

# Climate Change in the Midwest

## Projections of Future Temperature and Precipitation

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## Executive Summary

Climate conditions typical of the Midwest are already changing in noticeable ways. Average temperatures have risen, particularly in winter. There have been a number of major heat waves in recent years, accompanied by a scarcity of cold waves. Ice on lakes and rivers in the region has been forming later in fall, and melting earlier in spring. The date of the last spring frost has been progressively advancing earlier and earlier in the year, lengthening the growing season by about a week over the last century. The frequency of heavy rainfall events has approximately doubled over that same time, increasing the risk of flooding for states with major rivers including Illinois, Iowa, and Missouri.

Recent changes in Midwest climate are consistent with those expected due to increases in atmospheric greenhouse gas concentrations. Both global temperatures and temperatures over the Midwest are expected to warm further over coming decades, as anthropogenic emissions of greenhouse gases continue. However, the extent of future warming and the impacts that will result from that warming depend strongly on the magnitude of future emissions. For that reason, in estimating potential future impacts from climate change, this analysis focuses on two alternative futures.

In the IPCC Special Report on Emission Scenario's A1fi "higher" emission scenario, the world continues to depend on fossil fuels as the primary energy source, and atmospheric carbon dioxide levels rise from their present-day levels of 385 parts per million (ppm) to almost 1000 ppm by the end of the century. Under the B1 "lower" emission scenario, a focus on sustainability and conservation results in atmospheric carbon dioxide levels of about 550 ppm by the end of the century. It is important to note, however, that the lower scenario does not represent a lower boundary on possible futures. It is very probable that timely and aggressive action to reduce emissions over the next few decades, such as that laid out in the Chicago Climate Action Plan, could limit climate change to below that projected under the "lower" emissions scenario examined here.

Given a specific scenario, determining the climate change that would result is still uncertain due to limitations in scientific understanding of the climate system and how it will respond to increasing emissions from human activities. In this report, we address scientific uncertainty by using simulations from three different atmosphere-ocean general circulation models (AOGCMs). The AOGCMs used here cover the accepted range of how the climate system is likely to respond. These three models were selected based on several criteria, including their ability to represent the past climate, particularly over the United States and the Midwest, and the availability of simulations for the higher and lower emission scenarios used here.

Beginning with temperature, this analysis shows that the Midwest is likely to experience substantial increases in annual and seasonal temperatures and extreme heat events, particularly under the higher emissions scenario. Specifically:

- Seasonal and annual temperatures are extremely likely to increase over the coming century. Over the next few decades, changes on the order of 2.4-2.8°F are likely, depending on the state. By the end of the century, under lower emissions, temperature could increase by 5°F; under higher emissions, by up to 10°F.
- Greater temperature increases are projected for northern Midwest states in winter (likely related to feedbacks between reduced snow cover and rising temperatures). For southern Midwest states, greater temperature increases are projected for summer (possibly related to feedbacks between temperature and soil moisture).
- The number of hot days (over 90°F) and extremely hot days (over 100°F) is very likely to increase. Looking at 9 urban centers in the Midwest (Chicago, Cincinnati, Cleveland, Detroit, Des Moines, Indianapolis, Milwaukee, Minneapolis-St. Paul, and St. Louis), the average number of days per year over 90°F are projected to increase 2-3 times by end-of-century under lower emissions, and 4-7 times under higher. Proportionally, an even larger increase is projected in days over 100°F, with 4-8 times more days by end-of-century under lower emissions, and 15-30 more days under higher.
- For all 9 urban centers, there is a greater than 50% chance of experiencing at least one heat wave with similar characteristics to the Chicago 1995 event (to which almost 700 deaths are attributed) before 2040. By the end of the century projected frequency ranges from one such event per decade (for Milwaukee, under lower emissions) up to six such heat waves each year (for St. Louis, under higher emissions).
- The difference between “apparent temperature” (how hot it actually feels due to both humidity and temperature) and actual air temperature is likely to increase as the climate warms. In other words, hot days could feel even hotter due to increased humidity, creating more severe heat stress conditions in the future than suggested by projected increases in air temperature alone. Currently, locations in the Midwest experience between 6 and 18 days with heat index values greater than 95°F each year. By the end of the century, Great Lake states can expect 1.5 to 3 weeks’ worth of such days under lower emissions and up to 6 weeks’ worth of days under higher emissions. More southern Midwest states can expect 4 to 6 weeks’ worth under lower emissions and over 12 weeks’ worth each year under higher emissions.

The projected increases in extreme temperatures over the coming century, with more frequent summer heat waves, could have a number of adverse impacts on human health and welfare. Extreme temperatures and resulting decreases in air quality can lead to increases in both morbidity (illnesses) as well as mortality (deaths), although warmer winters would also reduce cold-related mortality. In particular:

- An “analog city” analysis, which transposes the weather conditions from the European Heat Wave of 2003 (responsible for 70,000 deaths across Europe), estimates that if a similar heat wave were to occur over Chicago, Indianapolis, or Minneapolis, given those cities’ present-day infrastructure, demographics, and emergency preparedness, more than ten times the annual average number of heat-related deaths in Chicago and Indianapolis and 5 times the annual average number of heat-related deaths in Minneapolis would occur in just a few weeks.

- Climate projections indicate that an EHW-type event is likely before 2040, and by the end of the century one such event could be occurring as frequently as once a decade, under lower emissions, and once every other year, under higher emissions.
- The number of days with temperatures below freezing (32°F) are projected to decrease significantly; by 3 to 5 weeks under lower emissions and 6 to 8 weeks under higher emissions by the end of the century.

As climate changes, precipitation patterns over the Midwest are also expected to change. These changes range from shifts in seasonal distributions to changing proportions of rain vs. snow. In particular:

- Although relatively little change in annual average precipitation is expected, relatively large seasonal shifts are likely.
- Winter and spring precipitation is likely to increase, by about 20% by the end of the century under lower emissions and 30% under higher.
- Little change in summer and fall precipitation is expected under lower emissions, but summer decreases and fall increases on the order of 10% are expected by the end of the century under higher emissions.
- The frequency of heavy precipitation events—measured in terms of number of days per year with more than 2 inches of rain, and annual maximum 24-hr, 5-day and 7-day rainfall totals—is likely to continue to increase, with slightly greater increases for regions closer to the Great Lakes.
- More precipitation will fall as rain and less as snow, particularly in southern Midwest states and towards the end of the century, when reductions of 30 to 50% in annual snow days are expected under lower emissions, and 45 to 60% under higher. By the end of the century, all states can expect no more than an average of 20 snow days per year under lower emissions; for Illinois, Indiana, and Missouri, less than 10 snow days per year on average.

Although some future changes are unavoidable, because of past emissions, the greatest of the projected changes do not have to happen if prompt action is taken to significantly reduce emissions. Decisions made by individuals, cities, states, and nations will determine whether we follow a higher or lower emissions pathway into the future. Through reducing our energy use and preparing for future change, we can help protect our communities, economy, and ecosystems.

## CHAPTER 1

# MIDWEST CLIMATE

Midwest climate conditions are largely determined by the region's location, in the center of the North American continent. They are also affected by its relatively flat topography, carved out by the glaciers that covered the region for thousands of years during the last Ice Age.

Far from the moderating effects of the oceans, Midwest weather conditions can vary widely over the course of a year. Sudden changes of weather, large daily temperature ranges, and unpredictable precipitation patterns are all staples of regional weather.

The Midwest typically experiences four distinct seasons, although those seasons can be highly variable and year-to-year variations can be large. In the winter, the absence of significant mountain barriers to the north allows bitterly cold air masses from the Arctic to move southward into the region. The polar jet stream is often located near or over the region during the winter, with frequent storm systems bringing cloudy skies, windy conditions, and precipitation. In contrast, Midwest summers are characteristically hot and humid due to a semi-permanent high pressure system in the subtropical Atlantic that draws warm, humid ocean air into the area. Summer also tends to be the rainiest season, with short-lived rainfall and thunderstorms.

### Climate Change in the Midwest

"Climate" refers to the average conditions in a given location over time scales of decades to centuries. Year-to-year weather patterns average out to give a picture of what a typical or "climatological" year might look like. Over longer time scales, however – on the order of centuries to millennia – climate or "average" conditions in the Midwest have been very different than today.

Eighteen thousand years ago, for example, when temperatures were an estimated 10 to 15°F cooler than they are today (Petit et al., 1999), the region was covered by a mile-thick ice sheet. By 10,000 years ago, the climate had warmed and the glaciers retreated, depositing layers of soil and rock debris that characterize the southern part of the region, and scouring out the many lakes and rocky shores typical of the more northern states.

In the past, most large-scale climate variations in the Chicago area and around the world have been driven by natural causes. These causes include gradual, long-term shifts in the amount of energy the Earth receives from the Sun, amplified by natural feedbacks within the earth-ocean-atmosphere system. Climate changes have also been caused by sudden, short-term changes caused by events such as volcanic eruptions or meteorite collisions.

Today, however, the story is very different.

Since the Industrial Revolution, atmospheric concentrations of greenhouse gases such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) have been rising because of increasing emissions from human activities. The primary source of CO<sub>2</sub> is the burning of fossil fuels such as coal, oil, and natural gas. CO<sub>2</sub> is also produced by land use changes, including tropical deforestation. Agricultural activity and waste treatment are important sources of CH<sub>4</sub> and N<sub>2</sub>O

emissions. Atmospheric particles released during fossil fuel combustion, such as soot and sulfates, also affect climate.

Atmospheric levels of carbon dioxide are now higher than they have been at any time in at least the last 800,000 years (Lüthi et al., 2008). Average surface temperatures in the Northern Hemisphere have risen by 1.3°F over the past 150 years (IPCC, 2007). Based on these and many other lines of evidence, the Intergovernmental Panel on Climate Change, which represents the work of thousands of climate scientists around the world, has concluded that it is very likely that most of the climate changes observed over the last fifty years have been caused by emissions of heat-trapping or greenhouse gases from human activities (IPCC, 2007).

### **Indicators of Recent Change**

Although definitive attribution of regional-scale climate change to human causes is still difficult due to the relatively large year-to-year variability in local climate, changes that are at least consistent with global, human-induced warming are already under way across the Midwest. Since 1970, the region has been warming at a rate of more than 0.4°F per decade. Winter temperatures have risen even faster, at a rate of 0.9°F per decade from 1970 to 2000 (Kling et al., 2003). This warming has been correlated with many noticeable changes (as summarized by Kling et al., 2003; Hayhoe et al., 2009), including:

- Increases of 2.6°F in annual average temperatures since 1980, with the greatest increases of almost 4°F occurring in winter
- A scarcity of cold waves during the 1990s, accompanied by several major heat waves, particularly those in 1995, 1999, and 2006
- A progressive advance in the date of last spring freeze, with current dates approximately 1 week earlier than the beginning of the 1900's.
- A lengthening of the growing season, by about one week during the twentieth century
- An increase in rain days and a doubling in the frequency of heavy rainfall events since the early 1900s, increasing the risk of flooding in Iowa, Missouri and Illinois
- Shifts in the hydrological cycle, with decreasing spring snow cover leading to earlier dates for spring melt, peak streamflow, and high lake levels.
- Later formation of ice on the Great Lakes and inland lakes, and a shorter overall duration of winter lake ice, with some years being nearly entirely ice-free
- An increase in Great Lakes near-shore water temperatures of almost 0.2°F per decade since 1920 (measured at Sault Ste. Marie and Put-In-Bay), accompanied by an increase of more than 2 weeks in the duration of summer stratification.

The recent warmth is comparable in magnitude to the warm periods the Midwest experienced during the 1930s and 1950s. However, the warm periods in the past were much more regional in scale and did not display the same large-scale "fingerprint" of recent warming. In contrast, recent patterns of change are very similar to those seen elsewhere around the globe, strongly suggesting a connection to human-driven climate change.

### **Climate Change Over the Coming Century**

The climate of the Midwest - and the rest of the planet - is expected to continue to warm over the coming century in response to increasing emissions of heat-trapping gases from human activities. At the global scale, temperature increases anywhere from 2°F up to 13°F are expected

(IPCC, 2007). This range is a function of the uncertainty in predicting future greenhouse gas emissions and, to a lesser but still important degree, the uncertainty in predicting the response of the Earth's climate system to human-induced change.

As human-induced climate change continues, even more dramatic changes are projected—changes that have the potential to dramatically alter many aspects of the region's climate that are vital to its economy, ecosystems, character, and quality of life. As illustrated in the sections that follow, however, the extent of this warming and the magnitude of many of the resulting impacts will be determined by choices that determine future emissions of greenhouse gases at both the regional and the global scale.

The research results presented here describe the changes that might be expected in the Midwest over the coming century based on two different emissions scenarios and simulations by three global climate models. As described in Section 2, model simulations have been downscaled to the Midwest using two different state-of-the-art statistical methods. Section 3 shows how temperature, precipitation, and related indices are likely to be affected by climate change in the near future (2010-2039), by mid-century (2040-2069) and towards the end of the century (2070-2099). Section 4 concludes with a brief summary of the impacts of global climate change on Midwest climate this century.

## SECTION 2

# CLIMATE PROJECTIONS: DATA AND METHODS

To examine future changes in climate, we rely on climate model simulations driven by future assumptions about population, energy use, and technology. These are known as emission scenarios, as they quantify emissions of greenhouse gases and other radiatively-active species that would occur under those assumptions. Emission scenarios are then used as input to multiple global climate model simulations in order to calculate the changes in temperature, precipitation, and other aspects of climate likely to result from that set of assumptions. As the spatial resolution of these global climate models is too coarse to provide valuable information on climate change on scales smaller than a few hundred kilometers, advanced statistical downscaling methods are applied to relate projected large-scale changes in climate to local conditions on the ground. Each of these datasets and methods are described in more detail below.

### Historical Simulations

Historical simulations correspond to the Coupled Model Intercomparison Project's "20th Century Climate in Coupled Models" or 20C3M scenarios (Covey et al., 2003). These represent each modeling group's best efforts to simulate observed climate over the past century, including changes in solar radiation, volcanic eruptions, human emissions of greenhouse gases and other radiatively-active species, and secondary changes in tropospheric ozone and water vapor.

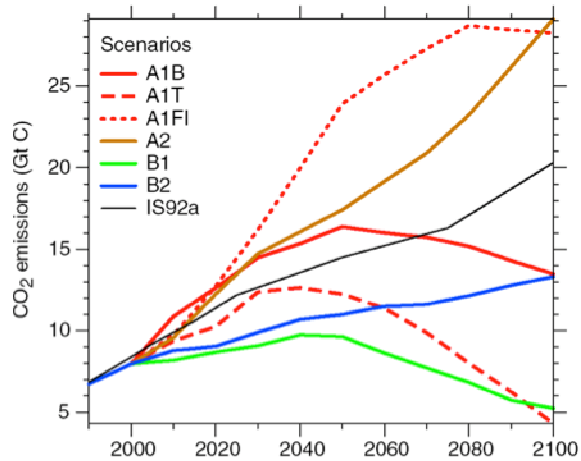
Although the 20C3M simulations are all intended to represent the same historical total-forcing scenarios (including both natural variability as well as the effect of human emissions on climate), simulations by individual modeling groups do not necessarily have identical boundary conditions. Therefore, some differences between model simulations themselves as well as between simulations and observations identified here may also be a result of differing input conditions.

### Future Emission Scenarios

Before estimating potential changes in climate during the rest of the century, answers to questions such as these are needed:

- How will human societies and economies develop over the coming decades?
- What technological advances are expected and how will they affect emissions?
- Which energy sources will be used in the future to generate electricity, power transportation, and serve industry?





**Figure 1.** Projected future carbon emissions for the SRES emission scenarios. Emissions for the higher scenario (A1fi) corresponds to the red dotted line, while emissions for the lower (B1) scenario are indicated by the solid green line.

The answers to these questions will affect future emissions of greenhouse gases from human activities. And these emissions will in turn determine future climate change at both the global level and in the Midwest.

To address these questions, the Intergovernmental Panel on Climate Change (IPCC) has developed a set of future emissions scenarios known as SRES (Special Report on Emissions Scenarios, Nakicenovic et al., 2000). These scenarios use a wide range of projections for future population, demographics, technology, and energy use to estimate the greenhouse gas emissions that would result from a variety of possible futures. In doing so, they cover a wide range of plausible futures that illustrate differences in the extent and severity of the global warming that result from alternative emissions

choices (Figure 1).

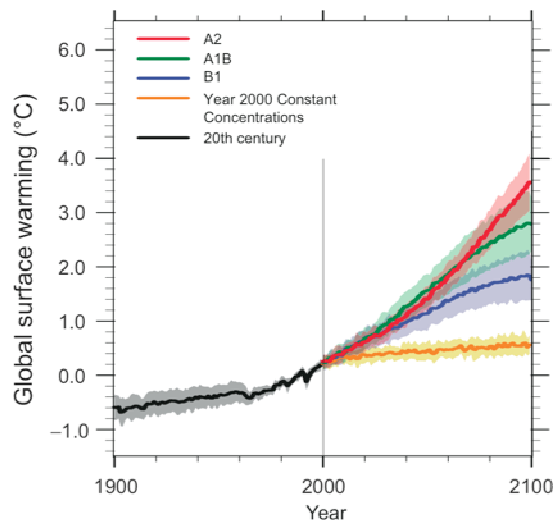
As diverse as they are, the SRES scenarios still do not cover the entire range of possible futures. At the high end, CO<sub>2</sub> emissions today are already on a pathway set to end up higher than any of these scenarios (Raupach et al., 2007). On the low end, reductions in emissions—on the order of 80% by 2050, as proposed by a number of studies—could reduce CO<sub>2</sub> levels below the lowest SRES emission scenario. Nonetheless, the substantial difference between the SRES higher- and lower-emissions scenarios used here is sufficient to illustrate the potential range of changes that could be expected, and how these depend on future emissions.

This assessment compares projected climate changes under the SRES A1fi (fossil-intensive) and the B1 scenarios. The higher-emissions scenario (A1fi) represents a world with fossil fuel-intensive economic growth and a global population that peaks mid-century and then declines. New and more efficient technologies are introduced toward the end of the century. In this scenario, atmospheric carbon dioxide concentrations reach 940 parts per million (ppm) by 2100—more than triple pre-industrial levels.

The lower-emissions scenario (B1) also represents a world with high economic growth and a global population that peaks mid-century and then declines. However, this scenario includes a shift to less fossil fuel-intensive industries and the introduction of clean and resource-efficient technologies. Emissions of greenhouse gases peak around mid-century and then decline. Atmospheric carbon dioxide concentrations reach 550 ppm by 2100—about double pre-industrial levels.

## Global Climate Models

Emissions scenarios are used as input to global climate models, also known as atmosphere-ocean general circulation models (AOGCMs). These are large, three-dimensional coupled models that incorporate the latest understanding of the physical processes at work in the atmosphere, oceans, and Earth's surface. As output, AOGCMs produce geographic grid-based projections of precipitation, temperature, pressure, cloud cover, humidity, and a host of other climate variables at daily, monthly, and annual scales.



**Figure 2.** Projected future global temperature change for the SRES emission scenarios (degreesC). The range for each individual emission scenario indicates model uncertainty in simulating the response of the Earth system to human emissions of greenhouse gases.

Because of the complexity of these models, they are generally designed and run by large research teams at supercomputing centers. Models are constantly being enhanced as scientific understanding of climate improves and as computational power increases. Over time, the number of global climate models has grown. By 2008, 16 international climate modeling teams had submitted historical and future simulations from 25 different climate models to the Intergovernmental Panel on Climate Change's Fourth Assessment Report.

Some models are more successful than others at reproducing observed climate and trends over the past century. However, all future simulations agreed that both global and regional temperatures will increase over the coming century in response to increasing emissions of greenhouse gases from human activities (Figure 2).

In this study, we rely on simulations from three of these global climate models (see Table 1 below): the U.S. National Atmospheric and Oceanic Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 (Delworth et al., 2006), the United Kingdom Meteorological Office's Hadley Centre Climate Model, version 3 (HadCM3, Pope et al., 2000), and the National Center for Atmospheric Research's Parallel Climate Model (PCM, Washington et al., 2000). These models were chosen based on several criteria, as follows.

First, only well-established models were considered, those already extensively described and evaluated in the peer-reviewed scientific literature. The models must have participated the Coupled Model Intercomparison Project or otherwise been evaluated and shown to adequately reproduce key features of the atmosphere and ocean system. Key features include seasonal circulation patterns, atmosphere-ocean heat fluxes, El Niño, and other teleconnection patterns affecting climate in the region (Covey et al., 2003; AchutaRao & Sperber, 2006; Chapman & Walsh, 2007; Stoner et al., 2009; Vrac et al., 2006).

Second, the models chosen must encompass the greater part of the range of uncertainty in climate sensitivity. Climate sensitivity is defined as the equilibrium temperature change that would result from a doubling of atmospheric carbon dioxide concentrations relative to pre-industrial times. Climate sensitivity determines the extent to which temperatures will rise under a given increase in atmospheric concentrations of greenhouse gases.

Because many of the processes at work in the earth-atmosphere system are not yet fully understood, these are represented somewhat differently in different AOGCMs. For this reason, GFDL and HadCM3 have medium to medium-high climate sensitivities, while PCM has a relatively low climate sensitivity (Tebaldi et al., 2006). Together, these three models span more than two-thirds of the IPCC's range of estimated climate sensitivity (IPCC, 2007). The ranges in projected temperature change and other climate variables presented in this report arise from the different climate sensitivity of these models.

Lastly, simulations of temperature, precipitation, and other key variables must be available at daily resolution for both the SRES A1fi and B1 emission scenarios. While all AOGCMs have produced

simulations for the mid-high A2 and lower B1 emissions scenarios, few have done so for A1fi. Emissions in 2007, however, were already above the highest of the SRES projections for that year. If present-day growth rates continue, emission will far exceed even the A1fi emissions scenario by the end of the century. For this reason it is essential to use the highest emission scenario available in order to avoid massively under-estimating the implications of a “business as usual” scenario for future climate. Furthermore, many AOGCMs fail to archive the daily outputs of key variables required for climate analysis and downscaling to the regional scale.

The AOGCMs selected for this analysis are three of the four for which daily output from A1fi and B1 simulations are available. The fourth A1fi simulation, by the NCAR CCSM3 model, was completed too late for inclusion in this analysis but will be incorporated into future work.

Model	Host Institution	Horizontal Spatial Resolution	Reference
GFDL CM2.1	National Ocean and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory (USA)	1.8 degrees	Delworth et al., 2006
HadCM3	U.K. Meteorological Office, Hadley Centre (U.K.)	2.5 x 3.75 degrees	Pope et al., 2000
PCM	National Center for Atmospheric Research (USA)	2.8 degrees	Washington et al., 2000

**Table 1.** Description of the three global climate models used in this analysis.

### Statistical Downscaling of Global Model Simulations

The geographic grid cells that form the basis of AOGCMs typically range in size from 100 to 500 miles per side. In general, this type of resolution is too coarse to capture the fine-scale changes experienced at the regional scale. For this reason, two robust, well-documented statistical downscaling techniques are used here to transform global climate model output into higher-resolution projections capable of resolving the impacts of climate change on local conditions.

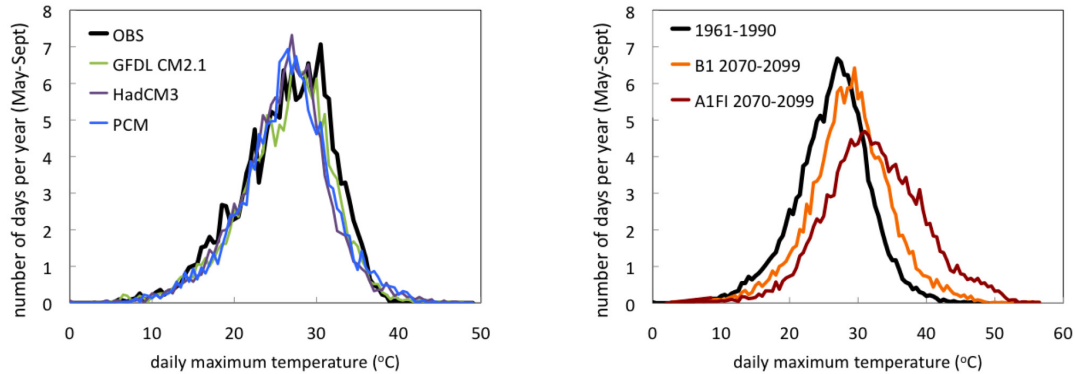
Statistical downscaling relies on historical instrumental data for calibration at the local scale. A statistical relationship is first established between AOGCM output for a past “training period,” and observed climate variables of interest (here, daily maximum and minimum temperature and precipitation). This relationship is averaged over at least two decades, to remove year-to-year fluctuations. The historical relationship between AOGCM output and monthly or daily climate variables at the regional scale is then tested using a second historical “evaluation period” to ensure the relationship is valid. If so, then the relationship is finally used to downscale future AOGCM simulations to that same scale.

Unlike regional climate modeling, statistical downscaling assumes that the relationships between large- and small-scale processes remain fixed over time. This assumption may not always be justified, particularly for precipitation. However, analysis of 37 stations in the state of Illinois suggests that this relationship only breaks down for the most extreme precipitation events above the 99<sup>th</sup> percentile of the distribution (Vrac et al., 2007). Analyses for the Northeast (Hayhoe et al., 2008) further indicate that, in areas of variable topography such as mountains and coastlines, statistical methods trained to match historical spatial patterns may perform better than regional

climate models that are limited by their convection schemes. In addition, statistical downscaling has a substantial time and cost advantage; hundreds of years of model simulations can be downscaled using the same computing resources required to run only a few years of regional-model downscaling.

For these reasons, two statistical methods were used here to downscale AOGCM-based temperature and precipitation fields corresponding to the A1fi and B1 emissions scenarios. In the first method, monthly AOGCM temperature and precipitation fields were statistically downscaled to daily values across the entire Midwest region with a resolution of 1/8 degrees. This downscaling approach uses an empirical statistical technique that maps the probability density functions for modeled monthly and daily precipitation and temperature for the climatological period (1961–1990; Maurer et al., 2002) onto those of gridded historical observed data, so the mean and variability of both monthly and daily observations are reproduced by the climate model outputs. The bias correction and spatial disaggregation technique is one originally developed for adjusting AOGCM output for long-range streamflow forecasting (Wood et al., 2002; Van Rheen et al., 2004), later adapted for use in studies examining the hydrologic impacts of climate change. The method compares favorably to regional climate model simulations (Wood et al., 2004).

The second method uses an asynchronous regression approach to rescale daily AOGCM temperature values by individual quantile. AOGCM-simulated time series are first modified so overall probability distributions of simulated daily values approximate observed probability distributions of air temperatures at weather stations in each city (as shown for the Chicago Midway station in Figure 3(a), after Dettinger et al. 2004). The regression relations derived from the historic observed and model-simulated time series are then applied to future simulations, such that rescaled values share the weather statistics observed at the selected stations (Figure 3(b)).



**Figure 3.**(a) Observed (black) and historical simulated distribution of daily maximum summer temperatures by three AOGCMs for the Chicago Midway station for evaluation period 1980-1999. (b) Observed historical (black) and future projected daily maximum summer temperature under the SRES higher (red) and lower (orange) emission scenarios. Values shown are the average of the three AOGCM simulations.

## SECTION 3

# PROJECTED CHANGES IN MIDWEST CLIMATE

The Midwest is already experiencing changes consistent with human-induced warming at the global scale. Annual average temperatures are rising, accompanied by a reduction in snow and ice cover, a longer growing season, and increased frequency of extreme rainfall events. All of these changes are expected to continue in the future, with the amount of change depending on future greenhouse gas emissions as well as on the sensitivity of the Earth's climate system to human emissions.

### Seasonal and Annual Temperature

Climate change will increase temperatures throughout the region. Temperature changes will be greater under a higher emission scenario as compared to a lower, and by end-of-century as compared to earlier time periods.

Over the near term (2010-2039), annual temperature increases of 2.4 to 2.8°F are expected. The higher end of this range represents the relatively greater increases for the more southerly states of Illinois, Indiana, Iowa and Missouri, and the lower end represents slightly smaller increases projected for the more northerly states of Minnesota and Wisconsin. There is no significant difference between higher vs. lower emissions over this time period.

By the middle of the century, temperatures are projected to rise from 3.8 to 3.9°F under lower emissions and 6.0 to 6.5°F under higher emissions. By the end of the century, temperatures are projected to rise 4.9 to 5.1°F under lower emissions and 9.7 to 10.3°F under higher emissions. Again, temperature increases are larger for southerly states and smaller for northern states.

There are also strong seasonal differences in the projected temperature increases. In particular, much greater increases are expected in summer as compared to winter and spring. By the end of the century, for example, summer temperature increases range from 12.5 to 14°F under higher emissions, while winter temperature increases range from 7.6 to 10.2°F (Table 2) and spring temperature increases are only 7.2 to 8.6°F.

	ANNUAL		WINTER (DJF)		SUMMER (JJA)	
	Lower emissions	Higher emissions	Lower emissions	Higher emissions	Lower emissions	Higher emissions
2010–2039	2.6	2.6	3.1	3.1	3.3	3.3
2040–2069	3.9	6.2	4.0	5.5	4.8	8.6
2070–2099	5.0	10.0	5.3	8.9	5.7	13.3

**Table 2.** Projected increases in annual, winter, and summer temperatures projected for the Midwest. Values shown are the average of three AOGCMs for the SRES higher (A1fi) and lower (B1) emissions scenario.

Temperature increases for spring, summer and fall are strongest for more southern states. The opposite pattern is seen in winter, where temperature increases are greatest for northern states such as Wisconsin and Minnesota. This may be due to the feedbacks between melting snow and

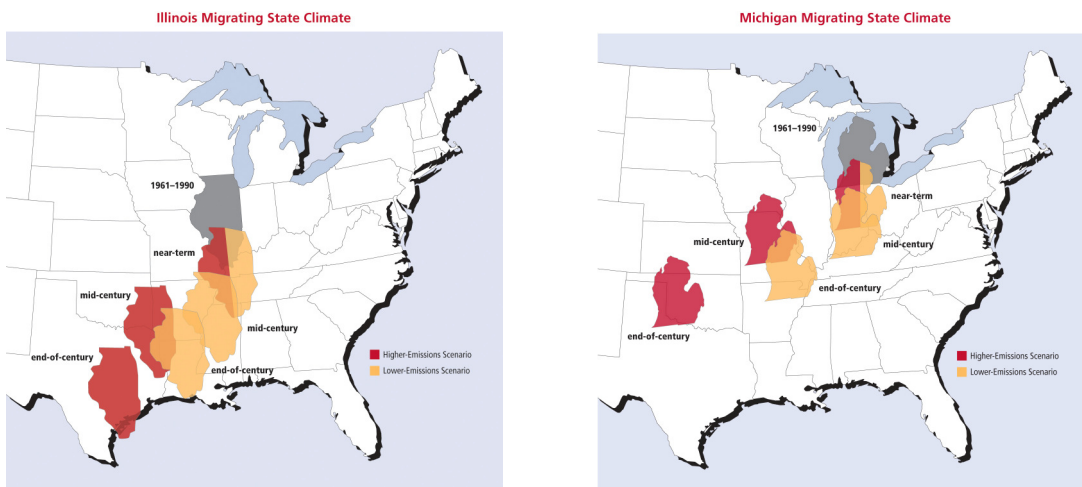
temperature increase. A similar effect has already been observed in the U.S. Northeast, where winter temperatures are rising at twice the rate of the annual average.

### “Migrating” States

A tangible measure of how climate change may affect Midwestern states is provided by a “migrating state” analysis. First used in an assessment of climate change impacts on the Great Lakes (Kling et al., 2003), the migrating state analysis consists of quantifying projected future climate conditions in a given state, then searching for present-day analogues to those conditions in other states today.

Here, average summer temperature and rainfall are used to characterize Midwest summer climate conditions. For the Midwest states of Michigan and Illinois, projected changes in average summer temperature and rainfall are expected to make the states feel as if they are shifting south and westward over time (Figure 4). Within a decade or two, summer in central Illinois is likely to feel more like southern Illinois does today, while Michigan summers may feel more like those of Indiana do today.

Over the rest of the century, both Illinois and Michigan summers are expected to become progressively hotter and drier, particularly under higher emissions. By the end of the century, Illinois summers may feel like East Texas does today under higher emissions, and like Arkansas under lower. Michigan may feel like western Oklahoma does under higher emissions, and like Missouri under lower.



**Figure 4.** Projected changes in summer average temperature and rainfall for Illinois and Michigan (shown here) indicate that summers in these states will feel progressively more like summers currently experienced by states to their southwest under both higher (red) and lower (yellow) future emissions scenarios. Both states are projected to warm considerably, and have less summer rainfall.

Care must be taken when interpreting these results, as local climate is also sensitive to regional topography and other characteristics. Although summer temperature and precipitation may *feel* like that of East Texas or Oklahoma, that does not mean that all other characteristics of those states will automatically transfer. Michigan will still experience the moderating effect of the Great Lakes on its climate, while Illinois will still own the rich soils that make it part of the nation’s bread basket. Ecosystems typical of these regions, while sensitive to climate changes, can take decades to centuries to adjust to climate change. Hence, it is important to acknowledge that this analysis is

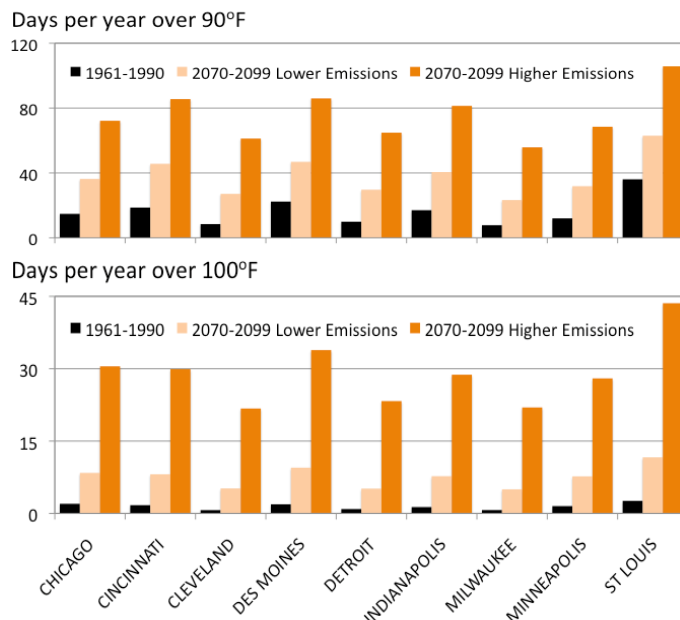
illustrative of climate conditions only, not of other aspects of the physical environment that characterize those states.

### Extreme Heat and Heatwaves

Climate extremes are also projected to change, with both individual hot days and prolonged periods of extreme heat, or heat waves, becoming more frequent and severe. Here, three measures are used to quantify projected increases in extreme heat: (1) average number of days per year with maximum daily temperature over 90°F and 100°F for 9 urban centers (Table 3); (2) frequency of severe heat wave events in those same 9 urban areas, with severe heat waves defined as having meteorological characteristics matching those of the 1995 Chicago heat wave; and (3) average number of days per year with daily maximum heat index over 95°F and 100°F for 8 Midwestern states.

**Urban Heat Days.** Most days with temperatures in the 90s or soaring over 100°F would be considered hot by Midwest residents. Here, thresholds of maximum daily temperatures at or above 90°F and 100°F are used to define “hot days” and “extremely hot days” for 9 urban centers: Chicago, Cincinnati, Cleveland, Detroit, Des Moines, Indianapolis, Milwaukee, Minneapolis-St. Paul, and St. Louis. Currently, these cities experience an average of 7 (Milwaukee) up to 36 (St. Louis) days over 90°F each year, while number of days over 100°F range from one every two years up to an average of two per year (Figure 5).

The frequency of both types of days are projected to increase in the future, with proportionally larger increases under higher as compared to lower emission scenarios, by end-of-century as compared to earlier in the century, and for days over 100°F as compared to days over 90°F. By 2070-2099, the number of days over 100°F is projected to increase by a factor of 4 to 8 times relative to 1961-1990 values under lower emissions, and 15 to 30 times under higher emissions



**Figure 5.** Historical simulated and projected future number of days over 90°F and 100°F for 9 Midwest urban centers under lower and higher emissions for 2070-2099. Value shown are the average of 3 AOGCMs.

(Figure 5a). For days over 90°F, increases of 2 to 3 times 1961-1990 values are expected under lower emissions and 4 to 7 times under higher (Figure 5b).

**Severe Heat Waves.** In July of 1995, the city of Chicago experienced a heat wave unprecedented in its 123-year-old weather records (Livezey & Tinker, 1996). Maximum daily temperatures were equal to or greater than 90°F for seven consecutive days, and greater than 100°F for two days at the peak of the heat wave. Even more importantly, there was no relief at night, as nighttime minimum temperatures were over 80°F during the hottest days. The heat wave is estimated to

have been responsible for at least 700 heat-related deaths (Kaiser et al., 2007).



Using these meteorological criteria, it is possible to calculate the frequency of Chicago 1995-like heat waves for key Midwest urban centers (Table 3). When this is done it is clear that, even for Chicago, such an event is relatively unusual. The probability of having such an event during the historical reference period 1961-1990 range from essentially zero (for Milwaukee and Cleveland) up to 100% (for St. Louis). Within just a few decades however, it is more likely than not that every city except for Milwaukee and Cleveland will experience at least one such event each decade. By mid-century, there may be on average anywhere from 1 to 10 such events under lower emissions and anywhere from 3 to 30 such events each decade under higher emissions, depending on the city—in other words, from one heat wave every three years to three heat wave events per year. By the end of the century, only slightly greater numbers of heat waves are expected as compared to mid-century under lower emissions; under higher emissions, however, projected heat wave event frequencies range from at least one each decade (for Milwaukee) up to 6 such events per year (in St. Louis).

City	1961-1990	2010-2039	2040-2069		2070-2099	
			Lower	Higher	Lower	Higher
CHICAGO	0.11	1.33	2.56	11.78	4.22	27.44
CINCINNATI	0.11	0.61	0.67	7.78	1.44	21.44
CLEVELAND	0.00	0.17	0.11	2.78	0.33	11.11
DES MOINES	0.56	2.22	3.11	15.11	4.33	34.44
DETROIT	0.11	0.83	1.00	7.00	1.44	19.33
INDIANAPOLIS	0.22	0.61	1.00	9.78	2.11	24.56
MILWAUKEE	0.00	0.22	0.67	4.44	0.78	12.67
MINNEAPOLIS	0.11	0.50	0.89	7.33	1.89	19.67
ST LOUIS	1.33	6.44	10.11	29.56	11.11	59.89

**Table 3.** Simulated frequency of Chicago 1995-like heat waves; in units of number of events per decade for the time period indicated. Values shown are the average of 3 AOGCMs for higher and lower emission scenarios.

**Heat Index.** The heat index combines temperature and humidity to calculate how hot it actually feels. Changes in extreme heat can be quantified through examining projected changes in extreme heat days, with heat index values greater than 95°F and 100°F.

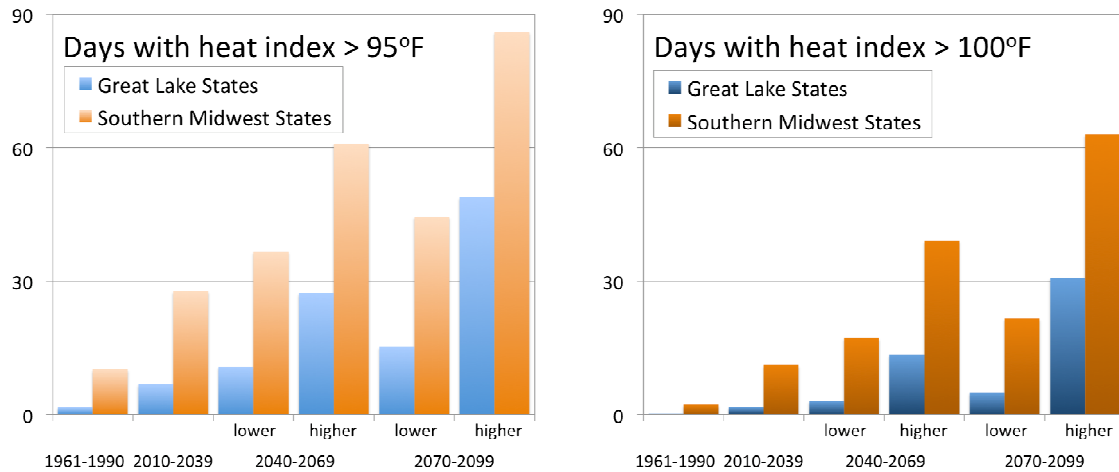
Currently, the southern Midwest states experience between 6 (Indiana and Iowa) and 18 (Missouri) days per year with a heat index over 95°F. Northern states and states that border the Great Lakes such as Michigan and Ohio experience less than 3 days per year (Figure 6a). In the near-term (2010-2039), these numbers are projected to increase by about 3-5 additional days for Great Lake states and 10-24 additional days for the southern Midwest states. By mid-century, under lower emissions the number of days per year is likely to increase by 6 (Michigan) up to 33 (Missouri) additional days as compared to 1961-1990. Under higher emissions, anywhere from 19 (MI) to 59 (MO) additional days per year are expected. These numbers increase further by end of century. Under lower emissions, Great Lakes states can expect from 10-22 more such days per year while southern Midwest states could see 26 to 41 such days. Under higher emissions, a total of 44 (MI) and 85 (MO) days per year with heat index values over 95°F are expected.



Days with a heat index value greater than 100°F are currently very rare. Great Lake states currently experience only one such day every other (Ohio) to every ten (Michigan, Wisconsin) years. The southern Midwest states experience anywhere from one (Indiana, Iowa) to 5 (Missouri) such days each year.

Within the next few decades, every state will begin to experience at least one day per year with a heat index greater than 100°F (Figure 6b). Some states, such as Illinois and Missouri, could see over 10 such days each year. By mid-century northern states will see on average 3 days per over 100°F under lower emissions and 13 under higher. Southern states see an average of more than two weeks' worth of days over 100°F each year under lower emissions and almost 40 days under higher. By the end of the century, under lower emissions northern states could experience about 5 days per year, while southern states have about three weeks of such days each year. Under higher emissions, northern states would see about 30 days over 100°F each year, while southern states would experience more than double, 63 days per year.

Although projected increases in extreme heat under the lower-emissions scenario are less than those projected under the higher-emissions scenario, it is important to recognize that the number of extreme heat days are projected to be much greater than today under either scenario.



**Figure 6.** Projected changes in average number of days per year with heat index values greater than (a) 95°F and (b) 100°F. Relatively smaller changes are projected for Great Lake states (Michigan, Minnesota, Ohio and Wisconsin) while greater changes are expected for southern Midwest states (Illinois, Indiana, Iowa, and Missouri).

## Impacts of a 2003 European Heat Wave Event on Chicago, Indianapolis, & Minneapolis

Extreme heat and oppressive heat events are known to produce elevated rates of both illness and death due to heat stress (Schär et al., 2004). In addition to their direct impacts, sustained extreme heat events exacerbate pre-existing cardiovascular, respiratory, and other conditions (Kalkstein & Valimont, 1987).

A direct effect of rising temperatures is an increase in the frequency and severity of extreme heat and heat wave events. As climate changes, very hot days and heat wave events are projected to become more frequent and severe (Tebaldi et al., 2006). At the same time the risk of severe, prolonged heat wave events, such as occurred over Chicago in 1995 and Europe in 2003, is also increasing (Meehl & Tebaldi, 2004).

Excessive heat is currently the leading cause of weather-related deaths across the U.S. Though some research has suggested an overall decrease in heat vulnerability in recent decades (Davis et al., 2002), there is still a clear vulnerability to heat, and dramatic mortality episodes have occurred in the U.S. within the last ten years (Klinenberg, 2002). One recent study indicates that, following a decline from the 1970s to the early 1990s, heat vulnerability has remained relatively constant since and may even be increasing in some cities (Sheridan et al., 2008).

During the summer of 2003, western Europe was impacted by a heat wave of historic proportions (Trigo et al., 2005). The most extreme conditions centered in France where from June 1 through August 31, 2003, maximum temperatures were above average for all but eight days in Paris and, for at least half of those days, average maximum temperatures were exceeded by 10°F or more. Minimum daily temperatures were also abnormally high.

Analysis of the 2003 European Heat Wave (EHW) indicates that its duration and magnitude is beyond that of any similar event that has occurred in the United States or Europe over the last 150 years. Initial estimates of its death toll centered around 30,000 (UNEP, 2004). More recently, a total of 70,000 excess deaths in 16 European countries have been identified during the summer of 2003 (Robine et al., 2008). Much can be learned regarding the potential impact of climate change on extreme heat and heat-related health concerns for Midwestern cities by examining the meteorological conditions leading to these events, and their impact on urban mortality and morbidity rates.

A heat wave comparable to the EHW in duration and intensity has yet to occur over North America. At the same time, there is a well-documented pattern of increased mortality in U.S. cities as a result of extreme heat waves (e.g., St. Louis, 1966, 1980, 2006; New York, 1975, 1984, 2006; Philadelphia, 1991, 1993; Chicago, 1995, 1999). Given projected future changes in summer temperatures, it is likely only a matter of time until such an event occurs. For that reason, we first calculate the impact an EHW-like event would have on heat-related mortality if it were to occur over Chicago, Minneapolis, or Indianapolis.

Following the methodology described by Hayhoe et al. (2009), an “analog city” approach developed by Kalkstein et al. (2008) is used to superimpose the meteorological conditions in Paris during the EHW event on these three Midwestern cities. All other conditions in the cities remain the same as observed today in those locations, including their demographics, vulnerability, and infrastructure. No AOGCM projections are required for this analysis; rather, it simply assesses the potential impact of a single event on Chicago, Indianapolis, or Minneapolis, regardless of when it might be projected to occur.

Minneapolis	Indianapolis	Chicago
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Metro Population (2000 census)	382,618	781,870	2,836,658
<b>Summer heat-related mortality</b>			
Average summer	30	25	94
Hottest historical summer	120 (1988)	98 (1988)	556 (1995)
EHW analog summer	141	282	1073
<b>Summer heart-related mortality per 100,000 population</b>			
Average summer	10.6	3.2	3.3
Hottest historical summer	31.6 (1988)	12.5 (1988)	19.6 (1995)
EHW analog summer	36.8	36.1	37.8
Analog percent deaths above hottest historical summer	18%	188%	193%

**Table 4.** Historical observed heat-related mortality for Chicago, Indianapolis, and Minneapolis and comparison with estimated heat-related mortality impacts of a 2003 European Heat Wave-like event.

Historical observed heat-mortality relationships for Chicago, Indianapolis, and Minnesota indicate that these cities experienced their hottest summers in 1995 and 1998, respectively. In those years, summer mortality rates ranged from 13 to 32 per 100,000 people, as compared to the average of 3 to 11 per 100,000 (Table 4). Superimposing the meteorological conditions of the EHW on these cities, however, gives mortality rates of 36 to 38 per 100,000 people—far exceeding that of even the hottest summer previously on record. To put this into further perspective: during an average summer in Chicago, about 94 people die from the heat. These numbers are smaller for Indianapolis and Minnesota; 25 and 30, respectively. Using 2000 census values for urban (not metro area) populations, if an EHW-like event occurred today, it would incur 1,073, 282, and 141 deaths in the urban center of Chicago, Indianapolis, and Minnesota, respectively (Table 4). Clearly, a heat wave of this magnitude would tax the health care system even more than past events.

### Projected Frequency of Future EHW-Like Events

The previous analysis only evaluates the likely impacts of an EHW-like event. However, the mortality characteristics of an EHW-like event (for Chicago, for which year-by-year mortality estimates were previously developed; Hayhoe et al., 2009b) and the meteorological characteristics of the EHW (for Indianapolis and Minneapolis, for which year-by-year mortality estimates are not available) can be used to estimate the likely timing of such an event, and the frequency of an EHW-type event by mid- and end-of-century under higher and lower emission scenarios.

In terms of mortality characteristics, an EHW-like event is defined as at least 13.4 deaths per 100,000 (in comparison, the 1995 Chicago heat wave had a mortality rate of 11.5 per 100,000). In terms of meteorological conditions, such a heat wave is defined as occurring during a period of at least 45 consecutive days where daytime maximum and nighttime minimum temperatures are above average for at least 43 of those days. A heat wave occurs when at least 10 days exceed daytime maximum temperature records are exceeded on at least 10 of those days, and minimum temperature records on at least 11 of the nights.

Using the definition of an “EHW-like” event, the likely frequency of such an event occurring in future decades can be calculated (Figure 7). Averaging the results from the three different climate models used here, historical simulations suggest no such event has yet occurred – which is, in fact, the case. Over the near term (2010-2039), however, simulations for both Chicago and Indianapolis indicate a 100% likelihood of at least one such event, while the probability is slightly smaller, at 70%, for Minneapolis-St. Paul.

By mid-century (2040-2069), there are projected to be another 2 such heat waves under the lower emissions scenario but anywhere from 6 to 8 under the higher emissions scenario. By the end of the century, under lower emissions EHW-like heat waves can be expected on average once a decade and approximately every other year under higher emissions.

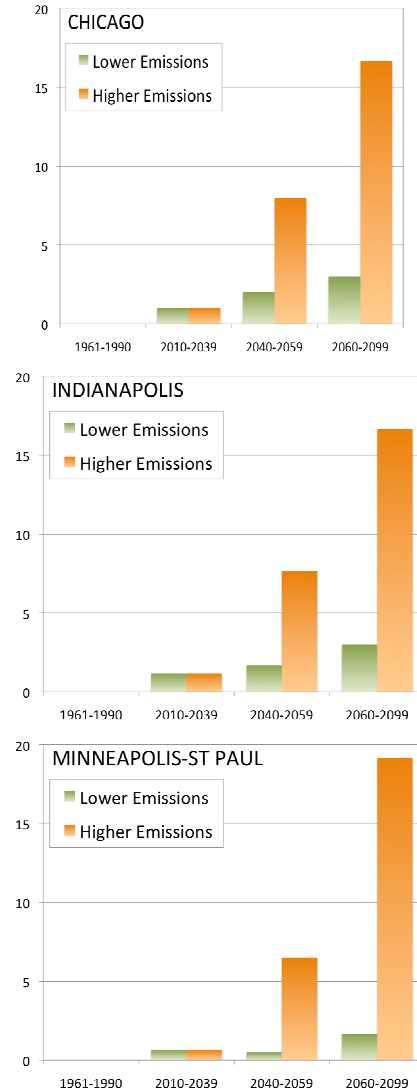
The fact that an EHW-like summer is projected to occur within several decades under either the higher or the lower emissions scenario has important implications for adaptation, suggesting that even with stringent mitigation strategies, adaptive measures should be put in place to deal with such a situation.

### Days Below Freezing (<32°F)

The corollary to projected increases in extreme heat are that the likelihood of cold days is also likely to decrease. The Midwest currently experiences between 108 (Missouri) up to 177 (Minnesota) days with minimum temperatures below zero each year. These numbers are projected to decrease significantly in coming decades, again with greater changes under higher as compared to lower emissions, and by the end of the century compared to near-term changes (Figure 8).

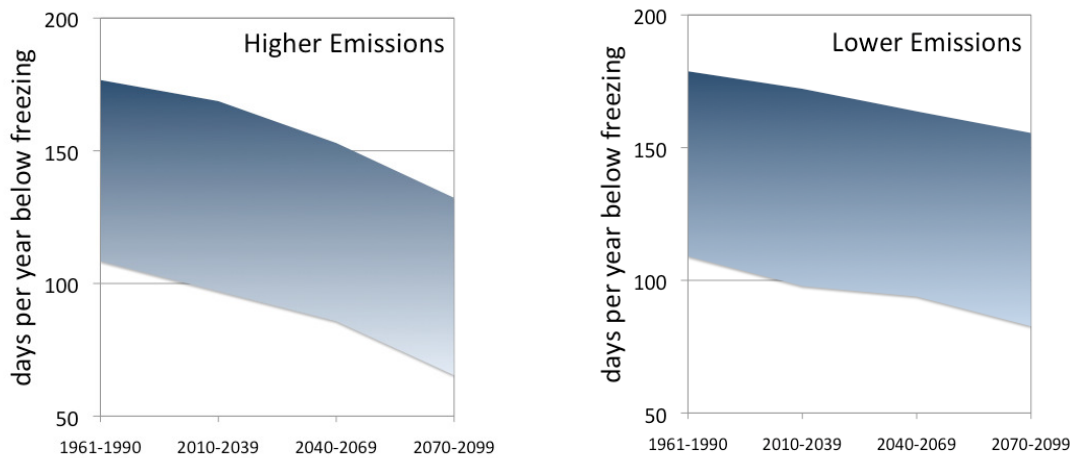
For the period 2010-2039, the number of days below freezing each year is projected to decrease by about 7 to 13. By mid-century, there are likely to be between 14-20 less days below freezing each year under lower emissions, depending on the state, and 23 to 28 less days under higher emissions. Smaller changes are expected for more northern states as compared to southern states. This is likely because a much greater fraction of winter days in those states are substantially below freezing, so a warming of a few degrees does not produce as significant a shift in the number of days below freezing as for a more southern location where fewer days are below freezing and temperature on those days is closer to the freezing mark.

By the end of the century, under lower emissions 23 to 33 less days each year are expected below freezing, while under higher emissions 43 to 58 less days are expected (Figure 8). For the



**Figure 7.** Projected frequency of 2003 EHW-like heat wave events for Chicago, Indianapolis, and Minneapolis-St. Paul. Values shown are the projected number of events per 30-year climatological period.

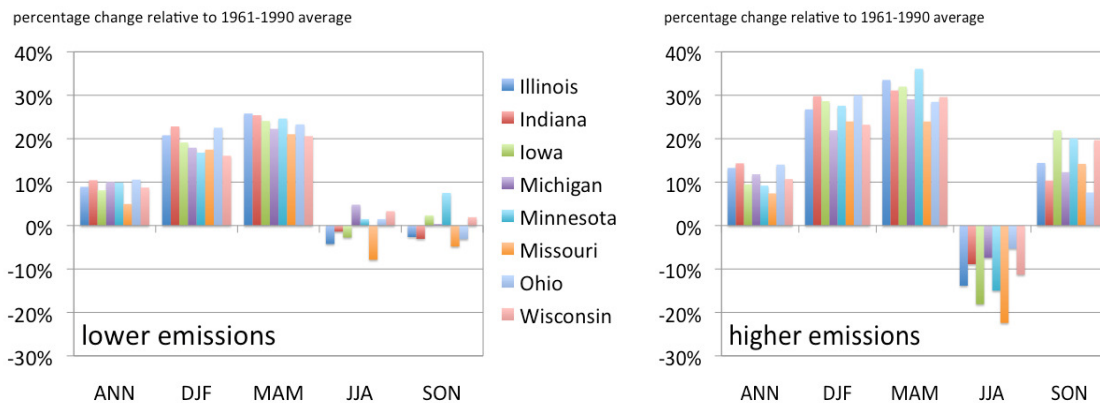
states of Missouri, Ohio, Illinois and Indiana, this means there are less than two and a half month's worth of days with minimum (nighttime) temperatures below freezing on average, each year.



**Figure 8.** Projected changes in average number of days per year below freezing. Range shown covers the 8 Midwest states, with the upper end of the range showing days below freezing for Minnesota and Wisconsin, the mid part of the range indicative of Iowa, Michigan, and Ohio, and the lower end showing Missouri, Illinois, and Indiana.

### Annual and Seasonal Precipitation

Climate change is expected to bring the Midwest no more than slight increases in annual average precipitation. Projected changes are on the order of 2-5% over the near term, 0-6% by mid-century, and 5-14% by end-of-century, depending on the state and the climate model used. These relatively small changes in average precipitation, however, mask much larger shifts at the sub-annual scale. As shown in Figure 9, climate change is expected to significantly alter the distribution of seasonal precipitation.



**Figure 9.** Projected changes in end-of-century average annual and seasonal precipitation, by state. Values shown are the average of simulations by three AOGCMs under higher and lower emissions for 2070-2099 relative to 1961-1990.

Relatively large increases in winter and spring precipitation are projected to occur for all states, with larger changes under higher emissions as compared to lower (~+30% vs. ~+20%), and by end-of-century as compared to closer time periods. Precipitation increases tend to be smaller for

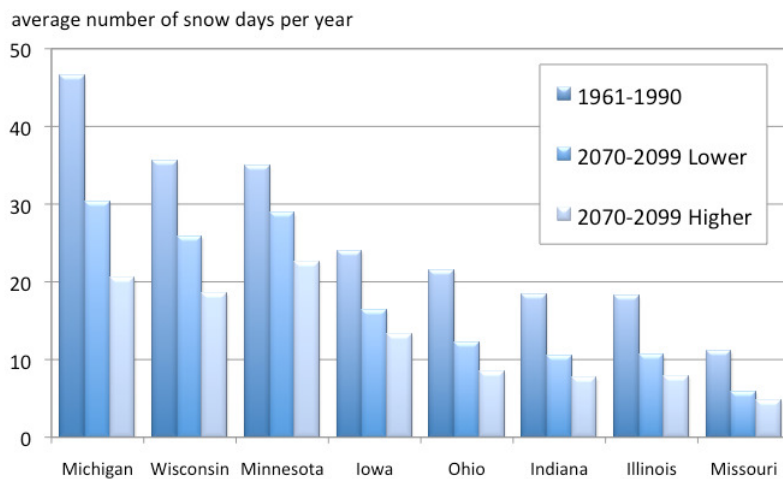
Missouri than for other states, but larger for the Midwestern states that lie south of the Great Lakes: Illinois, Indiana, and Ohio.

In contrast, summer and fall precipitation is expected to show little change under lower emissions. Under higher emissions, summer precipitation decreases by 5% to 22%, depending on location, while fall precipitation increases by a similar amount, 8% to 22%.

### Snow vs. Rain

This shift in precipitation from summer to winter and spring also has implications for the number of rain and snow days. Overall, no significant change is expected in the average number of precipitation days each year. However, warming temperatures means that precipitation on more of those days will fall as rain, and less will fall as snow.

As winter temperatures have warmed across the region, more precipitation has been falling as rain and less as snow. Since 1980, almost 3 out of 4 winters have seen below-average snowfall.



**Figure 10.** Projected change in the average number of snow days per year; 1961-1990 compared to 2070-2099 average under lower and higher emissions, by state. Values shown are the average of three AOGCM simulations.

Over the next few decades, little change is expected in the number of snow days for more northern states, although more southern states could lose between 2 and 4 snow days each year. By end of century, though, across the region the average number of snow days per year is expected to decrease. Decreases on the order of 30 to nearly 50% are expected under lower emissions, depending on location, and 45 to 60% under higher (Figure 10).

### Extreme Precipitation Events

Extreme precipitation can damage homes, businesses, public infrastructure, and ecosystems, as well as disrupt economic activity. Heavy precipitation that leads to flooding can damage crops and cause soil erosion, contaminate the water supply, promote infectious disease, disrupt transportation, and lead to property damage or loss. In urban centers such as Chicago, located near large bodies of water, extremely heavy precipitation events can lead to storm water discharge of contaminants into water bodies.

The frequencies of heavy rain events (defined as occurring on average once per year during the past century) have doubled since the early 1900s (Kunkel et al., 1999). Increases in the number of individual rainy days, multi-day heavy rain events, and week-long heavy rain events have also been observed (Changnon & Westcott, 2002; Changnon et al., 2001; Angel & Huff, 1997).

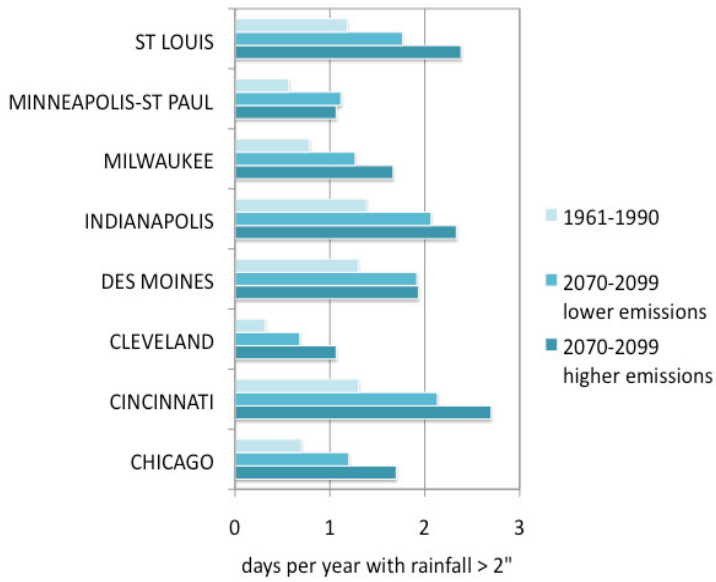
Projected changes in extreme rainfall events can be quantified in multiple ways, including the metrics used here: (1) the number of days each year with more than 2 inches of rain, and (2) the maximum annual 24-hr, 5-day, and 7-day precipitation totals.

All measures of extreme rainfall used here are consistent in projecting future increases, increases that become larger over time, and that in general are slightly higher under higher

emissions relative to lower (although the differences may not be significant, as they are well within the range of inter-model variability; Table 5). Proportionally greater increases—on the order of 1.5 to 3 times 1961-1990 average values—are seen for number of days with rainfall greater than 2 inches (Figure 11). Slightly larger increases tend to be projected for cities closer to the Great Lakes as compared to cities located in more inland locations.

**Table 5.** Historical simulated and future projected annual maximum precipitation events, measured in terms of the 24-hr, 5-day, and 7-day totals. Values shown are the average of three AOGCMs. Projections for Chicago and Detroit not available.

		1961-1990	2010-2039	2040-2069		2070-2099	
				Lower	Higher	Lower	Higher
<b>CINCINNATI</b>							
	24hr	2.4	2.6	2.4	2.9	2.9	3.1
	5-day	4.1	4.4	4.3	4.8	4.9	5.4
	7-day	4.8	5.1	4.9	5.5	5.5	6.1
<b>CLEVELAND</b>							
	24hr	1.8	2.0	2.4	2.2	2.3	2.4
	5-day	3.2	3.4	3.7	3.7	4.0	4.2
	7-day	3.5	4.0	4.0	4.1	4.4	4.6
<b>DES MOINES</b>							
	24hr	2.6	3.1	3.5	3.0	3.2	3.4
	5-day	4.3	5.0	5.5	4.7	5.2	5.8
	7-day	4.9	5.5	5.9	5.4	5.8	6.5
<b>INDIANAPOLIS</b>							
	24hr	2.4	2.8	2.7	3.0	3.2	3.1
	5-day	4.4	4.6	4.6	4.9	5.2	5.3
	7-day	5.0	5.1	5.1	5.5	5.8	6.1
<b>MILWAUKEE</b>							
	24hr	2.1	2.7	2.9	2.6	2.8	3.2
	5-day	3.5	4.1	4.5	4.1	4.3	4.8
	7-day	3.8	4.6	4.9	4.5	4.8	5.4
<b>MINNEAPOLIS-ST PAUL</b>							
	24hr	2.3	2.4	2.3	2.4	2.6	2.7
	5-day	3.5	4.0	3.9	3.9	4.2	4.5
	7-day	3.9	4.4	4.4	4.4	4.7	5.1
<b>ST LOUIS</b>							
	24hr	2.3	2.9	2.7	2.6	2.9	3.2
	5-day	4.2	5.3	4.9	5.5	5.1	5.8
	7-day	4.7	5.7	5.4	6.0	5.5	6.3



**Figure 11.** Projected change in the average number of days per year with more than two inches of precipitation in 24 hours or less. Values shown are the average of three AOGCM simulations for 8 individual urban centers across the Midwest.