Projected Impacts of Climate Change for the Province of Newfoundland & Labrador

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Executive Summary of Regional Climate Change Projections

Through the integration of available observations and a collection of state-of-the-art regional climate model projections of the 21st century (2038-2070), a summary of the expected impacts of climate change has been compiled for the province of Newfoundland and Labrador. Projected changes in 19 key climate indices are presented, ranging from simple descriptions of temperature to indicators of energy expenditure, agricultural potential, heavy precipitation, and drought severity.

Additional site-specific details on the current climatology, projected change, and uncertainty are presented for locations where suitable observations are available. Additional work presents estimates of changes in extreme precipitation ('return period' events); these were calculated in a manner that accounts for errors in climate model output. Results are intended to assist the Province and it's citizens in identifying vulnerabilities and opportunities associated with climate change, and provide guidance for adaptation efforts. Key findings are summarized below.

In terms of robustness, spatial extent, and seasonal consistency, the clearest impacts of climate change are related to temperature. Daily mean, minimum, and maximum temperatures all demonstrate statistically significant increases at every model grid cell and in every season. However, the degree of expected change differs between locations and seasons:

a. Temperature shifts are most pronounced in winter (+2-3°C for the Island of Newfoundland; +3-4°C for most of Labrador), and generally smaller (by ~1°C) in summer and autumn.

b. Seasonal differences in projected changes are generally smaller in Newfoundland than Labrador. This reflects the moderating influence of the ocean on Newfoundland. Ocean areas respond relatively slowly to temperature changes (either seasonal or long-term climate trends), keeping maritime climates like Newfoundland locked within a limited temperature range. The Labrador interior lacks this moderating influence, and temperatures consequently see a greater response to climate change.

c. Temperature changes vary strongly with latitude, increasing to 4-6°C in northern Labrador. As a result, some of the coldest places see the greatest warming.

d. Minimum temperatures generally change more than the mean or maximum; this is due to reduced nighttime cooling under an enhanced greenhouse effect. In practical terms, this suggests a greater decrease in morning frost events than might be expected from mean daily temperatures alone.

These changes closely mirror projected patterns of global climate change. In some locations and seasons, small temperature changes may have a greater impact on day-to-day activities than in others. Temperature shifts of a few degrees will have the greatest direct impact on locations where:

a. Seasonal mean temperatures are close to zero degrees, e.g. the Avalon Peninsula during winter and spring. The expected increases in temperature imply precipitation will fall more often as rain than snow. This does not mean there will no longer be snow in these seasons; changes are not large enough to eliminate these events entirely. The transition from snow to rain has economic impacts (e.g. related to snow clearing budgets, winter flooding events, winter recreation etc.), but also strongly impacts the perception of climate change; as rain replaces snow, inhabitants often become acutely aware of cold season climate change[1].

b. The onset of freezing conditions impacts daily life/economic pursuits. For example, parts of Labrador that rely on frozen ground or stable sea ice for winter transportation may be negatively impacted by delayed freeze-up, early melt, or (particularly in southerly and coastal locations) increased mid-winter thaws.

The shoulder (or transition) seasons of spring and autumn tend to become less like winter and more like summer. This is particularly clear as a dramatic decrease in the number of frost days, suggesting later freeze-up, earlier melt, and a decrease in perceived winter length. With a projected 10-15 fewer frost days in one or both shoulder season, winter may effectively become shorter by several weeks.

The three degree day measures included in the analysis are intended to address specific economic concerns around heating costs (heating degree day), cooling costs (cooling degree day), and agricultural/forestry potential (growing degree day). All show widespread, statistically significant changes in one or more seasons; however, in practical terms they are not all economically significant.

a. Heating degree days (HDD) decrease by 12-19% of the annual total across the entire province. Typical annual totals for Newfoundland are ~4000-5000 HDD; decreases projected for 2038-2070 are on the order of 700-850 HDD, or the value expected in a typical autumn. Labrador's climatological values of ~6000-7000 HDD decrease by 850-950; roughly half the typical spring total.

b. Cooling degree days (CDD) increase slightly in the province (~50 CDD for the island, and 30 CDD for Labrador). Although statistically significant, these

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[1] Hamilton & Keim, 2009.

small changes will not carry a significant economic cost; summers will remain mild enough to keep cooling costs low.

c. Most locations on the island see an additional 150-200 growing degree days (GDD), for a 30-45% increase in total GDD. A measure of heat accumulated for plant growth, an increase in GDD implies a more productive growing season. If other limiting factors (such as high winds or a lack of soil) are not present, this increase will lead to i) a more reliable growing season, ii) northwards migration of the tree line, and iii) potential for the introduction of new plant species to the province. This may also translate into increased spread or activity of pest species, as the maturity and reproductive cycle of insects can also be related to GDD heat accumulation; as such, span worm, spruce budworm, or other insect infestations may offset agricultural/forestry growth due to increased heat.

Results do not suggest any noticeable change in heat wave frequency or duration in the province. Classically defined heat waves are so rare in the province that an accurate climatology cannot be established; neither observations nor model projections show more than one or two events at any location in the period of record, and most models show none. The only season that sees any significant change is winter, when heat waves have no obvious health or safety implications.

Observations suggest frequent droughts (an extended period without rain) are not currently a concern anywhere in the province, with dry spells (period between precipitation events) typically lasting less than five days at any location. Dry spells long enough to be of concern (10-14 days or more) are rare. The frequency and intensity of dry spells and/or drought is not expected to change in a significant way; if anything, the data examined suggests dry spells may decrease slightly under a warmer climate. This suggests that issues around drought-driven water shortages and water-stress on vegetation are not a growing concern for the province. Projected changes in the mean length of dry spells are typically too small to be noticeable. If anything, the length of dry spells is expected to decrease very slightly.

The impact of climate change on precipitation is most apparent in consideration of intense or multi-day events (maximum 3, 5, or 10 day precipitation). Modest increases in mean precipitation are observed over the island in winter and spring, and through most of Labrador year round, but values are not as large as projected for other parts of Eastern Canada. There is, however, a relatively large increase in the mean intensity of events (0.5-1mm/day) on the island. The Labrador interior also experiences intensity increases (0.2-0.5mm/day) in summer, while southern Labrador sees similar increases from spring through autumn. Other changes related to increased intensity or heavy precipitation events include:

a. Winter increases in the number of days with substantial precipitation (more than 10mm) for most of the island, and summer increases in the Labrador interior.

b. Widespread increases in the maximum precipitation over consecutive 3, 5, and 10 day periods. On the island, these changes are strongest in winter, when precipitation is driven by the passage of low pressure systems and associated fronts; peaks are also apparent near the Burin and Avalon peninsulas in autumn, likely related to warmer early-season lows tracking to the southeast. In Labrador, the biggest changes are observed in summer, likely related to increased diurnal heating and resulting warm season precipitation.

c. Cold season temperature increases suggest precipitation will increasingly favor rain over snow in regions and seasons that currently experience both. However, snow is expected to remain a relatively common event. Because mean event intensity is expected to increase, the snow events that do occur will be heavier on average. The economic impact of fewer, heavier snow events may be as high (or higher) than that of frequent lighter events.

d. The majority of the models examined predict an increase in extreme precipitation, as represented by higher precipitation for return period events. The best estimate of expected change shows increases in extreme precipitation (20 year return period or more) at all locations. In some places the probability of exceeding the current 100 year event is approximately doubled; that is, the current 100 year event becomes the future 50 year event. For 24 hour duration events, the projected 50 year event is greater than or equal to the current 100 year event in 10 of the 19 communities examined. Should these projections occur, building structures to withstand the 100 year flood based on the current climate would leave those structures highly vulnerable to climate change. However, it is important to note that the uncertainty associated with return period projections are very high, and these results in particular must be interpreted with caution.

Major Impacts By Region

Eastern Newfoundland: This region experiences the smallest increases in temperatures (1.5-2.5 ^{o}C). However, because temperatures in this region are close to 0^{o}C between September and May, these small changes will have a large impact on winter perception and weather hazards. This is particularly true of the southeast. The result is a) a large decrease in frost days throughout winter, autumn, and spring, and b) a movement away from snow towards rain. Agricultural potential also increases considerably, both during summer and autumn. Precipitation intensity increases are relatively large along the south coast. Increases are particularly pronounced in the southeast, where substantial changes in intensity are expected in winter, summer, and fall. This represents the most persistent (cross-season) changes in intensity projected for the province. Similar patterns for the southeast (Avalon & Burin Peninsulas) are found in 90th percentile and maximum 3, 5, and 10 day precipitation, pointing to increasing hazards associated with heavy precipitation through much of year.

Western Newfoundland: The west coast experiences greater increases in temperature than eastern NL in all seasons, gaining an additional 0.25-0.6 °C relative to the southeast (e.g. St. John's). However, winters remain colder than eastern Newfoundland, while summers typically remain warmer. The largest increases in agricultural/forestry potential for the province are expected in the west/southwest (e.g. Stephenville, Deer Lake, Corner Brook), and the region also sees some of the greatest reductions in heating costs on the island. Changes in the number of frost days decrease rapidly away from the coast, and are generally less pronounced than in the east.   Precipitation intensities increase primarily during winter, with the highest values concentrated along the west/southwest coasts.

Great Northern Peninsula: As with the west coast, temperature increases are larger than those projected for eastern NL. However, generally colder temperatures mean the winter temperature increase has little impact on frost free days during winter, pushing the decrease into spring and summer instead. Increases in agricultural potential are much lower than the rest of the island, suggesting limited change to the sparsely vegetated landscape. Changes in intense & multi-day precipitation are generally smaller than regions further south and east, and concentrated in winter; because mean temperatures in this season remain well below freezing, the majority of this increase will be delivered as snow.

Northern Labrador: Northern Labrador is expected to see the largest increases in winter temperatures, reaching 5-6 °C at the northernmost point. However, summer temperature increases are lower than the rest of Labrador. Because temperatures remain cold during summer, there is no change in agricultural potential; the region will remain above the tree line and sparsely vegetated. Frost-free days change very little in winter and spring, but decrease sharply in summer (2-3 weeks) and autumn (about 10 days), suggesting an earlier thaw and later freeze-up.   Although not explicitly examined in the current study, warmer temperatures and fewer frost days will likely promote permafrost retreat. Significant changes in precipitation intensity are limited to the summer.

Southern Labrador: Winter temperature changes are smaller in southern Labrador than the rest of the region, but still higher than most of Newfoundland (3-4°C). The only significant increase in agricultural potential in Labrador is seen here, suggesting faster plant growth, a northwards migration of the tree line, and a possible increase in insect pests. Winters remain cold, but decreases in frost days during spring and autumn suggest an earlier thaw and later freeze (1-2 weeks on either side). Changes in precipitation intensity occur from summer through the end of winter. The greatest changes occur in winter; given the low temperatures, this implies heavier snow events.

Labrador Interior vs. Labrador Coast: Coastal Labrador typically sees less warming than the interior at any given latitude, although the impact is generally small (less than 1^{o}C difference in most seasons). Increases in precipitation intensity and long duration precipitation totals are also generally stronger in the interior than the coast; this contrast is clearest in winter and autumn, when the majority of the coast sees no significant change but the southern interior sees large increases.

Introduction

The following work summarizes climate projections for the province of Newfoundland and Labrador, in order to assist the provincial government, communities, and industry in the assessment of their climate vulnerabilities and related adaptation options. Projections were derived from an ensemble of seven regional climate model (RCM) simulations produced for the North American Regional Climate Change Assessment Project (NARCCAP)[2]. Projected change from the modern era (1968-2000) to the mid-21st century (2038-2070) is described. Whenever possible, projected changes are interpreted in the context of reliable climate observation data sets, including the Environment Canada (EC) Adjusted Homogenized Canadian Climate Data archive (AHCCD)[3][4], yearly maximum precipitation data used for EC's Intensity/Duration/ Frequency (IDF) curves, and temperature data from the North American Regional Reanalysis (NARR)[5].

The bulk of results focus on spatial patterns of change in key climate variables identified as being of interest by the Provincial Government's Office of Climate Change, Energy Efficiency, and Emissions Trading (CCEEET). These variables are largely drawn from the suite of climate indices used in the Statistical and Regional Dynamical Downscaling of Extremes for European Regions (STARDEX) project. Additional analysis was performed to estimate bias-corrected precipitation return periods for select communities. Results represent a current 'best-guess' at the climate Newfoundland can expect by mid-century. As with any forecasting product, there is considerable uncertainty in these projections; however, they provide reasonable guidance for short-term adaptation planning. Users interested in longer-term change can expect the trends outlined here to continue beyond the 21st century, with the magnitude of the continued response strongly dependent on the international response to the problem of human-induced climate change.

The results of this report should be re-evaluated when a new multi-model regional climate change assessment for North America becomes available. Based on the timeline of the original NARCCAP project, results from such a project are unlikely to become available prior to 2019.

A technical description of data sets, pre-processing, and the ensemble averaging scheme follows; these have been provided for completeness, but are not necessary for most readers. Users interested in examining and applying results can skip to the *Projected Change in Climate Variables* (pg. 16) and *Extreme Precipitation* (pg. 114) sections.

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[2] Mearns, et al., 2009.
[3] Mekis & Vincent, 2011.
[4] Vincent et al., 2011.
[5] Mesinger et al., 2006.

Data Sets

The primary data source for the current project are regional climate model (RCM) simulations provided by the North American Regional Climate Change Assessment Project, or NARCCAP. NARCCAP provides a useful complement to the General Circulation Model (GCM) projections that have traditionally been used to assess long-term climate change. While GCMs provide global data with limited spatial and temporal resolution, NARCCAP provides a more detailed description of North America; a typical GCM will represent Newfoundland with 1-5 spatial data points and daily data output, while the NARCCAP RCMs cover it with a few dozen points at 3-hourly intervals. This allows for improved treatment of weather systems, topographic effects, and local processes, making RCMs more suitable for regional planning than coarse GCMs; many climatologists feel that RCMs are currently the best available source of information for regional adaptation planning. However, RCMs remain an imperfect planning tool. As with GCMs, NARCCAP simulations contain various biases and overly simplify many important weather processes. They are also partially driven by GCM simulations, and problems with GCMs can therefore be passed on to the RCMs. For these reasons, NARCCAP projections must be interpreted with caution. Although they can provide some context for climate adaptation planning, they should not be interpreted as a certainty; the true climate response may be stronger or weaker than NARCCAP simulations suggest.

Table 1: List of NARCCAP ensemble members used in the current study[6]

Short Name	**Regional Climate Model**	**Global Climate Model Used for Boundaries**
CRCM_ccsm	Canadian Regional Climate Model (Canada)	Community Climate System Model (USA)
CRCM_cgcm3	Canadian Regional Climate Model (Canada)	Coupled Global Climate Model, version 3 (Canada)
HRM3_gfdl	Hadley Regional Model 3 (UK)	Geophysical Fluid Dynamics Laboratory GCM (USA)
HRM3_hadcm3	Hadley Regional Model 3 (UK)	Hadley Centre Coupled Model, version 3 (UK)
RCM3_cgcm3	Regional Climate Model version 3 (USA)	Coupled Global Climate Model, version 3 (Canada)
RCM3_gfdl	Regional Climate Model version 3 (USA)	Geophysical Fluid Dynamics Laboratory GCM (USA)
WRFG_ccsm	Weather Research and Forecasting Model (USA)	Community Climate System Model (USA)

At the time this report was being prepared, seven complete NARCCAP simulations suitable for analysis of Newfoundland & Labrador were available (Table 1). Each

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[6] Details on the models are available from the NARCCAP website (http://www.narccap.ucar.edu/)

projection in this 7-member ensemble was produced through a unique combination of a specific GCM (to provide boundary forcing) and RCM (for dynamical downscaling), and includes a 20th century simulation (1968-2000) and mid-21st century projection (2038-2070). Although all data was provided at a spatial resolution of ~50km, the specific latitude/longitude grids used by individual RCMs varies. In order to compare models, all projections were interpolated to a common grid. Spatially smooth variables (e.g. temperature and sea level pressure) were interpolated using the Cressman scheme, which is commonly used in meteorology. The Cressman algorithm calculates values as an inverse-distance weighted average of points within a critical radius (R) of the destination grid point:

$$V_{new} = \frac{\sum_i w_i V_{old}}{\sum_i w_i};$$

$$w_i = \frac{R^2 - d_i^2}{R^2 + d_i^2}$$

where d_i is the distance of the ith point on the original grid to the destination point on the new grid. For the current work, a critical radius of 200km was used. This approach is less suitable for interpolation of spatial inhomogeneous data such as precipitation, due to excessive smoothing of the field. For this reason, nearest-neighbour interpolation was used for precipitation data.

Model projections have been compared against observations collected by Environment Canada (EC) climate stations and the North American Regional Reanalysis (NARR). Two EC data sources have been used:

> a) the Adjusted Homogenized Canadian Climate Data (AHCCD) archive, which provided daily mean, maximum, and minimum temperatures along with 24 hour precipitation totals for select stations.
>
> b) the annual precipitation maxima data used in for the official EC Intensity-Duration-Frequency (IDF) curves.

AHCCD is particularly useful, as the data provided has been rigorously examined and corrections have been made for biases associated with equipment updates, failure, or station relocation. The IDF data provides greater detail on precipitation, and allows short duration precipitation extremes to be examined in addition to the 24 hour AHCCD-based analyses.

As a complement to station data, NARR presents high-resolution (25km) gridded meteorological data for the North American region, saved at 3 hour intervals. As an atmospheric *reanalysis*, this product represents an integration of direct observations of the earth system (e.g. from station data, satellites, radiosondes, and observations-ofopportunity) with numerical weather forecasting tools and techniques. This blend of simulation and observations represents a 'best-guess' of the atmospheric state for a given time. Problems have been identified with its treatment of precipitation outside of the United States, but other available fields (e.g. pressure, temperature, winds etc) are considered reliable.

It is important to note that NARCCAP, NARR, AHCCD, and EC IDF data are provided free of charge for noncommercial purposes. Results of the analysis of this data cannot be used for commercial purposes (i.e. the results cannot be sold to other potential users).

Figure 1: Location of AHCCD stations with all necessary data on the island of Newfoundland.

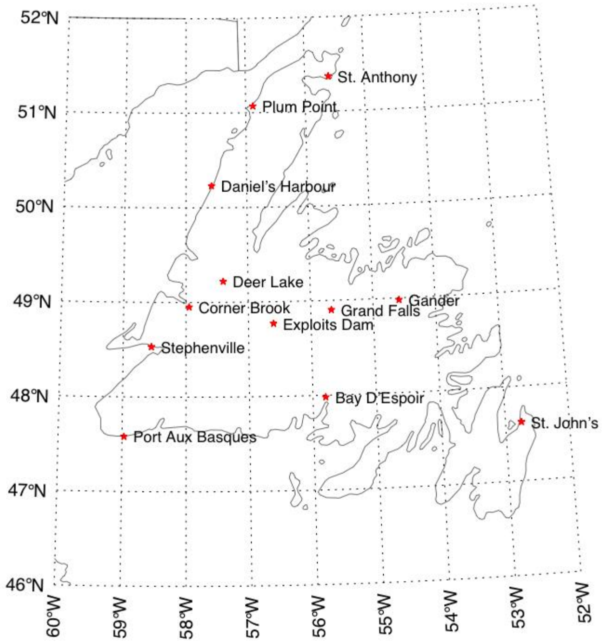
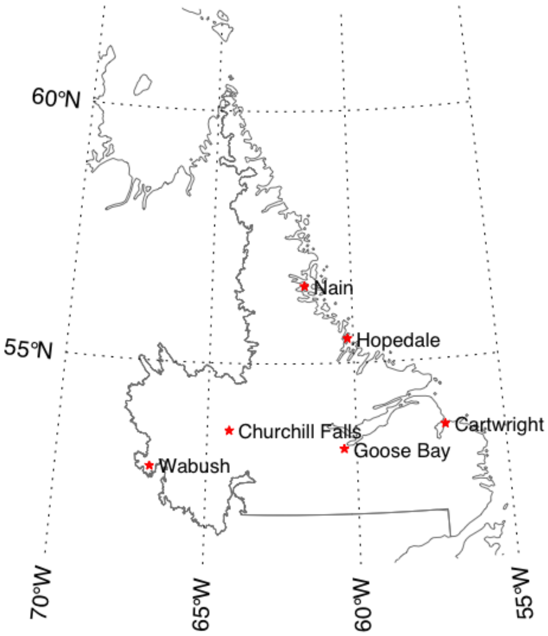


Figure 2: Location of AHCCD stations with all necessary data in Labrador.



Model Performance and Weights

Because climate models (whether GCMs or RCMs) all a) feature unique biases and b) respond differently to specified forcings (e.g. changing greenhouse gas concentrations), multiple simulations from different models should be examined whenever possible; such a collection of simulations is commonly referred to as a *multi-model ensemble*.

Averaging predictions over all ensemble members reduces the influence of individual model biases. Ensembles also allow uncertainty in projections to be estimated, albeit to a limited degree; full treatment of uncertainty would require many more models and simulations than can feasibly be produced (on the order of tens of thousands, rather than the dozen typically available). However, certain models are better suited to specific regions than others, and giving equal consideration to all ensemble members does not necessarily produce the best estimate of the future climate. Rather, many studies suggest that 'weighting' models on the basis of some performance criteria can lead to a clearer, more concise estimate of future conditions and reduce uncertainty. Various weighting schemes have been proposed, based on estimated model bias, convergence of projections[7], the ability to replicate observed weather systems with a reasonable frequency[8,9,10], or the ability to replicate extreme events[11]. At present, there

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[7] Giorgi & Mearns, 2002.

[8] Cassano et al., 2006.

is no single, universally accepted weighting criteria or calculation scheme, but applying a weighting scheme does appear to improve forecasts relative to an unweighted ensemble average[12] [13]. For the current study, the ensemble has been weighted following a simplified adaptation of the scheme presented by Christensen et al. (2010).

For the current study, the 'best-guess' estimates of climate change were based on a weighting scheme with four criteria: a) Bias in mean annual temperatures in Newfoundland and Labrador (NL), b) divergence in projected NL annual temperature change, b) the ability to replicate the extreme precipitation statistics at three long-term climate stations, and c) representation of sea level pressure synoptic climatology. This is essentially a simplified subset of the multi-weight scheme proposed by Christensen et al. 2010. Weights for these individual criteria were calculated for each ensemble member, then normalized to give a value between zero and one. Individual criteria were then multiplied to give a single weight for each ensemble member.

$$W = W_B W_D W_L W_{SL}$$

Calculation of the four criteria was as follows:

a) Temperature Bias & Divergence of Annual Temperature:

Bias and projection divergence are merged in the Reliability Ensemble Averaging (REA) scheme proposed by Giorgi & Mearns (2002); we use this approach in the current work. Models are scored on the basis of regional mean temperature biases (B_T) estimated from 20th century climate simulations, and divergence (D_T) from the ensemble-mean temperature change predicted for the 20th century:

$$B_T = \overline{T}_{Model} - \overline{T}_{reanalysis}$$

$$D_T = \Delta T_{Model} - \overline{\Delta T}$$

where $\overline{T}$ is the average annual temperature for the NL region, D_T is the predicted change under the future climate (here, the change from 1968-2000 to 2038-2070), and $\Delta \overline{T}$ is the ensemble mean predicted change. Bias (W_{bias}) and divergence ($W_{diverge}$) were calculated as:

$$W_B = \frac{\varepsilon_T}{abs(B_T)}$$

$$W_D = \frac{\varepsilon_T}{abs(D_T)}$$

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[9] Sanchez et al., 2004.
[10] van Ulden et al, 2007.
[11] Lenderink, 2010.
[12] Christensen, 2010.
[13] Knutti et al., 2010.

where $abs(\,)$ is the absolute value and ε_T is standard deviation of mean annual NL temperature, smoothed with a 15 year running mean. Weights greater than one (i.e. where B_T or D_T is smaller than natural variability, ε_T) were reset to one.

b) Extreme Precipitation Statistics

For each model, time series of maximum annual 24 hour precipitation at grid cells closest to St. John's, Gander, and Goose Bay were calculated. These time series were then compared to the probability distributions used to generate Environment Canada's official 24 hour return period events. A multi-site negative log likelihood (L)[14] score was calculated for each model :

$$L = -\sum_{m=1}^{3}\sum_{t=1}^{N} \log\{f_m[x_m(t)]\}$$

where m is the climate station location, t is the year (1968-2000), and f_m is the probability density function; in this case, f_m is a Gumbel distribution fit to the official EC Intensity-Duration-Frequency (IDF) data provided by Environment Canada (see discussion of precipitation return periods for details). Weights were calculated as:

$$W_L = \frac{(L_{Model} - \min(L))}{\min(L)}$$

where L_{Model} is a given model likelihood, and $min(L)$ is the minimum likelihood score over all models (i.e. the best match to observations).

c) Sea Level Pressure Synoptic Climatology

A synoptic climatology of 3-hr sea level pressure (SLP) data was created for a domain covering Eastern Canada and the Labrador Sea, using the method of Self-Organizing Maps[15,16]. Essentially, this approach condenses the full range of SLP data into a set of archetypal patterns of pre-determined size (99 for the current study). The occurrence frequency (f_i) of each pattern was then calculated by comparing 3-hr data from NARR to the archetypal patterns, and identifying the best match. Following Cassano et al. (2006), model performance was calculated as the correlation of model simulated occurrence frequency ($f_{i,Model}$) to the NARR value ($f_{i,NARR}$); scores were normalized relative to the highest performing model:

$$W_{SLP} = \frac{correlation(f_{NARR}, f_{Model})}{\max(correlation(f_{NARR}, f_{Model}))}$$

Perfect correlation implies the model replicates the pattern frequencies found in NARR exactly; that is, the model recreates key weather patterns with the correct

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[14] Cannon, 2008.

[15] Cassano, et al, 2006.

[16] Hewitson & Crane, 2002.

frequency. Lower correlations imply less agreement, or a model that emphasizes certain weather events at the expense of others.

Ensemble Averaging and Uncertainty: REA Approach

The spatial patterns of climate change presented in the following section are based on a weighted ensemble average of model projections similar to the REA proposed by Giorgi & Mearns (2002):

$$\overline{\Delta V} = \frac{\sum_i W_i \Delta V_i}{\sum_i W_i}$$

where *i* indicates individual ensemble members, and V is the variable being averaged. Similarly, uncertainty was calculated following the REA scheme as:

$$\Delta V_+ = \overline{\Delta V} + \delta_{\Delta T}$$
$$\Delta V_- = \overline{\Delta V} - \delta_{\Delta T}$$
$$\delta_{\Delta T} = \left[\frac{\sum_i W_i (\Delta V_i - \overline{\Delta V})^2}{\sum_i W_i} \right]^{1/2}$$

These calculations were performed at every grid cell. Results are presented as a series of maps, with color indicating the ensemble average projected change and cross-hatching applied to grid cells with a statistically significant change (i.e. $[\Delta V_-, \Delta V_+]$ does not contain zero). It is important to note that the REA approach may not be ideally suited to variables that are not normally distributed; several of the climate variables discussed below fall into this category to some degree or another. However, addressing uncertainty in non-normally distributed variables is beyond the scope of the current work, and the REA scheme has consequently been applied to all presented variables. For this reason, the uncertainty presented should be considered a *low* estimate.

Projected Change in Key Climate Variables

Change is presented for Labrador and the island of Newfoundland on a seasonal basis, with separate plots for winter (December/January/February, or DJF), spring (MAM), summer (JJA), and autumn (SON). Colour shading indicates the weighted mean value projected by the multi-model NARCCAP ensemble (i.e. the ‘best guess’ value for future change), and cross-hatching was used to mark grid cells that undergo a statistically significant change (i.e. a change that the model ensemble agrees is very likely).

Tabulated data for locations associated with reliable, long-running bias-corrected Environment Canada climate stations (AHCCD stations) within the province are also provided as a complement to the plots, giving the mean climatological value recorded at the station and REA estimates of change and uncertainty. Users interested in incorporating projections into adaptation planning can use the images together with the nearest station(s) to best interpret their projected future climate state. Values examined are listed in Table 2.

Changes in annual values were not included in the plots or tables, but can be inferred from the tables provided as follows:

i) Seasonal values based on an average can simply be averaged to get an annual value.

ii) Annual change for variables based on maximum occurrences can be estimated by taking the highest of the seasonal values.

iii) Annual change for values based on a summation over a season can be calculated by adding the seasonal numbers together.

The variables reported here are all derived from some combination of the following time series: daily mean temperature at 2m above the ground, daily maximum temperature (2m; T_{max}), daily minimum temperature (2m; T_{min}), and daily total precipitation. Daily mean temperatures and total precipitation were calculated from NARCCAP data reported at 3 hour intervals (i.e. 8x daily); daily maximum and minimum temperatures were reported directly by models for each day. In all cases, the day was measured from midnight-to-midnight, Coordinated Universal Time (UTC; essentially Greenwich Mean Time).

As an example of how this information might be used, consider the case of Bishop's Falls. Located on the Exploits River, this community may be interested in the potential impacts of climate change on river flow. Suppose the community identifies ice jam flooding events as a particular concern, and recognizes that increases in daily minimum temperatures, daily maximum temperatures, and the number of frost days could trigger river ice break-up. Using the maps, planners can quickly determine that all three variables change significantly in the region near Bishop's Falls, and that these changes are significant in winter and spring (the seasons of concern for ice jams). The tables could then be used to estimate the magnitude of changes with greater accuracy, using data for the nearest AHCCD location (here, Grand Falls). A future projection with an uncertainty range can be estimated by:

1. Calculating the range of expected change as [Projected Change – Uncertainty, Projected Change + Uncertainty]. That is, the range will fall between these two values.
2. Adding the resulting change range to the current climate value, to give [Lower projection bound, upper projection bound].

Table 2: List of climate indices examined, with units and calculation type indicated[17].

Short Name	Long Name	Units	Calculation Type
TAV	Average Daily Mean Temperature	^{o}C	Average
TNAV	Mean Daily Minimum Temperature	^{o}C	Average
TXAV	Mean Daily Maximum Temperature	^{o}C	Average
TCDD	Cooling Degree Day	Degree Day	Sum
THDD	Heating Degree Day	Degree Day	Sum
TGDD	Growing Degree Day	Degree Day	Sum
TNFD	Number of Frost Days	Days	Sum
TXHWD	Maximum Heat Wave Duration	Days	Maximum
PAV	Mean Daily Precipitation	mm	Average
PINT	Mean Intensity of Precipitation Events	mm/day	Average
PQ90	90th Percentile of Precipitation Events	mm	Alternate
PX3D	Maximum 3-day Precipitation	mm	Maximum
PX5D	Maximum 5-day Precipitation	mm	Maximum
PX10D	Maximum 10-day Precipitation	mm	Maximum
PN10mm	Number of Days With 10mm or More of	Days	Sum
PXCDD	Maximum Number of Consecutive Dry Days	Days	Maximum
PDSAV	Average Dry Spell Length	Days	Average
PDSMED	Median Dry Spell Length	Days	Alternate
PDSSDV	Standard Deviation of Dry Spell Length	Days	Alternate

For daily minimum temperature, the values for winter in Grand Falls are (in ^{o}C; taken from Table 4):

20th Century Climate	Projected Change	Uncertainty
-10.8	3.3	1.4

Calculation 1) then gives:

[Projected Change - Uncertainty,   Projected Change + Uncertainty]
= [3.3 – 1.4,   3.3 + 1.4]
= [1.9, 4.7]

That is, NARCCAP expects Grand Falls to experience a winter increase in daily mean temperature between 1.9 and 4.7 ^{o}C. The current climatological value for winter is -10.8 ^{o}C. Adding this to the projected change gives an expected future climatological value of:

[Lower projection bound,   Upper projection bound]

---

[17] Calculation Type indicates whether the variable is based on a seasonal average, total (sum), or maximum value, for the purposes of extracting annual values from the seasonal data provided. Calculation type 'alternate' indicates a calculation for which a simple annual value cannot be extracted from seasonal results.

= -10.8 ^{o}C + [1.9, 4.7]
= [-8.9, -6.1]

That is, the future climatological value is expected to fall between -8.9 to -6.1 ^{o}C.

Daily Mean Temperature (^{o}C)

Summary: Daily mean temperatures are projected to increase throughout the province, with the largest changes in winter.

Daily mean temperature is the variable most commonly associated with climate change; essentially, the average temperature. The immediate, direct impact of human-induced climate change is generally summarized as 'global warming'; however, not every location experiences the same degree of warming, and a small number of locations may even respond to climate change with a weak cooling. Alone, this variable is of little use in community adaptation planning. It is, however, a useful starting point, and provides context for other variables of potentially greater value. Here, the value is based on the average of 3-hourly temperatures for a height 2m above the ground.

Results suggest the entire province can expect to experience warming. Projected changes show the largest increases at high latitudes (e.g. northern Labrador) and away from coastlines (e.g. the Labrador interior). Regions located near large water bodies experience less of a change, as open water changes temperature slowly, keeping climate moderate and reducing the immediate impact of a warming planet. This moderating influence is reduced when sea (or lake) ice forms, as the ice effectively insulates the atmosphere from the underlying ocean. Some of the higher changes on the Great Northern Peninsula, coastal Labrador, and near Ungava Bay during the cold season are related to changing ice conditions (later freeze-up, earlier melt, and thinner ice on average). The lessened impact on the Avalon and Burin peninsulas is due to the fact that open water is located nearby throughout the year.

In locations/seasons with mean temperatures close to zero (e.g. St. John's), upward trends suggest less precipitation in the form of snow, and more in the form of rain. However, the temperature trends are low enough that snow events will still occur. Precipitation analyses (see mean precipitation event intensity, mean daily precipitation etc. below) suggest more precipitation will fall in individual events, but no significant decrease in the number of precipitation events. Together, temperature and precipitation trends suggest regions like the Avalon will experience a) fewer, yet heavier, snow storms, and b) more frequent and heavier rain events during the cold season. Colder locations (e.g. Great Northern Peninsula; Labrador) can expect similar changes in the shoulder seasons, transitioning to heavier snow events in winter.

Figure 3: Changes in daily mean temperature (^{o}C) projected for 2038-2070. Significant changes are indicated by cross-hatching.

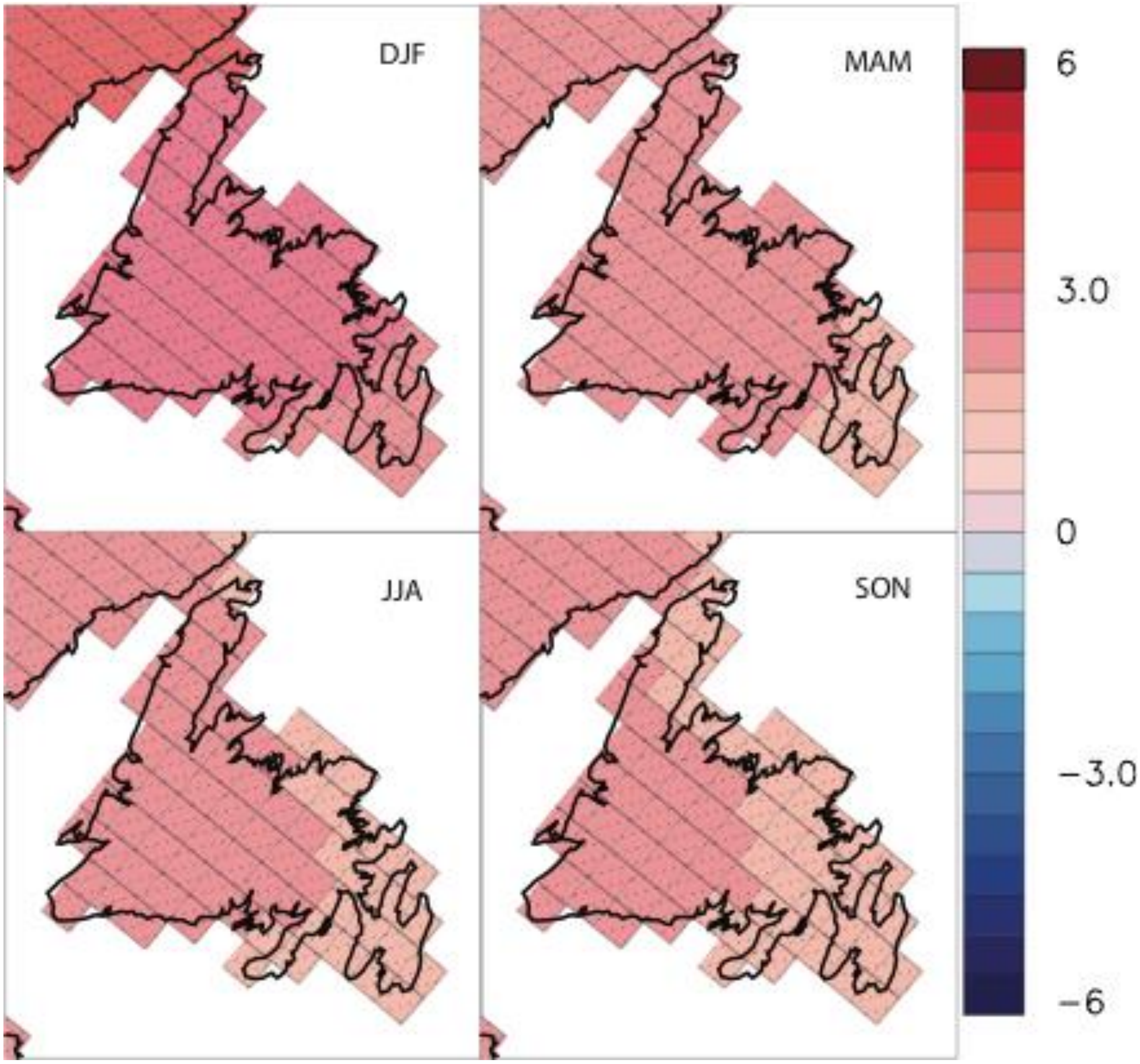

Table 3: Daily mean temperature (^{o}C) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	-5.33	2.68	1.06
	MAM	2.63	2.12	0.33
	JJA	14.92	2.04	0.36
	SON	7.32	2.01	0.51
Corner Brook	DJF	-4.89	2.84	1.29
	MAM	2.26	2.25	0.37
	JJA	15.62	2.10	0.38
	SON	7.44	2.05	0.54
Daniel's Harbour	DJF	-6.20	2.93	1.30
	MAM	0.49	2.28	0.44
	JJA	13.18	2.16	0.53
	SON	6.37	2.02	0.60
Deer Lake	DJF	-6.86	2.86	1.26
	MAM	1.27	2.23	0.36
	JJA	14.98	2.10	0.41
	SON	6.36	2.05	0.55
Exploits Dam	DJF	-7.09	2.83	1.19
	MAM	0.55	2.20	0.35
	JJA	14.13	2.10	0.40
	SON	5.88	2.06	0.54
Gander	DJF	-5.55	2.69	1.30
	MAM	1.46	2.08	0.39
	JJA	14.91	1.94	0.44
	SON	6.69	1.90	0.55
Grand Falls	DJF	-6.18	2.79	1.22
	MAM	1.97	2.15	0.36
	JJA	15.62	2.06	0.44
	SON	6.89	2.01	0.56
Plum Point	DJF	-8.24	2.95	1.26
	MAM	-0.34	2.22	0.48
	JJA	12.96	2.13	0.58
	SON	5.66	1.99	0.62
St. Anthony	DJF	-9.37	2.98	1.52
	MAM	-1.37	2.12	0.55
	JJA	12.32	1.91	0.60
	SON	4.70	1.85	0.60
St. John's	DJF	-3.45	2.31	1.11
	MAM	1.79	1.87	0.29
	JJA	14.07	1.78	0.40
	SON	7.67	1.76	0.53
Stephenville	DJF	-4.93	2.85	1.41
	MAM	1.92	2.30	0.39
	JJA	14.85	2.09	0.37
	SON	7.52	2.04	0.52

Figure 4: Changes in daily mean temperature (^{o}C) projected for 2038-2070. Significant changes are indicated by cross-hatching.

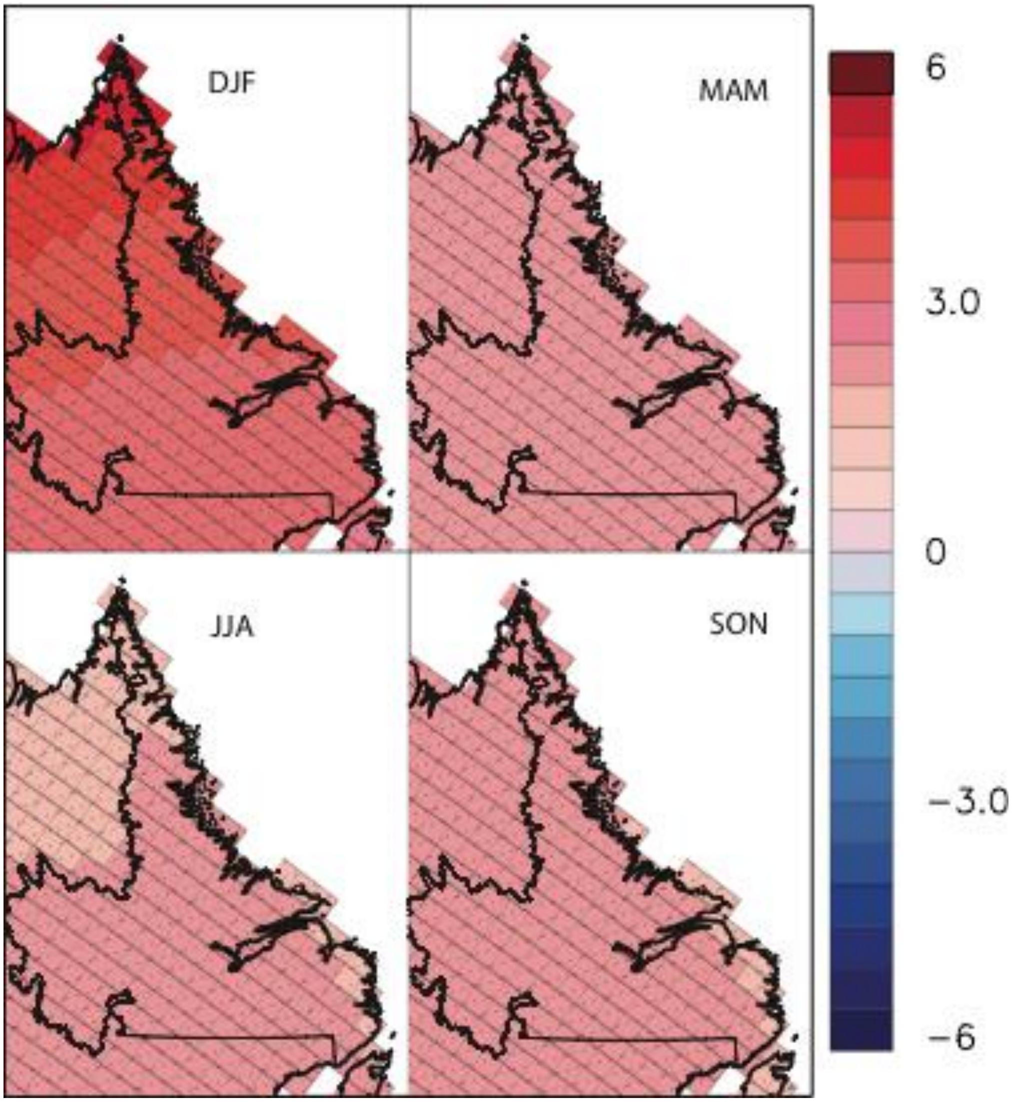

Table 4: Daily mean temperature (°C) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	-11.46	3.34	1.53
	MAM	-2.31	2.14	0.71
	JJA	11.02	1.97	0.76
	SON	3.31	1.93	0.69
Churchill Falls	DJF	-19.55	3.41	1.07
	MAM	-4.84	2.06	0.48
	JJA	12.13	2.10	0.53
	SON	-0.05	2.31	0.67
Goose Bay	DJF	-14.68	3.30	1.13
	MAM	-1.56	2.08	0.50
	JJA	14.14	2.06	0.55
	SON	3.21	2.27	0.69
Nain	DJF	-15.70	3.83	1.48
	MAM	-4.94	2.16	0.59
	JJA	9.28	2.10	0.77
	SON	1.58	2.14	0.78
Wabush Lake	DJF	-19.46	3.38	1.01
	MAM	-4.43	2.07	0.45
	JJA	12.43	2.18	0.46
	SON	0.13	2.33	0.62

Daily Minimum Temperature (°C)

Summary: Daily minimum temperatures are projected to increase throughout the province, with the greatest changes expected in winter. Changes are greater than those of the daily mean or maximum temperatures (3-4 °C in NL; 3-6 °C in Labrador).

Mean daily minimum temperature is calculated by averaging the minimum temperature recorded for each day in a given season. Under typical conditions, and in the absence of passing weather systems, the timing of the daily minimum is determined by the timing of sunshine, occurring at dawn when the rising sun interrupts nighttime cooling.

The mean daily minima has value as an indicator of frost events during the growing season and thaws during the cold season: regions with daily minima close to 0°C in a relevant season can expect more of these events. Because rising greenhouse gases limit nighttime cooling, daily minima often change more than either mean temperatures or daily maximum temperature in response to human-induced climate change. This results in a smaller mean temperature range (maxima warm a little; minima warm a lot) in many locations. Spatial patterns of minima change projected for Newfoundland & Labrador closely follow daily averages, although the magnitude is typically a little larger.

Figure 5: Changes in mean daily minimum temperature (^{o}C) projected for 2038-2070. Significant changes are indicated by cross-hatching.

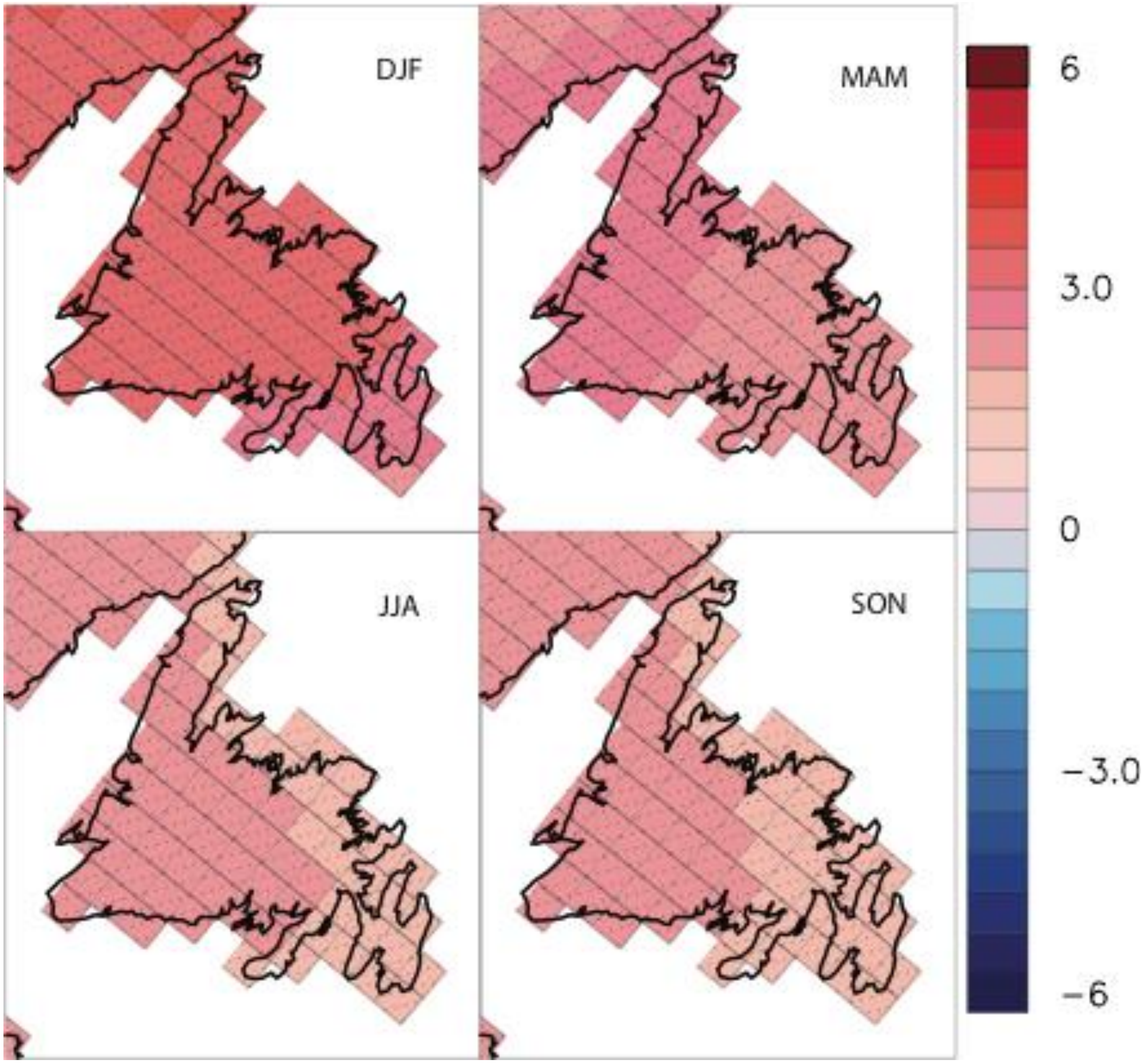

Table 5: Mean daily minimum temperature (^oC) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	-10.2	3.2	1.4
	MAM	-2.4	2.5	0.6
	JJA	9.3	2.1	0.4
	SON	2.7	2.0	0.5
Corner Brook	DJF	-8.3	3.4	1.6
	MAM	-1.8	2.6	0.7
	JJA	10.9	2.1	0.4
	SON	3.8	2.1	0.5
Daniel's Harbour	DJF	-9.7	3.4	1.4
	MAM	-3.0	2.7	0.7
	JJA	10.0	2.1	0.6
	SON	3.4	2.0	0.5
Deer Lake	DJF	-11.3	3.4	1.5
	MAM	-3.8	2.6	0.7
	JJA	9.1	2.1	0.5
	SON	1.9	2.1	0.5
Exploits Dam	DJF	-11.7	3.4	1.4
	MAM	-4.7	2.5	0.6
	JJA	8.0	2.1	0.4
	SON	1.2	2.1	0.5
Gander	DJF	-9.1	3.2	1.5
	MAM	-2.7	2.4	0.7
	JJA	9.9	1.9	0.5
	SON	3.0	1.9	0.5
Grand Falls	DJF	-10.8	3.3	1.4
	MAM	-2.8	2.5	0.6
	JJA	9.9	2.0	0.5
	SON	2.5	2.0	0.5
Plum Point	DJF	-12.0	3.4	1.2
	MAM	-4.1	2.6	0.7
	JJA	9.5	2.0	0.6
	SON	2.9	2.0	0.5
St. Anthony	DJF	-13.5	3.4	1.6
	MAM	-5.1	2.5	0.8
	JJA	7.6	1.8	0.7
	SON	1.1	1.8	0.5
St. John's	DJF	-6.7	2.8	1.5
	MAM	-1.9	2.1	0.6
	JJA	9.5	1.8	0.5
	SON	4.2	1.7	0.5
Stephenville	DJF	-8.3	3.4	1.8
	MAM	-2.0	2.7	0.9
	JJA	11.0	2.1	0.4
	SON	4.1	2.1	0.5

Figure 6: Changes in mean daily minimum temperature (^{o}C) projected for 2038-2070. Significant changes are indicated by cross-hatching.

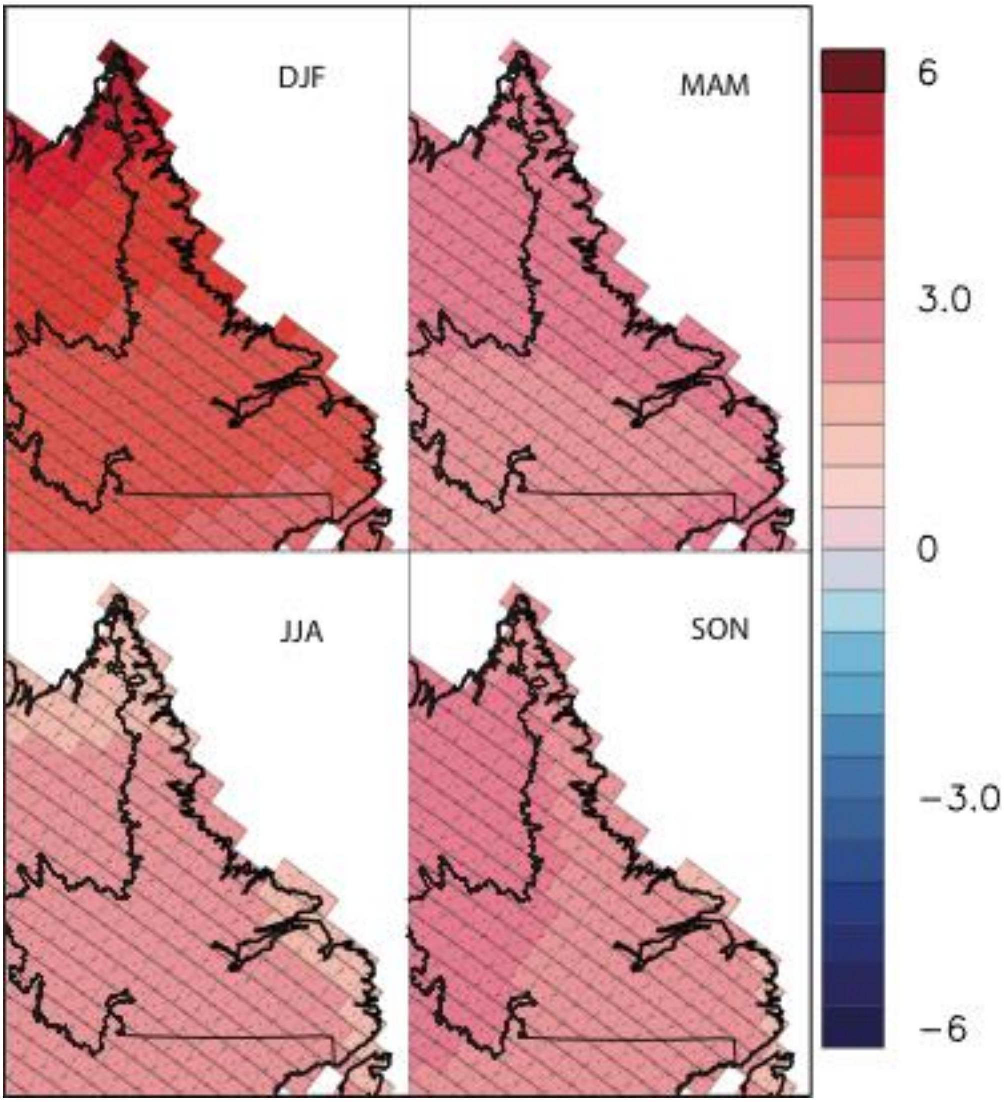

Table 6: Mean daily minimum temperature (^oC) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	-15.2	3.7	1.4
	MAM	-6.2	2.5	0.9
	JJA	6.0	1.9	0.8
	SON	0.1	2.0	0.7
Churchill Falls	DJF	-25.1	3.7	1.0
	MAM	-10.7	2.4	0.6
	JJA	6.8	2.1	0.5
	SON	-3.9	2.5	0.6
Goose Bay	DJF	-19.1	3.6	1.1
	MAM	-6.5	2.4	0.6
	JJA	8.9	2.0	0.6
	SON	-0.6	2.4	0.7
Nain	DJF	-19.9	4.1	1.3
	MAM	-9.4	2.5	0.8
	JJA	4.4	2.0	0.8
	SON	-1.9	2.3	0.8
Wabush Lake	DJF	-24.4	3.8	1.0
	MAM	-9.9	2.4	0.6
	JJA	7.4	2.3	0.5
	SON	-3.3	2.5	0.5

Daily Maximum Temperature (^{o}C)

Summary: Increases in daily maximum temperature are projected throughout the province, with the greatest change expected in winter. Changes are smaller than those of the minimum (1-3^{o}C in NL; 2-5 ^{o}C in Labrador).

Mean daily maximum temperature is calculated by averaging the maximum temperature recorded for each day in a given season. As with daily minima, the timing of the maxima is strongly related to the diurnal cycle in solar heating; daily maximums are expected mid-to-late afternoon, several hours after solar intensity begins to decrease.

Seasons/locations with daily maxima close to zero and minima considerably below freezing will see a larger number of daily freeze/thaw cycles associated with the daily temperature cycle. These become less common as both maxima and minima increase. Spatial patterns of projected change closely follow those of the daily average and minima.

Figure 7: Changes in mean daily maximum temperature (^{o}C) projected for 2038-2070. Significant changes are indicated by cross-hatching.

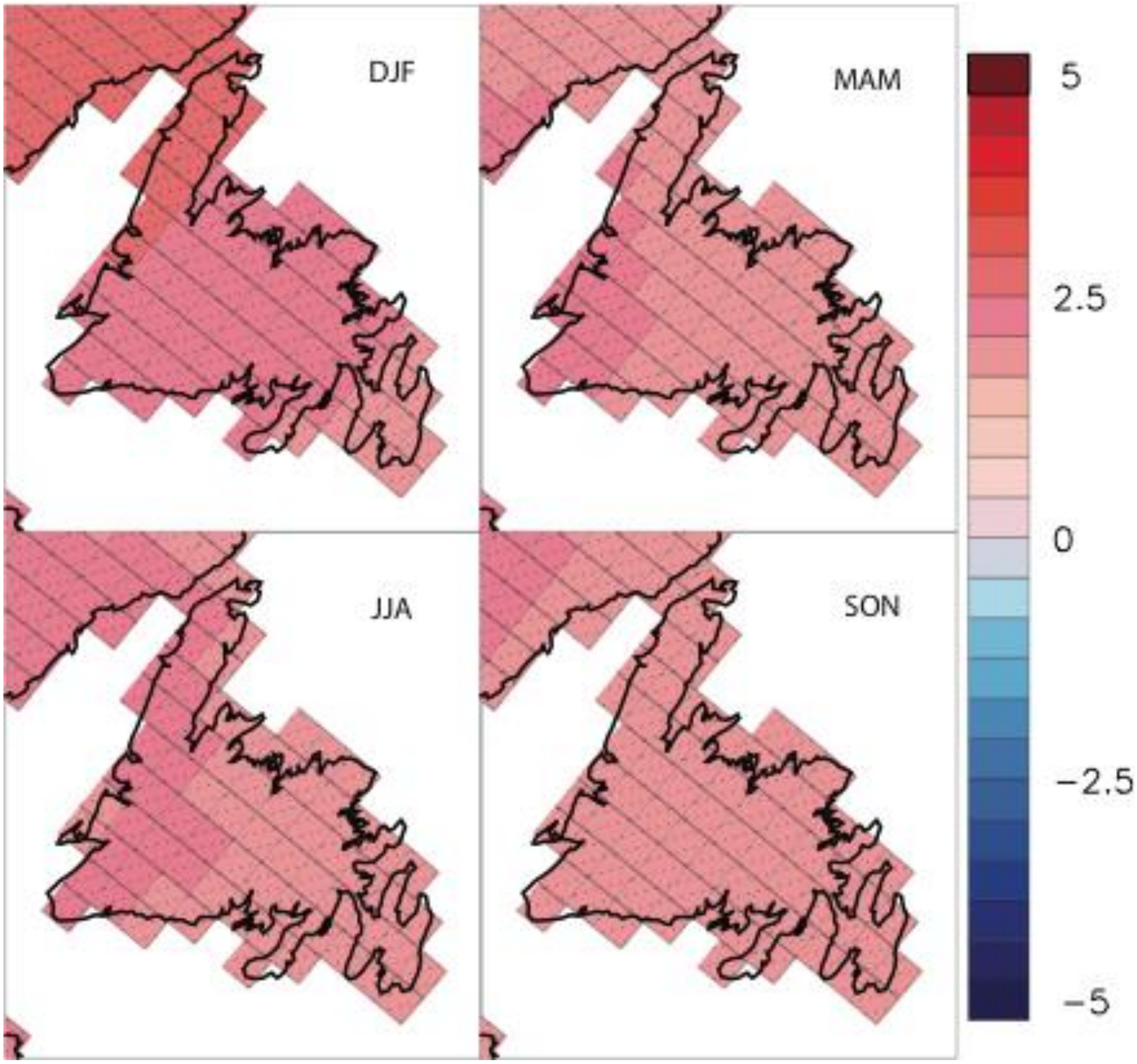

Table 7: Mean daily maximum temperature (°C) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	-0.4	2.3	0.6
	MAM	7.7	2.0	0.3
	JJA	20.5	2.0	0.4
	SON	11.9	2.0	0.4
Corner Brook	DJF	-1.5	2.4	0.8
	MAM	6.3	2.1	0.3
	JJA	20.3	2.1	0.4
	SON	11.0	2.0	0.4
Daniel's Harbour	DJF	-2.7	2.6	0.9
	MAM	4.0	2.1	0.5
	JJA	16.4	2.2	0.6
	SON	9.3	2.0	0.5
Deer Lake	DJF	-2.3	2.5	0.8
	MAM	6.4	2.1	0.4
	JJA	20.8	2.1	0.4
	SON	10.8	2.0	0.4
Exploits Dam	DJF	-2.4	2.4	0.7
	MAM	5.8	2.1	0.4
	JJA	20.3	2.1	0.4
	SON	10.5	2.0	0.4
Gander	DJF	-2.0	2.3	0.9
	MAM	5.6	1.9	0.4
	JJA	19.9	1.9	0.5
	SON	10.4	1.9	0.5
Grand Falls	DJF	-1.6	2.4	0.8
	MAM	6.8	2.0	0.4
	JJA	21.3	2.0	0.5
	SON	11.3	2.0	0.4
Plum Point	DJF	-4.5	2.6	1.0
	MAM	3.4	2.0	0.6
	JJA	16.4	2.1	0.7
	SON	8.4	2.0	0.5
St. Anthony	DJF	-5.2	2.6	1.2
	MAM	2.4	1.9	0.6
	JJA	17.0	1.9	0.6
	SON	8.3	1.8	0.5
St. John's	DJF	-0.2	2.0	0.6
	MAM	5.4	1.7	0.2
	JJA	18.6	1.8	0.4
	SON	11.1	1.8	0.5
Stephenville	DJF	-1.5	2.5	0.9
	MAM	5.9	2.1	0.3
	JJA	18.7	2.1	0.4
	SON	10.9	2.0	0.4

Figure 8: Changes in mean daily maximum temperature (^{o}C) projected for 2038-2070. Significant changes are indicated by cross-hatching.

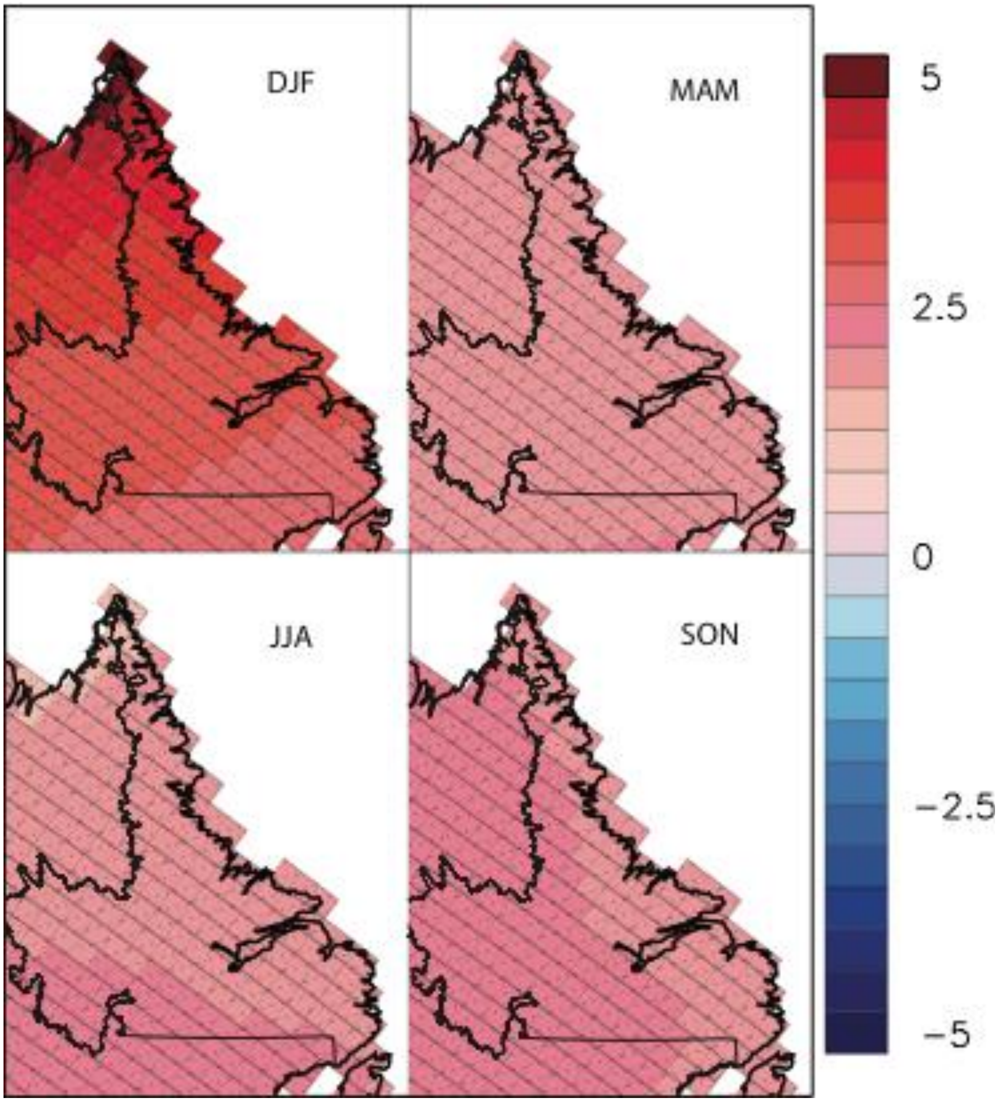

Table 8: Mean daily maximum temperature (^{o}C) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	-7.7	3.0	1.2
	MAM	1.6	1.9	0.7
	JJA	16.0	1.9	0.8
	SON	6.5	1.9	0.6
Churchill Falls	DJF	-13.9	3.1	0.7
	MAM	1.1	1.9	0.5
	JJA	17.4	2.1	0.6
	SON	3.8	2.1	0.5
Goose Bay	DJF	-10.2	3.0	0.8
	MAM	3.4	1.9	0.6
	JJA	19.3	2.0	0.6
	SON	7.0	2.1	0.5
Nain	DJF	-11.5	3.6	1.2
	MAM	-0.4	1.9	0.5
	JJA	14.1	2.0	0.8
	SON	5.0	2.0	0.6
Wabush Lake	DJF	-14.4	3.1	0.7
	MAM	1.0	1.9	0.5
	JJA	17.4	2.1	0.5
	SON	3.6	2.2	0.5

Cooling Degree Days

Summary: Cooling degree days are projected to increase during the summer, but the changes are small enough to be ignored.

Cooling degree days (CDD) are used to estimate the energy required for cooling of buildings in warm seasons. It is essentially a measure of the accumulated heat deficit below a predetermined threshold (in this case, T_{th}=16^{o}C). The formula varies with daily minimimum (T_{min}) and maximum (T_{max}) temperatures, as follows:

CDD = 0;	If $T_{max} < T_{thr}$
CDD = $(T_{max}-T_{thr})/4$;	If $(T_{max}+T_{min})/2 < T_{thr}$
CDD = $(T_{max}-T_{thr})/2-(T_{thr}-T_{min})/4$;	If $T_{min} <= T_{thr}$
CDD = $(T_{max}+T_{min})/2-T_{thr;}$	If $T_{min} > T_{thr}$

The projected change in total CDD is significant in most of the province from a statistical standpoint; that is, models agree that an increase is very likely. However, in economic terms, the change is insignificant. Currently, CCD values are small enough that cooling costs are negligible throughout the province, and the projected change (~50 CDD/year) is too small to have an economic impact.

Figure 9: Changes in cooling degree days projected for 2038-2070. Significant changes are indicated by cross-hatching.

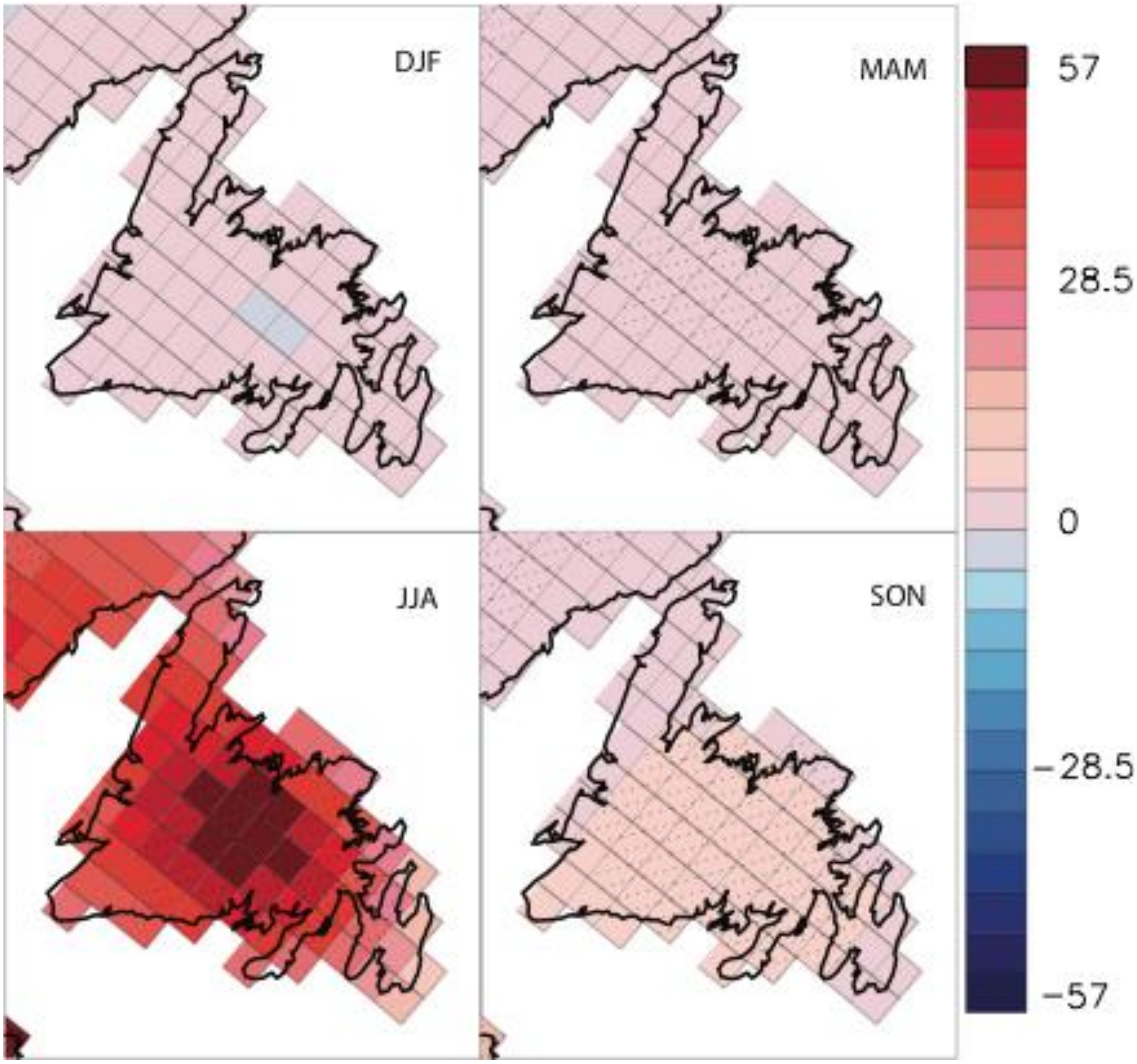

Table 9: Cooling degree day climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	0.0	0.0	0.0
	MAM	6.5	1.5	1.8
	JJA	151.0	51.2	40.1
	SON	22.7	8.0	5.7
Corner Brook	DJF	0.0	0.0	0.0
	MAM	5.9	0.7	0.8
	JJA	180.0	43.7	46.2
	SON	24.5	5.6	5.2
Daniel's Harbour	DJF	0.0	0.0	0.0
	MAM	1.1	0.4	0.4
	JJA	54.4	39.8	56.9
	SON	7.8	3.6	4.0
Deer Lake	DJF	0.0	0.0	0.0
	MAM	7.9	1.3	1.2
	JJA	178.1	47.6	47.7
	SON	22.7	6.0	5.3
Exploits Dam	DJF	0.0	0.0	0.0
	MAM	5.7	2.0	1.7
	JJA	146.1	52.2	44.5
	SON	17.7	7.2	5.6
Gander	DJF	0.0	0.0	0.0
	MAM	7.0	1.0	1.2
	JJA	172.9	39.6	38.0
	SON	21.8	6.0	4.8
Grand Falls	DJF	0.0	0.0	0.0
	MAM	9.9	2.3	1.9
	JJA	204.0	52.7	46.3
	SON	27.1	7.7	5.7
Plum Point	DJF	0.0	0.0	0.0
	MAM	0.8	0.3	0.4
	JJA	53.7	34.7	50.6
	SON	6.3	2.8	3.0
St. Anthony	DJF	0.0	0.0	0.0
	MAM	1.2	0.0	0.0
	JJA	81.4	18.7	37.8
	SON	7.6	0.9	1.2
St. John's	DJF	0.0	0.0	0.0
	MAM	4.2	0.1	0.3
	JJA	129.2	17.0	20.1
	SON	20.2	3.6	4.3
Stephenville	DJF	0.0	0.0	0.0
	MAM	3.0	0.1	0.1
	JJA	116.9	34.0	48.9
	SON	16.0	4.1	4.9

Figure 10: Changes in cooling degree days projected for 2038-2070. Significant changes are indicated by cross-hatching.

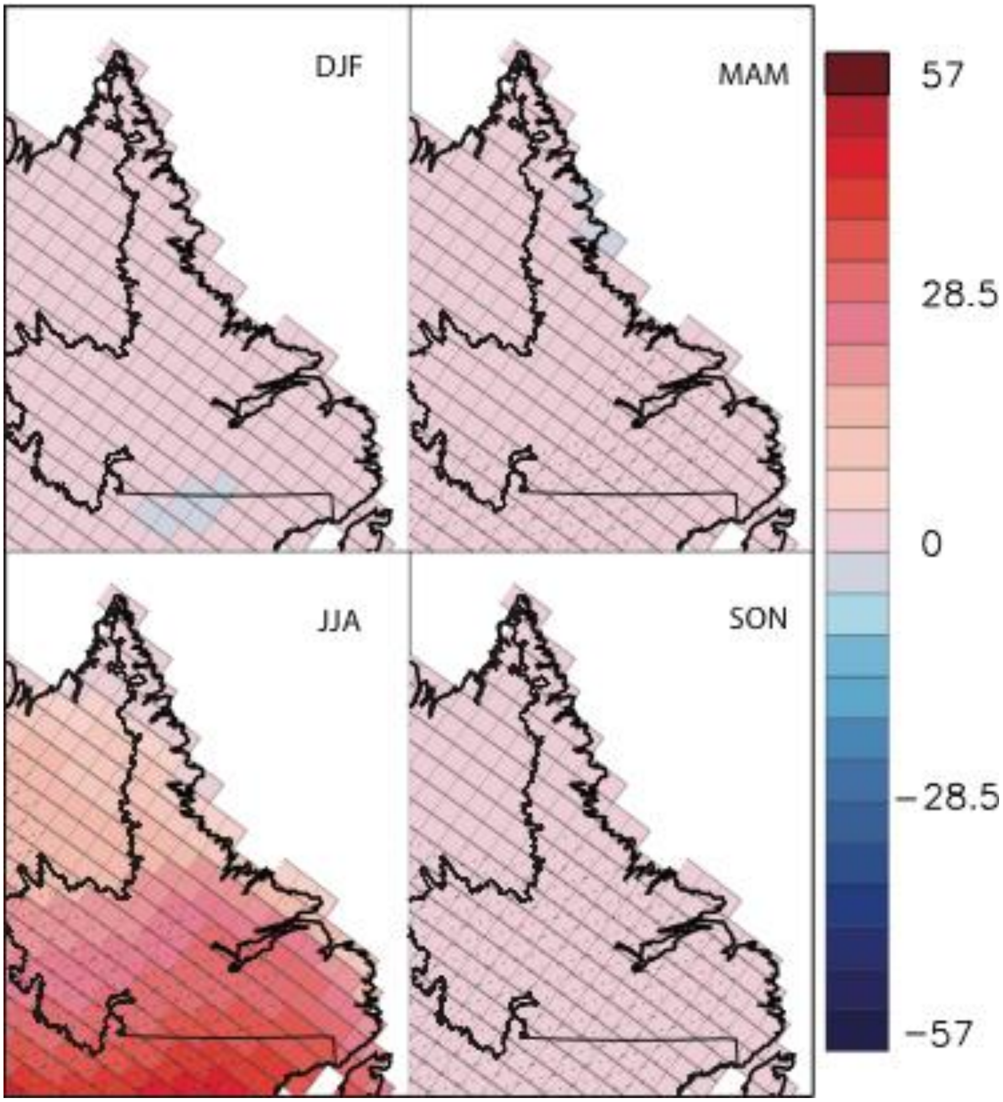

Table 10: Cooling degree day climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	0.0	0.0	0.0
	MAM	1.9	0.1	0.2
	JJA	75.4	14.0	21.1
	SON	6.7	0.9	1.0
Churchill Falls	DJF	0.0	0.0	0.0
	MAM	3.8	0.9	0.9
	JJA	84.8	24.6	23.5
	SON	4.8	1.7	1.5
Goose Bay	DJF	0.0	0.0	0.0
	MAM	5.8	1.4	1.4
	JJA	151.1	31.0	29.2
	SON	14.0	2.6	2.3
Nain	DJF	0.0	0.0	0.0
	MAM	0.7	0.0	0.0
	JJA	43.5	7.8	9.3
	SON	3.6	0.3	0.3
Wabush Lake	DJF	0.0	0.0	0.0
	MAM	3.8	1.0	1.0
	JJA	82.8	25.4	22.1
	SON	5.2	1.8	1.7

Heating Degree Days

Summary: Heating degree days are projected to decrease considerably on an annual basis, with the greatest change expected in winter. Annual decreases are economically significant, implying a substantial decrease in heating costs.

Heating degree days (HDD) are similar to cooling degree days, but measure energy requirements for heating homes to comfortable temperatures. It is defined relative to a selected threshold temperature ($T_{th}=16^{o}$C was used here). The calculations use daily minimum (T_{min}) and daily maximum (T_{max}) temperatures, following:

$HDD = 0;$ if $T_{min} > T_{thr}$
$HDD = (T_{thr}-T_{min})/4;$ if $(T_{max}+T_{min})/2 > T_{thr}$
$HDD = (T_{thr}-T_{min})/2-(T_{max}-T_{thr})/4;$ if $T_{max} >= T_{thr}$
$HDD = T_{thr}-(T_{max}+T_{min})/2;$ if $T_{max} < T_{thr}$

Under the current climate, total HDD is relatively large, and becomes greater as temperatures drop in given seasons/locations. The models universally predict large, statistically significant decreases in HDD across the complete province during all seasons. The distribution in space and seasons closely follows daily mean, minimum, and maximum temperatures, with the largest decreases in Northern Labrador during winter, and the smallest changes over coastal Newfoundland during summer. Regardless of the location, annual decreases in HDD are economically significant. For Newfoundland, the annual decrease is roughly equivalent to the current HDD for Autumn; in Labrador, the decrease is roughly half the spring values. This points to substantial savings on heating costs arising from climate change.

Figure 11: Changes in heating degree days projected for 2038-2070. Significant changes are indicated by cross-hatching.

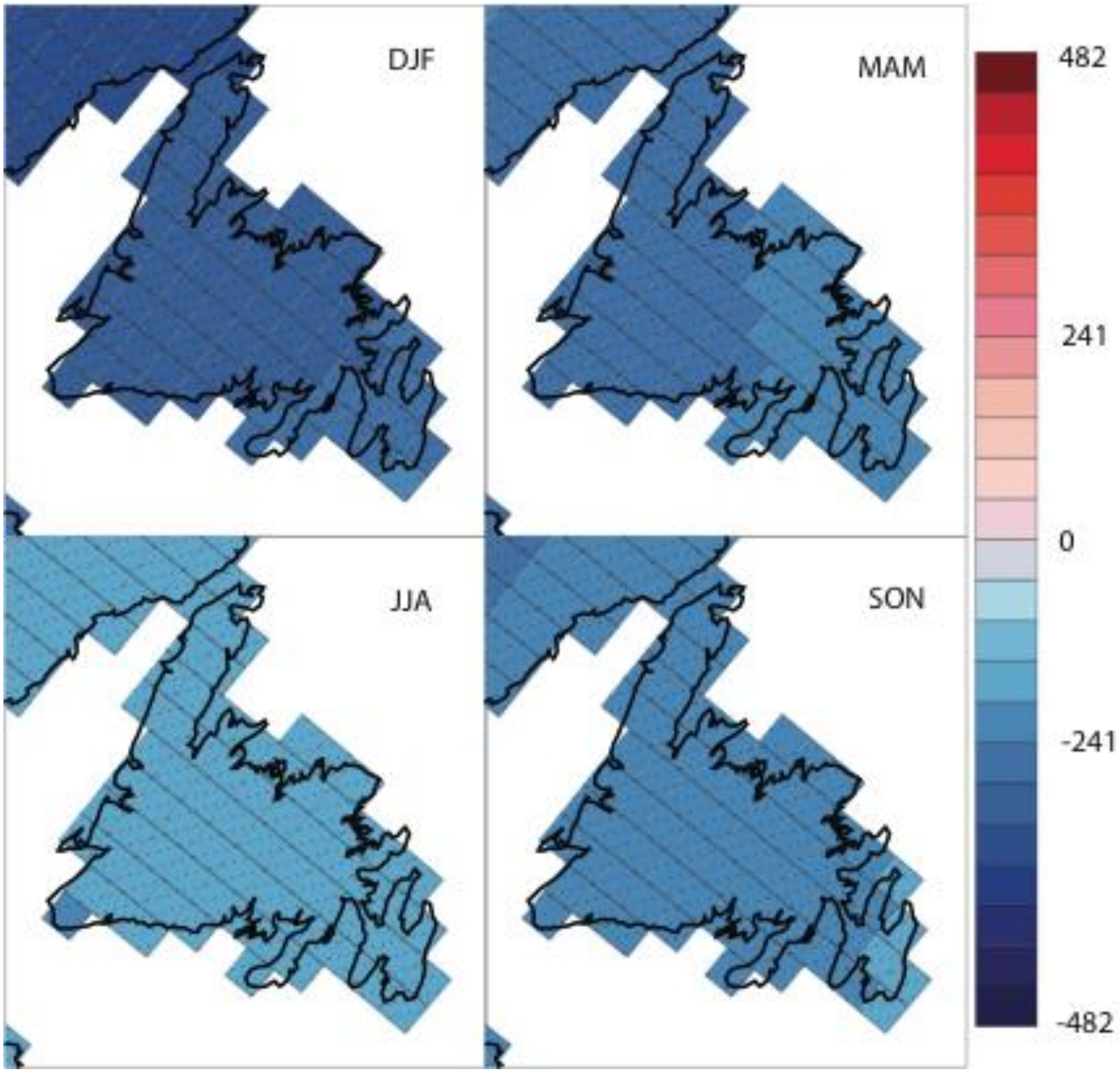

Table 11: Heating degree day climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	1889.3	-251.5	97.7
	MAM	1217.2	-201.4	39.9
	JJA	251.8	-136.8	13.9
	SON	800.2	-175.9	38.9
Corner Brook	DJF	1878.3	-266.1	116.4
	MAM	1267.6	-214.7	44.8
	JJA	217.7	-147.3	17.0
	SON	800.7	-184.0	41.1
Daniel's Harbour	DJF	1988.7	-275.2	113.8
	MAM	1414.1	-216.6	51.9
	JJA	313.4	-154.2	28.3
	SON	875.0	-184.0	48.2
Deer Lake	DJF	2058.2	-267.8	113.5
	MAM	1362.4	-212.1	43.4
	JJA	274.1	-143.5	16.9
	SON	900.5	-183.9	42.5
Exploits Dam	DJF	2057.3	-265.1	107.7
	MAM	1418.3	-208.2	40.6
	JJA	319.0	-139.4	15.5
	SON	934.4	-183.1	41.9
Gander	DJF	1943.6	-252.7	117.0
	MAM	1345.2	-196.5	44.6
	JJA	275.8	-136.0	11.7
	SON	870.5	-168.5	45.0
Grand Falls	DJF	1985.2	-262.1	109.5
	MAM	1292.5	-202.0	41.0
	JJA	243.9	-134.0	14.1
	SON	854.7	-177.8	43.9
Plum Point	DJF	2185.5	-276.1	110.2
	MAM	1501.1	-210.4	53.0
	JJA	335.3	-155.6	28.4
	SON	948.2	-182.4	52.5
St. Anthony	DJF	2285.7	-275.6	135.2
	MAM	1596.9	-201.3	57.2
	JJA	420.4	-152.3	30.8
	SON	1032.5	-169.5	54.4
St. John's	DJF	1752.3	-217.4	103.8
	MAM	1312.6	-176.5	36.2
	JJA	310.0	-146.1	20.4
	SON	772.8	-157.4	44.5
Stephenville	DJF	1883.5	-266.9	127.7
	MAM	1295.1	-220.4	49.5
	JJA	224.5	-156.0	20.2
	SON	786.1	-184.1	39.9

Figure 12: Changes in heating degree days projected for 2038-2070. Significant changes are indicated by cross-hatching.

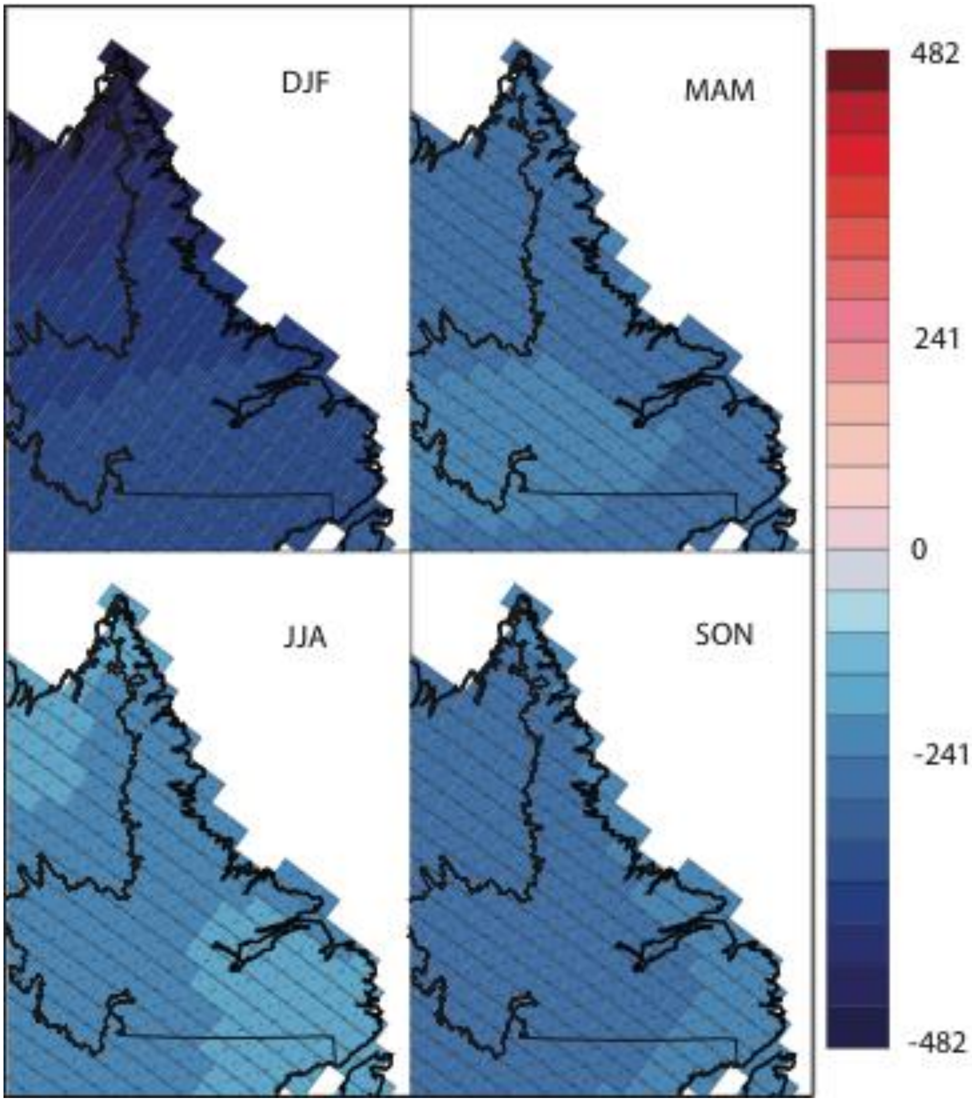

Table 12: Heating degree day climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	2475.9	-309.9	131.6
	MAM	1685.9	-202.4	70.7
	JJA	535.4	-161.5	51.0
	SON	1162.1	-179.4	62.4
Churchill Falls	DJF	3189.3	-317.9	90.1
	MAM	1913.4	-197.8	45.9
	JJA	430.6	-169.6	36.5
	SON	1458.5	-212.9	55.7
Goose Bay	DJF	2765.0	-307.0	96.4
	MAM	1621.0	-200.0	48.3
	JJA	324.4	-157.6	34.1
	SON	1178.7	-208.1	58.4
Nain	DJF	2856.2	-356.8	125.3
	MAM	1925.5	-203.4	56.3
	JJA	663.8	-181.3	64.1
	SON	1315.8	-199.4	69.5
Wabush Lake	DJF	3193.6	-316.4	83.1
	MAM	1882.5	-198.1	44.3
	JJA	413.2	-176.1	35.9
	SON	1449.4	-215.5	49.8

Growing Degree Days

Summary: An increase in growing degree days is projected across the province. Changes are greatest in summer, and largely concentrated in Newfoundland and southern Labrador. This should increase agricultural and forestry potential in places where such activities are currently viable. Higher growing degree days also suggest an increase in the activity of insect pests (e.g. spruce budworm).

Growing degree days (GDD) are a measure of energy availability for plant growth, measured as *heat accumulation* over a number of days. It is used in agriculture, silviculture, and horticulture as a guide to plant/crop selection. The formula for GDD used here is:

$$GDD=\sum_{days}\left[\left(\frac{T_{max}-T_{min}}{2}\right)-10^{\circ}C\right];$$

where T_{max} & T_{min} are the daily maximum and minimum temperatures, respectively. The S indicates we sum up the value over a period of days (e.g. June 1st through August 31st for total summer GDD). Only days with T_{max} above 10°C are included in the calculation; days with $T_{max} <= 10^{\circ}C$ are excluded. This means there is no such thing as a *negative* GDD.

The key point is that a greater GDD implies more plant growth and earlier plant maturation, both because there are more days during which plants can undergo photosynthesis and/or greater potential for growth during those days. In regions where soils are favorable and water is plentiful, GDD increases can bring increased agricultural productivity and greater annual tree growth. Because GDD and growing season length are major factors preventing some species from moving into cool areas like Newfoundland, rising GDD may be accompanied by a shift in vegetation types. At the very least, an increase in mean summer GDD implies more reliable agricultural activity on the island, and fewer of the poor harvests seen in unusually cold years (e.g. 2011 in eastern Newfoundland).

GDDs can also be used to predict pest populations, as the timing of insect maturation and the health of insect populations also depend on heat accumulation. Spruce bud worm and spanworm populations may benefit from increases in GDD; however, so will beneficial species such as honeybees.

Newfoundland and Southern Labrador are expected to undergo a substantial increase in total GDD during summer, with smaller (but still significant) increases in autumn. The greatest changes are expected on the south coast, west coast, and interior of the island; total annual changes of ~200 GDD are expected.

Figure 13: Changes in growing degree days projected for 2038-2070. Significant changes are indicated by cross-hatching.

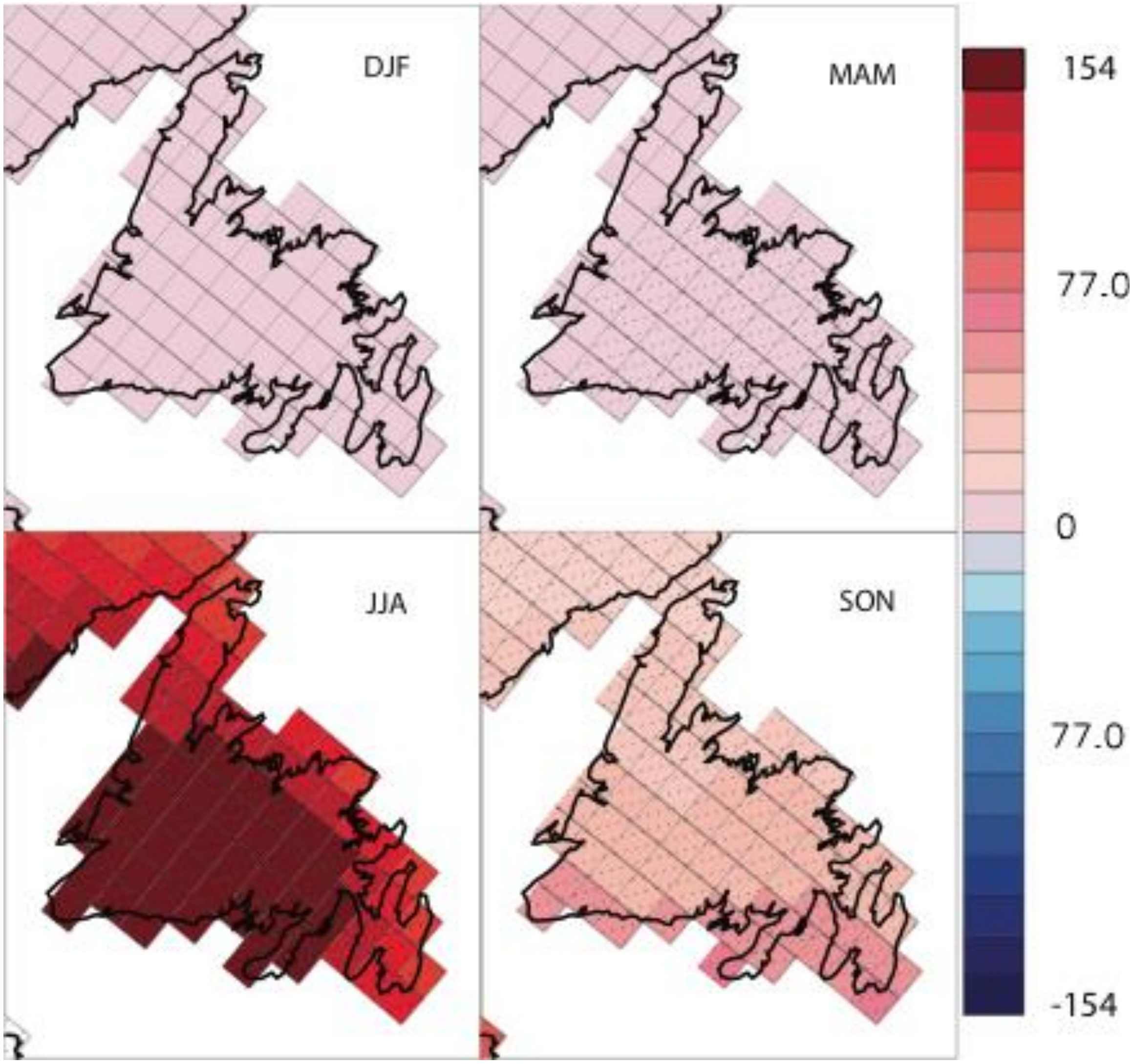

Table 13: Growing degree day climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	0.1	0.1	0.1
	MAM	15.4	8.8	5.9
	JJA	460.3	153.5	41.6
	SON	99.7	49.0	19.6
Corner Brook	DJF	0.1	0.0	0.0
	MAM	19.5	6.6	6.4
	JJA	531.4	147.3	49.7
	SON	108.3	41.8	19.6
Daniel's Harbour	DJF	0.2	0.0	0.0
	MAM	5.1	5.6	8.1
	JJA	330.3	138.5	66.9
	SON	68.0	33.9	20.3
Deer Lake	DJF	0.0	0.0	0.0
	MAM	15.7	7.8	7.4
	JJA	480.6	146.7	51.4
	SON	83.1	38.9	19.0
Exploits Dam	DJF	0.0	0.0	0.0
	MAM	9.2	9.3	7.2
	JJA	407.3	149.8	47.9
	SON	61.1	39.8	18.6
Gander	DJF	0.1	0.0	0.0
	MAM	20.1	6.7	5.2
	JJA	487.9	132.6	50.3
	SON	96.5	40.7	20.6
Grand Falls	DJF	0.1	0.0	0.0
	MAM	23.8	10.1	7.5
	JJA	534.7	145.2	50.6
	SON	98.5	39.1	19.0
Plum Point	DJF	0.0	0.0	0.0
	MAM	2.6	4.4	6.1
	JJA	316.1	124.9	70.0
	SON	58.9	27.3	18.8
St. Anthony	DJF	0.0	0.0	0.0
	MAM	2.5	1.7	3.5
	JJA	289.6	87.3	73.6
	SON	44.1	19.7	18.3
St. John's	DJF	0.2	0.0	0.0
	MAM	13.6	1.7	1.6
	JJA	420.6	113.6	45.9
	SON	104.9	50.5	26.6
Stephenville	DJF	0.1	0.0	0.0
	MAM	15.5	4.1	5.5
	JJA	462.7	143.3	52.9
	SON	102.3	47.3	21.8

Figure 14: Changes in growing degree days projected for 2038-2070. Significant changes are indicated by cross-hatching.

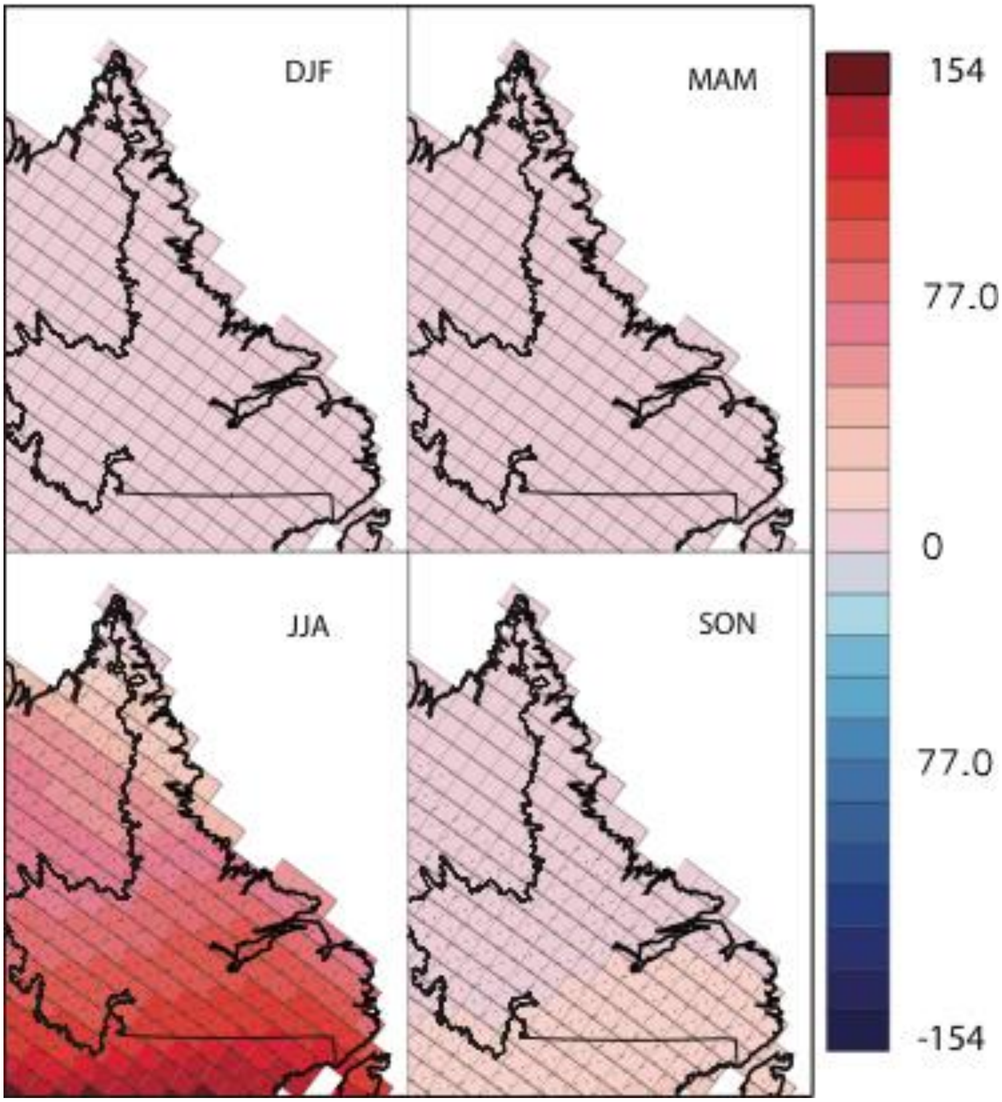

Table 13: Growing degree day climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	0.00	0.00	0.00
	MAM	3.18	1.00	1.82
	JJA	223.13	71.57	69.25
	SON	27.97	10.70	11.55
Churchill Falls	DJF	0.00	0.00	0.00
	MAM	6.43	3.07	3.65
	JJA	271.28	88.37	52.80
	SON	18.22	9.84	8.60
Goose Bay	DJF	0.00	0.00	0.00
	MAM	11.29	4.34	4.63
	JJA	422.86	98.88	54.71
	SON	51.72	13.18	10.81
Nain	DJF	0.00	0.00	0.00
	MAM	1.06	0.14	0.27
	JJA	126.91	50.64	49.30
	SON	12.92	3.66	4.03
Wabush Lake	DJF	0.00	0.00	0.00
	MAM	7.48	3.63	4.04
	JJA	287.36	92.17	48.63
	SON	22.50	10.59	8.90

Number of Days With Frost

Summary: The number of days that see temperatures below freezing are expected to decrease, especially in spring and autumn (5-19 fewer days). Regions/seasons with near-freezing temperatures see the greatest decrease (e.g. the Avalon Peninsula in spring; northern Labrador in summer).

The number of days with a minimum temperature below freezing; that is, the number of days during which frost can form. These numbers provide a sense of winter severity and length. They also provide some sense of freeze/thaw event frequency and length. If frost days decrease, freezing events (frosts, re-freezes etc) become less common and/or shorter.

For the island, the shoulder seasons (spring and autumn) are expected to see a substantial decrease in frost days. The largest changes are found in locations with mean temperatures near freezing (e.g. most places aside from the Great Northern Peninsula and interior during spring, and the Avalon in winter). Decreases in spring can be as large as 20 fewer frost days.

In Labrador, spring changes are relatively modest, as cold winter conditions persist well into summer through much of the region. These persistently cold regions (e.g. Northern Labrador) see large decreases in summer (up to 20 days), suggesting an earlier ‘spring’ melt (though not early enough to move it to climatological spring, or March-April-May). Widespread decreases (~10-15 days) are also found in autumn, suggesting later freeze-up and/or more freeze/thaw cycles in the transition to winter.

Figure 15: Changes in the number of frost days projected for 2038-2070. Significant changes are indicated by cross-hatching.

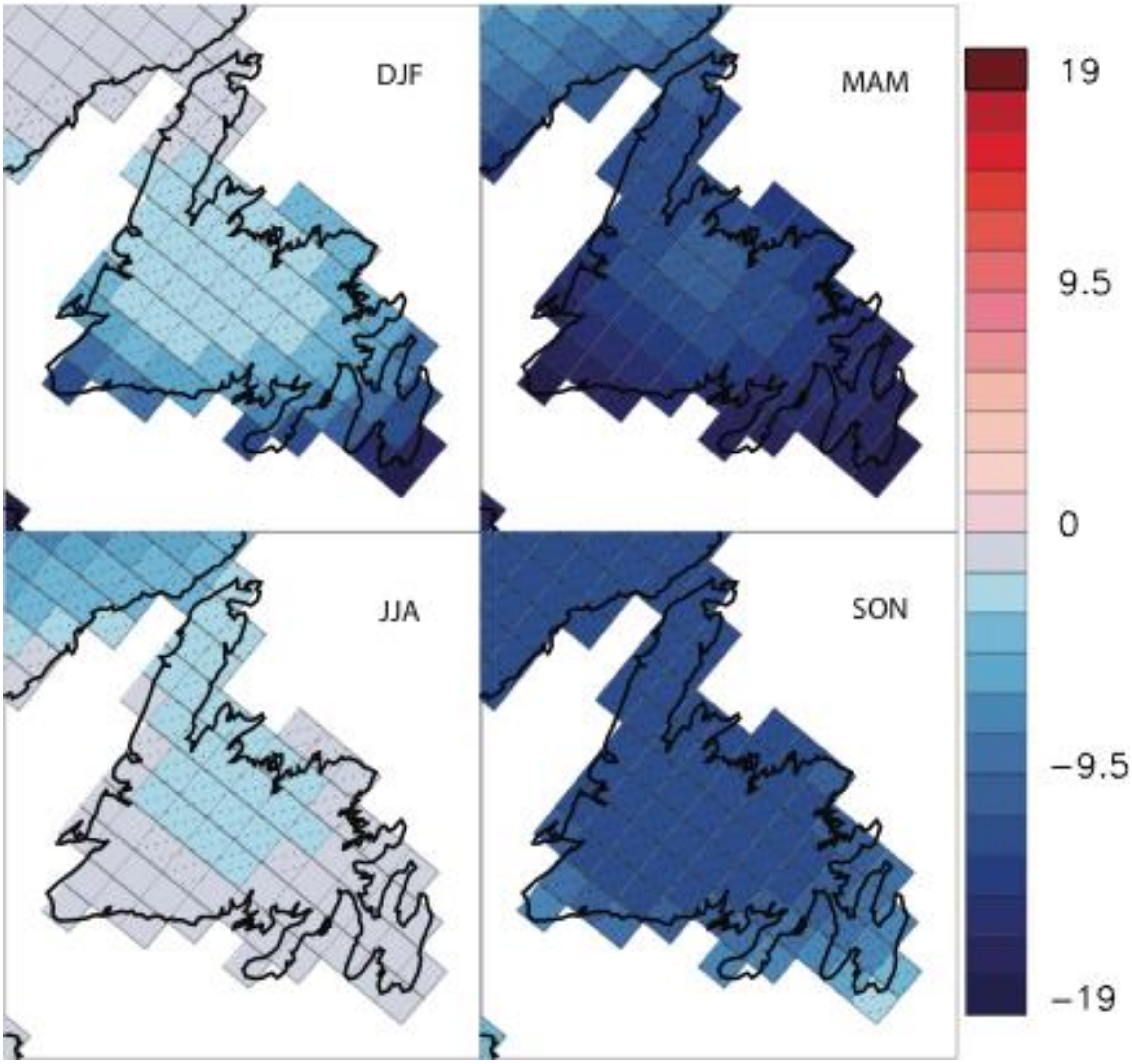

Table 15: Number of frost days climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	81.3	-3.4	2.0
	MAM	51.9	-13.6	1.9
	JJA	1.6	-1.1	1.2
	SON	29.4	-11.5	2.7
Corner Brook	DJF	81.8	-3.0	1.6
	MAM	48.5	-13.5	1.9
	JJA	0.2	-1.1	1.1
	SON	19.3	-12.2	2.5
Daniel's Harbour	DJF	84.4	-1.9	1.0
	MAM	57.8	-12.6	2.1
	JJA	0.3	-1.3	1.4
	SON	23.4	-11.4	2.0
Deer Lake	DJF	86.5	-2.2	1.3
	MAM	62.6	-12.0	1.8
	JJA	1.9	-1.7	1.4
	SON	33.5	-12.3	2.6
Exploits Dam	DJF	85.6	-1.9	1.3
	MAM	66.0	-11.2	2.0
	JJA	3.2	-2.2	1.9
	SON	35.4	-12.4	2.6
Gander	DJF	85.3	-3.2	2.5
	MAM	61.1	-12.8	3.3
	JJA	0.7	-1.4	1.3
	SON	26.0	-11.5	2.7
Grand Falls	DJF	83.8	-1.8	1.4
	MAM	54.7	-10.8	2.7
	JJA	0.7	-2.3	2.0
	SON	28.0	-12.4	2.5
Plum Point	DJF	86.6	-1.2	0.8
	MAM	60.1	-11.3	3.1
	JJA	0.4	-2.2	2.1
	SON	25.8	-11.9	2.6
St. Anthony	DJF	88.8	-1.8	1.2
	MAM	74.1	-11.9	4.5
	JJA	1.8	-2.3	2.1
	SON	36.0	-11.4	2.6
St. John's	DJF	81.5	-11.6	5.2
	MAM	57.9	-16.5	2.0
	JJA	0.5	-0.3	0.4
	SON	17.2	-6.7	3.2
Stephenville	DJF	83.2	-6.1	2.0
	MAM	51.6	-16.0	1.6
	JJA	0.2	-0.2	0.3
	SON	18.8	-10.4	2.2

Figure 16: Changes in the number of frost days projected for 2038-2070. Significant changes are indicated by cross-hatching.

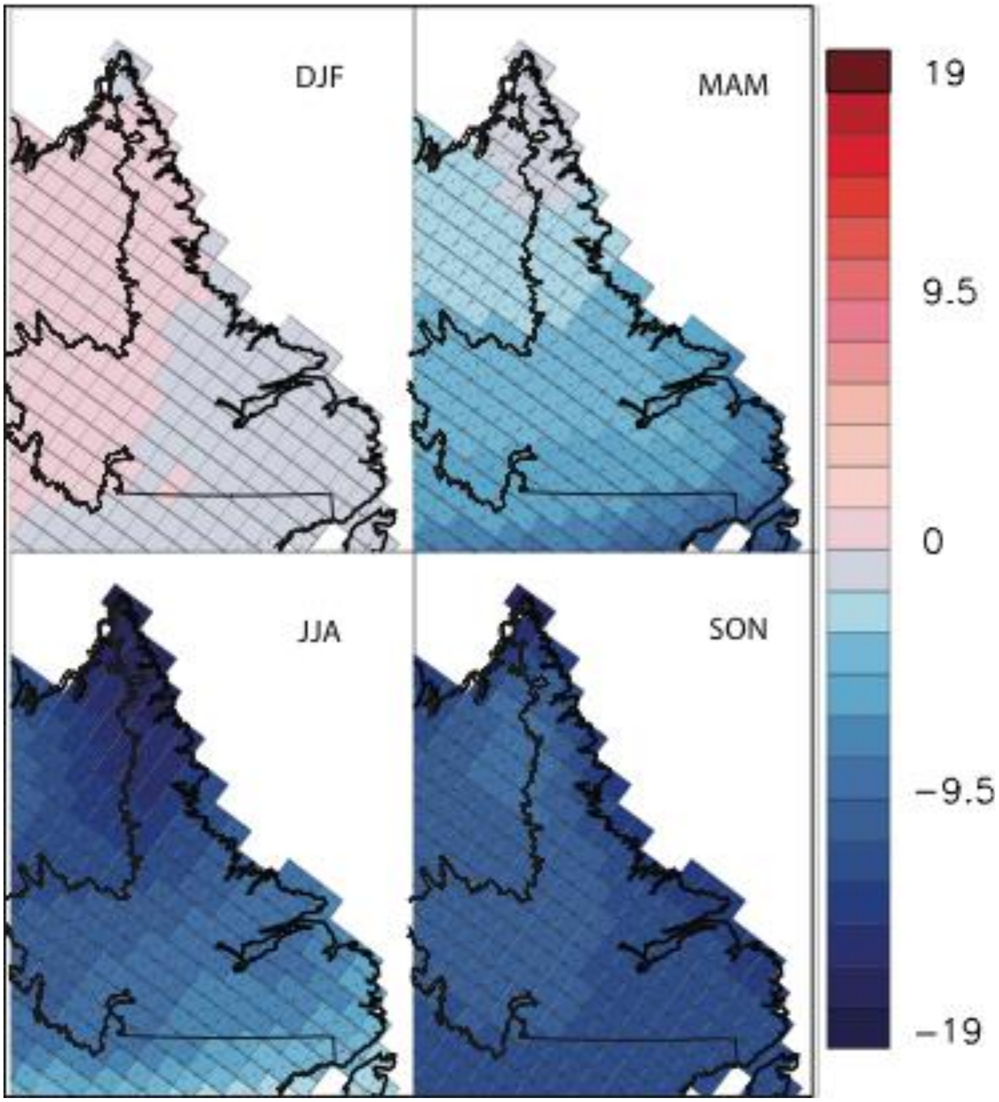

Table 16: Number of frost days climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	87.24	-0.69	1.13
	MAM	73.58	-7.16	6.27
	JJA	4.80	-6.64	3.68
	SON	40.37	-13.21	3.56
Churchill Falls	DJF	89.68	0.02	0.24
	MAM	78.76	-4.30	2.17
	JJA	3.88	-9.53	6.15
	SON	58.68	-10.44	2.51
Goose Bay	DJF	88.67	-0.05	0.41
	MAM	67.53	-4.65	2.46
	JJA	1.17	-7.99	5.32
	SON	43.60	-11.23	2.99
Nain	DJF	89.34	0.04	0.29
	MAM	82.00	-2.72	2.16
	JJA	7.09	-12.53	6.36
	SON	50.42	-12.29	4.31
Wabush Lake	DJF	89.69	0.05	0.23
	MAM	76.90	-4.59	2.16
	JJA	3.34	-9.94	5.64
	SON	56.84	-10.69	1.78

Maximum Heat Wave Duration (days)

Summary: Projected changes in heat waves are small enough to ignore.

Heat waves are a significant health concern in many parts of Canada and the United States, but not a concern in a mild (cool) climate like that of Newfoundland (Labrador). Here, heat waves are defined as a period of consecutive days with maximum temperatures 5^{o}C or more above normal; events less than 6 days in length are not counted.

Results show no significant increase in summer heat wave duration for the province; only winter and spring show any significant change, and heat waves have no clear relevance in these seasons. Consider St. John's: the average summer heat wave duration is less than one day, implying most years don't actually experience a heat wave. Projected changes are zero for all seasons. This is typical of the entire province: climatology is lower than one day, and changes by less than one day.

Figure 17: Changes in the maximum heat wave duration for 2038-2070. Significant changes are indicated by cross-hatching.

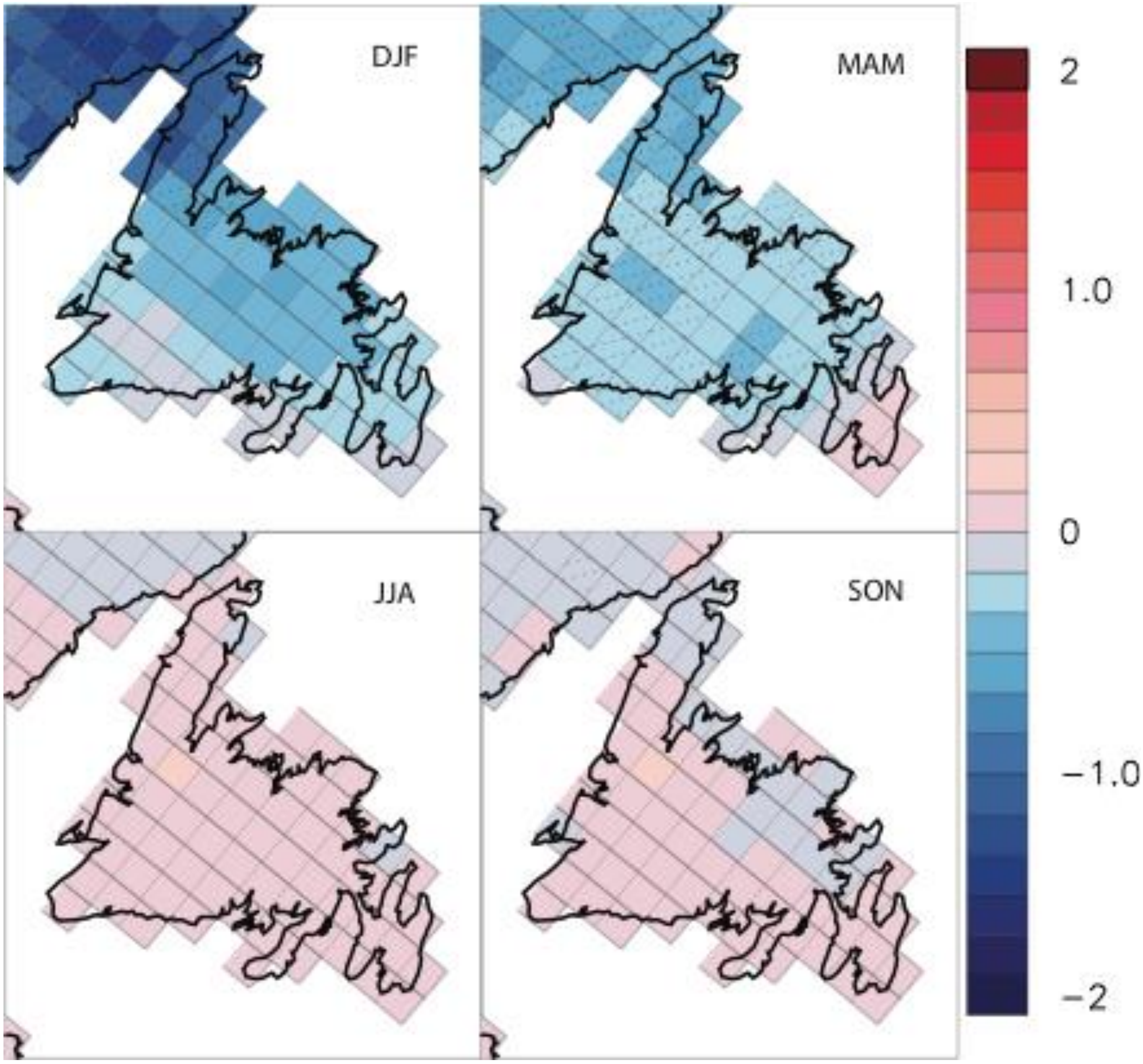

Table 12: Maximum heat wave duration climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	0.0	-0.4	0.7
	MAM	0.0	-0.4	0.3
	JJA	0.0	0.1	0.1
	SON	0.0	0.0	0.2
Corner Brook	DJF	0.0	-0.2	0.6
	MAM	0.0	-0.3	0.2
	JJA	0.0	0.1	0.2
	SON	0.0	0.1	0.4
Daniel's Harbour	DJF	0.0	-0.9	1.0
	MAM	0.0	-0.3	0.2
	JJA	0.0	0.1	0.2
	SON	0.0	0.0	0.2
Deer Lake	DJF	0.4	-0.4	0.5
	MAM	0.1	-0.4	0.3
	JJA	0.0	0.1	0.2
	SON	0.0	0.1	0.3
Exploits Dam	DJF	0.1	-0.4	0.7
	MAM	0.2	-0.4	0.2
	JJA	0.0	0.0	0.1
	SON	0.1	0.1	0.3
Gander	DJF	0.5	-0.5	0.7
	MAM	1.4	-0.2	0.2
	JJA	0.4	0.0	0.2
	SON	0.5	0.0	0.1
Grand Falls	DJF	0.0	-0.5	0.6
	MAM	0.0	-0.3	0.4
	JJA	0.0	0.1	0.2
	SON	0.0	0.0	0.3
Plum Point	DJF	0.0	-1.1	1.2
	MAM	0.3	-0.4	0.3
	JJA	0.2	0.1	0.2
	SON	0.0	-0.1	0.1
St. Anthony	DJF	0.0	-0.8	0.8
	MAM	0.0	-0.4	0.4
	JJA	0.0	0.0	0.1
	SON	0.0	0.0	0.1
St. John's	DJF	0.0	-0.2	0.4
	MAM	0.0	0.0	0.2
	JJA	0.0	0.0	0.0
	SON	0.0	0.0	0.0
Stephenville	DJF	0.0	-0.3	0.6
	MAM	0.0	-0.3	0.2
	JJA	0.0	0.1	0.2
	SON	0.0	0.0	0.1

Figure 18: Changes in the maximum heat wave duration for 2038-2070. Significant changes are indicated by cross-hatching.

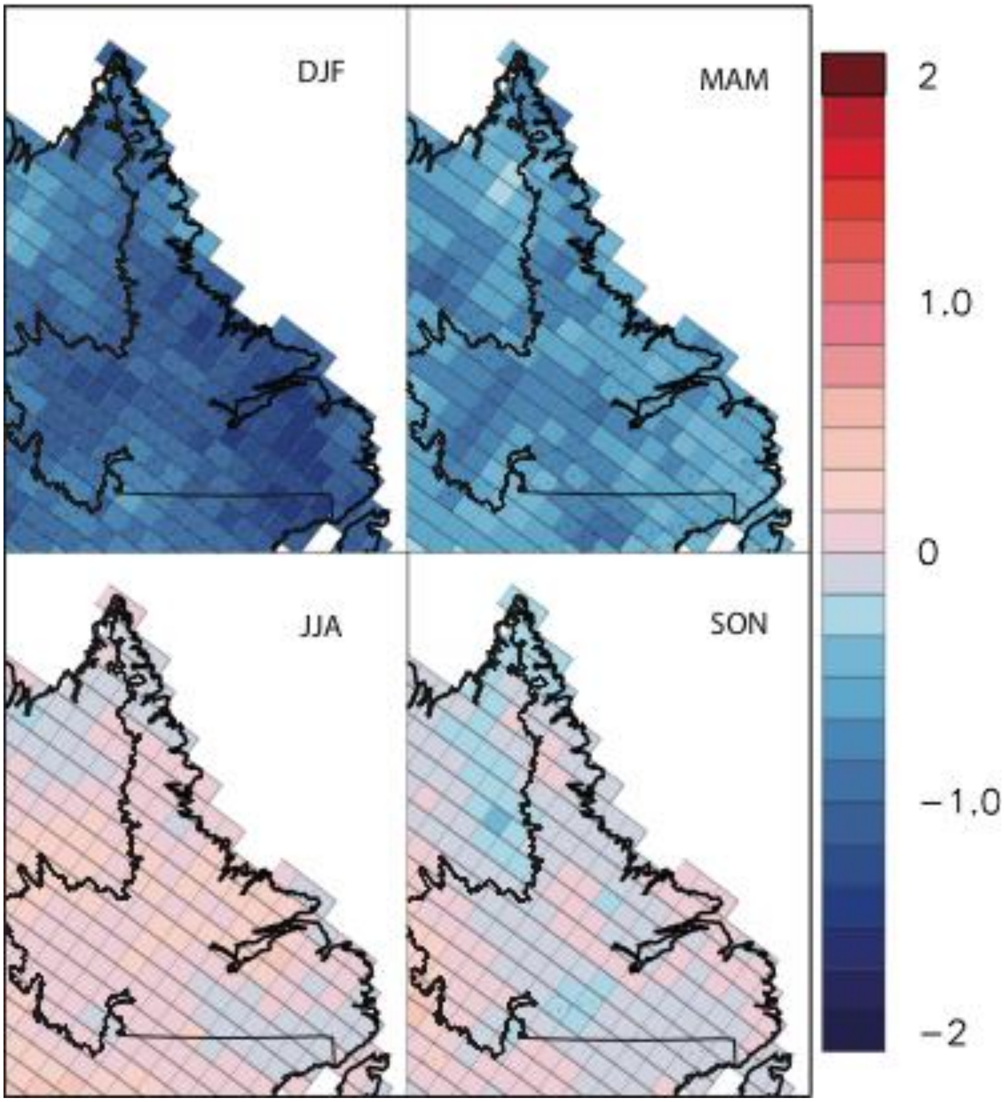

Table 12: Maximum heat wave duration climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	0.00	-1.07	1.36
	MAM	0.00	-0.61	0.83
	JJA	0.00	0.10	0.29
	SON	0.08	-0.02	0.11
Churchill Falls	DJF	0.00	-1.12	0.77
	MAM	0.00	-0.74	0.94
	JJA	0.00	0.09	0.42
	SON	0.00	-0.13	0.42
Goose Bay	DJF	5.10	-1.15	0.54
	MAM	2.07	-0.67	0.72
	JJA	0.76	0.04	0.50
	SON	0.30	0.03	0.18
Nain	DJF	0.00	-1.00	1.06
	MAM	0.00	-0.57	0.72
	JJA	0.00	0.01	0.39
	SON	0.00	-0.04	0.26
Wabush Lake	DJF	4.44	-1.06	0.75
	MAM	2.81	-0.78	0.92
	JJA	0.42	0.14	0.51
	SON	0.25	0.25	0.47

Mean Daily Precipitation (mm)

Summary: Mean daily precipitation is expected to increase throughout the province by (on average) 0.1 to 0.3 mm per day.

This is the mean precipitation falling in a 24 hr period (12AM – 12 AM, UTC). Because most days experience no precipitation, values of mean daily precipitation are typically small. Consequently, changes in this field are also small. However, these changes are often significant when taken over a full season; for example, a 0.5mm/day change for a 90 day season amounts to 45mm, or a roughly 10% change in total seasonal precipitation for a location like St. John's.

In Newfoundland, widespread significant increase is expected for winter and spring (about 0.1-0.3mm per day). Significant changes are expected year-round on the Avalon Peninsula and Great Northern Peninsula. In Labrador, significant increases are expected in most locations year-round, but are strongest in the north during summer.

Figure 19: Changes in mean daily precipitation (mm) for 2038-2070. Significant changes are indicated by cross-hatching.

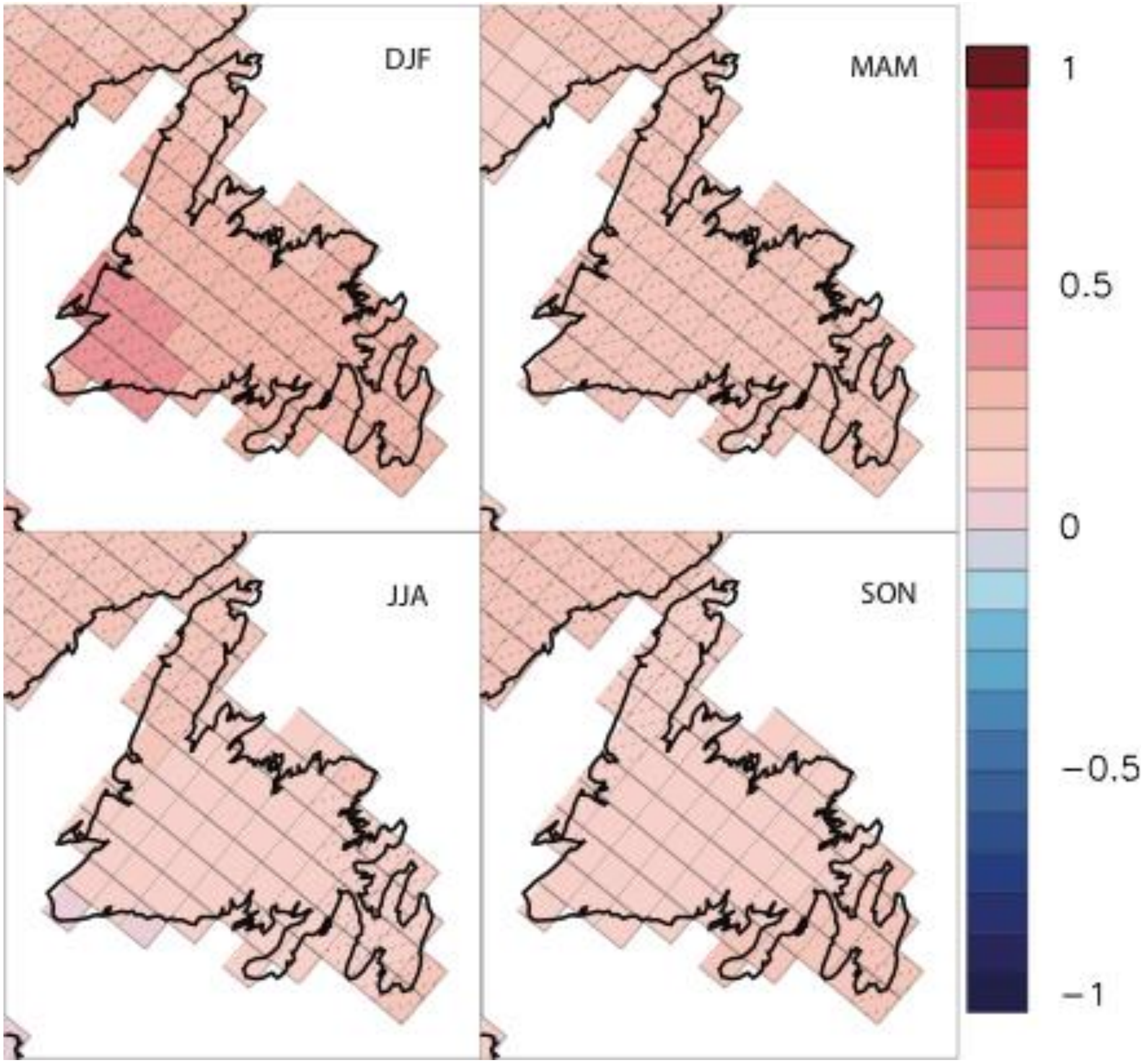

Table 19: Mean daily precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	6.2	0.3	0.1
	MAM	4.1	0.2	0.1
	JJA	3.8	0.1	0.2
	SON	5.1	0.1	0.2
Corner Brook	DJF	4.9	0.3	0.1
	MAM	2.8	0.2	0.1
	JJA	3.0	0.1	0.2
	SON	4.0	0.1	0.1
Daniel's Harbour	DJF	4.1	0.3	0.1
	MAM	2.8	0.2	0.1
	JJA	3.5	0.2	0.2
	SON	3.5	0.1	0.1
Deer Lake	DJF	4.0	0.3	0.1
	MAM	2.6	0.2	0.1
	JJA	3.0	0.1	0.2
	SON	3.4	0.1	0.1
Exploits Dam	DJF	3.9	0.3	0.1
	MAM	2.9	0.2	0.1
	JJA	3.2	0.1	0.2
	SON	3.6	0.1	0.1
Gander	DJF	5.0	0.3	0.1
	MAM	3.7	0.2	0.1
	JJA	3.1	0.2	0.2
	SON	3.9	0.1	0.2
Grand Falls	DJF	3.5	0.3	0.1
	MAM	2.8	0.2	0.1
	JJA	3.1	0.1	0.2
	SON	3.4	0.1	0.1
Plum Point	DJF	4.5	0.2	0.1
	MAM	3.2	0.2	0.1
	JJA	3.6	0.2	0.1
	SON	3.8	0.2	0.1
St. Anthony	DJF	4.6	0.2	0.1
	MAM	3.3	0.2	0.1
	JJA	3.3	0.2	0.1
	SON	3.7	0.2	0.1
St. John's	DJF	7.0	0.3	0.1
	MAM	4.6	0.2	0.1
	JJA	3.3	0.2	0.1
	SON	5.0	0.2	0.2
Stephenville	DJF	5.1	0.4	0.1
	MAM	3.1	0.2	0.1
	JJA	3.6	0.1	0.2
	SON	4.3	0.1	0.2

Figure 20: Changes in mean daily precipitation (mm) for 2038-2070. Significant changes are indicated by cross-hatching.

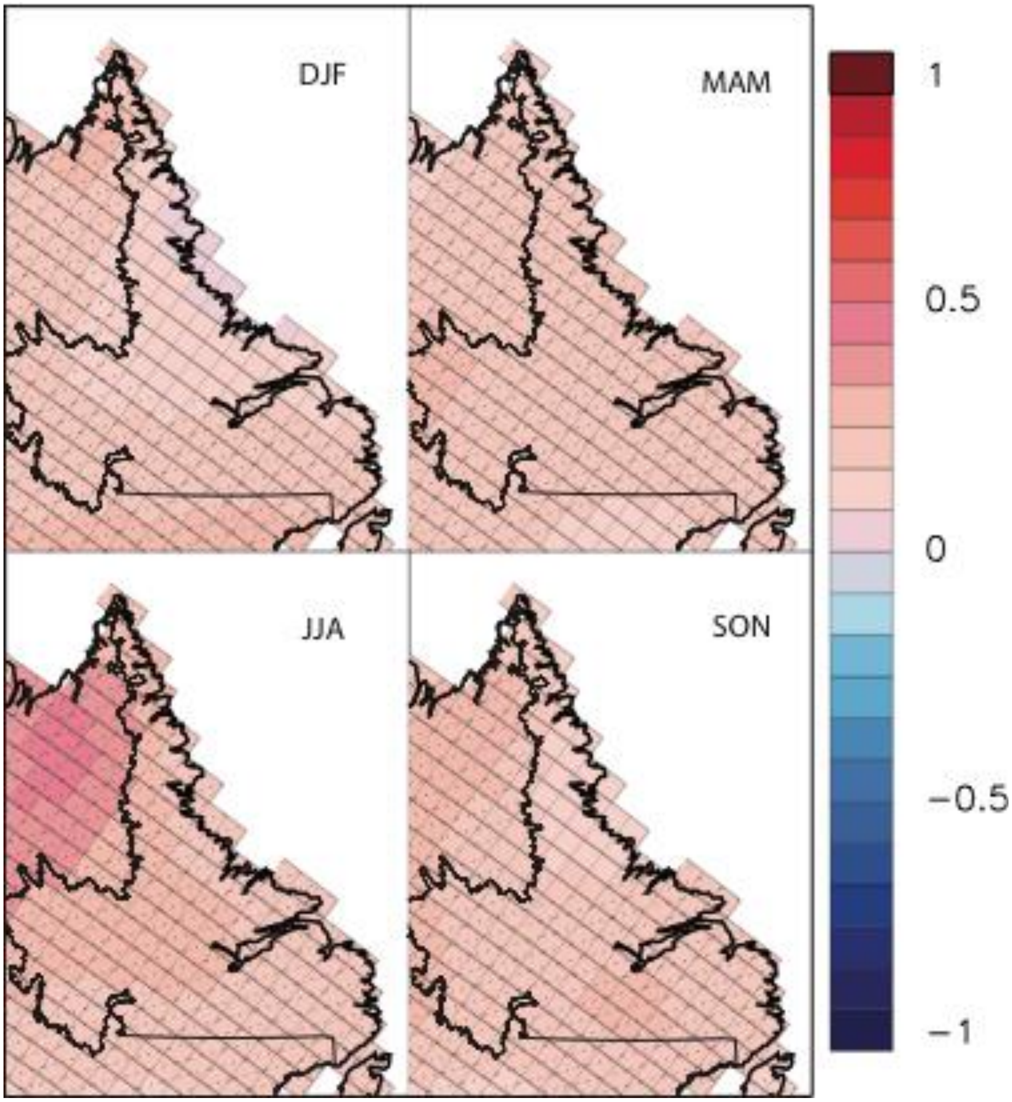

Table 20: Mean daily precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	3.8	0.1	0.2
	MAM	3.3	0.2	0.1
	JJA	3.1	0.2	0.1
	SON	3.2	0.2	0.1
Churchill Falls	DJF	2.6	0.2	0.1
	MAM	2.4	0.2	0.1
	JJA	3.5	0.3	0.1
	SON	3.4	0.2	0.2
Goose Bay	DJF	2.8	0.2	0.2
	MAM	2.5	0.2	0.2
	JJA	3.4	0.3	0.1
	SON	2.9	0.2	0.1
Nain	DJF	3.3	0.1	0.2
	MAM	3.0	0.2	0.1
	JJA	2.8	0.2	0.1
	SON	2.9	0.1	0.2
Wabush Lake	DJF	2.6	0.2	0.1
	MAM	2.3	0.2	0.1
	JJA	3.5	0.3	0.2
	SON	3.2	0.3	0.2

Mean Intensity of Precipitation Events (mm/day)

Summary: The typical precipitation event is expected to become more intense under a warming climate. Changes are greatest during winter on the island (0.5-0.7 mm/day). Most of Labrador sees the greatest change in summer (0.3-0.5 mm/day).

The 24hr mean precipitation intensity, calculated over all days with measurable precipitation (more than 1mm). While mean daily precipitation gives a sense of how total precipitation changes, mean intensity describes changes in the typical event; an increase in mean daily precipitation can be produced by *fewer* rain events, if mean intensity increases to a sufficient degree. Basically, fewer stronger events can have the same impact on total precipitation as a higher number of normal events.

The model ensemble predicts mean intensity increases for all of Newfoundland in all seasons, with the Avalon and Burin seeing the greatest increases (autumn; ~ 0.7-0.8 mm/day). The island as a whole sees the greatest change in winter. Changes are less pronounced in Labrador, with only southern Labrador seeing year-round shifts. In the north and interior, winter and autumn changes are negligible.

Figure 21: Changes in mean intensity of precipitation events (mm/day) for 2038-2070. Significant changes are indicated by cross-hatching.

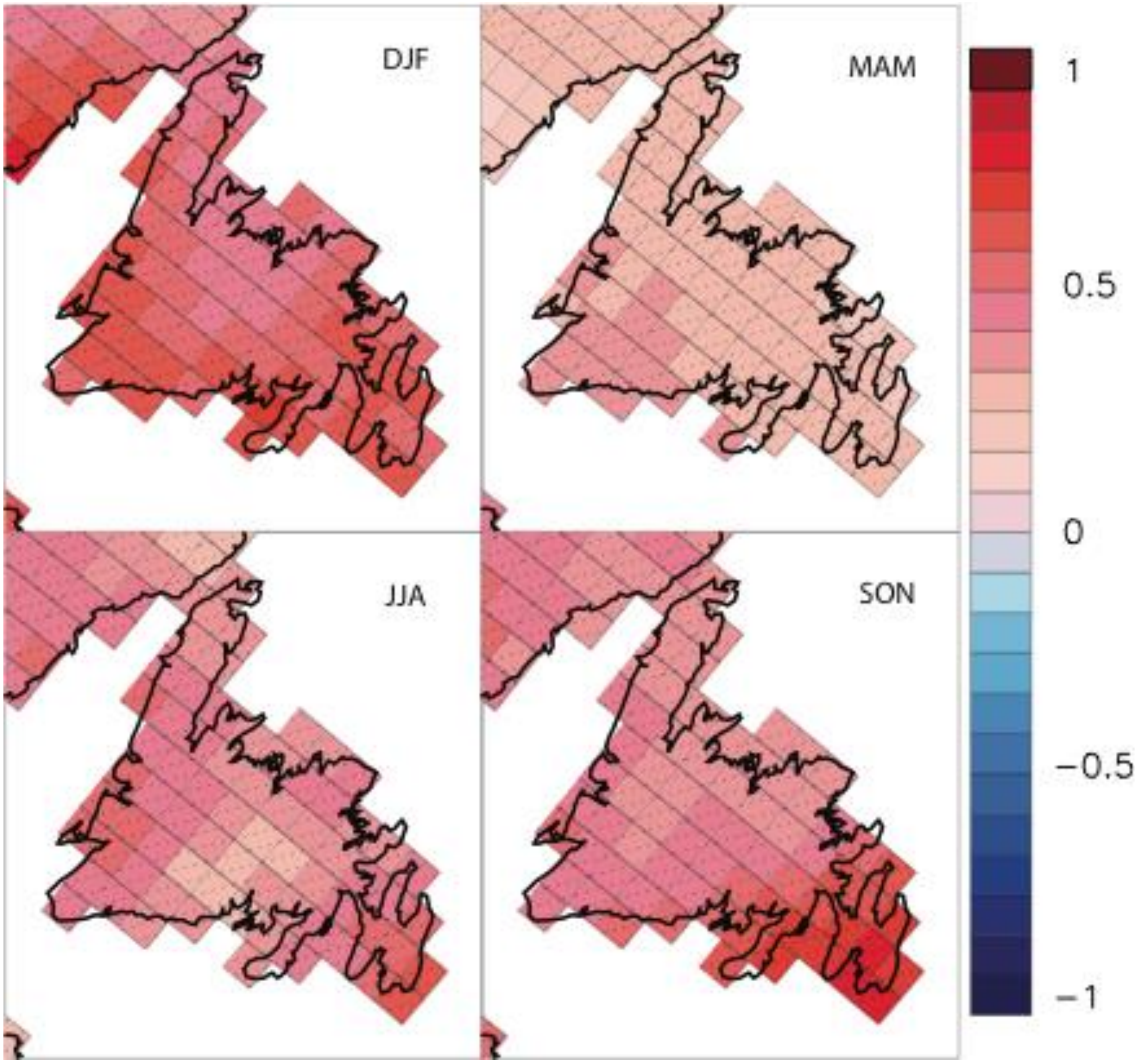

Table 21: Mean precipitation event intensity (mm/day) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	13.6	0.6	0.2
	MAM	10.7	0.3	0.1
	JJA	10.0	0.3	0.3
	SON	11.7	0.5	0.2
Corner Brook	DJF	7.9	0.6	0.3
	MAM	6.9	0.3	0.1
	JJA	7.9	0.5	0.3
	SON	7.9	0.4	0.2
Daniel's Harbour	DJF	7.3	0.6	0.2
	MAM	7.2	0.3	0.2
	JJA	9.2	0.5	0.2
	SON	8.2	0.4	0.3
Deer Lake	DJF	8.1	0.5	0.3
	MAM	7.5	0.3	0.1
	JJA	8.3	0.5	0.3
	SON	8.0	0.4	0.2
Exploits Dam	DJF	9.9	0.5	0.3
	MAM	8.0	0.3	0.1
	JJA	7.9	0.4	0.3
	SON	8.7	0.4	0.2
Gander	DJF	9.3	0.5	0.2
	MAM	8.0	0.3	0.2
	JJA	8.0	0.4	0.1
	SON	8.4	0.4	0.2
Grand Falls	DJF	9.1	0.4	0.2
	MAM	7.7	0.3	0.1
	JJA	8.3	0.4	0.2
	SON	8.5	0.4	0.2
Plum Point	DJF	7.8	0.5	0.2
	MAM	7.1	0.3	0.1
	JJA	8.6	0.4	0.2
	SON	7.9	0.4	0.3
St. Anthony	DJF	9.6	0.5	0.2
	MAM	8.2	0.3	0.1
	JJA	8.8	0.3	0.2
	SON	9.0	0.3	0.2
St. John's	DJF	12.3	0.6	0.4
	MAM	10.0	0.2	0.1
	JJA	9.3	0.5	0.2
	SON	10.5	0.7	0.2
Stephenville	DJF	7.7	0.6	0.3
	MAM	7.6	0.3	0.1
	JJA	9.5	0.6	0.2
	SON	8.8	0.5	0.2

Figure 22: Changes in mean intensity of precipitation events (mm/day) for 2038-2070. Significant changes are indicated by cross-hatching.

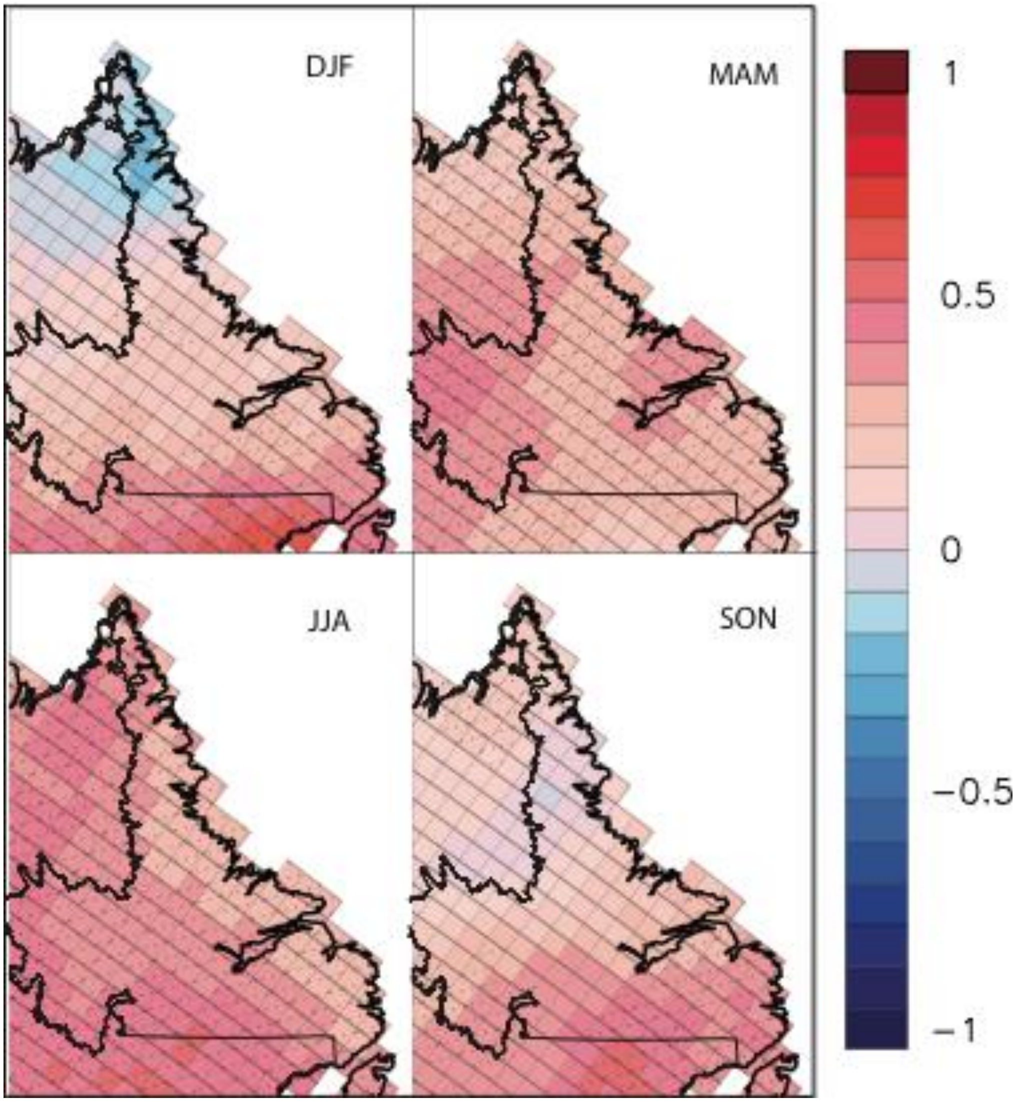

Table 22: Mean precipitation event intensity (mm/day) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	8.9	0.3	0.3
	MAM	7.9	0.3	0.2
	JJA	7.2	0.3	0.2
	SON	7.6	0.3	0.2
Churchill Falls	DJF	6.6	0.3	0.2
	MAM	6.5	0.4	0.2
	JJA	7.5	0.4	0.2
	SON	6.9	0.3	0.3
Goose Bay	DJF	7.5	0.3	0.3
	MAM	7.1	0.3	0.3
	JJA	8.0	0.4	0.2
	SON	7.6	0.3	0.4
Nain	DJF	10.2	0.1	0.2
	MAM	9.2	0.3	0.2
	JJA	8.2	0.3	0.2
	SON	8.2	0.1	0.3
Wabush Lake	DJF	6.3	0.3	0.2
	MAM	6.4	0.4	0.2
	JJA	7.4	0.4	0.3
	SON	6.5	0.3	0.3

Maximum 3-day Precipitation (mm)

Summary: Maximum precipitation falling over three consecutive days increases by 1-6mm. The greatest increases occur on the island in winter. Increases are generally smaller in Labrador.

Hazardous precipitation events often occur over several days, during which reservoirs, soil moisture capacity, and water bodies gradually become overwhelmed, leading to flooding even if precipitation intensity remains low. This index is much more variable than the other precipitation indices discussed, due to variations in the length, intensity, and procession of individual precipitation systems occurring over consecutive 3-day periods. However, in many cases it can provide a better estimate of increased flooding potential, as it covers heavy precipitation events occurring over multiple days and slow-building flooding events. In addition to the three day maximum, maximum 5 and 10 day precipitation are presented.

Projected changes in maximum 3, 5, and 10-day precipitation all follow spatial patterns similar to those described for mean precipitation intensity, particularly in Newfoundland; the greatest changes on the island occur in winter, and are concentrated along the south coast, west coast, and Avalon Pensinsula, with the Avalon and Burin also demonstrating a pronounced change in autumn. Changes in Labrador are concentrated to the north in summer, with the interior and parts of the coast seeing increases in spring as well.

Figure 23: Changes in maximum 3-day precipitation for 2038-2070. Significant changes are indicated by cross-hatching.

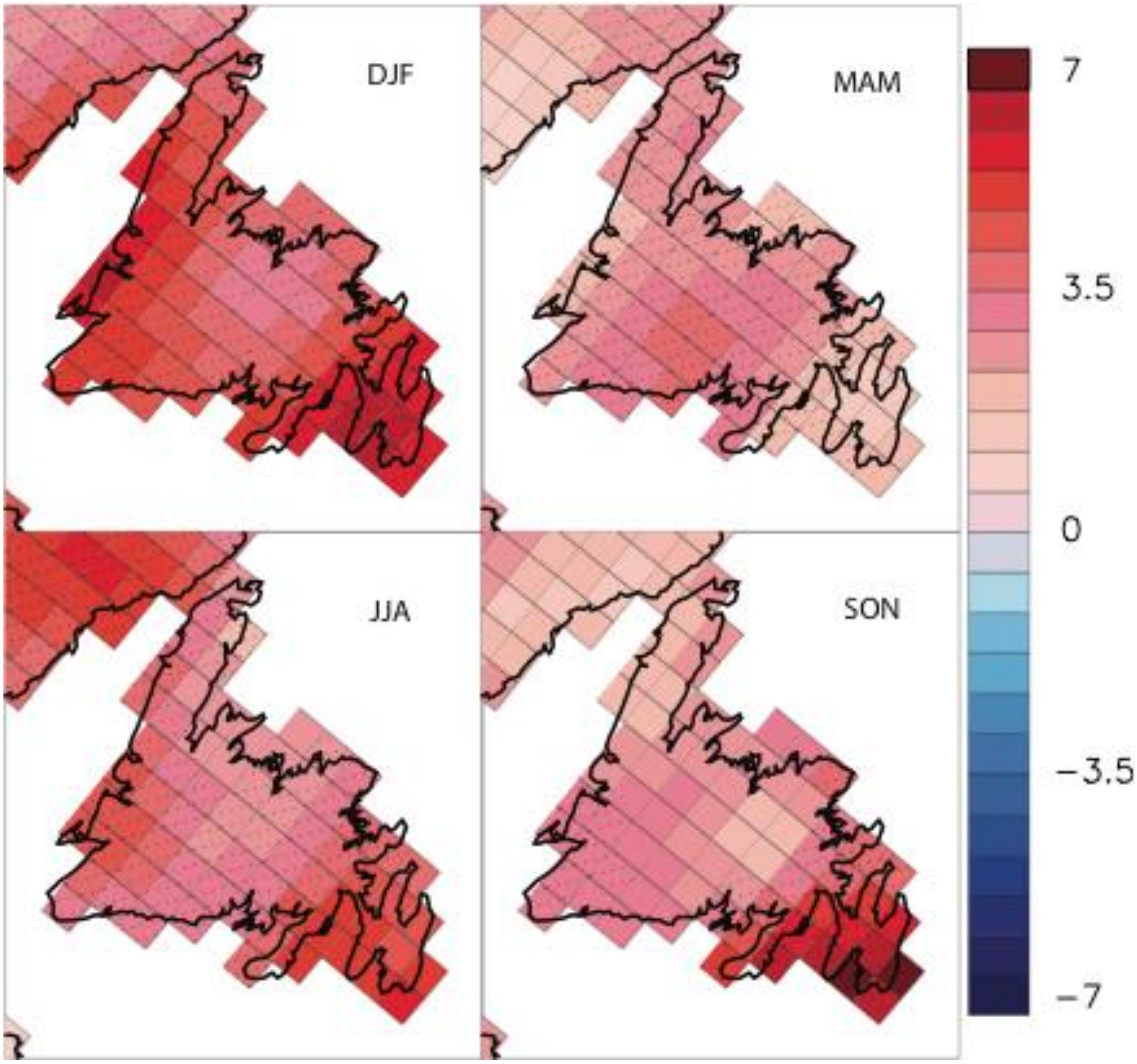

Table 23: Maximum 3-day precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	92.5	3.8	3.7
	MAM	69.5	3.4	2.6
	JJA	64.5	3.3	2.8
	SON	77.8	2.7	2.6
Corner Brook	DJF	56.3	5.2	2.9
	MAM	42.8	2.6	1.9
	JJA	50.7	4.2	2.6
	SON	55.6	3.4	3.4
Daniel's Harbour	DJF	55.7	5.3	2.9
	MAM	45.9	2.4	2.1
	JJA	64.3	3.7	2.3
	SON	55.0	2.1	4.0
Deer Lake	DJF	51.4	5.2	3.0
	MAM	47.0	2.5	1.9
	JJA	49.6	3.8	2.7
	SON	49.1	3.2	4.0
Exploits Dam	DJF	54.7	4.3	2.7
	MAM	51.6	3.0	1.9
	JJA	52.8	3.5	2.4
	SON	57.3	3.2	4.0
Gander	DJF	66.5	3.5	3.2
	MAM	60.9	2.7	1.7
	JJA	50.7	3.2	1.8
	SON	60.3	2.8	3.1
Grand Falls	DJF	55.8	3.5	3.1
	MAM	47.4	2.6	1.9
	JJA	53.4	2.6	2.5
	SON	54.2	2.6	3.7
Plum Point	DJF	51.6	4.2	2.3
	MAM	47.3	2.8	1.4
	JJA	60.1	3.4	1.5
	SON	53.3	2.1	4.4
St. Anthony	DJF	60.4	3.8	2.6
	MAM	53.8	2.7	1.6
	JJA	54.6	2.1	1.8
	SON	57.6	2.8	4.7
St. John's	DJF	86.8	5.8	4.3
	MAM	76.2	1.6	1.7
	JJA	58.9	4.5	6.2
	SON	75.0	5.8	3.9
Stephenville	DJF	59.2	5.8	3.0
	MAM	49.3	2.3	2.1
	JJA	59.7	4.4	2.5
	SON	59.6	2.9	2.5

Figure 24: Changes in maximum 3-day precipitation for 2038-2070. Significant changes are indicated by cross-hatching.

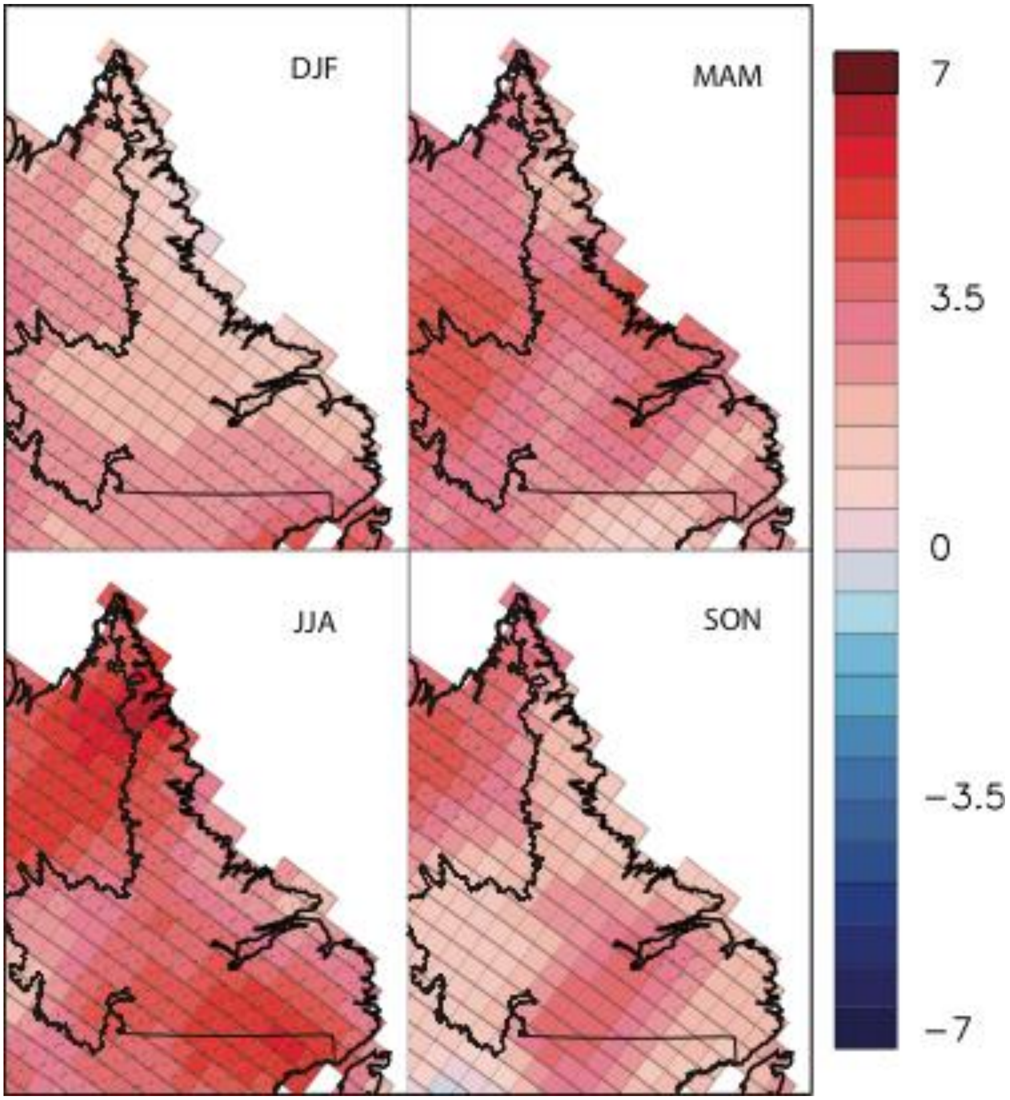

Table 24: Maximum 3-day precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	67.4	1.6	1.9
	MAM	61.2	2.5	2.1
	JJA	49.2	2.8	2.0
	SON	54.9	1.6	2.0
Churchill Falls	DJF	41.8	1.9	3.0
	MAM	42.0	3.3	1.9
	JJA	48.5	3.7	3.2
	SON	46.0	1.6	3.4
Goose Bay	DJF	46.4	2.1	3.1
	MAM	44.0	3.7	3.4
	JJA	53.4	4.2	2.2
	SON	48.1	3.7	4.9
Nain	DJF	75.3	0.9	2.9
	MAM	64.2	3.4	1.2
	JJA	54.2	3.4	3.2
	SON	53.1	1.4	2.7
Wabush Lake	DJF	40.8	2.5	2.1
	MAM	39.9	3.8	1.1
	JJA	47.6	2.3	3.4
	SON	40.1	1.4	4.4

Maximum 5-day Precipitation (mm)

Summary: Maximum precipitation falling over five consecutive days increases by 1.5-9mm. The greatest increases occur on the island in winter. Increases are generally smaller in Labrador.

Same as maximum 3-day precipitation but calculated over five consecutive days. Projected changes in maximum 3, 5, and 10-day precipitation all follow spatial patterns similar to those described for mean precipitation intensity, particularly in Newfoundland; the greatest changes on the island occur in typically occur in winter, and are concentrated along the south coast, west coast, and Avalon Peninsula, with the Avalon and Burin also demonstrating a pronounced change in autumn. Changes in Labrador are concentrated to the north in summer, with the interior and parts of the coast seeing increases in spring as well.

Figure 25: Changes in maximum 5-day precipitation for 2038-2070. Significant changes are indicated by cross-hatching.

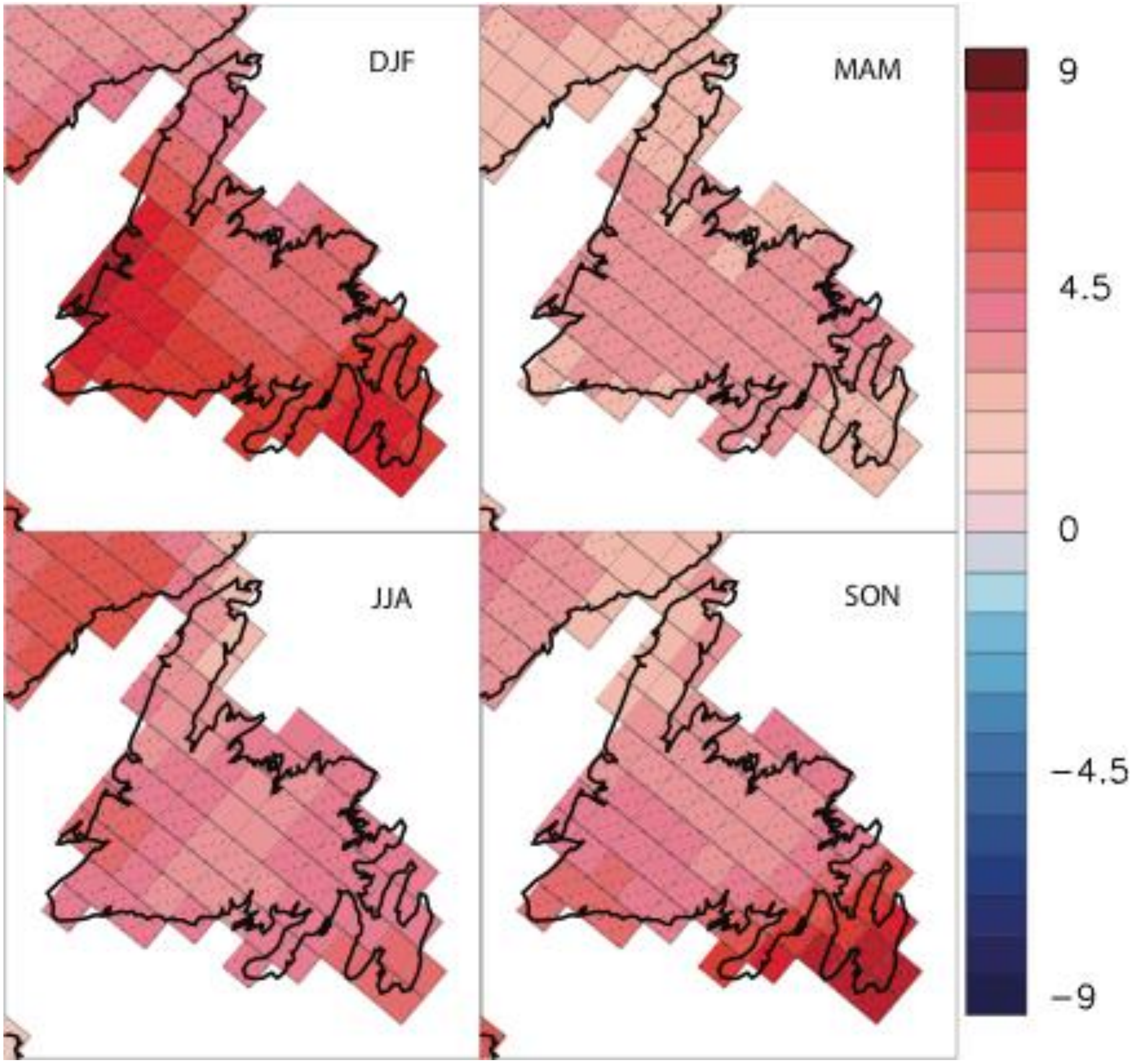

Table 25: Maximum 5-day precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	111.4	5.5	3.4
	MAM	85.0	3.3	2.7
	JJA	77.4	3.7	3.3
	SON	99.3	4.0	3.4
Corner Brook	DJF	72.5	7.4	2.9
	MAM	53.8	3.2	2.4
	JJA	60.8	4.6	2.7
	SON	69.1	4.2	2.7
Daniel's Harbour	DJF	69.1	5.8	3.9
	MAM	56.1	3.2	2.8
	JJA	73.0	3.8	2.2
	SON	63.0	3.0	3.8
Deer Lake	DJF	63.5	7.0	3.1
	MAM	56.3	3.1	2.6
	JJA	58.4	4.2	3.1
	SON	60.1	3.8	3.0
Exploits Dam	DJF	65.7	6.3	2.7
	MAM	62.0	3.3	2.8
	JJA	64.8	4.1	3.0
	SON	67.1	4.0	3.2
Gander	DJF	81.3	4.7	3.6
	MAM	73.3	3.4	3.0
	JJA	59.9	3.9	2.7
	SON	73.4	3.7	2.9
Grand Falls	DJF	67.3	4.6	3.3
	MAM	58.0	3.0	2.5
	JJA	64.5	3.7	4.0
	SON	65.2	3.4	3.3
Plum Point	DJF	65.2	4.3	3.0
	MAM	59.5	2.6	2.3
	JJA	70.0	3.4	1.9
	SON	64.9	2.8	3.8
St. Anthony	DJF	74.9	3.9	3.0
	MAM	65.0	2.4	2.2
	JJA	65.8	2.2	2.6
	SON	68.7	3.4	3.4
St. John's	DJF	107.6	6.3	5.0
	MAM	88.8	2.7	2.0
	JJA	69.0	4.5	6.3
	SON	91.4	7.4	5.4
Stephenville	DJF	76.4	7.7	3.0
	MAM	59.6	3.0	2.7
	JJA	70.8	4.7	3.1
	SON	72.7	3.9	2.4

Figure 26: Changes in maximum 5-day precipitation for 2038-2070. Significant changes are indicated by cross-hatching.

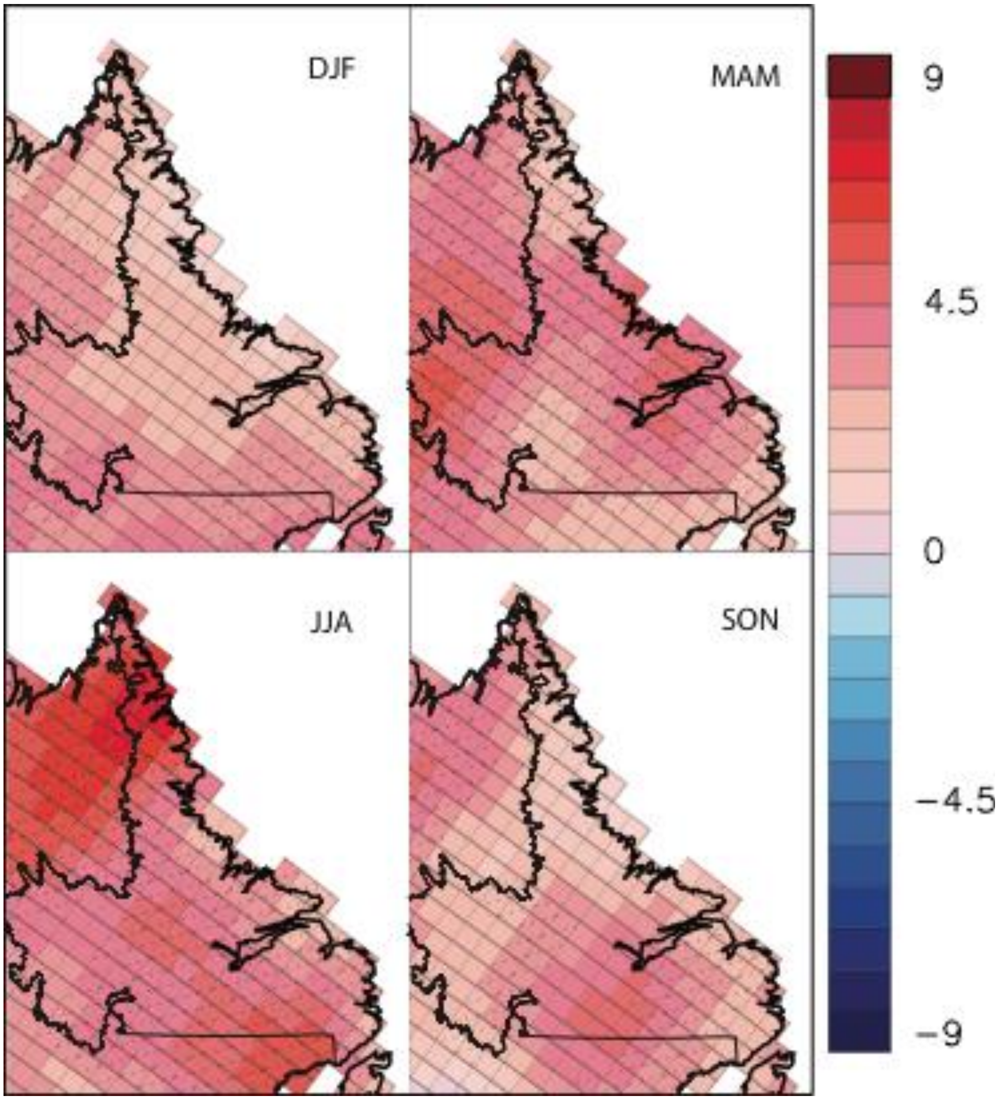

Table 26: Maximum 3-day precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	82.7	2.4	2.0
	MAM	75.7	3.4	2.7
	JJA	59.6	2.9	2.8
	SON	67.1	2.7	2.0
Churchill Falls	DJF	48.8	3.0	4.3
	MAM	50.8	3.5	2.5
	JJA	60.1	4.4	3.9
	SON	54.4	3.1	2.9
Goose Bay	DJF	55.6	2.7	3.8
	MAM	52.9	4.1	3.0
	JJA	62.9	4.4	2.4
	SON	57.4	4.4	5.1
Nain	DJF	85.5	1.5	3.8
	MAM	76.7	3.6	1.8
	JJA	63.5	3.4	3.6
	SON	64.3	1.3	2.7
Wabush Lake	DJF	47.6	3.4	3.3
	MAM	47.9	5.0	1.6
	JJA	59.2	3.2	4.7
	SON	50.1	2.6	4.1

Maximum 10-day Precipitation (mm)

Summary: Maximum precipitation falling over ten consecutive days increases by 1-11mm. The greatest increases occur on the island in winter. Increases are generally smaller in Labrador.

Maximum precipitation falling in a 10-day consecutive period. Projected changes in maximum 3, 5, and 10-day precipitation all follow spatial patterns similar to those described for mean precipitation intensity, particularly in Newfoundland; the greatest changes on the island occur in typically occur in winter, and are concentrated along the south coast, west coast, and Avalon Peninsula, with the Avalon and Burin also demonstrating a pronounced change in autumn. Changes in Labrador are concentrated to the north in summer, with the interior and parts of the coast seeing increases in spring as well.

Figure 27: Changes in maximum 10-day precipitation for 2038-2070. Significant changes are indicated by cross-hatching.

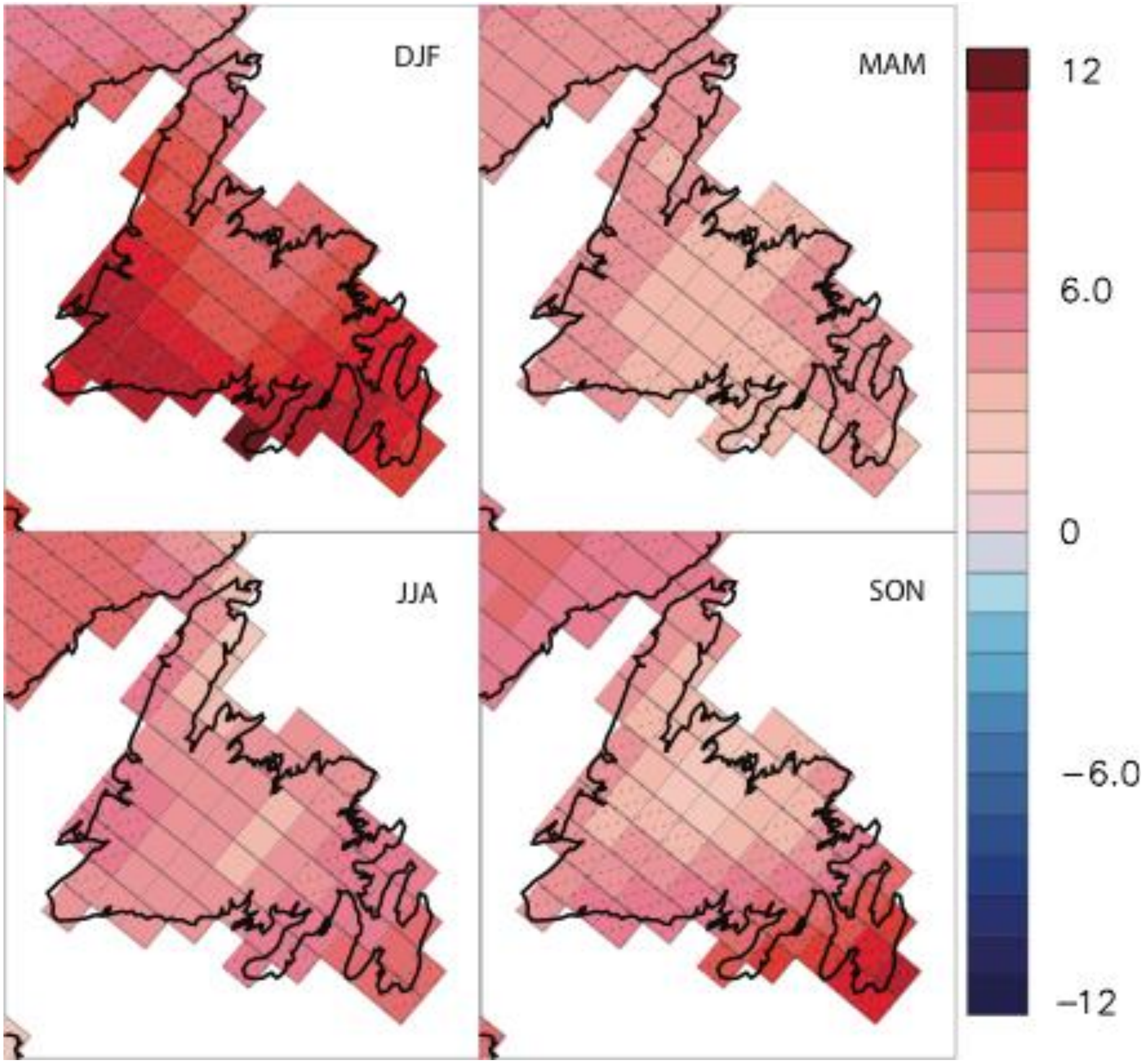

Table 27: Maximum 10-day precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	165.8	8.9	2.6
	MAM	124.2	3.6	3.3
	JJA	108.7	4.4	5.4
	SON	139.2	5.1	3.6
Corner Brook	DJF	113.8	10.0	2.8
	MAM	80.3	4.5	3.8
	JJA	85.7	5.3	5.0
	SON	102.7	4.0	2.5
Daniel's Harbour	DJF	104.2	8.4	4.6
	MAM	78.9	4.3	3.4
	JJA	97.0	5.4	4.0
	SON	91.0	4.7	4.9
Deer Lake	DJF	97.0	9.2	3.0
	MAM	79.6	4.2	4.0
	JJA	80.9	5.1	5.3
	SON	87.8	3.5	3.1
Exploits Dam	DJF	98.1	8.5	2.7
	MAM	86.8	3.6	4.2
	JJA	91.1	4.7	5.5
	SON	95.9	3.5	3.4
Gander	DJF	124.1	7.5	3.2
	MAM	104.8	4.3	2.8
	JJA	86.7	4.6	4.5
	SON	104.3	3.8	2.8
Grand Falls	DJF	97.4	6.4	3.8
	MAM	82.5	3.2	3.3
	JJA	89.0	4.3	6.0
	SON	92.8	2.6	4.2
Plum Point	DJF	103.1	6.3	4.0
	MAM	90.0	4.4	2.7
	JJA	97.1	4.5	3.8
	SON	93.5	4.7	5.5
St. Anthony	DJF	112.7	5.2	4.2
	MAM	92.1	4.4	2.2
	JJA	93.3	2.8	4.4
	SON	100.5	4.5	4.6
St. John's	DJF	163.4	9.1	5.2
	MAM	129.7	4.1	1.6
	JJA	97.2	6.2	6.9
	SON	135.4	8.8	5.7
Stephenville	DJF	115.5	10.3	3.3
	MAM	88.4	4.9	4.4
	JJA	101.9	5.7	4.8
	SON	106.0	4.6	2.4

Figure 28: Changes in maximum 10-day precipitation for 2038-2070. Significant changes are indicated by cross-hatching.

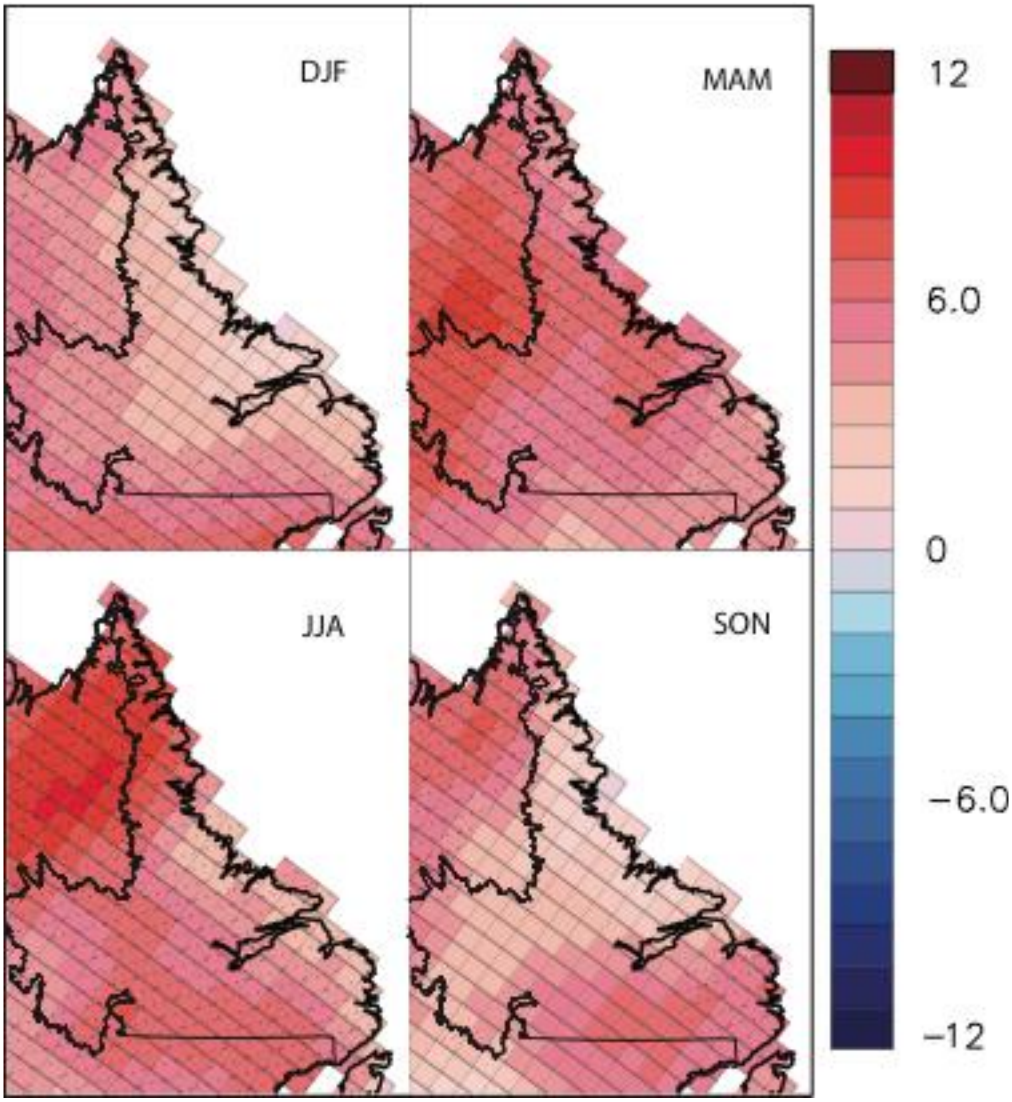

Table 28: Maximum 10-day precipitation (mm) climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	115.6	2.5	3.6
	MAM	106.2	4.0	2.8
	JJA	81.5	3.8	4.1
	SON	90.9	4.9	4.7
Churchill Falls	DJF	74.9	4.2	4.0
	MAM	72.1	6.0	3.4
	JJA	86.5	6.2	3.3
	SON	83.6	3.7	5.7
Goose Bay	DJF	81.1	3.4	4.8
	MAM	73.2	6.2	4.8
	JJA	88.5	5.4	2.7
	SON	78.6	4.8	7.7
Nain	DJF	120.7	2.1	4.5
	MAM	101.3	5.9	2.8
	JJA	85.3	4.7	3.4
	SON	88.6	1.0	3.4
Wabush Lake	DJF	70.8	5.1	3.5
	MAM	67.1	7.4	2.0
	JJA	86.8	4.3	6.0
	SON	77.6	3.7	5.7

Number of Days with 10mm or more Precipitation

Summary: The number of days with 10mm or more of precipitation increases across the province. Newfoundland sees the largest increases in winter (1 or 2 days), while in most of Labrador the change is concentrated in summer (1-2 days).

This indicates the number of days with significant precipitation. Depending on the intensity of rainfall (amount/time), 10mm rain events can prove hazardous, leading to flooding and associated erosion.

Changes are generally modest (~ 1 additional event) outside of winter on the Island and summer in Labrador.

Figure 29: Changes in the number of days with precipitation > 10mm projected for 2038-2070. Significant changes are indicated by cross-hatching.

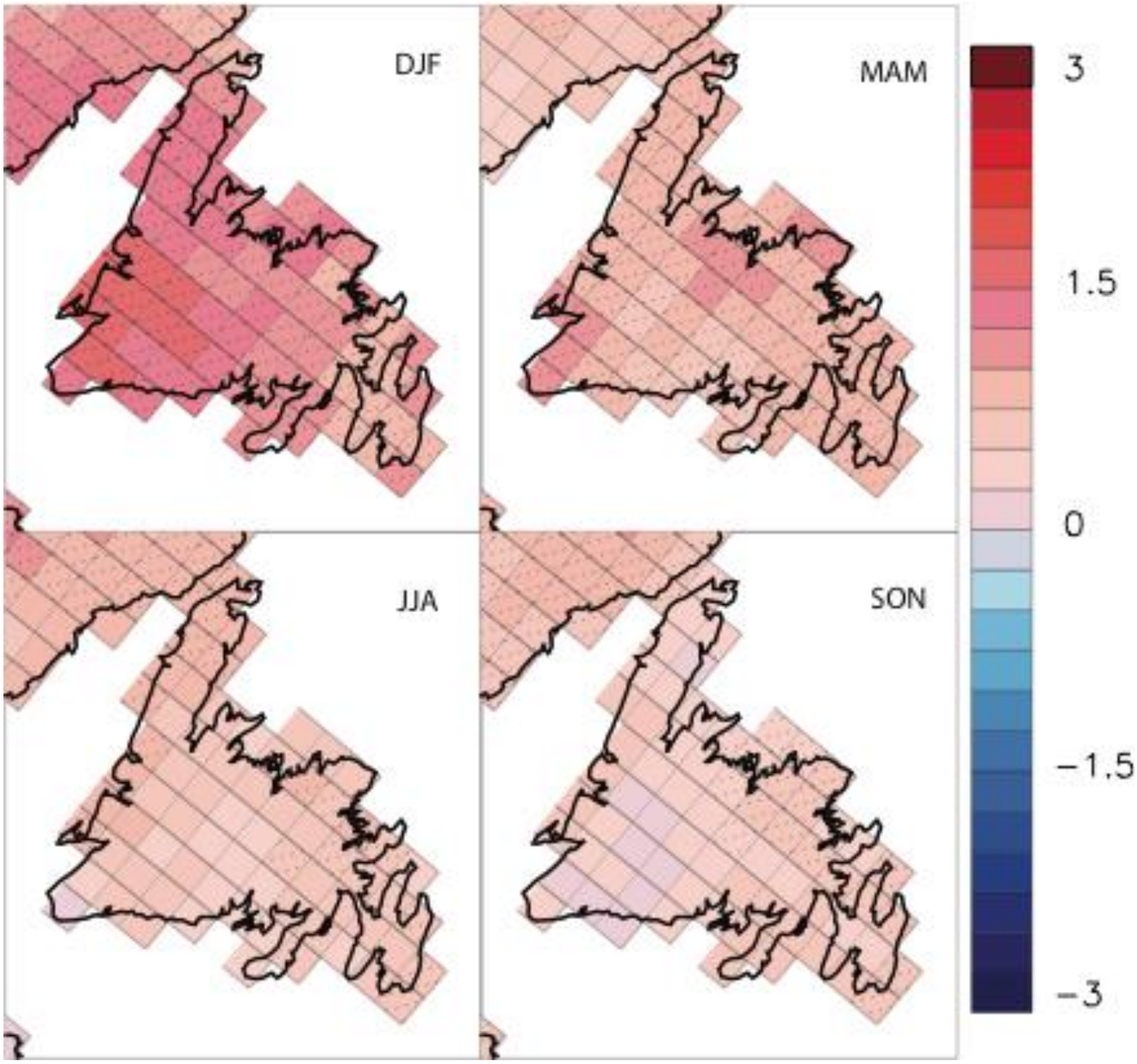

Table 29: Number of events with 10mm or more of precipitation; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	18.2	1.2	0.5
	MAM	12.9	0.6	0.5
	JJA	11.3	0.5	0.9
	SON	14.3	0.5	0.7
Corner Brook	DJF	13.8	1.7	0.7
	MAM	7.5	1.0	0.5
	JJA	8.3	0.8	1.1
	SON	11.3	0.3	0.7
Daniel's Harbour	DJF	10.5	1.4	0.4
	MAM	7.4	0.9	0.4
	JJA	10.2	0.9	0.9
	SON	9.6	0.6	0.9
Deer Lake	DJF	12.1	1.6	0.7
	MAM	7.3	0.8	0.4
	JJA	9.1	0.7	1.3
	SON	9.8	0.2	0.7
Exploits Dam	DJF	13.3	1.5	0.8
	MAM	9.0	0.7	0.4
	JJA	9.5	0.6	1.2
	SON	11.0	0.0	0.6
Gander	DJF	14.5	1.0	0.5
	MAM	10.5	0.8	0.4
	JJA	8.9	0.7	0.6
	SON	11.1	0.6	0.3
Grand Falls	DJF	11.3	1.2	0.4
	MAM	8.3	1.1	0.5
	JJA	9.0	0.6	0.9
	SON	10.3	0.4	0.4
Plum Point	DJF	13.8	1.4	0.4
	MAM	9.4	0.8	0.5
	JJA	10.4	0.9	0.6
	SON	11.1	0.5	0.6
St. Anthony	DJF	14.3	0.9	0.3
	MAM	10.0	1.1	0.5
	JJA	9.8	0.8	0.9
	SON	11.0	0.5	0.7
St. John's	DJF	21.9	1.1	0.6
	MAM	13.7	0.9	0.5
	JJA	9.4	0.7	0.6
	SON	14.4	0.6	0.3
Stephenville	DJF	14.1	1.6	0.7
	MAM	8.8	1.0	0.6
	JJA	10.9	0.9	0.9
	SON	13.5	0.5	0.7

Figure 30: Changes in the number of days with precipitation > 10mm projected for 2038-2070. Significant changes are indicated by cross-hatching.

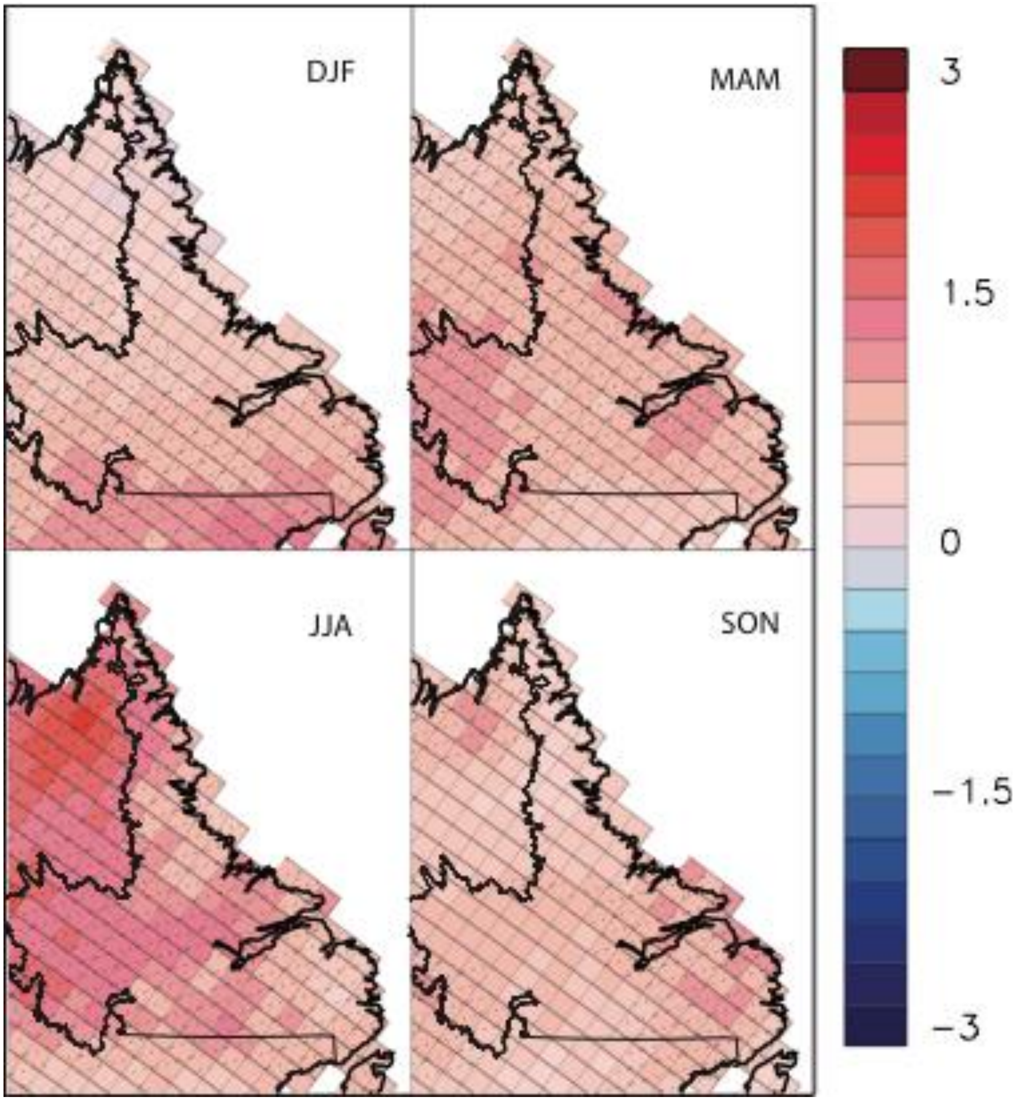

Table 30: Number of events with 10mm or more of precipitation; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	11.4	0.9	0.8
	MAM	9.1	0.9	0.7
	JJA	8.6	0.5	0.3
	SON	8.9	1.1	0.5
Churchill Falls	DJF	6.5	0.7	0.5
	MAM	6.1	1.0	0.6
	JJA	10.0	1.4	0.6
	SON	9.0	0.9	1.0
Goose Bay	DJF	7.9	0.8	0.5
	MAM	7.1	0.9	0.8
	JJA	10.0	1.0	0.3
	SON	8.2	0.9	0.7
Nain	DJF	9.8	0.4	0.6
	MAM	8.3	0.9	0.2
	JJA	8.3	0.6	0.4
	SON	8.0	0.5	0.9
Wabush Lake	DJF	5.8	0.9	0.5
	MAM	5.9	1.2	0.5
	JJA	10.0	1.6	0.8
	SON	8.1	0.9	0.8

90th Percentile of Precipitation Events (mm)

Summary: The 90th percentile of precipitation events shows the greatest increase on the island during winter (0.5-1mm); similar changes are expected for Labrador in summer.

While values such as 3/5/10-day maximum precipitation give a sense of hazards associated with long duration precipitation events, the 90th percentile illustrates changes in intensity of individual days (in this case, for 24 hr periods). The maximum 10% of precipitation events will be above the 90th percentile; this then measures the change in these often serious events.

Recurring patterns are found in all examined variables related to precipitation intensity, and the 90th percentile precipitation again resembles mean intensity, 3-day maximum precipitation etc. On the island, the largest changes occur in winter; the Burin and Avalon also experience a marked increase in spring and autumn. The biggest shifts in Labrador occur in the interior during summer, with an additional regional winter increase over southern Labrador.

Figure 31: Changes in the 90th percentile of precipitation projected for 2038-2070. Significant changes are indicated by cross-hatching.

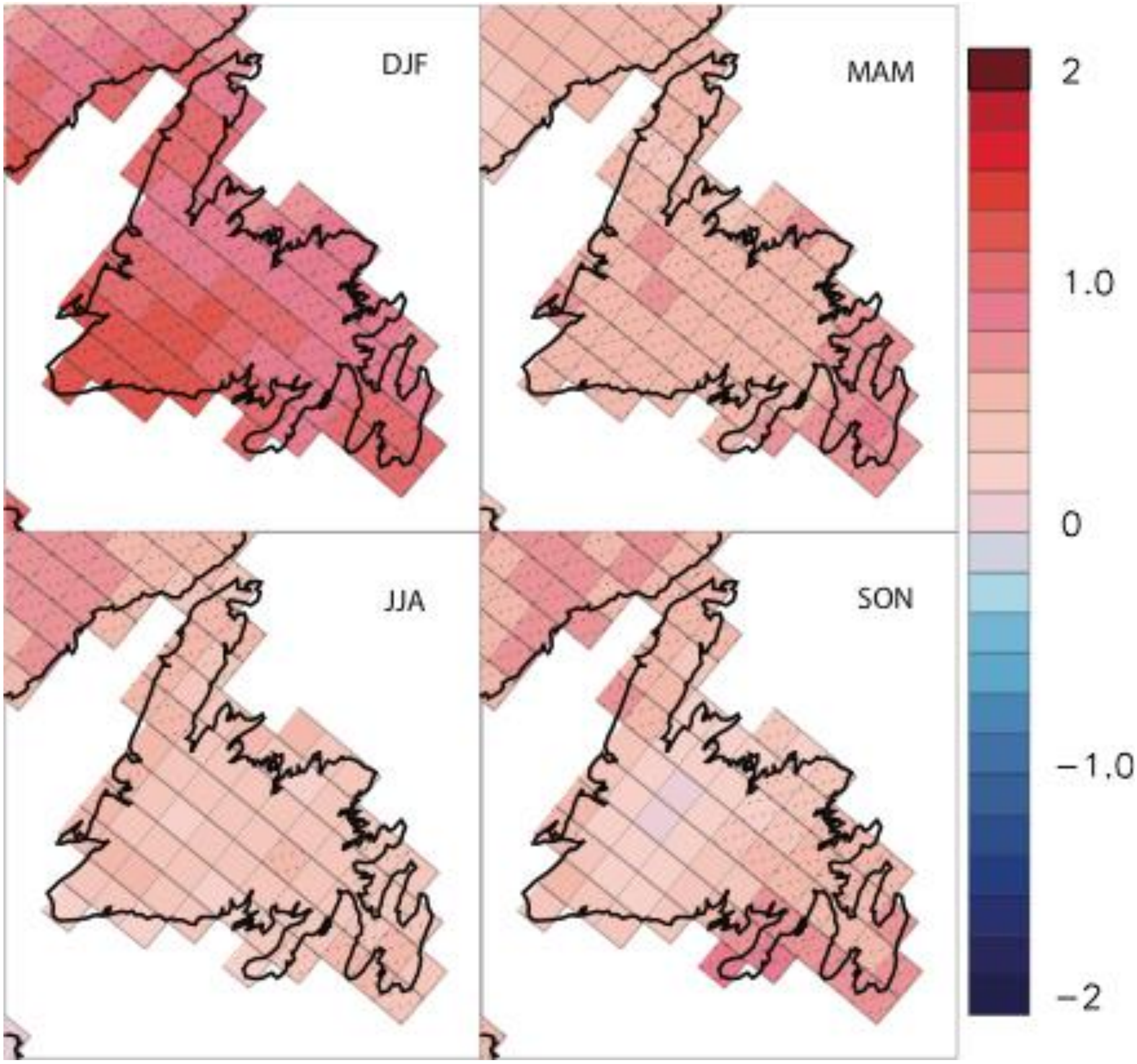

Table 31: 90th percentile of precipitation events (mm); climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	18.9	1.0	0.4
	MAM	12.9	0.6	0.2
	JJA	11.1	0.4	0.5
	SON	14.8	0.5	0.5
Corner Brook	DJF	12.8	1.2	0.4
	MAM	8.1	0.6	0.3
	JJA	8.5	0.4	0.8
	SON	10.9	0.3	0.6
Daniel's Harbour	DJF	10.9	1.1	0.3
	MAM	7.9	0.5	0.3
	JJA	9.5	0.6	0.5
	SON	9.8	0.7	0.5
Deer Lake	DJF	11.4	1.1	0.4
	MAM	7.5	0.6	0.4
	JJA	8.7	0.4	0.9
	SON	9.4	0.2	0.6
Exploits Dam	DJF	12.8	1.1	0.4
	MAM	8.9	0.7	0.3
	JJA	9.4	0.3	0.8
	SON	10.6	0.0	0.7
Gander	DJF	14.4	1.0	0.2
	MAM	10.3	0.6	0.2
	JJA	8.9	0.4	0.5
	SON	10.6	0.4	0.3
Grand Falls	DJF	11.4	0.9	0.2
	MAM	8.0	0.5	0.3
	JJA	9.1	0.4	0.7
	SON	10.0	0.3	0.4
Plum Point	DJF	12.3	1.1	0.2
	MAM	9.3	0.5	0.4
	JJA	10.2	0.5	0.4
	SON	10.6	0.6	0.4
St. Anthony	DJF	13.6	0.8	0.3
	MAM	9.5	0.6	0.4
	JJA	9.4	0.5	0.6
	SON	11.1	0.5	0.4
St. John's	DJF	20.0	1.0	0.4
	MAM	13.0	0.7	0.2
	JJA	8.9	0.4	0.3
	SON	13.9	0.7	0.4
Stephenville	DJF	12.8	1.2	0.4
	MAM	8.6	0.7	0.4
	JJA	10.6	0.5	0.8
	SON	12.0	0.6	0.6

Figure 32: Changes in the 90th percentile of precipitation projected for 2038-2070. Significant changes are indicated by cross-hatching.

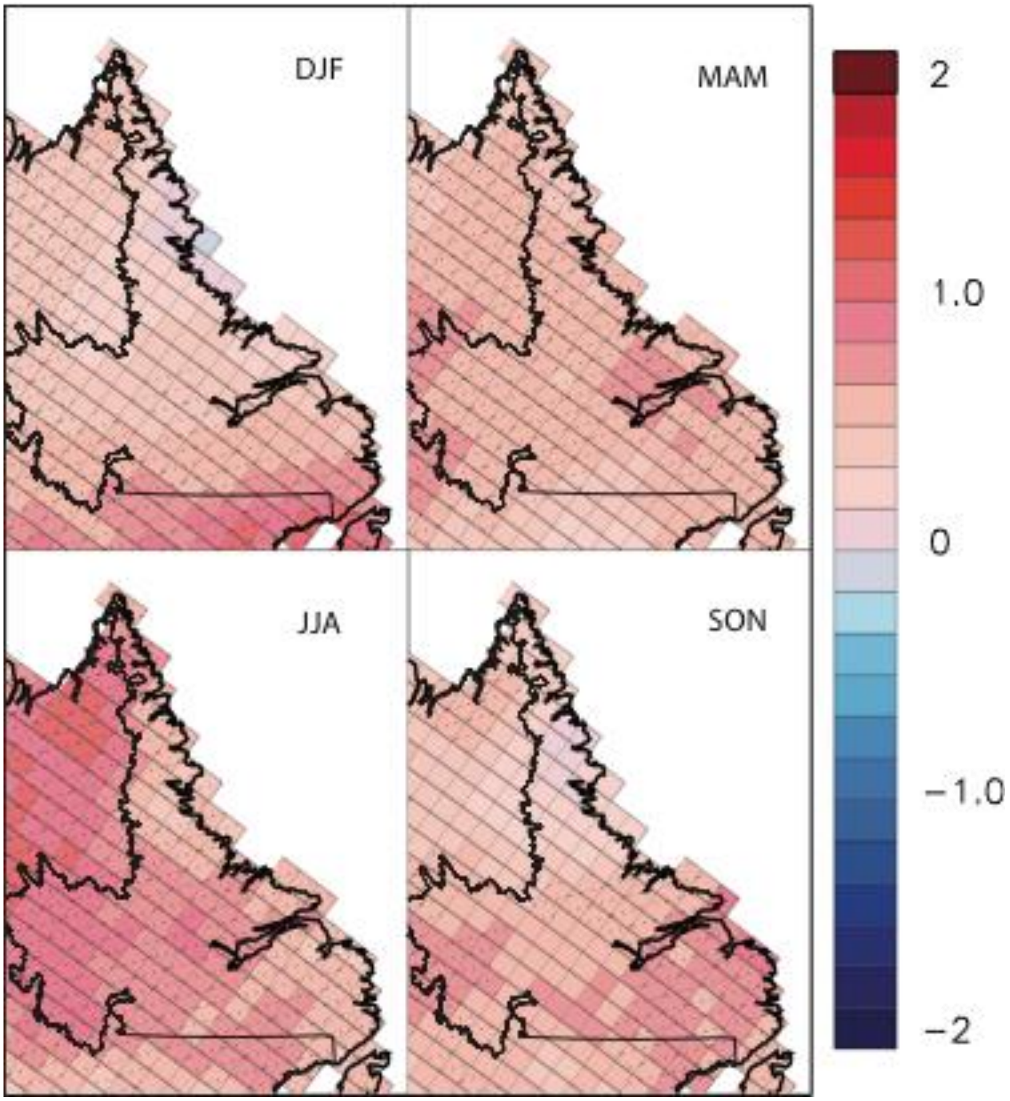

Table 32: 90th percentile of precipitation events (mm); climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	11.3	0.4	0.8
	MAM	9.3	0.7	0.4
	JJA	8.6	0.5	0.3
	SON	8.6	0.9	0.2
Churchill Falls	DJF	7.3	0.4	0.5
	MAM	7.0	0.5	0.2
	JJA	9.8	0.9	0.3
	SON	9.2	0.6	0.8
Goose Bay	DJF	8.3	0.5	0.4
	MAM	7.4	0.6	0.5
	JJA	9.6	0.8	0.3
	SON	8.0	0.6	0.7
Nain	DJF	10.0	0.1	0.5
	MAM	8.3	0.6	0.4
	JJA	8.1	0.5	0.3
	SON	8.4	0.2	0.7
Wabush Lake	DJF	7.0	0.5	0.4
	MAM	6.5	0.7	0.2
	JJA	9.7	0.9	0.4
	SON	8.6	0.7	0.7

Maximum Number of Consecutive Dry Days (days)

Summary: Results show few noticeable changes in maximum number of consecutive dry days. The only exception is northern Labrador in winter, which sees a decrease of about 2-4 days.

Calculated as the longest stretch of days without precipitation in a given year, this is the first of several indices intended to examine potential issues around drought. For each year, the maximum dry spell is identified; the average is then calculated over all years. This is useful as an indicator of changing drought severity (droughts defined as an extended period without precipitation).

Results suggest droughts are not a growing concern for the province; significant changes are rare, and typically show a decrease in the maximum stretch of dry days (i.e. shorter 'drought'). The only exception is northern Labrador in winter, which sees a decrease of about 2-4 days.

Figure 33: Changes in the maximum number of consecutive dry days projected for 2038-2070. Significant changes are indicated by cross-hatching.

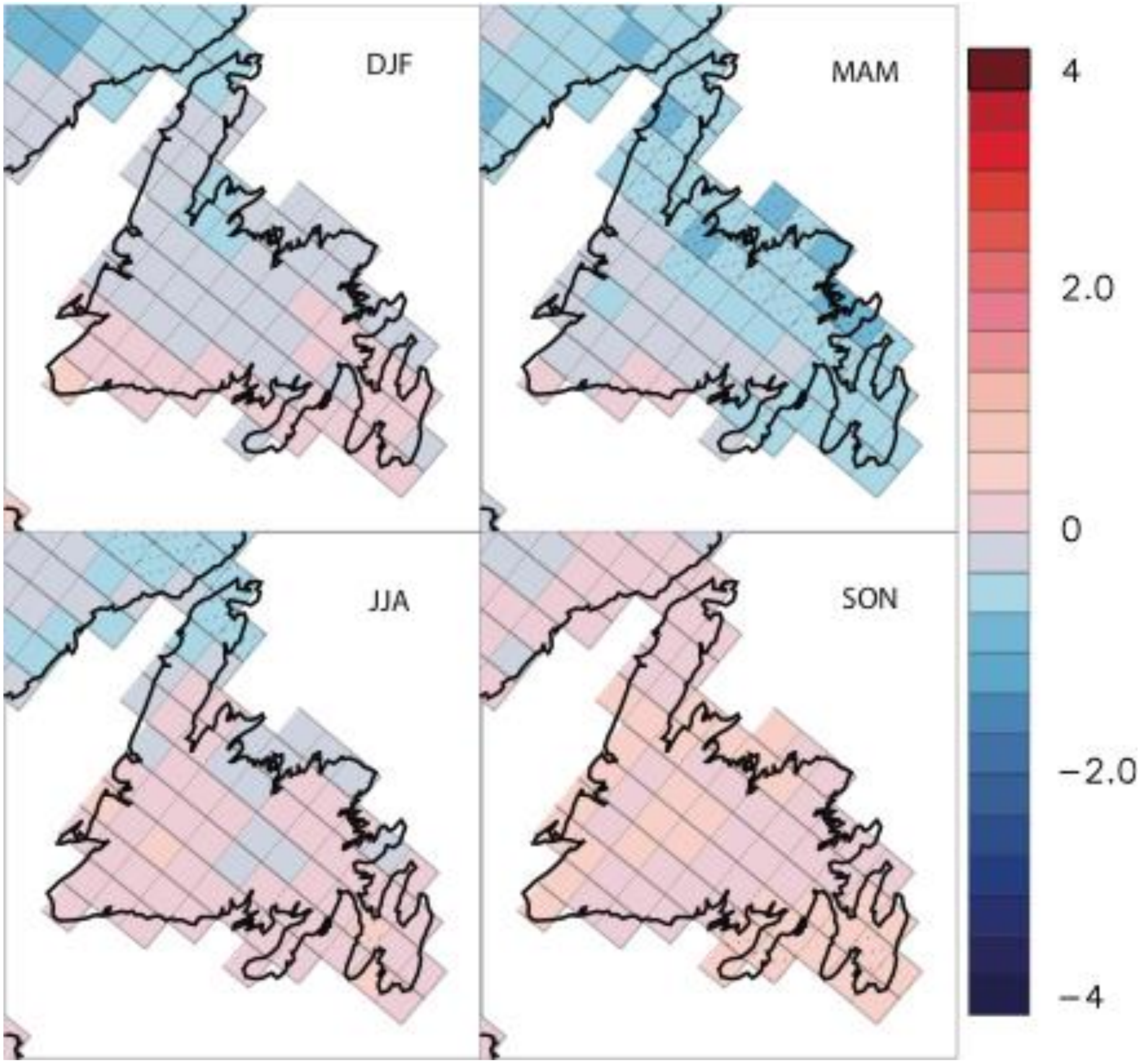

Table 33: Maximum number of consecutive dry days; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	7.5	-0.2	0.7
	MAM	10.7	-0.3	0.6
	JJA	8.8	0.0	0.4
	SON	7.5	0.1	0.7
Corner Brook	DJF	6.0	0.0	0.8
	MAM	9.8	-0.3	0.5
	JJA	8.7	0.3	0.4
	SON	7.6	0.3	0.7
Daniel's Harbour	DJF	7.0	-0.3	0.8
	MAM	10.9	-0.4	0.4
	JJA	9.0	-0.1	0.5
	SON	8.3	0.4	0.8
Deer Lake	DJF	8.7	-0.1	0.7
	MAM	11.7	-0.2	0.4
	JJA	9.6	0.2	0.4
	SON	8.3	0.2	0.8
Exploits Dam	DJF	8.8	-0.2	0.6
	MAM	10.2	-0.2	0.5
	JJA	8.6	0.1	0.5
	SON	7.8	0.5	0.7
Gander	DJF	6.1	-0.1	0.7
	MAM	8.5	-0.6	0.4
	JJA	9.3	0.0	0.3
	SON	7.3	0.3	0.7
Grand Falls	DJF	9.4	-0.1	0.4
	MAM	10.3	-0.6	0.3
	JJA	9.6	-0.1	0.4
	SON	8.1	0.3	0.9
Plum Point	DJF	6.2	-0.2	0.8
	MAM	9.9	-0.7	0.5
	JJA	8.4	-0.3	0.5
	SON	7.1	0.3	0.7
St. Anthony	DJF	8.0	-0.5	0.7
	MAM	10.4	-0.7	0.5
	JJA	9.7	-0.7	0.4
	SON	9.0	0.2	0.4
St. John's	DJF	5.4	0.1	0.6
	MAM	7.7	-0.5	0.4
	JJA	9.8	0.2	0.2
	SON	7.6	0.5	0.6
Stephenville	DJF	5.9	0.1	0.7
	MAM	10.6	-0.2	0.4
	JJA	9.5	0.2	0.4
	SON	6.8	0.5	0.7

Figure 34: Changes in the maximum number of consecutive dry days projected for 2038-2070. Significant changes are indicated by cross-hatching.

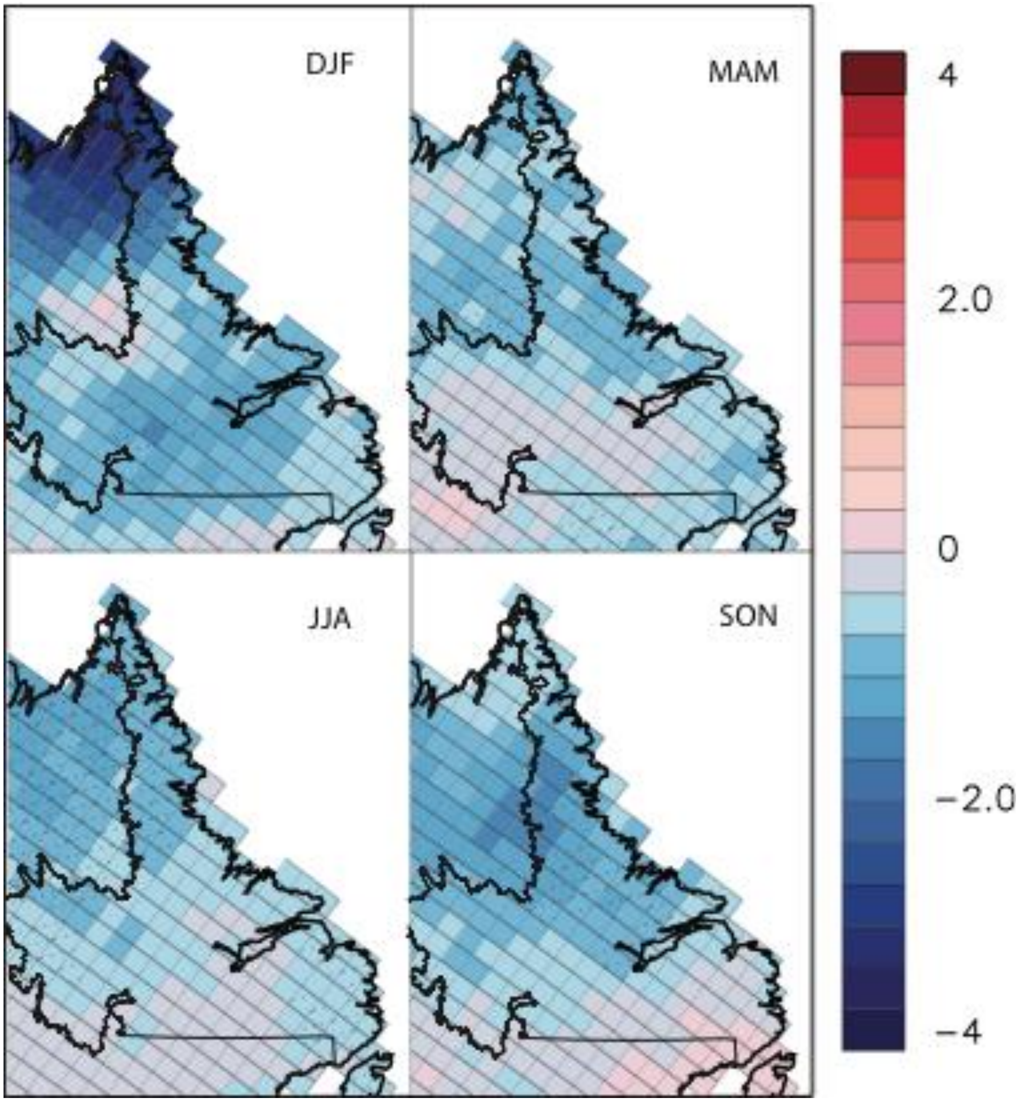

Table 34: Maximum number of consecutive dry days; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	9.1	-0.3	1.3
	MAM	10.6	-0.4	0.5
	JJA	8.4	-0.6	0.3
	SON	8.6	-0.3	0.8
Churchill Falls	DJF	9.9	-1.1	1.1
	MAM	11.4	-0.2	0.6
	JJA	8.1	-0.7	0.8
	SON	7.4	-0.6	0.7
Goose Bay	DJF	11.1	-1.0	1.2
	MAM	13.4	-0.2	0.7
	JJA	8.4	-0.3	0.7
	SON	9.5	-0.8	0.7
Nain	DJF	13.0	-0.9	1.4
	MAM	14.2	-0.8	1.0
	JJA	11.1	-0.5	0.9
	SON	10.9	-1.0	0.9
Wabush Lake	DJF	8.8	-0.9	1.0
	MAM	12.3	-0.4	1.1
	JJA	8.2	-0.5	0.5
	SON	7.5	-0.5	1.0

Mean Dry Spell Length (days)

Summary: Results show few noticeable changes in the length of dry spells. The only exception is northern Labrador in winter, which sees more frequent precipitation (typical dry spell length decreases by about 1-2 days).

The average number of days between precipitation events. Dry spell length gives an indication of:

1) Water stress on vegetation, as longer spells mean a greater chance of dehydration/heat stress
2) Potential flood frequency, as smaller spells mean less time for water courses to route precipitation from one event out of a region before the next event occurs.

The current report also examines the median (i.e. value that has a 50% chance of being exceeded) and standard deviation (i.e. typical range) of dry spells. None of these values show a large response to climate change in the models examined; there are some statistically significant shifts (notably in northern Labrador in winter, with decreases of 1-2 days), but generally projected changes are considerably less than a day. There is a weak indication that dry spells will become slightly shorter in the future, but the changes are both statistically insignificant in most locations and small enough that no serious impact is likely. In short, the *frequency* of precipitation is unlikely to change in a dramatic fashion, unlike the *intensity* of the events that do occur.

Figure 35: Changes in the mean dry spell length projected for 2038-2070. Significant changes are indicated by cross-hatching.

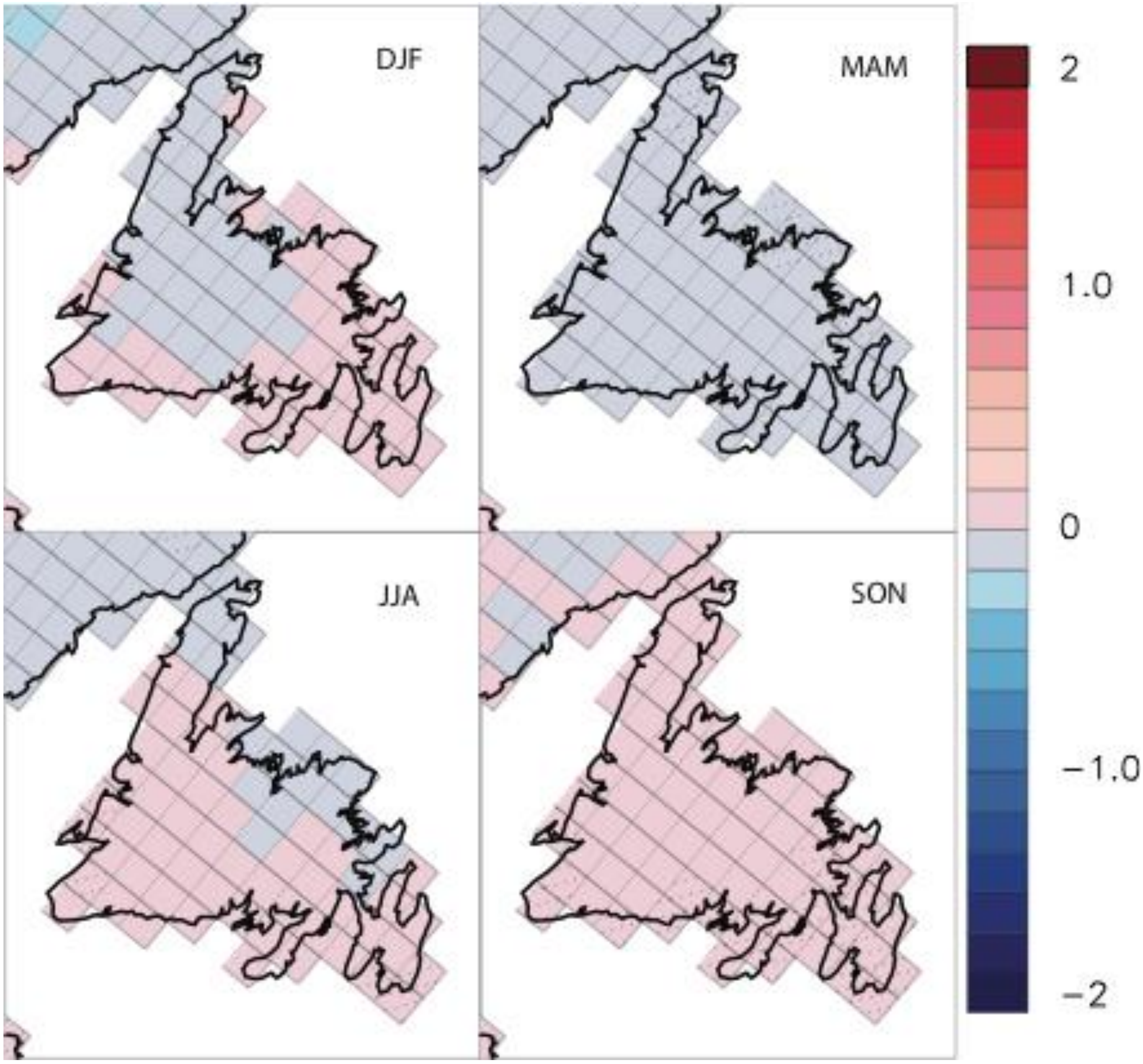

Table 35: Mean dry spell length; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	2.5	0.0	0.1
	MAM	3.2	0.0	0.1
	JJA	3.0	0.0	0.1
	SON	2.6	0.1	0.1
Corner Brook	DJF	2.1	0.0	0.2
	MAM	3.0	0.0	0.1
	JJA	3.0	0.0	0.1
	SON	2.5	0.1	0.1
Daniel's Harbour	DJF	2.3	0.0	0.2
	MAM	3.4	-0.1	0.1
	JJA	3.0	0.0	0.1
	SON	2.6	0.1	0.1
Deer Lake	DJF	3.4	0.0	0.2
	MAM	3.5	0.0	0.1
	JJA	3.1	0.0	0.1
	SON	2.8	0.1	0.1
Exploits Dam	DJF	2.8	0.0	0.2
	MAM	3.1	0.0	0.1
	JJA	2.9	0.0	0.1
	SON	2.7	0.1	0.1
Gander	DJF	2.1	0.0	0.1
	MAM	2.7	-0.1	0.1
	JJA	2.9	0.0	0.1
	SON	2.5	0.1	0.1
Grand Falls	DJF	2.9	0.0	0.1
	MAM	3.3	-0.1	0.1
	JJA	3.1	0.0	0.1
	SON	2.8	0.1	0.2
Plum Point	DJF	2.1	0.0	0.2
	MAM	2.8	-0.1	0.1
	JJA	2.7	0.0	0.1
	SON	2.4	0.1	0.1
St. Anthony	DJF	2.7	0.0	0.2
	MAM	3.3	-0.1	0.1
	JJA	3.1	-0.1	0.1
	SON	2.9	0.0	0.1
St. John's	DJF	1.9	0.0	0.1
	MAM	2.5	0.0	0.1
	JJA	3.2	0.0	0.1
	SON	2.5	0.1	0.1
Stephenville	DJF	2.0	0.0	0.2
	MAM	3.1	0.0	0.1
	JJA	3.1	0.1	0.1
	SON	2.4	0.1	0.1

Figure 36: Changes in the mean dry spell length projected for 2038-2070. Significant changes are indicated by cross-hatching.

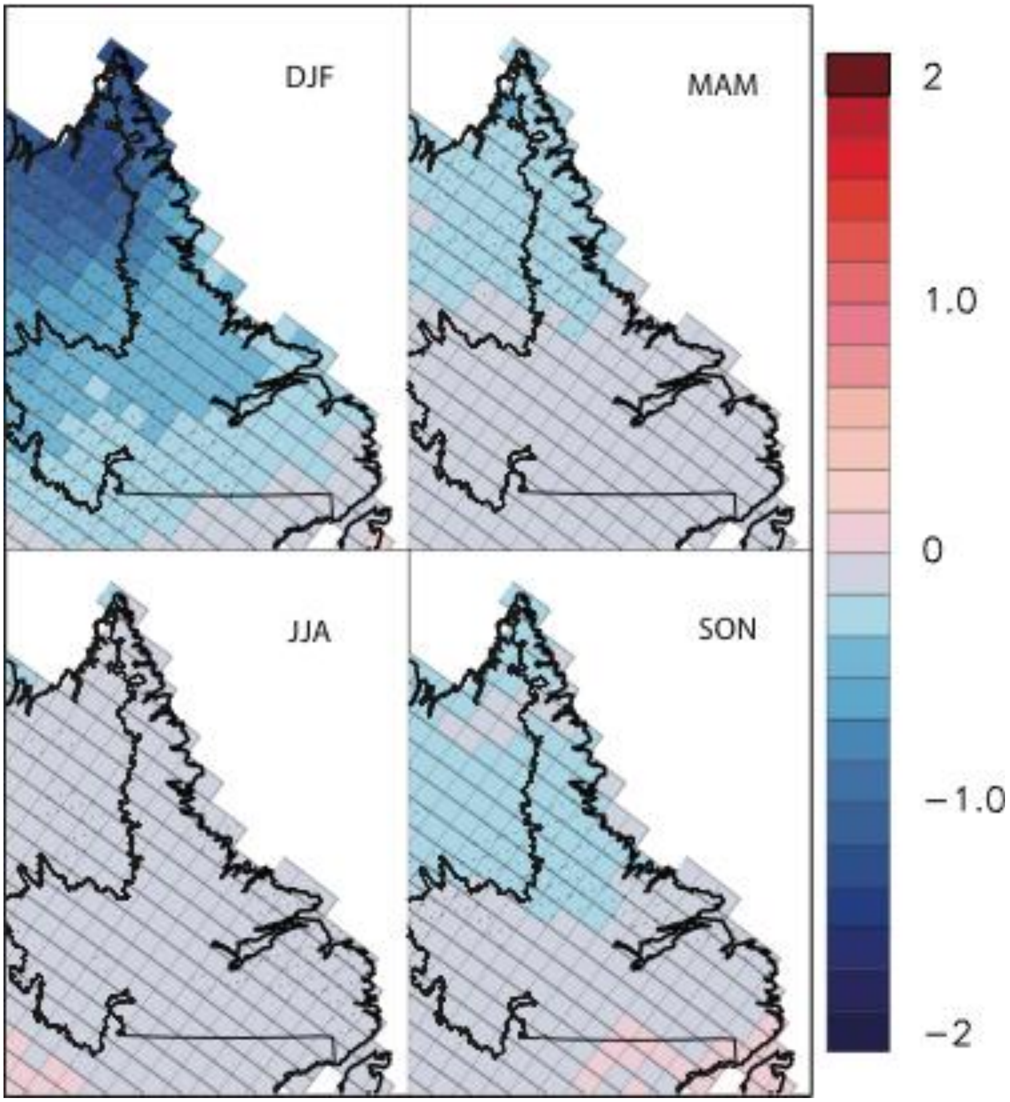

Table 36: Mean dry spell length; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	3.1	-0.2	0.4
	MAM	3.3	-0.1	0.1
	JJA	2.8	-0.1	0.1
	SON	2.9	-0.1	0.1
Churchill Falls	DJF	3.3	-0.3	0.3
	MAM	3.5	-0.1	0.1
	JJA	2.5	-0.1	0.1
	SON	2.4	-0.1	0.1
Goose Bay	DJF	3.5	-0.3	0.3
	MAM	3.9	0.0	0.2
	JJA	2.8	-0.1	0.1
	SON	3.2	-0.1	0.1
Nain	DJF	4.7	-0.5	0.4
	MAM	4.7	-0.2	0.2
	JJA	3.5	-0.1	0.1
	SON	3.6	-0.2	0.2
Wabush Lake	DJF	3.0	-0.4	0.2
	MAM	3.9	-0.1	0.2
	JJA	2.5	0.0	0.1
	SON	2.4	-0.1	0.1

Median Dry Spell Length (days)

Summary: Results show few noticeable changes in the length of dry spells under a warming climate. The only exception is northern Labrador in winter, which sees more frequent precipitation (typical dry spell length decreases by about 1-2 days).

Similar to the mean dry spell length, but giving the median (rather than mean) number of days between precipitation events. Changes are inconsequential, with only northern Labrador experiencing any statistically significant change (a decrease of 1-2 days in winter).

Figure 37: Changes in the median dry spell length projected for 2038-2070. Significant changes are indicated by cross-hatching.

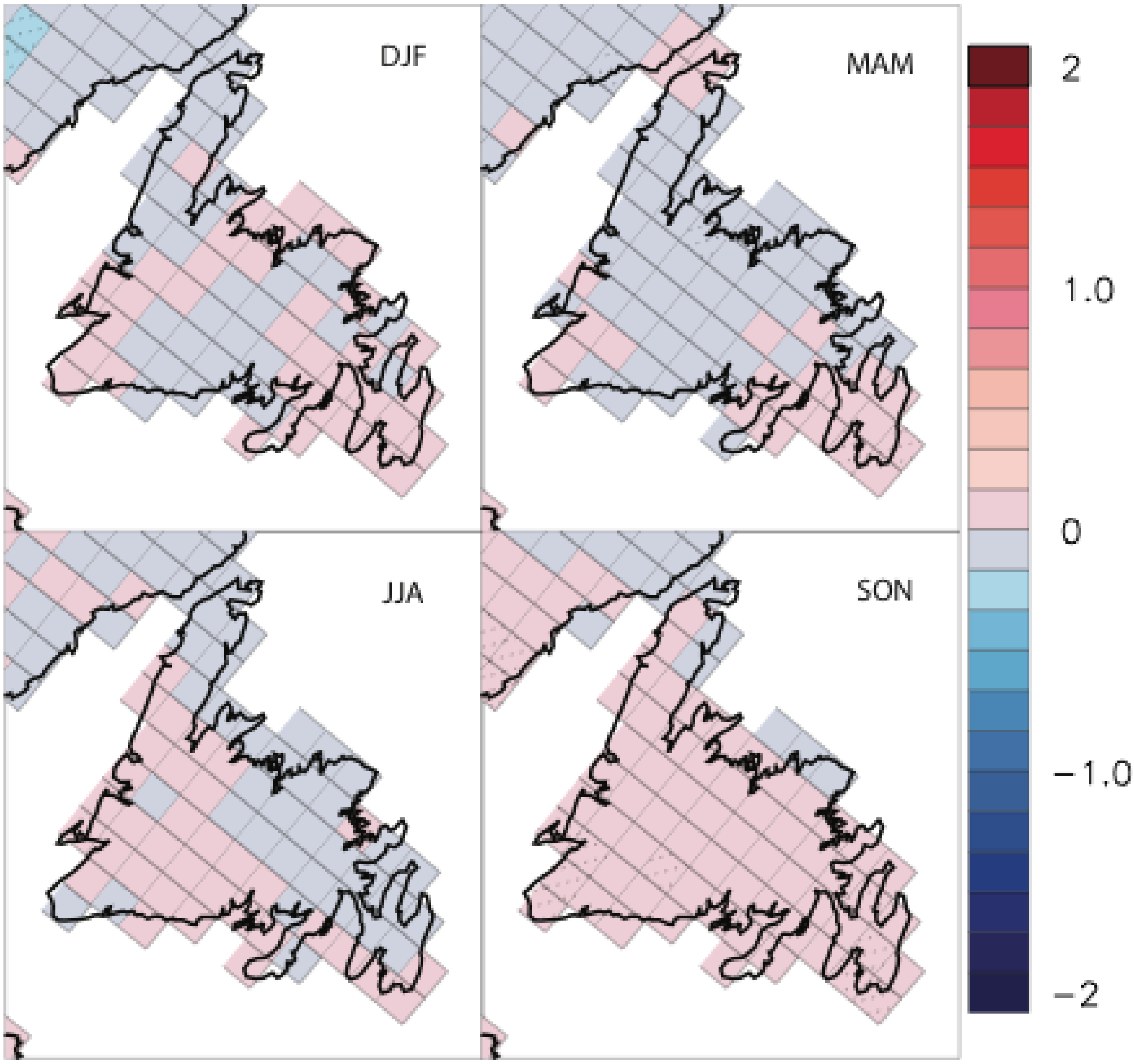

Table 37: Median dry spell length; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	2.0	0.0	0.2
	MAM	2.3	0.0	0.1
	JJA	2.4	0.0	0.1
	SON	2.1	0.0	0.1
Corner Brook	DJF	1.6	0.0	0.2
	MAM	2.3	0.0	0.1
	JJA	2.4	0.0	0.1
	SON	1.9	0.1	0.1
Daniel's Harbour	DJF	1.7	0.0	0.2
	MAM	2.4	-0.1	0.1
	JJA	2.3	0.0	0.1
	SON	1.9	0.1	0.1
Deer Lake	DJF	2.8	0.0	0.2
	MAM	2.6	-0.1	0.1
	JJA	2.3	0.0	0.1
	SON	2.2	0.1	0.2
Exploits Dam	DJF	2.1	0.0	0.2
	MAM	2.4	0.0	0.2
	JJA	2.3	0.0	0.1
	SON	2.2	0.0	0.1
Gander	DJF	1.6	0.0	0.1
	MAM	2.0	0.0	0.2
	JJA	2.2	0.0	0.1
	SON	2.0	0.0	0.1
Grand Falls	DJF	2.2	0.0	0.2
	MAM	2.5	0.0	0.1
	JJA	2.4	0.0	0.2
	SON	2.3	0.1	0.1
Plum Point	DJF	1.5	0.0	0.2
	MAM	2.1	0.0	0.1
	JJA	2.1	0.0	0.1
	SON	1.8	0.0	0.1
St. Anthony	DJF	2.0	0.0	0.3
	MAM	2.5	0.0	0.1
	JJA	2.4	-0.1	0.1
	SON	2.2	0.0	0.1
St. John's	DJF	1.4	0.0	0.2
	MAM	1.9	0.1	0.1
	JJA	2.5	0.0	0.1
	SON	1.9	0.1	0.1
Stephenville	DJF	1.4	0.0	0.3
	MAM	2.3	0.0	0.1
	JJA	2.3	0.1	0.1
	SON	1.9	0.1	0.1

Figure 38: Changes in the median dry spell length projected for 2038-2070. Significant changes are indicated by cross-hatching.

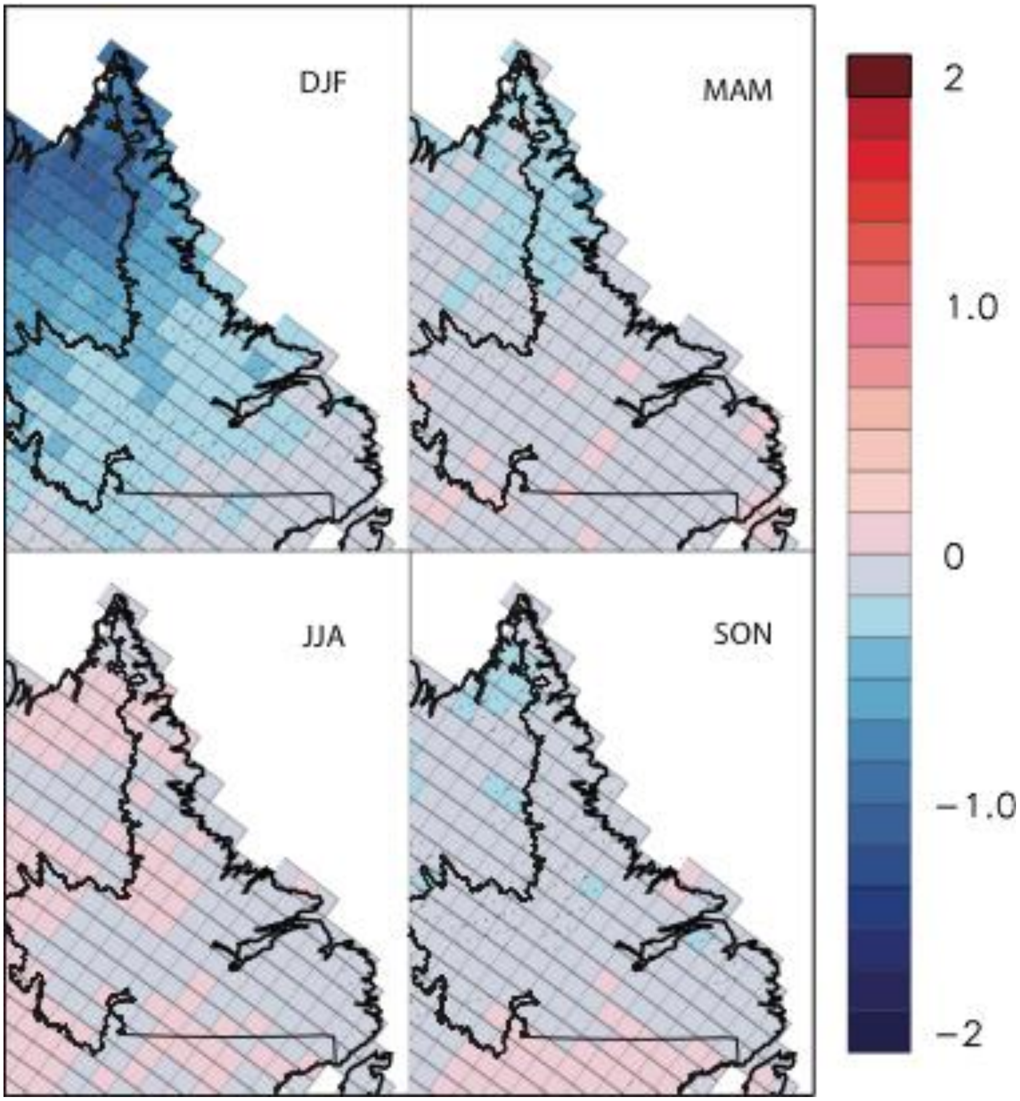

Table 38: Median dry spell length; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	2.5	-0.2	0.2
	MAM	2.4	-0.1	0.1
	JJA	2.2	0.0	0.1
	SON	2.2	-0.1	0.1
Churchill Falls	DJF	2.5	-0.3	0.2
	MAM	2.5	-0.1	0.1
	JJA	1.9	-0.1	0.1
	SON	1.8	-0.1	0.1
Goose Bay	DJF	2.6	-0.2	0.2
	MAM	2.7	-0.1	0.2
	JJA	2.1	0.0	0.1
	SON	2.5	0.0	0.2
Nain	DJF	3.6	-0.5	0.3
	MAM	3.5	-0.1	0.1
	JJA	2.5	0.0	0.1
	SON	2.8	-0.1	0.2
Wabush Lake	DJF	2.6	-0.3	0.2
	MAM	2.7	-0.1	0.2
	JJA	1.8	0.0	0.1
	SON	1.8	-0.1	0.1

Standard Deviation of Dry Spell Length (days)

Summary: Results show no noticeable change in range of expected dry spell lengths (variability in length) under a warming climate. Expected change is approximately 0 to 0.1 days.

Included to give context to the mean and median dry spell length; the standard deviation is a measure of variability (spread) around the mean. Higher values imply a wider range of dry spell length. Changes are inconsequential, with only northern Labrador experiencing any statistically significant change (a decrease of 1-2 days in winter; i.e. dry spells stay closer to the mean length in a warmer climate).

Figure 39: Changes in the standard deviation of dry spell length projected for 2038-2070. Significant changes are indicated by cross-hatching.

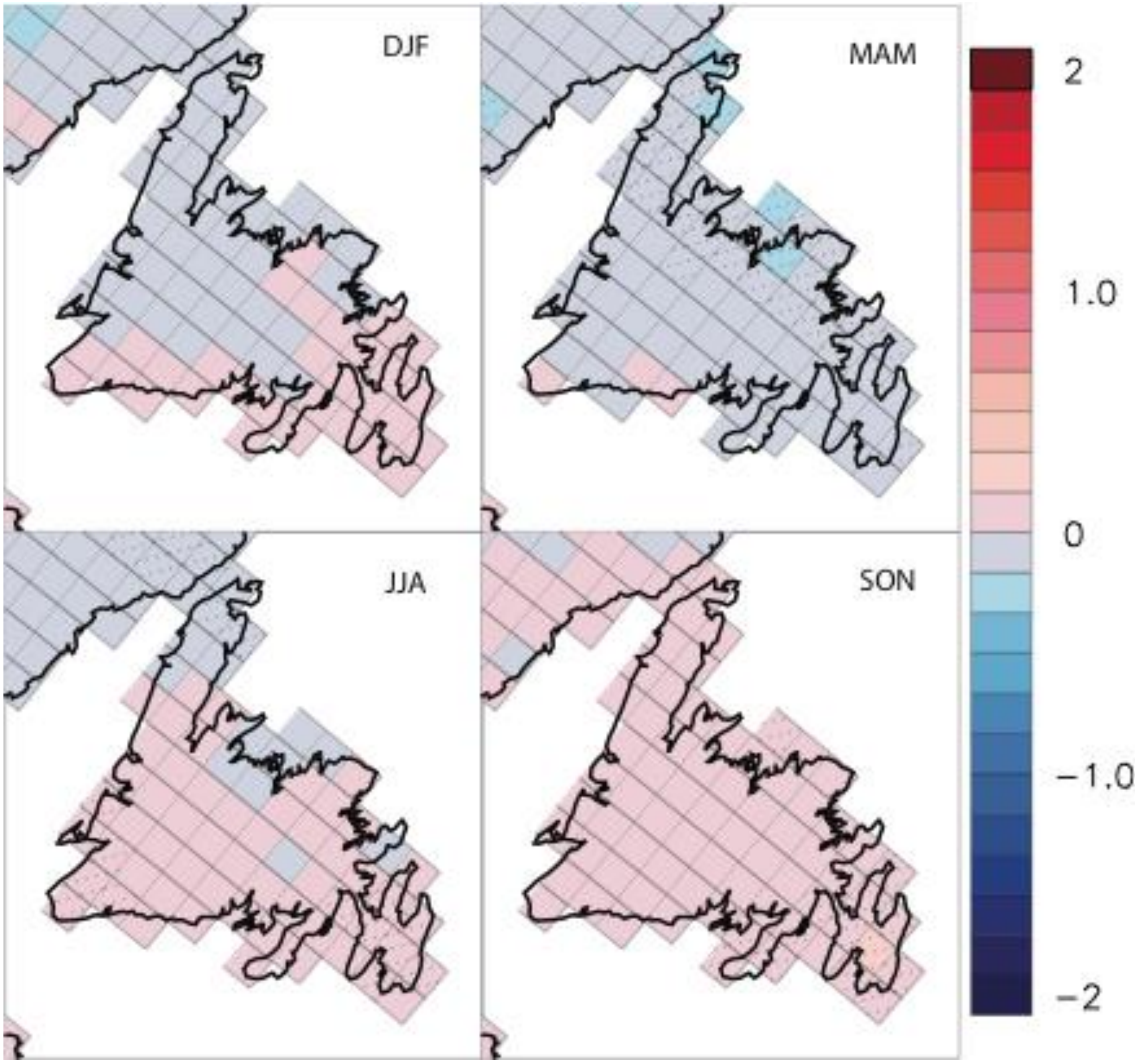

Table 39: Standard deviation of dry spell length; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Bay D'Espoir	DJF	1.9	0.0	0.2
	MAM	2.7	-0.1	0.1
	JJA	2.2	0.0	0.1
	SON	1.8	0.1	0.2
Corner Brook	DJF	1.5	0.0	0.2
	MAM	2.5	-0.1	0.1
	JJA	2.2	0.1	0.1
	SON	1.9	0.1	0.2
Daniel's Harbour	DJF	1.7	-0.1	0.2
	MAM	2.9	-0.1	0.1
	JJA	2.3	0.0	0.1
	SON	2.0	0.1	0.2
Deer Lake	DJF	1.9	0.0	0.2
	MAM	3.1	0.0	0.1
	JJA	2.4	0.1	0.1
	SON	2.1	0.1	0.2
Exploits Dam	DJF	2.2	0.0	0.2
	MAM	2.6	0.0	0.1
	JJA	2.2	0.0	0.1
	SON	1.9	0.1	0.2
Gander	DJF	1.5	0.0	0.2
	MAM	2.1	-0.1	0.1
	JJA	2.3	0.0	0.1
	SON	1.8	0.1	0.2
Grand Falls	DJF	2.3	0.0	0.1
	MAM	2.6	-0.1	0.1
	JJA	2.5	0.0	0.1
	SON	2.0	0.1	0.2
Plum Point	DJF	1.5	0.0	0.2
	MAM	2.5	-0.1	0.1
	JJA	2.1	-0.1	0.1
	SON	1.7	0.1	0.2
St. Anthony	DJF	2.0	-0.1	0.2
	MAM	2.8	-0.2	0.1
	JJA	2.4	-0.1	0.1
	SON	2.3	0.1	0.1
St. John's	DJF	1.2	0.0	0.2
	MAM	1.9	-0.1	0.1
	JJA	2.5	0.1	0.0
	SON	1.8	0.1	0.1
Stephenville	DJF	1.5	0.0	0.2
	MAM	2.7	0.0	0.1
	JJA	2.4	0.1	0.1
	SON	1.7	0.1	0.2

Figure 40: Changes in the standard deviation of dry spell length projected for 2038-2070. Significant changes are indicated by cross-hatching.

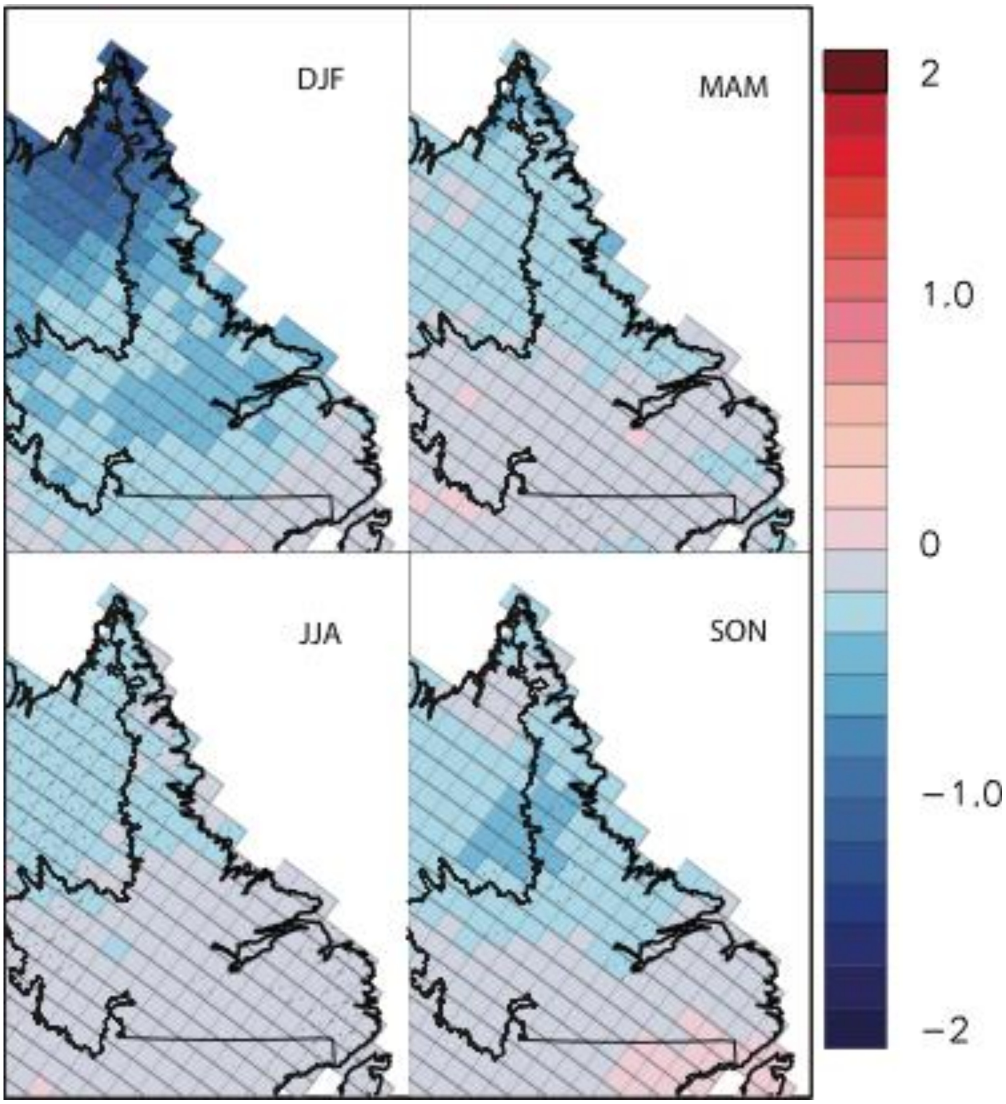

Table 40: Standard deviation of dry spell length; climatology and projected change.

		20th Century Mean	Projected Change	Ensemble Uncertainty
Cartwright	DJF	2.3	-0.2	0.4
	MAM	2.8	-0.1	0.1
	JJA	2.1	-0.2	0.1
	SON	2.3	-0.1	0.2
Churchill Falls	DJF	2.6	-0.4	0.4
	MAM	3.0	0.0	0.2
	JJA	2.0	-0.2	0.2
	SON	1.8	-0.1	0.2
Goose Bay	DJF	2.9	-0.4	0.3
	MAM	3.6	0.0	0.2
	JJA	2.1	-0.1	0.1
	SON	2.5	-0.2	0.2
Nain	DJF	3.8	-0.4	0.5
	MAM	4.2	-0.3	0.3
	JJA	2.9	-0.1	0.2
	SON	2.9	-0.3	0.3
Wabush Lake	DJF	2.3	-0.3	0.3
	MAM	3.5	-0.1	0.2
	JJA	2.0	-0.1	0.1
	SON	1.8	-0.1	0.2

Extreme Precipitation: Return periods

The frequency and intensity of natural hazards are often reported as return periods, or recurrence intervals, which provide an estimate of the time between events of a given magnitude. For example, events meeting or exceeding a 100 year event can be expected roughly once a century. It is important to note, however, that the specified interval is rarely met in the real world. For example, it is possible, though unlikely, to see the 100 year event exceeded twice in two consecutive years. A better interpretation of the return period is as a *probability*; a 10 year return period has a 1 in 10 chance of occurring in a given year, a 20 year has a 1 in 20 chance, and so on. This emphasizes the fact that, in the absence of some change in the probability distribution, every year has the same chance of seeing a 100 year event.

Return periods are used to describe extreme precipitation by engineers and planners, who often design structures, drainage systems, and transportation networks to withstand events with a specific return period. Design criteria derived from return period events are typically based on historical observations. This approach assumes that the precipitation probabilities will not change significantly during the lifetime of the structure or infrastructure being designed. Climate change violates this assumption, leading to potential under-design problems. However, although engineering guidelines may need to be re-evaluated in the context of climate change, estimating future return periods is a much more difficult problem than estimating changes in mean temperature or precipitation. Regional models can provide guidance in this regard, but it is necessary to interpret results with caution. This is particularly true for longer return period estimates, as uncertainty increases as the probability of an event decreases. Similarly, uncertainty increases as the period of record decreases; e.g. estimating the 100 year event from ~30 years is problematic, yet often done. For example, many IDF curves for Canadian locations are based on 10-15 years (e.g. La Scie, St. Albans, and Nain, among other Newfoundland & Labrador examples).

The following numbers were extrapolated from available observations (Environment Canada IDF curves and the AHCCD) and climate simulations from NARCCAP, using the same approach employed by Environment Canada (EC) for their official IDF curves. In this approach, return periods are given by a Gumbel probability distribution, or type I extreme value distribution. This distribution is commonly used in hydrology and precipitation analysis, and depends on two parameters: location (μ) and scale (β). Following EC practices, these were estimated using the method of moments, where:

$$\tilde{\beta} = \frac{s\sqrt{6}}{\pi}$$

$$\tilde{\mu} = \overline{X} - 0.5772\tilde{\beta}$$

where ~ denotes an estimate of the true value, *s* is the sample standard deviation, and $\overline{X}$ is the sample mean. Other methods have been proposed for estimating these parameters, and some appear to give improved results[18]; however, to maximize compatibility with the official EC curves familiar to most users, the method of moments will be used.

Distributions are fit to time series of annual maximum precipitation within a specified duration; distributions are fit individually to each duration examined (6, 12, and 24 hour durations for the current study). Once fit, the resulting cumulative density function is then used to find events associated with selected probabilities; i.e., the 100 year event would have a 1/100 probability of being exceeded, the 50 year event a 1/50 year probability, etc.

It is important to note that extreme precipitation changes in response to climate change should not be interpreted directly from GCM or RCM output, without first examining the output for biases and considering means of correcting these biases. Models have a tendency to underestimate extreme events, due to a) an inability to accurately replicate small-scale physics responsible for the most intense precipitation events and b) the need to distribute precipitation evenly over a grid cell. Cursory comparison of NARCCAP members with available observations indicate the models do not replicate observed statistics NL well under a modern climate; however, as a group they suggest events should become more extreme under a warming climate.

The results presented below represent an estimate of bias-corrected IDF values for the 2038-2070 projection period, based on the assumption that the models capture *changes* in Gumbel distribution parameters reasonably well, even if the estimates of the true value of these parameters under the current climate are flawed. For each model, Gumbel distributions were fit to the 1968-2000 simulation and 2048-2070 projection at grid cells collocated with operational climate stations. The change in location and scale parameters between these periods was calculated, and this change was then applied to scale and shape parameters estimated from the climate station observations. Return period events were then extracted from this 'climate perturbed' distribution. The approach removes the 20th century bias in the model, to focus entirely on simulated changes. Uncertainty in the results remains high, however, and these numbers should only be considered a rough guideline.

Results are provided for a) 6, 12, and 24 hour durations for stations with an IDF curve provided by EC, and b) 24 hour durations for precipitation-reporting stations from the AHCCD archive.

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[18] Martins & Stedinger, 2000.

Figures 41-43 provide an example of the results, focusing on the 24 hour duration 100 year event for all AHCCD precipitation-recording locations in the province. Black columns indicate the current climatological value; that is, the values commonly used in planning. White columns give the corrected NARCCAP ensemble mean projection for 2038-2070, with error bars indicating the range demonstrated by the individual ensemble members (projected minimum through to projected maximum). True change is likely to fall somewhere between these error bars.

The magnitude of the climatological 100 year event varies considerably across the province (67.9mm in Wabush to ~ 160mm in St. John's and North Harbour). Similarly, the magnitude of expected change varies considerably, both between locations and individual models. In general, the ensemble suggests an increase of 5-15mm of precipitation can be expected by the middle of the 21st century. However, because extreme precipitation analysis can be very sensitive to one or two large events, the models show considerable disagreement. In general, the 'worst-case' model predicts increases ~20-50mm of additional precipitation. The 'best-case' models most often show an increase of 5-15mm, although some suggest a weak decrease in intensity (usually a few mm, although Mary's Harbour and St. Anthony show decreases ~10-20mm). It is important to note that no single model consistently predicts a decrease in extreme precipitation, and rarely do multiple models predict decreases for the same location. Rather than truly indicating a potential decrease, the low projected minima reflect the fact that a) the periods of simulation (1968-2000; 2038-2070) and observation (variable; >100 years to < 30 years depending on the station) are relatively short, and b) we are considering rare events. This is a problem familiar to engineers and hydrologists; it is difficult to estimate the 100 year event from only 30 years of information. If longer simulation periods were available, results suggest projected decreases would disappear and the ensemble mean would shift towards the projected maximum change.

Figure 41: Climatology (black) and projected 2038-2070 (white) precipitation for the 24 hour duration 100-year event. Lines indicated the NARCCAP ensemble spread in projected change across the seven model ensemble examined.

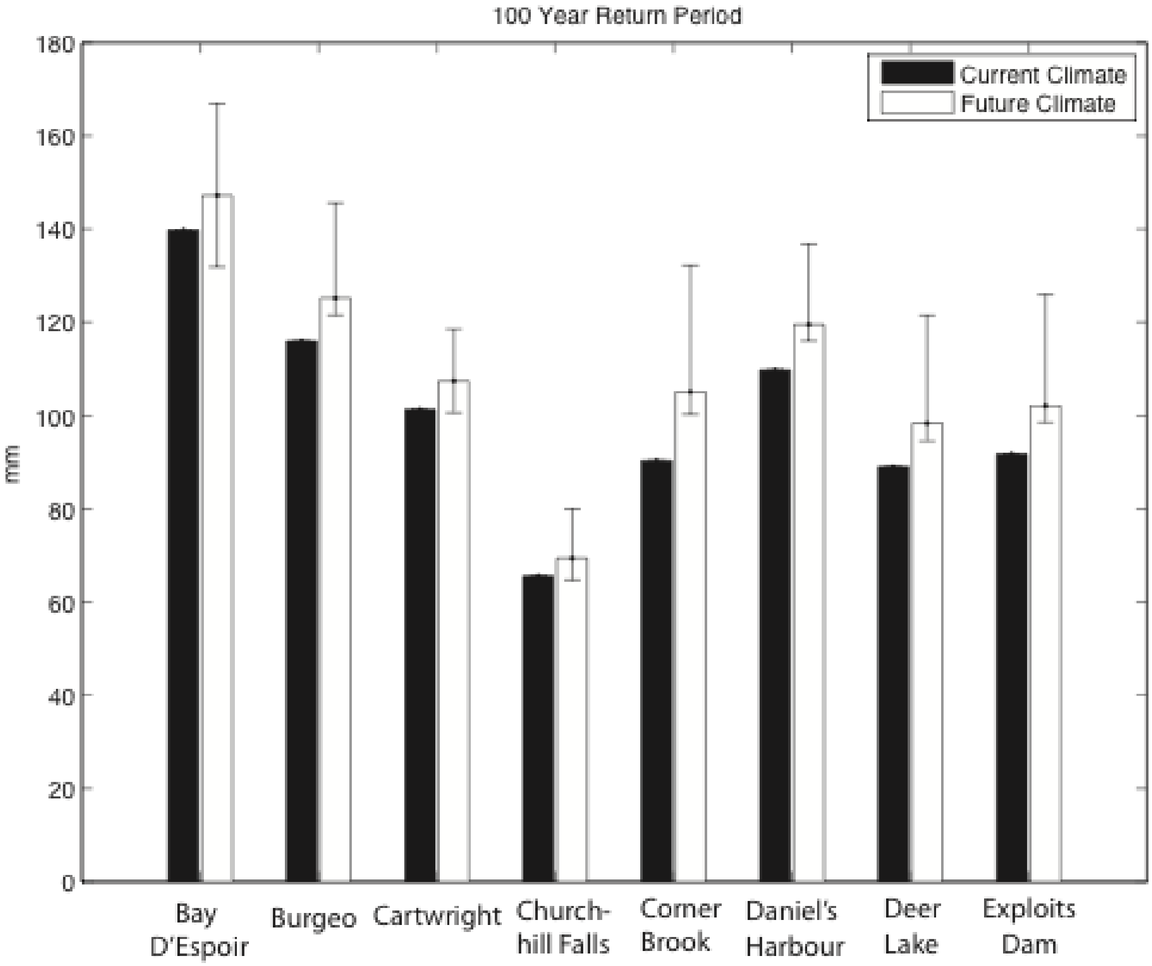


Figure 42: Climatology (black) and projected 2038-2070 (white) precipitation for the 24 hour duration 100-year event. Lines indicated the NARCCAP ensemble spread in projected change across the seven model ensemble examined.

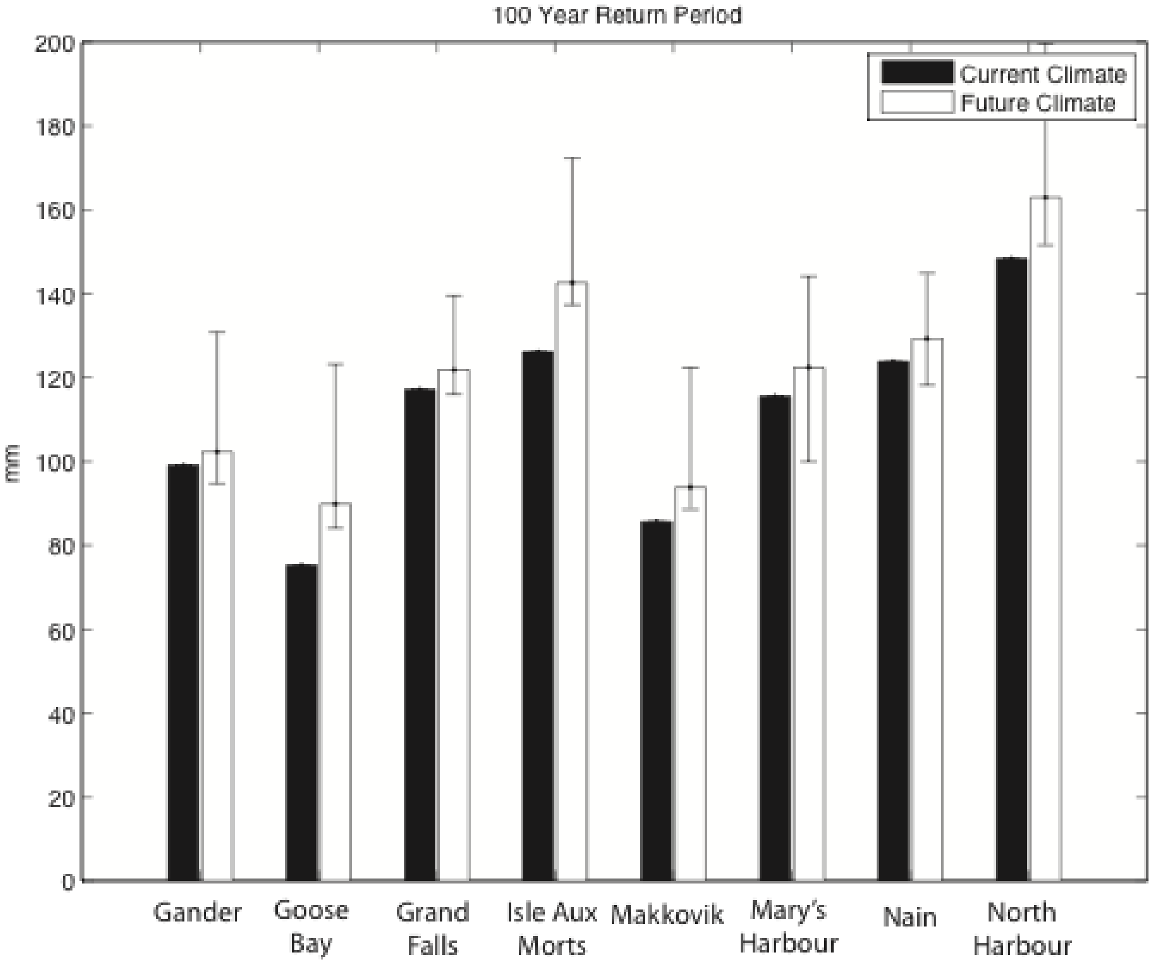
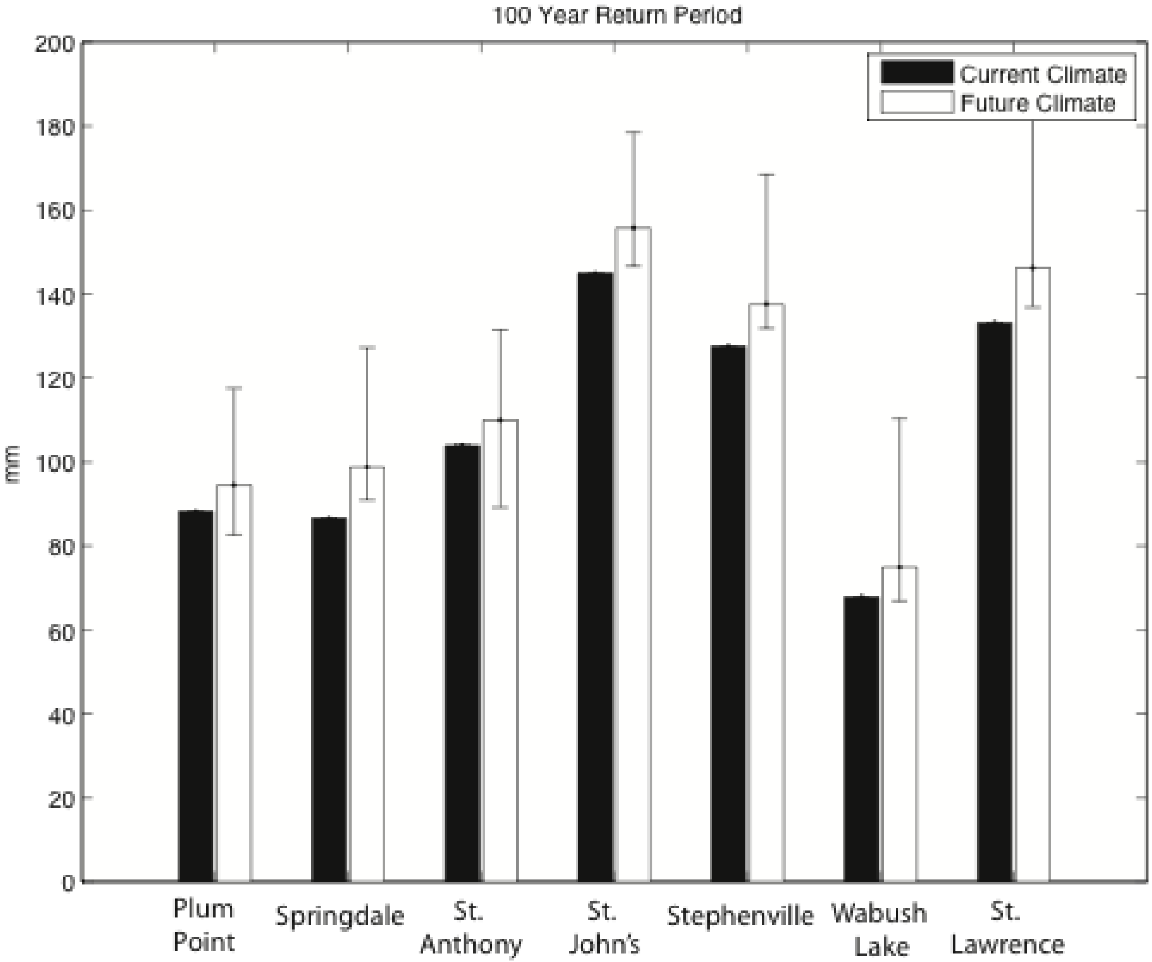


Figure 43: Climatology (black) and projected 2038-2070 (white) precipitation for the 24 hour duration 100-year event. Lines indicated the NARCCAP ensemble spread in projected change across the seven model ensemble examined.



IDF-Derived Results

24 Hour Duration

Table 41: Return period climatology and projections, for 24 hour duration event.

		2yr	5yr	20yr	25yr	50yr	100yr
Argentia	Current Climate	68.5	106.4	155.5	163.1	186.7	210.0
	Projected Mean	76.6	115.8	166.5	174.4	198.7	222.7
	Projected Max	83.0	127.1	184.2	193.1	220.4	247.6
	Projected Min	69.2	103.8	148.8	155.8	177.3	198.6
Burgeo	Current Climate	72.1	85.6	103.2	106.0	114.4	122.8
	Projected Mean	77.3	92.3	111.8	114.8	124.1	133.3
	Projected Max	82.7	98.5	122.8	126.7	138.9	151.0
	Projected Min	72.9	85.6	101.5	103.9	111.5	119.0
Comfort Cove	Current Climate	44.9	57.3	73.4	75.9	83.7	91.3
	Projected Mean	48.6	61.1	77.3	79.9	87.6	95.4
	Projected Max	54.1	70.8	92.5	95.8	106.2	116.5
	Projected Min	44.4	50.8	59.1	60.4	64.4	68.4
Daniel's Harbour	Current Climate	54.2	76.9	106.3	110.8	124.9	138.9
	Projected Mean	59.6	83.6	114.7	119.6	134.5	149.2
	Projected Max	65.6	91.2	124.4	129.6	145.4	161.2
	Projected Min	53.7	75.6	104.0	108.4	122.0	135.5
Deer Lake	Current Climate	42.9	51.9	63.5	65.3	70.9	76.4
	Projected Mean	47.4	57.2	69.9	71.8	77.9	83.9
	Projected Max	50.4	59.8	72.3	74.4	81.1	87.7
	Projected Min	45.7	54.4	63.0	64.3	68.4	72.5
Gander	Current Climate	46.3	60.2	78.1	80.9	89.5	98.1
	Projected Mean	50.0	64.0	82.2	85.0	93.7	102.4
	Projected Max	56.4	75.2	99.5	103.3	115.0	126.5
	Projected Min	44.4	53.0	64.2	65.9	71.3	76.6
La Scie	Current Climate	51.6	63.3	78.6	80.9	88.2	95.5
	Projected Mean	56.4	69.9	87.3	90.1	98.4	106.7
	Projected Max	61.3	77.0	98.5	101.8	112.1	122.3
	Projected Min	50.7	63.2	76.8	78.9	85.3	91.6
Port Aux Basque	Current Climate	71.5	91.1	116.7	120.6	132.8	144.9
	Projected Mean	78.5	99.7	127.2	131.4	144.6	157.6
	Projected Max	81.5	103.9	136.0	141.1	156.5	171.8
	Projected Min	75.7	96.1	121.8	125.7	138.0	150.2
St. Alban's	Current Climate	83.3	109.9	144.4	149.8	166.2	182.6
	Projected Mean	89.9	118.9	156.7	162.5	180.6	198.5
	Projected Max	96.3	128.5	170.1	176.6	196.6	216.4
	Projected Min	83.8	111.3	141.3	146.0	160.3	174.6
St. Anthony	Current Climate	51.0	63.3	79.2	81.6	89.2	96.8
	Projected Mean	55.1	68.4	85.7	88.4	96.6	104.8
	Projected Max	58.5	75.6	97.7	101.2	111.8	122.3
	Projected Min	51.0	60.0	71.6	73.5	79.0	84.6
St. John's	Current Climate	62.0	75.0	91.9	94.5	102.6	110.6
	Projected Mean	68.9	83.6	102.6	105.5	114.6	123.7
	Projected Max	74.5	92.4	115.5	119.1	130.2	141.2
	Projected Min	62.5	73.0	86.5	88.6	95.1	101.5

Table 41, Continued

		2yr	5yr	20yr	25yr	50yr	100yr
St. Lawrence	Current Climate	71.2	87.9	109.6	113.0	123.4	133.7
	Projected Mean	77.8	95.7	118.9	122.5	133.7	144.7
	Projected Max	88.7	111.1	140.1	144.6	158.5	172.3
	Projected Min	71.5	81.7	95.0	97.0	103.4	109.7
Stephenville	Current Climate	59.0	79.0	104.8	108.9	121.3	133.5
	Projected Mean	64.6	84.8	110.9	115.0	127.5	139.9
	Projected Max	69.0	94.6	127.7	132.8	148.6	164.4
	Projected Min	60.6	71.5	85.7	87.9	94.7	101.5
Battle Harbour	Current Climate	44.7	55.8	70.2	72.5	79.4	86.2
	Projected Mean	48.9	61.6	78.0	80.6	88.4	96.2
	Projected Max	54.8	68.1	87.4	90.7	100.5	110.4
	Projected Min	45.0	54.9	66.6	68.5	74.1	79.7
Churchill Falls	Current Climate	34.9	42.6	52.8	54.3	59.2	64.0
	Projected Mean	38.7	48.2	60.5	62.4	68.3	74.2
	Projected Max	41.0	52.6	68.6	71.1	78.8	86.4
	Projected Min	34.0	41.3	50.7	52.2	56.7	61.2
Goose Bay	Current Climate	40.6	51.5	65.6	67.8	74.5	81.2
	Projected Mean	46.1	59.7	77.4	80.1	88.5	96.9
	Projected Max	51.9	68.7	90.4	93.8	104.2	114.6
	Projected Min	42.7	54.1	67.9	70.0	76.6	83.1
Mary's Harbour	Current Climate	39.7	53.6	71.7	74.5	83.1	91.7
	Projected Mean	43.2	58.1	77.5	80.5	89.8	99.0
	Projected Max	49.8	65.8	88.9	92.6	104.3	115.8
	Projected Min	36.2	45.0	56.5	58.3	63.8	69.3
Nain	Current Climate	41.6	51.2	63.7	65.6	71.6	77.5
	Projected Mean	44.2	54.7	68.3	70.4	76.9	83.3
	Projected Max	48.6	59.9	75.4	78.0	86.2	94.3
	Projected Min	40.6	46.0	53.0	54.1	57.4	60.8
Wabush Lake	Current Climate	34.3	43.1	54.4	56.2	61.6	67.0
	Projected Mean	37.1	46.7	59.1	61.0	67.0	72.9
	Projected Max	45.2	60.5	80.4	83.5	93.0	102.4
	Projected Min	32.9	40.0	49.3	50.7	55.1	59.5

12 Hour Duration

Table 42: Return period climatology and projections, for 12 hour duration events.

		2yr	5yr	20yr	25yr	50yr	100yr
Argentia	Current Climate	56.2	94.3	143.6	151.3	174.9	198.3
	Projected Mean	62.7	102.3	153.6	161.5	186.1	210.4
	Projected Max	66.6	108.8	163.5	172.0	198.1	224.1
	Projected Min	57.1	93.5	138.0	144.8	165.9	186.9
Burgeo	Current Climate	60.2	71.2	85.4	87.6	94.5	101.2
	Projected Mean	63.9	74.8	89.0	91.2	98.0	104.8
	Projected Max	66.8	78.0	93.6	96.0	103.5	110.8
	Projected Min	58.9	68.0	79.7	81.5	87.1	92.7
Comfort Cove	Current Climate	37.3	48.4	62.7	65.0	71.8	78.6
	Projected Mean	41.7	53.3	68.3	70.6	77.8	84.9
	Projected Max	44.2	58.5	77.1	80.0	88.9	97.7
	Projected Min	39.2	48.6	60.0	61.7	66.9	72.0
Daniel's Harbour	Current Climate	42.3	56.9	75.8	78.8	87.8	96.8
	Projected Mean	47.0	61.8	81.1	84.1	93.3	102.4
	Projected Max	52.9	69.2	90.4	93.7	103.8	113.8
	Projected Min	40.7	53.9	70.9	73.6	81.8	89.9
Deer Lake	Current Climate	36.9	44.7	54.8	56.3	61.2	65.9
	Projected Mean	42.1	50.5	61.5	63.2	68.4	73.6
	Projected Max	47.1	54.9	66.5	68.6	74.8	81.1
	Projected Min	39.2	47.8	57.2	58.7	63.1	67.5
Gander	Current Climate	38.4	48.4	61.4	63.4	69.7	75.8
	Projected Mean	43.3	54.7	69.5	71.8	78.9	86.0
	Projected Max	47.1	61.2	79.6	82.5	91.2	100.0
	Projected Min	38.7	47.4	58.8	60.6	66.0	71.4
La Scie	Current Climate	40.2	52.0	67.4	69.8	77.1	84.4
	Projected Mean	45.6	59.5	77.5	80.3	88.9	97.4
	Projected Max	50.6	67.3	89.0	92.4	102.8	113.1
	Projected Min	40.4	53.2	67.6	69.8	76.3	82.8
Port Aux Basque	Current Climate	57.8	73.2	93.0	96.1	105.6	115.1
	Projected Mean	62.6	79.3	101.1	104.5	114.9	125.2
	Projected Max	67.2	85.7	109.7	113.4	124.9	136.3
	Projected Min	60.4	75.9	95.6	98.7	108.1	117.4
St. Alban's	Current Climate	65.0	78.6	96.2	98.9	107.3	115.7
	Projected Mean	69.8	84.2	102.9	105.8	114.8	123.7
	Projected Max	74.4	92.0	114.8	118.3	129.3	140.1
	Projected Min	64.6	76.1	88.0	89.8	95.5	101.2
St. Anthony	Current Climate	40.3	48.1	58.3	59.9	64.8	69.6
	Projected Mean	43.9	52.7	64.1	65.9	71.4	76.8
	Projected Max	46.8	56.3	70.2	72.4	79.2	86.0
	Projected Min	40.7	46.9	54.9	56.1	59.9	63.8
St. John's	Current Climate	52.2	63.5	78.2	80.5	87.6	94.5
	Projected Mean	57.4	69.6	85.4	87.8	95.4	102.9
	Projected Max	63.3	78.9	99.2	102.4	112.1	121.8
	Projected Min	53.8	61.6	71.3	72.8	77.4	82.0

Table 42, continued

		2yr	5yr	20yr	25yr	50yr	100yr
St. Lawrence	Current Climate	62.3	76.1	93.9	96.7	105.3	113.7
	Projected Mean	68.1	82.5	101.1	104.0	113.0	121.8
	Projected Max	75.1	94.8	120.4	124.3	136.6	148.7
	Projected Min	61.3	74.0	88.0	90.1	96.4	102.7
Stephenville	Current Climate	46.9	61.4	80.1	83.0	92.0	100.9
	Projected Mean	51.3	65.8	84.7	87.6	96.6	105.5
	Projected Max	55.4	73.6	97.3	101.0	112.3	123.5
	Projected Min	47.8	53.4	60.7	61.8	65.3	68.8
Battle Harbour	Current Climate	35.4	42.4	51.6	53.0	57.3	61.7
	Projected Mean	38.7	46.1	55.7	57.2	61.7	66.3
	Projected Max	44.2	53.5	65.7	67.8	74.2	80.6
	Projected Min	33.7	39.0	45.9	46.9	50.2	53.5
Churchill Falls	Current Climate	27.6	34.8	44.2	45.6	50.1	54.5
	Projected Mean	31.4	40.0	51.2	53.0	58.3	63.6
	Projected Max	35.0	45.6	61.0	63.4	70.7	78.1
	Projected Min	26.8	33.1	41.3	42.6	46.5	50.3
Goose Bay	Current Climate	32.1	40.5	51.3	53.0	58.1	63.3
	Projected Mean	36.0	46.0	59.0	61.0	67.2	73.3
	Projected Max	40.7	54.3	71.9	74.7	83.1	91.5
	Projected Min	33.1	42.4	53.6	55.2	60.2	65.2
Mary's Harbour	Current Climate	32.1	40.5	51.4	53.1	58.3	63.5
	Projected Mean	35.1	43.6	54.6	56.4	61.6	66.9
	Projected Max	40.9	51.6	65.6	68.0	75.2	82.4
	Projected Min	30.5	37.1	45.8	47.1	51.2	55.3
Nain	Current Climate	33.8	42.0	52.6	54.3	59.3	64.4
	Projected Mean	36.8	46.4	58.9	60.8	66.8	72.7
	Projected Max	42.4	55.9	73.4	76.1	84.5	92.8
	Projected Min	33.9	41.9	50.5	51.8	55.9	60.0
Wabush Lake	Current Climate	27.6	34.5	43.3	44.7	49.0	53.2
	Projected Mean	30.7	38.6	49.0	50.6	55.5	60.4
	Projected Max	36.3	48.0	63.1	65.5	72.7	79.9
	Projected Min	26.5	32.7	40.4	41.5	44.9	48.3

6 Hour Duration

Table 43: Return period climatology and projections, for 6 hour duration events.

		2yr	5yr	20yr	25yr	50yr	100yr
Argentia	Current Climate	43.6	72.0	108.8	114.5	132.2	149.6
	Projected Mean	48.7	78.2	116.4	122.4	140.7	158.9
	Projected Max	52.6	85.9	129.1	135.8	156.5	177.0
	Projected Min	43.7	70.9	106.3	111.8	128.7	145.5
Burgeo	Current Climate	46.8	56.5	69.0	71.0	77.0	82.9
	Projected Mean	49.8	60.0	73.2	75.2	81.5	87.8
	Projected Max	52.6	64.1	78.9	81.2	88.3	95.3
	Projected Min	46.0	53.8	63.9	65.4	70.3	75.1
Comfort Cove	Current Climate	29.4	38.7	50.9	52.8	58.6	64.3
	Projected Mean	33.3	43.4	56.5	58.5	64.7	70.9
	Projected Max	37.1	49.8	66.2	68.8	76.6	84.4
	Projected Min	31.8	41.2	53.5	55.4	61.2	66.9
Daniel's Harbour	Current Climate	32.4	41.9	54.3	56.2	62.2	68.1
	Projected Mean	36.0	45.9	58.9	60.9	67.1	73.2
	Projected Max	40.7	51.6	65.6	67.8	74.5	81.2
	Projected Min	32.0	40.8	52.3	54.0	59.5	65.0
Deer Lake	Current Climate	29.7	36.4	45.0	46.4	50.5	54.6
	Projected Mean	33.8	41.6	51.6	53.1	57.9	62.7
	Projected Max	35.3	44.0	55.8	57.6	63.2	68.9
	Projected Min	32.2	39.0	44.0	44.7	47.1	49.4
Gander	Current Climate	30.0	38.0	48.4	50.1	55.1	60.0
	Projected Mean	34.5	44.0	56.3	58.2	64.1	69.9
	Projected Max	37.0	49.6	66.0	68.5	76.3	84.1
	Projected Min	32.2	40.6	50.9	52.5	57.5	62.4
La Scie	Current Climate	27.1	35.7	47.0	48.7	54.1	59.4
	Projected Mean	31.4	41.5	54.6	56.7	62.9	69.2
	Projected Max	35.3	47.7	63.9	66.4	74.1	81.7
	Projected Min	27.4	36.3	48.0	49.8	55.3	60.9
Port Aux Basque	Current Climate	44.9	58.6	76.4	79.2	87.7	96.2
	Projected Mean	49.3	64.1	83.4	86.4	95.6	104.8
	Projected Max	55.2	69.9	89.0	92.0	101.1	110.5
	Projected Min	46.5	60.7	78.9	81.7	90.1	98.6
St. Alban's	Current Climate	47.6	53.4	61.0	62.1	65.7	69.3
	Projected Mean	51.6	58.5	67.5	68.9	73.2	77.5
	Projected Max	56.0	64.2	74.8	76.4	81.5	86.5
	Projected Min	48.6	54.9	62.3	63.3	66.6	69.8
St. Anthony	Current Climate	30.7	36.6	44.4	45.5	49.2	52.9
	Projected Mean	33.8	40.8	49.7	51.1	55.4	59.7
	Projected Max	35.8	44.3	55.2	57.0	62.2	67.4
	Projected Min	31.0	36.4	43.5	44.6	48.0	51.4
St. John's	Current Climate	40.9	51.0	64.0	66.1	72.3	78.5
	Projected Mean	45.2	55.7	69.3	71.4	78.0	84.4
	Projected Max	47.8	61.3	78.8	81.5	89.9	98.2
	Projected Min	41.4	50.7	60.8	62.3	67.2	72.0

Table 43, continued

		2yr	5yr	20yr	25yr	50yr	100yr
St. Lawrence	Current Climate	51.4	64.7	82.0	84.6	92.9	101.1
	Projected Mean	56.5	70.4	88.4	91.2	99.9	108.4
	Projected Max	61.4	78.2	99.9	103.2	113.6	123.9
	Projected Min	53.1	65.5	79.4	81.6	88.3	94.9
Stephenville	Current Climate	38.2	49.9	65.1	67.5	74.8	82.0
	Projected Mean	41.7	52.9	67.4	69.7	76.6	83.5
	Projected Max	43.5	56.7	73.8	76.5	84.7	92.8
	Projected Min	39.8	42.9	45.8	46.3	47.7	49.0
Battle Harbour	Current Climate	25.0	30.4	37.4	38.4	41.8	45.1
	Projected Mean	27.4	32.5	39.2	40.2	43.4	46.5
	Projected Max	30.9	36.8	44.5	45.7	49.4	53.1
	Projected Min	24.3	28.7	34.3	35.2	37.9	40.6
Churchill Falls	Current Climate	20.5	26.1	33.3	34.4	37.8	41.3
	Projected Mean	23.7	30.2	38.8	40.1	44.2	48.2
	Projected Max	26.8	35.3	46.4	48.1	53.4	58.8
	Projected Min	19.8	24.0	29.4	30.2	32.8	35.4
Goose Bay	Current Climate	24.0	31.1	40.3	41.7	46.1	50.5
	Projected Mean	27.0	35.6	46.8	48.5	53.8	59.2
	Projected Max	30.1	40.1	53.0	55.0	61.3	67.7
	Projected Min	25.3	32.3	41.1	42.5	46.7	50.8
Mary's Harbour	Current Climate	24.7	29.7	36.2	37.2	40.3	43.4
	Projected Mean	26.8	31.4	37.4	38.3	41.1	44.0
	Projected Max	30.5	36.1	43.4	44.5	47.9	51.4
	Projected Min	24.0	28.0	33.2	34.0	36.5	38.9
Nain	Current Climate	24.2	31.9	41.9	43.5	48.3	53.0
	Projected Mean	26.3	34.9	46.2	47.9	53.3	58.6
	Projected Max	30.8	41.7	55.8	58.0	64.8	71.5
	Projected Min	23.7	31.7	40.1	41.4	45.4	49.4
Wabush Lake	Current Climate	20.7	26.5	34.1	35.3	38.9	42.5
	Projected Mean	23.6	30.6	39.6	41.0	45.4	49.7
	Projected Max	27.7	37.1	49.3	51.2	57.1	62.9
	Projected Min	20.7	26.1	33.0	34.0	37.3	40.6

AHCCD-Derived Results

24-hour Duration

Table 44: Return period climatology and projections from AHCCD stations, for 24 hour duration events.

		2yr	5yr	20yr	25yr	50yr	100yr
Bay D'Espoir	Current Climate	72.6	90.6	114.0	117.6	128.8	139.8
	Projected Mean	76.3	95.3	119.9	123.7	135.5	147.2
	Projected Max	80.0	101.3	128.9	133.2	146.4	159.5
	Projected Min	70.7	86.8	104.7	107.4	116.0	124.5
Burgeo	Current Climate	68.0	80.9	97.6	100.2	108.1	116.1
	Projected Mean	73.0	87.0	105.1	107.9	116.6	125.2
	Projected Max	78.7	93.8	113.4	116.5	125.9	136.4
	Projected Min	68.9	80.9	95.8	98.1	105.3	112.3
Cartwright	Current Climate	48.0	62.3	80.8	83.7	92.5	101.3
	Projected Mean	51.1	66.2	85.8	88.8	98.2	107.5
	Projected Max	52.0	67.9	88.7	92.0	102.2	112.4
	Projected Min	49.5	61.5	77.1	79.6	87.0	94.5
Churchill Falls	Current Climate	36.5	44.3	54.4	55.9	60.8	65.6
	Projected Mean	39.5	47.5	57.9	59.5	64.5	69.4
	Projected Max	43.3	51.3	63.1	64.9	70.5	76.1
	Projected Min	35.1	42.0	51.0	52.4	56.7	60.9
Corner Brook	Current Climate	44.8	57.0	72.8	75.3	82.8	90.3
	Projected Mean	52.3	66.4	84.7	87.6	96.3	105.0
	Projected Max	57.5	70.2	92.6	96.1	106.8	117.5
	Projected Min	49.2	61.5	77.4	79.9	87.6	95.1
Daniel's Harbour	Current Climate	47.2	64.0	85.7	89.1	99.5	109.8
	Projected Mean	52.3	70.3	93.6	97.2	108.4	119.5
	Projected Max	56.4	74.8	99.0	102.9	114.9	127.1
	Projected Min	46.7	62.7	83.4	86.6	96.6	106.4
Deer Lake	Current Climate	46.1	57.6	72.5	74.8	82.0	89.0
	Projected Mean	51.0	63.6	80.1	82.7	90.5	98.4
	Projected Max	56.5	71.4	90.7	93.7	103.0	112.1
	Projected Min	48.8	60.1	72.0	73.8	79.5	85.2
Exploits Dam	Current Climate	49.9	61.1	75.7	77.9	84.9	91.8
	Projected Mean	55.2	67.8	84.0	86.6	94.4	102.1
	Projected Max	58.1	72.6	93.0	96.2	105.9	115.6
	Projected Min	52.0	61.7	74.2	76.2	82.2	88.2
Gander	Current Climate	52.8	65.2	81.3	83.8	91.5	99.1
	Projected Mean	56.2	68.6	84.6	87.1	94.7	102.3
	Projected Max	62.9	80.2	102.7	106.2	116.9	127.6
	Projected Min	51.8	63.3	77.4	79.4	85.5	91.4
Goose Bay	Current Climate	40.7	50.0	62.0	63.8	69.6	75.3
	Projected Mean	45.8	57.6	72.9	75.3	82.6	89.8
	Projected Max	52.0	67.2	86.8	89.9	99.3	108.6
	Projected Min	39.7	47.7	58.1	59.7	64.6	69.6

Table 44, continued

		2yr	5yr	20yr	25yr	50yr	100yr
Grand Falls	Current Climate	48.6	67.0	90.8	94.5	105.9	117.2
	Projected Mean	53.4	71.8	95.5	99.2	110.6	121.8
	Projected Max	55.8	76.9	104.4	108.7	121.8	134.9
	Projected Min	49.7	66.2	87.7	91.0	101.2	111.4
Isle Aux Morts	Current Climate	61.2	78.6	101.1	104.6	115.4	126.1
	Projected Mean	67.6	87.7	113.7	117.8	130.2	142.6
	Projected Max	69.7	91.9	121.9	126.7	141.3	155.8
	Projected Min	65.5	83.6	106.3	109.8	120.6	131.4
Makkovik	Current Climate	38.7	51.3	67.6	70.1	77.9	85.7
	Projected Mean	41.1	55.3	73.6	76.4	85.2	93.9
	Projected Max	47.5	65.3	88.5	92.1	103.1	114.1
	Projected Min	38.6	50.1	64.4	66.7	73.5	80.4
Mary's Harbour	Current Climate	45.2	64.0	88.5	92.3	104.0	115.6
	Projected Mean	48.5	68.3	94.0	97.9	110.2	122.4
	Projected Max	55.3	76.3	103.8	108.5	123.0	137.3
	Projected Min	41.7	55.5	73.3	76.1	84.7	93.1
Nain	Current Climate	52.0	71.2	96.2	100.1	112.0	123.8
	Projected Mean	54.6	74.6	100.6	104.6	117.0	129.3
	Projected Max	59.1	80.0	107.7	112.1	125.8	139.4
	Projected Min	51.6	68.2	89.3	92.6	102.7	112.7
North Harbour	Current Climate	72.6	92.9	119.2	123.3	135.9	148.4
	Projected Mean	79.6	101.9	130.8	135.3	149.2	162.9
	Projected Max	86.9	113.2	147.4	152.7	169.0	185.2
	Projected Min	73.3	90.3	112.5	115.9	126.5	137.0
Plum Point	Current Climate	47.1	58.2	72.4	74.6	81.5	88.2
	Projected Mean	51.5	63.0	77.9	80.3	87.4	94.5
	Projected Max	58.6	72.7	91.0	93.9	102.6	111.3
	Projected Min	45.6	53.9	64.6	66.2	71.3	76.4
Springdale	Current Climate	43.6	55.1	70.0	72.4	79.5	86.6
	Projected Mean	48.1	61.6	79.2	82.0	90.4	98.7
	Projected Max	52.9	69.1	90.9	94.3	104.7	115.0
	Projected Min	42.9	52.5	65.0	66.9	72.8	78.8
St. Anthony	Current Climate	41.2	58.0	79.8	83.2	93.6	103.9
	Projected Mean	44.8	62.2	84.8	88.3	99.2	109.9
	Projected Max	48.6	69.2	95.9	100.0	112.8	125.5
	Projected Min	37.8	49.9	65.7	68.1	75.7	83.2
St. John's	Current Climate	67.7	88.4	115.3	119.4	132.3	145.0
	Projected Mean	74.6	96.3	124.5	128.9	142.3	155.7
	Projected Max	80.1	103.6	134.0	138.8	153.3	167.8
	Projected Min	68.2	86.4	109.9	113.5	124.8	136.0

Table 44, continued

		2yr	5yr	20yr	25yr	50yr	100yr
Stephenville	Current Climate	46.7	68.4	96.5	100.8	114.2	127.6
	Projected Mean	52.5	75.3	104.8	109.4	123.6	137.6
	Projected Max	56.8	84.0	119.3	124.8	141.6	158.4
	Projected Min	49.8	70.9	95.0	98.8	110.3	121.8
Wabush Lake	Current Climate	37.1	45.3	56.0	57.7	62.8	67.9
	Projected Mean	40.1	49.4	61.5	63.4	69.2	74.9
	Projected Max	48.0	62.8	82.0	85.0	94.2	103.3
	Projected Min	35.4	42.0	50.4	51.8	55.8	59.9
St. Lawrence	Current Climate	62.4	81.4	106.0	109.8	121.5	133.2
	Projected Mean	69.2	89.8	116.6	120.7	133.5	146.2
	Projected Max	79.9	104.5	136.4	141.4	156.6	171.8
	Projected Min	63.4	80.0	100.8	104.1	114.0	123.9

Appendix A: Abbreviations Used

	Abbreviation	Full term
Background	AHCCD	Adjusted & Homogenized Canadian Climate Data
	CCEEET	Office of Climate Change, Energy Efficiency, and Emissions Trading
	EC	Environment Canada
	GCM	General Circulation Model
	IDF	Intensity-Duration-Frequency
	NARCCAP	North American Regional Climate Change Assesment Project
	NARR	North American Regional Reanalysis
	NL	Newfoundland & Labrador
	RCM	Regional Circulation Model
	REA	Reliability Ensemble Average
	STARDEX	Statistical and Regional Dynamical Downscaling of Extremes for European Regions
Study Periods	DJF	Winter (December-January-February)
	MAM	Spring (March-April-May)
	JJA	Summer (June-July-August)
	SON	Autumn (September-October-November)
	ANN	Annual

Appendix B: Glossary

Bias: Disagreement between a model and the system it is intended to represent. For example, a climate model with a 'warm bias' tends to overestimate temperatures relative to observed climatology.

Boundary forcing: Regional climate models mathematically represent weather within specific region of the Earth. In order to run, they require information about the edges (boundaries) of this region; this 'boundary forcing' information is typically supplied by general circulation model with global coverage at lower resolutions.

Cooling degree day (CDD): A measure of energy required to cool a building to comfortable levels. The actual energy needed will vary with building standards, energy source, and other factors. However, an increases in CDD translates into some increase in energy spending.

Downscaling: The process of extracting information relevant at small spatial scales (high resolution) from information available at large spatial scales (low resolution).

Dry Spell: A period without measurable precipitation.

Dynamical downscaling: The process of extracting high resolution information from low resolution forecasts through the use of high resolution model; usually a regional climate model.

Ensemble: A collection of model forecasts for a single period. By including multiple model runs, an ensemble provides a sense of forecast uncertainty: if the runs agree with one another, the ensemble average forecast is considered reliable; if they diverge, the forecast is less reliable. A multi-model ensemble is generated using runs from different models.

Frost day: A day in which the minimum daily temperature drops below the freezing point; i.e. a day when freezing occurs at some point.

General Circulation Model (GCM): A model that approximates circulation of the atmosphere and/or ocean, with global coverage. These are typically low resolution models (100s of km between grid points).

Greenhouse Effect: An increase in surface temperatures due to the presence of specific gases in the atmosphere. The addition of these 'greenhouse gases' to the atmosphere by human activity is the driver of human-induced climate change.

Growing degree day (GDD): A measure of heat accumulation, used to determine whether a given plant or insect species will thrive in a region. The energy needed for plants/insects to mature can be estimated in GDD; regions with lower GDD cannot support these species.

Heating degree day (HDD): A measure of energy required to heat a building to comfortable levels. The actual energy needed will vary with building standards, heat source, and other factors. However, an increases in HDD translates into some increase in heating costs.

Heat Wave: A period of prolonged temperatures well above normal. The definition used here is a period of at least six days, in which mean temperatures are consistently 5 ^{o}C above normal.

Intensity-duration-frequency curve: A tool used to estimate extreme precipitation events, based on how much precipitation falls (intensity) in a given period of time (duration), and how often events of a given magnitude occur (frequency).

Likelihood function: A measure of how probable a series of events are, given a probability distribution. Higher likelihood implies a better match to the probability distribution. For computational purposes, the negative log likelihood (NLL) function in used in place of the standard likelihood (L) function; minimizing NLL is equivalent to maximizing L.

Median: The value in a probability distribution that has a 50% chance of being exceeded.

Percentile: A probability distribution or a series of observations can be broken into percentiles, by identifying events that are exceeded with a specific frequency. For example, the 90th percentile marks the highest number of lowest 90% of events; it has a 10% of being exceeded. The 70th percentile marks the top of the lowest 75% of events; it has a 25% chance of being exceed.

Probability distribution: A description of the frequency with which different potential outcomes occur.

Radiosonde: A tool used for the measurement of temperature, moisture, and winds through the depth of the atmosphere, using an instrument package attached to a weather balloon.

Reanalysis: An atmospheric reanalysis is a ‘best guess’ estimate of the state of the atmosphere at a given point in time, generated by blending direct weather observations with weather forecast model output. It can be considered weather model output, corrected to match available observations.

Regional Climate Model (RCM): A model used provide a detailed representation of the atmosphere or ocean within s specific region of the planet. Typically run at much higher resolution than general circulation models (1-50km, typically).

Topographic: Relating to the topography, or shape of the Earth's surface. The slope, orientation, and altitude of the surface can have a strong influence on the climate of a given location.

Self-organizing map: A method of clustering (organizing) a large data set into a set of general patterns (or 'archetypal' patterns). The map organizes these patterns in ways that facilitate visual interpretation, and has become popular in climatology and meteorology applications.

Standard Deviation: A measure of the 'spread' in a probability distribution. In climatology, a greater standard deviation implies a more variable climate.

Synoptic: Relates to specific spatial (~1000km) and temporal (~a week) time scales in meteorology. Examples of synoptic weather systems include warm fronts, cold fronts, and the low pressure systems responsible for winter storms in Newfoundland and Labrador.

Synoptic climatology: A description of climate in terms of synoptic weather events. For example, a description of the typical number of low pressure systems that occur in a year.

Weather system: An interaction between air masses, winds, and/or pressure features. The passage of weather systems (such as low pressure systems) is responsible for the day-to-day fluctuations in weather at a location.

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