IOP Publishing Environmental Research Letters
Environ. Res. Lett. **7** (2012) 014028 (8pp) doi:10.1088/1748-9326/7/1/014028

Observed decreases in the Canadian outdoor skating season due to recent winter warming

Nikolay N Damyanov[1,3], H Damon Matthews[2,3] and Lawrence A Mysak[1,3]

[1] Department of Atmospheric and Oceanic Sciences, McGill University, 805 Sherbrooke Street West, Montréal, QC H3A 2K6, Canada
[2] Department of Geography, Planning and Environment, Concordia University, 1455 de Maisonneuve Street, H 1255-26, Montréal, QC H3G 1M8, Canada
[3] Global Environmental and Climate Change Centre (GEC3), McGill University, 805 Sherbrooke Street West, Montréal, QC H3A 0B9, Canada

E-mail: dmatthew@alcor.concordia.ca

Received 17 November 2011
Accepted for publication 14 February 2012
Published 5 March 2012
Online at stacks.iop.org/ERL/7/014028

Abstract
Global warming has the potential to negatively affect one of Canada's primary sources of winter recreation: hockey and ice skating on outdoor rinks. Observed changes in winter temperatures in Canada suggest changes in the meteorological conditions required to support the creation and maintenance of outdoor skating rinks; while there have been observed increases in the ice-free period of several natural water bodies, there has been no study of potential trends in the duration of the season supporting the construction of outdoor skating rinks. Here we show that the outdoor skating season (OSS) in Canada has significantly shortened in many regions of the country as a result of changing climate conditions. We first established a meteorological criterion for the beginning, and a proxy for the length of the OSS. We extracted this information from daily maximum temperature observations from 1951 to 2005, and tested it for significant changes over time due to global warming as well as due to changes in patterns of large-scale natural climate variability. We found that many locations have seen a statistically significant decrease in the OSS length, particularly in Southwest and Central Canada. This suggests that future global warming has the potential to significantly compromise the viability of outdoor skating in Canada.

Keywords: global warming, impacts, outdoor hockey, skating rinks

1. Introduction

Outdoor hockey and ice skating are important recreational activities in many northern countries, and especially in Canada, where it is deeply ingrained in the culture, economy and well being of people. Since 1950, winter temperatures in Canada have increased by more than 2.5 °C, more than three times the globally averaged warming attributed to anthropogenic global warming (Environment Canada 2011, Hansen *et al* 2006). In addition to the trend towards overall milder Canadian winters, studies indicate that the frequency, duration and intensity of winter cold spells have decreased in most of Canada since the 1950s (Shabbar and Bonsal 2003). Also, the relative severity of winter temperatures, as measured by changes in minimum and maximum temperatures, has decreased in all of Canada except the Northeast (Zhang *et al* 2010). Given the requirement of cold winter temperatures for the initiation and maintenance of outdoor skating rinks,

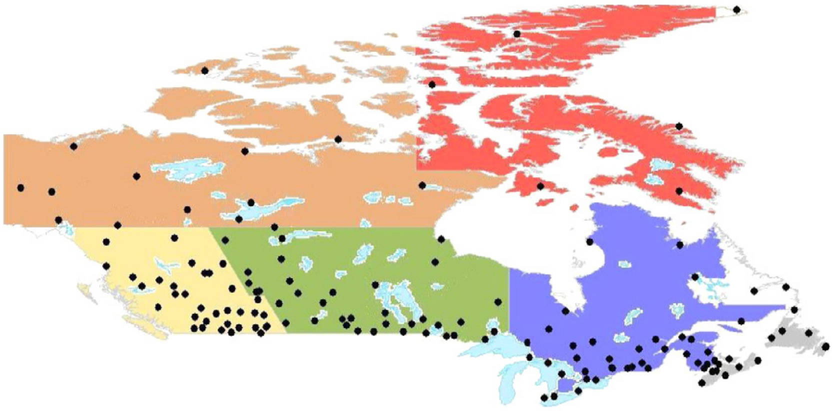

Figure 1. Locations of the 142 meteorological stations and six climatic regions used in this study. Western regions include Southwest (yellow), Prairies (green) and Northwest (brown). Eastern regions are Central (blue), Atlantic Canada (grey) and Northeast (red). Parts of Newfoundland and Labrador and Nunavut have been excluded from consideration due to incompatibility with other regions and are thus not coloured.

we expect that the observed winter warming, and particularly changing daily maximum temperatures, have the potential to have affected the length and quality of the outdoor skating season.

We are not aware of any previous analysis of the possibility of changes in the outdoor skating season in Canada or elsewhere. There have been studies on the historic changes of ice-on and ice-off dates of natural water bodies, which can provide some background to the current study; these include studies of changes in the opening and closing dates of the Tulita–Norman Wells ice road in the Northwest Territories (Knowland *et al* 2010), the effects of temperature changes on the ice-in dates of North American lakes (Williams *et al* 2004) and the past trends in lake and river ice cover in the northern hemisphere (Magnuson *et al* 2000). Most of the water bodies analyzed in these and other studies were found to have their annual ice-free period lengthened over the period for which they were studied. While these findings are of interest here, we expect that the conditions required to freeze natural water bodies will differ somewhat from those for skating rinks constructed on bare ground or snow.

Based on information solicited from officials responsible for maintaining public outdoor skating rinks in various Canadian cities (notably the Cities of Hampstead and Beaconsfield in Quebec, and City Rinks Toronto in Ontario), we have developed a meteorological criterion to mark the beginning of the outdoor skating season (OSS), and a proxy for its length. Using these definitions, have quantified observed changes in the meteorological conditions conducive to the creation and maintenance of outdoor skating rinks, using observations of daily maximum temperature changes at 142 meteorological stations covering six general climatic regions across Canada (figure 1). We have estimated historic trends in the OSS start date and length during 1951–2005, and tested the resulting time series for significant changes over time associated with human-induced climate warming. In addition, we have tested for an effect on the OSS of two patterns of natural climate variability: the Pacific North American (PNA) teleconnection pattern and the North Atlantic Oscillation (NAO).

2. Methods

2.1. Definition of the outdoor skating season

We define here the beginning of the OSS as the last day in a series of the first three consecutive fall/winter days with a maximum surface air temperature below −5 °C; this is based on the requirement of several consecutive cold days to lay the initial ice foundation of a rink (Cities of Hampstead and Beaconsfield, Quebec 2010). This definition was informed by personal communication with various ice rink officials at different Canadian cities, notably Hampstead and Beaconsfield on the Island of Montreal. The precise criterion used by city officials varied somewhat among individuals and cities, between maximum daily temperatures of −5 and −10 °C, and from 3 to 5 consecutive days (Cities of Hampstead and Beaconsfield, Quebec 2010). We selected the above criterion of three consecutive days where temperatures do not exceed −5 °C as being representative of the minimum requirements for initiation of an outdoor skating rink.

In contrast with the OSS start date, which has a well defined meteorological requirement, the OSS end date is not as easily measured due to difficulties in determining the exact timing of ice-breakup based solely on daily temperatures. For example, an established rink may be able to withstand several days of warm temperatures early in the season, or even intermittent rainy conditions, provided that there is a suitable base of established ice. By contrast, the same period of warm temperatures may mark the end of the rink later in the season when a higher sun angle causes a greater degree of melt due to solar absorption (City Rinks Toronto, Ontario 2010). Drawing on our conversations with city officials, we have derived here a proxy of the OSS length based on the number of suitable rink-flooding days between the start of the season and the beginning of March. The definition is based on the advice of rink officials that the number of viable ice-laying days is a strong determinant of the strength of the ice base of a rink, and its ability to withstand warming spring temperatures (Cities of Hampstead and Beaconsfield, Quebec

2010). Furthermore, as many cities stop maintaining ice rinks at the end of February, we have taken the number of ice-laying days prior to the beginning of March as a suitable proxy for the thickness and quality of an established ice rink, and therefore as a representative proxy for overall season length. Thus, in the analysis presented below, we have defined the proxy for OSS length as the total number of days with a maximum temperature below −5 °C after the OSS start date, and before the beginning of March.

2.2. Data

This study is based on the homogenized daily surface air temperature dataset developed by the Meteorological Service of Canada. The data have been corrected for non-climatic step variations such as those caused by station relocation, changes in instrumentation or nearby vegetation growth (Vincent *et al* 2002). The dataset consists of daily average, maximum and minimum surface air temperature data for 210 relatively evenly distributed Canadian weather stations, collected over roughly the past century. For the purpose of having a consistent timeframe across all stations, we have analysed here only the period 1951–2005. The dataset we have used excluded stations that became operational after 1950 (Turner and Gyakum 2010), and we have also decreased the total number of stations to 142 (figure 1) because of missing data or due to the lack of outdoor skating rinks in areas with mild climates such as southwest British Columbia. For the analysis presented here, we have used daily maximum temperatures to estimate the meteorological conditions suitable for outdoor rinks.

For the establishment of connections between the OSS and large-scale climate patterns, we have used PNA and NAO index data. The PNA dataset includes monthly values of the PNA index computed by the Joint Institute for the Study of the Atmosphere and Ocean (http://jisao.washington.edu/data/pna/) based on the formula provided by Wallace and Gutzler (1981). We have created annual three-month means of this index, using the October–November–December data. Similarly, we have used an October–November–December NAO index provided by the Climate Analysis Section of the National Center for Atmospheric Research (NCAR), based on the three-month seasonal computations of the NAO index by Hurrell (1995).

2.3. Statistical model

We began by calculating the OSS start dates and OSS lengths for each year at each station on the quality-checked dataset, and created time series of both OSS start dates and OSS lengths for each station. We used a linear regression model to test for significant changes in these variables with time, and in association with the NAO/PNA indices. The statistical model has the form

$$y = a + bx + cz \qquad (1)$$

where y is the time series of OSS start date or OSS length at a given station, a is the overall mean, x is the time in years from 1951 to 2005, and z is the climate pattern index. We ran the statistical model for both OSS start date and OSS length at each station, and tested for the significance of the regression coefficients b (year) and c (climate variability). We also verified that there is no collinearity between the two predictors in the model, with variance inflation factors for both year and climate pattern index very close to 1. For each station, we plotted the effects of year (figure 2) and climate variability (figure 4) on the calculated OSS start date and OSS length changes on a map of Canada. For stations west of the Great Lakes, we used the PNA index (the dominant mode of climate variability in these regions) in the regression model, while for stations to the east, we used the NAO index as representing the dominant mode of climate variability in Central and Eastern Canada.

2.4. Regional analysis

In addition to the analysis on the individual stations described above, we have also analysed the data grouped into six climatic regions. We calculated the regional trends by spatially averaging the annual OSS start dates and lengths from each station within each region. The boundaries of these six regions are based on well-established definitions of Canadian climate zones, geographical proximities and similarities between calculated trends in the OSS start dates and lengths. The regions are shown as the coloured areas in figure 1, and are named and characterized as follows:

- Southwest Canada (interior and eastern British Columbia, southwest Alberta);
- Prairies (eastern and northern Alberta, Saskatchewan, Manitoba, western Ontario);
- Northwest Canada (Yukon Territory, Northwest Territories, western Nunavut);
- Central Canada (southern and eastern Ontario, southern Québec, New Brunswick);
- Atlantic Canada (Nova Scotia, Prince Edward Island, southern Newfoundland);
- Northeast Canada (northern Québec, eastern Nunavut).

3. Results and discussion

The trends in the OSS start date and length for each station across Canada are shown in figure 2. For the calculated start date of the skating season, only a few of the individual stations show a statistically significant trend over time towards later start dates (red circles with a cross indicating the significance). However, there is a certain amount of spatial coherence to the results, with many stations in Southwest Canada, as well an in Central and Eastern Canada, indicating a trend towards later season start dates (figure 2(a)).

By contrast, our proxy for OSS length shows that many individual locations have seen a statistically significant decrease in the number of viable ice-flooding days, suggesting a significant shortening of the length of the OSS over much of the country between 1951 and 2005 (figure 2(b)). The trends towards shorter OSS length are the largest (and most

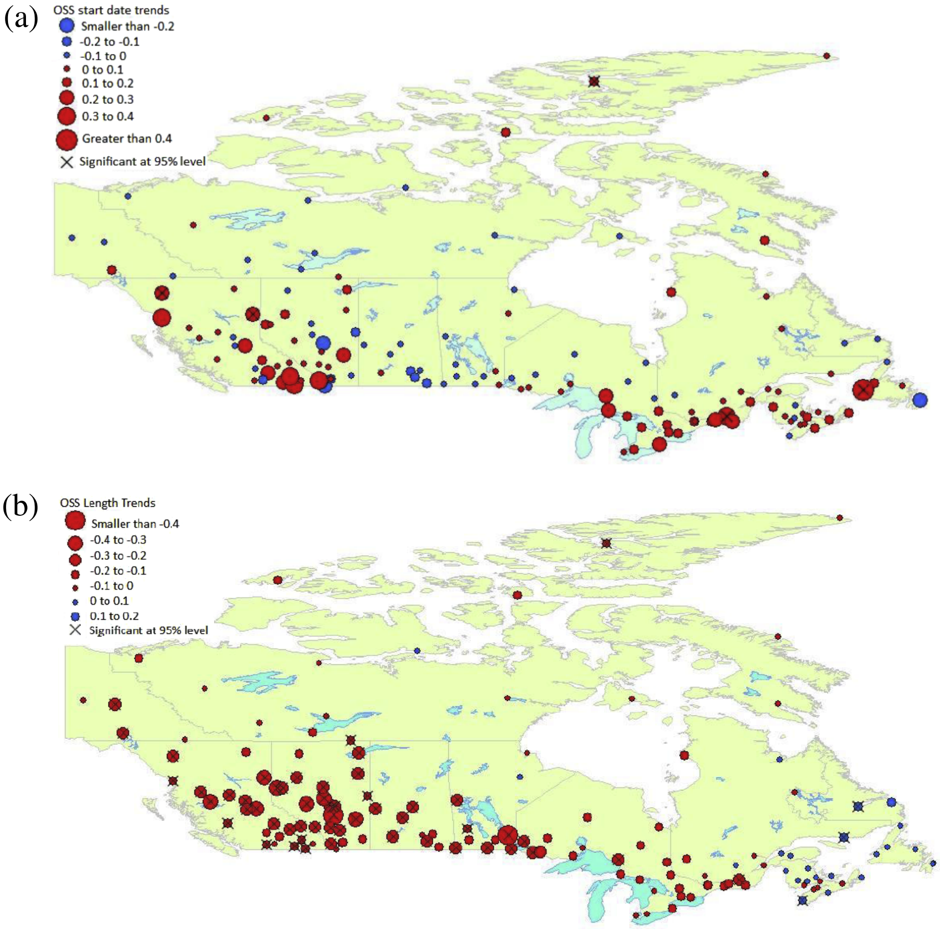

Figure 2. OSS start date (a) and OSS length (b) trends for individual stations, in days yr^{-1}. Filled circles represent the values of b (the change over time) computed from equation (1) for each station. Red colouring indicates changes that are consistent with warming temperatures (later OSS start date or shorter OSS length over time), while blue colouring indicates changes associated with cooling temperatures (earlier OSS start date or longer OSS length). The sizes of the circles correspond to the magnitude of b: the smallest circles correspond to absolute values between 0 and 0.1 days yr^{-1} with each incremental increase in size corresponding to an increase in absolute value of 0.1 days yr^{-1}; the largest circles thus represent absolute values greater than 0.4 days yr^{-1}. Crossed circles indicate trends that are significant at the 95% level.

significant) in the Prairies and Southwest Canada. As in the case of the OSS start date, there is also a coherent spatial trend towards shorter OSS throughout Ontario and Southern Quebec, although there are only a few statistically significant individual stations in these regions. The only region of the country that does not show a shortening OSS is Atlantic Canada, which has a mix of stations with increasing and decreasing trends, as well as a few stations showing a statistically significant increase in the number of viable ice-flooding days.

The average OSS start date and length trends over each of the six regions in figure 1 are shown in figure 3. The trends at a regional level mirror those for individual stations: the Southwest and Prairie regions as a whole show a significant decrease in OSS length (Southwest: $p = 0.001$; Prairie: $p = 0.009$). In addition, the Northwest region shows a near-significant decrease in length ($p = 0.058$). Overall, five of the six regions as a whole show a trend towards a shorter OSS season over 1951–2005, and four of the six regions show a trend towards a later start date. At this regional level, only one of the OSS start date regional trends is close to statistically significant (the Northeast: $p = 0.076$), though we caution that this result is based on only a handful of individual stations.

These changes are supported by general analyses of winter climate change in Canada. For example, the Southwest and parts of the Prairies showed the most statistically significant OSS length decreases, though with no significant trend in the OSS start date. This is consistent with the findings of Zhang *et al* (2010), who showed that spring maximum temperatures in the southwest part of Canada have dramatically increased during 1950–98; in contrast, maximum temperatures in the fall for the same period over Alberta, Saskatchewan and Manitoba decreased (though this latter trend is not statistically significant). As another example, Atlantic Canada was the only region in this study where there was the suggestion of (though no significant overall trend towards) a lengthened OSS over this time. This also consistent with previous work which has shown that Eastern Canada is the only Canadian region to show a cooling temperature trend over the past half-century (Zhang *et al* 2010).

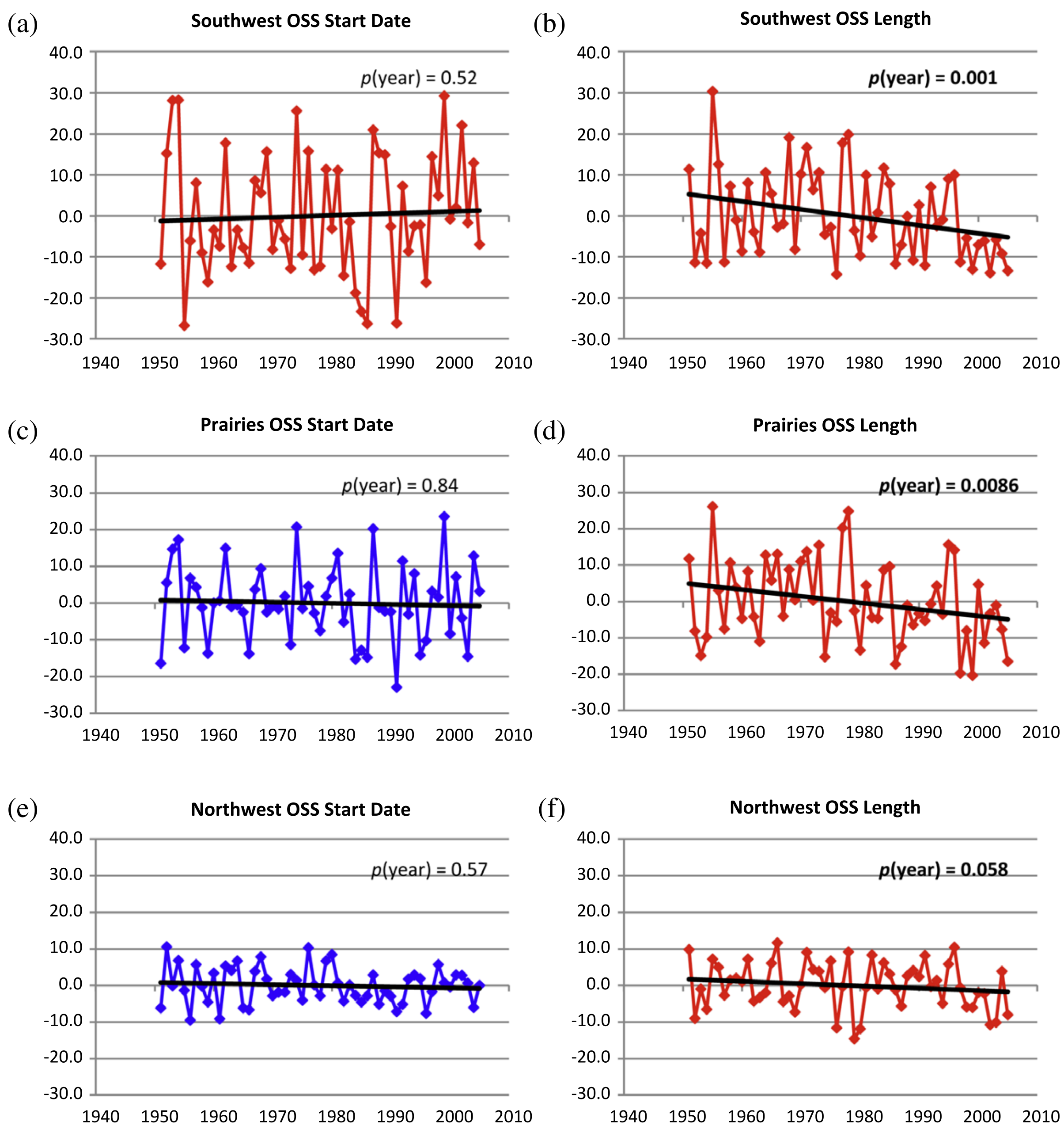

Figure 3. Time series of the OSS start date (left) and OSS length (right) for the data averaged over each of the three western ((a)–(f)) and eastern ((g)–(l)) regions defined in this study. The data are plotted here as anomalies (in days) with respect to the 1951–2005 average for each region. The best fit lines on each graph show the direction of the linear trend with time, with the colour of the time series indicating the nature of the overall trend (blue representing an earlier start date or longer season with time, red representing a later start date or shorter season). We have also included the *p*-values indicating the significance of the slope of the trendline, calculated using the regression model shown in equation (1).

The spatial patterns of changes to the start date and length of the skating season also suggest a relationship with average maximum temperatures, whereby locations with generally warmer maximum temperatures (i.e. Southwest Canada, Southern Ontario and Quebec, and the Atlantic provinces) are more likely to show a trend towards a later season opening or a shorter season. This is consistent with the results of a recent analysis of changes in the number of snowfall days relative to overall precipitation days in Switzerland, which showed that lower altitude regions with higher average temperatures showed a stronger trend towards decreasing snowfall days (Serquet *et al* 2011). While there is not a consistent relationship with average maximum temperature in our data (e.g. changes in the Atlantic region were much smaller than changes that occurred at similar average temperatures in the Southwest region), there is some evidence that the skating season in areas of milder winter climates in Canada may be more sensitive to climate warming than areas with generally colder winter temperatures.

Figure 4 shows the effect of natural climate variability on the time series of OSS start date and OSS length. In this analysis, we have used indices for the dominant modes

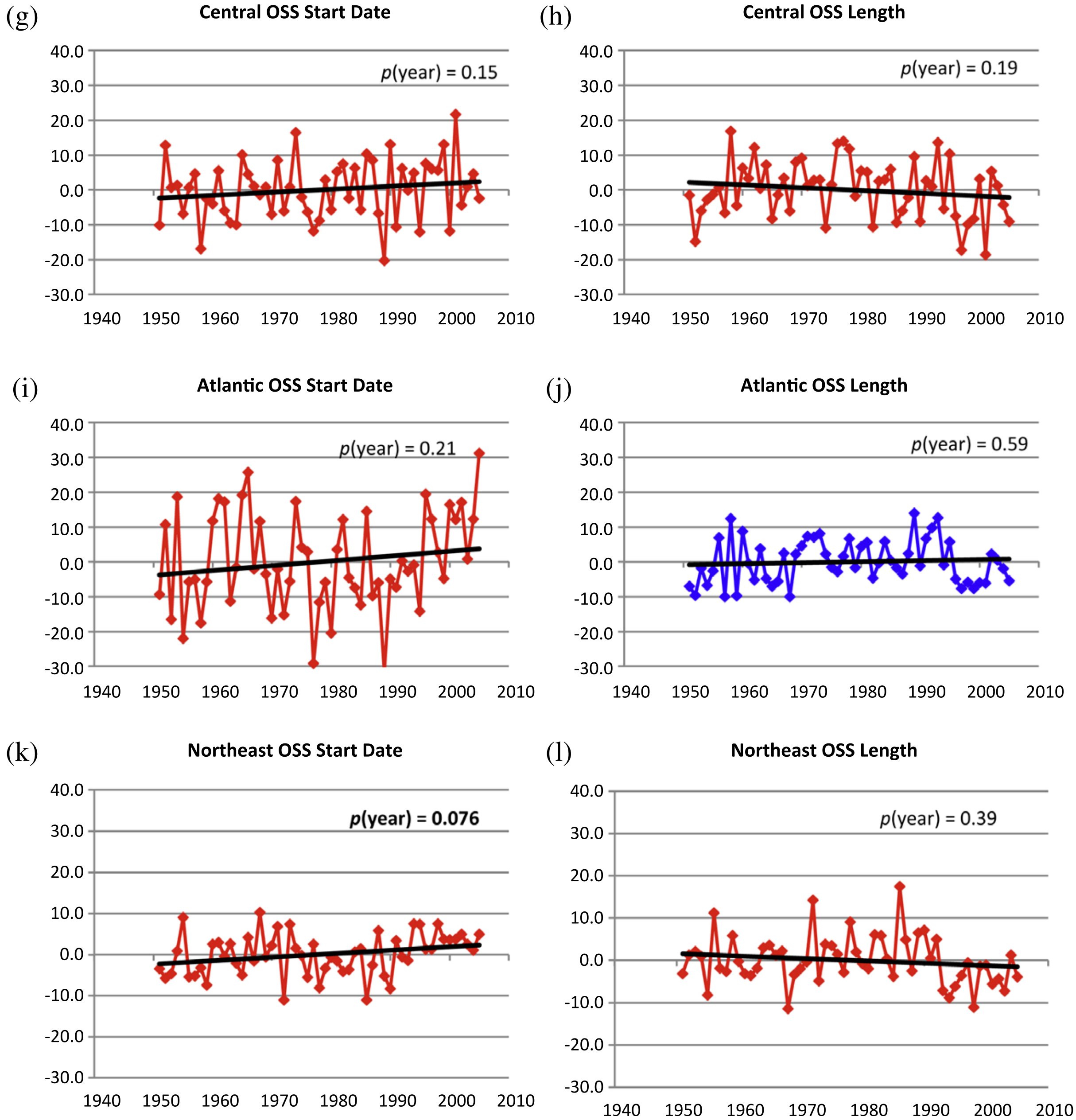

Figure 3. (Continued.)

of climate variability affecting Canada: the Pacific North American teleconnection pattern (PNA) index for western stations, and the North Atlantic Oscillation (NOA) index for eastern stations (see section 2). Many of the individual station data series showed a statistically significant response to climate variability. In general, the effect of climate variability explained a larger portion of the total variance in the data, given its effect on the interannual variability in the data series; by contrast, though the long-term trend represented a smaller component of the total variance, there were nevertheless many stations which showed significant trends over time, as reported above. With respect to the effect of climate variability, in Southwest Canada and the Prairies, years with positive values of the PNA index resulted in later OSS start dates, whereas in Eastern and Central Canada, positive NAO index years led to earlier OSS start dates (figure 4(a)). For the OSS length, over almost all of Southern Canada, positive NAO and PNA years resulted in shorter OSS lengths (figure 4(b)), with a high degree of statistical significance associated with the effect of the PNA index on the OSS length in both the Prairie and Southwest regions. In Central Canada, the OSS start dates and lengths appear to have been less influenced by the two climate patterns, although we found some significant results with respect to the OSS length in Western Ontario and the OSS start date in southern Ontario and Quebec.

The results shown in figure 4 are physically consistent with the general effects of these modes of variability on Canadian climate patterns. Positive PNA index values typically lead to warmer conditions in western Canada (Van Loon and Madden 1981) due to the combination of a deep Aleutian low (Szeto *et al* 2007) and a strong Alberta

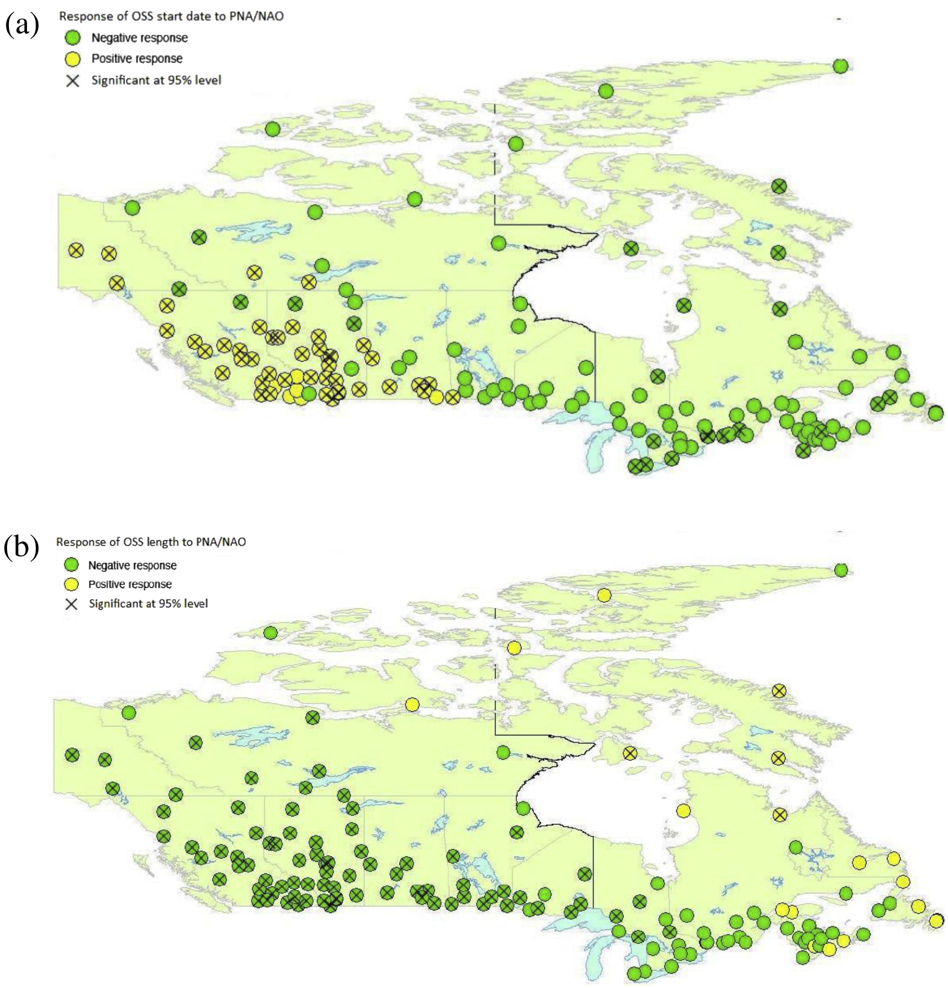

Figure 4. Impact of the PNA or NAO on OSS start date (a) and OSS length (b). Filled circles represent the value of c computed from equation (1) for each station. Green colouring corresponds to a negative response to climate variability (earlier OSS start date or OSS shortening during positive PNA/NAO phases), while yellow colouring corresponds to a positive response (later OSS start date or OSS lengthening during positive PNA/NAO phases). Crossed circles indicate significant values at the 95% level. For stations to the west of the solid black line, we used PNA index data in the statistical model, whereas for those to the east we used NAO index data.

high (Wallace and Gutzler 1981) funnelling in warmer air from the south or southwest. This pattern of warming resulted in a later OSS start date and a shorter OSS length in this region. By contrast, the NAO has its strongest climate effect in the Northeast: during a positive NAO phase, the deep Icelandic low channels cold Arctic air into Northeast Canada (Hurrell 1995), which results in earlier OSS start dates and longer durations of the OSS.

4. Conclusions

In this letter, we have provided evidence that the observed warming of winter temperatures in Canada has had a deleterious effect on the outdoor skating season. Many locations across the country have seen significant decreases in the length of the OSS, as measured by the number of cold winter days conducive to the creation of rink ice. This is particularly true across the Prairies, and in Southwest Canada, which showed the largest (and most statistically significant) decreases in the calculated OSS length between 1951 and 2005. In addition, some locations have also experienced a later start date of the OSS, as measured by the requirement for several consecutive cold days in early winter to lay the initial ice foundation for a rink. While there are fewer individual stations showing a significant change in the OSS start date, there is a spatially coherent pattern suggesting generally later start dates in Southwest Canada, and across most of Central and Eastern Canada. In addition to the temporal trends, we have also identified high statistical significance associated with the internal climate variability (as measured by the PNA and NAO indices) on regional OSS start dates and lengths. In particular, many of the effects on the OSS start date/length in the Southwest, Prairies, Northwest and Northeast are significant at the 99% level, indicating a strong relationship between changes in the OSS from year to year and the state of the PNA/NAO.

This study has focused on observed changes in the Canadian outdoor skating season. Though we have not projected these changes into the future, we would expect all regions of Canada to see a decreased viability of outdoor skating under continued winter climate warming, as suggested by model projections of increasing winter temperatures in Canada over the coming decades (Christensen *et al* 2007). In the most extreme case of the Southwest Canada region, a simple linear extrapolation of the OSS length trend from the last 30 yr of our record into the future shows that the number of viable rink-flooding days could reach zero by mid-century. In the absence of efforts to maintain artificially cooled outdoor rinks, this result implies a foreseeable end to outdoor skating in this region within the next few decades. While other Canadian regions have not seen such dramatic decreases, we nevertheless expect outdoor skating throughout Canada to be significantly negatively affected in the coming decades by continued anthropogenic global warming.

The ability to skate and play hockey outdoors is a critical component of Canadian identity and culture. Wayne Gretzky learned to skate on a backyard skating rink; our results imply that such opportunities may not available to future generations of Canadian children.

Acknowledgments

This study was made possible by the NSERC Discovery Grants awarded to HDM and LAM, as well as a Global Environmental and Climate Change Centre Scholarship awarded to NND. We would like to thank all the ice rink officials that we contacted at the different Canadian cities; without their guidance on outdoor skating rink maintenance practices it would have not been possible to establish an appropriate meteorological criterion for the OSS start date and length. We also wish to thank Navin Ramankutty for suggesting the statistical model used in this study and Tanya Graham for her contribution to a pilot study of winter temperature trends in Montreal, as well as Mike Hudema, Shawn Marshall and Sarah Turner for conversations that led to the conceptualization of this project.

References

Christensen J H *et al* 2007 Regional climate projections *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* ed S Solomon, D Qin, M Manning, Z Chen, M Marquis, K B Averyt, M Tignor and H L Miller (Cambridge: Cambridge University Press)

Cities of Hampstead and Beaconsfield, Quebec 2010 Personal communication

City Rinks Toronto, Ontario 2010 Personal communication

Environment Canada 2011 *Climate Trends and Variations Bulletin: Winter Summary 2010/2011* (www.ec.gc.ca/adsc-cmda/default.asp?lang=En&n=8C03D32A-1, accessed 3 November 2011)

Hansen J, Sato M, Ruedy R, Lo K, Lea D W and Medina-Elizade M 2006 Global temperature change *Proc. Natl Acad. Sci. USA* **103** 14288–93

Hurrell J W 1995 Decadal trends in the North Atlantic oscillation: regional temperatures and precipitation *Science* **269** 676–9

Knowland K E, Gyakum J R and Lin C A 2010 A study of the meteorological conditions associated with anomalously early and late openings of a Northwest Territories winter road *Arctic* **63** 227–39

Magnuson J H *et al* 2000 Historical trends in lake and river ice cover in the northern hemisphere *Science* **289** 1743–6

Serquet G, Marty C, Dulex J-P and Rebetez M 2011 Seasonal trends and temperature dependence of the snowfall/precipitation-day ratio in Switzerland *Geophys. Res. Lett.* **38** L07703

Shabbar A and Bonsal B 2003 An assessment of changes in winter cold and warm spells over Canada *Natural Hazards* **29** 173–88

Szeto K K, Stewart R E, Yau M K and Gyakum J R 2007 Northern tales: a synthesis of MAGS atmospheric and hydrometeorological research *Bull. Am. Meteorol. Soc.* **88** 1411–25

Turner J K and Gyakum J R 2010 Trends in Canadian surface temperature variability in the context of climate change *Atmos.-Ocean* **48** 147–62

Van Loon H and Madden R A 1981 The southern oscillation. Part I: global associations with pressure and temperature in northern winter *Mon. Weather Rev.* **109** 1150–62

Vincent L A, Zhang X, Bonsal B R and Hogg W D 2002 Homogenization of daily temperatures over Canada *J. Clim.* **15** 1322–34

Wallace J M and Gutzler D S 1981 Teleconnections in the geopotential height field during the northern hemisphere winter *Mon. Weather Rev.* **109** 784–812

Williams S G, Layman K L and Stefan H G 2004 Dependence of lake ice covers on climatic, geographic and bathymetric variables *Cold Reg. Sci. Technol.* **40** 145–64

Zhang X, Vincent L A, Hogg W D and Niitsoo A 2010 Temperature and precipitation trends in Canada during the 20th century *Atmos.-Ocean* **38** 395–429