Winter roads and ice bridges: anomalies in their records of seasonal usage and what we can learn from them

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Abstract

Most believe that the warming of the earth's climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

One possible effect for winter roads and ice bridges in Canada's North is that the mean length of time each road or ice bridge is operationally open will progressively shorten. Tracking the recorded start- and end-of-season dates and thus the length of season over time for each confirms that – for most cases. But in some cases, the recorded seasonal length has actually *increased* over time.

Global warming will continue to be imposed on Canada. Clearly there are lessons to be learned from the case histories of those winter roads and ice bridges that saw increased seasonal usage. These lessons could be applied to other roads and ice bridges to great benefit, to adapt to the changing climate.

The paper provides the detailed statistical record of the seasonal usage of selected winter roads and ice bridges in the Northwest Territories, identifying those cases where the length of the operational season has increased. It then examines what may have caused the lengthening of the seasonal usage of those winter roads and ice bridges, in the face of climate change.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) states that the warming of the earth's climate system is unequivocal (IPCC, 2007), as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. Al Gore has captivated audiences with *An inconvenient truth: the planetary emergency of global warming and what we can do about it* (Gore, 2006), in which he shows dramatic "then and now" photos of famous glaciers. Media reports of global warming and climate change lend a sense of urgency to the situation.

In the Northwest Territories, warmer winters are affecting DoT's ability to construct and maintain river crossings and sections of winter roads on frozen lakes[1]. It is becoming more difficult to build sufficient

[1] personal communication, Greg Cousineau, Government of NWT, Yellowknife. 2009 07 02

thicknesses of ice to support commercial vehicles. In 2006, a massive airlift costing more than $100 million was required because one road could not be brought to full capacity.

But Canada's contribution to global warming is only a small fraction of the overall total, so no matter what we Canadians do – from nothing through to completely eliminating all Canadian sources of greenhouse gases – climate change will continue to be imposed on us.

There are two courses of action open to us. First, we can find individuals or groups to blame, and influence them to stop or slow down their emission of the greenhouse gases that contribute to climate change. But whatever others do, our climate will continue to change. Thus the second course of action, adaptation, is a necessity. Infrastructure, particularly that in the Arctic, will feel the brunt of climate change; ways must be found to accommodate the changes in climate, if we are to continue to operate successfully in the Arctic.

Arctic road transportation could be particularly hard-hit. It is anticipated that the operational season of winter roads and ice bridges will be progressively shortened as the climate warms; Gore (2006) alludes to this with a graph that purports to show that climate change is responsible for a steady decline in the number of days winter Alaskan tundra travel is permissible, Figure 1.

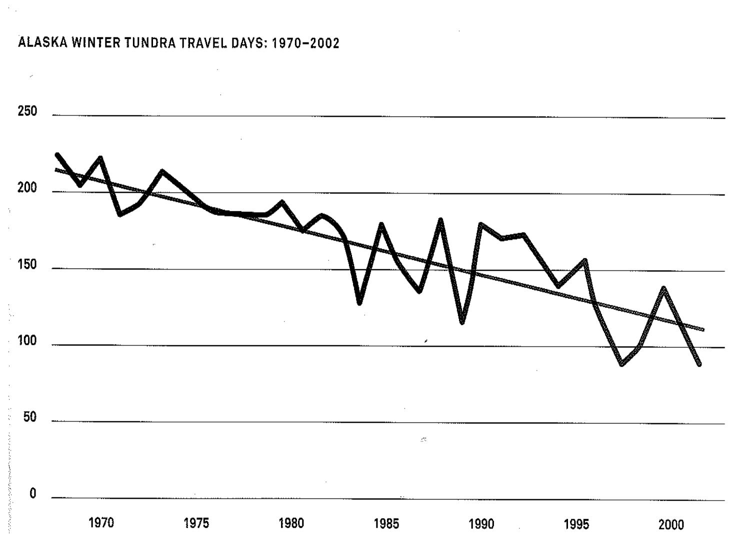


Figure 1. Trend in Alaskan winter tundra travel days (Gore, 2006).

Tracking the recorded start and end of operating season dates and plotting the length of season over time for each winter road or ice bridge should confirm that, and indeed it does – for most cases. But in some cases, the recorded seasonal length has actually *increased* over time. This paper explores the anomalies.

Trend Analysis

First, to explore temperature data, a detailed statistical analysis was performed on the temperature records for three locations: Inuvik, Norman Wells, Fort Simpson, and Yellowknife. Trends in mean annual temperature and mean temperatures for the winter (taken to be December, January and February) and spring (March, April and May) periods were determined over the period 1984 to 2008. Trends were evaluated by fitting a linear model to the data using Sen's nonparametric model (Salmi *et al.*, 2002). The statistical significance of the observed trends is determined using the Mann-Kendall test which is applicable to the detection of a monotonic trend in a time series with no seasonal cycle. The analysis uses a two-tailed test to determine significance at the 90th, 95th, 99th and 99.9th percentile levels. A trend that is determined to be significant at the 99.9th percentile level means that there is a 99.9 percent probability that the direction of the trend is correct, whereas a trend that is not determined to be significant at the 90th percentile is classified as being "not statistically significant". Calculations of trends and tests of statistical significance were accomplished using the model developed and distributed by the Finnish Meteorological Institute (Salmi *et al*., 2002). The results of the analysis are shown in Table 1.

Table 1
Temperature trend data – 1984-2008, inclusive

Parameter	Climate Station	Trend (°C/year)	Test for Statistical Significance
Mean annual temperature	Inuvik	+0.080	*
	Norman Wells	+0.043	*
	Fort Simpson	+0.046	significant at the 90th percentile
	Yellowknife	+0.061	*
Winter temperature (during Dec-Jan-Feb period)	Inuvik	+0.158	significant at the 90th percentile
	Norman Wells	+0.032	*
	Fort Simpson	+0.040	*
	Yellowknife	+0.127	significant at the 90th percentile
Spring temperature (during Mar-Apr-May period)	Inuvik	-0.003	*
	Norman Wells	-0.046	*
	Fort Simpson	-0.036	*
	Yellowknife	-0.026	*

** not statistically significant*

As shown in Table 1, only three of the nine results were statistically significant and those three showed a warming trend. The mean annual temperatures showed a warming of about a half degree centigrade per decade on average, but only the result of the analysis for Fort Simpson was statistically significant. Winter temperatures were getting progressively warmer for all four stations, although only the results for Inuvik and Yellowknife were statistically significant. Conversely, the spring temperatures were getting progressively cooler for all four stations, although the none of the results was statistically significant.

Next, a detailed statistical record of the operational seasons of four ice bridges, five winter roads, and nine community access roads in the Yukon and Northwest Territories was also performed using the same analysis techniques. The results are given in Table 2.

Table 2
Winter road and ice bridge operational season trends – generally 1984-2008 except as noted

Type of road	Road section	Change in season *length* (days / year) / Level of statistical significance	Change in *opening date* (days / year) / Level of statistical significance	Change in *closing date* (days / year) / Level of statistical significance
Ice Bridges	Mackenzie River Crossing Fort Providence	-0.50	+0.36	+0.00
		*	*	*
	Liard River Crossing at Fort Simpson	-0.63	+0.33	+0.00
		*	*	*
	Mackenzie River Crossing at Tsiighetchic	-0.09	+0.00	-0.04
		*	*	*
	Peel River Crossing	+0.00	+0.00	+0.00
		*	*	*
	Mackenzie River Crossing at Camsell Bend	**+0.80**	-0.02	**+0.73**
		90%	*	**99%**
Winter Roads	Ft. Simpson - Wrigley (Highway #1) (1984-1994)	**+4.44**	**-2.25**	+1.75
		99%	**99.9%**	*
	Wrigley - Tulita (Highway #1)	+1.03	-1.00	-0.38
		*	*	*
	Tulita - Norman Wells (Highway #1)	+0.32	-0.41	+0.00
		*	*	*
	Norman Wells - Ft. Good Hope (Highway #1) (1989-2008)	**+2.06**	**-1.49**	+0.12
		95%	**95%**	*
	Tibbitt-Contwoyto Winter Road (1989-2008)	+0.59	+0.00	+0.54
		*	*	*
Community Access Roads	Deline Access	**-0.66**	**+0.30**	-0.30
		90%	**90%**	*
	Trout Lake Access	+0.00	-0.50	**-0.65**
		*	*	**95%**
	Nahanni Butte Access	**+0.61**	**-0.82**	**-0.52**
		90%	**99%**	**95%**
	Wha Ti Access	**-0.87**	**+1.55**	**+0.72**
		95%	**99.9%**	**99%**
	Gameti Access	**-1.14**	**+2.00**	**+0.72**
		99%	**99.9%**	**99%**
	Dettah Access	**-0.74**	**+0.89**	+0.00
		90%	**99%**	*
	Tuktoyaktuk Access	**+0.60**	**-1.00**	-0.20
		90%	**95%**	*
	Aklavik Access	-0.07	-0.16	-0.10
		*	*	*
	Colville Lake Access (2001-2008)	**+7.83**	-7.80	+0.00
		90%	*	*

** not statistically significant*

Looking only at the statistically-significant results in Table 2, the operating season was actually *lengthening* for 6 of 10 ice bridges, winter roads, and community access roads. The average lengthening was 2.7 days/year, or 1.7 days/year if the result for Colville Lake Access road is ignored (only 7 years of data are available).

Examining the season opening dates and season closing dates, 4 of 8 roads were opening progressively *sooner* (negative trend), and 3 of 5 were closing *later*.

For the three cases where there are statistically significant results for all of the season length, opening date, and closing date, the following is observed in the data:

- Nahanni Butte Access Road: season lengthening (+0.61 days/yr), opening day coming earlier (-0.82 days/year), closing day also coming earlier (-0.52 days/yr), but not by as much as the opening day;
- Wha Ti Access Road: season shortening (-0.87 days/yr), opening day coming later (+1.55 days/year), closing day also coming later (+0.72 days/yr), but not by as much as the opening day; and
- Gameti Access Road: season shortening (-1.14 days/yr), opening day coming later (+2.00 days/year), closing day also coming later (+0.72 days/yr), but not by as much as the opening day.

Thus the strongest evidence (Nahanni, Wha Ti, and Gameti roads) is that one of three roads was experiencing a *lengthening* of operating season, in the face of a general warming of the climate across the Canadian Arctic.

If one relaxes the importance of the statistical significance, there is other evidence of roads "bucking the expected trend" – 9 of 19 showed a lengthening trend, whether statistically significant or not, 2 showed no trend, and 8 showed a shortening of operating season.

These first analyses indicated that examining the data in terms of global warming, measured only by the mean annual temperature, was not sufficient to provide the full picture. While the mean annual temperatures and winter temperatures (Dec-Jan-Feb) were rising (Table 1), spring temperatures (Mar-Apr-May) were actually cooling. The overall trend is a rise in mean temperature, but the cold season was "moving" in time – coming later in the calendar year. Reflected by the changes in opening and closing dates (Table 2), the operating season could be seen to be moving in time as well as lengthening or shortening. The season lengthened or shortened according to the relative movement of the start and end dates. In two of three statistically-significant cases, the operating season was shifting to later in the calendar year, while simultaneously becoming shorter.

However, in the third statistically-significant case, the season was *lengthening* and coming *earlier* in the calendar year. This could be caused by:

- the effects of other climatic parameters; or
- differences in the actual operating procedures for the winter roads and ice bridges

First, other climatic indicators will be explored, then the design and operation of the winter roads and ice bridges will be discussed.

Analysis of Other Climatic Indicators

Others have reported cases where winter road operating seasons have lengthened. The information Gore (2006) cited without reference ultimately originated from Hinzman *et al.* 2005, who noted that although the closing date was changing (coming earlier), the opening date was changing even more substantially (coming later). However, there was some question as to whether the shortening of the operating season was caused more by a change in the criteria for permission to haul over tundra than climatic effects. Citing an unpublished paper by Hinzman *et al.*, the Arctic Council (2005) noted that while there was a reduction in season length for roads on the North Slope of Alaska, and a trend of later opening for the Wha Ti road, the Inuvik-Tuktoyaktuk road was experiencing an increased operating season over time. Thus the following can be inferred from the literature:

- despite a general warming trend indicated by the increase in the average annual temperature, not all winter roads are experiencing a shortened operating season;
- the average annual temperature may be the wrong climatic parameter to use to explain the changes in winter road and ice road operational season length; and
- operational or regulatory factors may explain the changes in operational season length.

With these points in mind, other climatic parameters were explored, and winter road operators were contacted to gather anecdotal accounts of their experience.

Other climatic indicators

In this first examination of the parameters, average temperatures and precipitations (water equivalents) were selected, running over:

- the winter period (December, January, February);
- the spring period (March, April, May);
- a given road’s or ice bridge’s individual operating season;
- the 30-day period prior to the individual opening date for a given road or ice bridge; or
- the 30-day period prior to the individual closing date for a given road or ice bridge.

Climatic statistics, generally for the years 1984-2008, were obtained for the nearest climate station. Only the statistically-significant results were examined. A summary of the results is provided in Table A1, in the Appendix.

Table 3 captures the results that apply to the operating season. Six of ten roads had statistically-significant *lengthening* trends in their operating seasons, from +0.60 to +7.83 days per year. The three most extreme values were for shorter time records (7 to 19 years). There were two statistically-significant observations of the trend in average annual temperature, Fort Simpson at +0.05°C/year and Inuvik at +0.08 °C/year, and no significant trends in the average annual precipitation. During the operating season, Wha Ti Access Road and Gameti Access Road both showed warming and drying trends.

If the extreme record (Fort Simpson to Wrigley, Highway 1, 10 year record 1984-94) is believed, there was a relationship where the operating season became longer if the rainfall over the operating season decreased (Figure 2(c)).

Table 4 deals with the statistics of the operating season start date. Four of eight roads had progressively *earlier* start dates, from 0.82 to 2.25 days per year earlier. Two climate stations, Inuvik and Yellowknife, had statistically-significant warming trends in the winter months, at +0.16 and +0.13°C/year respectively. These winter values were much larger than the average annual values, so must have been compensated by much smaller values (and possibly cooling values) during other parts of the year. Fort Simpson and Norman Wells both showed drying trends over the winter, at -3.65 and -1.70/-1.07 mm/year respectively. The results were different for roads associated with the Norman Wells station because they covered different segments of the time history of precipitation observations (1989-2008 and 1984-2008). For the period 30 days prior to the operating season's opening date, the Norman Wells to Fort Good Hope (Highway 1) road had warming, but drying trends that corresponded to a trend to earlier start dates (-1.49 days per year over 1989-2008).

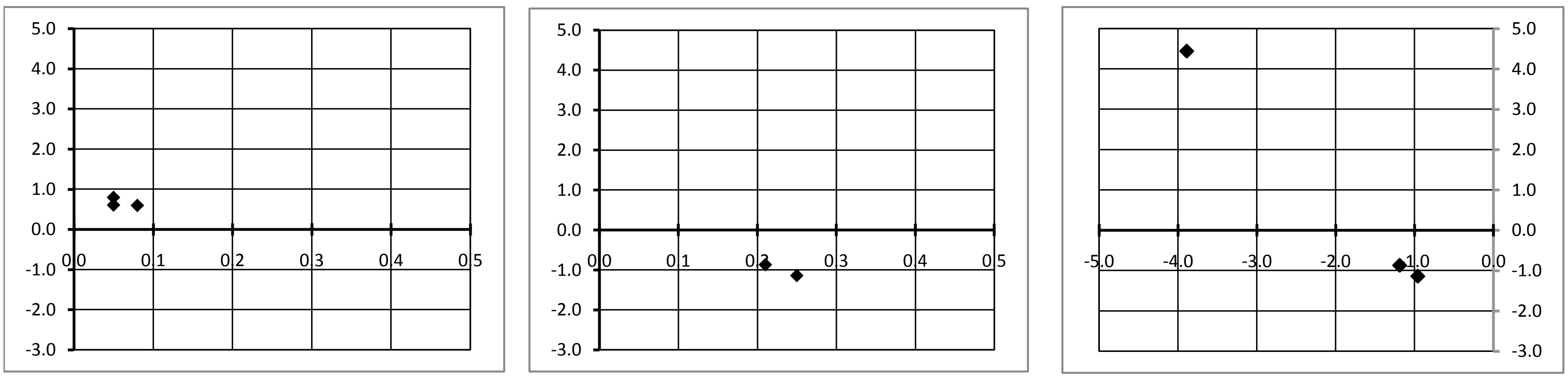
Plotting the change in opening date against the change in average winter precipitation (Figure 3(b)) suggests that the start date came earlier for progressively drier winters.

Closing date statistics are presented in Table 5. Three of five roads had a statistically-significant trend to *later* closing dates. Of the temperature and precipitation trends during the spring (March, April, May period) only the precipitation trend, for roads associated with Fort Simpson, were statistically significant, with an increase of 1.19 mm/year over the years 1984-2008. All five roads had statistically-significant trends in temperature during the 30-day period prior to closing. Where the temperature trend was toward *cooling* (negative), the closing date trended *earlier*. The opposite also was observed; the relationship is reflected in Figure 4. While this is counter-intuitive, it may be that the closing dates were just arbitrarily pushed later in the year, when temperatures are naturally warmer.

Table 3: Operating season statistics

Road section: 1984-2008 except as noted	Associated climate station	Annual conditions		During operating season		Change in op season *length* (days / year)
		ΔTemp °C/yr	ΔPrecip mm/yr	ΔTemp °C/yr	ΔPrecip mm/yr	
Deline Access	Norman Wells					-0.66
Wha Ti Access	Yellowknife			0.21	-1.19	-0.87
Gameti Access	Yellowknife			0.25	-0.96	-1.14
Dettah Access	Yellowknife					-0.74
Mackenzie River Crossing at Camsell Bend	Fort Simpson	0.05				0.80
Ft. Simpson - Wrigley (Highway #1) (1984-1994)	Fort Simpson				-3.89	4.44
Norman Wells - Ft. Good Hope (Highway #1) (1989-2008)	Norman Wells					2.06
Nahanni Butte Access	Fort Simpson	0.05				0.61
Tuktoyaktuk Access	Inuvik	0.08				0.60
Colville Lake Access (2001-2008)	Norman Wells					7.83

6/10 +ve

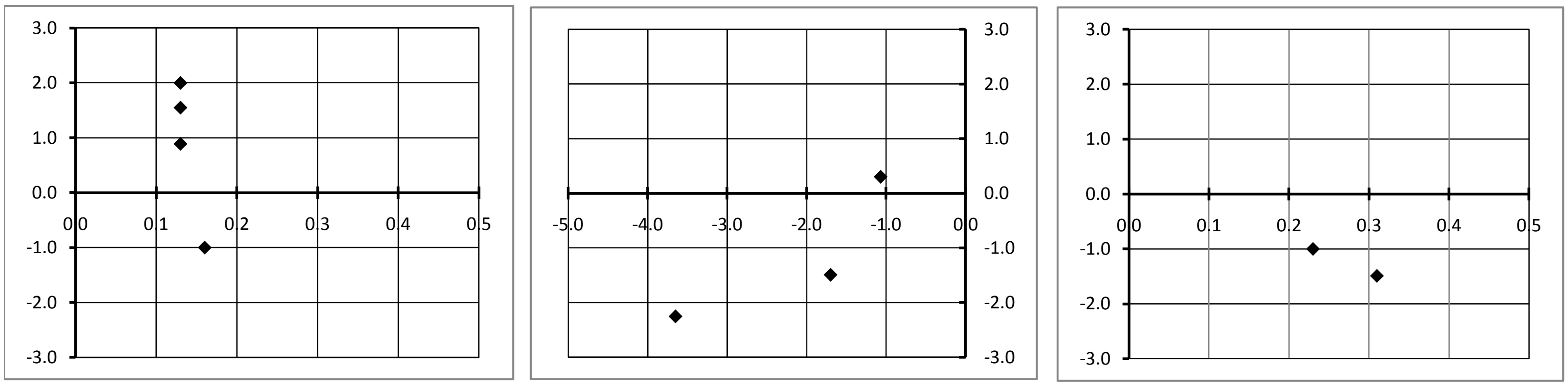


(a) (b) (c)

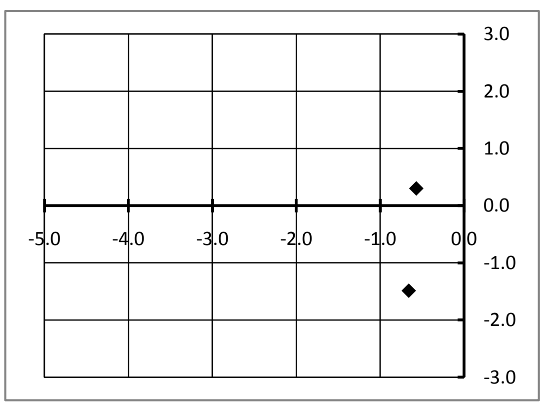
Figure 2. Change in operational season length (days/year) vs (a) change in average annual temperature (°C/year), (b) change in average operational season temperature (°C/year), and (c) change in average operational season precipitation (mm/year).

Table 4: Starting date statistics						
Road section: 1984-2008 except as noted	**Associated climate station**	**During Dec, Jan, Feb period**		**30 day period prior to opening date**		**Change in *opening date* (days / year)**
		ΔTemp °C/yr	**ΔPrecip mm/yr**	**ΔTemp °C/yr**	**ΔPrecip mm/yr**	
Ft. Simpson - Wrigley (Highway #1) (1984-1994)	Fort Simpson		-3.65			-2.25
Norman Wells - Ft. Good Hope (Highway #1) (1989-2008)	Norman Wells		-1.70	0.31	-0.66	-1.49
Nahanni Butte Access	Fort Simpson					-0.82
Tuktoyaktuk Access	Inuvik	0.16		0.23		-1.00
Deline Access	Norman Wells		-1.07		-0.57	0.30
Wha Ti Access	Yellowknife	0.13				1.55
Gameti Access	Yellowknife	0.13				2.00
Dettah Access	Yellowknife	0.13				0.89

4/8 -ve



(a) (b) (c)



(d)

Figure 3. Change of opening date (days/year) vs (a) change in average Dec-Jan-Feb temperature (°C/year), (b) change in average Dec-Jan-Feb precipitation (mm/year), (c) change in average temperature 30 days prior to opening (°C/year), and change in average precipitation 30 days prior to opening (mm/year).

Table 5: Closing date statistics						
Road section: 1984-2008 except as noted	**Associated climate station**	**During Mar, Apr, May period**		**30 day period prior to closing date**		**Change in *closing date* (days / year)**
		ΔTemp °C/yr	**ΔPrecip mm/yr**	**ΔTemp °C/yr**	**ΔPrecip mm/yr**	
Trout Lake Access	Fort Simpson		1.19	-0.20		-0.65
Nahanni Butte Access	Fort Simpson		1.19	-0.19		-0.52
Mackenzie River Crossing at Camsell Bend	Fort Simpson		1.19	0.21		0.73
Wha Ti Access	Yellowknife			0.27		0.72
Gameti Access	Yellowknife			0.25		0.72

3/5 +ve

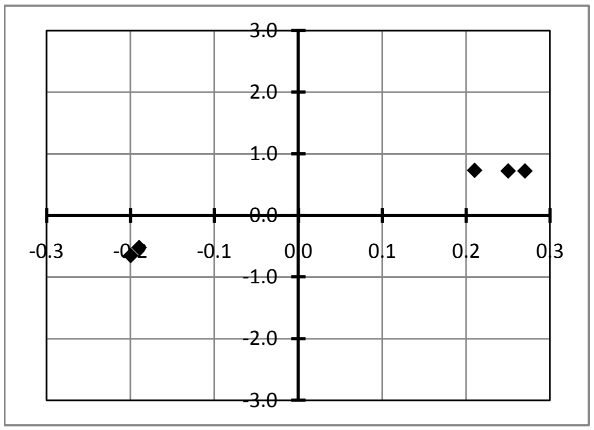


Figure 4. Change in closing date (days/year) vs change in average temperature 30 days prior to closing (°C/year).

Operational considerations

Three operational practices that may help lengthen operating seasons came to light in informal interviews with operational personnel:

1. It is has become widespread practice in recent years to spray ice roads and ice bridges, to thicken the ice structure. This pushes back the closing date, as it takes longer to melt the additional ice thickness.
2. Ground penetrating radar is being used to determine ice sheet thickness.
3. Plowing snow off the road alignment enhances the freezing effect, leading to a thicker ice sheet.
4. Towards the end of the hauling season, some operators restrict hauling to hours of darkness, when the ice sheet is somewhat stronger.

In the Northwest Territories, at present, the winter road choke point can be lakes and streams[2]. In response, at least 30 permanent bridges have been constructed over the last few years. Seasons are now longer, thanks to the bridges, but in future, the land-based segments of winter routes may become the weak links. Cold weather with little insulating snow is required at the start of the season.

Discussion

It is evident that the simple warming trend in the average annual temperature does not account for the trends in the operating season for winter roads and ice bridges – a substantial number of them in the Canadian Arctic buck the trend. Operational considerations compound the picture, and are good examples of the adaptation of arctic methods to arctic climate change.

Other climatic parameters may explain the observed trends in operational season lengths. This first examination points out that trends in precipitation may have over-ridden trends in temperature. It appears that drier conditions over the operating season and/or drier winters lead to lengthening operating seasons.

Conclusions and Recommendations

The discussion in the paper generally covered the period 1984 to 2008, with four exceptions, and was limited to results statistically significant at at least the 90th percentile level. Based on this preliminary analysis, the following are concluded:

1. There is a general warming trend in the western Canadian Arctic, of at least 0.04°C/year.
2. Six of ten roads in the study with statistically-significant trends in operational season length had a *lengthening* of the operational season.

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[2] personal communication, Greg Cousineau, Government of NWT, Yellowknife. 2009 07 02

3. Four of eight roads in the study with statistically-significant trends in the operational season start date had progressively *earlier* start dates.
4. Three of five roads in the study with statistically-significant trends in the operational season end date had progressively *later* closing dates.
5. Progressively drier operating seasons may result in lengthening operating seasons.
6. Progressively drier early winters (December, January, February) may result in progressively earlier operational season start dates.
7. Operational techniques can be applied to lengthen operational seasons. These include:
    a. flooding winter roads
    b. plowing snow from winter road road allowances early in the season
    c. restricting hauling to night hours towards the end of the operational season

A constant challenge during the preparation of this paper was the decision of which climatic parameters to use. There may be others that are more applicable than those we have selected. Further analysis is called for.

It is recommended that each of the roads covered in the paper be studied in greater depth. Specific operation of the roads should be examined, and site-specific weather and climatic data collected and analyzed, in order to better delineate how Canadian Arctic practitioners are successfully adapting to climate change.

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APPENDIX

Table A1: Statistically significant results

Type of road	Road section: 1984-2008 except as noted	Associated climate station	Annual conditions		During Dec, Jan, Feb period		During Mar, Apr, May period		During operating season		30 day period prior to opening date		30 day period prior to closing date		Change in op season *length* (days / year)	Change in *opening date* (days / year)	Change in *closing date* (days / year)
			ΔTemp °C/yr	ΔPrecip mm/yr	ΔTemp °C/yr	ΔPrecip mm/yr	ΔTemp °C/yr	ΔPrecip mm/yr	ΔTemp °C/yr	ΔPrecip mm/yr	ΔTemp °C/yr	ΔPrecip mm/yr	ΔTemp °C/yr	ΔPrecip mm/yr			
Ice Bridges	Mackenzie River Crossing Fort Providence	Fort Simpson	0.05					1.19									
	Liard River Crossing at Fort Simpson	Fort Simpson	0.05					1.19									
	Mackenzie River Crossing at Tsiighetchic	Inuvik	0.08		0.16				0.11		0.25						
	Peel River Crossing	Inuvik	0.08		0.16				0.11		0.28						
	Mackenzie River Crossing at Camsell Bend	Fort Simpson	0.05					1.19					0.21		0.80		0.73
Winter Roads	Ft. Simpson - Wrigley (Highway #1) (1984-1994)	Fort Simpson				-3.65				-3.89			1.32		4.44	-2.25	
	Wrigley - Tulita (Highway #1)	Norman Wells				-1.07											
	Tulita - Norman Wells (Highway #1)	Norman Wells				-1.07						-0.45					
	Norman Wells - Ft. Good Hope (Highway #1) (1989-2008)	Norman Wells				-1.70	-0.15				0.31	-0.66			2.06	-1.49	
	Tibbitt-Contwoyto Winter Road (1989-2008)	Yellowknife			0.19												
Community Access Roads	Deline Access	Norman Wells				-1.07						-0.57	-0.20		-0.66	0.30	
	Trout Lake Access	Fort Simpson	0.05					1.19					-0.20				-0.65
	Nahanni Butte Access	Fort Simpson	0.05					1.19					-0.19		0.61	-0.82	-0.52
	Wha Ti Access	Yellowknife			0.13				0.21	-1.19			0.27		-0.87	1.55	0.72
	Gameti Access	Yellowknife			0.13				0.25	-0.96			0.25		-1.14	2.00	0.72
	Dettah Access	Yellowknife			0.13										-0.74	0.89	
	Tuktoyaktuk Access	Inuvik	0.08		0.16						0.23				0.60	-1.00	
	Aklavik Access	Inuvik	0.08		0.16						0.20						
	Colville Lake Access (2001-2008)	Norman Wells													7.83		
															6/10 +ve	4/8 -ve	3/5 +ve