Changes in Asphalt Binder Grade Due to Climate Change in Canada

Surya T. Swarna, M. Tech.
Ph.D. Candidate
Department of Civil Engineering
Advanced Road & Transportation Engineering Lab (ARTEL)
Memorial University of Newfoundland
St. John's, Newfoundland, A1B 3X5, CANADA
Email: stswarna@mun.ca

Dr. Kamal Hossain, Ph.D., P.Eng.
Assistant Professor
Department of Civil Engineering
Advanced Road & Transportation Engineering Lab (ARTEL)
Memorial University of Newfoundland
St. John's, Newfoundland, A1B 3X5, CANADA
Email: kamalh@mun.ca

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Abstract

In recent years, average temperatures in Canada have been continuously increasing, owing to changes in the global climate. This can be attributed to a surge in the concentration of greenhouse gases in the atmosphere. Climate scientists predict the trend to further aggravate in the near future. Pavement performance models show that changing climate will result in accelerated pavement deterioration. To mitigate pavement deterioration, various adaptation strategies have been suggested in the recent literature. One of these adaptation strategies is upgrading the superpave asphalt binder grade. It is well known that asphalt binder is highly sensitive to climate factors such as temperature and percent sunshine. Hence, reviewing asphalt binder grade is a vital step, and that can help decelerate pavement deterioration. The goal of this research is to determine new asphalt binder grades across Canada based on the projected climate data. To achieve this goal, the analysis was carried out in four phases. In the first phase, statistically downscaled climate change models were gathered from the Climate Change model database. Then in the second phase, python code is written to extract the maximum and minimum temperatures from the climate change models for a particular location. Later in the third phase, from the extracted maximum and minimum temperature, average seven-day maximum pavement temperature and minimum pavement temperature are determined using the LTPP pavement temperature prediction model. Lastly, high-temperature grade (XX) and low temperature grade (YY) of an asphalt binder (PG XX – YY) are estimated using the average seven-day maximum and minimum pavement temperature respectively and tabulated in an easy-to-use format for application by the transportation agencies in Canada. Note this paper presents a very brief summary of this research project and five climate models used in the analysis. Finally, this paper also presents the revised asphalt binder grades for ten different locations, each from one of the provinces.

Keywords: Climate change, Superpave asphalt binder grade, downscaling, pavement deterioration

Introduction

Anthropogenic climate change has an adverse effect on Canadian weather. The last 50 years have seen a rapidly increasing trend in average annual temperatures. Precipitation has been unpredictable, with high-intensity rainfall occurring in a shorter period of time. These severities are in line with global changes in climate, occurring due to an increase in concentrations of greenhouse gases in the atmosphere. With the current emission scenarios, scientists predict the trends to further intensify in the near future. Also, several studies noticed a temperature rise due to climate change in Canada (Vincent et al. 2018), United States (Paquin, De Elía, and Frigon 2014), South America (Marengo et al. 2012), Europe (Meleux, Solmon, and Giorgi 2007), Africa (Jones and Thornton 2009), Middle East (Evans 2009), China (Zhai and Pan 2003), India (Dash et al. 2007), Central Asia (Lioubimtseva and Henebry 2009), Southeast Asia (Gasparrini et al. 2017) and Australia(Hughes 2003). Pavement performance models show that changing climate will result in accelerated pavement deterioration. A recent study by Rana et al. identified temperature rise as a significant factor that affects the pavement performance in Newfoundland, Canada (Rana, Swarna, and Hossain 2020). To mitigate pavement deterioration, various adaptation strategies have been suggested in the recent literature. One of these adaptation strategies is upgrading the superpave asphalt binder grade. It is well known that asphalt binder is highly sensitive to climate factors such as temperature and percent sunshine. Therefore, this study aims to quantify the impact of climate change on asphalt binder grade selection.

Mills et al. estimated the change in superpave binder grade for seventeen sites in southern Canada using two climate change scenarios A2x and B21 from Coupled Global Climate Model 2 (CGCM2A2x) and the Hadley Climate Model 3 (HadCM3B21) experiments respectively. This revealed that six out of 17 sites needed an upgrade to the high-temperature grade, and at eight out of 17 sites, there was a rise in low-temperature grade by 2050 compared to a baseline climate of 1961 - 1990 (Mills et al. 2009). Similar work has been done by Viola and Celauro in Italy to evaluate the asphalt binder upgrade at 71 different locations (Viola and Celauro 2015). In this study, a change in temperature was estimated for 2033 using spatial interpolation based on historical data (1984-2013), corresponding pavement temperature was also computed. It was noted that there is an increase of one grade in high-temperature grade over 27% of the Italian territory.

On the other hand, there was no noticeable change in low-temperature grades in this territory (Viola and Celauro 2015). A similar study estimated the asphalt binder grade in Chile using the MICRO5 climate change model for RCP 2.6 and RCP 8.5 emission scenarios (Delgadillo et al. 2018). A total of 94 weather stations were considered in the selection of asphalt binder grades throughout the country. This study identified a significant number of stations in need of a change in binder grade. Fletcher et al. estimated the change in pavement temperature for selecting superpave asphalt binder grade for the future climate in Canada. The author considered 10 GCM simulations for the SRESA2 emissions scenario. The study concluded that nine out of 17 cities exhibited an increase in high-temperature asphalt binder grade (Fletcher et al. 2016).

In very recent years, a study was carried out to assess the upgrade of asphalt binder grade in the United States. The study noticed that, over the 799 observed weather stations, 35% of station's asphalt binder grade based on 1965-1996 is different from binder grade based on 1985-2014 weather data (Underwood et al. 2017). This study illustrated a contour map for average seven-day maximum temperature and average minimum temperature changes for 2010–2039, 2040–2069 and 2070–2099 with respect to a baseline period of 1966 – 1995, as presented in Figure 1.

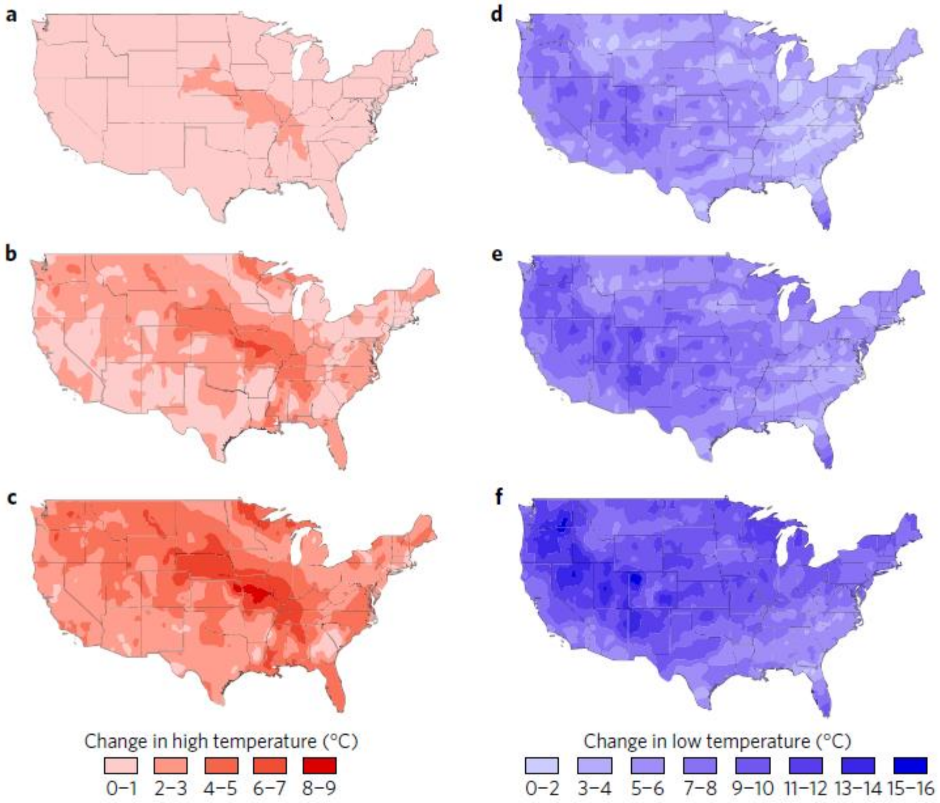

Figure 1: Expected change in pavement temperatures for 2010–2039, 2040–2069 and 2070–2099 (Underwood et al. 2017)

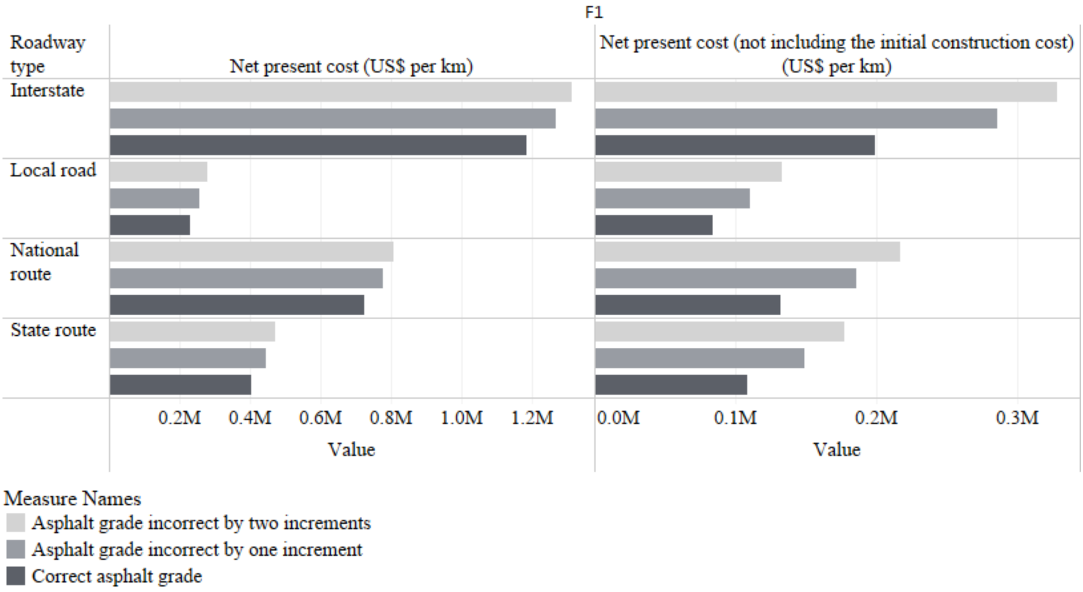

Figure 2: economic costs of a flexible pavement with the use of correct and incorrect asphalt grade, (a) Net present cost not including the initial construction cost and (b) Net present cost including the initial construction cost (Underwood et al. 2017)

Underwood et al. estimated the economic costs of a flexible pavement with the use of correct and incorrect asphalt grade for all roadway types, as illustrated in Figure 9 (Underwood et al. 2017). For 2040, the estimated costs across the United States are US$19.0 and US$26.3 billion for RCP 4.5 and RCP 8.5, respectively. Similarly, for 2070, the estimated costs across the United States are US$21.8 and US$35.8 billion for RCP 4.5 and RCP 8.5, respectively. This increased economic costs clearly explain, selecting the correct grade of asphalt binder plays an essential role in the economic costs of pavement.

All of these studies used different climate change models, different locations and different methods for the estimation of pavement temperature from air temperature. However, the mutual conclusion of the studies is that climate change leads to a change in temperature. Upgrading the asphalt binder grade is one of the adaptation strategies for the climate warming regions.

Objective and Scope

The primary objective of this study is to estimate the change in asphalt binder grade in various geographic regions in all provinces in Canada under the changed climate. This paper presents a summary this project and some results for ten different locations (each from one of the provinces). Furthermore, the analysis presented in this paper is restricted to a one analysis period, that is, 2040 – 2070 period.

The scope of this study includes the extraction of daily maximum and minimum temperature data from the five climate models downloaded from the pacificclimate.org and estimating the pavement temperatures using LTPP climate models. Finally, finding out the asphalt binder grade for 2040-2070.

Factors and levels

Ten locations are considered for this study; these locations are one from each of ten provinces in Canada. The locations studied are Vancouver (BC), Edmonton (AB), Regina (SK), Winnipeg (MB), Toronto (ON), Quebec City (QC), Fredericton (NB), Charlottetown (PEI), Halifax (NS), and St. John's (NL). Besides, the climate change models considered in this study are Meteorological Research Institute (MRI-CGCM3), Canadian Centre for Climate Modeling and Analysis (CCCMA-CanESM2), Institute for Numerical Mathematics (INM-CM4), ARC Centre of Excellence for Climate System Science (ACCESS1.0) and Model for Interdisciplinary Research On Climate (MIROC5).

Methodology

The methodology of this study is divided into four phases. In the first phase, statistically downscaled climate change models were gathered from the Climate Change model database. Then in the second phase, python code is written to extract the maximum and minimum temperatures from the climate change models for a particular location. Later in the third phase, from the extracted maximum and minimum temperature, average seven-day maximum pavement temperature and minimum pavement temperature are determined using the LTPP pavement temperature prediction model. Lastly, high-temperature grade (XX) and low temperature grade (YY) of an asphalt binder (PG XX – YY) are estimated using the average seven-day high and low pavement temperature respectively and tabulated in an easy-to-use format for application by the transportation agencies in Canada.

Phase 1: Gathering climate change models

Pacific Climate Impacts Consortium (PCIC) is a Canadian climate database, which offers statistically downscaled climate scenarios at a grid resolution of 1/8th degrees (300 arc-seconds or approximately 10 km) for a period of 1950 – 2100. The variables included in this climate scenarios are maximum and minimum daily temperature. These data are available for three different Representative Concentration Pathways (RCPs) (Meinshausen et al. 2011) such as RCP 2.6, RCP 4.5 and RCP 8.5. These climate scenarios are a combination of historical data and the downscaled climate change model. These downscaled models were constructed using Canadian historical daily data and Global Climate Model (GCM) projections from the Coupled Model Intercomparison Project Phase 5 (Taylor, Stouffer, and Meehl 2012). From all the available climate models, ten climate models were selected based on data availability and method of statistical downscaling.

Data from the GCM sources available in the pacific climate database were downscaled to a very fine resolution using two different statistical downscaling methods such as Bias-Correction Spatial Disaggregation (BCSD) and Bias Correction/Constructed Analogues with Quantile mapping reordering (BCCAQ). BCCAQ is a hybrid method that associations with both Bias Correction/Constructed Analogues (BCCA) (Maurer et al. 2010) and quantile mapping (QMAP) (Gudmundsson et al. 2012). In this study, Models with BCCAQ statistical downscaling method were used. The climate change models used in this study are downloaded from the Pacific Climate data (https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios).

Phase 2: Climate change data extraction

To extract the daily maximum and minimum temperature from the climate change models for the selected location, the python code is written and executed. As the downscaled model contain a square grid of size approximately 10 km x 10 km (1/8°), it is not possible to extract data for the exact location. Therefore, a short distance square method is used to select the nearest grid point. It is assumed that there is no temperature difference between the actual location and the nearest grid point. The python code writer was used to extract the daily maximum and minimum temperature for the selected location.

Phase 3: Determining the average seven-day maximum and minimum pavement temperature

From the extracted daily maximum and minimum air temperature, the average seven-day high and low air temperature are determined for every year from 2040 to 2070. Later, average seven-day high and low pavement temperatures are estimated for the 2040-2070 time period using the LTPP pavement temperature prediction model (Mohseni 1998; 2005), as illustrated below.

$$T_{P\,max} = 54.325432 + 0.78\ T_{air\,max} - 0.0025\,Lat^2 - 15.41\ \log_{10}(H + 25) + z(9 + 0.61\sigma^2_{Tair\,max})^{0.5} \quad (1)$$

$$T_{P\,min} = -1.56 + 0.72\ T_{air\,min} - 0.004\,Lat^2 + 6.26\ \log_{10}(H + 25) + z(4.4\ +\ 0.52\,\sigma^2_{Tair\,min})^{0.5} \quad (2)$$

Where,

$T_{P\,max}$ = Average seven-day high pavement temperature (°C)
$T_{air\,max}$ = Average seven-consecutive-day high air temperature (°C)
$\sigma_{air\,max}$ = Standard deviation of seven-day high pavement temperature (°C)
$T_{P\,min}$ = Low pavement temperature (°C)
$T_{air\,min}$ = Low air temperature (°C)
$\sigma_{air\,min}$ = Standard deviation of low pavement temperature (°C)
Lat = Latitude (in degrees)
H = Depth (mm)
Z = Standard normal distribution value (depends on reliability) = 2.055 for 98% reliability

These seven-day high and low pavement temperatures are estimated at a depth of 20 mm and 0 mm, respectively. Where a seven-day high pavement temperature threshold about 20 mm (H = 20 mm) from the surface of the pavement and low pavement temperature threshold at the surface (H = 0 mm) of the asphalt pavement. Also, the reliability considered in this study as 98%, which has a standard normal distribution value (z) equals to 2.055. These pavement temperatures are computed for five different climate change models.

Phase 4: Assigning Asphalt binder grade

From the estimated mean or median of average seven-day high and low pavement temperatures, the high temperature and low temperature grades are assigned. The grades are assigned in increments of 6°C for both high temperature and low temperature. For example (Vancouver), if the average seven-day high pavement temperature is 54.98°C, then the high-temperature grade assigned is 58°C. Similarly, if the low pavement temperature is -12.19°C, then the low temperature grade assigned is -16°C. Therefore, the performance asphalt grade is PG 58 – 16. The asphalt binder grades are assigned for all the selected locations following the procedure explained in methodology.

Results and Discussions

The annual average daily maximum and minimum temperatures are determined using climate change models and illustrated in Figure 3. From Figure 3, it has been noticed that the maximum and minimum temperatures are significantly increasing due to climate change. From Figure 3, it is also noticed that the climate change model predicts that the annual average daily maximum and minimum temperatures will increases drastically between 2040 to 2100 when compared to 1950 to 2040.

Average seven-day high and low pavement temperatures for all the five models are estimated, and a boxplot of these temperatures is illustrated in Figure 4. It was noticed that there are few outliers in the data, which represent that data is not normally distributed. It is confirmed from the quartile distribution in the boxplot. Therefore, the different conditions of models such as cold model, median model and hot models are considered to determine the upgraded binder for 2040 – 2070. then, the three models are identified, and corresponding average seven-day high and low pavement temperatures are computed to assign the asphalt binder grade. The average seven-day high and low pavement temperatures for the median model are presented in Figure 5.

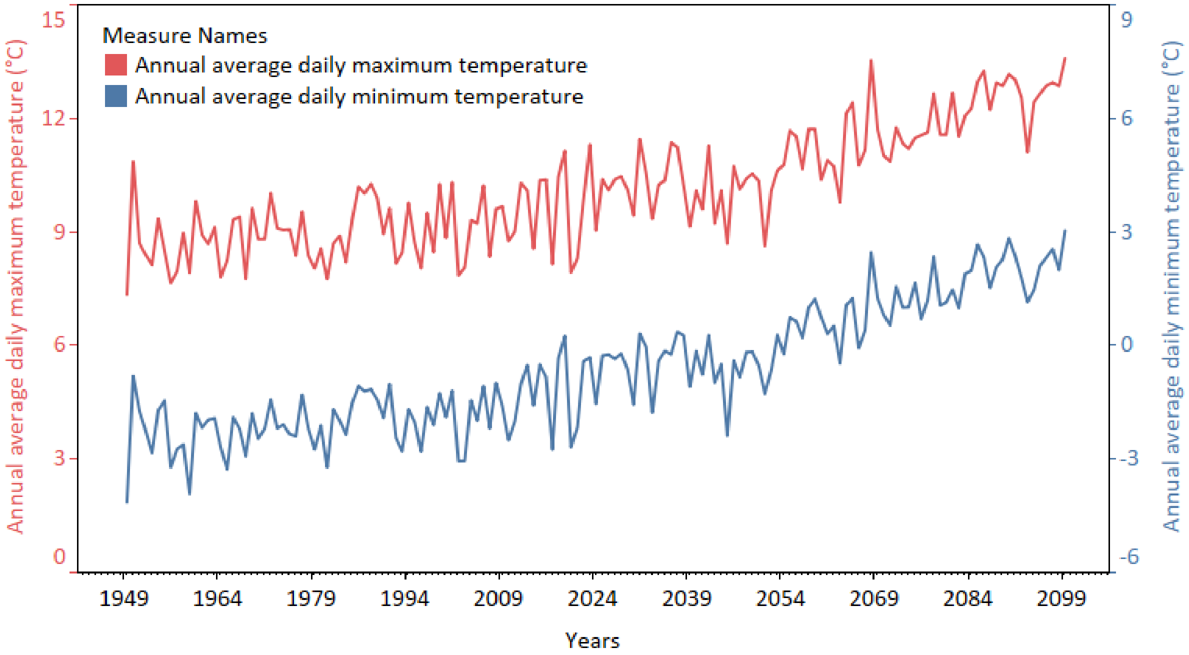

Figure 3: Annual average daily maximum and minimum temperature for St. John's, NL, Canada

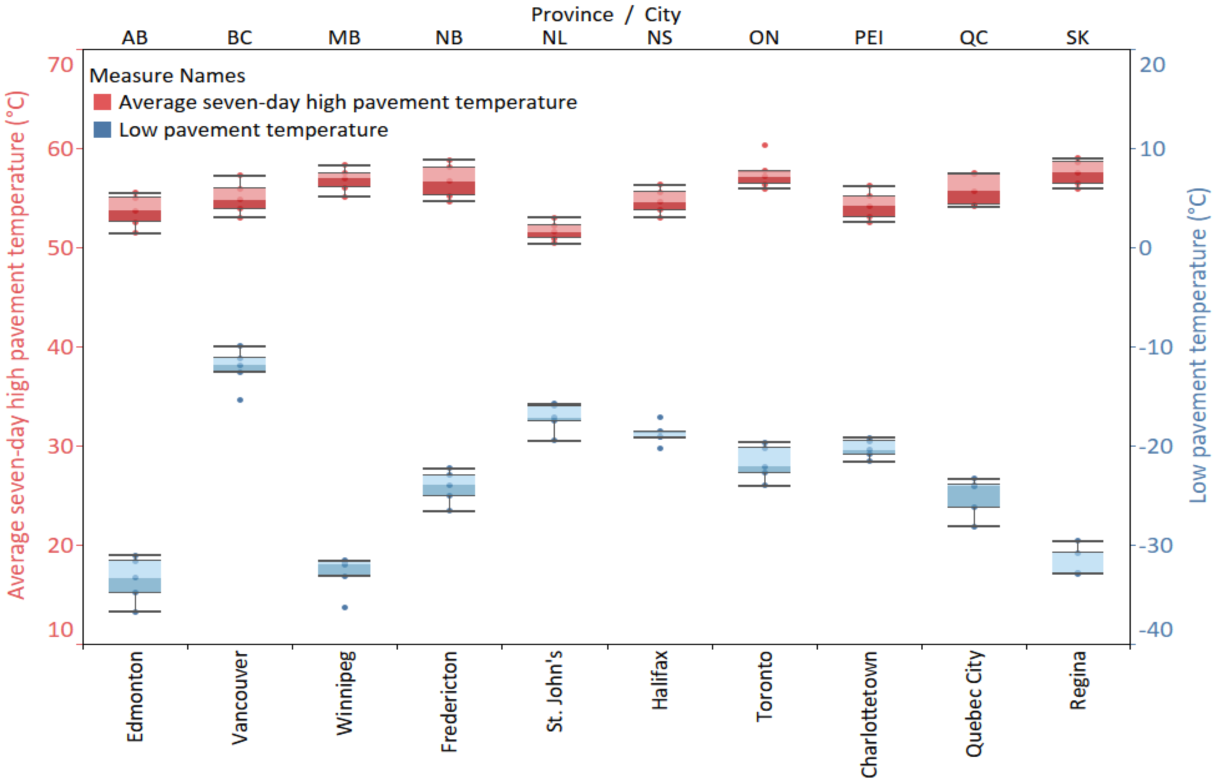

Figure 4: Boxplot for average seven-day high and low pavement temperatures

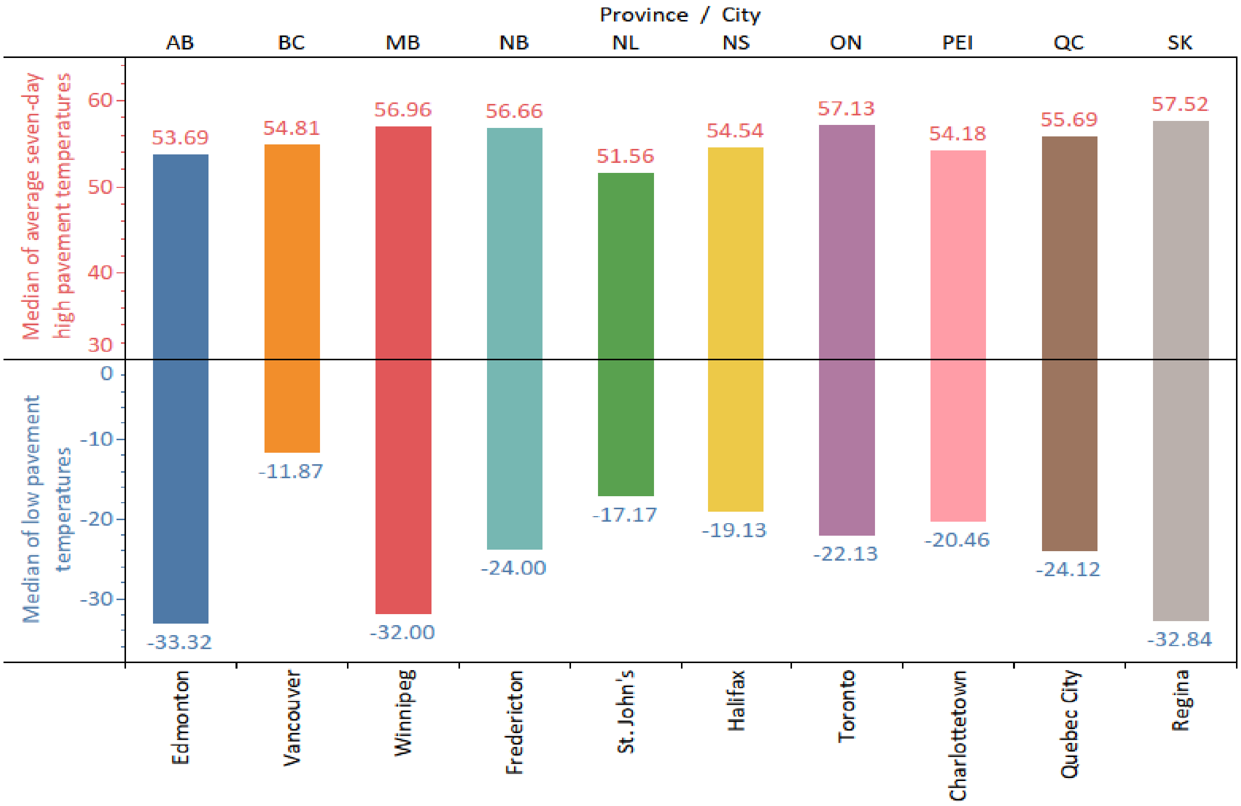

Figure 5: Median values of pavement temperatures from different climate change models

For the computed average seven-day high pavement temperature and low pavement temperatures, the asphalt binder grades are assigned following the procedure explained in methodology, phase 4. The assigned binder grades are presented in Table 1.

Table 1: Expected change in asphalt binder grade for 2040 - 2070

Province	City	Base Binder	Upgraded Binder		
			Cold model	Median model	Hot model
British Columbia	Vancouver	PG 58-34	PG 58-16	PG 58-16	PG 58-10
Alberta	Edmonton	PG 58-34	PG 52-40	PG 58-34	PG 58-34
Saskatchewan	Regina	PG 58-34	PG 58-34	PG 58-34	PG 64-34
Manitoba	Winnipeg	PG 58-34	PG 58-40	PG 58-34	PG 64-34
Ontario	Toronto	PG 58-28	PG 58-28	PG 58-28	PG 64-22
Quebec	Quebec City	PG 58-28	PG 58-34	PG 58-28	PG 58-28
New Brunswick	Fredericton	PG 58-28	PG 58-28	PG 58-28	PG 64-28
Prince Edward Island	Charlottetown	PG 58-28	PG 58-22	PG 58-22	PG 58-22
Nova Scotia	Halifax	PG 58-28	PG 58-22	PG 58-22	PG 58-22
Newfoundland	St. John's	PG 58-28	PG 52-22	PG 52-22	PG 58-16

From Table 1, It was noted that the predicted asphalt binder grade for 2040 – 2070 using the median climate change model is approximately equal to the binder that the most provincial DOT’s are using. However, in the case of the hot climate change model, Regina, Winnipeg, Toronto, and Federation need an upgrade in high-temperature asphalt grade. Similarly, in the case of the cold model, Edmonton, Winnipeg, and Quebec City need an upgrade in low-temperature asphalt grade. However, further analysis is needed to select the optimal climate change model for the analysis.

Conclusions

This paper presents an analysis conducted to determine the change in asphalt binder grade over ten different locations (capital cities of Canadian provinces). This analysis aimed to understand the impact of climate change on the selection process of asphalt grade. Results from this analysis will be helpful for selecting the appropriate asphalt binder grade based on future climatic conditions. This study collected five different bias-corrected statistically downscaled climate change models from the pacific climate database. Also, a python algorithm is used to extract the temperature data for the selected location using a short distance square method. Finally, the pavement temperatures were determined using the LTPP prediction model at 98% reliability, and asphalt binder grades are assigned. The results from this study enable us to make these conclusions:

- There is a significant increase in annual average temperature due to climate change throughout Canada, noticed in the climate change models.
- The predicted asphalt binder grade for 2040 – 2070 using the median climate change model is approximately equal to the binder that the most provincial DOT's are using.
- Edmonton, Winnipeg, and Quebec City need an upgrade in low-temperature asphalt grade in the case of cold climate change model. Similarly, Regina, Winnipeg, Toronto, and Federation need an upgrade in high-temperature asphalt grade in the case of hot climate change model.
- The limitation of this study is that the complete analysis is assessed based on a particular location in the province. It is necessary to select more locations in each of the provinces to better under the spatial impact of climate change.

Reference

Dash, S. K., R. K. Jenamani, S. R. Kalsi, and S. K. Panda. 2007. "Some Evidence of Climate Change in Twentieth-Century India." *Climatic Change* 85 (3–4): 299–321. https://doi.org/10.1007/s10584-007-9305-9.

Delgadillo, Rodrigo, Leandro Arteaga, Carlos Wahr, Ricardo Alcafuz, Rodrigo Delgadillo, Leandro Arteaga, Carlos Wahr, and Ricardo Alcafuz. 2018. "The Influence of Climate Change in Superpave Binder Selection for Chile." *Road Materials and Pavement Design* 0 (0): 1–16. https://doi.org/10.1080/14680629.2018.1509803.

Evans, Jason P. 2009. "21st Century Climate Change in the Middle East." *Climatic Change* 92 (3–4): 417–32. https://doi.org/10.1007/s10584-008-9438-5.

Fletcher, Christopher G., Lindsay Matthews, Jean Andrey, and Adam Saunders. 2016. "Projected Changes in Mid-Twenty-First-Century Extreme Maximum Pavement Temperature in Canada." *Journal of Applied Meteorology and Climatology* 55 (4): 961–74. https://doi.org/10.1175/JAMC-D-15-0232.1.

Gasparrini, Antonio, Yuming Guo, Francesco Sera, Ana Maria Vicedo-Cabrera, Veronika Huber, Shilu Tong, Micheline de Sousa Zanotti Stagliorio Coelho, et al. 2017. "Projections of Temperature-Related Excess Mortality under Climate Change Scenarios." *The Lancet Planetary Health* 1 (9): e360–67. https://doi.org/10.1016/S2542-5196(17)30156-0.

Gudmundsson, L., J. B. Bremnes, J. E. Haugen, and T. Engen-Skaugen. 2012. "Technical Note: Downscaling RCM Precipitation to the Station Scale Using Statistical Transformations – A Comparison of Methods." *Hydrology and Earth System Sciences* 16 (9): 3383–90. https://doi.org/10.5194/hess-16-3383-2012.

Hughes, Lesley. 2003. "Climate Change and Australia: Trends, Projections and Impacts." *Austral Ecology* 28 (4): 423–43. https://doi.org/10.1046/j.1442-9993.2003.01300.x.

Jones, Peter G., and Philip K. Thornton. 2009. "Croppers to Livestock Keepers: Livelihood Transitions to 2050 in Africa Due to Climate Change." *Environmental Science and Policy* 12 (4): 427–37. https://doi.org/10.1016/j.envsci.2008.08.006.

Lioubimtseva, E., and G. M. Henebry. 2009. “Climate and Environmental Change in Arid Central Asia: Impacts, Vulnerability, and Adaptations.” *Journal of Arid Environments* 73 (11): 963–77. https://doi.org/10.1016/j.jaridenv.2009.04.022.

Marengo, Jose A., Sin Chan Chou, Gillian Kay, Lincoln M. Alves, J. F. Pesquero, Wagner R. Soares, Daniel C. Santos, et al. 2012. “Development of Regional Future Climate Change Scenarios in South America Using the Eta CPTEC/HadCM3 Climate Change Projections: Climatology and Regional Analyses for the Amazon, São Francisco and the Paraná River Basins.” *Climate Dynamics* 38 (9–10): 1829–48. https://doi.org/10.1007/s00382-011-1155-5.

Maurer, E. P., H. G. Hidalgo, T. Das, M. D. Dettinger, and D. R. Cayan. 2010. “The Utility of Daily Large-Scale Climate Data in the Assessment of Climate Change Impacts on Daily Streamflow in California.” *Hydrology and Earth System Sciences* 14 (6): 1125–38. https://doi.org/10.5194/hess-14-1125-2010.

Meinshausen, Malte, S. J. Smith, K. Calvin, J. S. Daniel, M. L.T. Kainuma, J. Lamarque, K. Matsumoto, et al. 2011. “The RCP Greenhouse Gas Concentrations and Their Extensions from 1765 to 2300.” *Climatic Change* 109 (1): 213–41. https://doi.org/10.1007/s10584-011-0156-z.

Meleux, Frederik, Fabien Solmon, and Filippo Giorgi. 2007. “Increase in Summer European Ozone Amounts Due to Climate Change.” *Atmospheric Environment* 41 (35): 7577–87. https://doi.org/10.1016/j.atmosenv.2007.05.048.

Mills, Brian, Susan Tighe, Jean Andrey, James Smith, and Ken Huen. 2009. “Climate Change Implications for Flexible Pavement Design and Performance in Southern Canada.” *Journal of Transportation Engineering* 135 (10): 773–82. https://doi.org/10.1061/(asce)0733-947x(2009)135:10(773).

Mohseni, A. 1998. *LTPP Seasonal Asphalt Concrete (AC) Pavement Temperature Models, FHWA-RD-97-103*. Vol. 7.

Mohseni, A. 2005. “LTPPBIND V3.1 A SUPERPAVE Binder Selection Program, Washington Pavement Systems LLC, Maiden, MD.”

Paquin, Dominique, Ramón De Elía, and Anne Frigon. 2014. “Change in North American Atmospheric Conditions Associated with Deep Convection and Severe Weather Using CRCM4 Climate Projections.” *Atmosphere - Ocean* 52 (3): 175–90. https://doi.org/10.1080/07055900.2013.877868.

Rana, Masud, Surya Swarna, and Kamal Hossain. 2020. “Climate Change Impact on Pavement Performance in Newfoundland , Canada.” In *99th Annual Meeting of the Transportation Research Board (TRB) of National Academies of Science and Engineering, Washington DC, USA*.

Taylor, Karl E., Ronald J. Stouffer, and Gerald A. Meehl. 2012. “An Overview of CMIP5 and the Experiment Design.” *Bulletin of the American Meteorological Society* 93 (4): 485–98. https://doi.org/10.1175/BAMS-D-11-00094.1.

Underwood, Shane, Zack Guido, Padmini Gudipudi, and Yarden Feinberg. 2017. “Increased Costs to US Pavement Infrastructure from Future Temperature Rise Increased Costs to US Pavement Infrastructure from Future Temperature Rise,” no. September. https://doi.org/10.1038/nclimate3390.

Vincent, L. A., X. Zhang, Mekis, H. Wan, and E. J. Bush. 2018. “Changes in Canada’s Climate: Trends in Indices Based on Daily Temperature and Precipitation Data.” *Atmosphere - Ocean* 56 (5): 332–49. https://doi.org/10.1080/07055900.2018.1514579.

Viola, Francesco, and Clara Celauro. 2015. “Effect of Climate Change on Asphalt Binder Selection for Road Construction in Italy.” *Transportation Research Part D: Transport and Environment* 37: 40–47. https://doi.org/10.1016/j.trd.2015.04.012.

Zhai, Panmao, and Xiaohua Pan. 2003. “Trends in Temperature Extremes during 1951-1999 in China.” *Geophysical Research Letters* 30 (17). https://doi.org/10.1029/2003GL018004.