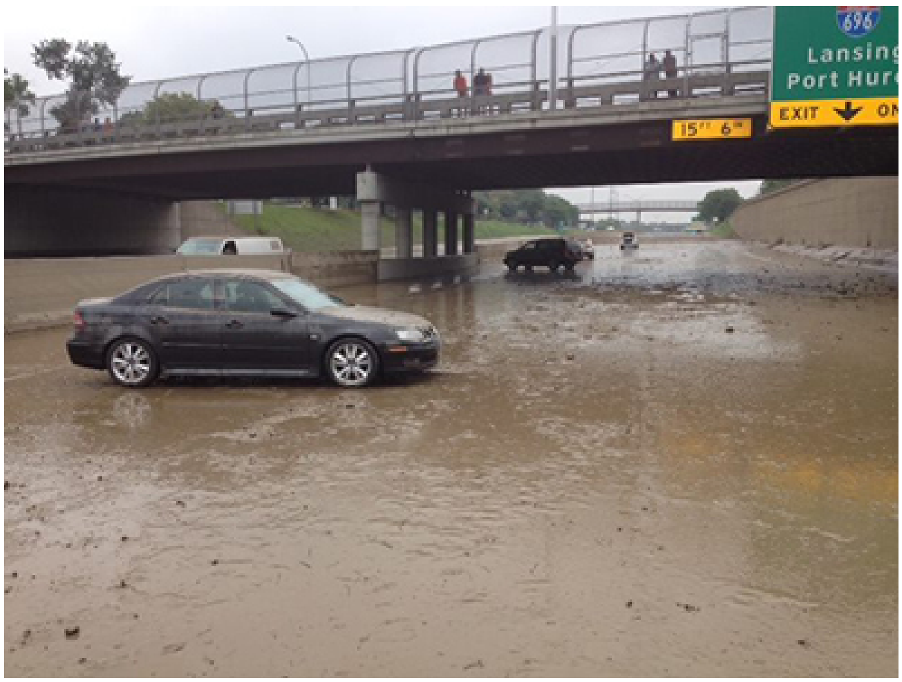
Michigan Climate and Health Profile Report

2015

Building Resilience Against Climate Effects on Michigan's Health



Michigan Department of Health and Human Services
Division of Environmental Health
Climate and Health Adaptation Program (MICHAP)

&

Great Lakes Integrated Sciences Assessments Program (GLISA)

Michigan Department of Health & Human Services
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List of Acronyms

AMU	Air Monitoring Unit
AQD	Air Quality Division
AQI	Air Quality Index
ASTHO	Association of State and Territorial Health Officials
BRACE	Building Resilience Against Climate Effects
BRFSS	Behavioral Risk Factor Surveillance System
CAA	Clean Air Act
CAP	Climate Action Plan
CDC	Centers for Disease Control & Prevention
CHPR	Climate and Health Profile Report
CMAQ	Community Multi-scale Air Quality
CMIP3	Climate Model Inter-comparison Project phase 3
CO	Carbon Monoxide
CRSCI	Climate Ready States & Cities Initiative
CSO	Combined Sewer Overflow
CSTE	Council of State and Territorial Epidemiologists
CWS	Community Water System
DCAC	Detroit Climate Action Collaborative
DEJ	Detroiters for Environmental Justice
DEQ	Michigan Department of Environmental Quality
DS	Downscaler
DVRHS	Division for Vital Records and Health Statistics
ED	Emergency Department
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GCM	Global Climate Models
GHG	Greenhouse Gas Emissions
GLISA	Great Lakes Integrated Sciences + Assessments Program
HAAS	Haloacetic Acids
IPPC	The United Nations Intergovernmental Panel on Climate Change
LHD	Local Health Department
LIAA	Land Information Access Association
MALEHA	Michigan Association of Local Environmental Health Administrators
MAP	Michigan Association of Planners
MCC	Michigan Climate Coalition
MDHHS	Michigan Department of Health and Human Services
MDHHS-DEH	Michigan Department of Health and Human Services Division of Environmental Health
MDHHS-MICHAP	Michigan Department of Health and Human Services Climate and Health Adaptation Program

MDSS	Michigan Disease Surveillance System
MGC	Michigan Green Communities
MiBRFS	Michigan Behavioral Risk Factor Survey
MICHAP	Michigan Climate & Health Adaptation
MIDB	Michigan Inpatient Database
MiSWIMS	Michigan Surface Water Information Management System
MML	Michigan Municipal League
MPHA	Michigan Public Health Association
MRLC	Multi-Resolution Land Characteristics
MSSS	Michigan Syndromic Surveillance System
MSU	Michigan State University
NAAQS	National Ambient Air Quality Standards
NARCCAP	North American Regional Climate Change Assessment Program
NLCD	The National Land Cover Database
NNDSS	National Notifiable Diseases Surveillance System
NOAA	National Oceanic and Atmospheric Administration
NTNCWS	Non-Transient Non-Community Water System
NWS	National Weather Service
OPHP	Office of Public Health Preparedness
RCM	Regional Climate Models
RTB	Retention Treatment Basin
SDWIS	Safe Drinking Water Information System
SES	Socio-Economic Status
SSO	Sanitary Sewer Overflows
TNCWS	Transient Non-Community Water System
TTHM	Trihalomethanes
U of M	University of Michigan
WICCI	Wisconsin Climate Change Initiative’s
WMEAC	West Michigan Environmental Action Council
WNV	West Nile Virus
WRD	Water Resources Division

Executive Summary

Through the 20th and into the 21st century, Michigan's climate has changed in measurable and impactful ways. Since 1951 the average annual temperature has increased by 0.6°F in the southeastern Lower Peninsula, and up to 1.3°F in the northwestern Lower Peninsula. During that same period total annual average precipitation across the state increased by 4.5%, or 1.4 inches. Additional changes include an increased frequency of some types of weather extremes such as heavy precipitation events. These changing climate conditions have had an impact on both environmental and human systems, representing an emerging threat to public health in Michigan. In response, the Michigan Department of Health and Human Services Climate and Health Adaptation Program (MDHHS – MICHAP) in partnership with the Great Lakes Integrated Sciences Assessments Program (GLISA) is using the Centers for Disease Control and Prevention's (CDC) Building Resilience Against Climate Effects (BRACE) framework to build capacity for public health adaptation at the state and local levels. This Climate and Health Profile Report is the initial step of the BRACE framework, laying the foundation for future assessments of vulnerability, disease burden, and interventions.

Based on current trends and projections of the most recent period for which information is available, 2021 – 2050, the most likely impacts from climate change in Michigan are extreme heat events, defined as prolonged periods of increased temperatures and humidity; changes in precipitation patterns, including excess rain leading to flooding; and extreme weather such as heavy snow and freezing rain. For Michigan, five priority climate-related health outcomes have been identified: respiratory diseases, heat related illnesses, waterborne diseases, vector-borne diseases, and injuries, specifically carbon monoxide (CO) poisoning. Conceptual pathways were created to describe how each climate impact directly and indirectly affects those priority health outcomes based on Michigan's vulnerabilities that were identified and classified as either relating to *exposures* or *sensitivities*. Combining the vulnerabilities, priority health outcomes, and climate projections, a qualitative synthesis of the relationship between expected future climate conditions and the likely health burden on Michigan's communities was created. A summary of findings is shown here:

1. **Respiratory Diseases**: Overall, projected conditions favor increased air pollution and worsening respiratory disease. Climate projections also favor earlier and longer growth period for plants indicating increased pollen levels, which could increase allergies and exacerbate symptoms including asthma.
2. **Heat Illness**: Air mass stagnation events may increase in frequency if high humidity occurs with high temperature and low winds, leading to increased heat stress-related morbidity and mortality. Projected increasing numbers of high heat days by mid-century suggest there will likely be large direct impacts on human health, especially if occurring simultaneously with other variables such as urban heat island effect.
3. **Water-borne Diseases:** In general, climate conditions leading to flooding will be the same or more intense in the future. This leaves areas vulnerable to sewage/septic failures and runoff at an increased risk for waterborne diseases and in certain areas, development of harmful algal blooms.
4. **Vector-borne Diseases:** Projections point to warmer winters, earlier springs, and warmer summers, conditions suitable for West Nile Virus and its mosquito vector. Similarly, current and future conditions are suitable for Lyme disease and its tick vector although there is greater difficulty in projecting the burden based on the complex sequence of climate conditions and the tick's life cycle needs.
5. **Injury and CO Poisoning:** Extreme weather events conducive to power outages are projected to increase, especially in winter, leading to increased use of generators and thus increased risk of CO poisoning. Clean up after an event utilizing power washers may also increase risk of CO poisoning. Freezing rain and flooding increases will raise traumatic injury risk.

I. Building a Resilient Public Health System

"The systemic reaction resulting from changing climate conditions has impacted environmental and human processes; representing an emerging threat to public health in Michigan. This threat requires altered response strategies from public health officials to confront the new pathways for disease and illness as well as the added stress placed on many existing public health problems." (pg. 10)

Introduction

The United Nations Intergovernmental Panel on Climate Change (IPPC) in their *Fifth Assessment Report* concludes that, "warming of the climate system is unequivocal and many of the observed changes are unprecedented over decades to millennia" (IPCC, 2014). The U.S. Global Change Research Program's *Third National Climate Assessment*, conducted by more than 300 experts guided by a 60-member Federal Advisory Committee from 13 Federal Departments, formed similar conclusions finding that "Temperatures at Earth's surface, in the troposphere (the active weather layer extending up to about 5 to 10 miles above the ground) and in the oceans, have all increased over recent decades. This warming has triggered many other changes to the Earth's climate" (Walsh, et al., 2014). What is of greatest concern for decision makers at all levels and across all sectors is that "Worldwide, the observed changes in average conditions have been accompanied by increasing trends in extremes of heat and heavy precipitation events, and decreases in extreme cold" (Walsh, et al., 2014). This has led to "shorter duration of ice on lakes and rivers, reduced glacier extent, earlier melting of snowpack, reduced lake levels due to increased evaporation, lengthening of the growing season, changes in plant hardiness zones, increased humidity, rising ocean temperatures, rising sea level, and changes in some types of extreme weather" (Walsh, et al., 2014).

The systemic reaction of global changes in precipitation and temperature leading to environmental and human system impacts represents an emerging threat to public health. This threat requires altered response strategies from public health officials to confront the new pathways for disease and illness as well as the added stress placed on many existing public health problems (Luber et al., 2014). Furthermore, officials will have to consider more than ever how their communities and citizens are vulnerable and if the health care infrastructure and delivery systems are capable of meeting those new challenges. This will require cooperation and action between multiple sectors as climate change poses indirect threats to health through impacts on fish and wildlife populations, energy and industry demands, natural features, transportation systems, tourism and recreation, water quality and quantity, and agriculture (Luber et al., 2014).

Acknowledging the need for a strategic and action oriented response, in 2010 the Michigan Department of Health and Human Services' Division of Environmental Health (MDHHS-DEH) established the Michigan Climate & Health Adaptation Program (MICHAP) following a one-year strategic planning activity funded by a grant from the Association of State and Territorial Health Officials (ASTHO). MICHAP was charged with protecting the health of Michigan's citizens from threats related to climate change, with the support and guidance of the Centers for Disease Control & Prevention's (CDC) - Climate Ready States & Cities Initiative (CRSCI).
(www.cdc.gov/climateandhealth/climate_ready.htm)

After successfully creating and implementing Michigan's climate and health strategic plan (MDHHS, 2011) from 2010 to 2013, the MDHHS - DEH was awarded a second grant from the CDC called *Building Resilience Against Climate Effects (BRACE) in State Health Departments.* The CDC's BRACE framework builds upon the planning and preliminary implementation work completed from the two previous grants. Their framework is composed of five steps which are described in Table 1.1.

Rationale and Objectives

This Climate and Health Profile Report (CHPR) establishes the foundation upon which the five steps of the BRACE framework will be completed and implemented at the State and local levels in Michigan.

The alignment of the BRACE framework with MICHAP's activities and ultimate outcomes is further explained in Table 1.1.

As the initial step in the BRACE framework the CHPR is intended to: (1) Inform internal and external stakeholders of the most current climate science as it relates to existing and future temperature and precipitation changes in Michigan leading to environmental and health impacts; (2) Describe the direct and indirect pathways by which climate changes impact health outcomes; (3) Characterize the variables that will be used to assess the vulnerabilities of the people and places within the State; (4) Explore the relationships between current vulnerabilities, future climate change projections, and the potential pathways of impact to better understand the additional burden to new and existing health outcomes; (5) Identify MICHAP's key collaborators and stakeholders, how they can be engaged and how these partnerships will lead to successful implementation of BRACE at the State and local levels.

Table 1.1: Michigan Climate & Health Adaptation Program BRACE Goals and Objectives

Goal: Enhance local, regional, and state capacity to predict, assess, and effectively respond to extreme weather and climate events to reduce and prevent the negative public health impacts associated with climate change.

BRACE Steps	MICHAP Objectives (3 year)	Purpose & Application
1. Data analysis and climate projections	- Create MI *Climate and Health Profile Report (CHPR)* - Develop comprehensive *Vulnerability Assessment*	- Describe state climatology, related exposures, health factors and health outcomes of concern, and the populations and systems most vulnerable to these changes - Identify and describe communities and geographic areas at greatest risk for climate-related health outcomes - Act as resource for local public health decision makers and communities in developing plans and for adaptation and emergency response
2. Project health impacts and disease burden	- Create *Burden of Disease Report*	- Describe the magnitude, trend and estimation of additional burden of health outcomes due to climate change.
3. Identification of best intervention strategies	- Develop *Climate & Health Intervention Assessment*	- Identify and prioritize the most appropriate interventions to address vulnerabilities and health impacts for each region in Michigan
4. Adaptation planning and implementation	- Assist local health departments (LHDs) to plan for relevant health impacts and vulnerable populations - Work with regional research partners to strengthen existing/develop new climate related tools - Develop and deliver BRACE framework training	- Advance the application of climate science to public health practice - Develop and put in place a process for ensuring that climate change factors are considered adequately in public health program operations. - Promote consideration of public health in climate adaptation planning in other sectors - Support local climate health adaptation planning
5. Evaluate and revise adaptation plan	- Update existing *Climate & Health Adaptation Plan*	- Incorporate BRACE approach. - Prepare principal climate and health preparedness guideline for local health departments

History of MDHHS Engagement with Climate and Health

The Michigan Department of Health and Human Services received funding from ASTHO in 2009 to conduct a statewide needs assessment and develop an adaptation plan for Michigan. The planning process focused on two specific deliverables; a Needs Assessment and Strategic Plan. In 2010, MDHHS received a three-year grant from CDC that funded MICHAP to implement the Strategic Plan as part of the national CRSCI. The MICHAP made great progress to build capacity in the state to address climate and health issues through both the planning and implementation grants. Table 1.2 reflects the objectives and results of those projects. Grant Final Reports and products are available from MICHAP staff upon request or by visiting www.michigan.gov/climateandhealth.gov.

Table 1.2: Previous Michigan Climate and Health Program Grants: Objectives & Key Findings

Grant	Objective	Findings and Results:
Strategic Planning	Understand existing community stakeholder interest in, capacity to, and knowledge of climate & health impacts and implementing adaptation strategies.	**Key stakeholder feedback** - Widespread interest but lack of knowledge regarding health impacts of climate change - Strong desire to identify partners with other organizations to address the issue
	Identify long-term goals, objectives, strategies to form the impetus for future initiatives	**Advisory Committee agreed upon goals** - Climate change is recognized as a public health issue & integrated into public health practice - Public health agencies have the tools, resources, and activities to respond to climate change impacts within existing programs - Vulnerable populations are explicitly considered in programs and policies addressing climate change impacts
	Identify the priority climate-driven health impacts	**Advisory Committee & Staff agreed upon priority issues** - Increasing number of heat events with related illnesses and deaths - Declining air quality as a result of increased production of ozone and particulate matter from heat and drought events - Adverse changes to water quality and quantity following severe weather events
Implementation	Integrate identified issues, resources, and strategies into state and local public health planning, assessments, outreach/education, partnerships, and tool development	**Advisory Committee & Staff agreed upon activities** - Incorporated extreme weather considerations into emergency planning - Supported climate-related Health Impact Assessments (HIA) in 3 communities and heat health surveys in two - Initiated health effects surveillance and calculated Indicators - Trained partners on climate health effects, HIA tool, and emergency response

Geographic Scope

MICHAP is a statewide initiative with a mandate to identify the unique health impacts from climate change for various communities and regions within Michigan and to integrate adaptation strategies and actions into their local health departments, municipalities, or other planning organizations depending upon the scale of the potential health impact and recommended interventions. This CHPR is intended to act as a resource to direct and inform this initiative, and is anchored in the breadth of political, social and physical characteristics of the state as summarized below.

Jurisdictional Features

Michigan is located in the eastern north-central United States. The state is composed of two peninsulas, the Upper and Lower. The Upper Peninsula is bordered by Lake Superior to the north, by Wisconsin on the west and on the south by Lake Michigan and Lake Huron. The Lower Peninsula is bordered on the west by Lake Michigan and on the east by Lake Huron and Lake Erie. On the south it is bordered by Indiana and Ohio. Michigan is divided into 83 counties, 257 villages, 276 cities and 1,240 townships. Additionally, the state is covered by 45 Local Public Health Departments with some encompassing several counties (Michigan Legislative Service Bureau, 2013). Figure 1.1 depicts the relevant jurisdictional boundaries of interest to MICHAP.

Fig. 1.1

Social Features

The 2010 U.S. Census identifies Michigan as the eighth most populous state in the U.S., with a total population of 9,883,640. County populations range from a low of 2,156 in Keweenaw County (North Western Upper Peninsula) to slightly less than two million persons in Wayne County (South Eastern Lower Peninsula). Michigan's largest city by population and area is Detroit (South Eastern Lower Peninsula) followed by Grand Rapids (Western Lower Peninsula), as shown in Table 1.3.

Table 1.3: Michigan's Largest Cities

City	Population	Area (sq. mi)
Detroit	688,701	142
Grand Rapids	192,294	45
Warren	134,873	34
Sterling Heights	131,224	36
Ann Arbor	117,025	28
Lansing	113,972	36
Flint	99,763	34

Source: U.S. Census Bureau, 2014 (estimated 2013)

Forty four percent of Michigan's total population is located in the Detroit Eligible Metropolitan Area (DEMA), which encompasses Wayne, Macomb, Oakland, Monroe, St. Clair, and Lapeer Counties (U.S. Census, 2013). Population density of Michigan by census tract is visualized in Figure 1.2.

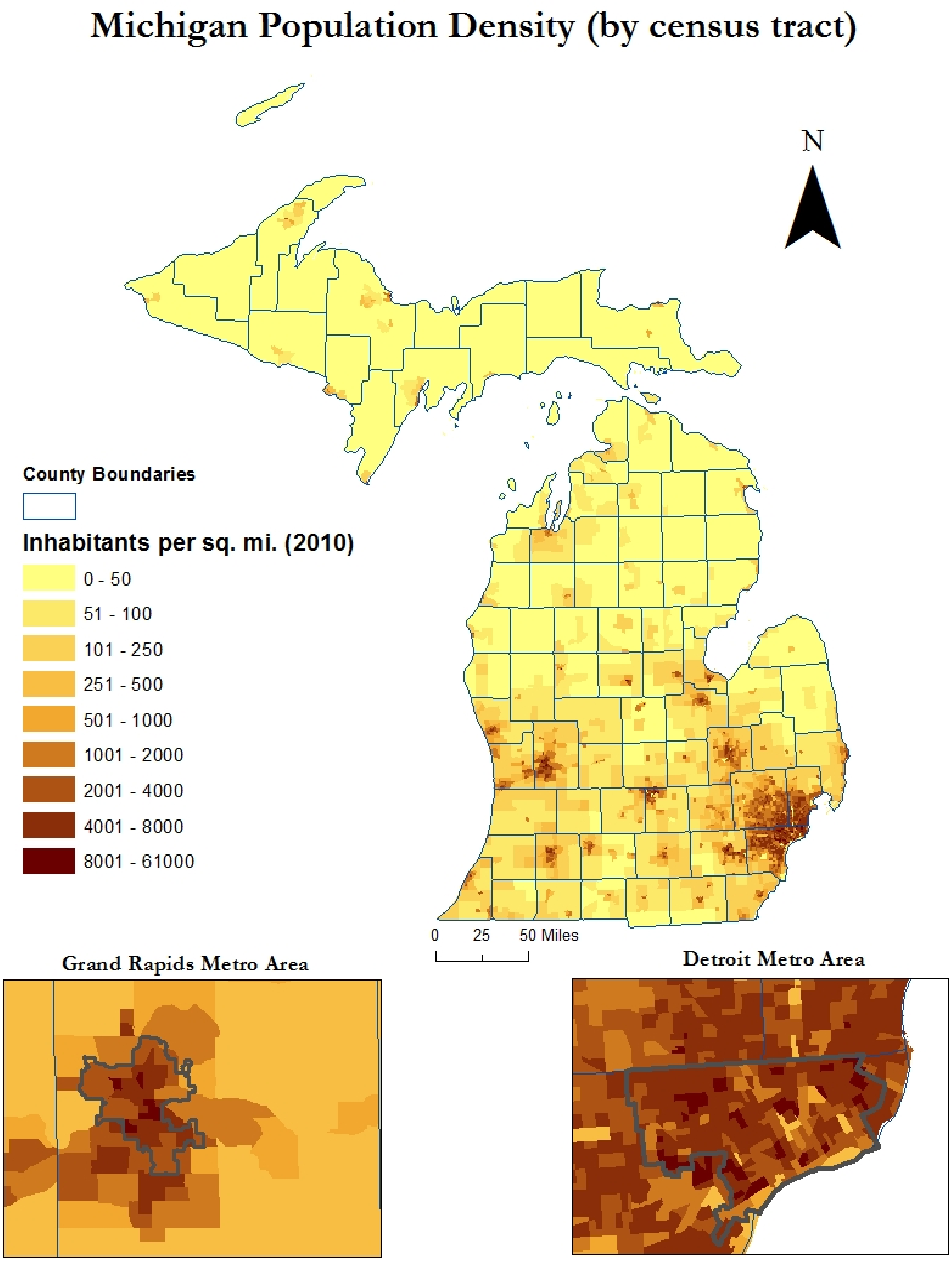

Fig. 1.2 (U.S Census Bureau, American Community Survey, 2010)

The racial and ethnic compositions and median ages of the State of Michigan and its two largest metropolitan areas, Grand Rapids and Detroit, are presented in Table 1.4. The percentage of non-white populations and the median ages within census tracts of Michigan are visualized in Figures 1.3 & 1.4.

Table 1.4: Demographic characteristics of Michigan and the two largest cities

Race (percent)	Michigan	Detroit	Grand Rapids
White	77.0	10.6	64.6
Black	14.0	82.7	20.9
Asian	2.0	1.1	1.9
American Indian	0.5	0.4	0.7
Other	6.5	5.2	11.9
Median Age (years)	38.9	31.0	30.8

Source: U.S. Census Bureau, 2014

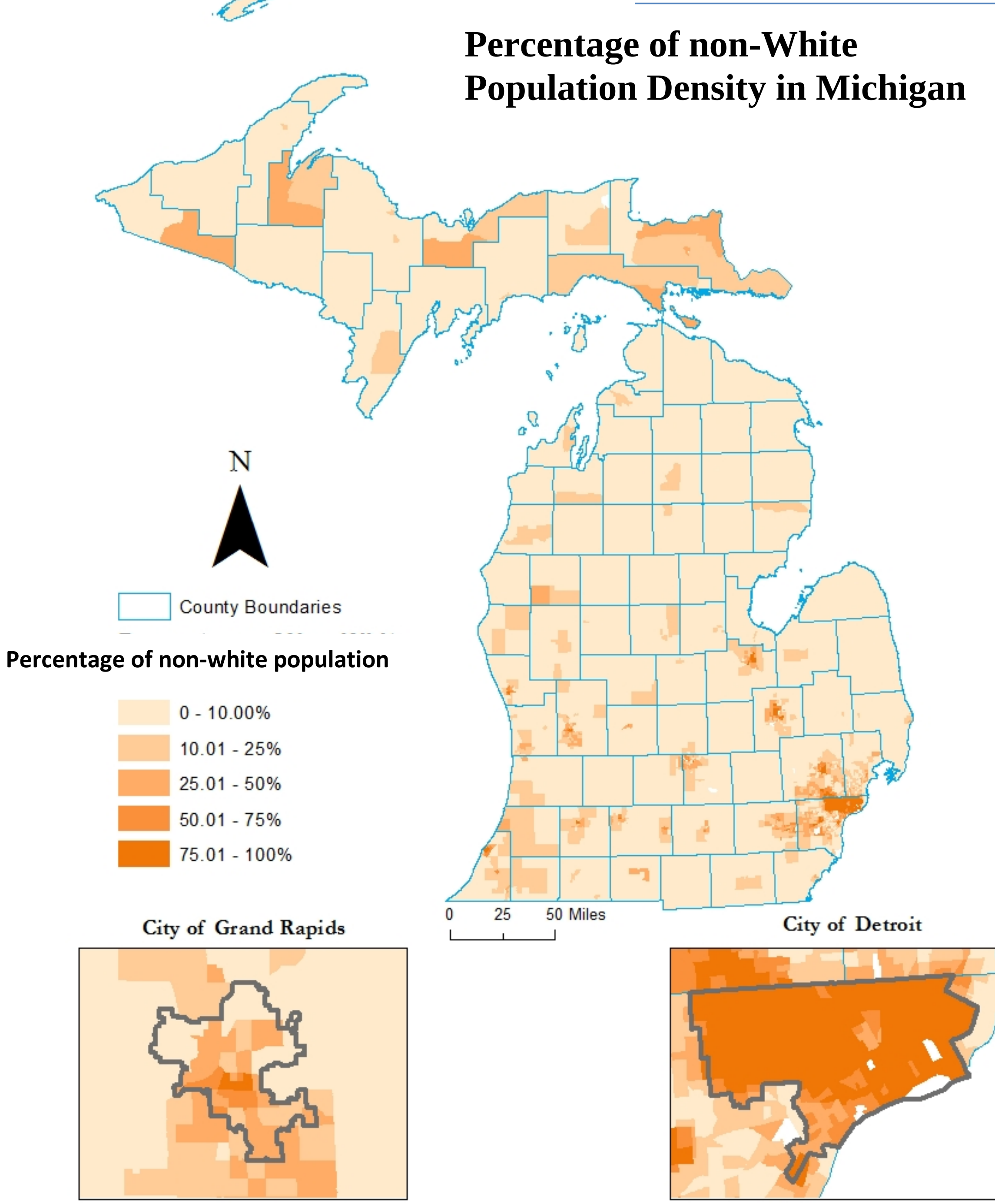

Fig. 1.3 (U.S Census Bureau, American Community Survey, 2010)

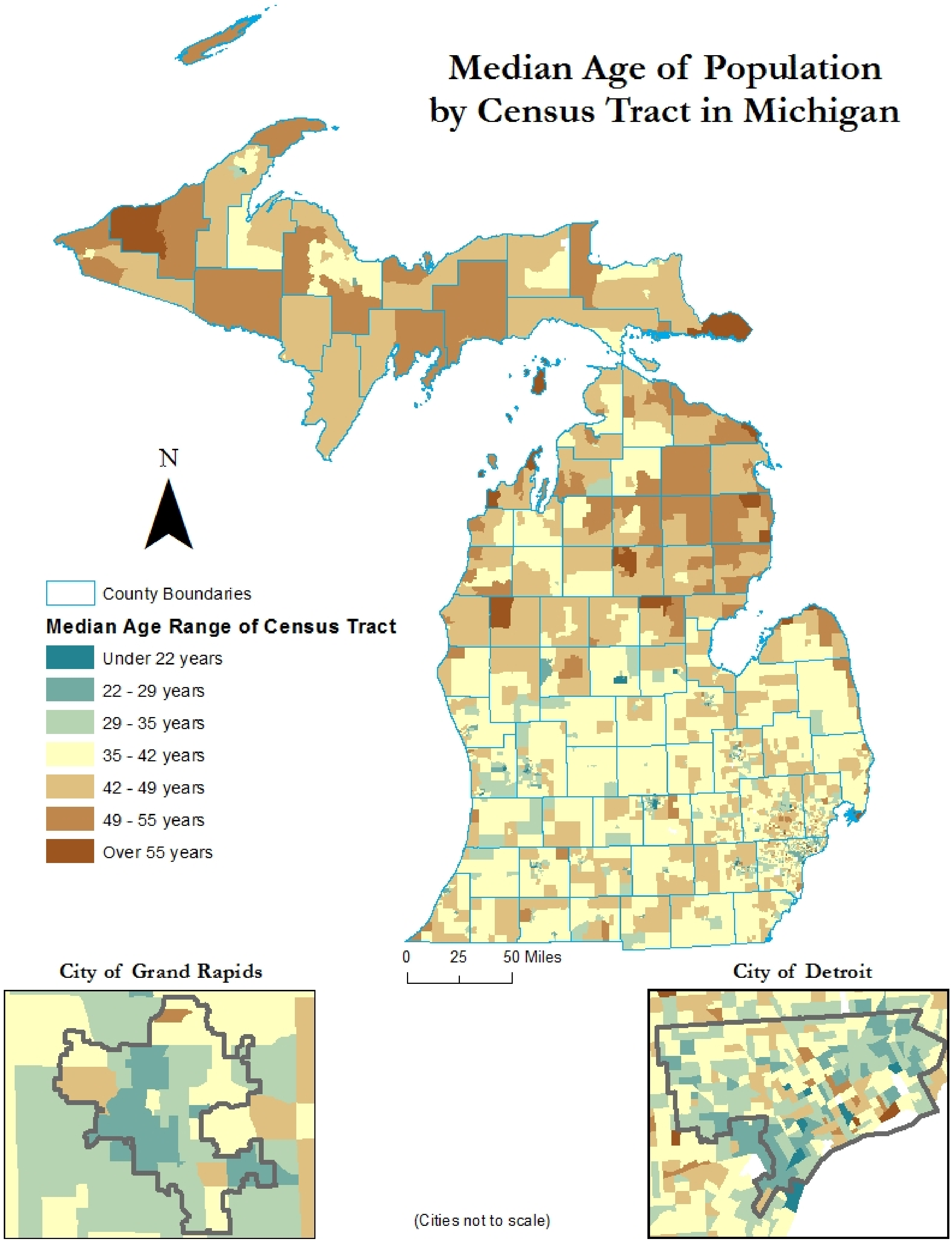

Fig. 1.4 (U.S Census Bureau, American Community Survey, 2010)

Economic Features

Michigan's economy is predominantly driven by the manufacturing, agriculture, tourism, and mining industries. Changes in temperature and precipitation from climate change can have significant impacts on these systems, including occupational health hazards and economic stressors. Four primary economic features are highlighted in Table 1.5.

Table 1.5: Michigan Industries' contributions to Gross Domestic Product, employment, and services

Category	Economic Output (billions)	Number of Jobs	Primary Contributions
Manufacturing	$58.2	> 470,000	Automobiles, chemicals, paper, furniture, breakfast foods
Food & Agriculture	$91.4	923,000	Farming, wholesale and retail distribution
Tourism	$20.9	> 150,000	Rural/urban recreation, freshwater recreation, hiking, winter activities
Mining	$2.4	N/A	Peat, bromine, calcium-magnesium chloride, gypsum & magnesium compounds

Source: MI Economic Development Corporation, 2014

Natural Features

Glaciers covered Michigan as recently as 14,000 years ago, leaving behind hills and valleys, snake-shaped eskers, patterned mounds of drumlin fields, steep end moraines, and old weathered mountain ranges. As the modern day Great Lakes receded about 4,000 years ago, broad flat lakebeds were exposed, sandy beaches were formed, and large sand dunes were created (Michigan Department of Natural Resources, 2014).

Michigan has over 19.3 million acres of forests covering more than half the land area of the state, mainly in the Upper Peninsula and northern Lower Peninsula. Michigan has the fifth largest amount of timberland (forestland that can produce commercial timber) in the United States. Hardwoods such as maple, aspen, and oak make up 75% of the trees in the state, while softwoods, including pine, spruce, and cedar comprise the remaining 25%. Distribution of forests, along with wetlands, developed land, bodies of water, etc. is displayed in Figure 1.5 (Michigan Department of Natural Resources, 2014).

Perhaps the State's greatest natural feature is the abundance of fresh water. The five Great Lakes and their connecting waterways that define the region hold 6 quadrillion gallons of water representing 90% of the United States' surface freshwater supply. The Great Lakes basin (the surface area of the Great Lakes and the land draining into the Lakes) covers more than 295,000 square miles and is home to over 33 million people in the United States and Canada Figure 1.6 (Great Lakes Information Network, 2014). Additional vital natural features are described in Table 1.6.

Table 1.6: Michigan Natural Feature Statistics

Total Land Area	58,110 sq. mi.
Total Great Lakes Water Area	38,575 sq. mi.
Total Inland Water Area	1,305 sq. mi.
Highest Point	Mount Arvon – 1,979 feet
Lowest Point	Lake Erie Surface – 571 feet
Rivers and Streams	36,600 miles
Freshwater Coastline	> 3,200 miles
Number of Inland Lakes	> 11,000

Source: Michigan Department of Natural Resources, 2014

Natural Features of Michigan

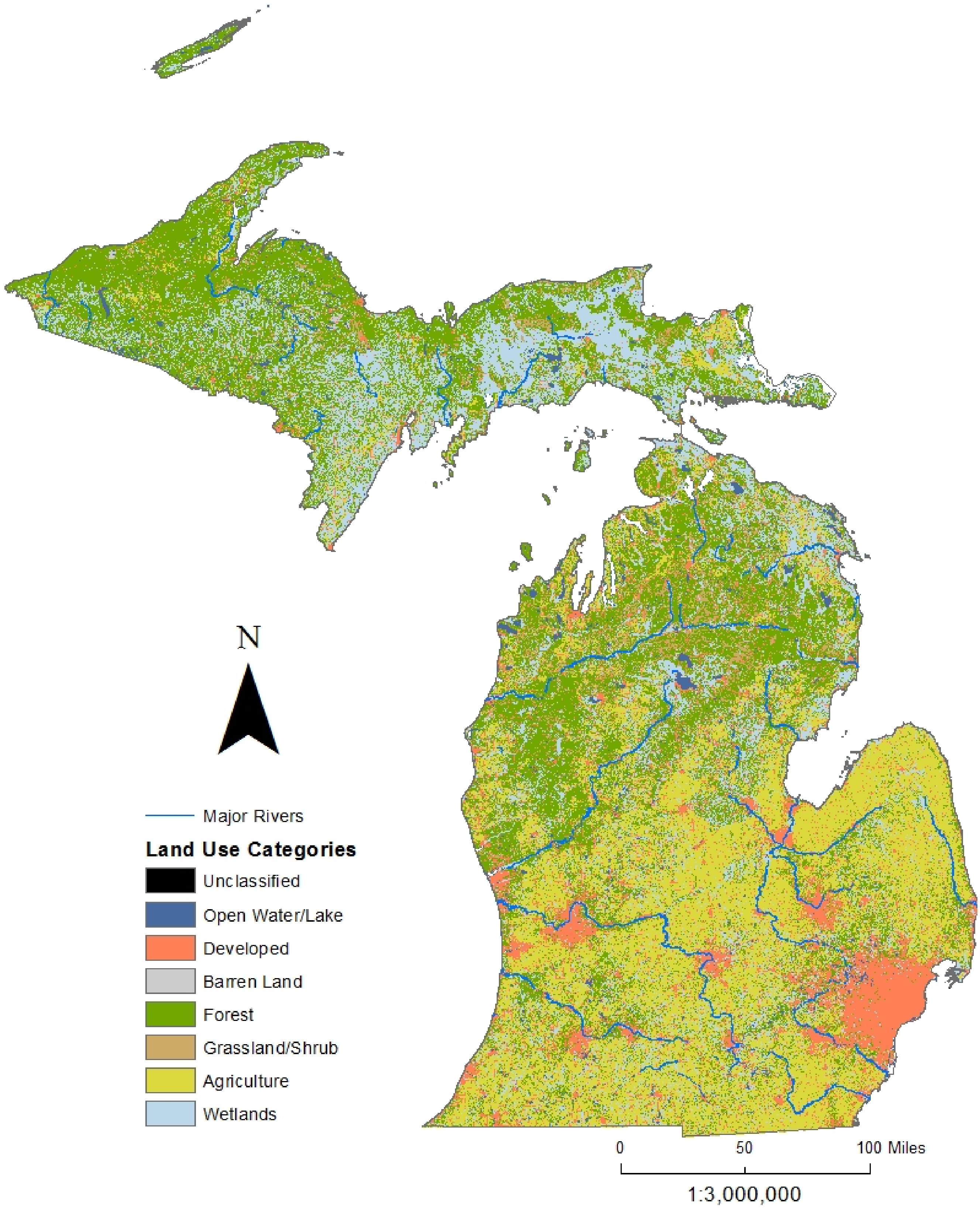

Fig. 1.5

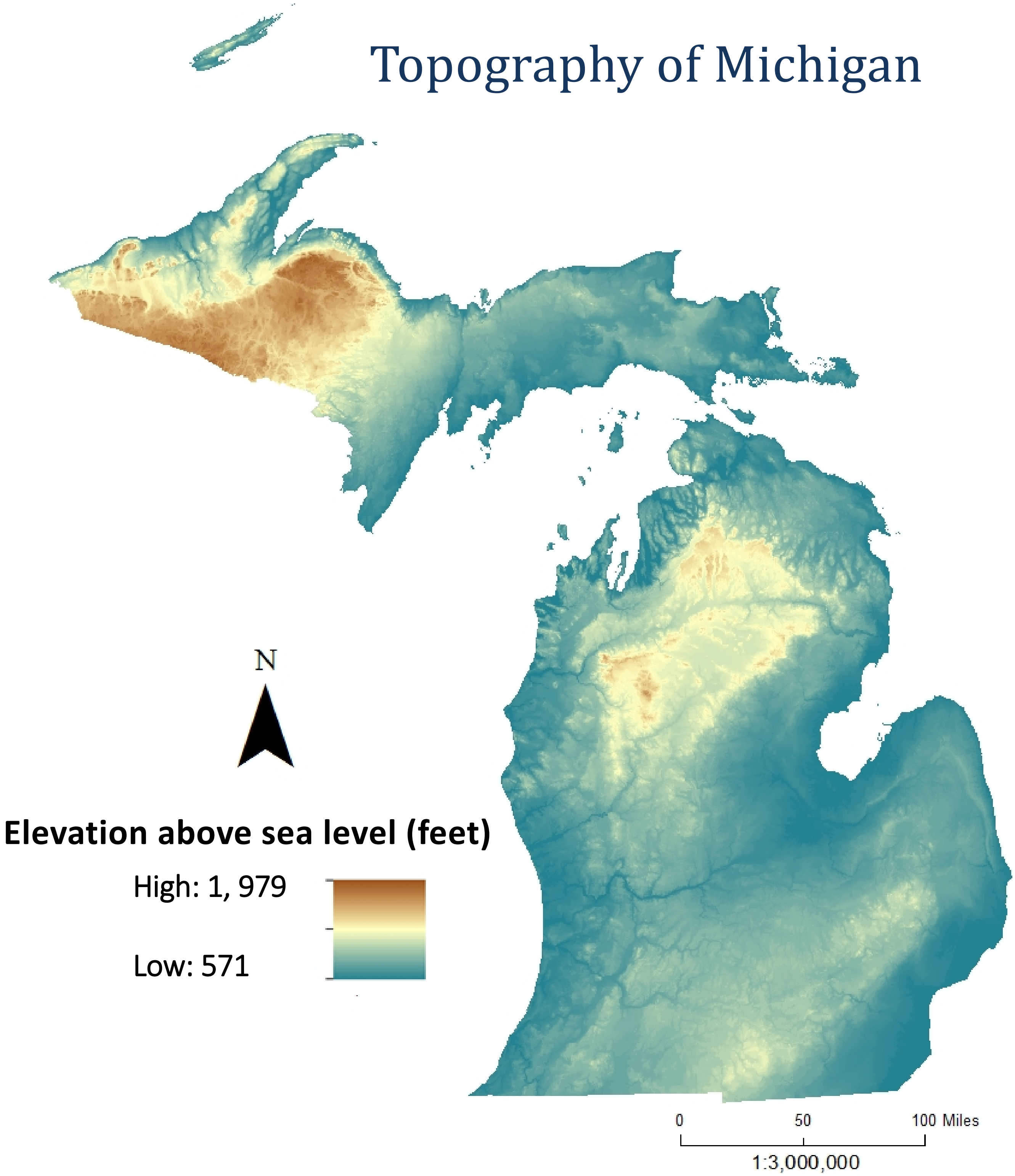
Topography of Michigan
N
Elevation above sea level (feet)
High: 1, 979
Low: 571
0
50
100 Miles
1:3,000,000

Fig. 1.6

Introduction to Michigan’s Climate

Michigan’s climate is influenced largely by the Great Lakes. The Lakes moderate the temperatures of the surrounding land, cooling the summers and warming the winters. Michigan has a humid continental climate, although there are two distinct regions. The southern and central parts of the Lower Peninsula have a warmer climate with hot summers and cold winters. The northern part of Lower Peninsula and the entire Upper Peninsula have a more severe climate, with warm, but shorter summers and longer, cold to very cold winters. For an in-depth description of Michigan’s current and future climate statistics and trends see **Chapter II: Michigan’s Current and Future Climate Conditions**.

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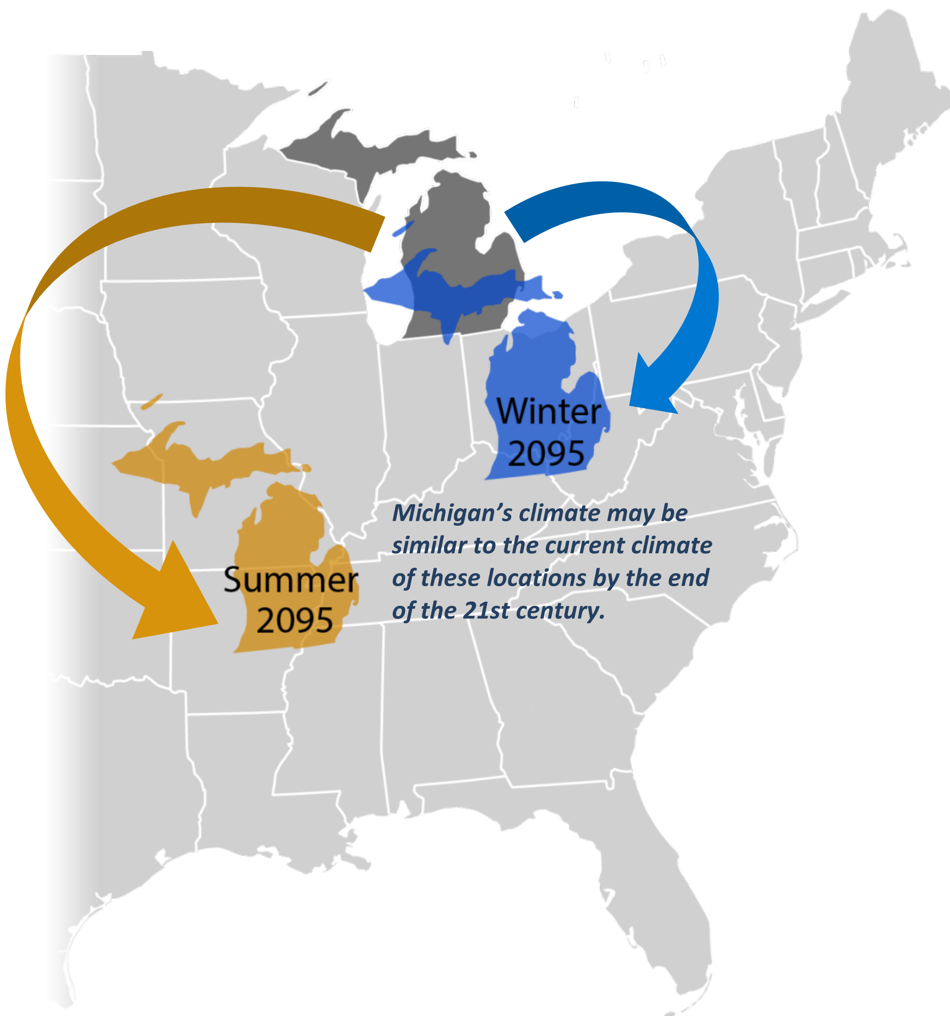
II. Michigan's Current and Future Climate Conditions



Source: Hayhoe, VanDorn, Croley II, Schlegal, & Wuebbles. (2010), modified

"The projections should be considered only one piece of information about future climate that fits into a larger context of: 1) how climate has already changed based on observations and 2) what we know from expert knowledge and local/regional future climate research" (pg. 33).

Baseline Climate Description

Average weather conditions across the State of Michigan vary greatly as a result of the state's north-to-south latitude coverage and its unique positioning among several Great Lakes (see Figure 2.1). For example, the average annual temperature of Ironwood, Michigan in the Western Upper Peninsula (U.P.) is 40.1° F, while the annual average temperature of Adrian, Michigan in the Southeastern Lower Peninsula (L.P.) is 48.6° F. These vast differences point to the need for localized information, especially for planning purposes across the State of Michigan. In this chapter we summarize current climate conditions, the physical drivers of our State's weather and climate, and projected future climate changes for the State of Michigan using local observed weather data and climate model projections, respectively.

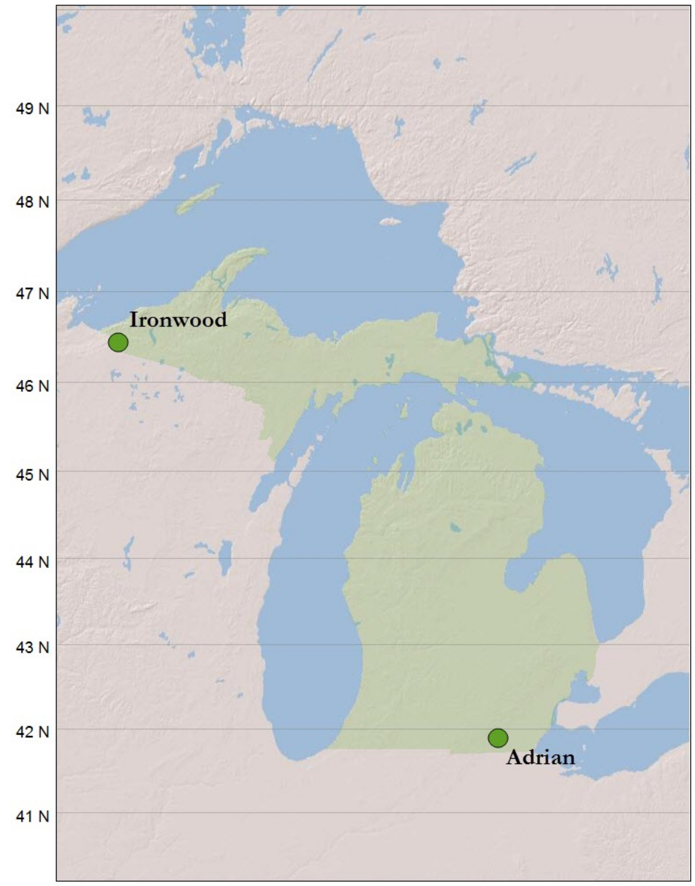


Fig. 2.1: Michigan reference map indicating the latitudinal coverage of the state and the geographic distance between the Southeast and Northwest areas of the State.

Observed Weather Data

Michigan's historic climate data in this report comes primarily from a series of twenty-two weather observation stations located throughout the state. **These stations have reliable temperature and precipitation measurements that have been systematically collected since 1950 and can be used to document historic changes annually and by season.** These point-based station data have been collected along with observational climate division data from the National Oceanic and Atmospheric Administration (NOAA) to produce historic averages for representative locations and all Michigan Climate Divisions. See Figure 2.2; map of climate stations and divisions. Findings are summarized below.

Current Climate Conditions

In general, the northwestern Upper Peninsula (U.P.) experiences harsh, long winters and mild summers, and the Lower Peninsula (L.P.) experiences milder winters with hot, humid summers. Winter temperatures often fall below 0°F, and the summers in the L.P., particularly the southern portion, commonly experience several humid days with temperatures upwards of 90°F. The greatest seasonal temperature difference from the summer occurs between December and February, with the coldest temperatures observed in northern inland areas away from the Great Lakes. Average annual precipitation (all precipitation types converted to their equivalent amount of liquid water) is somewhat consistent across the state, ranging from 30 inches per year in the northwestern L.P. to 38 inches per year in the southwestern L.P. The greatest contributions of precipitation generally occur during the summer, but frozen winter precipitation can have just as great or greater impact on society.

Snowfall in Michigan is usually associated with either large weather patterns or with lake effects, often leading to highly variable snowfall totals over short distances. Snowfall in the Keweenaw Peninsula commonly exceeds 240 inches per year, making it the snowiest region in the United States east of the Rocky Mountains. Municipal records from Delaware, Michigan, for example, report the seasonal snowfall total reached 390 inches during the winter of 1978-1979. This is a stark contrast to southern sections of Michigan where snowfall is often sparse, averaging a little over 30 inches per year.

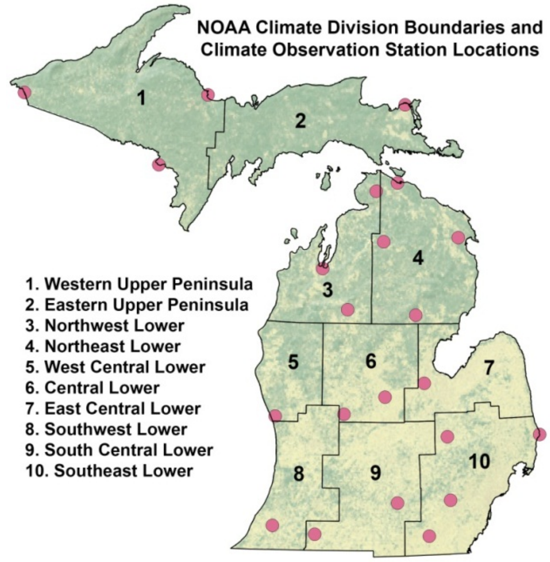


Fig. 2.2: NOAA Climate Divisions and high-quality climate observation stations. Red dots represent station locations that have consistent records since 1951.

Climate Changes Already Experienced

Through the 20th and into the 21st century, Michigan's climate has changed in measurable and impactful ways.

Warmer Temperatures

Average temperatures have increased in Michigan, roughly consistent with global trends over the past century. There is tremendous short-term variability in regional temperatures, however, and there have been multiple points in time when the multi-year regional trend did not reflect the global pattern. Annual mean temperature over the Midwest increased by approximately 0.11° F per decade during the 1900-2010 period, increased 0.22° F per decade for the period 1950-2010, and 0.47° F per decade for the period 1979-2010 (Brohan et al., 2006). For comparison, global temperatures have increased by about 1.4° F since 1850 (IPCC, 2007). Most locations throughout the state have warmed during the past century. Most stations in Michigan with reliable, long-term records show increases in average annual temperature from the 1951-1980 period to the 1981-2010 period. Overall, average low temperatures have increased slightly faster than high temperatures, but there is great variability across stations by season (see Table 2.1). **All Climate Divisions in Michigan experienced warmer average annual temperatures during the 1981-2010 period than during the 1951-1980 period. Increases ranged from 0.6° F in southeastern parts of the state up to 1.3° F in the Northwestern Lower peninsula.**

Table 2.1: Changes in average annual and seasonal temperatures (in degrees F) from the 1951-1980 period to the 1981-2010 period for Michigan's ten NOAA Climatic Divisions

Michigan Climate Division	Annual	Winter (Dec/Jan/Feb)	Spring (Mar/Apr/May)	Summer (Jun/Jul/Aug)	Fall (Sep/Oct/Nov)
Western Upper Peninsula (1)	1.0	2.0	1.1	0.6	0.2
Eastern Upper Peninsula (2)	1.1	1.8	1.3	0.9	0.4
Northwest Lower (3)	1.3	2.4	1.6	0.9	0.4
Northeast Lower (4)	1.2	2.1	1.4	0.9	0.3
West Central Lower (5)	1.0	2.3	1.2	0.4	0.1
Central Lower (6)	0.9	1.9	1.0	0.4	0.1
East Central Lower (7)	0.6	2.0	0.7	-0.2	-0.2
Southwestern Lower (8)	0.9	1.9	1.1	0.6	0.2
South Central Lower (9)	0.7	1.8	0.9	0.1	-0.1
Southeastern Lower (10)	0.6	1.4	0.9	0.3	-0.1
State Average (Area Weighted)	1.2	2.3	1.3	0.8	0.6

Across Michigan, average temperatures have increased faster during winter than other seasons. In some areas, mean summer and fall temperatures have actually decreased with time, possibly due to increased use of land for agriculture, which can have an overall cooling effect (Pan et al., 2004). Over the United States and the Midwest, much of the warming in recent decades has also been due to warmer nighttime (minimum) temperatures (Lorenz et al., 2009a; Easterling et al., 1997), (see Table 2.2) resulting in a narrower daily temperature range.

Table 2.2: Changes in average annual temperatures, average mid-day high temperatures, and average overnight low temperatures (in degrees F) from 1951-1980 to 1981-2010 for 22 weather observation stations in Michigan

Weather Station	Annual	Mid-Day High	Overnight Low
Adrian	0.0	0.2	-0.1
Alma	-0.5	-0.1	-0.9
Alpena	1.1	0.6	1.5
Ann Arbor	0.4	0.4	0.3
Cheboygan	-0.4	-0.5	-0.2
Eau Claire	1.3	1.1	1.4
Flint	1.0	1.2	0.8
Gaylord	0.5	-0.2	1.2
Greenville	0.0	0.4	-0.4
Iron Mountain	0.5	0.7	0.3
Ironwood	-0.3	-0.9	0.4
Jackson	0.6	0.6	0.6
Lake City	0.2	-0.2	0.6
Marquette	0.8	1.2	0.3
Muskegon	0.8	0.8	0.9
Pellston	1.6	1.3	1.8
Port Huron	0.0	-0.1	0.1
Saginaw	0.6	0.7	0.5
Sault Ste. Marie	1.4	1.4	1.4
Three Rivers	0.2	0.4	0.0
Traverse City	1.3	1.0	1.7
West Branch	0.3	1.1	-0.4
All station average	0.52	0.50	0.54

Changing Precipitation

Annual precipitation across the Midwest has increased overall during the past century (Groisman & Easterling, 1994; Andresen et al., 2013). The winter and fall months have seen the greatest relative changes in precipitation, while precipitation during the spring and summer has remained relatively stable or decreased slightly. **Overall, total annual precipitation in Michigan increased by 4.5% (or 1.4 inches) from the 1951-1980 average to the 1981-2010 average, but there has been large regional variation** (see Table 2.3).

Table 2.3: Percent change in mean total annual and seasonal precipitation from the 1951-1980 period to the 1981-2010 period for Michigan's ten NOAA Climate Divisions

Michigan Climate Division	Annual	Winter (Dec/Jan/Feb)	Spring (Mar/Apr/May)	Summer (Jun/Jul/Aug)	Fall (Sep/Oct/Nov)
Western Upper Peninsula (1)	-2.9	0.1	-7.8	-9.7	8.1
Eastern Upper Peninsula (2)	-2.8	-3.5	-9.6	-6.2	7.4
Northwest Lower (3)	5.6	6.6	3.9	2.4	10.1
Northeast Lower (4)	2.4	1.9	-1.3	1.4	7.9
West Central Lower (5)	6.8	-1.6	6.0	4.3	15.8
Central Lower (6)	8.6	10.0	8.8	2.3	15.4
East Central Lower (7)	11.5	5.3	8.4	7.9	23.8
Southwestern Lower (8)	7.0	3.8	3.0	4.1	16.9
South Central Lower (9)	10.1	8.4	5.4	4.9	24.8
Southeastern Lower (10)	9.5	7.3	2.0	4.5	27.7
State Average (Area Weighted)	4.5	3.5	0.5	0.1	14.6

Annual precipitation totals have declined or remained largely unchanged across the U.P. and the northernmost sections of the L.P. of Michigan, while southern areas of the state report increases of approximately 8-13%. The U.P. is also the only area to see declining precipitation in the spring and summer months. Similarly, when looking at station data, most locations across Michigan show increased annual precipitation. These changes are usually distributed unevenly throughout the year, with historically wet months seeing increases in precipitation and historically dry months seeing lesser increases or decreases (see Table 2.4). Ann Arbor is an extreme case, with 25% more precipitation per year during the 1981-2010 period than during the 1951-1980 period; while the northern city of Pellston showed the largest decline of 7.6%.

Table 2.4: Percent change in total annual precipitation from 1951-1980 to 1981-2010 for 22 Michigan weather observation stations

Weather Station	Change (%)
Adrian	9.3
Alma	11.2
Alpena	-4.3
Ann Arbor	25.0
Cheboygan	12.7
Eau Claire	7.3
Flint	8.4
Gaylord	5.6
Greenville	4.8
Iron Mountain	2.1
Ironwood	1.6
Jackson	8.0
Lake City	13.1
Marquette	-6.0
Muskegon	5.2
Pellston	-7.6
Port Huron	12.6
Saginaw	3.2
Sault Ste. Marie	-0.6
Three Rivers	13.4
Traverse City	8.3
West Branch	10.7
All station average	6.5

Lake Warming and Reduced Ice Cover

Great Lakes surface water temperatures, evaporation from the lakes, and the seasonality of lake freezing and thawing are key drivers of weather for many Michigan communities. Significant changes to any of these physical characteristics could have profound implications for Michigan's climate. **The Great Lakes have warmed faster than nearby air temperature in recent years. Lake Superior summer (July–September) surface water temperatures increased approximately**

4.5° F from 1979-2006, a significantly faster rate than regional atmospheric warming of 0.6 to 0.9^0 F. Declining winter ice cover is the largest driving factor of this amplified lake warming. The Lakes are freezing later in the year and thawing earlier, allowing a longer period to warm during the summer and amplifying the effects of warmer air temperatures (Colman & Austin, 2007). Aside from altering nearby air temperatures over land, warmer water temperatures can increase the risk of water contamination and increase the likelihood of algal blooms.

Table 2.5: Change in average number and percent of days per year with precipitation >1 inch from 1951-1980 to the 1981-2010 period for 22 Michigan weather observation stations

Weather Station	Number of Days	% Change
Adrian	0.9	14.1
Alma	0.8	16.2
Alpena	-0.6	-15.1
Ann Arbor	1.3	29.4
Cheboygan	0.0	0.4
Eau Claire	0.6	10.5
Flint Bishop	0.6	13.2
Gaylord	-0.1	-3.3
Greenville	0.5	9.7
Iron Mountain	-0.1	-1.8
Ironwood	0.8	15.7
Jackson	1.4	33.6
Lake City	1.0	24.7
Marquette	-0.1	-2.1
Muskegon	0.7	16.2
Pellston	-0.4	-8.1
Port Huron	0.4	7.2
Saginaw	1.4	32.8
Sault Ste. Marie	0.2	5.1
Three Rivers	1.7	26.9
Traverse City	1.3	36.1
West Branch	1.1	27.4
All Station Average	0.6	13.1

Extreme Precipitation

Across the Upper Midwest, extreme precipitation events have become more intense and more frequent over the past century. Several studies examining different thresholds of precipitation and varying durations of precipitation events have arrived at similar conclusions. Twenty-two percent of the stations considered in a study by Pryor et al., 2009, identified significant increases in the total accumulated precipitation during the top-10 wettest days of the year. The occurrence of intense precipitation events has also risen substantially in recent decades. In the Midwest, the number of 24 hour, 20% annual chance storms (storms that have a 20% chance of occurring in a given year, also known as 5-year storms) has increased by about 4% per decade since the beginning of the 20th century (Kunkel, 2003, updated), and the amount of precipitation falling in the 1% heaviest precipitation events has increased by 37%, (Walsh et al., 2014). **Michigan has experienced a similar change between the time periods of 1951-1980 and 1981-2010, with most observational stations recording increased number of days with precipitation exceeding 1 inch (see Table 2.5). The average change over the twenty-two stations was 13.1% or an increase of 0.6 days per year**; the greatest increases were reported from Traverse City (36.1%), Jackson (33.6%) Saginaw (32.8%), and Ann Arbor (29.4%). The trend towards heavier rainfall has amplified the risk of flooding across the region (Walsh et al., 2014), but in many urban areas the increased flood risk has been attributed more strongly to changes in land use than changes in climate (Scharffenberg & Fleming, 2006; Changnon et al., 1996).

Extreme Temperatures

The first few decades of the 20th century and the years from 1965-1995 were periods of relatively frequent intense cold waves, while they were infrequent from the 1920s through 1960 and from 1996 to present. Though there have been notable exceptions, extreme heat waves have also occurred less frequently in recent years in comparison to other historical periods (Andresen et al., 2013).

The number of days per year exceeding 90° F and 95° F has not changed significantly for most locations in Michigan. Although some locations have reported declines in the number of days exceeding 90°F, the overall average change was less than 0.1 days per year (see Table 2.6).

Alternatively, heat waves defined by both temperature and humidity driven by weather systems such as air masses have shown a different pattern of change. **The frequency of heat waves defined by the presence of tropical air masses has significantly increased in Southeastern Michigan; while the number of dry, cool days during summer has significantly declined (UCS, 2012).** From 1959 through 2011, Detroit saw slight but statistically significant increases in hot, humid days and hot, dry days. The effect of rising temperatures was more clearly seen in a decline of 10.5 cool, dry days per year during summer months (UCS, 2012).

Table 2.6: Change in average number of days with extreme heat (>90°F) and extreme cold (< 32° F) temperatures from 1951-1980 to 1981-2010 for 22 Michigan weather observation stations

Weather Station	Days > 90°F	Days < 32°F
Adrian	-2.5	-6.0
Alma	0.1	9.5
Alpena	0.2	-8.5
Ann Arbor	0.5	-2.8
Cheboygan	-0.2	-1.2
Eau Claire	1.5	-11.3
Flint Bishop	1.6	-3.6
Gaylord	-0.6	-3.8
Greenville	-0.7	4.7
Iron Mountain	2.4	-2.6
Ironwood	-0.4	0.9
Jackson	-3.9	-8.2
Lake City	-0.2	-1.1
Marquette	-0.7	-3.4
Muskegon	-0.9	-6.7
Pellston	0.7	-7.2
Port Huron	-0.5	-0.7
Saginaw	-0.4	-3.6
Sault Ste. Marie	0.2	-9.2
Three Rivers	-0.9	-1.1
Traverse City	-0.7	-10.7
West Branch	0.2	3.8
All station average	-0.2	-3.3

Drought

As precipitation has increased across the region during the past several decades, the incidence and geographic extent of drought has decreased with time (Mishra et al., 2010). For the agricultural industry, the trend towards a wetter climate and decreasing drought frequency has generally been a positive impact, with relative increases in crop yields due to less moisture stress and more favorable growing conditions overall (Andresen et al., 2001).

Michigan's Weather and Climate Drivers

Weather for the State of Michigan is driven primarily by the characterization of air masses entering the region, large-scale atmospheric oscillations, and local influences from the Great Lakes. Each of these factors acts on different time scales and durations. Short-term weather patterns lasting less than a few weeks are generally driven by the polar jet stream in the winter, spring, and fall. Tropical air masses tend to influence weather in the southern parts of the state to a greater degree during the summer months (Andresen & Winkler, 2009).

Fig. 2.3: Air masses over the United States. Source: www.srh.noaa.gov/jetstream/synoptic/airmass.htm

Three primary air mass types from three source regions dominate the climatic patterns of Michigan (Figure 2.3). Maritime tropical air masses usually originate from the Gulf of Mexico. Continental polar air masses enter the region from Eastern Canada, and maritime polar air masses come from the Pacific Northwest/Northern Rockies (Shadbolt et al., 2006). In general, the tropical air masses carry more moisture with them than the continental air masses. Occasionally, airflow originates from the East Coast and western Atlantic or the Southwestern United States, but these air masses appear sporadically from year to year and are of lesser importance in the northern parts of the state.

Natural Variations

Natural drivers of weather variability over multi-year periods have far greater impact on the day to day weather Michigan experiences than human-caused climate change. El Niño and La Niña are opposite phases of what is known as the El Niño-Southern Oscillation (ENSO) cycle (Figure 2.4), a scientific term that describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific. During El Nino events, the Midwest tends to experience weaker winds, fewer storms and milder than average temperatures (Climate Prediction Center, 2005). La Niña events tend to bring either much above or below normal temperatures and enhanced precipitation in the southernmost parts of Michigan. Other large-scale oscillations may modify the magnitude of El Nino/La Nina (Birka et al., 2010, Rogers et al., 2004) and help drive multi-year temperature and ice cover patterns on the Great Lakes. (Wang et al., 2011) As a result, the state and region have experienced periods of intense heat even as long-term average temperatures have risen.

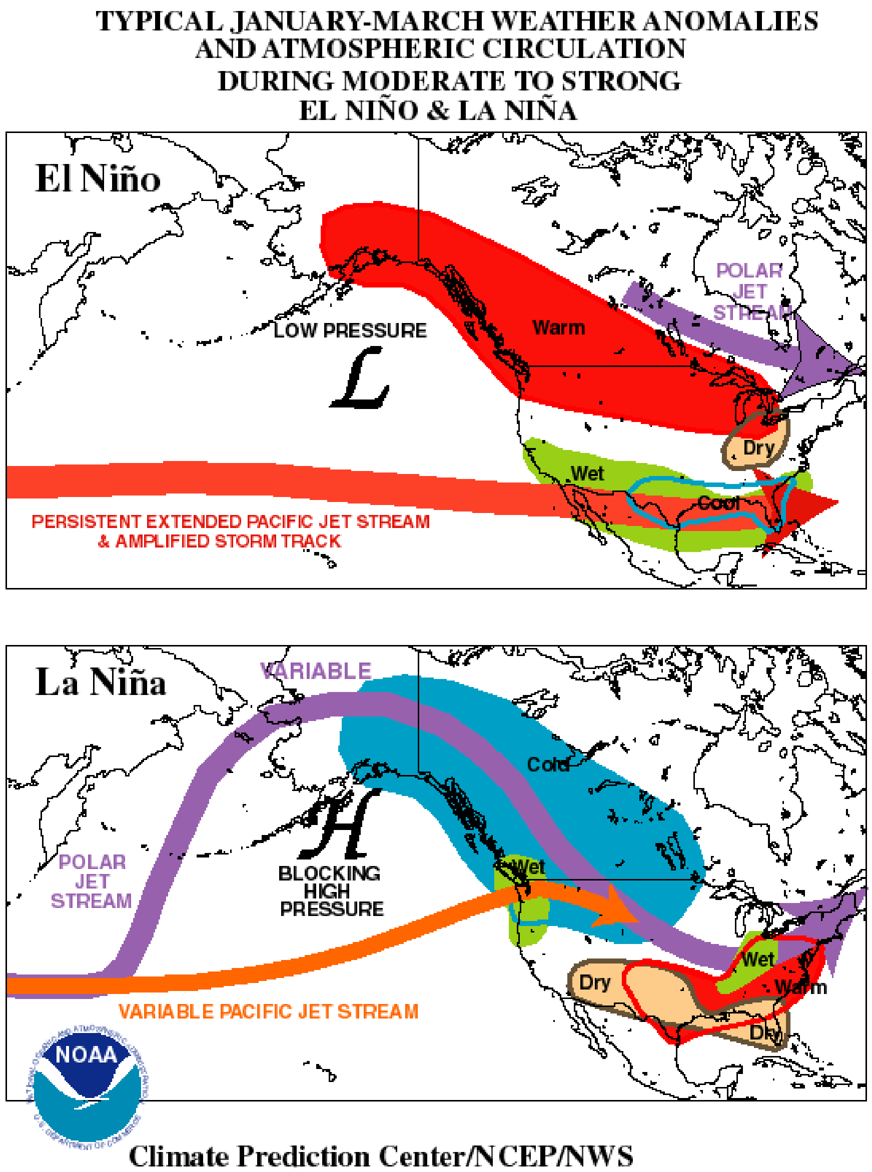


Fig. 2.4: El Nino- and La Nina-induced conditions over the U.S. Image Source: http://www.srh.noaa.gov/jan/?n=el_nino_and_la_nina

Lake Effects

Michigan's location among the Great Lakes has a profound influence on its climate (Scott and Huff 1996). 'Lake effects' in winter result in a cloudier, wetter, and more moderate climate in areas downwind of the Lakes. On average, areas downwind of the lakes receive 75% less solar insolation than areas upwind of the Lakes at the same latitude, making many parts of Michigan some of the cloudiest areas of the country. During the late spring and summer, lake water temperatures are often cooler than nearby land surfaces, and the lake effect is reversed; cloudiness is suppressed over and immediately downwind of the lakes (Andresen & Winkler, 2009).

Air temperatures are also modified by the Lakes. Winters in lake effect zones are mildly warmer and summers are mildly cooler than areas further inland. **Estimated winter maximum and minimum temperatures downwind of the Lakes are both approximately 6% warmer than locations upwind of the Lakes. Summer maximum temperatures on the downwind side are 3% cooler than in upwind areas, and summer minimum temperatures are 2% cooler** (Changnon & Jones, 1972). The Lakes moderate extreme minimum temperatures more noticeably. Extreme minimum temperatures within 30 miles of the shores of the Great Lakes are as much as 20^0 F warmer than inland temperatures at the same latitude. Extreme minimum temperatures in the summer season experience less of an impact, but are still as much as 14^0 F cooler than those at inland locations (Eichenlaub et al., 1990).

Perhaps the most significant influences the Lakes have on the regional climate are altered precipitation patterns. Lake effect snowfall strongly amplifies the seasonal snowfall totals of areas within approximately 150 miles of the downwind shores of the Lakes (Norton & Bolsenga, 1993). Sections of Michigan affected by lake-effect snow are the western portion of the L.P. and the northern edge of the U.P. as illustrated in Figure 2.5. **An estimated 25-50% of annual snowfall totals along the eastern shores of Lake Michigan are attributed to lake-effect snowfall** (Braham & Dungey, 1984).

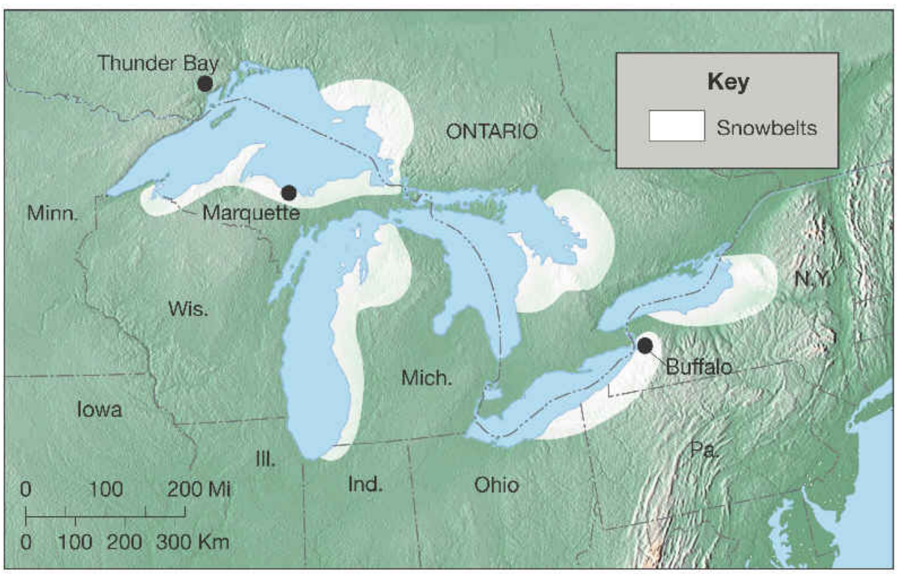


Fig. 2.5: Approximate extent of major lake-effect snow belts in the Great Lakes region. To read more about lake-effect snow please visit: http://glisa.umich.edu/resources/lake-effect-snow-great-lakes-region

Recent and future changes of Michigan's climate are in part related to how the physical drivers are changing in response to increasing CO_2. One of the greatest changes, as mentioned above, is how quickly the Great Lakes are warming and the subsequent impact on local weather patterns. In the next section we focus on information about future climate for Michigan based primarily on climate model data.

Summary of Climate Projections: Description and Rationale

Climate projections for Michigan highlighted in this report are taken from several sources to best represent the overall consensus of the future climate of the region. There are many variations in the design of individual climate models, and no single model performs the best at simulating all aspects of future climate. For this reason, *ensembles* (groups of models) with different strengths are used to identify consistent trends in future projections; this is the approach used for the National Climate

Assessment Midwest Report (Pryor et al., 2014). A summary of projected temperature and precipitation changes are presented in Tables 2.7 and 2.8, respectively, in the Appendix of this chapter.

Defining Global and Downscaled Models

Climate models use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate.

Global climate models (GCMs)

These types of models are designed to project changes in climate at a global or continental scale. While the most prominent model ensembles in use offer a robust simulation of the climate and provide a sound range of projections in broad brush strokes, they generate output at a coarse resolution. In many cases, 4-6 output grids cover an area roughly the size of the state of Michigan. This resolution is too coarse to distinguish climate differences between two nearby cities, for example. The smallest appropriate spatial scale for the use of GCM simulations is at the U.S. Climate Division boundaries. For Michigan, this equates to areas of 5-10 counties each.

Downscaled Regional Climate Models

In comparison to GCMs, downscaled models attempt to identify trends in climate at a finer, more tangible resolution than what GCMs are able to provide. Output data are usually arranged in grids at roughly the size of large Michigan counties. There are tradeoffs to using downscaled data, however. Downscaled models may more accurately simulate smaller-scale weather systems, extreme events, and the effects of local topography on climate, but downscaled models still rely on global climate models to provide input from a global perspective, and these global inputs are downscaled over the region of interest. This process introduces an additional layer of uncertainty by requiring additional statistical observations and assumptions of local weather patterns, land cover, and geography. Downscaled models therefore depend on both the accuracy of the global climate simulation they are derived from, and the accuracy of other observations and assumptions used to downscale the global outputs to a finer scale. At a given location a downscaled model output may provide more accurate projections, but may also increase the margin of error when compared to global climate model outputs over the same area. Data downscaled or simulated at higher resolution does not necessarily imply a better representation of climate. An evaluation of the quality of information coming from each model product used in this report is discussed below.

Emissions Scenarios

Emissions scenarios are sets of assumptions based on the future rate of greenhouse gas emissions, human interaction with their environment, technological advancement, and population growth. They provide logical, quantitative pathways that describe how climate may change in the future.

The IPCC 4th Assessment Report (IPCC 2007) and the Third National Climate Assessment (Walsh et al.,. 2014) are based in part on widely-used, heavily scrutinized emissions scenarios. Of these scenarios some are more practical for describing plausible future conditions. The A2 scenario, sometimes referred to as a "high scenario,” or “business-as-usual scenario," assumes greenhouse gas concentrations will continue to increase throughout the 21st century. The B1 scenario, sometimes referred to as a "low scenario," consists of relatively slight increases in greenhouse gases throughout the 21st century. This report focuses primarily on the higher scenario (A2), since it has been the best indicator of greenhouse gas emissions during the recent past and atmospheric carbon dioxide trends continue to increase.

Future Timeframe Considered

Future projections are available for different 30-year periods out to the year 2100, and we focus on the most recent period (2021-2050) for which information is available, since most public health and community planning occurs over short time frames. Mid- and late-century period projections (2041-2070 and 2070-2099, respectively) are also common, and we bring in relevant information from them when earlier data are not available.

Climate projections used in this Climate and Health Profile Report

All of the climate projection products described here rely on information from the Climate Model Inter-comparison Project phase 3 (CMIP3) global climate models (Meehl et al., 2007). Statistically downscaled climate model projections were generated based on CMIP3 simulations to which are added regional observations and assumptions to create higher spatial resolution information. The North American Regional Climate Change Assessment Program (NARCCAP) dynamically-downscaled simulations use regional climate models (RCMs) that operate at higher spatial resolutions, but still require input from global climate models regarding changing conditions outside the region of interest. As stated below, there are tradeoffs with each approach regarding the quality of the model information versus the spatial scale.

Quality of Climate Projections

Before presenting the results of each set of climate projections, consider the quality of the information coming from each source. GLISA has extensively studied the CMIP3 GCMs for the Great Lakes region to better understand uncertainties coming from the models. Their findings for the Great Lakes region can be applied directly to the State of Michigan. One of the largest sources of uncertainty in the models is their poor representation of the Great Lakes. The low spatial resolution of GCMs does not allow them to accurately capture the spatial structure of the Great Lakes. Some of the GCMs use one body of water to represent all of the Great Lakes, or a swamp or moist soil classification to represent the land surface where the lakes would normally reside, and very few GCMs include any form of simulation of the lakes and their dynamics. A major consequence of the poor representation of the lakes in the climate models is that the lakes' influence on local and regional climate is not realistically simulated. The lakes are known to modify local and regional air temperatures and precipitation patterns and intensities. Lakeshore air temperatures are modified by the relative cool or warm influences of the Great Lakes. Lake water temperatures change more slowly than air temperatures, so relatively warm waters in winter increases local air temperatures, and relatively cool waters in summer decreases local air temperatures. Lakeshore precipitation effects are generally experienced on the downwind sides of the lakes. One of the most well-known lake-weather impacts is lake-effect snowfall. In Michigan, the greatest lake-effect precipitation occurs to the east of Lake Michigan and the southern shore of Lake Superior (see Figure 2.5). Lake-effect zones start at the lakeshore and extend inland about 50 miles and sometimes farther. Lake-effect precipitation is simply not detectable in GCMs because the model resolution is too coarse. At best, a GCM may be able to capture the large-scale regional effects of the lakes, such as a large reduction in precipitation over and around Lake Superior in the summertime. For a more in-depth discussion on these effects in Michigan, refer to the ***Lake Effects*** section above.

Even at higher spatial resolutions, the statistically-downscaled projections have the same lake-climate issues, because downscaling does not improve the physical representation of the lakes. Dynamically-downscaled models may capture lake-effects since their simulations are performed at higher spatial resolutions, but even the NARCCAP simulations have caveats for the Great Lakes region. Lake temperatures are not well simulated in several of the NARCCAP RCMs, which negatively affects the simulation of lake-weather processes. Some RCMs assign the same temperature of the air to the lake surface, which is not realistic at most times and prevents the lake from modifying local air temperatures and precipitation in these models. Even RCMs that model lake surface temperatures do not include the impact of lake ice formation, a drawback since lake ice plays a major role in winter and early spring by suppressing lake-effects when ice completely covers the lakes.

Given the limitations and caveats in each set of climate projections for the Great Lakes region, there is little evidence that climate projections are taking into account the interaction of the lakes with local and regional weather. **The projections should be considered only one piece of information about future climate that fits into a larger context of: 1) how climate has already changed based on observations, and 2) what we know from expert knowledge and local/regional future climate research.**

The next sections discuss the climate parameters that were studied from the projections and the information that the models provide about how those parameters may change in the future. The last section integrates the information about the quality of the projections with the projections for each parameter to provide a more robust description of future climate for Michigan.

Summary of Climate Projections: Spatial and Temporal

This analysis starts by summarizing annual and seasonal trends for the most common climate parameters: mean temperature and precipitation. Additional parameters identified as highly valuable for the health sector include: heat events, extreme precipitation events, humidity levels, air stagnation events, snowfall, and wind patterns. Although each of these parameters will be discussed in the following section, the certainty surrounding each parameter is variable. Mean temperature is the most robust simulation in the climate models, and parameters related to precipitation and winds are more uncertain, because the models have greater difficulty simulating those variables. Each of these parameters, and combinations of parameters, contribute to increased risk of respiratory diseases, heat-related morbidity and mortality, CO poisoning, waterborne toxins, and vector-borne diseases.

The future state of Michigan's climate depends on many factors. Climate models incorporate information related to human activities and natural events that can cause changes to the climate. The primary mechanism for representing human-induced climate forcing in climate models is through the concentration of greenhouse gases and aerosols present in the atmosphere. For example, if fossil fuel based energy usage increases in the future, there will be greater concentrations of carbon dioxide in the atmosphere. Climate models are run under different scenarios for future greenhouse gas concentrations, and as previously mentioned, this report uses the highest emissions scenario A2 since this is the current measured trajectory. Choice of emission scenario is less critical for near-term climate simulations, so there is not a lot of added uncertainty from choosing the high scenario for this analysis.

Land use change is another human-induced factor that can greatly alter local and regional climate, but land use-related climate changes are often not captured well, if at all, in many climate models. Land use changes should be considered in addition to climate model projections.

Climate models do simulate non-human causes of climate change such as releases of greenhouse gases and aerosols from volcanic eruptions. However, atmospheric concentrations of these constituents have increased beyond the natural historical range as a result of human activities (IPCC, 2007). The human component of climate change, whether through release of greenhouse gases or through land use changes, is the primary driver of recent climate changes and it will likely continue to play a major role in the future.

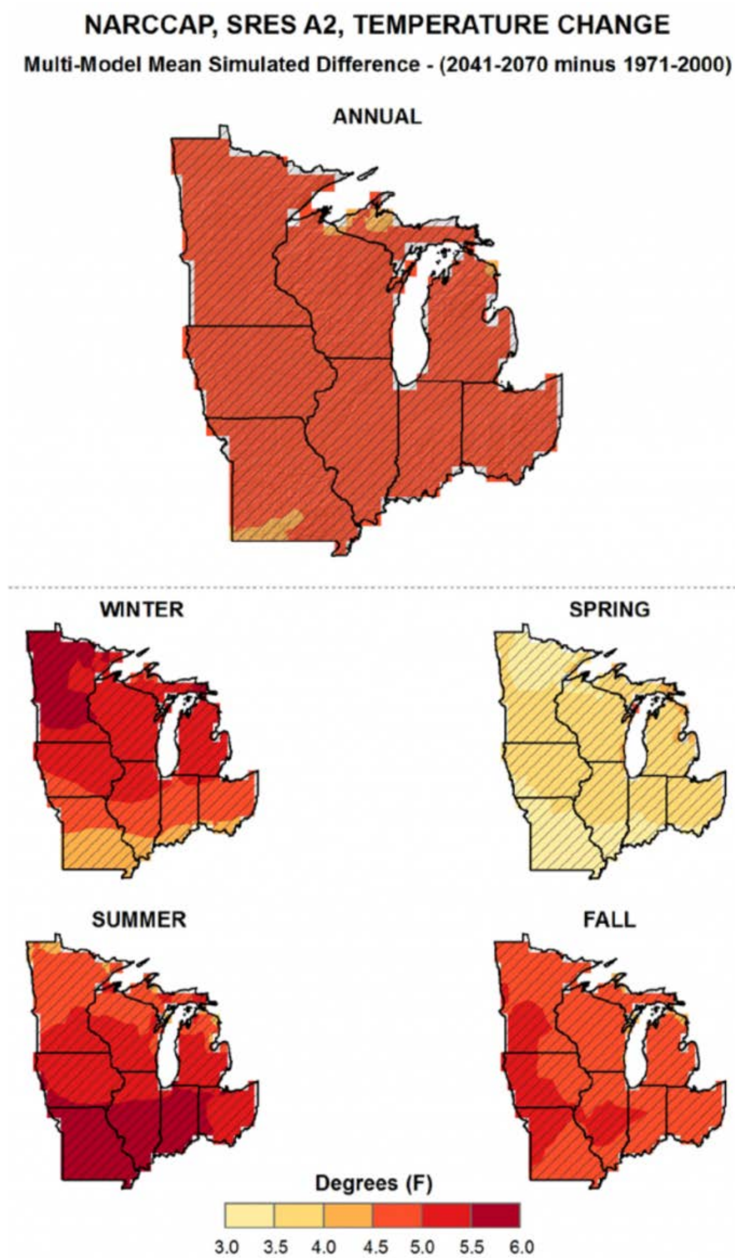


Fig. 2.6: Projected annual and seasonal temperature changes (degrees F) averaged from the NARCCAP models. Winter temperatures are projected to increase the most in the north and summer temperatures are projected to increase the most in the south. Spring is projected to have the smallest increases. Hatching (areas with slanted lines) indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source: Kunkel et al., 2013.

One of the largest regional factors affected by climate change that will impact Michigan's climate is the response of the Great Lakes to warming temperatures. The Great Lakes are a major mechanism for modifying Michigan's climate, and warming air temperatures are changing the dynamics of the Lakes and how they interact with regional weather systems. One example of observed change is the trend of reduced lake ice during winter that allows the Lakes to continue interacting with the atmosphere by providing heat and moisture to fuel weather systems. The climate projections do not realistically capture the Lakes to show these relationships, so information about the Lakes' impact on climate is missing from the projections. Regional climate modeling studies are useful for filling the information gap that is present in the global climate models.

Although climate projections do not provide a complete and certain picture of future climate, they can provide a general foundation of information to build on and be further supplemented by expert guidance. Several sources of climate projections were consulted for the description of Michigan's future climate, but the CMIP3 GCMs are most important since they provide the foundational information for all of the other products used for this report.

Temperature Projections

All projections show a consistent message of increasing average temperatures (Figure 2.6), but **there is variability in the magnitude of increase ranging from about 1.5 to 4.5° F by 2050. In the near term, temperature changes will be closer to the lower bound of the range.** Although the projections agree that temperatures will increase on average, there is some uncertainty in the degree of warming for seasonal projections.

The global climate models show each season's temperature increasing by approximately the same amount with similar ranges of variability among individual models. **The NARCCAP models simulate twice as much warming in the winter and summer (6^0 F) compared to spring (3^0 F) across Michigan by mid-century, contrasting the downscaled CMIP3 projections by Hayhoe et al. (2010) that found larger increases in winter compared to spring and summer in the near-term and a reversal in the seasonal temperature trend by the end of the century.** Differences between each set of seasonal projections emphasize the uncertainty in relative seasonal temperature increases, but there is consistent evidence to suggest warmer temperatures during all seasons in the future.

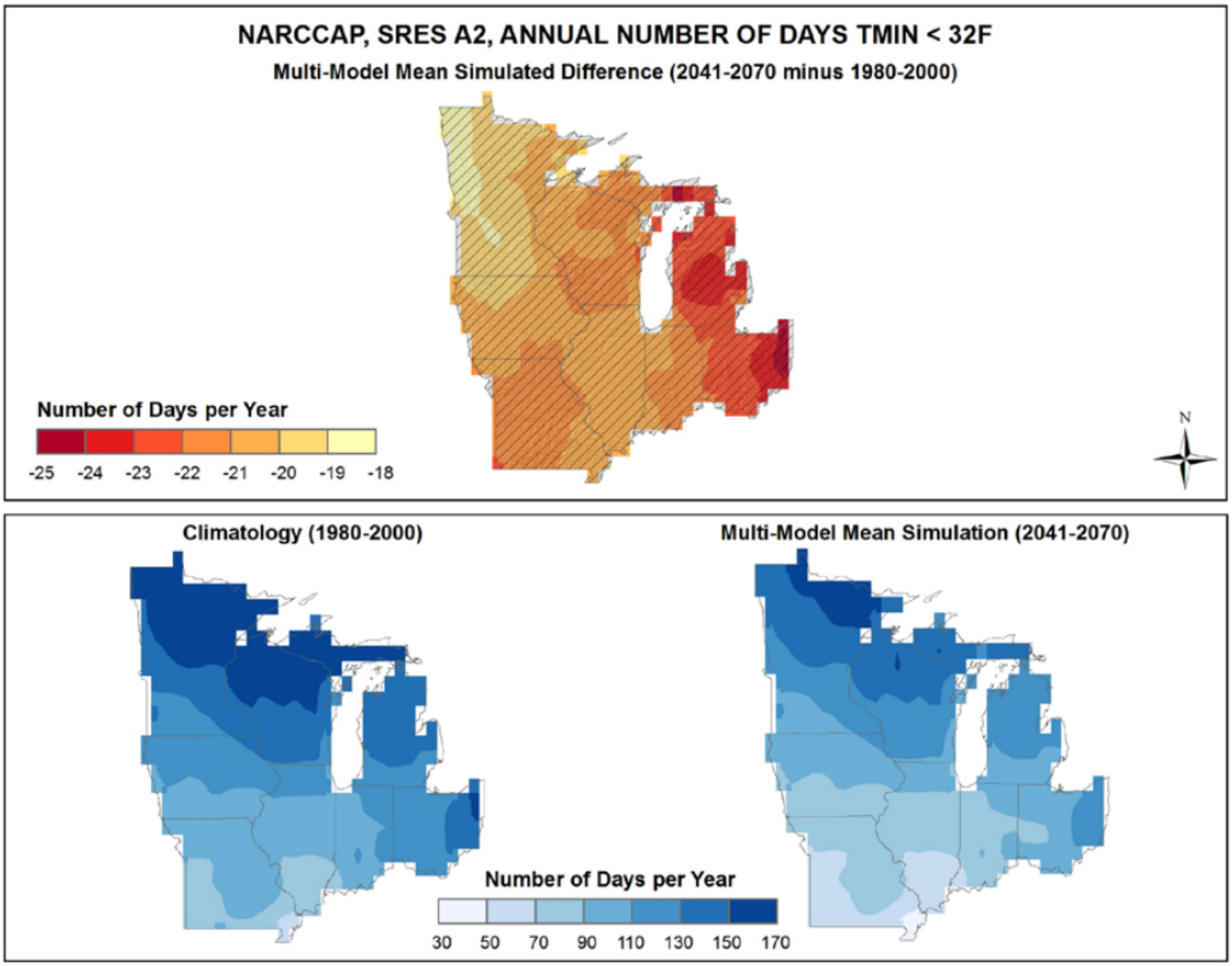


Fig. 2.7: Projected change in annual number of days falling below 32^0 F averaged from the NARCCAP models. The average number of cold days is projected to decrease across Michigan by 20-25 days per year. Observed values are shown in the lower left. Simulated values are shown in the lower right. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source: Kunkel et al., 2013.

Average temperatures are warming and **there are fewer below-freezing cold days (Figure 2.7) expected across Michigan by 20 days or more per year**, with the greatest decrease in central areas of the Lower Peninsula.

Days with maximum temperatures above 95^0 F (Figure 2.8) are projected to increase by five to 25 days, but most of the projections are for the lower bound of that range. In Michigan, the greatest increases for days above 95^0 F are in the southern half of the L.P., and the U.P. ranges from no change to a few additional days above 95^0 F per year.

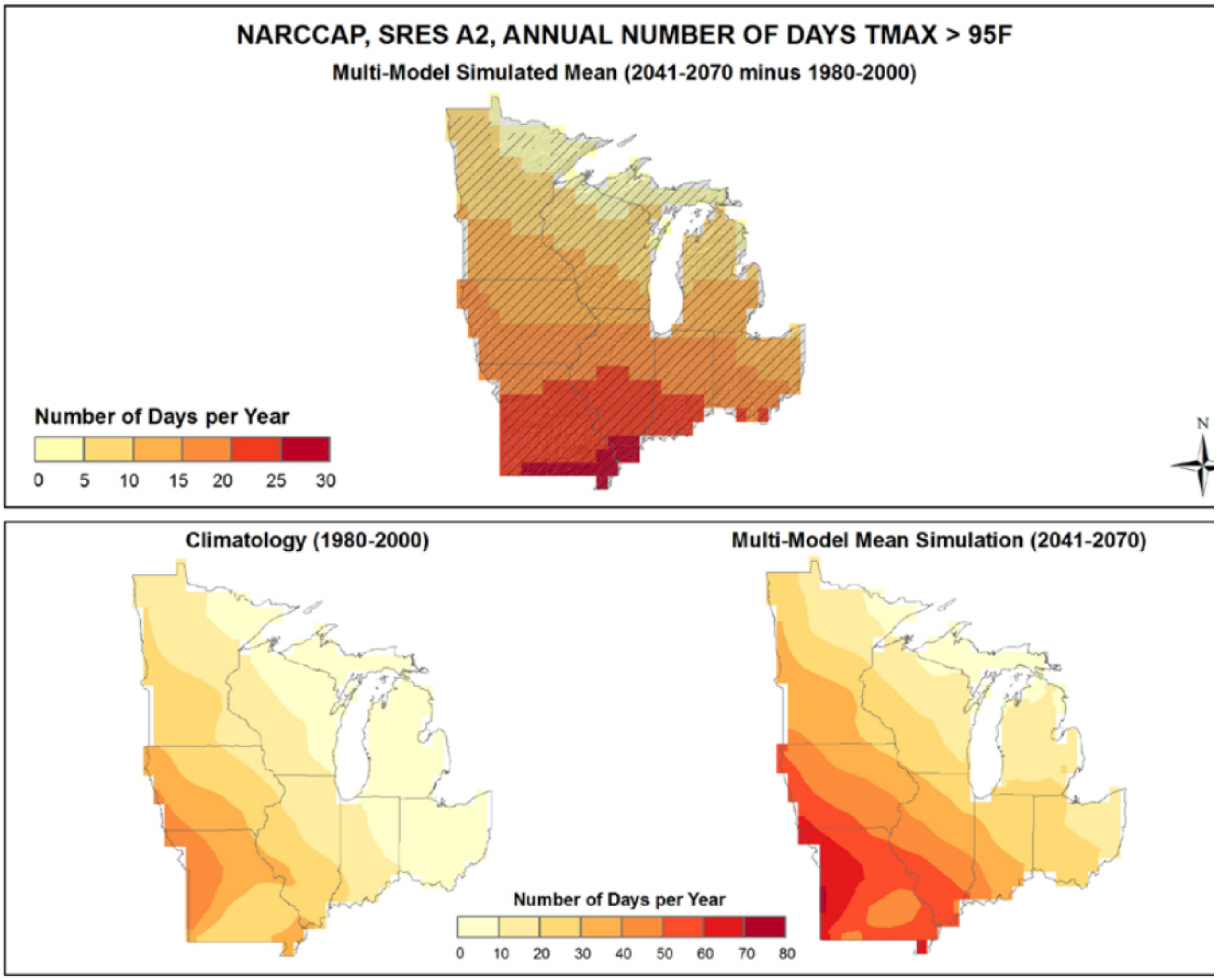


Fig. 2.8: Projected annual number of days exceeding 95^0 F averaged from the NARCCAP models. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source: Kunkel et al., 2013.

Projections indicate that 'heat waves', consecutive days with maximum temperatures over 95^0 F (Figure 2.9) will remain the same or increase by a few days across the state of Michigan. Summer heat index values are projected to increase, leading to increased heat stress, but most of the changes are related to increased humidity as opposed to increased temperatures.

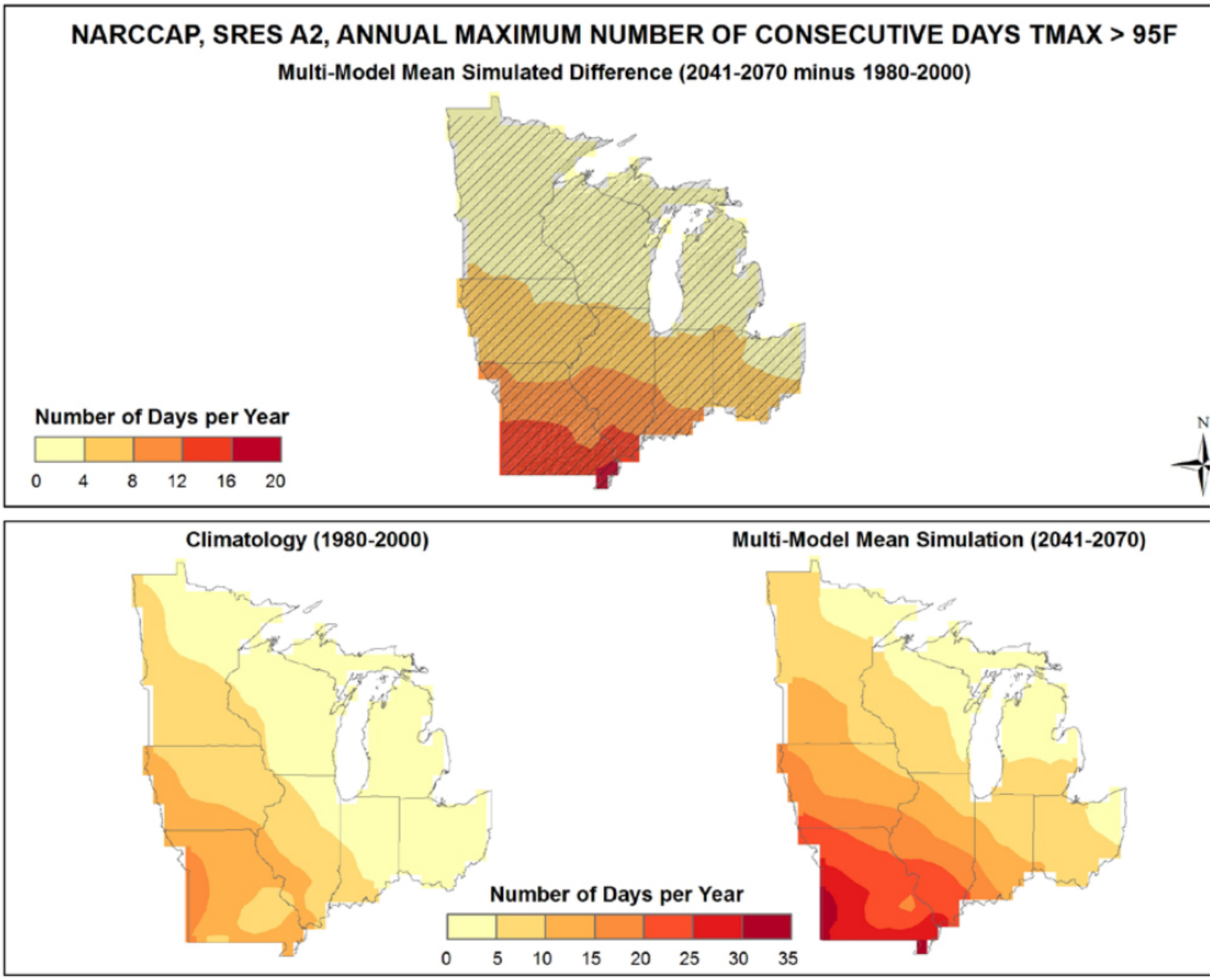


Fig. 2.9: Projected annual number of consecutive hot days exceeding 95^0 F averaged from the NARCCAP models. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source Kunkel et al., 2013.

As the number of days below freezing decrease, **the freeze-free growing season (Figure 2.10) is expected to increase by up to three weeks by mid-century.** Projected increases in the freeze-free season are not necessarily in locations where the historical freeze-free season has been longest. For example, the easternmost part of the U.P. has historically had a longer freeze-free period than the western U.P., but projections indicate that the western freeze-free season will increase by more days than in the east (Figure 9). On average, the last spring freeze is expected to occur about a week earlier by mid-century.

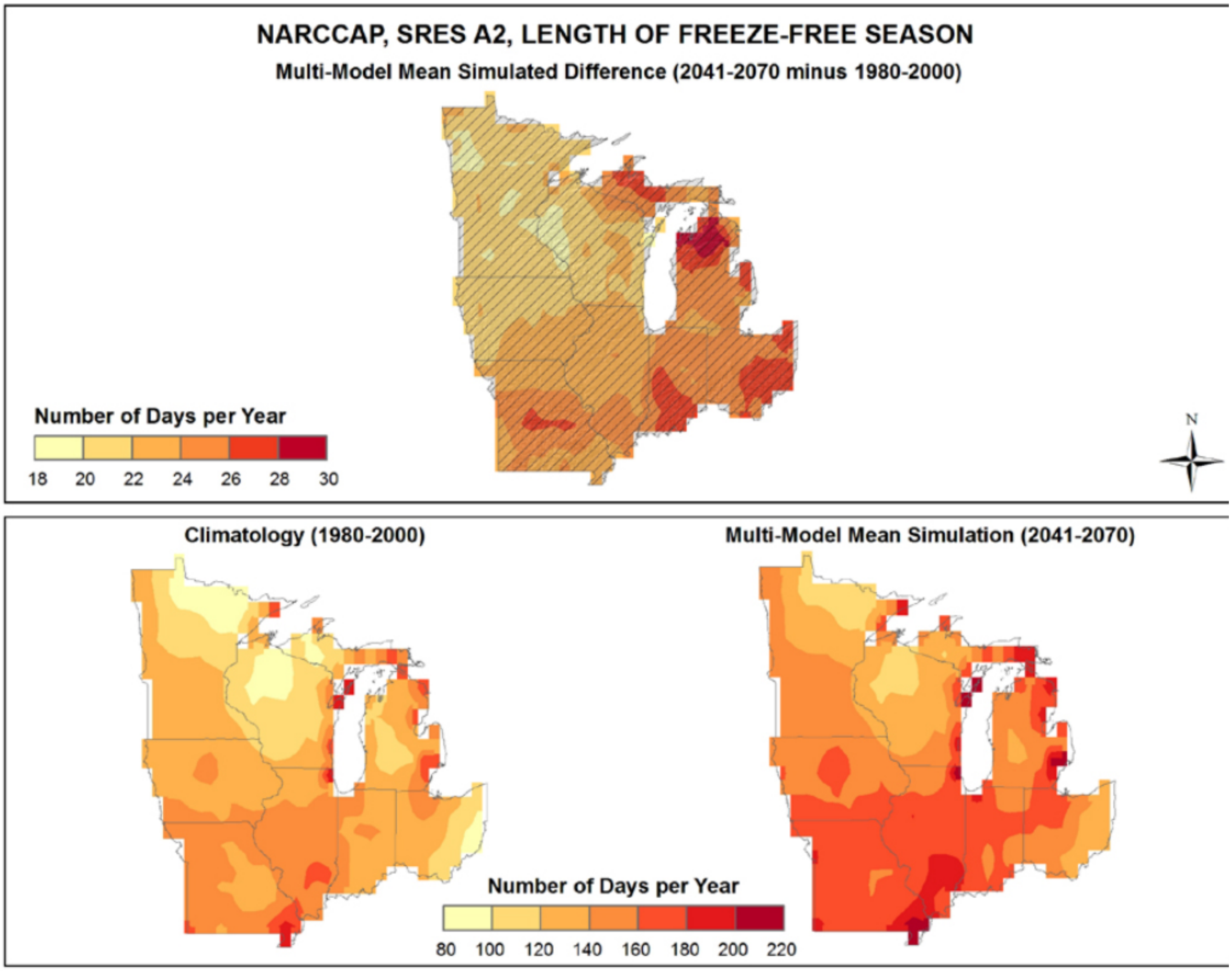


Fig. 2.10: Projected change in the number of days in the freeze-free season (top), and observed (bottom left) and simulated (bottom right) freeze-free days per year. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source: Kunkel et al., 2013.

Precipitation Projections

In the near-term, precipitation changes are not statistically significant across most of the collective Midwest. For Michigan however, projections are more consistent with the majority of models agreeing that annual mean precipitation will increase (Figure 2.11). **Most of Michigan is projected to experience increases of 3-6% in annual mean precipitation, with slightly less in the southernmost part of the state.** Michigan's annual precipitation pattern is projected to show greater increases moving from the southeast to the northwest, but there is a small region in southwest Michigan near Lake Michigan that is projected to experience the greatest rate of increase from the present.

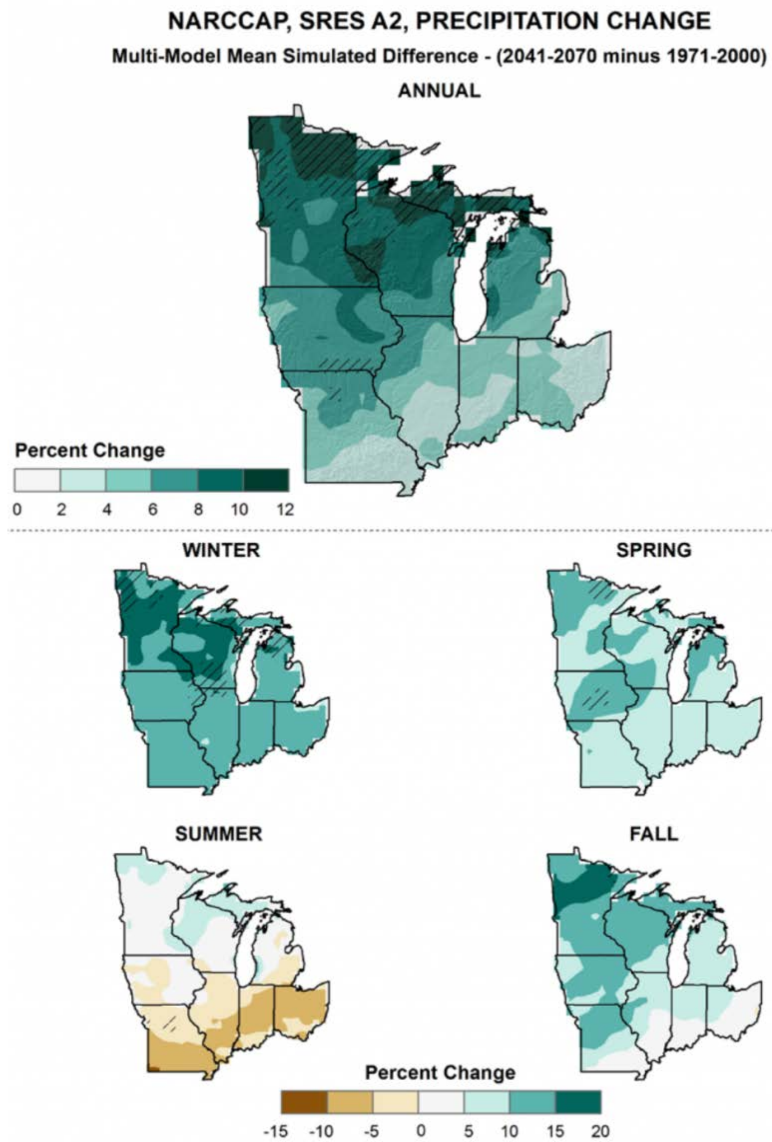


Fig. 2.11: Projected annual and seasonal precipitation changes (%) averaged from the NARCCAP models. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. In Michigan, the models are in the greatest agreement during winter in the north. Image Source: Kunkel et al., 2013.

Seasonal projections consistently show summer months having the greatest uncertainty, since the average change is near zero but the models range from about -10 to +10% change in precipitation. **Summer and fall precipitation projections indicate the greatest potential for decreasing trends. Summer is also when the pattern of change across the state is the most variable**: In summer, the U.P. has increases in precipitation while the Lower Peninsula has a small region of increase in the southwest along Lake Michigan and decreases in the southeast. Most of the L.P.'s spatial distribution of changing summer precipitation patterns is uncertain since some individual models show positive changes and others, negative changes. **Winter precipitation is consistently projected to increase in the Upper Peninsula among many different models, and more of that precipitation is expected to fall as rain or freezing rain.** Although seasonal averages (except for summer) indicate positive changes across the Midwest, the majority of models do not agree on the sign of precipitation change at any given location.

Projecting extreme precipitation events (i.e. daily precipitation totals that exceed 1 inch) is more challenging than annual or seasonal projections, because the models do not simulate the intensity of events well. In Michigan **the majority of models agree that the annual number of days with greater than one inch of precipitation (Figure 2.12) will increase by about 10% in the south and up to 40% in the north by mid-century.** The Wisconsin Climate Change Initiative's (WICCI) downscaled climate projections for Michigan further indicates that the more intense extreme precipitation events (those producing greater than 2 inches of rain) are projected to increase in frequency by a greater degree than those extreme events producing 1 – 2 inches (Saunders, Easley, Mezger, Findlay, & Spencer, 2014). One study indicated that intense precipitation events will stay the same or increase regardless of changes in annual precipitation.

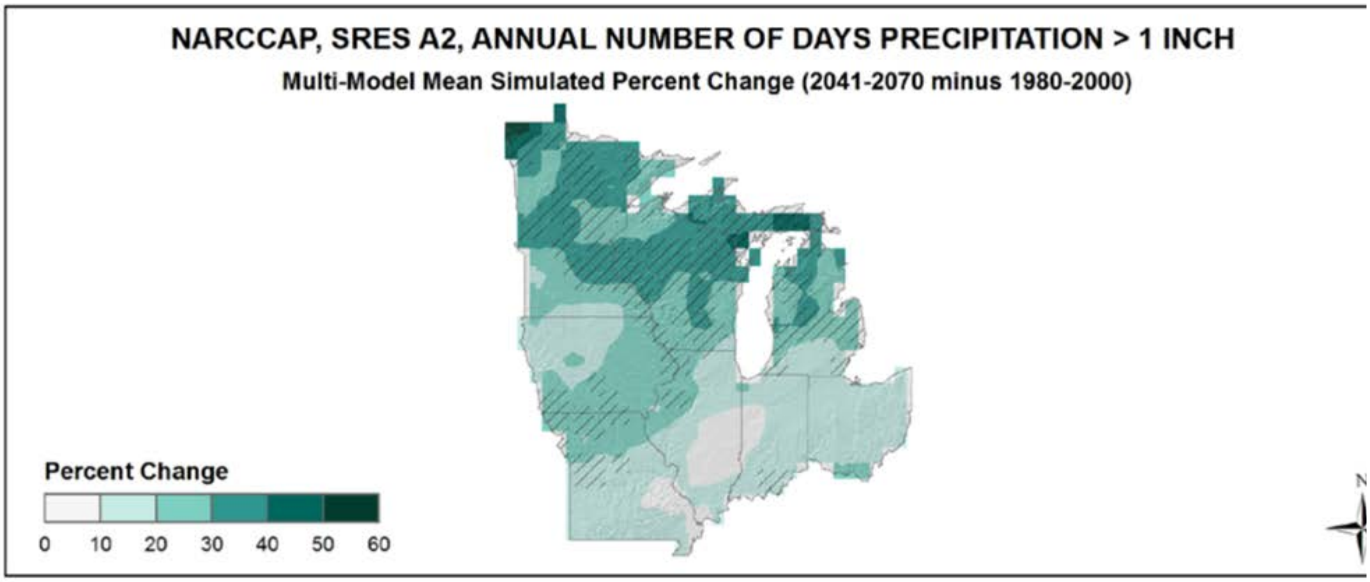


Fig. 2.12: Projected annual number of days with more than 1" of precipitation averaged from the NARCCAP models. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source Kunkel et al., 2013.

Drought conditions are estimated by projecting the number of consecutive 'dry' days with <3mm (0.01 in) precipitation. **The maximum number of consecutive 'dry' days (Figure 2.13) is projected to decrease in the Upper Peninsula, but the Lower Peninsula shows both increases and decreases.** There are no available projections on the timing of when these extreme events may occur.

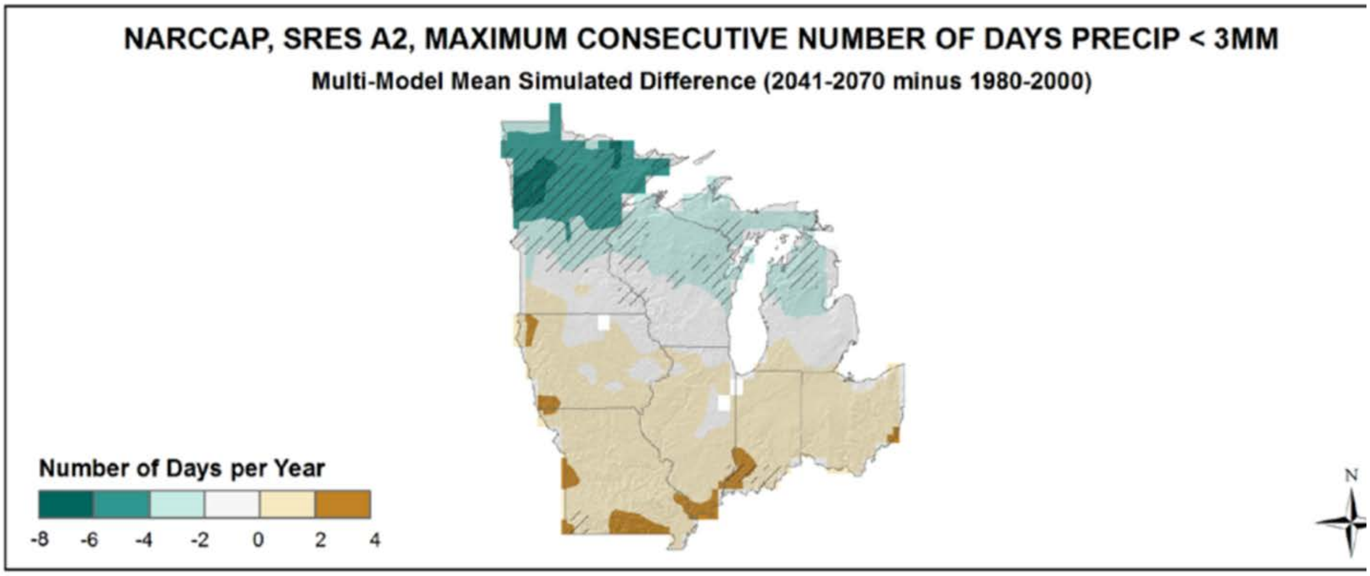


Fig. 2.13: Projected annual number of days with less than 3mm (0.1 in.) of precipitation averaged from the NARCCAP models. Hatching indicates that more than 50% of models show statistically significant changes and more than 67% agree on the sign of the change. Image Source: Kunkel et al., 2013.

Appendix

Table 2.7: Temperature Projection Summary for Michigan

Climate Parameter	Summary
Annual Mean Temperature	All projections show an increase in annual mean temperatures with greater increases farther into the future. Models range between increases of 1.5 to 4.5 degrees F by 2050. Annual changes are consistent across the Midwest.
Seasonal Mean Temperature	All seasons are expected to have increasing temperature, however, there is uncertainty as to which (if any) season(s) will warm more than the others. The downscaled models agree that summer warming will be greatest in the south and winter warming will be greatest in the north. The growing season is projected to increase up to three weeks by mid-century and the last spring freeze is projected to occur one week earlier.
Extreme Temperatures	There will be several fewer days with below freezing temperatures and a few more days above 95^0 F. Consecutive days above 95^0 F may increase by a few days in MI.

Table 2.8: Precipitation Projection Summary for Michigan

Climate Parameter	Summary
Annual Mean Precipitation	The amount of mean annual precipitation is expected to increase by 3-6% with slightly less in southern Michigan.
Seasonal Mean Precipitation	Winter precipitation is projected to increase in the Upper Peninsula with more precipitation falling as rain or freezing rain. Spring precipitation is projected to increase in most of the models; however, there is greater uncertainty at any given location. Summer and fall are when individual models show both strong negative and positive changes, so uncertainty is high.
Extreme Precipitation Events	There is great uncertainty in extreme precipitation projections, but intense precipitation events are projected to stay the same or increase, and consecutive days with very little precipitation are expected to decrease in the Upper Peninsula.

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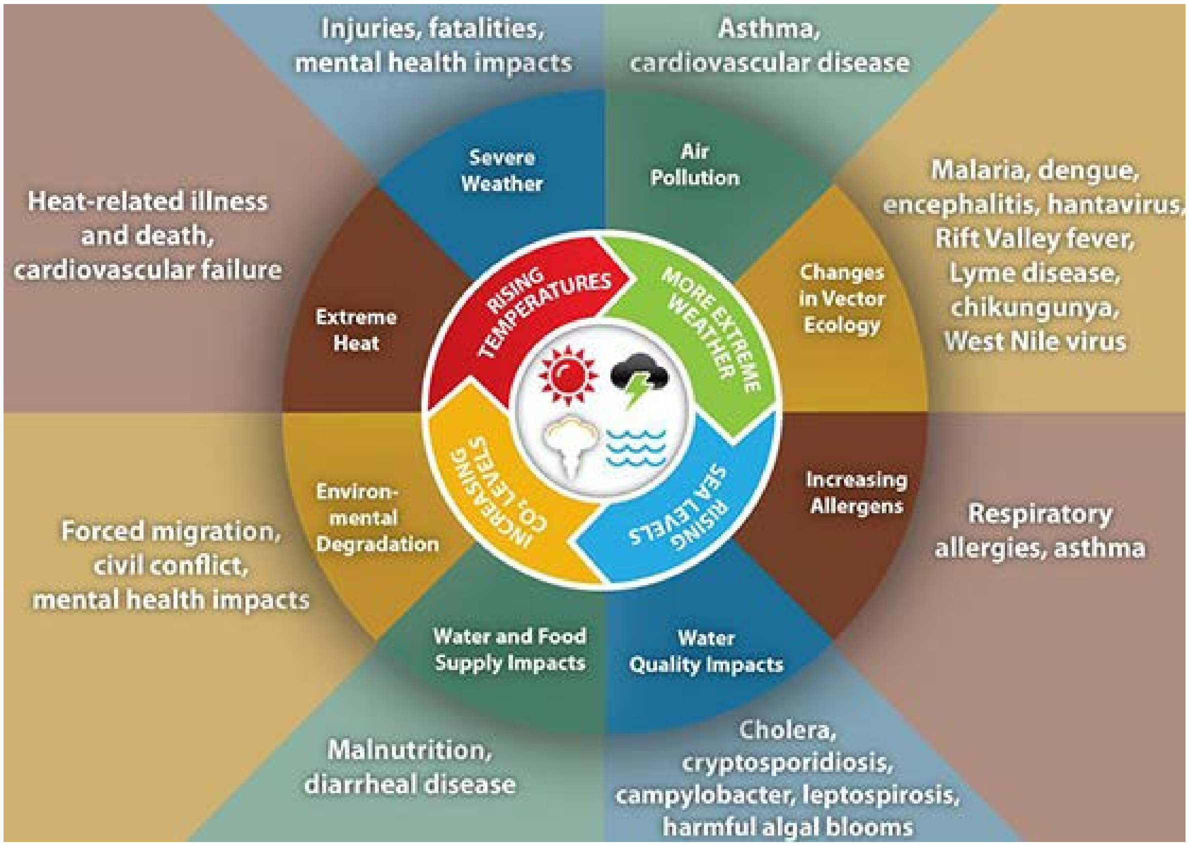
III. Linking Climate Changes to Health Outcomes



Source: Centers for Disease Control and Prevention, http://www.cdc.gov/climateandhealth/effects/default.htm

"Many of the conceptual pathways using changing climate as an exposure have similar human health outcomes, but the route in which these exposures cause disease, both directly and indirectly, is varied and affect many natural and built environments (pg. 60)."

Introduction

This section reviews current knowledge regarding three key conceptual pathways that describe how climate impacts health, focusing on the key health outcomes for Michigan resulting from potential climate changes as identified in Chapter II. These three pathways - heat, precipitation, and extreme weather - model how exposure to a weather event can directly impact human health outcomes, and also how the relationship can be indirect, as when a weather event changes aspects of an environmental exposure which then impacts human health outcomes. For example, increasing heat (weather event) may lead to plant stress and less environmental green space (a change in the exposure environment). Less green space can then lead to elevated incidence of heat stress (health outcome) in an area. This review includes the range of anticipated health effects (mild, moderate, severe) resulting from the anticipated change in the weather event, as well as statistics on the current population rates, counts and trends for key health outcomes in Michigan. Finally, the data sources for monitoring both the key health outcomes and related exposures are summarized.

Climate Related Health Impact Pathway Descriptions

Heat Pathway

As described in Chapter II, Michigan is projected to become warmer over the next century. While this trend may represent a decrease in cold related morbidity and mortality, these reductions are not expected to offset the increase in heat related morbidity and mortality resulting from the projected increase in frequency and duration of extreme heat events (Hayhoe et al., 2010; Luber et al., 2014). During the July 2012 heat wave, for example, air temperatures were 102^0 F and 104^0 F in Grand Rapids and Detroit, respectively, and sustained above 90^0 F for several days (Evans, 2012). The heat wave also contributed to the record breaking 2012 North American drought, which impacted large areas of southeast Michigan (Andresen, 2012). Rising temperatures resulting in extreme heat events can directly and indirectly influence several health outcomes in Michigan residents as shown in Figure 3.1.

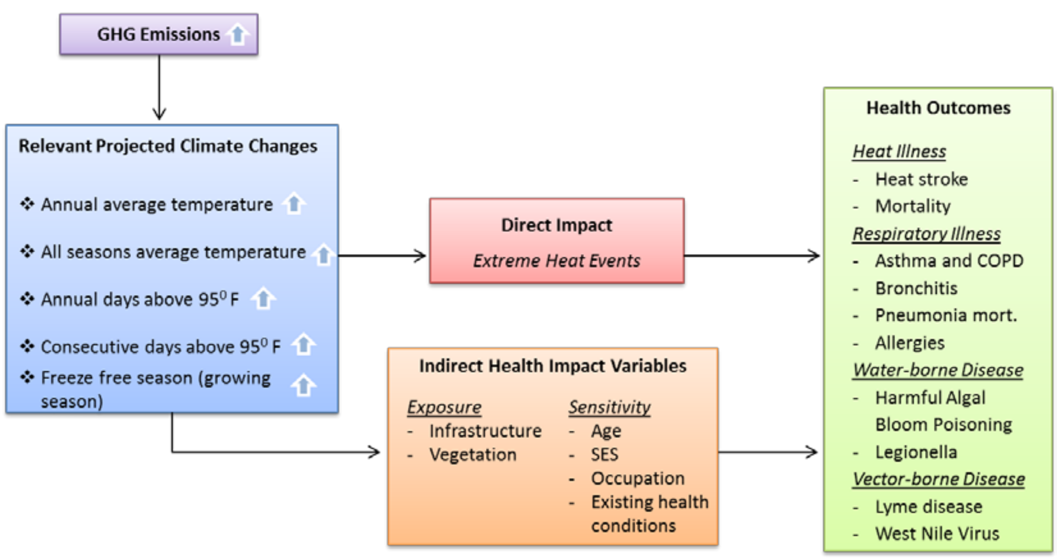


Fig. 3.1: Extreme heat related direct and indirect conceptual human health impact pathway based on climate changes resulting from increased Greenhouse Gas Emissions (GHG).

Heat Illness

Heat waves have several direct effects on health. Extreme heat events have been linked to increased all-cause mortality (Basu, 2009; Curriero et al., 2002). Individuals with pre-existing conditions including chronic obstructive pulmonary disease (COPD), congestive heart failure, myocardial infarction or diabetes are at increased risk of mortality during extreme heat events (Zanobetti et al., 2012). Increased hospitalization rates for respiratory and cardiovascular diseases can also occur as a consequence of extreme heat exposure (Ostro et al., 2009). Heat stress occurs when the body's means of controlling internal temperature starts to fail and can lead to a number of adverse health outcomes, resulting in illness, hospitalization, and even death (Luber et al., 2014).

Adverse health outcomes directly related to heat stress range from mild (heat cramps, heat edema, heat rash) to moderate (heat exhaustion, heat syncope characterized by dizziness and fainting) to severe heat stroke (body temperature of 104^0 F or higher and complete or partial loss of consciousness), hyperpyrexia (elevated body temperature) and death (CDC, 2014). These severe outcomes can result in damage to the brain, kidneys and heart and may require hospitalization (Mastrangelo et al., 2007).

Indirectly, prolonged periods of high temperatures can have adverse effects on plant life reducing green space and tree canopy coverage. In urban environments a lack of green space exacerbates the existing urban heat island effect, which has been reported to increase the detrimental effects of heat on health outcomes (Akbari et al., 1997).

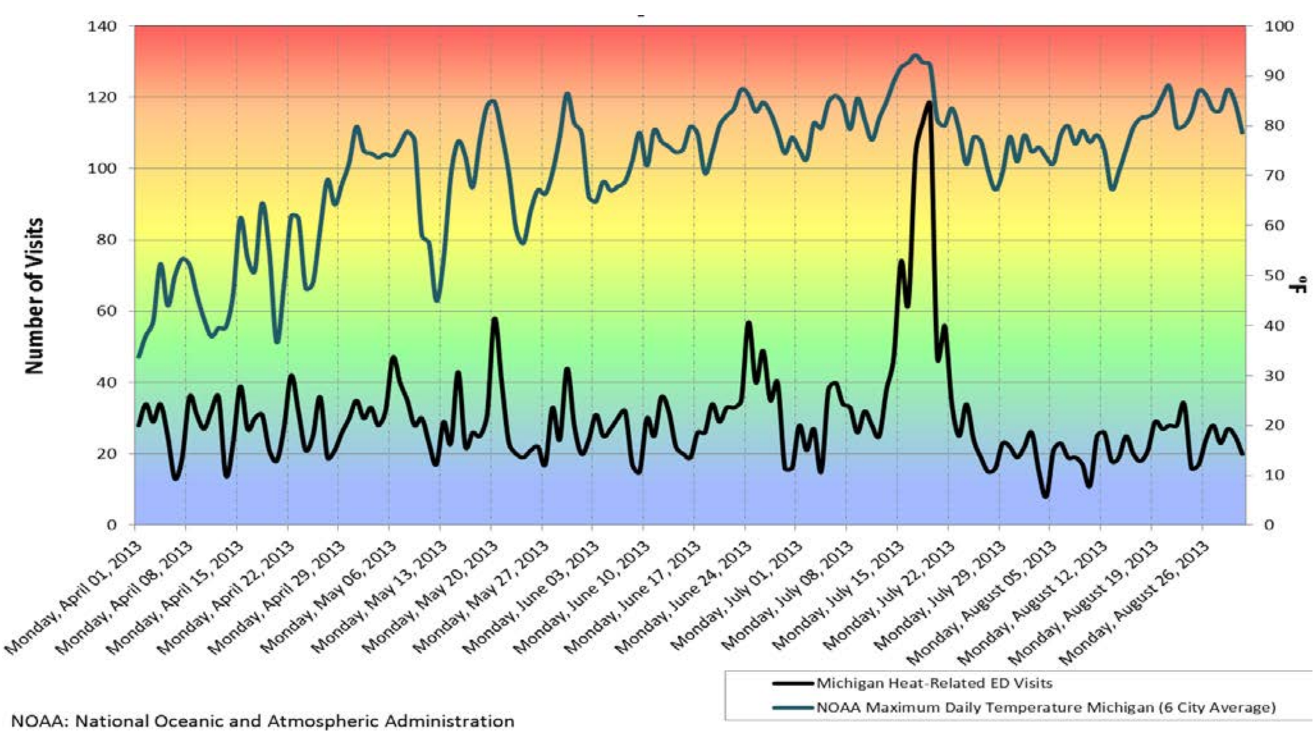


Fig. 3.2: Statewide Heat-Related ED Visits as reported to the Michigan Syndromic Surveillance System and National Oceanic and Atmospheric Administration (NOAA) Maximum Daily Temperature Averages for 6 Select Cities (April 1 – August 31, 2013) (Mamou et al., 2013)

Heat-related hospitalizations are monitored as one indicator of potential climate change related health effects among Michigan residents (Cameron et al., 2013). Since 2001, rates have varied from <1 per 100,000 in 2004 and 2009 to over 4 per 100,000 in 2011 and 2012 (Cameron et al., 2013). Figure 3.2 shows the relationship between rising temperatures and emergency department visits during the summer of 2013.

Respiratory disease and heat

Climate change can affect respiratory diseases as air quality is impacted by changes in temperature and wind patterns. For Michigan the most concerning of those includes increased concentrations of ground level ozone, particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), other fine particles, and the production of aeroallergens such as pollen and mold spores (Kinney, 2008; Irfan, 2012). Ozone production is directly related to temperature, while the relationship of particulate matter to future climate is more variable and depends on the frequency of stagnant air episodes, wildfires, precipitation and volatile emissions, as well as future energy demands (EPA 2009).

Air pollution exposure has been associated with a variety of health effects, such as respiratory diseases (including asthma and changes in lung function), cardiovascular diseases, adverse pregnancy outcomes (such as preterm birth), lung cancer and increased mortality (NIEHS 2015). Acute ground-level ozone exposure is linked to childhood Respiratory disease, exacerbations of asthma and, more specifically, increased emergency department visits for asthma (reviewed in Sheffield et al., 2011). For example, during the Atlanta Olympics in 1996 when peak daily ozone dropped by 28%, there was an 11% reduction in pediatric emergency department visits for asthma and an over 40% reduction in acute care asthma events (Friedman et al., 2001). The severity of health outcomes ranges from coughing and throat irritation (mild) to chest tightness, wheezing, or shortness of breath (moderate) to asthma attacks, resulting in emergency department visits, hospitalization or even death (severe).

$PM_{2.5}$ was estimated to cause approximately 7 million premature deaths in 2012, making it the 13th leading cause of mortality worldwide (WHO, 2014). $PM_{2.5}$ causes worsening respiratory symptoms (mild), more frequent medication use, decreased lung function (moderate), recurrent health care utilization and increased mortality (severe) (Anderson et al., 2012; Delfino et al., 2008; Barnett et al., 2005). More specifically, higher ambient levels of $PM_{2.5}$ are associated with worsening symptoms and lower lung function in adults with asthma (Balmes et al., 2014). The $PM_{2.5}$ health impacts are generally considered to be greater than those from the larger PM particles and are associated with increased risk of several asthma outcomes, cardiovascular disease mortality and hospitalizations, and cerebrovascular disease (McConnell et al., 2003; Brunekreef et al., 2009; Chen et al., 2008; Shah et al., 2013).

Along with increasing overall temperatures in Michigan, climate change is expected to cause seasonal shifts which could lead to earlier and longer growing seasons and later first frost. Already, the eastern U.S. has seen its growing season extend approximately eight days since the late 1980's. (EPA, 2013). This shift means plants are releasing pollen earlier and longer than in the past. In addition, as CO_2 increases it signals pollen producing plants to produce three to four times more pollen, and the pollen itself may actually be more potent (EPA, 2006). Consequently the prevalence of allergic rhinitis is also rising (Shea et al., 2008). A rise in seasonal hay fever and allergic asthma in the U.S. has also been reported, where the pollen season has lengthened up to 16 days since 1995 (Ziska et al., 2011). The allergy symptoms range from mild, such as itchy eyes and hives, to severe life-threatening events when airways swell shut. These allergic and asthmatic symptoms already afflict 40 - 50 million people in the

U.S. (AAFA, 2015). In Michigan, allergic disease hospitalizations have been steadily increasing from 700 per 100,000 in 2001 to nearly 1,200 per 100,000 in 2012 (see Figure 3.3); 90% of these hospitalizations are due to asthma (Cameron et al., 2013, with 2011 and 2012 data from HCUP).

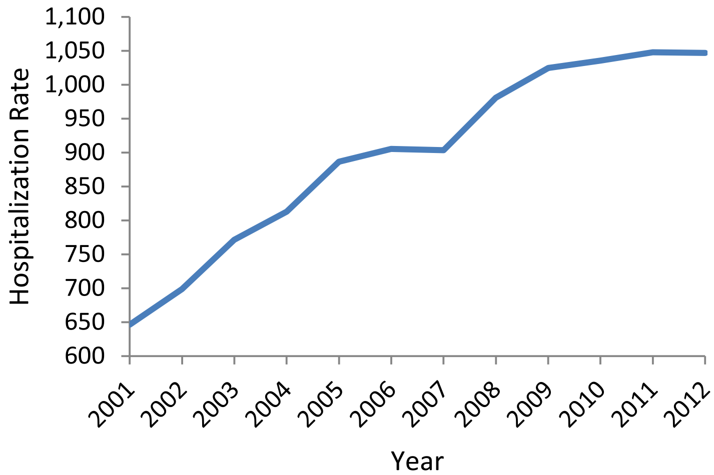


Fig. 3.3: Annual rate of allergic disease-related hospitalizations in Michigan

An increase in drought, defined as natural phenomena in which rainfall is lower than average for an extended period of time resulting in inadequate water supply, is expected as a consequence of increasing temperatures associated with climate change in parts of the U.S. Frequent or extended droughts are associated with environmental impacts such as loss of green space, lower amounts of rainfall, dust and wildfires. All four impacts can lead to an increase in air pollution. Loss of green space negatively affects individuals with asthma and COPD (Lovasi et al., 2008; Zanobetti et al., 2012), in part due to increased levels of air pollutants. Wildfires produce smoke which leads to increased air pollution, further loss of green space, mental distress and economic impacts (Luber, 2014). Consequently, a range of adverse health outcomes ensue including possible increase in respiratory irritation (mild), and respiratory diseases or exacerbations (asthma and COPD) (moderate), and emergency department visits, hospitalizations, and death (severe) may occur more frequently.

A recent review of the effects of climate change on indoor air quality noted that measures to reduce energy use by buildings, such as reducing reliance on air conditioning coupled with decreased air exchange, can concentrate indoor environmental problems such as humidity, allergen loads from pests and molds, and chemical air pollution (NRC, 2011).

Waterborne disease

Waterborne disease is a common cause of illness in the U.S. and in Michigan. For 2009 - 2010, CDC's National Waterborne Disease and Outbreak Surveillance System reported 33 outbreaks with 1,040 cases of illness and nine deaths associated with drinking water, and 12 outbreaks with 234 cases of illness and six deaths associated with water not intended for drinking. *Legionella* accounted for 58% of drinking-water outbreaks and 7% of illnesses; while *Campylobacter* accounted for 12% of outbreaks and 78% of illnesses. Other waterborne pathogens included *Giardia* with 2 outbreaks and 14 cases, and *Cryptosporidia* with 1 outbreak and 34 cases. A large proportion of drinking water outbreaks were associated with untreated ground water and deficiencies in public drinking water infrastructure (CDC, 2013). Many of these pathogens can cause disease by multiple routes of exposure; a CDC workgroup identified giardiasis, cryptosporidiosis, Legionnaires' disease, acute or malignant otitis externa and non-tuberculous pulmonary mycobacterial infection as the infections primarily (over 50%) transmitted by water (Collier et al., 2012). Roughly 500 cases of giardiasis are reported each year in Michigan, while cryptosporidiosis averages 150-300 reported cases (CDC, 2012-2014). Other enteric infections such as those caused by *Salmonella, E. coli* and enterovirus are much more common, but many of these illnesses go unreported and the source of these infections are often undetermined (Rose et al., 2001). Possible sources of waterborne infection may be via drinking water, recreational or other water contact, or indirectly by consuming food contaminated in the field through contact with contaminated water (Rose et al., 2001).

Waterborne disease and heat

The warming climate may be increasing the risk of some infectious waterborne diseases in Michigan. *Legionella* is a common bacteria found naturally in the environment, usually in warm water. Exposure through inhalation of mists or vapors from contaminated water can cause lung infections known as Legionnaires' disease or (rarely) Pontiac fever, collectively known as legionellosis. *Legionella* is the most frequently reported cause of water-related disease outbreaks in the U.S., and is usually associated with exposure to water in conditions of heat, stasis, and aerosolization that optimize transmission. An estimated 8,000 to 18,000 people are hospitalized with Legionnaires' disease each year in the U.S. (CDC, 2013a), and roughly 200 cases of Legionellosis are reported to the CDC from Michigan each year (CDC, 2012-2014). *Legionella* species colonize outdoor water reservoirs including potable water systems and cooling towers, and the organisms grow rapidly at temperatures between 85 – 110 degrees F. Studies in the eastern U.S. and Europe suggest that Legionnaire's disease outbreaks may be associated with warm humid weather (Fisman et al., 2005; Philips, 2008), possibly due to increased *Legionella* growth stimulated by warming of potable water in reservoirs and plumbing. Another aquatic pathogen, *Naegleria fowleri,* is known to cause fatal primary amebic meningoencephalitis in recreational swimmers exposed to warm freshwater in the southern U.S. However, in 2010 a fatal case occurred after swimming in freshwater in Minnesota, 550 miles further north than any other known U.S. case. Consistently warmer summer temperatures have been suggested as means for an increased possibility of exposure in other northern water bodies (Kemble et al., 2012). On the other hand, warm temperatures may reduce the survival in water of some enteric pathogens such as *E. coli*, *Campylobacter*, and enteroviruses (Hunter, 2003). Warm temperatures may also increase population contact with recreational waters, increasing the opportunity for exposure to pathogens in the water.

Rising temperatures can have significant effects on aquatic ecosystems. An algal bloom is a rapid increase in the population of one or a few species of algae that occur naturally in an aquatic system, freshwater or marine. Any algal bloom has the potential to deplete oxygen levels in the water and block sunlight, which can lead to the death of other species in the water ecosystem. Certain blooms are composed of species that naturally produce biotoxins that are harmful to human, animal, and ecosystem health; these toxin-producing blooms are called harmful algal blooms (HABs). Recent research suggests that, in addition to nutrient contamination from anthropogenic sources, the impacts of climate change may promote the growth and dominance of HABs through a variety of mechanisms including, but not limited to: warmer water temperatures, increases in atmospheric carbon dioxide concentrations, and changes in rainfall patterns (EPA, 2015). Changes in meteorological patterns may have helped trigger a record-setting bloom of toxic algae that covered a remarkable and unprecedented one-fifth of Lake Erie in 2011, an event that may be a warning of more severe blooms in the future (Michalak et al., 2013). In August 2014, another HAB in Lake Erie contaminated the water supply for more than 400,000 people in Michigan and Ohio, resulting in states of emergency declarations in one Michigan and three Ohio counties, and activation of the Ohio National Guard. (Kozacek, 2014).

Harmful Algal Blooms in the Great Lakes region are typically made up of blue-green algae, or more accurately, cyanobacteria that contain chlorophyll similar to true algae. They reproduce rapidly, and are typically found at or near the surface of the water (Michigan Sea Grant, accessed 2015). All cyanobacteria can produce dermatotoxins (skin irritants) under certain conditions, and some can produce multiple types of the more harmful toxins, including neurotoxins, liver toxins (hepatotoxins), and cell toxins. The most common species of toxic cyanobacteria in the Great Lakes are *Microcystis aeruginosa, Anabaena circinalis, Anabaena flos-aquae, Aphanizomenon flos-aquae*, and *Cylindrospermopsis raciborskii*. The most prevalent toxin in Michigan and U.S. waters is microsystin, a hepatotoxin which in humans causes abdominal pain, vomiting and diarrhea, liver inflammation and hemorrhage, pneumonia, dermatitis and potential tumor growth promotion (EPA, 2014). Sensitivity to all these toxins varies widely among individuals (GLERL, accessed 2015). The most common exposures to cyanobacteria and their toxins are believed to occur during recreational activities in contaminated bodies of water via oral, dermal, and inhalation routes. Other major routes of human exposure are through ingestion of cyanotoxin-contaminated drinking water, inhalation while showering, dietary intake via consumption of cyanotoxins in contaminated foods and algal dietary supplements, and exposure from water used in medical treatments (e.g., medical dialysis) (EPA, 2014).

Wildlife, domesticated, and farm animals can be sickened or killed by drinking water contaminated with HABs (IJC, 2014). Production of HAB neurotoxins also affects aquatic birds, turtles, and mammals, and can cause mass mortalities in fish. In Michigan, HABs can result in beach closures, loss of sport or commercial fishing, and disruption of drinking water supplies, with major economic consequences (IJC, 2014). Michigan is currently in the process of developing surveillance systems to capture HABs events and human cases of HABs-related illness (personal communication, L Tyndall-Snow 2014).

Please see the section*, **Waterborne disease and excess rain***, for discussion of other waterborne infectious diseases impacted by climate change.

Vector-borne disease and heat

Mosquitoes and ticks act as vectors for a variety of diseases. In the U.S. and in the Midwest, these insect vectors will likely survive in greater numbers as winters become milder and summers become longer and warmer. Climate-related changes in the vectors' habitat and host species populations will also influence future disease risk.

Mosquito species in Michigan are able to carry and transmit many harmful arboviruses, including: West Nile Virus, St. Louis Encephalitis Virus, LaCrosse Virus, and Eastern Equine Encephalitis Virus. Of these, West Nile Virus (WNV) has been the major public health concern since arriving in the U.S. in 1999 and in Michigan in 2002. Changes in temperature and precipitation have reportedly increased human infection. The *Culex* mosquito, which transmits West Nile, thrives on warm, wet winters and springs followed by hot, dry summer weather. With the heat and drought conditions in 2012, there were a large number of human WNV cases throughout the nation and in Michigan.

Approximately 80% of West Nile Virus (WNV) infections are believed to be asymptomatic and therefore not reported (CDC, 2013d). Even so, there have been more than 39,000 reported WNV cases in the U.S. and more than 1,100 in Michigan since 2002. In 2012 there was a peak of 202 cases and 17 deaths in Michigan (CDC 2014, Stobierski et al., 2014). The most common clinical condition is an acute systemic febrile illness (moderate). However, a few (≤ 1%) clinical cases proceed to a condition known as West Nile neuroinvasive disease (WNND), which typically manifests as encephalitis, meningitis, or acute flaccid paralysis (AFP) and has a mortality rate of approximately 10% (severe) (Barret, 2014). Most patients with meningitis or non-neuroinvasive West Nile infections recover completely, but this may take months. Patients who recover from encephalitis or AFP often have residual neurologic sequelae.

Michigan residents may acquire other arboviral infections during travel to endemic areas; for example, Michigan had 16 imported cases of Dengue Fever in 2013 (USGS, 2013). However, local transmission of other emerging mosquito-borne diseases such as chikungunya and Dengue in Michigan is unlikely as the disease-transmitting *Aedes* mosquitoes have not been identified in the state (Anez & Rios, 2013).

Different from the previously mentioned viral diseases transmitted by mosquitoes, Lyme disease is a multisystem, multistage, inflammatory tick-borne disease caused by the spirochete bacteria *Borrelia burgdorferi*. Transmitted through bites from *Ixodes scapularis "*black legged" ticks, this Lyme vector is projected to expand throughout the U.S. and Canada as temperatures gradually increase (Brownstein et al., 2002, Ogden et al., 2013). Lyme disease is now endemic in the Northeast and much of the north central United States including Wisconsin, Illinois, Indiana, and Pennsylvania. in Michigan, Lyme is considered an emerging disease with over 1,000 human cases occurring since infected ticks were first detected in the state in 1992. Historically, the only endemic region in Michigan has been Menominee County in the Upper Peninsula, bordering a highly endemic region of Wisconsin. The tick vector is becoming established across the state (personal communication, E. Foster, 2014), and recently, populations of infected black-legged ticks have been found in southwest Michigan (Berrien, Cass, Van Buren, Allegan, and Ottawa Counties) as shown in Figure 3.4 (Foster 2014, Hamer et al., 2010; Michigan Lyme Disease Risk Map, 2015).

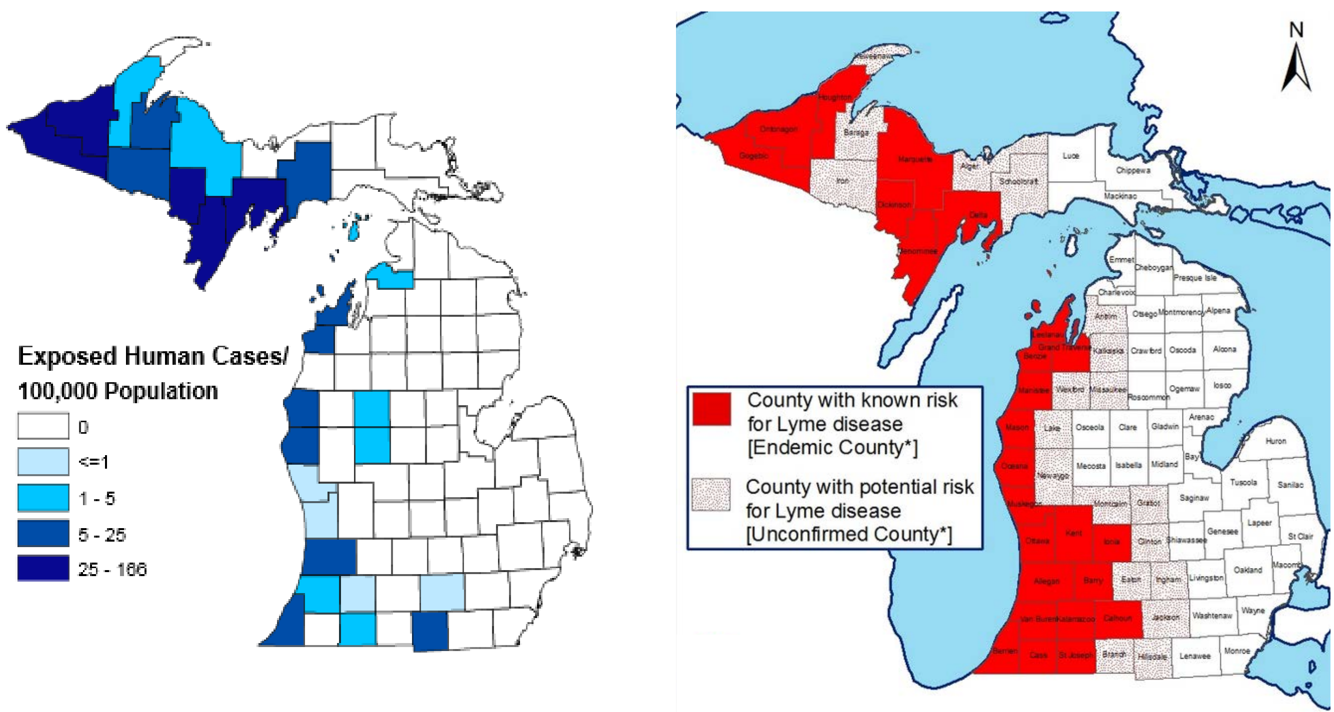


Fig. 3.4: Map of 2013 Michigan 'exposed' Lyme disease cases per 100,000 (Stobierski et al., 2014) (left), and 2015 map of risk of encountering infected ticks based on field surveys (MDHHS Emerging & Zoonotic Infectious Disease Section, 2015) (right). The endemic range of infected ticks has increased over time .

Lyme disease has three medically described phases: 1) early localized disease usually presenting with expanding rash called *erythema migrans* (mild); 2) early disseminated disease with heart and nervous system involvement, including palsies and meningitis (moderate); and 3) late disseminated stage of disease which includes intermittent bouts of arthritis and severe joint pain and swelling (severe). Chronic neurological complaints may develop in about five percent of patients whose infections are untreated (CDC, 2015).

Each year, more than 30,000 cases of Lyme disease are reported to CDC, making it the most commonly reported tick-borne illness in the United States. However, an analysis of medical claims data led CDC to estimate that the actual number of people diagnosed with Lyme disease is roughly 10 times higher than the reported number indicates, or around 300,000 per year for the U.S. (CDC, 2013). In 2013, the highest on record, 165 human cases were reported in Michigan, with most exposures occurring in the Upper Peninsula and western L.P (Stobierski et al., 2014).

Other tick-borne diseases are emerging as serious public health concerns in Michigan. As black-legged tick populations expand in the state, diseases such as anaplasmosis, Ehrlichia muris-like (EML), deer-tick virus and babesiosis will become more frequent. The Lone Star tick *Amblyomma americanum* is also being detected more frequently in Michigan, however localized populations have yet to be discovered. This tick readily bites people and companion animals, and is the vector of ehrlichiosis and tularemia. Climate changes may be influencing the number and species of ticks directly or indirectly by impacting the numbers and movements of their animal hosts (deer, birds, rodents, etc.) or their habitat.

Precipitation Pathway

Flooding and excess rain events can cause a range of adverse human health effects via alterations of the built and natural environment as shown in Figure 3.5. These include injury and death from damage to housing and infrastructure and from Carbon Monoxide (CO) poisoning from improper generator use during power outages. Additionally, contaminated water resulting from infrastructural damage can

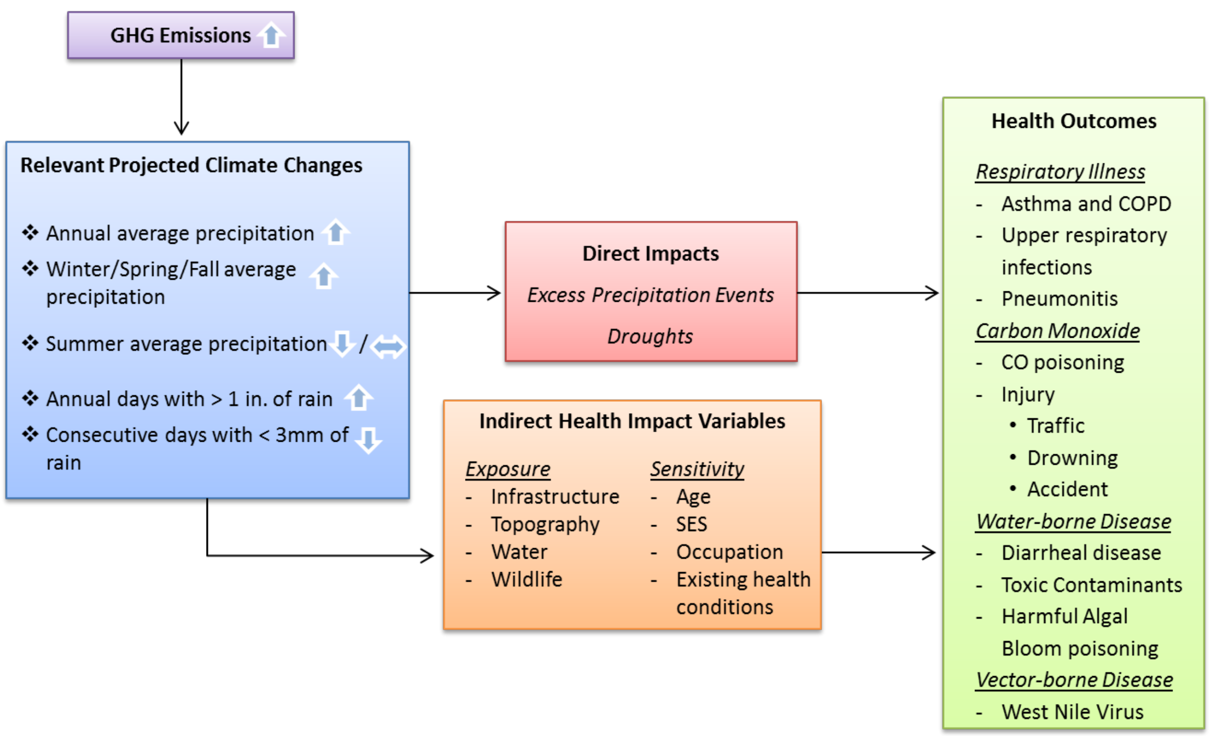


Fig. 3.5: Precipitation related direct and indirect conceptual human health impact pathway based on climate changes resulting from increased Greenhouse Gas Emissions (GHG).

carry a range of hazardous toxins, as well as human pathogens. There is also the risk of increasing the geographic range of disease-carrying insects and rodents and introducing dangerous molds within houses. Resulting social disruption from flooding and any of these occurrences can eventually lead to mental distress. Altered precipitation trends can result in floods and droughts that directly and indirectly influence several health outcomes in Michigan residents.

Respiratory disease and excess rain

Mold growth occurs when there is moisture from water damage, excessive humidity, water leaks, condensation, water infiltration, or flooding (CDC, 2010). Indoor exposure to mold has been linked to upper respiratory tract symptoms, cough, and wheeze in otherwise healthy people; symptom exacerbations in asthmatics; and onset of hypersensitivity pneumonitis in susceptible individuals (NRC, 2004). Runoff from rain events could also play a role in the growth of Legionella in water sources and thus increase risk of Legionnaire's disease (Fisman et al., 2005).

Carbon Monoxide poisoning and excess rain

Excess rain can lead to extreme precipitation events and flooding. The subsequent cleanup poses a variety of hazards including traumatic injuries (Du et al., 2010) and CO poisoning from gas-powered power washers and heaters (Waite et al., 2014). This topic is discussed in the section on ***Extreme weather events pathway***.

Water-borne disease and excess rain

As water infrastructure in Michigan communities ages and deteriorates, the risk for water-main breaks will increase along with the risk of pathogen introduction into community drinking water systems through those breaks. In addition, older cities like Detroit, Flint and Lansing with combined sewer systems (which carry sewage and rain water in the same pipes), are at greater risk for sewage spills or Combined Sewage Overflows (CSOs). During heavy rains, these pipes cannot handle the volume of both storm water and wastewater, and untreated sewage is often discharged into surrounding waterbodies that could be used for drinking, swimming and playing, or can back up through drains into basements. Residential septic systems are also common sources of water contamination in Michigan. Exposure to waterborne pathogens from sewage and unclean water can cause diseases like cryptosporidiosis, giardiasis, and infections by Salmonella, *E. coli* enteroviruses, and other enteric pathogens (Hunter 2003). These CSO discharge events have been projected to increase by 50 to 120% by 2100 for Lake Michigan alone, raising the risk of drinking water contamination substantially (Patz et al., 2008). A recent analysis of 'large' (i.e., 50 million gallons or more overflow) Michigan CSOs from 2008 - 2012 found that 76% were caused by storms of two inches or more of precipitation per day (Saunders et al., 2014). A review of 548 outbreaks in EPA's waterborne disease database found that 68% of outbreaks were preceded by precipitation events above the 80th percentile of intensity (Curriero et al., 2001). An English review paper summarized multiple studies which documented increased pathogen detection in surface waters after a rain event, due to contamination from runoff (Hunter, 2003).

Agricultural runoff after rain events is another source of water contamination and disease risk. An increasing source of runoff contamination in Michigan is waste from Concentrated Animal Feeding Operations, or CAFOs, which are becoming more common across the state. The sheer amount of manure produced by one large operation can exceed 1 million tons per year (NALBH, accessed 2015), much of it stored in pits and lagoons or sprayed on fields. Fecal microbial pathogens and other contaminants can be washed into surface waters and vulnerable private wells causing widespread contamination, increasing the potential for human disease. Even more concerning, CAFO livestock are often treated with antibiotics and can be a source of antibiotic-resistant strains of E. coli and other pathogens. (Burkholder et al., 2007). Surface water contamination by agricultural runoff containing phosphorus and nitrogen can also contribute to algal blooms; see discussion in ***Waterborne disease and heat***, above. Flooding and contaminated runoff can also infiltrate the private wells that are a source of drinking water for over one million Michigan households (Saunders et al., 2014). Community exposure to disinfection by-products, many of which are potential carcinogens and asthma triggers, may increase as water treatment plants deal with increased turbidity and pathogen loads in source water by adding more disinfectants in the finishing process.

Waterborne disease and drought

Drought can put communities at risk of running out of drinking and irrigation water, as well as increase exposure to and use of contaminated water. Rural communities where residents rely on wells for drinking water are at particular risk as contaminants in the groundwater may become more concentrated with less water available to dilute them. Droughts can cause increased concentrations of effluent pathogens, overwhelming water treatment plants and contaminating surface water. Older water treatment plants are particularly at risk. (NIEHS, 2014). During droughts, the ground becomes hard and impervious; likely causing runoff during the next rain event and carrying viruses, protozoa, and bacteria which can pollute both groundwater and surface water. People who get their drinking water from private wells may also be at higher risk for drought-related infectious disease (CDC, 2012). *Water-washed diseases* are those caused or spread by lack of hygiene. *Salmonella* and toxin-producing *E. coli* are two common examples of infectious diseases more easily spread from person to person or by food handling when hand washing is compromised by a perceived or real lack of available water. Food contamination can also occur when water is scarce and farmers turn to recycled or alternative contaminated water sources for irrigation. During drought, drinking water supplies are also susceptible to harmful algal blooms and other microorganisms (CDC, 2012).

Vector-borne disease and precipitation

A change in rainfall patterns has been shown to influence the seasonal activity length of several Michigan mosquito species responsible for transmitting arboviruses such as West Nile. For more information on health conditions associated with these diseases, see the vector-borne disease section of the ***Heat Pathway***.

Extreme Weather Events Pathway

Climate change may be affecting the frequency and severity of some extreme weather events, while others are too complex to predict. However, Michigan experiences extreme wind, snow and ice storms throughout the seasons and they have significant public health impacts directly and indirectly as shown in Figure 3.6.

Summer weather events

As discussed previously the major summer events include extreme heat events, heavy rain, droughts, and floods. Besides these impacts, Michigan can experience tornadoes and high winds leading to systems disruptions such as infrastructure destruction, power outages, and social disruption. Health impacts include injuries, CO poisoning, mental distress and death. There have been 341 tornadoes and almost 7,500 high wind events in Michigan since NOAA’s upgraded weather surveillance in 1996 (NOAA, 2014). However, the link between severe wind events and climate change is unclear and there is no real evidence of historic trends in frequency or severity of tornadoes (Anonymous, 2014).

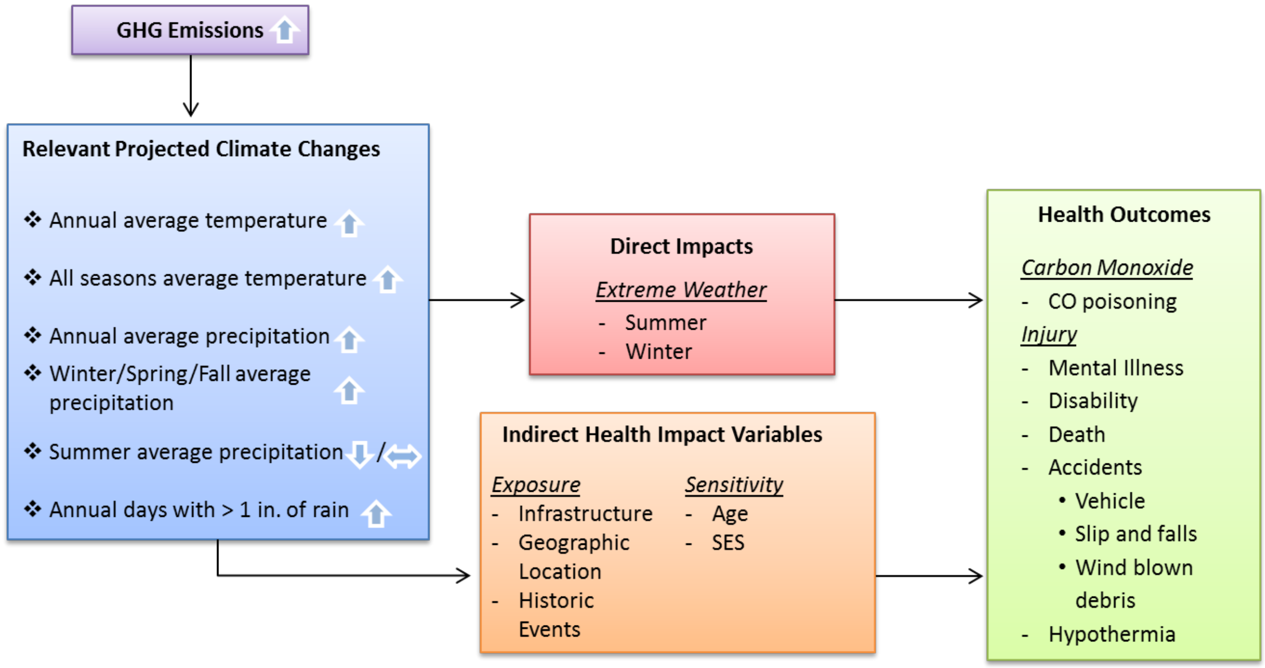


Fig. 3.6: Summer and winter extreme weather event related direct and indirect conceptual human health impact pathway based on climate changes resulting from increased Greenhouse Gas Emissions (GHG).

Winter weather events

Winter weather events include extremely low temperatures, heavy snowfall and ice storms. There is some evidence that lake-effect snow and ice storm events are related to climate change in Michigan and will continue to increase in frequency, at least short term; and some climatologists have linked the occurrence of extreme cold events to disruption in the arctic jet stream (see Figure 2.3) caused by melting polar ice (Kim et al., 2014). These weather events can also indirectly lead to health impacts through changes in the built environment. Health effects include the risk of CO poisoning and death from improperly used heaters and generators, hypothermia, and physical injuries from accidents due to snow and ice. In Michigan, almost 1,000 people are unintentionally poisoned by CO every year, and 20-23 die from CO poisoning. The main sources of exposure are faulty furnaces and hot water heaters, and improper use of gas-powered equipment such as generators and power washers (MDHHS and MSU, 2009-2012).

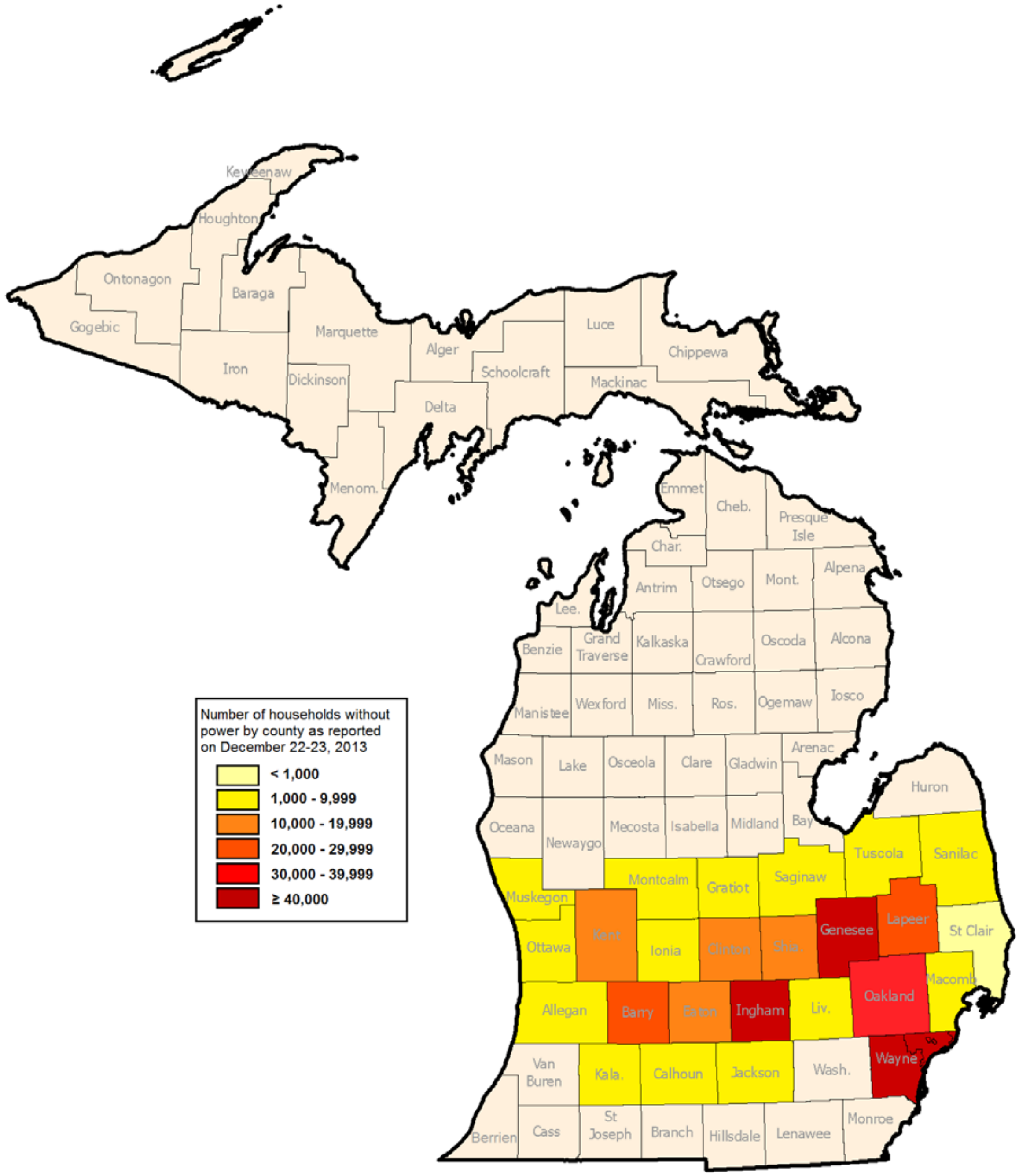


Fig. 3.7: Household power outages by county as reported in the press on December 22-23, 2013 (Mamou et al., 2014)

For example, a severe ice storm struck Michigan December 21-29, 2013. The weight of the ice toppled trees and knocked down power lines over a large area. Over 400,000 Michigan households lost power, and there were 81 reported emergency department (ED) visits related to complaints of CO poisoning, as shown in Figures 3.7 and 3.8, respectively (Mamou et al., 2014).

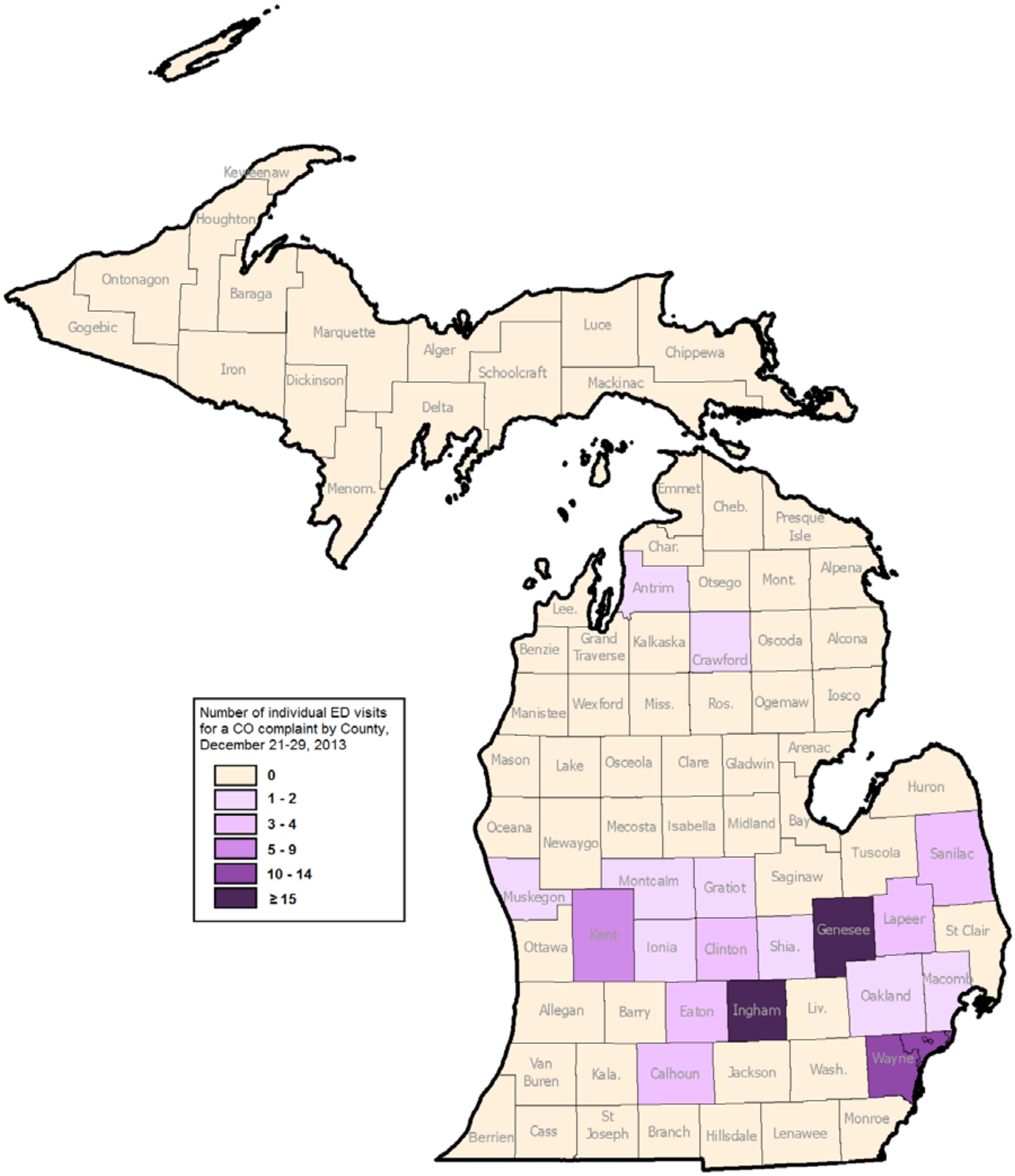


Fig. 3.8: Carbon Monoxide chief complaint emergency department visits by county of residence December 21-29, 2013 (Mamou et al., 2014)

Conclusions

Many of the conceptual pathways using changing climate as an exposure have similar human health outcomes, but the route in which these exposures cause disease, both directly and indirectly, is varied and affect many biophysical environmental variables. Heat, drought, floods and extreme weather events are ever changing and dynamic exposures that require complex assessments in order to protect vulnerable human populations and environments from negative consequences. The next section will briefly summarize surveillance systems for monitoring key health outcomes and exposures related to climate change in Michigan.

Health Outcomes Surveillance Systems

The following data sources are used to monitor key climate-sensitive health effects in Michigan. Each data source and its utility are described.

Michigan Disease Surveillance System (MDSS)

A web based disease reporting system developed for the State of Michigan as part of the CDC's National Notifiable Diseases Surveillance System (NNDSS), which provides information on the occurrence and spread of state-reportable and nationally notifiable infectious diseases and conditions. Physicians, health care providers, and laboratories are mandated to report in a timely manner and in a standard format. MDSS is the source for Michigan's official notifiable diseases statistics, and can be used to monitor data and trends on the following climate-sensitive conditions: vector borne diseases including West Nile, Dengue, *Ehrlichia*, Lyme Disease, *Rickettsia*, *Hantavirus*, *Histoplasma*, and outbreaks of a number of water-borne infectious agents including Amebiasis, *Campylobacter*, certain strains of *Escherichia coli*, *Giardia*, *Legionella*, *Salmonella*, *Shigella*, some *Staphylococcus* and *Streptococcus*, and *Vibrio*. These statistics are useful for monitoring outbreaks; however, many cases (especially gastrointestinal infections) are severely underreported. MICHAP primarily uses MDSS to track human cases of West Nile and Lyme disease. Weekly reports are available at MDHHS's Communicable Disease Information & Resources website: http://www.michigan.gov/MDHHS/0,4612,7-132-2945_5104_53072---,00.html. For a list of reportable diseases, see: http://www.michigan.gov/documents/Reportable_Disease_Chart_2005_122678_7.pdf. Official disease counts are also available at the CDC's National Disease Surveillance System (NDSS) website (http://www.cdc.gov/mmwr/distrnds.html).

Michigan Syndromic Surveillance System (MSSS)

Since 2003, the MSSS is used as a voluntary emergency department (ED) reporting system in Michigan. Designed to rapidly detect unusual outbreaks of illness resulting from either naturally occurring or intentional events that pose potential public health threats and emergencies it is a vital component of routine communicable disease surveillance for the state as well as an early-warning system for outbreaks related to bioterrorism. Currently, 88/136 (65%) of hospital EDs participate in MSSS, providing coverage for 83% of Michigan's population. Data from EDs are securely transmitted to the MDHHS in real time and currently average over 8,000 ED visits per day. Each data message consists of: each visit's date and time, and the patient's age, sex, home ZIP code, and chief complaint on intake. Chief complaints are classified into one of seven syndromic categories. Detection algorithms run every hour and an email alert is sent to State and Regional epidemiologists if a deviation is detected. MSSS epidemiologists have created new climate-related syndrome categories including: heat, cold, and CO poisoning, which are run following heat, cold, or storm events or when temperatures exceed preset thresholds to detect climate-related 'outbreaks'. MICHAP uses these climate-related syndrome surveillance weekly reports to monitor for sentinel events and direct interventions. General information on MSSS is at: http://www.michigan.gov/MDHHS/0,1607,7-132-2945_5104_31274-107091--,00.html.

Michigan Inpatient Database (MIDB)

Created by the Michigan Health and Hospital Association, the MIDB contains discharge data on all acute-care hospitalizations among Michigan residents, including principal diagnosis and up to 45 additional diagnoses, as well as limited demographic, disposition and insurance information about the case. This database is most appropriate for long-term tracking of trends and associations and has the advantage of providing true population-based estimates. Data are available in a standard format from 1999, but the most recent information is typically about two years older than the present date. Data files are provided to MICHAP epidemiologists through an agreement with the MDHHS Division for Vital Records and Health Statistics (DVRHS) for analysis. Michigan's new public health tracking program, MI Tracking, will use MIDB to track and map hospitalization rates for asthma, CO poisoning, and heat illness starting in 2016. MICHAP is currently using MIDB to monitor hospitalization rates for asthma and heat illness, and to investigate other chronic diseases that are associated with heat and water-borne infectious diseases. Also provides a source of information on the prevalence of conditions such as diabetes that increase the risk of many climate-sensitive diseases.

Michigan Resident Death Files

Michigan Resident Death Files contain information from the death certificates of Michigan residents, including demographics, location, circumstances, and causes (underlying and 17 contributing) causes of death, and is available by request from the DVRHS or through CDC Wonder at: http://wonder.cdc.gov/mcd.html. Deaths from extreme weather events are quite rare, and there are roughly five heat-related deaths per year, so death files are not a primary source for climate-sensitive health outcome surveillance.

Michigan Behavioral Risk Factor Survey (MiBRFS)

Since 1986 the MiBRFS has been conducted annually, as a statewide telephone survey of Michigan adults aged 18 years and older through a collaborative effort between MDHHS and the Centers for Disease Control and Prevention (CDC's) national Behavioral Risk Factor Surveillance System (BRFSS). These surveys act as the only source of state-specific, population-based estimates of the prevalence of various behaviors, medical conditions, and preventive health care practices among Michigan adults. The annual Michigan surveys follow the CDC survey protocol and use the annual standardized core questionnaire, but also include about 25 state-added questions each year. Roughly 10,000 individuals participate each year; this sample when weighted produces annual prevalence estimates and 95% confidence intervals that are representative of the Michigan population. Data may be aggregated across several years to produce county or region-level estimates. MICHAP uses MiBRFS sub state estimates to assess the prevalence of asthma and of chronic diseases and conditions such as obesity, diabetes, renal, cardiovascular and chronic lung diseases that increase risk of climate-sensitive diseases. Data are available from the MDHHS Michigan Behavioral Risk Factor Surveillance System website: http://www.michigan.gov/MDHHS/0,1607,7-132-2945_5104_5279_39424---,00.html or by request from the Program Epidemiologist.

Other Data Sources

As needed, additional sources are used to provide information that does not fall within the scope of the five previously described databases. Michigan's CO Surveillance System collects death, hospitalization, and Poison Control Center information on cases of CO poisoning in Michigan, including the circumstances of exposure (i.e., use of generator or alternate heat source). CO surveillance data is available at: http://www.michigan.gov/MDHHS/0,1607,7-132-54783_54784_54787---,00.html or by request from the Project Manager. Data from the Children's Hospital of Michigan Regional Poison Control Center are available to some MDHHS staff or can be directly requested from the Center by email or phone 1-800-222-1222. The Poison Control Center also collects information on calls regarding waterborne diseases and exposures (e.g. algal blooms), which can be helpful during outbreaks in measuring the impact of a climate event.

Exposure Surveillance Systems

The following data sources are used to monitor key climate-sensitive exposures in Michigan.

Air quality data

The federal Clean Air Act (CAA) requires the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) for six criteria pollutants considered harmful to public health and the environment. These are monitored by the Michigan Department of Environmental Quality (DEQ) Air Quality Division (AQD) and include ozone (O_3) and particulate matter smaller than 10 and 2.5 microns in diameter (PM_{10} and $PM_{2.5}$, respectively). The AQD's Air Monitoring Unit (AMU) ensures that all data collected and reported from the 41 monitors they maintain are of high quality and meet federal requirements.

MIair is an internet tool that provides real-time air quality information via the DEQ's webpage. The www.deqmiair.org hotlink opens to the current Air Quality Index (AQI) map and displays air quality forecasts for the current and subsequent days. *MIair* also hosts *EnviroFlash*, the automated air quality forecast notification system. The AQI is a simple tool developed to communicate current air quality information to the public, using color-coded AQI values, ranging from Good to Hazardous. AQD meteorologists also provide air pollution forecasts to alert the public when air pollution levels may become elevated. "Action! Days" are declared when levels are expected to reach or exceed the Unhealthy for Sensitive Groups AQI health indicator. The DEQ also supplies Michigan air monitoring data to *AIRNow*, the EPA's nationwide air quality mapping system, available at www.epa.gov/airnow. Both of these sites can be used during climate events to monitor for hazardous respiratory exposures. Annual monitoring data summaries are available from the DEQ AQD by monitor and location, and air quality reports are available that summarize findings by county, metropolitan area, and monitor approximately one year post-data collection; these data can also be tabulated, mapped and downloaded at the EPA's *Air Data* website http://www.epa.gov/airdata/.

The U.S. Centers for Disease Control and Prevention (CDC) and U.S Environmental Protection Agency (EPA) together developed two types of air quality indicators and measures for CDC's National Environmental Public Health Tracking Network. EPA provided ozone and particulate matter (PM2.5) monitoring data from 1999-2013 to CDC, and the two agencies collaborated to develop county based measures of air quality from the data. In addition, since many areas of the country do not have air monitors, EPA developed daily estimates of air quality for Ozone and $PM_{2.5}$ from 2001-2011 using a Bayesian space-time model known as the Downscaler (DS) model. This model fuses monitoring data with results from EPA's Community Multiscale Air Quality (CMAQ) model. CDC processed these daily modeled estimates and derived county-based measures of air quality. Both monitored and modeled data are available on the *National Environmental Public Health Tracking Network*. http://ephtracking.cdc.gov/showAirMonModData.action.

Land surface characteristics data

The National Land Cover Database (NLCD) serves as the definitive Landsat-based, 30-meter resolution, land cover database for the nation. NLCD provides spatial reference and descriptive data for land surface characteristics such as thematic class (for example, urban, agricultural, and forested land cover), percent impervious surface, and percent tree canopy cover for the years 1992, 2001 and 2011. NLCD supports a wide variety of federal, state, local, and nongovernmental applications that seek to assess ecosystem status and health, understand the spatial patterns of biodiversity, predict effects of climate change, and develop land management policy. NLCD products are created by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of federal agencies led by the U.S. Geological Survey. These data are used to describe physical exposure characteristics that influence climate vulnerability. NLCD 2011 is the most recent national land cover product created by the MRLC Consortium, and provides the capability to assess spatially explicit national land cover changes and trends from 2001 to 2011. MICHAP primary uses NLCD data to evaluate heat-related and respiratory vulnerability in terms of vegetation, impervious surface, and urbanicity. All NLCD data products are available for download at no charge to the public from the MRLC Web site http://www.mrlc.gov and the Michigan Geographic Data Library Catalog http://www.mcgi.state.mi.us/mgdl/ .

Tick & mosquito surveillance

Michigan State University (MSU) and MDHHS researchers have been conducting a long-term surveillance project for *Ixodes scapularis* (black-legged tick), the vector species for Lyme disease, in Michigan's western Lower and Upper Peninsulas since 2001. This study has involved looking for the presence of the black-legged tick, testing those ticks for infection with *Borrelia burgdorferi* and looking for evidence of infection in rodents and dogs in the area. These data are used to generate maps of counties determined to be either "endemic", with human cases or infected tick populations; or "at risk" due to their proximity to the counties with known tick populations. The latest maps and the underlying tick data are available to MICHAP through MDHHS's vector-borne disease program staff, with historic annual summary data available at the Emerging Diseases website http://www.michigan.gov/emergingdiseases/. Similarly, mosquito surveillance data are available by county and species. The data include test results for West Nile Virus and other arboviruses and risk maps, and are available at the Emerging Diseases website or through MDHHS's vector-borne disease program staff. Risk maps include distribution of human and animal cases as well as maps of locations of negative and positive mosquito pools submitted for testing for West Nile Virus.

Utility power outage surveillance

Information on electrical utility service areas is available from the Michigan Public Service Commission at http://www.dleg.state.mi.us/mpsc. During an outage event, most utilities post power outage maps which can be used to identify areas to monitor for CO poisonings, injuries or other effects, and to target public health messaging.

Water quality surveillance

Michigan's water quality data are mostly under the purview of the Michigan Department of Environmental Quality (DEQ) Water Resources Division (WRD). These data sources are evolving in content and availability, as is their use for exposure surveillance, either real-time or historical.

SSO/CSO and Retention Treatment Basin Discharge data

Sanitary sewer overflows (SSOs) are discharges of raw or inadequately treated sewage from municipal separate sanitary sewer systems, which are designed to carry domestic sanitary sewage only. When an SSO occurs, raw sewage may be released into basements, city streets, properties, rivers, and streams. A combined sewer is a sewer that is designed to carry both sanitary sewage and storm water runoff. A discharge from a combined sewer system, or combined sewer overflow (CSO), occurs in response to rainfall and/or snowmelt because the carrying capacity of the combined sewer system is exceeded. These discharges do not receive all treatment utilized under ordinary dry weather conditions. Retention Treatment Basin (RTB) discharges are treated discharges from facilities installed to collect and adequately treat combined sewer system overflows.

Discharge information for these events is available at the website: http://www.deq.state.mi.us/csosso/. The Discharge Information database contains information about specific discharges since June 1, 1999 for which a written report has been filed with DEQ, and can be searched by either the receiving water, county of discharge, or by the responsible entity. The Recent Discharge Events page can be searched for information on recent discharges where DEQ has not yet received a written report. Details of each reported event include: reporting entity, event type, event start and end dates/times; volume of discharge, precipitation type, amount, start and end dates /times; discharge locations, receiving water body, volume of discharge, water quality of discharge, discharge start and end dates/ times. These data could be accessed to identify locations and entities that have more frequent and larger discharges, as an indicator of vulnerability. Although required by state law, it is unclear how completely incidents of water discharges are reported.

Michigan Surface Water Information Management System (MiSWIMS)

MiSWIMS is an interactive map-based system that allows users to view information about Michigan's surface water. Users are able to view and download data and maps collected and maintained by the DEQ and DNR from surface water monitoring sites located throughout Michigan. Relevant monitoring data available by station include: coliforms, fish contaminants, waste water discharges, and septage haulers. This information could be used to identify areas of historic vulnerability to water contamination. MiSWIMS is available at: http://www.mcgi.state.mi.us/miswims/

Michigan Public Beach Information

This DEQ site contains information about Michigan inland and Great Lakes public beaches and recreational-use waterways, including beach closings, monitoring efforts and *E. coli* test results. The data in the beach monitoring systems are collected and entered by the local health department offices, and include lists of public beaches by county that are and are not monitored. Annual summary reports are available at this site: http://www.michigan.gov/deq/0,4561,7-135-3313_3686_3730---,00.html. The site also has links to **Michigan Beach Guard System** http://www.deq.state.mi.us/beach/, a public resource provided by Michigan DEQ for ongoing monitoring information on Michigan beach water quality sampling results and beach advisories and closures, and to **Beachcast** http://glin.net/beachcast/, a website and mobile application maintained by the Great Lakes Information Network for several Great Lakes states and Windsor, Ontario to provide similar real-time information about public beach advisories and closures in the Great Lakes region to potential beachgoers.

DEQ Onsite Wastewater Program

This site has information on DEQ's administrative rules for on-site water supply and sewage disposal systems. Noteworthy are Michigan 2009 and 2013 Statewide Failed Sewage System Evaluation Summary Reports which summarize data collected and submitted by local health departments on 'failed sewage systems' in their jurisdictions. This data collection project is an ongoing cooperation between DEQ and the Michigan Association of Environmental Health Administrators in support of local public health accreditation programs. These data could be used to identify locations historically vulnerable to sewage backup and contamination which could be exacerbated by precipitation events. Available at: http://www.michigan.gov/deq/0,4561,7-135-3313_51002---,00.html.

Water Quality and Pollution Control in Michigan Integrated Reports

Every two years, the DEQ WRD prepares and submits an Integrated Report to the EPA to satisfy requirements of the federal Clean Water Act. These Integrated Reports, most recently completed in 2014, describe the status of water quality in Michigan and include list of water bodies that are not attaining Michigan Water Quality Standards and require the establishment of pollutant Total Maximum Daily Loads, including pathogens and other public health indicators used to permit recreational body contact, along with maps and estimates of lengths of rivers and lakes affected. Reports are available at: http://www.michigan.gov/deq/0,4561,7-135-3313-12711--,00.html. These reports could be used to identify areas of historic vulnerability to water contamination.

Safe Drinking Water Information System (SDWIS)

The DEQ is the State's Drinking Water Agency responsible for collecting, monitoring, and reporting on public drinking water system regulatory violations to the EPA. Regulations establish maximum contaminant levels, treatment techniques, and monitoring and reporting requirements to ensure that water systems provide safe water to their customers (at EPA SDWIS site, below). Public drinking water systems are categorized as:

- *Community Water System (CWS):* A public water system that supplies water to the same population year-round.
- *Non-Transient Non-Community Water System (NTNCWS):* A public water system that regularly supplies water to at least 25 of the same people at least six months per year, but not year-round. Some examples are schools, factories, office buildings, and hospitals which have their own water systems.
- *Transient Non-Community Water System (TNCWS)*: A public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time.

Currently only CWS violations for Trihalomethanes (TTHM) and Haloacetic Acids (HAAS) are tracked in the DEQ SDWIS, which is not available to the public. However, those contaminants along with others of concern are available for viewing based on water system name, county, population served, and/or system status at the EPA's SDWIS website: http://www.epa.gov/enviro/facts/sdwis/search.html. Each CWS operating agency provides its customers with an annual report of Public Water System Violations. Those and other contaminants will be made available on SDWIS in the future along with Non-community Water Systems, as it is transitioned to an EPA cloud storage site.

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IV. Michigan's Vulnerabilities to Climate Change

"Exposure refers to the susceptibilities that exist due to climate change based on the magnitude, frequency, duration, and geographic extent of various climate related events. Sensitivity is the ability of a community to withstand the range of climate exposures and associated impacts based on physiological, socioeconomic, and infrastructure characteristics (pg.74)."

Defining Vulnerability Assessments

The Third National Climate Assessment defines vulnerability as, "a function of the character, magnitude, and rate of climate variations to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2012)." Figure 4.1 illustrates the key connections between exposure, sensitivity, and adaptive capacity that collectively determine human health vulnerability resulting from climate change.

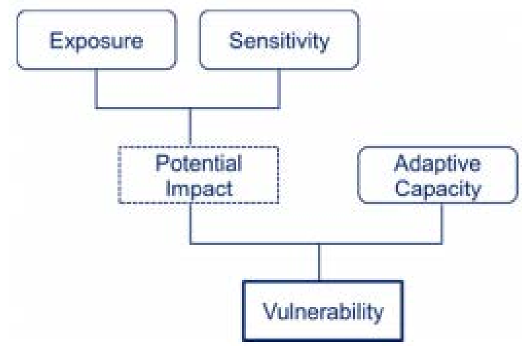

Fig. 4.1: Vulnerability Assessment Model
Source: CDC Climate and Health Program, 2014

Exposure refers to the susceptibilities that exist due to climate change based on the magnitude, frequency, duration, and geographic extent of various climate related events. The Climate and Health Profile focuses on the exposures in relation to those that are detrimental to human health. Sensitivity is the ability of a community to withstand the range of climate exposures and associated impacts based on physiological, socioeconomic, and infrastructural characteristics. The presence or absence of those factors, depending on how they are measured and perceived, can increase the susceptibility of individuals to climate exposures. Adaptive capacity then is the capacity for governments, organizations, businesses, and individuals to respond to an event in order to reduce the potential public health impact (Manangan et al., 2014)

The sections below describe the existing human health vulnerabilities in Michigan based on projected climate changes as they relate to impacts on socioeconomic characteristics, health risk factors, and the built or natural spatial environment. These characteristics influence potential health outcomes resulting from climate exposures for various geographic areas and populations.

Sensitivity

Underserved individuals with limited access to resources and care are the most vulnerable to health risks attributable to climate change. This group includes elderly persons, children, the socially isolated, certain minority populations, the impoverished, the undereducated, the underinsured, outdoor workers, those with existing illness, and those who are immunocompromised (Frumkin et al., 2008).

Age

Elderly persons are physiologically sensitive to extreme climate events and are also more likely to have pre-existing adverse health conditions. Northern Michigan and certain block groups in metropolitan Michigan contain many areas where the median age is over 55 years (See Section II). Conversely, children under the age of 5 years are also sensitive to severe climate events. Smaller body mass and naïve immune systems make children more susceptible to complications from both chronic illness and infectious disease. Spending more time outdoors also increases children's duration of exposure to disease causing factors (Balbus, 2009).

Socioeconomic Status

Over 16% of Michigan's population is below the poverty line and roughly 12% of adults have not graduated from high school. Vulnerabilities to heat stress, extreme weather events and respiratory complications are generated from inadequate shelter, confined living spaces, and limited access to sources of relief such as air conditioning or access to healthcare. The impoverished have less control over how they adapt to severe weather events and tend to live in crowded, low-quality housing, which can exacerbate impacts from temperature and precipitation. Additionally, having less than a high school education has been associated with adverse health outcomes (Balbus, 2009).

Ethnic minorities make up approximately 24% of Michigan's population and while that alone does not account for increased vulnerability, certain groups are more exposed and/or sensitive to climate effects (Portier et al., 2010; Luber et al., 2014). For example, Native Americans located in the Upper Peninsula are sensitive to resource depletion and water contamination due to extreme heat and drought while many African American and Latino neighborhoods are typically located in high poverty and low air quality areas (Morello-Frosch et al., 2009).

Occupational Groups

Certain occupational groups may be at higher risk of climate-related health outcomes because of the elevated amount of time they spend outdoors. Those with jobs involving parks, recreation, wildlife, water quality, agriculture or construction may face prolonged periods of exposure to potentially harmful weather conditions. Additionally, individuals commuting to and from their places of employment are at elevated risks of traffic-related injury during times of extreme weather (Balbus, 2009).

Health Risk Factors

Many residents are also particularly vulnerable to the adverse effects of climate change based on certain physiologic health characteristics such as obesity (31% prevalence in Michigan) and overweight/obesity (61%). This vulnerability has continued to increase in recent years as Michigan's obesity prevalence rose 25% from 2003 to 2012 and in 2012 was tenth highest in the United States (Centers for Disease Control and Prevention, 2012). Over 15% of Michigan adults and 24% of children have been diagnosed with asthma (Trust for America's Health, 2014). Over 2 million Michigan residents have preexisting cardiovascular or pulmonary risk factors that could be exacerbated by climate change (MDHHS CVD Fact Sheet, 2013).

The demographic groups and those with chronic health conditions noted above that have an elevated vulnerability to climate-related health outcomes represent a large segment of the population. While the "sensitivity" branch of the definition of vulnerability can identify vulnerable people, the "exposure" branch can locate several vulnerable places.

Exposure

Across Michigan there are dense-to-sparsely developed urban communities, rural landscapes dominated by agriculture, and nearly untouched wilderness areas. Each of these unique areas are connected via natural waterways, man-made infrastructure, and human interaction. Climate change will impact each of these areas separately while also having the potential to generate cascading effects on human health in different areas and in unexpected ways. Those relationships are explored in more depth in chapter III: **Linking Exposures to Health Outcomes**. Described here is a set of the priority geospatial risk factors that increase the human health vulnerabilities to climate change.

Natural Environment

Vegetation

The amount of green space, along with creating an aesthetically pleasant environment, has been linked to both human health benefits and concerns. Increases in green space and tree canopy in urban environments have been shown to drastically reduce surrounding air and surface temperatures (Nowak, accessed 2015). Likewise, presence of vegetation can reduce harmful carbon emissions, $PM_{2.5}$ levels, and ozone levels (Nowak, accessed 2015). Conversely, increases in certain pollen producing plants can increase asthma hospitalizations and allergic episodes. Insects and vermin that harbor infectious disease may be drawn to areas with higher amounts of specific vegetation. Additionally, the surrounding soil can also have a role in harboring vectors that transmit disease and draining water levels during extreme precipitation events.

Water

In Michigan, there are over 36,000 miles of streams, and more than 11,000 lakes and ponds (MI Department of Environmental Quality, 2014a). For residents these water sources along with the Great Lakes represent sources of drinking water, irrigation, waste management, and recreation. However, the abundance of surface water is also a source of vulnerability from climate change in terms of flooding, water contamination, and quality. In addition to one's proximity to bodies of water, households with private wells may be at increased risks for water-borne or respiratory diseases depending on water levels (Luber, 2014).

Topography

Uplands and lowlands exist in both urban and rural settings and offer different exposures to climate change. In Michigan, of particular concern are the lowlands. The term "floodplain" pertains to the land area that will be inundated by the overflow of water resulting from a 100-year flood – an area that has a 1% chance of flooding any given year given the elevation and soil type. Approximately 6% of Michigan's land is estimated to be in the 100-year flood plain, or the Federal Emergency Management Agency's (FEMA) Special Flood Hazard Area, including about 200,000 buildings (MI Department of Environmental Quality, 2014b).

Built Environment

Urban development

Michigan is classified as having just over 6% urban development. However, the urban areas contain nearly 75% of the population (U.S. Census Bureau, 2013). This has resulted in certain areas being densely developed and often divided along social and economic lines. Urban vulnerabilities from climate change stem from urban heat island effect, lack of green space or tree canopy coverage, and lack of access to adaptive resources such as food, healthcare, or cooling centers for large populations.

Infrastructure

Michigan is ranked 8th highest in rental vacancy rates with a rate of 11.5% (U.S. Census Bureau, 2013). Those who rent their homes have less control over modifying their built environment in response to weather-related stressors and are considered more vulnerable. Of the 50 most populous counties in the United States, Wayne County ranks 48th in median household value at an estimated 118,100 dollars (U.S. Census Bureau, 2013). Wayne County also consists of high proportions of households below the poverty line and minorities. Those in households with low-median incomes may not have access to sources of relief from climate events. In addition, buildings with low value may experience climate-related damages more easily. Studies have also shown that not having access to medical care within 1 hour of driving time constitutes as a geographic vulnerability (Hsia, 2011). Hospitals are sparsely located in Northern Michigan and rural dwelling residents may not have ready access to hospitals during severe climatic events.

Historic Events

Finally, historic weather data are informative in discovering which geographic areas of Michigan are historically burdened by specific weather events. Cumulative “extreme heat” or “heavy rain” days derived from historic NOAA Severe Storm data inform us about the frequency of events a county in Michigan has experienced. Wayne, Macomb and Oakland Counties have had 13 “extreme heat” days from 1996 to 2013 according to NOAA, at least some of which were likely associated with or enhanced by the urban heat island effect. Counties in the Upper Peninsula and along the western coast of the Lower Peninsula have the greatest frequencies of winter weather events such as blizzards, ice storms, and lake-effect snow. Knowing the frequency and geographic extent of certain storms for each county can improve a community’s adaptive capacity to climate exposures just by knowing what to expect.

Priority Health Outcome Vulnerabilities

The following section explains how the sensitivities and exposures listed in table 4.1 collectively affect each of the Michigan Climate and Health Program’s five priority health outcomes: heat-related illness, respiratory disease, vector-borne diseases, water-borne diseases and CO/Injury related outcomes. The sensitivities and exposure-related risk factors that contribute to increased vulnerability to specific climate events have been identified and described in further detail below.

Table 4.1: Summary of “sensitivity” and “exposure” risk factors of vulnerability for 5 priority health outcomes in Michigan.

Sensitivities						Exposures					
Risk Factor	Heat	Respiratory	Vector-borne	Water-borne	CO Poison & Injury	**Risk Factor**	Heat	Respiratory	Vector-borne	Water-borne	CO P & In
Children (< 5 Years)	x	x	x	x		Green Space	x	x	x		
Elderly (> 65 Years)	x	x	x	x	x	Impervious surface	x			x	
Living alone	x				x	Severe Storm events	x	x	x	x	
Racial minority	x	x		x	x	Soil type			x	x	
Low education	x	x		x	x	Private wells				x	
Low household income	x	x		x	x	Proximity to hospital					
Outdoor workers	x	x	x			Elevation		x	x	x	
Commuting to work					x	Ozone & PM 2.5	x	x			
Existing chronic illness	x	x				Proximity to water		x		x	
Access to heat relief	x					Rental housing	x	x		x	
						Median household value	x	x		x	

Heat-related Illness

Populations who are elderly, young, of low socioeconomic status, socially isolated or concurrently inflicted with a chronic illness may face physical and environmental barriers in order to alleviate the effects of extreme heat and are therefore considered vulnerable. Limited mobility within the elderly and socially isolated populations may inhibit them from seeking sources of relief, such as cooling stations (Kovats et al., 2008). Likewise, low income and urban dwelling residents may be unable to afford air conditioning devices, transportation services or feel uncomfortable leaving windows open for ventilation during heat waves (Semenza et al., 1999). Combinations of these demographics may further aggravate heat vulnerability and require elevated attention as average summer air temperatures and humidity are projected to rise across Michigan (Dan Brown, GLISA, Personal Communication; Frumkin et al., 2008).

The surrounding environment also dictates susceptibility to adverse health outcomes in terms of extreme heat events. Developed cities, such as Detroit and Grand Rapids, often suffer from an “urban heat island” effect that drastically increases temperatures within metropolitan borders compared to surrounding rural areas (Frumkin et al., 2008). Impervious surfaces, such as roads and building materials that trap heat rather than reflect, a lack of green space that would normally improve air quality and mitigate heat, and excess production of greenhouse gases all contribute to the urban heat island phenomenon (Bolund et al., 1999). Occupational hazards also exist for workers who spend excess time outdoors and are exposed to elevated temperatures for extended periods of time (Frumkin et al., 2008).

Respiratory Disease

Elderly persons, children, those with low socioeconomic status, and those with existing respiratory conditions, such as COPD or asthma, may face more respiratory complications as warming air temperatures can increase ozone, pollen, and mold levels (Portier et al., 2010). The growing season in Michigan is expected to increase in length, so plants will have a longer period of time to thrive and produce not only more allergenic pollen, but also greater quantities of pollen (Shea et al., 2008). Extremely hot days are not projected to substantially increase in Michigan, so the degree of impact on the health parameters will depend on the sensitivities of the at risk populations (see section III).

Harmful molds and dusts, and pathogens such as Coccidioidomycosis can be produced from floods and cause significant respiratory problems in humans (Portier et al., 2010). These respiratory problems are often magnified by a lack of green space (also caused by droughts) so people who work or recreate outside may be at higher risks for adverse respiratory health outcomes (Luber et al., 2014). Location may also define respiratory vulnerability from flood events. For example, Detroit city sits at a low elevation near Lake Erie and is prone to flooding. Households of low monetary value or poor infrastructure may experience harmful molds after flooding events (Tollestrup et al., 2014; Swerdlow et al., 1992). Mold growth has been associated with extreme precipitation and flooding events. The intensity of flooding is determined partially by the design of the built infrastructure.

Vector-borne Disease

The projected increase in average seasonal temperatures and mean total precipitation also has implications for vector-borne disease, as mosquito, tick and vermin vectors will begin to expand their habitats. West Nile Virus and Lyme disease are just two of the communicable diseases that might increase in prevalence in Michigan as climate and habitat changes occur.

The two vector-borne diseases of most concern in Michigan are West Nile Virus (WNV) infections and Lyme disease. In general, individuals who are very young, old and/or poor are more vulnerable to these vector-borne health outcomes. Additional demographic risk factors for acquiring vector-borne diseases include spending extended amounts of time outdoors (working or recreating). Having co-morbidities that affect health (e.g., cardiovascular diseases, asthma) or immune response can sometimes exacerbate symptomatic effects as well.

In regard to spatial risk factors, historically in Michigan, a majority of WNV activity has occurred in the Detroit Metro Area and the Grand Rapids Metro Area (Ruiz et al., 2007), suggesting that certain features of urban living provided environments favorable for the *Culex* mosquitoes and WNV. Historic mosquito collection and testing in the Detroit Metro Area indicated that WNV rates were much higher than in other areas of the state (West Nile Virus briefing information, 2012). In 2013, the highest number of WNV cases occurred in southeastern Michigan, which includes the Detroit area. The WNV case rate was considerably higher for urban dwellers living in the inner suburbs, where 1940–1960 era housing dominates, vegetation cover is moderate, population density is moderate and the population is mostly white.

The vector for Lyme disease, the black-legged *Ixodes scapularis* tick, and Lyme disease were first reported in Michigan in 1985. Cases have now been reported in both the Upper and Lower Peninsula, although, most cases are still acquired out-of-state. Historically, the only endemic region in Michigan has been Menominee County in the Upper Peninsula, bordering a highly endemic region of Wisconsin. Recently, however, populations of infected black-legged ticks have been found in southwest Michigan and several counties along the Lake Michigan shoreline (Michigan Zoonotic & Vector-Borne Disease Surveillance Summary, 2013). The number of cases reported in the state is thus anticipated to continue increasing due to the expanding tick distributions and Michigan's suitable habitat.

Water-borne Disease

The elderly, children, and those with existing health concerns are also expected to experience more severe complications from water-borne parasites that could stem from climate exposures (Frumkin, 2008). Those who recreate or work around water systems are also vulnerable for water-borne disease outcomes due to prolonged exposures to potentially contaminated sources (Frumkin et al., 2008). A majority of Michigan's Native American population resides in the Upper Peninsula where mean total precipitation is projected to decrease. With heavy reliance on water quantity and quality for agriculture and drinking sources, drought and excess precipitation events could make Native Americans more susceptible to foodborne and mental illnesses through pathways discussed in section IV (Portier et al., 2010). Heavy runoff after severe rainfall can also contaminate recreational waters and increase the risk of ear, nose, and throat, respiratory or gastrointestinal illness through higher bacterial counts. Less abundant and potentially more severe waterborne diseases such as hepatitis, giardiasis, cryptosporidiosis, and toxic algal blooms pose serious health threats to vulnerable human populations.

Geographically in Michigan, areas bordering the Great Lakes coast and residents located within floodplains are more vulnerable to flooding events over time (MI Department of Environmental Quality, 2014b). Detroit, which is a low lying coastal city, is vulnerable to flooding. Detroit has a combined sewer system and is susceptible to discharges of untreated sanitary sewage into water ways when storm water accumulation is aggressive. This problem is exacerbated by impervious surfaces in Detroit, which increases both the volume and velocity of storm water runoff. Grand Rapids is also prone to seasonal flooding although the City has undertaken a complete combined sewer separation due to be completed in 2015/16. The DEQ completed a Source Water Assessment for the City of Grand Rapids water supply, which is Lake Michigan, in 2003 and found a moderately high susceptibility to contaminants such as viruses and bacteria from sewage, livestock and wildlife.

Some of this raw sewage ends up in lakes and streams, as well as underground aquifers that supply drinking water wells. There are about 1.3 million on-site wastewater treatment systems in Michigan, most of which are septic systems for single-family homes. State officials estimate that 10 percent of those (130,000) have failed, due to a combination of system failure and heavy precipitation, and are polluting the environment. Some counties requiring septic system inspections during real estate transactions report a 20 - 25% failure rate (Alexander, 2013). According to DEQ data, Michigan's municipal wastewater treatment facilities discharged 7.8 billion gallons of raw sewage and another 21.6 billion gallons of partially treated sewage into lakes and rivers in 2011. Most of those discharges occurred in Detroit and other cities where heavy rainfall overwhelmed combined sewer systems that treat both wastewater and storm water (Alexander, 2013).

CO Poisoning/Injury

The elderly are often socially isolated which may delay assistance after physical or infrastructural damage occurs from extreme temperatures or precipitation. Additionally, those with low Socio-economic Status (SES) may not have properly functioning, or even be in possession of, CO detectors when power outages occur from infrastructure damages. In the event of power outages, CO exposure, often due to the improper use of gas generators, is responsible for many poisonings and even death. For example, a powerful ice storm in December 2013 was responsible for a massive spike in CO poisoning emergency department visits in several counties (Quiggle, Stanbury, Rosenman, 2015).

Additionally, climatic events may geospatially segregate certain populations when heavy infrastructural or flood-related damage occurs. Falling debris created from buildings or vegetation can directly contribute to weather-related mortality and injury. Indirectly, debris can alter human health via traffic accidents, power outages, and subsequent CO poisoning. These damages may result in social disruption which can exacerbate stress and mental illness in predisposed populations. Infrastructural integrity and adequate emergency response preparedness also determine how vulnerable populations are to injuries resulting from climate exposures.

Commuters may experience more traffic-related injury or death due to future projected increases in freezing-rain events from increased winter precipitation combined with temperatures warming above the point of producing snow. Areas downstream of the Great Lakes are expected to have greater amounts of winter precipitation due to the lake-effect. Finally, census data indicates the northern Michigan population tends to be older and may have lower quality of housing. Housing structure integrity in these areas could exacerbate hypothermia, CO poisoning, and other chronic health conditions that may not be addressed in a timely manner because hospital are more sparsely located in northern Michigan.

Climate exposures, vulnerability, and health outcomes

The sensitivities and exposures of vulnerability span many health outcomes and are affected by several climate factors. The vulnerabilities identified highlight populations and locations that need heightened attention when considering climate and health. They also intensify many of the causal pathway links highlighted in section IV. Through Step 1 of the BRACE Framework, MDHHS strives to reduce health disparities by servicing the vulnerable sectors of Michigan.

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U.S. Census Bureau; American Community Survey, 2013*: American Community Survey 1-Year Estimates*; generated by Robert Walker; using American FactFinder; factfinder2.census.gov.

V. The Burden of Climate Change and Human Health

Source: National Institute of Environmental Health Sciences,
http://www.niehs.nih.gov/research/programs/geh/climatechange/health_impacts/asthma/index.cfm

"Temperatures are trending upward and are projected to continue over the long-term; the rate of change in precipitation is more difficult to project, and extreme events are very difficult to model, resulting in qualitative rather than quantitative predictions of future climate. Local vulnerability factors and population trends will likely have a larger impact on health burden than the rate of climate change in Michigan (pg. 88)."

Introduction

In chapter II: **Michigan's Current and Future Climate Conditions**, the baseline climate conditions along with future climate projections were described for the entire state. Chapter III: **Linking Climate Changes to Health Outcomes** introduced the priority climate related health outcomes along with the potential pathways by which changes in Michigan's climate may impact those specific public health outcomes. Those relationships were further explored in chapter IV: **Michigan's Vulnerabilities to Climate Change** as the geophysical, socioeconomic, and health characteristics of the state were described in terms of their capacity to alter the vulnerability of Michigan's population of being negatively impacted by climate change.

Here, the conclusions of those sections are synthesized to better inform how future climate conditions may exacerbate those existing vulnerabilities and health impacts. This high level view of climate and health in the state will be used as the framework for further analysis of how and by how much climate change may alter disease burden for citizens in Michigan.

Future Health Impacts from Climate Change

Respiratory Disease

Respiratory diseases are related to levels of atmospheric ozone, pollen, mold, and other particulates, which are influenced by air temperatures, humidity levels, precipitation/drought events, and the movement of air throughout a region. Warmer air temperatures can increase risks due to ozone, pollen, and mold levels. For Michigan, there is agreement among the projections that average temperatures will increase over the next century (see Figure 2.6). There is less agreement on the timing of the warming; although more warming is expected to occur on the coldest days versus the hottest (see Figures 2.7 and 2.8, respectively). Given that warming is associated with a longer growing season, plants will have a longer period of time to thrive and potentially produce more pollen (see Figure 2.10). Extremely hot days are not projected to substantially increase (see Figure 2.9) so the degree of impact on health will depend on the sensitivity of the populations being exposed to the heat. However, high humidity has also been shown to increase risks due to its role in low level ozone creation and mold levels. In Michigan the number of high humidity days is projected to increase during summer.

Mold levels have also been associated with extreme precipitation and flooding events, and although the degree of flooding is determined in part by the design of the infrastructure in place to manage it, extreme precipitation events are expected to stay the same or increase (see Figure 2.12). The Wisconsin Climate Change Initiative's (WICCI) downscaled climate projections for Michigan further indicate that the more intense extreme precipitation events (those producing greater than 2 inches of rain) will increase in frequency by a greater degree than those extreme events producing 1 – 2 inches. However, the projections consulted did not provide information about the seasonal timing of these events.

Lastly, the movement (or lack of movement) of air masses affects ozone levels whether the air is stagnant and ozone is able to disperse or if ozone from far away sources is moved into the region. The movement of air masses is largely determined by wind patterns that are especially difficult to simulate at the local scale. Increases in temperature and humidity would exacerbate existing air stagnation events if the conditions occur simultaneously. In the near term, wind patterns are not likely to change significantly.

Heat-related illness

Heat-related morbidity (e.g. heat exhaustion, heat stroke, etc.) and mortality are correlated with air mass stagnation events and extreme heat events. As previously mentioned, air mass stagnation events are difficult to project at the local scale because simulated wind patterns are uncertain. However, projections do point toward increasing summertime humidity that would exacerbate air mass stagnation events if they occur. In the near term, wind patterns are not likely to change significantly, so the frequency of air mass stagnation events will either stay the same or increase (increases will occur if higher humidity levels allow an event to be characterized as an air mass stagnation event when it previously would not have crossed that threshold). Most projections indicate that days above 95^0 F will increase only a few days per year on average, but the upper simulated range of 25 more days per year could have significant health impacts (See Figure 2.8). The frequency of consecutive days above 95^0 F is projected to remain the same or increase by a few days across the state**.** Summer heat index values are projected to increase, leading to increased heat stress, but most of the changes are related to increased humidity as opposed to increased temperatures (See Figure 2.9). The Milder winters may also reduce the amount of morbidity and Mortality

CO poisoning and traumatic injuries

Carbon monoxide poisoning can occur when people improperly use household appliances, such as gas stoves, or use generators inside their home during power outages, cold spells, flood clean-up, and similar events. Although the frequency of events such as power outages and flood clean-ups is determined more by the integrity of the structures in place to carry power and prevent indoor flooding, extreme weather events create the right conditions for failure of these systems.

Extreme weather events, such as floods, ice and snow storms, and tornadoes, may also lead to traumatic injuries and deaths. In the future there may be more freezing-rain events as temperatures warm above the point of producing snow (see Table 2.8). Tornadoes are not simulated in climate models because they occur on too small of spatial scales. In general it is best to prepare for an increase of extremely hot days and more extreme precipitation events because the projections do not indicate that these events are expected to decrease (see Figures 2.8 and 2.12, respectively). Impacts related to extremely cold days may decrease since fewer days below freezing are projected for the future (see Figure 2.7).

Water-borne illness

Water-borne toxins and diseases increase during climate-related events such as algal blooms, flooding, and changes to ecosystems where new pathogens are introduced. Algal blooms increase when temperatures increase and extreme precipitation events occur. Algal bloom events are also dependent on factors such as nutrient laden agricultural run-off, so events will be localized to areas where this occurs. Flooding events can lead to well contamination, increased surface runoff, and sewage overflows that put surface and drinking water systems at risk for health concerns. Projections indicate that warming is expected, and summer warming is expected to be greatest in southern regions while winter warming is most pronounced in the north (see Figure 2.6). Precipitation projections are more uncertain. Spring mean precipitation is projected to increase in most models, although there is great variability at any given location. Summertime mean precipitation events show large increases and decreases in the models, which indicates high uncertainty (see Figure 2.11). The most intense precipitation events are projected to stay the same or increase, but the timing of those events is uncertain (see Figure 2.12). New water-borne pathogens can come about from increasing water temperatures and humid weather conditions that foster growth. Warmer average temperatures at all times of the year coupled to more humid summers may accelerate new pathogen growth. In general, future climate conditions will be the same or more conducive to water-borne toxins.

Vector-borne disease

Vector-borne diseases and their link to climate conditions is especially complex because several climate variables are involved, and the timing of climate conditions is an important factor. The climate conditions that are favorable to West Nile Virus (WNV) and its mosquito vector are a warm winter and early spring followed by a hot, dry summer. Climate projections indicate that all seasons are warming and spring will occur earlier as the growing season expands (see Figure 2.10). Summer humidity is projected to increase, but there is uncertainty about summer precipitation projections (see Figure 2.11). Most of the projected changes align with climate conditions that are favorable to WNV.

Another complex human health concern is Lyme disease, which is impacted by warm, snowy winters followed by warm, rainy, humid springs that favor the proliferation of the tick vector *Ixodes scapularis*. Lyme disease has potential to persist later in the year if fall conditions are warm and humid. Again, projections indicate that all seasons will warm, but precipitation and humidity information is more uncertain. The projections indicate that more winter precipitation will fall as rain across the Midwest, but annual lake-effect snowfall amounts have already increased and regional modeling studies suggest a continuation of that trend in the future (see Figure 2.11). Rain versus snow for winter precipitation will be determined by the degree of warming and whether freezing thresholds are met. The Upper Peninsula is expected to warm more during the winter than the Lower Peninsula, but temperatures in the north are farther from the threshold for producing rain. In general, snow is a complex variable to model, so it is best to anticipate greater precipitation variability in Michigan’s winter season (i.e., rainy and/or snowy winters). Spring precipitation is projected to increase in most of the models, but the consulted projections did not indicate whether spring or fall humidity levels will change in the future. From a temperature standpoint, climate conditions will be favorable to the increase of Lyme disease in the future. However, the complex nature of precipitation modeling and uncertainty associated with whether the right combination of climate conditions for more than one consecutive season will occur make it difficult to project whether Lyme disease will become more widespread in the future. In the near term, lake-effect snowfall amounts will likely continue to increase. Therefore Lyme disease may become more prominent in the lake-effect zones.

Regional Considerations

Detroit and Southeastern Michigan – Climate Division 10

Detroit and southeast Michigan will face many of the same changes in climate as the surrounding geographic area, but its urban to suburban setting alters and amplifies many vulnerabilities. Land use, pre-existing infrastructure design, and socioeconomic capacity are among many characteristics that will either reveal strengths or pose obstacles in adapting to climate change and associated health risks.

There are many potential impacts of climate change that cut across many sectors and jurisdictions. Southeast Michigan, Detroit in particular, is expected to face the following critical challenges in the coming decades:

- As average temperatures rise throughout the region, the probability of heat waves and hot days will grow, increasing the risk of heat-related illnesses. The number of days over 90°, 95°, and 100° F are all expected to increase through the coming century, assuming greenhouse gas emissions will continue to increase. Heat islands in urban centers that house less mobile populations are particularly vulnerable.
- As severe rainstorms become more frequent and more intense, flooding will increase the risk of sewage overflows, water contamination, and algal blooms. Many communities in southern Michigan employ combined sewer systems that transport both sewage and storm water. Extreme storms overwhelm these systems and discharge untreated sewage into waterways.
- More storm activity will also amplify the risk of damage to infrastructure, and in severe cases, may limit the effectiveness of emergency responders.
- Detroit likely will see an increase in the number of unhealthy ozone days due to climate change. The Detroit area includes many fossil fuel emission sources, and the region is projected to see an increase in the number of hot days that will increase ozone production.

Grand Rapids and Southwest Michigan – Climate Divisions 5, 6, 8

Grand Rapids and southwest Michigan have already seen impacts of climate change. The presence of major waterways through agriculturally-dominated and urban settings that have been subject to a number of land uses are a vital resource to the region, but also a consistent thread of vulnerability in communities. Existing problems of flooding, water quality, and infrastructure damage will be amplified due to climate change without appropriate adaptation measures.

Southwest Michigan and Grand Rapids are expected to face the following critical challenges in the coming decades:

- As average temperatures rise throughout the region, the probability of heat waves and hot days will grow, increasing the risk of heat-related illnesses. Heat islands in urban centers that house less mobile populations are particularly vulnerable.
- As severe rainstorms become more frequent and more intense, flooding will increase the risk of sewage overflows, water contamination, and algal blooms. Many communities in southwestern Michigan employ combined sewer systems that transport both sewage and storm water. Extreme storms overwhelm these systems and discharge untreated sewage into waterways.
- The risk of flooding, particularly along the Grand River, will be amplified by more storm activity. Without adaptation or intervention, the risk of infrastructure damage and health hazards will increase.
- Much of southwestern Michigan may see an increase in the number of poor air quality days resulting from air stagnation during an increasing number and duration of heat waves.

The Upper Peninsula and Northern Lower Michigan – Climate Divisions 1-4

Northern sections of the state have warmed faster than areas to the south and have seen dramatic increases in average winter temperatures (see Table 2.1). Changes in winter seasonality specifically may be a factor in public health impacts and emergency response. While extreme summer heat (e.g., days exceeding 95^0 F) comparable to southern Michigan is not a concern, the prevalence of air conditioning is far less in the North, and populations are less adapted to warm temperatures. The number of days exceeding 80^0 F has increased and is expected to increase throughout the next century. Even these moderately warm temperatures can increase risks in communities not accustomed to them.

The frost-free period, the number of days between the last spring freeze and the first autumn freeze, has grown longer by 5-10 days in many northern Michigan locations. By mid-century, the Upper Peninsula and northwest Lower Peninsula of Michigan will likely see a frost-free season that is 3-4 weeks longer than during the recent past. These rapid changes in seasonality could alter disease vectors and impact ecosystems in other ways that indirectly affect human health risks.

The Upper Peninsula's sparse population forces emergency responders to cover larger geographic areas than the rest of the state. As extreme precipitation continues to increase throughout the Upper Peninsula and issues currently limited to southern areas appear farther north, emergency response teams may see increased activity. On the other hand, a shorter winter season could reduce the period of the year that emergency response is challenged by snow and ice, making ground transportation safer.

East and South Central Lower Michigan- Climate Divisions 7 and 9, respectively.

These regions are predominantly agricultural but contain urban areas such as Bay City, Saginaw, Lansing and Jackson. The East Central region surrounds Saginaw Bay and encompasses the Saginaw Bay watershed which is the largest contiguous freshwater coastal wetland system in the United States. Both regions are trending upward in total precipitation and, at a 25% increase from the 1951 – 1980 period to the 1981 – 2010 period, report the largest relative increases in Fall precipitation for the entire state (see Table 2.3). This increases the potential for flooding and water contamination due to runoff from agricultural areas and septic systems.

Summary and Synthesis

In the short term, which is within the next 15-20 years, current climate patterns will generally persist. Temperatures are trending upward and are projected to continue over the long-term. The rate of change in precipitation is more difficult to project, and extreme events are very difficult to model. This necessitates qualitative rather than quantitative predictions of future climate. It is likely that local vulnerability factors and population trends will have a larger impact on health burden than the rate of climate change in Michigan.

Overall, based on the best evaluation of climate patterns and a synthesis of the best model projections by GLISA climatologists, the climate impacts on priority health conditions listed in Table 5.1 can be expected in Michigan.

Key: Table 5.1 Climate Projection with Related Health Impacts

+	Projected increase in the variable
-	Projected decrease in the variable
+/=	Projected variable increases or remains the same
-/=	Projected variable decreases or remains the same
?	Unclear or cannot project the variable
NC	No change in the projected variable

Table 5.1: Summary of Future Impacts to Priority Health Outcomes Based on Existing Vulnerabilities and Climate Change Projections

Environmental Exposures	Climate Stressors	Climate Projections (2021 – 2050) with Related Health Impacts
Respiratory Disease		
- Ozone Levels - Particulates	warm air temperatures, high humidity, air stagnation, wind patterns	+ Air temperatures, especially for days below freezing. + Summer humidity, producing more unfavorable conditions during air mass stagnation events ? Cannot project frequency of air mass stagnation events **NC** Large-scale wind patterns in the near term ? Cannot simulate local-scale winds
Conclusion: 1. Climate conditions leading to worsening ozone levels will likely stay the same or intensify. 2. Increased combustion to meet electricity demands for air conditioning during hot humid weather could lead to increased particulate levels. 3. Air toxics levels may increase during air stagnation events. Overall, projected conditions favor increased air pollution and worsening respiratory disease.		
- Pollen Levels	warm air temperatures, growing season length, date of first frost, Carbon dioxide levels	+ Air temperatures, especially for days below freezing. + Days of frost-free growing season, with day of last spring freeze up to a week earlier by 2050 + Carbon dioxide levels in atmosphere
Conclusion: 6. Climate projections favor earlier and longer growth period for plants 7. Pollen levels are expected to increase which could exacerbate respiratory diseases including allergic asthma		
- Mold Levels	extreme precipitation events, high humidity, especially in fall	+/= extreme precipitation; >2 in. events project an increased frequency by greater degree than 1-2 in. events ? Cannot project timing of these events **NC** Fall humidity levels
Conclusion: Cannot project if climate conditions favorable for mold growth will change given the importance of timing for mold, so impact on allergic diseases is uncertain.		
- Particulate Levels (dust, forest fires)	drought	- Number of consecutive dry days/year in northern Lower Peninsula -/= Number of consecutive dry days/year for remaining portions of the state
Conclusion: Drought related climate stressors on particulate levels should be minimal overall, and therefore drought's impacts on respiratory diseases are projected to be minimal.		

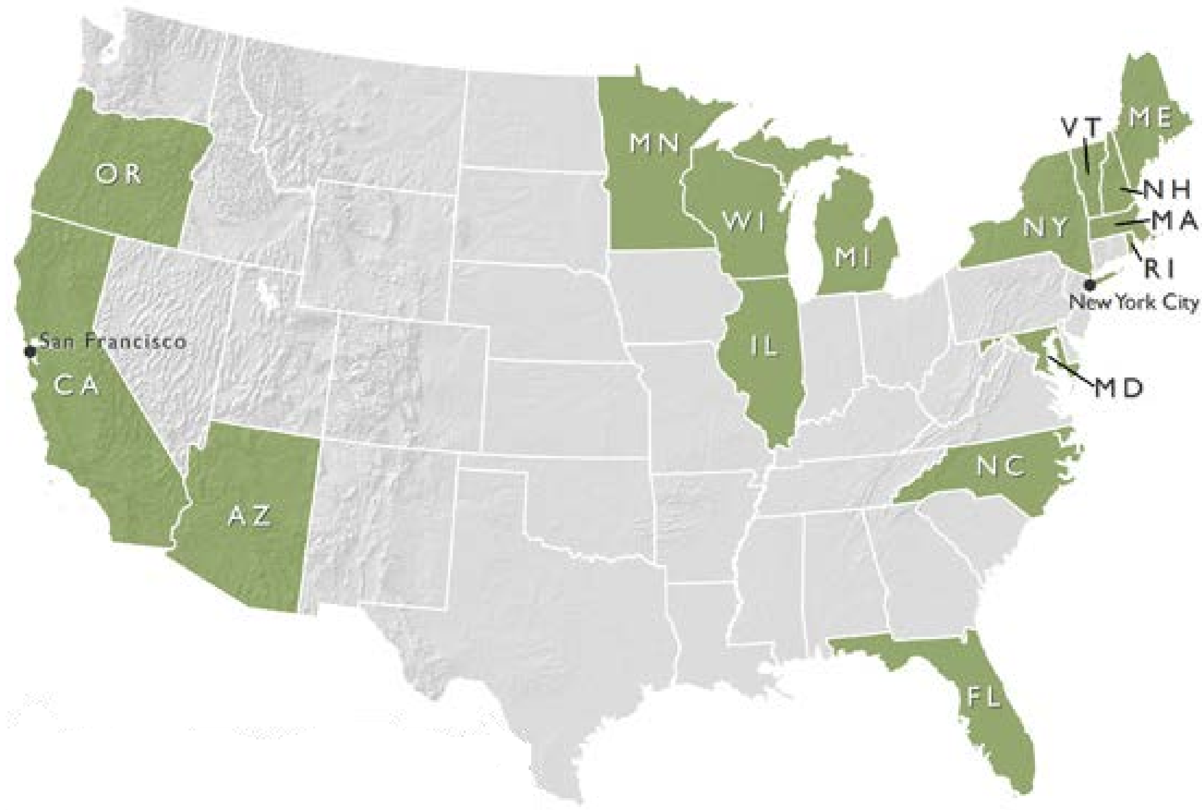
Environmental Exposures	Climate Stressors	Climate Projections (2021 – 2050) with Related Health Impacts
Heat-related Morbidity and Mortality		
- Elevated Temperatures	air stagnation	+ Summer humidity, producing more unfavorable conditions during air mass stagnation events ? Cannot project frequency of air mass stagnation events **NC** Large-scale wind patterns in the near term ? Cannot simulate local-scale winds
<u>Conclusion:</u> Air mass stagnation events may increase in frequency if high humidity occurs with high temperature and low winds, leading to increased heat stress-related morbidity and mortality.		
- Elevated Temperatures	extreme heat events	+ A few more (near-term) up to 25 more (long-term) days/ per year over 95^0F ? Consecutive high-heat days over 95^0F
<u>Conclusion:</u> Projected increasing numbers of high heat days by mid-century, which will likely have large impacts on human health, especially if there are consecutive high-heat days over 95^0F.		
Carbon Monoxide (CO) Poisonings and Traumatic Injury/Death		
- Power Outages - Trauma Risk	extreme weather events flooding, snow and ice storms, tornadoes	+ Extremely hot days and extreme precipitation events => increased stress on power grid + Winter precipitation as freezing rain rather than snow => downed power lines +/= extreme precipitation; >2 in. events project an increased frequency by greater degree than 1-2 in. events ? Cannot simulate local-scale winds
<u>Conclusion:</u> 1. Extreme weather events conducive to power outages are projected to increase, especially in winter, leading to increased use of generators and thus increased risk of Carbon monoxide poisoning. Power outages during hot weather increase risk for heat stress and for food and water contamination. 2. Freezing rain increases risk for ice and thus for traumatic injury, as does flooding.		
- Flood Clean-up	extreme precipitation events	+/= extreme precipitation; >2 in. events project an increased frequency by greater degree than 1-2 in. events ? Cannot project timing of these events
<u>Conclusion:</u> 1. Intense precipitation events are projected to stay the same or increase, which will increase flood risk in vulnerable areas. 2. Clean up utilizing power washers may increase risk of carbon monoxide poisoning.		

Environmental Exposures	Climate Stressors	Climate Projections (2021 – 2050) with Related Health Impacts
- Cold Spells	extreme cold days	- Days below freezing. ? Extreme cold events
Conclusion: Projected warming generally reduces the need for indoor heating and associated risk of CO poisoning will likely decrease.		
Water-borne Toxins and Disease		
- Algal Blooms	warm temperatures, extreme precipitation	+ Average temperatures across all seasons; greatest summer time increase for southern Michigan +/= extreme precipitation; >2 in. events project an increased frequency by greater degree than 1-2 in. events ? Cannot project timing of these events
Conclusion: In general, climate conditions will be the same or more conducive to the development of algal blooms in the future. Southern regions are most vulnerable to runoff due to intense precipitation.		
- Flooding - Sewage/Contaminants	warm temperatures, extreme precipitation	+ Average temperatures across all seasons; greatest summer time increase for southern Michigan +/= extreme precipitation; >2 in. events project an increased frequency by greater degree than 1-2 in. events ? Cannot project timing of these events
Conclusion: 1. In general, climate conditions leading to flooding will be the same or more intense in the future, with southern regions most likely to see increases. 2. Areas vulnerable to sewage/septic failures and runoff have an increased risk for water-borne diseases.		
- New Pathogens - Ecosystem Changes	warm temperatures, high humidity	+ Average temperatures across all seasons; greatest summer time increase for southern Michigan, and greatest winter time increase in northern Michigan + Summer humidity
Conclusion: Projected increases in temperature and humidity may be favorable to the emergence of new pathogens in the state.		

Environmental Exposures	Climate Stressors	Climate Projections (2021 – 2050) with Related Health Impacts
Vector-Borne Diseases		
- Mosquito vector (West Nile Virus)	warm winters, early springs, followed by hot dry summer	+ Average temperatures across all seasons; greatest summertime increase for southern Michigan; and greatest winter time increase in northern Michigan + Days above freezing, with day of last spring freeze up to a week earlier by 2050 ? Summer-time precipitation; some models predict large increases and others large decreases.
Conclusion: In general the projections point to warmer winters, earlier springs, and warmer summers, climate conditions suitable for West Nile Virus and its mosquito vector.		
- Tick vector (Lyme Disease)	warm and snowy winter followed by warm, rainy, humid spring followed by warm humid fall	+ Average temperatures across all seasons; greatest summer time increase for southern Michigan, and greatest winter time increase in northern Michigan + Winter precipitation as rain/freezing rain rather than snow except for lake-effect snow, which should increase **NC** Spring and fall humidity levels.
Conclusion: Cannot project the complex sequence of climate conditions suitable for Lyme disease and its tick vector.		

VI. Partnerships and Collaborations

CDC Climate-Ready States & Cities Initiative Grantees



"There is a growing recognition that the magnitude of health 'co-benefits,' like reducing both pollution and cardiovascular disease, could be significant, both from a public health and an economic standpoint (pg. 94)."

Introduction

The Human Health chapter of the National Climate Assessment noted, "There is a growing recognition that the magnitude of health 'co-benefits,' like reducing both pollution and cardiovascular disease, could be significant, both from a public health and an economic standpoint" (Luber et al., 2014). Moreover, while the BRACE framework requires the assessment of climate impacts on health and the public health system, the interventions to adapt to those climate impacts often reside in other sectors such as economic development, community planning, public works, and energy. Since 2010, MICHAP, through the previous Strategic Planning and Implementation grants, has established a strong network of multidisciplinary stakeholders and collaborators to comprehensively address the health impacts associated with climate change and identify the "co-benefits" of various interventions in order to fully value costs and benefits. These partnerships and collaborations are described below.

Description of Partnerships and Collaborations

MICHAP Advisory Committee

Formed in 2010 as an offshoot of the strategic planning group, these 12 experts drawn from partnerships in academia and public health practice provide feedback and consultation to MICHAP on work plans and products.

Michigan Department of Environmental Quality (DEQ)

In 2010, DEQ facilitated and participated in development of the Michigan Climate Action Plan and the MICHAP strategic plan, key roles in the formation of the Michigan Climate Coalition. They will continue to provide data and resources relevant to climate adaptation, including air and water quality data. In addition, MICHAP will look to build interagency climate planning capacity by meeting with climate related work groups.

Michigan Climate Coalition (MCC)

Created from the Michigan Climate Action Planning process, MCC is a collective open to all with an interest in climate science, energy efficiency, sustainability and related disciplines from the public and private sectors, including non-governmental organizations (NGOs), businesses, government, and educational institutions. Provides MICHAP a platform to distribute climate and health information and learn of climate related initiatives from other potential collaborators.

National Weather Service Regional Office (NWS)

Since 2010, the regional NWS has been a key partner who provided information for the Heat Response Plan and co-presented with MICHAP staff at Michigan's Homeland Security Conference and UM grand rounds. They will continue to provide expert advice, technical assistance, data, and communications channels to ensure the public is made aware of extreme heat and other climate related public health threats.

Michigan Association of Planners (MAP)

Beginning in 2010, MAP participated in the MICHAP strategic planning process, and worked to bolster outreach and education through their membership regarding the public health impacts of climate change. As the deliverables of the BRACE framework are completed, MAP will continue to provide a platform for presenting those results to community planners while also providing valuable feedback and opportunities to best relate those tools and data to partners and planning processes outside of traditional public health.

Great Lakes Integrated Sciences and Assessments Program (GLISA)

An integral partner since the development of the first strategic plan in 2010, GLISA staff has worked with MICHAP to provide expert advice and technical assistance using climate data and to identify tools and climate models that are needed by Local Health Departments (LHDs) in order to plan for extreme weather events and other climate-related health outcomes. Specifically, they provided historic and projected climate data for each of Michigan's climate regions and are co-authors of this Climate and Health Profile Report. They will continue to be a technical and communications resource throughout the BRACE Grant for Michigan as well as the entire Midwest BRACE collaborative.

University of Michigan (U of M)

Through the previous Implementation Grant, MICHAP funded 4 summer internships for students in the U of M Masters of Public Health program. The students assisted with informing heat and health research, analysis of climate change indicators, the scoping and assessment phases of an HIA, writing reports and developing educational materials. Moving forward in the BRACE grant, students and staff will continue to be engaged in various aspects of the project from providing data and information sources to guiding MICHAP staff in best practices related to climate and health adaptation strategies and communication tools.

Michigan State University (MSU)

Previously, MSU faculty worked with MICHAP to develop an interactive model predicting deaths and hospitalizations during heat waves in Michigan cities. The model was presented to local health officials, and stakeholder feedback was incorporated into the model development. Moving forward with the BRACE framework staff and students will be sought in regards to producing climate and health communications along with how to best engage and train planning and local public health officials in adopting the BRACE process.

Local Health Departments (LHDs)

The ultimate goal for MICHAP is to engage LHDs in the BRACE process and partner with them to best utilize the data, tools, and materials as a means of intervention against the climate related health impacts identified in the CHPR, Vulnerability Assessment, and Disease Burden Projections. Through the previous Implementation Grant, health impact assessment (HIA) training was conducted that resulted in the funding of two HIAs and served as a catalyst for the inclusion of environmental health factors in many projects and plans. MICHAP will seek to follow a similar strategy for training and engagement of LHDs in the BRACE framework.

Michigan Public Health Association (MPHA)

A long standing partner, MPHA was an original participant in the strategic planning process and works with MICHAP on outreach and education to their membership regarding the public health impacts of climate change. MICHAP has presented every year at MPHA's annual public health conference and will continue to do so as the BRACE steps are completed and vital data and tools are made available.

Office of Public Health Preparedness (OPHP)

A key partner in the development and implementation of the BRACE framework at the state and local levels, OPHP is the emergency preparedness and response arm of the Michigan Department of Health and Human Services. MICHAP will look to leverage their expertise and role as the entity responsible for the protection of the health of Michigan citizens before, during and after an emergency through the integration of public health and medical preparedness initiatives. Previously, MICHAP developed the 'natural disasters' emergency response plan annex in collaboration with OPHP to address the public health emergency response to severe weather events, including extreme heat, floods, and other weather-related events. OPHP will continue to serve as a point of contact to interact and educate LHD Emergency Preparedness Coordinators. MICHAP will also seek to partner with OPHP to develop toolkits that aid in the preparation and response to climate related emergencies.

Land Information Access Association (LIAA)

MICHAP partnered with LIAA to develop a grant proposal to the American Public Health Association (APHA) and the Kresge Foundation to create a comprehensive master planning approach in multi-jurisdictional communities to reduce vulnerability and increase resilience. Through that LIAA was awarded 3 year funding from the Kresge Foundation to increase the resilience of Michigan communities. MICHAP staff is providing public health expertise, data and technical assistance to the community action teams, LHDs, and ultimately each community's master plan.

Detroit Climate Action Collaborative (DCAC)

The Detroiters for Environmental Justice (DEJ) established the DCAC to develop the City of Detroit's first climate action plan (CAP). MICHAP's Project Manager was a past chair of the Public Health Workgroup and continues to be a member of the steering team. Workgroup members are currently drafting the public health section for the CAP and are partnering to conduct a public health sector based meeting during the spring of 2015. A key component of the sector based process is to obtain important input from Detroit leaders across sectors including municipal, environmental, private business, and residential. In addition MICHAP is leading the development of a climate and health surveillance system through existing state and local public health processes and infrastructure.

Michigan Municipal League (MML)

In 2011 MICHAP Principal Investigator Lorraine Cameron joined MML's Michigan Green Communities (MGC) Challenge Steering Committee. The MGC serves as a guide for communities to measure their progress toward sustainability, encourages friendly and productive competition between Michigan communities, provides a framework for peer-to-peer benchmarking, and recognizes communities for their sustainability accomplishments. MICHAP will work with MGC to incorporate metrics developed as part of BRACE into the challenge while also providing expertise in ways that communities can achieve public health benefits through the goals and metrics they are already working towards.

West Michigan Environmental Action Council (WMEAC)

MICHAP will support WMEAC in their efforts to develop and implement a collaborative planning process for communities in the West Michigan region, particularly in the Lake Michigan Coastal area, by providing important climate change and health impact data, utilizing MICHAP's past experience in working with diverse groups of decision makers, planners, and local health officials to plan comprehensively for climate change.

Michigan Association of Local Environmental Health Administrators (MALEHA)

In partnering with this organization, whose goal is to promote and strengthen all facets of environmental health delivery systems, MICHAP will focus on understanding what the most effective and efficient methods are for developing trainings, policies and procedures that incorporate the BRACE framework into traditional local public health planning processes.

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