CLIMATE CHANGE IN THE GREAT LAKES REGION AND DAYTON, OHIO

GLISA
A NOAA RISA TEAM

This document describes the City of Dayton's exposure to historic, current, and projected future changes in weather and climate.

Great Lakes Regional Summary

- Average air temperature in the Great Lakes region has increased by 2.3°F
- Average air temperature is projected to rise 3°F to 6°F by the mid-21st century.
- Total annual precipitation has increased by 14% in the region with significant intra-regional variation.
- The total volume of rain falling in the most extreme 1% of events has increased 35%.
- Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain).

A. Climate Change Profile for the Great Lakes Region

The climate of cities throughout the Great Lakes region is already changing. Rising temperatures are leading to more storm activity in our atmosphere, helping to fuel extreme weather and increased precipitation. While heat, drought, and other changes associated with climate change remain a concern for the future, many areas of the region are already facing challenges associated with more total precipitation and more frequent downpours.

Temperature

Average annual temperatures in the Great Lakes region have increased by 2.3°F since 1951, faster than the global and national rates. Most of this warming has been observed during the late spring and early winter, and in overnight low temperatures. The average temperature for the Great Lakes region is projected to increase in the future (3°F to 6°F by 2050), and many of the northern parts of the region will likely experience the most change. The region is projected to see increases in the number of hot and very hot days by the end of the 21st century, with projections indicating the region will see 17 to 42 more days over 90°F in an average year compared to the late 20th century.

Precipitation

The Great Lakes region has experienced changes in the frequency, amount, and form of precipitation. Total precipitation has increased by 14% since 1951 across the region, though this change varies within the region. Therefore, more local data should be used where available. In addition, heavy precipitation (over 1.25" of rainfall in 24hrs) has increased rapidly throughout the region. The amount of rain falling in the most extreme events (heaviest 1% of storms) has increased by 35% and these events have generally become more frequent since 1951. Much of the region is projected to experience more average annual precipitation with total amounts ranging from an additional 2 to 6 inches per year by the end of the 21st century. In addition, the Great Lakes themselves are projected to contribute more water vapor to the air. This increase in moisture combined with rising temperatures, which are necessary for storm formation, will likely produce more intense storms in the future.

Climate change will likely accelerate in the future.

The observed trends in temperature, precipitation, and seasonality are projected to continue or accelerate into the future. The rate of warming has been fastest during the winter, with some locations experiencing twice the annual warming rate of the Great Lakes region. Temperatures will continue to warm at a pace near or faster than the current rate, and precipitation will likely continue to increase, though variability and multi-year dry periods should still be anticipated. By mid-century, summer and spring temperatures may have greater increases compared to fall and winter.

Preparing for the next normal, not a new normal.

The climate system is dynamic and will continue to change rapidly due to greenhouse gas emissions and inherent feedback systems. The challenges, priorities, and risks of the current or next generation climate will continually change and will affect all sectors. Importantly, climate and weather conditions will not change to a new set of static conditions. This means long-term planning efforts in all departments should regularly evaluate climate and be as flexible and adaptable as possible. Assessing vulnerabilities of a city's assets is a first step toward this goal.

The following table summarizes how various climate risk factors in the Great Lakes region are expected to change in the future. The number and direction of arrows indicate the relative projected trend for mid-century and end of century. A single arrow indicates a projected moderate increase or decrease by mid-century, and two arrows indicate a substantial increase or decrease by end of century.

Table 2: Climate Change in the Great Lakes Region

Risk	By Mid Century	By End of Century	Summary
Convective Weather (Severe Winds, Lightning, Tornadoes, Hail)	**Uncertain***	**Uncertain***	While extreme precipitation has increased in the region, specific severe weather types (e.g., tornadoes and hail) have remained relatively stable over time.
Severe Winter Weather (Ice/Sleet Storms, Snow Storms)	**Uncertain***	↑	Warmer, shorter winters will reduce the length of winter and winter-related impacts. However, some areas may see more ice, sleet, freezing rain, and wet snow with slightly warmer winter temperatures.
Extreme Heat	↑	↑↑	The number of extremely hot days, those over 95°F and 100°F, will likely increase, though not as fast as in areas farther south. Overnight lows have warmed faster than daytime highs, which may lessen opportunities for relief during heat waves.
Extreme Cold	↓	↓↓	The number of extremely cold days (i.e., days below 10ºF) have decreased in the region and are projected to decrease even more in the future.
Dam Failures	↑	↑↑	Stronger and more extreme precipitation events coupled with aging dam infrastructure will increase the probability of dam failure, if appropriate measures are not taken.
Flood Hazards	↑	↑↑	Stronger and more extreme precipitation events will be more likely to overwhelm stormwater infrastructure without appropriate adaptation efforts.
Wildfires	**Uncertain***	↑	Summer drought and the number of consecutive dry days may increase in the future, despite more precipitation annually, increasing the risk of wildfires.
Drought	**Uncertain***	↑	Summer drought and the number of consecutive dry days may increase in the future.
Infestation	↑	↑	With shorter winters and longer growing seasons, conditions may become more suitable for invasive species and pests currently found elsewhere and distribute vector-borne illnesses.

**Boxes labeled uncertain reflect either a lack of available data to discern a trend or no apparent trend from existing data.*

The arrows in this table reflect a qualitative assessment made by the project team based on the best available data for the Great Lakes region. While these trends hold true for projections for most of the region, they should not be assumed to hold true for any particular location. Data used to make this assessment is provided by the NOAA Technical Report NESDIS 142-3 and the Third National Climate Assessment.

B. Dayton City Summary

Dayton City Summary

- Average air temperature in Dayton has increased by 0.9°F.
- Average air temperature is projected to rise 3°F to 5°F by the mid-21st century.
- Total annual precipitation has increased by 28.5%.
- The total volume of rainfall in extreme events (heaviest 1% of storms) has increased by 71%.
- Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain).

The following is a summary of historic as well as projected changes in climate specific to Dayton. This information is valuable in helping us understand what changes we have already experienced as well as what changes we anticipate.

Table 3: Historic and Projected Changes in Climate for the City of Dayton

	Historic (1981-2010)	Mid-Century Projections (High Emissions)	End of Century Projections (High Emissions)	Change Mid-century/ End of century	Percent Change* Mid-century/ End of century
Average Temperature	52.2°F	55 to 57°F	57 to 62°F	3 to 5°F / 5 to 10°F	5 to 9% / 9 to 19%
Winter	30.1°F	31 to 34°F	35 to 38°F	1 to 4°F / 5 to 8°F	3 to 13% / 16 to 26%
Spring	51.4°F	53 to 56°F	56 to 62°F	2 to 5°F / 5 to 11°F	3 to 9% / 9 to 21%
Summer	72.7°F	77 to 80°F	82 to 85°F	4 to 7°F / 9 to 12°F	6 to 10% / 13 to 17%
Fall	54.3°F	56 to 60°F	58 to 66°F	2 to 6°F / 4 to 12°F	3 to 10% / 7 to 22%
Average Low Temperature	42.8°F	46 to 48°F	49 to 53°F	3 to 5°F / 6 to 10°F	7 to 12% / 14 to 24%
Average High Temperature	61.6°F	65 to 68°F	67 to 72°F	3 to 6°F / 5 to 10°F	6 to 10% / 9 to 17%
Days/Year Greater than 90°F	10.7 days	32 to 52 days	52 to 86 days	21 to 41 days / 41 to 75 days	199 to 386% / 386 to 704%
Days/Year Greater than 95°F	1.9 days	7 to 19 days	Not Available	5 to 17 days / Not Available	268% to 900% / Not Available
Days/Year Less than 32°F	105.3 days	81 to 84 days	Not Available	-24 to -21 days / Not Available	-23% to -20% / Not Available
Total Annual Precipitation	40.9 in.	37 to 45 in.	37 to 47 in.	-4 to 4 in. / -4 to 6 in.	-10 to 10% / -10 to 15%

Table 3: Historic and Projected Changes in Climate for the City of Dayton					
Winter	8.1 in.	7 to 15 in.	6 to 17 in.	-1 to 7 in. / -2 to 9 in.	-14 to 85% / -26 to 110%
Spring	12.1 in.	9 to 15 in.	10 to 17 in.	-3 to 3 in. / -2 to 5 in.	-26 to 24% / -17 to 40%
Summer	11.2 in.	9 to 13 in.	8 to 13 in.	-2 to 2 in. / -3 to 2 in.	-20 to 16% / -29 to 16%
Fall	9.4 in.	8 to 10 in.	8 to 11 in.	-1 to 1 in. / -1 to 2 in.	-15 to 6% / -15 to 17%
Heavy Precipitation Days	6.1 days (> 1.25")	5.7 to 9.7 days	6.1 to 10.5 days	-0.4 to 3.6 days / 0 to 4.4 days (> 1")	-7 to 59% / 0 to 72%

**Percent change is calculated as the difference between the projected values and the historic average, divided by the observation and multiplied by 100.*

Data provided in this table is described in the "About the Data" section for "GHCN", "CMIP3", and "Dynamically Downscaling for the Midwest and Great Lakes Basin."

Temperature and Hot/Cold Extremes

Average Temperature

The average air temperature in Dayton has increased by 0.9ºF from 1951 to 2017, with the current annual average temperature being 52.2ºF. Average seasonal temperatures have also increased, with spring experiencing the greatest increase of 2.2ºF. Average temperatures in Dayton are projected to increase 3.0 to 5.0ºF by mid-century under a business as usual (i.e., high emissions) scenario, with winter having the greatest increases of 4.0 to 7.0ºF.

Hot Days

Days with temperatures at or above 90°F are common with multiple occurrences in most years and no clear increasing or decreasing trend. Many years on record have experienced 2 to 6 consecutive days over 90°F, with events of 7 to 16 consecutive days occurring less frequently. By mid-century (i.e., 2050), models suggest an increase of anywhere from 21 to 41 more days per year over 90°F, and an increase of 41 to 75 more days per year over 90°F by end of century. Models are not able, however, to tell us if those days will be consecutive or not.

Days with high temperatures at or above 95°F are much rarer, with many years seeing at least one occurrence of more than one consecutive day experiencing maximum temperatures over 95°F. By mid-century (i.e., 2050), models suggest an increase of 5 to 17 days over 95°F. However, such hot days will not necessarily occur consecutively.

Heat waves can result from a combination of different drivers including high humidity, daily high temperatures, high nighttime temperatures, stagnant air movement, etc. In the future, models project an increase in the number of days experiencing high temperatures that could lead to additional heat waves, especially since air stagnation events are projected to increase. There is greater certainty that summer nighttime low temperatures will continue to increase, thereby making it more difficult to cool off at night during extended heat events. In addition, any periods of future drought will also contribute to extreme heat.

Cold Days

On average, Dayton experiences 105.3 days per year that fall below freezing (32°F). Historical records show this number has decreased already. The city is projected to experience fewer nights below 32°F, with decreases of 21 to 24 days by mid-century.

Days with temperatures at or below 10°F are very common and have not experienced any clear trends over time. Consecutive days at or below 10°F are also frequent, and typically last for 2 to 5 days with less frequent occurrences lasting 6 to 12 days. In the future, there are projected to be even fewer very cold days, so this type of event will be even rarer.

Precipitation and Flood/Drought Indicators

Average Precipitation

The amount of total annual precipitation in Dayton has increased by 28.5% (9.9") from 1951 to 2017. An increase in precipitation was observed in all four seasons, with the fall seeing the greatest percentage increase of 53.3% (3.8"). Average annual precipitation in Dayton is projected to increase by up to 4 inches by mid-century and by up to 6 inches by the end of the century.

Heavy Precipitation

The frequency and intensity of severe storms has increased historically, with an 85% increase in the number of extreme precipitation events (heaviest 1% of storms) and a 71% increase in the total volume of rainfall during these events between 1981-2010. Dayton is projected to experience an increase of up to 3.6 days of heavy precipitation (days with over 1" of rainfall) per year by mid-century and by up to 4.4 days per year by end of century.

Flooding results when rainfall volumes exceed the capacity of natural and built infrastructure to handle precipitation. Stormwater managers look at several different "design" storms (inches falling over a certain length of time) when designing and managing their systems. These "design" storms are effectively the probability of any given amount of precipitation falling in a set period of time, based on historical experience. Monitoring over time shows that the volumes falling during these "design" storms are increasing. What this means is that the values used to build our existing infrastructure (Bulletin 71 (Huff and Angel, 1992), used data through 1986, and Atlas 14 (NOAA HDSC) added a longer period of data into the 21st century) are dependent on fluctuating estimates of rainfall.

The table below shows precipitation volumes in inches for both Bulletin 71 and Atlas 14 (Bulletin 71/Atlas 14) along with percent change between the two in brackets. This data shows how the "design" storm has changed over time.

In the Great Lakes region, projected changes in seasonal mean precipitation span a range of increases and decreases. In the winter and spring, the region is projected to experience wetter conditions as the global climate warms. By mid-century, some of this precipitation may manifest in the form of increasing snowfall, but projected warmer conditions by end of century suggests such precipitation events will most likely be in the form of rainfall (Wuebbles et al. / USGCRP, 2017).

Precipitation events of more than 2" in a day (i.e., 24-hour period) are projected to increase by up to one day by mid-century and up to about 2 days by end of century. Precipitation events of more than 3" in a day are projected

Table 4: Precipitation Frequencies for the City of Dayton

	1-Yr	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr
1-hr	1.10 in. / 1.11 in. [0.9%]	1.34 in. / 1.34 in. [0%]	1.64 in. / 1.65 in. [0.6%]	1.88 in. / 1.89 in. [0.53%]	2.21 in. / 2.20 in. [0.5%]	2.50 in. / 2.45 in. [-2%]	2.84 in. / 2.69 in. [-5.3%]
12-hr	2.03 in. / 1.93 in. [-4.9%]	2.49 in. / 2.31 in. [-7.2%]	3.04 in. / 2.83 in. [-6.9%]	3.47 in. / 3.25 in. [-6.3%]	4.09 in. / 3.81 in. [-6.8%]	4.63 in. / 4.26 in. [-8.0%]	5.25 in. / 4.72 in. [-10.1%]
24-hr	2.33 in. / 2.26 in. [-3.0%]	2.86 in. / 2.71 in. [-5.2%]	3.49 in. / 3.32 in. [-4.9%]	3.99 in. / 3.80 in. [-4.8%]	4.70 in. / 4.45 in. [-5.3%]	5.32 in. / 4.98 in. [-6.4%]	6.04 in. / 5.51 in. [-8.87%]

This table does not show projections for how the design storm may change in the future due to climate change.

to increase by less than a day by both mid-century and by end of century.

Annual snowfall totals have been variable, with a slight increasing trend in the last 40 years. There has been a slight decreasing trend in days with snowfall (over 0.1" of snowfall in 24 hrs), with varying year-to-year conditions. Warmer temperatures in the future will cause some winter precipitation to transition from snow to rain over time. The projected change in annual snowfall is variable. Annual snowfall is projected to decrease by 2" to 10" by mid-century, with decreases of 7" to 15" by end of century.

Rain Free Periods (3-week events with less than 0.5" of rain)

Drought, defined here as periods of 3 weeks with less than 0.5" of rainfall, has been highly variable year-to-year, with an overall decreasing trend most prominent in summer events. In the future, even though more annual precipitation is projected overall, more is anticipated to fall in shorter, extreme events. Thus, there will be longer periods of time that experience no rainfall, increasing the potential for drought.

About the Climate Change in the Great Lakes Region and Dayton Data

Coupled Model Intercomparison Project (CMIP) Version 3. The future (mid-century) climate projections for Dayton are based on the Coupled Model Intercomparison Project Version 3 (CMIP3) A2 emissions scenario, representing "business as usual" high emissions scenario. These data were selected because they were used in the Third National Climate Assessment (Melillo et. al., 2014). More information is available at: https://www.wcrp-climate.org/wgcm-cmip

"Dynamical Downscaling for the Midwest and Great Lakes Basin." Future projections are based on the dynamically downscaled data set for the Great Lakes region developed by experts at the University of Wisconsin-Madison. There are a total of six downscaled models that represent how a variety of different variables are projected to change (mid-century, 2040-2059, compared to the recent past, 1980-1999). The ranges are comprised of the lowest and highest values from all six dynamically downscaled data sets. The regional data are available for download at: http://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php.

National Oceanic and Atmospheric Administration National Centers for Environmental Information Global Historical Climatology Network Station Observations (GHCN). More information about this station located in Dayton, OH from 1981-2010 is available at: http://glisa.umich.edu/station/W00093815

"National Oceanic and Atmospheric Administration ThreadEx Long-Term Station Extremes for America". ThreadEx is a data set of extreme daily temperature and precipitation values for 270 locations in the United States. For each day of the year at each station, ThreadEx provides the top 3 record high and low daily maximum temperatures, the top 3 record high and low daily minimum temperatures, the top 3 daily precipitation totals, along with the years the records were set for the date (NCAR, 2013). ThreadEx data: http://threadex.rcc-acis.org/

National Oceanic and Atmospheric Administration Hydrometeorological Design Studies Center Atlas 14 Precipitation Frequency Estimates. Data are available at: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

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