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Entitled
Exploring the Potential Impacts of Climate Change on North America's Laurentian Great Lakes Tourism Sector

For the degree of Doctor of Philosophy

Is approved by the final examining committee:

Keith A. Cherkauer
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Approved by Major Professor(s): Keith A. Cherkauer

Approved by: Bernard A. Engel, Linda S. Lee 10/11/2016

Head of the Departmental Graduate Program Date

EXPLORING THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON NORTH AMERICA'S LAURENTIAN GREAT LAKES TOURISM SECTOR

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Natalie Chin

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

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Purdue University

West Lafayette, Indiana

For my parents and sisters.

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ABSTRACT

Chin, Natalie Ph.D., Purdue University, December 2016. Exploring the Potential Impacts of Climate Change on North America's Laurentian Great Lakes Tourism Sector. Major Professor: Keith A. Cherkauer.

Climate change is one of the major challenges facing the global hospitality and tourism sector in the coming century and, given the important role that weather and climate play in all aspects of the tourism experience, tourism businesses owners need to start thinking about and enacting climate change adaptation strategies now. This work has utilized a combination of social science and physical science methods to (1) understand how the Great Lakes tourism sector could be impacted by climate change and (2) provide some insights into how researchers can help business owners prepare for these potential impacts. Overall, the results of this work illustrate the challenges that tourism managers face in terms of adapting to climate change despite their high awareness of the importance of weather and climate to their businesses; however, creative methods of communicating climate change science, such as through the use of data visualization techniques and scenario planning, could help overcome some of these barriers. In addition, the results of the analysis of atmospheric-ocean general circulation models (AOGCMs) and Variable Infiltration Capacity (VIC) model simulations show that climate change could lead to significant changes in winter weather and extreme weather in the Great Lakes region and, subsequently, impact the region's tourism sector. Future research can build on these findings by continuing to explore the best means of quantifying climate change impacts for the tourism sector, evaluate the best way of translating those findings into actionable science for tourism business owners, and expand the dialogue around weather preparedness and long-term sector sustainability.

1. INTRODUCTION

1.1 Problem Statement

Climate change is one of the most significant problems facing the global community in the coming century. The hospitality and tourism industry, which contributed over $7 trillion (USD) to the world economy and nearly $1.5 billion to the U.S. economy in 2015, is an economic sector that could be especially impacted by climate change [1, 2]. Climate and weather affect all aspects of a tourist's travel experience, from trip conception to trip completion (Figure 1.1).

Fig. 1.1. Aspects of a Tourist's Travel Experience Impacted by Weather and Climate

When it comes to trip conception, a destination's weather or climate, both actual and perceived, is often an important component of a tourist's decision to travel to that destination (see, for example, [3–6]. When it comes to travel to a destination, poor or extreme weather can disrupt travel plans or even lead to trip cancellation [7, 8]. During the actual travel experience, weather affects a tourist's ability to engage in different activities and experiences [9]. Poor or extreme weather can also lead tourists to cut their travel short or make other changes to their travel plans [7]. Finally, upon trip completion, a tourist's satisfaction with his or her travel experience is affected by the weather that he or she experienced during that trip, both directly and indirectly [10–12]. If the experience was particularly poor, a tourist could choose not to travel to that destination again in the future.

On the business side, tourism managers have to take into account all of the ways that tourists' behavior can change as a result of weather and climate. In addition, weather and climate affect many other aspects of a business, including employees, general operations and practices, and infrastructure. Extreme weather events, especially, can have devastating impacts on tourism businesses [13,14]. Recent findings in the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (AR5), as summarized by Scott et al. [15], suggest that "all tourism destinations will need to adapt to climate change." In general, existing research suggests that tourism managers are highly aware of the importance of climate and weather to their businesses and are often willing to respond to poor conditions in the short-term, but responses in terms of climate change have been limited and primarily reactive to experiences with severe weather [16].

Understanding how business owners in the hospitality and tourism sector perceive climate change, what responses, if any, they are using to mitigate these threats and what barriers they face in terms of enacting these strategies are key to helping them prepare for the future. In addition, producing actionable climate change science for tourism managers could help these individuals effectively strategize for the future. Part of creating actionable science includes exploring changes in climate that are most important to tourism businesses at an appropriate spatial and temporal scale, which is also a guiding factor for this research. In this dissertation, potential changes in winter weather and extreme weather have been analyzed at a regional scale because these are aspects of the climate that tourism managers have said are important and already perceived to be changing.

1.2 Hypotheses and Research Questions

The work presented in this dissertation aims to address two primary objectives: (1) to explore how climate change could impact the hospitality and tourism sector in North America's Laurentian Great Lakes region and (2) to provide additional insights into how researchers can help tourism stakeholders in key destination communities prepare for climate change. In order to accomplish these tasks, four main hypotheses and sets of research questions have been addressed through this research:

- Hypothesis 1a: Tourism managers are highly aware of climate and weather.
- Hypothesis 1b: Tourism managers face barriers to climate change adaptation other than general awareness of climate and weather.

    1. How do tourism businesses perceive that they are impacted by climate and weather?
    2. How do tourism businesses perceive that they could be impacted by climate change?
    3. How are tourism businesses preparing for future weather and climate?
    4. What are barriers to climate change adaptation?

- Hypothesis 2: Producing actionable climate change science can help overcome some of the barriers to communication with tourism managers about climate change.

    1. What are tourism managers' beliefs when it comes to climate change?
    2. What useful information are tourism managers currently getting about climate change?
    3. How can data visualization techniques be used to develop useful climate change scenarios for stakeholders in the tourism sector?

- Hypothesis 3a: Climate change will have significant impacts on winter weather in the Great Lakes.

- Hypothesis 3b: Climate change impacts on winter weather in the Great Lakes will have major implications for the region's winter tourism sector.

    1. How will climate change affect winter weather and winter tourism businesses in the Great Lakes through the end of the century?
    2. How will climate change impacts on winter weather vary spatially and temporally?
    3. What insights can be gained by using both climate model simulations and hydrologic model simulations to simulate winter processes important to winter recreation and tourism?

- Hypothesis 4a: Climate change will have significant impacts on extreme weather events in the Great Lakes.

- Hypothesis 4b: Changes in the Great Lakes region in terms of extreme weather events will have major impacts on its hospitality and tourism sector.

    1. How will climate change affect the frequency, duration, and severity of extreme precipitation and temperature events in the Great Lakes through the end of the century?
    2. How will climate change impacts on extreme weather events vary spatially and temporally across the Great Lakes region?
    3. How could these impacts vary in importance based on the type of tourism business?

1.3 Organization

The subsequent chapters of this dissertation are organized as follows:

Chapter 2 details work that has been completed to understand how tourism business owners perceive weather, climate, and climate change; what actions these stakeholders have taken to adapt to climate change; and what barriers to adaptation exist using qualitative interviews based on the sense, anticipate, adapt, and learn (SAAL) framework for two Great Lakes destination case study communities.

Chapter 3 describes research conducted to develop actionable climate change science in the form of tourism-focused future climate change scenario infographics for the two case study communities studied in Chapter 2. These infographics were used in qualitative interviews to understand tourism managers' beliefs about climate change, determine whether they are currently getting any useful information about climate change, and investigate whether developing actionable science can help overcome barriers to climate change communication with tourism managers.

Chapter 4 contains information about modeling work used to investigate how climate change could impact winter weather in the Great Lakes, both spatially and temporally, and the tourism businesses that rely on it. Output from general circulation models (GCMs) and hydrologic model simulations was analyzed to gain a more complete picture of these potential impacts.

Chapter 5 discusses additional modeling work completed to understand how climate change could impact extreme precipitation and temperature events in the Great Lakes and its potential effects on the region's hospitality and tourism sector. Analysis has been conducted for both annual and seasonal trends in climate variables to determine whether certain types of businesses could be more vulnerable than others across the region to changes in extreme weather events.

Chapter 6 contains a summary of the findings of this research as well as overall conclusions and potential future research directions.

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2. EXPLORING TOURISM BUSINESSES' ADAPTIVE RESPONSE TO CLIMATE CHANGE IN TWO GREAT LAKES DESTINATION COMMUNITIES

2.1 Abstract

Climate change is one of the most significant challenges facing the global hospitality and tourism sector. Tourism businesses have been encouraged to take proactive steps to prepare for climate change, but adaptation has been limited thus far. In this study, qualitative interviews based on the sense, anticipate, adapt, and learn (SAAL) framework were used to explore how businesses in two Great Lakes destination case study communities perceive and are adapting to weather, climate, and climate change and what barriers may be preventing adaptation. Results support findings of existing research that tourism businesses have a strong awareness of how they are impacted by weather and climate. Many interviewees were also able to discuss potential impacts of climate change on their businesses but were generally not doing anything to prepare. Common barriers to adaptation mentioned by interviewees include limited resources, schedule or location inflexibility, lack of knowledge of adaptation options, and a belief that adaptation is unnecessary. Short-term planning horizons are also argued to be a key barrier to climate change adaptation by tourism businesses. The results of this study could have public policy implications as well as help to inform strategies for climate change preparedness for the tourism sector.

2.2 Introduction

The hospitality and tourism industry, which contributed over $7 trillion (USD) to the global economy and nearly $1.5 billion to the U.S. economy in 2015, is an economic sector that could be especially impacted by climate change [1, 2]. Tourism is closely linked to weather because of its importance to tourists when planning vacations and other leisure travel [3–5]. Favorable weather can be a motivator for travel and a major destination asset, while unfavorable weather can discourage travel to a given destination or negatively impact the travel experience [3, 5–8].

In general, climate change could have major impacts on the physical resources that support tourism and influence the viability of different types of tourism and tourism destinations [9–13]. For example, skiing areas in the Northeastern and Midwestern regions of the United States are likely to become less economically viable due to warming temperatures and less reliable snowfall in the coming century [14, 15]. Higher temperatures may be beneficial, on the other hand, for coastal destinations but increases in extreme weather events and sea level rise could offset any gains [16–18].

The impacts of climate change on tourism could be even more significant if they result in the ultimate business impact: business demise. Recent research investigating differences between businesses that closed after Hurricane Katrina and those that remained open suggest that businesses located in coastal geographical regions were more vulnerable to the storm surge and likely to have never reopened [19]. Subsequently, hospitality and tourism businesses located along coastal areas, which are extremely popular for the sector, could be especially impacted by future climate change because these regions incubate and intensify impacts in ways that more inland regions do not [20–22].

Recent findings in the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (AR5), as summarized by Scott et al. [23], suggest that "all tourism destinations will need to adapt to climate change." In addition, there is broad acknowledgment of the risks faced by tourism businesses from climate change [24]; however, much of the existing research examining the potential impacts of climate change on the hospitality and tourism sector has focused on understanding tourists' preferences when it comes to weather and climate and how these preferences could affect travel to destinations affected by climate change in the future [24–29]. While understanding potential changes in visitor patterns is important, considering business response to climate change and barriers to adaptation are also key to understanding how the tourism sector could be impacted in the future.

Overall, climate change poses the greatest risks to tourism businesses in terms of physical risk, e.g., damage to physical infrastructure or visitor and employee well-being from extreme weather events, and reputational risk, e.g., customers' perceptions of tourism businesses or destinations may decline if their travel experiences are negatively impacted by climate change [30]. Disaster preparedness and other adaptation strategies could help offset some of these risks, but, up to this point, tourism businesses' responses to climate change have been limited and primarily reactive to experiences with severe weather [31]. Proactive strategies could help businesses take advantage of potential benefits from climate change and limit costs associated with managing risks [30].

Firm size, ownership, and type and experience with disasters have all been found to correspond with business preparedness [32, 33]; subsequently, there may need to be special efforts to help certain types of businesses adapt to climate change. Understanding how businesses in the hospitality and tourism sector perceive climate change; what responses, if any, they are using to mitigate these threats; and what barriers they face in terms of enacting these strategies are some of the key questions that first need to be answered. This work attempts to help close some of these research gaps by looking at two destination communities in a major U.S. tourism region, the Great Lakes, at a local scale and applying a new framework, the sense, anticipate, adapt, learn (SAAL) framework, to answer these questions in a methodical way.

The SAAL framework describes one process through which resilient complex systems prepare for and recover from disruptive events [34]. Within this context, "sense" describes the ability to monitor stresses; "anticipate" is the ability to foresee potential crises and disasters; "adapt" is the ability to act on information that is sensed and anticipated to prevent failure; and "learn" is the ability to take knowledge from the past and apply it to the future [34]. The SAAL framework shares characteristics with frameworks that have been previously developed to explain organizational resilience, e.g., the "Sense, Interpret, Decide, Respond" and "Plan, Do, Check, Act" cycles [35].

2.3 Literature Review

2.3.1 Awareness of Weather, Climate, and Climate Change

Weather and climate play an important and well-known role in the success of tourism businesses [36]. As previously mentioned, a tourist's decision to travel to a given destination is often highly motivated by its climate and weather or existing perceptions of its climate and weather [5, 18, 28, 37–40]. Subsequently, bad or unusual weather can lead to a tourist's dissatisfaction with a travel experience and have economic repercussions for tourism businesses [6, 41]. Many tourism businesses already incorporate weather forecasts and predictions into their daily planning and decision-making, especially those that are nature-based [42].

Awareness of climate change is also argued to be well-known throughout the tourism sector, and there are many existing studies looking at how climate change will impact tourism in the future [4, 10, 18, 23, 28, 37, 43–47]. However, there are far fewer studies considering how tourism professionals perceive climate change. Existing studies suggest that location, type of business, experience with extreme weather, and personal interests can all affect the extent to which climate change is considered an important issue by business owners [47–50]. As demonstrated by these findings, increasing awareness of weather, climate, and climate change may not be the main challenge in terms of encouraging adaptation and preparedness, but this is something that needs to be confirmed through additional research.

2.3.2 Awareness of Need to Adapt and Potential Adaptation Strategies

The need for tourism businesses to adapt to climate change has also been well-documented in existing literature; however, tourism business owners' beliefs in the need to adapt is not necessarily consistent with this assertion [24]. More often, business owners do not see climate change as a critical issue or are confident in their ability to adapt, as they deal with weather variability on a daily basis; however, as previously noted, these beliefs are affected by a number of factors that are often unique to an individual or dependent on their location [47, 48, 51].

When it comes to organizational response to climate change, research in other sectors has shown that businesses may need to adapt a variety of practices including their basic routines and practices, their supply chains, and their target customer base with changes likely being made incrementally when businesses face new situations [52–56]. Berhout et al. [52] conducted a series of interviews aimed at understanding perceptions of climate change and organizational adaptation in the housing and water utility sectors. Based on their findings, they proposed four different strategies that encompass industry adaptive responses to climate change: wait and see; risk assessment and options appraisal; bearing and managing risks; and sharing and shifting risks.

Common adaptation approaches proposed for tourism businesses, specifically, include: diversification of products; locational changes; adoption of technological solutions, such as artificial snow; and destination rebranding [4, 24]. While these practices may allow businesses to manage climate change impacts to some extent, they may not be feasible for all tourism businesses or sustainable for the long-term. Furthermore, some adaptation strategies that work for businesses can have repercussions for their surrounding communities [24]. For example, snowmaking, a common approach used by the skiing industry to deal with inconsistencies in snowfall, will become increasingly expensive as temperatures continue to rise and could affect regional water and energy supplies [24, 57]. In addition, businesses do not necessarily have the option to relocate if their current location is an integral part of their image and operations or they play a key role in their local communities. Furthermore, small and medium-sized enterprises (SMEs), which make up much of the tourism industry, may lack the resources necessary for product diversification.

In most cases, the default response for tourism businesses is to ”wait and see” when it comes to climate change, which could be extremely detrimental to the sector in the long-run, especially when it comes to disaster preparedness [31, 48, 58]. Increasing understanding of business owners’ perceptions of the need to adapt and the complexities facing climate change adaptation through qualitative, local-scale information could help promote better strategies for climate change adaptation in the tourism sector.

2.3.3 Barriers to Adaptation

Even when tourism operators believe in the need to respond to climate change, there are a number of challenges associated with adaptation. Some of the reasons previously mentioned include that businesses do not consider climate change adaptation a priority or cannot prepare due to a lack of resources [24, 49–51, 59]. Existing research has also shown that major predictive factors for general disaster preparedness by businesses are larger firm size, ownership (versus rental), type of business (specifically lodging establishments), and experience with disasters [31–33, 60].

An additional explanation for the lack of adaptation is that tourism managers have not had options effectively communicated to them [61]. Hoffmann et al. [62] found that general awareness of the potential impacts of climate change can increase adaptation by a business. A lack of information and shortcomings in the appropriateness of climate change information have also been cited as barriers to climate change adaptation for the hospitality and tourism industry [24, 63]. Sievnen et al. [47] and Tervo-Kankare [50], for example, highlighted the need for local climate change scenarios for the Finnish tourism industry to help business owners understand how they could be impacted by climate change and develop adaptation strategies.

An absence of stronger partnerships with local governments, communities and industry organizations could also have an influence on tourism businesses’ adaptation decisions. Broader networks and partnerships could be key to the development of holistic and proactive climate change adaptation approaches for the sector as a whole [31,59,62,64]. Mileti et al. [65] highlighted the important role that government and other organizations play in providing targeted, "dense" information, or information from multiple sources and via multiple channels, to motivate preparedness action. Local governments also have the capacity to provide incentives to tourism businesses to act, especially small and medium-sized businesses, which may require greater assistance to prepare for climate change [32].

Once again, the barriers that exist to climate change adaptation are dependent on local realities; thus, considering this question in the context of community-based research can help build a greater understanding of how to help tourism businesses prepare for climate change.

2.3.4 Support for Methodology

While there have been studies looking at tourism, business owners' perceptions of climate change, and industry adaptation, existing research is limited, and there is much that is still unknown. In this case, an exploratory study using case studies and qualitative interviews is appropriate, as the findings can contribute to existing theory and lead to future explanatory work [66, 67]. Case studies are often used to explore "how" or "why" research questions and allow researchers to gain an in-depth understanding of the subject(s) of their research [68, 69]. In addition, the use of qualitative and, in this case, semi-structured interviews allow for the exploration of different points of view and the discovery of broad themes that can capture the multiple perspectives of the interviewees in each case study community [70].

The instrument used for the qualitative interviews conducted as part of this research was written based on the SAAL framework to determine how tourism businesses "sense" that they are impacted by weather and climate; "anticipate" that they could be impacted by climate change in the future; and "adapt" based on information about climate change. Interviewees were not directly asked about the "learn" aspect of the framework, as the two case study communities have not recently been impacted by significant disruptive weather events.

The overall aim of this work is to develop a more in-depth understanding of tourism business perceptions of and responses to climate change through the use of in-depth, semi-structured interviews based on the SAAL framework for two case study tourism destinations communities in the Great Lakes region. It is theorized that improving understanding and awareness of the potential impacts of climate change on tourism businesses, as well as existing barriers to adaptation, could help encourage effective adaptation. This study addresses the following research questions within the context of the two case study communities:

1. How do tourism businesses perceive that they are impacted by climate and weather?
2. How do tourism businesses perceive that they could be impacted by climate change?
3. How are tourism businesses preparing for future weather and climate?
4. What are the barriers to climate change adaptation?

2.4 Methodology

2.4.1 Case Study Locations

This study employed a two-case study design focused on two major and similar Great Lakes tourism destination communities: Indiana Dunes, Indiana, and Muskegon, Michigan. These two communities were selected for this study because their tourism industries are important to their state economies, are of a similar size, and are comprised of a number of SMEs (Table 2.1). These two communities also provide similar outdoor recreational opportunities and have peak operating seasons in the summer, though winter recreation is also popular in both locations (Table 2.1).

Table 2.1
Summary of Case Study Community Characteristics Related to Tourism

	Indiana Dunes, IN (Porter County)	Muskegon, MI (Muskegon County)
Importance of destination to state economy	2nd in Indiana for tourism spending [71]	10th in Michigan for tourism revenue [72]
Size of tourism sector [73]	∼320 accommodations and food services businesses	∼340 accommodations and food services businesses
Types of tourist activities	Iconic and new attractions; beach recreation; bird-watching; outdoor recreation [74]	Outdoor recreation; water recreation; water parks; ship displays; museums; summer festivals [75, 76]
Peak tourism season	Memorial Day - Labor Day	Memorial Day - Labor Day

The subunits of analysis for this work were tourism SMEs operating in these two communities. Twelve businesses were interviewed in the Indiana Dunes and eleven in Muskegon to account for business diversity and achieve data saturation. The goal of these case studies was to gain a representative picture of how tourism businesses are affected by weather and climate, how they could be affected by climate change in the future, how they may be adapting to climate change, and what barriers to adaptation exist in each location.

2.4.2 Participants

The main goals of interviewee selection were to include individuals who represented a mix of business types and captured the broad perspectives of the tourism sector in each community. A sample of potential businesses was provided by local tourism experts in each location and contacted by phone to request their participation in the study. The local experts consulted were individuals who hold leadership roles in major tourism organizations in their respective communities.

Businesses were purposively sampled to cover a mix of hotels, restaurants, local attractions, events, national or state parks, and, in the case of Muskegon, boat cruises. The events included in this study were classified as businesses as they exist as their own entities or organizations, engage in long-term planning, generally several years in advance, and serve important roles in their local tourism sectors by bringing in visitors and economic revenue. The characteristics of the groups of businesses were generally consistent across the two communities (Table 2.2).

Table 2.2
Summary of Business Characteristics for Each Case Study Community

Indiana Dunes

Business Type	Length of Operation (in Years)	Peak Operating Season	Perceived Reliance on Nature-Based Tourism
Event: 1 Hotel: 2 Local Attraction: 5 National/State Park: 2 Restaurant/Food Truck: 2	Less than 3: 1 3 to 5: 1 6 to 10: 0 11 to 20: 3 More than 20: 7	Spring Shoulder: 5 Summer: 11 Fall Shoulder: 4 Winter: 0	High: 4 Medium: 6 Low: 1 Not Sure: 1

Muskegon

Business Type	Length of Operation (in Years)	Peak Operating Season	Perceived Reliance on Nature-Based Tourism
Boat Cruises: 2 Event: 2 Hotel: 1 Local Attraction: 1 National/State Park: 2 Restaurant/Food Truck: 3	Less than 3: 1 3 to 5: 3 6 to 10: 0 11 to 20: 3 More than 20: 4	Spring Shoulder: 2 Summer: 9 Fall Shoulder: 0 Winter: 2	High: 4 Medium: 6 Low: 1 Not Sure: 0

2.4.3 Development of Interview Guide

The interview guide was designed to cover (1) the basic characteristics of each business; (2) the "sense," "anticipate," and "adapt" elements of the SAAL framework and potential barriers to adaptation; and (3) the usefulness of scientific information about climate change (see Chapter 3).

The interview guide was reviewed by the same local tourism experts who were consulted for potential interviewees and pilot tested with two individuals in each case study location. Feedback from these individuals was used to modify and edit the interview guide. The final version of the interview guide (Appendix A) and the overall study was approved by Purdue University's Institutional Review Board (IRB Protocol #: 1507016248).

All of the interviews were conducted by the author and recorded. The length of the interviews ranged in length from 10-60 minutes, on average taking 30 minutes. Despite the diversity of businesses included in this study, data saturation appeared to be reached in both case study locations with respect to the research questions being considered [77].

2.4.4 Data Analysis

Interview data was transcribed verbatim by the author and one research assistant. A selection of interviews and the interview guide were used to develop a detailed codebook. This codebook was used by three members of the research team, including the author, to individually code an initial set of interviews. Results of the first round of coding were discussed by these members of the research team and used to modify, clarify, and finalize the codebook (Appendix B) and check for intercoder reliability.

Intercoder reliability was checked using the Kappa coefficient [78]. The overall Kappa value was calculated to be 0.79, indicating acceptable agreement between the three researchers [79]. The final codebook was used by the author to code all of the remaining interviews using NVivo 11. Themes that emerged are discussed in the results section and illustrated by representative quotes.

2.5 Results

2.5.1 How do climate and weather impact tourism businesses?

The first area of interest addressed by the interviews was how tourism businesses "sense" that they are impacted by weather and climate. All of the interviewees included in this study indicated that weather and climate have an impact on their business, and, in many cases, the impact is significant and seen in multiple aspects of the business. Weather and climate were most commonly perceived to impact customers, such as customer numbers and customer safety, and business operations, such as whether to stay open in the case of severe storms, but were also seen to have an effect on everything from profits to the number of employees hired to business reputation.

> "But, in previous years, there was a few where I think to myself, we lost out on, you know, a hundred or a couple thousand dollars just weather-related."

The types of weather and climate most commonly named as having an impact on businesses were rain, severe storms, and unseasonably high or low temperatures. In the case of Muskegon, wind was indicated by many (9 out of 11) of the interviewees as being one of the most significant types of weather that affects their business, whereas only 3 out of 12 interviewees in the Indiana Dunes identified wind as being important. The timing of weather events also seemed to be important, regardless of location. For example, some businesses are very busy regardless of the weather during their peak seasons, so the effects of weather and climate are seen more in terms of walk-ins or other, more sporadic visitation.

> "[T]his year we have definitely seen the climate and weather make a big impact and what we've seen is that the rain, particularly on our, on weekends is a big impact. We had, so I guess we had 50,000 visitors last year, almost 50,000, and based on that we were expecting 60,000, and we stayed about even this year because, and we do believe that it is largely because of the weather."

> "So our camping numbers pretty much stay the same regardless, they'll fluctuate a little bit, but full is full, you can't put any more campers in the campground. Our day-use is where we really feel the impact of a really hot summer or a really cool summer."

The type of business appeared to be a factor in determining the effects of weather and climate in both case study locations, as certain types of businesses, such as national and state parks, were generally more highly impacted by climate and weather than others, such as restaurants and food trucks (Table 2.3). In addition, some businesses are affected differently by certain types of weather; for example, extreme heat in the summer can push more people to engage in beach and outdoor water recreation, hurting businesses that are reliant on indoor or other non-water related outdoor activities. Weather and climate also seemed to have the highest impact on businesses that rely heavily on outdoor and other nature-based tourism (Table 2.3).

Table 2.3
Comparison of Business Type and Reliance on Nature-Based Tourism with Overall Impact of Climate and Weather on the Business

Overall Impact of Climate and Weather on the Business	Business Type	Reliance on Nature-Based Tourism
High	Boat Cruises: 1 Event: 1 Hotel: 1 Local Attraction: 4 National/State Park: 4 Restaurant/Food Truck: 1	High: 8 Medium: 4 Not Sure: 1
Medium	Boat Cruises: 1 Event: 1 Hotel: 1 Local Attraction: 1 Restaurant/Food Truck: 4	Medium: 7 Low: 1
Low	Hotel: 1 Local Attraction: 1	Medium: 1 Low: 1

2.5.2 How could future climate change impact tourism businesses?

All of the interviewees indicated a belief in climate change with the exception of three who were not sure and one who did not believe in climate change. In addition, most of the interviewees perceived that future changes in climate and weather could have an impact on their business (19 of 23), though only a few believed that the impact would be significant for more than a few aspects of the business. Similar to current perceptions of weather and climate, future climate change was seen most often to have the potential to affect customers, such as customer numbers and safety, and operations, such as operating costs and operating season. Other potential business impacts included impacts on employees, such as their availability and safety, and business inventory or offerings.

Interviewees were also shown an infographic summarizing future climate change projections for their location, such as increases in seasonal temperatures and warmer lake temperatures, and asked how they thought their business would be affected if the projections came true (more details about the development of the infographics are provided in Chapter 3). The types of changes in climate and weather that were focused on most by interviewees in both case study locations were the lengthening of the shoulder seasons (discussed by 7 of 12 in the Indiana Dunes and 5 of 11 in Muskegon) and the increase in extreme weather events (discussed by 7 of 12 in the Indiana Dunes and 6 of 11 in Muskegon). The lengthening shoulder seasons generally elicited a positive reaction, since it was expected that this would lead to increased customer numbers in traditionally off-seasons times of the year, particularly for businesses with peak operating seasons in the summer. An increase in extreme weather, on the other hand, was seen as overwhelmingly negative because of the potential for increased damage and threats to customers' health and well-being.

About half of the interviewees believed that the impact of future climate change would be mixed for their business in both case study locations (6 of 12 in the Indiana Dunes and 6 of 11 in Muskegon).

> "The longer spring is definitely an asset. The fall, what you have there for fall is just a nightmare, you know, all the storms and stuff, that just isn't going to work. The warmer summers, I can see more people wanting to come out, more people wanting to maybe do the touring and stuff."

A few interviewees saw climate change as being positive for their business (1 of 12 in the Indiana Dunes and 2 of 11 in Muskegon) and one saw it as being negative (in the Indiana Dunes). The remainder believed that the impacts would be insignificant or easily overcome (4 of 12 in the Indiana Dunes and 3 of 11 in Muskegon) with respect to the business.

> "I don't think public traveling or tourism will increase because of climate change. I don't believe that will happen."
>
> "I think last year was the worst year that we've had in many, many years, and it did have an impact on business, you know, and for those particular days that gets very cold. But in the moment that the weather gets good, you get double the business, so one thing balances the other."

An interviewee's belief in climate change did not necessarily correspond with a belief that climate change would have an impact on the business (see Table 2.4).

Table 2.4
Comparison of Interviewee Belief in Climate Change and Overall Impression of Climate change for for the Business

	Interviewee's Belief in Climate Change		
Interviewee's Overall Impression of Climate Change for the Business	Yes	Not Sure	No
Positive	3	-	-
Mixed	10	2	-
Negative	1	-	-
None	5	1	1

2.5.3 How are tourism businesses preparing for future weather and climate?

While most of the interviewees included in this study (16 of 23) readily identified that their business could be impacted by future climate change, many of them were not currently doing anything to prepare for or adapt to potential impacts. There were three cases where climate change adaptation was actively occurring in response to (1) perceived shifts in the seasons, (2) shortening winters and (3) changes in conditions in Lake Michigan. One of the businesses currently adapting to climate change was located in the Indiana Dunes and two were located in Muskegon.

More often, there were examples of businesses adapting to past experiences with weather. Six of these businesses were located in the Indiana Dunes and three were located in Muskegon. Some of the strategies businesses are currently using to deal with unfavorable weather and climate include ensuring that emergency procedures are in place and diversifying offerings, e.g. adding snowshoes to winter offerings to deal with less consistent winters.

> ”We’re always looking for ways to, to work with that ebb and flow of the winters and, so, like I said, we added the snowshoes, that was new last year, and that was just a small thing, but, we’re really thinking about our indoor spaces and how they can be used more effectively, as well as whether what we’re doing warrants a new indoor space.”

These approaches are consistent with those described by Kaján and Saarinen [24] and Pang et al. [4] for tourism businesses in other locations. In all cases, the businesses currently adapting to climate change, climate and weather were also indicated by interviewees to be strongly impacted by weather and climate. These businesses included four local attractions, four national or state parks, two events, one boat cruise company, and one restaurant or food truck.

Some of most commonly proposed strategies for adapting to future climate change included making operational changes, i.e., expanding the length of a restaurant’s patio season to take advantage of the longer shoulder seasons, relying more on indoor offerings and spaces, or making changes to equipment, i.e., getting larger or heated tents for outdoor events.

> ”You know, I mean, well, we’ve talked about having more, we want more indoor, like, square footage...we’d probably would want to, like, advertise that we are open, you know, year-round...and then staffing, that’s a big

> thing, too, we might want to hire later, you know what I mean? Hire people later, rather than hire them right at the beginning of spring."

> "You know, do you think of maybe an alternate location? It's very hard on some things, it's just not possible to do a rain date...tent sizes maybe a little bigger, depending on the event."

These strategies fall into the "bearing and managing risks" and "sharing and shifting risks" categories proposed by Berhout et al. [52].

2.5.4 What are the barriers to climate change adaptation?

The most common barrier to climate change adaptation mentioned by the interviewees was limited resources, particularly financial.

> "Well, financial is always an issueby the time you take some of these things that you have to do, I've got maybe $10,000 left over, so, yeah, I mean, financial is always, always a concern."

In the case of many of the events, there is also inflexibility in terms of location or schedule.

> "I do watch the weather a lot. I know the vendors watch the weather a lot. So, as far as preparing, yeah, just watching the weather. There's not much you can do. It's on Saturday, it's, you know, it's meant to be on Saturday."

A lack of knowledge about adaptation options was also mentioned by interviewees when asked what they would like to do in response to future climate change projections.

> "As far as preparing ourselves, you know, bolstering ourselves against it in some physical manner, there's not a lot that I'm aware of, you know,

> there're maybe people out there a lot smarter than me that say, oh well, you could, should do this, this, and this, as far as the things that I can think to prepare for, we don't have a whole lot."

There also seemed to be an underlying attitude, even with interviewees who believed in climate change, that adaptation would not be necessary, most often because the impacts of climate change would not be significant or would happen very slowly or that being adaptable and flexible is the best strategy for dealing with weather unpredictability.

> "I mean, when you own a business, I'm going to be very honest with you. The last thing I am going to think about is weather."

> "Things are going to change and they're not going to change fast so it's easy to adapt. I just think we have to roll with it. Be very flexible in both event planning and life in general."

These reactions to climate change are not unexpected based on findings from previous research.

Another barrier that was not directly mentioned by interviewees but implied by the fact that only half of them (11 of 23) engage in strategic planning at least 3-5 years into the future and only 3 of them have included weather in those discussions is that many tourism businesses do not operate based on timeframes under which climate change will be most salient. A lack of local, state or national government efforts to prepare for climate change was identified by only two interviewees as being a potential barrier to future adaptation, but there is still likely a role for local governments and larger tourism organizations to play in business preparedness and adaptation.

2.6 Discussion

The main goals of this study were to understand how tourism businesses perceive climate, weather and climate change (sense/anticipate), are preparing for climate change (adapt), and what barriers to adaptation exist in two tourism destination case study communities around Lake Michigan.

The findings of this work support conclusions found in existing literature that tourism business owners have strong perceptions of how weather and climate impact their businesses (sense), as acknowledged by all of the interviewees who participated in this study. The types of weather and climate that were concerning to interviewees were generally consistent between the two locations, with the exception of wind being much more important in Muskegon than in the Indiana Dunes. In general, extreme weather, such as extreme storms and extreme temperatures, has the greatest impact on the businesses in these two locations. The extent of the impact of weather and climate on a business depends on the business. Certain types of businesses, like national and state parks and others that are highly reliant on nature-based tourism, were generally found to be more strongly impacted by climate and weather than others.

Many of the interviewees were also able to perceive how their business could be impacted by climate change in the future (anticipate), though how these perceptions align with what the actual impacts of climate change will be cannot be measured. Most interviewees believed that climate change impacts would be mixed for their business and focused on changes in the lengths of the shoulder seasons and extreme weather events. An encouraging finding was that the few interviewees who indicated that they did not believe in climate change were not necessarily unwilling to consider how climate change could impact their businesses in the future.

As expected based on the findings of existing studies, there were only a few cases where tourism businesses were actively adapting to climate change (adapt), though there were several more cases where businesses were acting in response to past experiences with weather. In all cases, the businesses currently adapting to weather, climate or climate change were also businesses that were indicated by the interviewees to be highly impacted by climate and weather. Neither of these findings was surprising, but they do suggest some willingness by the businesses in this region to act based on perceptions and experiences with climate and weather.

The barriers to adaptation mentioned by the interviewees who participated in this study agreed with findings in existing research, such as financial barriers and the need for more information about climate change and adaptation options. Subsequently, there may be opportunities to encourage business adaptation through better communication of risk information and adaptation options. The lack of incentives and motivation to change from "business as usual" as expressed by many of the interviewees also demonstrates that partnerships, such as with local governments, may be needed to encourage any type of significant action, especially given businesses' short-term planning horizons.

2.7 Implications and Future Research

The fact that the tourism businesses included in this study have both a strong awareness of how they are impacted by weather and climate and could be impacted by climate change in the future suggests that providing basic information about climate change is not necessarily the primary need when it comes to encouraging adaptation in the tourism sector. While the accuracy of these perceptions should be more thoroughly evaluated in subsequent studies, climate change communication strategies should be bolstered by tourism businesses' perceptions of the importance of weather and climate. In addition, the willingness of tourism business to respond to recent, past experiences with weather demonstrates that they have at least some flexibility to adapt to climate change.

Resource limitations, location or schedule inflexibility, and lack of knowledge of adaptation options were all mentioned by interviewees as being barriers to adaptation, but these issues have feasible solutions. The main challenges to encouraging tourism businesses to adapt may actually be their perceptions that climate change adaptation is unnecessary and their short-term planning horizons, especially given that (1) significant negative impacts from climate change, which could help motivate action, will manifest in the long-term, (2) many businesses do not necessarily strategically plan, even 3-5 years into the future, and (3) weather is rarely seen as something that needs to be considered in strategic planning. While a "wait and see" approach could be sufficient for gradual shifts in climate, the potential increase in extreme weather events requires more proactive action and, subsequently, for businesses to be proactive and expand the scope of their planning to longer timeframes.

Subsequently, these findings have important implications for framing strategies and policymaking. The fact that interviewees did not necessarily associate perceived changes in the region's climate with climate change suggests that the most effective mean of encouraging adaptation may be to frame it as "weather preparedness" or "resilience." In addition, emphasizing the benefits of adaptation in terms of business outcomes may be necessary [80].

The ability for tourism businesses to make adjustments quickly and tactically, versus strategically, supports the need for policy interventions to encourage forward-looking adaptation strategies. Policymakers should consider incentivizing adaptation practices that can provide long-term benefits for tourism businesses without significant costs in the short-term, especially when it comes to preparing for extreme weather events and natural disasters. As discussed by Ritchie [81], tourism businesses need to achieve three goals when it comes to disaster preparedness: "developing proactive scanning and planning; implementing strategies when crises or disasters occur; and, evaluating the effectiveness of these strategies to ensure continual refinement of crisis management strategies" all of which would benefit from outside support, research and coordination [82–84]. Policymakers should work with leaders in the tourism sector to determine the best way to move the industry forward.

Finally, while the findings of this work are not generalizable beyond these two locations, comparing interview results between case studies suggests that there may be commonalities that could be built upon in future work, such as the importance of business type and the overall impact of weather and climate on a business when considering communication about climate change adaptation strategies. The findings of these interviews could also be used as the basis for a quantitative survey that could be administered in other destination communities throughout the Great Lakes, or other regions, to establish a baseline for how tourism businesses are sensing, anticipating, and adapting in response to climate change and a better understanding of existing barriers to adaptation.

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3. DEVELOPING FUTURE CLIMATE SCENARIOS FOR TOURISM STAKEHOLDERS IN THE GREAT LAKES

3.1 Abstract

Developing actionable climate change science is an essential part to helping stakeholders in the hospitality and tourism sector develop and implement effective adaptation strategies. Projections from an ensemble of climate change models were used, in combination with innovative data visualization techniques, to create tourism-focused infographics summarizing future climate change projections for two case study communities in the Great Lakes. These infographics were presented to tourism stakeholders in an interview setting and used to better understand their perceptions of climate change, to determine whether they are currently getting any useful information about climate change, and to investigate how data visualization and scenario planning can be used to produce useful climate change information for this group of decisionmakers. Overall, the results of this work suggest that tourism professionals do not see climate change as being a priority despite their awareness of the importance of climate and weather to their businesses; however, very few of the study participants said they were currently getting any information about climate change. The use of future climate projection infographics that are informed by data visualization techniques could be beneficial to closing the gap between the production of climate change science and its communication to stakeholders in the hospitality and tourism sector. Future research should build on the creative approach used here to improve climate change information usability as well as to explore potential "thresholds" and policy interventions around adaptive behavior.

3.2 Introduction

Climate change is one of the most significant challenges facing the planet with the potential to affect every population, place, and economic sector. The tourism sector, especially, could be impacted because of its strong connection to climate and weather (see reviews by [1, 2]). Climate and weather are key components of motivation for travel, customer satisfaction, destination image and tourism businesses' operations [1, 3–11].

Climate change presents both risks and opportunities for the tourism sector [12]. For example, existing studies have predicted that changes in global climate will shift tourist travel patterns poleward, favoring destinations at higher latitudes, while extreme weather events could have significant detrimental effects on tourism businesses, regardless of location [13–16]. Overall, there will be winners and losers in the tourism sector when it comes to climate change [1,17–19]. In many cases, the "losers" are likely to be small and medium sized enterprises (SMEs) and destinations whose economies are more heavily reliant on tourism [20–24].

The sustainability of the tourism sector is important to global and local economies in many ways [25]. Subsequently, the tourism sector has been encouraged to take proactive adaptive action to prepare for climate change [12]; however, the complexities involved in understanding climate change and its potential impacts make proactive adaptive behavior difficult [26–28]. Tourism businesses often struggle with long-term visioning and preparedness, as would be required for effective climate change adaptation strategies, because they operate and plan based on short timescales and locally-focused geographical scales [29, 30]. In addition, many tourism managers deal with weather variability on a daily basis and, subsequently, do not necessarily connect regional changes in climate and weather with potential business impacts or see the need for significant changes to business operations in response to projected changes in climate [31, 32].

It is known from previous work that tourism managers are highly aware of how their businesses are impacted by climate and weather, but their knowledge of climate change risks is more mixed [33–35]. This is important because stakeholders' perceptions of climate change, including at the business-level, have been shown to affect their willingness to adapt to climate change [28, 36–39]. Belief in the ability to do something about climate change is also an important motivator for action, meaning that appropriately framed information about climate change adaptation options could help encourage proactive behavior by stakeholders even when there is a high level of information uncertainty [36, 40].

Producing actionable climate change science for tourism managers is one way to help meet the need for appropriately framed and stakeholder-responsive climate change information and, perhaps, help overcome some of the existing barriers to adaptation. In this study, actionable science, in the form of future climate change scenarios, were produced for tourism managers using data visualization techniques and scenario planning in order to see if the use of these methods could lead to the development of future climate change projections that facilitate conversations about climate change and adaptation. The use of data visualization techniques and scenario planning is a key component of this work because future climate information needs to be easily understandable, community-relevant, and reliable in order to be useful [41, 42].

This research was motivated by a desire to create actionable climate change science for tourism managers in North America's Laurentian Great Lakes as a first step towards helping them with adaptation planning. In order to inform future research, determining how tourism managers perceive and receive information about climate change were also key components of this study.

3.3 Literature Review

3.3.1 Belief in Climate Change, Framing, and Risk Communication

A March 2016 poll conducted by the Yale Program on Climate Change Communication and the George Mason University Center for Climate Change Communication found that 70 percent of U.S. citizens believe that climate change is happening [43]. Both gender and age have been found to play a role in climate change beliefs; however, environmental values, political values and recent experience with weather seem to play a stronger role in perceptions of climate change [44–50]. Existing studies of the perceptions of tourism business owners when it comes to climate change have shown them to be consistent with the general public. They are generally aware of climate change, though not necessarily convinced that it is a significant problem, and recent experience with weather has been shown to strengthen belief in climate change [30, 51].

Perceptions of climate change and its associated risks are important because an individual is unlikely to act in response to climate change unless he or she considers it to be real and wants to do something about it [28, 37, 52]. Motivating action in the case of climate change is difficult because it is often seen as being relatively low-risk and distant in terms of time and space [53, 54]. In the case of the tourism sector, existing research has shown a significant gap between awareness of climate change and a belief in the need to adapt [34, 51, 55].

There is also evidence, however, that beliefs in climate change can change and that belief in climate change is not the only thing that motivates behavior towards the environment [37, 48, 49]. Framing has been shown to play an important role in how individuals conceptualize risks especially when information is made locally relevant [40, 56]. In order to determine appropriate framing strategies to encourage climate change adaptation, tourism managers' perceptions of climate change need to be understood at the local scale, which is one of the goals of this research.

3.3.2 Actionable or Useful Science

The creation of actionable science, or useful science, describes an effort that has evolved over the last 50 years to incorporate stakeholders into the research process and close the gap between the "supply" of available information and the "demands" of decision makers (see reviews by [57, 58]). Actionable science has often been described in the literature as being salient, or relevant and responsive to stakeholders' needs and decision making requirements; credible, or of high technical quality and scientifically-sound; and legitimate, or produced through a process that is objective and transparent [58–64]. In addition, actionable science is often developed through on-going, two-way communication processes that treat stakeholders as partners, also known as coproduction [65].

The use of actionable science to communicate with stakeholders about climate change has also been shown to help with the conceptualization of climate change risk in spite of it being a highly complex concept and difficult to incorporate into decision making [56, 66, 67]. In addition, sustained, on-going communication about climate change can help increase awareness of climate change, encourage climate-friendly behaviors, and provide opportunities for learning, all of which enhance stakeholder understanding and investment in future climate change planning and outcomes [68, 69].

Developing actionable climate change science through a process that integrates stakeholders is also appropriate for this work because existing research has emphasized the need for tourism business owners to be consulted about their decision making requirements [7, 70]. For example, previous work has shown that tourism businesses operate and plan based on relatively short-time scales, so presenting information about climate change that focuses on far future climate scenarios could be ineffective for encouraging proactive adaptive behavior.

This research is a first step towards engaging in sustained communication about climate change with tourism business owners in the Great Lakes. In addition, the process being used here allows for the evaluation of criteria for effective actionable science through direct communication with stakeholders.

3.3.3 Support for Methodology

The process undertaken in this study is based on work conducted by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Tourism Queensland for its tourism sector [29]. Through this initiative, stakeholders were presented with a climate-relevant decision-making tool, "Climate Futures," which is made up of visualizations created on the basis of future climate change projections, at two different workshops [29]. The tool was used to help researchers understand tourism managers' perceptions of climate change and adaptation, as well as to help workshop participants think about potential climate change impacts and adaptation strategies [29, 35].

The CSIRO and Tourism Queensland's innovative use of data visualization techniques has been incorporated into this study in an attempt to make future climate information more accessible and relevant to tourism business owners. Future climate change information developed for this work focused on highlighting key points in the overall climate change narrative in order to make the information easier to understand and more familiar to tourism business owners (see Section 3.3.3). Similarly, scenario planning, which is one method that can be used to help businesses plan for the future by presenting a set of plausible futures that can help them evaluate risks, develop strategies to deal with potential risks, and contribute to "creative visioning," was used to summarize how a full ensemble of climate models are predicting the Great Lakes could be impacted by climate change in the near future, again, to make the information more relevant and relatable [71, 72].

Overall, this research aims to address some of the existing gaps in knowledge in terms of tourism managers' beliefs about climate change and information needs as well as to test an innovative approach to climate change communication using data visualization techniques and scenario planning for tourism stakeholders in two case study communities in the Great Lakes. This work focuses on the following three research questions:

1. What are tourism managers' beliefs when it comes to climate change?

2. What useful information are tourism managers currently getting about climate change?

3. How can data visualization techniques be used to develop useful climate change scenarios for stakeholders in the tourism sector?

3.4 Methodology

3.4.1 Overview

A two-case case study design was selected for this research as it allowed for the comparison of potential climate change impacts, information needs and messaging strategies for two different Great Lakes destination communities. Future climate scenarios for the two case study locations were developed through the analysis of existing climate model projections and a review of relevant literature. Model output from 20 atmospheric-ocean general circulation models (AOGCMs) were analyzed to quantify changes in climate characteristics that are important for tourism, such as changes in the length of the shoulder (spring and fall) seasons, average seasonal temperatures, and the number of extremely hot days per year (days over 90 ˚F). Existing literature was consulted to provide information about changes in extreme weather and lake levels. These findings were then used to develop infographics summarizing how climate change could impact the 2 case study locations being considered in this study, which were presented to and discussed with 23 tourism managers in semi-structured, qualitative interviews that took place in September and November 2015.

3.4.2 Location

The focus of this work was on two communities on the eastern side of Lake Michigan: Indiana Dunes, Indiana, and Muskegon, Michigan. These communities were selected for this work because they are of comparable size and rely on tourism as an important source of economic revenue. Outdoor recreation and nature-based tourism is of particular importance to these locations' tourism economies, making weather and climate of even greater interest to tourism professionals operating in these communities (see Chapter 2 for more infomation about the case study communities).

3.4.3 Development of Future Climate Scenarios

Based on existing literature, it was hypothesized that the impacts of climate change on Great Lakes communities will be highly dependent on location; therefore, local scale climate data for the two case study locations was used to examine potential future changes in climate. The primary focus of scenario development was to summarize how climate change could affect weather and climate characteristics most important to tourism. Given what is known from previous research, the intent here was to include a number of different variables that would capture the broad impact that climate change could have on the two case study communities [11]. It was assumed that seasonal and extreme temperatures and days with precipitation, especially heavy precipitation, would be of major interest to tourism professionals. Other forms of extreme weather events, such as heat waves, droughts, and severe storms, were also assumed to be of primary concern. Given the importance of Lake Michigan to tourism in the two case study communities, weather and climate impacts on lake properties, specifically water levels, water temperature and storm surge, were included, as well.

In order to complete this analysis, downscaled, bias-corrected daily climate model projections for a high emissions scenario (representative concentration pathway 8.5) were downloaded from the Downscaled CMIP3 and CMIP5 Climate and Hydrology

Projections archive for the two case study locations [73]. Similar to other climate change studies based on model projections, there is a degree of uncertainty inherent in this analysis. In order to try and address this limitation, all of the available AOGCM projections were included in this analysis. In total, daily 1/8° Bias-Correction Constructed Analogues (BCCA) observations for 40 runs from 20 different models for the time period from 2000-2045 were used for this analysis (Table 3.1).

Table 3.1
Model Centers and Names of AOGCMs Used for Future Climate Projections

Modeling Center (or Group)	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	ACCESS1.0
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1
Canadian Centre for Climate Modelling and Analysis	CanESM2
National Center for Atmospheric Research	CCSM4
Community Earth System Model Contributors	CESM1(BGC)
Centre National de Recherches Mtorologiques Centre Europen de Recherche et Formation Avance en Calcul Scientifique	CNRM-CM5
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-Mk3.6.0
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3 GFDL-ESM2G GFDL-ESM2M
Institute for Numerical Mathematics	INM-CM4
Institut Pierre-Simon Laplace	IPSL-CM5A-MR
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC-ESM MIROC-ESM-CHEM
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5
Max-Planck-Institut fr Meteorologie (Max Planck Institute for Meteorology)	MPI-ESM-LR MPI-ESM-MR
Meteorological Research Institute	MRI-CGCM3
Norwegian Climate Centre	NorESM1-M NorESM1-ME

Thirty-year averages around the present day (2015) and 2030 were calculated for a group of climate variables for each location and compared to determine how climate change could impact future weather and climate phenomenon assumed to be important to tourism managers and their businesses, specifically, average seasonal temperatures, the number of days with precipitation, the number of days with heavy precipitation (over 2.5 inches), the number of hot days (days over 90 °F), average seasonal precipitation, and the length of the shoulder season (days over 70 °F). This analysis was supplemented by a review of existing studies that examine variables that were assumed to be important for tourism but for which daily data was unavailable (e.g. water levels, water temperature, storm surge, and extreme weather events).

Analysis of existing model projections suggests that climate change could affect the two case study communities being used for this research in the ways summarized in Table 3.2.

Table 3.2
Projected Changes in 30-Year Averages for Climate Variables from 2015 to 2030

Factor	Location	Change in 2030
Average seasonal temperatures	Muskegon	+ 1.3°F
	Indiana Dunes	+ 1.4°F
Length of shoulder seasons	Muskegon	+ 6 days
	Indiana Dunes	+ 6 days
Number of hot days (over 90°F)	Muskegon	+ 4 days
	Indiana Dunes	+ 11 days
Average annual precipitation	Muskegon	+ 0.4 inches
	Indiana Dunes	+ 0.4 inches

A review of existing literature suggests that the following changes could also occur in and around Lake Michigan and potentially affect tourism.

- More extreme weather events [74]
- Increase in storm surge frequency and severity [75]
- Slight decrease in water levels in Lake Michigan [76]
- Increase in lake water temperatures [77]
- Reductions in air quality [78]

The most significant results of this analysis were translated into infographics for the two case study communities (Figure 3.1), with an emphasis on generating images that would be clear to follow and easily understandable to the interviewees [79]. Building on data visualization techniques, the infographics were intentionally designed in a way that would allow the interviewer to guide the interviewees through the larger climate change "narrative," for example by grouping icons related to specific weather events (storm surges and extreme weather) at the top of the graphic and those related to temperatures at the bottom of the graphic [80, 81]. Using simple icons with a basic color scheme to describe changes in the climate variables, rather than charts and graphs, was also intended to make the information more accessible to participants [82]. Similarly, the incorporation of photographic images from each of the two locations was intended to make the infographics more visually compelling and further enhance the messaging of the climate change information [83]. Subsequently, this work attempts to move data visualization and photo elicitation research around climate change in a new direction.

3.4.4 Interviews

A total of 23 tourism professionals, 12 in the Indiana Dunes and 11 in Muskegon, were interviewed as part of this work. These individuals, selected with help from local tourism experts, represented a mix of hotels, restaurants, local attractions, events, national or state parks, and, in the case of Muskegon, boat cruises. A summary profile of the individuals interviewed as part of this study is included in Table 3.3.

Interviews took place during 2 1-week periods in September 2015 and November 2015 and ranged in length from 10-60 minutes, taking an average of 30 minutes. Interviews were conducted in-person by the author and continued until data saturation was reached [84]. Interviewees were asked about their perceptions of current and future climate change (using the infographics), whether they have already been receiving information about climate change, what kinds of weather and climate infor-

Fig. 3.1. Infographics of Climate Change Projections for Muskegon and the Indiana Dunes

Table 3.3
Demographic Profile of Interviewees for Each Case Study Community

	Gender	Age	Job Titles
Indiana Dunes	Female: 8 Male: 4	20-29: 1 30-39: 2 40-49: 5 50-59: 3 60-69: 1	Assistant Director Assistant Winemaker Executive Director General Manager Innkeeper Manager Marketing and Public Relations Manager Owner (3) Property Manager Public Information Officer
Muskegon	Female: 6 Male: 5	20-29: 2 30-39: 4 40-49: 3 50-59: 2	Director Event Coordinator General Manager (3) Owner (3) Park Manager President State Park Interpreter

mation are useful to them when planning ahead, and whether they believe in climate change. The interview guide (Appendix A) and the overall study was approved by Purdue University's Institutional Review Board (IRB Protocol #: 1507016248).

Interview data was transcribed verbatim by the author and one research assistant and used to develop a draft codebook. Intercoder reliability was calculated based on the coding of a set of three interviews by three members of the research team using the Kappa coefficient and found to be acceptable (0.79) [85, 86]. This analysis also resulted in the development of the final codebook (Appendix B), which was then used by the author to code all of the remaining interviews in NVivo 11. Major interviews findings are summarized in the subsequent section using representative quotes.

3.5 Results

3.5.1 What are tourism managers' beliefs when it comes to climate change?

Most of the interviewees stated a belief in climate change (19 of 23) as well as a belief that their region's climate has been changing (15 of 19). Belief or disbelief in regional climate change seemed to draw on an individual's recent experience with weather more than age or gender (Table 3.4).

> "Well, in my 10 years here, they certainly seem to be, like I said, it, our weather events seem to be getting more, I guess, concentrated or just more extreme, you know. It just seems like, if, you know, if we get rain it's going to be 2 inches of rain, you know."

> "I don't know. I mean, it's a, as far as how it affects us, it's the same conversations. I've been on the board for 10 years and it's the same conversations we've always had. You know, same concerns during the same parts of the year that you've always had. Cool, rainy, windy concerns and the drizzily stuff in the spring, big pop-up showers or heat, too much heat, later on in the year. I don't think I've seen anything you can really put your finger on, change-wise."

Table 3.4
Comparison of Belief in Climate Change with Belief in Regional Climate Change, Age, and Gender of Interviewees

Belief in Climate Change	Belief in Regional Climate Change	Age	Gender
Yes: 19	Yes: 15 Not Sure: 3 No: 1	20-29: 3 30-39: 5 40-49: 7 50-59: 3 60-69: 1	Female: 13 Male: 6
Not Sure: 3	Not Sure: 2 No: 1	30-39: 1 50-59: 2	Female: 1 Male: 2
No: 1	Yes: 1	40-49: 1	Male: 1

The magnitude of anticipated impact of climate change did not necessarily correspond with climate change belief. Two individuals who stated belief in climate change also stated that the impacts of climate change would not be great or would be easily dealt with.

> "I mean, we don't get direct impacted by it so, [it's not like] we're going to have 40 degree increase in temperature or anything like that."

> "Things are going to change and they're not going to change fast, so it's easy to adapt. I just think we have to roll with it."

In addition, half of the eight interviewees who stated that they did not believe that their region's climate was changing or were not sure that their region's climate was changing also mentioned a belief that weather "works in cycles," implying that recent observed changes to the region's climate would not be permanent or significantly different.

> "That's hard to say. I look at is as a cycle. Everything's so, in the short-term, yes. I mean, I think we're having colder winters and hotter summers, but if you look over the course of time, I think it's just a cycle."

3.5.2 Are tourism managers currently getting any useful information about climate change?

Interviewees were asked if they have already been getting information about climate change after being shown the future climate scenario infographics. Only 2 of 23 interviewees said that they were currently getting information about climate change. The news was cited as the primary source for climate change information; however, other sources for weather and climate information mentioned by interviewees included Internet websites, weather apps, federal agencies, in particular the National Oceanic and Atmospheric Administration (NOAA), and academic institutions. The Internet could play a key role in future communication about climate change and adaptation strategies, as previous research has shown that it is a useful method for encouraging business preparedness [7, 87].

There are several different kinds of information that interviewees said would be useful in terms of future planning. The most common type of information that was seen as being useful is accurate short-term weather data and forecasts.

> "One of my biggest problems is the forecasters are so off. I mean, right now it's a light breeze? Really? I want to see you get in your canoe and go out there...I'm building my life this way, you know?"

Otherwise, general climate change information, trend data, both in terms of the weather and visitation, and real-time lake data were frequently mentioned as being helpful or important.

> "If there's groups that are putting together ideas, not ideas, but thoughts of where, where our visitors are coming from, and, I guess, weather forecasts, as well, but just any information we can get to help prepare and see some of the trends and get ahead of the curve is, so it doesn't sneak up on us...I mean, that's, that's something that just, you know, preparation, any information, information is power."

There were also two interviewees who stated that they put together annual reports comparing sales or visitation and weather on a daily basis.

> "Like I said, I look up the historical weather each year and pull up and say, okay, this is what, you know, we did last year, this is what the weather's projecting for this year, what do we need to do, you know, things like that..."
>
> "I mean, my, yeah, the analysis that I did was, you know, the internet has lovely things, so, you know, so I looked and, you know, and marked, you know, what happened on, every day, side by side. What happened on January 1st in 2014, what happened on January 1st in 2015, and so on..."

The importance of weather and climate to many tourism businesses suggests that there could be an audience for future climate change information, but, at this point, there seems to be a significant mismatch in terms of timescale.

3.5.3 How can data visualization techniques and scenario planning be used to develop useful climate change information for stakeholders in the tourism sector?

The future climate scenario infographics developed for this work were used to help facilitate conversations with the interviewees about future climate change and provide a concrete basis for discussing its potential impacts on their businesses. In two cases, interviewees went through all of the variables summarized in the graphic one by one and discussed how it could affect their business in the future, while nearly half of the interviewees discussed three or more variables and their potential impacts.

> "The more storm surges, like I told you...we've been affected there. The higher temperatures...may make the beaches more popular...the longer spring and fall season that can be positive, certainly. The more extreme weather, obviously that can have an effect on the health and safety of our

> visitors and staff, and also our budget...a warmer lake...you may actually increase the beach season, in theory...more days above 90 degrees means, well, we'll bring in more money at the beach, so there's a positive."

Out of the interviewees who did not think climate change would have a significant impact on their business (7 of 23), two were willing to discuss how changes in certain climate variables could have an impact in the future.

> "Maybe, depending on how severe everything was, but maybe a little bit, but not a whole lot because the warmer lake temperatures sounds good to me and even the higher seasonal average temperature, but don't really like the above 90 degrees...and spring and fall is okay, so not, not a whole lot."

Use of the infographics also uncovered interviewees' perceptions about how different elements of climate change could affect their business. Nine of the 23 interviewees expressed their belief that climate change could be both positive and negative for the business, while 4 believed that climate change would be negative and 4 believed that climate change would be positive. Isolating the individual variables allowed the interviewees to explore the complex ways in which their businesses could be impacted by climate change in the future.

Similar to the CSIRO and Tourism Queensland's study, the use of climate change scenarios in the form of infographics appear be a suitable method for presenting information about climate change to tourism professionals in the two case study communities. While interviewees were not asked to comment directly on the quality or presentation of the infographics, as the interviews were focused more on eliciting information about climate change perceptions and adaptation planning, two of the interviewees spontaneously commented that they "look[ed] nice" or were a "cool visual." None of the interviewees expressed a concern that the scenarios were too complex, which has been noted as an issue in existing studies [66]; however, also similar to existing research, the interviews uncovered additional variables that should be included in future iterations of the future climate scenarios and infographics, such as changes in winter weather and wind patterns [88].

3.6 Discussion

3.6.1 Development of Future Climate Scenarios

In general, consistent with the findings of previous research, climate change could be positive for the tourism industry in the two case study communities in this study because warmer seasonal temperatures and longer shoulder seasons could provide additional opportunities for outdoor recreation in the fall, winter and spring months. At the same time, the increased occurrence of extreme weather, storm surge, and extremely hot days could negatively impact tourism due to concerns about tourists' safety and comfort and damage to physical infrastructure. Increasing lake temperatures could be mixed in terms of its impacts, as warmer waters could beneficial for activities like beachgoing but harmful for the lake ecosystem.

Capturing this information in the form of infographics allowed for the utilization of innovative data visualization techniques that highlighted key findings from the analysis of the ensemble of AOGCMs; however, the interview results suggest that there is additional information that may need to be included in future iterations of these graphics to make them more useful and informative. For example, the infographics did not include any quantification of uncertainty in the future climate projections, discussion of any potential impacts, or presentation and evaluation of adaptation options.

3.6.2 Interviews

Most of the interviewees who participated in this study believe in both climate change and regional climate change, though many of them also believe that it is unnecessary to prepare for future climate change, even after being shown the infographics. This is not surprising given the findings of existing research. Interviewees saw climate change as being both low risk and slow-moving.

The fact that only a small fraction of interviewees stated that they were currently getting information about climate change demonstrates that there is a lack of actionable climate change science for tourism stakeholders. At the same time, the willingness of many of the interviewees (19 of 23) to engage on the subject, independent of their beliefs about climate change or its potential impacts on their business, demonstrates that there are opportunities for researchers and those in the hospitality and tourism sector to collaborate on strategies for climate change adaptation and preparedness. This research is a first step towards determining the most effective direction for this engagement process.

The results of the interviews conducted as part of this study also demonstrate that there is a challenge that exists in terms of generating information that is useful to tourism managers, given the scale at which they operate and the scale at which climate change information is able to be produced. On the one hand, the primary concern of many hospitality and tourism businesses is short-term weather (whether hourly, daily or weekly) and current lake conditions, though some also expressed interest in "longer" trends in weather, visitation patterns and general information about climate change. The challenge of how to encourage behavioral changes for a phenomena that will manifest over many years with businesses that are much more concerned with the short-term is a major one. Looking at the framing of risk information in other research areas, such as public health, may offer some potential strategies that could be explored through future research and stakeholder engagement [89].

Finally, data visualization, scenario development, and the use of infographics to present future climate projections to hospitality and tourism businesses in this study demonstrates that they are beneficial for facilitating conversations about climate change. The graphics seemed to achieve the goal of transforming complex climate change information into easily understandable future scenarios [90]. In addition, using images from each location in the infographics seemed to enhance communication with interviewees. Subsequent research could focus on exploring how the magnitude of change in different variables affects tourism managers' perceptions of climate change, as none of the interviewees discussed the figures associated with the different climate variables included in the infographic, i.e., an increase of 4 days above 90 degrees versus a general increase in the number of days above 90 degrees. Future research could also explore different mediums for displaying risk information, as different displays can influence how information is received [89]. An interactive tool such as the one created by the CSIRO and Tourism Queensland would be a logical step towards further engagement with tourism managers about climate change and adaptation.

3.7 Implications and Future Research

The findings of this work highlight many of the challenges involved in climate change communication with tourism business owners. On a basic scientific level, translating future climate change projections into actionable science is not a straightforward process. There is a balance that needs to be achieved between the complex information contained in climate models and the kinds of information that tourism managers can actually use to make decisions about the future. At this point, the capabilities of climate models to fully capture aspects of climate and weather that are important to tourism are limited, for example, when it comes to looking at extreme weather events and wind patterns at a local scale. At the same time, the level of detail contained in the infographics produced for this work facilitated conversations about climate change, though the depth of those conversations seemed to be dependent on the magnitude to which a business was impacted by weather and climate and reliant on nature-based tourism. There is obviously much more work to be done in terms of producing actionable climate change science for the tourism sector.

Another key point for this work is acknowledging the disconnect that exists between global climate change and regional or local scale impacts. Given the divisive and highly politicized nature of the discourse around climate change, a concerted effort was made to avoid the term "climate change" until the very end of the interviews (see Appendix A). It is not clear how avoiding this term affected engagement with the interviewees, especially since most of them indicated a belief in it, but it does demonstrate that it is possible to communicate about climate change and adaptive behaviors in a "politically-neutral" way. As suggested in Chapter 2, using this kind of approach, emphasizing weather preparedness and resilience, and highlighting the potential benefits of adaptation may be the smart approach to future discussions with tourism managers about climate change. In addition, taking a creative and innovative approach (data visualization) to present future climate information in a way that makes it more familiar (through the use of photographs) and easier to understand (through the use of simple icons) may help overcome some of the issues associated with relating global climate change with more regional and local scale impacts.

Finally, tourism managers' high awareness of weather, climate, and climate change should benefit communication efforts around adaptation; however, the fact that these individuals are used to dealing with weather variability and consider it to be a "normal" part of their day-to-day operations in many ways offsets this benefit. The skill to which tourism businesses are able to absorb losses due to short-term weather events and the flexibility that they have to respond to recent experiences with weather leads to an interesting question, which is whether or not tourism businesses really need to take any major actions to prepare for climate change. In the absence of a devastating extreme weather event, what would make the costs of adaptation "worth it," especially to small and medium sized businesses that have limited resources and planning capabilities? It would be interesting to explore in greater depth what "thresholds" determine adaptive action; for example, what experiences would lead a business to add a new building to increase its indoor space, i.e., make a major investment in order to reduce its vulnerability to weather? Alternatively, what experiences with the weather would lead a business to make smaller or more incremental changes to business practices? What are appropriate expectations for tourism businesses in terms of proactive adaptive behavior?

Some of the limitations of this study include its lack of generalizability and its depth in terms of communication about climate change impacts and the need for adaptation. Ideally, future research will involve additional iterations of interviews, focus groups, and other methods of communication to develop more robust and useful climate change science for tourism business owners. In terms of future scenario development work, it may be beneficial to put potential changes in climate into the context of other important tourism trends, such as visitation patterns. Conversations could also move into discussions of adaptation options for businesses and the evaluation of these different options. The infographics could also be translated from their static format into one that is more interactive or dynamic [79, 81]. In addition, there should be a larger dialogue about what the right path forward is for tourism businesses in terms of climate change adaptation. Can businesses be expected to take major proactive actions to prepare for climate change or should they be more focused on general business growth and resilience to less extreme weather events? Who or what should determine these expectations, e.g., should it be left up to individual businesses or do policymakers need to get involved? Overall, this study is just a first step towards coproducing actionable climate change science for tourism managers in the Great Lakes and a small piece to determining how the tourism industry should respond to global climate change.

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4. ASSESSING THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON WINTER WEATHER IN THE GREAT LAKES

4.1 Abstract

Perceived changes in winter weather have already started to motivate tourism professionals to adapt their businesses practices in the Great Lakes region. Existing analyses of trends in cold processes and future climate projections support these perceptions and predict further declines in cold and snow through the end of the century. Subsequently, the region's winter tourism industry could experience significant losses in the future as a result of climate change. This work builds on existing analyses of potential climate change impacts on winter tourism for the entire Great Lakes region. Changes in winter weather shown to be important to the sector have been quantified using downscaled and bias-corrected output data from general circulation models (AOGCMs) and Variable Infiltration Capacity (VIC) model simulations. The results of this work suggest that climate change could result in shorter winters, fewer cold days, and reductions in snow depths appropriate for skiing and snowboarding in the Great Lakes. In addition, spatial analyses show that these reductions will extend across the entire Great Lakes but that the region as a whole should remain viable for winter recreation and tourism through the end of the century.

4.2 Introduction

Cold season processes play an important role in the hydrology 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 [1]. Frozen soils and seasonal freeze-thaw patterns affect infiltration, soil properties, and overall land energy balances [2, 3]. Seasonal snowpack plays an important role in surface energy and water budgets, soil temperatures, surface albedo, and evapotranspiration [4–9]. Snowpack and snowmelt runoff also affect the development and replenishment of lakes and wetlands in the region [10].

Cold weather phenomena are important to many economic sectors in the Great Lakes, especially tourism. Winter tourism is highly dependent on temperature, snow cover, snowfall, and length of the snow season. In recent years, winter weather is perceived to have become less reliable by Great Lakes tourism professionals (see Chapter 2). Previous research has found 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 (see Chapter 2 and [11, 12]).

Existing analyses support tourism stakeholders' perceptions that winter weather has become less reliable in recent decades. Average winter and spring temperatures have both been increasing in the Great Lakes, while seasonally frozen ground has been decreasing over the last century, especially in the spring [6,8]. Similarly, the last spring freeze has shifted earlier in the year, leading to shorter winter seasons [13, 14]. The Great Lakes has also been experiencing shifts in precipitation from snow to rain, earlier annual snowmelt, and reductions in spring snow cover [7, 15–17].

Future climate change projections for the Great Lakes region suggest that winter weather will continue to change. Temperatures are expected to continue to increase, leading to reductions in cold spells and extremely cold days and further shortening winters [18, 19]. Increasing temperatures could also affect river and lake ice thickness and break-up [20]. Karl et al. [9] predict that decreases in snow cover could come in future decades as a result of temperature increases, despite findings that total annual snowfall will remain relatively steady [21]. The redistribution of precipitation as rain (versus snow) could lead to higher runoff and increased flooding in the region

[6, 9, 22, 23]. Increased winter and spring precipitation could also affect agricultural production by increasing soil moisture [14, 24].

Several studies have been conducted to determine how winter weather has changed in recent decades. Brown and Braaten [25] 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. Durand et al. [26] 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 depth in the French Alps from the late 1950s 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. [27] 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 athmospheric-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 [28].

In terms of climate change impacts on winter tourism specifically, Scott et al. [11, 29–31] used a snow model coupled with the Variable Infiltration Capacity (VIC) model to look at changes in snow depth 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. Durand et al. [26] and Hendrickx et al. [27] also state the potential for economic losses, specifically for ski resorts, due to decreases in snow cover duration and the amount of snow cover at elevations where these businesses typically operate.

Overall, these findings suggest that winter-based tourism businesses could face significant losses or even failure due to future climate change, particularly without some form of preparedness. While artificial snowmaking can be used to account for some decreases in snow reliability, it is a strategy that is very resource intensive, both financially and in terms of water use [32, 33]. In addition, research indicates that tourists' acceptance of artificial snowmaking is mixed [34]. Subsequently, winter tourism businesses need to be proactively preparing for potential changes in future cold and snow conditions as a result of climate change; and 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 important to tourism for the North American Laurentian Great Lakes region. Downscaled and bias-corrected climate data generated for the most recent IPCC report and VIC model simulations of snow processes have been used for this analysis. The overall objective of this work is to produce detailed information about potential climate change impacts on winter weather in the Great Lakes that is directly relevant to winter recreation and tourism and that can be incorporated into existing climate change scenarios being used to help tourism managers think about how they could be impacted by climate change and prepare for the future. In summary, the following research questions are being considered in this study:

1. How will climate change affect winter weather and winter tourism businesses in the Great Lakes through the end of the century?

2. How will climate change impacts on winter weather vary spatially and temporally?

3. What insights can be gained by using both climate model simulations and hydrologic model simulations to simulate winter processes important to winter recreation and tourism?

4.3 Methodology

4.3.1 Study Area

The North American Laurentian Great Lakes system is the largest freshwater system on Earth, containing about 20 percent of the global freshwater supply [35]. It is made up of five hydrologically connected lakes (Superior, Huron, Ontario, Michigan, and Erie) with a cumulative volume of roughly 22 quadrillion liters [36] and a drainage area of 770,000 square kilometers [37]. The Great Lakes are bordered by eight U.S. states and one Canadian providence. Across the Great Lakes region, average annual precipitation ranges from about 680 to 1190 mm and average temperature ranges from about -13 to -1 °C in January and 17 to 23 °C in July [15].

The total gross annual revenue of ski areas in Great Lakes states is $1.6 billion [38]. Snowmobiling, snowshoeing, snowboarding, and ice fishing are also popular forms of winter recreation. Overall, winter tourism provides over 52,000 jobs in Great Lakes states [12].

4.3.2 The Variable Infiltration Capactiy (VIC) Model

The VIC model is a land surface hydrology model that can be used to simulate water and energy balances for large watersheds, as well as streamflow, when paired with a routing model [39–43]. Typically, the VIC model is set up to run based on gridded locations, calculating a wide variety of output variables for each cell at the designated time step based on climate, soil, and vegetation input data. The VIC model runs based on the assumption that vertical transfers are more important than horizontal transfers in determining water and energy balances at each location at a large spatial scale, so each grid cell is resolved individually. Climate data is provided to the VIC model for, at least, daily precipitation, maximum and minimum temperature, and average wind speed for each grid cell, which was the time step used for these simulations; the model is also able to handle sub-daily time steps.

Each grid cell is comprised of a canopy layer as well as a given number of layers in the soil column. Properties of each soil layer, such as saturated hydrologic conductivity, thickness, and soil density, are provided to the model in a soil parameter file. The type of vegetation in each grid cell is similarly provided in a vegetation parameter file, which also designates root depths and monthly leaf area index values. If a grid cell contains multiple vegetation types, these are represented through a mosaic scheme. Properties of each vegetation type, such as vegetation resistance and albedo, must also be provided in a separate vegetation library file.

Once the climate data and parameter files are set up, a global control file is used to designate an additional set of parameters, such as the start and end dates for the simulations, temperature thresholds for rain and snow, and the output variables desired by the user. In addition, the user can set the algorithms that the VIC model uses to calculate aspects of the water and energy balances, such as baseflow. Since its development in the early 1990s, the VIC model has been modified to include a number of additional hydrologic processes, such as snow, frozen soils, and lakes and wetlands, as well as multiple soil levels, which can be turned on or off as needed. An example of the global control file used for the simulations completed for this work is provided in Appendix C. Much more detailed information about the VIC model can also be found at http://vic.readthedocs.io/en/master/.

In this study, the VIC model was used to simulate cold process to determine the potential impacts of climate change on winter weather in the Great Lakes. Simulations of snow depth were used to calculate the metrics described in the subsequent section. The VIC model determines changes in snow conditions through the energy balance for each individual grid cell. Snowpack is represented using a two-layer scheme with energy exchange occurring only at the surface [42,44]. For these simulations, changes in the density of snowpack were set to be calculated based on the Snow Thermal Model algorithm [45], while snow albedo was determined according to a U.S. Army Corps of Engineers algorithm [42]. Minimum and maximum temperature thresholds for rain and snow, respectively, determine the form in which precipitation falls. Values for the snow parameters used in these simulations were set according to the results of on-going model calibration and validation work.

The VIC model has been used in several different studies to examine cold processes in the Great Lakes, mostly for its western region. Sinha et al. [46] used the VIC model to examine the effects of historic climate variability on soil frost, soil temperature, and snow water equivalent in the Great Lakes, while Mishra et al. [47] and Mishra et al. [1] used the VIC model to examine historic trends in lake ice phenology. Mishra and Cherkauer [10] also used the VIC model to consider the role of cold season climate extremes and variability on the inundation extent of lakes and wetlands based on historic trends.

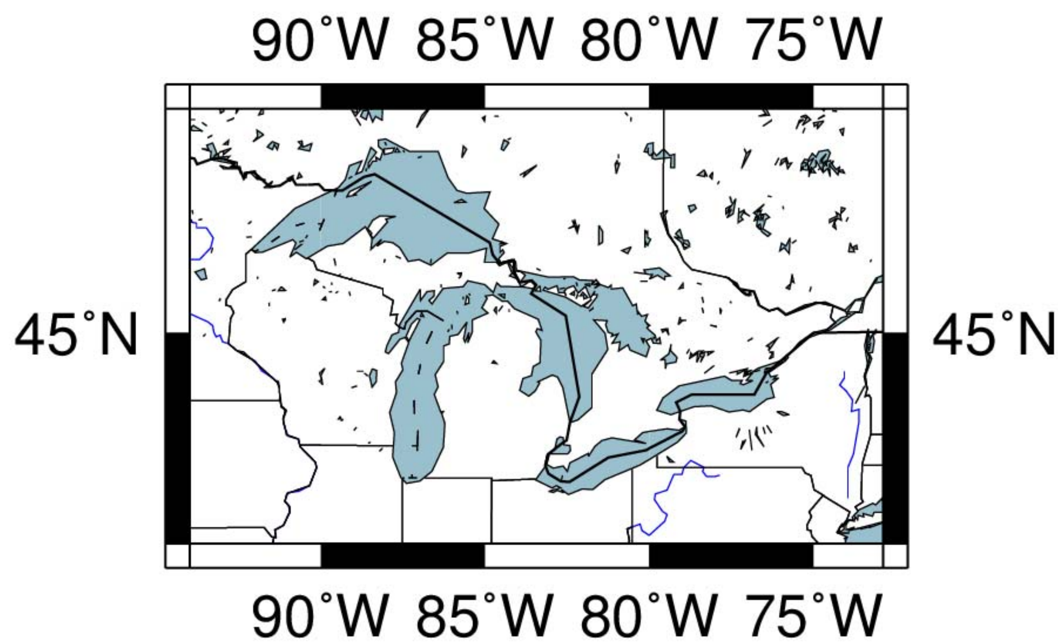


Fig. 4.1. Map of Study Region

For this study, the VIC model was set up for the entire geographical extent of the Great Lakes for 1/8° grid cells (Figure 4.1). Three soil layers were defined for this iteration of the model with soil properties for each grid cell being extracted from NASA's Land Data Assimilation Systems (LDAS) data. A total of twelve land cover types were defined for the model simulations. Values for the vegetation properties of each of these land cover types for the Midwest were previously developed by Mao and Cherkauer [48]. Land cover fractions for each grid cell were extracted from NASA's 2009 Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type product (MCD12Q1) with the International Geosphere-Biosphere Programme's (IGBP's) global vegetation classification scheme. Land use classes were reassigned to standard VIC model classes after extraction with water being removed and urban areas being represented as short grass. Elevation data for each grid cell (measured from its center) was extracted from digital elevation maps (W100N90.DEM, W100N40.DEM) made available by the U.S. Geological Survey's Earth Resources Observation and Science (EROS) Center.

4.3.3 Selection of VIC Model Climate Forcing Data

Climate forcing data for the VIC model was selected from the World Climate Research Programme's Coupled Model Intercomparison Program phase 5 (CMIP5) available data. The CMIP5 dataset is comprised of an ensemble of climate models produced through a coordinated effort by groups from around the world with the aim to meet the most major priorities of user communities (see Taylor et al. [49] for additional details).

Downscaled, bias corrected daily data for 1960-2100 from CMIP5 model runs was downloaded from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive in July and August 2016 for precipitation, maximum surface air temperature, and minimum surface air temperature. This data has been previously downscaled, bias-corrected, and gridded to a $1/8°$ resolution [50, 51]. The AOGCMs used and the modeling center or group that provides the model output are shown in Table 4.1. Daily wind data for 1960-2100 was downloaded from the Earth System Grid - Center for Enabling Technologies peer-to-peer (P2P) enterprise system.

CMIP5 model output for the 2.6 and 8.5 representative concentration pathways (RCPs) were used for the VIC model simulations completed as part of this work. These pathways represent the possible scenarios that could lead to a set of final radiative forcing trajectories, which have been determined using a combination of socioeconomic and climate factors [52]. RCP 2.6 describes a scenario in which carbon dioxide (CO_2) concentrations peak at about 490 parts per million (ppm) around the middle of the century and then decline, leading to a radiative forcing level of 2.6 W/m^2 by the end of the century [53]. RCP 8.5, on the other hand, describes a scenario in which CO_2 emissions rise to almost 1400 ppm by 2100, resulting in a radiative forcing level of 8.5 W/m^2 by the end of the century. RCP 2.6 and RCP 8.5 account for the lowest and highest levels of change in global average temperature in 2100 [52].

Table 4.1
AOGMCs and Modeling Center (or Group) Providing Model Output

AOGCM	Modeling Center (or Group)
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory
MRI-CGCM3	Meteorological Research Institute

All of the climate data used for these simulations was gridded to match the modeling region using the SYMAP algorithm and data from each grid cell's four nearest neighbors [54].

4.3.4 Selection of Variables

A review of existing literature determined the variables being used to evaluate changes in winter weather as part of this study. An emphasis was placed on variables that can most clearly highlight the potential impacts of climate change on winter recreation and tourism. One set of variables comes from the CCl/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI) extreme weather metrics [55]. These are:

- Length of winter: number of days between the first and last occurrences of at least 6 days with a daily average temperature of less than 5 °C
- Cold days: days with a daily maximum temperature of less than the 10th percentile

Percentiles for the cold days metric were calculated based on the methodology used by the U.S. National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Environmental Information and data for the historic period (1969-1999) [56]. Both of these metrics were calculated using the gridded climate data.

A second set of variables was determined based on a review of existing studies looking specifically at climate change and winter tourism, in order to ensure that this analysis would capture how climate change could impact winter tourism in the Great Lakes. Scott et al. [11] defined favorable conditions for skiing as a snow depth of 30 cm and for snowmobiling as a snow depth of 15 cm with a maximum daily temperature of less than 15 °C and a 2-day precipitation total of less than 20 mm. Kundzewicz et al. [57], on the other hand, defined appropriate snow depths for snowboarding as 30 cm and for skiing as 40 cm. Here, the Kundzewicz et al. metrics were used because Scott et al. included snowmaking in their analysis. Snowmaking has not been incorporated into the VIC model simulations completed for this work, so metrics accounting for it were deemed inappropriate for this application. This second set of variables was calculated based on simulated snow depth data from the VIC model.

In addition to looking at days with an appropriate snow depth for skiing (40 cm) and days with an appropriate snow depth for snowboarding (30 cm), two additional criteria that were used to evaluate climate change impacts on winter tourism were to: (1) determine areas that experience snow depths of at least 30 cm for over 100 days during the year and (2) evaluate average snow depths between December 22 and January 2, as both of these factors have been found to be directly related to the viability of ski resorts in existing research [11, 26]

Thirty-year averages for a historic period (1970-1999), a near future period (2020-2049), and a far future period (2070-2099) were calculated and compared for each variable, except where indicated otherwise. These averages were calculated by first finding the 30-year average for each grid cell and then computing a spatial average for the entire model domain. A year was defined as being from July 1 of the previous year to June 30 of the current year, to account for the entire winter season.

The results of this analysis are presented in the following section. For tables of annual 30-year averages, bolded values indicate those found to be significant using an unpaired t-test and a p-value of 0.05. Historical maps of 30-year averages are based on the average values for both AOGCMs. These values were also used to calculate changes between the historic period and the near and far future periods for all of the spatial analyses because the VIC model simulations were determined to be over-simulating snow depth based on a comparison of these values with simulations of snow depths using historic, observed data gridded for the study region (Table 4.2).

Table 4.2
Historic Annual 30-Year Averages for Variables Based on Simulations Using Different Sets of Gridded Climate Data

	Variable			
	Length of Winter Season	Number of Cold Days	Days for Skiing	Days for Snowboarding
Observed	164	13	35	53
GFDL-CM3	219	33	104	129
MRI-CGCM3	225	34	123	147

4.4 Results

The first variable considered is the *length of winter*. As shown in Table 4.3, both AOGCMs predict that the length of winter will decrease significantly from the historic to the future periods. Reductions in the near future period range from 9 to 23 days and in the far future period from 11 to 66 days.

Table 4.3
30-Year Averages for Length of Winter Season (in days)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
GFDL-CM3	2.6	219	**199**	**195**
MRI-CGCM3		225	**216**	**214**
GFDL-CM3	8.5	219	**196**	**153**
MRI-CGCM3		225	**214**	**191**

The AOGCMs also project that the number of *cold days* in the Great Lakes region will decrease significantly by the end of the century with the exception of the MRI-CGCM3 model for RCP 2.6 for the near future (Table 4.4). The GFDL-CM3 model predicts the number of cold days will decrease by 16 even under RCP 2.6 by the middle of the century. By the end of the century, the GFDL-CM3 model predicts even greater decreases in the number of cold days (in the case of RCP 8.5 to 0), while the MRI-CGCM3 model for RCP 8.5 predicts the number of cold days could decline by 25.

Plots illustrating spatial patterns for the number of cold days across the Great Lakes region are shown in Figures 4.2 and 4.3. Figure 4.2 shows historic 30-year annual averages in the number of cold days calculated from both AOGCMs as a reference. In agreement with the quantitative analysis, 30-year annual averages for the number of cold days could decrease by as much as 30 days in the near future and 60 days in the far future, resulting in an average of 0 cold days annually, for GFDL-CM3 (Figure 4.3, right). Predictions for the MRI-CGCM3 model follow similar spatial patterns

Table 4.4
30-Year Averages for Number of Cold Days

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
GFDL-CM3	2.6	33	**17**	**12**
MRI-CGCM3		34	31	**23**
GFDL-CM3	8.5	33	**12**	**0**
MRI-CGCM3		34	**28**	**9**

to the GFDL-CM3 model, but the reductions have a smaller magnitude across the Great Lakes (Figure 4.3, left).

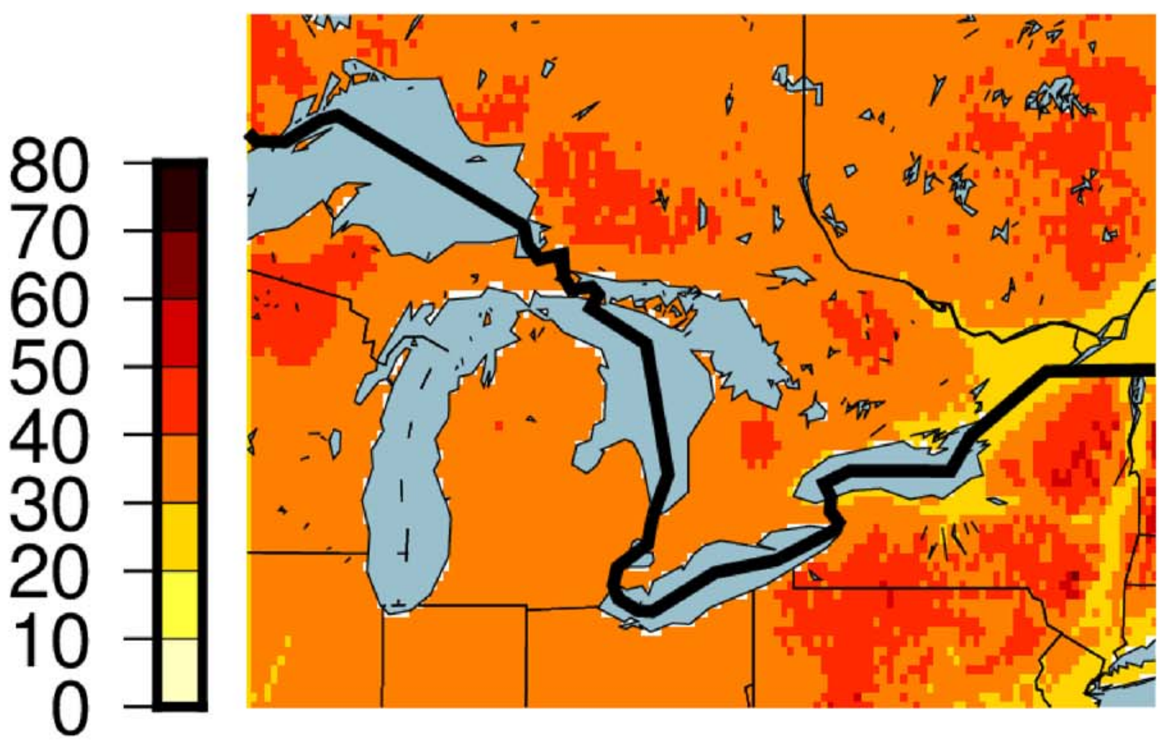
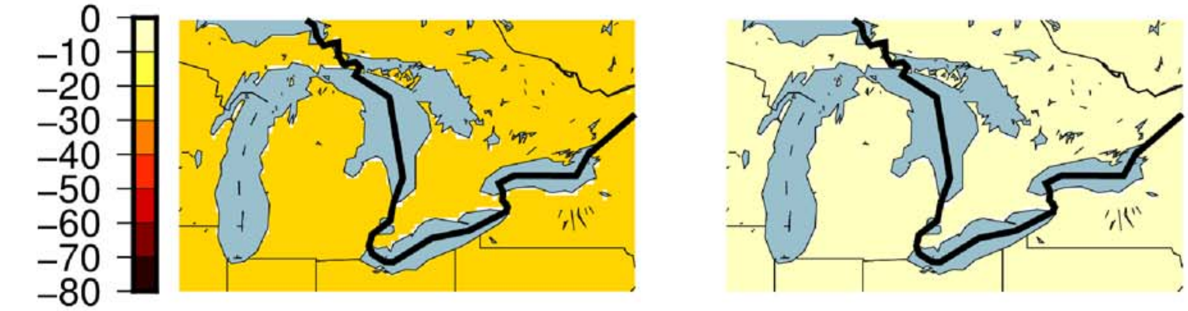
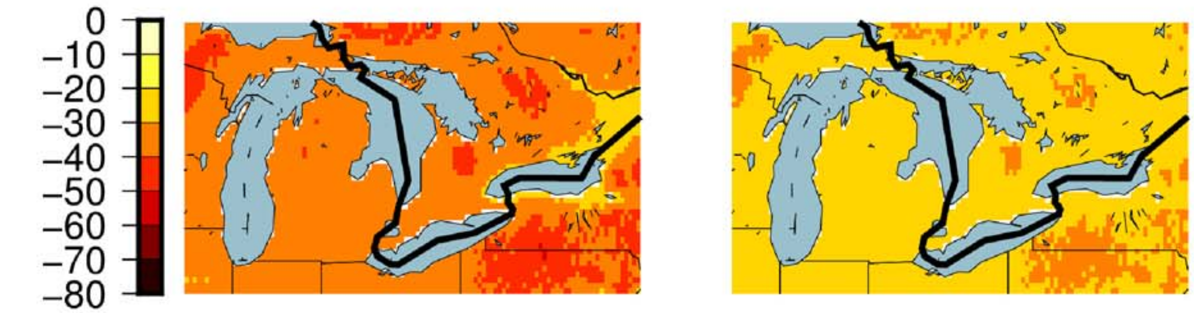


Fig. 4.2. Historic 30-Year Averages for Cold Days (in days)



(a) Historic to Near Future



(b) Historic to Far Future

Fig. 4.3. Change in Number of Cold Days for RCP 8.5 (Left: GFDL-CM3, Right: MRI-CGCM3)

In terms of *snow depth required for skiing* and *snow depth required for snowboarding*, the VIC model simulations based on the two AOGCMs predict a decrease in the number of days with appropriate snow depths for both activities with the exception of RCP 2.6 for the GFDL-CM3 model (Tables 4.5 and 4.6). For days with appropriate snow depths for skiing and days with appropriate snow depths for snowboarding, the GFDL-CM3 model for RCP 2.6 predicts a drop of 2 days for skiing and 3 days for snowboarding in the near future, followed by an increase of 10 days for skiing (a net change of +8 days) and an increase of 7 days for snowboarding (a net increase of 4 days) in the far future. Otherwise, the AOGCMs predict that days with an appropriate snow depth for skiing could decrease by as much as 26 and days with an appropriate snow depth for snowboarding could decrease by as much as 32.

Table 4.5
30-Year Averages for Number of Days with an Appropriate Snow Depth for Skiing

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
GFDL-CM3	2.6	104	102	112
MRI-CGCM3		123	122	116
GFDL-CM3	8.5	104	105	**78**
MRI-CGCM3		123	117	**107**

Table 4.6
30-Year Averages for Number of Days with Appropriate Snow Depth for Snowboarding

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
GFDL-CM3	2.6	129	126	133
MRI-CGCM3		147	146	138
GFDL-CM3	8.5	129	128	**97**
MRI-CGCM3		147	139	**126**

Changes in the number of days with appropriate snow depths for snowboarding also demonstrate spatial variations. Figure 4.4 provides the historical 30-year averages in the number of days with appropriate snow depths for snowboarding. In terms of 30-year averages for the number of days with an appropriate snow depth for snowboarding, the GFDL-CM3 model for RCP 8.5 predicts that, while some parts of the region could see reductions of up to 30 days, other parts could see declines of up to 60 days (Figure 4.5, right). The MRI-CGCM3 model for RCP 8.5 demonstrates similar spatial patterns to the GFDL-CM3 model but generally predicts the occurrence of a greater number of days with snow depths appropriate for skiing (Figure 4.5, left).

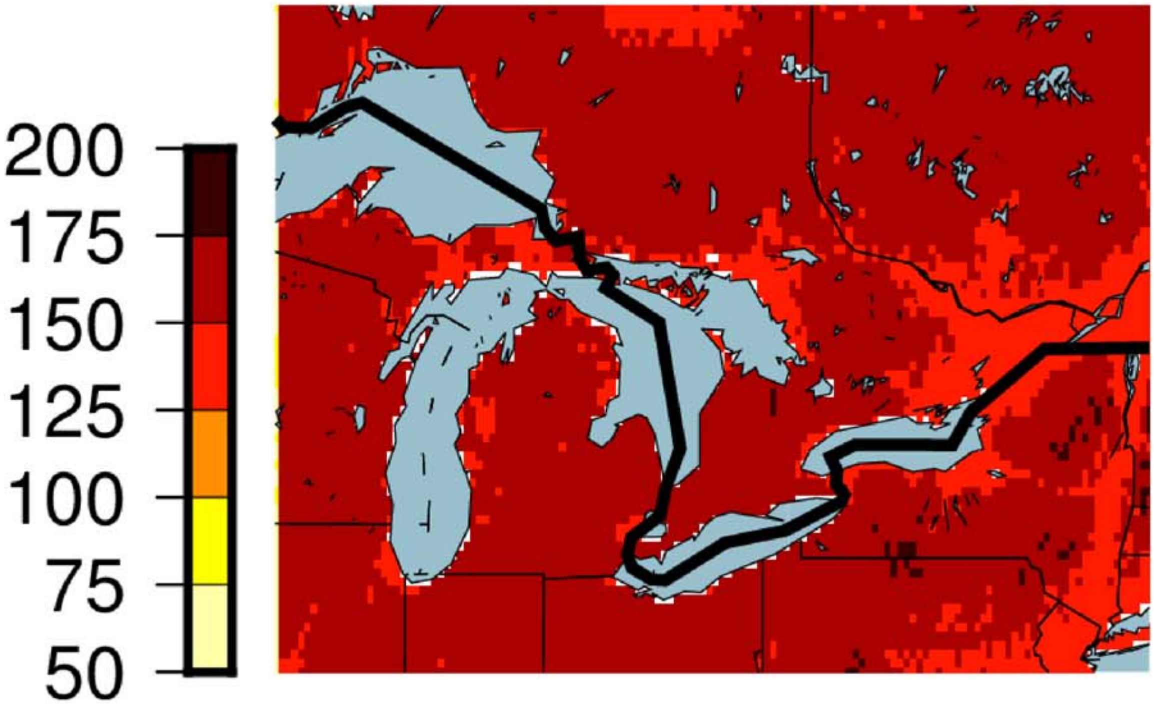
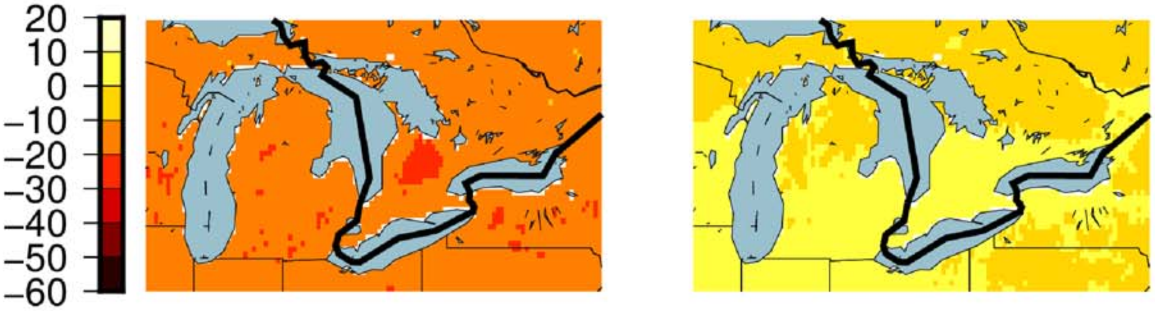


Fig. 4.4. Historic 30-Year Averages for Days with an Appropriate Snow Depth for Snowboarding

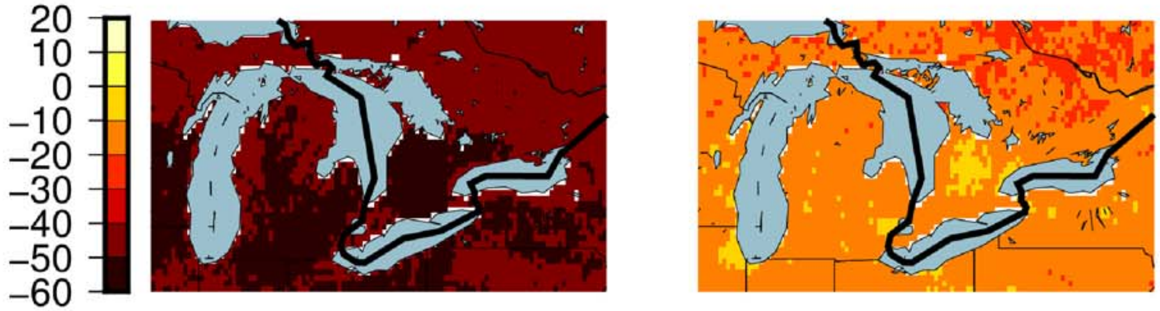
At the end of the century, these AOGCMs predict that the Great Lakes region will still experience close to (or more than) 100 days annually, on average, with snow depths of at least 30 cm. However, the GFDL-CM3 model predicts that the region will approach this threshold by the end of the century. Overall, these results suggest that the region will still remain viable for winter recreation and tourism.

4.5 Discussion

The AOGCMs analyzed in this study predict that cold weather in the Great Lakes region could decline noticeably by the end of the century as a result of climate change. While snow depths remain above the thresholds necessary to support winter recreation



(a) Historic to Near Future



(b) Historic to Far Future

Fig. 4.5. Change in Number of Days with an Appropriate Snow Depth for Snowboarding for RCP 8.5 (Left: GFDL-CM3, Right: MRI-CGCM3)

and tourism through the end of the century, the decrease in the length of the cold season presents obvious problems for the long-term sustainability of winter tourism businesses, as revenues will need to be made during timeframes that are shortened by up to two months. Businesses may be able to compensate for some shortening of operating season length by hiring fewer staff or planning to open and close at later or earlier dates, respectively; however, this would also likely stifle business growth over time.

The reduction in cold days, in this case days where the maximum daily temperature is less than the 10th percentile, may be of some benefit to Great Lakes tourism businesses, as customers may feel more inclined to participate in recreation and other outdoors activities on winter days where temperatures are warmer; however, whether or not these gains will overcome other losses from the reduction in cold temperatures is unknown. As shown in the results section, the number of cold days could fall to 0 or decrease by as much as month by the end of century across the Great Lakes, which could subsequently lead tourists to travel to other regions where cold and snow are perceived to be more reliable for longer durations during the year. Business failure or relocation could result from these trends, which would not only affect individual businesses but also the communities in which they are located.

When it comes to the number of days with snow depths appropriate for skiing and snowboarding, the AOGCMs for RCP 2.6 do not predict statistically significant changes. This is likely because RCP 2.6 predicts that emissions levels will decline by the end of the century and result in an overall warming of only 1.5 °C in 2100 [58]. For this scenario to come true, however, it would require global cooperation to immediately and drastically reduce CO_2 emissions, technological innovation, and reductions in non-CO_2 gases, which seem unlikely to occur in the near future [59]. RCP 8.5 is not only stastically significant for changes from the historic to far future period but may also be more realistic given that it represents a business as usual approach to climate change [60]. As shown in Tables 4.5 and 4.6, the AOGCMs predict that the number of days appropriate for skiing and snowboarding could decline by several weeks to several months in the Great Lakes region under RCP 8.5. These losses will likely require more drastic action from skiing and snowboarding-related businesses, as well as other nature-based winter tourism businesses, such as a diversification in winter offerings or an expansion of summer operations, to make up for less-reliable snow cover. As previously discussed in Chapter 2, there is evidence that some businesses in the Great Lakes are already taking these kinds of actions to respond to perceived reductions in snow reliability.

Spatial analyses of changes in 30-year averages for days with snow depths appropriate for snowboarding show that some states, like Michigan, could experience significant losses in terms of reliable snow cover for winter tourism and recreation by the middle of the century. By the end of the century, however, even under RCP 8.5, the region remains viable for winter recreation and tourism, as 30-year averages for days with snow depths of at least 30 cm remain above 100 days. Whether tourism businesses will choose to try and maintain their winter sports offerings given greater uncertainty in winter weather will be an important trend to monitor in the coming decades.

In general, the use of the VIC model to simulate changes in snow depths provides additional insights into how climate change could not only impact winter weather but also the tourism businesses that rely on it in the Great Lakes. While the AOGCMs were able to capture reductions in the length of the winter season and the number of cold days annually, the VIC model allowed for the visualization of spatial changes in snow depths, which could be helpful in future communications about climate change impacts with tourism business owners in the Great Lakes. Some possible next steps for this analysis would be to incorporate snow-making into these VIC model simulations, as done by Scott et al. [11], and to use the model to simulate processes that are important to other forms winter recreation and tourism activities, such as ice cover for ice fishing and measures of appropriate snow depths for snowboarding.

Overall, these findings are similar to those found by Scott et al. [11], but the magnitude of reductions in reliable ski areas are not as drastic as those predicted in their study. Scott et al. [11] is focused on the Northeastern United States and uses a different emissions scenario regime than this analysis, but one might predict, based on their results, that locations to the south would experience major losses in reliable snow cover. The metrics used here may not be capturing the full extent to which snow cover reliability could change in the future. Looking at fluctuations in snow depths around certain threshold snow depths (such as 30 cm) may better capture climate change impacts on winter weather in the Great Lakes. Comparing these results to VIC model simulations run based on historic, observed gridded climate data also show that these AOGCMs are generally over-simulating snow depths. Additional work to calibrate and validate the model and bias-correct the input data is needed to ensure that these simulations are realistic.

4.6 Implications and Future Research

The results of this work suggest that the impacts of climate change could be significant for winter tourism businesses in the Great Lakes, although the predicted magnitude of these impacts in this study, especially in the near future, may not be enough to encourage businesses that are used to operating on relatively short timescales to take action to prepare for the future. While there are some businesses that are already adapting to perceived reductions in the reliability of winter weather in the Great Lakes, it is unlikely that businesses that are less vulnerable to winter weather will be motivated to act. This analysis does, however, provide additional information that could be helpful for future communications with tourism business owners about climate change, as it provides information that can be easily summarized for different locations and quantifies changes that are directly relevant to winter tourism.

There are a number of directions in which this work could continue. When it comes to input data from the AOGCMs, better bias-correction of input data should take place to account for the model oversimulating snow depths. In addition, more advanced methods of downscaling and bias-correction should be applied to the input data to ensure that the results are acceptably simulating cold processes. The potential use of historic snow data from the National Snow and Ice Data Center to further calibrate and validate the VIC model is currently being explored, as well. Adding additional AOGCMs to this analysis could also help capture the range of possible climate change impacts on winter weather, as the two models used here demonstrated noticeable differences in the variables being considered for both the historic and future periods.

When it comes to understanding how climate change could impact tourism businesses, considering predicted changes in snow depths based on elevation has been shown to be important in existing research. Tourism businesses operating at different elevations may require different snow depths depending on their offerings, cross-country skiing versus downhill skiing, for example. Correlating changes in winter weather more closely with the locations of ski resorts, more thoroughly examining climate change impacts within the context of snowmaking or other adaptation strategies, further exploring how changes in winter weather directly relate to economic revenue, and using spatial maps like the ones generated here to communicate with tourism businesses owners are all future research directions that could provide important insights into how to help winter tourism businesses owners prepare for climate change. Metrics could also be added to evaluate how climate change could impact other winter sports, such as ice fishing and snowmobiling. Overall, this study comprises just a small part of the possible work that could be done to evaluate the long-term sustainability of the winter tourism sector in the Great Lakes.

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5. ASSESSING THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON EXTREME WEATHER EVENTS IN THE GREAT LAKES

5.1 Abstract

Climate change impacts on extreme weather events could have major implications for the global hospitality and tourism sector, as demonstrated by recent natural disasters. Understanding and quantifying the impacts of climate change on extreme weather events at a regional scale and providing this information to tourism managers in a useful way could help them with future planning and climate change adaptation efforts. This work explores trends in extreme precipitation and temperature events for North America's Laurentian Great Lakes region, as these types of events are of major concern to business owners and are already perceived to be changing. The results of this analysis demonstrate that climate change could have significant impacts on tourism in the Great Lakes when it comes to extreme precipitation and temperature events. Increases in extreme precipitation events will likely continue to negatively impact tourism businesses, while increases in extreme temperatures could benefit certain forms of tourism and hurt others. Key limitations to this work that should be addressed through future research are also discussed.

5.2 Introduction

Notable weather events in the United States over the last few years, such as Superstorm Sandy, Hurricane Isaac, and the Midwestern drought, have demonstrated the widespread impact that natural disasters can have on human populations [1–3]. The Intergovernmental Panel on Climate Change (IPCC) defines extreme weather events as the "occurrence of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable" [4]. The IPCC states that climate change is expected to affect the "frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and [could] result in unprecedented extreme weather and climate events" [4].

Research has shown a marked increase in the total monetary damages caused by extreme weather events over the last few decades, though not all of this can be attributed to climate change [5–7]. Extreme weather events can affect every aspect of human life and all economic sectors, including the hospitality and tourism sector. Some of the ways that extreme weather events affect tourism include impacts on tourists' and tourism professionals' health and safety, the physical infrastructure and natural resources that support the sector, visitors' decisions travel to a given destination and their satisfaction with their travel experience, and the overall image of a given destination [8–10].

Costs for tourism businesses located in countries recently impacted by extreme weather events range from hundreds of millions to billions of dollars and, in some cases, have lasted for many years beyond the actual event [11]. For example, the 2014 earthquakes in Nepal resulted in extensive trip cancellations and economic losses for the country's tourism sector [12]. Similarly, the 2004 Indian Ocean tsunami resulted in steep drops in tourist travel to Southern Thailand. In the United States, Superstorm Sandy caused about $950 million in estimated losses in tourism spending for New Jersey alone in 2012 [13].

Subsequently, the importance of understanding and quantifying the impacts of climate change on extreme weather events for the tourism sector is evident; however, there are significant limitations to understanding what the impacts of these events will be on regional and local scales. While scientists are highly confident that climate change will affect extreme weather events in the coming century because of their sensitivity to climate variability, it is impossible to determine exactly how these events will be distributed, both spatially and temporally [14–20]. In addition, it is extremely difficult to attribute single events to climate change because they are rare and also occur under natural climate conditions [14, 16, 17, 21].

Based on previous research, however, it is also known that tourism business owners are concerned about heavy rain and storm events and unseasonably cold or hot temperatures, which can both be investigated further using existing climate change projections (see Chapters 2 and 3). Changes in extreme heat and the length of the shoulder seasons are also important to these individuals (see Chapter 2). The purpose of this research is to explore how climate change impacts on extreme weather events in North America's Laurentian Great Lakes region could impact the region's tourism sector. Historical and future climate data is used to quantify trends in extreme weather events in the region with a focus on annual and seasonal variations. The focus of this research is on the following three research questions:

- How will climate change affect the frequency, duration, and severity of extreme precipitation and temperature events in the Great Lakes through the end of the century?
- How will climate change impacts on extreme weather events vary spatially and temporally across the Great Lakes region?
- How could these impacts vary in importance based on the type of tourism business?

5.3 Methods and Data

5.3.1 Study Area

Background information about the Great Lakes is provided in detail in Chapter 4. In general, future climate projections suggest that the region will experience a number of changes in terms of its weather and climate patterns over the next century. For example, it is likely to experience rapidly increasing winter temperatures and large temperature changes in the summer months [22]. In addition, there are likely to be changes in precipitation patterns, such as a decline in annual and spring snowfall, an increase in lake effect snow, and an overall increase in precipitation [23–27]. Extreme weather events, such as droughts, floods, and heat waves, are likely to become more intense in the Great Lakes as a result of climate change [23, 24, 28, 29]. For example, extreme precipitation events are predicted to rise significantly by the end of the 21st century [30–33] and, in some cases, at a greater level compared to other parts of the United States [34].

5.3.2 General Circulation Model (AOGCM) Data

Detailed information about the general circulation models (AOGCMs) and representative concentration pathways (RCPs) used in this analysis is provided in Chapter 4. Downscaled and bias-corrected climate data from the same AOGCMs and RCPs are used for this study. Output from the Canadian Centre for Climate Modelling and Analysis' CanESM2 model was similarly prepared and used for this work.

5.3.3 Selection of Variables

The following metrics were selected for evaluating changes in extreme weather events in the Great Lakes based on the methods and findings of a number of different studies looking at extreme weather events:

- Rain and Heavy Storms
  - Simple Daily Intensity Index: annual total precipitation divided by the number of wet days [35]
  - Fraction of Total Precipitation from 95th Percentile Events [35]
  - Maximum 5-Day Precipitation Total [35]
  - Number of 2-Day Heavy Precipitation Events (over 160mm) [36]
  - Number of 1-Day Heavy Precipitation Events (over 80mm) [37]

- Extreme and Unseasonable Temperatures
  - Heat Wave Duration Index: maximum period of at least 5 consecutive days with a maximum temperature higher than the normal by at least 5 °C [35]
  - Warm Nights: percentage of days when the minimum temperature is above the 90th percentile [35]
  - Warm Days: percentage of days when the maximum temperature is above the 90th percentile [38]
  - Cool Nights: percentage of days when the minimum temperature is less than the 10th percentile
  - Cool Days: percentage of days when the maximum temperature is less than the 10th percentile [38]
  - Tropical Nights: days when the minimum temperature is above 20 °C [38]
  - Summer Days: days when the maximum temperature is above 25 °C [38]

These metrics allow for the consideration of changes in the variability of climate rather than just its mean state, which is necessary to understand overall trends in extreme weather events [20,39,40]. These metrics also provide information necessary to understand the overall climate conditions that surround the occurrence of extreme weather events. For example, studies of heat waves have shown that overnight temperatures are important predictors of the intensity of an event's impacts on human populations rather than just high temperatures [41]. Additionally, these metrics have been selected based on existing studies looking at extreme weather events specifically in the Midwest, where possible. For example, a study of flooding in the United States showed that 2-day heavy precipitation events is one of the better predictors of Midwest flooding, compared to other metrics and other regions [36].

Thirty-year averages for the historic period (1969-1999), a near future period (2019-2049), and a far future period (2070-2099) were calculated and compared for each variable using all three sets of downscaled AOGCM data and each RCP. As with

Chapter 4, these averages were calculated by first finding the 30-year average for each grid cell and then computing a spatial average for the entire model domain, except where indicated otherwise. Variables were calculated based on annual values as well as seasonal values. A year was defined as being from September 1 of the previous year to August 31 of the current year. December, January and February were designated as winter; March, April and May were designated as spring; June, July and August were designated as summer; and September, October and November were designated as fall.

The results of this analysis are presented in the following section. For tables of annual 30-year averages, significant values, determined using an unpaired t-test and a significance level of p = 0.05, are shown in bold. For tables of seasonal 30-year averages, bold values are ones that were found to be significant for all three models for the indicated RCP. Historical maps of 30-year averages are based on the average values for all three GMCs and were the values used to calculate changes between the historic periods and the near and far future periods for all of the spatial analyses.

5.4 Results

In terms of the simple daily intensity index, annual 30-year averages calculated from all three AOGCMs and both RCPs predict an increase in the ratio of total precipitation to the number of days with precipitation in the near future and the far future (Table 5.1). In general, this is due to an increase in total annual precipitation rather than an increase in the number of wet days (see Tables 5.2 and 5.3). On a seasonal basis, the AOGCMs generally predict an increase in 30-year averages for the simple daily intensity index, but this change is only significant across all three AOGCMs in the far future for the winter and spring for RCP 8.5 (Table 5.4). On the other hand, the AOGCMs predict a significant decrease in the simple daily intensity index for the fall in the far future for RCP 2.6.

Table 5.1
Annual 30-Year Averages for Simple Daily Intensity Index (in mm/wet day)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	2.52	**3.15**	**3.04**
GFDL-CM3		2.62	**3.24**	**3.00**
MRI-CAOGCM3		2.76	**2.88**	**3.00**
CANESM2	8.5	2.52	3.01	**3.05**
GFDL-CM3		2.62	**3.33**	**3.34**
MRI-CAOGCM3		2.76	**2.44**	**3.62**

Table 5.2
Annual 30-Year Averages for Total Precipitation (in mm)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	682.38	**868.26**	**812.34**
GFDL-CM3		705.75	**878.98**	**788.78**
MRI-CAOGCM3		728.28	**773.54**	**798.10**
CANESM2	8.5	682.38	**823.55**	**826.54**
GFDL-CM3		705.75	**898.62**	**908.17**
MRI-CAOGCM3		728.28	**658.41**	**966.24**

When it comes to the fraction of total precipitation coming from 95th percentile events, both the CANESM2 model and the GFDL-CM3 model predict significant changes in annual 30-year averages in the near future for RCP 2.6 (Table 5.5). The GFDL-CM3 model also predicts a significant change in the near future for RCP 8.5.

Table 5.3
Annual 30-Year Averages for Wet Days (in days)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	268.73	274.09	265.43
GFDL-CM3		265.13	266.75	261.93
MRI-CAOGCM3		262.03	264.71	263.34
CANESM2	8.5	268.73	**270.90**	**268.87**
GFDL-CM3		265.13	268.93	270.68
MRI-CAOGCM3		262.03	268.55	264.69

Table 5.4
Seasonal 30-Year Averages for Simple Daily Intensity Index (in mm/wet day)

Season	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
Winter	2.6	2.70	2.90	3.13
Spring		2.66	2.71	2.78
Summer		2.69	2.93	2.94
Fall		2.82	2.66	**2.65**
Winter	8.5	2.70	2.71	**3.16**
Spring		2.66	2.56	**3.09**
Summer		2.69	2.81	3.04
Fall		2.82	2.81	3.09

All three AOGCMs predict significant changes in the far future for both RCPs. On a seasonal basis, only changes in 30-year averages in the far future for winter and spring for RCP 8.5 were found to be significant across all three AOGCMs (5.6).

Table 5.5
Annual 30-Year Averages for Fraction of Total Precipitation from 95th Percentile Events

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	0.28	**0.39**	**0.41**
GFDL-CM3		0.34	**0.36**	**0.39**
MRI-CAOGCM3		0.29	0.35	**0.40**
CANESM2	8.5	0.28	0.35	**0.28**
GFDL-CM3		0.34	**0.42**	**0.41**
MRI-CAOGCM3		0.29	0.28	**0.44**

Thirty-year annual averages for maximum 5-day precipitation totals are predicted to increase significantly for the GFDL-CM3 model and MRI-CAOGCM3 model in the near future and the far future for both RCPs (Table 5.7). The CANESM2 model also predicts significant increases in annual 30-year averages for maximum 5-day precipitation totals for both future periods for RCP 8.5. Seasonal changes in 30-year averages for maximum 5-day precipitation totals were only found to be significant across all three AOGCMs in the winter, spring and fall in the far future for RCP 8.5.

Spatial patterns for historic 30-year averages in maximum 5-day precipitation totals and percent changes in these totals between the historic and both future periods for RCP 8.5 are shown in Figures 5.1 and 5.2, respectively. The 30-year historic averages for the maximum amount of precipitation from 5-day events calculated from all three AOGCMs are shown in Figure 5.1 as a reference. In the near future, the CANEM2 model predicts a 20 to 30 percent increase, the GFDL-CM3 model a 70 to 80 percent increase, and the MRI-CAOGCM3 model a 0 to 10 percent decrease

Table 5.6
Seasonal 30-Year Averages for Fraction of Total Precipitation from 95th Percentile Events

Season	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
Winter	2.6	0.29	0.41	0.37
Spring		0.29	0.34	0.33
Summer		0.32	0.33	0.35
Fall		0.32	0.31	0.32
Winter	8.5	0.29	0.33	**0.43**
Spring		0.29	0.31	**0.43**
Summer		0.32	0.33	0.36
Fall		0.32	0.35	0.41

Table 5.7
Annual 30-Year Averages for Maximum 5-Day Precipitation Totals (in mm)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	37.94	53.04	59.94
GFDL-CM3		44.71	**51.40**	**52.48**
MRI-CAOGCM3		42.07	**45.65**	**56.42**
CANESM2	8.5	37.94	**67.22**	**47.43**
GFDL-CM3		44.71	**67.67**	**52.42**
MRI-CAOGCM3		42.07	**39.50**	**58.11**

for RCP 8.5 in maximum 5-day precipitation totals across the study region (Figure 5.2(a)). In the far future, the CANEM2 model, again, predicts a 20 to 30 percent

Table 5.8
Seasonal 30-Year Averages for Maximum 5-Day Precipitation Totals

Season	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
Winter	2.6	42.71	48.33	55.49
Spring		40.51	46.05	51.29
Summer		47.76	53.89	48.48
Fall		49.05	42.82	46.76
Winter	8.5	42.71	44.86	**52.51**
Spring		40.51	43.37	**55.74**
Summer		47.76	47.65	46.11
Fall		49.05	51.97	**57.79**

increase, the GFDL-CM3 model a 0 to 40 percent increase, and the MRI-CAOGCM3 model a 50 to 60 percent decrease for RCP 8.5 in maximum 5-day precipitation totals across the study region (Figure 5.2(b)).

Changes in 30-year annual averages for the heat wave duration index predict significant increases in the length of heat waves through the end of the century for all three AOGCMs and both RCPs, with the exception of the MRI-CAOGCM3 model in the far future for RCP 2.6 (Table 5.9). The largest increase in the heat wave duration index is predicted by the GFDL-CM3 model for RCP 8.5, which suggests that heat waves could more than double in length by the end of the century. Increases in heat wave duration are also predicted for both RCPs across all seasons in the far future (Table 5.10). These increases are also significant in the near future for the summer and fall and the far future for the spring, summer, and fall.

All three AOGCMs for both RCPs predict a significant increase in 30-year annual averages in the number of summer days (days where the maximum temperature is

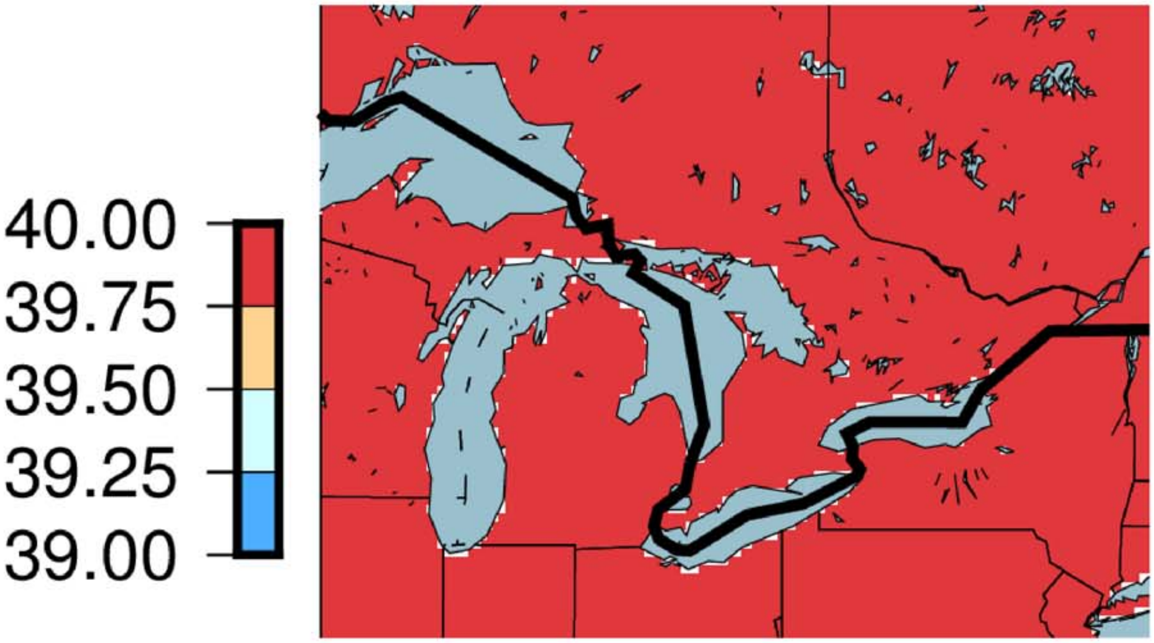
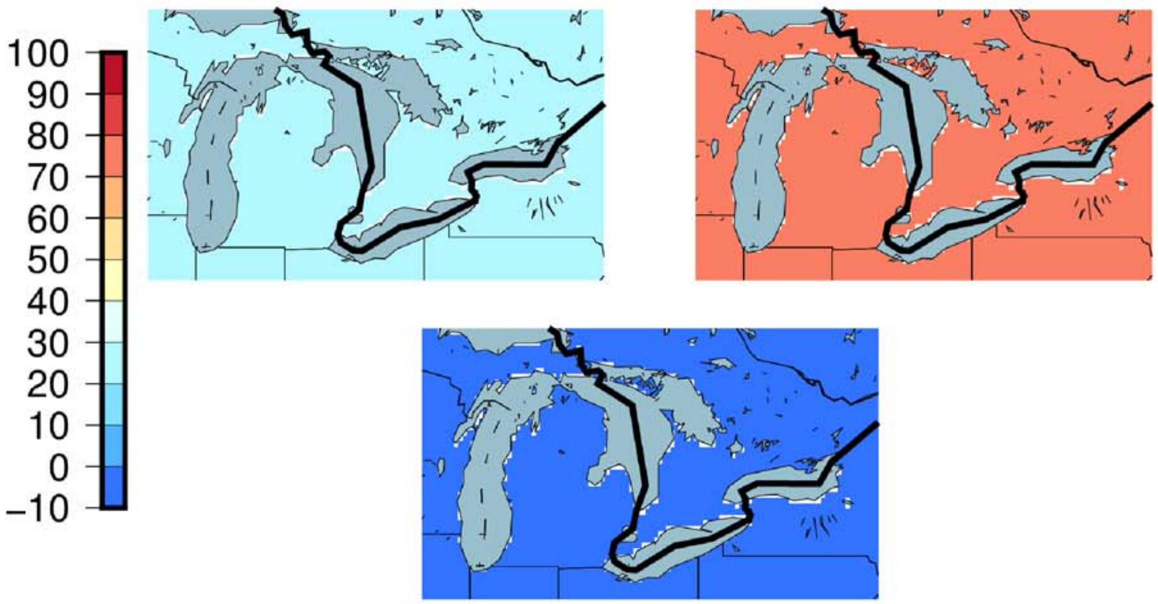


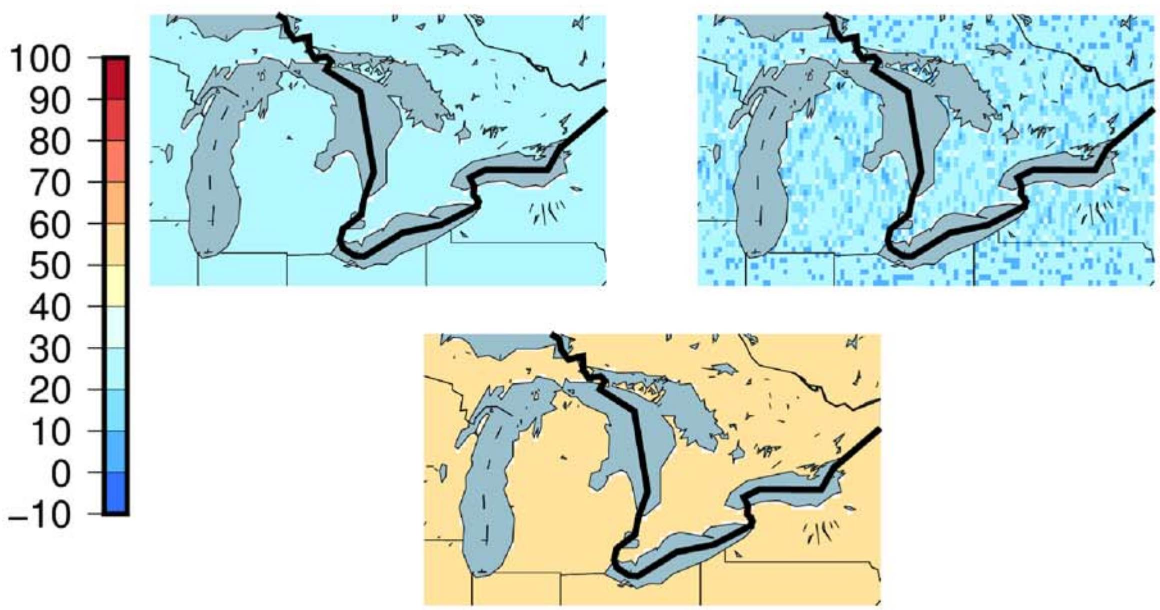
Fig. 5.1. Historic 30-Year Averages for Maximum 5-Day Precipitation Events (in mm)

Table 5.9
Annual 30-Year Averages in Heat Wave Duration Index (in days)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	36.77	**45.40**	**49.70**
GFDL-CM3		38.23	**47.41**	**50.73**
MRI-CAOGCM3		43.64	**45.54**	**41.97**
CANESM2	8.5	36.77	**41.03**	**58.74**
GFDL-CM3		38.23	**48.14**	**81.56**
MRI-CAOGCM3		43.64	**47.63**	**49.56**



(a) Historic to Near Future (Top Left: CANESM2, Top Right: GFDL-CM3, Bottom: MRI-CAOGCM3)



(b) Historic to Far Future (Top Left: CANESM2, Top Right: GFDL-CM3, Bottom: MRI-CAOGCM3)

Fig. 5.2. Percentage Change in 30-Year Averages for Maximum 5-Day Precipitation Events

Table 5.10
Seasonal 30-Year Averages for Heat Wave Duration Index for the GFDL-CM3 Model for RCP 8.5 (in days)

Season	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
Winter	2.6	36.85	43.60	**47.40**
Spring		11.18	48.43	**51.82**
Summer		35.72	**43.77**	**43.99**
Fall		35.11	**44.61**	**50.35**
Winter	8.5	36.85	40.13	**64.12**
Spring		11.18	**44.45**	**67.93**
Summer		35.72	**45.09**	**66.30**
Fall		35.11	**44.19**	**72.16**

over 25 °C) in the near and far future periods, except the GFDL-CM3 model for RCP 2.6, which predicts a significant decrease in the far future (Table 5.11). The GFDL-CM3 model for RCP 8.5 predicts the greatest increase in the number of summer days by the end of the century, an increase of nearly 1000 percent.

Fewer of the AOGCMs predict a significant increase in 30-year annual averages in the number of tropical nights (days where the minumum temperature is over 20 °C) in the near and far future periods (Table 5.12). Only the CANESM2 model predicts significant increases in the near and far future periods for both RCPs; however, all three AOGCMs predict significant increases for RCP 8.5. Once again, the GFDL-CM3 model for RCP 8.5 predicts the greatest increase in the number of tropical nights for the far future, with an increase in the number of days of over 2 weeks.

Seasonal changes in 30-year averages for the number of summer days and summer nights were only significant across all three AOGCMs for the summer season (Table 5.12). The number of summer days in the summer months (June, July and August)

Table 5.11
Annual 30-Year Averages in Summer Days (in days)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	10.72	**13.54**	**24.40**
GFDL-CM3		6.18	**16.39**	**5.05**
MRI-CAOGCM3		7.67	**13.28**	**16.81**
CANESM2	8.5	10.72	**20.07**	**41.19**
GFDL-CM3		6.18	**26.99**	**63.97**
MRI-CAOGCM3		7.67	**12.85**	**24.30**

Table 5.12
Annual 30-Year Averages in Tropical Nights (in days)

Model	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
CANESM2	2.6	0.03	**0.81**	**1.56**
GFDL-CM3		0.00	0.00	0.00
MRI-CAOGCM3		0.38	0.00	**0.64**
CANESM2	8.5	0.03	**0.58**	**2.59**
GFDL-CM3		0.00	**0.07**	**15.55**
MRI-CAOGCM3		0.38	**0.47**	**2.28**

across all three AOGCMs, on average, is predicted to increase over 5 times for RCP 2.6 and over 10 times for RCP 8.5 by the end of the century. The number of tropical nights in the summer months across all three AOGCMs, on average, is predicted to increase by up to a week by the end of the century, according to RCP 8.5.

Table 5.13
Summer Seasonal 30-Year Averages (in days)

Variable	RCP	Time Period		
		Historic (1969-1999)	Near Future (2019-2049)	Far Future (2069-2099)
Summer Days	2.6	3.95	**18.42**	**25.74**
	8.5	3.95	**14.98**	**51.36**
Tropical Nights	2.6	0.00	**0.32**	**1.27**
	8.5	0.00	**0.51**	**7.13**

A spatial plot of historic 30-year annual averages of summer days, as measured in terms of the number of weeks, is shown in Figure 5.3. Figure 5.4 shows changes in the number of weeks of summer days for RCP 8.5 for all three AOGCMs between the historic and future periods. The GFDL-CM3 model predicts that the number of weeks of summer days could increase by 2 to 4 in the near future (Figure 5.4(a), top right) and up to 10 in the far future (Figure 5.4(b), top right). The CANESM2 and MRI-CAOGCM3 models predict a lesser magnitude of change in terms of the number of weeks of summer days but still predict increases of up to 7 weeks and 3 weeks, respectively, by the end of the century (Figure 5.4(b), top left and bottom).

Spatial plots of historic 30-year annual averages for tropical nights and changes in the number of tropical nights for RCP 8.5 for all three AOGCMs between the historic and far future period are shown in Figures 5.5 and 5.6, respectively. As discussed above, the CANESM2 model and the MRI-CAOGCM3 model predict changes of less than 5 days, on average, in the number of tropical nights, while the GFDL-CM3 model predicts changes of up to a few weeks by the end of the century.

None of the AOGCMs predicted significant changes in annual or seasonal 30-year averages for heavy 1-day or 2-day precipitation events through the end of the century, so those results have been omitted from this analysis. Similarly, none of the AOGCMs

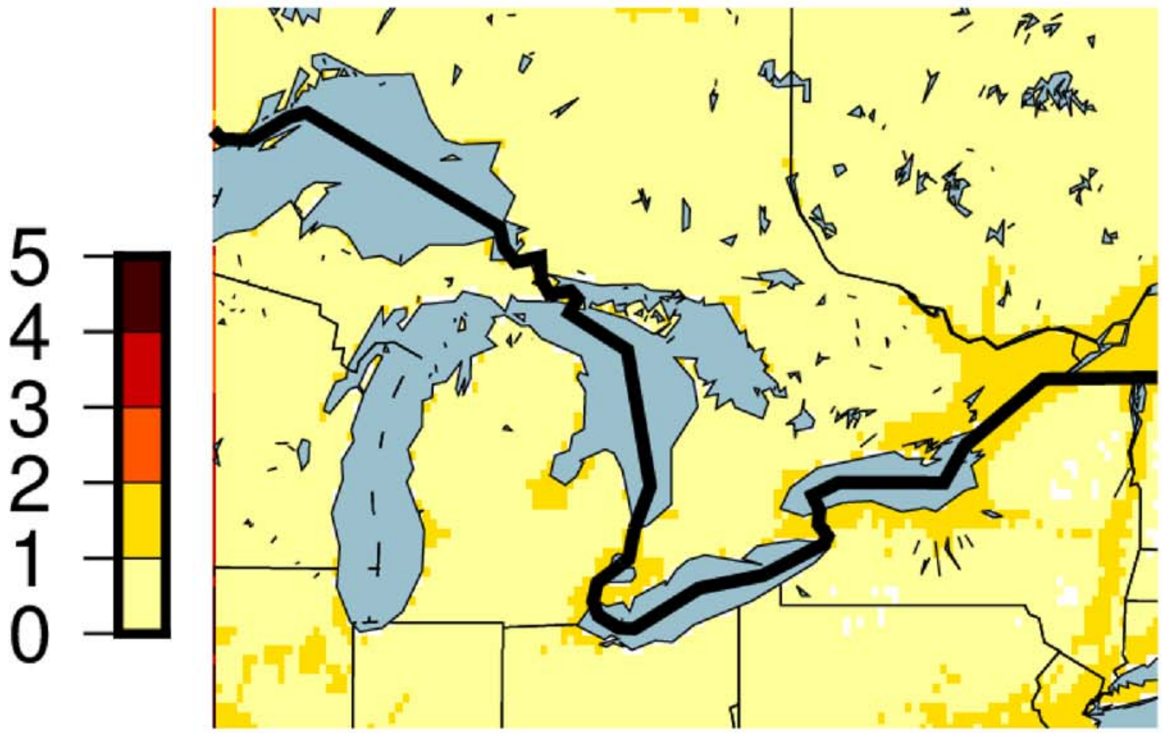
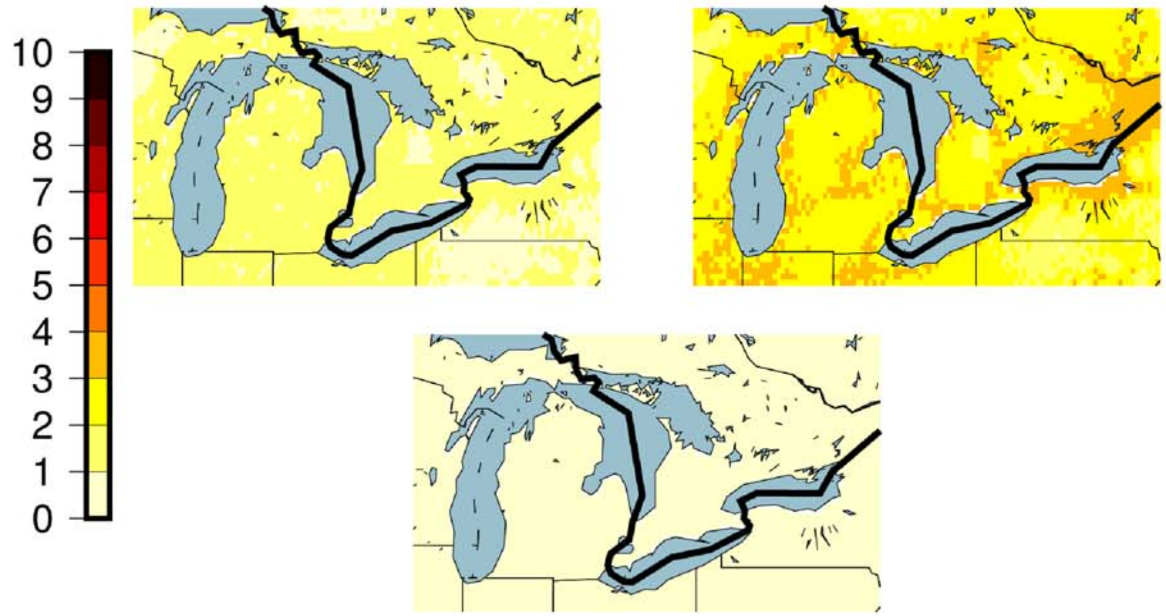


Fig. 5.3. Historic 30-Year Averages Summer Days (in weeks)

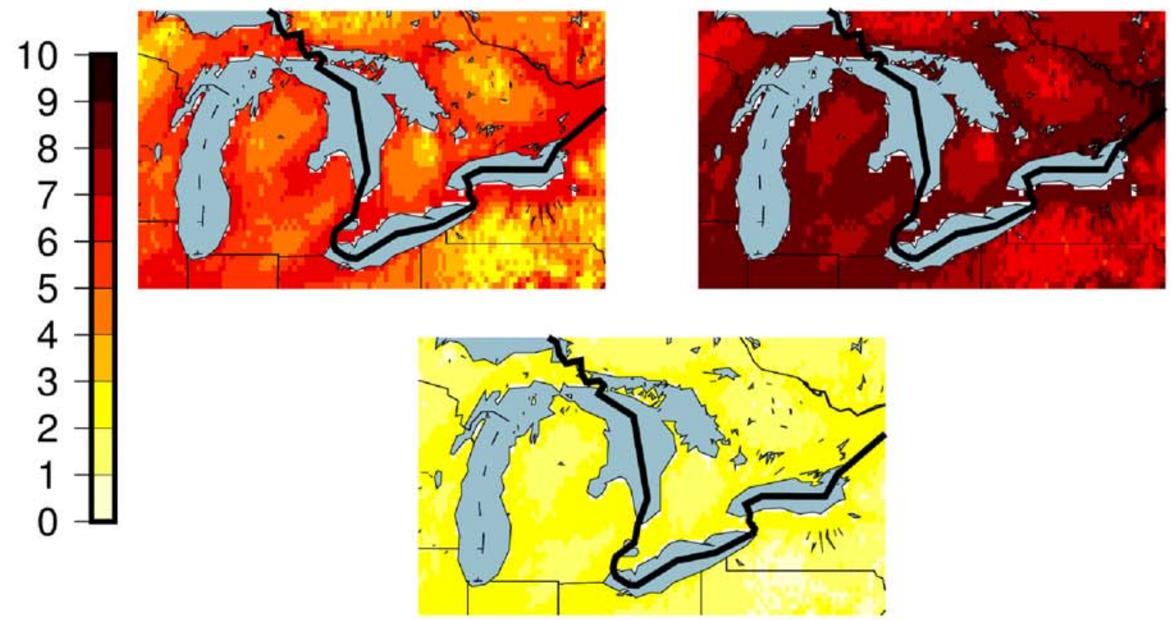
predicted significant changes in the number of warm nights, warm days, cool nights or cool days, so those results have also been omitted from this analysis.

5.5 Discussion

The results of this analysis suggest that there could be significant changes in extreme precipitation and extreme temperature events in the Great Lakes by the end of the century. In terms of all 3 extreme precipitation metrics (simple daily intensity index, fraction of precipitation from 95th percentile events, and maximum 5-day precipitation totals), the AOGCMs predict increases in annual 30-year averages, as well as seasonal 30-year averages for the winter and spring in the far future for RCP 8.5. These increases are likely due to increases in total annual precipitation rather



(a) Historic to Near Future (Top Left: CANESM2, Top Right: GFDL-CM3, Bottom: MRI-CAOGCM3)



(b) Historic to Far Future (Top Left: CANESM2, Top Right: GFDL-CM3, Bottom: MRI-CAOGCM3)

Fig. 5.4. Change in 30-Year Averages for for Summer Days (in weeks)

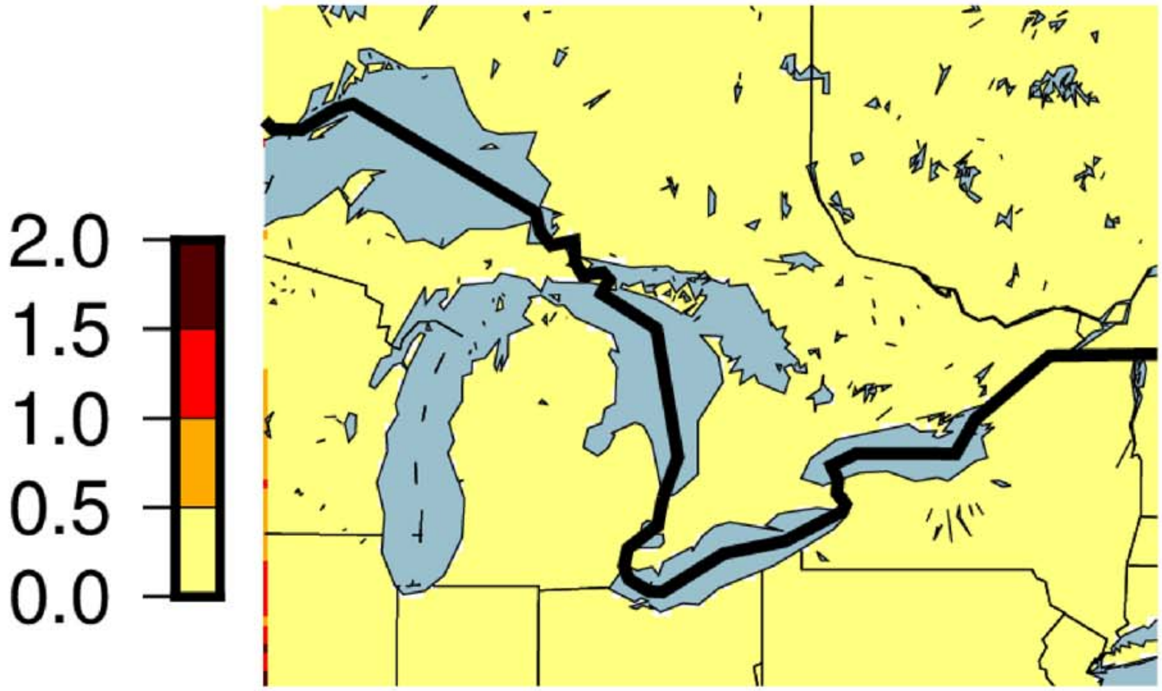


Fig. 5.5. Historic 30-Year Averages for Tropical Nights (in days)

than the number of wet days per year. In general, these trends agree with findings in existing work examining potential climate change impacts in the Midwest [42].

In terms of extreme temperature events, the AOGCMs also predict significant increases in 30-year annual averages for the heat wave duration index, the number of summer days, and, to a lesser degree, the number of tropical nights through the end of the century. While seasonal changes in 30-year averages for the heat wave duration index are also predicted to be significant in the far future for all seasons, only changes in summer days and tropical nights in the summer months were meaningful across all three AOGCMs. The overall finding, however, is that there will be significant temperature increases in the Great Lakes by the end of the century. These results also agree with findings in existing research [22].

In terms of what these changes could mean for the region's tourism sector, increased precipitation, especially in the form of extreme weather events, would be

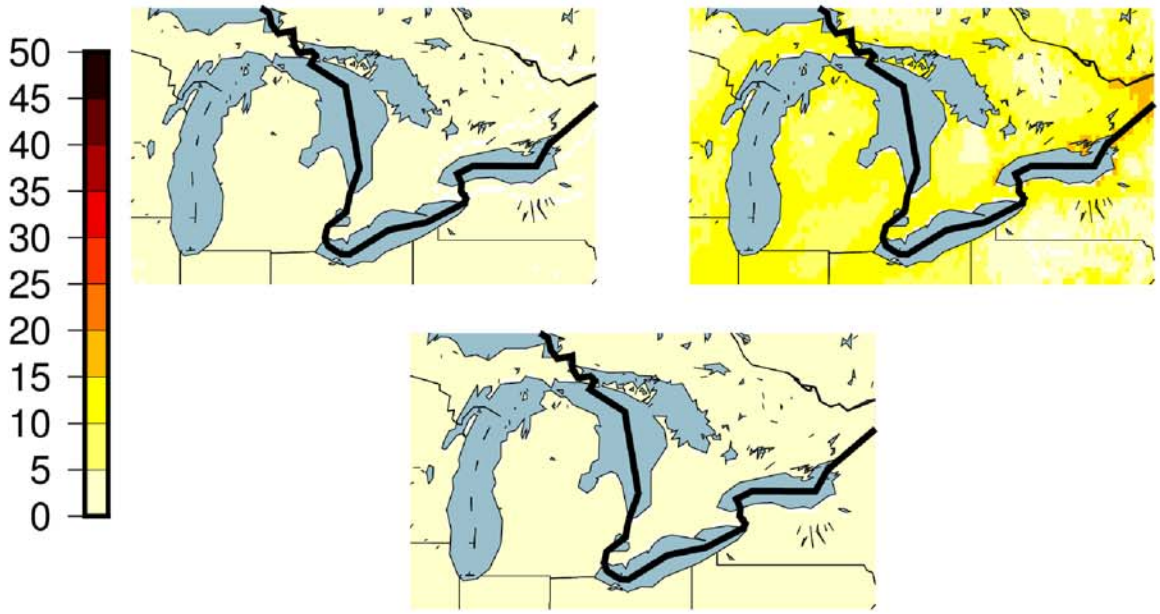


Fig. 5.6. Change in 30-Year Averages for Tropical Nights (in days), Historic to Far Future (Top Left: CANESM2, Top Right: GFDL-CM3, Bottom: MRI-CAOGCM3)

expected to continue to negatively impact tourism businesses in the Great Lakes. The magnitude of these negative impacts needs to be further explored, however, using more refined data sets and preferably coupled with other types of analyses to develop more accurate and complete predictions for the tourism sector, such as visitation patterns and sales data. The timing of rain events could also be considered on a sub-monthly or sub-weekly time scale to increase the usefulness of this information, as heavy rain events on the weekends during peak operating seasons would be more detrimental for tourism businesses than those at other times during the year.

Increases in annual and seasonal temperatures, on the other hand, may be beneficial for the Great Lakes' tourism sector, since it could increase shoulder season and summer tourism. The threshold defined for summer days corresponds with an increase of days over 75 °F, which was close to the 70 °F threshold used to define the shoulder seasons in previous analysis of future climate change projections (see

Chapter 3). The shoulder seasons are parts of the year in which many tourism business owners in the two case study communities studied in Chapters 2 and 3 would expect to see benefits from climate change in the form of increases in visitation and revenue. The expected increase in the number of summer days of almost 3 months could be a major positive for certain businesses, though they will need to be flexible and adaptive over time to take advantage of changes. An increase in heat could also increase beach-going in the Great Lakes, given that beach visitation increases with temperatures, according to previous conversations with tourism professionals in the region (see Chapter 2). Whether beach-going will continue to rise with the significant increases in summer days predicted by the end of the century is unknown. It would be useful to supplement this analysis with adjusted high temperature thresholds, in order to get a better sense for how the number of extremely hot days, e.g., days with maximum temperatures over 30 or 35 °C could rise in the Great Lakes by the end of the century.

On the other hand, increases in high temperatures could hurt other forms of summer recreation (see Chapter 2), as higher temperatures would push tourists towards beach-going and other forms of water recreation and away from other outdoor activities. An increase in 30-year annual averages for the number of tropical nights could also hurt tourism businesses in the Great Lakes because warm nights can affect tourists' comfort differently than warm days. For example, oppressive nighttime temperatures could have health and safety implications for campers, leading them to change their plans or travel to cooler destinations.

5.6 Implications and Future Research

In general, these results support findings in existing research that the Great Lakes region will experience increases in terms of both precipitation extremes and temperature extremes. This work also builds on analyses completed for Chapters 3 and 4 by expanding the region being considered to include the entire Great Lakes and including additional variables that can more fully capture how climate change could impact the region's hospitality and tourism sector; however there are also some key limitations to this work.

Firstly, the AOGCMs used for this analysis generally seem to be underpredicting both precipitation and temperature extremes on an annual and seasonal basis when compared to historical, observed data. While the models vary in magnitude in terms of this underprediction, additional efforts to bias-correct and quality check the AOGCM projections are needed in order to ensure that the results of this analysis are acceptably simulating regional trends in climate.

Secondly, while the results of this analysis demonstrate that climate change could have significant impacts on tourism in the Great Lakes when it comes to extreme weather events, the metrics used here do not fully capture how climate change could affect these types of events in the Great Lakes. More refined data sets and modeling capabilities are needed to better capture these effects, such as in terms of extreme storms, in order to generate useful information for tourism managers. Additionally, this analysis does not address other factors that the results of interviews with tourism managers have shown to be important, such as short-term weather, wind activity, and lake conditions.

A potential next step for this analysis is to use dynamically downscaled hourly data for the GFDL-CM3 model for RCP 8.5, which has been provided by colleagues in the Earth, Atmospheric and Planetary Sciences Department at Purdue University. This dataset has been prepared using the Weather Research and Forecasting - Advanced Research WRF (WRF-ARM) model version 3.6 to downscale GFDL-CM3 model output for the historical and future periods for the continental United States. The hourly output data for precipitation, temperature, and wind speed that can be extracted from this dataset would likely provide greater insights into potential trends in extreme weather events from climate change for the Great Lakes region.

Finally, additional spatial analyses of the results of improved analyses would also enhance the usability of this type of information for tourism stakeholders in the Great

Lakes. For example, considering impacts on a state-by-state basis could provide some useful insights into how regional scale changes could affect tourism businesses differently across the Great Lakes. Assessing differences in terms of the magnitude of changes in weather and climate characteristics between locations could also provide some interesting and useful insights.

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6. SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH DIRECTIONS

6.1 Summary

The work completed for this dissertation has utilized the strengths of multiple disciplines in order to address two main objectives: (1) to explore how climate change could impact the hospitality and tourism sector in North America's Laurentian Great Lakes region and (2) to provide additional insights into how researchers can help tourism stakeholders in key destination communities prepare for climate change.

Chapter 2 focused on the two hypotheses that tourism managers are highly aware of climate and weather (Hypothesis 1a) but face other barriers to climate change adaptation (Hypothesis 1b). All of the tourism managers interviewed for this study were highly aware of how their businesses are impacted by weather and climate. Many of them were also able to predict some of the ways they could be impacted by climate change in the future, though these impacts were often believed to be minimal. Given these findings, it is not surprising that most businesses were not taking steps to prepare for climate change; however, it was also encouraging that there were cases where businesses were responding to recent experiences with weather because this suggests that businesses have the flexibility and ability to adapt to changing conditions. Interview findings also suggest that tourism businesses face a number of barriers to adaptation, including limited resources, a lack of knowledge of adaptation options, and short-term planning horizons. Another challenge to climate change adaptation evident from interview results was that many tourism managers do not believe adaptation is necessary. Subsequently, both Hypothesis 1a and Hypothesis 1b are accepted. Overall, these results suggest that policy interventions may be needed to move the industry forward when it comes to climate change planning and adaptation.

Chapter 3 addressed the hypothesis that producing actionable climate change science can help overcome some of the barriers to communication with tourism managers about climate change (Hypothesis 2). The results of Chapter 3 show that many tourism managers believe in climate change but do not necessarily associate global climate change with regional and local scale impacts. In addition, very few interviewees said they were currently getting any information about climate change. Subsequently, the work completed here to apply a creative and innovative approach to developing actionable climate change science for tourism managers appears worthwhile. In addition, the use of data visualization techniques to present future climate change scenarios to interviewees seemed to facilitate open discussion about climate change, so Hypothesis 2 is also accepted. At the same time, the results of this work also illustrate the persistent challenge of convincing tourism managers that climate change impacts could be significant for their businesses and that there is a need for some degree of proactive adaptive action, though efforts to encourage adaptation should, perhaps, focus more on weather preparedness and resilience than climate change.

Chapters 4 and 5 described the results of modeling work completed to explore trends in weather and climate characteristics that were said to be important by interviewees in the two case study locations considered for Chapters 2 and 3, specifically winter weather and extreme weather. Analyses of downscaled climate data from atmospheric-ocean general circulation models (AOGCMs) and variable infiltration capacity model simulations were used to quantify trends in variables that measure changes in these types of weather. Specifically, Chapter 4 looked at the hypotheses that climate change could impact winter weather (Hypothesis 3a) and, subsequently, winter recreation and tourism in the Great Lakes (Hypothesis 3b), and Chapter 5 centered on the hypotheses that climate change will have significant impacts on extreme weather events in the Great Lakes (Hypothesis 4a) which will also impact the region's hospitality and tourism sector (Hypothesis 4b).

The results of these analyses suggest that climate change could have significant impacts on winter weather in the Great Lakes. Winter could shorten by up to 2 months, as predicted by the GFDL-CM3 model for RCP 8.5, and the number of cold days could decrease significantly. In addition, the number of days with appropriate snow depths for skiing and snowboarding could also decline by a month or more. Overall, however, the results of Chapter 4 suggest that the region will remain viable for winter tourism through the end of the century. Subsequently, Hypothesis 3a is accepted and Hypothesis 3b is rejected. The results of Chapter 5 show that intense precipitation events could increase significantly by the end of the century, especially in the winter and spring months. Extreme temperatures could also increase with the potential for the number of summer days to increase by as much as 60 in the far future under the GFDL-CM3 model for RCP 8.5. The results of Chapter 5 also show that the duration of heat waves and the number of tropical nights could increase significantly by the end of the century. Given these findings, Hypothesis 4a is accepted; however, how these changes could impact the region's tourism sector needs to be explored more thoroughly through future research, so Hypothesis 4b is neither accepted or rejected.

6.2 Conclusions

Overall, this work improves general understanding of how climate change could impact tourism in the Great Lakes, accomplishing the first objective of this research. While there is more work to be done to fully understand how climate change could affect the region's tourism sector, these findings demonstrate that the tools and modeling capabilities that currently exist make it possible to quantify general trends in weather and climate that can facilitate dialogue with tourism managers about climate change. As global and regional climate models improve, there will be many more opportunities to look more closely at weather and climate characteristics important to the tourism sector.

Reflecting on findings related to the second objective of this work, two main themes emerge that can provide researchers with some insights into they might help tourism stakeholders in key destination communities prepare for climate change. The first relates to what reasonable expectations are for tourism businesses in terms of climate change adaptation and the second relates to the complexities involved in translating complex climate information into actionable science.

In terms of expectations for tourism businesses when it comes to adaptation, despite the potential that climate change has to impact characteristics of the weather and climate that are important to tourism businesses in the Great Lakes, it seems unlikely that individual businesses in the region will start to take any major, proactive adaptive actions without either a devastating extreme weather event or intervention by policymakers. Though the tourism managers interviewed for this study were highly aware of the importance of weather and climate to their businesses, the level of changes predicted in the future climate scenarios did not seem to be enough to inspire action for many of them. As discussed in Chapter 3, whether there are thresholds in terms of climate change that would inspire action needs to be explored through additional research. The businesses that were found to be acting in response to perceived changes in weather and, in a few cases, climate change were ones that were also highly impacted by climate and weather, such as national and state parks and local outdoor events (see Chapter 2 for more detail). This presents an important dilemma. In regions, like the Great Lakes, that are generally less vulnerable to extreme weather events, does it make sense to expect all businesses to prepare for climate change or should it be left up to the individual business? Granted, it seems reasonable for there to be some basic preparation for extreme weather events in the case of all businesses, e.g., having emergency procedures in place, but do they really need to do more to prepare for conditions that could never happen?

As far as the second emerging theme from this research, in terms of the complexities involved in translating complex climate change information into actionable science, the work completed here demonstrates many of the difficulties involved in this process. At a fundamental level, there is a large gap between the kind of climate information that is produced and the types of information that tourism managers are interested in and can use for decisionmaking. For example, business owners generally operate on short timescales, sometimes on the order of a few days, which cannot be predicted with any degree of certainty in the analysis of AOGCMs, whether downscaled or not. In addition, granular changes in metrics like the ones used here for snow depth, intensity of precipitation events, and temperatures are unlikely to mean anything to tourism managers without some degree of generalization and translation. Focusing on overall trends in weather and climate makes sense for discussions with tourism managers, but attention needs to be given to ensure that summarizing climate information does not come at the expense of scientific rigor and reliability. In addition, creating actionable science at the appropriate spatial scale is a challenge. The limited availability of resources to perform this kind of analysis for individual locations means that there remains a huge gap in terms of the availability of reliable, tourism-relevant, and local-focused climate scenarios.

The challenge of creating actionable science becomes even more daunting when considering how tourism in a given destination is affected by factors other than that location's weather and climate. Considering the aspects of a tourists' experience that are affected by weather and climate as summarized in the Introduction, one could argue that numerous social and economic factors also impact the full extent of this process, from trip conception to trip completion. In addition, the relationship between destinations and how regional climate change could affect travel to and from one location and another introduces additional non-linearities. For example, Chicago will experience many of the same changes in terms of its weather and climate as the two case study destinations considered for this research. It is possible, therefore, that tourism to the Indiana Dunes from Chicago will increase, for example, if more people want to escape summer heat in the city. At the same time, people may also choose to travel further north in an attempt to escape extreme temperatures, leading to declines in tourism revenue in both locations.

6.3 Future Research Directions

There are numerous opportunities for future research to build on the findings of this work. In terms of additional social science research, qualitative interviews could be expanded to include additional locations. The interview guide used here could also be translated into a quantitative survey and applied to an even larger sample size to improve baseline understanding of tourism business owners' perceptions and beliefs about weather, climate, and climate change; what actions are being taken to prepare for climate change; what barriers are faced in terms of climate change adaptation; and the kinds of information getting to tourism stakeholders around the Great Lakes. Presenting stakeholders with additional scenarios focused on other future time periods, e.g., 30-year averages around 2050 or 2080, or that illustrate different possible climate futures could also be worthwhile. In addition, exploration into some of the major questions that have emerged from these results are deserving of more in-depth stakeholder engagement and communication, such as an investigation of adaptation thresholds.

In terms of the climate and hydrologic modeling work completed here, on a basic level, this analysis could be improved through the use of more refined datasets, better metrics, and additional models. Furthermore, additional layers of analyses could be applied to the development of future iterations of climate scenarios, as informed by the results of this dissertation, that will make the information more relevant and useful to stakeholders. In the near term, a primary focus will be on bias-correcting and quality checking the input AOGCM data to ensure that the analysis and simulation results are realistic. In addition, additional metrics, such as ice cover and snow depths for snowboarding, will be added to the analysis of potential climate change impacts on cold processes and winter weather in the Great Lakes. Finally, in the longer term, extreme weather will be examined using dynamically downscaled climate data for the Great Lakes region. In the longer term, efforts will be made to expand and build on this methodology for other sectors. It would also be interesting to explore the potential for integrating climate change information with tourism data, such as visitation patterns or sales numbers, to give additional context to the findings of this dissertation.

APPENDICES

A. INTERVIEW GUIDE

Thank you so much for taking the time out of your busy schedule to talk to me. As I mentioned before, the purpose of my study is to understand:

1. How weather and climate affect tourism businesses in this area;
2. How future changes to the climate might affect your business and how you may or may not want to respond; and
3. What types of information you find helpful when planning for the future.

Please don't worry about giving me right or wrong answers; I am really just interested in learning what you think. Also, if you don't mind, I'll be recording our interview to make sure I record everything accurately, but your answers will be kept confidential and your participation is voluntary. If there is a question you'd prefer not to answer, please let me know and we can skip over it. This interview should take approximately 30-45 minutes.

A.1 Background Questions

1. Is this your business? Do you own it? If not, what is your position in your company? Who owns the business?
2. Could you give me some indication of the size of the business? How many people do you employ? How many passengers do you transport per year?
3. How long has your business been operating?
4. What kinds of activities does your business offer to tourists? [For restaurants, do you offer breakfast, lunch and dinner? How important is catering to the business? Do you have multiple locations or a food truck?]

5. What times of the year are your busiest? Does your business operate during the winter months?

6. To what extent is your business reliant on nature-based tourism? For example, how many of your customers are also hiking/walking/boating around Lake Michigan?

A.2 Sensing

7. Do climate and weather impact your business?

   - If so, how?
   - Was your business impacted at all by the early summer rain? How about more recently, with the nice late summer and early fall that we're getting?
   - Have you had any problems with:

     Prompt:

     - Severe storms
     - Wind storms/tornadoes
     - Storm surge/wave activity
     - Snowfall/ice
     - Floods
     - Droughts
     - Heat waves
     - Hail
     - Other

     For example, in terms of:

     Prompt:

     - Inventory

- Equipment or facilities
- Customers
- Employees
- Profit or revenue
- Other

8. Summarize what has been discussed. Is there anything else you'd like to add at this point?

9. Do you think this region's climate and weather patterns are changing?

   - If so, how?

A.3 Adapting

10. Have you started to do anything to prepare your business for future weather-related issues?

    Prompt:

    - Purchased additional insurance?
    - Developed plans to protect your records?
    - Relocated your business or developed multiple locations?
    - Developed plans to contact employees in an emergency?
    - Developed evacuation plans?
    - Made any changes to your current facility (installed smoke alarms, sprinklers, backup generators, or improved drainage systems)?
    - Started working to reduce input costs, e.g., electricity and water usage?
    - Expanded business offerings?
    - Started marketing more to local consumers?

- Emphasized sustainability, environmental awareness or corporate responsibility in general business practices?
- Engaged in brainstorming/networking opportunities with other tourism business owners?
- Other

11. Do you do any kind of strategic or long-term planning, say 3-5 years out, for your business?

    - If so, what time frame do you usually consider?
    - How have you worked to implement your plan(s)?

12. Do you carry any type of business insurance, either all-risk or peril-specific?

    > Property insurance policies come in two basic forms: (1) all-risk policies covering a wide-range of incidents and perils except those noted in the policy; (2) peril-specific policies that cover losses from only those perils listed in the policy. Examples of peril-specific policies include fire, flood, crime and business interruption insurance. All-risk policies generally cover risks faced by the average small business, while peril-specific policies are usually purchased when there is high risk of peril in a certain area.

    - If so, how long have you had it?
    - Has your insurance protected you in any way up to this point?
    - What do you hope it will protect you from in the future?

13. Have you experienced any kinds of barriers or challenges in preparing your business for future weather-related issues?

    Prompt:

- Limited resources
- Unreasonable planning timeline
- Lack of experience with past extremes
- Scarcity of or uncertainty in scientific information
- Lack of useful information about options
- Lack of state/local government support
- Other

A.4 Anticipating

14. I'm now going to show you a set of infographics that describe how this region's climate could change in the next few decades.

    - Assuming that this takes place, how do you think your business might be impacted?

      Prompt:

      – Recreation activity offerings
      – Operating costs (electricity, water, insurance, marketing, etc.)
      – Infrastructure
      – Tourists' health and well-being, travel plans
      – Other

A.5 Adapting

- Is there anything you would want to do to prepare your business for these potential changes?
- Is there anything you would want your community/city to do?

- If so, what kinds of barriers or challenges might you expect to encounter when it comes to preparing your business for these future conditions?

  Prompt:

  - Limited resources
  - Unreasonable planning timeline
  - Lack of experience with past extremes
  - Scarcity of or uncertainty in climate change science
  - Lack of useful information about adaptation options
  - Lack of state/local government support
  - Other

- What about for the community/city?

A.6 Anticipating

15. How might changes in other locations' climate and weather affect your business? For example, if Chicago or Detroit were to become hotter and wetter, what would it mean for you?

A.7 Coproduction/Useful Science

16. If this scenario were to happen, what kinds of information would you want to be getting to help you prepare your business for the future?

17. Are you already getting some of this information?

    - If so, what is it?
    - Where does this information come from?

      Prompt:

  - Government reports/employees
  - Academic papers
  - Extension/other experts
  - Professional/trade organizations
  - Popular media (newspaper, radio, TV)
  - Friends/family
  - Tourism network
  - Other
- What do you like about it? What makes it useful to you?

Thank you so much for sharing all of this information with me. Now, I have just a few questions to wrap-up:

A.8 Wrap-Up Question

18. Do you believe that the climate is changing?
    - If so, do you believe that this is being caused by human activity?
19. Would you mind telling me where your age falls in the following ranges?
    - 20-29
    - 30-39
    - 40-49
    - 50-59
    - 60-69
    - 70 or over
20. Is there anything more you would like to add that you think would be helpful to my study?

21. Is there anyone else you can think of who it would be beneficial for me to talk to?

As I stated earlier, everything you've shared with me today will be kept confidential. If any questions or concerns arise after our interview today, please do not hesitate to contact me. Thank you again so much for your time.

B. CODEBOOK

- Business Type

  Describes the general type of tourism operation

  - Hotel
  - Restaurant
  - Local attraction
  - Boat cruises
  - Event
  - National/state park

- Business Size

  Refers to number of employees

  - 1-4
  - 5-9
  - 10-19
  - 20-49
  - 50+

- Length of Operation

  Refers to how long the business has been opened and operating

  - Less than 3 years
  - 3-5 years

  - 6-10 years
  - 11-20 years
  - More than 20 years

- Operating Season

  In which part(s) of the year does the business operate?

  - Spring shoulder: April through mid-June
  - Summer: mid-June through August
  - Fall shoulder: September through October
  - Winter: November through March
  - Bimodal: business operations/profits peak in summer and winter
  - Year-round: business operations/profits are consistent year-round

- Peak Operating Season

  In which part(s) of the year do business operations and profits peak?

  - Spring shoulder: April through mid-June
  - Summer: mid-June through August
  - Fall shoulder: September through October
  - Winter: November through March
  - Bimodal: business operations/profits peak in summer and winter
  - Year-round: business operations/profits are consistent year-round

- Reliance on NBT (Nature-Based Tourism)

  - High: business is entirely or almost entirely based on outdoor recreation and tourism

  - Medium: customers engage in outdoor recreation and tourism, but not exclusively
  - Low: customers barely or do not engage in outdoor recreation and tourism

- Sense

  Does the business have the ability to monitor stresses?

  - Yes
  - No

- Types of CW (Climate and Weather)

  Refers to types of climate and weather that currently affect the business; indicate as positive/negative/mixed (as appropriate)

  - Ice cover
  - Wind
  - Wave activity
  - High temperatures
  - Low temperatures
  - Rain
  - Hail
  - Snow
  - Lake levels
  - Lake temperatures
  - Sun
  - Severe storms
  - Winter weather

  - Weather forecasts
  - Beach closures
  - Humidity
  - Sleet

- Business Impacts

  Refers to aspects of the business that are currently affected by climate and weather; indicate as positive/negative/mixed (as appropriate)

  - Operations
  - Inventory or offerings
  - Equipment or facilities
  - Customers
  - Employees
  - Costs, profits, revenues, or sales
  - Business reputation
  - Maintenance
  - Vendors

- Overall Impact of CW (Climate and Weather)

  - High: climate and weather have a significant impact on several aspects of business
  - Medium: climate and weather have a significant impact on a few aspects of business
  - Low: climate and weather do not have a significant impact on business

- CC (Climate Change) Perception

  - Yes: believe the regions climate and weather patterns are changing
  - No: does not think that the regions climate and weather patterns are changing
  - Not sure: unsure if the regions climate and weather patterns are changing

- Regional Changes in Climate

  Refers to personal observations in terms of how the climate is changing

  - Cooler springs
  - Cooler temperatures
  - Cooler winters
  - Higher water table
  - Less consistency
  - Shorter summers
  - Cooler summers
  - Less intense precipitation
  - Shifting seasons
  - Less severe winters
  - Less snow
  - Longer summers
  - Longer winters
  - More extreme weather
  - More extremely cold days
  - More intense weather
  - More rain
  - More snow and ice

- Stronger winds
- Warmer falls
- Warmer summers
- Warmer temperatures
- Wetter summers

- Adapt

  Does the business have the ability to act on information that is sensed and anticipated to prevent failure?

  - Yes
  - No

- Current Preparedness Strategies

  Refers to things the business is currently doing to prepare for future weather-related issues

  - Alternative sources of inventory
  - Back-up generators
  - Being adaptable, flexible, and positive
  - Covered outdoor spaces
  - Customer education
  - Emergency procedures
  - Operational changes
  - Indoor offerings
  - Outdoor offerings
  - Marketing

  - Franchising
  - Diversification of offerings
  - Service upgrades
  - Employee training
  - Equipment changes
  - Facility maintenance
  - Electronic back-ups
  - Emergency fund
  - Environmentally-friendly practices
  - Event insurance
  - Flexibility in offerings
  - Flexibility in scheduling
  - Flexibility with employees
  - Partnerships with others in the community
  - Use of social media
  - Virtual workspace

- Strategic Planning

  Does the business do strategic planning?

  - Yes, weather related
  - Yes, not specifically weather related
  - No
  - Not sure

- Business Insurance

  Does the business have insurance?

  - Yes, general
  - Yes, weather-specific
  - No
  - Not Sure
  - Self-insured

- Climate Change Adaptation

  Is the business adapting to climate change?

  - Yes: the business is taking specific steps to prepare for climate change
  - No: the business is not taking specific steps to prepare for climate change
  - No, but adapting to weather
  - Not sure: unknown if the business is taking specific steps to prepare for climate change

- Anticipate

  Does the business have the ability to foresee the potential for climate change impacts, especially crises and disasters?

  - Yes, high: thorough discussion of potential climate change impacts
  - Yes, medium: discussion of some potential climate change impacts
  - Yes, low: little to no discussion of potential climate change impacts
  - No

- Reactions to Future Scenarios

  Indicate as positive/negative/mixed (as appropriate)

  - Higher seasonal temperatures
  - More extremely hot days

  - Longer shoulder season
  - More extreme weather
  - More storm surge
  - Warmer lake temperatures

- Overall Impression of CC (Climate Change)

  Classifies interviewees overall thoughts on potential impacts of climate change on business

  - Positive
  - Negative
  - Mixed
  - Uncertain
  - None or not important

- Potential Business Impacts

  Refers to potential impacts of climate change on the business

  - Operating season
  - Operating costs
  - Customer education
  - Customer health and well-being
  - Customer numbers or event attendance
  - Customer satisfaction
  - Event attendance
  - Profits or revenue
  - Damage to environment

  - Employee availability
  - Employee health and well-being
  - Equipment or facilities
  - Inventory or offerings
  - Maintenance requirements

- Proposed Adaptation Strategies
  - Operational changes
  - Staff training
  - Community revitalization
  - Marketing
  - Moving indoors or changing location
  - Business as usual
  - Community partnerships
  - Customer educations
  - Equipment changes
  - Expand offerings
  - Incentivize environmentally-friendly practices
  - Infrastructure upgrades
  - New facilities
  - Product development
  - Reduce outdoor offerings
  - Scheduling rain date
  - Staffing changes
  - Strategic planning

  - Weather insurance

- Barriers to Adaptation

  - Belief in ability to adapt
  - Belief that climate change will not have a significant impact
  - Business image
  - Limited resources
  - Timeframe
  - Lack of information
  - Lack of awareness of adaptation options
  - Lack of government support
  - Communication with customers, customer behavior
  - Economic uncertainty
  - Not necessary
  - Weather unpredictability
  - Impacts on other businesses
  - Schedule or location inflexibility
  - Environmental impact
  - Governance
  - Market forces
  - Information inaccuracy
  - Set-up requirements
  - Slow rate of climate change

- Residual Impacts

  Refers to impact of changes in other locations climate and weather on the business

  - Positive
  - Negative
  - Mixed
  - Uncertain
  - None
- Types of Useful Information
  - Climate averages, extremes
  - Trend data (visitors)
  - Trend data (weather)
  - Short-term weather data
  - Emergency preparedness or safety training
  - Real-time lake data
  - General climate change information
  - Seasonal forecasts
- Currently Getting CC (Climate Change) Information
  - Yes
  - No
- Source of Useful Information
  - Academic institutions
  - Federal agencies
  - Information hotline
  - News

  - Newspaper
  - Radio
  - Weather apps
  - Webinars or presentations
  - Websites or internet
  - Not sure

- Belief in CC (Climate Change)
  - Yes
  - No
  - Not sure

- Belief in Anthropogenic CC (Climate Change)
  - Yes
  - No
  - Not sure

- Gender
  - Male
  - Female

- Age
  - 20-29
  - 30-39
  - 40-49
  - 50-59

  - 60-69

- Location
  - Indiana Dunes
  - Muskegon

C. SAMPLE VIC MODEL GLOBAL FILE

```
#######################################################################
# VIC Model Parameters - 4.1.x
#######################################################################
# $Id$
#######################################################################
# Simulation Parameters
#######################################################################
NLAYER 3
NODES 15
TIME_STEP  3
SNOW_STEP 3
STARTYEAR 1915
STARTMONTH 01
STARTDAY 01
STARTHOUR 00
ENDYEAR  2012
ENDMONTH 12
ENDDAY 31
#######################################################################
# Energy Balance Parameters
#######################################################################
FULL_ENERGY  TRUE
#######################################################################
# Soil Temperature Parameters
#######################################################################
```

```
FROZEN_SOIL TRUE
QUICK_FLUX FALSE
IMPLICIT TRUE
QUICK_SOLVE FALSE
NO_FLUX FALSE
EXP_TRANS TRUE
GRND_FLUX_TYPE GF_410
TFALLBACK TRUE
#######################################################################
# Precip (Rain and Snow) Parameters
#######################################################################
SNOW_ALBEDO USACE
SNOW_DENSITY DENS_SNTHRM
BLOWING FALSE
COMPUTE_TREELINE FALSE
DIST_PRCP FALSE
PREC_EXPT 0.6
MAX_SNOW_TEMP 0.25
MIN_RAIN_TEMP -0.25
#######################################################################
# Turbulent Flux Parameters
#######################################################################
MIN_WIND_SPEED 0.1
AERO_RESIST_CANSNOW AR_406_FULL
#######################################################################
# Meteorological Forcing Disaggregation Parameters
#######################################################################
PLAPSE TRUE
SW_PREC_THRESH 0
```

```
MTCLIM_SWE_CORR TRUE
VP_ITER VP_ITER_ANNUAL
VP_INTERP TRUE
LW_TYPE LW_PRATA
LW_CLOUD LW_CLOUD_DEARDORFF
#######################################################################
# Miscellaneous Simulation Parameters
#######################################################################
CONTINUEONERROR TRUE
#######################################################################
# Forcing Files and Parameters
#######################################################################
FORCING1 20160602_GreatLakes_0.125deg_chin/data_
FORCE_FORMAT BINARY
FORCE_ENDIAN LITTLE
N_TYPES 4
FORCE_TYPE PREC UNSIGNED 40
FORCE_TYPE TMAX SIGNED 100
FORCE_TYPE TMIN SIGNED 100
FORCE_TYPE WIND UNSIGNED 40
FORCE_DT 24
FORCEYEAR 1915
FORCEMONTH 01
FORCEDAY 01
FORCEHOUR 00
GRID_DECIMAL 4
WIND_H         10.0
MEASURE_H      2.0
ALMA_INPUT FALSE
```

```
#######################################################################
# Land Surface Files and Parameters
#######################################################################
SOIL            SoilParams/SOIL_PARAM_LDAS_Gridded_adjusted_092116.txt
ARC_SOIL        FALSE
BASEFLOW ARNO
JULY_TAVG_SUPPLIED FALSE
ORGANIC_FRACT FALSE
VEGLIB         VegParams/adjusted_veg_lib_glbasinsims_chin.asc
VEGPARAM        VegParams/VegParams_Sorted_092116
ROOT_ZONES      3
VEGPARAM_LAI  TRUE
LAI_SRC  LAI_FROM_VEGLIB
SNOW_BAND 1
#######################################################################
# Output Files and Parameters
#######################################################################
RESULT_DIR      outputfiles_historic/.
OUT_STEP        24
SKIPYEAR  0
COMPRESS FALSE
BINARY_OUTPUT FALSE
ALMA_OUTPUT FALSE
MOISTFRACT  FALSE
PRT_HEADER TRUE
PRT_SNOW_BAND   FALSE
#######################################################################
# Output File Contents
#######################################################################
```

```
N_OUTFILES    2

OUTFILE       fluxes        4
OUTVAR        OUT_EVAP      %.4f OUT_TYPE_FLOAT 1
OUTVAR        OUT_RUNOFF    %.4f OUT_TYPE_FLOAT 1
OUTVAR    OUT_BASEFLOW      %.4f OUT_TYPE_FLOAT 1
OUTVAR    OUT_SOIL_MOIST      %.4f OUT_TYPE_FLOAT 1

OUTFILE       snow        3
OUTVAR        OUT_SNOW_COVER      %.4f OUT_TYPE_FLOAT 1
OUTVAR        OUT_SNOW_DEPTH      %.4f OUT_TYPE_FLOAT 1
OUTVAR    OUT_SNOWF      %.4f OUT_TYPE_FLOAT 1
```

VITA

VITA

Natalie Chin received her Bachelor of Science in Biological Resources Engineering from the University of Maryland - College Park. Following graduation, she worked for several different non-governmental organizations in Washington, DC, learning first-hand about the policy-making process and how scientific information is used by government decisionmakers. During this time, Ms. Chin also received a Master's in Public Policy from George Mason University.

It was a combination of this academic and professional experience that inspired and motivated Ms. Chin to pursue a Ph.D. in Agricultural and Biological Engineering with a concentration in Ecological Sciences and Engineering at Purdue University. One of her primary goals with her research was to develop the skills needed to pursue a career in which she can help bridge the gap between science and policy-making. During her time at Purdue, Ms. Chin has also earned a Graduate Teaching Certificate from the Center for Instructional Excellence and held leadership positions in the Agricultural and Biological Engineering Graduate Student Association and the Purdue Climate Change Research Center Graduate/Post-Doc Group.

Upon graduation, Ms. Chin will be working as a postdoctoral researcher with her advisor, Dr. Keith A. Cherkauer. In this role, she will be conducting social science and physical science research that will contribute to the Indiana Climate Change Impacts Assessment.