Climate Mapping in the Great Lakes Region as a Means for Inter-Urban Collaboration in Climate Adaptation Planning

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Abstract

There is a major disconnect between climate scientists and city planners. Accessing climate data generally requires specialized training that most urban planners do not have. Therefore, planners depend on scientists to translate the data into projected climate impacts. Fine scale climate mapping that helps translate climate data into impacts on cities could assist in the climate adaptation planning process by eliminating the need for urban planners to make this translation for themselves. This is especially significant in the Great Lakes region, where the unique geography creates many small microclimates that are not represented in broad summary documents such as the IPCC. Instead, these reports aggregate the microclimates into one set of impacts, calling the region simply "The Midwest." This project attempts to define a set of climate zones in the Great Lakes region that capture the unique microclimates, and statistically establish the homogeneity of each zone across samples of cities. These zones could become a basis of collaboration between cities with existing climate adaptation plans and those looking for inspiration for their own plans. Using statistically downscaled climate model projections, a second set of maps tracks how these zones shift over time in a changing climate. Additionally, planners in the Great Lakes Region were interviewed to assess what kind of data they find to be most useful, and to gain feedback on how this method can best benefit them. The planners expressed need for climate information that is precise, relevant to their city's unique situation, and offers "on the ground" impacts and response strategies. This method addresses this need by encouraging efficient use of existing information for use in the planning process. The maps produced in this paper provide recommendations for inter-municipal collaboration to share relevant strategies among cities facing similar climate impacts. This helps cities help themselves without specifically commissioning climate experts, thereby reducing extraneous expenditure and redundancy of research.

Introduction

The International Panel on Climate Change (IPCC) Fourth Assessment Report estimates that even under the best-case scenario, the global average temperature will rise roughly 2 degrees Celsius (3.6 F)[1]. This will result in climate change impacts regardless of mitigation efforts to reduce carbon emissions. For the Midwest, this means more frequent extreme heat events, droughts, and intensified storms among other impacts. This global change requires place-specific local actions to safely adapt to a warming climate. City planners lead many of these efforts at the local/municipal or regional level through climate action plans. Thus city planners must have access to climate data to tailor their response strategies to their unique challenges. However, local planners' abilities to incorporate climate data is impaired by a communication disconnect between planners and climate scientists. While planners need climate information to prepare climate adaptation plans, they generally lack the specialized training required to obtain and interpret it. Climate scientists are generally presenting the data in a way that is not useful to planners because it is either to complex or time-consuming to interpret.[2] As a result, many planners are uncertain how climate change is expected to impact their community. Furthermore, most small cities do not have the resources to commission city-specific studies that directly address their unique situation. Instead they must rely on very broad-scale summary reports such as the IPCC or the US Global Change Research Program (USGCRP). These reports provide broad recommendations but lack the detail local planners seek.

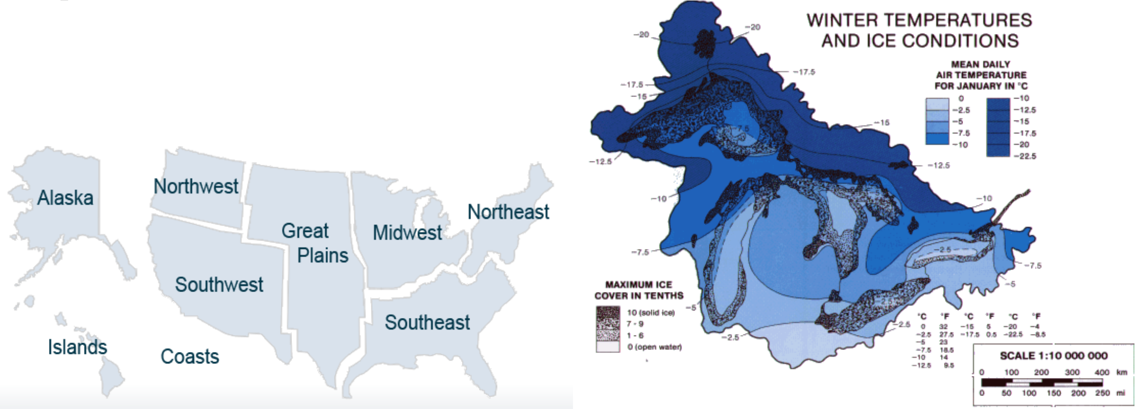


Figure 1. USGCRP regions (left)[3] vs. finer scale Great Lakes Region from the EPA, 1986 (right)[4]

Unfortunately, these summary reports often aggregate impacts over large geographical areas. For example, the USGCRP aggregates the Great Lakes Region into a homogeneous mega-region calling it simply “The Midwest.”[5] However, the unique structure of the Great Lakes region, most notably the lakes themselves, create a complex set of small microclimates that cannot be generalized into one overarching set of impacts.[6] These microclimates are largely a result of two things: the temperature moderating effect of the lakes and general movement of air masses from west to east. The lakes are slower to heat and cool than the surrounding land, staying cooler in the summer and warmer in the winter.[7] This creates a set of small microclimates that hug the lakes, making areas of similar temperature less intuitive than in other regions where temperature is largely a function of latitude and elevation. Figure 1 depicts average winter temperatures in the Great Lakes Region and illustrates the diversity of microclimates. Note that the relatively warmer lakes result in relatively warmer adjacent land compared to cooler inland areas. Additionally, as the cold eastbound air masses pass over the relatively warmer lakes, they pick up moisture, which is deposited as snow/precipitation on the leeward landmasses. These areas, sometimes referred to as “snow belts,” are shown in Figure 2. Thus, some common climate areas begin to emerge that are not necessarily intuitive or contiguous. This means that cities in this region may not rely on proximity alone to determine appropriate collaborative priority or case study selection. Unfortunately, current climate maps for the Great Lakes Region provided by the EPA date back to 1986.[8] Standard procedure for determining the “present climate” is to use a 30-year average, which means the data should cover 1971-2000 or ideally now 1981-2010. Therefore, the EPA’s current climate maps don’t capture current climate trends.

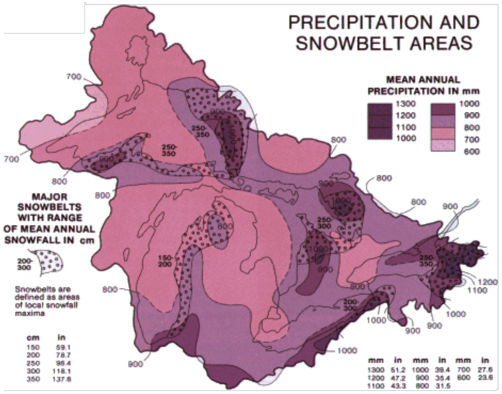


Figure 2: Snow belts just east of each lake dissipating as eastbound air moves inland[9]

Climate mapping on a scale fine enough to capture the region's microclimates, yet broad enough to cover multiple cities would help suggest potential collaborations among cities of similar climate. A series of homogeneous climate zones based on certain climate variables, such as temperature and precipitation, would represent many of the Great Lakes Region's microclimates. Planners could use these zones as a basis of comparison for adaptation strategy case studies and inter-municipal collaboration on a scale more precise than the large USGCRP or IPCC mega-regions. Large cities that have greater planning capacity and existing climate adaptation plans could share their information and work to date with smaller cities who have less planning capacity. There are some leading examples of cities that are making climate adaptation plans in the Great Lakes Region, such as the Chicago Climate Action Plan.[10] When cities without such plans begin to look for case studies to inspire their own plans, climate zone maps could define which cities to prioritize for strategy sharing and they may be able to piggyback on their data collection if they face similar climate impacts.

Looking forward, all cities in the Great Lakes Region are predicted to experience increasing average temperatures. However, precipitation will vary greatly across all of the cities with some receiving more precipitation on average and others less.[11] This is because precipitation and humidity are inherently more difficult to model compared to temperature, providing a great range of uncertainty. Sometimes this uncertainty results in some models predicting increased precipitation, while others predict decreased precipitation.[12] This variation further depends significantly on the resolution, type of climate model and the greenhouse gas emissions scenario used by the model. Thus there are several layers of uncertainty in climate modeling, introduced both by the models themselves and by human behavior. To a planner concerned about their city's combined sewer system, this is a critical weakness in climate data reliability. Because of these types of uncertainty and the requirement for in-depth interpretation of data across models, planners who need this data require more guidance to effectively utilize it. In the end, urban planners are interested in understanding how climate change will impact their city and the systems necessary to meet residents short and long term needs. But because the analysis depends heavily on the data creation process, uncertainty, and scale of the models, it is difficult for climate scientists to give a definite answer. For planning purposes, the projected changes in climate variables alone are less important than analyzing how those changes will impact a city's unique situation. They want to know what will happen to their city by translating the raw data into specific impacts in order to move to the next stage of finding similar community case studies and developing response strategies. Thus, planners require climate impact information specific to their city that is rarely readily available. Ultimately, qualitative data in the form of narratives of climate impacts require a quantitative basis from the climate models. This lack of specific local climate information increases the likelihood that local decision-makers may delay action.[13]

This paper to provides a middle ground for planners by creating a climate zone mapping strategy to encourage inter-municipal collaboration that can help planners use climate data more efficiently. If the climate zones can reasonably assume similarity between cities, then quantitative data collecting could be shared between cities as well as climate adaptation planning strategies. Though the adaptation techniques may be inherently different between cities of different size or density, the climate inputs should be consistent within predefined zones of homogeneous climate. These changes are significant across all cities regardless of size or density. This paper explores one approach to conveying climate data to aid in the planning process from the perspective of the urban planner. This method will help planners to attain greater autonomy in their planning preparation and research and lead to more effective discussions with scientists and deeper engagement in the link between science and application in the urban environment. Through interviews with urban planners and planning-related professionals in the Great Lakes Region, this paper seeks to define what kinds of climate data planners currently use and what information would be most useful to them. It further explores how municipalities currently collaborate with other cities and climate scientists. Finally, I ask for feedback on the climate zone method to determine whether they would utilize this approach, and how to improve its utility. Until a planner can adequately gather precise, reliable data specific to their city, they have little means of efficiently reducing risk without extraneous expenditure.

Literature Review

From the literature, I review three important issues. The first is literature that identifies why the communication gap between planners and climate scientists may exist. Second, I review literature related to climate zone mapping to understand the strengths and weaknesses and relevant practices. Finally, I review the concept of migrating climates in the Great Lakes Region.

The most significant issue is the ineffective communication between climate scientists and planners. In a changing climate, it may be inadequate to base measures like emergency management plans, land use planning and infrastructure replacements solely on historical climate information like frequencies of extreme events or water-level fluctuations.[14] Thus it is critical that urban planners can easily obtain and interpret climate information because they commonly use tools that can significantly help society adapt to climate change. However, working with climate data generally requires specialized training that planners do not have. Furthermore, if they can obtain the data, it is often too broad scale to be relevant to a city's specific needs. Planners are most concerned with information that is precise, relevant, and offers strategies to cope with expected climate changes. In the Great Lakes Region in particular, many planners are concerned with region-specific impacts such as lake level change, erosion, and stresses to human health.[15] Thus, they generally prefer information that has been translated into specific impacts to quantitative data alone that does not capture the complexity of these issues. These narratives are rarely available at a scale useful to planners without spending extra time and resources to commission climate experts. Fowler and Wilby (2007) noted this disconnection and concluded that the dialogue between suppliers and users of climate information must improve for practical application. For adaptation planning in particular, decision-makers must understand uncertainties demonstrated in climate modeling and downscaling while climate scientists must focus on more short-term impacts rather than end-of-century projections to better suit the timeframes common to planning.[16]

In 2011, Wong found that meteorologists seem to know little about the planning processes that consider urban climate factors, and planners generally have little understanding about the types of climate data available. This is because planners and meteorologists have separate “knowledge domains,” and explains why urban climate mapping has been slow to spread among urban planners.[17] One of the greatest examples of this disconnection is in data provision. In the early 2000s, the National Center for Atmospheric Research (NCAR) began working with the US Department of Energy to provide climate model output through a system called the Earth System Grid, designed to make data access easier for users who lack a specialized staff to interpret it.[18] However, the data comes in a format that requires programming experience. In an effort to overcome this challenge, the North American Regional Climate Change Assessment Program (NARCCAP) offers regular users’ workshops to provide the specialized training to access the data.[19] A simpler approach that prepares the information in a manner that is clear and useful to planners would be more likely to be adopted for use in adaptation planning. There are highly specialized tools that allow planners to view neighborhood-level climate mapping, such as the web-based Screening Tool for Estate Environment Evaluation, but data at that scale is not yet readily available and must be assembled prior to use. This requires the same kind of specialized training discussed above.[20] Tools such as this would fill the void between planners and scientists thereby expediting the planning process only if the underlying data were easily available and accessible to planners. This represents a dilemma of climate adaptation planning: data at a small enough scale to be useful to planners is not readily available and easily accessible by those planners. Thus climate scientists must either take that extra step closer to planning by removing the need for specialized data preparation or planners must find a simpler tool that presents useful data by other means. A planner is most likely to adopt a system that that already speaks their language. One such method is to present quantitative data through mapping techniques. This would remove the need for planners to prepare the data themselves, and would present the data in a way they can quickly and easily interpret.

In 2000, Eliasson conducted a survey to examine the level of climate expertise among planners. He hypothesized that urban climatologists may be inadequately communicating their results to planners.[21] He found that despite the extensive existing knowledge of urban climate among urban climatologists, the information had very little effect on the planning process. The majority of planners interviewed indicated that they had inadequate training to properly engage the data. Additionally, planners listed communication problems and lack of knowledge as key barriers to using climate data in the urban planning process. Specifically, this was due to a language barrier between climatologists and planners, and that planners felt inadequately informed to argue for the importance of climate in the planning process.[22] Many planners indicated that they employed consultants for climatic investigations.[23] However, this is not a possibility in most small cities that cannot afford such personalized investigations. As a result of these shortcomings, the majority of planners expressed a demand for increased access to climate knowledge through improved tools for use in the planning process. Though they suggested training programs like the courses NARCCAP offers, they specifically emphasize real-world examples rather than pragmatic theory. The majority of planners responded positively toward digital climatic maps created using Geographic Information Systems (GIS).[24] Eliasson recommends that climatologists improve urban climate awareness among planners through better communication and create tools and courses suitable for planners.[25] Thus, improved mapping or otherwise useful data interpretation methods specifically designed for planners that offer real world examples and case studies would significantly improve climate data utility in the planning process and could help improve communication between planners and climate scientists.

Climate Zone Mapping

The concept of creating climate zones is not new. One popular example is the USDA Plant Hardiness Zone Map. This map helps farmers and gardeners determine which plants will likely thrive within each zone.[26] This is an example of a dynamic zone classification because the boundaries are free to change with the climate variable on which the zones are based. It is based on average annual winter minimum temperatures, using 5.6-degree C (10 F) divisions. The latest version uses the standard 30-year average based on data from 1976-2005. Previously, they had been based on a shorter 1974-1985 average. With this update came an adjustment of the zones, resulting in a shift of roughly half a zone warmer.[27] As shown in Figure 3, these zones reflect the moderating effect of the lake, keeping the land immediately to the east of Lake Michigan warmer than the interior. One benefit of this map is that the zones capture the unique microclimates of the Great Lakes Region at a fine scale. However, the method uses a single variable (temperature) and planners need additional variables such as precipitation. Thus, if this concept were to be more closely aligned with variables important to planning, it would provide a much more useful resource for planners.

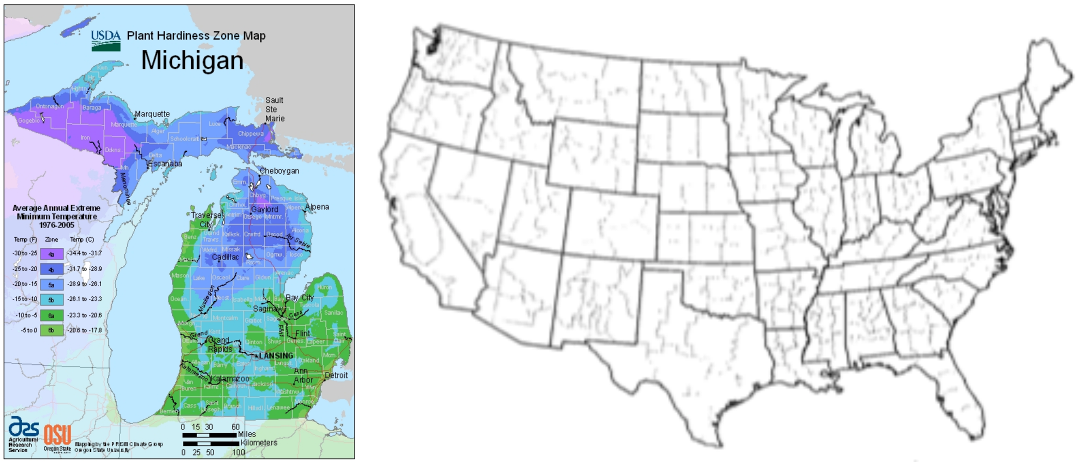


Figure 3: Michigan's USDA Plant Hardiness Zones (left)[28] and NCDC climate zone boundaries (right)[29]

Alternatively, the National Climatic Data Center (NCDC) has created a nationwide set of 344 climate zones that do not change freely with time as the USDA zones do.[30] This is because the NCDC climate zones are largely based on static physical parameters such as drainage basins and political boundaries such as counties. The concept underlying these zones is that it is difficult to define homogeneous divisions of universal application based on climate variables like temperature or precipitation alone.[31] Thus, the NCDC uses homogenizing indices that group the climate variables into useful ranges based on the end user, as with the USDA zones. For example, a certain crop may thrive only within a certain range of both temperature and precipitation, thereby grouping both variables and defining a range for each under the designation of a zone telling farmers where it is safe to plant this crop. Using this principle, the NCDC zones primarily use many drought indices grouping variables like soil moisture, stream flows and lake levels. But it is not limited to such uses, and has also included useful definitions such as heating and cooling degree days.[32] Most importantly, the NCDC also includes temperature and precipitation averages as a basis of climatological homogeneity.[33] Thus the NCDC climate zones can successfully aggregate many variables that may be useful to planners, but the static nature of the zones places many restrictions on observing a changing climate, which is most important for planners attempting to plan for the future.

Unlike selecting a crop for a single growing season, planning decisions have long-term impacts that must consider the impact of a changing climate over the lifetime of the plan. The most significant shortcoming for planners is that both the USDA Plant Hardiness Map and the NCDC zones are solely based on observed data and offer no projections. The current maps may be useful for current collaboration between cities, but for planners attempting to create climate adaptation plans it is much more important to explore what climate impacts are projected to occur within their cities. Furthermore, without this collaboration or associated translations to climate change impacts, the maps offer no suggestions on what each zone means on the ground for the planner. So, while both the USDA and NCDC approach have useful characteristics neither type of climate zone mapping is adequate for use in urban planning.

One way to think about local climate change and climate zone mapping is to compare a projected climate for a region to an existing climate elsewhere. Such a comparison is limited to average conditions and does not take into account certain place-specific characteristics such as mountains or the Great Lakes. However, when considering climate variables alone, such as average temperature and precipitation, it is possible to make a comparison.[34] For example, the Union of Concerned Scientists (UCS) predicts that by the end of the century Michigan's winter climate will become similar to that of Ohio today. Summer changes may occur much sooner. The UCS states that Michigan summers could become very similar to that of Ohio in a few decades, and are likely to resemble northern Arkansas by the end of the century.[35] This is because a warming climate effectively shifts familiar warm climates currently in the south further north into the Great Lakes Region. If the average temperature and precipitation of Michigan is projected to appear similar to those of Arkansas today, then the Arkansas climate has effectively shifted to Michigan even with the different local physical characteristics. Furthermore, because the NCDC has defined a climate by average temperature and precipitation, this is an adequate definition of a climate for mapping purposes. Visualizing migrating climates through climate mapping techniques can remove the abstractness of climate projections. Rather than simply stating a change in temperature and precipitation, this allows planners to directly study the way a particular climate impacts cities and can therefore learn how to prepare accordingly. Unfortunately, this type of mapping often focuses on end of the century projections that are less useful to planning timeframes.

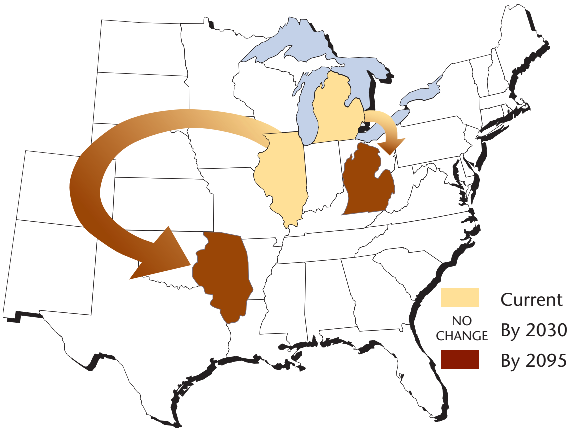


Figure 4: Visualizing migrating winter average climates in Michigan and Ilinois[36]

From the literature we see that insufficient communication between planners and climate scientists has resulted in a knowledge gap that hinders the use of climate information in the field of planning. And because climate data is currently difficult to obtain and interpret, decision makers are much more likely to utilize climate information that describes how climate change will impact cities and offers response strategies for adaptation planning. Planners are often familiar with mapping techniques and GIS tools, but current climate zone mapping techniques offered by the USDA and NCDC focus on observed climate data and therefore do not provide projections. On the other hand, the UCS migrating climate maps focus on changes beyond the useful planning time horizon of 5-10 years making them less relevant. Thus, a set of maps that uses zone mapping techniques similar to the USDA and NCDC that provide climate projections and impacts would help to fill the current knowledge gap between planners and climate scientists. Furthermore, increased communication among cities that face similar climate impacts could help to fill in the missing climate impact and response strategy analyses useful for adaptation planning.

Method

Data

There are two types of data needs in this project. The first is observed data on which to base the current climate zones, and the second is climate model data to produce the current and projected climate maps. Thus, the maps produced in this paper are based on publicly accessible data from two datasets: the Climatic Research Unit (CRU) gridded observation dataset[37] and the Maurer statistically downscaled climate model suite.[38] CRU is based on weather station observations from throughout the region. But because weather stations are not uniformly distributed, areas more heavily monitored can introduce a bias with a simple average. To correct this, the CRU gridded observation dataset provides a uniform grid of equally weighted and spatially averaged observed data. The CRU data was used to establish the climate zones, basing them on the current observed climate of the Great Lakes Region. Unlike CRU, Maurer provides climate projections based on the global climate models used by the IPCC. The global models use large grid cells, resulting in low-resolution data. The Maurer dataset uses statistical relationships to "downscale" the broad scale global model data to offer more precise projections at a finer scale. This extra step introduces greater uncertainty, but the finer scale more precisely captures microclimates such as those in the Great Lakes Region. Maurer was selected because it is a relatively high-resolution model, and the small grid cells allow for more appropriate assignment at the level of the city. A lower resolution model may include several cities within a single grid cell and therefore inadequately differentiate between them. Thus, temperature and precipitation data was collected from the Maurer statistically downscaled climate model suite over the same region and time period as CRU (1971-2000). The shift from CRU to Maurer is significant because if the link between the zones defined by CRU hold true in a climate model such as Maurer, it can help planners to understand the advantages of climate modeling. To show how the climate zones shift over time, Maurer projections are used to create a similar map based on the years 2041-2070. The IPCC global model results vary depending on the levels of greenhouse gas emissions programmed into the model calculations. The different potential outcomes are known as emissions scenarios, ranging from an optimistic low-emissions scenario that results in less climate change to a relatively high emissions scenario that results in greater change. This high emissions scenario represents a business-as-usual (BAU) path representing little to no greenhouse gas mitigation efforts. I have selected the BAU emissions scenario because the more drastic change offers the best illustrative example of shifting climates. Because Maurer consists of a suite of datasets derived from a variety of global models, I have selected four downscaled IPCC models to represent the model suite. Data was extracted from each of the four datasets and averaged together cell by cell to create what is known as a multi-model mean. By averaging out the variability introduced by the different global models, the resulting map is not biased toward any particular global modeling method, thereby representing the average Maurer business as usual scenario output.

Data Manipulation

Most climate data is publicly available, but requires computer programming skills to extract the data. By writing NCL (National Center for Atmospheric Research (NCAR) Command Language) scripts, I extracted temperature and precipitation data from the larger datasets. NCL is a programming language specifically designed to analyze climate data. These scripts create seasonal averages of temperature and precipitation for each grid cell in the Great Lakes Region. For this analysis, the Great Lakes Region is defined as the region between 41 and 50 degrees North, and -75 to -93 degrees West, shown in Figure 5.

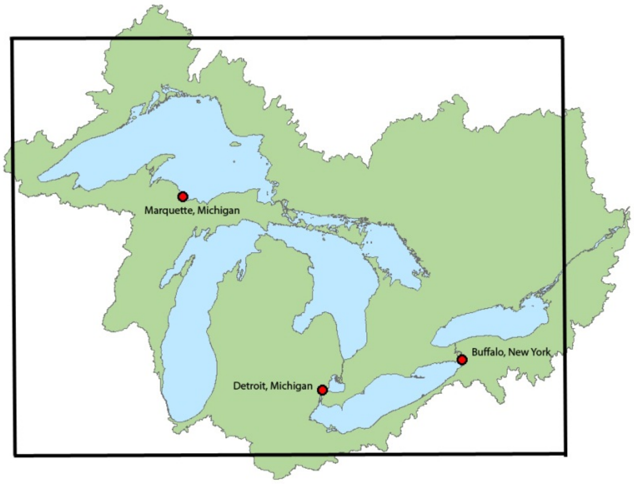


Figure 5: Extent of the Great Lakes Region compared to its watershed[39]

Zone Establishment

The first step in creating the climate zones is to identify the desired variables and select the appropriate ranges. As with the NCDC climate zone method, I have defined the zones based on average temperature and precipitation. In this case, the data is limited to average winter temperature and average winter precipitation intensity. Winter, defined by the months December, January and February (DJF), was chosen as the basis for these zones because it is a significant season in the Great Lakes Region for planning. It is significant in terms of precipitation because air moving eastward over the lakes picks up moisture, creating bands of heavy winter precipitation on the western coasts. These snow belts have significant planning implications such as snow removal, transportation safety and structural integrity of flat rooftops to support the weight of snow.[40] In terms of temperature, areas that stay close to the freezing point have a frequent freeze-thaw cycle that can damage infrastructure by the daily infiltration of water into cracks and subsequent expansion as it freezes overnight. Coastal areas will be at the greatest risk of an increased freeze/thaw cycle because of the temperature moderating effect of the lakes. The relatively warm lakes will keep these regions warmer than non-coastal regions in the winter, which can result in an average temperature closer to the freezing point.[41] Thus, this will be an important extra consideration for planners and city engineers in coastal cities.

The next step is to set the temperature and precipitation boundaries for each zone. It is important these zones be dynamic to show planners how the zones shift over time in a changing climate. Therefore, following the USDA Plant Hardiness Zone example, these zones are set by the variables themselves rather than physical boundaries. As with the USDA and NCDC, the zone designation must suit the audience. Originally, two precipitation zones were considered, to designate snow belts vs. non-snow belts. Unfortunately, snow belts are subjectively defined as simply regions that experience greater snowfall compared to their surroundings, not on an absolute range uniform across the region.[42] Thus, such a designation was unfeasible., But because both the premise of shifting zones and the planning profession itself are inherently spatial, it is appropriate to base the zone boundaries on spatial trends in the region. In order to find real, observed trends in the region, the boundaries are defined by observed present data using a standard 30-year climatology for the years 1971-2000 derived from the CRU gridded observation dataset. Each CRU grid cell represents a ½ degree by ½ degree area of land (roughly 3,400 mi^2 or 8,800 km^2 (111 km by 79 km)) so a histogram of the gridded data shows temperature and precipitation as a function of land area. It is on these spatial trends that the zones are based, as shown in Figure 6.

Temperature is relatively evenly distributed, so the boundaries are placed to create three equal zones across the range of temperature. The high-temperature division in Figure 6 is necessary to capture incoming warmer temperatures currently not experienced in the Great Lakes Region. However, precipitation has a more interesting bimodal distribution. The first peak represents the land to the west of the lakes, where eastbound air has not yet reached the lakes, while the second peak represents the relatively normal distribution of precipitation in the rest of the region. Therefore, one zone captures the first, drier peak of land to the west, the second captures the second peak closer to average precipitation, and the remaining zone represents the high precipitation tail, marking where it is most extreme in the region and likely translates to snow belts. Finally, the zones are defined in Figure 7 below as the intersections of these defined ranges. The precipitation ranges do not appear very large because the data is in terms of liquid precipitation. However, as this is the winter, the majority of this precipitation will be in the form of snow. In the Great Lakes Region the conversion for this is roughly 12-16 inches of snow for every inch of liquid precipitation depending on the type of snowfall.[43]

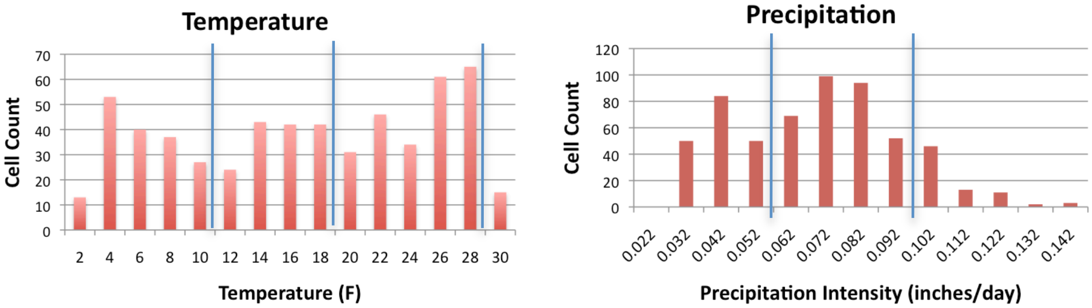


Figure 6. Temperature and Precipitation histograms based on CRU gridded observation data, with zone-defining boundaries

		Average Precipitation (inches/day)		
		0.022-0.059	0.059-0.098	0.098-0.142
Average Temperature (F)	(-0.4) - 10.076	Zone 4	Zone 8	Zone 12
	10.076 - 19.85	Zone 3	Zone 7	Zone 11
	19.85 - 29.62	Zone 2	Zone 6	Zone 10
	29.62 - 39.4	Zone 1	Zone 5	Zone 9

Figure 7. Definitions of the 9 climate zones using average winter (DJF) temperature and precipitation

Mapping Model Data

The Maurer model data temperature and precipitation data was mapped using ArcMap, a geographic information systems (GIS) program commonly used in the planning profession. The climate zones were created by first establishing temperature and precipitation zones defined by the boundaries in the table above, and overlaying them as shown. Additionally, it is important to explore how these zones will change over time, helping planners to quickly see how their local climate is projected to change. Thus, a similar map was created using Maurer projections for the years 2041-2070. The projection output is based on the business-as-usual (BAU) emissions scenario, also known as the IPCC scenario A2. This results in the greatest changes in climate, and therefore offers an illustrative example of a zone shift. From this data, the zones were recreated using the same boundaries to track how these climates migrate over time. The comparison between these two maps provides an efficient method of conveying potential climate change impacts. It may be useful for planners to consider both their current and projected zone and compare their situation to other cities within those zones. Using that knowledge, they may look to cities that will share their future zone, and prepare together accordingly.

However, these maps are not strictly limited to climate inputs alone. Though temperature and precipitation are important inputs that imply most climate impacts, it is most useful to planners to directly see these impacts. As these maps are of winter averages, the potential impact of a more frequent freeze/thaw cycle is very important for planners. Thus, included in the 2041-2070 projection map is an overlay zone showing which regions have an average temperature that is close to the freezing point. This implies a frequent (night/day) cycle of freezing and thawing, which can damage infrastructure. Cities that are not currently in danger of this frequent freeze-thaw cycle, but lie within the projected freeze/thaw overlay zone may have to begin preparations by mid-century to protect their infrastructure from major repairs in the future.

Validation of Homogeneity

As a basis of comparison within each zone, 4 cities were selected from each zone. The cities selected for this analysis are listed in Appendix Y. One multi-model mean winter temperature for each city meant 4 values per zone. To assess the homogeneity of the zones, I conducted a student's t-test on the present climate (1971-2000) multi-model means using each zone as the population, setting the significance level to 0.05. With such a small population, the student's t-test is an appropriate statistical test, as it is meant for populations of less than 30. The full set of cities and corresponding data used in the statistical test can be found in Appendix A. To prepare the data for the t-test, subtracting the mean from each population and dividing by the standard deviation normalized the data. Theoretically, if the populations pass the test, this will set the mean to 0. All of the above calculations as well as the hypothesis test were performed using Matlab. This test determined, with 95% confidence, whether each population shares a common mean. Therefore, the hypothesis test is as follows:

H_0: The temperature and precipitation mean is the same within each population
H_1: The temperature and precipitation means are different within each population

Because the cities in each zone share a range in temperature and precipitation, the null hypothesis, H_0, is likely to hold true. If so, then with 95% confidence, the mean is the same within each population, and the zone can therefore reasonably be considered homogeneous. Thus, urban planners can use these zones, both present and future, as a basis for inter-urban collaboration for climate adaptation planning.

Interviews

The purpose of this project is above all to provide a useful tool for planners. Therefore, a small convenience sample of professional city employees from throughout the region was contacted for interviews. The interviewees were selected for their respective cities' prior involvement with the University of Michigan through the Graham Environmental Sustainability Institute and their dispersed location throughout the region. Based on this selection criterion, the participating cities may have greater interest in climate and environmental issues. The 9 respondents in 6 locations represent planning or planning-related jobs in the city government. The first part of the interview asked about general environmental concerns, where they find climate information, how they use it in their own work, and about inter-municipal collaboration. The second part of the interview asks the planners to respond to the climate zone mapping technique. Specifically, it is important to know how they would use such a mapping technique and what other elements they would like to see added in further development.

To gather the sample, I first sent invitations directly to the target candidates by mail, and then sent a follow-up invitation by email. To those who responded, I sent a PDF containing a brief explanation of the project, some sample climate zone maps, and a chart of recommended collaboration and case study prioritization. Interviews were conducted by telephone or Skype and were recorded using an audio editing program called Audacity. All participants were asked to have the informational PDF available during the interview and to review it beforehand if possible. The interviews ranged in length between 20 and 60 minutes.

Results

Temperature Trends

Figures 8 and 9 below show a multi-model mean of temperature data alone for the present climate (1971-2000) and the mid-century projection (2041-2070). The data is broken into zones defined in Figure 7 in the previous section. Note that because temperature is largely based on latitude, the zones break the region into horizontal bands stacked vertically. The moderating effect of the lakes is also apparent in both maps, as warmer zones tend to cling to the lakes. This is most visible in the projected map, showing the warm red zone mostly in coastal regions.

The most important feature is the northward migration of each zone. The coldest blue zone greatly diminishes, while a new warm red zone enters the region from the south. This presents both a significant strength and weakness of this study. It is useful to note that a new temperature range is projected to enter the Great Lakes Region, especially one with winter average temperatures close to or far above the freezing point. But for this study, the restricted domain limits the basis of comparison for this populous section of the region.

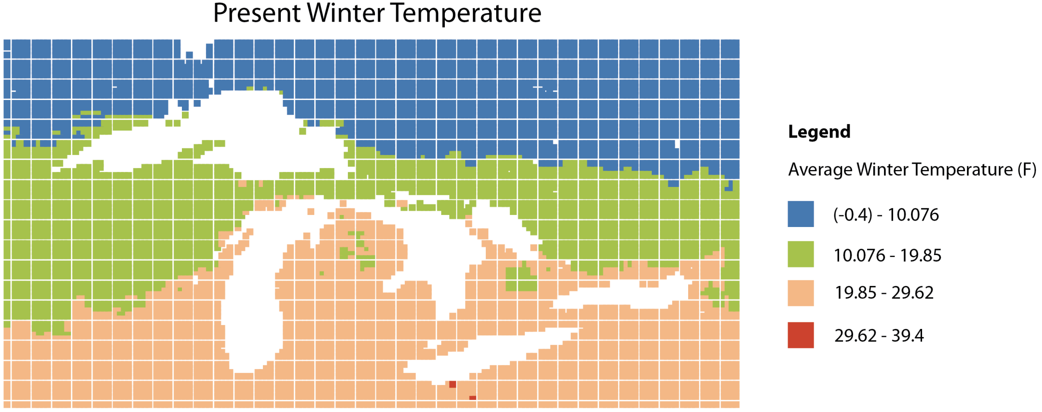


Figure 8: Vertically aligned present winter temperature zones (1971-2000)

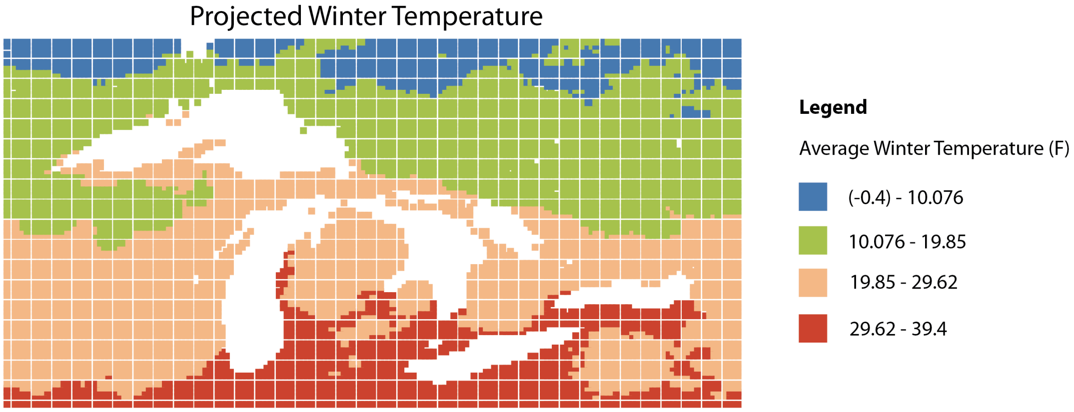


Figure 9: Northward shift of vertically aligned projected winter temperature zones (2041-2070)

Precipitation Trends

Figure 10 and 11 below show the precipitation intensity data alone for both time periods broken into the zones defined in Figure 7 in the previous section. Eastbound air masses pick up moisture from the relatively warm lakes resulting in east-west oriented zones of increasing precipitation. This causes areas of relatively high precipitation known as snow belts on land just to the east of each lake. The effect is most visible on the west coast of Michigan, compared to the relatively dry interior and east coast. These maps also display the subjective nature of snow belts. Though the EPA precipitation map in Figure 2 defines all of these areas simply as snow belts, Figure 10 below shows that some snow belts are actually more intense than others.

Unlike the shifting temperature zones shown above, these precipitation zones generally do not migrate by mid-century. Instead, higher-intensity zones grow outward into lower-intensity zones. The effect is most visible in central Michigan and in the southeast corner of the region. It is important to note that the values presented are in terms of liquid precipitation. As most of these zones are in regions with average temperatures below the freezing point, this precipitation would fall as snow. Recall that in the Great Lakes Region the conversion for this is roughly 12-16 inches of snow for every inch of liquid precipitation.[44]

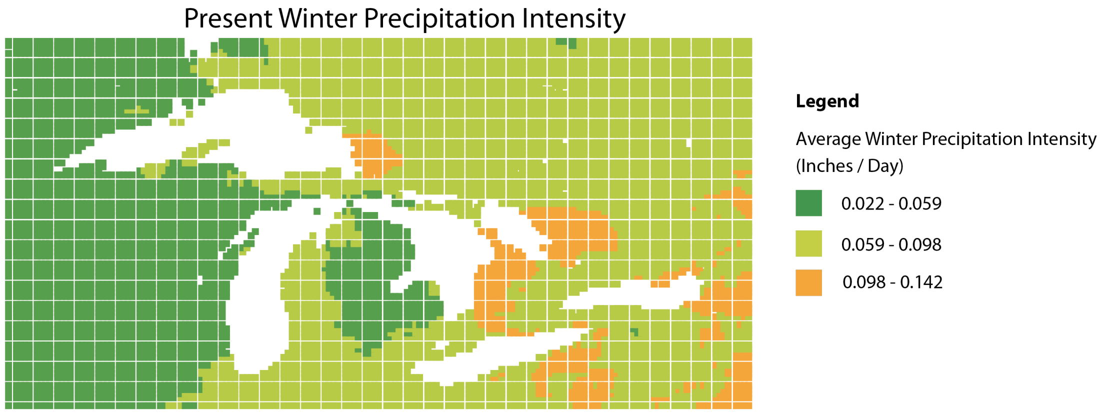


Figure 10: Generally horizontally aligned present winter precipitation intensity zones (2041-2070)

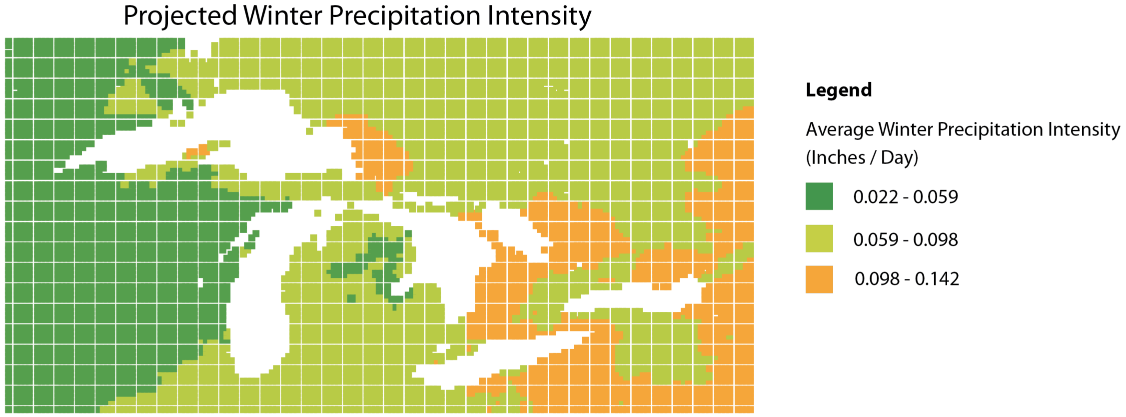


Figure 11: Projected winter precipitation intensity zones (2041-2070) indicate a general increase in the region as higher precipitation zones grow into lower precipitation zones

Alternatively, accumulated precipitation is illustrated below. These maps were created using a similar procedure to the other maps, but illustrate one alternative variable that may be of greater important to planners. The projected accumulated precipitation displayed a significant upward shift, so a fourth zone was created to accommodate the higher values similar to the high temperature zone in Figure 6. These maps present an interesting change by mid-century, in that they shift one zone to the west while generally maintain their shape. This means a larger rain or snowfall accumulation across the entire region. Given the rain-to-snow conversion, this could result in approximately 9.5 to 12.6 additional inches of snow across the region. It is generally assumed that two inches of snowfall constitutes a "plowable event," which means this change results in an average of roughly five to six more events per season across the region.[45] This type of map could be useful adjusting municipal budgets for extra snow removal costs, which can be expensive especially in big cities that must physically remove the snow from the city.

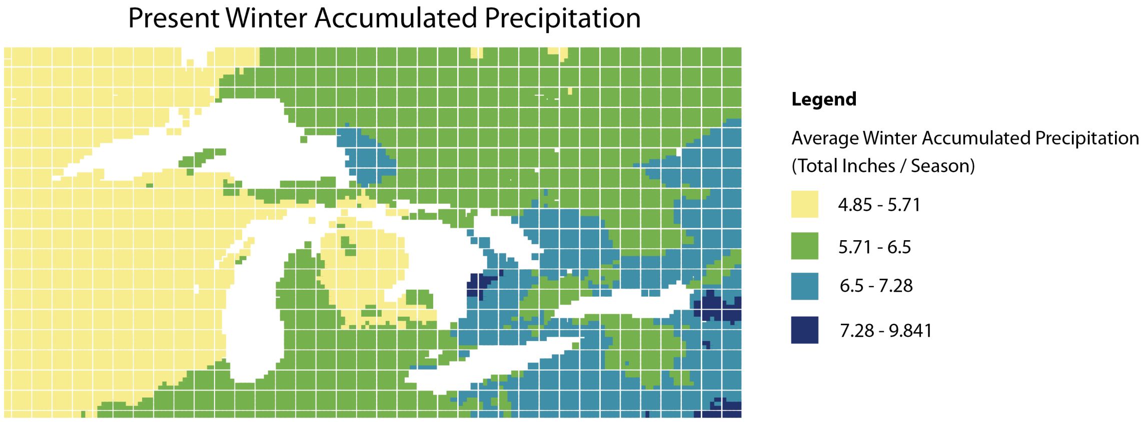


Figure 12: Generally horizontally aligned present winter accumulated precipitation (1971-2000).

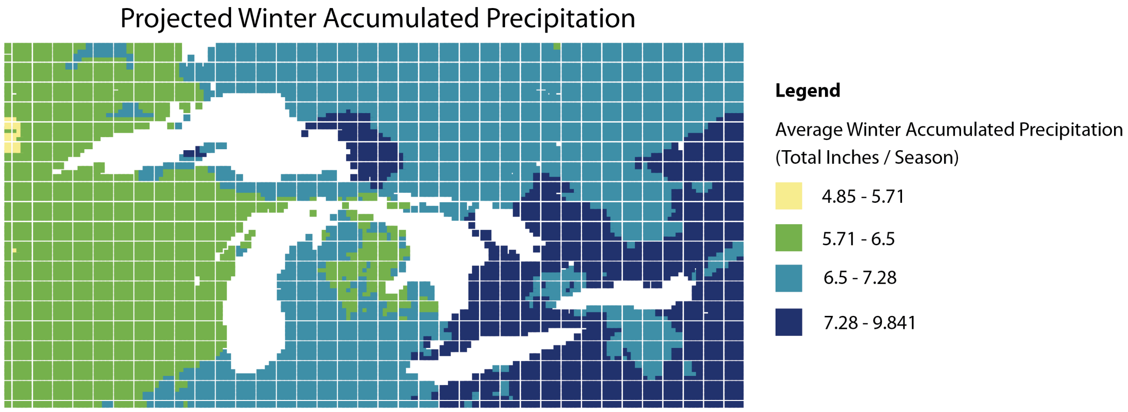


Figure 13: Westward shift of projected winter accumulated precipitation (2041-2070).

Climate Zone Maps

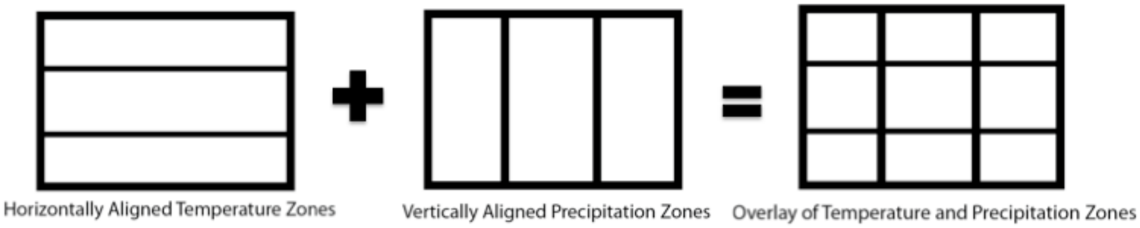


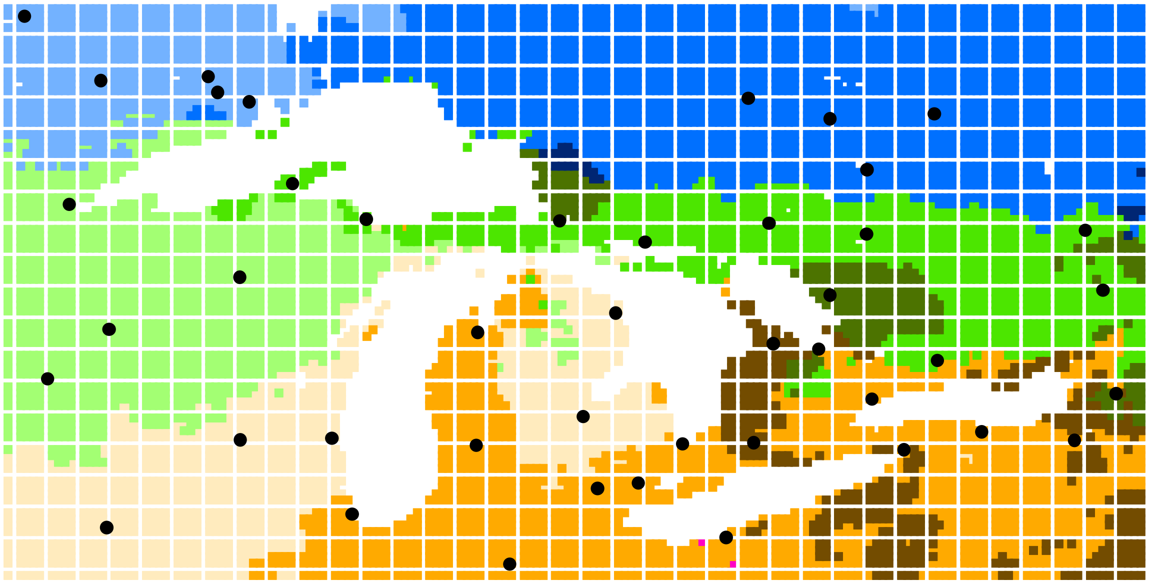
Figure 14: Zones of similar climate are defined by intersecting the individual temperature and precipitation zones forming a roughly grid-like structure across the region

Shown in Figure 15 below is the Maurer multi-model mean climate zone map for the Great Lakes Region. As shown in the figure, particularly by zones 2, 6, 10, and 11, the area covered by a particular zone is not necessarily intuitive. This non-contiguous nature shows that proximity is not necessarily a defining factor for the zones, and therefore the priority for case study selection does not always have to be a neighboring city. In viewing these zones, it is possible for an urban planner to look to even distant cities within their zone for inspiration or for collaborative efforts. As in Figure 9 depicting future temperature trends, Figure 15 shows the effect of a warming climate in the southern zones that have shifted northward, and in the greatly diminished northern zones. It is also important to note that zone 12 does not appear at all in the 2041-2070 map, as there is no location in the Great Lakes Region cold enough to fit the definition of the zone. Similarly, the zones 1, 5 and 9 only exist in the projected map, meaning these zones currently exist to the south of the Great Lakes Region. Figure 16 offers an alternative set of maps using accumulated precipitation. The microclimates appear similar between Figures 14 and 15, but Figure 15 displays a more drastic zonal shift due to the westward migration of accumulated precipitation zones depicted in Figure 13. This is just one example of how the maps may change depending on the selected climate variables.

Additionally, with these new zones come the freeze/thaw overlay zone for areas with an average temperature close to the freezing point, depicted in gray. This new overlay zone is defined to have an average winter temperature within 0.5 degrees C (0.9 F) of the freezing point, or roughly 31 to 33 F. This overlay spans several zones, as it is based on temperature but not precipitation. Thus, this shows that the temperature may prove to be problematic regardless of precipitation, but it is especially dangerous in locations with higher precipitation.

Regarding the homogeneity of the zones, every zone passed the student’s t-test for both temperature and precipitation using a Matlab analysis of each zone’s normalized population. Thus, with 95% confidence, each zone is considered homogeneous and can therefore be reasonably relied upon as a basis of similarity of climate for the cities within each zone.

Present Winter Climate Zones (1971-2000)



		Average Precipitation (inches/day)		
		0.022-0.059	0.059-0.098	0.098-0.142
Average Temperature (F)	(-0.4) - 10.076	Zone 4	Zone 8	Zone 12
	10.076 - 19.85	Zone 3	Zone 7	Zone 11
	19.85 - 29.62	Zone 2	Zone 6	Zone 10
	29.62 - 39.4	Zone 1	Zone 5	Zone 9

Projected Winter Climate Zones (2041-2070)

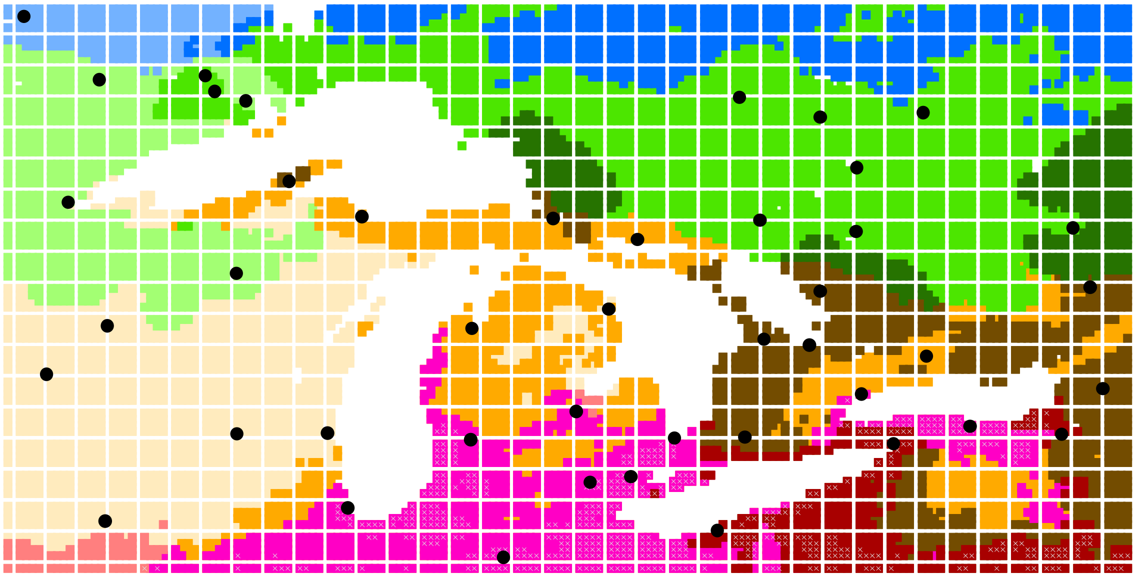
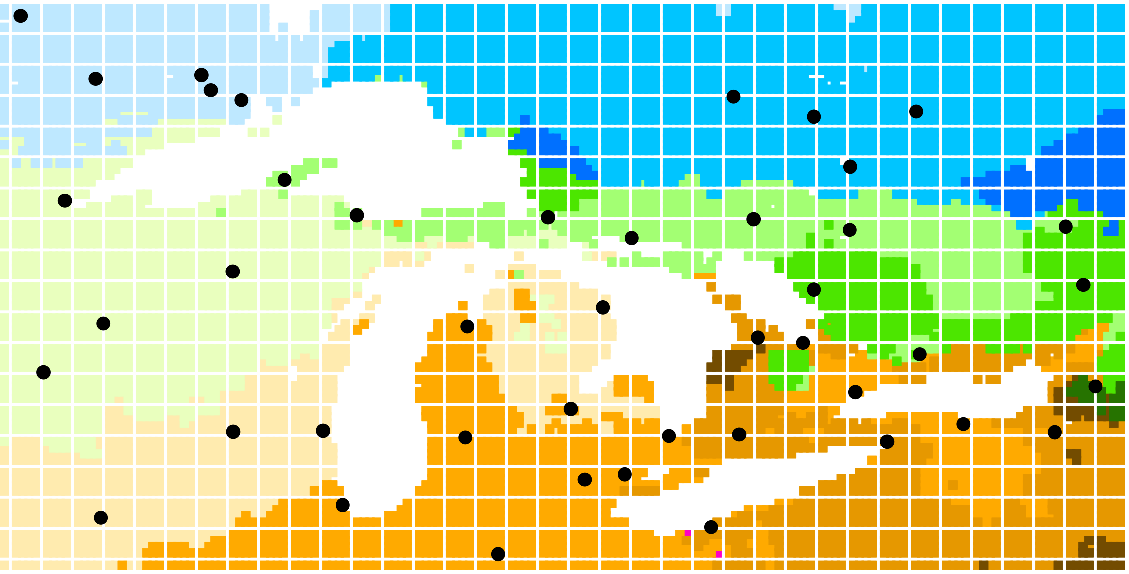


Figure 15. Great Lakes Region climate zones, using winter (December, January, February) seasonal average temperature and precipitation intensity, based on a multi-model mean of the Maurer statistically downscaled model suite, 1971-2000 (top) and 2041-2070 (bottom)

Present Winter Climate Zones (1971-2000)



Average Temperature (F)	Accumulated Precipitation (inches/season) 4.85 - 5.71	5.71 - 6.5	6.5 -7.28	7.28 - 9.84
(-0.4) - 10.076	Zone 4	Zone 8	Zone 12	Zone 16
10.076 - 19.85	Zone 3	Zone 7	Zone 11	Zone 15
19.85 - 29.62	Zone 2	Zone 6	Zone 10	Zone 14
29.62 - 39.4	Zone 1	Zone 5	Zone 9	Zone 13

Projected Winter Climate Zones (2041-2070)

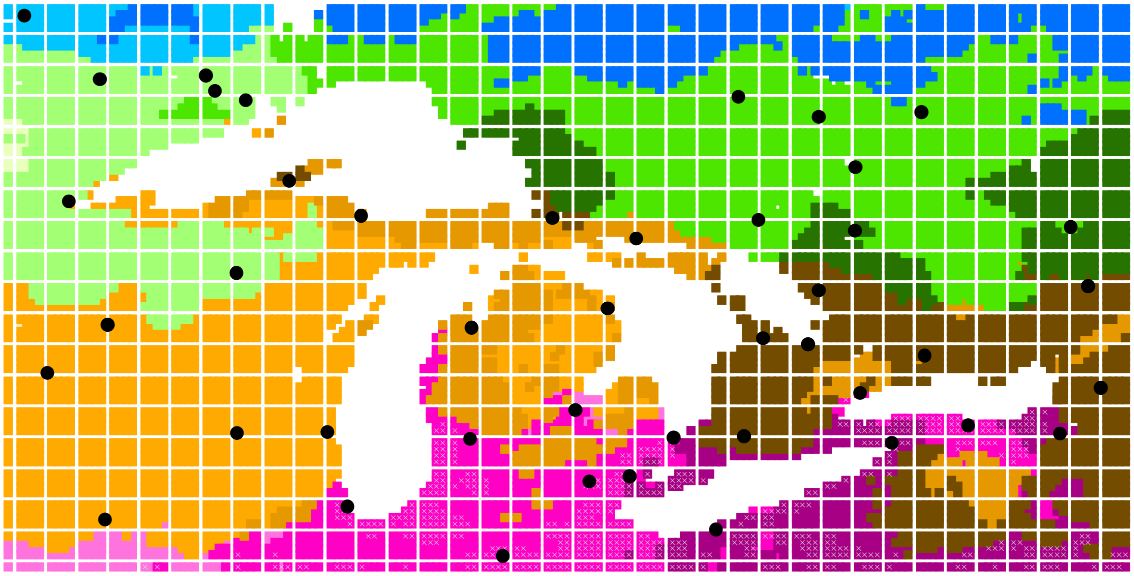
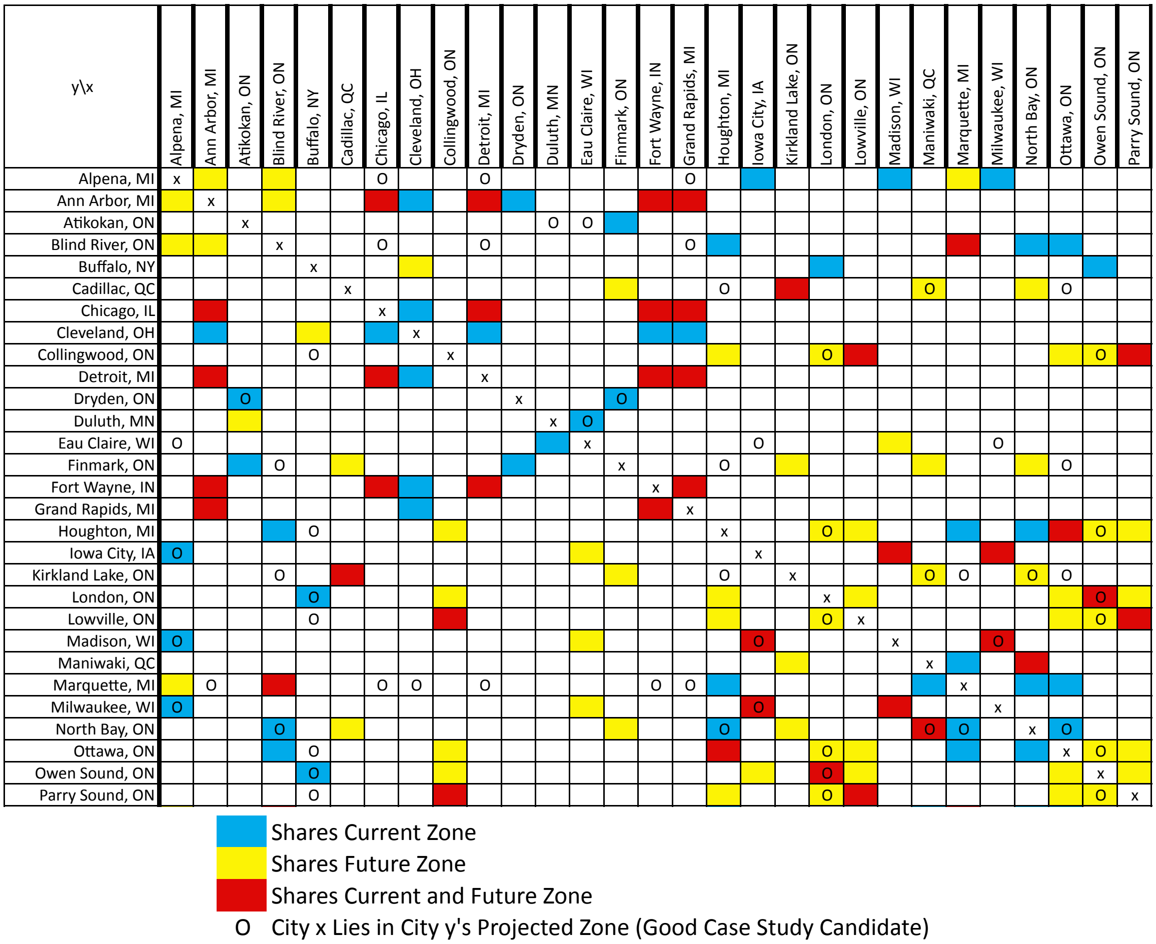


Figure 16. Great Lakes Region climate zones, using winter (December, January, February) seasonal average temperature and accumulated precipitation, based on a multi-model mean of the Maurer statistically downscaled model suite, 1971-2000 (top) and 2041-2070 (bottom)

Collaborative Priority

Depending on the time frame of a city's climate adaptation plan, it may be appropriate for planners to look ahead to the future map and plan according to their future zone. The table below is an effort to identify cities with similar climate to prioritize collaboration and case study selection. Assuming temperature and precipitation are adequate means of defining a climate, a migrating zone suggests a migrating climate. Thus, a planner can look to cities currently within their own city's projected zone to gain a sense of what climate issues they can expect by mid-century. For example, the city of Alpena, Michigan currently lies within zone 2, but is projected to be in zone 6 by mid-century (2041-2070). Bigger cities like Chicago, Illinois, Detroit, Michigan, and Grand Rapids, Michigan all lay within zone 6 at present (1971-2000). Thus, Alpena can look to current environmental reports and regular city operations from those cities to gain real-world examples of conditions that they are projected to experience under the A2 scenario. But given the climate scenario uncertainty, it would be prudent to consider alternative scenarios in this analysis. Unfortunately, one major limitation of the maps in this paper is the limited domain. The warmer zones in the projected map move northward into the region from south of the domain, so there are currently no case study recommendations for cities in the south. Furthermore, a final analysis of applicable climate adaptation strategies will depend on many other characteristics such as urban form and infrastructure capacity, but this grouping will give insight into the climate inputs. When combined with an assessment of a city's unique situation, this can provide for a more in-depth analysis of that city's vulnerabilities and beneficial adaptation strategies. Most importantly, it provides a greater depth of analysis than the mega-regional predictions of the IPCC or USGCRP alone. Examples of recommended case studies are represented in the chart below.

Moving beyond case studies, cities can also use this method for inter-municipal collaboration based on their current and projected zones. Cities that share a projected zone can work together to develop adaptation strategies that will be most beneficial in their common projected climate. A higher priority can be placed on cities that share both current and projected zones, as they will face similar incremental changes. This means they will face similar changes in their current procedures such as snow removal or storm water management. This provides a common set of challenges on which to base collaboration. Finding similar communities facing similar challenges will result in "on the ground" adaptation strategies that some planners find missing from the current climate literature.



y\x	Alpena, MI	Ann Arbor, MI	Atikokan, ON	Blind River, ON	Buffalo, NY	Cadillac, QC	Chicago, IL	Cleveland, OH	Collingwood, ON	Detroit, MI	Dryden, ON	Duluth, MN	Eau Claire, WI	Finmark, ON	Fort Wayne, IN	Grand Rapids, MI	Houghton, MI	Iowa City, IA	Kirkland Lake, ON	London, ON	Lowville, ON	Madison, WI	Maniwaki, QC	Marquette, MI	Milwaukee, WI	North Bay, ON	Ottawa, ON	Owen Sound, ON	Parry Sound, ON
Alpena, MI	x	🟨		🟨			O			O						O		🟦				🟦		🟨	🟦				
Ann Arbor, MI	🟨	x		🟨			🟥	🟦		🟥	🟦				🟥	🟥													
Atikokan, ON			x									O	O	🟦															
Blind River, ON	🟨	🟨		x			O			O						O	🟦							🟥		🟦	🟦		
Buffalo, NY					x			🟨												🟦								🟦	
Cadillac, QC						x								🟨			O		🟥				🟨 O			🟨	O		
Chicago, IL		🟥					x	🟦		🟥					🟥	🟥													
Cleveland, OH		🟦			🟨		🟦	x		🟦					🟦	🟦													
Collingwood, ON					O				x								🟨			🟨 O	🟥						🟨	🟨 O	🟥
Detroit, MI		🟥					🟥	🟦		x					🟥	🟥													
Dryden, ON			🟦 O								x			🟦 O															
Duluth, MN			🟨									x	🟦 O																
Eau Claire, WI	O											🟦	x					O				🟨			O				
Finmark, ON			🟦	O		🟨					🟦			x			O		🟨				🟨			🟨	O		
Fort Wayne, IN		🟥					🟥	🟦		🟥					x	🟥													
Grand Rapids, MI		🟥						🟦							🟥	x													
Houghton, MI				🟦	O				🟨								x			🟨 O	🟨			🟦		🟦	🟥	🟨 O	🟨
Iowa City, IA	🟦 O												🟨					x				🟥			🟥				
Kirkland Lake, ON				O		🟥								🟨			O		x				🟨 O	O		🟨 O	O		
London, ON					🟦 O				🟨								🟨			x	🟨						🟨	🟥 O	🟨
Lowville, ON					O				🟥								🟨			🟨 O	x						🟨	🟨 O	🟥
Madison, WI	🟦 O												🟨					🟥 O				x			🟥 O				
Maniwaki, QC																			🟨				x	🟦		🟥			
Marquette, MI	🟨	O		🟥			O	O		O					O	O	🟦						🟦	x		🟦	🟦		
Milwaukee, WI	🟦 O												🟨					🟥 O				🟥			x				
North Bay, ON				🟦 O		🟨								🟨			🟦 O		🟨				🟥 O	🟦 O		x	🟦 O		
Ottawa, ON				🟦	O				🟨								🟥			🟨 O	🟨			🟦		🟦	x	🟨 O	🟨
Owen Sound, ON					🟦 O				🟨									🟨		🟥 O	🟨						🟨	x	🟨
Parry Sound, ON					O				🟥								🟨			🟨 O	🟥						🟨	🟨 O	x

🟦 Shares Current Zone
🟨 Shares Future Zone
🟥 Shares Current and Future Zone
O City x Lies in City y's Projected Zone (Good Case Study Candidate)

Figure 17: A portion of the city relationship chart, showing recommended priorities for collaboration between cities in the Great Lakes Region and case study selection. This chart is presented in its entirety in Appendix B.

Interview Results

The chart below summarizes the survey respondents' professional positions and the cities they represent. Nine planners in six cities were asked about four major topics: current and expected environmental concerns, climate data use and accessibility, collaboration with other cities or climate experts, and responses to this climate zone analysis. Figure 19 below illustrates that though many of these cities are within the same climate zone, they vary greatly in size and location in the Great Lakes Region.

Title	City
Environmental Coordinator	Ann Arbor, MI
Planning Manager	Ann Arbor, MI
Energy Programs Associate	Ann Arbor, MI
Midwest Regional Sustainability Network Coordinator	Ann Arbor, MI
Office of Energy and Sustainability Director	Grand Rapids, MI
City Planner	Marquette, MI
Senior Environmental Specialist	Rochester, NY
Infrastructure and Operations Manager	Thunder Bay, ON
Director of Planning	Traverse City, MI

Figure 18: Cities and positions interviewed

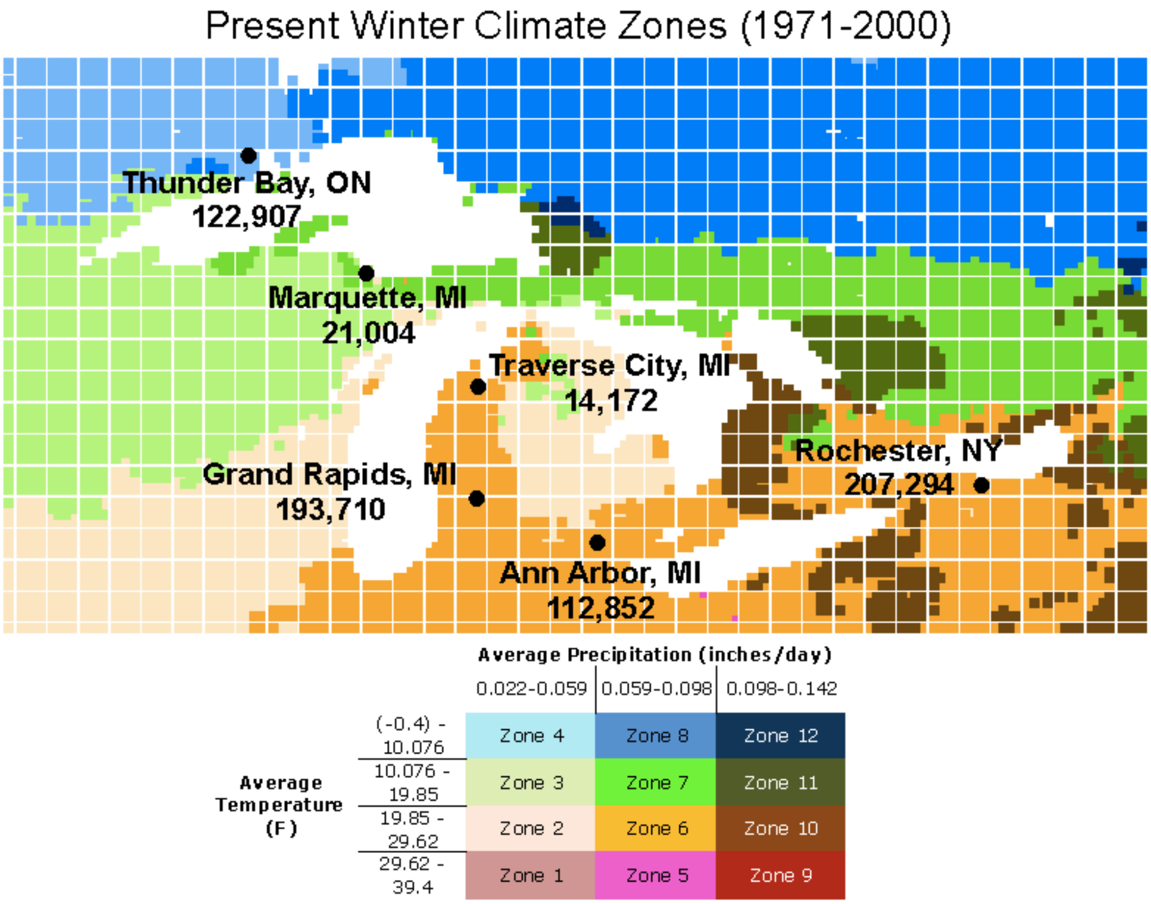


Figure 19: Location, population and current climate zone of interviewed cities

Environmental Concerns

It was important to first gain a sense of the current environmental concerns of Great Lakes cities so all respondents were asked what environmental hazards most concern their community. Given the range of microclimates in the Great Lakes Region, interviewees expressed a diverse range of environmental concerns. In the north, Thunder Bay and Marquette are most concerned with cold weather, snowfall and ice storms. In the south, Ann Arbor and Rochester are most concerned with flooding from high precipitation events. Rochester and Traverse City also listed pollution as a major environmental concern. Both cities listed properties contaminated by former industry, and Rochester added stormwater pollution from runoff and air quality issues from high ozone levels. Grand Rapids similarly expressed water quality issues as their greatest environmental concern. This shows that city history and geography have a large impact on environmental concerns, and they are not always directly linked to climate.

Regarding climate change, all major concerns stemmed from climate instability and extreme events. Five of the six cities listed increased flooding events from more intense precipitation as a major environmental issue. Three of the cities were most concerned with ice, whether from ice storms, hail, or changes in the freeze/thaw cycle. The Environmental Coordinator of Ann Arbor and the Infrastructure and Operations Manager of Thunder Bay agreed that this is because ice is one of the most damaging environmental hazards in the Great Lakes Region to property and infrastructure, making it very expensive for the city and citizens. However, Traverse City stated that the city is well prepared to handle an increased freeze/thaw cycle. Regarding the summer months, only Rochester in the south listed heat waves as a significant impact. However, three of the cities expressed interest in an extended growing season for tourism, food security and economic prosperity. Additionally, Thunder Bay listed invasive species, particularly the emerald ash borer as a concern. Grand Rapids was unique in mentioning greenhouse gas emissions as a climate-related environmental hazard. This provides an interesting perspective on the varying interpretations of climate impacts and illustrates the city's commitment to mitigation efforts. This range of expected climate change concerns shows that it is important to consider many climate-related variables and associated impacts, and it is likely that no single map will encompass all of a city's environmental concerns. However, because the northern cities are concerned with winter precipitation and ice while southern cities are concerned with flooding and the freeze/thaw cycle, climate zones that combine precipitation and temperature prove useful to address these issues.

Climate Information

Cities must respond to these anticipated climate change impacts to reduce their vulnerability. Cities are beginning to formally plan for these changes with climate action plans or sustainability plans. All cities interviewed currently have or will soon produce such a plan. However, the general sense is that planners are most concerned with current actions and operations and are not yet ready to formally adopt a stance on climate change. All interviewees indicated that climate change is openly discussed at the city level, but many added that the decision-makers are just beginning to look into climate projections. This results in plans with a more mitigation focus than adaptation. Traverse City explained that in this time of tight city budgets, cutting back on energy use is a major economic driver for sustainability. Further, Ann Arbor expressed that an adaptation plan alone is less useful than more specific operating plans with adaptive elements. So for many cities, climate adaptation is still in an exploratory phase. However, Grand Rapids stands out in that the sustainability plan is built into the city's master plan. Furthermore, it specifically identifies both mitigation and adaptation strategies. Because of this, the International Council for Local Environmental Initiatives (ICLEI) has mentioned Grand Rapids as an example for codifying mitigation and adaptation strategies.

Fortunately there are a variety of climate information resources available at all levels of expertise. In fact, the Infrastructure and Operations Manager of Thunder Bay claims that there is too much information available. But in writing a climate action plan, there is no formal approach for the application or interpretation of this information. The cities interviewed most commonly used reports from large organizations such as the EPA, NCDC, National Oceanic and Atmospheric Administration (NOAA), the Union of Concerned Scientists, or ICLEI. Grand Rapids found resources published by universities to be very helpful. But some interviewees indicated that these resources were too broad, and would prefer more regionally specific information. The Senior Environmental Specialist of Rochester expressed that it can sometimes be difficult to know where to look for useful information. Ann Arbor and Thunder Bay prefer more immediately relevant weather information. Thunder Bay finds projections on the scale of one week to three months to be most useful. Ann Arbor often uses Federal Emergency Management Agency (FEMA) flood maps to specifically address their major flood concerns. Ann Arbor's Environmental Coordinator claimed that the major reports do not say enough about how to respond to potential climate threats. Furthermore, he stated, "I don't want to be the one aggregating the data, I'm not a climate scientist." This displays the fundamental dilemma of climate information in the planning process. The most important aspect planners seek in climate data is relevance to their own needs. If it is presented on a scale too broad to suit their unique situation and does not provide solutions to the projected impacts, it becomes irrelevant.

In terms of relevant information, my interviews with planners help to reveal why climate modeling is rarely addressed in the planning process. Only two cities interviewed indicated that they use raw climate data like temperature or precipitation data. In most cases, climate data is too abstract to look only to absolute changes without linking it to specific impacts or familiar climates elsewhere. Many interviewees explicitly expressed the need for narratives linking these changes to "on the ground" impacts. Only two of the six cities have used information from an International Panel on Climate Change (IPCC) report, and only one has used a US Global Change Research Project (USGCRP) report. Resources such as these that deal more directly with climate projections lack both the precision and adaptation responses sought by planners. But more importantly, these more scientific resources are viewed to be currently beyond the scope of the planning process. Four of the six cities were familiar with the IPCC emissions scenarios, but all cities responded that they were not yet ready to fully engage the uncertainty between them. Thunder Bay's Infrastructure and Operations Manager explained that most planners are currently concerned with the direction of change (for example, warmer than the current climate) rather than the magnitude of change because "the degree of change is small, but the impact of change is large." Both he and the Environmental Coordinator of Ann Arbor expressed that planners are still confirming that climate change is something they need to plan for. Nonetheless, five of the six cities claim that the information that is available is adequate to begin planning for the predicted changes. The Environmental Coordinator of Ann Arbor explained that uncertainty is not necessarily the impediment for decision-makers that many believe it to be. Both Ann Arbor and Thunder Bay agreed that that decision makers would be willing to accept a certain level of uncertainty. On the other hand, the Energy and Sustainability Director of Grand Rapids expressed that current data is not adequate because of some significant knowledge gaps. He felt that often times planners and climate scientists don't speak the same language. Furthermore, long-term climate projections are less directly applicable to planning than 10-20 year projections that are more relevant to the 5-10 year planning cycle. He added that many planners may simply dismiss longer-term projections because they are beyond the scope and timeframe of most plans. These responses directly fit Fowler and Wilby's findings that short-term projections are more useful in climate adaptation planning and that better communication and mutual understanding between planners and climate scientists is critical to meaningful action.

Collaboration

Case studies and collaboration can be efficient methods to promote municipal action. Sharing information and resources between similar communities, can lead to overall economy of scale savings and reduce redundancy of research. All interviewees found case studies to be very useful in the planning process. Thunder Bay's Infrastructure and Operations Manager stated that case studies are particularly useful to help climate adaptation planning gain traction among decision makers. However, there is no standard procedure in selecting these case studies. All interviewees indicated the necessity of similarity or applicability to their city for case study selection, but the basis of similarity varies widely. Responses ranged from physical similarities such as similar climate, size, population, or surface permeability to more ideological similarity such as political mindset. All cities indicated that they actively collaborate with other municipalities on a variety of topics. For the more rural communities of Traverse City and Marquette the collaboration is more for economies of scale, in that shared resources can potentially save money. For now this includes sharing wastewater treatment facilities and equipment with neighboring municipalities, but could also include sharing climate resources. Grand Rapids expressed particular interest in sharing resources and strategies regarding climate adaptation. Three of the six cities mentioned regional planning efforts such as transportation corridors or regional park systems. Thunder Bay, Grand Rapids and Ann Arbor participate in information sharing networks. Thunder Bay participates in the Municipal Adaptation Train the Trainers Program through the Clean Air Partnership. This organization holds conferences for many Ontario municipalities to establish a climate network. According to Thunder Bay's Infrastructure and Operations Manager, they have discussed climate downscaling tools and strategies to communicate climate science and adaptation issues. Grand Rapids attends similar workshops and is a member of the Great Lakes and St. Lawrence Cities Initiative, (GLSLCI). The GLSLCI has members from all 7 US states and both Canadian provinces in the Great Lakes Region and collaborates on water issues and lake restoration.[46] Ann Arbor established the Michigan Green Communities as part of the Michigan Municipal League and participates in the Urban Sustainability Directors Network (USDN). Both organizations collaborate on sustainability issues, and the USDN forms topic-based subgroups that hold regular conference calls.

But despite this active inter-municipal collaboration, it is rare for a city to actively collaborate with climate scientists. Of the six cities, only Ann Arbor regularly communicates with climate scientists through the Great Lakes Regional Integrated Sciences and Assessments Center (GLISA). Most cities do not have the time or resources for this level of collaboration. It is also currently a low priority among cities that are still determining if and how climate change should be included in the planning process. Thunder Bay's Infrastructure and Operations Manager stated that the most useful resource a scientist could provide is downscaled data specific to a particular city's microclimate. It must also speak to that city's unique challenges and economically significant issues. He further noted that local climate experts gain a lot of traction in the planning process because of their perceived local expertise. Ann Arbor's Environmental Coordinator has found analyses of changes already occurring in Michigan to be the most helpful resource a scientist has provided for him. The Energy and Sustainability Director of Grand Rapids stated that scientists must make the data accessible to a wider population by translating it into impacts for local communities. Data becomes very helpful to planners once it is translated into impacts such as health or economic risk. Furthermore, he states that seeing the impacts visually, such as through mapping techniques can be particularly helpful. Thus, collaboration with scientists can be very useful, and there is great interest among decision makers to collaborate if the scientists can provide relevant and precise data.

Climate Zone Analysis

Finally, the interviewees were asked to provide feedback on the climate zone maps to determine how they could become a useful tool in the planning process. Four of the six cities indicated that precipitation intensity is more important than accumulated precipitation. Most cities responded that precipitation intensity was important for planning because it causes the most deviation from standard procedure. However, the interviewees appreciated the accumulated precipitation maps for regular operational purposes like plowing. The City Planner from Marquette noted that accumulated precipitation concerns communities that struggle with snow removal. In general, the interviewees were interested to see the zone shifts and found the concept intriguing. Four of the six cities stated that they would use a zonal approach such as this to communicate with other cities in a similar climate zone. For those that would not use this approach, the general idea was that the city is not yet ready to use this approach, but may in the future. The Planning Manager and Energy Programs Associate of Ann Arbor agreed that the Michigan Association of Planners is simply not to this stage yet.

Moving forward, the interviewees suggested approaches that would make this mapping method more useful in the planning process. All cities expressed interest in a summer version of the maps, and Grand Rapids expressed interest in all four seasons. The interest in summer is mostly due to tourism, as many of these cities are tourist destinations. Thunder Bay's Infrastructure and Operations Manager added that summer is also important for significant wind events. In general, the interviewees would prefer variables that are more closely related to extreme events and impacts of climate change. For example, interviewees found frequency and duration of droughts or extreme heat events, extreme precipitation events and changes in freeze/thaw cycle to be very useful variables. Ann Arbor's Energy Programs Associate noted that the most important information for action would be the qualitative narratives that would accompany these maps rather than the maps themselves. These responses indicate that the mapping and collaboration techniques described in this paper may indeed prove useful among urban planners if they can successfully link climate data to specific impacts and response strategies.

Discussion

In the end, urban planners want climate information that is precise, relevant to their city's unique situation, and offers "on the ground" impacts and response strategies. The maps presented in this paper offer a connection between the quantitative climate models and impact analysis through case study selection and inter-municipal collaboration. Translating the model data to impacts is especially useful to planners who perceive climate data as distant, uncertain and inaccessible. Additionally, in a time of dwindling city budgets, it is important to make efficient use of information sharing to avoid financial redundancies. Many planners in the Great Lakes Region believe they need to first acquire specialized software to obtain and interpret climate data, and this hesitation delays meaningful action.[47] But this reluctance to act leaves cities vulnerable to potentially expensive impacts like increased infrastructural damage or flooding. Therefore, planners and climate scientists must work collaboratively using common language and goals to push both fields forward and reduce any rationale for inaction. Given that the zones pass the student's t-test and therefore are adequately homogeneous, planners can begin to use maps like those presented in this paper to quickly gain information about their current and projected climate. Though adaptation techniques may inherently vary between different municipalities, the climate inputs are consistent within the climate zones. These impacts are significant across all types of urban form regardless of city size or density. Following the model of organizations like Michigan Green Communities or the Municipal Adaptation Train the Trainers Program, new climate zone-specific networks could efficiently group cities into common impacts and increment of change thereby improving relevance of climate adaptation strategies among the cities involved. Therefore, providing a means of information sharing through similarity of climate impacts will be an effective way to make efficient use of existing climate resources, and help cities help themselves without relying on commissioning assessments specific to their particular municipality.

Further Development

The maps produced in this paper are a first step toward effectively communicating climate data in a way relevant to urban planning. Planners are not concerned with temperature and precipitation alone, so there is much yet to be represented through overlay mapping. However, temperature and precipitation serve as significant inputs into the climate system, and therefore underlie many of the impacts that concern planners. Specifically, the interviewees recommended summer versions of these maps to analyze impacts such as heat waves, growing season, drought frequency and duration, and extreme precipitation events. The maps can represent such impacts either through new zone definitions or overlay zones like the Freeze/Thaw zone, creating layers of impacts that more comprehensively tell the story of climate change in the region. Further development of these maps must include a greater domain to provide southern cities with case study recommendations. Additionally, it would be useful for planners to offer more short-term climate projections that are closer to the 5-10 year range of most plans in addition to the longer-term projections presented in this paper. Ideally, this analysis should also account for other bases of similarity between municipalities. To ensure greater applicability of case studies, the set of recommended cities should also be filtered by other characteristics such as city size, population density or surface permeability. By implementing these changes, the interviewees responded they would be interested in using this zonal approach to communicate with other municipalities in a similar zone. Sharing resources and strategies through such collaboration will lead to more efficient use of climate data as well as municipal time and resources for planning. Further collaboration with climate scientists, ecologists and public health experts can help to create collective resources and means of collaboration in a format that planners commonly understand. In this way, planners can effectively and efficiently begin to promote meaningful change in the urban environment.

The climate zone method described in this paper is simply a proof of concept. These maps cover only one time period, one model type, one scenario, one set of climate variables and one definition of zone boundaries. Thus, the maps presented here are by no means a complete analysis of possibility. In order to gain a full analysis, a planner must consider a set of maps that best suit the specific needs of their city based on the variables most important to them, the emissions scenario they find most realistic, and the length of time for which they choose to plan.

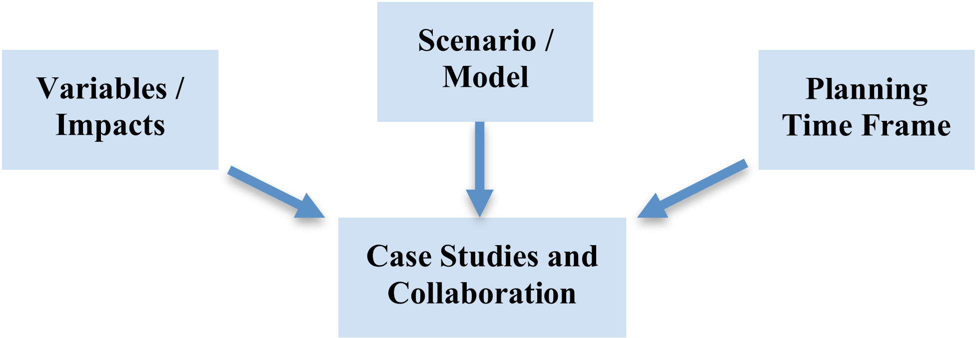


Figure 20: The three major components on which these maps are based. A city can select these to tailor a map to their specific needs and ability.

Given the layers of uncertainty in climate modeling, it is difficult for scientists to give planners definitive answers about how climate change will impact cities. Though there are no guarantees, the amount of climate information available is vast and is a critical consideration for urban planners. Many planners do consider the information adequate to plan for the future, so it is important that this information be accessible, precise and relevant so planners can make efficient use of existing resources. With these aspects in mind, urban planners and climate scientists may begin to reach a mutual understanding to advance both fields and increase climate data utility in the urban environment.

References

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[1] IPCC Fourth Assessment Report (AR4), Climate Change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change**,** Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. p.45

[2] Winkler, J.A., G.S. Guentchev, M. Liszewska, Perdinan, and P.-N. Tan, 2011: Climate scenario development and applications for local/regional climate change impact assessments: An overview for the non-climate scientist. Part II: Considerations when using climate change scenarios. *Geography Compass*, 5/6, 301–328. DOI 10.1111/j.1749-8198.2011.00426.x.

[3] United States Global Change Research Program, http://www.globalchange.gov/

[4] United States Environmental Protection Agency, "The Great Lakes: An Environmental Atlas and Resource Book," Chapter 2: Natural Processes in the Great Lakes. July 24, 2008. http://www.epa.gov/greatlakes/atlas/glat-ch2.html

[5] Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009. Page 117

[6] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson (2003). Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C.

[7] The Great Lakes: An Environmental Atlas and Resource Book, Natural Processes in the Great Lakes. U.S. Environmental Protection Agency, July 24, 2008. http://www.epa.gov/greatlakes/atlas/glat-ch2.html#Climate

[8] The Great Lakes: An Environmental Atlas and Resource Book, Sources for Maps and Production Credit. U.S. Environmental Protection Agency, September 9, 2008. http://www.epa.gov/greatlakes/atlas/glat-app.html#Sources%20for%20Maps

[9] The Great Lakes: An Environmental Atlas and Resource Book, Natural Processes in the Great Lakes. U.S. Environmental Protection Agency, July 24, 2008. http://www.epa.gov/greatlakes/atlas/glat-ch2.html#Climate

[10] City of Chicago Climate Action Plan, http://www.chicagoclimateaction.org/

[11] Hayhoe, K., VanDorn, J., Croley II, T., Schlegal, N., Wuebbles, D., (2010). Regional climate change projections for Chicago and the US Great Lakes. *Journal of Great Lakes Research, 36*, 7-21.

[12] Larsen, Steiner, Mallen, Tawfik, Kahn, Kalafatis, Sotherland, Ryen, Climate Downscaling and Urban Planning Implications in Three Great Lakes Cities, unpublished manuscript, in review at the Journal of Landscape Ecology

[13] Winkler, J.A., G.S. Guentchev, Perdinan, P.-N. Tan, S. Zhong, M. Liszewska, Z. Abraham, T. Niedźwiedź, and Z. Ustrnul, 2011: Climate scenario development and applications for local/regional climate change impact assessments: An overview for the non-climate scientist. Part I: Scenario development using downscaling methods. *Geography Compass*, 5/6, 275–300. DOI 10.1111/j.1749-8198.2011.00425.x. p. 276

[14] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson (2003). *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems.* Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. p.78

[15] Nelson et al, Laurentian Great Lakes Basin Climate Change Adaptation, National Oceanic and Atmospheric Administration, March 2011, p9

[16] Fowler, H. J. and Wilby, R. L. (2007), Beyond the downscaling comparison study. Int. J. Climatol., 27: 1543–1545. doi: 10.1002/joc.1616. p. 1545

[17] Nyuk Hien Wong, Steve Kardinal Jusuf, Chun Liang Tan, Integrated urban microclimate assessment method as a sustainable urban development and urban design tool, Landscape and Urban Planning, Volume 100, Issue 4, 30 April 2011, Pages 386-389

---

[18] National Center for Atmospheric Research, 2011 Annual Report. "A History of the Earth System Grid and Gateways." UCAR 2012. https://nar.ucar.edu/2011/lar/page/history-earth-system-grid-and-gateways-0

[19] North American Regional Climate Change Assessment Program, "NARCCAP Users' Workshops." UCAR 2007. http://www.narccap.ucar.edu/users/meetings.html

[20] Nyuk Hien Wong, Steve Kardinal Jusuf, Chun Liang Tan, Integrated urban microclimate assessment method as a sustainable urban development and urban design tool, Landscape and Urban Planning, Volume 100, Issue 4, 30 April 2011, Pages 386-389

[21] Eliasson, Ingegärd, The use of climate knowledge in urban planning, Landscape and Urban Planning, Volume 48, Issues 1-2, 20 April 2000, Page 34

[22] Eliasson, Ingegärd, The use of climate knowledge in urban planning, Landscape and Urban Planning, Volume 48, Issues 1-2, 20 April 2000, Page 38

[23] Eliasson, Ingegärd, The use of climate knowledge in urban planning, Landscape and Urban Planning, Volume 48, Issues 1-2, 20 April 2000, Page 39

[24] Eliasson, Ingegärd, The use of climate knowledge in urban planning, Landscape and Urban Planning, Volume 48, Issues 1-2, 20 April 2000, Page 40

[25] Eliasson, Ingegärd, The use of climate knowledge in urban planning, Landscape and Urban Planning, Volume 48, Issues 1-2, 20 April 2000, Page 42

[26] USDA Plant Hardiness Map, United States Department of Agriculture, 2012 http://planthardiness.ars.usda.gov/PHZMWeb/

[27] United States Department of Agriculture, "What's New." http://planthardiness.ars.usda.gov/PHZMWeb/AboutWhatsNew.aspx

[28] USDA Plant Hardiness Map, United States Department of Agriculture, 2012 http://planthardiness.ars.usda.gov/PHZMWeb/

[29] Guttman, Nathaniel and Quayle, Robert. "A Historical Perspective of U.S. Climate Divisions," National Climatic Data Center, Asheville, North Carolina. Bulletin of the American Meteorological Society, August 1995. pp 297

[30] Guttman, Nathaniel and Quayle, Robert. "A Historical Perspective of U.S. Climate Divisions," National Climatic Data Center, Asheville, North Carolina. Bulletin of the American Meteorological Society, August 1995. pp 293-303

[31] Guttman, Nathaniel and Quayle, Robert. "A Historical Perspective of U.S. Climate Divisions," National Climatic Data Center, Asheville, North Carolina. Bulletin of the American Meteorological Society, August 1995. pp 300

[32] Guttman, Nathaniel and Quayle, Robert. "A Historical Perspective of U.S. Climate Divisions," National Climatic Data Center, Asheville, North Carolina. Bulletin of the American Meteorological Society, August 1995. pp 299

[33] Guttman, Nathaniel and Quayle, Robert. "A Historical Perspective of U.S. Climate Divisions," National Climatic Data Center, Asheville, North Carolina. Bulletin of the American Meteorological Society, August 1995. pp 296

[34] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson (2003). *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems.* Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. p.19

[35] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson (2003). *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems.* Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. p.19

[36] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson (2003). *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems.* Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. p.42

---

[37] Climatic Research Unit, University of East Anglia

[38] Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were obtained from www.engr.scu.edu/~emaurer/global_data/. These data were downscaled as described by Maurer et al. (2009) using the bias-correction/spatial downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003).

[39] Larsen, Steiner, Mallen, Tawfik, Kahn, Kalafatis, Sotherland, Ryen, Climate Downscaling and Urban Planning Implications in Three Great Lakes Cities, unpublished manuscript, in review at the Journal of Landscape and Urban Planning

[40] Larsen, L., Rajkovich, N., Leighton, C., McCoy, K., Calhoun, K., Mallen, E., Bush, K., Enriquez, J., Pyke, C., McMahon, S., and Kwok, A. Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions. University of Michigan; U.S. Green Building Council, 2011., p C-33

[41] The Great Lakes: An Environmental Atlas and Resource Book, Natural Processes in the Great Lakes. U.S. Environmental Protection Agency, July 24, 2008. http://www.epa.gov/greatlakes/atlas/glat-ch2.html#Climate

[42] The Great Lakes: An Environmental Atlas and Resource Book, Natural Processes in the Great Lakes. U.S. Environmental Protection Agency, July 24, 2008. http://www.epa.gov/greatlakes/atlas/glat-ch2.html#Climate

[43] Baxter, M. A., Graves, C. E., & Moore, J. T. (2005). A climatology of snow-to-liquid ratio for the contiguous united states. *Weather and Forecasting, 20*(5), p.736

[44] Baxter, M. A., Graves, C. E., & Moore, J. T. (2005). A climatology of snow-to-liquid ratio for the contiguous united states. *Weather and Forecasting, 20*(5), p.736

[45] "Twin Cities Snowfall Event Count and Seasonal Snowfall Summary Statistics." *Minnesota Climatology Working Group*. State Climatology Office - DNR Division of Ecological and Water Resources, University of Minnesota, 2 Nov. 2011. http://climate.umn.edu/doc/twin_cities/snowmsp.htm.

[46] Great Lakes & St. Lawrence Cities Initiative, "About GLSLCI." http://www.glslcities.org/aboutus.cfm

[47] Nelson et al, Laurentian Great Lakes Basin Climate Change Adaptation, National Oceanic and Atmospheric Administration, March 2011, p10

Appendix A – Statistical Test Data

Zone	City	Longitude	Latitude	Average Precipitation (mm/day)	Average Temperature (C)
2	Milwaukee, WI	-87.96	43.07	0.1238	-4.6351
2	Saginaw, MI	-83.95	43.42	0.1289	-5.0555
2	Iowa City, IA	-91.53	41.66	0.0989	-3.9506
2	Alpena, MI	-83.44	45.06	0.1317	-5.3145
3	Duluth, WI	-92.12	46.78	0.0785	-10.043
3	Rhinelander, WI	-89.41	45.64	0.0890	-9.7112
3	Eau Claire, WI	-91.50	44.80	0.0773	-8.5985
3	Rochester, MN	-92.47	44.02	0.0736	-8.1176
4	Thunder Bay, ON	-89.26	48.42	0.1249	-12.707
4	Finmark, ON	-89.76	48.57	0.1356	-14.147
4	Raith, ON	-89.92	48.82	0.1324	-14.936
4	Atikokan, ON	-91.62	48.76	0.1088	-14.699
6	Chicago, IL	-87.63	41.87	0.1599	-2.6547
6	Detroit, MI	-83.08	42.36	0.1678	-2.3127
6	Grand Rapids, MI	-85.66	42.96	0.1686	-3.5853
6	Rochester, NY	-77.62	43.18	0.1776	-2.8303
7	Houghton, MI	-88.57	47.12	0.2054	-7.7937
7	Blind River, ON	-82.97	46.19	0.1972	-8.3838
7	Ottawa, ON	-75.69	45.42	0.2237	-8.4379
7	Sudbury, ON	-81.01	46.49	0.1936	-10.856
8	Timmins, ON	-81.33	48.47	0.1884	-14.710
8	Ville-Marie, QC	-79.44	47.34	0.1674	-12.979
8	Maniwaki, QC	-75.97	46.37	0.2109	-11.133
8	Cadillac, QC	-78.38	48.23	0.1818	-15.117
10	London, ON	-81.24	43.00	0.2568	-4.6447
10	Syracuse, NY	-76.15	43.05	0.2337	-4.0193
10	Owen Sound, ON	-80.93	44.58	0.3298	-5.1492
10	Buffalo, NY	-78.85	42.89	0.2485	-2.8745
11	Sault Ste Marie, ON	-84.33	46.52	0.2716	-8.6224
11	Parry Sound, ON	-80.03	45.35	0.3339	-7.9036
11	Collingwood, ON	-80.21	44.49	0.2473	-5.6855
11	Lowville, ON	-75.49	43.78	0.2526	-6.4861
12	Point 1	-75.30	46.20	0.2530	-12.320
12	Point 2	-75.30	46.70	0.2540	-12.693
12	Point 3	-83.90	47.30	0.2750	-12.209
12	Point 4	-84.20	47.60	0.2660	-12.834

This table contains the multi-model mean temperature and precipitation intensity data for the cities selected to represent each zone in the statistical test. Zones 1, 5 and 9 were not tested because they exist only in the mid-century projection. The four points in zone 12 do not correspond to cities because no cities are contained within that relatively small northern zone. Instead, these four points represent the zone. Each zone passed the student’s t-test with 95% confidence. Thus, the populations share a mean and can be considered homogeneous with 95% certainty.

Appendix B - City Relationship Chart

y\x	Alpena, MI	Ann Arbor, MI	Atikokan, ON	Blind River, ON	Buffalo, NY	Cadillac, QC	Chicago, IL	Cleveland, OH	Collingwood, ON	Detroit, MI	Dryden, ON	Duluth, MN	Eau Claire, WI	Finmark, ON	Fort Wayne, IN	Grand Rapids, MI	Houghton, MI	Iowa City, IA	Kirkland Lake, ON	London, ON	Lowville, ON	Madison, WI	Maniwaki, QC	Marquette, MI	Milwaukee, WI	North Bay, ON	Ottawa, ON	Owen Sound, ON	Parry Sound, ON	Peterborough, ON	Raith, ON	Rhinelander, WI	Rochester, MN	Rochester, NY	Sudbury, ON	Saginaw, MI	Sarnia, ON	Sault Ste Marie, ON	Syracuse, NY	Thunder Bay, ON	Timmins, ON	Toronto, ON	Traverse City, MI	Ville-Marie, QC
Alpena, MI	x	🟨		🟨			O			O						O		🟦				🟦		🟨	🟦					🟨				O		🟦							🟨	
Ann Arbor, MI	🟨	x		🟨			🟥	🟦		🟥	🟦				🟥	🟥																		🟥			🟥					🟥	🟦	
Atikokan, ON			x									O	O	🟦																	🟦	🟨	O							🟥				
Blind River, ON	🟨	🟨		x			O			O						O	🟦							🟥		🟦	🟦			🟥				O	🟦								🟨	
Buffalo, NY					x			🟨												🟦								🟦											🟥					
Cadillac, QC						x								🟨			O		🟥				🟨 O			🟨	O				🟨				O						🟥			🟥
Chicago, IL		🟥					x	🟦		🟥					🟥	🟥																	🟥			🟨	🟥					🟥	🟦	
Cleveland, OH		🟦			🟨		🟦	x		🟦					🟦	🟦																		🟦			🟦		🟨			🟦	🟦	
Collingwood, ON					O				x								🟨			🟨 O	🟥						🟨	🟨 O	🟥									🟥	O					
Detroit, MI		🟥					🟥	🟦		x					🟥	🟥																	🟥			🟨	🟥					🟥	🟦	
Dryden, ON			🟦 O								x			🟦 O																	🟦 O									🟦 O				
Duluth, MN			🟨									x	🟦 O																			🟥	🟦 O							🟨				
Eau Claire, WI	O											🟦	x					O				🟨			O							🟦	🟥			O								
Finmark, ON			🟦	O		🟨					🟦			x			O		🟨				🟨			🟨	O				🟥				🟨 O					🟦	🟨			🟨
Fort Wayne, IN		🟥					🟥	🟦		🟥					x	🟥																	🟥			🟨	🟥					🟥	🟦	
Grand Rapids, MI		🟥						🟦							🟥	x																					🟥					🟥	🟦	
Houghton, MI				🟦	O				🟨								x			🟨 O	🟨			🟦		🟦	🟥	🟨 O	🟨	🟦					🟦				O					
Iowa City, IA	🟦 O												🟨					x				🟥			🟥											🟦 O								
Kirkland Lake, ON				O		🟥								🟨			O		x				🟨 O	O		🟨 O	O			O	🟨				🟨 O						🟥			🟥
London, ON					🟦 O				🟨								🟨			x	🟨						🟨	🟥 O	🟨									🟨	🟦 O					
Lowville, ON					O				🟥								🟨			🟨 O	x						🟨	🟨 O	🟥									🟥	O					
Madison, WI	🟦 O												🟨					🟥 O				x			🟥 O									🟨		🟦 O								
Maniwaki, QC																			🟨				x	🟦		🟥				🟦														
Marquette, MI	🟨	O		🟥			O	O		O					O	O	🟦						🟦	x		🟦	🟦			🟥				O	🟦		O					O	🟨 O	
Milwaukee, WI	🟦 O												🟨					🟥 O				🟥			x								🟨			🟦 O								
North Bay, ON				🟦 O		🟨								🟨			🟦 O		🟨				🟥 O	🟦 O		x	🟦 O			🟦 O	🟨				🟥 O						🟨			🟨
Ottawa, ON				🟦	O				🟨								🟥			🟨 O	🟨			🟦		🟦	x	🟨 O	🟨	🟦					🟦			🟨	O					
Owen Sound, ON					🟦 O				🟨									🟨		🟥 O	🟨						🟨	x	🟨									🟨	🟦 O					
Parry Sound, ON					O				🟥								🟨			🟨 O	🟥						🟨	🟨 O	x									🟥	O					
Peterborough, ON	🟨	O		🟥			O	O		O					O	O	🟦						🟦	🟥		🟦	🟦			x				O	🟦		O					O	🟨 O	
Raith, ON			🟦	O							🟦			🟥			O		🟨				🟨 O			🟨	O				x				🟨 O					🟦	🟨			🟨
Rhinelander, WI			🟨									🟥 O	🟦 O																			x	🟦 O							🟨				
Rochester, MN	O											🟦	🟥		🟥			🟨 O				🟨			🟨 O							🟦	x			O						🟥	🟦	
Rochester, NY		🟥					🟥	🟦		🟥						🟥																		x		🟨	🟥							
Sudbury, ON				🟦 O		🟨								🟨			🟦 O		🟨				🟥 O	🟦		🟥	🟦 O			🟦	🟨				x						🟨			🟨
Saginaw, MI	🟦						🟨			🟨					🟨	🟨		🟦				🟦			🟦									🟨		x	🟨					🟨		
Sarnia, ON		🟥					🟥	🟦		🟥					🟥	🟥																		🟥		🟨	x					🟥	🟦	
Sault Ste Marie, ON					O				🟥								🟨			🟨 O	🟥						🟨	🟨 O	🟥										O					
Syracuse, NY					🟥			🟨												🟦								🟦											x					
Thunder Bay, ON	O		🟥								🟦	🟨		🟦				O							O						🟦	🟨				O				x				
Timmins, ON				O		🟥								🟨			O		🟥				🟨			🟨	O				🟨				🟨 O						x			🟥
Toronto, ON		🟥					🟥	🟦		🟥					🟥	🟥																	🟥			🟨	🟥					x	🟦	
Traverse City, MI	🟨	🟦		🟨			🟦 O	🟦		🟦 O					🟦 O	🟦 O								🟨						🟨			🟦 O				🟦					🟦 O	x	
Ville-Marie, QC				O		🟥								🟨			O		🟥							🟨	O				🟨				🟨 O						🟥			x

🟦 Shares Current Zone
🟨 Shares Future Zone
🟥 Shares Current and Future Zone
O City x Lies in City y's Projected Zone (Good Case Study Candidate)

Note: Several southern cities do not have case study recommendations because their projected zone lies south of the domain in the present climate map (1971-2000). This chart is based on the precipitation intensity and average temperature climate zones presented in Figure 15 in the text.