Research Article

One approach for downscaling climate change data towards regional implications in climate change scenarios: the case for Newfoundland and Labrador, Canada

Myron Robert King[1,2]

Received: 3 April 2020 / Accepted: 28 October 2020 / Published online: 21 November 2020

Abstract

Various global circulation models are now actively used to study climate change at a global level. For these models, tools are becoming more available to allow simplified handling and comparison of various climate change projection scenarios. A continuing goal of climate change researchers is to translate global circulation model data into more regionalized, locally meaningful analyses outcomes. This study details one simple geographical information systems (GIS) method of downscaling global climate change data that can allow greater regionalized climate change study involving several data variables. Key GIS processing methodology and programming techniques in generating local values are outlined. Results show that the eastern-most point of the continent of North America, the Canadian province of Newfoundland & Labrador could experience a nonlinear increase in seasonal temperature rise through the next 75 years. There is also considerable temperature variation at the regional level for climate change forecasts which could affect one locality's response versus another. The downscaling of available data allows distinct local-setting values for cities and towns to be estimated, providing a more solid forecast picture to both national and local officials about the local area. The methodology used to create this improved localized understanding of seasonal climate change impact could potentially be applied anywhere around the world to help local decision makers with the task of climate change planning. Finally, this study shows how different ways of framing the resulting data can further support a better understanding of climate change expectations for any audience.

Keywords Geographical information systems · Climate change · Climate change temperature modelling · Climate model down-scaling · Regional climate change assessment

Mathematics subject classification 58–08 · 58–11 · 58Z05

JEL classification Q54 · R11 · R58

✉ Myron Robert King, mking@grenfell.mun.ca | [1]Environmental Policy Institute, Memorial University of Newfoundland, Corner Brook, Canada. [2]Hull International Fisheries Institute, University of Hull, Hull, UK.

SN Applied Sciences (2020) 2:2039 | https://doi.org/10.1007/s42452-020-03776-x

1 Introduction

There are now many atmosphere and ocean-based general circulation models[1] (GCMs) worldwide, actively used to study changes in the atmosphere—'climate change' over certain time periods. Canada, the USA, Germany and a number of other countries have developed GCMs to study climate change. Often it is through the study of these GCMs, along with regional climate phenomena and greenhouse gas (GHG) emissions analysis, that scientists are actively recognizing the large-scale impacts of climate change [1]. Projections of changing climate through GCMs and modelling are directly linked to a growing body of evidence for temperature rise, precipitation frequency and intensification and more ocean-atmospheric phenomenon [2, 2], Solomon et al. 2007). The resulting awareness of what these future projections may yield in terms of climate change impacts for communities everywhere underscores the need for preparation.

The models involved to study climate change were created for and are largely dependent on global scale weather observations [4]. Such models seek patterns of fluctuation, temporal rising/falling and geographical dependencies in past and present climate observations and attempt to map out highly probable outcomes when combined with some form of contextual adjustment (e.g. if there is no change in GHG emissions). This approach of finding a pattern and then scaling the amount to be expected is referred to as pattern scaling [5]. It is a popular approach that is used considerably to help quantify the future global climatic picture. Often the exact magnitude of the scaled impact is set to a threshold value, and the pattern scaling approach then fine-tunes the atmospheric conditions around the globe that best represents it. For example, one popular major climate change scenario is to set the magnitude of greenhouse emissions induced global (average) temperature increase to 2 °C by 2050 [3]. The modelling then interprets this into global climatic variability based on climate pattern recognition. Druyan and Fulakeza [6] appear to improve climate change modelling for Africa by using downscaling to improve GCM projections over that country. Various degrees of complexity are evident in the various methodologies used to model climate change, with newer models now striving to use several GCM outputs simultaneously. Studies such as Chrysoulakis et al. [7] and Kusaka et al. [8] take advantage of multiple GCM data availabilities to showcase what the 'average' study is forecasting under climate change.

Climate change has grown to become a strong locally-focused area of concern for cities and communities [9–11]. With growing concern about the impacts potentially brought on by climate change, the need for highly accurate climate change predictions has increased. At a global scale, the study of GCM climate projection output has helped bolster international awareness, leading to recognition in many countries that mitigation action is desperately needed. With the expectations that temperature rise could be as much as several degrees through the next century [12], a more widely organized response is imperative [13]. National governments around the world have considered climate change, and many have created national policies to introduce and develop national-level strategies. Spanning into regional and local levels, these policies and plans trickle down to influence regional and local governance [14]. In numerous communities, the problems associated with climate change have become better known and this knowledge continues to evolve [15].

As information about climate change and its expected impacts has reached down into communities, the need for details regarding those impacts has steadily increased. Some of these details come from the GCM models and would help translate projected impacts at the global level into regional and locally relevant information. Meanwhile, regional and local authorities might adopt national and international policies regarding climate change, but it is possible that not all regions will experience the impacts of climate change equally. Some decisions could depend strongly upon the perceptions of risk, in combination with the anticipation of climate change impacts. Meanwhile, people often depend greatly upon their past experience to help them determine if a stated threat carries significant risk. What might be considered the slow onset of climate change during past years could be misinterpreted as plenty of time to react. This creates the false perception for many that there is low risk of impacts due to climate change. Simonelli [16] contends that the livelihoods most at risk in this respect are those in rural areas—a predominant type found around the world. Given the timescales of the expected changes however, the adaption and mitigation strategies are necessary and must be started now [2, 17, 18] and local areas are increasingly important in the adaption strategy [19], [20].

How would the scientific climate change temperature projection of 2 °C average increase, meaningfully translate for regions within a country? How about for local communities? These are questions being asked—and are reflected in many national governments in countries today where they need to provide direction and support for regional management. The role of government in climate change recognition and the associated adaptation and mitigation

---

[1] General circulation models (GCMs), also sometimes called global change models or general climate models, are a type of climate model that uses mathematics to model the general circulation of the earth's atmosphere and/or ocean environment.

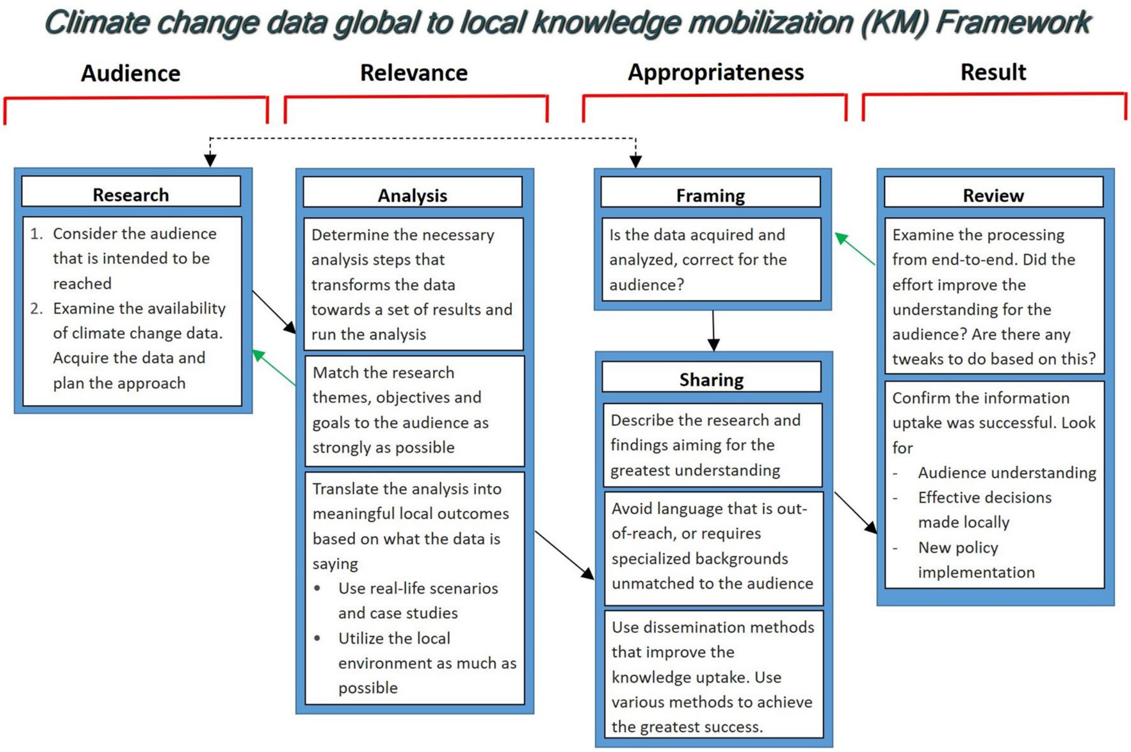

Fig. 1 Visualization of the knowledge mobilization framework followed for translating the global climate change data modelling exercise into meaningful regional climate change information suitable for local audiences

strategies is significant [14], [21]. Equally significant are local representatives who are already engaged in adaptation activities [7]. Overall, achieving relevant data results and the translation process of this data is the key to making this research effective. The need to mobilize the knowledge discovered through excellent research and to share that knowledge meaningfully to the appropriate audiences is paramount. Within an effective framework of knowledge mobilization, the data need to be spatially relevant, the people that we reach to inform about the data needs to be correct and the message must be presented to those people in a way that is understood. Good results of these efforts will be noticeable too, through the discussions, decisions and actions of local stakeholders who have understood the message and moved on it. See Fig. 1 for how this framework may be visualized for the context of climate change data research knowledge mobilization.

2 Case study location

The case study location is the Province of Newfoundland and Labrador, the eastern-most province in the country of Canada. This location could serve as an excellent example of potential climate change impacts, because it has geographical attributes that allows it be an example of various impacts related to setting. The province boasts a long coastal region, yet has interior landmass conditions also. The Newfoundland and Labrador landmass stretches across an extensive latitude span, therefore increasing the exposure and potential for a northward shift in climatic variations [22]. Finally, the province has an impressive combination of economic, community, industry and infrastructure attributes which can allow regionally focused climate change information to translate meaningfully for regional planning and decision-making action. Most of the populous live in the coastal zone, especially in the eastern corner of the Island of Newfoundland on the Avalon Peninsula. The mainland portion of the province, Labrador, while less populated with people, runs far north reaching into the Arctic Zone on the continent. Such a span creates a diversity throughout the province making it a worthwhile study location.

Newfoundland and Labrador's latitude span, along with the different geographies associated to the Island of Newfoundland in comparison to Labrador, means a careful examination of both areas must include individual and combined references in relation to climate [23]. Meanwhile, a strong industrial presence for mining, oil and gas and commercial fishing means climate change-induced storm surge activity could cripple much of the area. Developing climate change strategies at the local and municipal level is imperative towards a provincial climate change response framework [24]. The result is the need for greater understanding of the climate change behind such impacts, especially through the recognition, careful development and proper interpretation of climatic projections at the provincial level. This need also puts enormous pressure on government, as they must champion good climate change policy that strengthens climate change adaptation/mitigation while mediating powerful and potentially competing economic and industrial interests [25]. As Nightingale [26] points out, vulnerability to climate change is a real and present danger extending beyond any single jurisdiction or socio-economic boundary. A careful alignment of climate change recognition, adaptation and mitigation strategies across multiple jurisdictions with multiple government levels is necessary. What can be deduced is this understanding: The need for regional and local level climate change projections is substantial. This information can assist adaptation and mitigation strategies and plans in several ways. It sheds light on those areas where impact is likely to be greatest, while also continuing to encourage sustainable energy use practices.

Climate change and associated impacts are increasingly in focus in Newfoundland and Labrador [27]. There are a multitude of concerns that demand attention from industry and community impacts to awareness and opportunities. The federal Government of Canada also recognizes the importance of dealing with climate change [28]. This is evident through several years of reporting, in addition to continued commitments at both levels of government to increase focus on climate change preparation, mitigation and adaptation. Of course, there is room for improvement and strengthening of these efforts at both levels, particularly in terms of follow-through on stated actions and inter-governmental co-operation. Provincially speaking, having an extensive coastline and numerous coastal communities in Newfoundland and Labrador increases the risk of land-sea climate change impacts. These communities, like others in Atlantic Canada, are already experiencing severe storms and other associated impacts of climate change [29]. Importantly, there has not been significant regional or local community temperature forecasting released or published by the Government of Newfoundland and Labrador. Hence, there is great need for this case study (and more) to highlight the regional focus and help regional climate change planners increase their mitigation planning effectiveness.

3 Data considerations and sourcing

In the world of spatial data information, interpreting a value set from a broad, wide-ranging area into a narrower, more focused area is called downscaling. Downscaling is a relevant methodology when it is necessary to see finer details interpreted from a larger scale, less-detailed presentation piece. Consider a computer map image of a country, which we know has finer details that initially appear invisible. We know from our experience and knowledge that smaller regional areas, including communities, exist on that map. As you zoom into the map, the information about landscapes, lakes, highways and communities become visible. The information at the large-scale view is meaningful and may translate through multiple levels of mapping scale changes. Conversely, for global-level climate change data projections the information at the community level is less abundant, but increasingly necessary [30]. This information must be generated using an interpolation method so that as you zoom in to the community level it becomes visible. The interpolation analysis estimates the lower-scale information through the downscaling process. Matte et al. [31] increased the resolution in their European climate projections study from 50 to 12 km^2, showing that simple (down) scaling not only provided more localized temperature readability but also enabled better identification of trends. Downscaling to find out what is going on deeper inside the GCM picture is important for the regional view. This is evident in the regional focus study by Kjellström et al. [32] who discovered that regional warming actually exceeded that found as the global mean for parts of Europe. Their study used downscaling to a scale of 12.5 km^2. It seems clear that downscaling from a large point grid is certainly useful for achieving results with higher resolution. We must be careful however, as a continued increase in the complexity of a model potentially will render it useless because of the gains in uncertainty. This is reflected on by Rummukainen et al. [33] also in their study regarding the challenges of regional climate modelling using downscaling. Figure 2 shows this complexity of scale in a visual comparison of National (Eastern Canada) and Regional (Labrador) data views.

Developing projection scenarios for a globally based output from several potent GCM sources can help support strongly suggested model trends or reveal important differences. This multi-model approach is popular [7, 7], as it gains a more universal perspective of the scientific modelling data used to understand climate change. This expertise should furthermore be sought from multiple sources including globally, regionally, scientific and traditional

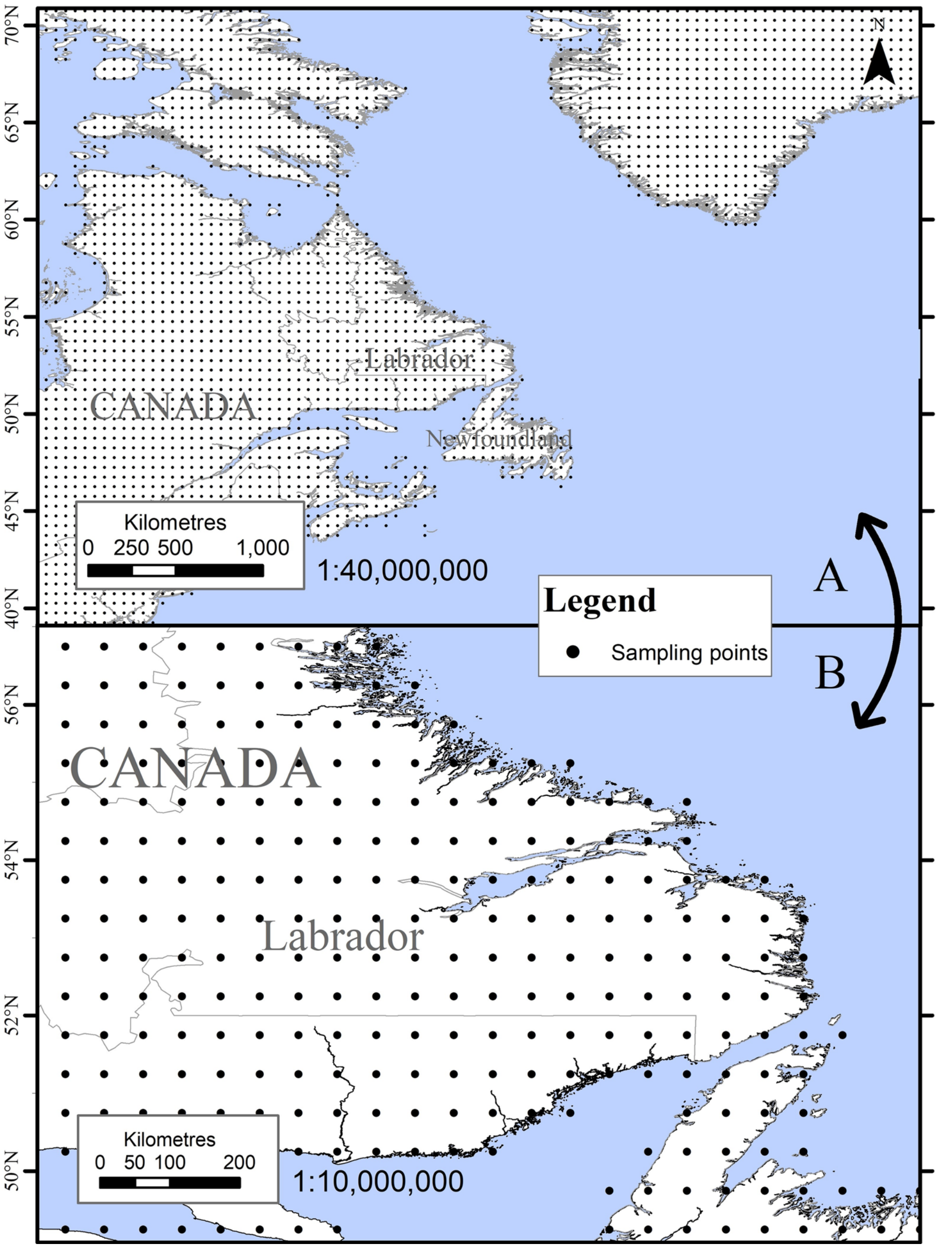

Fig. 2 The initial climate change modelling data when viewed at different scales. Box *A* showing example grid at 1:40,000,000 while box *B* showing the same data at 1:10,00,000. Map created using ArcGIS Desktop v. 10.4.1

sources [34]. It is useful to examine the outputs of multiple GCM's to frame a more-informed climate change data analysis. This approach is particularly true when a smaller geographical area of interest is chosen, as several GCMs may appear similar at large scales, but differ significantly at the increased resolution. The difference between using a single GCM and using many GCMs can therefore influence the deduced local (downscaled) climate change perspective greatly. Meanwhile, not all GCMs are created equal or with the same structures to allow for serious cross-comparison study. A tool that can be used to examine data across multiple GCM's is necessary if one hopes to be able to apply a similar analysis approach equally to the GCMs.

One good climate change tool turned data source capable of this is ClimGen (see [5]. ClimGen is a spatial climate scenario generator developed by the climate research unit (CRU) and tyndall centre for climate change research.[2] The software tool allows users to explore some of the uncertainties in future climate change projections at regional scales. Outputs generated by this tool, incorporating many different change models from a range of countries, can help increase the information examined as it relates to

---

[2] ClimGen information and associated climate data from CRU are available online for public access at https://crudata.uea.ac.uk/~timo/climgen/.

climate change. Seven GCMs, as offered through ClimGen, were used for analysis and framing in a local context in this study, stemming from climate projection data originally generated by ClimGen with further processing through NERC quest-global-scale impacts (GSI).[3] While several different variables are available through ClimGen under each GCM, the main variable chosen to examine related to climate projections was temperature. These global data are available at a resolution of 0.5 × 0.5° (decimal degrees), meaning every projected temperature point is 0.5° from the next point. To understand climate change and the impacts associated with it, the regional perspective must be brought into focus. In order to derive a more detailed understanding and therefore greater local value, the data need to be downscaled to a finer, more localized scale of interpretation. Without the downscaling, only a single point of temperature every few hundred kilometres is available from the original ClimGen data. Such a gap cannot easily help with regional climate change forecasting as it is too spatially restrictive.

Using climate change projections from a host of globally-set functional GCMs to gain some understanding of what to expect for Newfoundland is not a new idea. This project suggests one method that provides detailed resolution at a regional level deduced from multiple GCM emulations. It is hoped that the study and use of these projections, in combination with solid adaptation and mitigation strategies, can help guide regional and local representatives towards a more favourable climate change readiness position.

4 Methodology

The ClimGen derived data files for multiple GCM's (see Appendix 1) were downloaded from the CRU website. These GCM's originate from several sources around the world, with substantial investments in the science behind their developments. In output format, the ClimGen data files are available for download as text (ASCII). Each large single-variable file pertaining to each GCM contains all projection months and years together. Iterative-basis computer programming allowed separation of the projection data into single year multi-month global point grid data files. Each monthly point grid then received natural neighbour interpolation using GIS software tooling in ArcGIS.[4] This interpolation is an ideal treatment to translate the initial point grid projections into highly detailed projection maps, giving them increased potential for usability within regional and local climate change impact assessment. In this form of downscaling, the natural neighbour interpolation estimates the projection values at smaller scales by examining those starting points nearest the area in question. All 'in-between' areas of the original point grid are assigned new values, providing the resultant production mapping with substantial detail.

Each created map is a high resolution, natural-neighbour-interpolated monthly 'picture' of projected climate. Processing was completed for temperature climate projections for the seven GCMs employed and covering years 2050–2094. Observational temperature data, consisting of similar point grid data for the years 2000–2004, were also processed the same way. These real-world observations, detailed and available in the same single-variable format via the ClimGen website originate from real on-the-ground historical measures. They help form the 'current picture' basis for making any change comparisons at the temporal level.

Global monthly average temperature raster maps for each month (May–October) were further averaged over 5-year periods for each GCM. This timeframe coincides with the regular growing season, while also providing the traditional sequence of frost-free months during the year. The per-GCM seasonal average temperature was then calculated. Finally, the Multi-GCM (7 GCM) seasonal average temperature was deduced. This approach was taken for the 5-year reference period (observations) and then for temperature projections at final intervals at observations '+ 50 years', '+ 60 years', '+ 70 years', '+ 80 years' and '+ 90 years'.

Final temperature observation and projection period maps were further clipped to the Newfoundland and Labrador provincial boundaries study area for detailed visualization and regional/community analysis steps.

To examine projected temperature changes at community levels, an extensive community point layer was used to overlay the observation and projection temperature maps. A well-distributed mix of 934 different communities across the province provided the basis for a GIS regional / community seasonal temperature assessment. Values for all communities were extracted and analysed. To do so, the community point layer was overlayed with the raster temperature layers in the GIS system. These values could then be examined on both a per-community basis, or at a regional basis in combination with other local communities. To achieve the regional focus, a Newfoundland and Labrador boundary GIS layer which divides the province into Economic Zones was used (see Fig. 3). This layer is useful, because not only does it carry a geographical

---

[3] ClimGen information and associated climate data from CRU are available online for public access at https://crudata.uea.ac.uk/~timo/climgen/.

[4] Environmental Systems Research Institute (ESRI). *ArcGIS Desktop vs. 10.4.1*, https://www.esri.com (2019).

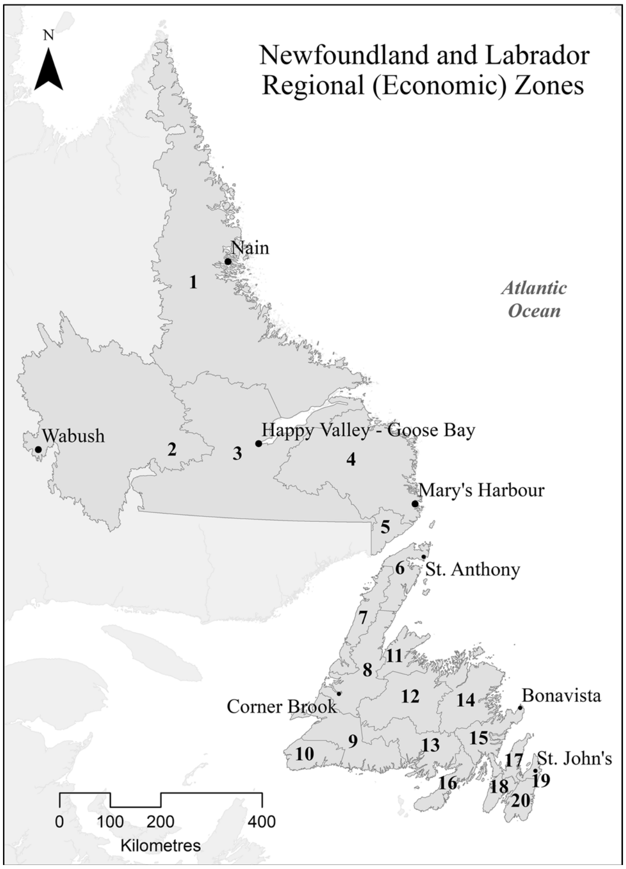

Fig. 3 The allotment of regional (economic) zones of Newfoundland & Labrador used for the case study. The names of the economic zones are identified in Table 1. Data source: Government of Newfoundland & Labrador. Map created using ArcGIS desktop v. 10.4.1

regional definition into the picture, but can also bring some economic understanding into the picture through additional studies that focus on Newfoundland and Labrador's economics.

Each regional average temperature value was calculated using the temperatures of all study communities that lay within the regional boundary. The regional temperature summary is thus a reflection of what each community is experiencing in that region. Using this method allows the regional summary to best represent the human habitation areas of the region, instead of averaging all regional sub-areas where non-populated lands would alter the intended focus. Change in temperature between the projection periods and the observations was calculated and sorting applied for final summaries.

5 Results

The seasonal temperature maps of Newfoundland and Labrador projections show nearly consistent rising seasonal temperatures throughout the province, for all the projection periods detailed under the averaged GCMs.

The visualization map in Fig. 4 shows the Island of Newfoundland with a predominantly seasonal monthly average temperature of 10–12 °C in the observations. The Northern Peninsula shows a little cooler while the Bonavista region is a little warmer at 12–14 °C. In Labrador, there is more variation with a mix of mid-range (6–10 °C) temperatures through the lower mainland east and west and colder seasonal temperatures towards the north.

At observations + 50 years, the projections indicate an increase in seasonal temperature of between 1 and 2 °C for almost all regions across the province. Much of Newfoundland for this period is now 13–14 °C, while significant interior warming to 10–12 °C is occurring in Labrador, spreading south-westerly. The colder Northern area is noticeably shrinking in size, as it too is seeing lower latitude temperature increases between 2–3 °C. This trend continues when we look at the projection map for + 60 years as well. For + 60 years, the higher temperatures seen during the observations period for the Bonavista region are increasing and accelerating this pattern in a ballooning southward expansion.

For + 70 years, Newfoundland and Labrador both remain a little more stable when compared with the + 60-year period, with slight seasonal temperature increase southward of the Bonavista area. There is also evidence in the projections of a slight decrease in temperatures during this period, occurring mainly in the south-east of Labrador.

When we reach observations + 80 years and then + 90 years, the trend of a rising temperature continues. The projections show most of the area of Labrador south now enduring average monthly seasonal temperatures of 10–12 °C, while the Island of Newfoundland is almost fully engulfed with 14–16 °C, an increase of between 4 and 6 °C from the observations period. The mainly increasing temperatures we see on the visualization maps are also noticeable for the different economic regions. A simple but effective way to show this is by examining the changes in temperature occurring on a per region basis. All regions show a significant increase in seasonal temperature during the + 50 year timeframe (see Table 1). Temperature increases during subsequent timeframes are also noticeable, although not everywhere as indicated for a few of the regions shown on the table.

Table 1 The resulting Newfoundland and Labrador (average) seasonal (May–October) temperature observations and climate change projections based on provincial regional (economic) zone division. The distribution of these economic zones is shown in Fig. 3

Newfoundland and Labrador climate change projections for regional (economic) zones

Seasonal(May–October) average monthly temperature

Zone	Name	Observations	+ 50 years	+ 60 years	+ 70 years	+ 80 years	+ 90 years
1	Nunatsiavut government	6.6	7.9	8.1	8.4	9.1	9.1
2	Hyron regional economic development corporation	7.6	9.4	10.1	9.9	10.8	11.3
3	Central labrador economic development corporation	9.2	10.6	10.8	11.1	11.8	11.8
4	South-east Aurora development corporation	8.3	9.8	9.7	9.3	10.9	10.7
5	Labrador Straits development corporation	9.0	10.6	10.7	10.5	11.8	11.7
6	Nordic economic development corporation	9.6	11.3	11.3	10.2	12.5	12.2
7	Red ochre regional board inc	10.5	12.3	12.5	12.5	13.6	13.6
8	Humber economic development board inc	11.5	13.4	13.8	13.8	14.7	14.9
9	Long-range regional economic development board	11.4	13.3	14.0	14.0	14.6	15.1
10	South-western marine and mountain zone corporation	10.7	12.6	13.5	13.3	13.9	14.6
11	Emerald zone corporation	11.6	13.6	13.7	13.1	14.8	14.8
12	Exploits valley economic development corporation	12.3	14.1	14.4	14.3	15.4	15.5
13	Coast of bays corporation	11.8	13.5	14.0	14.2	14.7	15.1
14	Kittiwake regional economic development corporation	12.0	13.6	13.9	13.9	14.8	14.9
15	Discovery regional development board	12.0	13.4	13.9	14.2	14.6	14.9
16	Schooner regional development corporation	12.2	13.6	14.2	14.4	14.9	15.2
17	Mariner resource opportunities network	12.2	13.6	14.0	14.3	14.7	15.0
18	Avalon gateway regional economic development	12.0	13.4	13.9	14.0	14.5	14.8
19	North-east avalon regional economic development corporation	12.2	13.5	14.0	14.2	14.7	14.9
20	Irish loop regional development board	12.0	13.3	13.9	14.0	14.5	14.8

Significantly, the province shows a stall of the temperature-rising trend and even regions with average temperature decrease at the regional view between + 60 years and + 70 years. This stalling is evident again for a few regions between + 80 years and + 90 years, but only minimally. A rising average temperature trend of approximately 1 degree Celsius through the latter 20 years (+ 70 to + 90 years) can clearly be seen across most economic regions.

Additional analysis for the community seasonal temperatures set was completed including average, sample variance,[5] and standard deviation. Comparisons for this analysis specifically targeted the change in projected seasonal temperature that the communities of Newfoundland and Labrador sampled would face between multiple 10 year periods. The initial + 50 year change period was factored by 0.2 to ensure equal representation was used. The tabular analysis results are indicated in Table 2.

On the Island of Newfoundland, the greatest projected seasonal temperature change for the first 50 years occurs in the Baie Vert Peninsula/White Bay communities. For example, Woodstock, Burlington and Nippers Harbour each increase significantly (+ 1.98 °C) and are located here. This is despite the highest temperatures for the observations period occurring on the Island's Burin Peninsula (example: Fortune (+ 1.46 °C) and Lamaline (+ 1.45 °C)). For Labrador, the communities that experience the greatest projected change for + 50 years were in the south-west including Labrador City (+ 2.11 °C) and Wabush (+ 2.10 °C) followed closely by communities on the south-east coast, Mary's Harbour (+ 1.67 °C) and Battle Harbour (+ 1.64 °C). Again this did not coincide with the highest observations period communities in Labrador where changes were less, yet still significant (Happy Valley-Goose Bay (+ 1.45 °C) and North West River (+ 1.47 °C)). This result for the province overall is perhaps a little counter-intuitive; the traditional thinking about seasonal temperatures is that the geographically interior communities would continue to have the highest temperatures period after period. Coastal areas have often benefited from cool sea-breezes that (on average) helped reduce their seasonal temperatures. However, the projection periods for seasonal temperatures in this study show coastal communities with the greatest

---

[5] Sample Variance included the Bessel's correction, i.e. using (*N-1*) vs. *N*.

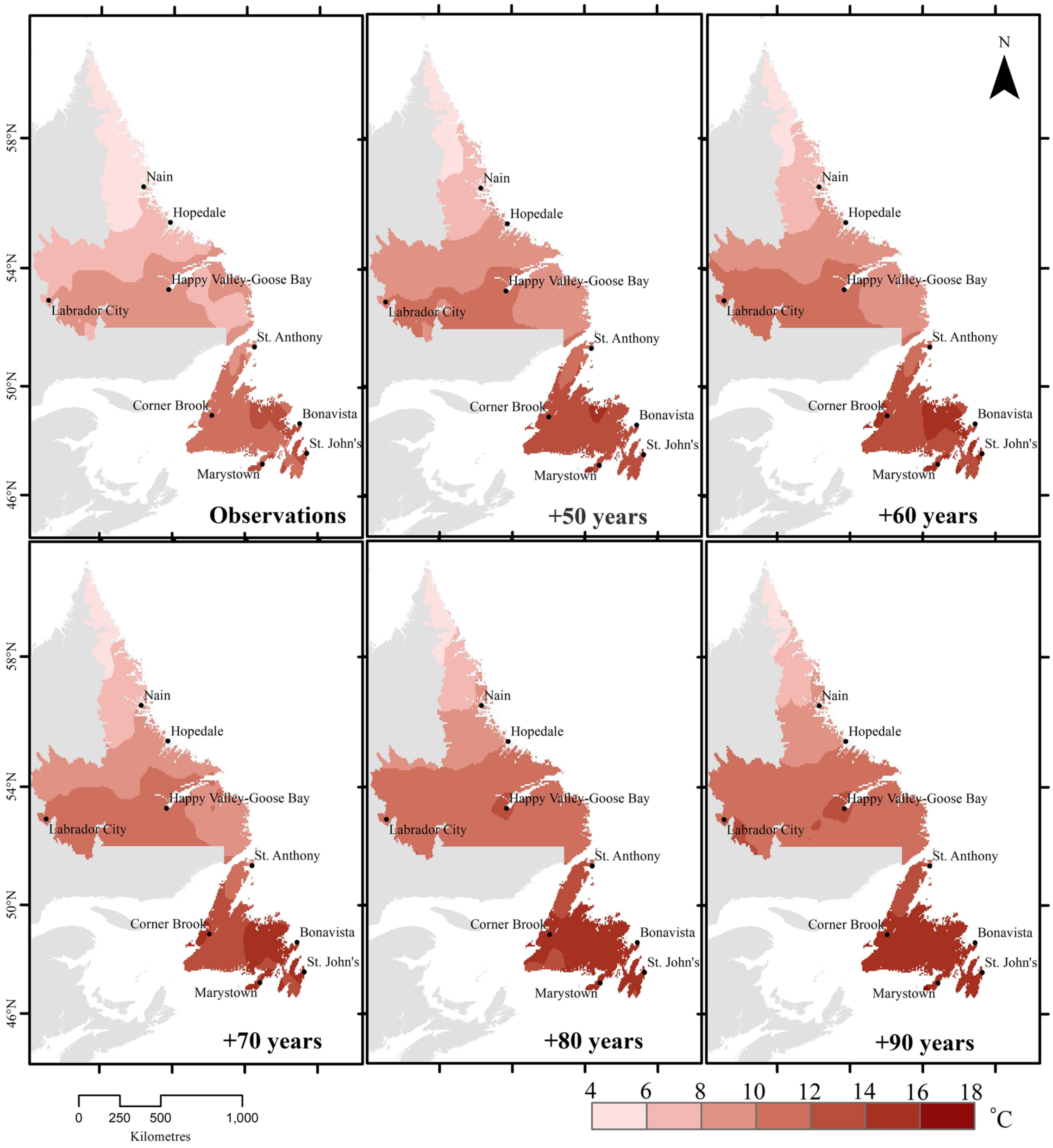

Fig. 4 Seasonal (May–October) monthly average temperature for Newfoundland and Labrador for the observations data (2000–2004) and for multiple GCM climate change projections of 5-year periods at + 50 years, + 60 years, + 70 years, + 80 years and + 90 years. Map created using ArcGIS Desktop v. 10.4.1

change over the initial 50-year period of time following initial observations.

Through the next 40-year period (+ 50 to + 90 years), the greatest change in seasonal temperature occur on the south-west corner of the Island and for Labrador occurring again in the south-west. The communities of Channel-Port aux Basques (+ 1.97 °C), Codroy (+ 1.98 °C) and Doyles (+ 1.97 °C) highlight top changers for Newfoundland and again Labrador City (+ 1.92 °C) and Wabush (+ 1.90 °C) change the most during these periods in Labrador. For both geographies, this appears to be a part of the greater trend for a Northward shift in seasonal climatic temperature for the entirety of North America as previously indicated in research [22].

In terms of population, a significant majority of the people of Newfoundland and Labrador live on the Avalon Peninsula. Seasonal temperatures are expected to rise here during the + 50-years period (for example: St. John's (+ 1.37 °C), Holyrood (+ 1.38 °C), Marystown (+ 1.44 °C) and Placentia (+ 1.39˚C)—all located on the Avalon).

Table 2 Newfoundland and Labrador 10-year change projections for seasonal (average) temperature. The difference in latitude between the Island of Newfoundland and the Labrador mainland contributes strongly to the variation in projections for the province

Newfoundland and labrador climate change projections

Community 10 year changes in seasonal (May–October) average monthly temperature

	Obs. to + 50 years*	+ 50 to + 60 years	+ 60 to + 70 years	+ 70 to + 80 years	+ 80 to + 90 years
Newfoundland					
Mean	0.320	0.439	− 0.005	0.785	0.234
Variance	0.002	0.040	0.143	0.282	0.039
Standard deviation	0.043	0.201	0.378	0.531	0.197
Labrador					
Mean	0.295	0.100	− 0.185	1.259	− 0.096
Variance	0.002	0.051	0.205	0.309	0.047
Standard deviation	0.042	0.226	0.452	0.556	0.218
Province					
Mean	0.318	0.415	− 0.018	0.819	0.210
Variance	0.002	0.049	0.149	0.298	0.046
Standard deviation	0.043	0.220	0.386	0.546	0.215

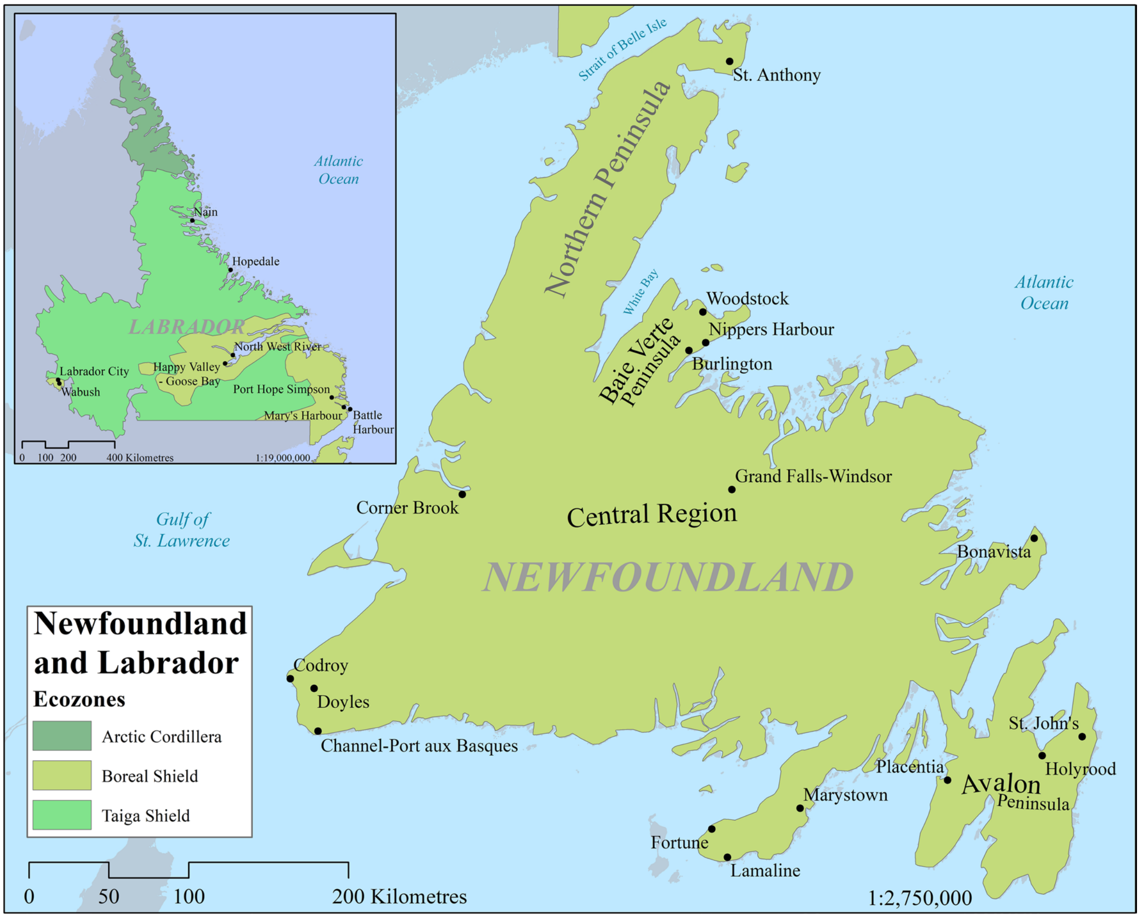

Fig. 5 Newfoundland and Labrador generalized map of ecozones. The island of Newfoundland is dominated by the Boreal Shield ecozone, while Labrador has Boreal Shield, Taiga Shield and Arctic Cordillera Ecozones. Map created using ArcGIS Desktop v. 10.4.1, based on information available at https://ecozones.ca/

These projected increases all occur on the Island's east coast in a region with extensive coastline proximity to the communities.

6 Discussion

Looking at the visualization map and with reference to Fig. 5, it is significant to see the seasonal temperature change that is projected through this study for the far northern region of Newfoundland and Labrador. This area, known as the Arctic Cordillera Ecozone,[6] shows significant warming after + 50 years and further continued warming by + 90 years. While this area is not known so much for domestication (agriculture, inhabitation, infrastructure placement, etc.), a projected seasonal temperature rise still translates effectively into changes that would have negative impacts. This mountainous region, with its polar ice fields and glacier coverage, will likely face the type of severe change that headlines many climate change impact reports stories in Canada. For example, see Canada's Changing Climate Report [35] which sternly warns of the increasing northern temperatures. The melting ice and shrinking glacier cover caused by the rise in temperature is clearly outlined as outcomes conceived through negative impact projections. Negative impacts might include rise in sea level, increasing ocean temperatures, more seasonal heat waves and increasing storm frequency and ferocity ([36–39]. Another outcome that we might include from a major temperature shift in this northern region is the wildlife impact, like the polar bear which frequent the Canadian North including this province. Polar bear populations would continue to be forced further north, possibly driving them out of Labrador completely [40, 41]. Under the projected temperature increases, the short and relatively cool summers currently experienced in the province's north region would heat up and expand in length. While these impacts do not seem to carry as much of an economic status at first glance—it still remains that devastation and loss of great northern resources would translate into loss of economic potential. The same kind of uncertainty for wildlife as a natural resource is spelled out well in Nichols et al. [42] in the face of climate change impacts.

The Taiga Shield is projected to see temperature increase in much the same way the north did. With the current Taiga climate generally consistent throughout western Labrador, an increase in seasonal temperature here could potentially begin to convert Taiga area to temperatures more akin to its southern ecozone neighbour, the Boreal Shield. The projections show this trend starting with + 50 years and remaining on a steady rise up through + 90 years. This could potentially drive increased vegetation patterns northward and have lasting consequences for the wildlife that exists in both ecozones at the present time [22, 42]. The potential for agricultural development increases through central Labrador as well where a northward shift of agricultural potential for the Boreal Shield is expected [22]. While southern Labrador is largely part of the Taiga Shield, there are areas in the southern coastal zone that are Boreal Shield zoning. The centrally located Happy Valley-Goose Bay and surrounding communities are also considered Boreal Shield with related climate, partly due to its proximity with Lake Melville. While these areas may not increase in temperature as significantly during later years in comparison to the Island of Newfoundland, their proximity to a water will mean other potential impacts such as increased lake effect and coastal storms are likely.

The Island of Newfoundland is a part of the boreal region of Canada, meaning the variety of climate change impacts seen here could be similar for boreal regions nationally. Forestry and wildlife that are found here are threatened under the projected temperature rise, mainly through increased risk of drought and forest fires. Meanwhile, a very significant consideration for Newfoundland is the long enduring coastline, where most of the communities and people of Newfoundland are located. Areas alongside the Strait of Belle Isle, highlighted in Newfoundland as the Northern Peninsula, appear to be less impacted overall in terms of projected temperature change from + 50 to + 90 years. A part of the reasoning for this may be the cold Labrador Current, flowing through the strait and bringing ice southward during the Spring season [43]. Increases in temperature for the remainder of the Island mean hotter seasonal temperatures could be expected through central Newfoundland and increased (but milder) ocean-regulated temperatures on the Avalon Peninsula. While these increases may not look significant on the temperature projection visualization map, it should be carefully considered what a few °C seasonal increase could do in relation to climate for the coastal area in the east. The Avalon Peninsula has a significant majority of Newfoundland and Labrador's population, with many communities (as previously noted) living in close proximity to the coast. Economically speaking, large quantities of commercial and residential infrastructure, road networks and industry dwell in the region—the highest density for the entire province. Increased seasonal temperatures

---

[6] Ecozones are a Canada-wide ecological classification framework developed by Environment and Climate Change Canada (Government of Canada) and the Commission for Environmental Cooperation (CEC).

translate into increased storm surges, increased frequency of storms and significant levels of storm-related events such as flooding and erosion. The coastal proximity means increased risk for many communities and their inhabitants under projected temperature increases and in consideration of the associated coastal and ocean consequences of higher temperatures due to a changing climate.

At a finer community level through the GIS community seasonal temperature approach, analysis shows an increasing temperature trend with some cyclic temperature activity for a couple of regions, across the province for climate change projections. This up and down seasonal temperature cycling is a noticeable characteristic among several regions through the time periods assessed in this study. The low-end of this cycle occurs during the + 60 to + 70 years timeframe and predominately occurs on the coast in Labrador south-east, as well as the Northern Peninsula of Newfoundland. These can be linked to the Labrador Current as previously noted, the cold current of water flowing past these regions. The trough is showing on the visualization map directly, but is evident through community tabular analysis as well.[7]

The Island's largest population region is the Avalon Peninsula, containing well over half of the provinces people. The usually milder seasonal temperatures here still see an increase that will have negative impacts as a result to climate change. The Avalon Peninsula already experiences storm surge activity resulting from the region's high exposure to North Atlantic Ocean weather events. Under a projection scenario where seasonal temperatures are continuously trending upward the risk of increasing storm ferocity and frequency can seriously challenge mitigation efforts and threaten the safety of many communities.

There are other implications of a seasonal temperature change that will have impact for Newfoundland and Labrador. With seasonal temperature linked directly to local determinations of water balance,[8] the province's agriculture stands to experience climate change impacts [44]. Crops that are traditionally grown in one community and have depended upon a certain range of seasonal temperatures, could see great diminishment or even elimination from that community [45]. Meanwhile, another community further north may develop the potential to have agricultural output, a resulting aspect of a northward seasonal temperature shift [22]. We should not be excited however, regarding a potential increase for agricultural development in any single community. This small improvement in agriculture-friendly temperature range may be little consolation in light of the increased risk of severe and frequent storm activity for the remainder of the province. The new ability for a more northerly located community to grow vegetables would do little to console the traditional and active farmers of today in the south and on the coast, who stand to lose agricultural potential. This scenario of agricultural devastation has a huge implication for the health of the province's economy too. Many agricultural operations including numerous agricultural businesses and jobs contribute greatly to the economic well-being of Newfoundland and Labrador. In this province like many coastal regional settings, climate change is poised to negatively impact economic well-being through agricultural upset and the upheaval of other resources of economic value [46, 47].

Another area of great uncertainty for Newfoundland and Labrador under the projected seasonal temperature increase scenario is the province's freshwater salmon. Climate change already has a real and continuing impact globally on freshwater fish [48]. The province of Newfoundland and Labrador is already experiencing significantly high freshwater temperatures during summer, as well as low water conditions affecting the number and health of salmon. Rivers that have traditionally been superb for a thriving salmon presence across the province are increasingly having to close early to anglers due to high temperatures. Bates et al. [49] reported that global mean land and surface-water temperature increases of 0.85 °C since 1880 has warmed freshwaters globally. A global mean temperature increase of 2 °C, as used for calculating the future projections in this study for Newfoundland and Labrador, indicates more of the same negative outcome. These rivers are inland rivers, snaking deep into the heart of Newfoundland and Labrador. The temperature projections for the terrain are the same that will impact such areas. A projected increase in seasonal temperatures causing continuing increase in water temperature for rivers, could spell disaster for provincial salmon populations [50]. Consequently, there would be no other choice for fisheries management but to close any associated salmon fishery. This negative outlook for salmon rivers of Newfoundland and Labrador in relation to rising temperature impacts due to climate change, demands further study to help gauge future impacts and assist managers formulate the best possible mitigation strategies.

---

[7] The trough is present, but isolated to just a couple of regions. Statistically this is playing out in the mean, variance and standard deviation numbers we see for all regions during + 60 to + 70 years and during + 70 to + 80 years.

[8] Water-balance can be determined through water outputs (evaporation and transpiration calculations) combined with water inputs (precipitation, snowfall). These all partly depend directly upon temperature (T) at the local level.

7 Conclusion

In this study, Global GCM model output data of climate change temperature projections were acquired and explored. An analysis approach of downscaling the point grid data into higher resolution raster images was completed. Such downscaling allows a detailed climate change temperature assessment at the regional and community level to be done. This study focused on the Eastern Canadian province of Newfoundland and Labrador, looking at economically themed regional divisions as well as individual communities under a downscaled climate change temperature scenario. Provincially Newfoundland and Labrador weather can vary greatly in latitude, which can be seen regularly through daily, monthly and seasonal temperature forecasts. Under a global 2 °C increase by 2050 scenario of climate change, this latitudinal difference as well as other locational aspects (such as coastal proximity) may play a role in the regional changes and impacts that occur. Seasonal temperature projections show that temperature for Newfoundland and Labrador overall will increase both during the initial 50-year period and the latter 40-year period for this century. Severe climate change impacts linked to temperature increase are already started and will expand in size and ferocity, especially given the extent to which Newfoundland and Labrador's people live predominately in coastal regions. Population centres, such as the Avalon Peninsula where the majority of housing and infrastructure are located, may bare the worst impacts economically from the projected seasonal temperature increases associated to climate change. These places face significant risk from increasing storm activity and frequency—outcomes that have been directly linked with temperature increase due to climate change and are evident under the scenario presented. Increased seasonal temperatures carry a lot of uncertainty, especially in locational aspects and the sustainability of varied provincial resources. Therefore, higher levels of detailed knowledge about climate change and the associated regional areas of impact will ultimately help regional stakeholders and decision makers understand the message and manage the response to climate change better overall.

Code availability Data analysis was performed using a combination of ESRI ArcGIS ArcMap version 10.4, Microsoft Excel and original python coding within the ArcMap software. The author should be contacted regarding any enquiries regarding coding within the applied methodologies.

Compliance with ethical standards

Conflicts of interest The author declares that he has no conflict of interest.

Availability of data and material Supporting data, python programming and original data source linkages are available through communication with the author at his primary email address.

Appendix 1

See Table 3

Table 3 Seven GCMs were employed. Datasets for the models are available through https://crudata.uea.ac.uk/~timo/climgen/data/questgsi/. GCM data were initially processed under ClimGen (Emissions GHG scenario, 2050–2094) with further work via NERC Quest-GSI (Global-Scale Impacts). Output grid files were processed under a prescribed global temperature change of + 2 °C by 2050

Coupled model Intercomparison project, phase 3 GCM (CMIP3 GCM)	
Model ID	Agency/model (country)
cccma_cgcm31	The third generation coupled global climate model, canadian centre for climate modelling and analysis, version 3.1 (Canada) (https://www.canada.ca/en/environment-climate-change/services/climate-change/centre-modelling-analysis/models/third-generation-coupled-global.html)
csiro_mk30	Commonwealth scientific and industrial research organisation (CSIRO) atmospheric research, Mk3 model (Australia)
ipsl_cm4	Institut pierre simon laplace climate modelling centre, climate model 4 (France) (cmc.ipsl.fr/ipsl-climate-models/)
Mpi_echam5	Max Planck institute for meteorology, atmospheric general circulation model ECHAM, version 5 (Germany) (www.mpimet.mpg.de/en/science/models/mpi-esm/echam/)
ncar_ccsm30	National center for atmospheric research, community climate system model, version 3.0 (USA) (www.cesm.ucar.edu/models/ccsm3.0/)
ukmo_hadcm3	United Kingdom Met Office, Hadley Centre Coupled Model, version 3 (United Kingdom) **(**www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadcm3**)**
ukmo_hadgem1	United Kingdom Met office, Hadley centre global environmental model, version 1 (United Kingdom) (www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem1)

References

1. Huntingford C, Booth BBB, Sitch S, Gedney N, Lowe JA, Liddicoat SK, Mercado LM, Best MJ, Weedon GP, Fisher RA, Lomas MR, Good P, Zelazowski P, Everitt AC, Spessa AC, Jones CD (2010) IMOGEN: an intermediate complexity model to evaluate terrestrial impacts of a changing climate. Geosci Model Dev 3:679–687. https://doi.org/10.5194/gmd-3-679-2010
2. Masson V, Marchadier C, Adolphe L, Aguejdad R, Avner P, Bonhomme M, Bretagne G, Briottet X, Bueno B, de Munck C, Doukari O, Hallegatte S, Hidalgo J, Houet T, Le Bras J, Lemonsu A, Long N, Moine M-P, Morel T, Nolorgues L, Pigeon G, Salagnac J-L, Viguié V, Zibouche K (2014) Adapting cities to climate change: a systemic modelling approach. Urban Clim 10:407–429
3. IPCC (2014) Climate Change 2014: Impacts, adaptation and vulnerability. In Barros VR, Field CB, Dokke, J. D, Mastrandrea MD, Mach KJ, Bilir TE, et al., (eds) Part b: regional aspects. contribution of working group ii to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, 688–1132
4. Christensen JH et al (2013) Climate phenomena and their relevance for future regional climate change. In: Stocker H et al (eds) The physical science basis contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781107415324.028
5. Osborn TJ, Wallace CJ, Harris IC, Melvin TM (2016) Pattern scaling using ClimGen: monthly-resolution future climate scenarios including changes in the variability of precipitation. Clim Change 134(3):353–369. https://doi.org/10.1007/s10584-015-1509-9
6. Druyan L, Fulakeza M (2018) Downscaling atmosphere-ocean global climate model precipitation simulations over Africa using bias-corrected lateral and lower boundary conditions. Atmosphere 9(12):493
7. Chrysoulakis N, Lopes M, San José R, Grimmond CSB, Jones MB, Magliulo V, Klostermann JEM, Synnefa A, Mitraka Z, Castro E, González A, Vogt R, Vesala T, Spano D, Pigeon G, Freer-Smith P, Corfee Morlot J, Kamal-Chaoui L, Donovan M, Cochran I, Teasdale PJ (2009) Cities, climate change and multilevel governance. (OECD environmental working papers, 14) OECD publishing. Available at: https://www.oecd.org/dataoecd/10/1/44242293.pdf
8. Kusaka H, Hara M, Takane Y (2012) Urban climate projection by the WRF model at 3-km horizontal grid increment: dynamical downscaling and predicting heat stress in the 2070's August for Tokyo, Osaka and Nagoya metropolises. J Meteorol Soc Japan 90:47–64
9. Kousky C, Schneider SH (2003) Global climate policy: will cities lead the way? Clim Pol 3(4):359–372
10. Reckien D et al (2018) How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. J Clean Prod 191:207–219
11. Rosenzweig C, Solecki W, Hammer SA, Mehrotra S (2010) Cities lead the way in climate-change action. Nature 467(7318):909–911
12. Intergovernmental panel on climate change (2013) The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (pp. 2216)
13. IPCC (2018) Global warming of 1.5 °C: IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty. Summary for Policy Makers. https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
14. Di Gregorioa M, Fatorellia L, Paavola J, Locatelli B, Pramova E, Nurrochmat DR, May PH, Brockhaus M, Sari IM, Kusumadewi SD (2019) Multi-level governance and power in climate change policy networks. Glob Environ Change 54:64–77
15. Aylett A (2015) Institutionalizing the urban governance of climate change adaptation: results from an international survey. Urban Clim 14:4–16
16. Simonelli andrea C (2016) good fishing in rising seas: Kandholhudhoo, Dhuvaafaru and the need for a development-based migration policy in the Madives. In: Milan A, Schraven B, Warner K, Cascone N (eds) Migration, risk management and climate change: evidence and policy responses Chpt 7. Springer International Publishing, Berlin
17. Hughes S, Sarzynski A (2015) Building capacity for climate change adaptation in urban areas: editor's introduction. Urban Clim 14:1–3
18. Vij S, Biesbroek R, Groot A, Termeer K (2018) Changing climate policy paradigms in Bangladesh and Nepal. Environ Sci Policy 81:77–85
19. Doherty M, Klima K, Hellmann J (2016) Climate change in the urban environment: advancing, measuring and achieving resiliency. Environ Sci Policy 66:310–313
20. Carter JG, Cavan G, Connelly A, Guy S, Handley J, Kazmierczak A (2015) Climate change and the city: building capacity for urban adaptation. Progress in Planning 95:1–66
21. Mehrotra S, Natenzon C, Omojola A, Folorunsho R, Gilbride J, Rosenzweig C (2009) Framework for city climate risk assessment. Fifth Urban Res Symp, World Bank
22. King M, Altdorff D, Li P, Galagedara L, Holden J, Unc A (2018) Northward shift of the agricultural climate zone under 21st–century global climate change. Sci Rep 8:7904. https://doi.org/10.1038/s41598-018-26321-8
23. Finnis J, Bell T (2015) An analysis of recent observed climate trends and variability in Labrador. Canad Geogr/Le Géogr Can 59(2):151–166
24. Irvine M, Vodden K, Keenan R (2016) Developing assessment and adaptation capacity: integrating climate change considerations into municipal planning in newfoundland and labrador. In: Hallstrom L, Beckie M, Hvenegaard G, Mündel K (eds) Sustainability planning and collaboration in rural Canada: taking the next steps. U of Alberta Press, Edmonton
25. Patterson JJ, Thaler T, Hoffmann M, Hughes S, Oels A, Chu E, Jordan A (2018) Political feasibility of 1.5°C societal transformations: the role of social justice. Curr Opin Environ Sustain 31:1–9
26. Nightingale A (2017) Power and politics in climate change adaptation efforts: Struggles over authority and recognition in the context of political instability. Geoforum 84:11–20
27. Government of Newfoundland and Labrador. (2017). Office of climate change annual report. St. John's, Newfoundland and Labrador. https://www.exec.gov.nl.ca/exec/occ/publications/OCC_2016-17_Annual_Report.pdf
28. Government of Canada. (2016). The Pan-Canadian framework on clean growth and climate change. Ottawa, Canada. https://www.canada.ca/content/dam/themes/environment/documents/weather1/20170125-en.pdf
29. Vasseur L, Thornbush M, Plante S (2017) Climatic and environmental changes affecting communities in Atlantic Canada. Sustain (Switz) 9(8):1–10. https://doi.org/10.3390/su9081293
30. Peter D, Richard L (2016) From Science to Survival: Using Virtual Exhibits to Communicate the Significance of Polar Heritage Sites in the Canadian Arctic. Open Archaeol 2(1):11–23

31. Matte D, Larsen MA, Dahl C, Bøssing O, Christensen JH (2019) Robustness and scalability of regional climate projections over Europe. Front Environ Sci. https://doi.org/10.3389/fenvs.2018.00163
32. Erik K, Grigory N, Gustav S, Ole BC, Daniela J, Klaus K, Robert V (2018) European climate change at global mean temperature increases of 1.5 and 2 degrees C above pre-industrial conditions as simulated by the EURO-CORDEX regional climate models. Earth Syst Dyn 9:459–478
33. Rummukainen M, Rockel B, Bärring L, Christensen J, Reckermann M (2015) Twenty-First century challenges in regional climate. Bull Am Meteorol Soc 96:135–138
34. Ford JD, Cameron L, Rubis J, Maillet M, Nakashima D, Willox AC, Pearce T (2016) Including indigenous knowledge and experience in IPCC assessment reports. Nat Clim Change 6(4):349
35. CCCR (2019). Canada's changing climate report. Bush, E. & Lemmen, D.S., editors. Government of Canada, Ottawa, CA; (pp. 444). https://changingclimate.ca/site/assets/uploads/sites/2/2019/04/CCCR_FULLREPORT-EN-FINAL.pdf
36. Guerrero-Meseguer M, Sanz-Lázaro. (2017) Future heat waves due to climate change threaten the survival of Posidonia oceanica seedlings. Environ Pollut 230:40–45
37. Dettinger M (2011) Climate Change, Atmospheric Rivers and floods in California—a multimodel analysis of storm frequency and magnitude changes1: climate change, atmospheric rivers and floods in California—a multimodel analysis of storm frequency and magnitude changes. JAWRA J Am Water Resour Assoc 47(3):514–523
38. Wolf J, Adger W, Lorenzoni I, Abrahamson V, Raine R (2010) Social capital, individual responses to heat waves and climate change adaptation: an empirical study of two UK cities. Glob Environ Change 20(1):44–52
39. Wilson K, Kay L, Schmidt L, Lotze M (2015) Effects of increasing water temperatures on survival and growth of ecologically and economically important seaweeds in Atlantic Canada: implications for climate change. Mar Biol 162(12):2431–2444
40. Hamilton C, Kovacs K, Ims R, Aars J, Lydersen C (2017) An Arctic predator–prey system in flux: climate change impacts on coastal space use by polar bears and ringed seals. J Anim Ecol 86(5):1054–1064
41. Molnar P, Derocher A, Thiemann G, Lewis M (2010) Predicting survival, reproduction and abundance of polar bears under climate change. Biol Cons 143(7):1612–1622
42. Nichols J, Koneff M, Heglund P, Knutson M, Seamans M, Lyons J, Williams B (2011) Climate change, uncertainty and natural resource management. J Wildl Manage 75(1):6–18
43. Han Ma, Deyoung F, Chen. (2011) Simulation of three-dimensional circulation and hydrography over the Grand banks of Newfoundland. Ocean Model 40(3–4):199–210
44. Altdorff D, Galagedara L, Unc A (2017) Impact of projected land conversion on water balance of boreal soils in western Newfoundland. J Water Clim Change 8(4):613–626
45. Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N (2014) A meta-analysis of crop yield under climate change and adaptation. Nat Clim Change 4(4):287–291
46. Liu J, Hertel T, Diffenbaugh W, Delgado N, Ashfaq S (2015) Future property damage from flooding: sensitivities to economy and climate change. Clim Change 132(4):741–749
47. Olayide O, Alabi T (2018) Between rainfall and food poverty: Assessing vulnerability to climate change in an agricultural economy. J Clean Prod 198:1–10
48. Ramirez A, Valbo-Jorgensen J, Harrod C, Funge-Smith S (2018) How climate change impacts inland fisheries. Impacts clim change fish aquacult Chpt 18:375–391
49. Bates BC, Kundzewicz ZW, Wu S, Palutikof JP, eds. (2008) Climate change and water. Technical Paper VI of the intergovernmental panel on climate change, Geneva, IPCC secretariat. 210 pp. (also available at https://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf)
50. Olusanya HO, Zyll V, de Jong M (2018) Assessing the vulnerability of freshwater fishes to climate change in Newfoundland and Labrador. PLoS ONE 13(12):e0208182. https://doi.org/10.1371/journal.pone.0208182