Development of a winter road climate risk and vulnerability review framework 2020-2021 update

Zhang, Merrina; Roghani, Alireza; Hill, Larry; Barrette, Paul

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Development of a Winter Road Climate Risk and Vulnerability Review Framework

2020-2021 Update

Prepared for:
Crown-Indigenous Relations and Northern Affairs Canada
& Transport Canada

Prepared by:
Merrina Zhang, Alireza Roghani, Larry Hill
Automotive and Surface Transportation Research Centre
&
Paul Barrette
Ocean, Coastal and River Engineering Research Centre

In collaboration with:
Sylvie Chenier, Chantal Edwards & Derek Morrell
Automotive and Surface Transportation Research Centre

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Prepared by:

Zhang, Merrina — Digitally signed by Zhang, Merrina DN: cn=Zhang, Merrina, c=CA, o=GC, ou=NRC-CNRC, email=merrina.zhang@nrc-cnrc.gc.ca Date: 2021.05.13 17:53:03 -04'00'

Merrina Zhang, P. Eng.
Senior Research Engineer

Roghani, Alireza — Digitally signed by Roghani, Alireza Date: 2021.05.17 14:00:47 -04'00'

Alireza Roghani, PhD, P. Eng.
Research Officer, Geotechnical Research

Hill, Larry — Digitally signed by Hill, Larry Date: 2021.05.14 09:41:39 -04'00'

Larry Hill, P. Eng.
Senior Project Engineer

Barrette, Paul — Digitally signed by Barrette, Paul DN: cn=Barrette, Paul, c=CA, o=GC, ou=NRC-CNRC, email=paul.barrette@canada.ca Reason: I am approving this document Date: 2021.05.14 14:10:39 -04'00'

Paul Barrette, PhD
Project Scientist

Reviewed and approved by:

Marsh, Philip — Digitally signed by Marsh, Philip DN: cn=Marsh, Philip, c=CA, o=GC, ou=NRC-CNRC, email=philip.marsh@canada.ca Date: 2021.05.31 13:59:59 -04'00'

Philip Marsh, P. Eng.
Director, Research and Development
Automotive and Surface Transportation Research Centre

Executive Summary

In Canada, there are approximately 8,000 km of official winter roads. Unlike roads that can be used all year round, winter roads are seasonally constructed, over frozen terrain and water bodies, such as lakes and rivers.

Winter roads are the lifelines of many northern and remote communities in Canada, which are totally disconnected from all-season roads. Winter roads are built every year, allowing a short time window (several weeks to a few months) to access the all-season road networks that connect the rest of the country. The winter road networks are often the only economical means for the transport of essential supplies such as food, fuel, medical supplies and construction materials, in addition to providing community members access for social and leisure activities, such as visiting relatives and friends in neighboring communities, and accessing employment and health care.

According to a scan of scientific literature by National Research Council Canada's National Science Library [1], Canada has one of the largest networks of winter roads in the world.

Winter roads are highly vulnerable to a warming climate, since a sufficient number of cold days are required for the ground and bodies of water to freeze to the required depth to create a strong foundation for the safe passage of traffic.

A warming climate is reducing the operating window of these roads across northern Canada. In addition, it is likely that many segments of the current network will become progressively riskier and less reliable and will need to be replaced with alternatives in the future.

There is a need to examine the winter road network in Canada, the factors that affect safety, and to develop a method to review and quantify the impact of climate change across the network. This would allow for better identification of vulnerabilities within the network, prioritization of high risk segments based on key factors, and to support more evidenced-based decision making of the future of different segments of the network in the context of a changing climate.

During FY2020-2021, a literature review of 54 documents was completed to examine Canada's winter road network, identify parameters that affect winter road safety, models that assess the impact of climate change on winter roads, and identify standards for climate risk assessment related to northern infrastructure.

A framework to review and assess the climate risk and vulnerability of winter roads in Canada was developed. This framework is intended to evolve over time. The foundation of the framework is based on published scientific methods, field data from winter road operations, as well as stakeholder observation, experience and concerns. A case study of the current iteration of the framework was performed on the James Bay Winter Road in Northern Ontario. Consultations with winter road stakeholders within the federal and provincial governments were completed to better understand the unique challenges and perspectives of each stakeholder. An initial review of relevant and available data for the project was completed, and the gaps in data identified.

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Glossary and Definitions

60^{th} Parallel	Latitude 60 degrees north of earth's equator (in Canada, the 60^{th} parallel is the approximate boundary line separating the provinces and the territories)
AST	Automotive and Surface Transportation Research Centre (NRC)
CCCS	Canadian Center for Climate Services
CIRNAC	Crown-Indigenous Relations and Northern Affairs Canada
CMIP	Coupled Model Intercomparison Project
CDF	Cumulative distribution function
ECCC	Environment and Climate Change Canada
ESCER	Ouranos consortium and the Centre pour l'étude et la simulation du climat à l'échelle régionale
FDD	Freezing degree days
FY	Fiscal year
GIS	Geographical information system
GPR	Ground penetrating radar
GPS	Global positioning system
IPCC	Intergovernmental Panel on Climate Change
IAAC	Impact Assessment Agency of Canada
ISC	Indigenous Services Canada
MNDM	Ministry of Northern Development and Mines (Ontario)
NRC	National Research Council Canada
NWT	Northwest Territories
OCRE	Ocean Coastal and River Engineering (NRC)
RCP	Representative Concentration Pathway
TC	Transport Canada
UBC	University of British Columbia
U of T	University of Toronto
US	United States

1 Introduction

In Canada, there are approximately 8,000 km of official winter roads (an example is shown in Figure 1). Unlike roads that can be used all year round[1] (i.e. highways, city streets and country roads), winter roads are seasonally constructed, over frozen terrain and water bodies, such as lakes and rivers.

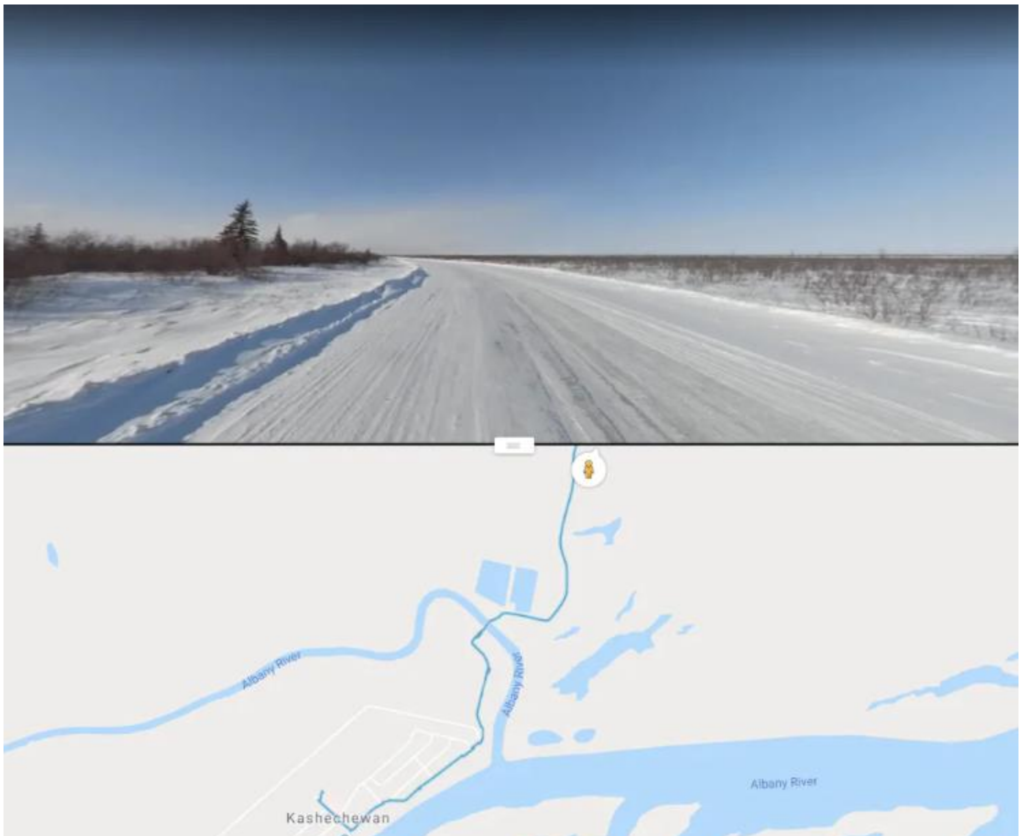

Figure 1: An Example Winter Road Segment in Northern Ontario (From Google Street View and Maps, https://www.cbc.ca/news/canada/sudbury/winter-road-google-maps-1.5072359)

Winter roads are the lifelines of many northern and remote communities in Canada, which are totally disconnected from all-season roads. Winter roads are built every year, allowing a short time window (several weeks to a few months) to access the all-season road networks that connect the rest of the country. The winter road networks are often the only economical means for the transport of essential supplies such as food, fuel, medical supplies and construction materials, in addition to providing community members access for social and leisure activities, such as visiting relatives and friends in neighboring communities, and accessing employment and health care.

[1] Also termed all-season roads or all-weather roads.

According to a scan of scientific literature by National Research Council Canada’s (NRC) National Science Library [1], Canada has one of the largest networks of winter roads in the world. A detailed list of winter roads generated from the scan is found in Appendix A (Table 5).

1.1 A Changing Climate

Canada’s Changing Climate Report [2] provided the following information with regards to the climate in Canada and in a global context:

- *There is overwhelming evidence that the Earth has warmed during the Industrial Era… This evidence includes increases in near-surface and lower-atmosphere air temperature, sea surface temperature, and ocean heat content.*
- *Because air in the Earth’s atmosphere and water in the global oceans flow freely, Canada’s climate is intimately linked to the global climate. Thus, changes in Canada’s climate are a manifestation of changes in the global system, modulated by the effects of Canada’s mountains, coastlines, and other geographical features.*
- *There is no doubt that Canada’s climate has warmed. Temperature has increased in all regions of the country and in the surrounding oceans. Annual and seasonal mean temperatures[2] across Canada have increased* (Figure 2) *at roughly double the global mean rate[3], with Canada’s mean annual temperature having risen about 1.7ºC over the 1948– 2016 period.*
- *Temperature is observed across Canada, though the distribution of temperature observation site is uneven with more sites in the populated portion of southern Canada, and more sparse observations for much of Canada, especially northern Canada (*Figure 3*), and very few observation sites predate 1948. As a result, the analysis of past changes in temperature for Canada as a whole is limited to the period since 1948, while 1900 can be used as a starting point for records in southern Canada* (Figure 2)*.*
- *Warming was not uniform across seasons, with considerably more warming in winter than in summer. The mean temperature increased by 3.3ºC in winter, 1.7ºC in spring, 1.5ºC in summer, and 1.7ºC in autumn between 1948 and 2016* (Table 1, Figure 4)*.*
- *As well, warming was unevenly distributed across the country. Annual mean temperature over northern Canada increased by 2.3ºC from 1948 to 2016, or roughly three times the global mean warming rate. Warming was much weaker in the southeast of Canada, where average temperature increased by less than 1ºC in some maritime areas.*

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[2] *Temperatures refer to surface air temperatures, typically measured at 2 m above the ground.*

[3] *0.8ºC increase for 1948–2016 is the global average according to the global mean surface temperature dataset produced by the Met Office Hadley Centre and the Climatic Research Unit at the University of East Anglia, United Kingdom, HadCRUT4.*

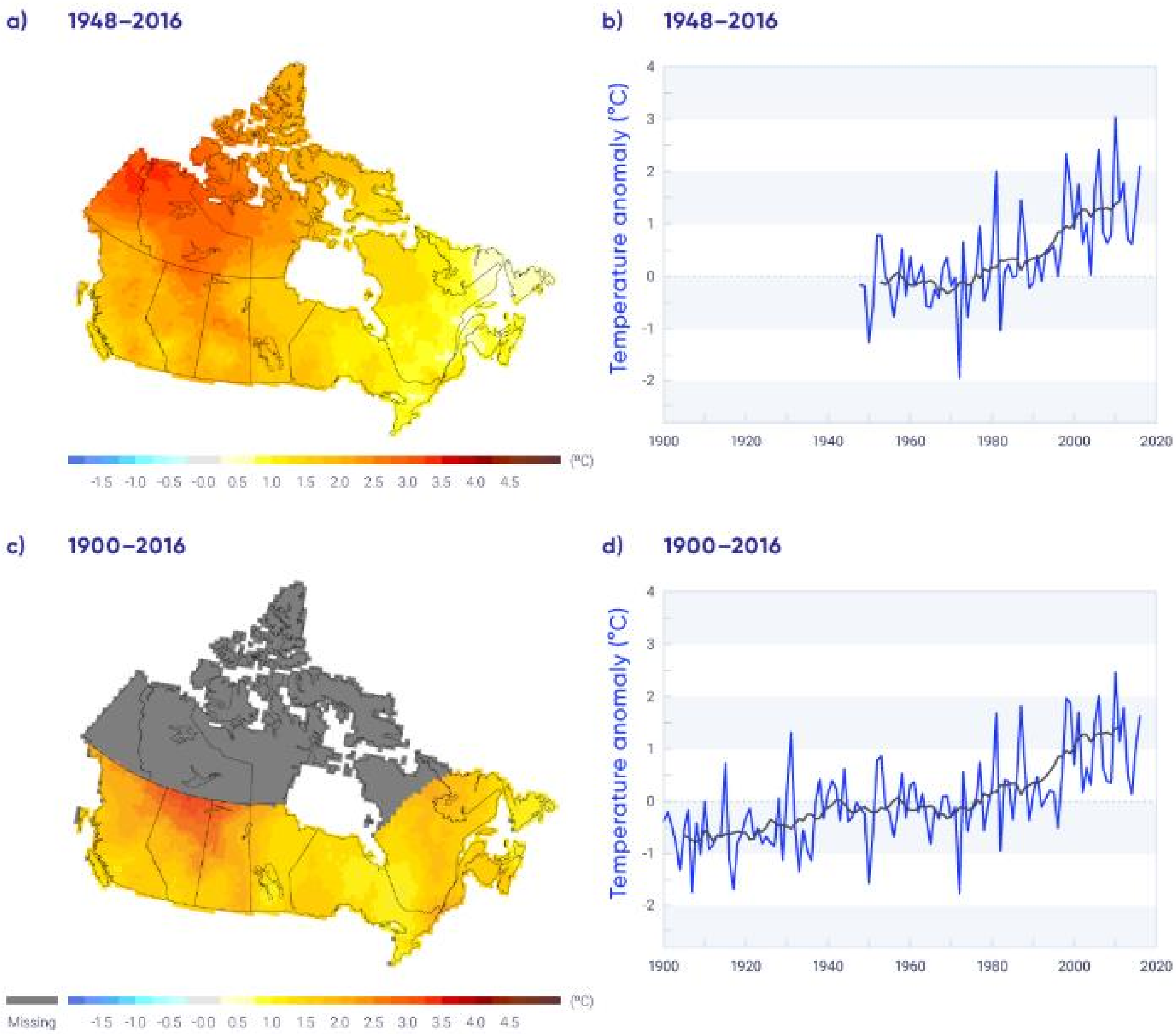

Figure 2: Trends in Annual Temperatures across Canada[4]

[4] *Observed changes (ºC) in annual temperature between (a) 1948 and 2016 and (c) 1900 and 2016. Changes are computed based on linear trends over the respective periods. Annual temperature anomalies (departures from baseline means) are expressed relative to the mean for the period 1961–1990 (b) for Canada as a whole and (d) for southern Canada (south of 60º north latitude); the black lines are 11-year running means. Estimates are derived from the gridded station data. There are insufficient data in northern Canada to confidently calculate warming trends from 1900 to 2016.*

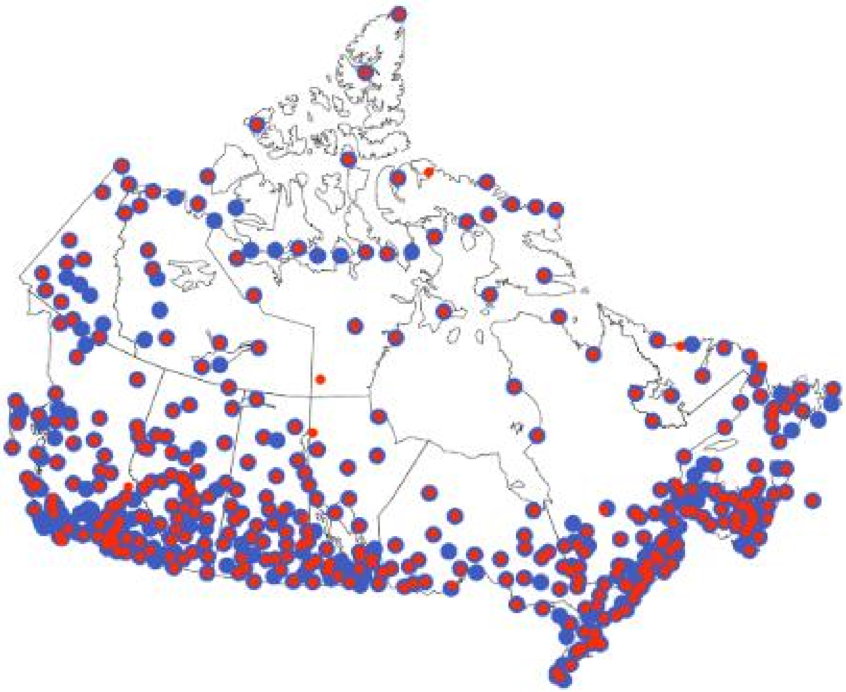

Figure 3: Long Term Temperature Observation Sites across Canada (Red-Observes Temperature, Blue-Observes Precipitation)

REGION	CHANGE IN TEMPERATURE, ºC				
	Annual	Winter	Spring	Summer	Autumn
British Columbia	1.9	3.7	1.9	1.4	0.7
Prairies	1.9	3.1	2.0	1.8	1.1
Ontario	1.3	2.0	1.5	1.1	1.0
Quebec	1.1	1.4	0.7	1.5	1.5
Atlantic	0.7	0.5	0.8	1.3	1.1
Northern Canada	2.3	4.3	2.0	1.6	2.3
Canada	1.7	3.3	1.7	1.5	1.7

Table 1: Observed Changes in Annual and Seasonal Mean Temperature between 1948 and 2016 for Six Regions and for All Canadian Land Area[5]

[5] *Changes are represented by linear trends over the period. Estimates are derived from the gridded station data. There is a lack of data for northern Canada* (Figure 2).

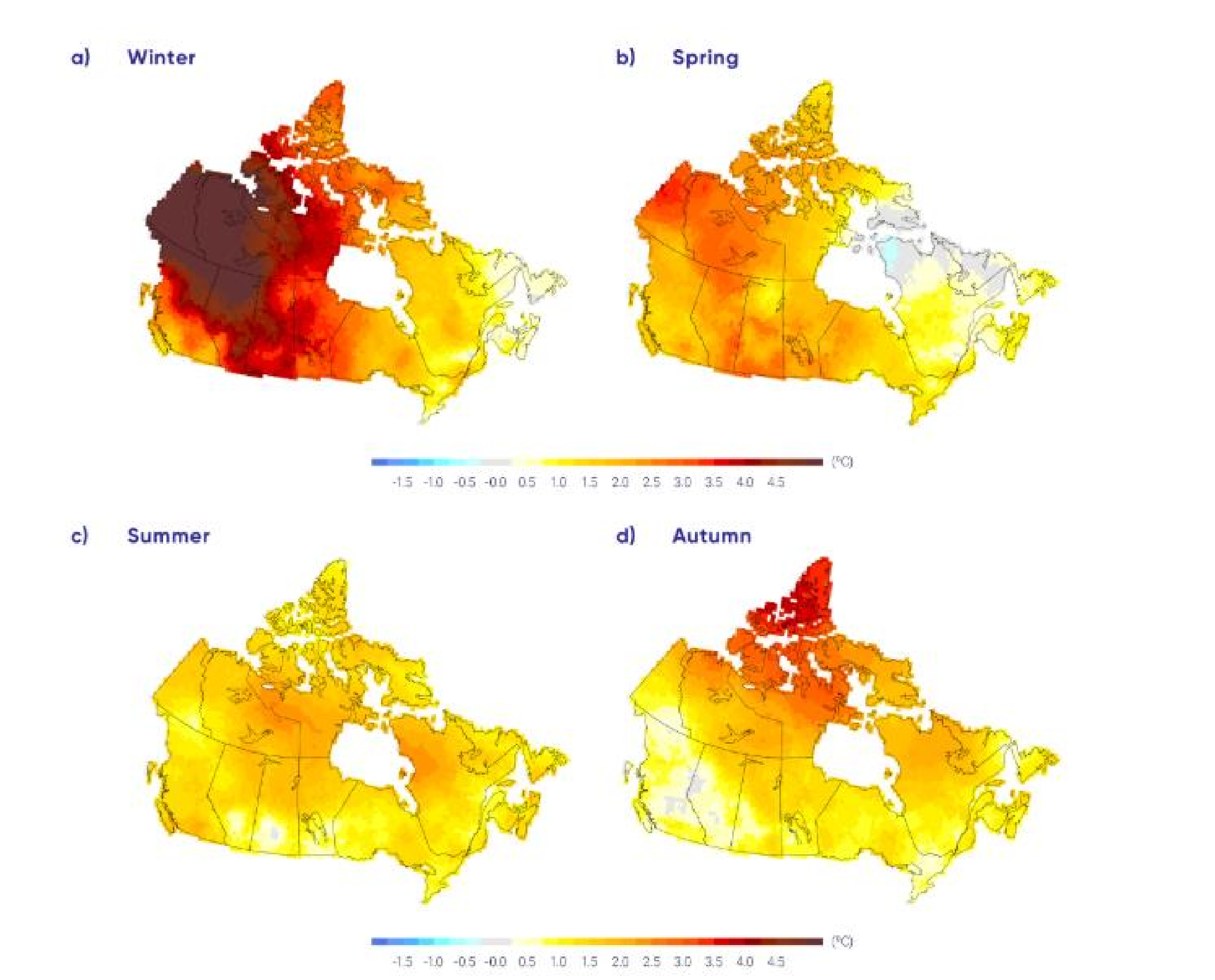

Figure 4: Trends in Seasonal Temperatures across Canada[6]

The Changing Climate Report [2] provided the following information with regards to the future climate in Canada:

- *Canada's climate will warm further, with warming projected in all seasons.*
- *Projected warming for Canada as a whole is almost double that of the global average, regardless of the emission scenario. Country-wide annual average temperature projections for the late century (2081-2100) range from an increase of 1.8ºC for a low emission scenario (Representative Concentration Pathways (RCP) 2.6 to 6.3ºC for a high emission scenario (RCP8.5).* Emission scenarios are discussed in more detail in section 3.3.
- *Projected warming under both low and high emission scenarios show a general pattern of change in the winter* (Figure 5)*. Consistent across scenarios, the smallest changes are projected for southernmost Canada and the largest changes are projected for Hudson Bay (and the Arctic).*

[6] *Observed changes in seasonal mean temperature between 1948 and 2016 for the four seasons. Estimates are derived based on linear trends in the gridded station data.*

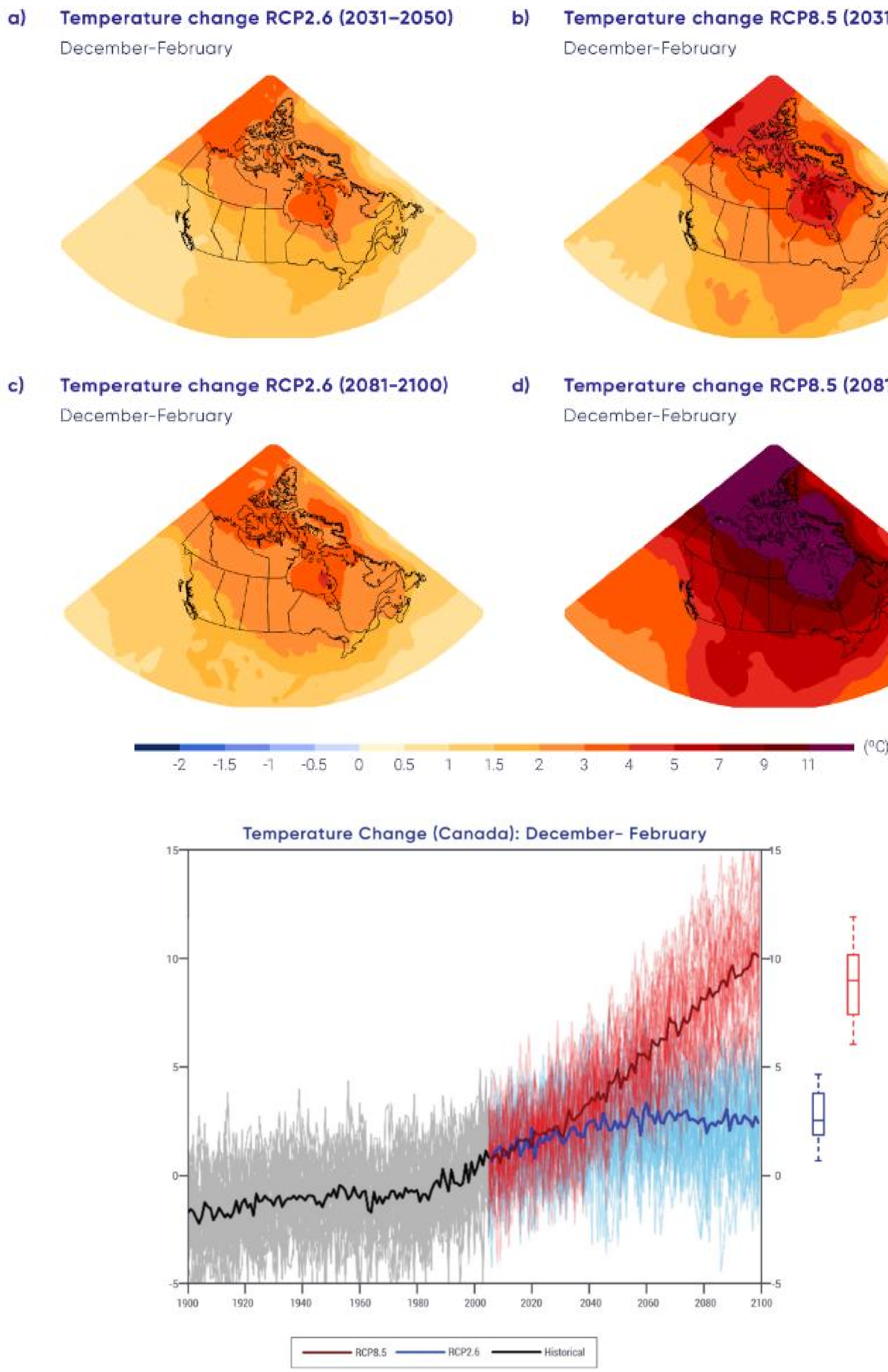

Figure 5: Projected Temperature Changes for Winter Season[7]

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[7]*Maps and time series of projected temperature change (ºC) for December, January, and February, as represented by the median of the Coupled Model Intercomparison Project (CMIP) 5 multi-model ensemble. Changes are relative to the 1986–2005 period.* CMIPs are discussed in more detail in section 3.3.

1.2 Impacts of a Changing Climate on Winter Roads

Unlike most other surface transportation systems, winter roads are mostly a product of the natural environment as seen in Figure 6, including the geology of the terrain, the gradient and characteristics of the waterways.

Winter roads are also highly dependent on air temperature, precipitation (snow), wind and solar radiation. As a result, they are highly vulnerable to a warming climate, since a sufficient number of cold days are required for the ground and bodies of water to freeze to the required depth to create a strong foundation for the safe passage of traffic.

Figure 6: Example Winter Road Segment in Northern Ontario (https://www.theglobeandmail.com/canada/article-the-thin-white-line-how-northern-ontarios-winter-roads-are-built-and/)

A warming climate is reducing the operating window of these roads across northern Canada. In addition, it is likely that many segments of the current network will become progressively riskier and less reliable and will need to be replaced with alternatives in the future.

There is a need to examine the winter road network in Canada, the factors that affect safety, and to develop a method to review and quantify the impact of climate change across the network. This would allow for better identification of vulnerabilities within the network, prioritization of high risk segments based on key factors, and to support more evidenced-based decision making of the future of different segments of the network in the context of a changing climate.

1.3 Project Objectives

The objectives of this project are as follows:

- Complete a literature review to examine Canada's winter road network, identify parameters that affect winter road safety, models that assess the impact of climate change on winter roads, and identify standards for climate risk assessment related to northern infrastructure
- Develop a framework to review and assess the climate vulnerability of winter roads in Canada
- Consult with stakeholders to better understand the challenges within the winter roads community
- Identify and gather relevant data available in the public domain[8]
- Identify data gaps

1.4 Linkages with Key Stakeholders within the Winter Road Community

This project directly supports the priorities and mandates of the following stakeholders within the winter road community:

- NRC
  - Automotive and Surface Transportation Research Centre's (AST) Resilient Ground Transportation Program, which focuses on research and development activities and technology development for the improvement of productivity, efficiency, and safety of the Canadian on/off-road transportation system.
  - Ocean Coastal and River Engineering (OCRE) Research Centre's ice engineering research, through its Arctic Program (2014-2021), to address the over ice segments of winter roads and their vulnerability to climate change, as these are often weak links in a road and present a significant risk to life in case of breakthroughs. Over the years, OCRE has been instrumental in building a stakeholder network, including federal, provincial and territorial governments, and universities in Canada and the United Kingdom, to address the needs of the infrastructure built over ice.
- Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC)
  - First Nation Adapt Program, which provides funding to First Nation communities located below the 60th parallel to assess and respond to climate change impacts on community infrastructure and emergency management. The program prioritizes First Nation communities most impacted by climate change related to sea level rise, flooding, forest fires, drought, fisheries and winter road failures. The winter road climate risk and vulnerability review framework will form the foundation for the winter road module of CIRNAC's Climate Risk Index Tool, as well as future winter road climate risk review, assessment and mediation efforts.

[8] The scope of this task is focused on the winter road network south of the 60th parallel during fiscal year (FY) 2020-2021.

- Transport Canada (TC)
  - TC's Strategic Policy and Innovation team and the Northern Transportation Adaptation Initiative team. The winter road climate risk and vulnerability review framework and the knowledge generated by the project will enable the TC teams to advance two of their core objectives, including developing new knowledge about how climate change is affecting transportation systems in the north and develop tools and practices to respond to these effects.

This project supports the following stakeholders within the winter road community through better identification of vulnerabilities within the network, prioritization of high risk segments based on key factors, and to support more evidenced-based decision making for the future of different segments of the network in the context of a changing climate:

- CIRNAC's Climate Change Preparedness in the North Program, Indigenous Community-Based Climate Monitoring Program, and Environmental Impact Assessment Program
- Indigenous Services Canada (ISC)'s Regional Infrastructure Delivery Branch, Manitoba Regional Office, Ontario Regional Office, Alberta Regional Office, Northwest Territory Regional Office, and Emergency Management Assistance Program
- Provincial governments
- Territorial governments
- Communities served by the winter road networks
- Private sector organizations building, maintaining and using the winter road networks

1.5 Synergies with Other Research Initiatives

NRC has been investigating winter roads since the 1960's. One of the most significant outcomes of this work is referred to as 'Gold's formula' [3], which estimates the bearing capacity of the over ice segments of the winter road network based on the thickness of the ice and breakthrough observations. Gold's formula is alluded to, either implicitly or explicitly, in virtually all official winter road guidelines in Canada[9].

In recent years, NRC has actively engaged with winter road stakeholders in Canada to better understand their respective needs and challenges. These efforts have revealed that the winter road transportation systems in Canada are poorly understood in the following aspects:

- Information on the physical elements of these networks (i.e. location, routing, characterization, etc.) is minimal, fragmented and not uniform across provincial and territorial boundaries.
- Currently, there is no coordination nor knowledge-sharing between the various jurisdictions, although guidelines have begun to align, such as the case between the Northwest Territories and the Provinces of Alberta and Ontario.

[9] Gold's formula is integrated into the proposed winter road climate risk and vulnerability framework, which is discussed in more detail in section 3.2.

- Information on road usage, goods movements, intermodal connectivity, access to health care and employment, is lacking, particularly in the Province of Ontario, which has the country's largest network of winter roads. As a result, decision-makers are unable to assess community vulnerability, especially in the context of a changing climate.

In order to address the data gap, NRC initiated the following two research activities, both focusing on the Territorial North (north of the 60th parallel):

- *A tool to optimize the effectiveness of the winter road network in the Canadian North*, is a project led by the University of Toronto (U of T) and funded by Transport Canada's National Trade Corridor Fund[10]. It is a five year project (May 2020 to April 2025) aimed at developing a user-friendly, web-based portal that will centralize critical information including transportation network technologies, climate data and simulations, logistics and transportation operational data, physical, socio-economic and cultural aspects of winter road and trail networks in the Northwest Territories (NWT) and Nunavut. Stakeholder engagement, community outreach and aboriginal consultations are an important part of the project's planned activities. The ultimate outcome is to improve transportation to and from northern communities, address capacity constraints and bottlenecks, increase their resiliency to a changing climate, and support safety and economic development.
- *Building a Multimodal Transportation Network Database and Exploring Data Collection Methods to Support Transportation Operations in the Canadian North*, is a project led by the University of British Columbia (UBC) and funded by NRC's Artificial Intelligence for Logistics Program[11]. It is a three year project (September 2020 to August 2023) to examine how winter road networks fit within the multimodal transportation network in the NWT and Yukon. This project will examine how winter roads are operated and used (leveraging the U of T project), in addition to characterizing and gathering data for connecting facilities (all-weather roads, marine) and hubs (aerodromes). It will also investigate technologies for automated data collection on remote transportation facilities operating in harsh and remote environments, and identify potential opportunities to fill critical data gaps. Lastly, the project will prepare information collected and/or created for secure transfer and integration into the NRC's logistics data vault. It is anticipated that this data can complement other data in the vault, to better understand the Canadian freight network.

Team members from this project, the U of T project and the UBC project are working together and leveraging resources, knowledge, technology and methods from each project. The three projects currently focus on different parts of the country, with this project focusing on the winter road network south of the 60th parallel, while the U of T project focusing on NWT and Nunavut, and the UBC project focusing on NWT and Yukon. Together, the research outcome will provide a more complete understanding of Canada's winter road network, unique regional differences, as well as common challenges that will support future adaptation efforts for both the provinces and the territories.

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[10] https://tc.canada.ca/en/programs/funding-programs/national-trade-corridors-fund

[11] https://nrc.canada.ca/en/research-development/research-collaboration/programs/artificial-intelligence-logistics-supercluster-support-program

2 Background

2.1 Overview of the Winter Road Network South of the 60th Parallel

In Canada, winter roads are generally grouped into three main categories, based on their management structure [4]:

- Provincial/Territorial – funded, built and maintained by the provincial or territorial governments. These winter road networks generally abide by standard procedures for construction, maintenance and quality assurance, including the monitoring of vehicle weights and ice thickness. The operators may be from the local communities.
- Local communities – managed by the local communities to service their needs including access to work, school, health care, air strips, fishing and hunting grounds, and leisure activities. Included within this category are privately-owned ice crossings. Operations run by local communities may not be as consistent as those managed by governments and the industrial sector in terms of construction and maintenance procedures, rules-of-the-road and safety monitoring. Also, communities may or may not have the required funding or resources to fix or accommodate critical problems causing road closures.
- Industrial sector – independently funded, built and maintained by the private sector, such as mining, pulp & paper and hydro power companies. These roads are normally built for industrial usage (with heavy loads such as 40+ tonnes), for which in-depth analysis of load distribution (i.e. for axle spacing) and ice bearing capacity is often conducted by specialized firms. Because of the higher loads and traffic density, industrial winter roads generally have a higher level of monitoring and control. Local communities may be given access to these roads.

2.1.1 The Network in Ontario

The winter road network in Ontario consists of 30 individual operations that connect 31 First Nations communities in northern Ontario to all-season roads or railway networks[12] (Appendix B, Figure 33) [5]. Of the 31 communities, 22 of the communities are reliant on diesel fuel for power generation. The cumulative network length is about 3,160 km (2019-2020 season), which is the longest network in Canada. Ontario's winter road season typically starts in mid-December and lasts until spring thaw. The roads are jointly funded by Ontario's Ministry of Northern Development and Mines (MNDM) and ISC.

2.1.2 The Network in Manitoba

The winter road network in Manitoba is funded jointly by the province's Department of Transportation and ISC[13]. Divided into a southern section (Appendix B, Figure 34) and a northern section (Appendix B, Figure 35), its cumulative length is about 2,383 km, with 60 ice crossings. There are 18 First Nations communities in Manitoba that rely on winter roads, four of the 18 are reliant on diesel fuel for power

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[12] https://www.mndm.gov.on.ca/en/northern-development/transportation-support/northern-ontario-winter-roads#simple-table-of-contents-3

[13] https://www.gov.mb.ca/mit/winter/index.html

generation. This network is used primarily by heavy traffic delivering bulk goods, but also by community members in smaller vehicles. Ice crossings must be able to withstand a weight of up to about 40 tonnes. Vehicles heavier than 7 tonnes have a speed limit of 15 km/h at a distance of at least 1 km from each other. Manitoba's winter road season is typically from mid-January to mid-March. Road conditions are updated via Manitoba 511 (http://www.manitoba511.ca/en/).

2.1.3 The Network in Saskatchewan

The winter road network in Saskatchewan is constructed and maintained by private organizations contracted by the Ministry of Highways and Infrastructure [6]. There are two main segments, the Wollaston Lake Winter Road (Appendix B, Figure 36) and the Athabasca Winter Road[14] (Appendix B, Figure 37) with a total length of approximately 217 km, as well as an ice crossing (Riverhurst, 2.1 km[15]). The winter road network services three First Nations communities, none of which are diesel dependent. Saskatchewan's winter road season is typically from early February to the end of March. Road conditions are updated via http://roadinfo.telenium.ca/iceroads.html.

2.1.4 The Network in Alberta

Within the Province of Alberta, the Regional Municipality of Wood Buffalo in northern Alberta maintains three winter roads or trails[16] (Appendix B, Figure 38):

- The Fort Chipewyan Winter Road (184 km)
- La Loche Winter Trail (57 km)
- Lac La Biche Winter Trail (11 km)

The information related to what distinguishes a 'winter trail' from a 'winter road' was not uncovered during initial reviews in fiscal year (FY) 2020-2021. Historically, a winter trail is defined as being narrower than a winter road, and can be built in a single pass by a vehicle fitted with a blade [7, 8]

Little Red River Cree Nation builds and operates two winter access to their community (Appendix B, Figure 39):

- Peace River Ice bridge[17] (40 km crossing of the Peace River)
- Southern (secondary) Access (58 km crossing of Wabasca River and Little Red River)

Parks Canada operates the Fort Smith Winter road (228 km) in Wood Buffalo National Park[18]. The road is usually open from mid-December to mid-March, depending on the winter conditions.

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[14] Also known as the Fond du Lac Winter Road.

[15] https://www.dangerousroads.org/north-america/canada/3236-riverhurst-crossing.html

[16] https://www.rmwb.ca/en/roads-and-construction/winter-roads.aspx#How-long-are-the-winter-roads

[17] Partially funded by ISC.

[18] https://www.pc.gc.ca/en/pn-np/nt/woodbuffalo/visit/visit1a

2.2 Winter Road Technical Overview

Unlike most surface transportation systems, where humans exercise a greater degree of control in the design, and selection of materials and foundation, winter roads are heavily dependent on the natural environment, including the climate and physical environment. Often referred to as ice roads, winter roads can be constructed over land, or over ice as shown in Figure 7. Most winter road segments in Canada, though not all, have both over land and over ice segments.

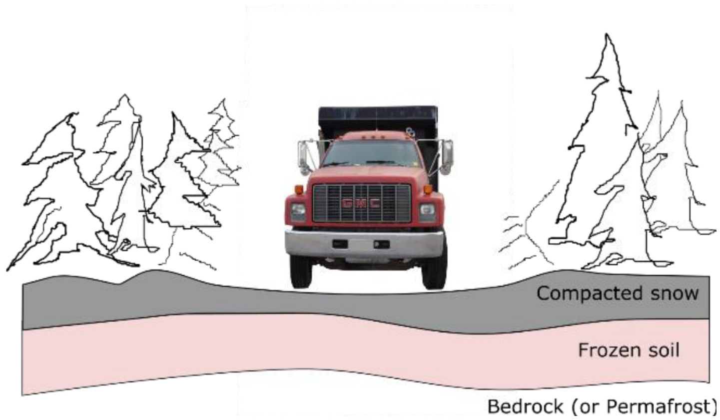

Figure 7: Schematic Representations of a Winter Road Segment Over Land and Over Ice

Winter roads differ from other engineered transportation systems in Canada since they are not built, maintained, managed, nor regulated in a consistent fashion across, and even within jurisdictions. Further, they vary substantially in the type of foundation, the width (right-of-way), grade, cross-slope, orientation, radius of curvature, over ice versus over land ratios, nature of shore-crossings, amongst other factors. These factors result in potential weak links in the network, which when coupled with a warming climate can result in mid-season closures or early season closures.

2.2.1 Types of Winter Roads

Table 2 provides an example of a classification for winter roads. It should be noted that the terminologies used by winter road stakeholders in Canada are not uniform. For instance, ‘ice road’ and ‘ice bridge’ are often used to designate a winter road segment on floating ice [e.g. 8].

Terrain	Road type	Category	Description
Over land	Compacted snow roads	C1	Road surface composed of compacted natural snow
	Ice-capped snow roads	C2	Compacted natural snow that is ice capped using water
	Aggregate ice roads	C3	Building ice surfaces by flooding with water or harvesting and flooding ice chips (aggregate)
Over ice	Floating ice road	C4	Roads that follow floating ice covers on lakes or rivers
	Grounded ice road	C5	Roads that follow ice covers grounded on a lake or river bottom

Table 2: Types of Winter Roads [modified after 7]

Compacted snow road (C1) is where the natural snow has been compacted enough to allow trafficability. It is the least expensive road to build. Compaction is done in a variety of ways, including with rollers and steel frame drags. In the years where snow fall is lower than usual, additional snow may be hauled from nearby locations. C1 roads are vulnerable to warm temperature and exposure to sunlight.

Over land ice-capped snow road (C2) involve surface flooding and allow for the passage of heavier vehicles than C1 roads. The reason is that an icy surface is stronger and more resistant to wear than a snow surface. In places, the sub-grade can be directly overlain with that ice layer (i.e. without a snow layer). However, adding water to the compacted snow complicates the logistics – water tankers or trucks have to be involved and nearby sources of water have to be available. The operators may require permission from environmental authorities to use the water. Lower traction on C2 roads has to be taken into account in road planning, for instance when considering grades and vehicle capabilities.

Over land aggregate ice roads (C3) can accommodate the highest vehicle weights and passage frequency, and are suitable for uneven terrains. An additional step in building them is the recourse to ice chips that are flooded with water. The road builder makes use of tractors equipped with rippers. The ice is hauled and dumped at the location (as would be done with gravel for an all-season road). The ice chip surface is then packed and saturated with water. This accelerates the rate of sub-grade thickening where it is required. C3 roads do not need a snow layer. Logistically, they are even more involved than C2 because they rely on the availability of water and ice, and may also require permission from environmental authorities to access both.

Floating ice roads (C4) are built over frozen water surfaces, which are very practical media for surface transportation. They are flat, require minimum maintenance and may run in a straight line (as opposed to over land segments, which must take into account the topography and vegetation. The limiting factor is climate, mainly the air temperature and the amount of snow fall, since these factors control the rate of ice growth. Human intervention can help to increase the rate, such as removing the snow cover, and thickening the ice by flooding or spraying water over the ice surface. The consequences of a breakthrough[19] in C4 roads remain a concern for winter road operators. Risk mitigation measures include adequate traffic management, ice thickness monitoring and quality inspection.

Grounded ice roads (C5) lie directly on the river or lake bed, typically near the shorelines. The ice can be fastened to the bottom. Alternatively, at shoals (i.e. in shallow lake areas), and where the ice cover has been thickened to a sufficient extent by surface flooding, the ice can sink down and end up resting on the lake's bottom. C5 roads are generally capable of supporting higher loads than C4 roads.

2.2.2 Winter Road Planning Considerations

There are a number of different guidelines in Canada for the construction, maintenance and usage of winter roads. [9], [7] and [10] are considered the most recent and comprehensive sources. Systematic comparisons between some of the guidelines are also available [7, 11, 12, 5].

The following list includes winter road planning requirements and considerations [4] [7]:

- Schedule and operating windows - the target road opening and closure dates, and the parameters that control these dates
  - Road opening is controlled by the maximum weight the road is expected to carry (for example some roads are meant to carry tractor trailers while others only handle light vehicles) and a sufficient number of cold days required to allow the ground[20] to freeze sufficiently/ice[21] to achieve a safe thickness. In November or December of each winter road season, depending on the location, the road may be first open to light vehicles, then to heavier vehicles. Air temperatures below freezing point, often measured in freezing-degree days (FDD), are required throughout the winter to keep the road surface strong enough.
  - Temporary road closures may happen during the season, when a weak link in the network becomes unusable/unsafe and a detour is not possible. [6]
  - Official road closure happens when an operation ceases its activities. This varies from year to year. Road closure can be due to the deterioration of the over land segments and their transition to the over ice segments, for example, where the road is darkened by the soil. Because of the lower albedo, sun rays are absorbed, contributing to the increased melting. Softening of the over ice surfaces can also be a factor. Some operators may close their road because there is no longer a need for it, such as cases when communities have received all shipments of essential fuel and materials. [6] [13]
  - Each winter road operation is different and there can be a number of factors contributing to its opening, mid-season or end of season closures.
- Traffic type and volume – the types of vehicles (weight, size, axel load distribution) and the number of passages expected
- The road right-of-way – road type, width, number of lanes, location, and type of work involved (servicing communities, mines, seismic program, etc.…)

[19] There is a gap in data related to statistics of breakthroughs and fatalities.

[20] For overland segments, snow is left in place and compacted. This preserves a high albedo and accelerates ground freezing, as well as providing a uniform surface. Albedo in this context refers to the amount of sunlight reflected by the ice/snow. If the ice/snow surface becomes dirty, for instance when it incorporates sand, it absorbs the sunlight, which accelerates melting because of stored heat.

[21] As discussed in section 2.2.1, C4 roads, ice growth can be accelerated by snow removal, as well as with flooding to artificially increase the thickness to the required target level.

- Environmental and regulatory requirements - factors such as the amount of water extraction, disturbance of aqueous wildlife and chemical or fuel spills need to be considered
- Over land route options – topography, water and snow requirements and the nature of the terrain, for example dry mineral soil is desirable while muskeg is not
    - Muskeg is mostly a mixture of organic material that is either alive (e.g. moss) or decomposing in an anaerobic environment (low oxygen). Its water table – the ground water upper surface – is near the surface and is therefore exposed to freezing in the winter. Its ability to sustain a vertical load depends on its composition – to avoid failure, one needs to ensure freezing depth is sufficient for the planned loads. In places, muskeg can be affected by water circulation. Moreover, because of extensive bacterial activity, whereby anaerobic conditions promote fermentation, muskeg is a methane-generating environment [14]. This gas is poorly soluble in water, and may contribute to the increase of ice porosity in the muskeg and a corresponding decrease in strength. Initial ice growth in muskeg is more sensitive to mild winters. Overall, the behavior of muskeg is mechanically unlike mineral soil. Winter road routing over this terrain requires careful consideration to avoid breakthroughs.
    - Permafrost, which is often associated with muskeg, is mostly found north of the 60th parallel. It is very sensitive to disturbance and weather patterns, and is also affected by climate change [15]. Permafrost can be several hundred years old. It is divided into two layers: an active layer that undergoes yearly freeze-thaw cycles, and a permanently frozen layer, extending several hundred meters in the colder regions, to a few meters where it is warmer. Permafrost is classified according to its distribution in terms of surface area it occupies at any given location into continuous (> 80%), discontinuous (30-80%), and sporadic (<30%). Even where it is discontinuous or sporadic, given this terrain's sensitivity, it is a significant factor in winter road management. Because winter roads are not used in the summer, they do not face the same engineering challenges of all-season roads, which have to contend with a thawing active layer. In other words, the active layer below a winter road is always frozen, thereby protecting the permanent layer below. Nonetheless, in these areas, it is recommended to [7] avoid ground known to be rich in ice, avoid peat deposits and muskeg, plan the route so it runs over coarse grained soils, such as moraines and outwash areas, and in areas of discontinuous permafrost, consider routing over south-facing slopes, which may be devoid of permafrost.
- Temperature and snow fall for over land segments - historical records of freezing degree days (FDD, section 3.2) and snow fall are critical parameters. [7] mentions that a FDD of 300 as a minimum for ground freezing, and 5-10 cm of snow to support traffic
- Over ice options – water currents (if any), availability of portages (over land bridge between lakes) and bathymetry, and water influx from nearby streams. Shallow areas and shoals can be problematic, for instance, to address issues related with vehicle speed
    - Over ice segments correspond to winter road C4 type. In wooded sectors, these roads may be more exposed to the sun compared to over land segments, since the latter may be sloping toward the north or benefit from the shade from evergreen vegetation. They may also be affected by the wind and, in places, water currents, bearing in mind the foundation – frozen water – is thin relative to the water column below it.
    - From a road construction and maintenance perspective, early snow removal "represents the greatest risk of a possible breakthrough" [7]. Breakthroughs also happen for a number of other reasons. Further, since the mechanical strength and elastic behavior of an ice cover is influenced by air temperature and solar radiation [e.g. 16, 17], higher risks are also associated with surface trafficability late in its operational time window.
- Ice conditions - similarly, historical ice thickness data should be consulted, along with freeze-up dates and ice cover disintegration/break-up dates.
- Climate change – better integration of warming trends will allow better planning and anticipate future winter road operating windows.

2.3 Standards for Climate Risk Assessment

A scan by NRC's National Science Library on international standards related to the assessment of risk due to climate identified the following three main standards:

- ASTM E3032 – Standard guide for climate resiliency planning and strategy
- ISO 14090 – Adaptation to climate change – principles, requirements and guidelines
- ISO/FDIS 14091 - Adaptation to climate change – guidelines on vulnerability, impacts and risk assessment

This section provides a summary of relevant items from the three standards.

2.3.1 ASTM E3032 – Standard Guide for Climate Resiliency Planning and Strategy

This standard [18] provides a generalized, systematic approach to voluntary assessment and risk management of extreme climate related events and conditions. The standard outlines a risk management process as follows:

- Establish the context – state the objectives, define which extreme weather scenarios will be used to inform the risk assessment, identify stakeholders, their objectives and how they will be engaged, define the external and internal factors that may give rise to climate risks or influence vulnerability, define the risk criteria to be used to assess likelihood and consequence, and define the scope, purpose and structure of the particular risk management activity.
- Risk identification – create a comprehensive list of risks based on available climate information that might significantly affect the settlement or infrastructure. This helps to better understand whether these risks may lead to beneficial or detrimental outcomes.
- Risk analysis – develop an understanding of the risk.
- Risk evaluation – used to help decide which risks need to be treated and their priority.
- Risk treatment – a range of possible options for treating each risks is required to allow the most appropriate actions to be selected.

In the simplest of terms, the standard is a guide for the process of identifying the risks for the objectives, prioritizing those risks, identifying the potential loss, and developing plans or measures to mitigate the risks.

The approach outlined by this standard has been specifically developed for the United States (US). The country is divided into eight different climate assessment regions, where each region has its susceptibility to certain types of extreme climatic events. A table is included in the standard that provides examples of extreme climatic events and identifies which events should be given priority in each region. The extreme climatic examples given are, but are not limited to:

- Extreme Temperature (hot or cold),
- Drought
- Fire
- Flood
- Storms
- Land Movement Subsidence
- Sea Rise and Tidal Effects

2.3.2 ISO 14090 Adaptation to Climate Change – Principles, Requirements and Guidelines

This standard [19] specifies the principles, requirements and guidelines for an organization to adapt to climate change. The document outlines how to integrate adaptation within or across an organization, how to identify and understand the impacts and uncertainties of climate change, and how to make informed decisions.

The document outlines a structured approach which includes:

- Pre-planning
- Assessing impacts including opportunities
- Adaptation planning
- Implementation
- Monitoring and evaluation
- Reporting and communication

Preplanning is a process that prepares the organization to implement the structured approach outlined in this standard. Pre-planning involves assessing, and where necessary establishing, the capability of the organization to undertake this structured approach as well as identifying interested parties and how it engages with them.

For assessing climate change impacts including opportunities, the organization shall:

- Assess how its activities, products and services might be impacted by climate change
- Access the organization's existing adaptive capacity to the impacts of climate change
- Identify opportunities that can arise from climate change
- Identify the uncertainties in climate scenarios, climate projections and data used in the decision making process and how this uncertainty can influence the results.

The standard identifies three methods to assess impacts:

- Risk assessment
- Vulnerability assessment
- Thresholds analysis

The organization should adopt the method(s) best suited to their needs.

For adaptation planning, the organization shall:

- Assemble an adaptation plan from varied sources of knowledge, information and data, in the context of existing policies, strategies, planning and decision-making processes
- Incorporate and embed climate change adaptation into its policies, strategies and plans
- Develop a decision making process and a mechanism for feedback and learning from the decisions made

For implementation, the organization shall prepare an implementation plan that:

- Documents the processes, including inputs and outputs, that ensure the actions identified in the adaptation plan are delivered

- Sets out contingencies in order to attain successful implementation where actions are found to be incapable of delivering the desired outputs
- Provides for adjustment where new learning and/or circumstances are recognized

Monitoring and evaluation are used to assess, inform and review the adaptation plan so that satisfactory progress is confirmed and indications of unsatisfactory progress are highlighted early enough, triggering when additional action is needed and allowing corrective action to be taken. The organization shall prepare a monitoring and evaluation plan that assesses progress against the implementation plan. The monitoring and evaluation plan should include an assessment of actions, inputs, outputs, resources, roles and responsibilities, processes, capacities and any other relevant aspects. Monitoring and evaluation is used to inform the organization about the progress of its climate change adaptation. It can generate knowledge, learning and evidence that can then inform adaptive management.

For reporting and communication, an organization may communicate its climate change adaptation to interested parties external to the organization. When an organization makes an external climate change adaptation communication it shall be supported by a climate change adaptation report that is easily accessible to any interested party and is free of charge.

2.3.3 ISO/FDIS 14091 - Adaptation to Climate Change – Guidelines on Vulnerability, Impacts and Risk Assessment

This standard [20] belongs to an emerging family of standards on adaptation to climate change under the umbrella of **ISO 14090** "*Adaptation to climate change — principles, requirements and guidelines"* (section 2.3.2).

This standard is part of the second list item from section 2.3.2 under 'assessing impacts including opportunities'. Risk assessment made using the approach in this standard provides a basis for the subsequent elements of ISO 14090, including adaptation planning, implementation, and monitoring and evaluation.

This standard provides guidance for assessing the risks related to the potential impacts of climate change. It describes how to understand vulnerability and how to develop and implement a sound risk assessment in the context of climate change.

Climate change risks differ from other risks. Often little can be said about their short term or long term probability so a conventional risk assessment which uses statistical probabilities can be ineffective. For this reason, various approaches have been developed for assessing climate change risks and this document is a guide to the use of *screening level assessments and impact chains*. The screening level approach can serve as a stand-alone, simplified risk assessment for a straight forward system at risk or those with a limited budget, or serve as a pre-assessment prior to the use of impact chains.

The document defines the components for risk assessment as:

- The hazard
- Exposure of a given system to the hazard
- Sensitivity of the system to the hazard
- (Potential) climate change impact (risk without adaptation)

- Risk with adaptation (in the future)

The document defines the steps of a risk assessment process and expands upon each of the following:

- Preparing a climate change risk assessment
  - Establishing the context
  - Identifying objectives and expected outcomes
  - Establishing a project team
  - Determining the scope and methodology
  - Setting the Time Horizon
  - Gathering relevant information
  - Preparing an implementation plan
  - Ensuring transparency
- Implementing a climate change risk assessment
  - Screening impacts and developing impact chains
  - Identifying indicators
  - Acquiring and managing data
  - Aggregating indicators and risk components
  - Assessing adaptive capacity
  - Interpreting and evaluating the findings
  - Analysing cross-sectoral interdependencies
- Reporting and communicating climate change risk assessment results
  - Climate change risk assessment report
  - Communication of climate change risk assessment results and outcomes
  - Reporting findings as a basis for appropriate adaptation planning

The standard provides several annexes as to how to apply this method.

2.4 Examples of Climate Risk/Vulnerability Assessments as related to Winter Roads

The project team attempted to located examples of climate related risk/vulnerability assessments in literature on winter roads. 22 documents were reviewed in search of examples on winter roads either in Canada or internationally.

During FY2020-2021, no true example was located of a risk assessment or vulnerability assessment that follows the procedures outlined in ISO 14090, related to pre-planning, assessing impacts including opportunities, adaptation planning, implementation, monitoring and evaluation, and reporting and communication.

3 Proposed Winter Road Climate Risk and Vulnerability Review Framework

The development of the framework to review winter road climate risk and vulnerability is intended to be a process that will evolve over time. The foundation of the framework is based on published scientific methods, field data from winter road operations, as well as stakeholder observation, experience and concerns. This section describes the iteration of the framework as of FY2020-2021.

3.1 Framework Overview

The key factors that significantly impact the performance of winter roads, as identified from the scientific literature and technical documents and reports produced by winter road stakeholders, are broadly organized into four categories, including climate factors, road characteristics, operational characteristics and socioeconomic factors[22], as illustrated in the framework concept map in Figure 8.

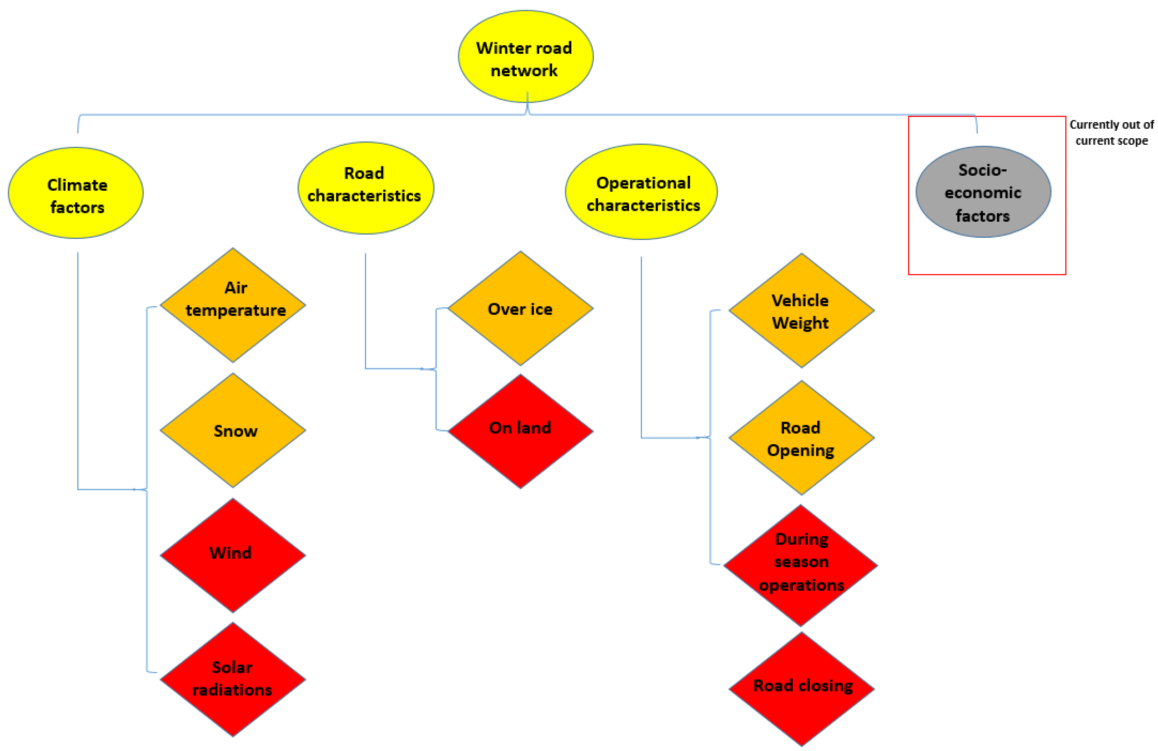

Figure 8: Winter Road Climate Risk and Vulnerability Review Framework Concept Map[23]

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[22] Referring to factors related to (but not limited to) cultural, economic, community living and ecological.

[23] Yellow coloured items are incorporated into this iteration of the framework; Orange coloured items are incorporated into this iteration of the framework; Red coloured items have been identified as important, but have not been incorporated into this iteration of the framework; Grey coloured items have not been incorporated into this iteration of the framework.

As of FY2020-2021, the factors related to climate, road characteristics and operational characteristics are incorporated into the framework.

Within the category of climate factors, air temperature and snow have been incorporated into the framework, as these parameters have emerged as the most significant factors for winter road construction, operations and maintenance. This was consistent with the literature review as well as through the consultations with provincial government officials. Within operational characteristics, since the weight of vehicles travelling across the network establishes the load limits the roads need to sustain, it is one of the first parameters incorporated into the framework. Consultations with provincial governments also revealed that the controlling parameter for being able to open road segments is whether the over ice segments have accumulated sufficient thickness to carry the designated load limits, while the over land segments are often the controlling parameter for mid-season interruptions, as well as season closures. The work completed during FY2020-2021 (this report) focused on incorporating models for over ice segments, as well as integrating the road season opening into the framework. Opening date is a very important parameter when assessing present and future road effectiveness, and historical information on this parameter is available from many operations.

There are two key steps within the winter road climate risk and vulnerability review framework:

1. Establishment of baseline operating conditions
2. Project operational conditions using future climate models
    - 2.1 Compare observed climate data with the predicted historical climate by climate models to determine calibration/transfer function (this step is usually referred to as statistical downscaling), and integrate calibration/transfer function into future climate projections
    - 2.2 Down scale calibrated future climate projections from monthly averages to daily temperatures
    - 2.3 Project future operating conditions using downscaled future daily temperature data and parameters from baseline operating conditions

The steps are discussed in detail in the sections that follow.

3.2 Establishment of Baseline Operating Conditions

The method to establish baseline operating conditions is illustrated Figure 9. The framework proposes to examine the known weak links within each network in detail. Depending on the location of the weak link, whether it is over ice or over land, the proposed analytical method is different due to the differences in operating conditions.

As mentioned in the previous section, the parameters incorporated to date focus on integrating models for the on-ice segments of the network, which are the controlling factors for determining winter road season opening, since the over ice segments are the slowest within winter road networks to accumulate sufficient thickness to carry the designated load limits.

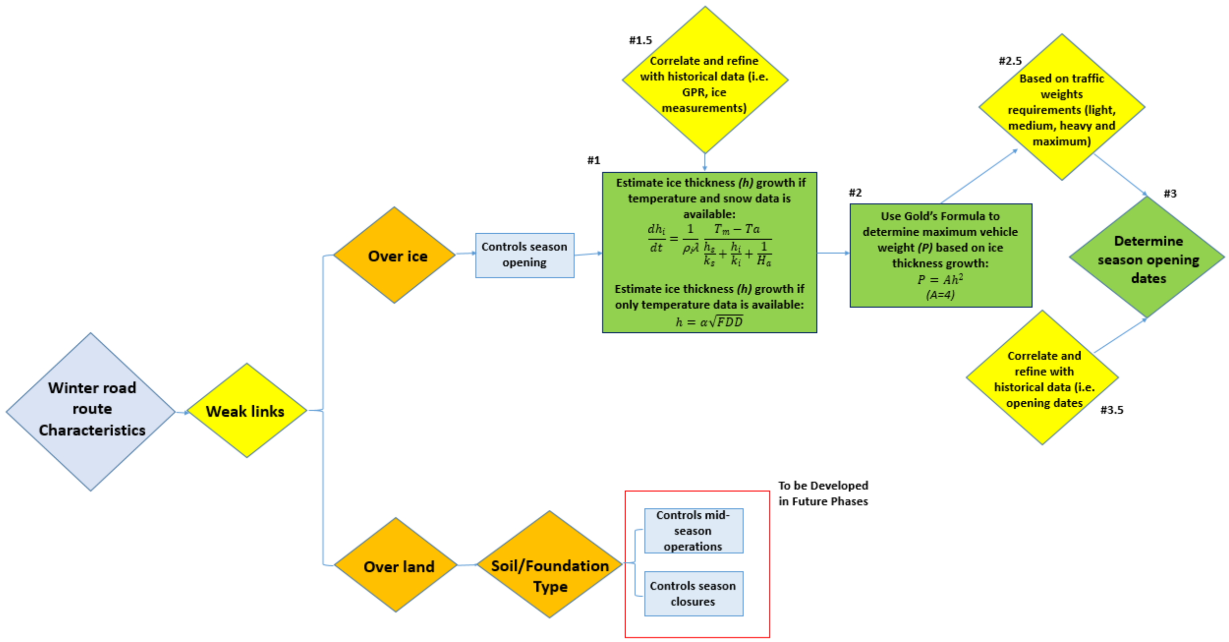

Figure 9: Winter Road Climate Risk and Vulnerability Review Framework, Step 1 Baseline Operating Conditions

The primary model for the over ice portion of the network is the formula to estimate ice thickness growth (#1 in Figure 9), as proposed by [21], which incorporates air temperature and snow. The formula estimates ice growth by balancing the heat flux from the ice surface to air with the heat flux required for the heat of fusion of ice as follows:

$$\frac{dh_i}{dt} = \frac{1}{\rho_i \lambda} \frac{T_m - T_a}{\frac{h_s}{k_s} + \frac{h_i}{k_i} + \frac{1}{H_a}} \qquad \text{Eq. 1}$$

where,

- ρ_i is the density of ice (taken as 917 kg/m^3)
- λ is the latent heat of fusion for ice (taken as 3.34×10^5 J/kg)
- k_i is the thermal conductivity of ice (taken as 2.24 W/m·°K)
- k_s is the thermal conductivity of snow (taken as $3.2 \times 10^{-6} {\rho_s}^2$, where ρ_s is the density of snow and ranging from 180 to 300 kg/m^3)
- h_i and h_s[24] are the thickness of the ice and snow cover, respectively
- T_m and T_a are the temperature at the ice/water interface(0°C) and air temperature some distance above the snow surface, respectively
- H_a[25] is a heat-transfer coefficient between the snow surface and air (taken as 25 W/m^2 °K)

[24] Parameter drops out of equation if there's no snow data.

[25] Parameter drops out of equation if there's no snow data.

- t is time

In other words, for ice growth to occur, heat needs to be removed from the water at the interface with the ice along the bottom surface. The heat gets transferred upward through the ice cover, then through the snow cover (if there is one). These two layers have different heat transfer capabilities. The main driving mechanism is the difference in temperature between the air and that at the ice/water interface. This process is captured by Eq. 1.

In the absence of snow data, Eq.1 becomes the following (also known as Stefan's equation):

$$h = \alpha \sqrt{FDD} \qquad \text{Eq. 2}^{26}$$

$$FDD = \sum(-Average\ daily\ temperature) \qquad \text{Eq. 3}$$

where,

- h is ice thickness in cm
- FDD is freezing degree days, also known as the freezing index. It's a common method used to quantify the severity of a given winter [22]. FDD is defined as the sum of the degrees of the number of days below 0ºC, as per Eq. 3
- α is an empirical coefficient (when using the above-mentioned values for ice density, thermal conductivity of ice, and latent heat of fusion for ice. α = 3.5 for when there is no snow, and the US Army Corps of Engineers recommends a number of α values for different locations and snow conditions as shown in Table 3)

Condition	Typical value for α
Windy lake with no snow	2.7
Average lake with snow	1.7-2.4
Average river with snow	1.4-1.7
Sheltered small river	0.7-1.4

Table 3: Typical α Values for Stefan's Equation as Recommended by US Army Corps of Engineers [23]

The ice thickness (h) calculated from Eq. 1 or Eq. 2 (correlated and refined with historical data) is applied to Gold's formula (Eq. 4) to calculate the maximum vehicle weight permitted as follows:

$$P = Ah^2 \qquad \text{Eq. 4}$$

where,

- P is the maximum allowable vehicle weight based on the ice thickness, in kg
- A is an empirical coefficient, based on breakthrough observations (correlated with ice thickness). In Canada, a range of A is used depending on jurisdiction, road conditions, and operational requirement, from more conservative values of 3.5 to less conservative values of 7. A=4 has been selected for the purpose of this work, based on consultations with provincial government officials, in kg/cm^2
- h is ice thickness in cm

[26] Eq. 2 could also be used for the over land segment using different α values.

Vehicle weight, which is classified into light, medium or heavy traffic, and maximum allowable weight as is stipulated by the provinces is shown in Table 4. For the purpose of this project, the season opening dates are determined from Eq. 4 (correlated with historical data) and the weight limits as per Table 4.

Province	Light Traffic Load Limit	Medium Traffic Load Limit	Heavy Traffic Load Limit	Maximum Allowable Load Limit
Ontario	Community decides weight limit 11 tonnes (25,000 lb)	Community decides weight limit	Community decides weight limit 36 tonnes (80,000 lb)	36 tonnes (80,000 lb)
Manitoba	≤ 7 tonnes (15,000 lb)	≥ 7 tonnes (15,000 lb) ≤ 15 tonnes (33,000 lb)	≥ 15 tonnes (33,000 lb) ≤ 39.5 tonnes (87,000 lb)	> 39.5 tonnes (87,000 lb) require special permits maximum vehicle weight[27] = 57 tonnes (125,000 lb) across ice
Saskatchewan	≤ 9.6 tonnes (21,000 lb)	≥ 9.6 tonnes (21,000 lb) ≤ 15.4 tonnes (34,000 lb)		34.5 tonnes (76,000 lb)
Alberta	≥ 5 tonnes (11,000 lb) ≤ 15 tonnes (33,000 lb)	≥ 15 tonnes (33,000 lb) ≤ 27.5 tonnes (60,000 lb)	≥ 27.5 tonnes (60,000 lb) ≤ 65 tonnes	65 tonnes (143,300 lb)

Table 4: Winter Road Vehicle Weight Limit from Provinces

An example of the establishment of baseline operating conditions is provided in the case study of the James Bay Winter Road (section 4.1).

3.2.1 Evaluation of Ice Thickness Estimation Models

To evaluate the suitability of Eq. 1 and 2 to estimate ice growth, data (ice thickness and snow depth measurements) from three sites that were part of Government of Canada's Ice Thickness Program[28] (Alert, Eureka and Baker Lake) were collected and compared against the values calculated from the above equations and using snow thickness and average daily temperature recorded by a weather station with the same name as the ice site measurements (Figure 10).

[27] Without the need to complete additional safety assessments.

[28] https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/archive-overview/thickness-data.html

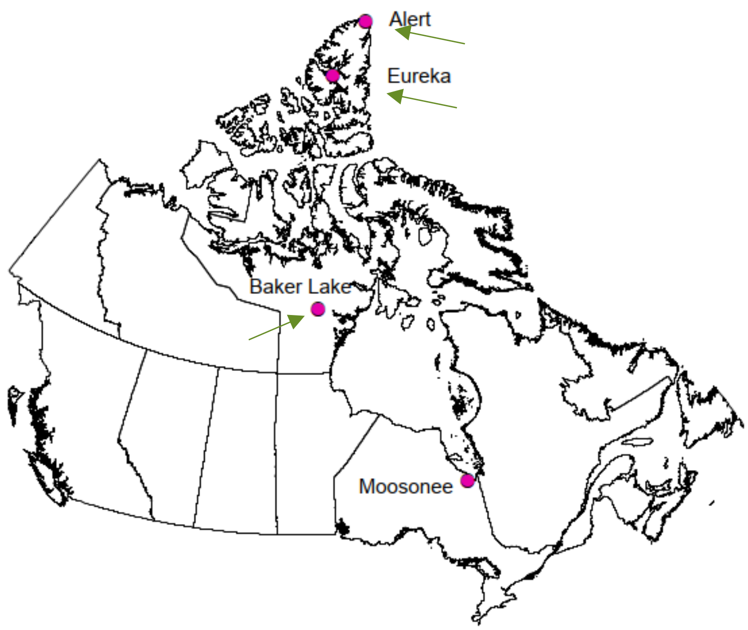

Figure 10: Location of Weather Station that were Part of Government of Canada's Ice Thickness Program (Green Arrows)

Although the location of Baker Lake is more relevant to winter roads, data from as far North as the Alert and Eureka locations are used herein mainly for the purpose of this exercise.

Figure 11a compares the snow on ground values measured at the Alert ice site with the values recorded at the Alert weather station. The measured values correlate well with each other in some years (winter 2015-2016 and 2016-2017), but not in other years (winter 2018-2019). Figure 11b shows the variation of mean daily temperature and the FDD between 2014 and 2020 recorded at Alert weather station. It should be noted that the convention used in this plot to calculate FDD for each year is to start from the first day after July 1st, as soon as the mean daily temperature is below zero for at least seven consecutive days and continue until the end of May of the following year. Similar plots are available for Baker Lake and Eureka sites in Figure 13 and Figure 15, respectively.

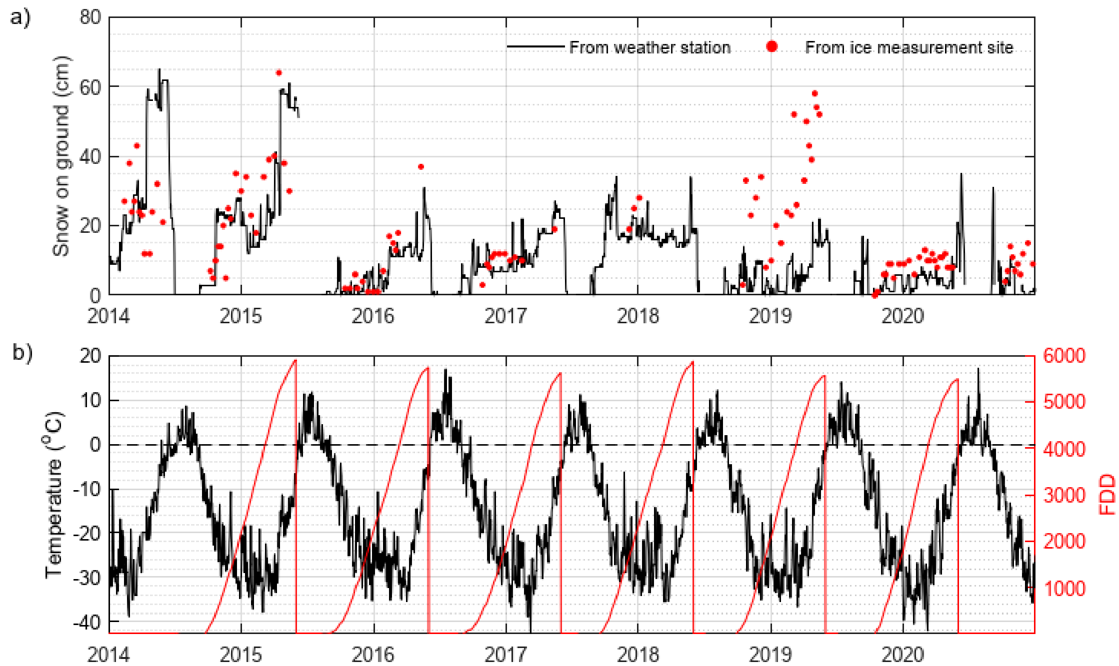

Figure 11: a) Plot Comparing Snow on Ground Recorded at the Alert Ice Site Measurements with Values Recorded at the Alert Weather Station, and b) Variation of Mean Daily Temperature Recorded at the Alert Weather Station and the Calculated FDD

Figure 12 compares the ice thickness measurement values at Alert site with values calculated from:

1) Eq. 1 and using mean daily temperature from Alert weather station and snow on ground values from Alert ice site (since the snow measurement at the ice sites are not continuous, a linear interpolation between the measurement dates has been used)

2) Eq. 1 and using snow and mean daily temperature, both from the weather station

3) Using Stefan's equation with α=1.7 (assuming average lake and river with snow)

4) Using Stefan's equation with α=3.5 (assuming no snow)

As can be seen in Figure 12, the accuracy of the ice thickness estimate varies between different methods and also from year to year. For example, according to Figure 11a, there was a thick snow cover on the ground during winter 2014-15 and as a result the calculated ice thickness using Stefan's equation with α=3.5 does not provide a good estimate of the measured values. On the other hand, for winter 2019-2020 the snow on ground data recorded at the ice site is very well aligned with the weather station records and as a result the ice thickness calculated by using Eq.1 and snow on ground from the weather station provides a fairly accurate estimate of the actual measured ice thickness.

A similar analysis was conducted for Eureka and Baker Lake sites and the results are presented in Figure 14 and Figure 16 respectively.

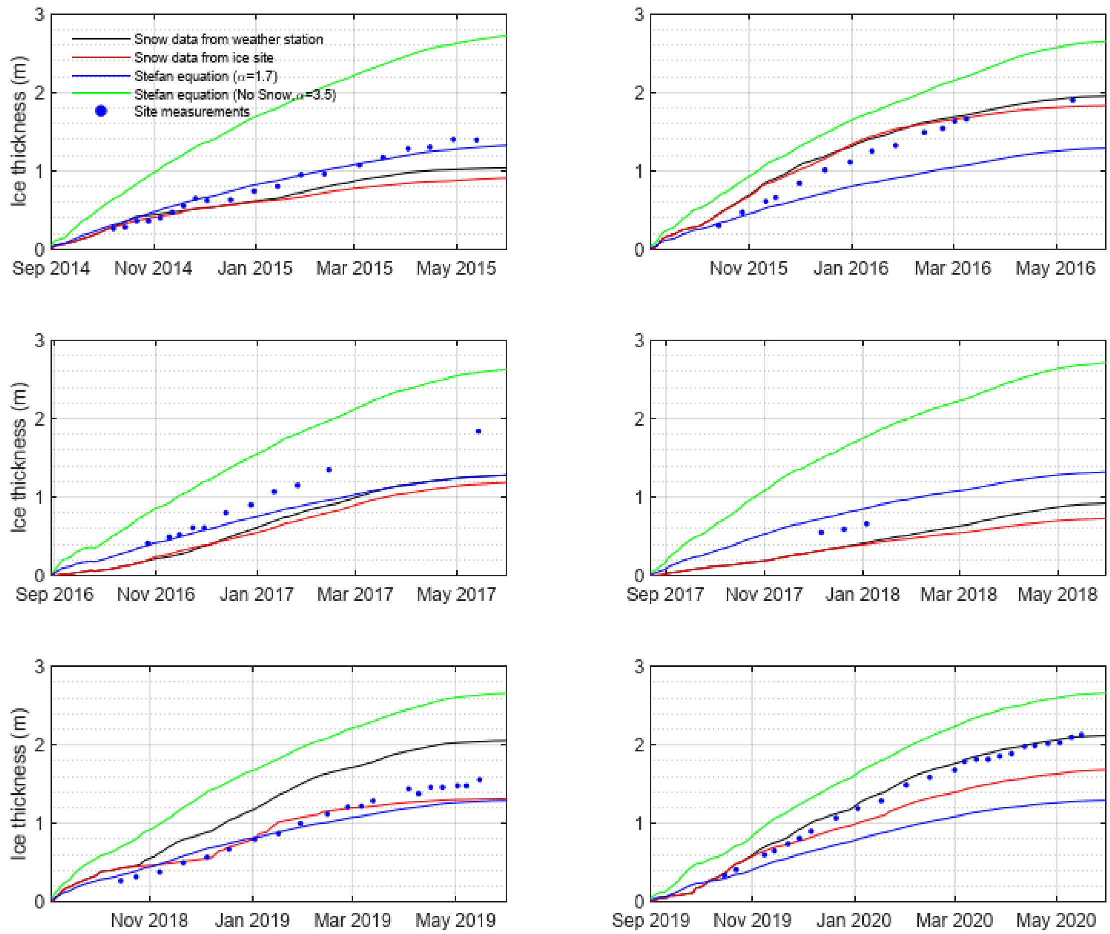

Figure 12: Plots Compare the Ice Thickness Measurements at the Alert Site with Ice Estimate using Eq. 1 with Snow Data from Ice Site and Snow Data from the Weather Station and Stefan's Equation Using α=3.5 (No Snow) and α=1.7 (Average Lake/River) With Snow

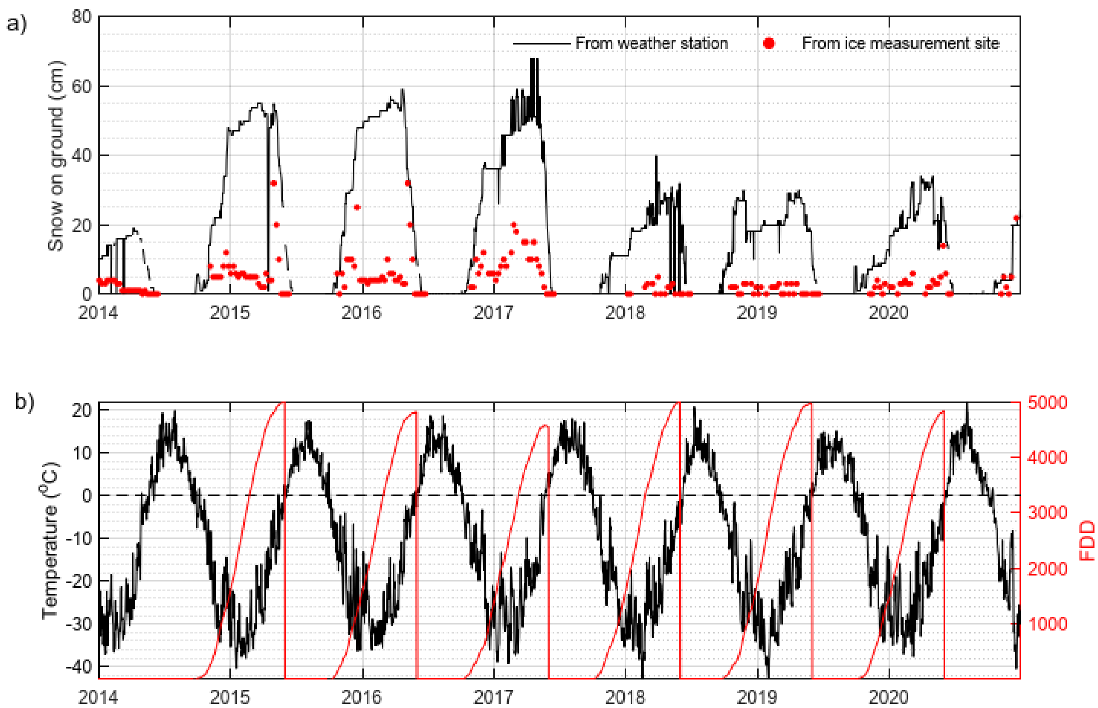

Figure 13: a) Plot Comparing Snow on Ground Recorded at the Baker Lake Ice Site Measurements with Values Recorded at the Baker Lake Weather Station, and b) Variation of Mean Daily Temperature Recorded at the Baker Lake Weather Station and the Calculated FDD

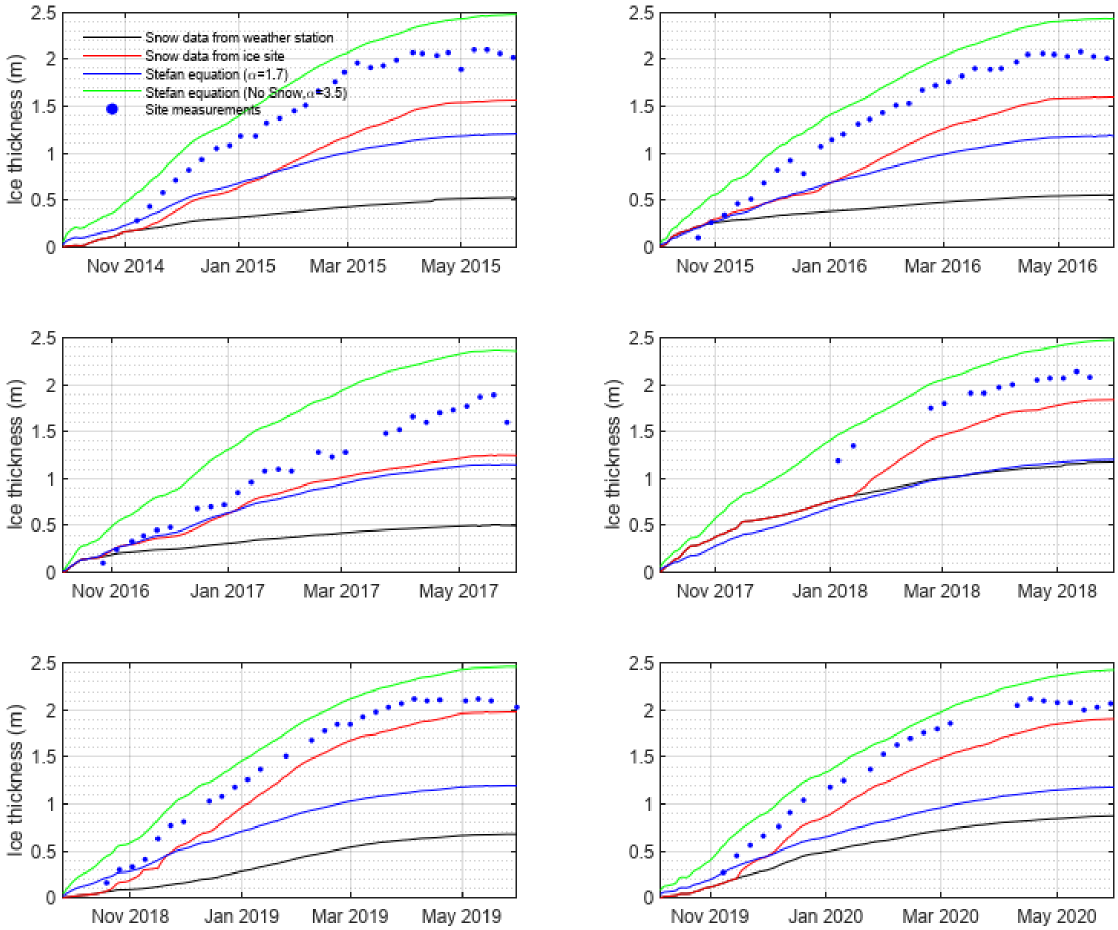

Figure 14: Plots Compare the Ice Thickness Measurements at the Baker Lake Site with Ice Estimate using Eq. 1 with Snow Data from Ice Site and Snow Data from the Weather Station and Stefan's Equation Using α=3.5 (No Snow) and α=1.7 (Average Lake/River) With Snow

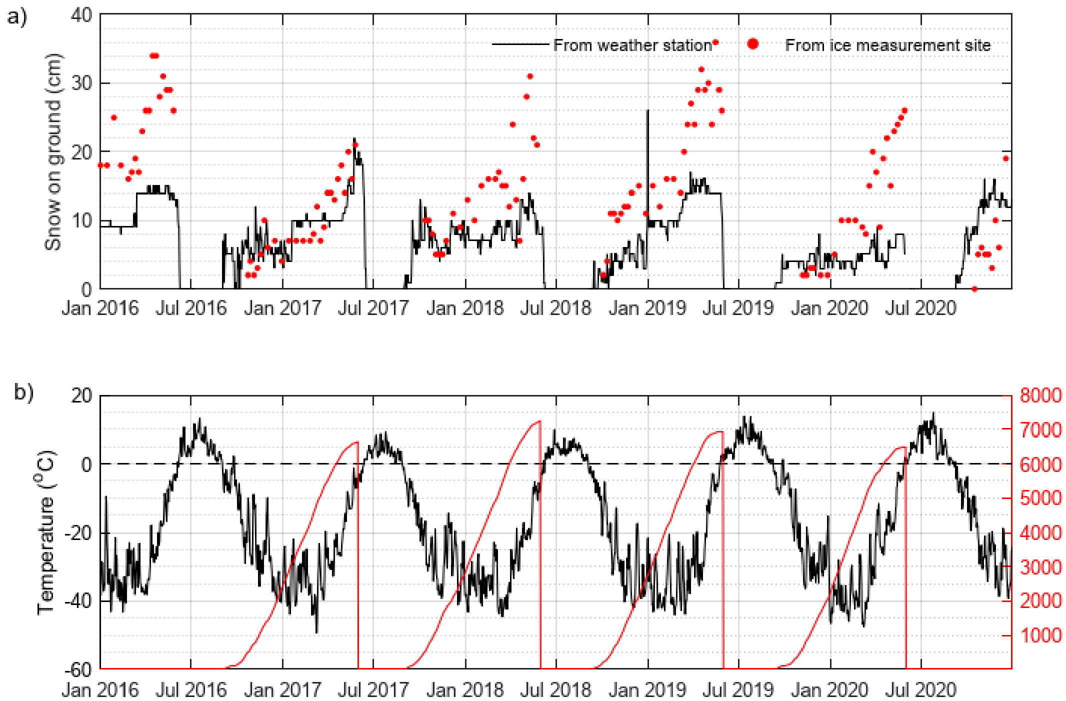

Figure 15: a) Plot Comparing Snow on Ground Recorded at the Eureka Ice Site Measurements with Values Recorded at the Eureka Weather Station, and b) Variation of Mean Daily Temperature Recorded at the Eureka Weather Station and the Calculated FDD

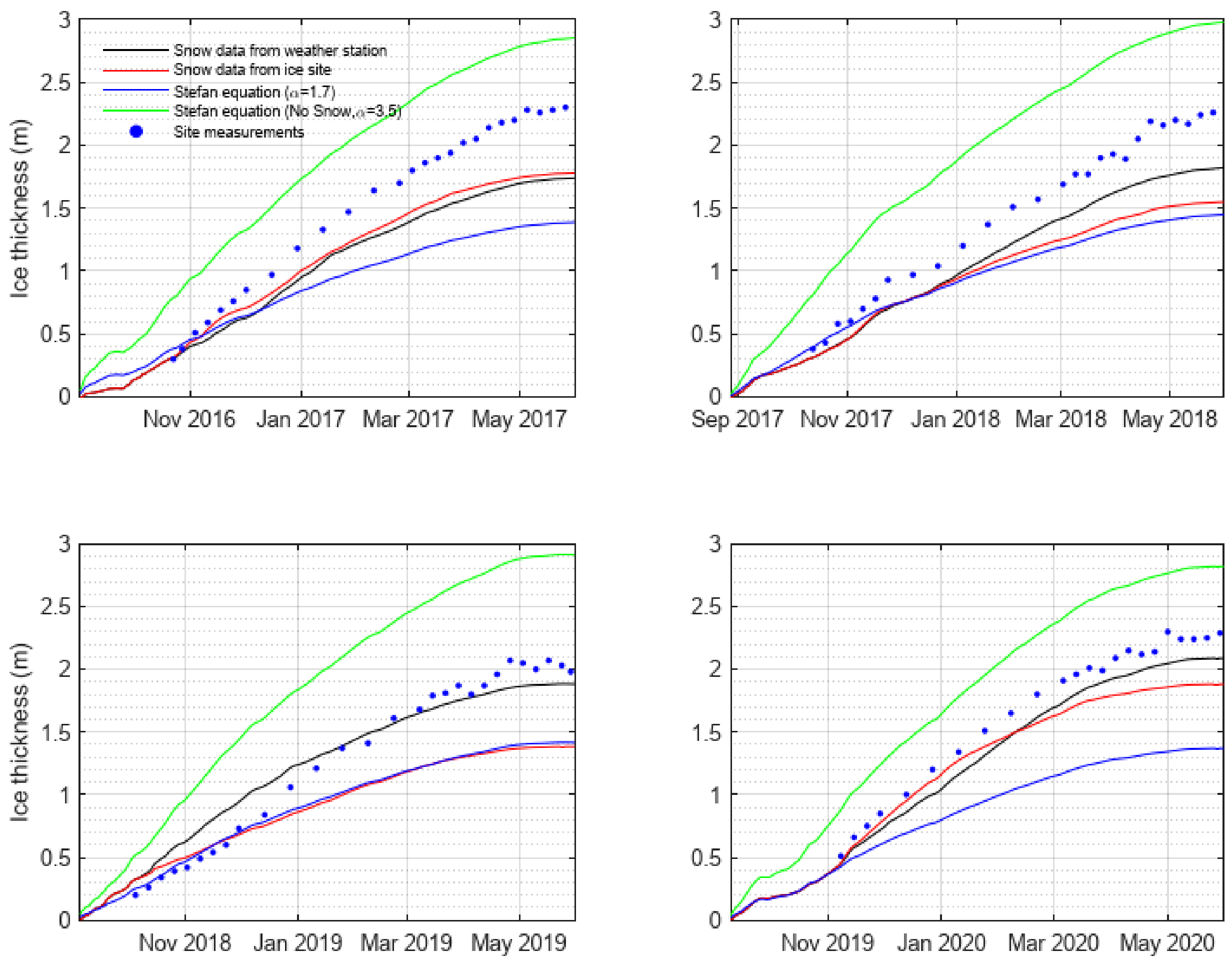

Figure 16: Plots Compare the Ice Thickness Measurements at the Eureka Site with Ice Estimate using Eq. 1 with Snow Data from Ice Site and Snow Data from the Weather Station and Stefan's Equation Using α=3.5 (No Snow) and α=1.7 (Average Lake/River) With Snow

Sensitivity analysis

As can be seen in Figure 12, Figure 14 and Figure 16, ice thickness is strongly affected by the combination of snow cover and air temperatures. This is also consistent with field observations, as confirmed by provincial government officials, as well as regional office staff from ISC. In order to see the relative influence of each factor (air temperature and snow cover), a sensitivity analysis was conducted.

In this analysis, the daily ambient temperature and snow on ground data recorded at the Eureka station during winter 2018-2019 were selected as the baseline. This data set was selected due to the fact that, as can be seen in Figure 16, using Eq. 1 and data from the Eureka weather station provides a fairly good estimate of ice thickness.

The following scenarios of various degrees of climate warming and cooling, and snow thickness were considered:

1) Keeping the snow on ground values constant and changing the temperature values by +0.5°C, +1.0°C, +1.5°C, +2.0°C, -0.5°C, -1.0°C, -1.5°C, -2.0°C (T_a in Eq. 1)

2) Keeping the temperature constant and changing the thickness of snow cover by +5%, +10%,+15%,+20%,-5%,-10%,-15%,-20% (H_s in Eq. 1)

Figure 17a shows how increasing and decreasing the ambient temperature affects the ice thickness. For example, a 2.0ºC increase in ambient temperature may lead to up to 20 cm decrease in ice thickness (with the same amount of snow cover). On the other hand, as shown in Figure 17b, a 20% decrease in snow cover may lead to an increase in ice thickness of nearly 15 cm.

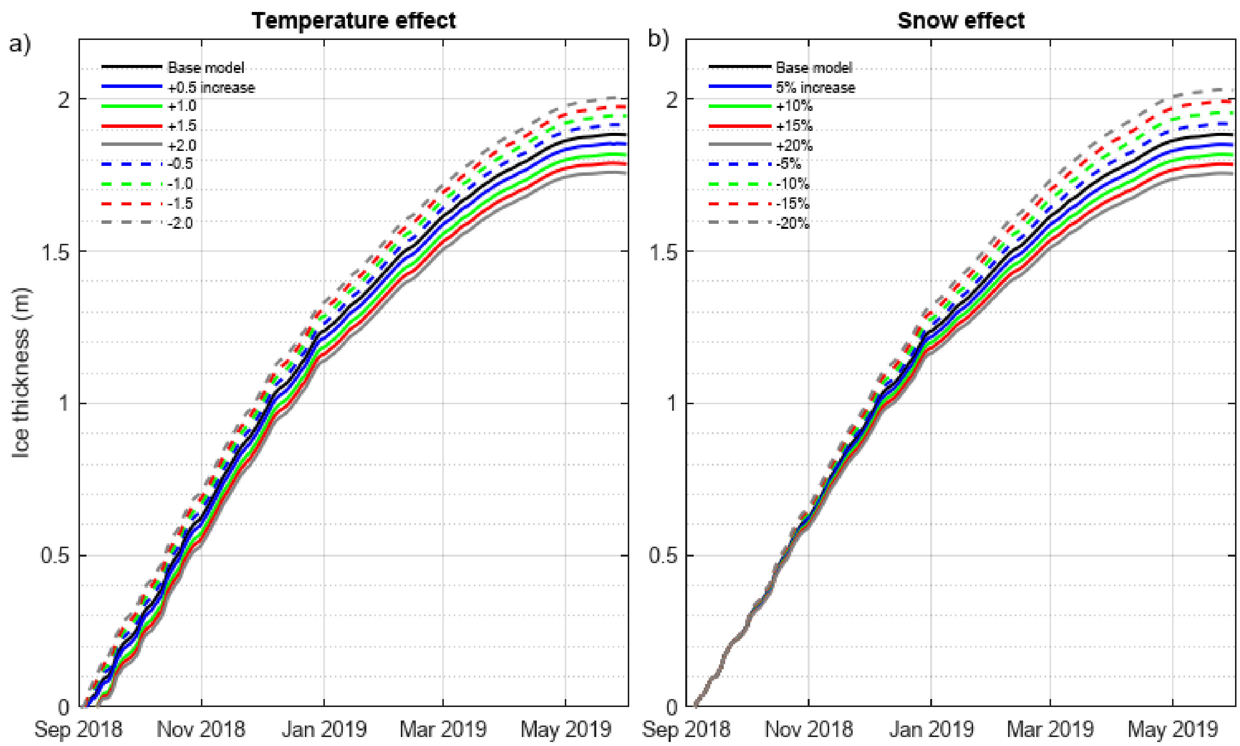

Figure 17: Plots Show the Sensitivity of Ice Thickness to a) Change in Air Temperature and b) Snow Thickness (Note: The Baseline Model uses Ambient and Snow on Ground Values Recorded during Winter 2018-2019 at the Eureka Weather Station)

The purpose of this exercise is to illustrate the effect of a difference in temperature, which might be predicted by different climate models (for a given snow depth), in addition to examining the effect of snow depth and provide guidance in assessing the relevance of snow in future analyses (and of the importance of improved snow monitoring). This also provides an indication that other factors can potentially contribute significantly to the differences in ice thicknesses with the same air temperature regime other than snow thickness (for example wind).

3.3 Projections under Future Climate Scenarios

Once baseline operating conditions are established as per section 3.2, the next step is to project operating conditions (season opening dates, potential mid-season interruptions and season closures) under future climate scenarios. In order to do so, it is important to first note how climate projections are done, as well as the limitations and uncertainties associated with climate models.

Canada's Changing Climate Report [2] provided the following information with regards to the projections of future climate:

- *Earth system models are based on a mathematical representation of the behaviour of the atmosphere, ocean, land surface, and cryosphere. They simulate a virtual planet using powerful supercomputers, allowing scientists to probe the connections between various physical and biogeochemical processes, e.g., how the ocean takes up heat and carbon, stores and then redistributes it.* (Figure 18)
- *Earth system models are used to simulate historical climate, driven by observationally based climate forcing (e.g., historical changes in GHG concentrations), and make projections of future climate.*
- *While Earth system models can simulate the climate system's response to human emissions of GHGs, they cannot predict future human activities. Therefore, projections are made using various scenarios, or pathways, of future GHG concentrations, aerosol loading and land-use change.*
- *The projections described in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment (2013) were based on a suite of future forcing scenarios called Representative Concentration Pathways (RCPs) that cover the period from 2006 onward. The RCPs are identified by a number indicating the change in radiative forcing — the imbalance between the solar radiation entering the climate system and the infrared (longwave) radiation leaving it caused by greenhouse gases and other external drivers — by the end of the 21st century. RCP2.6 represents a low emission pathway with a change in radiative forcing of roughly 2.6 W/m^2, RCP4.5 and RCP6 represent intermediate emission pathways, and RCP8.5 represents a pathway with continued growth in GHG emissions, leading to a radiative forcing of roughly 8.5 W/m^2 at the end of the century.*
- *All models used to project climate have some uncertainty associated with them, owing to approximations that must be made in representing certain physical processes. To understand the uncertainty in models, scientists compare them with other models and evaluate how much the models differ in their projections. To determine this, an ensemble of models is needed* (Figure 19)*, allowing a range of simulations and projections to be analyzed and compared. The World Climate Research Programme has established the Coupled Model Intercomparison Project (CMIP) specifically for this purpose. An agreed-upon suite of historical simulations and future climate projections are performed using the same external forcing (changing GHGs, land-use, etc.). The outputs from the models are archived in a common format for analysis by the climate research community.*
- *The most recent, fifth phase of this project, CMIP5, provided climate model results that were assessed in the IPCC Fifth Assessment Report, and many of these results are available from the Canadian Climate Data and Scenarios website[29]. Future climate projections in CMIP5 used the RCP emission scenarios. A new version, CMIP6, is currently underway and will serve as input to the IPCC Sixth Assessment.*

[29] https://climate-scenarios.canada.ca/?page=main

- *One method of measuring whether models can realistically represent the complex interconnections among climate processes is to gauge their ability to reproduce past changes. Simulations using observationally based historical forcing from 1850 onward provide the opportunity to directly compare model results to observations.*

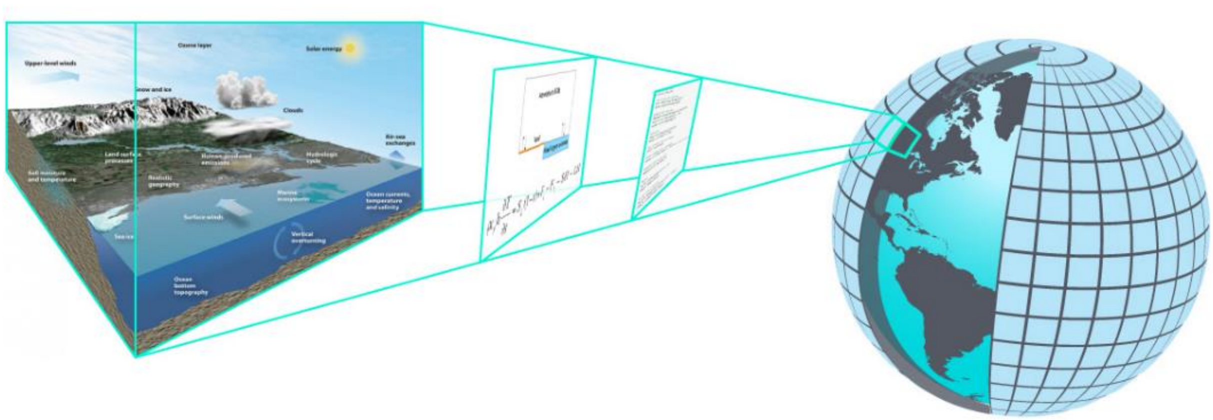

Figure 18: Graphical Representation of How Earth Systems Models are Built [2]

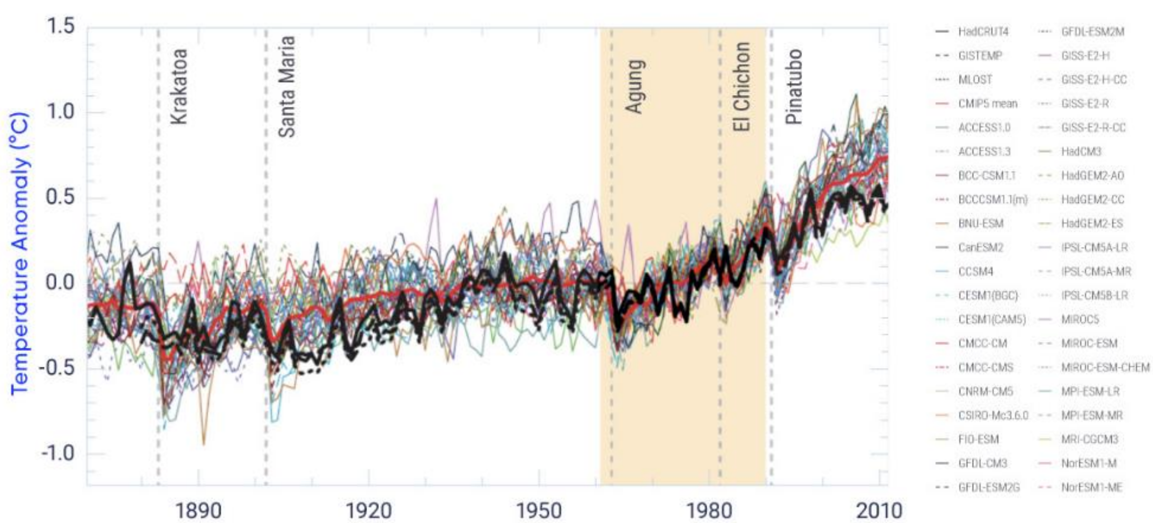

Figure 19: Graphical Representation of an Ensemble of Climate Models[30] (Canada's Climate Model is the CanESM) [2]

[30] *Figure Caption: global annual mean surface air temperature anomalies from 1850 to 2012 (anomalies are computed relative to the 1961–1990 average shown by yellow shading). The heavy black lines represent three different reconstructions of temperature based on observations. Each of the thin coloured lines represents a simulation from one of 36 climate models. The heavy red line indicates the multi-model average. The overall warming trend is evident in both observations and simulations, particularly since about 1960, and both show cooling following large volcanic eruptions (vertical dashed lines).*

3.3.1 Overview of Projections under Future Climate Scenarios

An overview of the proposed method to project operational conditions using future climate models is shown in Figure 20, which consist of the following steps:

- Step 2.1: part 1 - compare observed climate data with predicted historical climate (in climate models) to determine whether they correlate well, or whether a calibration/transfer function is needed to better correlate the results
- Step 2.1: part 2 - integrate the calibration/transfer function from part 1 into future climate projections
- Step 2.2: down scale the calibrated future climate projections (step 2.1, part 2) from monthly temperature averages to daily temperatures
- Step 2.3: project operating conditions using downscaled future daily temperature data and parameters from baseline operating conditions

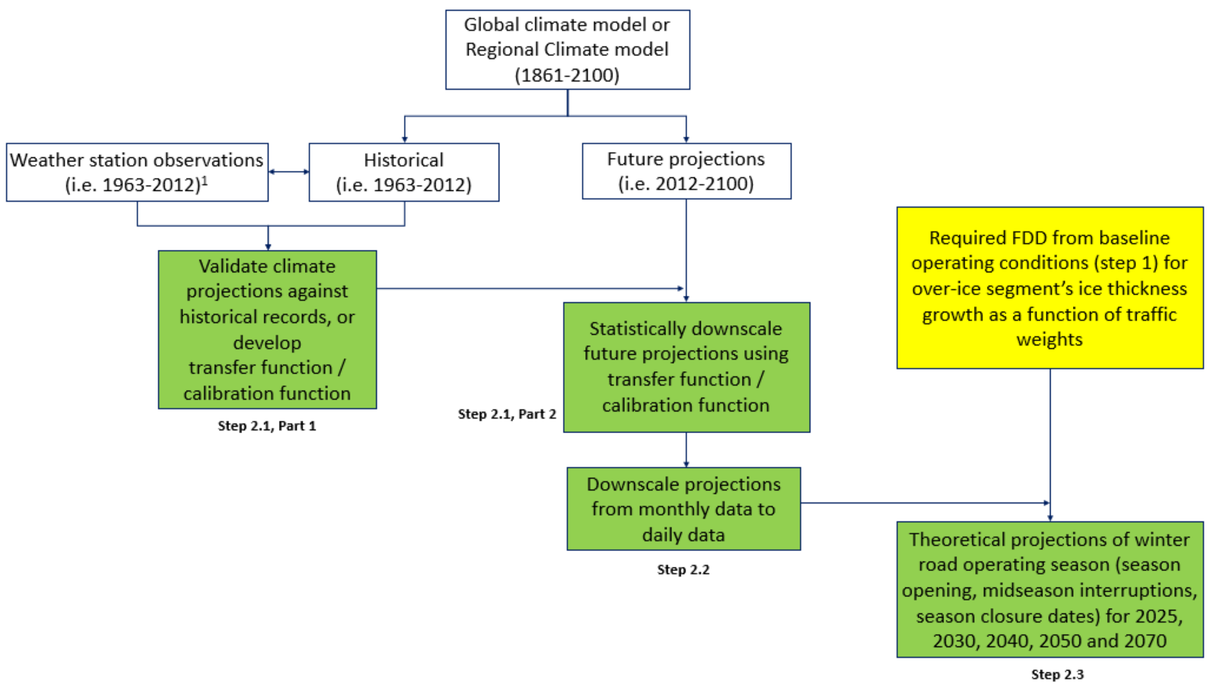

Figure 20: Winter Road Climate Risk and Vulnerability Review Framework, Step 2.1, Step 2.2 and Step 2.3

Climate Model Resolutions

According to Canada's Changing Climate Report [2], "*climate projections must be made using global models because many of the processes and feedbacks that shape the response of the climate system to external forcing operate at the global scale… however, for other applications, global climate model projections are not adequate, as they typically have horizontal spatial resolution, or grid spacing, of 100 km or coarser…when climate information at a higher spatial- or temporal-resolution is needed, there are several approaches available to take global climate model projections and "downscale" them to higher resolution for a region of interest (or even a single location)…*The differences in resolution of a global climate model and a regional one is shown in Figure 21… *Statistical downscaling is a form of climate model "post-processing" that combines climate model projections with local or regional observations to* *provide climate information with more spatial detail... statistical post-processing methods typically downscale to higher resolution and correct systematic model biases*".

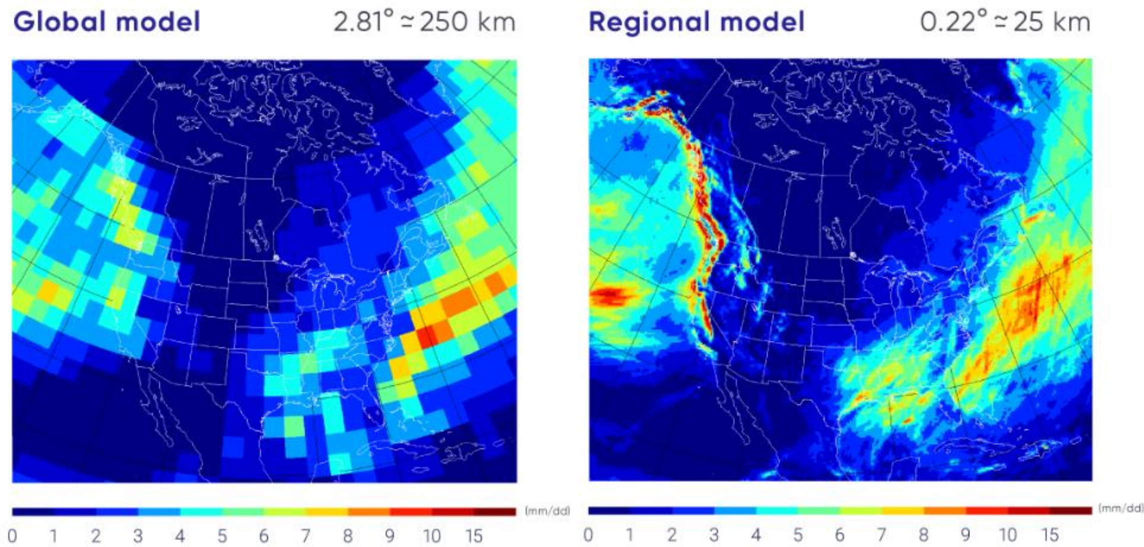

Figure 21: Graphical Comparison of the Resolutions of a Global Model versus a Regional Model [2]

Step 2.1 Comparison of Observed Climate Data with Climate Models

As discussed in earlier sections, climate models typically have a predicted historical climate as shown in Figure 22 in grey, and projections of future climate shown in Figure 23 in colour, under various RCP scenarios.

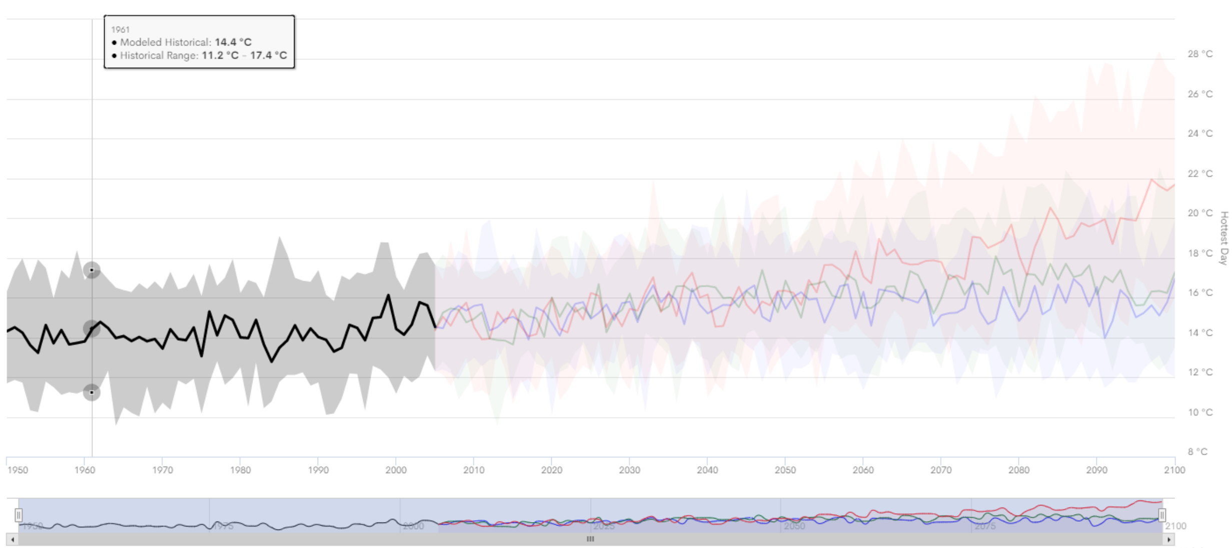

Figure 22: Example of Predicted Historical Climate from Climate Models of a Location Near the Eureka Weather Station, Nunavut (https://climatedata.ca)

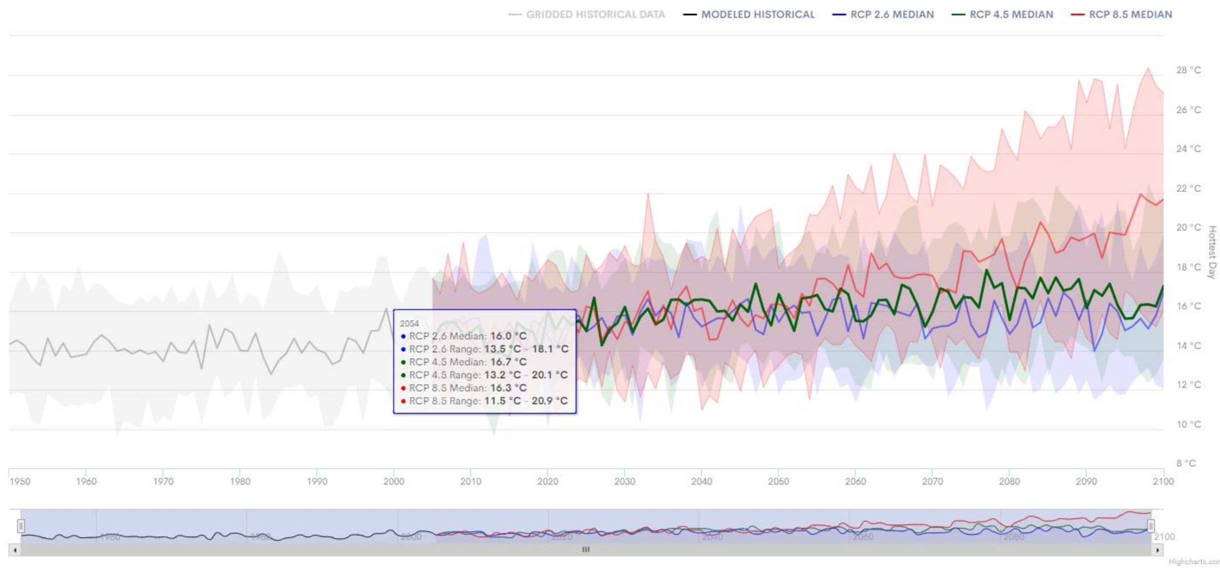

Figure 23: Example of Projected Future Climate from Climate Models of a Location Near the Eureka Weather Station, Nunavut (https://climatedata.ca)

Step 2.1 compares the observed climate data with the predicted historical climate by climate models to determine whether they correlate well, or whether a calibration/transfer function is needed to better correlate the results. This step is usually referred to as statistical downscaling.

An example of this analysis is provided in the case study of the James Bay Winter Road (section 4.1).

The calibration/transfer function is then integrated into future climate projections to produce a calibrated dataset.

3.3.1.3 Step 2.2: Down Scale of Calibrated Future Climate Projections from Monthly Temperature Averages to Daily Temperatures

Step 2.2 requires the downscaling of the calibrated future climate projections (usually in the form of monthly temperature averages) to daily temperatures in order to calculate FDD under future climate scenarios.

There are many methods for performing downscaling, including statistical downscaling (delta change, enhanced change factors, synoptic map) and dynamic downscaling methods.

As of FY2020-2021, the project team is still exploring different downscaling methods to be used for the framework.

Step 2.3: Projections of Future Operating Conditions

Step 2.3 proposes to project FDD with the downscaled future daily temperature data, then integrate the projected FDD with the baseline operating parameters (step 1) to project winter road seasons opening dates for the year 2025, 2030, 2040, 2050 and 2070.

In the future, this analysis can also be applied to project future midseason interruptions, as well as future season closures, thus providing more insight into the length of future operating seasons and the vehicle weights that can be sustained along each network segment in 5, 10, 20, 30 and 50 years.

3.4 Required Data Sets

The analysis and results from the methods proposed by the framework are only as good as the input data. There are three broad types of data that are required:

- Climate projections[31], there are a number of regional climate models and downscaled results for Canada, including:
  - Ouranos consortium and the Centre pour l'étude et la simulation du climat à l'échelle régionale (ESCER) at the Université du Québec à Montréal (15 km resolution, https://www.ouranos.ca/en/program/climate-simulation-and-analysis/)
  - Pacific Climate Impacts Consortium (daily temperature and precipitation data, approximately 10 km resolution, https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios)
  - ClimateData.ca (10 km resolution, https://climatedata.ca/about/)
- Climate records[32] (i.e. from weather stations)
  - Daily temperature
  - Snow on the ground
  - Ice thickness measurements
- Winter road operational data[33]
  - Historical opening dates, closure dates and seasonal interruptions
  - Rated traffic weight limits
  - Shape files for winter road routes
  - Information on route changes
  - Known weak links in the network
  - Historical ground penetrating radar data, or ice thickness measurements

[31] The project team is currently working with the dataset from the IPCC 5th assessment, though it is anticipated that the 6th assessment data will be released either in 2021 or 2022.

[32] Although there are weather stations located in the remote north, it is important to note that the stations are very sparse, and might not provide sufficiently accurate weather information for the different winter roads.

[33] There is a huge gap related to winter road operational data.

4 Case Study - James Bay Winter Road (Ontario)

The James Bay Winter Road was selected as a case study for the proposed winter road climate risk and vulnerability review framework as discussed in section 3. This winter road network was selected due to the availability of data, as well as past work by U of T for comparison purposes.

As shown in Figure 24, the James Bay Winter Road connects the communities of Moose Cree, Albany, Kashechewan and Attawapiskat to the rail lines at Moosonee. [6]

Figure 24: James Bay Winter Road Northern Ontario (https://www.mndm.gov.on.ca/sites/default/files/en_-_northern_ontario_winter_roads_map_2019.pdf)

The historical data from the Moosonee weather station (Figure 25) has been used to estimate the opening date of the James Bay Winter Road (assuming that the season opening is controlled by the over ice portion of the winter road network).

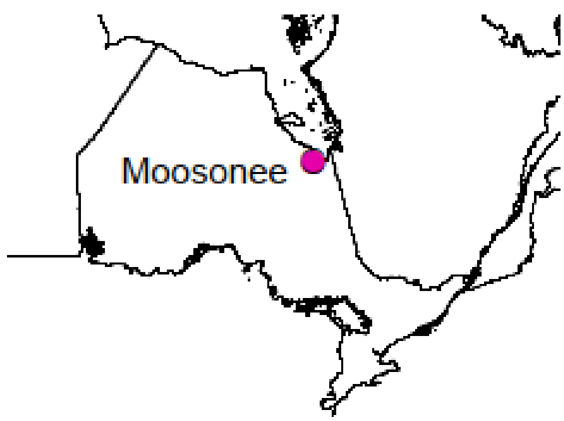

Figure 25: Location of Moosonee Weather Station

The Moosonee weather station has daily surface temperature data from 1932 and snow on ground data from 1956. Data from some years are missing from this weather station as seen in Figure 26. Figure 26 shows the variation of FDDs between 1940 and 2020 with a clear decreasing trend after 1990. It is also clear from Figure 26 that the winter road season in 2009-2010 was the warmest season with a total of only around 1,400 FDDs.

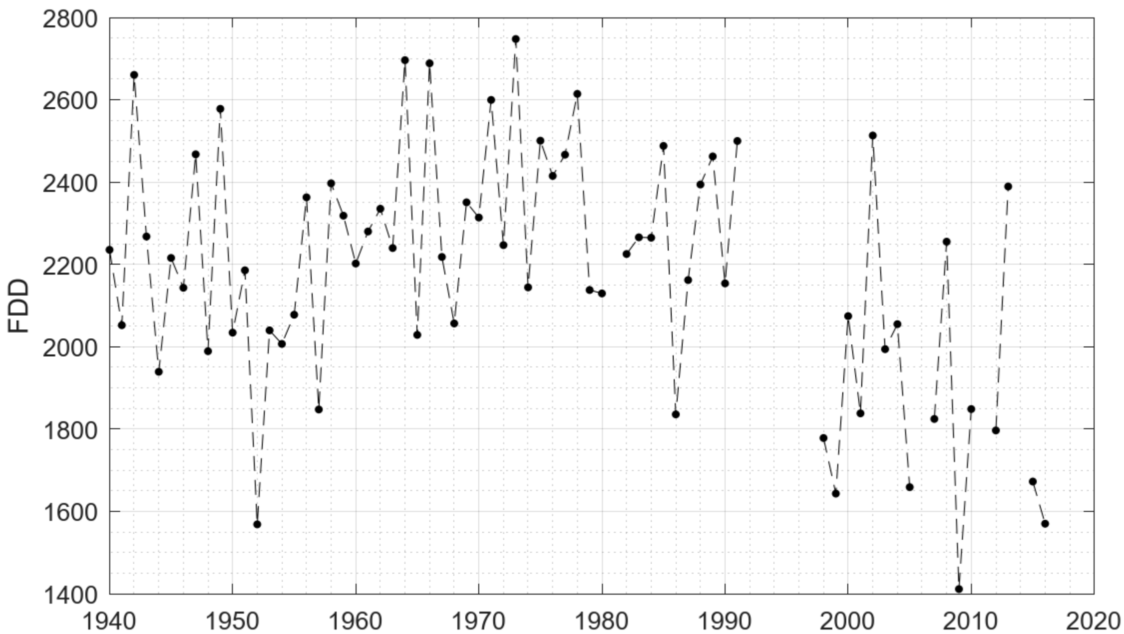

Figure 26: Variation of FDD at Moosonee Weather Station[34]

4.1 Establishment of Baseline Operating Conditions

For every year after 1956[35], the estimate of ice thickness formation has been completed by using the following three methods:

a) Eq. 1, snow on ground and mean daily temperature records from the Moosonee weather station
b) Eq. 2, α=1.7 (assuming average lake and river with snow)[36]
c) Eq. 2, α=3.5 (assuming no snow)

[34] In this plot, the FDD accumulation for each year starts from the first day after October 1st when the mean daily temperature is below zero for seven consecutive days and continues until May 31st of the following year.

[35] Snow on the ground records are available from the Moosonee weather station after 1956.

[36] Consultation with officials from MNDM later revealed that the over water portion of the James Bay Winter Road consists of a mixture of fresh water and sea water due to tidal actions from the bay, thus indicating the need to revise α in future analysis to more accurately capture ice growth in this type of unique ice conditions.

The results of ice thickness estimate for each of the above-mentioned methods are presented in Figure 27c for winter 2009-2010 and the maximum equivalent load capacity according to Eq. 4 (A=4.0) is presented in Figure 27d.

As can be seen from Figure 27c, ice thickness growth without snow (Eq. 2, with α=3.5) is by far the thickest compared to the other two methods, both assuming some level of snow accumulation on the ice. Ice thickness estimates using Eq. 1 and snow on ground from weather station results in the smallest ice thickness growth, which is consistent with the fact that for winter road construction, the snow is removed to accelerate ice growth.

As can be seen from Figure 27d, the trend is similar for the derived vehicle load from the ice thickness estimates, where the maximum bearing capacity of the ice without snow is above 60 tonnes, while for average lake and river ice with snow it is under 20 tonnes, and for Eq. 1 and snow on the ground as reported from weather station data is below 10 tonnes. The result from this analysis is consistent with observations from the winter road community that snow removal has a very significant impact on thickening of the ice cover and its capacity to carry heavier loads.

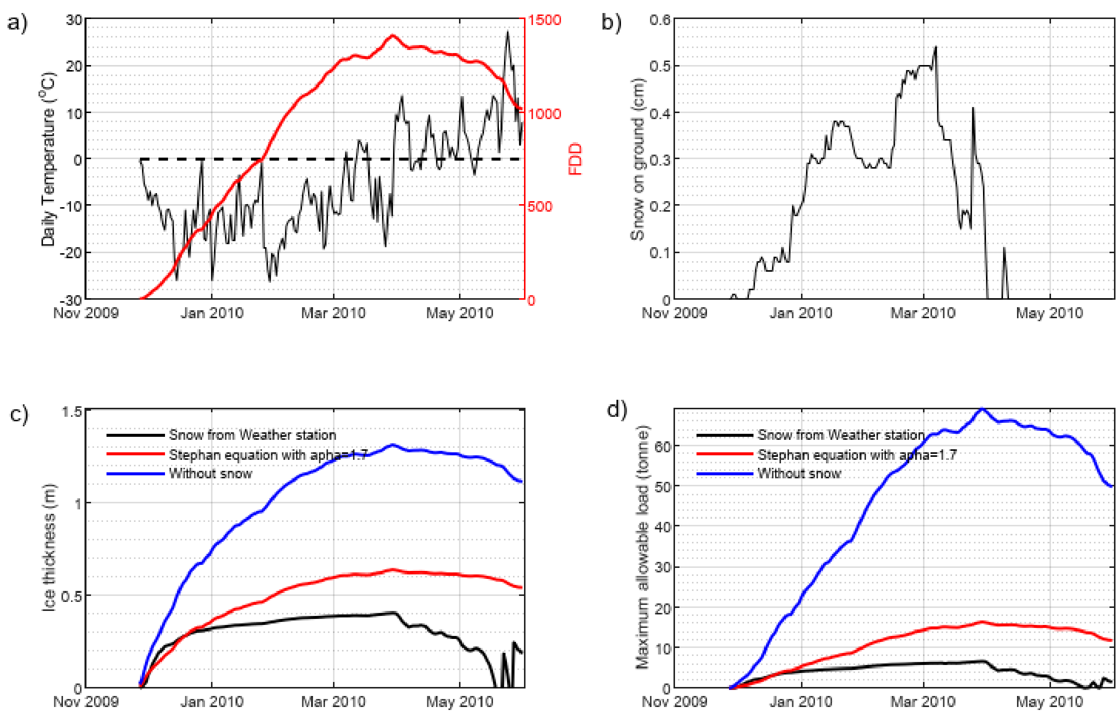

Figure 27: Plots Show a) Mean Daily Temperature Recorded at Moosonee Weather Station and Calculated FDD, b) Snow on Ground Measured at Moosonee Weather Station, c) Ice Thickness Estimate using Eq.1 and Eq. 2 with α=1.7 and 3.5, and d) Maximum Load Capacity of Ice using Eq. 4, and A=4.0.

Figure 28 shows the results from the analysis to determine the date at which the maximum load capacity reached 5, 10, 15, and 20 tonnes according to Eq. 2 with α=1.7 for the years from 1956 to 2020. The y-axis on this figure is the number of days it took from Dec. 1st for the ice to grow to sufficient thickness to allow for the specified load. For instance, if for a certain year it took 20 days for the ice to grow to sufficient thickness to allow a 5-tonne load, it meant that in that year the road could be opened to a 5-

tonne load on Dec 21st. Figure 28 also shows the recorded date at which James Bay Winter Road has been opened to less than full load (7.5 tonnes) and full load (55 tonnes) for recent years as reported by Yukari Hori from U of T [6].

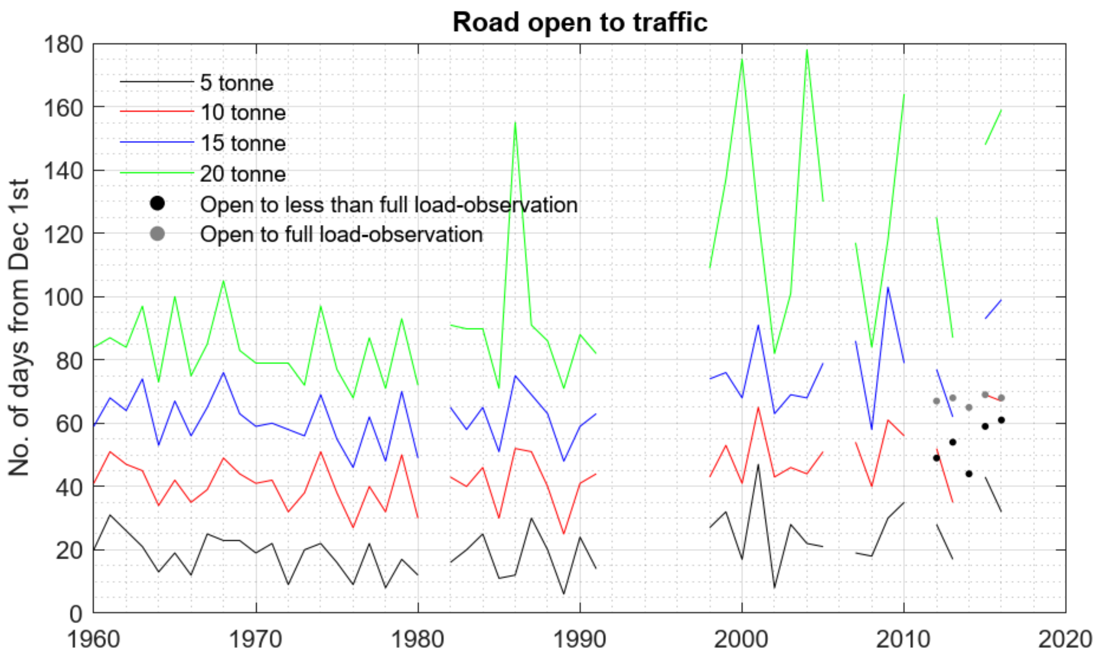

Figure 28: Plot Shows the Number of Days after Dec. 1st of Each Year When Maximum Load Capacity of Ice Reached 5, 10, 15, and 20 tonnes (According to Eq. 2, with α=1.7) and Compare Them with Observations from James Bay Winter Road Presented in Yukari Hori's Paper [6].

As can be seen in Figure 28, the result from the analysis of season opening dates for "light traffic load limit" (10 tonnes) correlates well with the limited season opening date records available for "opening to less than full load-observation". While the result for "opening to full load-observation" correlates well with "medium traffic load limit" (15 tonnes), it does not correlate well with the rated full load limit of 55 tonnes for the James Bay Winter Road. This may be due to a variety of factors, one of which could be the α value (1.7) used in the analysis, which is recommended for freshwater lakes with snow, rather than a mixture of fresh and sea water conditions found along the James Bay Winter Road. This illustrates the need to develop an α value more suitable for the James Bay Winter Road region and revisit the analysis. Another factor to consider is that in addition to snow removal, winter road builders often artificially flood or spray water over the ice to accelerate ice thickness growth, which can only happens after sufficient ice thickness is initially formed early in the season due to climate actions to enable equipment to safely go on the ice. This could explain why the "open to less than full load-observation" dates earlier in the season correlate well with the analysis, which is primarily based on climate actions, but not necessarily "opening to full load-observation" which occurs later in the season, and potentially have had some levels of human intervention. This again emphasizes the need to incorporate data from different winter road operations across Canada so that these factors and parameters can be better quantified and incorporated into the framework and analysis to improve the accuracy of results.

4.2 Projections under Future Climate Scenarios

To evaluate the impact of future climate on the opening of the James Bay Winter Road, projected temperature data from a cell (10 km resolution) near the Moosonee weather station was extracted from ClimateData.ca (Figure 29). The climate model data from this dataset are in the form of average monthly format consisting of two parts:

1) Historical data, showing how climate models predict different climate variables in the past (the historical data within this dataset is from 1950 to 2005).

2) Projected climate data, showing how the models project future data under various RCP scenarios (RCP2.6, RCP4.5 and RCP8.5). For each RCP scenario, three values are provided: median, low, and high to reflect the uncertainty within the models.

Figure 29: Examples of Gridded Cells near the Moosonee Weather Station from ClimateData.ca (10 km Resolution)

4.2.1 Step 2.1 Comparison of Historical Records with Predicted Historical Climate

Figure 30 compares the average monthly temperature recorded at the Moosonee weather station with the values predicted from climate models. In most of the cases, the observed values are within the predicted low and high range.

While the analysis for step 2.2 and 2.3 are not yet completed. The following analysis and observations are made:

- Figure 31 compares the cumulative distribution function (CDF) of the average monthly temperature observed at Moosonee weather (1950-2005) station with the projected temperatures under different RCP scenarios (2006-2100). As shown in the figure, the distribution of the projected future temperature can be higher by up to 10ºC during the pre-season months of

November and December, as well the winter road season months of January, February and March.

– Figure 32 shows the projected average monthly temperature under various RCP scenarios (2025 to 2100). During the critical pre-season of October, November and December, the climate models indicate an increase of 5ºC under the RCP 8.5 scenarios. During the winter road season months of January, February and March, the model indicated that while temperature will increase during these months, the temperature conditions likely will sustain winter road operations until at least the 2050 timeframe.

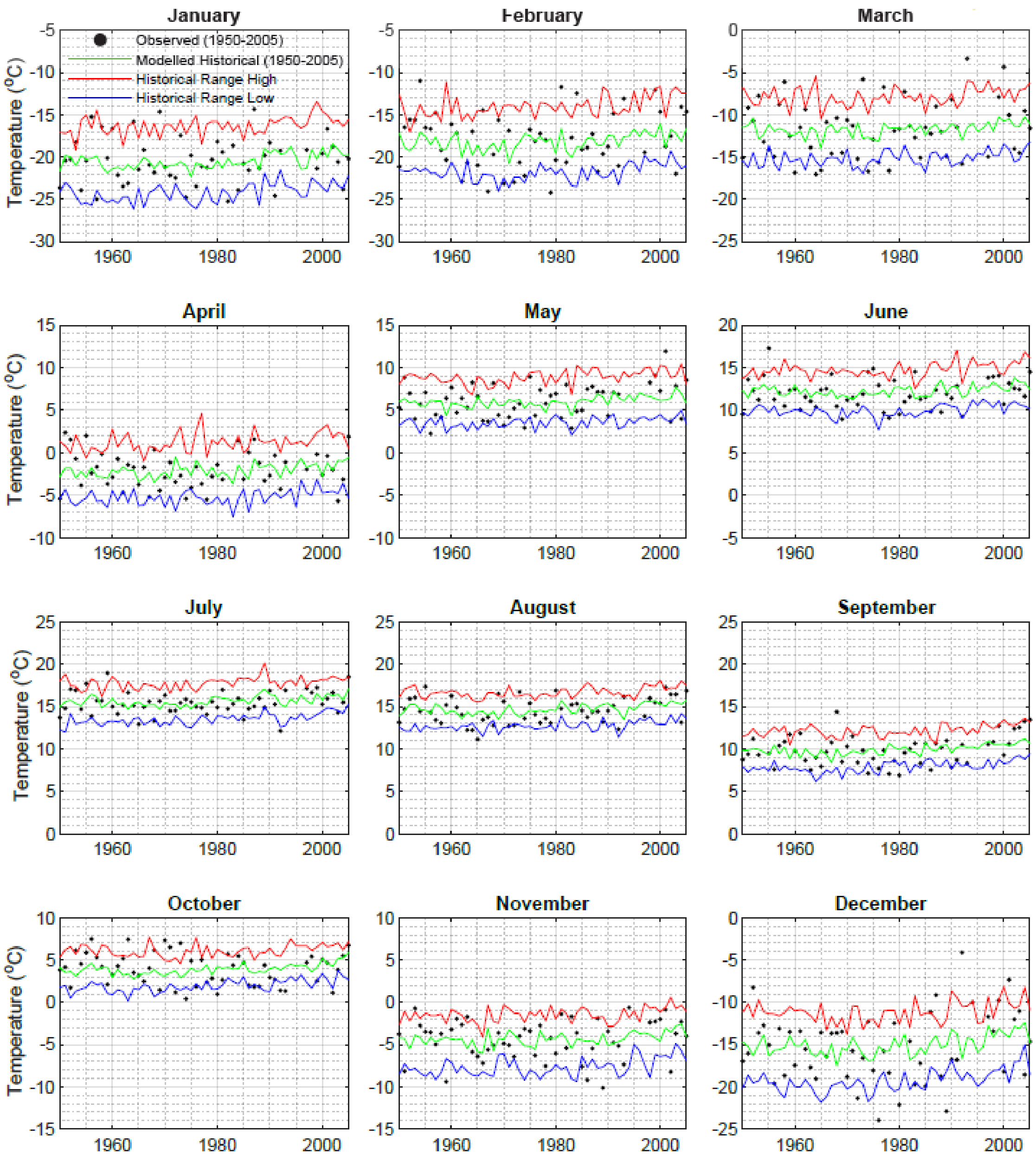

Figure 30: Comparing the Average Monthly Temperature observed at Moosonee Weather Station with the Values Resulted from Climate Modelling (Data Extracted from https://climatedata.ca/)

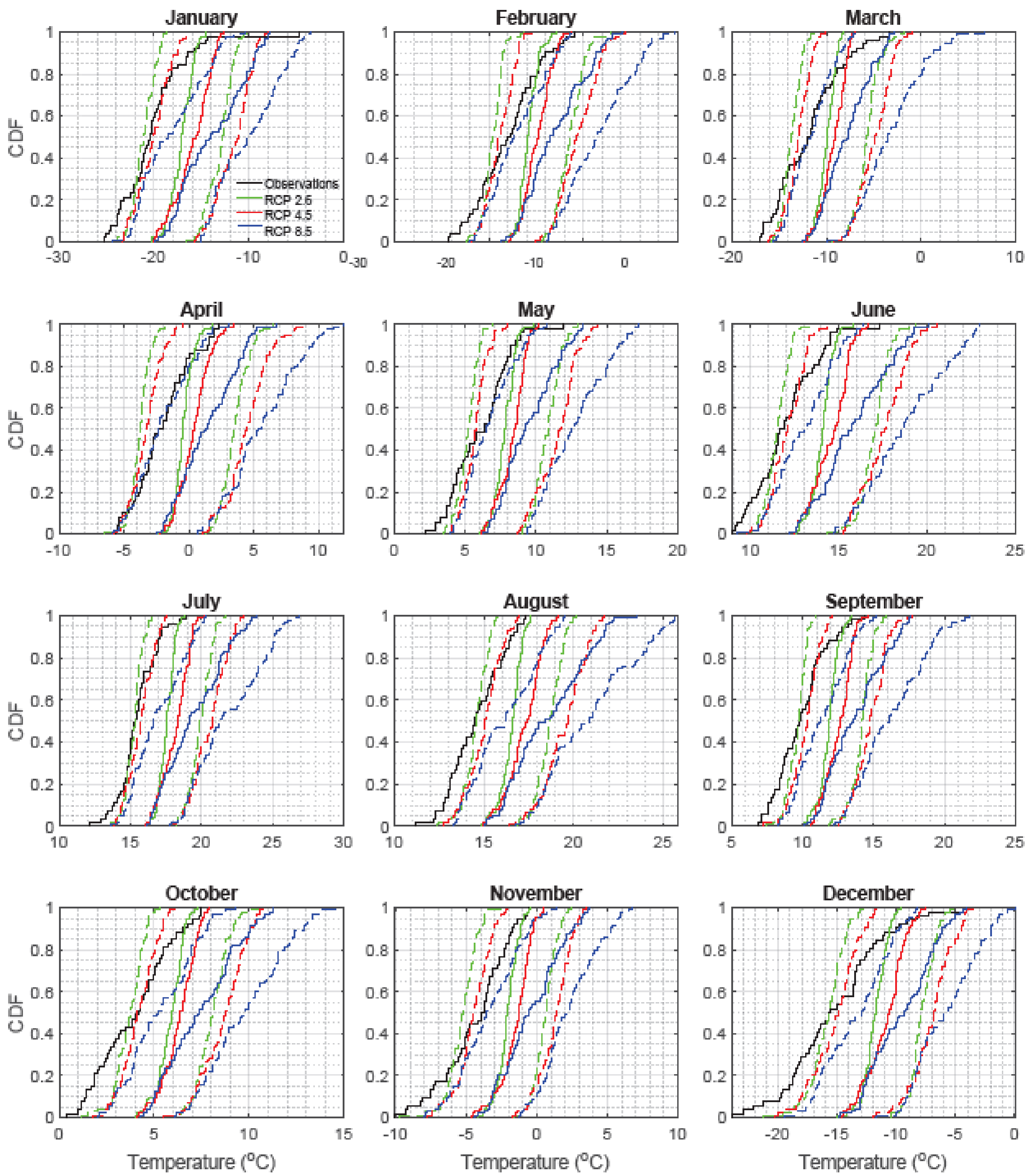

Figure 31: Comparing Monthly Average Temperature Observed at the Moosonee Weather Station with Projected Temperature under Each RCP Scenarios

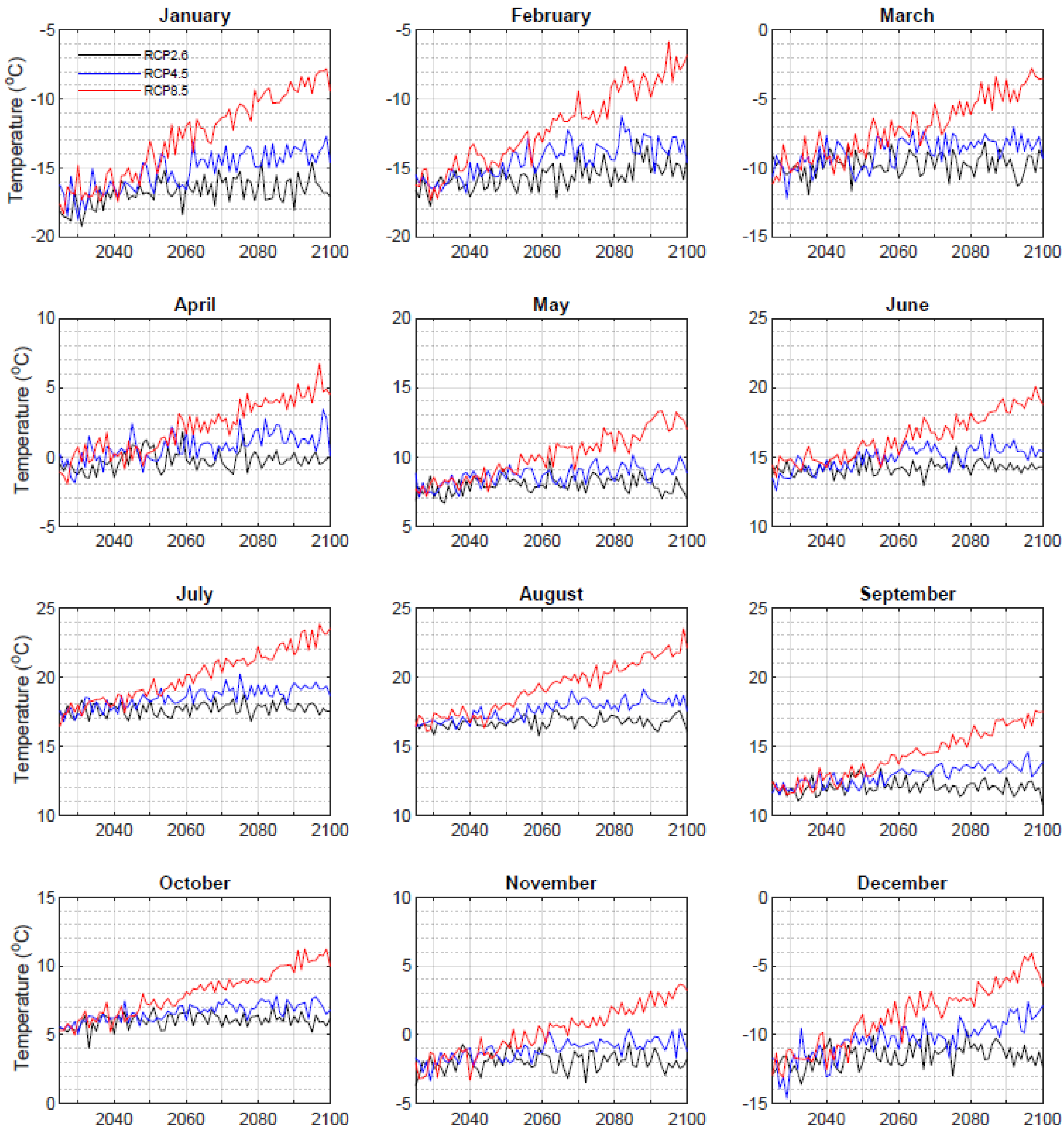

Figure 32: Projected Average Monthly Temperature at Moosonee Weather Station under Various RCPs (Mean Values) from Climate Modelling (Data Extracted from https://climatedata.ca/)

5 Stakeholder Consultations

Consultations with stakeholders within the winter road community is an important element of this project in order to better understand the unique challenges and perspectives of each stakeholder.

During FY2020-2021, meetings with the following stakeholders were completed (detailed meeting notes are found in Appendix C):

- CIRNAC
- TC
- ISC
- Province of Manitoba
- Province of Ontario
- Province of Saskatchewan

Attempts were made to engage with officials within the Province of Alberta, but the efforts were not successful during FY2020-2021.

In the future, the project team plans to expand the consultation to communities served by winter roads, territorial governments, Geological Survey of Canada, Environment and Climate Change Canada, the academic sector, as well as the private sector organizations who are building, maintaining and using the winter road networks.

6 Conclusions

During FY2020-2021, a literature review of 54 documents was completed to examine Canada's winter road network, identify parameters that affect winter road safety, models that assess the impact of climate change on winter roads, and identify standards for climate risk assessment related to northern infrastructure.

The following two international standards for climate risk assessment were identified to be the most relevant for this work:

- ISO 14090 – Adaptation to climate change – principles, requirements and guidelines
- ISO/FDIS 14091 - Adaptation to climate change – guidelines on vulnerability, impacts and risk assessment

A framework to review and assess the climate risk and vulnerability of winter roads in Canada was developed. The foundation of the framework is based on published scientific methods, field data from winter road operations, as well as stakeholder observation, experience and concerns.

There are two key steps within the winter road climate risk and vulnerability review framework:

1. Establishment of baseline operating conditions
2. Project operational conditions using future climate models

During FY2020-2021, four equations (as per section 3.2) are identified and integrated into the framework to establish baseline operation conditions, incorporating key parameters from climate related factors (air temperature and snow), road characteristics (over ice segments), and operational characteristics (vehicle weights and road opening).

To evaluate the suitability of Eq. 1 and 2 to estimate ice growth, data from three sites that were part of Government of Canada's Ice Thickness Program[37] (Alert, Eureka and Baker Lake) were collected and compared against the values calculated from the above equations and using snow thickness and average daily temperature recorded by a weather station with the same name as the ice site measurements.

The snow on ground data from Alert weather station and the Alert ice site correlated better, compared to the snow on ground data from Baker Lake weather station and the Baker Lake ice site, as well as the Eureka weather station and the Eureka ice site. This is reflected in the resulting plots using Eq. 1 to 3. The calculated ice thickness using Eq. 1 to 3 correlated better with ice thickness measurements from Alert ice site compared to those from Baker Lake, and Eureka. What can be concluded from this exercise are as follows:

[37] https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/archive-overview/thickness-data.html

- Ice thickness growth estimated by the equations is reasonable if accurate temperature and snow data is available
- There may be errors and uncertainties related to snow on ground data from weather stations
- In absence of snow data, Eq. 2 can provide reasonable estimates of ice thickness growth, if an appropriate α for the winter road segment can be identified through better correlation or calibration with historical site data such as ground penetrating radar data

A sensitivity analysis was performed to better understand what impact air temperature and snow have on the over ice segments of winter roads using Eq. 1. A 2.0ºC increase in ambient temperature may lead to up to 20 cm decrease in ice thickness (with the same amount of snow cover), and on the other hand, a 20% decrease in snow cover may lead to an increase in ice thickness of nearly 15 cm.

Once baseline operating conditions are established, the next step is to project operating conditions under future climate scenarios, consisting of the following steps:

- Step 2.1: part 1 - compare observed climate data with predicted historical climate (in climate models) to determine whether they correlate well, or whether a calibration/transfer function is needed to better correlate the results
- Step 2.1: part 2 - integrate the calibration/transfer function from part 1 into future climate projections
- Step 2.2: down scale the calibrated future climate projections (step 2.1, part 2) from monthly temperature averages to daily temperatures
- Step 2.3: project operating conditions using downscaled future daily temperature data and parameters from baseline operating conditions

In order to carry out the analysis required from the methods proposed, there are three broad types of data that are required:

- Climate projections
- Climate records
  - Daily temperature
  - Snow on the ground
  - Ice thickness measurements
- Winter road operational data
  - Historical opening dates, closure dates and seasonal interruptions
  - Rated traffic weight limits
  - Shape files for winter road routes
  - Information on route changes
  - Known weak links in the network
  - Historical ground penetrating radar data, or ice thickness measurements

A case study of the current iteration of the framework was performed on the James Bay Winter Road in Northern Ontario. Analysis of past temperature record (1940 and 2020) show a clear warming trend after 1990 with winter 2009-2010 being the warmest season (approximately 1,400 FDD). One of the findings from the case study was consistent with observations from the winter road community that snow removal has a very significant impact on the thickening of the ice cover and its capacity to carry heavier loads. An analysis was performed to estimate the date at which the maximum load capacity reached 5, 10, 15, and 20 tonnes using Eq. 2 with α=1.7 for the years from 1956 to 2020. The result from the analysis of season opening dates for “light traffic load limit” (10 tonnes) correlates well with season opening date records available for “opening to less than full load-observation”. While the result for “opening to full load-observation” correlates well with “medium traffic load limit” (15 tonnes), it does not correlate well with the rated full load limit of 55 tonnes for the James Bay Winter Road. This may be due to a variety of factors, one of which could be the α value (1.7) used in the analysis, which is recommended for freshwater lakes with snow, rather than a mixture of fresh and sea water conditions found along the James Bay Winter Road. This illustrates the need to develop an α value more suitable for different winter road regions. Another factor to consider is that in addition to snow removal, winter road builders often artificially flood or spray water over the ice to accelerate ice thickness growth, which can only happens after sufficient ice thickness is initially formed early in the season due to climate actions to enable equipment to safely go on the ice. This could explain why the “open to less than full load-observation” dates earlier in the season correlate well with the analysis, which is primarily based on climate actions, but not necessarily “opening to full load-observation” which occurs later in the season, and potentially have had some levels of human intervention. This again emphasizes the need to incorporate data from different winter road operations across Canada so that these factors and parameters can be better quantified and incorporated into the framework and analysis to improve the accuracy of results.

Even though projections under future climate scenarios were not completed for the James Bay Winter Road during FY2020-2021, a comparison of observed climate data with the predicted historical climate by an ensemble of climate models (1950-2005) was completed for the James Bay Winter Road region, and it was found that the two datasets correlated well.

Future climate trends were examined through a cumulative distribution function (CDF) of the average monthly temperature observed at Moosonee weather (1950-2005) station with the projected temperatures under different RCP scenarios (2006-2100). It was found that the distribution of the projected future temperature can be higher by up to 10ºC during the pre-season months of November and December, as well the winter road season months of January, February and March. In addition, projected average monthly temperature under various RCP scenarios (2025 to 2100) was also examined. During the critical pre-season of October, November and December, the climate models indicate an increase of 5ºC under the RCP 8.5 scenarios. During the winter road season months of January, February and March, the model indicated that while temperature will increase during these months, the temperature conditions likely will sustain winter road operations until at least the 2050 timeframe.

7 Next Steps and Recommendations

The following activities are proposed as next steps to this research:

- Since data is critical for the analysis required by the winter road climate risk and vulnerability review framework, a concerted effort is proposed to seek out and obtain relevant data, in addition to following up with federal and provincial counterparts that might have access to complementary datasets
- Completing additional case studies to validate and refine the methodologies and models proposed by the current iteration of the framework
- Performing additional literature review to integrate the following parameters into future iterations of the framework:
  - Road length – a winter road is as reliable as its weakest link, thus the longer the road, the higher the probability it will contain weaker links that will make it inoperable
  - Proportion of distance over ice versus over land – since the over ice portion of a winter road network is often the controlling factor for season opening, it is likely that for some operations in the coming year, an insufficient number of FDDs over the winter will eventually prevent these segments from achieving the desired target thickness
  - Number of transitions (or shoreline crossings) – transition points can be problematic for many reasons, for example the slope of the ramp and low albedo, they are often weak links in the system – this includes creeks and narrow rivers
  - Topography – steeper terrains can become more readily unusable because they rely on good traction more so than a flatter terrain
  - South-facing slopes – south-facing slopes are unavoidable, however since they are more exposed to the sun, especially in steeper terrains, they can become weak links in the system
- Refining the framework to include models to quantify impacts from parameters not yet included, such as the over land segments, the effects from wind and solar radiation, as well as mid-season interruptions and end of season closures
- Expanding the stakeholder consultation to include communities served by winter roads, territorial governments, Geological Survey of Canada, Environment and Climate Change Canada, the academic sector, as well as the private sector organizations are building, maintaining and using the winter road networks

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Appendix A: Winter Road Network in the Rest of the World as per Literature Scan

As per [1], this list is non-exhaustive due to a variety of reasons including the non-official status of many roads and language barriers.

Location	Length (km)	Note
South Pole Traverse (McMurdo-South Pole Highway), Antarctica	1,601.0	- Trail of compacted snow for logistics transports of fuel and materials.[34]
Ross Ice Shelf, Antarctica	800.0	- Largest body of floating ice.[35]
Phoenix Runway, Antarctica	NA	- 21 km from McMurdo on the McMurdo Ice Shelf.[36]
Williams Field ice runway, Antarctica	NA	- 15 km from McMurdo on the Ross Ice Shelf.[36]
Triigi-Tärkma, Estonia	17.0	- Accessible to the public.[37]
Piirissaar-mainland, Estonia	8.0	- Accessible to the public. - On lake Peipus.[38]
Hiiumaa-mainland, Estonia	26.0	- Europe’s longest ice road. - Between the island of Hiiumaa and Estonia’s mainland.[39]
Hiiumaa-Saaremaa, Estonia	15.0	- Accessible to the public.[40]
Vormsi-mainland, Estonia	12.0	- Accessible to the public.[40]
Kihnu-mainland, Estonia	15.0	- Accessible to the public.[40]
Haapsalu-Noarootsi, Estonia	3.0	- Accessible to the public.[40]
Laaksaar-Piirissaar, Estonia	8.0	- Accessible to the public.[40]
Lao–Kihnu, Estonia	13	- Maintained by the Republic of Estonia Road Administration.[41,42]
Kuivastu-Virtsu, Estonia	6.5	- Maintained by the Republic of Estonia Road Administration.[41,43]

Location	Length (km)	Note
Sõru–Triigi, Estonia	NA	- Maintained by the Republic of Estonia Road Administration.[41]
Rohuküla–Sviby, Estonia	10.2	- Maintained by the Republic of Estonia Road Administration.[41,44]
Räisälä ice road, Finland	NA	- Over Lake Kemijärvi.[45]
Koli ice road, Finland	7.0	- On Lake Pielinen. - From Koli to Lieksa.[46] - Accessible to the public. - Maintained by the Finnish Transport Agency.[47] - Maintained by the Finnish Transport Agency.[47]
Oulunsalo-Hailuoto Finland	9.0	- Accessible to the public. - Maintained by the Finnish Transport Agency.[47]
Finland	NA	- Apparently, there are more than the three official winter roads above. Language may be a barrier to find them.[47]
Norway	NA	- Apparently, there are two ice roads over Tana River, and more, but no satisfying source could be found. Language may be a barrier to find them.[48]
Yakutsk-Northern District, Russia	15.6	- 11th longest ice road in the world. - Over Lena River.[49]
Heilongjiang-Blagoveshchensk, China-Russia	0.6	- On the Amur River, connecting the Heilongjiang province (China) and Blagoveshchensk City (Amor Oblast, Russia).[50]
Norderön-Verkön, Sweden	2.6	- Over Storsjön Lake. - Part of the national highway system - Replace the ferry service.[51]
Luleå Archipelago, Sweden	15.0	- Connects the port of Hindersöstallarna with islands Hindersön, Stor-Brändön and Långön. - Longest ice road in Sweden.[52]

Table 5: Winter Roads in the Rest of the World as per Literature Scan by NRC's National Science Library

Appendix B: Maps of Winter Roads under Provincial Jurisdiction

Figure 33: Winter Road Network in Northern Ontario (Dashed Red Lines, https://www.mndm.gov.on.ca/sites/default/files/en_-_northern_ontario_winter_roads_map_2019.pdf)

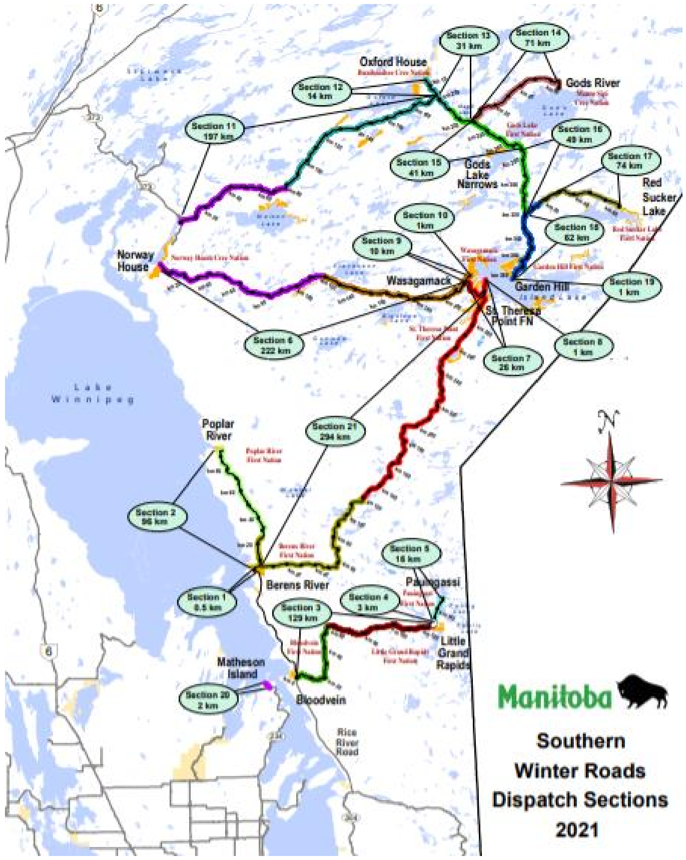

Figure 34: Winter Road Network in Southern Manitoba (https://www.gov.mb.ca/mit/winter/pdf/reports/southern_dispatch_map.pdf)

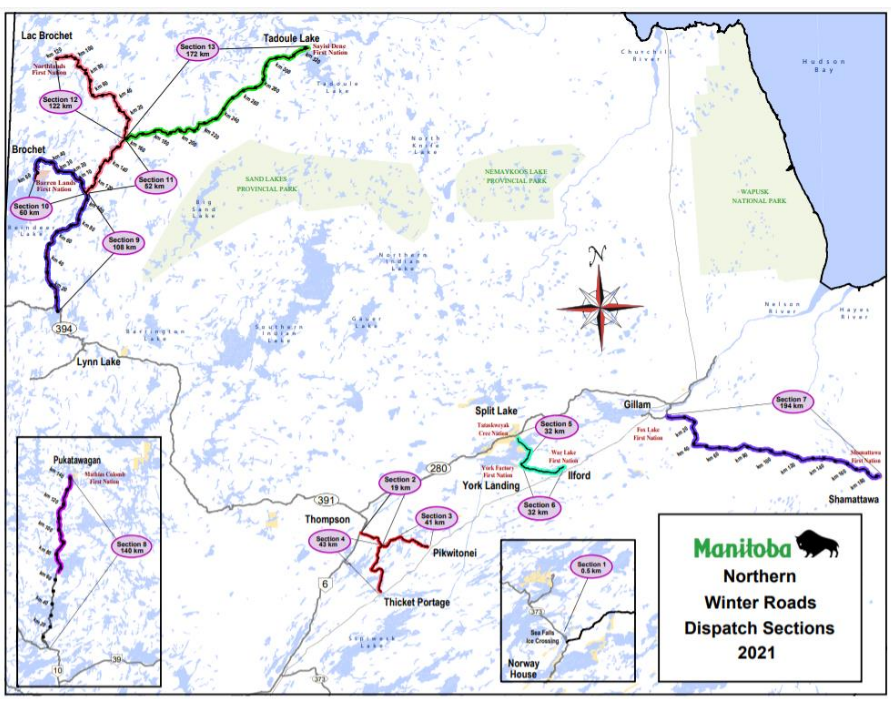

Figure 35: Winter Road Network in Northern Manitoba (https://www.gov.mb.ca/mit/winter/pdf/reports/northern_dispatch_map.pdf)

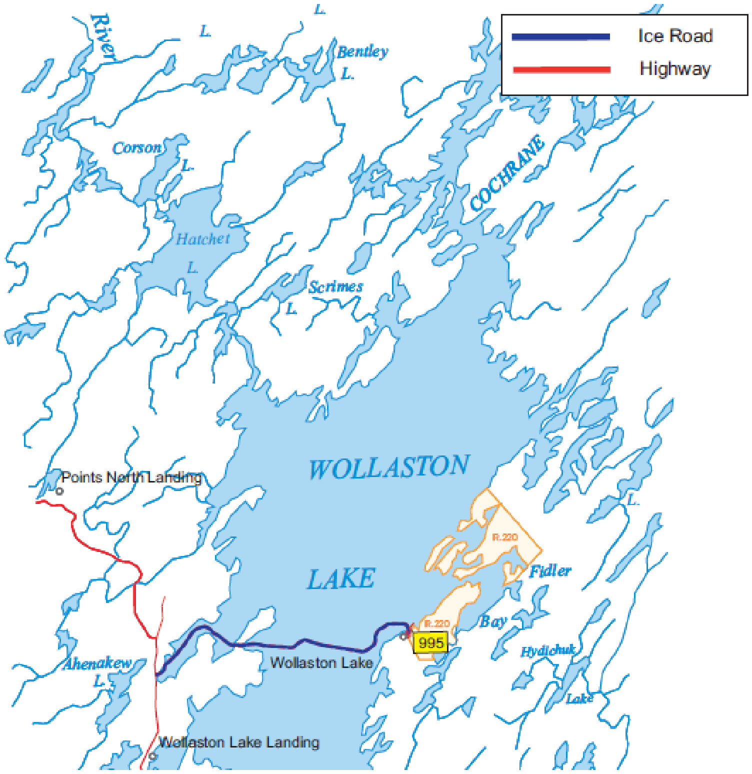

Figure 36: Winter Road Network in Saskatchewan (Wollaston Lake Winter Road, https://www.saskatchewan.ca/government/news-and-media/2007/february/08/ice-road-construction-underway-in-far-north)

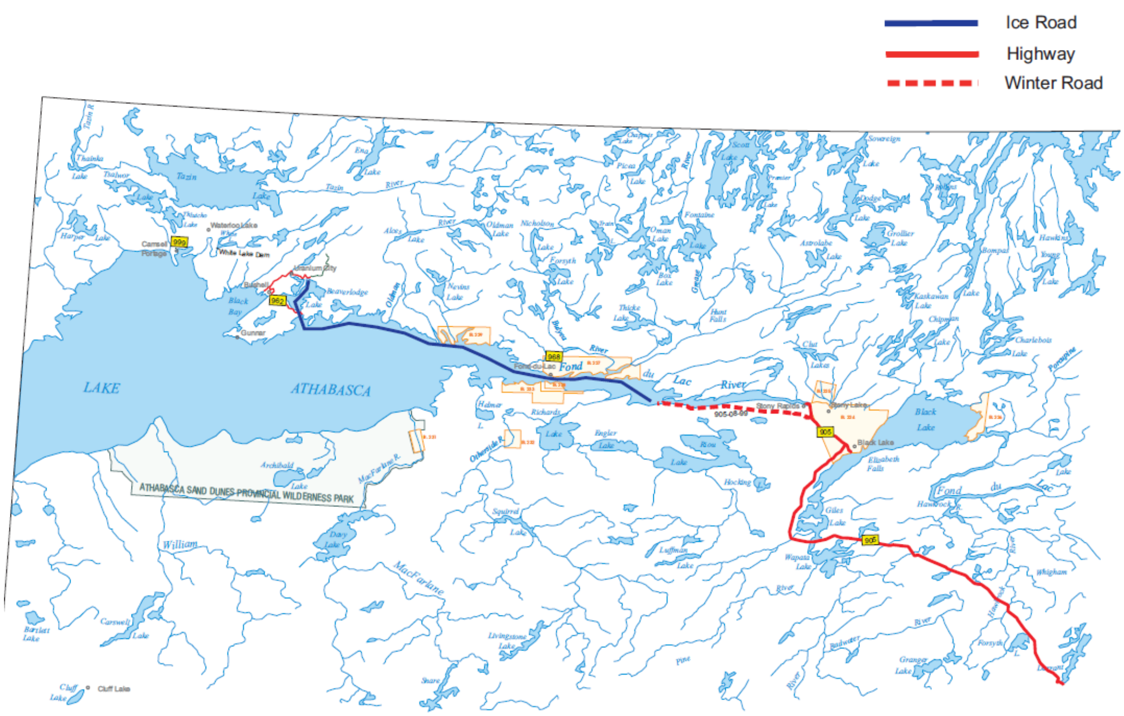

Figure 37: Winter Road Network in Saskatchewan (Athabasca Winter Road, https://www.saskatchewan.ca/government/news-and-media/2007/february/08/ice-road-construction-underway-in-far-north)

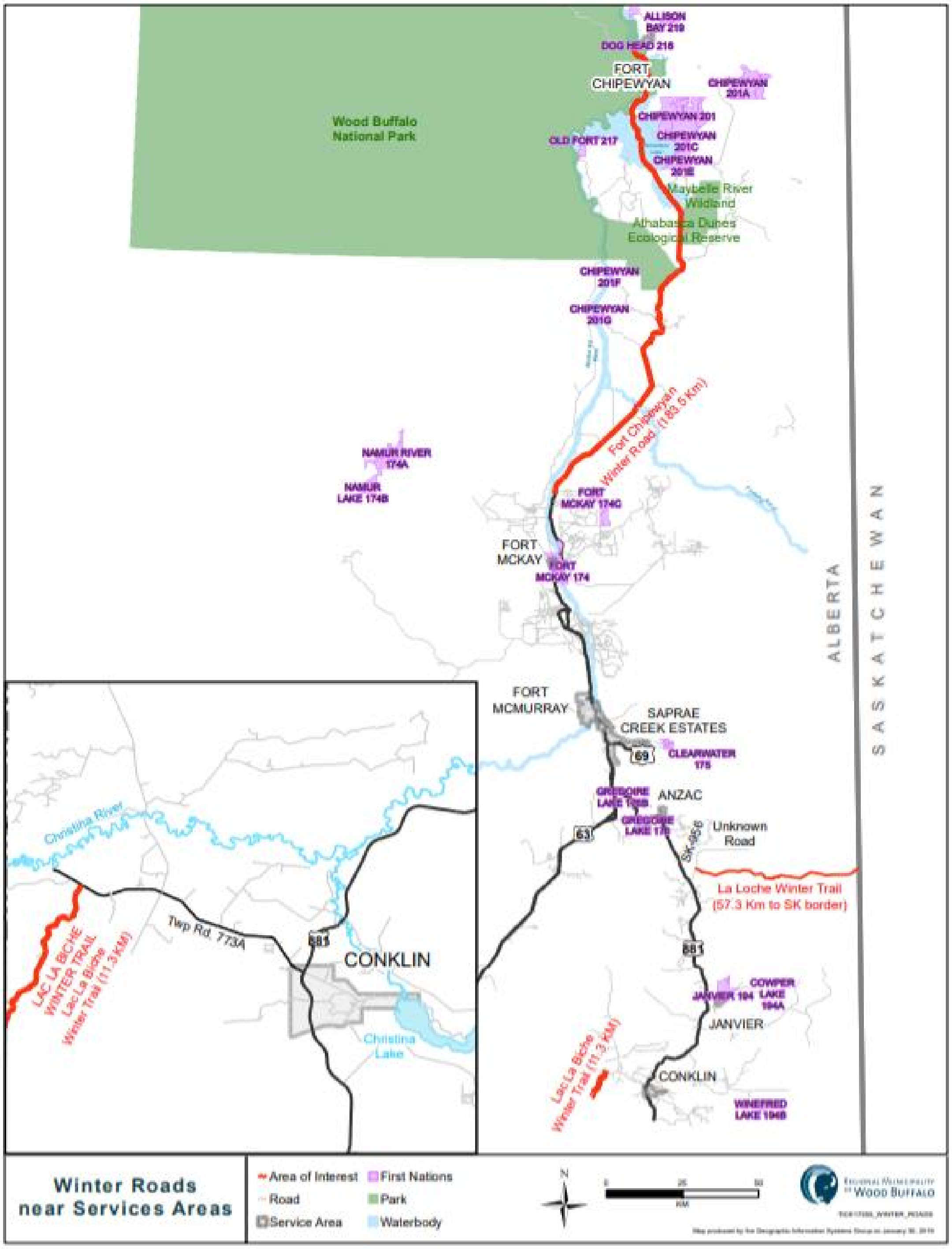

Figure 38: Winter Road Network in Alberta (Fort Chipewyan Winter Road, La Loche Winter Trail, Lac La Biche Winter Trail, https://www.rmwb.ca/en/roads-and-construction/resources/Documents/winter-roads-map.PDF)

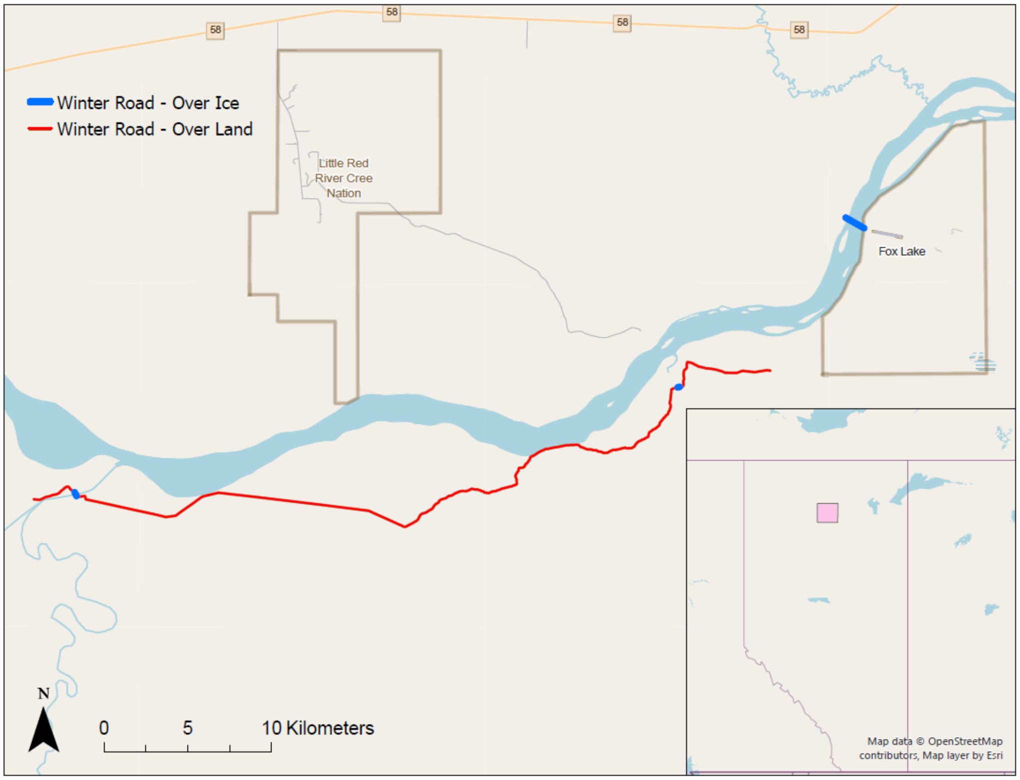

Figure 39: Winter Road Network in Alberta (Little Red River Cree Nation Winter Roads[38])

[38] The winter road routes and segments on this map are estimated, as official maps were not available at the time of publication.

Appendix C: 2020-2021 Stakeholder Consultation Meeting Notes

February 22, 2021
2:00 pm to 3:30 pm Eastern time

Development of a Framework for the Review of Climate Risk and Vulnerability for Winter Roads in Canada Discussions (National Research Council and Crown-Indigenous Relations and Northern Affairs Canada)

NRC Meeting Attendees:
Merrina Zhang – NRC, Automotive and Surface Transportation Research Centre
Alireza Roghani – NRC, Automotive and Surface Transportation Research Centre
Chantal Edwards – NRC, Automotive and Surface Transportation Research Centre
Sylvie Chenier – NRC, Automotive and Surface Transportation Research Centre

CIRNAC Meeting Attendees:
Aviva Shiller – CIRNAC, First Nation Adapt Program
Erica Weterings – CIRNAC, First Nation Adapt Program
Yves Theriault – CIRNAC, Climate Change Preparedness in the North
Marijo Cyr – CIRNAC, Climate Change Preparedness in the North
Lucie Meunier-Doyon – CIRNAC, Indigenous Community-Based Climate Monitoring Program

TC Meeting Attendees:
Janice Festa – TC, Strategic Policy

Opening:

Merrina shared her presentation and highlighted the following items for discussion:

- The vulnerabilities identified through the literature review of the winter road network
- The goal of the project related to better forecasting and planning for the future
- The proposed framework to assess climate vulnerability, and methodology (Ali discussed slide 3 and 4)
- The need to compare with the observations, experience and data from the field side
- Getting feedback on whether we on the right track
- Discussions on available data
    - Records of historical opening dates / closing dates / interruptions
    - Traffic weights
    - Shape files (geographical information system (GIS)) of winter road routes for mapping
    - Changes in routes from year to year
    - Known weak links
    - Available ground penetrating radar (GPR) data or ice measurements
    - Most pressing issues related to roads?
    - Suggested stakeholders for future phases?
- Discussions on current challenges on winter roads from the stakeholders around the table

Questions and Discussions:

1. From CIRNAC: How many case studies are planned for this fiscal year?

Ideally, we would like to do one case study per province. However, it very much depend on the availability of data and the quality of the data. We have not received any data to date, but we are anticipating that several provinces will be sharing the data they have available with the team shortly.

2. From CIRNAC: For case studies, which RCP scenario to use. For First Nation Adapt Program, RCP 8.5 is generally used.

The RCPs chosen will depends on the time frame. From climatedata.ca[39], it looks like projections for the three RCPs are similar until about the year 2045. The case studies will provide more insight.

3. From NRC: What timeframe (i.e. in 5 years, 10 years, 20 years, and 30 years) is useful for case study analysis?

Erica – For the First Nation Adapt Program, the timeframe used is generally longer term, such as in the range of 2050 and 2080. It is interesting to hear that provinces and other ODGs are interested in more near term projections. Though, it is also likely that from a community scale or an operational point of view, a shorter timeline would be more preferred.

Aviva – Winter roads are different compared to the other modules within the Climate Risk Index, such as wild fires, flooding and coastal erosions, which are all hazards. Winter roads are more complex, since they are impacted by weather, and they are a built infrastructure. Down the line, it might be helpful to have resources and tools, as well as knowing where all this information is kept. Engagement of the broad winter road community will be important to better understand what it is they need, in order to tailor our future work to the stakeholders. We are planning outreach as soon as travel restrictions are lifted, so let us know if you are interested in participating.

4. From CIRNAC: Have the territories been contacted?

The scope of the current phase (until the end of March) is focused on the network within the provinces, so the territories have not been directly consulted. We do collaborate with the provinces through our university partners (UBC and U of T), who are working with all three territories. We do hope to directly connect with them in future phases.

5. From CIRNAC: Often is the case of when projects are submitted in the north, the owner of the winter road might be community based or privately owned. How might this project be applied to those scenarios?

[39] Data for a 29-member ensemble of CMIP5 global climate models for three RCPs (2.6, 4.5 and 8.5) for the period 1900-2100.

Though the project's current focus is on official road segments located south of the 60, the framework and methodology can be applied to any winter road network, as long as there is sufficient data.

6. From CIRNAC: The method is very science based. How can this be communicated in more user-friendly way to the communities?

The team is well aware of the need to consider traditional knowledge and to better communicate with communities. This will be integrated into the project in future phases. It might be easier once the team has more analytical results. The information and results could better communicate and demonstrate the value of the research to communities.

3. From NRC: Data wish list

- **Records of historical opening dates / closing dates / interruptions**
- **Traffic weights**
- **Changes in routes from year to year**
- **Known weak links**
- Aviva –The First Nation Adapt Program has funded 2 winter roads project in Ontario and 2 from Manitoba. Will check with the project recipients to see if there are data to share.

- **Shape files (GIS) of winter road routes for mapping**
- Aviva – CIRNAC knows which communities are on official winter roads. CIRNAC's geomatics team likely already have the shape files. Will check to see if the shape files can be shared.

- **Available GPR data or ice measurements**
- Aviva –The First Nation Adapt Program has funded 2 winter roads project in Ontario and 2 from Manitoba. Will check with the project recipients to see if there are data to share
- Lucie – Will check within the Indigenous Community-Based Climate Monitoring Program to see if there are projects with ice measurements and records. It is not certain at this time whether those projects are winter road projects.
- Marijo – Will check with colleagues within the territories. This is no current consolidation of data of this nature.

Action items:

- ➢ Merrina to send the notes from the meeting for review and approval to be included in the final report
- ➢ Merrina to send the updated presentation and data wish list to the meeting participants
- ➢ Merrina to share final report
- ➢ Aviva to check with CIRNAC's Geomatics Team about sharing shape files of communities that are on official winter roads
- ➢ Aviva to check with funded winter road project recipients of whether they have the data on the data wish list to share
- ➢ Lucie to check within the Indigenous Community-Based Climate Monitoring Program to see if there are projects with ice measurements and records related to winter roads
- ➢ Marijo to check with colleagues in the territories of whether there is data on the data wish list to share

February 11, 2021
2:30 to 4:00 pm Eastern time

Development of a Framework for the Review of Climate Risk and Vulnerability for Winter Roads in Canada Discussions (National Research Council and Transport Canada)

NRC Meeting Attendees:
Merrina Zhang – NRC, Automotive and Surface Transportation Research Centre
Alireza Roghani – NRC, Automotive and Surface Transportation Research Centre (left at 3:00 PM)
Paul Barrette – NRC, Ocean, Coastal and River Engineering Research Centre (joined at 3:15 PM)
Sylvie Chenier – NRC, Automotive and Surface Transportation Research Centre

TC Attendees:
Jenna Craig – TC, Northern Transportation Adaptation Initiative
Ludovic D’Souza – TC, Ontario Region
Janice Festa – TC, Innovation Policy
Keri Holtby Levine– TC, Ontario Region
Lorelle Juffs – TC, Prairie and Northern Region
Trish Rea – TC, Prairie and Northern Region
Matthew Whelen – TC, Economic Analysis

CIRNAC Meeting Attendees:
Aviva Shiller – CIRNAC, First Nation Adapt Program

Opening:

Merrina shared her presentation and highlighted the following items for discussion:

- The vulnerabilities identified through the literature review of the winter road network
- The goal of the project related to better forecasting and planning for the future
- The proposed framework to assess climate vulnerability, and methodology (Ali discussed slide 3 and 4)
- The need to compare with the observations, experience and data from the field side
- Getting feedback on whether we on the right track
- Discussions on available data
    - Records of historical opening dates / closing dates / interruptions
    - Traffic weights
    - Shape files (GIS) of winter road routes for mapping
    - Changes in routes from year to year
    - Known weak links
    - Available GPR data or ice measurements
    - Most pressing issues related to roads?
    - Suggested stakeholders for future phases?
- Discussions on current challenges on winter roads from the stakeholders around the table

<u>Questions and Discussions (including exchanges after the meeting)</u>:

Lorelle (TC, Prairie and Northern Region):

- (From Trish): The Prairie and Northern Region is very interested in the proposed future activity of the Winter Road Atlas. The region might be able to provide resources and contributions for this task.
- (From NRC): The current focus of the winter roads are on the segments of the network that are within direct jurisdiction of the provinces and territories. Private and commercial roads are not part of the scope at the moment.
- The Prairie and Northern Region would like to see (included in the Winter Road Atlas) information with regards to the governing structure of the road segments (i.e. who provides funding, who is responsible for building/managing/safety of the roads)
- The government of North West Territories provides historical data on winter roads, 20 year average and 5 year average of opening and closing dates (https://www.inf.gov.nt.ca/en/services/highways-ferries-and-winter-roads/winter-roads-average-openclose-dates), as well as an interactive map of current open winter road conditions (https://www.dot.gov.nt.ca/Highways/Highway-Conditions), and a system map (https://www.inf.gov.nt.ca/sites/inf/files/resources/nwt_highway_facilites_february_2018_0.pdf)
- In Nunavut, the SMART ICE project provides a climate change adaptation tool to integrate traditional knowledge of sea ice with advanced data acquisition and remote monitoring technology. The system provides up-to-date/weekly ice conditions of northern communities. They are now trying to implement a similar system on freshwater ice. (https://smartice.org/, https://smartice.org/data, app: https://siku.org/about)
- (From NRC): OCRE is aware of SMART ICE project. CIRNAC's Climate Change Preparedness in the North program funded this work.

Matthew (TC, Economic Analysis):

- Published maps for winter roads from territories/provinces: https://www144.statcan.gc.ca/tdih-cdit/index-eng.htm
- Action: Matthew to reach out to Josh to see if we could get Shape files for these maps.
- Action: Matthew to see if TC Economic Analysis have any data on traffic (freight and passenger) on winter roads.

Jenna (TC, Northern Transportation Adaptation Initiative):

- Northern Transportation Adaptation Initiative does not have data to contribute at this time, but the program is glad to see the engagement with the provinces, and excited to see where this project will lead.
- Wish list for future phases:
  - A Map of winter road network
  - Mapping tool that shows vulnerability and highlights in the order of priorities (due to climate vulnerability) of which road segments needs to replace by all season roads
  - Information on the ownership/governance structure included in mapping

Ludovic (TC, Ontario Region):

- Provided contacts to NRC for Ontario's Ministry of Northern Development and Mines.

Keri (TC, Ontario Region):

- Is NRC working with PTO/Indigenous & Remote Communities or Tribal Councils (ex. Mushkegowuk council at James Bay has the contract to manage the roads, and probably have lots of data).
- (From NRC): During fiscal year 2020-2021, NRC is focused on consulting with provincial stakeholders, but have plans to reach out to winter road communities in the future. Yukari Hori from the University of Toronto is helping the project to gather data in the James Bay region.

- Is NRC working with IAAC (Impact Assessment Agency of Canada)?
  https://www.canada.ca/en/impact-assessment-agency.html
  IAAC is working on environmental assessment of all season roads with two First Nations communities.

  Nishnawbe Aski Nation (NAN)
  Jennifer Guerrieri | Transportation Policy Analyst | 807.625.4925
  jguerrieri@nan.on.ca

  Mushkegowuk Council
  http://www.mushkegowuk.com/?page_id=3577
- IAAC is also working on the Ring of Fire region in northern Ontario, which has a winter roads aspect.

  Ring of Fire Regional Assessment
  The area centred on the Ring of Fire mineral deposits in northern Ontario, approximately 540 kilometres northeast of Thunder Bay and 1,000 kilometres north of Toronto
  https://iaac-aeic.gc.ca/050/evaluations/proj/80468
  Contact: debra.myles@canada.ca

Aviva (CIRNAC):

- The Canadian Center for Climate Services (CCCS) provides one-on-one support on climate data downscaling.
- CIRNAC and ISC are planning a series of workshops with First Nations communities. Winter roads will be one of the key topics of the workshops. The timeline will depend on when face-to-face meetings can be held. Aviva Shiller and James Winkel (ISC) will be the point of contact and are the leads in the planning. They would like to coordinate a larger federal effort.
- Action: Aviva to send CCCS contact to NRC.
- Action: NRC to contact CCCS.

Action items:

- Merrina to send the notes from the meeting for review and approval to be included in the final report
- Merrina to send the updated presentation and data wish list to the meeting participants
- Merrina to share final report
- NRC to contact Lorelle about future collaborations for the development of Winter Road Atlas
- Matthew to reach out to Josh to see if there are Shape files for the winter roads maps in https://www144.statcan.gc.ca/tdih-cdit/index-eng.htm
- Matthew to see if TC Economic Analysis have any data on traffic (freight and passenger) on winter roads
- Aviva to send CCCS contact to NRC
- NRC to contact CCCS

February 17, 2021
10:30 am to 12:00 pm Eastern time

Development of a Framework for the Review of Climate Risk and Vulnerability for Winter Roads in Canada Discussions (National Research Council and Indigenous Services Canada)

NRC Meeting Attendees:
Merrina Zhang – NRC, Automotive and Surface Transportation Research Centre
Alireza Roghani – NRC, Automotive and Surface Transportation Research Centre
Paul Barrette – NRC, Ocean, Coastal and River Engineering Research Centre
Chantal Edwards – NRC, Automotive and Surface Transportation Research Centre
Sylvie Chenier – NRC, Automotive and Surface Transportation Research Centre

ISC Meeting Attendees:
James Winkel – ISC, Regional Infrastructure Delivery Branch – Structural Mitigation, Chairperson for Winter Roads Working Group
Chantal Myers – ISC, Emergency Management Directorate
Jianjun Peng – ISC, Manitoba Regional Office
Ken Einarsson – ISC, Manitoba Regional Office
Karen Waite – ISC, Ontario Regional Office
Shah Alamgir – ISC, Ontario Regional Office
Kari-Ann Roveredo – ISC, Alberta Regional Office
Naman Boodram – ISC, Alberta Regional Office
Susan Hannaford – ISC, Alberta Regional Office

CIRNAC Meeting Attendees:
Aviva Shiller – CIRNAC, First Nation Adapt Program

Opening:

Merrina shared her presentation and highlighted the following items for discussion:

- The vulnerabilities identified through the literature review of the winter road network
- The goal of the project related to better forecasting and planning for the future
- The proposed framework to assess climate vulnerability, and methodology (Ali discussed slide 3 and 4)
- The need to compare with the observations, experience and data from the field side
- Getting feedback on whether we on the right track
- Discussions on available data
    - Records of historical opening dates / closing dates / interruptions
    - Traffic weights
    - Shape files (GIS) of winter road routes for mapping
    - Changes in routes from year to year
    - Known weak links
    - Available GPR data or ice measurements
    - Most pressing issues related to roads?

    - Suggested stakeholders for future phases?
- Discussions on current challenges on winter roads from the stakeholders around the table

Questions and Discussions (including exchanges after the meeting):

1. The Gold's formula used in the methodology, what A factor is being used by the province and private sector?

Paul – The A factor used in the formula, the choice is based on a compromise between minimizing risks (toward a lower A number) and optimizing resources (toward a higher A number).

Ken – In Manitoba, an A factor of 4 is used when the road is being constructed and the A factor is switched to a 5 when the road is open for public use. The majority of the private winter roads are located in the Island Lake area and the A factor used is 7. In the past, the winter roads in Manitoba were constructed to an A factor of 7 as well, but the inquest in the early 2000 resulted in ISC and the Province moving to use a lower A factor to mitigate risk. A study was conducted by EBA to look at the procedures of winter road construction and it was the basis of the TAC document "*Guidelines for the Construction and Operation of Winter Roads*".

Ken – Manitoba no longer distinguishes between white ice or blue ice, but rather just the total thickness. GPRs used today do not distinguish the different ice types as what was done previously in past years. **Data is available from past years on white/blue ice on certain trouble spots.**

Paul – With regards to white ice, when it is produced with proper methods, it is considered the same in the thickness measurements as blue ice.

2. Winter road opening perspective

Jianjun - In Manitoba they open the road segments when they reach a certain capacity. Some segments open at 15 tonnes and some segments at 25 tonnes, it's important to keep this in mind during the analysis.

3. Perspectives from ISC NCR

James – there is a good exchange of information between NCR and the regions, though the frequency of information exchange is not the same between the difference provinces. NCR's concern is related to operational delays. Delays may result in fuel needing to be shipped by air (much more expensive) instead of by road. All the information and data help inform funding planning. The timeframe of 5 years, 10 years, 20 years, and 30 years, is useful.

4. Perspectives from ISC Manitoba Region

The winter road network in Manitoba spans a length of approximately 2,200 km and services 18 First Nations communities.

Ken – There are areas in the northwest corner of the province that are not freezing, even in -40ºC. (Email communications: For the most part the winter road in the northwest quadrant is mainly located on eskers for roughly 70% of the road distances. Where the road is off the eskers, the roads are mainly located in areas of muskeg. The weight of the snow might be squeezing the moss which is bringing the water, located under the moss, to the surface. The water then has no way to travel, so it surfaces above the snow and flows through the creeks in cold temperatures. This has never been looked previously in determining what causes this to occur most winters in this quadrant. This condition does not occur in other areas of the province.) **Global Positioning System (GPS) co-ordinates of the North West quadrant where the creeks flow in the middle of winter can be provided (April/May). Data can be provided in the form of a chart which tracks the opening date and closing dates on the various road sections in the province and also tracks how the load rating changes during the winter road season (last 15 years).**

Jianjun – The most pressing issue is a much shortened season. COVID has resulted in many contactors not able to mobilize early/fast enough this season, resulting in a shortened window. It would be useful to have some predictions of what climate would be like in future seasons. The timeframe of 5 years, 10 years, 20 years, is useful. In addition, better construction methods to strengthen roads and lengthen the roads would be useful, such as the work that Paul is doing.

5. Perspectives from ISC Ontario Region

Ontario has the largest network of winter roads serving 32 remote First Nations communities that are not connected by all-season roads. In 2015−2016, approximately 3,200 km of winter roads are constructed and maintained under the Province of Ontario’s Winter Road Program

Light weight traffic = 25,000lb
Heavy weight traffic = 80,000lb

Karen – When the roads were originally built they were not built for the current traffic. They need to be widened, need to be realigned, and they need passing lanes. There are security concerns, since the distance in the far north is so vast. If a truck breaks down, it is a long time before another vehicle passes by. ISC Ontario region is starting to work on determining the locations of the roads (GPS routing, depths and measurements), traffic counts, water crossing, bridges, muskeg and creeks that won’t freeze, rocky crops that need more snow. We fix what we can where there are issues, for example, there are some water creeks that are not freezing properly this year. A winter road atlas would be very useful. The data from this project will be helpful in the long run. **There are data and can be shared after this season, including capacity they can open up, light or full loads.**

Shah – There are future plans for new traffic counters to install and new routes.

6. Perspectives from ISC Alberta Region

The 280 km winter road between Fort Chipewyan to Fort McMurray (serving Athabasca

Chipewyan, Mikisew Cree, and Little Red River Cree First Nations) has been managed by the Regional Municipality of Wood Buffalo. The project team was not able to engage anyone from the Province of Alberta on this project, and hope that ISC Alberta Region will help connect us with the province.

Light weight traffic

- Range 5,000kgs to 15,000 kg
- Usually non-commercial vehicles in this range
- Fuel transportation could not occur until over 15,000kgs

Heavy weight traffic

- 27,500 to 65,000 kg
- In regards to hauling fuel, 27,500 kilogram capacity is required for full loads to be transported.

Maximum capacity goals for winter roads is 65,000 kg

Kari-Ann – The network in Alberta is problematic this year due to a mild winter. Very concerned about this winter road season, since the roads are just now opening to light weight traffic and not able to transport real amounts of fuels. Long term goal would be to understand what type or funding is needed, for construction of all-weather roads or to get around some of the trouble areas. Flooding (i.e. at deltas near communities) are the biggest problems. **Have data for opening and closing dates. Have data for ice thickness for all roads. But most of the rest of the data will have to come from the Province. Will try to provide contacts from the province and communities for data follow up.** The timeframe of 1 year, 5 years, 10 years, 20 years, is useful.

Susan – A longer term perspective what planning can be done is useful, as well as assisting the communities to have the ability to get to where they need to do over the ice road. Looking forward to see how the project evolves.

Action items:

- Merrina to send the notes from the meeting for review and approval to be included in the final report
- Merrina to send the updated presentation and data wish list to the meeting participants
- Merrina to share final report
- Data wish list
    - Records of historical opening dates / closing dates / interruptions
    - Traffic weights
    - Changes in routes from year to year
    - Known weak links
    - Shape files (GIS) of winter road routes for mapping
    - Available GPR data or ice measurements
- Ken to provide data from past years on white/blue ice on certain trouble spots
- Ken to provide GPS co-ordinates of the North West quadrant where the creeks flow in the middle of winter (in April/May). As well as the opening date and closing dates on the various road sections in the province and how the load rating changes during the winter road season (last 15 years)

- Karen to provide Ontario data, including capacity they can open up, light or full loads and GPS/shape file if available
- Kari-Ann to provide Alberta data for opening and closing dates, ice thickness for all roads, and contacts from the province and communities for data follow up
- Shah Alamgir to provide contacts to be added to the consultation list (Western University)

February 9, 2021
3:30 to 4:30 pm Eastern time

Development of a Framework for the Review of Climate Risk and Vulnerability for Winter Roads in Canada Discussions (National Research Council and the Province of Manitoba)

NRC Meeting Attendees:
Merrina Zhang – NRC, Automotive and Surface Transportation Research Centre
Alireza Roghani – NRC, Automotive and Surface Transportation Research Centre
Paul Barrette – NRC, Ocean, Coastal and River Engineering Research Centre
Chantal Edwards – NRC, Automotive and Surface Transportation Research Centre

Province of Manitoba Meeting Attendees:
Shane Wass – Province of Manitoba, Winter Road Project Manager (Southern)
Doug Jansen – Province of Manitoba, Program Manager

Opening:

Merrina shared her presentation and highlighted the following items for discussion:

- The vulnerabilities identified through the literature review of the winter road network
- The goal of the project related to better forecasting and planning for the future
- The proposed framework to assess climate vulnerability, and methodology (Ali discussed slide 3 and 4)
- The need to compare with the observations, experience and data from the field side
- Getting feedback on whether we on the right track
- Discussions on available data
- Discussions on current challenges from the field that research could look for solutions in the future

<u>Questions and Discussions</u>:

1. What weight are the roads designed to support in the province?

- Light weight vehicle traffic ≤ 7 tonnes (cars, pickup trucks)
- 7 tonnes ≤ Medium weight vehicle traffic ≤ 15 tonnes
- 15 tonnes ≤ Heavy weight vehicle traffic ≤ 39.5 tonnes
- > 39.5 tonnes require special permits, maximum vehicle weight = 57 tonnes (across ice)

Doug confirmed the province try to open the roads up as early as possible. The on ice segments generally control the road opening, while the surface segments control road closing. Once the roads are fully open, the focus is then shifted to monitoring, and anticipating interruptions and closures.

2. Are there changes to the routes from year to year?

Shane – The routes don't change significantly, but there might be minor variations from year to year. The province is getting away from larger lake crossings, as well as eliminating some of the former routes from the East Side Program.

3. How are road conditions communicated?

Road conditions are communicated to the public via manitoba511.ca (https://www.gov.mb.ca/mit/winter/reports.html). Shane and David provide updates as needed.

4. Do the routes have known weakness?

Shane – Yes, there are known weakness within different routes. Creeks are often the weak links. The weak links for each segment is well known to all those working on the segment.

5. Factors for consideration for closing a route/season?

Shane – The roads over land will deteriorate first. When the trucks can no longer move across usually leads to the decision of shutting down a road/segment.

Doug – Mid-season warming can also be very problematic for over land routes, one warm day (above 0 ºC) can be destructive enough to shut down the season. Ice crossing on the lakes are usually the last to thaw (May or June). The roads close when the creeks over flow. The anticipating closing date is communicated via manitoba511.ca. It is usually communicated at least a week before complete road closure to allow trucks to be able to complete their roundtrip delivery.

6. The next steps in the current project phase will be to conduct case studies, using winter road network data, climate models, and historical weather station data, to determine the robustness of the framework. Does the province keep data and historical records, and can the data be shared with the NRC to be used in the case studies (data examples: historical opening and closing dates, route locations, weak links, GPR data)?

Shane confirmed that the province has a record of historical opening and closing dates. The format is not consistent across the years. The province is currently working on a more general format and a central database. That work is likely not going to be completed until the spring. In the meantime, data in its current formats can be shared. Merrina mentioned that NRC is not concerned with the format of the data, as we likely have the tools to sort through it.

Shane confirmed that the province has the winter road network data, and this can be shared. Merrina mentioned that NRC can map the data in ArcGIS and can provide the layers back to the province, since the province is planning on moving to a GIS based system in the future.

Shane confirmed the province have their own GPR units and routinely use it for inspection. There is data records for the past ten years, which can be shared with the NRC.

In consideration of the large volume of data, Merrina suggested that NRC can set up an FTP server to facilitate information exchange.

7. What are some of the biggest concerns and challenges?

Doug – One of the challenges is the variation in winter road quality. Some winter road constructions are better than others. The quality of the roads depends on a number of factors, including the contractor, site specific characteristics. Some segments are problematic to keep open, which affect segments that connect to it. Some locations don't reach full loading. Some of the southern routes actually stays open the longest. Contractors change from year to year in some segments, while other segments have the same contractors from year to year. When looking and comparing data year after year, it's important to note that different contractors might do things differently, which would impact the road quality/season. If you have the same contractor, it would remove the variation in construction quality from the equation. A suggestion for the initial case studies would be to examine segments with the same contractor. For example, <u>Matheson, which is the longest ice crossing in the province at 2km, has had the same contractor, and might be a good candidate for the first case study</u>.

Doug – The current mandate is to reduce the number of ice crossing by shifting to more over land segments. The current network is 2,383 km long with 60 ice crossings.

8. Should the project team also consider temperature conditions in the fall?

Doug – Yes, since temperature conditions in the fall very much influences road opening, while temperature conditions in the winter months control road closing. A cool fall (daily highs below 10 ºC) like 2019, the lakes (400 feet deep) were frozen a month early, enabling an early start of the winter road season. Mild winters, which is key comes spring time will likely prompt early closures. Some key temperature conditions used in the province:

- warm fall: daily highs between 10 to 15 ºC
- cool fall: daily highs below 10 ºC
- A temperature of -20 ºC with no snow is good for the on ice segments
- At temperature conditions of -35 or -40 ºC, equipment begins to breaks down.

Some key date considerations/trends:

- Temperatures from September to mid-October
- Construction typically start mid-November
- Season closure happen around mid-March

Action items:

- ➢ Merrina will provide a summary of discussion for Shane and Doug to review;
- ➢ Merrina will reach out to Shane with a wish list for winter road data;
- ➢ Merrina to set up an FTP site for sharing data;
- ➢ Merrina to share the final project report
- ➢ Shane to get back to Merrina if there are any additional tools/products that the province might be needing for winter roads, and most useful format, so this can be integrated into the project either in the current phase or in a future phase.

February 19, 2021
10:30 to 12:00 pm Eastern time

Development of a Framework for the Review of Climate Risk and Vulnerability for Winter Roads in Canada Discussions (NRC and Province of Ontario)

Internal Meeting Attendees:
Merrina Zhang – NRC, Automotive and Surface Transportation Research Centre
Alireza Roghani – NRC, Automotive and Surface Transportation Research Centre
Sylvie Chenier – NRC, Automotive and Surface Transportation Research Centre
Chantal Edwards – NRC, Automotive and Surface Transportation Research Centre

Province of Ontario Meeting Attendees:
Ken Coulter – Senior Transportation Advisor, Ministry of Northern Development and Mines (MNDM)
Jason Scott – Manager of Transportation Infrastructure, MNDM

CIRNAC Meeting Attendees:
Aviva Shiller – CIRNAC, First Nation Adapt Program

Opening:

Merrina shared her presentation and highlighted the following items for discussion:

- The vulnerabilities identified through the literature review of the winter road network
- The goal of the project related to better forecasting and planning for the future
- The proposed framework to assess climate vulnerability, and methodology (Ali discussed slide 3 and 4)
- The need to compare with the observations, experience and data from the field side
- Getting feedback on whether we on the right track
- Discussions on available data
    - Records of historical opening dates / closing dates / interruptions
    - Traffic weights
    - Shape files (GIS) of winter road routes for mapping
    - Changes in routes from year to year
    - Known weak links
    - Available GPR data or ice measurements
    - Most pressing issues related to roads?
    - Suggested stakeholders for future phases?
- Discussions on current challenges on winter roads from the stakeholders around the table

<u>Questions and Discussions:</u>

1. What weight are the roads designed to support in the province?

Jason – 80,000 lb is the maximum allowable weight on Ontario's Winter Road Network. Individual communities decide when the roads can open for light, medium and heavy traffic. Similar to the Province of Manitoba, the on ice portion (ice thickness) of the network controls the opening of the winter road segment.

Ken – The winter road program in Ontario works differently than other provinces, where the MNDM provide funding, and the roads are built by communities. There is a document of guidelines on winter roads for Ontario, which can be shared. Where the province of Manitoba is responsible for winter road construction, and are the owners of those roads within their jurisdiction. Currently, the **most pressing issues** in Ontario is how unpredictable and unreliable the winter seasons are becoming.

The Transportation Association of Canada also publishes guidelines on winter roads.

2. Discussion of data

Ken – There is lack of winter roads data in Ontario. MNDM relies on community reporting, which usually only occurs at the end of the season when the survey is sent out (opening, closing, season date, and material qualitative measures). The returned surveys data is inconsistent, with different levels of completeness and details. Due to COVID, the data from winter road season 2019-2020 is missing. <u>The data on opening and closing dates can be shared</u>, though there is a need to be cautious because the dates are not verified, and can be misleading as it does not mean the roads were open for the entire period, since they can be temporarily closed due to weather (storms, sudden warming). MNDM uses Lessard Welding in Sudbury for portable bridges. Ken can provide a contact to see if there are mapping data related to the structures and ice bridges. Those locations are where MNDM wants to put culverts.

Jason – The type of data being gathered for this project would be very relevant for MNDM. Ice thickness is not measured by MNDM. ISC collect the winter road status data on a weekly basis directly from the communities, related to which roads are under construction, open to light, partial or fully opened. The ice has to be 3 feet thick to support 36 tonnes.

3. Discussion of weak links within the networks

Ken – When the weather stays cold enough, ice will grow to suitable depths on major ice crossing. When there are weather spikes, they can result in washouts of creeks and roads. The creeks and smaller rivers are shorter spans of water crossings. They control road closures (temporary or season ending). MNDM have been trying for years to get portable bridges to make these crossings safer thus extending the window of the season. MNDM have been asking for this information from the communities, but there is a definitely a data gap. Permafrost is another issue, they have to drive the frost down on the ground more than before which is more challenging on the slopes. There are a lot of hills in northern Ontario, and because they are not freezing like they used to, rocks are getting loose or the truck will dig in because the frost is not there.

Aviva – Currently roads are funded on a per kilometre basis. Though, some segments are much more challenging to build than other segments. This type of work could give more information on whether it would make sense to provide funding based on the route characteristics and geography.

4. How much confidence in climate data/models

Ali – The confidence levels of climate models related to temperature prediction is very high, while the predictions for other parameters such as snow and rain fall, wind, are much less certain.

5. Discussion of the future of winter roads

Jason – There are a number of tribal council and community examining options for all season roads, especially in the ring of fire region. Though not every community wants all season roads, since some communities wants to keep drugs and alcohol out of their communities. Due to the unpredictable climate, there is a lack of certainty of whether or not the winter roads will continue to be feasible. There is a need to look at alternatives. MNDM's current efforts are focused on building more resiliency within the current network, such as building permanent structures like bridges and avoiding large water crossing if possible.

Aviva – If a community is thinking about the options related to all weather roads, they can contact CIRNAC's First Nation Adapt Program ($9 million annually), which provides funding for feasibility studies. The program works with the community to develop the funding proposal. There is an on-going solicitation process. Aviva will provide the contact for the program after the meeting. In addition, CIRNAC and ISC are planning a series of workshops with First Nations communities. They would like to engage the communities in Ontario. The timeline will depend on when face-to-face meetings can be held. Aviva Shiller and James Winkel (ISC) will be the point of contact and are the leads in the planning.

6. What timeframe (i.e. in 5 years, 10 years, 20 years, and 30 years) is useful for case study analysis?

From an operational point of view this set of timeframes works well.

Action items:

- Merrina to send the notes from the meeting for review and approval to be included in the final report
- Merrina to send the updated presentation and data wish list to the meeting participants
- Merrina to share final report
- Ken to share Ontario's winter road guidelines
- Ken to share MNDM's record on road opening and closing
- Ken to share the -contact on mapping data related to structures and ice bridges
- Aviva to provide a list of communities that has received funding from CIRNAC's First Nation Adapt Program
- Aviva will provide contact details of CIRNAC's First Nation Adapt Program

February 22, 2021
10:30 to 12:00 am Eastern Time

Development of a Framework for the Review of Climate Risk and Vulnerability for Winter Roads in Canada Discussions (National Research Council and Province of Saskatchewan)

NRC Meeting Attendees:
Merrina Zhang – NRC, Automotive and Surface Transportation Research Centre
Alireza Roghani – NRC, Automotive and Surface Transportation Research Centre
Chantal Edwards – NRC, Automotive and Surface Transportation Research Centre
Shane Wallace – NRC, Automotive and Surface Transportation Research Centre

Province of Saskatchewan Meeting Attendees:
Jason Senga – District Operation Manager, Province of Saskatchewan

Opening:

Merrina shared her presentation and highlighted the following items for discussion:

- The vulnerabilities identified through the literature review of the winter road network
- The goal of the project related to better forecasting and planning for the future
- The proposed framework to assess climate vulnerability, and methodology (Ali discussed slide 3 and 4)
- The need to compare with the observations, experience and data from the field side
- Getting feedback on whether we on the right track
- Discussions on available data
    - Records of historical opening dates / closing dates / interruptions
    - Traffic weights
    - Shape files (GIS) of winter road routes for mapping
    - Changes in routes from year to year
    - Known weak links
    - Available GPR data or ice measurements
    - Most pressing issues related to roads?
    - Suggested stakeholders for future phases?
- Discussions on current challenges on winter roads from the stakeholders around the table

<u>**Questions and discussions**</u>:

1. What weight are the roads designed to support in the province?

- Road building starts when ice thickness = 10”
- Light weight vehicle traffic ≤ 8,500 lb/3,856 kg (ice thickness of 16”, up to the weight of a half-tonne)
- 8,500 lb/3,856 kg ≤ Medium weight vehicle traffic ≤ 34,000 lb/15,400 kg (ice thickness of 18”)
- Maximum allowable vehicle weight = 76,000 lb or 34,500 kg (ice thickness of 30”)

All winter road segments in the province are fully opened as of Friday February 19, 2021.

GPR is performed (on sleigh pulled behind a pickup truck) every two weeks, but can also be performed weekly depending on the need. One measurement is made per meter. Before road opening, the measurements are made on the centre line and the outer perimeters. Once the road opened, the measurements are made on the outer perimeters only, since that is the weakest points. The bearing capacity of the road is determined by the ice measurements from the GPR.

2. How many over land portions do you have?

There are 52 km of over land road in Saskatchewan.

For the over land routes, there is a preference of going east to west, since it is historically less problematic, and more sheltered. North to south routes tend to get blowing snow which require clearing of the entire lane, where east to west routes often only require snow clearing around the edges. But the limitation is that the over land routes need to be where they are based on the on-ice portion of the network and the location of the communities.

3. Comments on the methodology/most pressing challenges.

The province currently use the Gold Formula for calculating ice thickness, A=6.

Snow is one of the most important factors to consider on the over ice segment before opening date. Heavy snow fall will provide a layer of insulation on the forming icing that will minimize the effects of cold temperature. Snow is a key factor on how fast the roads can be built. The province does not keep records of snow accumulation.

Water levels and the current of the lakes is another key consideration, as both factors have resulted in the need to reroute the road segment in the past. For example, high water flow combined with warmer temperatures on Lake Athabasca last year eroded the bottom of the ice formation by 3-4” within a few days. Merrina shared the climate.ca map and Jason showed different parts where the water level has changed.

Temperature swings is another major challenge. Temperature swings this year from -49ºC to +2ºC causes ice ridge formations, which may cause the need to reroute or shutdown ice bridges.

Midseason interruptions can also be due to major storms which are safety hazards to travel.

Wind is another factor for consideration. Wollaston Lake, the larger, deeper and more southern lake froze before Athabasca Lake this year. Normally Athabasca Lake freezes first. This is likely due to the effects from wind since there have been many days of strong wind. Many days of the barge season was lost due to wind (October). Early freeze can be problematic, since once the ice forms, any snow is accumulated on top, insulating the ice, rather than falling into the water.

4. What timeframe (i.e. in 5 years, 10 years, 20 years, and 30 years) is useful for case study analysis?

From an operational point of view this set of timeframes works well.

The groups that does policy planning might prefer a longer forecast. There have been talks of plans to build all weather roads. Northern Saskatchewan has large areas of rocks and muskeg, which makes building all weather roads very challenging.

Has COVID affected this winter road season?

COVID has not been a factor for this winter road season, as the province is on schedule with standard opening date.

6. Are contractors who build the roads consistent from year to year?

For the most part they are consistent from year to year, at least at the parent company level. Sometimes portions of the work might be subcontracted.

7. Are the weak links the same from year to year?

The opening of the season depends on the on-ice portion of the network, while the closing of the season is controlled by the over land section, especially over muskeg and creeks.

When the creeks are flooded, the roads gets shutdown since we cannot guaranty safety.

Muskeg behaves differently than other types of soil matters. The water content is so high that sometimes there will be water on the road, even when the temperature is -40ºC and the road is frozen. If the problem is localised, we will go out and fix the section or reroute it. But, when the issue gets beyond a few spots, then it becomes unfeasible to keep the operation going.

8. How are changes on the winter road network communicated within the province?

Provincial highway hotline: https://hotline.gov.sk.ca/mobile/#cameras/highway/ice_roads

There is also an email list that the province uses to communicate road updates with key stakeholders, include FN community band offices, RCMP, trucking company, industry….

9. NRC: Data wish list

- **Records of historical opening dates / closing dates / interruptions**
- Jason – There is records of historical opening and closing dates and can be shared. There is no records of midseason interruptions.
- **Traffic weights**
- Jason – Traffic weights are not tracked.
- **Changes in routes from year to year**
- Jason – routes can changed from year to year, on lakes, on rivers and on land. The records are contained in the GPR data.
- **Known weak links**
- Jason – the over land segments (creeks, portages, transitions, muskeg) are the weak links. The province spent a lot of money last year trying to keep those sections open. COVID caused some delays of shipment to the communities last season. The province tried as much as possible to keep the roads open as long as possible.
- **Shape files (GIS) of winter road routes for mapping**

- Jason – There is no shapefiles. Though one of the private roads owned by a forestry company might have shapefiles. The GPR data has GPS locations.
- **Available GPR data or ice measurements**
- Jason – GPR data, calibrations, and drilled test holes data can be shared. Will check with Brent as to how many years of records there are, likely there are at least 5 years of data.

Action items:

- Merrina to send the notes from the meeting for review and approval to be included in the final report
- Merrina to send the updated presentation and data wish list to the meeting participants
- Merrina to set up an FTP site for sharing data
- Merrina to share final report
- Jason to share the province’s Winter Roads Manual
- Jason to share records of historical opening and closing dates
- Jason to share GPR data, calibrations, and drilled test holes data
- Jason to provide suggestion of the best route segment for case study
- Jason to get back to Merrina if there are any additional tools/products that the province might be needing for winter roads, and most useful format, so this can be integrated into the project either in the current phase or in a future phase