The consideration of a changing climate for continuously welded rail

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The consideration of a changing climate for continuously welded rail

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ABSTRACT

Canada's climate has been warming at a rate that is approximately double the global average between 1948 and 2016. Climate change is impacting Canada more than the world as a whole, with climate models predicting further warming during all four seasons, ranging from an increase of a low of 1.8 ºC to a high of 6.3 ºC depending on the emissions trajectory (or representative concentration pathway). Canada's extensive rail network of 46,000 km traverses from coast to coast through different climate zones. Without expansion joints to release thermal stress buildup due to changes in ambient temperature, continuously welded rail (CWR) is vulnerable to climate change. The increase in magnitude and frequency of extreme temperature events projected under future climate will induce additional longitudinal stress in the rail. This paper examines how the projected changes in climate will impact CWR, latest climate data and models, as well as propose a method, along with a case study to incorporate future climate scenarios into CWR thermal stress management practices for specific sites.

1 INTRODUCTION

Canada has one of the most extensive rail networks in the world. Its 46,000 km of track stretches from the pacific west coast all the way to the Maritimes, in addition to providing vital connections for communities in the far north (Transport Canada, 2020). As a result, the system traverses through some of the harshest climatic zones in the world, including the dry, humid mesothermal, humid microthermal and polar, (Natural Resources Canada, 1957) where temperatures can vary from −63 ºC[1] (Government of Canada, 2019) to 49.6 ºC[2].

Continuously welded rail (CWR) is the preferred main track construction in Canada, where long sections of rail steels are welded together to form the running surfaces for trains. Since CWR eliminates the gaps that allows for rail steels to expand or contract with changes in temperature, it is vulnerable to temperature fluctuations and extremes, as large thermal stresses can build up potentially leading to rail buckles in hot weather conditions and rail breaks in cold weather conditions.

Meteorological observations and records show that the climate around the world is changing, and that the change is impacting Canada at a faster rate, which will in turn magnify the CWR vulnerability.

The objective of this paper is to provide information on (1) how the projected changes in climate will impact CWR, (2) climate data and models, (3) a method derived from the latest climate research to incorporate future climate scenarios into future CWR thermal stress management practices, (4) results from a case study, and (5) recommendations for the future.

2 CURRENT CWR THERMAL STRESS MANAGEMENT METHODS

Track systems generally consist of a superstructure (rails, anchors and ties) and a substructure (ballast, sub-ballast and subgrade).

For new CWR construction, the track system is pre-stressed during initial install such that it experiences no thermal stress at a set temperature point, also known as the rail neutral temperature (RNT). For Canada, RNT for new CWR construction is generally 32 ºC, though this value may be adjusted based on the climatic conditions of different locations. Track systems (superstructure and substructure) that is well constrained will resist movements induced by thermal stresses. However, track resistance will weaken over time from wear and tear due to rail operations and maintenance, as well as climatic actions such as freeze-thaw cycles, and temperature fluctuations and extremes, making the system increasingly more vulnerable to failure due to large stress buildup (Zhang et al., 2018). In addition, RNT changes over time due to a variety of reasons including track maintenance activities. These factors make it difficult for track engineers to estimate the thermally induced longitudinal stress in CWR.

[1] Recorded in Snag, Yukon (1947)

[2] Recorded in Lytton, British Columbia (2021)

Railways employ a variety of methods to manage thermal stress in CWR, including (1) *track inspections* (*visual and automated)* to identify physical evidence of stress buildup, (2) *speed restrictions*, often imposed as temporary measures during extreme temperature conditions, as well as after maintenance activities such as tamping, (3) *rail de-stressing*, where the rail is cut to release excessive compressive stress buildup, (4) *rail re-stressing*, where rail lengths are adjusted using heaters or coolers, (5) *rail repair*, where plug rails are added to repair rail sections. (Ahmad et al., 2009)

3 THE IMPACT OF AMBIENT TEMPERATURE ON CWR

Thermal stress buildup in CWR is a complex relationship between a variety of factors, including RNT, the temperature of the rail steels and track resistance, all of which are difficult to measure on a network wide basis.

Even though rail temperature can be affected by factors such as sun exposure, wind conditions, shade and topography, it is strongly influenced by ambient temperature conditions, a parameter that is measured and recorded across Canada, and more readily available.

Several railways in North America use equations 1 and 2 to determine rail temperature using ambient measurements in summers and winters, respectively, (Ahmad et al., 2009)

$$T_r = T_a + 16.6 \qquad [1]$$

$$T_r = T_a \qquad [2]$$

where T_r is the rail temperature, and T_a is ambient temperature, both in ºC.

4 THE CONTEXT OF A CHANGING CLIMATE IN CANADA

Official temperature measurements are typically done at a height of 2 m above the ground in Canada. While some weather stations have been operating since the 1840's, few official observation sites' records predate 1948. For this reason, 1948 is most often used as the starting point for climatic analysis in Canada.

Between 1948 and 2016, the average temperature in Canada increased by 1.7ºC, approximately double the global average. As shown in Table 1, the warming trend is expected to continue in the future in every region across the country.

Table 1. Projected changes in annual mean surface air temperature, based on Coupled Model Intercomparison Project Phase 5 multi-model ensemble, relative to 1986-2005. (Government of Canada, 2019)

Region	Scenario; Period; Median Temperature Change (25th, 75th percentile), ºC			
	Low Emission Scenario		High Emission Scenario	
	2031-2050	2081-2100	2031-2050	2081-2100
British Columbia	1.3 (0.8, 1.9)	1.6 (1.1, 2.1)	1.9 (1.4, 2.5)	5.2 (4.3, 6.2)
Prairie	1.5 (1.1, 2.1)	1.9 (1.2, 2.2)	2.3 (1.7, 3.0)	6.5 (5.2, 7.0)
Ontario	1.5 (1.1, 2.1)	1.7 (1.0, 2.1)	2.3 (1.7, 2.9)	6.3 (5.3, 6.9)
Quebec	1.5 (1.0, 2.1)	1.7 (1.0, 2.2)	2.3 (1.7, 2.9)	6.3 (5.3, 6.9)
Atlantic	1.3 (0.9, 1.8)	1.5 (0.9, 2.0)	1.9 (1.5, 2.4)	5.2 (4.5, 6.1)
North	1.8 (1.2, 2.5)	2.1 (1.3, 2.5)	2.7 (2.0, 3.5)	7.8 (6.2,8.4)
Canada	1.5 (1.0, 2.1)	1.8 (1.1, 2.5)	2.3 (1.7, 2.9)	6.3 (5.6, 7.7)

5 POTENTIAL IMPACTS OF THE PROJECTED CHANGES ON CWR TRACK

Warming has been observed across Canada, however the rate of warming has not been uniform. From 1948 to 2016, Canada's northwest experienced the most rapid rates of warming, where the average temperature of some regions increased by more than 3ºC (approximately 3 times the global average). Comparatively, over the same time period, Canada's southeast underwent the slowest rate of warming, where the average temperature in some maritime regions increased by less than 1ºC. In most parts of Canada, warming has impacted winter more than other seasons, especially in northern British Columbia (BC) and Alberta, Yukon, Northwest Territories, and western Nunavut, where average temperatures have increased between 4ºC to 6ºC. This trend is consistent in Ontario and the Prairie provinces, though the warming in these regions has been occurring at a comparatively slower rate. In contrast, Quebec and Atlantic Canada experienced more rapid rates of warming in the summer months than in the winter months. Going forward, accelerated warming is projected to disproportionally impact more northern latitudes. These trend signals the need to incorporate more regional approaches to CWR stresses management based on the local climate.

Warmer winters across Canada have resulted in a country-wide average decrease of more than 15 frost days[3] and 10 ice days[4] from 1948 to 2016. This trend is expected to continue, along with snow shifting to rain in the spring and autumn. In addition, since 1948, the number of extreme hot days[5] have increased in Canada and the trend is expected to drastically continue. By the end of the century, as seen in Figure 1, under high emissions scenarios, the number of hot days could be increased by 50 per year in regions that

[3] Daily minimum temperature ≤ 0ºC
[4] Daily maximum temperature ≤ 0ºC
[5] Daily maximum temperature ≥ 30ºC

currently experience them. These trends signal a potential future shift of needing to manage more compressive stresses due to warmer weather than tensile stress resulting from cold weather, including potentially more inspections due to hot days, more hot weather slow orders, and more rail destressing. These factors also signal the need to review RNT values for future new CWR construction, especially in regions projected to undergo more rapid warming.

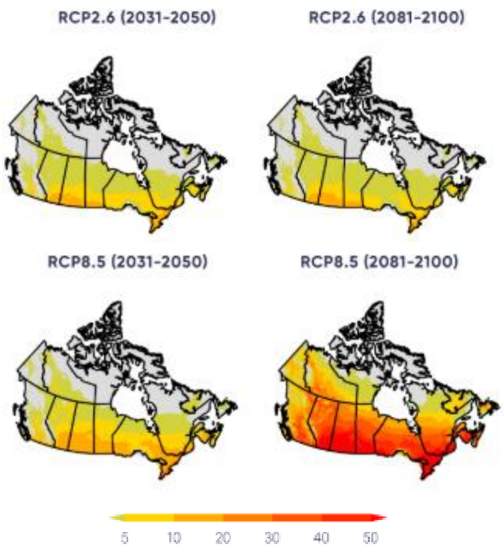

Figure 1. Projected number of annual hot days under different emissions scenarios. (Government of Canada, 2019)

The next sections provide information on modelling of future climate, available data, as well as a method derived from current climate science that could be employed to incorporate climate projections into future CWR thermal stress management practices.

6 CLIMATE MODELS AND DATA

Climate models are simulated by earth systems models, which consists of mathematical representations of the complex physical and biogeochemical processes related to the atmosphere, ocean, land surface, and cryosphere (Government of Canada, 2019). These processes are global in nature, are typically examined at a resolution of 100 km or more, and are used to simulate historical climate as well as make projections of future climate based on expected human activities (or emission scenarios).

All climate models have uncertainties since the mathematical representations used are approximated. To compensate for this, an ensemble of different climate models, each with its own set of assumptions, methodologies and projections, is often used for analytical purposes. The Coupled Model Intercomparison Project (CMIP) established by the World Climate Research Programme sets out standards and experimental protocols that allows for direct comparisons of different models, assumptions and results under a common set of conditions and scenarios. The climate models and projections developed within the fifth phase of the project (CMIP5), was used in the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report (released in 2014). The CMIP5 emission scenarios are referred to as *representative concentration pathways* (RCP) with an associated number indicating the change in radiative forcing (W/m^2). RCP2.6 represent a low emission scenario, while RCP8.5 represent a high emission scenario. A new phase of the project (CMIP6) is currently underway with an expanded set of standards and modified emissions scenarios. Projections from the newest suite of climate models are expected to be incorporated into IPCC's 6th assessment reports, scheduled for release from late 2021 through to 2022. The ensemble approach enables researchers to examine how climate models differ, how parameters affect results, and the range of results produced under the same scenarios.

At the time of writing, there are a number of curated future climate projections datasets available for use in the public domain. They are downscaled from ensembles of CMIP5 global climate model projections of 100 km+ resolution to a resolution of 10 km to 15 km for regions within Canada (Zhang et al., 2021). These datasets include, Ouranos (Consortium sur la climatologie régionale et l'adaptation aux changements climatiques, 2021), the Pacific Climate Impacts Consortium (Parific Climate Impact Consortium, 2021), and ClimateData.ca (Environment and Climate Change Canada et al., 2018). With the release of CMIP6, it is expected that datasets from the new suite of climate models will be available for use in the near future.

Climate records such as daily temperature observations from weather stations are readily available in Canada through the historical data site of the Government of Canada (Government of Canada, 2021a) and ClimateData.ca. As shown in Figure 2, there is a relatively extensive distribution of weather stations along key rail corridors.

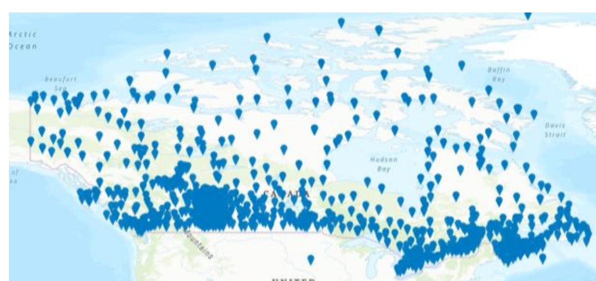

Figure 2. Meteorological stations across Canada. (Government of Canada, 2021b)

7 PROPOSED METHOD TO INCORPORATE FUTURE CLIMATE SCENARIOS INTO CWR THERMAL STRESS MANAGEMENT PRACTICES

The proposed method makes use of data readily available in the public domain, including climate projections and historical temperature records as described in section 6.

Results from climate models typically have a simulated historical climate as shown in Figure 3 in grey, and projections of future climate as shown in Figure 4 in colour, under various emissions scenarios.

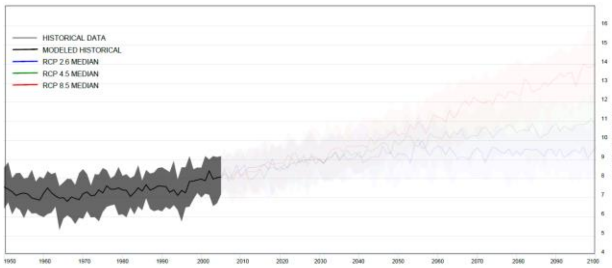

Figure 3. An example of simulated historical climate by climate models. (Environment and Climate Change Canada et al., 2018)

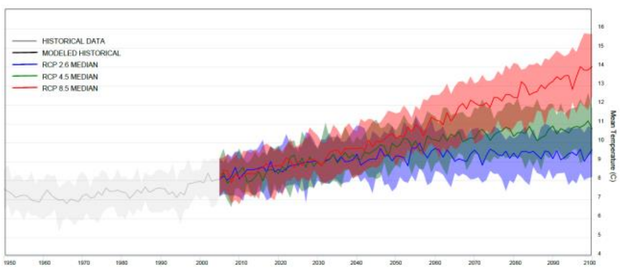

Figure 4. An example of predicted future climate by climate models. (Environment and Climate Change Canada et al., 2018)

The first step is to evaluate how realistic the selected climate model (or ensemble) represents the key earth systems that drive the model. This is done by comparing its simulated past climate with actual historical temperature records (observations) from weather stations as shown in Figure 5, and determining whether a calibration/transfer function is needed to correlate the two datasets.

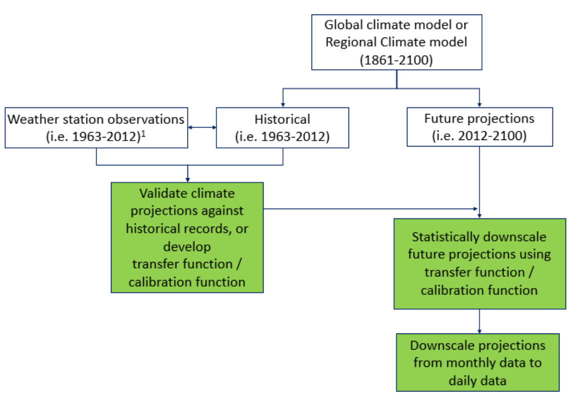

Figure 5. Schematic of the proposed method to derive future data for analytical purposes.

The next step is to integrate the calibration/transfer function into future projections as per Figure 5, to produce a calibrated dataset. This step is also known as statistical downscaling.

Future temperature projections within climate models (Figure 4) are often available in the form of monthly averages. For analysis requiring daily temperature projections, it will be necessary to generate daily temperature datasets using one of many established downscaling methods, such as delta change, enhanced change factors, and synoptic map, etc. (Zhang et al., 2021).

These projected monthly/daily temperatures can be used to compare with historical and present baseline environmental conditions to determine how the climate has changed, and the projected change, along with the rate of projected change within a 5-year, 10-year, 20-year and 30+ year window. This information will be valuable in determining the regions within Canada most vulnerable to climate change, whether there is a need to review current CWR thermal stress management methods, including RNT values.

8 CASE STUDY AND ANALYSIS

Kamloops, BC was selected as a case study for the initial phase of this research for a number of reasons. The Kamloops A weather station, as shown in Figure 6, has continuous observational records dating back to 1951. The region is situated near a key rail corridor where both Canadian Pacific Railway and Canadian National Railway Company operate. The region experienced record heat during the summer of 2021. In addition, as shown in Figure 1, the number of annual hot days for the region is projected to increase under all future emission scenarios.

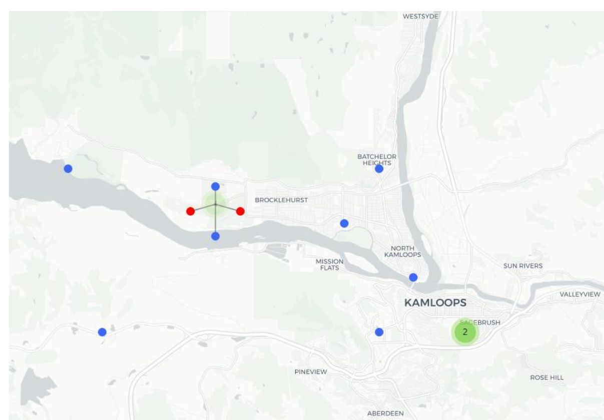

Figure 6. Location of Kamloops A weather station (the red dot on the right stores data from 1951 to 2013, the red dot on the left stores data from 2013 to present). (Environment and Climate Change Canada et al., 2018)

To evaluate how the climate within the region has been changing, as well as the impact of future climate on CWR, the full dataset from the Kamloops A weather station cell (Figure 6, 10 km resolution) was extracted from ClimateData.ca. The extraction included the actual temperature records from the weather station, as well as temperature projections from a 24-model ensemble. The simulated historical temperature by the climate model ensemble is from 1950 to 2005. The projected future climate is in the form monthly averages under different emission scenarios. For each RCP, low, median, and high are provided to reflect the range of uncertainties within the models. (Environment and Climate Change Canada et al., 2018)

As can be seen in Figure 7, the climate models projected an increase of annual average temperature for the region starting at around 1960. At around 2030, the rate of increase will diverge depending on the emission scenario, ranging from an increase of around 2 ºC to more than double by century end (compared to 1960).

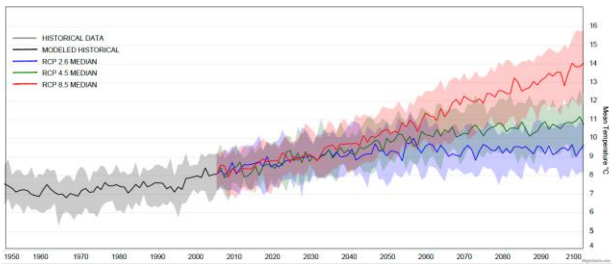

Figure 7. Projected mean annual temperature by climate models. (Environment and Climate Change Canada et al., 2018)

Figure 8 compares the climate projections with actual temperature records from the weather station. Due to data availability, only the median value of each emission scenario is plotted in Figure 8. In general, the temperature records (from 1951 to 2021) indicate that the annual average temperature ranged between 6.5 ºC and 11 ºC, and is at least 1 ºC higher than the projected historical range (Figure 7) by the climate models. If this trend was to continue, it would appear that the future annual average temperature increase would be more in line with a medium or high emission scenario. This set of climate projections only requires minor calibrations to correlate with the Kamloops A weather station data.

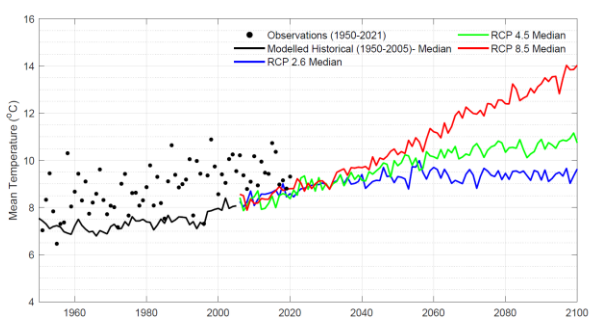

Figure 8. Comparison of mean annual temperature observations versus climate model projections. (Environment and Climate Change Canada et al., 2018)

The coldest annual temperatures projected by climate models (Figure 9) also indicate a warming trend for the region. Though, there appears to be more overlap in the range of projected future coldest annual temperatures under the different emission scenarios, as there is not a clear diverging trend in the rate of change until the 2070’s.

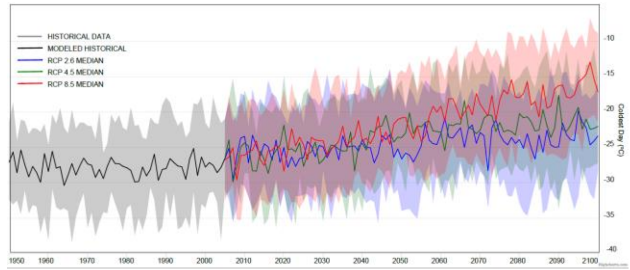

Figure 9. Projected coldest annual temperature by climate models. (Environment and Climate Change Canada et al., 2018)

Figure 10 compares the projections of the coldest annual temperatures with actual temperature records from the weather station. The temperature records (from 1951 to 2021) indicate that the annual coldest temperature ranged between -37.5 ºC and -13 ºC. Since 1980, rarely has the coldest annual temperature dropped below -29 ºC. In general, temperature observations are either within the projected historical range of the climate models, or higher than the projected range (by up to 13 ºC). Since there is quite an overlap between the projected future temperature ranges of the different emissions scenarios, the current trend appear to be in line with all three scenarios in the near future. Compared to average annual temperature dataset, this set of climate projections requires more calibrations to correlate with the Kamloops A weather station data.

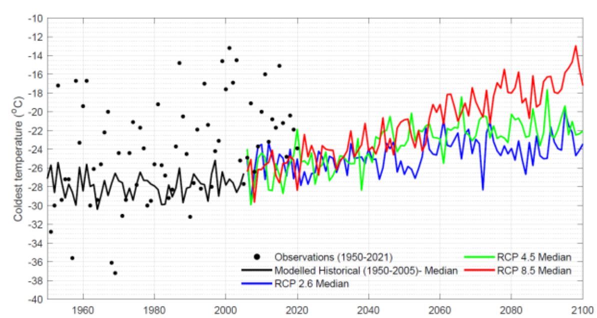

Figure 10. Comparison of coldest annual temperature observations versus climate model projections. (Environment and Climate Change Canada et al., 2018)

The number of annual days with temperature less than -25 ºC projected by climate models, as shown in Figure 11, is decreasing for the region. Depending on emission scenario, the region might not experience below -25 ºC starting as early as the mid 2030’s.

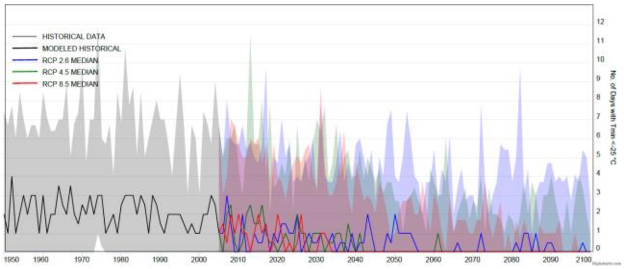

Figure 11. Projected number of annual cold days by climate models. (Environment and Climate Change Canada et al., 2018)

Figure 12 compares the projections of the number of <-25 ºC days with actual temperature records from the weather station. In general, the temperature records (from 1951 to 2021) indicate that most years had 6 or less cold days, with many winters without any cold days, which is within the projected historical range by the climate models. This trend appears to be in line with future projections regardless of emission scenario. This set of climate projections only requires minor calibrations to correlate with the Kamloops A weather station data.

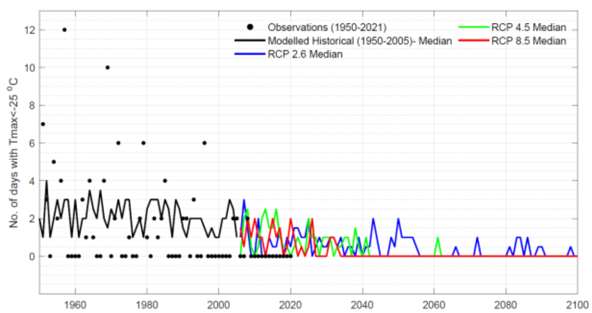

Figure 12. Comparison of the number of annual cold days recorded versus climate model projections. (Environment and Climate Change Canada et al., 2018)

The hottest annual temperatures projected by climate models (Figure 13) also indicate a warming trend for the region starting around the mid 1970's. At around 2045, the rate of increase will diverge depending on the emission scenario, ranging from an increase of around 2 ºC to 12 ºC by century end (compared to 1975).

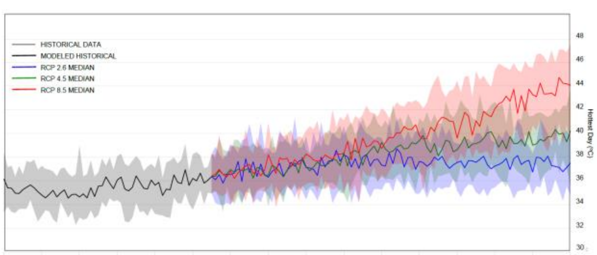

Figure 13. Projections of hottest annual temperature by climate models. (Environment and Climate Change Canada et al., 2018)

Figure 14 compares the projections of the hottest annual temperatures with actual temperature records from the weather station. The temperature records (from 1951 to 2021) indicate that the annual hottest temperature ranged between 32.5 ºC and 41 ºC, and in general is either within the projected historical range of the climate models, or higher than the projected range by around 2 ºC. If this trend was to continue, it would appear that the future hottest annual temperature increase would be more in line with a medium or high emission scenario. This set of climate projections only requires minor calibrations to correlate with the Kamloops A weather station data.

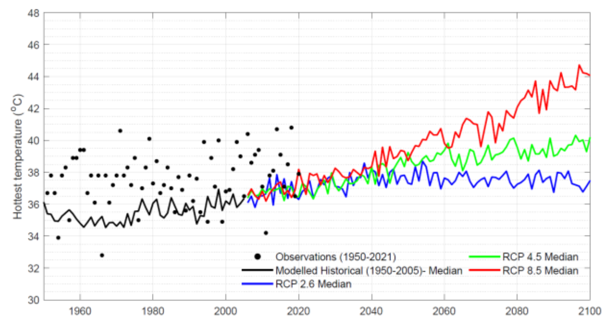

Figure 14. Comparison of hottest annual temperature observations versus climate model projections. (Environment and Climate Change Canada et al., 2018)

The number of annual hot days projected by climate models, as shown in Figure 15, is increasing for the region starting around the 1970's. Depending on emission scenario, the upward range of the number of hot days per year could increase to around 70 days by 2050, and to more than 100 days by century end.

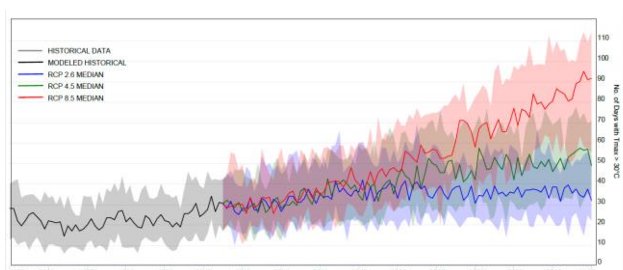

Figure 15. Projections of the number of annual hot days by climate models. (Environment and Climate Change Canada et al., 2018)

Figure 16 compares the projections of the number of hot days with actual temperature records from the weather station. The temperature records (from 1951 to 2021) indicate that the number of hot days within a given year ranged from as few as 4 days, to as many as 67. Quite a number of years had 10 to 15 more hot days than projected by climate models. The trend appears to be more in line with a future medium or high emission scenario. Compared to other datasets, this set of climate projections requires more calibrations to correlate with the Kamloops A weather station data.

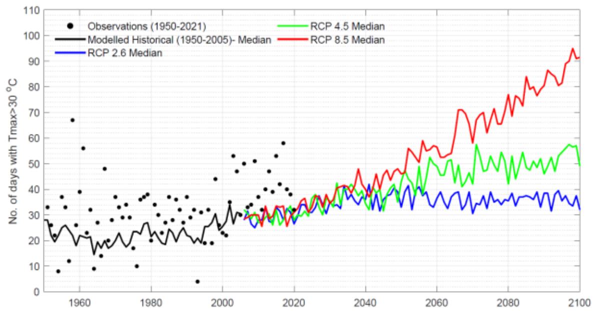

Figure 16. Comparison of the number of annual hot days recorded versus climate model projections. (Environment and Climate Change Canada et al., 2018)

9 CONCLUSIONS

Without expansion joints to release thermal stress buildup due to changes in ambient temperature, CWR is vulnerable to climate change.

This paper explored how projected future changes in ambient temperature will impact CWR, provided information on currently available climate models and data, as well as a method derived from climate research on how to incorporate future climate scenarios into CWR thermal stress management considerations.

A case study was performed on the Kamloops, BC region. Temperature records from 1951 were compared with the projected temperatures from a 24-climate model ensemble with respect to (1) the average annual temperature, (2) the coldest annual temperature, (3) the number of cold days per year, (4) the hottest annual temperature and (5) the number of hot days per year. The simulated historical temperatures by climate models compared well to historical records in 3 of the 5 datasets, with the coldest annual temperature and the number of hot days per year needing additional calibration. The trend indicated that the average annual temperature of the region is on track to increase to a range of 8 ºC to 11 ºC by 2030 and 2040, 8 ºC to 12 ºC by 2050 (from a baseline of 6 ºC to 11 ºC, 1951 to 2021). The coldest annual temperature is on track to increase, potentially significantly from a baseline of -37.5 ºC to -13 ºC (1951 to 2021). The number of cold days a year is on track to decrease to less than 6 per year by 2030 and 2040 (in line with the baseline, 1951 to 2021), and where many years could potentially experience no cold days. The hottest temperature is on track to increase to a range of 35 ºC to 41 ºC by 2030, to upwards of 42 ºC by 2040 and 2050 (from a baseline of 32.5 ºC to 41 ºC, 1951 to 2021). The number of hot days per year is also on track to increase, potentially significantly compared to the baseline of 4 to 67 per year from 1951 to 2000, and 20 to 60 per year from 2000 to 2021, indicating a potential need to review future RNT for the region and possible prolonged operation in extreme heat annually.

10 RECOMMENDATIONS

As evident in temperature observations across the country, a changing climate has already impacted every region within Canada, though the rate of change has not been uniform. An important next step is to determine which regions/locations along key rail corridors that are most vulnerable to climate change with respect to the parameters most relevant to CWR thermal stress management, including the rate of warming, projected extreme temperature fluctuations, as well as the number of projected cold days and hot days.

Another recommendation is to examine past climate records, RNT, maintenance records, and operating speed records in those vulnerable locations, to determine whether a changing climate has already impacted CWR thermal stress management.

It is also recommended to use the latest climate models and data to project future climate scenarios similar to that used in the case study to review current construction, operation and maintenance methods to determine whether there will be a need to better adapt them within a 5-year, 10-year, 20-year and 30+ years timeframe.

11 ACKNOWLEDGEMENT

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