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Assessing potential winter weather response to climate change and implications for tourism in the U.S. Great Lakes and Midwest

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ABSTRACT

Study Region: Eight U.S. states bordering the North American Laurentian Great Lakes.
Study Focus: Variable Infiltration Capacity (VIC) model simulations, based on data from an ensemble of atmospheric-ocean general circulation models (AOGCMs) used for the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (AR5), were used to quantify potential climate change impacts on winter weather and hydrology in the study region and understand implications for its tourism sector.
New Hydrologic Insights for the Region: By the 2080s, climate change could result in winters that are shorter by over a month, reductions of over a month in days with snow depths required for many kinds of winter recreation, declines in average holiday snow depths of 50 percent or more, and reductions in the percent area of the study region that would be considered viable for winter tourism from about 22 percent to 0.3 percent. Days with temperatures suitable for artificial snowmaking decline to less than a month annually, making it potentially less feasible as an adaptation strategy. All of the region's current ski resorts are operating in areas that will become non-viable for winter tourism businesses under a high emissions scenario. Given the economic importance of the winter tourism industry in the study region, businesses and communities should consider climate change and potential adaptation strategies in their future planning and overall decision-making.

1. Introduction

Cold season hydrologic processes play an important role in shaping the physical behavior of North America's Laurentian Great Lakes. Low air temperatures have a significant impact on the formation and break-up of lake ice and, subsequently, lake dynamics in warmer months of the year (Mishra et al., 2011b). Frozen soils and seasonal freeze-thaw patterns affect infiltration, soil properties, and overall land energy balances (Cherkauer and Lettenmaier, 1999; Lemke et al., 2007). Seasonal snowpack plays an important role in surface energy and water budgets, soil temperatures, surface albedo, and evapotranspiration (Cohen and Rind, 1991; Dyer and Mote, 2006; Karl et al., 1993; Mortsch et al., 2000; Rodell and Houser, 2004; Sinha and Cherkauer, 2008). Snowpack and snowmelt runoff also affect seasonal streamflow behavior, including peak streamflow during the spring, and the development and replenishment of lakes and wetlands in the region (Mishra and Cherkauer, 2011).

Cold weather phenomena are also important to many economic sectors in the Great Lakes, especially tourism. Winter tourism is

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highly dependent on temperature, snow cover, snowfall, length of the snow season, and the presence or absence of snow during winter holidays. In recent years, desirable conditions for winter tourism are perceived to have become less reliable by Great Lakes tourism professionals (Chin, 2016). Previous research has also shown that tourism business owners are already adapting to changing conditions, for example, by offering snowshoes in lieu of cross-country skiing and adopting snowmaking to account for reductions in snowfall and snowpack (Burakowski and Magnusson, 2012; Chin, 2016; Scott et al., 2008).

Quantitative hydrologic analyses support tourism stakeholders' perceptions that winter weather has become less suitable for winter recreation in recent decades. Average winter and spring temperatures have both been increasing in the Great Lakes region, while seasonally frozen ground has been decreasing over the last century, especially in the spring (Mortsch et al., 2000; Sinha and Cherkauer, 2008). Similarly, the last spring freeze has shifted earlier in the year, leading to shorter winter seasons (Pryor, 2013; Pryor et al., 2014). The Great Lakes has also been experiencing shifts in precipitation from snow to rain, earlier annual snowmelt, and reductions in spring snow cover (Brown, 2000; Brown and Goodison, 1996; Dyer and Mote, 2006; Hodgkins et al., 2007).

Several studies have been conducted to determine how winter weather has changed in recent decades. Brown and Braaten (1998) examined changes in monthly snow depth and snow cover duration in Canada and found that both had decreased from 1946 to 1995, especially in March. Mote et al. (2005) found in their study evidence of declines in winter snowpack for western North America from 1916–2002. Durand et al. (2009) looked at daily snow depth, the number of days with snow on the ground, the maximum continuous time period with snow coverage, and minimum 100-day snow depths in the French Alps from the late 1950 s to early 2000s and found a decreasing trend in snow coverage at low elevations, though this was not the case for medium to high elevations. Similarly, Hendrikx et al. (2012) investigated potential changes in mean peak snow water equivalent (SWE), snow duration, fraction of precipitation as snow, and average maximum SWE in New Zealand using output from atmospheric-ocean general circulation models (AOGCMs) and found decreases in snow coverage at low elevations and, in a few cases, marginal increases at very high elevations. In addition, the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (AR5) states that both cold temperature extremes and the amount of snow and ice have been decreasing globally since 1950 and are likely to continue to do so with future climate change (IPCC, 2014; Mote et al., 2005).

Future climate change projections for the Great Lakes region support the conclusion that changes to its winter weather and hydrology will continue and intensify (Byun and Hamlet, 2018; Winkler et al., 2014). Temperatures are expected to continue to increase, leading to reductions in cold spells and extremely cold days and further shortening winters (Hayhoe and Wubbles, 2007; Wuebbles et al., 2010). Increasing temperatures could also affect river and lake ice thickness and break-up (Bates et al., 2008). Karl et al. (1993) predict that decreases in snow cover could come in future decades as a result of temperature increases, despite some past findings that total annual snowfall will remain relatively steady (Hayhoe and Wuebbles, 2007). The redistribution of precipitation as rain versus snow could lead to higher runoff and increased flooding in the region (Byun et al., in review.; Hayhoe et al., 2010; Karl et al., 1993; Mortsch et al., 2000; Rosenzweig et al., 2002).

In terms of how these changes will affect winter tourism specifically, Scott et al. (2006, 2003), Scott and McBoyle (2007) used a snow model coupled with the Variable Infiltration Capacity (VIC) model to look at changes in snow depths appropriate for skiing and snowmobiling in the northeastern United States and Canada using climate projections from three different AOGCMs for two emissions scenarios. They found the potential for significant losses for the ski and snowmobiling industries due to declines in seasonal snowpack, though artificial snowmaking reduced some of this vulnerability. Studies by Durand et al. (2009) and Hendrikx et al. (2012) also indicate the potential for economic losses, specifically for downhill ski resorts, due to decreases in snow cover duration and the amount of snow cover at elevations where these businesses typically operate. Wobus et al. (2017) recently quantified potential losses for winter recreation due to climate change as being in the hundreds of millions of dollars across the United States.

Overall, these findings suggest that, without adaptation, winter-based tourism businesses could face significant losses or even failure due to future climate change impacts on Great Lakes winter weather and hydrology. While artificial snowmaking might mitigate some decreases in snow reliability, it is a strategy that is very resource intensive, both financially and in terms of water use (Rixen et al., 2011; Steiger and Mayer, 2008). In addition, research indicates that tourists' acceptance of artificial snowmaking is equivocal (Pütz et al., 2011). Technological advances will also likely be needed for snowmaking to be effective in the future, due to current limitations on temperatures for snowmaking (usually below -2 °C) (Wobus et al., 2017). Subsequently, alternative strategies need to also be considered in discussions about climate change preparedness. These findings also support the argument that winter tourism businesses need to be proactively preparing for potential changes in future cold and snow conditions in a way that takes into account a number of competing interests. Regional scale analyses of future climate projections related to winter weather can assist with these efforts.

This work builds on existing analyses by considering how climate change could impact winter weather and hydrology important to tourism for the U.S. portion of the North American Laurentian Great Lakes region. Statistically-downscaled climatic data from AOGCMs, which constitute IPCC AR5, have been used to run VIC model simulations of snow processes for this analysis. The overall objective of this study is to produce detailed information about potential climate change impacts on winter weather and hydrologic response in the Great Lakes that is directly relevant to winter recreation and tourism and that can be used to help tourism managers think about climate change and adaptation strategies for the future. In summary, the following research questions are being considered:

1 How will climate change affect winter conditions in the Great Lakes through the end of the century?
2 How could changes in winter processes affect winter recreation and tourism in the region?