Chapter 9: Climate of the Midwestern US

Climate is a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years. These factors interact with and are influenced by other parts of the Earth **system**, including geology, geography, insolation, currents, and living things.

Because it is founded on statistics, climate can be a difficult concept to grasp, yet concrete examples can be illuminating. Terms like “desert,” “rain forest,” and “tundra” describe climates, and we have gained a general understanding of their meaning. Climate can also encompass the cyclical variations a region experiences; a region with a small temperature variation between winter and summer—for example, San Francisco—has a different climate from one that has a large variation, such as Buffalo. Scientists have settled on 30 years as the shortest amount of time over which climate can be defined, but of course it can also refer to millions of years.

You cannot go outside and observe climate. **Weather**, on the other hand, can be observed instantly—it is 57 degrees and raining *right now*. Weather varies with the time of day, the season, multi-year cycles, etc., while climate encompasses those variations. Our choice of clothing in the morning is based on the weather, while the wardrobe in our closet is a reflection of climate. Residents of the Midwest are owners of a very diverse wardrobe. The entire area experiences the greatest seasonal variation of any place in the US, especially in the northern parts.

Past Climate of the Midwest

Climate, like other parts of the Earth system, is not static but changes over time, on human time scales and even on much longer time scales. Latitude, for example, has a very direct effect on climate, so as the continents shift over **geologic time**, the climates on them also shift. Furthermore, the conditions on the Earth as a whole have varied through time, altering what kinds of climates are possible. What is now the Midwest has gone from being ice-covered to tropical and back during its long history!

Ancient climates are reconstructed through many methods. Written records and tree rings go back hundreds of years, glacial ice cores hundreds of thousands of years, and **fossils** and rocks that indicate different climates go back hundreds of millions of years. These clues, coupled with modeling and a knowledge of physics and chemistry, help climatologists put together an increasingly detailed history of the Earth’s climate, and of that of the Midwest. Unfortunately, we do not have as clear an understanding of climate for the earliest part of Earth

Review

system • *a set of connected things or parts forming a complex whole.*

geologic time scale • *a standard timeline used to describe the age of rocks and fossils, and the events that formed them.*

fossil • *preserved evidence of ancient life.*

CHAPTER AUTHORS

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Past

volcanism • *the eruption of molten rock onto the surface of the crust.*

salt • *a mineral composed primarily of sodium chloride (NaCl).*

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

energy • *the power derived from the use of physical or chemical resources.*

greenhouse gases • *a gas in the atmosphere that absorbs and emits heat.*

iron • *a metallic chemical element (Fe).*

crust • *the uppermost, rigid outer layer of the Earth, composed of tectonic plates.*

mantle • *the layer of the Earth between the crust and core.*

history as we do for the later parts because the oldest rocks are much more difficult to come by. But for those very old times, we can still say something about the climate of the Earth as a whole, and that relates to the very important information related to atmospheric chemistry.

Ancient Atmosphere

Not long after the Earth first formed, more than 4.5 billion years ago, its atmosphere was composed mostly of hydrogen and helium. **Volcanic** activity and collisions with meteorites and comets added water vapor, carbon dioxide, and nitrogen. As the Earth cooled enough for liquid water to form, the vapor in the atmosphere formed clouds from which the rain poured forth in such a deluge as will never be repeated. These torrential rains were constant for *millions* of years, absorbing **salt** and other **minerals** from the earth as the rainwater coursed to the lowest areas, forming Earth's oceans and seas.

At this time, the sun produced significantly less **energy** than it does today, so one might expect that once the oceans formed, they would continue to cool and eventually freeze. Yet temperatures stabilized, perhaps because there was a greater concentration of potent **greenhouse gases** in the atmosphere and less land surface to reflect light, so temperatures remained high enough for liquid water to exist. Indirectly, the ocean was responsible for the final ingredient of the modern atmosphere because it was home to the first life on Earth. Photosynthetic bacteria appeared perhaps as early as 3.5 billion years ago, but the abundant **iron** and organic matter quickly absorbed the oxygen they produced. After hundreds of millions of years, these sinks were exhausted, and free oxygen could finally build up in the atmosphere. With this addition, the modern atmosphere was complete, though the relative amounts of the gases composing it would, and still continue to, shift. *The composition of the atmosphere and the huge volume of water on Earth are two of the most important factors affecting climate.*

Much of the light from the sun passes unimpeded through the atmosphere and hits the Earth. Approximately 70% of that light is absorbed and retransmitted from the surface as heat. The transmitted heat, which has a longer wavelength than light, is trapped by gases in the atmosphere including water vapor, carbon dioxide, and methane. The similarity between this process and that which warms a greenhouse earned these "greenhouse gases" their moniker.

While the atmosphere was forming above, the surface of the Earth was cooling to form a solid **crust** of rock about 3.7 billion years ago (although there are indications that this process may have started as early as 4.4 billion years ago). Regardless of precisely when this took place, it represented the beginning of tectonic processes that have continued ever since. Molten rock from the **mantle** constantly wells up from deep fissures and solidifies into relatively dense rock, while less-dense rock floats higher on the **magma** and is pushed around on the slow conveyor belts of mantle-formed rock (*Figure 9.1*). The denser rock forms oceanic **plates** that are lower and covered in water, and the lighter rock forms continental plates, though part or all of a continental plate may be submerged under a shallow sea. The motion of these plates, the rearranging of the continents, and the amount and types of minerals exposed to the atmosphere play a huge role in the climate. Not only do the continents and oceans move through different climate zones, but the continents also affect climate based on their size, and the **weathering** of rock on the continents plays a large role in the composition of the atmosphere. For example, rock that is enriched in organic matter will release abundant amounts of carbon dioxide as it weathers, while rock rich in **feldspar** and **mica** will take up carbon dioxide.

See Chapter 3: Fossils for information about banded iron formations as indicators of some of the earliest life on Earth.

Nearly one billion years ago, the Earth began fluctuating between warm and cool periods lasting roughly 150 million years each. During the cool periods, there is usually persistent ice at the poles; during the warm periods there is little or no glaciation anywhere on Earth. Today, we are still in a cool period. The world has been much hotter for much of its history, but it has also been a bit cooler. Through the shifting global climate and the movement of the tectonic plates, what is now the Midwest has at times been at the bottom of a shallow sea; a plain with swamps, rivers, and grasslands; and under very thick ice.

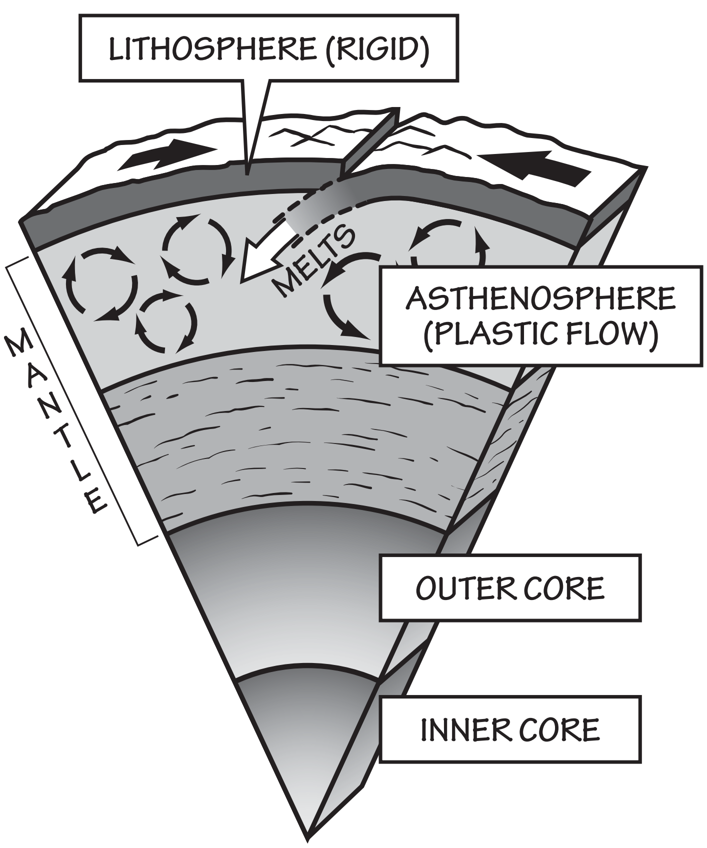


Figure 9.1: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.

magma • *molten rock located below the surface of the Earth.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

weathering • *the breakdown of rocks by physical or chemical means.*

feldspar • *an extremely common, rock-forming mineral found in igneous, metamorphic and sedimentary rocks.*

mica • *a large group of sheetlike silicate minerals.*

9 Climate

Past

Snowball Earth

There is evidence suggesting that several times the entire surface of the planet was covered in ice, a hypothesis called Snowball Earth (*Figure 9.2*). Glacial deposits discovered near Lake Huron and elsewhere show that starting about 2.4 billion years ago the entire surface of the Earth may have been covered in ice for as long as 300 million years, an event known in North America as the **Huronian glaciation**. At that time the continental plates made up less than half as much of the Earth's surface as they do today and were unified as the continent Arctica. It may have been early life's production of oxygen that reacted with and lowered the amount of the greenhouse gas methane in the atmosphere, which tipped the Earth toward a series of cooling feedbacks, causing ice to spread from pole to pole.

An ice-covered planet would stay ice-covered because almost all of the sun's energy would be reflected back into space, but this did not happen on Earth because of tectonics: The Snowball Earth cycle was eventually disrupted by volcanic activity. While the Earth was covered in ice, volcanoes continued to erupt, dumping carbon dioxide and methane into the atmosphere. These gases are usually removed from the atmosphere by organisms and the weathering of rocks, but this was not possible through miles of ice! After millions of years, the concentrations of methane and carbon dioxide increased to the point that greenhouse warming began to melt the **ice sheets**. Once the melting started, more of the sun's energy was absorbed by the surface, and the warming feedbacks began. Because the oceans had been covered, nutrients from volcanic gases and chemical changes in the rocks accumulated in the waters. Once they were re-exposed to light, a population explosion of cyanobacteria produced more and more oxygen capable of combining with freshly thawed carbon sources to make more carbon dioxide, further enhancing the warming. Rocks in the Midwest do not contain direct evidence for this Snowball Earth, or for Earth history for several tens of millions of years afterward.

See Chapter 6: Glaciers for more information about glaciations.

For the next 1.5 billion years, the Midwest, free of ice, drifted around the surface of the Earth. A new supercontinent—**Rodinia**—formed, and the part that is now North America was stable, forming what is known as a craton, or continental interior relatively free of the folding and **faulting** that characterizes continental margins that are subjected to mountain building and other plate tectonic processes. The Midwest was under water for most of this time, and the simple lifeforms sustained on it produced the **stromatolites**, **banded iron formations**, and other evidence found in rocks of the Superior Upland Basin.

About 850 million years ago, during the **Cryogenian**, the Earth entered a 200-million-year **ice age**. The part of Rodinia that would eventually become North America was near the equator. There were two more Snowball Earth cycles during this time. The fact that North America was at such a low latitude yet

Huronian glaciation • *a glaciation beginning about 2.4 billion years ago, that covered the entire surface of the Earth in ice for as long as 300 million years.*

ice sheet • *a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

stromatolite • *regularly banded accumulations of sediment created by the trapping and cementation of sediment grains in bacterial mats.*

banded iron formation • *rocks with regular, alternating thin layers of iron oxides and either shale or silicate minerals.*

Past

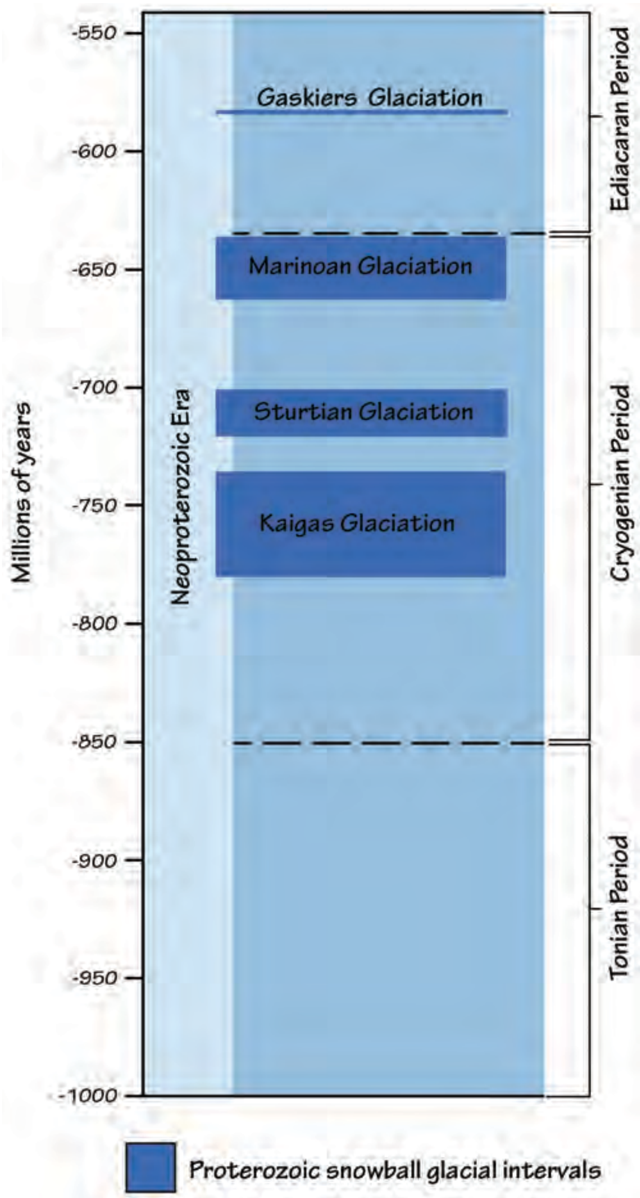


Figure 9.2: Snowball Earth periods during the Proterozoic.

contained **glaciers**, is strong evidence that the Earth really did freeze over completely. These events are not recorded in Midwestern rocks.

Life and Climate

By 635 million years ago, the Earth had warmed again, and the North American continent, of which the Midwest was the central part, moved towards the equator. During the **Ordovician**, much of the Midwest was covered by very pure, **quartz**-rich **sand**. This **sandstone**, now known as the **St. Peter Sandstone**, is an enduring enigma to geologists because it is not clear how all the non-quartz minerals could have been removed. Quartz is extremely resistant to weathering, and it is often the last mineral left when other minerals have weathered away. This suggests that the climate was intensely wet and warm and that the sand

Cryogenian • *a geologic period lasting from 850 to 635 million years ago, during the Precambrian.*

ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and glaciers.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

quartz • *the second most abundant mineral in the Earth's continental crust (after feldspar), made up of silicon and oxygen (SiO_2).*

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

sandstone • *sedimentary rock formed by cementing together grains of sand.*

Past

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

was washed or blown (or both!) back and forth for a long time before being buried. This weathering is all the more remarkable because land plants, which play a huge role in the weathering of rock on the continents today, were only just evolving. But they were similar to lichens, and even lichens can contribute to the weathering of rock.

After deposition of this sand, fossil evidence in Wisconsin and elsewhere in the Midwest shows that, with the warmer temperatures and higher sea level, at least some of the Midwest continued to be covered by a warm **inland sea**, this time with **limestone** that had formed from the innumerable remains of living creatures as the predominate sediment. This sea persisted in some form for several hundred million years, and, despite a global dip in temperature from 460 to 430 million years ago during yet another ice age, it was warm enough to maintain tropical reef ecosystems for much of that time (*Figure 9.3*). These reefs were among the largest the world had ever seen, and one of the largest was in the Midwest. It grew around the shallow edges of a wide basin centered on Michigan. Today, the reef deposits (as limestone) can be found in much of the Midwest, but they are thickest in Indiana and Illinois—as thick as 300 meters (1000 feet)! Although much of this limestone is under the surface, limestone quarries throughout the area have yielded building stones that show the richness of the fauna that constructed these impressive structures. Many buildings in the Midwest have facings or walls made of stone quarried from these ancient reefs (*Figure 9.4*).

See Chapter 2: Rocks to learn more about the formation of sedimentary rocks.

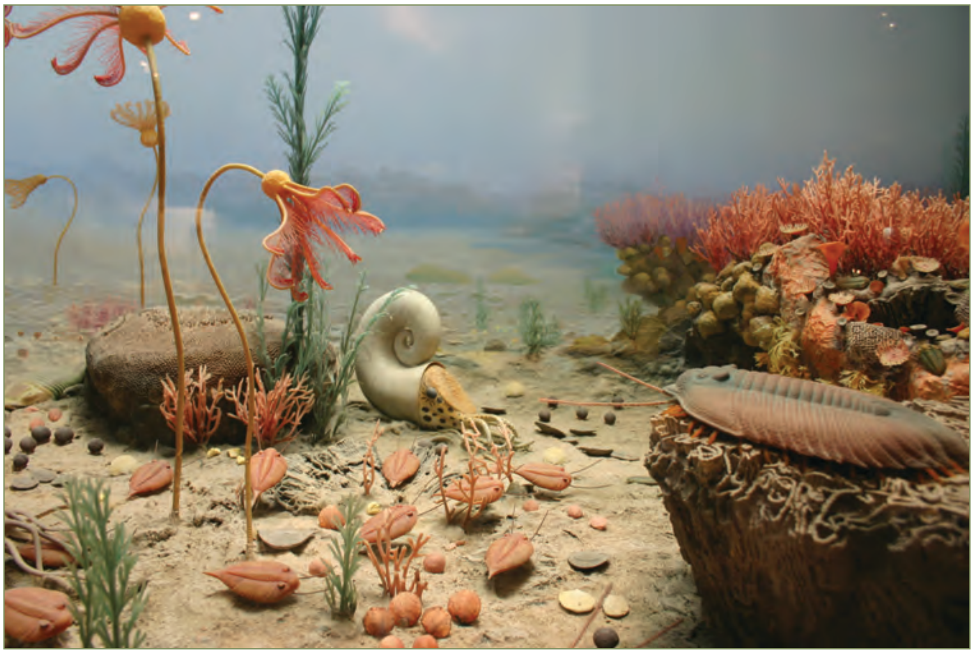


Figure 9.3: Life in the Silurian reefs.

Past

Figure 9.4: A building in Indiana with a facing made of Bedford limestone.

Silurian deposits of salt centered on Michigan indicate that the North American climate experienced little precipitation during the warm period beginning 430 million years ago. Eventually, the salinity in the shallow seas of the ancient Midwest returned to normal in the **Devonian**, and a rich and diverse fauna occupied the sea floor, including reefs and other habitats. At the end of the Devonian, however, the fauna suffered a **mass extinction** that eliminated many of the more important groups of reef-builders and other animals that occupied the shallow seas. The causes of this mass extinction, which actually occurred in a series of steps, are still uncertain.

See Chapter 3: Fossils to learn about the fossils of the Midwestern inland seas.

As the continent continued across the Tropic of Capricorn and the equator, the cycle of warming and cooling repeated yet again, and, by 360 million years ago, glaciers formed near the South Pole. Although the Earth's temperature was falling during this time, the Midwest remained relatively warm, and the shallow, tropical seas continued to cover most of the Midwest until sea level dropped in the middle of the **Carboniferous**.

By this time, complex land plants had evolved and diversified, and they rapidly colonized the newly exposed landscape. Terrestrial fossils from this time show that the climate was humid and supported swampy forests. These swamps eventually became the **coal** deposits of the southern Midwest, especially in southern Illinois, Indiana, and Ohio. Farther north, the land was exposed and no record exists of this time, although it is likely that the area was traversed by rivers. The ice age that had started near the end of the Devonian around 360 million years ago intensified during the later part of the Carboniferous. Deposits in the southern part of the Midwest, in particular, show a cyclicity of rising and falling sea level that was caused by advance and retreat of the large ice cap

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*

Devonian • *a geologic time period spanning from 419 to 359 million years ago.*

mass extinction • *the extinction of a large percentage of the Earth's species over a relatively short span of geologic time.*

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

Past

Permian • *the geologic time period lasting from 299 to 252 million years ago.*

erosion • *the transport of weathered materials.*

Pangaea • *supercontinent, meaning "all Earth," which formed over 250 million years ago and lasted for almost 100 million years.*

in the Southern Hemisphere. This ice age lasted well into the **Permian** period, ending about 260 million years ago, when warm temperatures again became the norm.

Tectonic forces had by then pushed the Midwest above sea level, and **erosional** forces tended to dominate, so little direct evidence of the climate during this time is preserved, although adjacent areas have evidence that climate in the area was very warm and relatively arid. Worldwide temperatures, however, began to dip again around 150 million years ago, though perhaps not enough for ice sheets to form, and the tropics, presumably including the Midwest itself, became more humid. **Pangaea**, a supercontinent composed of nearly all the landmass on Earth, broke up into continents that would drift into increasingly familiar positions. By the Cretaceous, the world was heating up again, and a new body of water, the Western Interior Seaway (*Figure 9.5*), covered parts of North America, leaving fossils of tropical marine animals in Iowa and Minnesota.

Figure 9.5: The Western Interior Seaway.

Past

extinction • *the end of species or other taxonomic groups, marked by death of the last living individual.*

Figure 9.6: Eskers are composed of sand and gravel deposited by streams that flowed under the ice, partially filling the sub-ice channel. When the ice melts, the sinuous deposit remains.

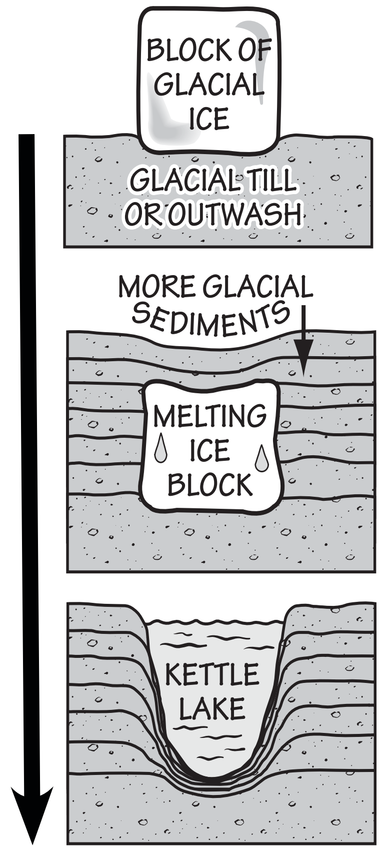


Figure 9.7: Kettle lakes formed where large, isolated blocks of ice became separated from the retreating ice sheet. The weight of the ice left a shallow depression in the landscape that persists as a small lake.

With the end of the Cretaceous and the **extinction** of the dinosaurs 65 million years ago, the world was cooling again. Antarctica moved south, and by 30 million years ago temperatures were low enough that glaciers were growing on its mountains. About 15 million years ago, ice covered much of that continent and had begun to form on Greenland. Eventually, by about 2 million years ago, a sheet of sea-ice formed over the Arctic, and other sheets spread over northern Asia, Europe, and North America and then pushed their way south. This is where the geologic record of climate in the Midwest picks up again.

Since just 800,000 years ago, a kind of equilibrium has been reached between warming and cooling, with the ice caps growing and retreating primarily due to the influence of astronomical forces. During the ice's maximum extent, it reached from the North Pole to where Chicago is now located, covering the northern half of the Midwest, while the southern half was far colder than it is today. The temperatures in areas not then covered in ice were moderated by its presence; the summers were much cooler, yet the winters were only a little cooler than they are today. The area was also somewhat wetter than it is

Great Lakes • *the largest group of freshwater lakes on Earth (by total surface area and volume), located on the US-Canadian border.*

esker • *a sinuous, elongated ridge of sand and gravel.*

kettle • *a lake formed where a large, isolated block of ice became separated from the retreating ice sheet.*

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

today, with wetlands and forests covering much of what would later become grassland. The glaciers last retreated from the area around 10,000 years ago, leaving behind the **Great Lakes** and many geologic features that define the landscape of the upper Midwest today, including **eskers** (*Figure 9.6*), **kettles** (*Figure 9.7*), and thick deposits of sand and gravel. The climate was warmer and slightly drier, much like that we experience today.

Present Climate of the Midwest

Nearly all of the Midwest has a humid continental climate, describing temperatures that vary greatly from summer to winter, and appreciable precipitation year-round. This is represented in the Köppen system with the prefix "D." Southernmost Illinois and Indiana are closer to a humid subtropical climate, or "C," the primary difference being warmer winters than are found in a D climate. While averages are important factors in describing climate, the Midwest has unusually extreme annual variation in temperature. At an average temperature of 10°C (50°F), it seems similar to that of England, which has an average of 8°C (47°F). But England's average high temperature of 21°C (70°F) and low of 2°C (35°F) is more indicative of how different their climate truly is. Average highs in the Midwestern states are around 29°C (85°F), with lows around -9°C (15°F), a variation fully twice as great as England's. Furthermore, each state has record high temperatures of more than 43°C (110°F) and lows of less than -34°C (-30°F)—a variation of a whopping 77°C (140°F)!

The Midwest is one of the most productive agricultural areas in the world, and the economies of its states depend on farmland. Its excellent **soil**, relatively flat geography, and bodies of water make it uniquely suited to cropland. Yet without a humid climate with warm summers, agriculture here would be completely different. It is one of the few places on Earth where huge amounts of corn and soybeans can be grown with little or no irrigation.

See Chapter 8: Soils for more on the soils and agriculture of the Midwest.

Weather

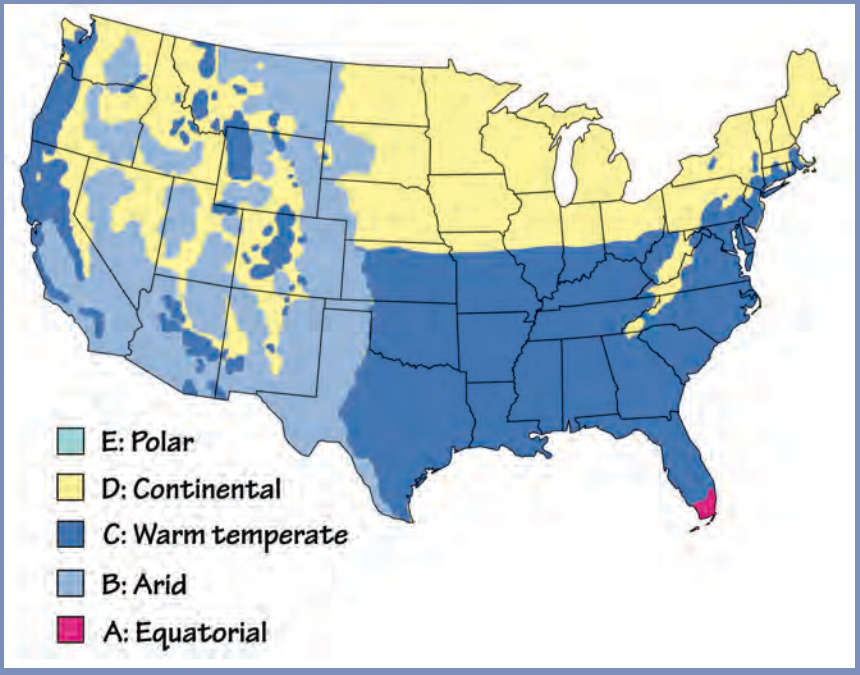
In part because of its climate's extreme temperature variation and humidity, the Midwest experiences nearly every variety of severe weather. Because the states are so far from the coasts, they rarely experience hurricanes, but heat and cold waves, droughts, floods, blizzards, and tornados are all fairly regular events.

Thunderstorms

The geography and climate of the Midwest are nearly ideal for the formation of thunderstorms. Storms occur when there is strong convection in the atmosphere. Because warm air can hold more moisture than cool air can, convective mixing with cool air forces moisture to condense out of warm air, as vapor (clouds) and precipitation. It is hypothesized that the formation of precipitation causes the

The Köppen Climate Map

Wladimir Köppen developed a commonly used system of climate categorization based on the kinds of vegetation areas sustain. He defined 12 climate types, many of which are familiar: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.



electrical charging that produces lightning. Of course, air cannot mix without moving, and that movement is caused by the **wind**.

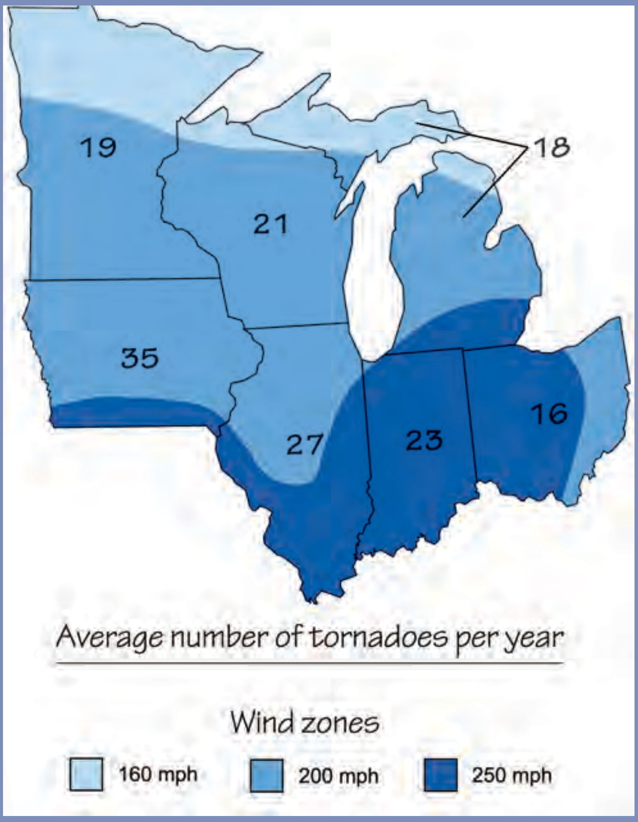
A strong temperature difference at different heights creates instability—the warmer the air near the surface is relative to the air above it, the more potential energy it has to move up. The Midwest frequently gets warm, moist air moving north from the Gulf of Mexico, and cold, dry air moving in from the Rocky Mountains or Canada. Where they meet, vigorous mixing causes storms. Typically, a storm blows itself out once the warm air has moved up and the cool air down—a vertical column turning over as a unit. But because the lower air from the Gulf is moving north while air higher up is moving west, more heat and moisture is constantly added to the system, allowing the storm to persist and strengthen. This movement in different directions is also the reason for the area's unusually high incidence of powerful tornados.

Tornados

Tornado Alley is a nickname for an area extending from Texas to Minnesota (including the western Midwest) that experiences a high number of exceptionally strong tornados. Correcting for size, Indiana and Iowa are the states with the third and fourth most tornados respectively. A few other places in the world see tornados more frequently per given area, but those in central North America tend to be much more powerful. The thunderstorms discussed above can sometimes produce dozens of violent tornados, called tornado outbreaks.

Midwestern Tornado Map

Number of average tornadoes per year in the Midwestern states.



Lake Effect
The Great Lakes create an interesting phenomenon primarily on their eastern shores, mainly affecting Michigan as well as parts of the Northeast, known as the lake effect. During the winter, the huge volume of water in the Great Lakes acts as a reservoir of heat, making the air above it relatively warm and humid. When cold air moves across the warmer lake, convection begins, and, as described above, a storm can form. The moisture from the lake begins to precipitate soon after the air cools. The Upper Peninsula of Michigan usually receives over five meters (200 inches) of snow per year, second only to Tug Hill Plateau in New York, which also gets lake effect snow.

All of the states of the Midwest experience winter storms to some extent, during which several inches of snow falls. While inconvenient and damaging to infrastructure, these storms do not frequently cause widespread disruption, as residents and governments are usually prepared to clear roads and repair damage. Additionally, schools have snow days calculated into their schedules. Ice storms can be more dangerous; as rain freezes to trees, power lines, and rooftops, they may collapse under the weight. If you are able to un-encase your car, the icy roads are even more dangerous to drive on than snowy ones.

Future Climate of the Midwest

While climate describes conditions over a long period of time, it does change, however slowly. In a previous section of this chapter, past changes were discussed. Using some of the techniques that help to reconstruct past climates, plus tracking trends in the present, we can predict how current climates might change. Overall, the world is warming, yet, because we are still in an ice age, eventually the current **interglacial** period will end, and glaciers will begin advancing towards the equator again, although likely not for about 100,000 years. Because the Earth is already getting warmer, the effects of **anthropogenic** sources of warming are amplified through feedback. Some scientists worry that, if not curbed, human activity could actually disrupt the cycle and knock the planet entirely out of the interglacial period, melting all the ice on Earth.

Causes of Change

While astronomical and tectonic forces will continue to cause climates to change, their work is so slow that it will be overshadowed in the near term by human-induced effects. The burning of **fossil fuels**, removal of forests, and all manner of human activities are altering the composition of the atmosphere.

The Earth's orbit, tilt, and wobble alter its position with respect to the Sun, affecting the global climate. These changes in the Earth's movement are cyclical, and the changes in Earth's climate associated with them are known as *Milankovitch Cycles*.

See Chapter 6: Glaciers for more about interglacial periods.

interglacial • *a period of geologic time between two successive glacial stages.*

anthropogenic • *caused or created by human activity.*

fossil fuels • *fuel for human use that is made from the remains of ancient biomass.*

Future

permafrost • *a layer of soil below the surface that remains frozen all year round. Its thickness can range from tens of centimeters to a few meters.*

aerosol • *tiny solid or liquid particles in the air.*

biofuel • *carbon-based fuel produced from renewable sources of biomass like plants and garbage.*

natural gas • *a hydrocarbon gas mixture composed primarily of methane (CH4), but also small quantites of hydrocarbons such as ethane and propane.*

Most dramatically, we are adding huge amounts of carbon dioxide and other greenhouse gases, which trap heat radiated by the Earth. Since plants remove carbon dioxide from the atmosphere, deforestation compounds the issue.

There is a finite amount of carbon on the planet, and the ways in which it changes states and locations are almost innumerable. This makes it extremely difficult to predict the outcome of putting increasing amounts of carbon (as carbon dioxide) into the atmosphere, but there are several important reinforcing effects already being observed. The increasing heat is causing glaciers and sea ice around the globe to melt, and as the ground and ocean they covered is exposed, these darker surfaces absorb and re-radiate increasing amounts of heat.

As **permafrost** in high latitudes melts, the carbon in the soils will become free to enter the atmosphere and, worse, to be converted by bacteria into the even more potent greenhouse gas, methane. Less directly, higher temperatures lead to more frequent and severe droughts, which, in turn, lead to more wildfires that release carbon and **aerosols** into the atmosphere. Aerosols can have a cooling effect as they reflect away radiation from the sun, but they can also pose a public health hazard.

Water is extremely good at absorbing heat: water vapor is the most effective greenhouse gas. Higher temperatures allow more water to be held in the air, as well as increase evaporation. While water vapor feedback is the most significant reinforcer of climate warming, water tends to move out of the atmosphere in a matter of weeks—other greenhouse gases linger in the atmosphere for years.

The Midwest has a unique combination of contributors to climate change. The population of any industrialized, and particularly wealthy, country produces pollution. The more than 50 million residents of the Midwest use electricity, transportation, and products that come from carbon-rich fossil fuels. But it is also a major center for agriculture, manufacturing, and coal, gas, and **biofuel** production, each of which release greenhouse gases. The Midwestern states are also developing unique ways to curb their effect on the climate. Minnesota has some of the most aggressive energy objectives in the US and is on track to produce 25% of its energy from clean fuel sources by 2025. In fact, Minnesota and Iowa already produce more than 10% of their energy from wind and, along with Wisconsin, 50% from biofuel! A distinction should, however, be drawn between production and consumption—these states consume far more coal and **natural gas** than anything else.

Temperature, Precipitation, and Storms

The average temperature in the Midwest is predicted to continue to increase for the foreseeable future—likely 3°C (5°F) by 2100. Of course, this doesn't mean this will occur steadily or evenly. For example, since 1980, the average annual temperature for northern Illinois has increased from around 7°C (45°F) to 9°C (49°F), a change of 2°C (4°F), yet the average *winter* temperature has increased by 4°C (8°F)! Perhaps because of its distance from the moderating influence of the oceans, the Midwest appears to be affected by warming more quickly than are many other areas. Interestingly, higher temperatures and higher carbon dioxide levels are, up to a point, expected to extend the growing season and increase crop yields. The US Government's Global Change Research Program expects the plant hardiness zones for the Midwest to become warmer by up to one zone every 30 years, rapidly changing what kinds of plants and crops can survive. Translating this change to the Köppen climate classification, much of the Midwest will soon be redesignated as humid subtropical. Coupled with less precipitation overall, a garden you planted in Michigan as a child will look like one from Arkansas by the time you are an adult, and then like one from Texas after 30 more years!

We can also expect more incidences of extreme weather. The causes of specific weather events are incredibly complex, but strong correlations and consequences from climate change are already apparent, and they offer clues about what to predict. Because higher temperatures mean greater evaporation and the ability of the air to hold more water, precipitation will occur in greater amounts at a time, but less frequently. During the cooler spring this will lead to flooding, while in hot summers, droughts will become more frequent. Higher atmospheric moisture content has also been correlated with an increased incidence of tornados—a particular concern in the Midwest.

Resources

Books

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Climate Literacy & Energy Awareness Network (CLEAN). (A rich collection of resources for educators.)
http://www.cleanet.org.

Envisioning Climate Change Using a Global Climate Model, by Youngman, B., Chandler, M., Sohl, L., Hafen, M., Ledley, T., Ackerman, S., and Kluge, S., SERC Earth Exploration Toolkit, http://serc.carleton.edu/eet/envisioningclimatechange/index.html.

Global Climate Change: Vital Signs of the Planet, NASA. (Climate data particularly from satellite-based remote sensing)
http://climate.nasa.gov.

Global Warming and Hurricanes, Geophysical Fluid Dynamics Laboratory, 2013.
http://www.gfdl.noaa.gov/global-warming-and-hurricanes.

Intergovernmental Panel on Climate Change, Fifth Assessment Report (AR5).
http://www.ipcc.ch/.

National Climate Assessment. (Reports summarizing impacts of climate change)
http://nca2014.globalchange.gov.

National Hurricane Data Center, NOAA. (News on current hurricane forecasts.)
http://www.nhc.noaa.gov.

National Weather Service, NOAA, http://www.weather.gov.

Regional Climate Trends and Scenarios for the US National Climate Assessment, NOAA.
http://www.nesdis.noaa.gov/technical_reports/142_Climate_Scenarios.html.

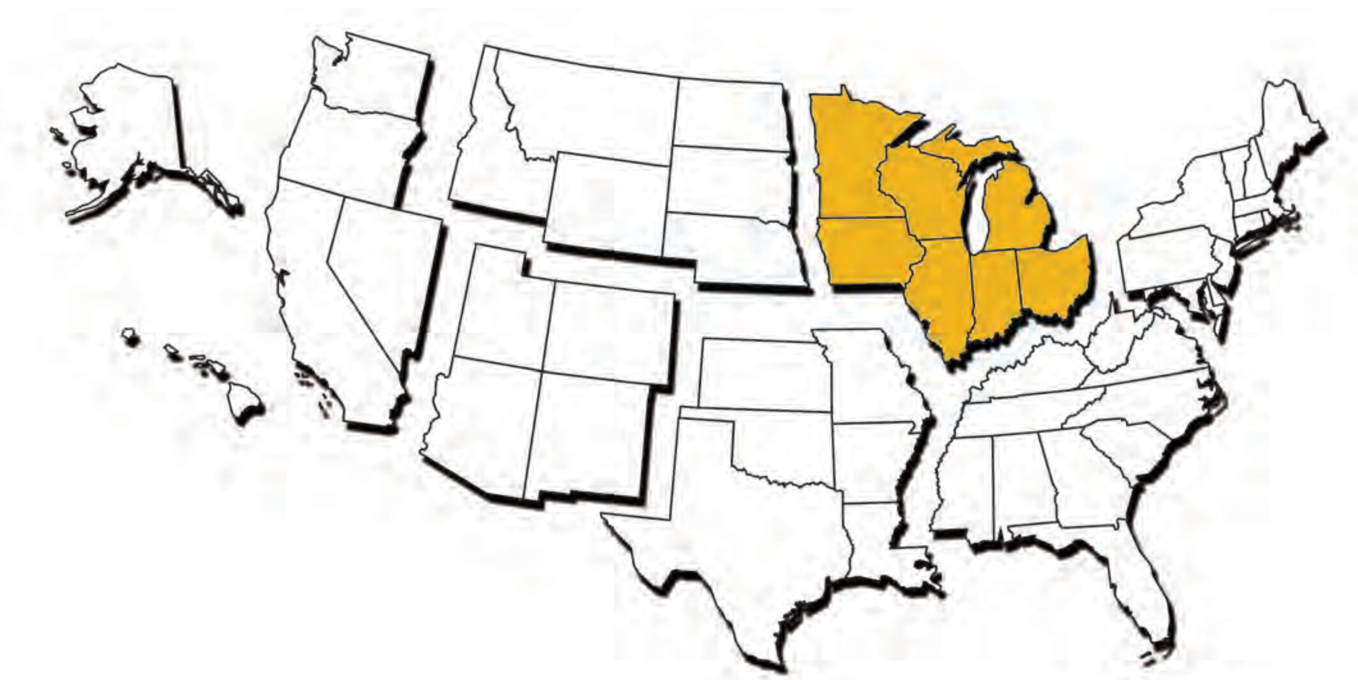
Weather Base. (Weather and climate data by country, state, and city.)
http://www.weatherbase.com.

Weatherunderground maps. (Variety of types of weather maps, including surface, temperature, moisture, wind, cloud cover, precipitation.)
http://www.wunderground.com/maps.

Why Does the U.S. Midwest Get So Many Severe Thunderstorms?, Cliff Mass Weather Blog Monday, 23 May 2011.
http://cliffmass.blogspot.com/2011/05/why-does-midwest-us-get-so-many-severe.html.

The **Teacher-Friendly** Guide™

to the Earth Science of the Midwestern US



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On the back cover: Blended geologic and digital elevation map of the Midwest. Each color represents the age of the bedrock at the surface. Adapted from Barton, K.E., Howell, D.G., Vigil, J.F., *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, http://pubs.usgs.gov/imap/i2781.