Geddy Davis, The Ohio State University

A thunderstorm lights up the night sky around The Ohio State University's West Campus.

Climate and weather

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Learning objectives

- Define weather and climate and the differences between them, and identify ways in which each affect society and the natural world.
- Understand Ohio's unique location and how it affects our weather and climate.
- Learn how geography, weather patterns, and global climate zones are all connected.
- Recognize both natural and human-caused climate change and the differences between them.
- Learn the primary impacts of climate change in Ohio and how they influence phenology (behaviors and interactions of living things), natural resources, and society.
- Incorporate weather and climate awareness into both OCVN responsibilities and volunteer service of your interest, including community science and education.

Few things on Earth are more dynamic than weather and climate. They bring about distinct beauty and enjoyment but also harsh conditions that can negatively impact communities and ecosystems. Whether it is your everyday sunshine, rain shower, or the larger shift of the seasons, weather and climate affect every part of our lives. As enjoyers and observers of nature, you have no doubt been influenced by these forces. Daily preparations for both work and play are often guided by weather forecasts, and seasonal activities are based on what the region's local climate has to offer. Cool-weather hikes to enjoy foliage? Reserve that for Autumn. That ski trip? Anytime after the winter holidays, please. Catching lightning bugs? Save that for warm summer nights.

Ohio Certified Volunteer Naturalists are often asked questions about the annual progression and variations of the state's plant and animal species. When do tree buds typically burst? Why do we see certain insects only in the summer? What is the best time of year for the growth of a certain plant? Why did those wildflowers bloom earlier than normal? Why are we seeing a larger population of this insect than usual? The truth is weather and climate are key components of the answers to these questions.

With climate change impacts increasing as the planet warms, you are likely to encounter questions about how changes in Ohio's climate may influence the environment, ecosystems, the growing season, and people. This module is designed to boost your knowledge about the differences between weather and climate, how both influence Ohio's unique environment and ecosystems, and things you can do to mitigate and adapt to climate change within the scope of your duties as a volunteer naturalist.

This Climate and Weather chapter is being made available for summer programming. It will be a part of the revised Ohio Certified Volunteer Naturalist (OCVN) Handbook which will be available for purchase later this year at extensionpubs.osu.edu. Content is subject to change.

Weather versus climate

Weather

Weather is defined simply as the current state of the atmosphere with respect to our everyday lives and activities. As a result, weather variables typically include things we can measure, like temperature, humidity, precipitation, wind speed, and direction. The definition of weather focuses on what the atmosphere is doing over short time scales made up of minutes, hours, and days. For example, during the summer in Ohio, it is common for meteorologists to track showers and thunderstorms that form during hot and humid afternoons. An individual rain shower or thunderstorm may be very small in geographic size and typically only lasts a few minutes. On the other hand, organized winter storms that usually impact a region in the winter months are large, can impact numerous states, and may go on for multiple hours or even days.

Multiple types of weather can even occur in a single day, such as the passage of a frontal system that often starts with a warm morning, followed by a stormy afternoon, and finishes with a cool, cloudy evening. Weather forecasts focus on this short time scale. For example, it is difficult to find an accurate weather forecast that extends beyond seven days simply because tiny errors in short-term forecasts grow into massive forecast errors after a week or two. Attempts to keep up with these errors often lead to inconsistent forecasts.

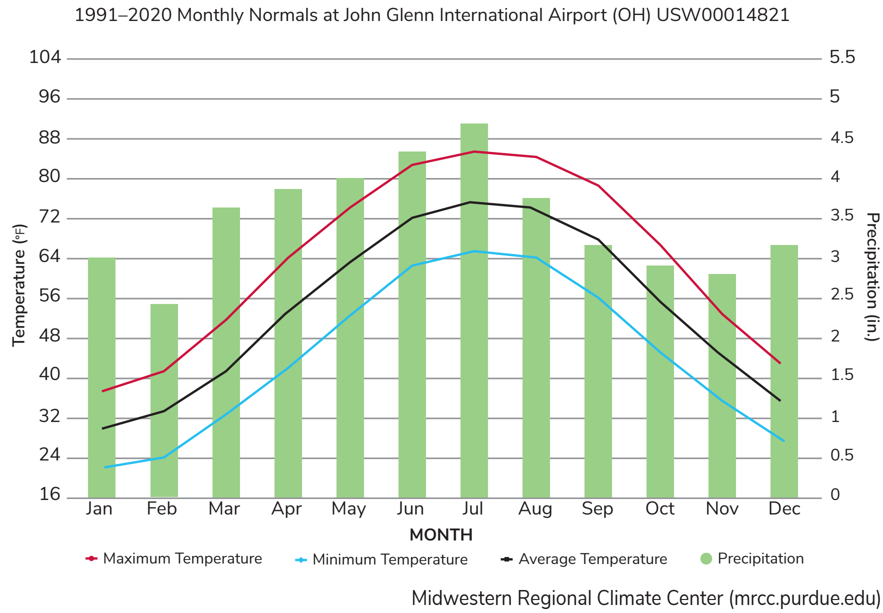
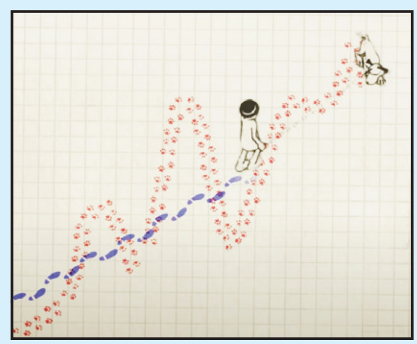


Figure 3-1. An example of plotted climate data from John Glenn Columbus International Airport.

TRY IT!

Weather v. climate

After reading the Weather and Climate section, search online for the video, "From Walking the Dog To Weather and Climate." Using the reading or the video, describe the similarities and differences between weather and climate.



Video: "Extreme Weather in a Warming World"—**vimeo.com/737206004/b157ab42ba**.

Climate

Climate is defined as the long-term pattern of weather variables, such as temperature and precipitation. The phrase "long-term" indicates that the timescale of climate is much larger than weather. In this case, climate covers months to years of time. Climate data is represented by statistics, such as averages and extremes, and help to determine patterns among measurements of temperature, precipitation, and and other weather variables. These statistics can be based on different windows of time, but the National Weather Service usually uses a 30-year window. Climate statistics describe the conditions that cities and regions of the world may expect for a particular month or year. A simple baseball analogy can help clarify this: Individual days of weather can be represented by the measure of what happens in individual at-bats, whereas climate equates to the statistics that measure a player's season or entire career. For example, using the most recent 30-year normal (1991–2020) for precipitation, Ohio receives an average of 3.51 inches during the month of August. Likewise, we can state that the normal temperature in Columbus in February is 32.5 degrees Fahrenheit, because that was the average of all Februaries from 1991 to 2020. Sometimes it is useful to compare averages from one period to the averages of a different period to see how conditions have changed over time. In Ohio, for example, we can compare temperatures and precipitation from the first half of the 20th century (a drier period in Ohio's historical record) to the past 30 years (the wettest period in recent history).

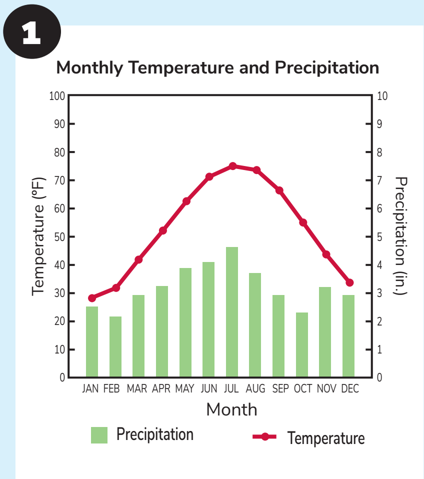
TRY IT!

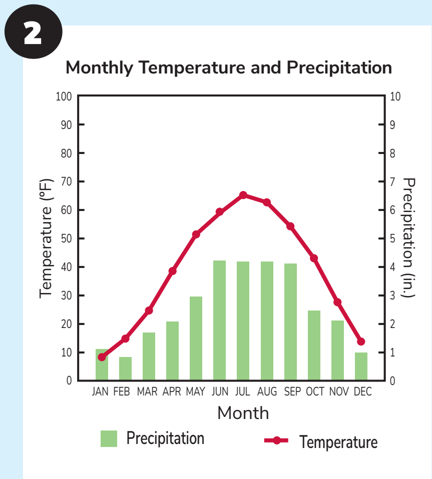
Traveling climates of the United States

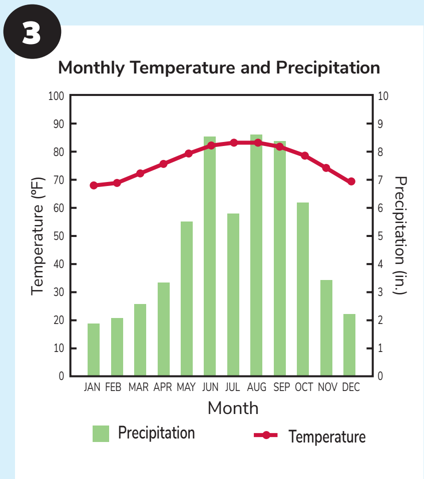
This activity was developed by Ohio State's Byrd Polar and Climate Research Center to compare the climates near cities around the United States.

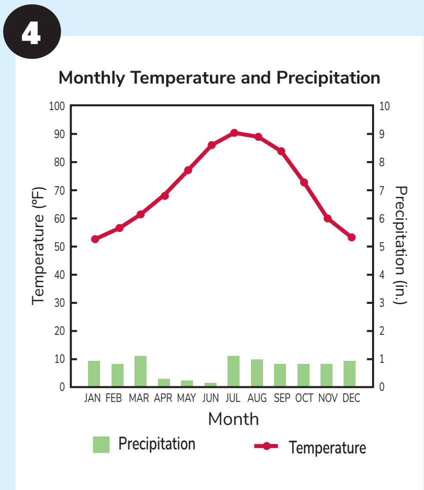
Part 1: You have likely traveled elsewhere in the United States and have a sense of the climate in that location. See if you can match each of the six photos with the location on the map where they were taken. What features in the photo are particularly valuable in making these matches? Give yourself a moment for this question to "grow" on you.

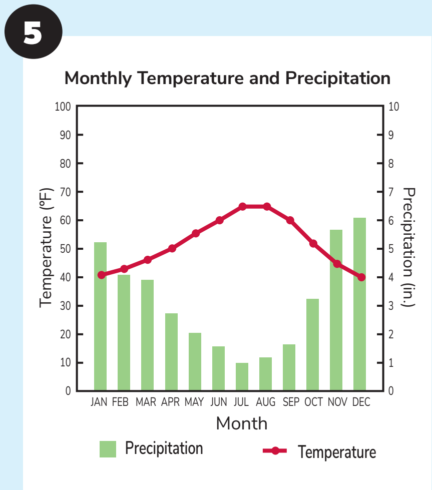
Part 2: You will now be given monthly climate averages (1981–2010) for temperature and precipitation for weather stations near each of the six locations. See if you can match these. Remember, you can always look back to the photos. Which locations are easiest to make matches? What features of temperature and precipitation stood out and helped you make the matches? How are the other five locations different from Columbus, Ohio?

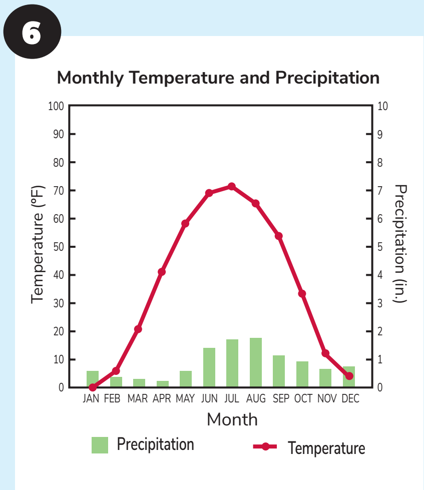












Answer Key

Columbus, OH: B,1
Duluth, MN: A, 2
Miami, FL: C, 3
Phoenix, AZ: D, 4
Seattle, WA: E, 5
Utqiagvik, AK: F, 6

Tools to study weather and climate

While tools to measure weather and climate have been around since the mid-1700s (thermometers, rain gauges, etc.), we have also had numerous technological advances. Doppler radar and satellites are more advanced technologies used to observe and measure weather and climate in conjunction with more traditional on-ground methods, such as backyard thermometers and rain gauges. Researchers are also able to indirectly measure weather and climate from the distant past using different physical “proxies,” such as pollen, tree rings, and ice and sediment cores. Some of these records extend tens of thousands to even hundreds of millions of years ago and are especially useful in comparing our current climate with that of ages past. Ohio State’s Byrd Polar and Climate Research Center specializes in some of these measurements.

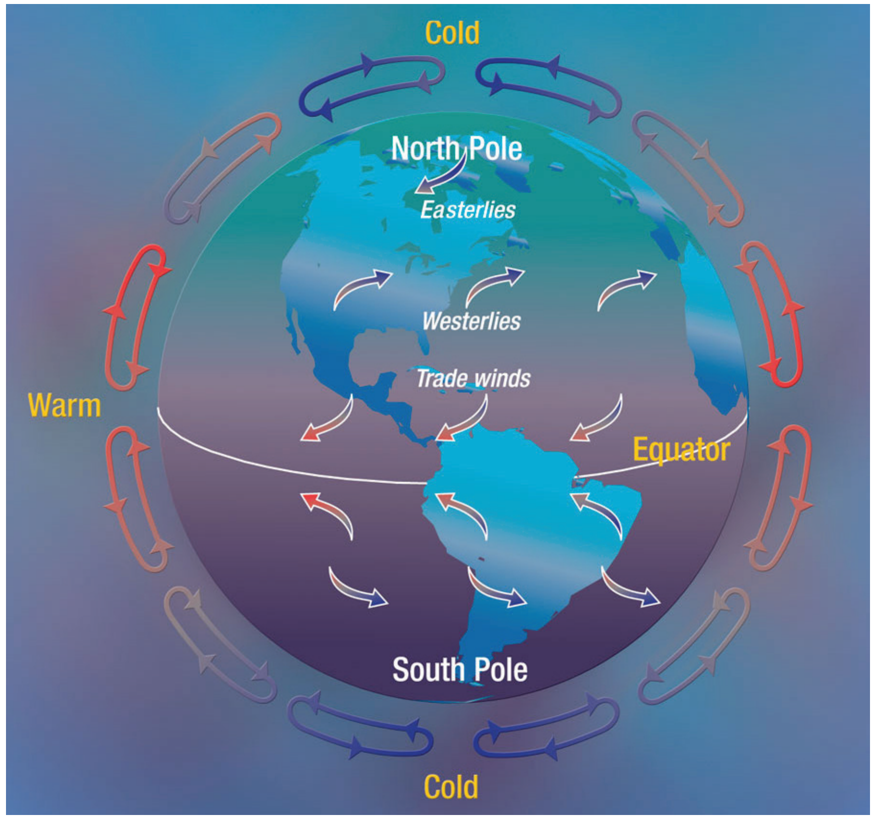
Understanding place

To understand Ohio's weather and climate, we first need to know where Ohio exists within what is known as Earth's climate system. The climate system is primarily influenced by five interacting components: atmosphere (air), lithosphere (land), hydrosphere (water), cryosphere (ice), and biosphere (living things). It is also heavily influenced by the sun, which is the primary source of energy for all five of these spheres.

Greenhouse effect

The sun serves as fuel for Earth's climate system, with differing interactions among solar radiation, Earth's surface, and atmosphere. These interactions serve to establish or alter weather and climate patterns across the globe. Incoming solar radiation from the sun enters Earth's atmosphere, which is composed primarily of nitrogen, oxygen, and a small percentage of other gases, such as water vapor, carbon dioxide, and methane. A large majority of incoming solar radiation is unimpeded by the gases in our atmosphere. In other words, they are not very good at absorbing this type of short wavelength energy. We call it the atmospheric window. What is not reflected or absorbed by clouds strikes Earth's surface. Here, the incoming solar energy can again be reflected or absorbed, depending on the type of surface and its albedo—a measure of a surface's reflective ability.

Darker surfaces have low albedos and absorb most of the incoming light and solar radiation, and brighter surfaces have higher albedos that serve to reflect most incoming solar radiation and light back into the atmosphere. Surfaces with low albedos convert most of this absorbed energy into heat, which is then radiated into the surrounding environment. Most people can recognize this effect on a sunny, cold day in winter. A dark black jacket keeps the wearer warmer than a lighter-colored jacket as a result of its lower albedo and larger absorption of energy.



Source: University Corporation for Atmospheric Research

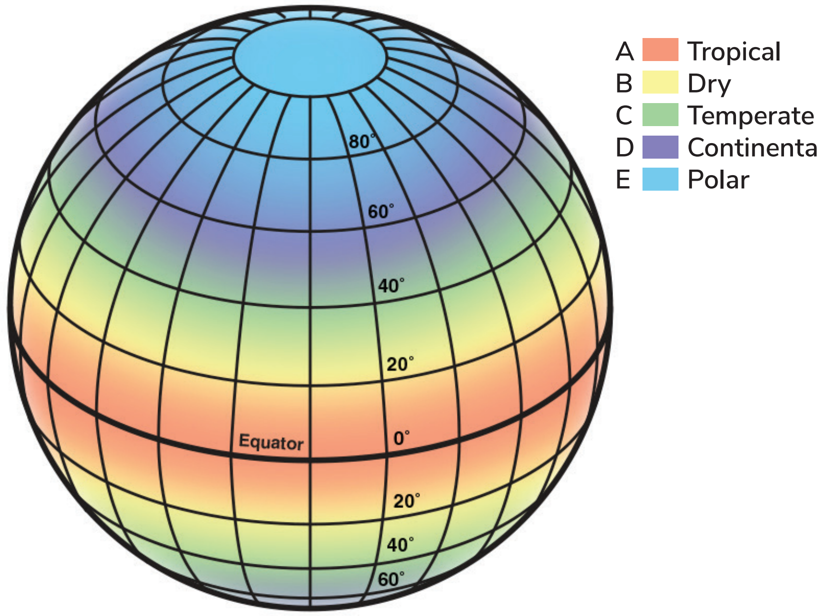
Figure 3-2. A basic image of Earth's atmospheric circulation

Most of the heat that is radiated into the atmosphere from the surface is gradually absorbed and radiated back towards the surface by trace gases that make up the atmosphere, known as greenhouse gases. These gases include water vapor, carbon dioxide, and methane. This limits the loss of heat to space and moderates Earth's global temperature to a level where life is sustainable. This is called the greenhouse effect. Without it, heat would be given off into space and Earth would be much colder. (WMO, 2019).

Atmospheric circulation

The impacts of the sun-atmosphere-surface interaction can be found by discussing two geographically important regions of Earth's climate: the poles and the equator. The North Pole and South Pole are at opposite geographic points: latitude 90 degrees north and 90 degrees south, respectively. The equator (latitude 0 degrees) is halfway between the poles and serves as a "dividing line" between Earth's hemispheres. Regions around the equator are known as the tropics. Here, the sun's rays strike Earth the most directly and consistently. With their most consistent exposure to sunlight and available moisture from the oceans, the tropics have warm, wet conditions. This is the opposite of the polar regions, where the sun's rays hit Earth at a low and sharp angle. This sharp angle means the sunlight is more spread out on the surface, so there's less energy per unit surface area to absorb. This also means sunlight has to pass through more of the atmosphere, so more of it gets absorbed or reflected by clouds before reaching the surface. As a result, these regions see significantly less sunlight and, due to the presence of snow and ice with high albedo, reflect most of it skyward.

The temperature and energy differences between these two regions lead to circulations of air, with warm air rising and flowing north/south away from the equator toward the poles. This air then cools and sinks, gradually making its way back toward the equator. As Earth rotates counterclockwise around its axis of rotation, this air does not travel straight north/south. It instead is steered into multiple cells, meandering via the impacts of the Coriolis effect. The Coriolis effect is an apparent force that, due to the rotation of Earth, makes currents of air appear to steer off their straight-line trajectory. You can study this effect on a small scale, such as attempting to throw a ball on a moving merry-go-round at your local park. This leads to circulating air being deflected toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere (NOAA Ocean Service, 2013). This circulatory process drives all weather and climate on Earth (Figure 3-2).



Source: National Oceanic and Atmospheric Administration SciJinks (scijinks.gov/climate-zones)

Figure 3-3. A generalized overview of Earth's climate zones, from the equator to the poles. Polar latitudes begin at 66.5 degrees north (Arctic Circle), Midlatitudes range from 23.5 degrees north to 66.5 degrees north (average around 40 degrees north), and tropics begin south of 23.5 degrees north.

Seasonal variability

Ohio is neither tropical nor polar in nature. Rather, it lies somewhat in the middle of these two regions in an area called the midlatitudes. As a result, Ohio often sees a surprising variety of weather and changing seasons. Seasons occur due to Earth's tilt as it orbits eliptically around the sun.

We observe four seasons in Ohio: winter, spring, summer, and autumn. During winter, the Northern Hemisphere is tilted away from the sun while in orbit, resulting in a lower sun angle and shorter days. This is why shadows in the winter are longer throughout the day. This is the opposite in summer, when the Northern Hemisphere is angled toward the sun in orbit, resulting in a higher sun angle and longer days. Spring and autumn are 'transitions' when the sun is shining equally on both Northern and Southern hemispheres. It's important to note that the distance between the sun and Earth does not change in an appreciable way over the course of a year, contrary to a common misconception.

This variance also influences the circulatory processes previously mentioned. In winter, for example, less sunlight in the midlatitudes means polar air migrating south toward the equator is colder and more persistent. During the summer, the midlatitudes see more sunlight, and more equatorial air migrating north. Each season, as a result, has its own distinct look and feel. Other local factors, such as elevation and the proximity of oceans and mountain ranges, mean that climates can be quite different between two locations even if they are the same distance from the equator.

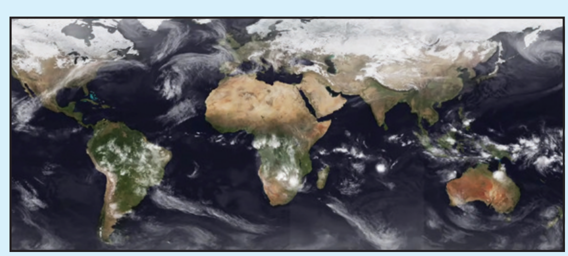
Climate zones

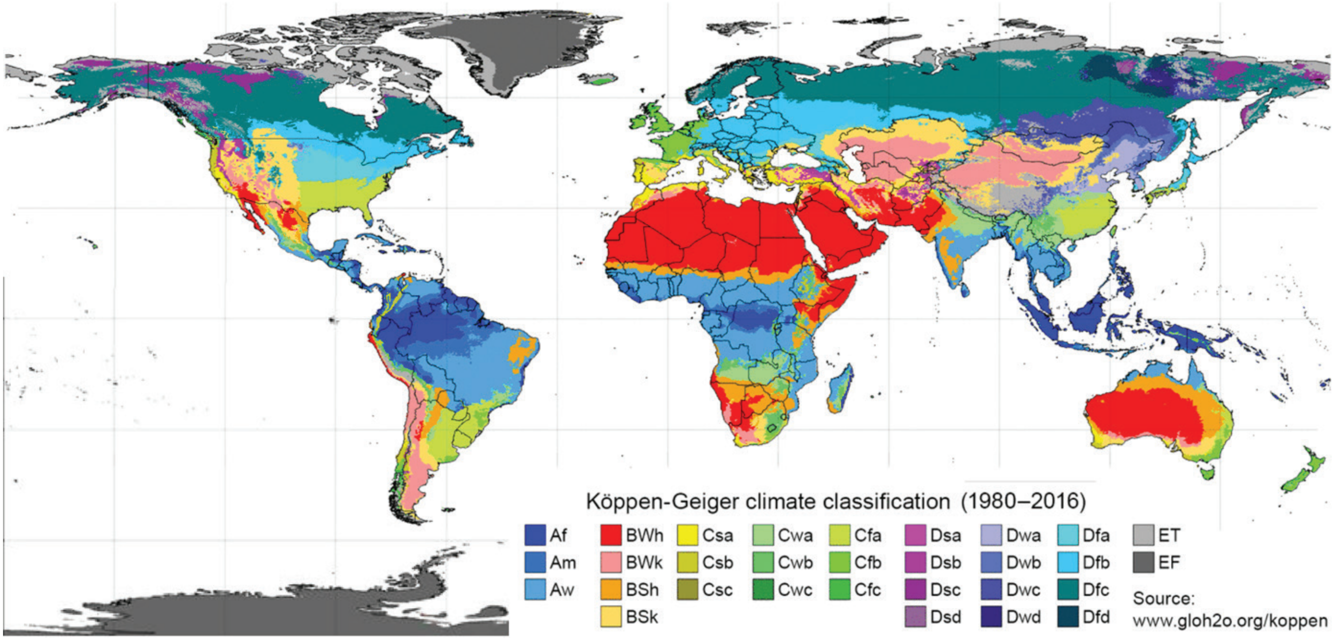
To help organize locations on Earth that have similar conditions, scientists who study the atmosphere and ecosystems have divided the planet into different climatic zones (Figure 3-3). One of the most widely used climate zoning methods that integrates both Earth's atmospheric circulation and such outside factors as geography and vegetation is the Köppen-Geiger climate classification system (Beck et al., 2018) (Figure 3-4). For more information on the system, search online for "National Geographic – Koppen Climate Classification" (**education.nationalgeographic.org/resource/koppen-climate-classification**).

TRY IT!

Weather patterns

Watch this satellite imagery loop, "A Year of Weather 2013," at **youtube.com/watch?v=m2Gy8V0Dv78** (from EUMETSTAT). Focusing on North America (top left), are the clouds random? Are they often organized into particular patterns? What do those patterns look like?





Af	Tropical, rainforest
Am	Tropical, monsoon
Aw	Tropical, savannah
BWh	Arid, desert, hot
BWk	Arid, desert, cold
BSh	Arid, steppe, hot
BSk	Arid, steppe, cold
Csa	Temperate, dry summer, hot summer
Csb	Temperate, dry summer, warm summer
Csc	Temperate, dry summer, cold summer
Cwa	Temperate, dry winter, hot summer
Cwb	Temperate, dry winter, warm summer
Cwc	Temperate, dry winter, cold summer
Cfa	Temperate, no dry season, hot summer
Cfb	Temperate, no dry season, warm summer
Cfc	Temperate, no dry season, cold summer
Dsa	Cold, dry summer, hot summer
Dsb	Cold, dry summer, warm summer
Dsc	Cold, dry summer, cold summer
Dsd	Cold, dry summer, very cold winter
Dwa	Cold, dry winter, hot summer
Dwb	Cold, dry winter, warm summer
Dwc	Cold, dry winter, cold summer
Dwd	Cold, dry winter, very cold winter
Dfa	Cold, no dry season, hot summer
Dfb	Cold, no dry season, warm summer
Dfc	Cold, no dry season, cold summer
Dfd	Cold, no dry season, very cold winter
ET	Polar, tundra
EF	Polar, frost

Source: Beck et al. via gloh2o.org/koppen, Peel et al., 2007

Figure 3-4. Global picture of the Köppen-Geiger climate classification system at its most recent, along with color key.

TRY IT!

Climate zones

Look at the map of the climate zones. What is the zone (roughly) for Ohio? What about for Florida? Alaska? How do you expect the climate to be different in those two states?

To recap:

- Ohio is within the midlatitudes.
- Ohio experiences seasonal variations that are based on:
  1. uneven distribution of sunlight and heat at the surface due to tilt of Earth's axis
  2. resultant circulation of air that flows between the equator and poles influenced by Earth's rotation

Reflect and discuss

Using the prior module, videos, and the Traveling Climates activity (pages 21–22):

- Where does Ohio's climate seem to fall on the globe?
- Given your experiences and background knowledge, is Ohio in an equatorial, polar, or midlatitude region?
- What further zones could Ohio fall under?
- Explain your reasoning with examples of types of weather, seasonal variations, etc., that you see year in and year out.

Despite subtle climate differences from the humid continental north to the more humid subtropical south, most of Ohio's forests are composed of such trees as hickory, oak, maple, beech, and birch, according to the Ohio Department of Natural Resources Division of Wildlife.

Understanding science

We continue by reviewing how Ohio's current climate is classified. Ohio is in the midlatitudes of North America and is not close to an ocean, so it experiences what is called a "continental" climate. A continental climate is described as one with large variations in temperature (mild/hot summers and cool/cold winters) and a moderate amount of precipitation. We often find ourselves oscillating between cooler and drier "continental-polar" air masses (think of those that sweep south out of Canada) and warm, moist "maritime-tropical" air masses (think of those that push northward from the Gulf of Mexico) during many points of the year (Beck et al, 2018).

Short-term climate variability

Ohio experiences 2–5 inches of precipitation on average in all months of the year (MRCC, 2023). As a result, Ohio is humid and without a defined dry season. This is driven by the state's location, which receives moist air flowing from the Gulf of Mexico during our hot and humid summers. The state also sees repeated midlatitude cyclones, which are eastward-moving, low-pressure storm systems associated with the jet stream. Midlatitude cyclones contribute to the regularity of precipitation, particularly in the often cloudy and wet winter months from December to March. As a result, the state primarily experiences a "humid continental" climate, and sees four distinct seasons with much variability and interesting weather throughout.

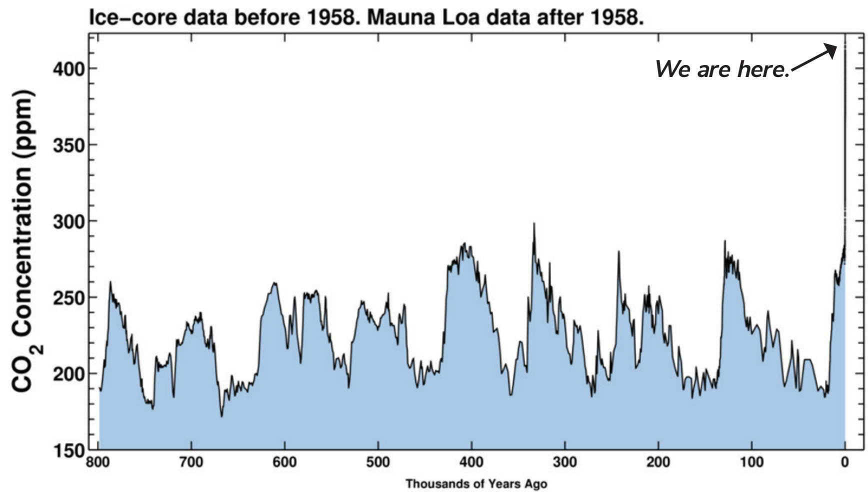
Although Ohio is a midsize state, it has significant geographic variation in climate. Parts of southern Ohio, where warm maritime air masses and moisture from the Gulf of Mexico influence climate the most, are considered humid subtropical instead of humid continental. In northeast Ohio, cold winds blowing over Lake Erie boost lake-effect snow totals in the region, making winters much snowier than the rest of the state (Frankson et al, 2022). These regions still see defined seasons and plenty of variability, but conditions here are also notably impacted by present moisture sources, wind patterns, and geography. Other parts of Ohio see even smaller-scale variations in climate, known as microclimates. Microclimates can be found in both urban and rural areas alike where differences in terrain, land cover, or other factors influence the resulting climate. For example, in urban centers like Columbus, a phenomenon known as an urban heat island acts to create warmer average temperatures near the city center compared to surrounding rural areas. This is due to the large quantities of dark, urban land cover with low albedo, such as blacktop, dark roofs, and pavement, absorbing more incoming sunlight and, consequently, radiating the energy as heat. City centers also have less vegetation to absorb heat through evapotranspiration. Similarly, in rural areas with varying terrain and vegetation, such as Hocking Hills State Park, cool air will sink and settle in valleys, leading to cooler temperatures compared to elsewhere. Importantly, regional climates in Ohio, on both small and large scales, play a direct role in how natural and seasonal processes play out and the plant life you can find in the surrounding environment.

Deciphering worldwide data to find patterns

Stories of extreme or unusual weather exist throughout history all over the globe. Galileo is often credited with inventing the predecessor to our modern-day thermometer in the late 1500s, with the evolution of the thermometer occurring over the 17th to 19th centuries. Since then, atmospheric scientists have collected a variety of daily weather measurements from around the globe and have noted years with more extreme or unusual weather. For example, a year with above-average summertime heat that persists into the autumn season may climb its way into the record books as a warmer-than-normal year. In other years, lower-than-normal temperatures may dominate. The manner in which different parameters of climate (such as temperature and precipitation) differ from an average is called climate variability. Climate variability is often due to natural and/or periodic changes in the circulation of the air and oceans (e.g., El Niño and La Niña), as well as volcanic eruptions that launch large volumes of ash and particulates into the atmosphere, reflecting incoming energy from the sun.

Long-term climate variability

While most of the climate variability listed above is short-term, longer-term climate change is the result of shifts in incoming solar radiation reaching Earth's surface due to orbital configurations. Our ice and sediment core proxy records show that over the past 800,000 years, Earth's climate has oscillated between warmer interglacial (less ice worldwide) and colder glacial (more ice worldwide) periods due to changes in Earth's path around the sun (eccentricity), the slow movement of Earth as it rotates around its axis (precession), and changes to the magnitude of Earth's tilt (obliquity). For example, ice and sediment cores include the transition between the last interglacial period—known as the Eemian (130,000–115,000 years ago; 1–2 degrees Celsius warmer; sea levels 6–9 meters, or 20–30 feet, higher than today)—and our Last Glacial Maximum (26,500–20,000 years ago; 4–6 C colder; sea levels 125 meters, or ~410 feet, lower than today). Since the Last Glacial Maximum, Earth has been on an overall warming trend as glacial ice has retreated and oceans warmed. There have been short-term interruptions to this warming, such as the Younger Dryas around 13,000–11,500 years ago, when an intense expulsion of freshwater into the North Atlantic from the receding Laurentide ice sheet spurred an abrupt cooling period (NCEI, 2021). We also likely reached the Holocene Maximum 10,000–5,000 years ago, a warmer period due to these natural variations in climate (Cartapanis et al, 2022). Note the wide-ranging dates delivered here. As more scientific advancement is made, we get a firmer idea of when these events took place. Details can be found in sources like Cartapanis et al. and other references.



Source: NOAA and Scripps, Accessed August 13, 2020

Figure 3-5. A combination of ice-core data (before 1958) and data sampled at the Mauna Loa volcano (after 1958) shows the natural variation of CO_2 concentrations in Earth's atmosphere across a large timescale. The large spike in CO_2 concentration over recent decades shows how unusual this rapid increase really is.

Anthropogenic climate change

However, a more rapid warming trend has emerged from climate data over the past 150 years that, thus far, looks unlike the rest. This warming trend coincides with a rapid increase in the concentration of greenhouse gases in the atmosphere due to industrialization and fossil fuel combustion. Overwhelming scientific consensus has concluded that this increase in global temperature is a direct result of what is now known as anthropogenic climate change. Anthropogenic climate change is caused by such non-natural activity as land cover change and emissions from the burning of fossil fuels, such as coal, natural gas, or oil. Specifically, the emission of greenhouse gases such as carbon dioxide and methane have been found to make up a large portion of this increase in greenhouse gases in our atmosphere. Since the mid-to-late-1800s, our energy needs have been met almost exclusively by burning fossil fuels. The resulting greenhouse gas emissions have warmed Earth as the additional gas molecules inhibit energy from escaping to space, thereby warming the atmosphere, and radiating more energy back toward Earth's surface. Scientists have looked at other causes of climate change beyond emissions from fossil fuels, such as natural sources like volcanic emissions and solar cycles, but research has found that these other sources, although measurable, are small in comparison to greenhouse gases. Thus, these are not major drivers of the contemporary warming period (Figure 3-5).

Consequently, this warming has a rippling effect on weather and all aspects of the climate system, including the rapid progression in the melting of glaciers and mountain snowpacks, rising levels of Earth's oceans, and shifts in the life cycles of some plants and animals.

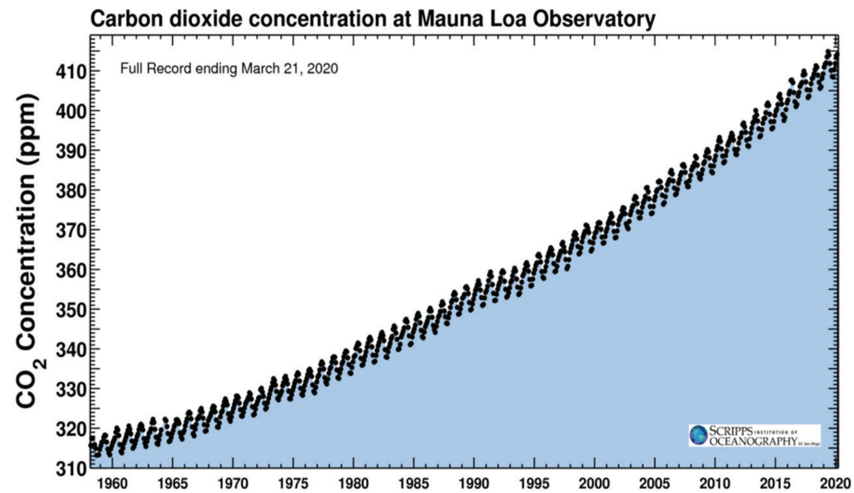
TRY IT!

Keeling Curve

To the right is a copy of the Keeling Curve that shows carbon dioxide levels on Earth since the 1960s. This is one of the most famous graphs in atmospheric sciences.

What was the carbon dioxide level when you were born? What about when you graduated from high school? Describe two patterns that you see on the graph. What do you think causes these two patterns?

Once you've had an opportunity to reflect, search online for the video "Keeling's Curve: The Story of CO_2," from the American Museum of Natural History to gain a historical perspective and learn more: **amnh.org/explore/videos/earth-and-climate/keeling-s-curve-the-story-of-co2**.



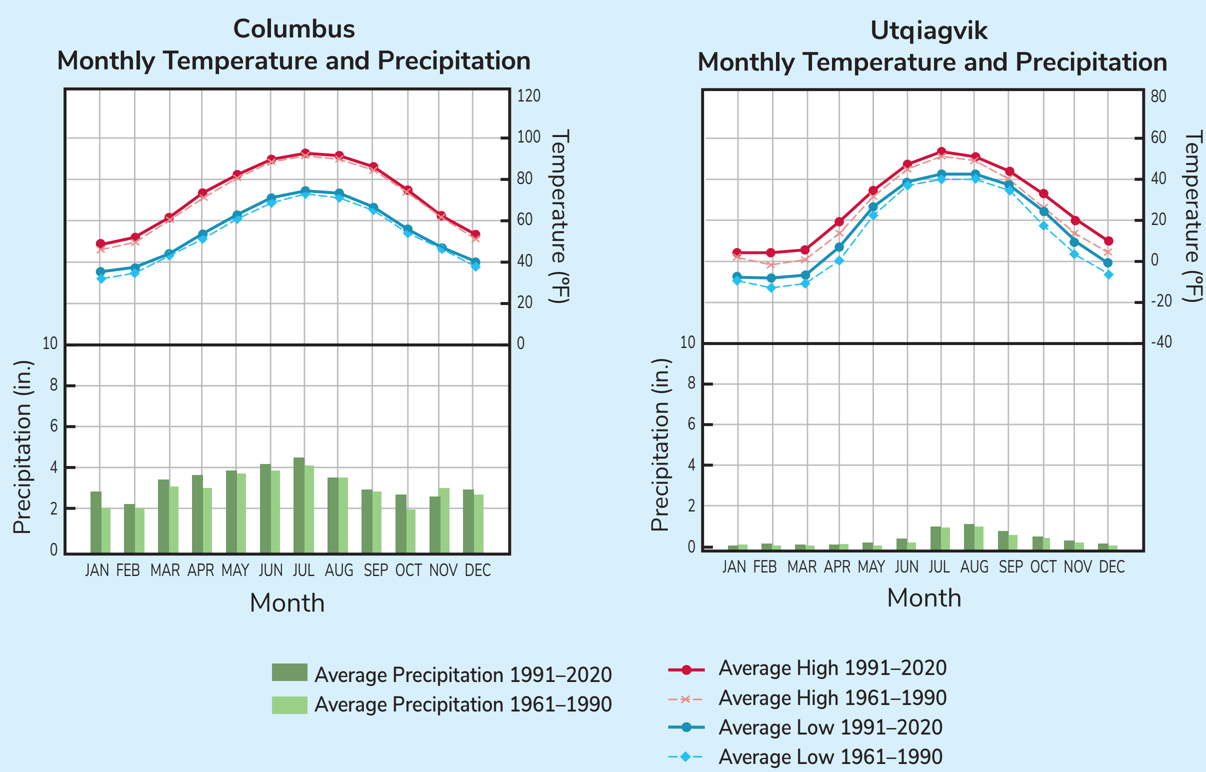
Source: NOAA and Scripps, Accessed March 19, 2020

Figure 3-6. The Keeling Curve, sampled at the Mauna Loa volcano after 1958

TRY IT!

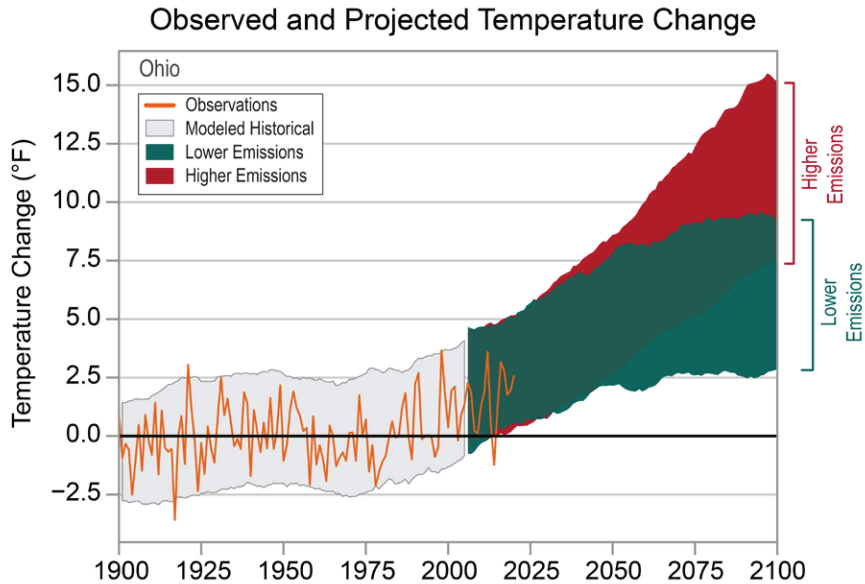
Averages over time

Look at the older and newer temperature and precipitation averages for a pair of global cities: Columbus, OH and Utqiagvik, AK. What are some of the similarities and differences you see between the older and newer averages?



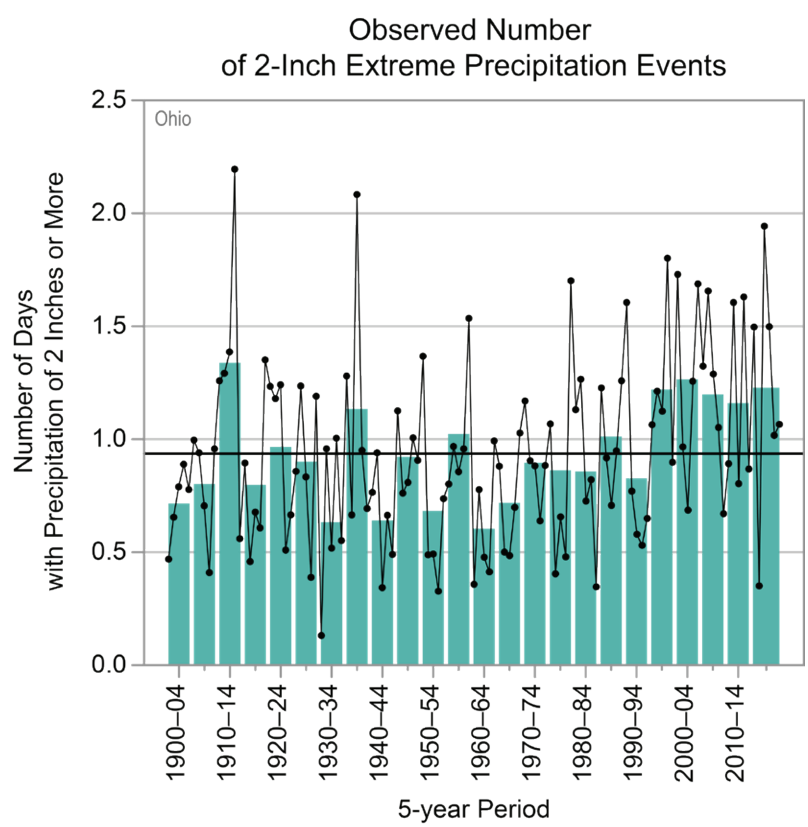
Observed changes in Ohio

So what does contemporary climate change look like in Ohio? Changes can be broadly summarized according to temperature and precipitation. Since the beginning of the 20th century, observed temperatures in Ohio have risen more than 1.5 F (Figure 3-7), with eight of the 10 warmest years on record (1895–2022) occurring since 1990. Ohio has experienced a warming trend in all seasons, with the strongest trends occurring in winter and spring. Summer daytime temperatures have not warmed significantly, and Ohio has not experienced an increase in the number of very hot days (e.g., daytime highs > 95 F). However, rising average summer temperatures are the result of a strong warming trend in overnight low temperatures. This has been linked to an increase in atmospheric water vapor (i.e., humidity) that prevents daytime highs from reaching extremes but keeps the atmosphere warmer at night as energy is not able to escape to space as effectively as it does in a drier atmosphere (Frankson et al., 2022).



Source: CISESS and NOAA NCEI (statesummaries.ncics.org/chapter/oh)

Figure 3-7. Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Ohio. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Shading indicates the range of annual temperatures from the set of models.



Sources: CISESS and NOAA NCEI; data from GHCN-Daily from 25 long-term stations (statesummaries.ncics.org/chapter/oh)

Figure 3-8. Observed annual number of 2-inch extreme precipitation events for Ohio from 1900 to 2020. Dots show annual values. Bars show averages over five-year periods (last bar is a six-year average). The horizontal black line shows the long-term (entire period) average of just under one day. A typical reporting station experiences one event per year. Ohio has experienced a substantial increase in the number of heavy rain events, with the past 26 years having some of the highest levels on record since the historic peak from 1910 to 1914.

Annual precipitation has increased 5%–15% across Ohio since the beginning of the 20th century, now averaging between 34 inches across northwest Ohio to more than 44 inches near the Ohio River. Since 1980, increases in precipitation have occurred mainly in fall, winter, and spring. Additionally, Ohio has experienced a significant increase in the number of 2-inch or more extreme precipitation events since the mid-1990s (Figure 3-8). With increased water vapor, fronts and storms tap into the "extra moisture," leading to significantly greater rainfall rates (Frankson et al, 2022).

Evidence also suggests that a warmer atmosphere influences the jet stream and air currents within, leading to shifts in weather patterns. The caveat with these changes is that many will often not show up in day-to-day weather. Where they do show up is in the extremes, meaning the statistical highs and lows of climate analysis. This includes periods of 90-plus F days in summer, periods of unusually warm (40–60 F) days in winter, dry spells, and heavy precipitation events.

If this sounds like weather to you—specifically, "extreme weather"—you are correct. Climate change manifests several impacts through extreme weather. However, attributing every extreme weather event to climate is complex (Carbon Brief, 2024). Smaller-scale extreme weather events, such as tornadoes, hailstorms, snow squalls, and straight-line windstorms (including derechos), are more difficult to detect and fully understand. However, scientists better understand changes in large-scale events, such as heat waves, droughts, and flash floods—events that are easier to detect and monitor over long periods of time. This leads to a very important framework for understanding and communicating these events, where the frequency, intensity, and duration are important factors to consider.

Significant rainfall events can affect both human and natural systems.

We return to our baseball analogy in which weather is an individual at bat and climate considers the stats over a batter's entire season or career. In this analogy, climate change is like steroids. While steroids do not hit home runs, they make hitting home runs more likely. This impact is best seen by looking at not just one or two at bats but also the trends in the stats of a batter before and after they begin taking steroids. Subsequently, climate change does not directly cause extreme weather, but it can make certain events more likely. This impact is best seen by looking at trends of observed data and events over a long period of time versus analyzing one or two occurances.

Future projections of Ohio's climate

Many impacts of anthropogenic climate change are already being experienced across Ohio. The question that lingers once these impacts are revealed is: What will we see next? While many impacts have yet to be determined—and many projections come with some degree of uncertainty—there is consensus on a list of changes that the state is likely to see. Future projections of Ohio's climate include the following:

- warmer temperatures (primarily in the winter and overnight in springs/summers)
- more liquid precipitation (especially in winter and spring)
- a longer growing season (as a result of the first two points)
- higher humidity
- increased intense rainfall and flooding events

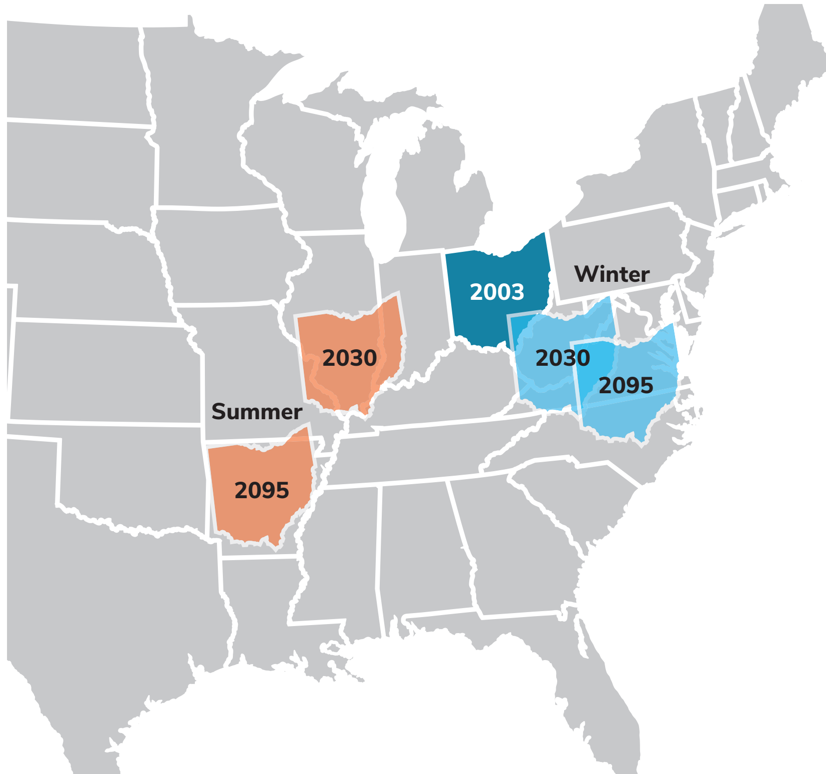
TRY IT!

Climate impacts

What climate impacts have you witnessed in your work, home, or service?

To learn more about the greenhouse effect, science of climate change, climate change impacts, and the scientific consensus, watch this overview video prepared for educators by the Byrd Polar center's Jason Cervenec (2018) in partnership with the Environmental Education Council of Ohio: **https://vimeo.com/737205940/85c6312de1**.

Under these projections, Ohio would have a much different climate from what we currently experience. While additional impacts of climate change, like sea level rise, would not be felt here, these projections coming true would result in a much more subtropical climate equivalent to the southeast United States region (Figure 3-9). This in turn would have major impacts on infrastructure, agriculture, and energy practices in the state and would trigger notable changes in ecosystems and the flora and fauna that compose them.



Source: Hayhoe and Wuebbles

Figure 3-9. Based on current projections, Ohio's future summer and winter climates may look much different from what is currently experienced. While this may be challenging to visualize, Hayhoe and Wuebbles in 2003 adjusted Ohio's geographic position to portray what these climatic changes could be like, where summers resemble what is more common in Arkansas and winters more similar to those in parts of Virginia or North Carolina.

Field skills

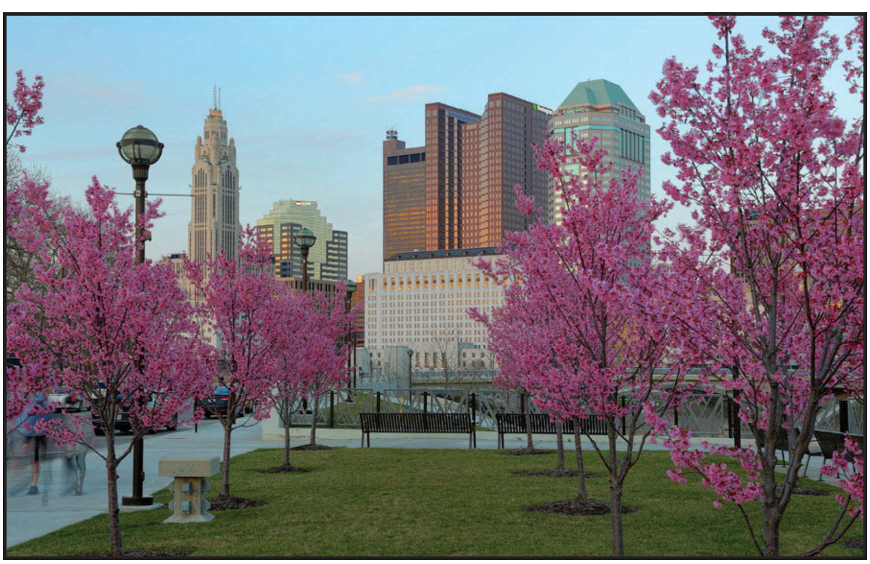
Written and proxy records, as well as modern technology, help in deducing past climate patterns, forecasting current weather, and projecting future climate. While these tools are advanced, the resulting data can be accessed and analyzed through a variety of sources. Additionally, there are more traditional on-ground methods that you can use on your own to keep track of weather events and even form the basis of your own individual local climate record.

- The Midwestern Regional Climate Center covers Ohio as well as other states around the Great Lakes and Midwest regions. Here, climate data and tools are readily available to be downloaded, visualized, and employed. To access the widest range of tools, you can register for a free account (**mrcc.purdue.edu**).
- NOAA's National Centers for Environmental Information provides "Climate at a Glance," a free monitoring tool updated monthly with rankings, time series, and mapping from the global to county level (**ncei.noaa.gov/access/monitoring/climate-at-a-glance**).
- Sign up for the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS, **cocorahs.org**): a NOAA-sponsored citizen science initiative to monitor precipitation across the United States. Our teams at OSU use CoCoRaHS data to monitor flooding, drought, and agricultural impacts in Ohio.
- Basic thermometers, anemometers, and wind vanes are all intuitive tools to gather additional information on temperature, wind speed, and wind direction at your location.
- Regular data on a range of topics can be collected as part of the three-decades-old GLOBE Program, an international youth education initiative at **globe.gov**. Collaboration with other educators can also occur here.

Communicate

A warming world has and will continue to have a multifaceted impact on weather, climate, agriculture, ecosystems, and countless other environmental factors in Ohio. Such seasonal variations as frost/freeze timings, spring budbreak and leaf-out, and important pollinator/bird connections to ecosystems are altered by the changing climate. So, too, are the plants and trees that can grow in the changing environmental conditions. These short- and long-term impacts are discussed in this section, as well as how you as a volunteer naturalist can communicate these changes.

A drone's aerial view of farmland in western Ohio on a sunny summer morning



Eastern redbud trees blooming in a park in downtown Columbus

Land and agronomy

Changes to climate and the resultant weather conditions bring more than just direct impacts; They also influence the many natural systems that we depend on as humans. The agricultural and natural resource sectors are critical across the state, contributing about 5% to Ohio's economic output and 6% to Ohio's employment (Ohio Food, 2017). Outdoor recreation in Ohio's natural areas contributes an additional 1.3% to Ohio's economic output and employs nearly 2% of the population (Gioglio et al., 2019). However, climate change affects Ohio's farms, forests, and outdoor recreational pursuits.

A changing climate impacts the growing season, with warming likely to extend the duration of when crops can grow in the state (EPA, 2016), and influences the blooming and leafing of regional flora and fauna. These changes present opportunities to grow new crops, develop additional markets, conserve energy, and reduce maintenance costs. However, it also has the potential to disrupt many of the growing and agricultural processes Ohioans currently practice.

For example, a warming climate alters common final frost/freeze timings, which normally serve as indicators that it is time to plant crops and gardens. Final spring frosts and freezes are occurring earlier than normal, according to the Midwestern Regional Climate Center (Search "MRCC Freeze Date Tool" or visit **mrcc.purdue.edu/freeze/freezedatetool.html**). Highly variable late winter and spring temperatures lead to additional crop injury risk and uncertainty around planting dates. An earlier and longer growing season also increases the potential for arrivals of pests that can harm plants earlier in their development as well as multiple generations of insects in one growing season. For more information on specific wildlife impacts, check out chapters 8–10.

Changes in precipitation will also have negative effects on the growing season, with increasingly wet springs affecting soil conditions and disrupting planting times. This can lead to the development of harmful fungi, which can damage plants and crops early in their growth. Heavy precipitation events rapidly degrade fields, wash away seeds and saplings, and displace fertilizers, which can inflict significant damage on growth/yields and harm water quality. Erosion and loss of soil structure through floods and other events, such as drought, gradually make topsoil layers thinner, making planting and soil maintenance more difficult. Rapid shifts between extreme wet and dry conditions hinder agricultural water management and increase stress on farmers (Wilson et al., 2023). Nutrient leaching of soil also occurs, leading to a shortage of important components such as nitrates and iron in the root zones of plants and crops. This displacement of nutrients, fertilizers, and other elements of the soil through precipitation is known as runoff, which can bring about its own set of problems depending on where it "runs off" to.

Water

Runoff contributes water to our rivers, lakes, and associated ecosystems. Increased runoff from heavy rain or flooding events can lead to larger quantities of fertilizers, pesticides, and minerals entering our water sources. Combined with warmer lake temperatures, runoff can lead to increased foul water and algal blooms, which can limit both human activity around the water sources and native animal activity within it. Flooding and untreated runoff from urban and suburban areas can also introduce higher quantities of trash and synthetic material into water sources and ecosystems, leading to a decline in plant, animal, and human health. This also increases the amount of work necessary for stormwater and wastewater infrastructure to perform.

Ohio State University Extension

Standing water affects the growth of corn, as shown in an Ohio farm field.

Geddy Davis, The Ohio State University

Flooding occurred in the Grandview Heights suburb of Columbus, Ohio, after a strong thunderstorm produced multiple inches of rain in about an hour.

Areas that cannot upgrade this infrastructure, or experience failures in these systems, risk disrupting their drinking water and experiencing additional property damage during back-ups. Flooding can also leave behind molds and waterborne pathogens. To learn more about water resources and the impact of increased runoff, see Chapter 4.

Ag impacts

To hear about the agricultural impacts of climate change in Ohio, check out this short discussion by Byrd Polar and Climate Research Center scientist Dr. Aaron Wilson: **vimeo.com/737207327/3b7a8ef30d**.

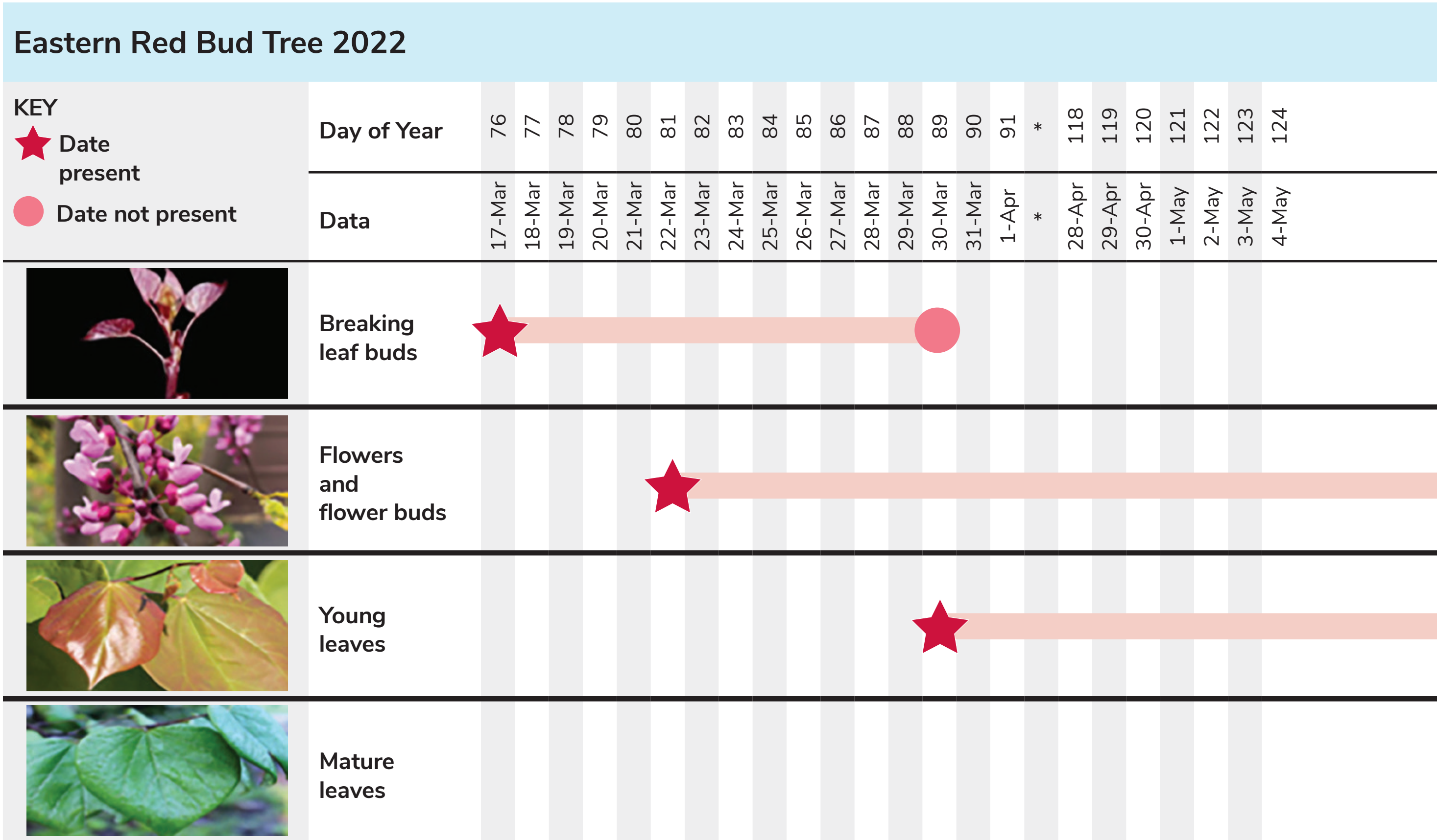


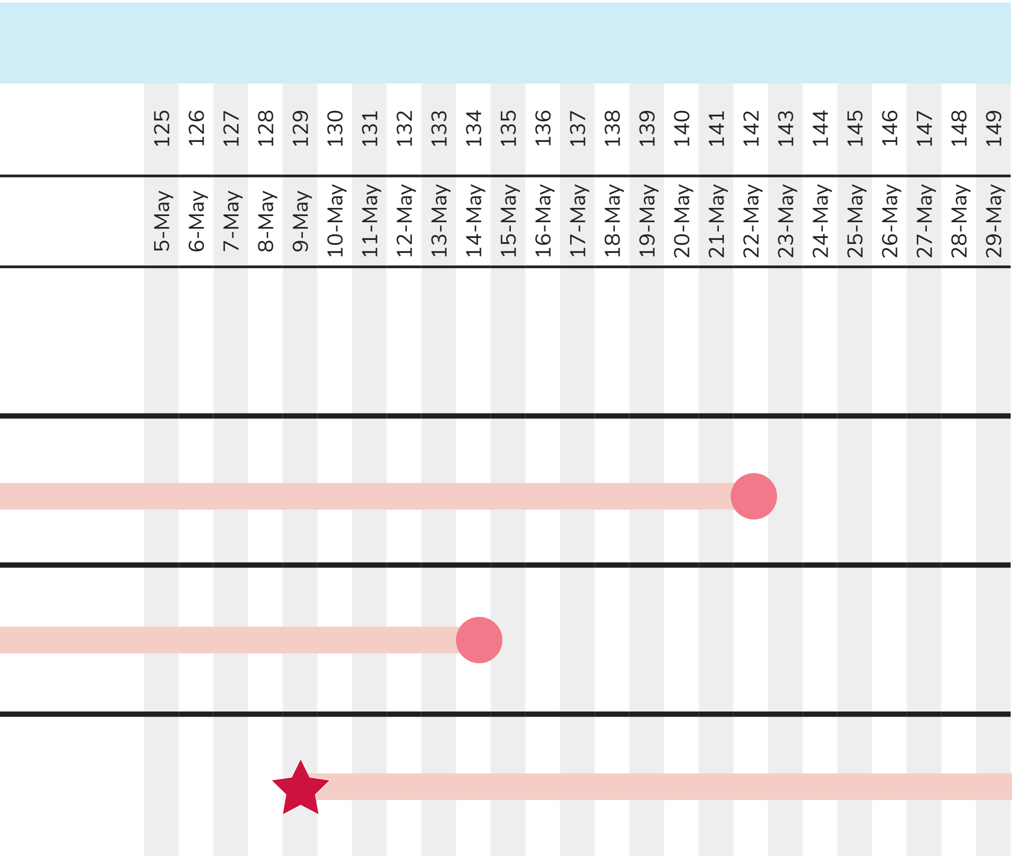
Figure 3-10. A phenology chart of the eastern red bud tree's seasonal progression, with special thanks to Maria Scaccia for the adaptation. The chart is adapted from the Association of Fish & Wildlife Agencies' *Project WILD Climate & Wildlife*, published in 2022 and reprinted with permission from the Project WILD K-12 Curriculum and Activity Guide and the *Project WILD Climate & Wildlife* module. The complete Project WILD K-12 Curriculum and Activity Guide can be obtained by attending a Project WILD professional development workshop. For more information about workshops in your state or to learn more about Project WILD materials, including how to acquire the Climate & Wildlife module, visit **projectwild.org**.

TRY IT!

Climate communication

Research informs us that few people talk about climate change with any regularity in our state, but the population is overwhelmingly receptive to such conversations. Likewise, our climate change communication efforts should address six facets: it's real, it's us, experts agree, it's bad, others care, and there's hope. Read a piece in *The Columbus Dispatch*, authored by a team from the Byrd Center/State Climate Office of Ohio, articulating the importance of genuine dialogue and knowing our audience: **dispatch.com/story/opinion/columns/guest/2023/07/12/ohio-state-university-experts-6-facts-we-must-face-about-climate-change-enviroment-extreme-heat/70399124007**.

The timing of regional species' return migrations, such as that of the ruby-throated hummingbird, can be monitored using phenology.



The eastern rebdud tree attracts pollinators to Ohio. It has clusters of pink-purple flowers lining twigs and branches providing nectar/pollen for bees, hummingbirds, and lepidopterans as well as aesthetic value. Leafcutter bees may cut leaf segments for use in nesting cells. Learn more at **ohioline.osu.edu/factsheet/hyg-5815**.

Phenology

A scientific study that combines weather and climate with the observation of natural cycles of species and ecosystems is called phenology. Many of these natural cycles, such as the bursting of flower buds, growth of new leaves, migrations of birds and butterflies, and peak pollination times, are highly dependent on that season's climate variations. As a result, observing these cycles and recording both their duration and background conditions can serve as a valuable tool when studying both current climate change and reconstructing past climates (Figure 3-10). The connection between the weather and climate and natural cycles is especially emphasized when abnormal years disrupt the timing or duration of blooms, buds, or migrations. This can be as simple as noticing leaf buds bursting earlier than usual in the spring, due to sunnier and warmer-than-normal weather, or it can be more complex, such as a migration of a certain species arriving later than normal.

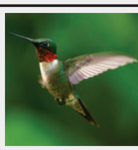
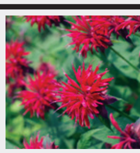
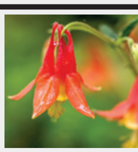
On occasion, biological interactions are disrupted by the change in timing, leading to what is known as a phenological mismatch. Mismatches can occur on a plant-to-plant, animal-to-animal, or plant-to-animal basis and can have negative consequences, especially if the species' well-being depends on the interaction. For example, if a plant's flowers bloom earlier than normal but the key pollinator species does not arrive until its usual time, fewer flowering plants will be available to pollinate. This will lead to a decline in the plant's reproduction and subsequent population the following year. Concurrently, the animal species will have a more difficult time surviving during the current season if the flowering plant's nectar is used as a food source. To visualize these mismatches, phenological charts can be employed to plot the first and final instances of natural cycles. These two events can then be connected in order to have a record of duration for that species' cycle for the year.

TRY IT!

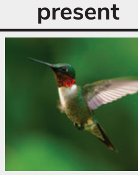
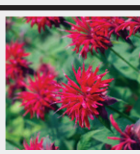
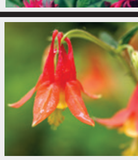
Phenology

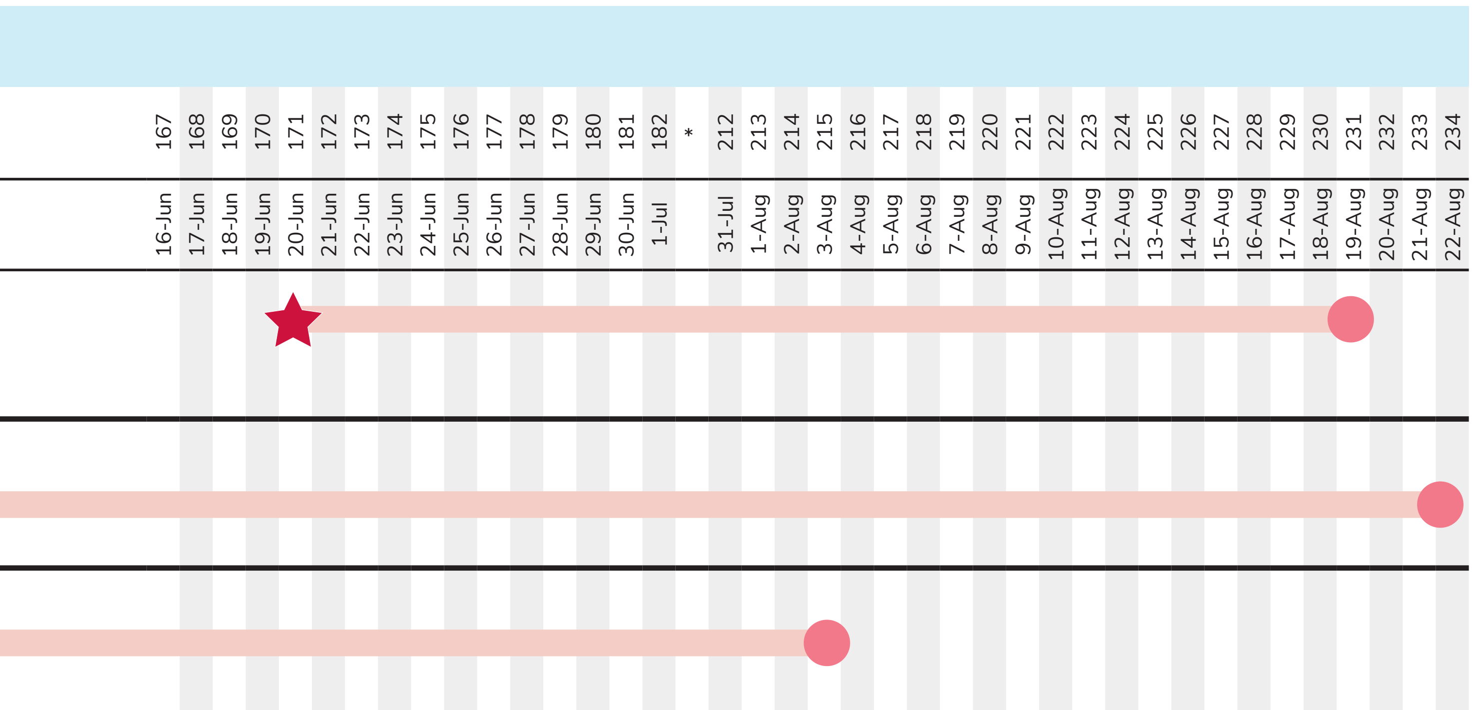
Two charts and two datasets at the same point over two different years are provided for the following: ruby-throated hummingbird (*Archilochus colubris*), whose summer breeding ground includes Ohio and much of the Great Lakes; eastern U.S. native red columbine plant (*Aquilegia canadensis*); and eastern U.S. native scarlet beebalm plant (*Monarda didyma*). One dataset offers a phenologic match, while the other does not. Identify which chart and species has a mismatch. Then, using what you know about the mutualistic relationship between hummingbirds and flowers, what might happen as a result of the mismatch? How will this impact the relationship in the next year's season?

Dataset 1: Ruby-throated hummingbird, scarlet beebalm, and red columbine

KEY ★ Date present ● Date not present	Day of Year	110	111	112	113	114	115	116	117	118	119	120	121	*	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166
	Data	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	1-May	*	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun
	Ruby-throated hummingbird																													
	Scarlet beebalm (flowering)																						★							
	Red columbine (flowering)														★															

Dataset 2: Ruby-throated hummingbird, scarlet beebalm, and red columbine

KEY ★ Date present ● Date not present	Day of Year	110	111	112	113	114	115	116	117	118	119	120	121	*	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166
	Data	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	1-May	*	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun
	Ruby-throated hummingbird																													
	Scarlet beebalm (flowering)																						★							
	Red columbine (flowering)		★																											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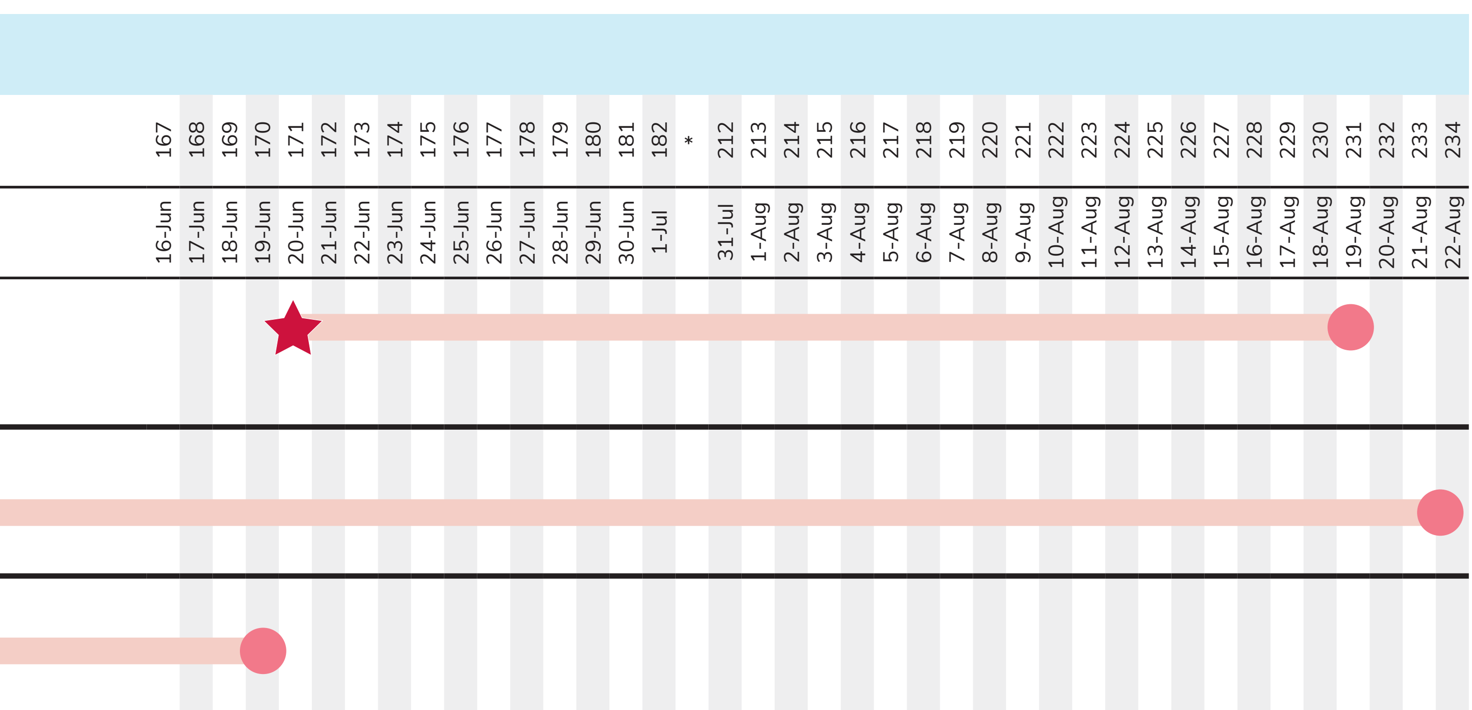
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Conserve and protect

In this chapter, you had an opportunity to look at Ohio through the lens of weather and climate. Ohio's distinct location means it experiences changes in climate specific to its placement on Earth, no matter if these changes are influenced by natural or human-caused conditions. Climate not only affects our natural world, but our society as well. You explored the short- and long- term effects that climate change has on Ohio's plant life, resources, and infrastructure. Now that you understand the basics of climate change and its impacts for Ohio, your work isn't over! It's time to share your knowledge as climate ambassadors!

Ohio's landscape and lifestyle are intertwined with changes in climate. As you have discovered, many of your interests as naturalists, and citizens of Ohio, interact with these changes. As Ohioans who are deeply interested in the natural world, pursuing your interests will only further the ability to learn and share this information to those around you. Climate data is ever-changing, and the knowledge we gain from research is continually changing, too. There are many ways to integrate climate knowledge while you continue to dig deeper into your naturalist activities. Community science projects are a great way to add to our scientific understanding of weather and climate in Ohio and help park visitors build their knowledge and stewardship. As you continue, you will have a wide opportunity to share verified climate data and research. No matter if your focus is on agriculture, animals, plants, or more, you can explore how climate interacts with your interests through a variety of resources. Below are a few ways for you, or anyone, to continue to participate and educate.

Resources

- For a high-level look at the latest science about climate change and its impacts in the United States, explore the U.S. Global Change Research Program: **globalchange.gov**. In particular, check out the Fifth National Climate Assessment at **nca2023.globalchange.gov**.
- Explore climate change solutions by sector with Project Drawdown: **drawdown.org**.
- Join a variety of citizen science programs through National Geographic: **education.nationalgeographic.org/resource/citizen-science-projects**.
- Start a project or volunteer as an expert for a community science project as part of the AGU Thriving Earth Exchange: **thrivingearthexchange.org**.
- Collect regular data on a range of topics and collaborate with other educators as part of the GLOBE project, which was started in the early 1990s. For more information on the GLOBE project, visit **globeproject.com**.
- Gather ideas from trusted outdoor and community education partners at The Wild Center in New York (**wildcenter.org/our-work/youth-climate-program/resources/**) and Climate Generation in Minnesota (**climategen.org**).
- Further educate yourself and others with the Byrd Center's lessons and activities at **byrd.osu.edu/engage/education/lessons**. Or, reach out to the Center's Education and Outreach Team by emailing byrd-contact@osu.edu to ask questions, schedule a speaker, or brainstorm ideas.
- To track emergences of plants and animals in Ohio and gather local phenology data, check out OSU's Phenology Calendar: **weather.cfaes.osu.edu/gdd**
- For information on potential climate change impacts on species distribution of birds and trees, check out the USDA Climate Change Atlas (includes tutorials) **fs.usda.gov/nrs/atlas**.
- Participate in Budburst at **budburst.org** to collect plant phenology data and visualize data for your educational programs. Check out the Ohio State Phenology Calendar that uses growing degree days to forecast insect and plant phenology in Ohio.
- Find more climate educational resources and activities through the CLEAN search tool, **cleanet.org**, or join their weekly webinars with climate change educators across the U.S.

References

Angel, J. R., Swanson, C., Boustead, B. M., Conlon, K., Hall, K. R., Jorns, J. L., Kunkel, K. E., Lemos, M. C., Lofgren, B. M., Ontl, T., Posey, J., Stone, K., Takle, E., & Todey, D. (2018). Chapter 21: Midwest impacts, risks, and adaptation in the United States. *The Fourth National Climate Assessment,* 2. doi.org/10.7930/nca4.2018.ch21

Beck, H., Zimmermann, N., McVicar, T., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data* 5, Article 180214. doi.org/10.1038/sdata.2018.214

Cartapanis, O., Jonkers, L., Moffa-Sanchez, P., Jaccard, S. L., & de Vernal, A. (2022, October 3). Complex spatio-temporal structure of the Holocene Thermal Maximum. *Nature News*. doi.org/10.1038/s41467-022-33362-1

Cervenec, J., Wilson, A. B., Dipre, G. R., Shockey, A., & Celebrezze, D. (2018). *Columbus climate adaptation plan.* Byrd Polar and Climate Research Center. byrd.osu.edu/columbus

Crimmins, A. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Stewart, B. C., & Maycock, T. K. (2023). The fifth national climate assessment. U.S. Global Change Research Program. doi.org/10.7930/NCA5.2023

Frankson, R., Kunkel, K. E., Champion, S. M., & Easterling, D. R. (2022). Ohio State climate summary 2022. NOAA technical report NESDIS 150-OH. NOAA National Centers for Environmental Information. statesummaries.ncics.org/downloads/Ohio-StateClimateSummary2022.pdf

Gioglio, R., Sohngen, B., Haab, T., & Bruskotter, J. (2019). *Economic valuation of natural areas in Ohio.* College of Food, Agricultural, and Environmental Sciences (CFAES) at The Ohio State University

National Centers for Environmental Information and Purdue University. (n.d.). *Freeze date tool*. Midwestern Regional Climate Center. mrcc.purdue.edu/freeze/freezedatetool.html

National Centers for Environmental Information. (2021). *The Younger Dryas.* Paleo Perspectives. ncei.noaa.gov/sites/default/files/2021-11/3%20The%20Younger%20Dryas%20-FINAL%20NOV%20(1).pdf

National Ocean Service. (n.d.). The Coriolis effect. National Oceanic and Atmospheric Administration. oceanservice.noaa.gov/education/tutorial_currents/04currents1.html

Pidcock, R., & McSweeney, R. (2022, May 8). Mapped: How climate change affects extreme weather around the world. *Carbon Brief*. carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world/

World Meteorological Organization. (2019). *The sun's impact on the Earth.* wmo.int/suns-impact-earth

University of California Museum of Paleontology. (n.d.). *How the Earth system works.* Understanding Global Change. ugc.berkeley.edu/earth-systems/how-the-earth-system-works

United States Environmental Protection Agency. (2016, August). *What climate change means for Ohio.* (U.S. EPA Report No. 430-F-16-037). 19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-oh.pdf

Wilson, A. B., Baker, J. M., Ainsworth, E. A., Andresen, J., Austin, J. A., Dukes, J. S., Gibbons, E., Hoppe, B. O., LeDee, O. E., Noel, J., Roop, H. A., Smith, S. A., Todey, D. P., Wolf, R., & Wood, J. D. (2023). Ch. 24. Midwest. In A. R. Crimmins, C. W. Avery, D. R. Easterling, K. E. Kunkel, B. C. Stewart, & T. K. Maycock (Eds.), *Fifth National Climate Assessment*. U.S. Global Change Research Program.

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