Modelling the historic and projected near-surface temperature trends across Canada

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Key Points:

- Near-surface temperature across Canada is warming, with the spatial and temporal extent of the warming determined by present emissions.
- Modelling near-surface temperature change across Canada allows us the opportunity to adapt to rising temperature change.

Abstract

This article explores the impact that SSP 1-2.6 and 5-8.5 have on near surface temperature across Canada. This is achieved through the use of model ensembles, made up of CMIP5 data, to establish both the historic record of near surface temperature across Canada, as well as how this is predicted to change in the future given the two SSP emission scenarios. The conclusions drawn from this modelling and analysis is valuable in the context of sustainable development and both climate mitigation and climate adaptation discussions. Specifically, an understanding of the spatial extent of warming trends, across Canada, will allow for a more specific and tailored approach to be taken towards adaptation and can ensure appropriate measures are taken in good time.

1 Introduction

Canada is at the forefront of the climate change crisis, facing devastating impacts in recent years, including record flood events, alongside intensifying storm events and resultant coastal erosion (Austen and Isai, 2021). In this report we use projections from the models included in the fifth Coupled Model Intercomparison Project (CMIP5) to analyse near-surface temperature records and projections across Canada between the years 1850-2100. The Shared socio-economic pathways (SSP) of 1-2.6 and 5-8.5 are focused upon to determine future temperature changes, with SSP 1-2.6 representing a focus on sustainable development compared to SSP 5-8.5 relating to fossil-fueled development (Riahi et al., 2017), allowing for the impacts of both a “best case” and “worst-case” scenario of greenhouse gas emissions to be considered across the region.

2 Materials and Methods

We used monthly resolution CMIP5, single-level, near-surface air temperature data in all datasets used for the report. The models that were selected to contribute to the model ensembles are ACCESS-CM2, BCC-CSM2-MR, CAMS-CSM1-0, CESM2, HadGEM3-GC31-LL and MIROC6. For the SSP 1-2.6 and 5-8.5 modelling with the CanESM5 model is also employed. All data was downloaded from Copernicus’ Climate Data Store and was processed using RStudio

2021. All of the datasets were cropped to reflect solely the study area of Canada, achieved through masking and cropping the datasets using the raster mask and raster crop functions included in the raster package alongside the wrld_simpl data included within the maptools package, and were formatted into degrees celsius, by subtracting 273.15 from each of the values included in each dataset.

To begin, we constructed a model ensemble of historical near-surface temperature data from ACCESS-CM2, BCC-CSM2-MR, CAMS-CSM1-0, CESM2, HadGEM3-GC31-LL and MIROC6 using a time range of 01/01/1850 - 01/12/2014. Each of the cropped datasets were merged together to form a single ensemble of historical near-surface temperature data and was then converted into long format using the melt function from the reshape2 package. The ensemble was plotted using the ggplot function from the ggplot2 package, providing a line graph of Historical model ensemble mean for near surface temperature.

We repeated the process of creating a model ensemble, with the SSP 1-2.6 and SSP 5-8.5 projections for the same models, cropping them in the same manner to reflect solely Canada and graphing the datasets with the ggplot function from the ggplot2 package.

Following this, we created a frequency distribution plot comparing the CanESM5 model data of both SSP 1-2.6 and SSP 5-8.5. This involved creating a single dataset of historical, SSP 1-2.6 and SSP 5-8.4 data of the CanESM5 model. The three datasets were combined into a single RasterBrick object using the brick function in the Raster package and the names function included in base R was used to label the attributes. The data was plotted using the levelplot function from the lattice package, the hist function in the graphics package and the bwplot function from the rgr package - creating a levelplot, histogram and boxplot of the data respectively.

To create a line graph comparing the SSP scenarios we begin by converting both datasets into raster time series, achieved through the rts function of the rts package. Following this we use the apply.yearly function of the xts package to work out the yearly mean for each data set. We then use the cellStats function of the raster package to convert each of the datasets into a dataframe and plot them using the ggplot function from the ggplot 2 package.

When mapping historical data against the SSP scenario data, the same process is run, this time including the historical CanESM5 data alongside the SSP scenario data.

To create and plot a 1981 – 2010 baseline period temperature norms plot from the CanESM5 model, we began by subsetting the data to the specific range of 1981 to 2010, using the subset function included in base R using the dates 01/01/1981 - 01/12/2010. We define months as January to December and create a Raster object of calculated monthly means via a for loop. We use the levelplot function from the lattice package to generate a levelplot of monthly near-surface temperature norms for 1981 - 2010 from the CanESM5 model.

For generating anomaly plots for the SSP 1-2.6 and SSP 5-8.4 scenarios for the CanESM5 model this involved subsetting (subset command in base R) both the SSP scenario datasets to the dates 01/01/2015 - 01/12/2100. Months are again defined as January to December and a Raster object of calculated monthly means is created via a for loop. Once we have generated monthly near-surface temperature norms for 2015-2100 for both the SSP scenario datasets, we overlay the monthly data for the SSP 1-2.6 data and the SSP 5-8.4 data across the baseline period (separately to one another) using the overlay function in the raster package. Following this the datasets are both transformed into raster time series using the rts command from the rts package, then plotted them with the levelplot function in the lattice package.

3 Results

3.1 How has near-surface temperature changed between 1850 and 2014?

Looking at the mean data of the ensemble in figure 1 we can see an upwards trend of warming across the period, from an average temperature of around -7°C to -4.5°C, a 2.5°C warming of near-surface temperature. There is an observable trend of warming beginning around 1975, which we can suggest is representative of greater greenhouse gas emissions driving near-surface temperatures (Ritchie and Roser, 2020). There is also natural variability in near surface temperature, seen through the inter-annual temperature patterns, with temperature falling and rising, while forming a consistent trend of warming on decadal to centennial scales. The near-surface temperature trends between 1850 to 2014 across the region is shown clearly in figure 2, which again shows roughly a 2.5°C warming across the period and significant warming beginning around 1975.

3.2 How is near-surface temperature projected to change between 2015 and 2100 under

scenarios SSP1-2.6 and SSP5-8.5, both spatially and temporally.

1. ***What are the differences in near-surface temperature change between scenarios SSP1-2.6 and SSP5-8.5?***

As shown by figure 5, SSP 1-2.6 follows the pattern of historic warming trends to around 2045, before near surface temperatures remain steady around -1°C to -2°C across the region, totaling a 1-2°C change across the region. Contrastingly, the SSP 5-8.5 scenario shows rampant warming across the region for the entire period, reaching upwards of 7°C in 2100. Resultantly, the SSP 5-8.5 scenario represents a ~12°C warming across the 85-year period. The rate of change for the two scenarios remains largely similar before SSP 1-2.6's stagnation, at a rate of around 2°C warming every 20 years. Between the two scenarios specifically, the SSP 5-8.5 scenario represents a greater warming of around 8-9°C for the period. Looking to figure 6 we can see that Northern areas experience less warming overall compared to the more Southernly areas, with this spatial trend and pattern of warming being largely if not entirely identical between SSP 1-2.6

and SSP 5-8.5. When comparing figures 3 and 4 we can see the large variability that is present between models, with there being around a 7-10°C range for the models. This being said, the mean projection from the ensembles largely correlates with the projections of the CanESM5 model.

1. ***For scenarios SSP1-2.6 and SSP5-8.5, how is temperature forecast to change relative to the 1981 – 2010 baseline period?***

From figure 9 we can clearly see that both SSP 1-2.6 and SSP 5-8.5 initially follow a similar trajectory as the baseline period. Specifically, both scenarios remain largely coupled until around 2035 where near-surface temperatures in the SSP 1-2.6 scenario stagnate. This stagnation that is present in SSP 1-2.6 is reflective of the baseline period from around 1981-1990, where there was little to no change in near-surface temperature, representative of the lower greenhouse gas emissions throughout this period (Ritchie and Roser, 2020). SSP 5-8.5 however, retains the projection of temperature present in the baseline period between 2005-2010 for the entire 85-year modelled period and resultantly sees the study area warm far more - around 13-14°C warmer in the SSP 5-8.5 scenario in contrast to the end of the baseline period. In figures 3, 4 & 5 we can see that there is greater disagreement for future near-surface temperature projections compared to historical data projections, which can be attributed to the observational record that exists of past conditions.

1. ***Are there are particular months when projected temperature change is greatest relative to the baseline period?***

From figure 10, we can see that months November-March are largely similar, forming a 'winter pattern', while April and October act as transitory months between the switch to a 'summer pattern' of near-surface temperatures present with May-September. Comparing this to figure 11, we can see that this seasonal pattern of near-surface temperatures is largely reflected, albeit to a lesser degree than the baseline period. Notably from SSP 1-2.6 there is a trend of both cooler winter months and warmer summer months. This is best illustrated by the months of January and February alongside June and July.

Looking at figure 12, there is a clear constant pattern of warmer temperatures for each of the months in comparison to the baseline, in line with the previous projections of near-surface temperature. This being said, especially in the months of January, February, March and April there is a lack of near-surface temperature anomalies for parts of the country.

Finally, comparing figure 11 and 13 to one another, we see that March is the month that has the greatest near-surface temperature anomalies in both SSP scenarios, which suggests that the month is abnormally cool in comparison to the others in the baseline.

4 Discussion

Canada has on average experienced a 2.5°C warming of near-surface temperature change (figure 1 & 2), since 1850, which is compared to the observed and generally agreed upon figure of ~1°C as a global average (Hawkins et al., 2017). This suggests that climate change and global warming is spatially variable, and that there are other underlying controls on climate change beyond simply atmospheric conditions. This observation can be furthered when looking at the anomaly maps (figure 11 & 12) of near surface temperature relative to a baseline period, notably the geographical patterns within the trends suggest that there is a wider control of physical geography e.g., topography that plays a role in near-surface temperature trends.

Beyond this, there is an observable ‘lag’ between increased greenhouse gas emissions and near-surface temperature change. This phenomenon has been widely reported in academic literature and studies (Zickfeld and Herrington, 2015) and when comparing the data from Ritchie and Roser, 2020 against figure 1 it is clearly illustrated. There is a steady rise in emissions at ~1950, whereas with the near-surface temperature change graph, this steady increase begins around 1975 in comparison. From figure 5 we can see this ‘lag time’ in the SSP projections, notably there is a steady rise in near-surface temperature for around 35 years in SSP 1-2.6, which is representative of the transition to sustainable energy and the natural ‘lag time’ that exists.

Finally, as briefly covered in section 3C), the historic data of near-surface temperature across Canada saw the months of January, February, March and April be relatively warm compared to both the other months of the historical data alongside the SSP 1-2.6 and SSP 5-8.5 scenarios (figures 10,11 & 12). From this we can suggest again that warming of near-surface temperature is both spatially and temporally variable and there are further influences to the experienced near-surface temperature than simply greenhouse gas emissions. Furthermore, the observations highlight a weakness in global climate models in relation to the use of averaged historic data for variables informing future predictions. This being that there can often be anomalous conditions in variables, and therefore the averaged data can be skewed and thus unrepresentative of trends (Skelton, Kirchner and Kockum, 2020).

5 Conclusions

In conclusion, we can see that near-surface temperature has changed markedly across both historical timescales and such change is expected to only grow in the future. The rate of growth is determined largely by future global development norms and associated greenhouse gas emissions, yet irrespectively we can still expect further near-surface temperature in the future attributable to the observed warming lag (Samset, Fuglestvedt and Lund, 2020). The large variability of potential future warming is illustrated by the scenarios SSP 1-2.6 & SSP 5-8.5, with there also being notable spatial and temporal variation within the warming present in both scenarios, which is more pronounced when appreciated in relation to the historical near-surface temperature trends.

Figures

Figures

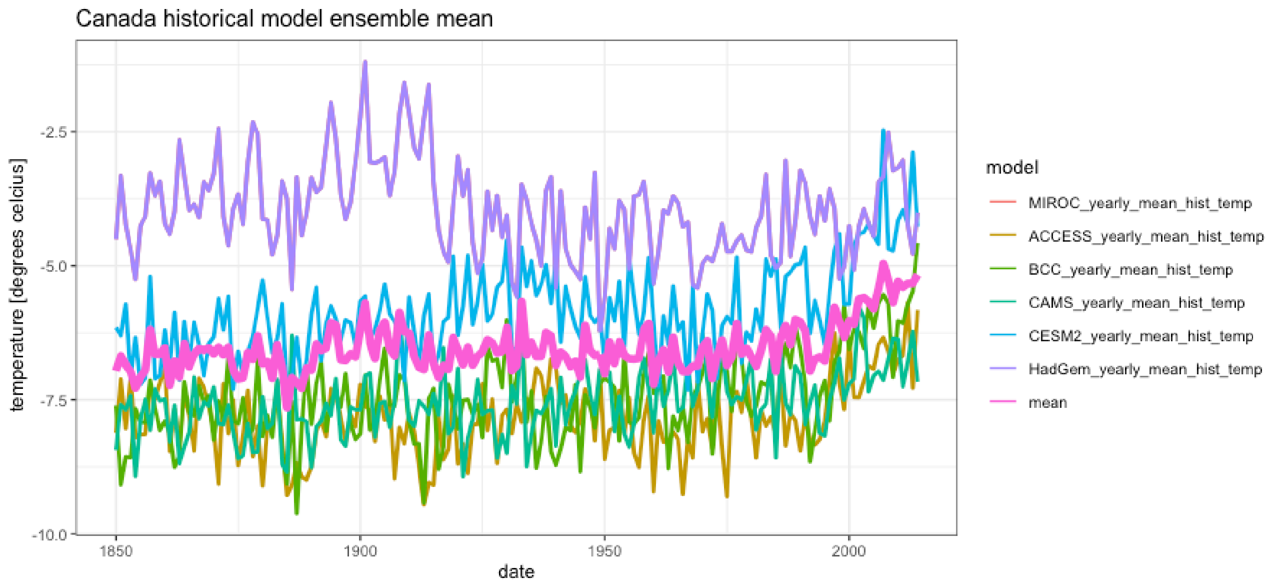

Figure 1 - Line graph of model ensemble mean of historical near-surface temperature from 1850-2014 across Canada

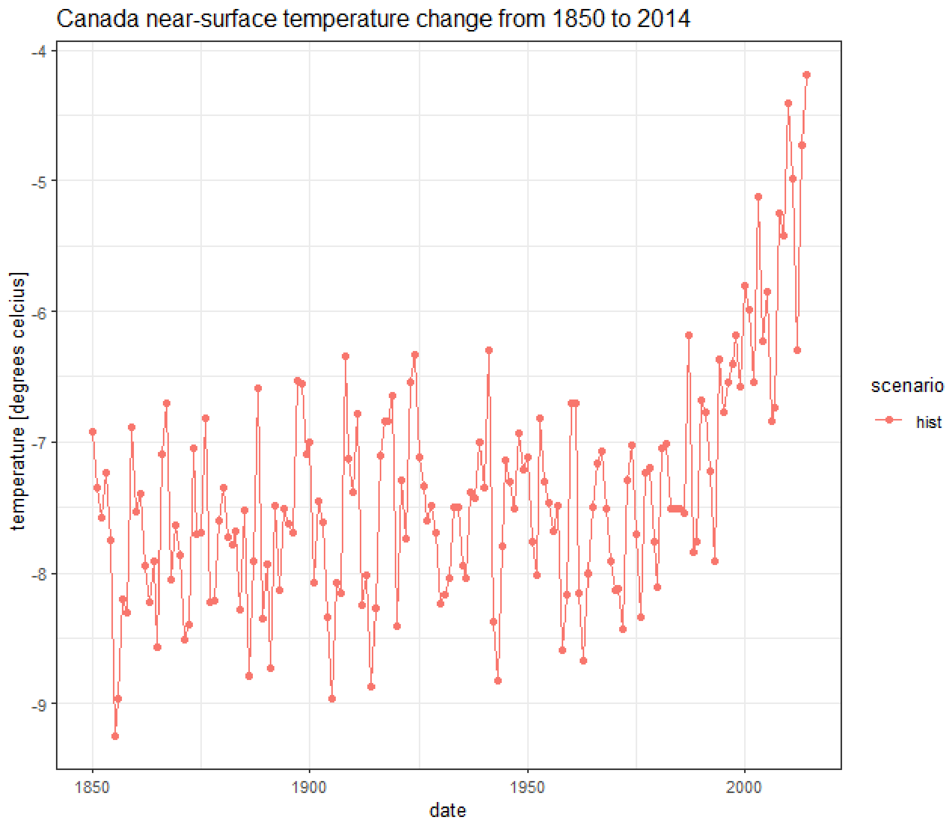

Figure 2 - Line graph of near-surface temperature change across Canada between 1850 - 2014, from the CanESM5 model.

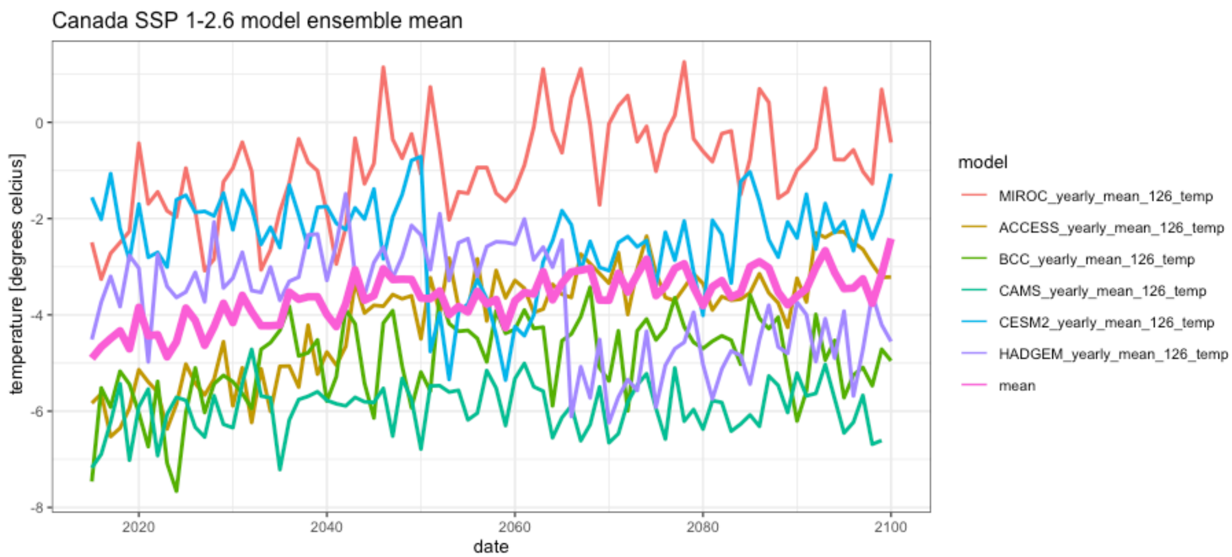

Figure 3 - Line graph of model ensemble mean of near-surface temperature change across Canada between 1850 - 2014 from the SSP 1-2.6 scenario

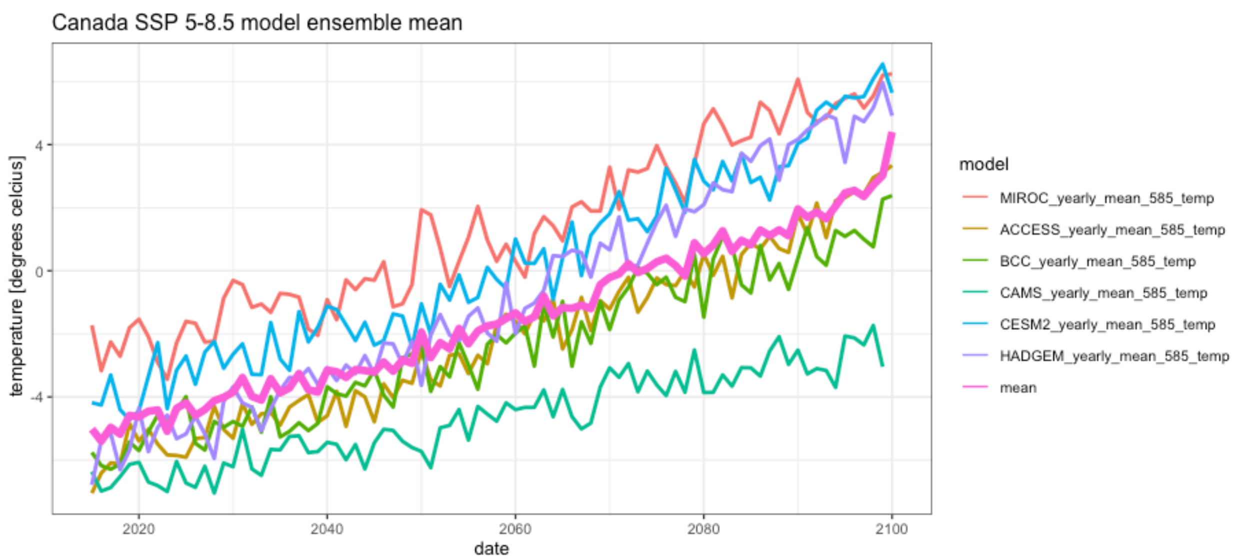

Figure 4 - Line graph of model ensemble mean of near-surface temperature change across Canada between 1850 - 2014 from the SSP 5-8.5 scenario

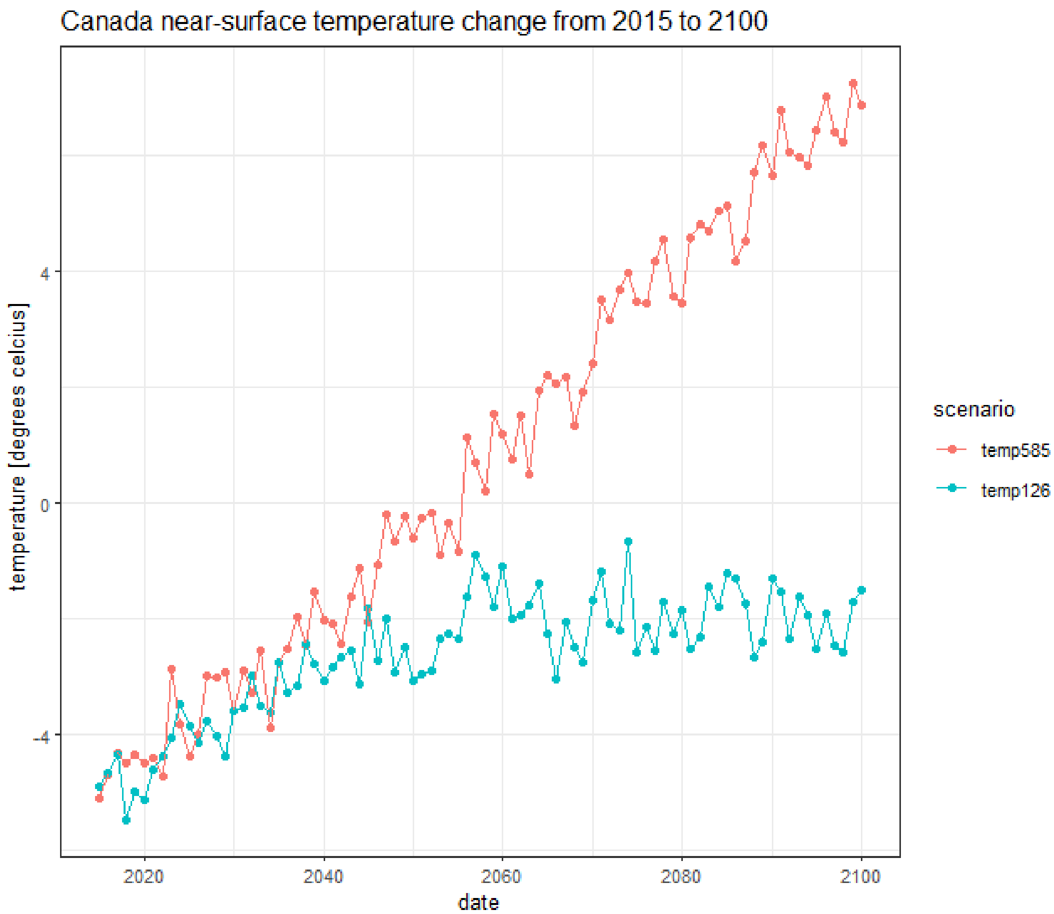

Figure 5 - Line graph of ear-surface temperature change projections of the SSP 5-8.5 and SSP 1-2.6 scenarios from the CanESM5 model, from 2015 to 2100.

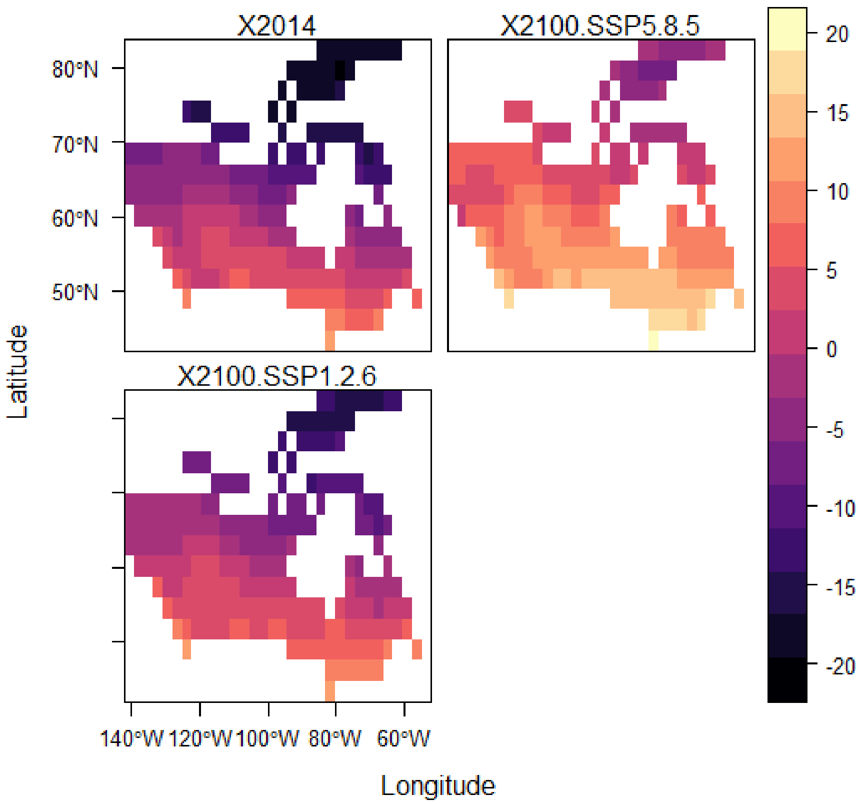

Figure 6 - Frequency distribution level plot of SSP 1-2.6, SSP 5-8.5 and historical data of the CanESM5 model across Canada.

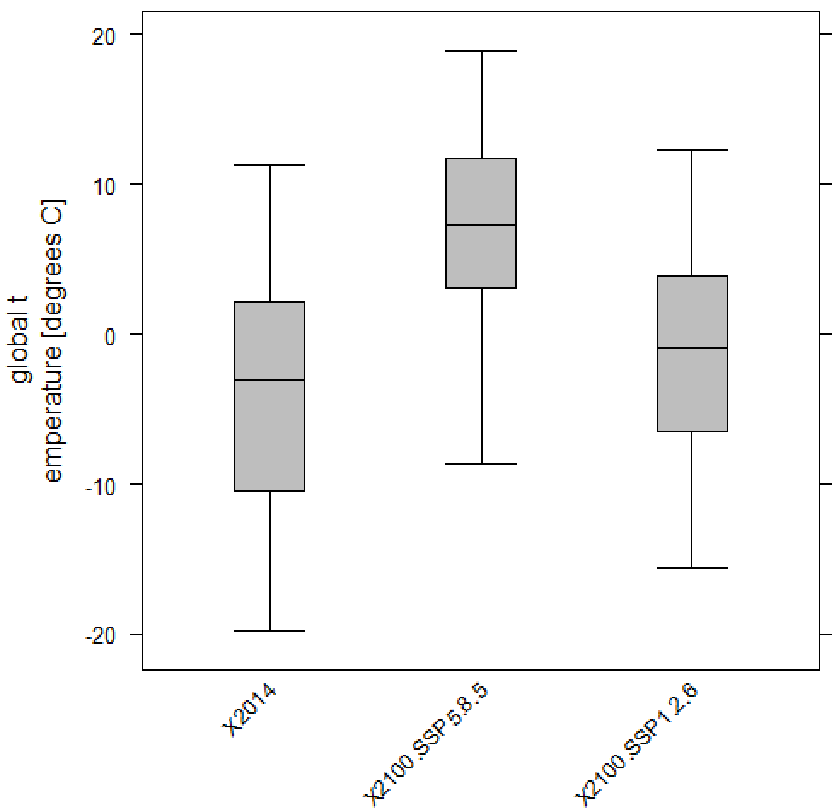

Figure 7 - Box plot showing frequency distribution of historical data alongside SSP 5-8.5 and SSP 1-2.6 scenarios of near surface temperature across Canada from the CanESM5 model

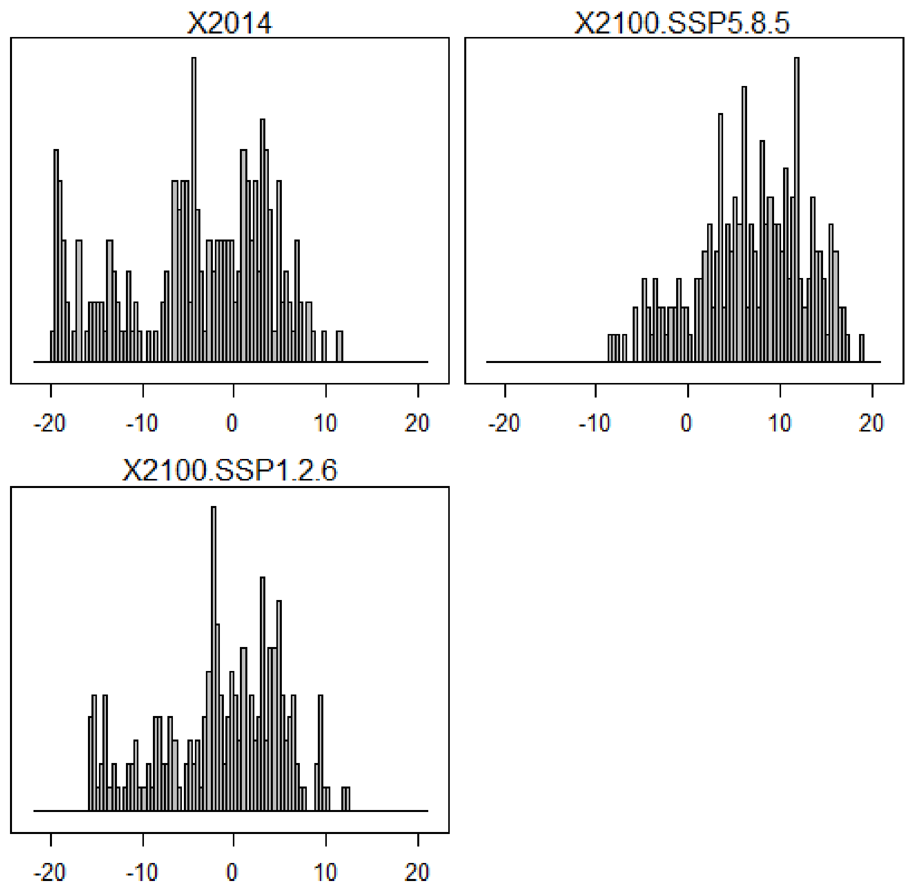

Figure 8 - Histogram showing frequency distribution of historical data alongside SSP 5-8.5 and SSP 1-2.6 scenarios of near surface temperature across Canada from the CanESM5 model

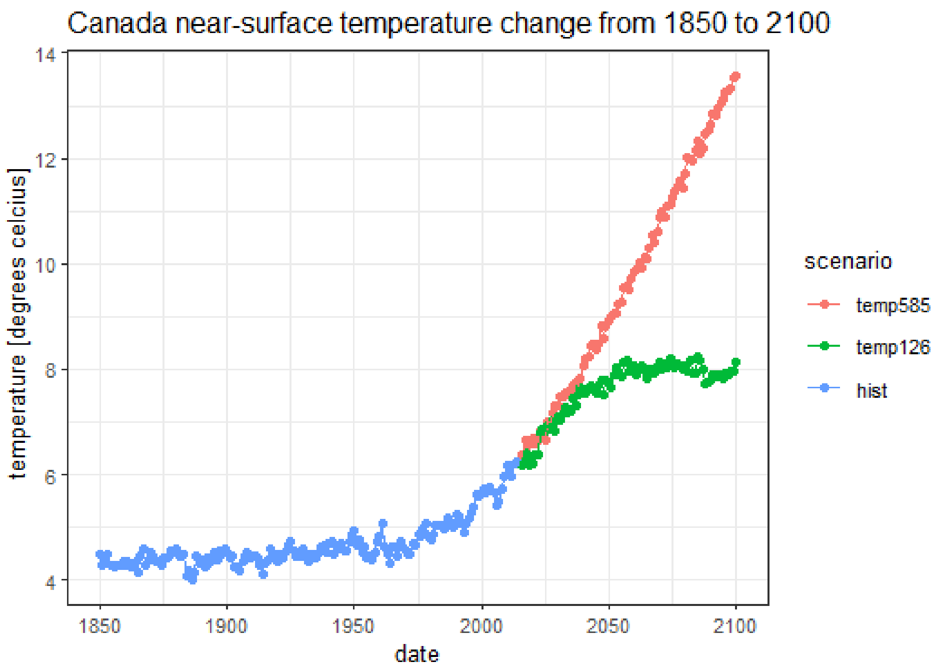

Figure 9 - Line graph of historical near-surface temperature across Canada (1850-2014) alongside SSP 5-8.5 and SSP 1-2.6 near-surface temperature projections across Canada from the CanESM5 model

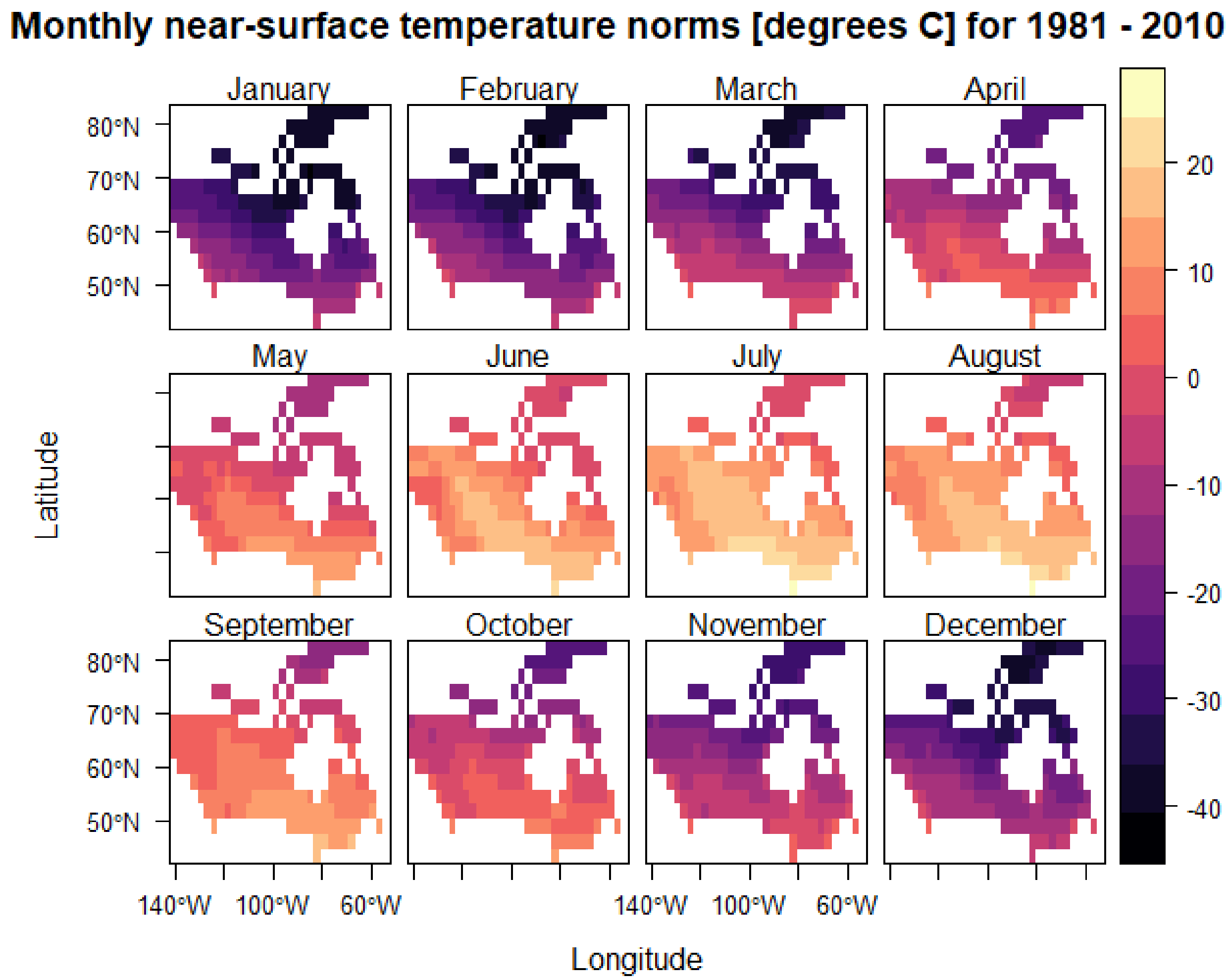

Figure 10 – Level plot of the monthly near-surface temperature norms across Canada for the 1981-2010 baseline period from the CanESM5 model

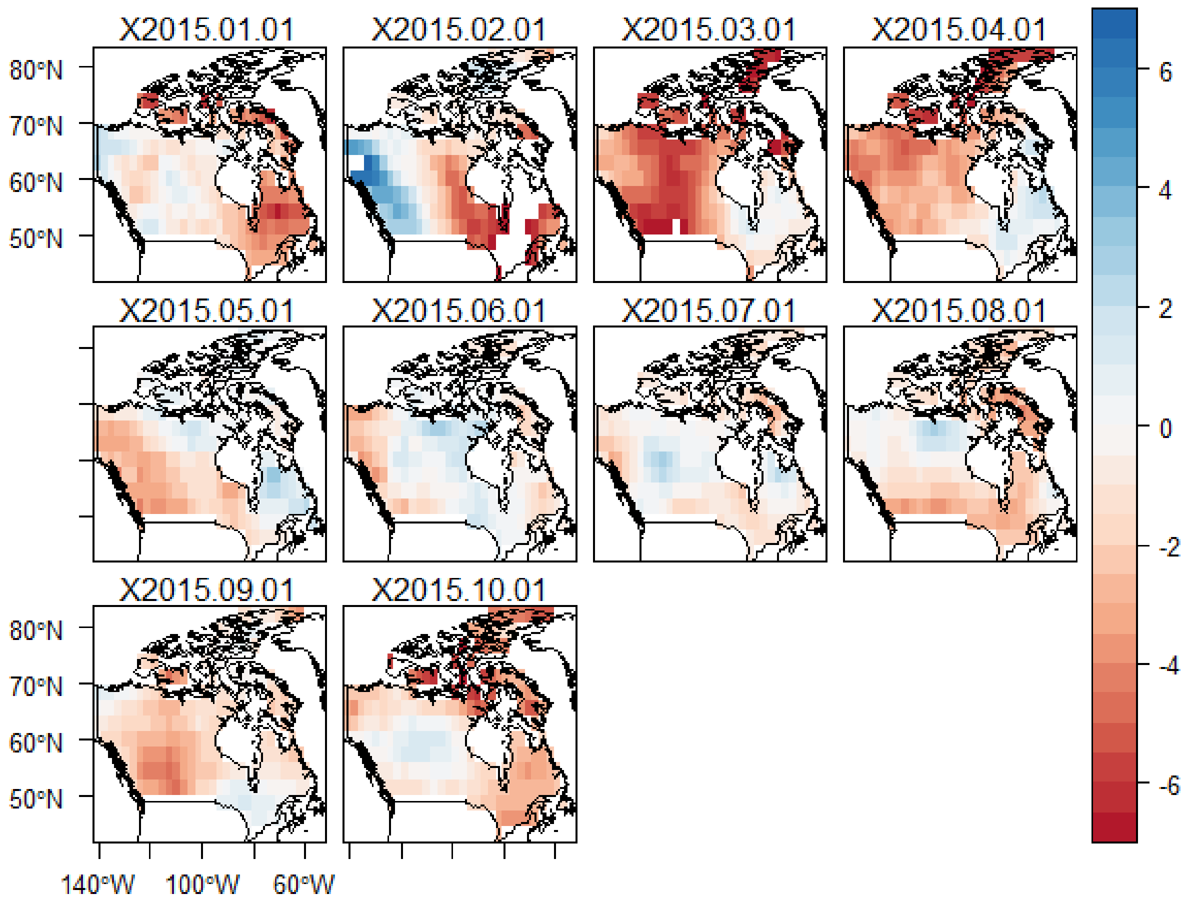

Figure 11 – Level plot illustrating monthly near-surface temperature anomalies of the SSP 1-2.6 scenario across Canada in comparison to the baseline period of historical near-surface temperatures from 1981-2010

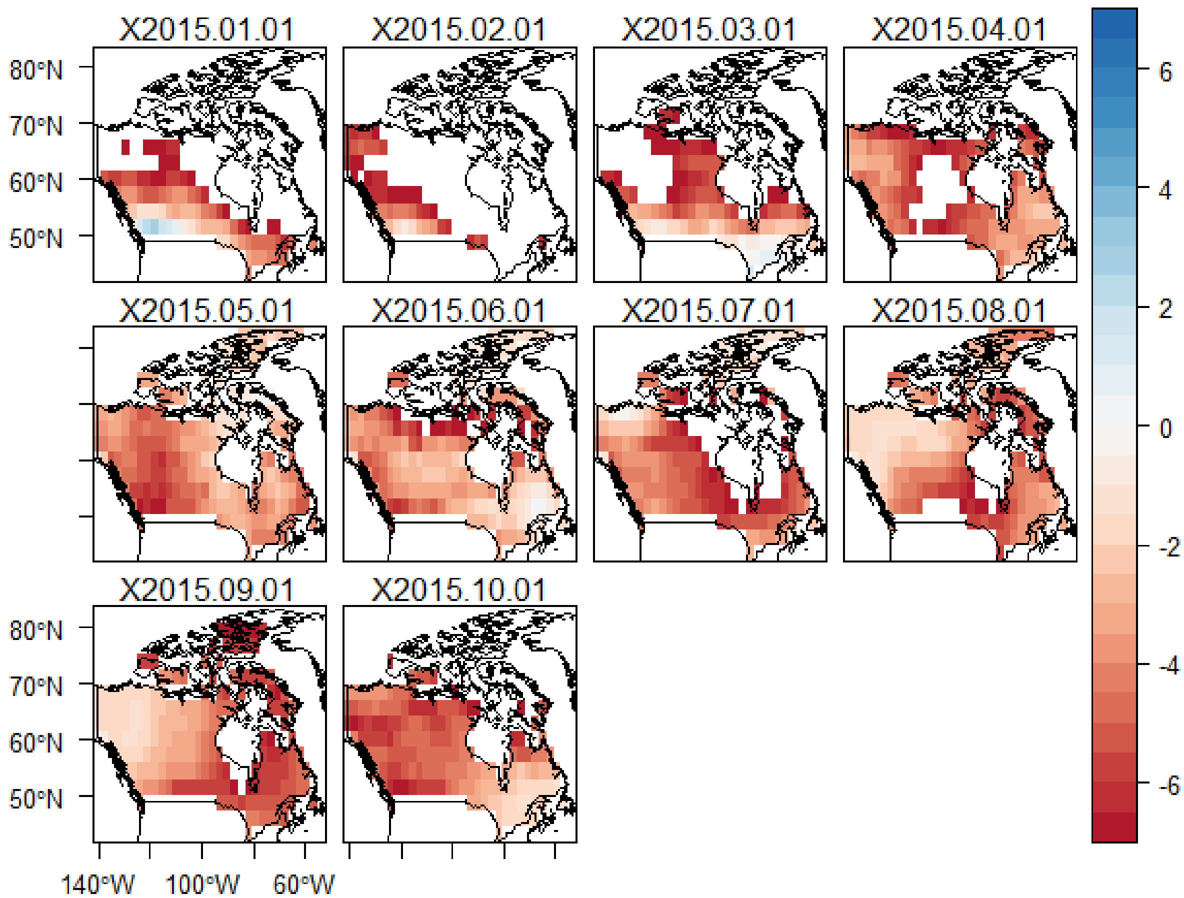

Figure 12 – Level plot illustrating monthly near-surface temperature anomalies of the SSP 5-8.5 scenario across Canada in comparison to the baseline period of historical near-surface temperatures from 1981-2010

Acknowledgments

N/A

Open Research

AGU requires an Availability Statement for the underlying data needed to understand, evaluate, and build upon the reported research at the time of peer review and publication. Additionally, authors should include an Availability

Statement for the software that has a significant impact on the research. Details and templates are in the Availability Statement section of the Data & Software for Authors Guidance. For physical samples, use the IGSN persistent identifier, see the International Geo Sample Numbers section.

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