show a much weaker signal.

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APPENDICES

Appendix A: Climate indices definitions

Appendix B: CMIP5 Global Climate Models description

Appendix C: Regional Climate Models results

Appendix D: Excel File Description

APPENDIX A CLIMATE INDICES DEFINITIONS

The following climate indices have been calculated for the historical period (1981-2010) and for future periods (2020, 2050 and 2080). The last column specifies the criteria, for the calculation of a given index. If these criteria are not met for a given year, the climate index is not calculated.

Table A.1 Definition of selected climate indices.

ID	Climate Variable and Acronyms	Unit	Definition	Criteria
1	Mean Temperature (AnnTemp)	C	Mean temperature is the average temperature for the calendar year, calculated from daily observations.	At least 85% of data
2	Winter Mean Temperature (DJFTemp)	C	Winter mean temperature is the average temperature for the months of December, January and February.	At least 85% of data in the months December-January-February
3	Spring Mean Temperature (MAMTemp)	C	Spring mean temperature is the average temperature for the months of March, April and May.	At least 85% of data in the months March-April-May
4	Summer Mean Temperature (JJATemp)	C	Summer mean temperature is the average temperature for the months of June, July and August.	At least 85% of data in the months June-July-August
5	Autumn Mean Temperature (SONTemp)	C	Autumn mean temperature is the average temperature for the months of September, October and November.	At least 85% of data in the months September-October-November
6	Annual Total Precipitation (AnnPrec)	mm	Annual total precipitation is the average total of rainfall and snowfall for the calendar year.	100% of the data
7	Winter Total Precipitation (DJFPrec)	mm	Winter total precipitation is the average total of rainfall and snowfall for the months of December, January and February.	100% of the data in the months December-January-February
8	Spring Total Precipitation (MAMPrec)	mm	Spring total precipitation is the average total of rainfall and snowfall for the months of March, April and May.	100% of the data in the months March-April-May
9	Summer Total Precipitation (JJAPrec)	mm	Summer total precipitation is the average total of rainfall and snowfall for the months of June, July and August.	100% of the data in the months June-July-August
10	Autumn Total Precipitation (SONPrec)	mm	Autumn total precipitation is the average total of rainfall and snowfall for the months of September, October and November.	100% of the data in the months September-October-November
11	Annual Number of Days with Maximum Temperature >25°C (AnnTxFr25)	Days	Annual Number of Days with Maximum Temperature >25°C is the average number of days per year when the temperature exceeds this threshold.	100% of the data between May 1st and September 30th
12	Annual Number of Days with Maximum Temperature >30°C (AnnTxFr30)	Days	Annual Number of Days with Maximum Temperature >30°C is the average number of days per year when the temperature exceeds this threshold. Also known as "hot days".	100% of the data between June 1st and August 31st
13	Annual Number of Days with Maximum Temperature >35°C (AnnTxFr35)	Days	Annual Number of Days with Maximum Temperature >35°C is the average number of days per year when the temperature exceeds this threshold. Also known as "very hot days".	100% of the data between June 1st and August 31st

ID	Climate Variable and Acronyms	Unit	Definition	Criteria
14	Annual Number of Days with Maximum Temperature <0°C (AnnTxFrLT0)	Days	Annual Number of Days with Maximum Temperature <0°C is the average number of days when the maximum temperature is below zero degrees Celsius.	100% of the data between January 1st and April 30th and between October 1st and December 31st
15	Annual Number of Days with Maximum Temperature <-10°C (AnnTxFrLTM10)	Days	Annual Number of Days with Maximum Temperature <-10°C is the average number of days when the maximum temperature is below minus 10 degrees Celsius. Also known as "cold days".	100% of the data between January 1st and March 31st and between November 1st and December 31st
16	Annual Number of Days with Maximum Temperature <-20°C (AnnTxFrLTM20)	Days	Annual Number of Days with Maximum Temperature <-20°C is the average number of days when the maximum temperature is below minus 20 degrees Celsius. Also known as "very cold days".	100% of the data between January 1st and February 28th and between October 1st and December 31st
17	Annual Cooling Degree Days (CoolDegDays)	CDD	°Cooling Degree Days are calculated by checking the daily mean temperature against a baseline of 18 °Celsius. Days with mean temperature below 18°C have zero cooling degree days. A day with a mean temperature of 20°C would represent 2 cooling degree days. Annual cooling degree days is the average total for the whole year.	100% of the data between April 1st and October 1st
18	Annual Heating Degree Days (HeatDegDays)	HDD	Heating Degree Days are calculated by checking the daily mean temperature against a baseline of 18 Celsius. Days with mean temperature above 18C have zero heating degree days. A day with a mean temperature of 5C would represent 13 heating degree days. Annual heating degree days is the average total for the whole year.	100% of the data between January 1st and May 31st and between September 1st and December 31st
19	Annual Corn Heat Units* (CHU) * As used in CCCSN Scenario Ensemble Dataset supplied by Neil Comer, EC, June 2011	CHU	Corn Heat Units are temperature units calculated in a similar manner to growing degree days, but the calculation is specifically tuned to the growth of corn.	100% of the data during the Growing Season Length
20	Annual Freeze-Thaw Days (AnnFT)	Days	Annual Freeze-thaw days: the average number of days per year when the daily maximum temperature equals or exceeds 0 degrees Celsius AND the daily minimum temperature is less than 0 degrees Celsius.	100% of the data between January 1st and April 30th and between October 1st and December 31st
21	Spring Freeze-Thaw Days (MAMFT)	Days	Spring freeze-thaw days: the average number of days in the months of March, April and May when the daily maximum temperature equals or exceeds 0 degrees Celsius AND the daily minimum temperature is less than 0 degrees Celsius.	100% of the data in the months March-April-May

ID	Climate Variable and Acronyms	Unit	Definition	Criteria
22	Autumn Freeze-Thaw Days (SONFT)	Days	Autumn freeze-thaw days: the average number of days in the months of September, October and November when the daily maximum temperature equals or exceeds 0 degrees Celsius AND the daily minimum temperature is less than 0 degrees Celsius.	100% of the data in the months September-October-November
23	Winter Freeze-Thaw Days (DJFFT)	Days	Winter freeze-thaw days: the average number of days in the months of December, January and February when the daily maximum temperature equals or exceeds 0 degrees Celsius AND the daily minimum temperature is less than 0 degrees Celsius.	100% of the data in the months December-January-February
24	Growing Season Length (GSL)	Days	Growing season length: The number of days* between the dates when the mean daily temperature exceeds 5 degrees Celsius. * These days need not be consecutive.	100% of the data between February 1st and May 31st and between October 1st and December 31st
25	Annual Total Rain Days	Days	Annual Total Rain Days is the average number of days per year with at least 0.2 mm of rainfall.	100% of the data
26	Annual Total Snow Days (AnnSD)	Days	Annual Total Snow Days is the average number of days per year with at least 0.2 cm of snowfall.	100% of the data
27	Freeze-Free days (FFD)	Days	Freeze-free days is the average number of days per year that can be expected to have a minimum temperature above zero Celsius.	100% of the data between March 1st and October 31st
28	Annual Growing Degree Days >10°C (GDB10)	GDD	Annual Growing Degree Days >10°C is the average annual total of growing degree days, calculated against a baseline temperature of 10°C. If the daily mean temperature is 20C, this indicates a growing degree day total of 10 for that day.	100% of the data between April 1st and October 31st
29	Annual Growing Degree Days >5°C (GDB5)	GDD	Annual Growing Degree Days >5°C is the average annual total of growing degree days. This is calculated against a baseline temperature of 5°C. If the daily mean temperature is 10°C, this indicates a growing degree day total of 5 for that day.	100% of the data between April 1st and October 31st

APPENDIX B CMIP5 GLOBAL CLIMATE MODELS DESCRIPTION

Table B.1 Details of each GCM used in the project's ensemble.

Model	Modeling Center	Institution	# of members
ACCESS1-0	CSIRO-BOM	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	1
ACCESS1-3	CSIRO-BOM	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	1
[1]BCC-CSM1.1	BCC	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	1
BNU-ESM	GCESS	College of Global Change and Earth System Science, Beijing Normal University	1
CanESM2	CCCma	Canadian Centre for Climate Modelling and Analysis	5
[1]CCSM4	NCAR	National Center for Atmospheric Research	1
CMCC-CM	CMCC	Centro Euro-Mediterraneo per I Cambiamenti Climatici	1
CNRM-CM5	CMCC	Centro Euro-Mediterraneo per I Cambiamenti Climatici	1
CMCC-CMS	CNRM-CERFACS	Centre National de Recherches Météorologiques	1
CSIRO-Mk3-6-0	CSIRO-QCCCE	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence	10
FGOALS-g2	LASG-CESS	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University	1
GFDL-CM3	NOAA GFDL	Geophysical Fluid Dynamics Laboratory	1
GFDL-ESM2G	NOAA GFDL	Geophysical Fluid Dynamics Laboratory	1
GFDL-ESM2M	NOAA GFDL	Geophysical Fluid Dynamics Laboratory	1
INM-CM4	INM	Institute for Numerical Mathematics	1
IPSL-CM5A-LR	IPSL	Institut Pierre-Simon Laplace	4
IPSL-CM5A-MR	IPSL	Institut Pierre-Simon Laplace	1
IPSL-CM5B-LR	IPSL	Institut Pierre-Simon Laplace	1
MIROC5	MIROC	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	3
MIROC-ESM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research	1

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[1] These models are only available for precipitation based climate indices

Model	Modeling Center	Institution	# of members
		Institute (The University of Tokyo), and National Institute for Environmental Studies	
MIROC-ESM-CHEM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	1
MPI-ESM-LR	MPI-M	Max Planck Institute for Meteorology (MPI-M)	3
MPI-ESM-MR	MPI-M	Max Planck Institute for Meteorology (MPI-M)	1
MRI-CGCM3	MRI	Meteorological Research Institute	1
NorESM1-M	NCC	Norwegian Climate Centre	1

APPENDIX C REGIONAL CLIMATE MODELS RESULTS

Regional climate models (RCM) are high-resolution versions of global climate models that focus on a limited area. Because weather phenomena are dependent on conditions all over the globe, regional models are driven at the top of the atmosphere and at the boundaries by global climate model simulations. Regional climate modeling is referred to as a downscaling method, one of various techniques that convert low-resolution spatial information into local scale information. From a climate change analysis point of view, regional simulations have advantages and disadvantages. Their finer spatial and temporal resolution allow studies of phenomena that are not seen by global models due to their low-resolution, orographic effects are better represented, as are land-ocean contrasts and wind channeling effects. These advantages come at the expense of considerable resources required to run and archive simulations. This limits the size of simulations ensemble compared to global climate model ensemble.

C.1 Ensemble

Regional climate simulations over North America are generated by multiple modeling teams, including Ouranos. Some of the RCM simulations analyzed here are contributions to a project called the North American Regional Climate Change Assessment Program (NARCCAP) described in Mearns et al. (2009), whose objective is to compare results across various regional and global climate models.

Additional simulations from the Canadian Regional Climate Model (CRCM4) were provided by Ouranos (de Elía & Côté 2010; Music & Caya 2007). These simulations use the GHG scenario called A2, described in the Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000).Compared to the RCP scenarios used in the main document, the radiative forcing of the A2 scenario is slightly lower than the RCP 8.5 scenario (Figure C.1). These simulations are part of the CMIP3 generation of models.

Although global CMIP5 simulations have been available since 2013, still few regional simulations driven by the CMIP5 model generations exist over North America. A project called CORDEX is underway to coordinate and share regional modeling experiments, but progress is slow. At the time of writing, only 6 CMIP5 regional simulations (3 for RCP 4.5 and 3 for RCP 8.5) were available. Considering the small ensemble size, all simulations will be mixed together (contrary to CMIP5 ensemble where simulations were separated by the RCP forcing scenario) for the common future time horizon of 2041-2070.

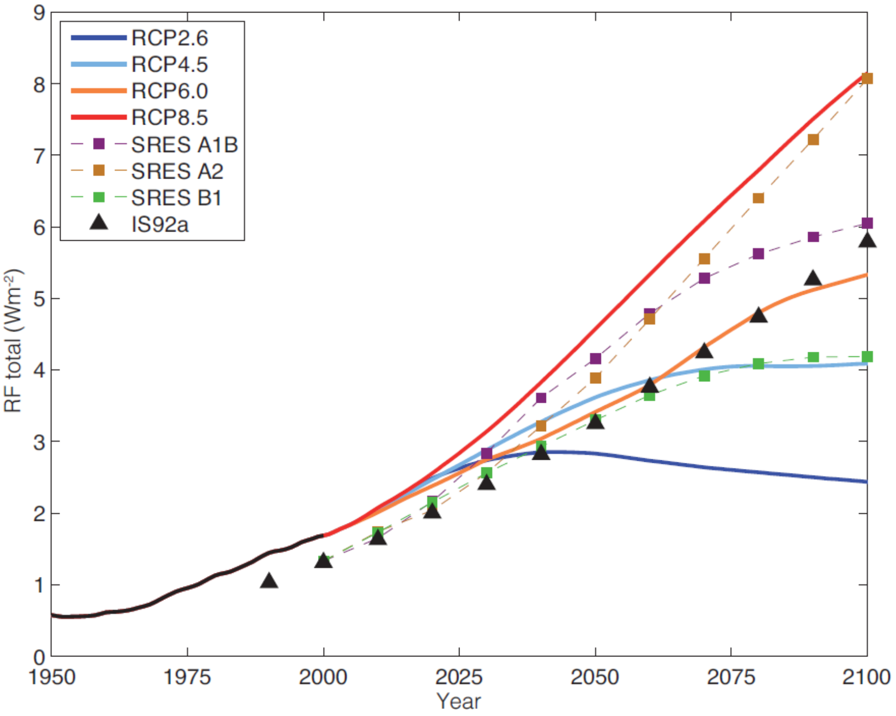

Figure C.1 Historical and projected total anthropogenic Radiative Forcing (W m–2) relative to preindustrial (about 1765) between 1950 and 2100. Previous IPCC assessments (SAR IS92a, TAR/AR4 SRES A1B, A2 and B1) are compared with representative concentration pathway (RCP) scenarios. The total RF of the three families of scenarios, IS92, SRES and RCP, differ for example, for the year 2000, resulting from the knowledge about the emissions assumed having changed since the TAR and AR4. Source : Cubasch et al., 2013

Table C.1 Details of each RCMs used in the project's ensemble.

	RCM	Driving GCM (#member)	Ensemble/ Archival resolution	Modeling center
1	CRCM4	CGCM3#1	Ouranos/ 6-h	Ouranos
2	CRCM4	CGCM3#2	Ouranos/ 6-h	Ouranos
3	CRCM4	CGCM3#3	Ouranos/ 6-h	Ouranos
4	CRCM4	CGCM3#4	Ouranos/ 6-h	Ouranos
5	CRCM4	CGCM3#5	Ouranos/ 3-h	Ouranos
6	CRCM4	ECHAM5#1	Ouranos/ 6-h	Ouranos
7	CRCM4	ECHAM5#2	Ouranos/ 6-h	Ouranos
8	CRCM4	ECHAM5#3	Ouranos/ 3-h	Ouranos
9	CRCM4	CNRM_CM3.3	Ouranos/ 6-h	Ouranos
10	CRCM4	CCSM3	NARCCAP/ 3-h	Ouranos
11	CRCM4	CGCM3	NARCCAP/ 3-h	Ouranos
12	HRM3	HadCM3	NARCCAP/ 3-h	Hadley Centre
13	RCM3	GFDL_CM2.5	NARCCAP/ 3-h	UC Santa Cruz
14	CanRCM4	CanESM2	CORDEX/ daily	Canadian Centre for Climate Modelling and Analysis
15	RCA4	CanESM2	CORDEX/ daily	Rossby Centre
16	RCA4	EC-EARTH	CORDEX/ daily	Rossby Centre

C.2 Ensemble spread

Similarly to Section 3.3, the spread of the RCM ensemble is shown here. For each city, the color is used for the CMIP3-driven simulations (Ouranos and NARCCAP). Grey (RCP4.5) and black (RCP 8.5) dots show the CMIP5-driven simulations (CORDEX).

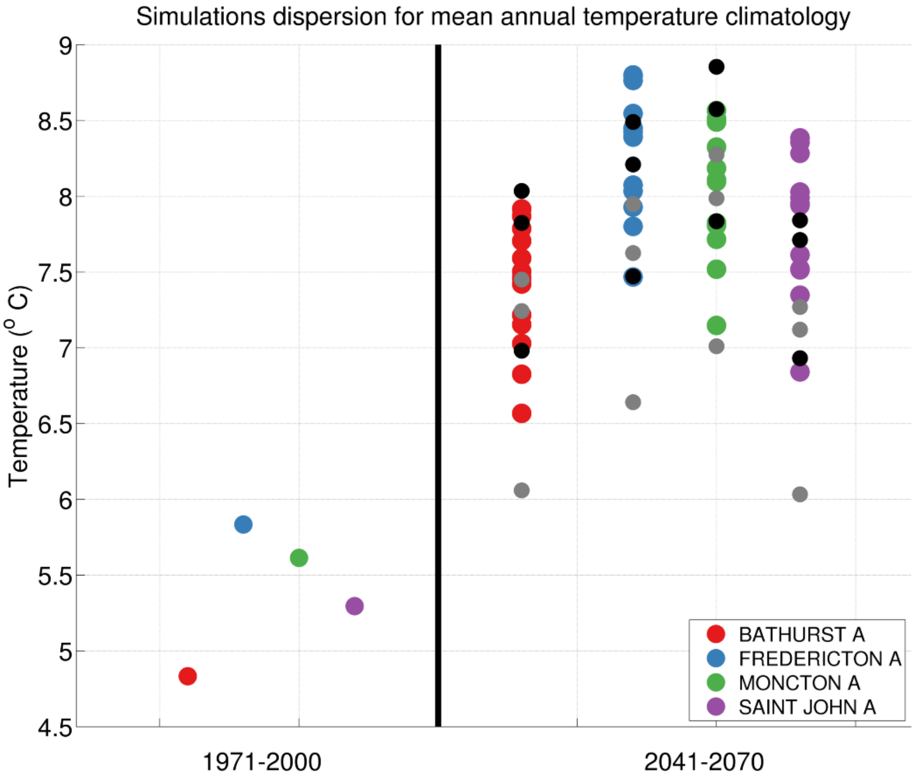

Figure C.2 Simulations dispersion for annual mean temperature

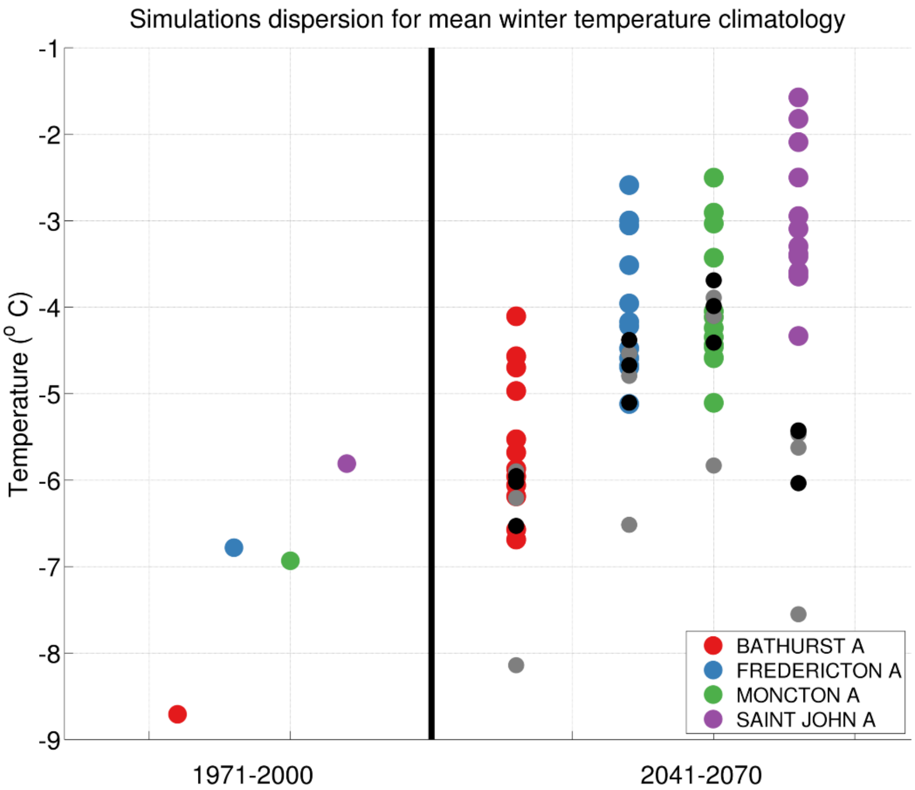

Figure C.3 Simulation dispersion for winter mean temperature

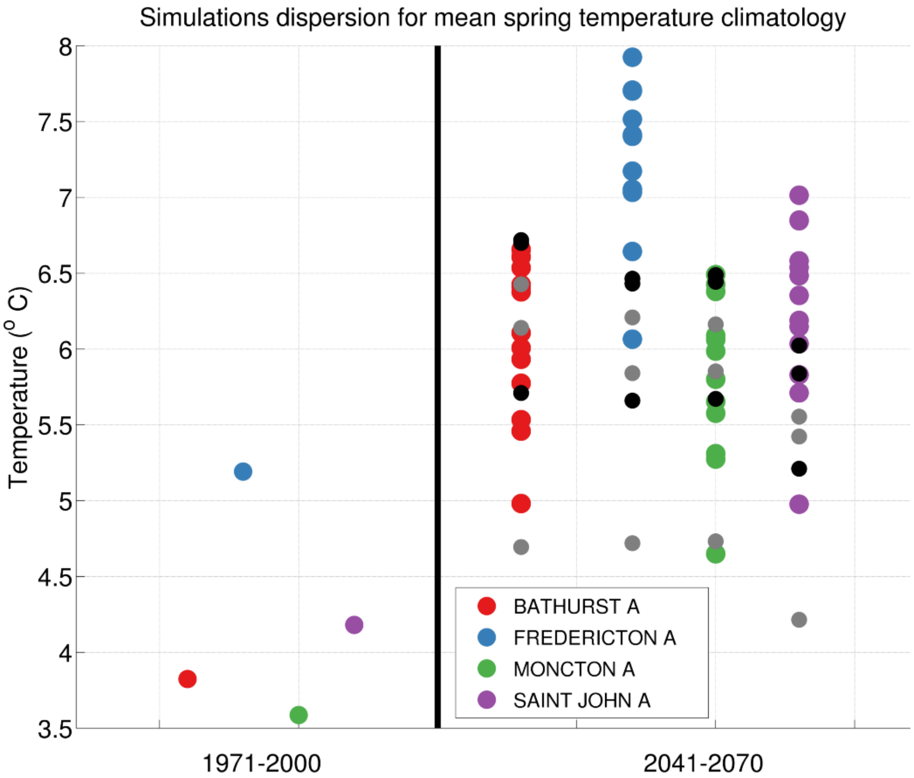

Figure C.4 Simulations dispersion for spring mean temperature

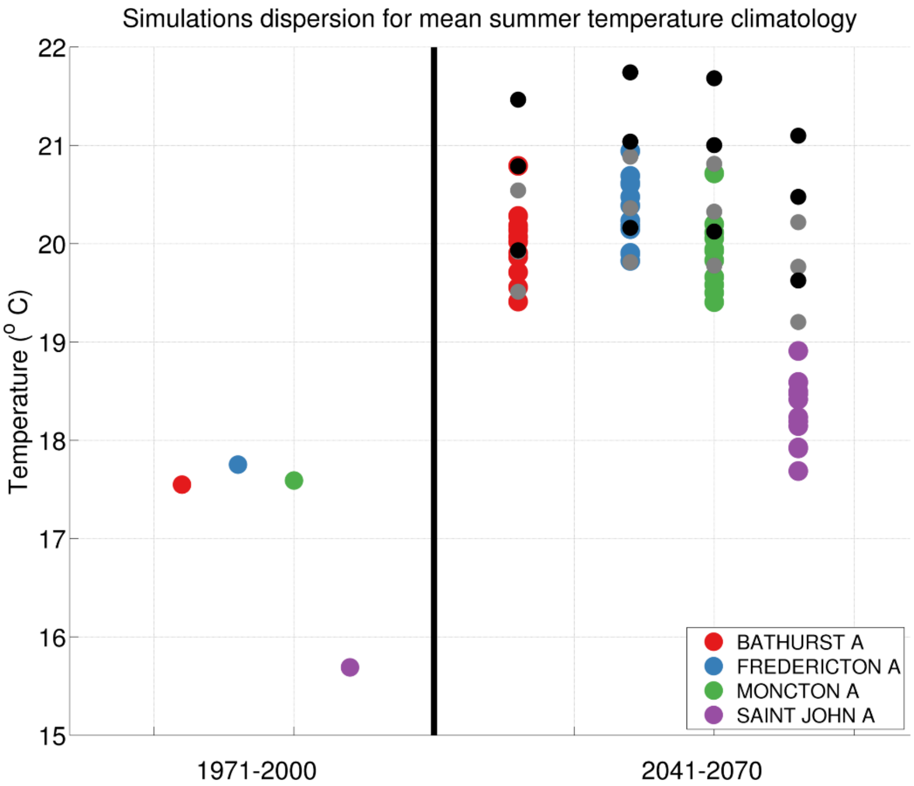

Figure C.5 Simulations dispersion for summer mean temperature

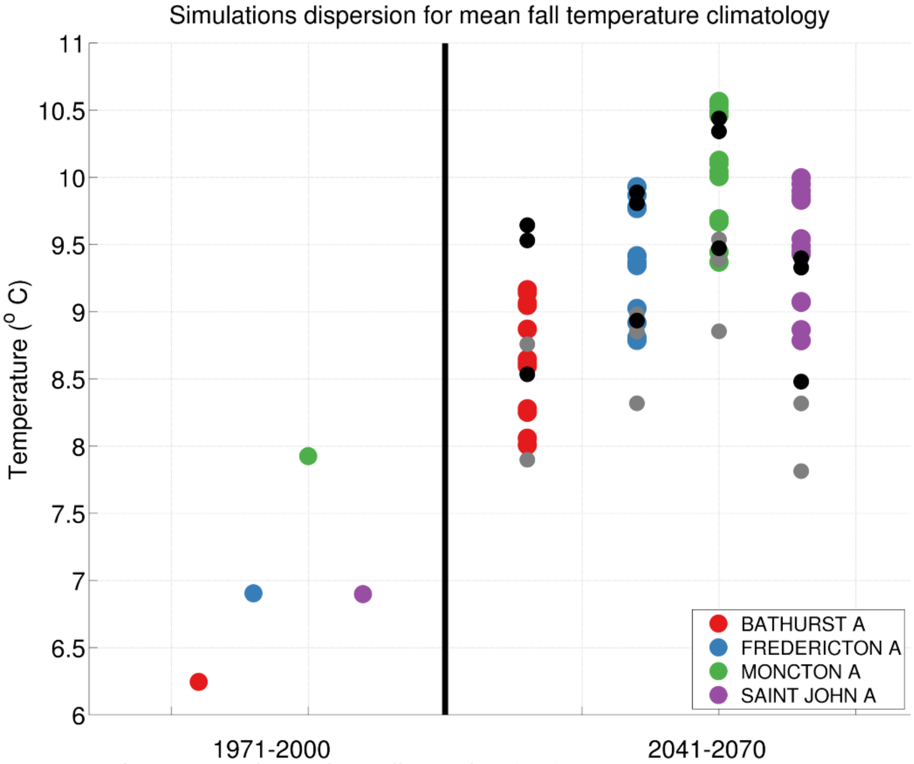

Figure C.6 Simulations dispersion for fall mean temperature

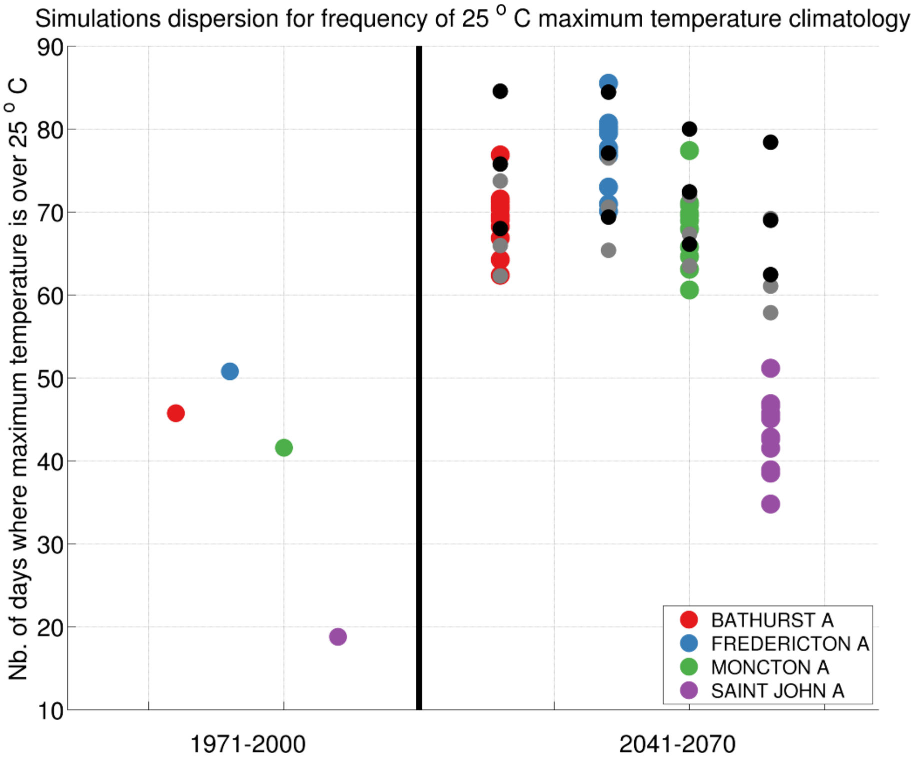

Figure C.7 Simulations dispersion for the number of days with daily maximum temperature higher than 25 °C

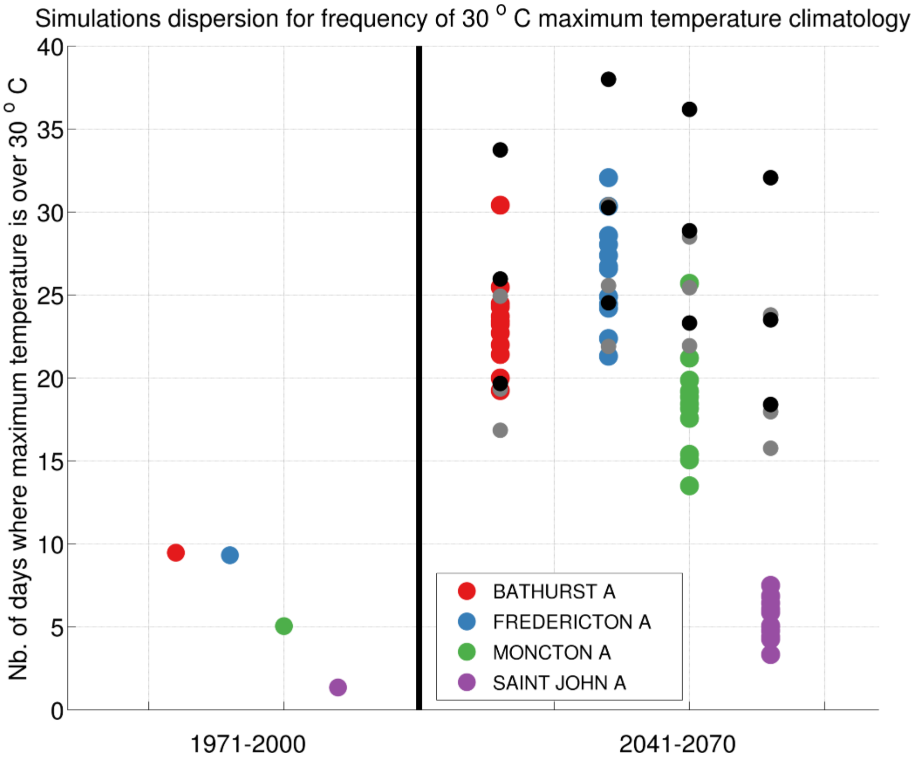

Figure C.8 Simulations dispersion for the number of days with daily maximum temperature higher than 30 °C

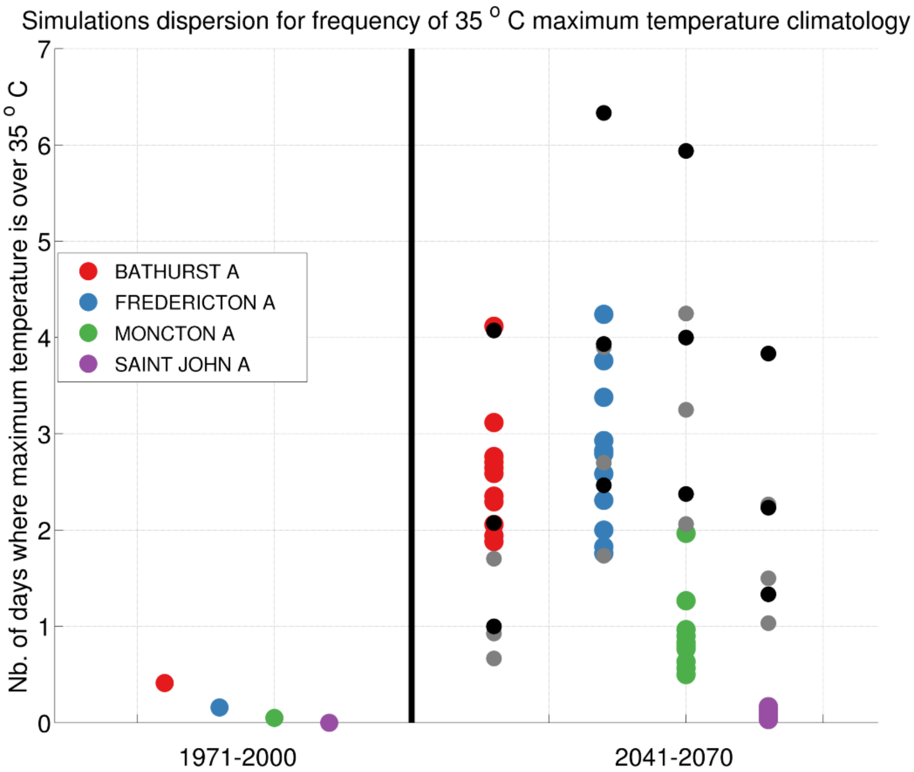

Figure C.9 Simulations dispersion for the number of days with daily maximum temperature higher than 35 °C

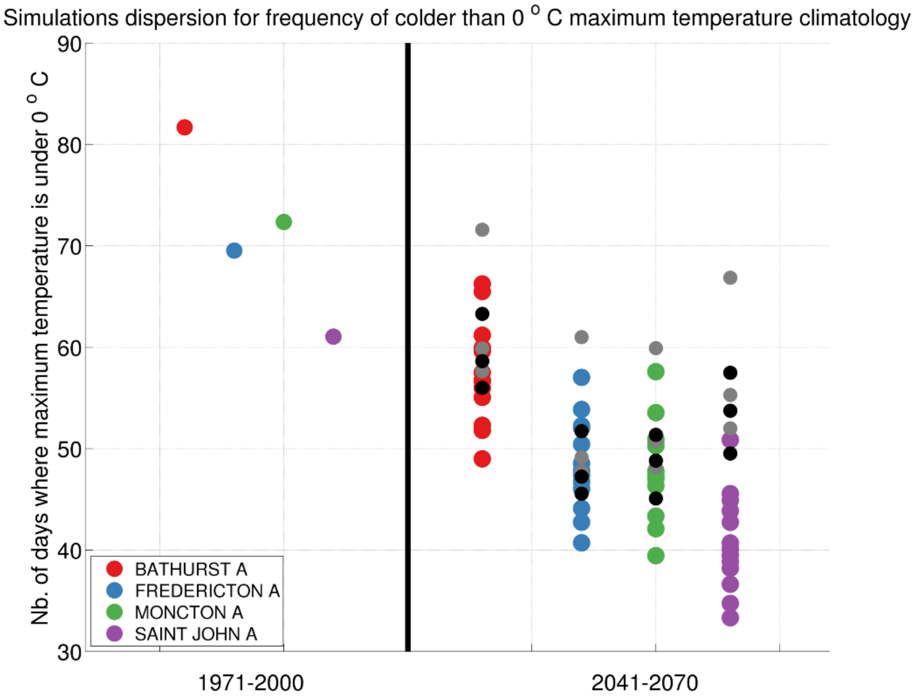

Figure C.10 Simulations dispersion for the number of days with daily maximum temperature lower than 0 C

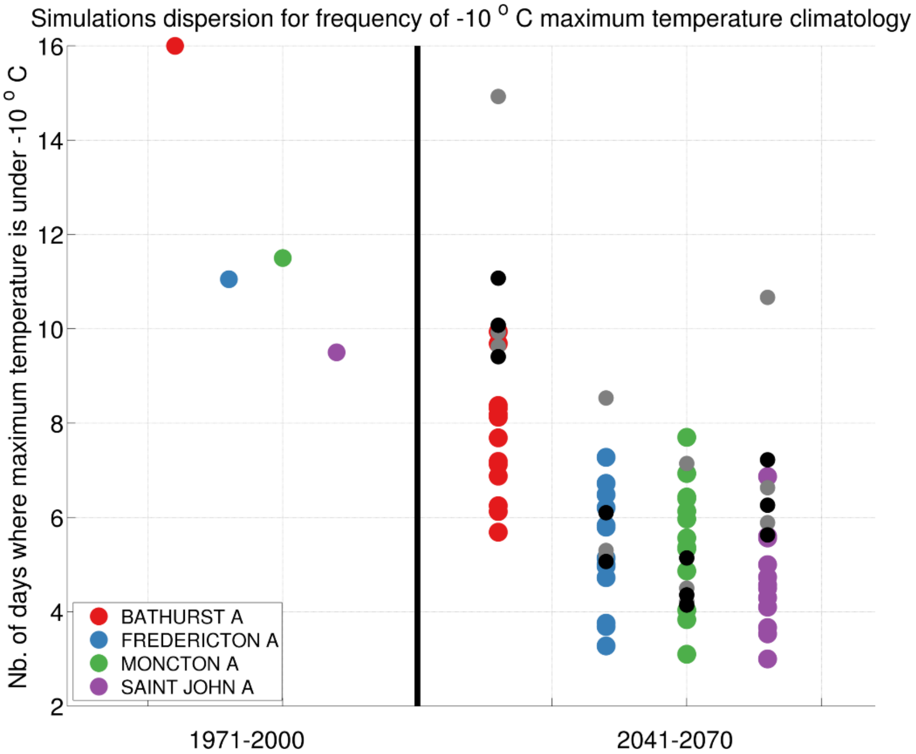

Figure C.11 Simulations dispersion for the number of days with daily maximum temperature lower than - 10 °C

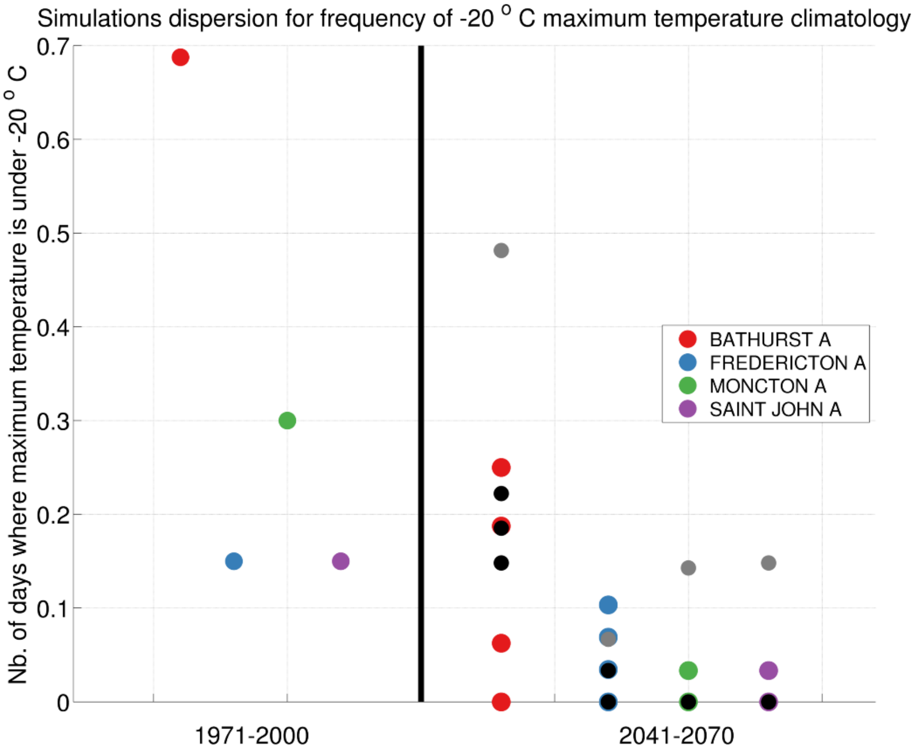

Figure C.12 Simulations dispersion for the number of days with daily maximum temperature colder than - 20 °C

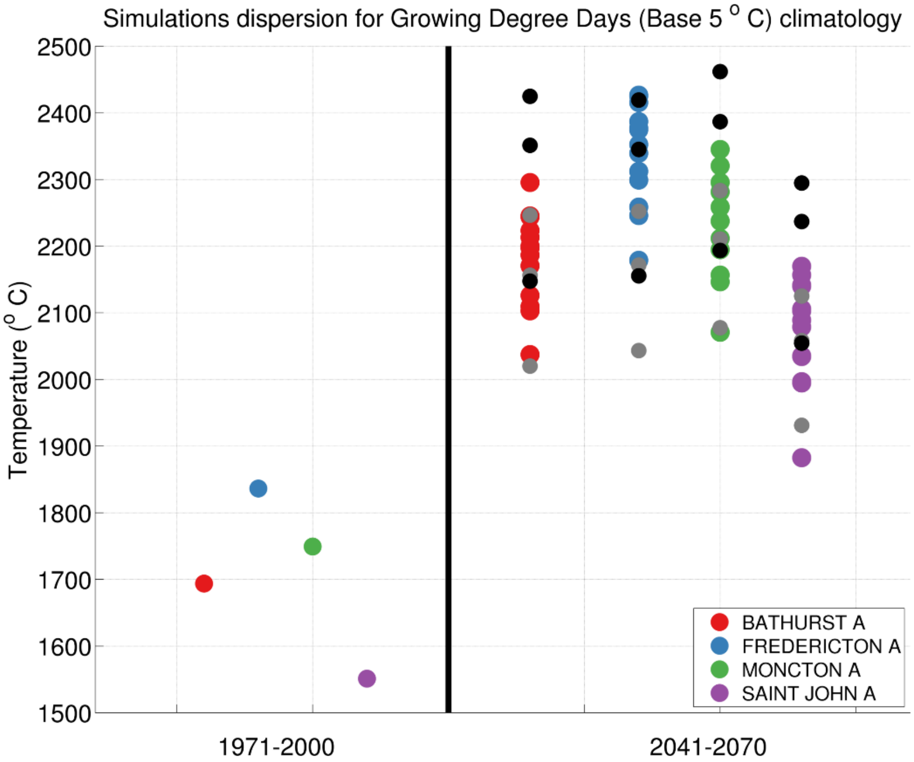

Figure C.13 Simulations dispersion for annual growing degree days (Base 5 °C)

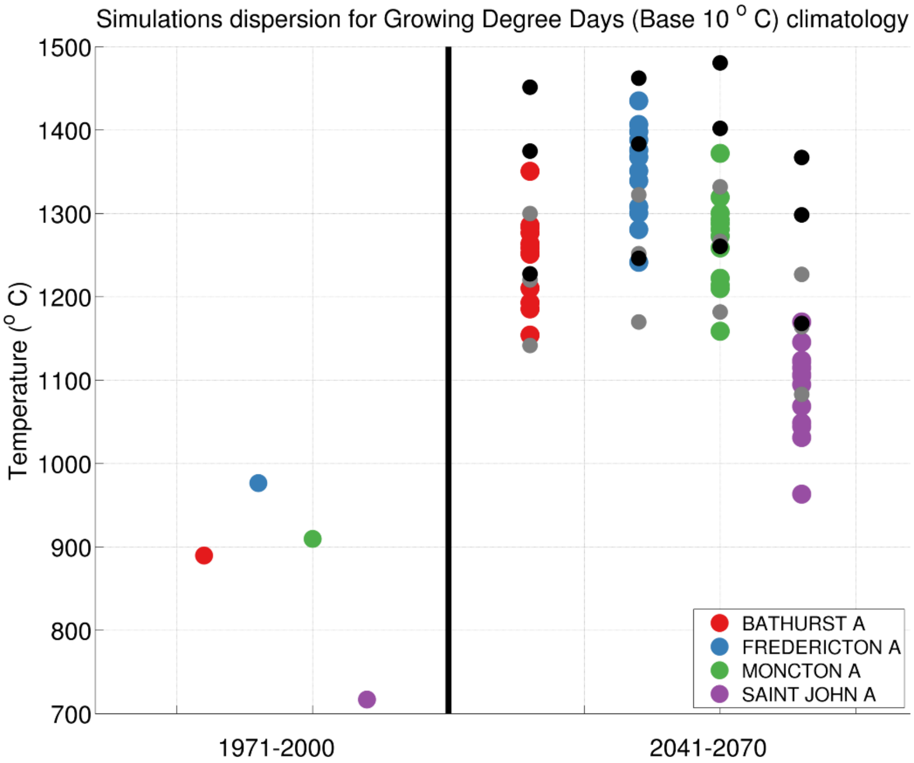

Figure C.14 Simulations dispersion for annual growing degree days (Base 10 °C)

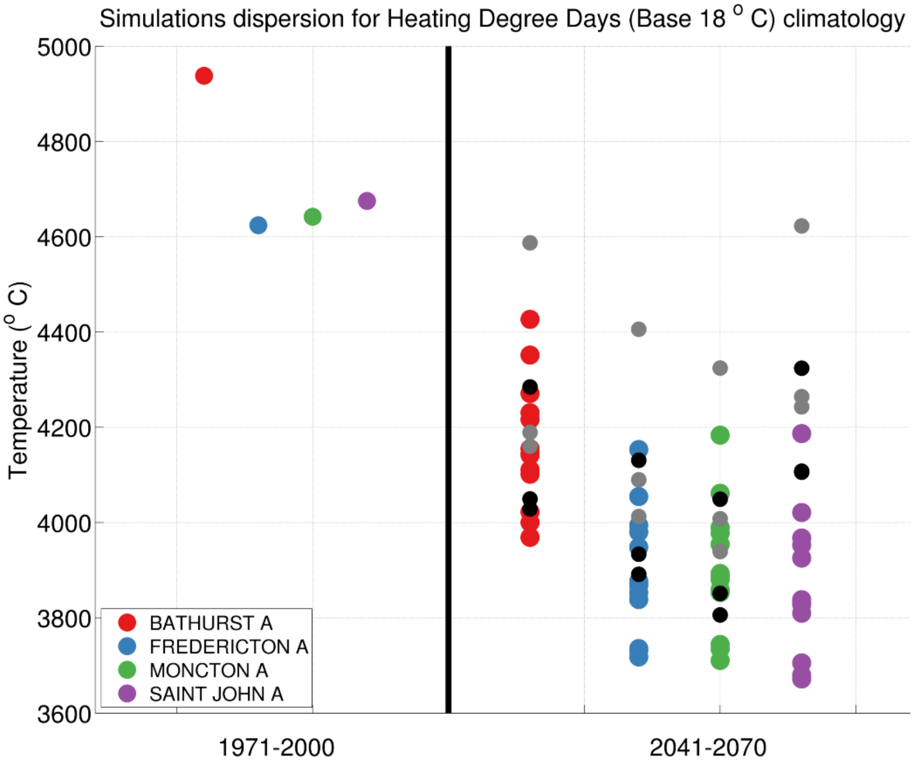

Figure C.15 Simulations dispersion for annual Heating degree days (Base 18 °C)

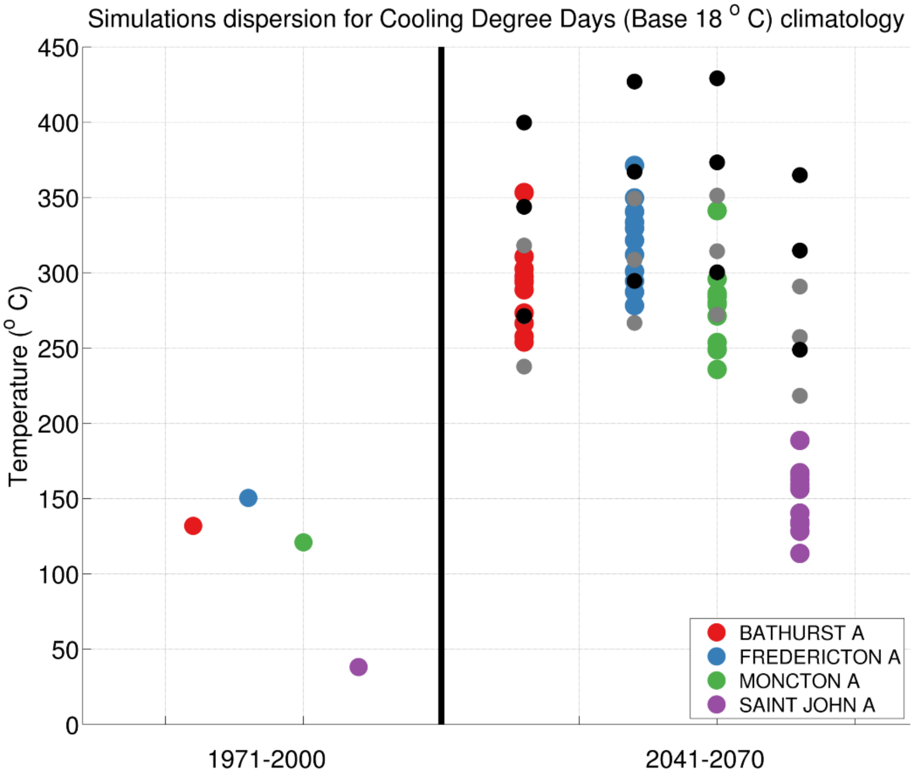

Figure C.16 Simulations dispersion for annual Cooling degree days (Base 18 °C)

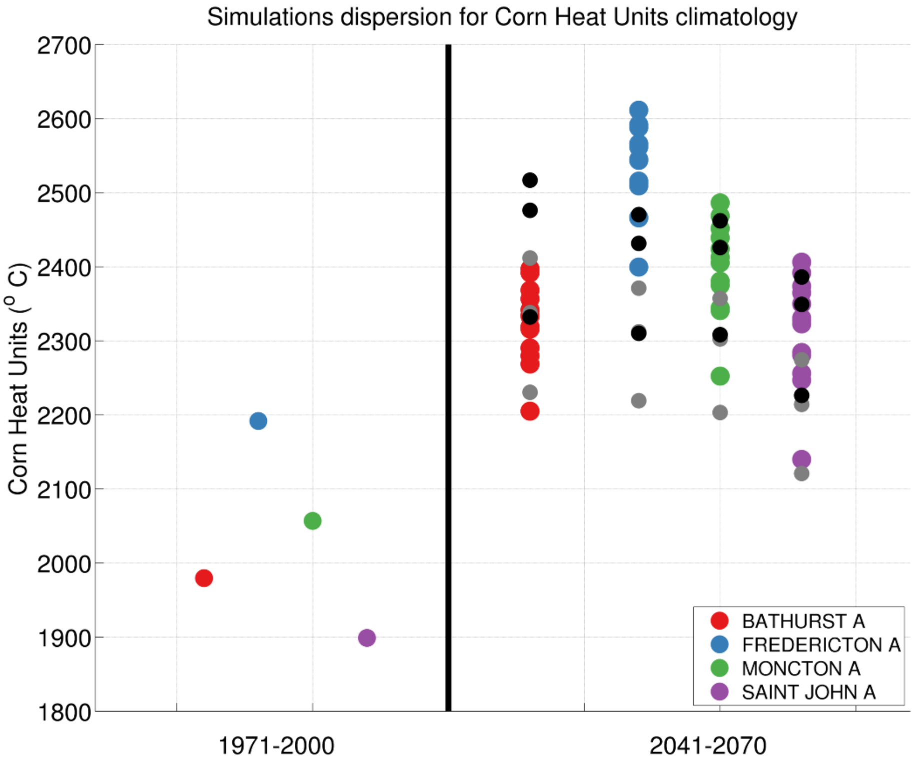

Figure C.17 Simulations dispersion for annual Corn Heat Unit

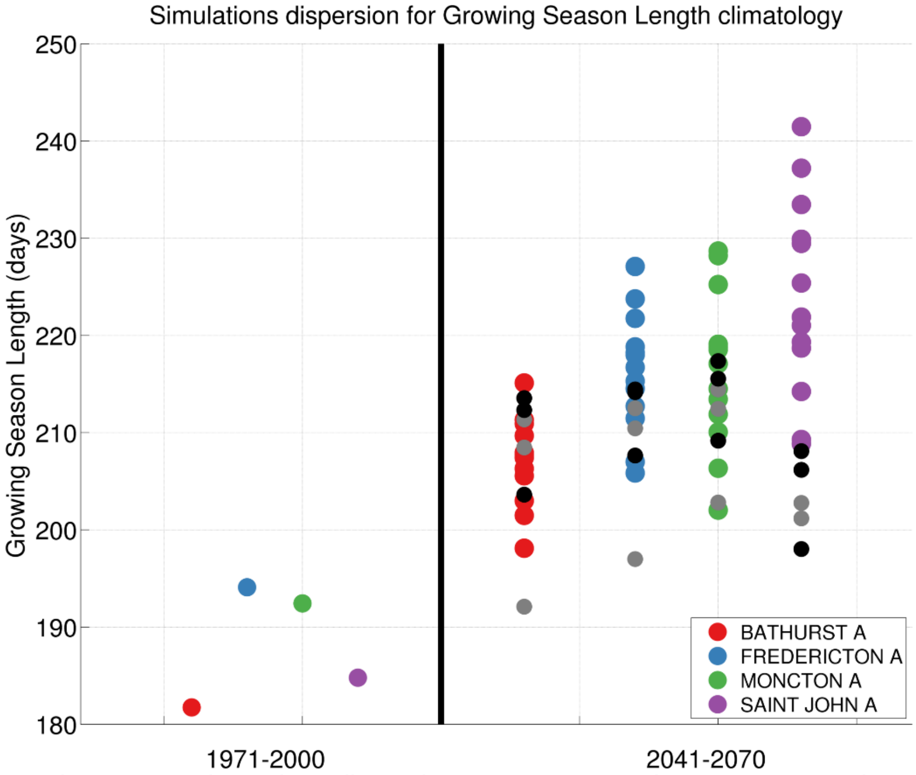

Figure C.18 Simulations dispersion for annual Growing Season Length

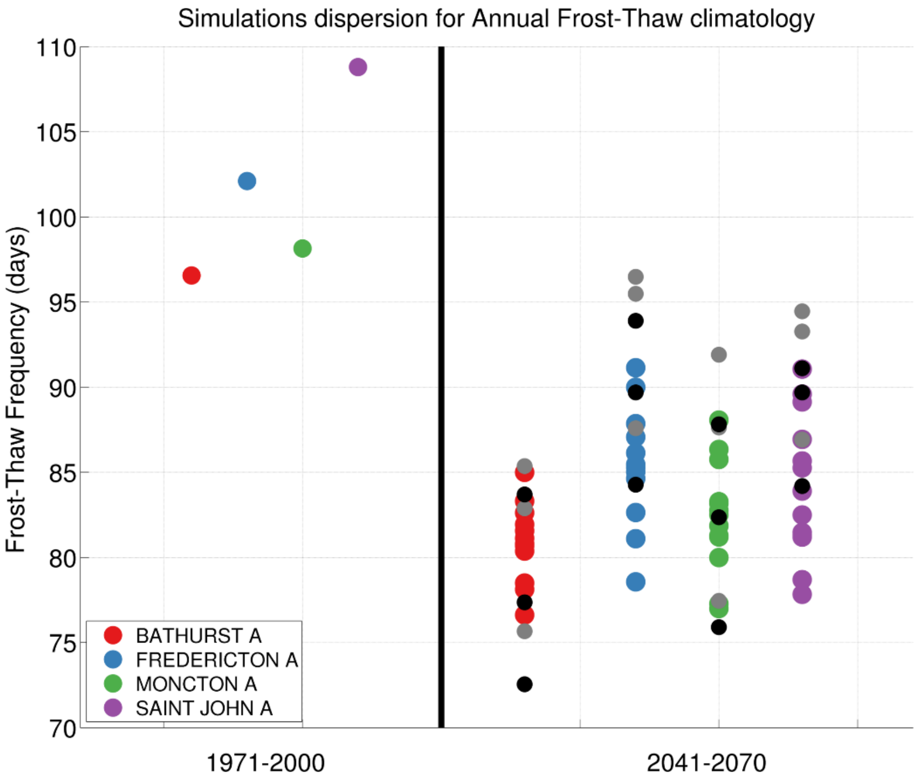

Figure C.19 Simulations dispersion for annual frost-thaw occurrence

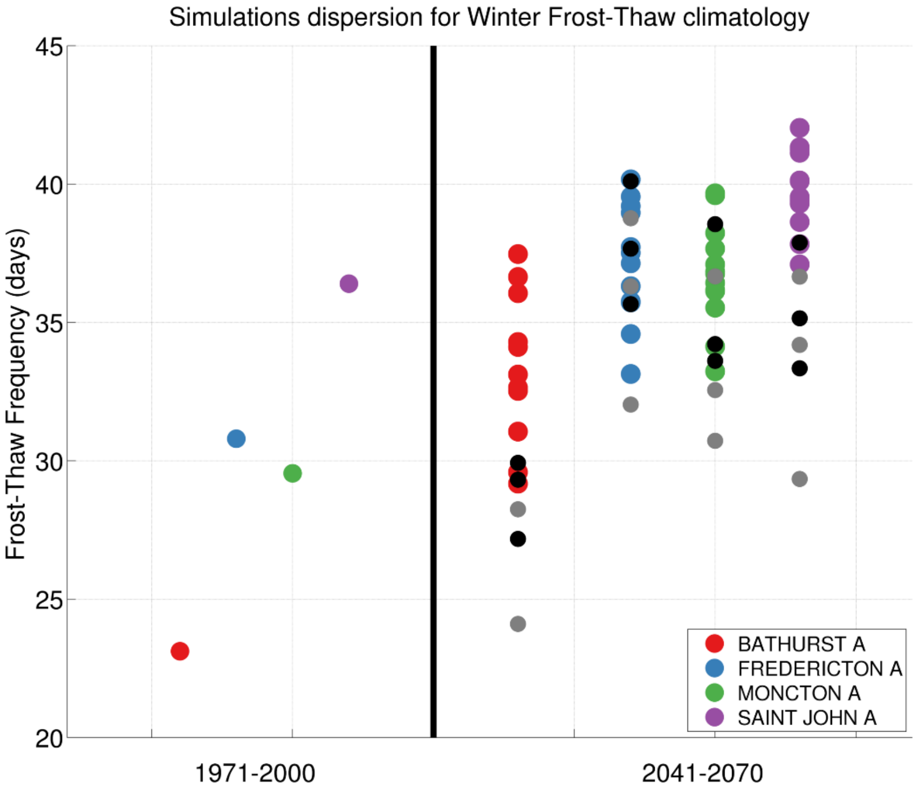

Figure C.20 Simulations dispersion for winter frost-thaw occurrence

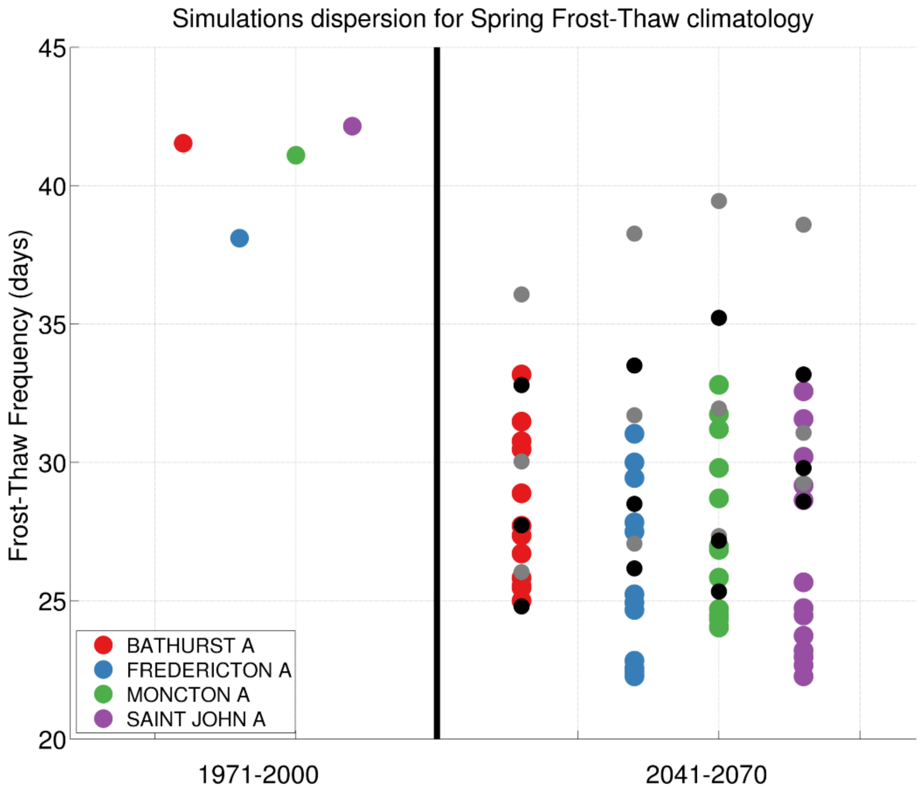

Figure C.21 Simulations dispersion for spring frost-thaw occurrence

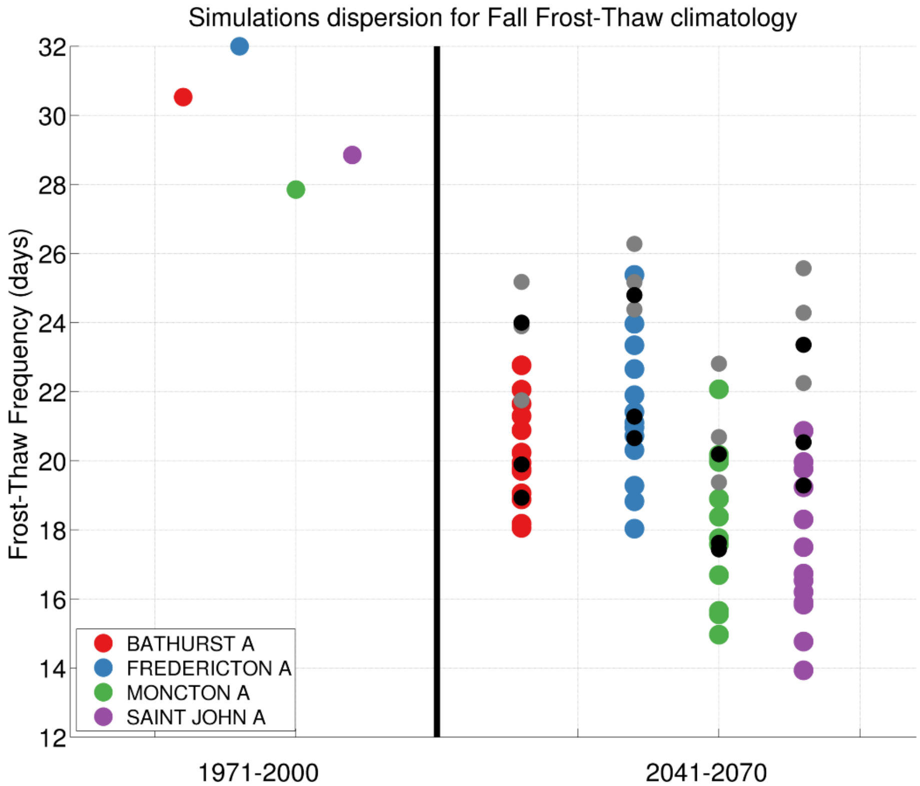

Figure C.22 Simulations dispersion for fall frost-thaw occurrence

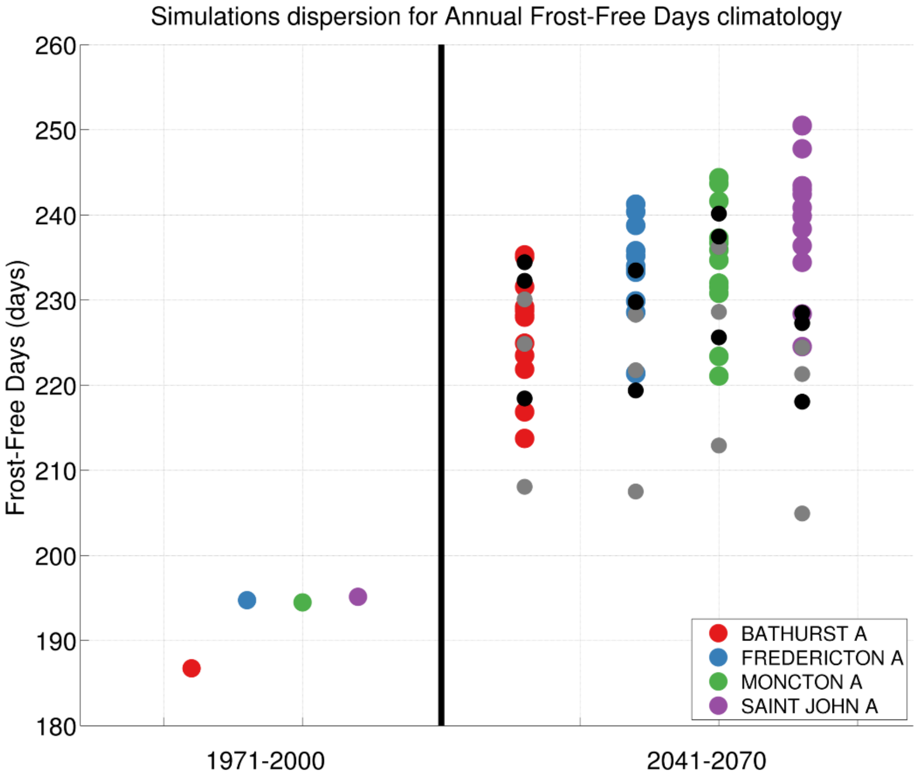

Figure C.23 Simulations dispersion for annual number of frost free days

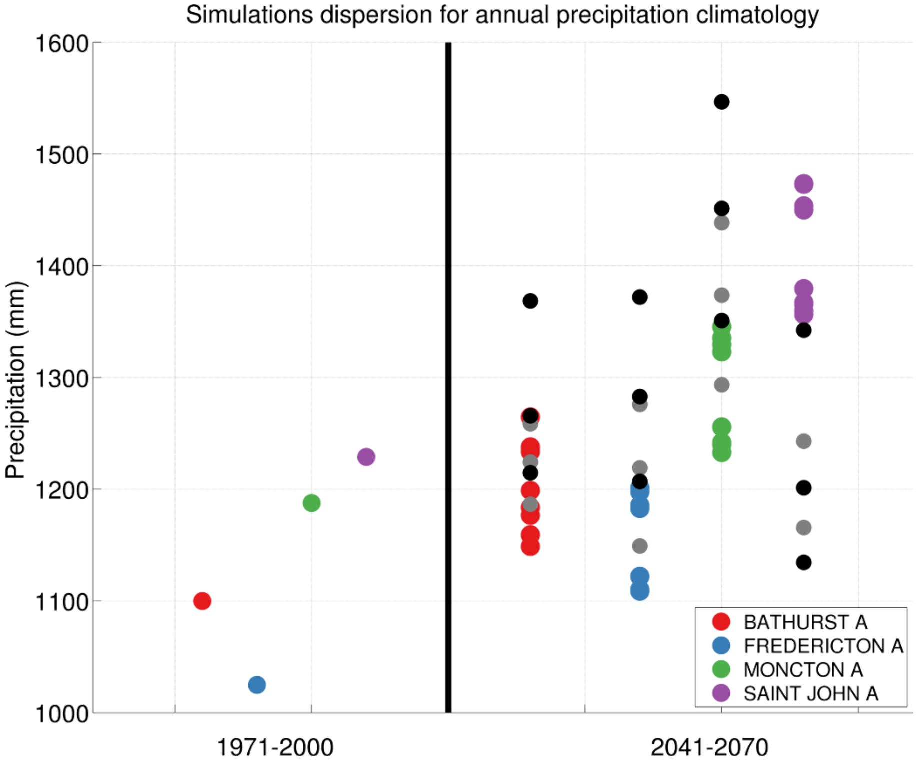

Figure C.24 Simulations dispersion for mean annual precipitation accumulation

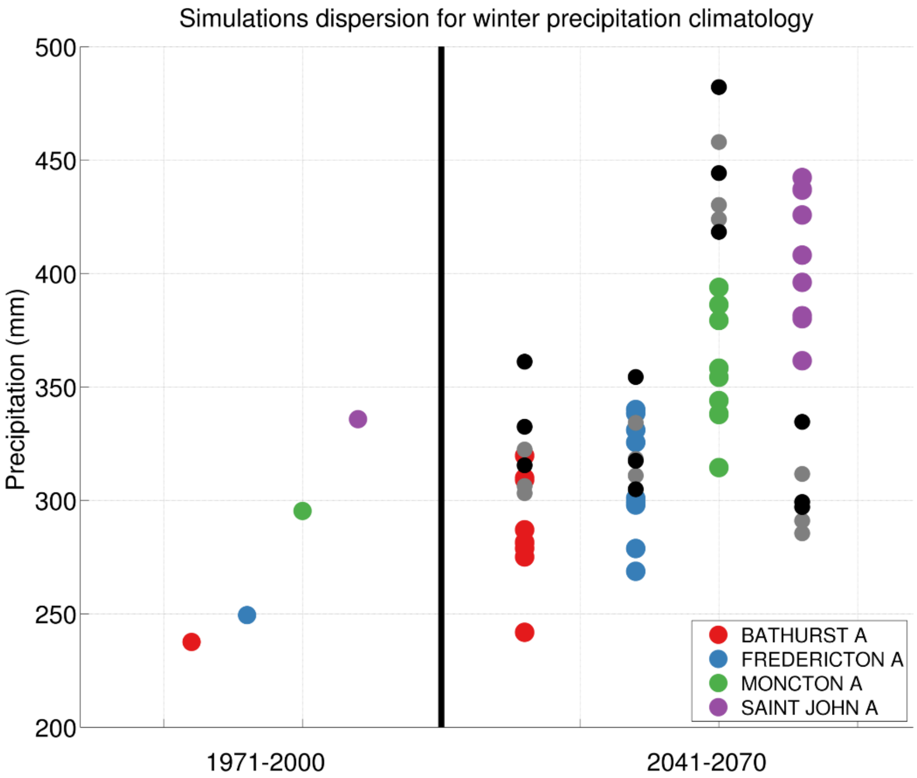

Figure C.25 Simulations dispersion for mean winter precipitation accumulation

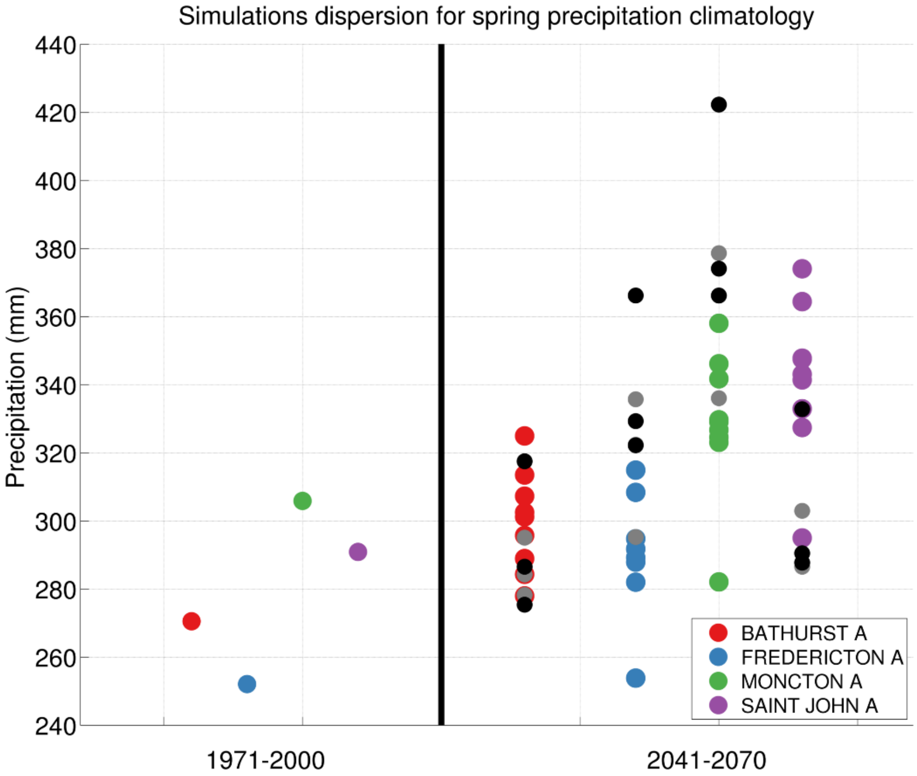

Figure C.26 Simulations dispersion for mean spring precipitation accumulation

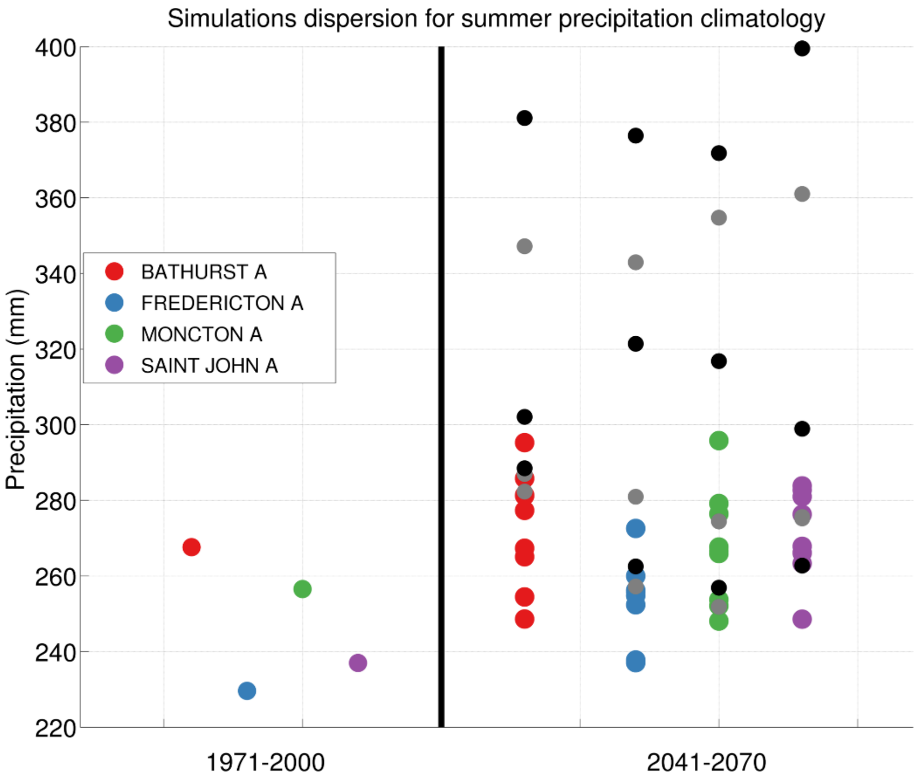

Figure C.27 Simulations dispersion for mean summer precipitation accumulation

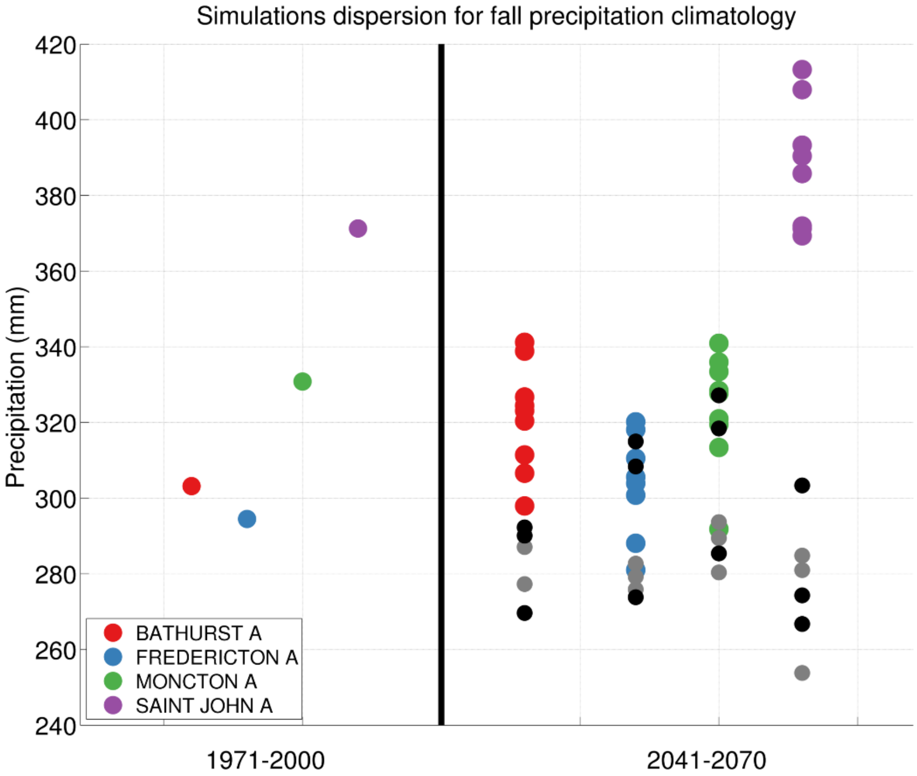

Figure C.28 Simulations dispersion for mean fall precipitation accumulation

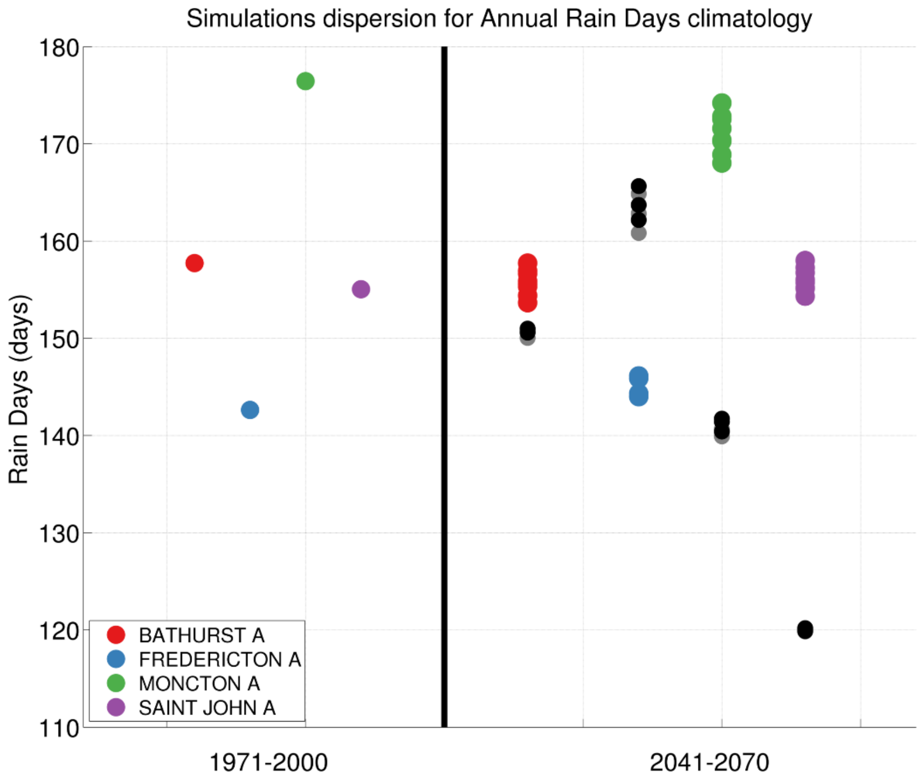

Figure C.29 Simulations dispersion for annual number of rain days

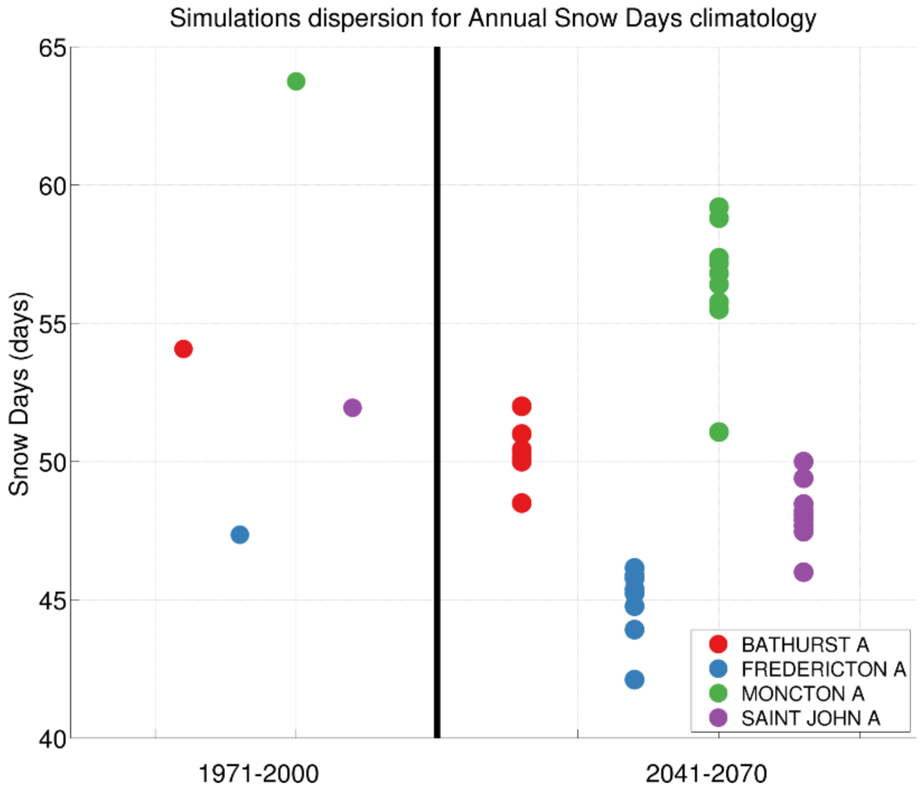

Figure C.30 Simulations dispersion for annual number of snow days

C.3 Analysis

Results from RCM simulation suggest that the climate change signals are similar to those obtained from GCM simulations. The broad similarity between RCMs and GCMs is expected since the RCMs are driven at their boundary by GCMs and the added value from the higher resolution of the RCMs is usually smoothed out when the climatology (i.e. time averages) is considered. However, one notable exception is the small increase in summer precipitation accumulation for Saint John (Figure C.27), whereas there was no climate change signal from CMIP5 GCM simulations (Figure 3.88). However, this result should be taken with the broad overview given by the results from the CMIP5 ensemble since the RCM ensemble is rather small compared to the size of the CMIP5 ensemble.

Differences between CMIP3- and CMIP5-driven RCM simulations are important for some indices and most of these differences involves the maritime city of Saint John:

- Winter mean temperature (Saint John);
- Summer mean temperature (Saint John);
- Annual days with temperature higher than 25 °C (Saint John)
- Annual days with temperature higher than 30 °C (Saint John)
- Annual days with temperature higher than 35 °C (Moncton and Saint John);
- Winter precipitation accumulation (Moncton and Saint John);
- Fall precipitation accumulation (Saint John);
- Annual rain days (Fredericton, Moncton and Saint John);
- Frost free days (Saint John);
- Growing season length (Saint John);
- Cooling degree days (Saint John);
- Heating degree days (Saint John);
- Growing degree days with base 10 °C (Saint John).

APPENDIX D EXCEL FILE DESCRIPTION

1) Filename

Filename template: “IndexName_RCPXX_HYYY.xls”

IndexName: The short name is the index. See Table A.1 for a complete listing of the short names.

RCPXX: The RCP used (for time horizons 2020, 2050 and 2080 only). Either RCP45 or RCP85.

HYYYY: The time horizons. Either H1990, H2020, H2050 or H2080.

Hence, MAMTemp_RCP85_H2050.xls contains the results of the mean spring temperature for the RCP 8.5 for the time period 2050.

2) File contents

Eight columns of data are provided inside each Excel file. Missing values are assigned with value - 9999.

1st column: Station ID

2nd column: Meteorological station name

3rd column: Quality flag (see Table 2.2)

4th column: Mean climatological value of index “IndexName” of the CMIP5 simulations ensemble.

5th column: 10th percentile value of index “IndexName” of the CMIP5 simulations ensemble.

6th column: 25th percentile value of index “IndexName” of the CMIP5 simulations ensemble.

7th column: 75th percentile value of index “IndexName” of the CMIP5 simulations ensemble.

8th column: 90th percentile value of index “IndexName” of the CMIP5 simulations ensemble.

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Ouranos was created in 2001 as a joint initiative by the Quebec government, Hydro-Québec and Environment Canada, with the financial support of Valorisation-Recherche-Québec. Ouranos brings together some 450 scientists and professionals from different disciplines and it focuses in two main themes: climate science and vulnerabilities, impacts and adaptation. Its mission is to acquire and develop knowledge on climate change, its impacts and related socioeconomic and environmental vulnerabilities, in order to inform decision makers about probable climate trends and advise them on identifying, assessing, promoting and implementing local and regional adaptation strategies.