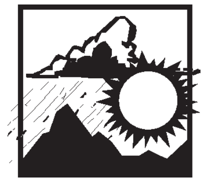


Chapter 9: Climate of the South Central US

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—San Francisco, for example—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 it can of course also define time periods millions of years in length.

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 South Central have a diverse wardrobe. While the entire area experiences seasonal change, the greatest variation occurs in the north, so those living in the interior states have a greater need for warm winter clothes than do those who live along the coast.

Past Climates

Climate, like other parts of the Earth system, is not static but changes over time, on both human and **geologic 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 Earth as a whole have varied through time, altering what kinds of climates are possible. The land that is now the South Central US has been arid, warm-temperate, and tropical at different times during the past 500 million years!

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 South Central. Unfortunately, we do not have as clear an understanding of climate for the earliest part of Earth history as we do for the later parts, because the oldest rocks are much more

atmosphere • *a layer of gases surrounding a planet.*

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

weather • *the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.*

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

tree • *any woody perennial plant with a central trunk.*

fossil • *preserved evidence of ancient life.*

CHAPTER AUTHORS

Richard A. Kissel
Judith T. Parrish

difficult to find. However, we can still say something about the climate of the ancient Earth, in large part due to our knowledge of 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 (CO_2), and nitrogen to the atmosphere. As the Earth cooled enough for liquid water to form, the vapor formed clouds from which the rain poured forth in such a deluge as the planet will never experience again. These torrential rains were constant for *millions* of years, absorbing **salt** and other **minerals** from the soil 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 filled, 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 about 3.7 billion years ago, the surface of the Earth was cooling to form a solid **crust** of rock (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 more buoyant rock floats higher on the **magma** and is pushed around on

Past

helium *• a gaseous chemical element (He), which is the second most abundant and second lightest element in the universe.*

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.*

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.*

the slow conveyor belts of mantle-formed rock (*Figure 9.1*). Denser rock forms oceanic **plates** that are lower and covered in water, and 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.

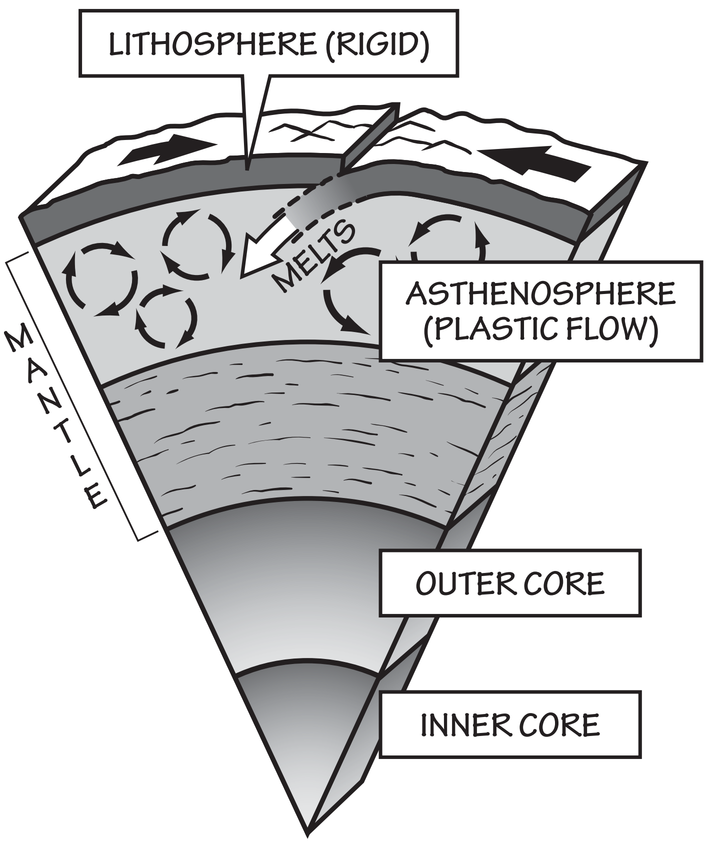


Figure 9.1: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.

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, while during the warm periods there is little or no glaciation anywhere on Earth. Today, we are still in a cool period—although the world has been cooler than it is at present, it has been much hotter for much of its history (*Figure 9.2*). Through the shifting global climate and the movement of the continents, what is now the South Central has at times been submerged beneath a shallow sea, a verdant plain filled with swamps and rivers, and even buried under ice.

density • *a physical property of minerals, describing the mineral's mass per volume.*

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.*

Past

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.*

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

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).*

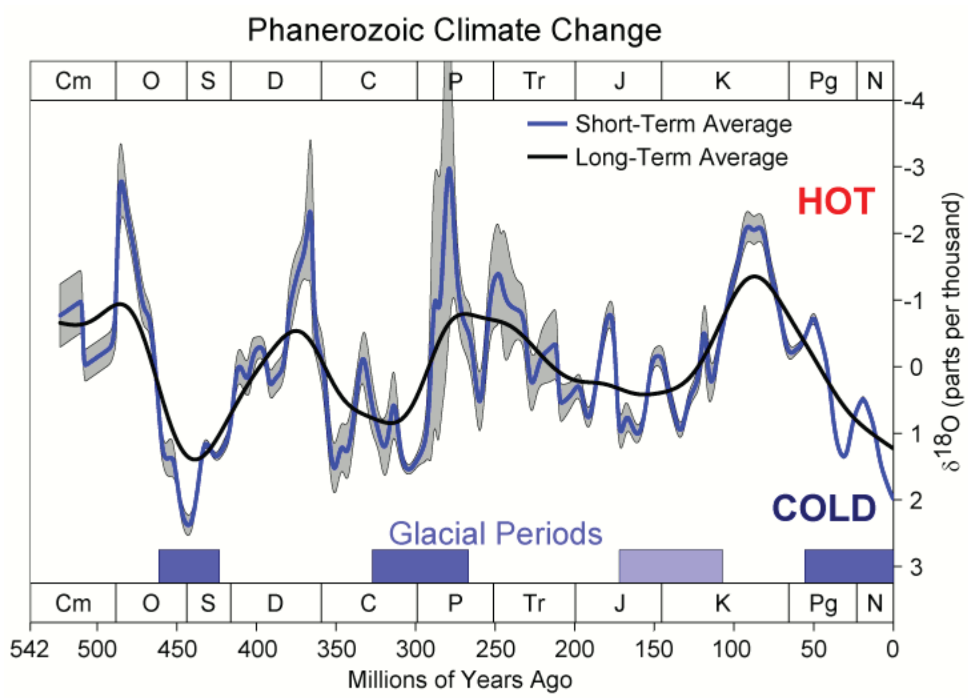


Figure 9.2: Changing global climate throughout the last 542 million years. These data were compiled using the ratios of stable oxygen isotopes found in ice cores and the carbonate skeletons of fossil organisms. (See TFG website for full-color version.)

Snowball Earth

There is evidence suggesting that the entire surface of the planet has been covered in ice several times, a hypothesis called Snowball Earth (*Figure 9.3*). 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 towards a series of cooling feedbacks, causing ice to spread from pole to pole.

See Chapter 6: Glaciers to learn more about past glaciations.

An ice-covered planet would remain in that state because almost all of the sun's energy would be reflected back into space, but this did not happen on Earth because of **plate 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. While these gases are usually removed from the atmosphere by organisms and the weathering of rocks, this was not possible through miles of ice! After millions of years, the concentrations of methane and CO_2 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

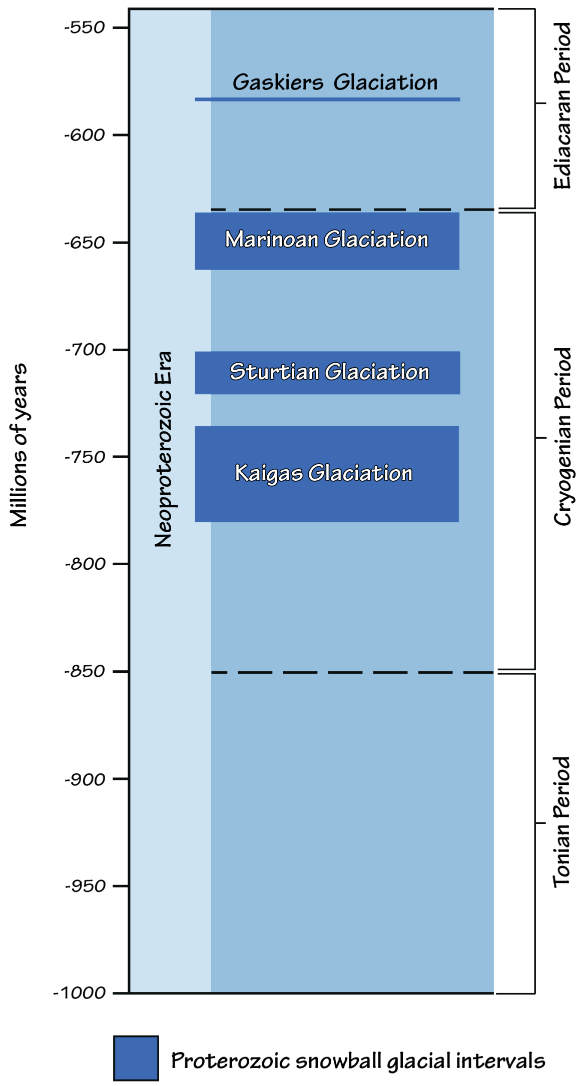


Figure 9.3: Snowball Earth periods during the Proterozoic.

feedbacks began. Because the oceans had been covered, nutrients derived 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, which was capable of combining with freshly thawed carbon sources to make more carbon dioxide, further enhancing the warming.

For the next 1.5 billion years, the South Central, 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. About 850 million years ago, during the **Cryogenian**, the Earth entered a 200-million-year **ice age**, during which there were two more Snowball Earth cycles. Although the part of Rodinia that would eventually become North America was located near the equator, the fact that North

Past

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

craton • *the old, underlying portion of a continent that is geologically stable relative to surrounding areas.*

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.*

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

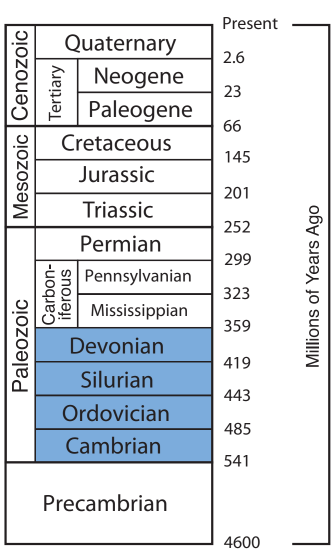
ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and glaciers.*

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

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

trilobite • *an extinct marine invertebrate animal characterized by a three-part body and a chitinous exoskeleton divided longitudinally into three lobes.*

brachiopod • *a marine invertebrate animal characterized by upper and lower calcareous shell valves joined by a hinge, and a crown of tentacles (lophophore) used for feeding and respiration.*



America was at such a low latitude, yet had **glaciers**, is strong evidence that the Earth really did freeze over completely. However, no direct evidence for any of the Snowball Earth cycles comes from rocks in the South Central.

Life and Climate

With the start of the **Paleozoic** era, climates across the world were warm, and North America was located in the low and warmer latitudes of the Southern Hemisphere. As the **Cambrian** progressed, North America moved northward; by about 480 million years ago, what would become the South Central US was located just below the equator (*Figure 9.4*). In Texas, the presence of Cambrian **sandstone** indicates that sediments were carried to the sea from the land to the northwest. East of the sandstone, a rich and diverse marine fauna, including **trilobites**, **brachiopods**, **bivalves**, **sponges**, and other invertebrates, is contained within **dolomite** and **limestone** units. Although **sedimentary rocks** of Cambrian age are only exposed in Texas, most of the South Central was probably home to warm, shallow seas that persisted into the **Ordovician**.

See Chapter 3: Fossils for more information about life in the Paleozoic.

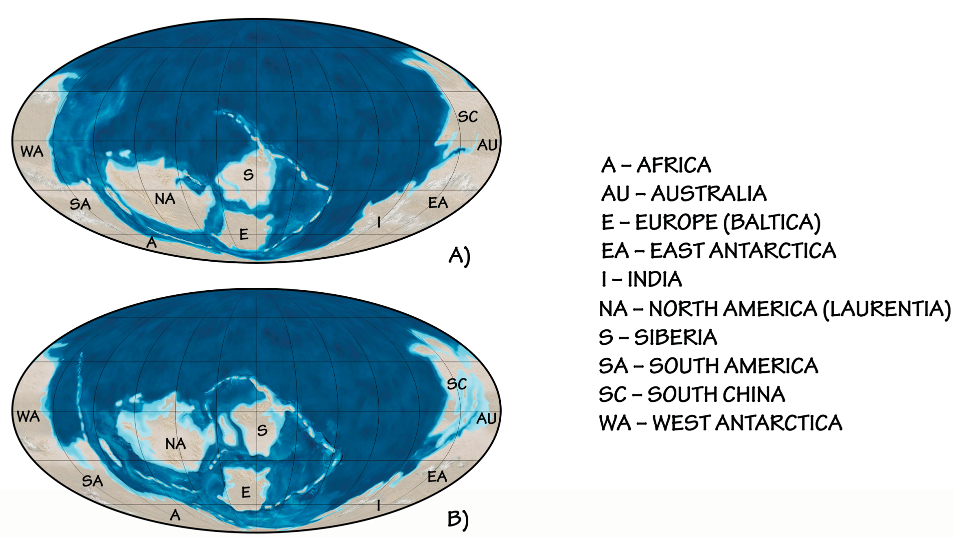


Figure 9.4: The location of the continents during the A) early and B) late Cambrian. Note the position of North America relative to the equator.

At the end of the Ordovician, from 460 to 430 million years ago, the Earth fell into another ice age, but **Silurian** and **Devonian** fossils in Oklahoma (including trilobites and brachiopods) indicate that the South Central still contained warm, shallow seas through the early Devonian. After an episode of **uplift** and **erosion**, however, the environment changed dramatically. The seas became deeper, and plankton productivity grew so high that it depleted all the oxygen from the seafloor and sediments. The lack of oxygen allowed organic matter to accumulate instead of decaying, leading to the deposition of black, carbon-rich

shale. Drill cores show us that this rock occurs throughout the subsurface in the western two-thirds of Oklahoma and northern Texas; it is one of the richest sources of **petroleum** in those states.

From 430 to 300 million years ago, North America moved north across the equator, and the cycle of warming and cooling was repeated yet again. Glaciation in the southern hemisphere occurred during the late Devonian, while the supercontinent **Gondwana** was located over the South Pole. At the same time, while the South Central States were still submerged, the oceans between Gondwana and North America began to close (*Figure 9.5*). By the early **Carboniferous**, ice capped the South Pole and began to expand northward. Although the Earth's temperature fell during this time and the growing glaciers far to the south caused sea levels to drop, the northern part of the South Central returned to a warm, shallow sea with limestone and abundant marine life, including brachiopods, corals, and **echinoderms**, while the southern part accumulated thick deposits of sandstone and shale. By the late Carboniferous, North America had collided with Gondwana, advancing the formation of **Pangaea**— a supercontinent composed of nearly all the landmass on Earth. The Ouachita Mountains, remnants of what was once a chain of mountains that may have been as high and broad as the Tibetan Plateau, bear witness to this event. Sedimentary rocks indicate that most of the South Central was now covered by rivers and plains; Oklahoma, Kansas, and Arkansas had flourishing coastal swamps filled with vegetation that has since been transformed into rich **coal** beds by heat and pressure. Many Carboniferous rocks in the South Central, especially in Kansas, are cyclic, showing repeated episodes of sea level fall and rise as the **ice cap** in the Southern Hemisphere advanced and retreated.

See Chapter 1: Geologic History to learn more about the formation of Pangaea.

During the **Permian**, as sea levels dropped, shallow marine waters gave way to lowland coastal areas, and most of the South Central also became terrestrial. The Permian Basin in western Texas remained marine, however, and an enormous barrier **reef** formed around its rim. Part of this reef can be seen at El Capitan in Guadalupe Mountains National Park (*Figure 9.6*). During the Permian, the climate was drier than that of the Carboniferous, and extensive salt and **gypsum** deposits indicate that evaporation rates were high. A shift in plant type—from water-loving ferns and **horsetails** to plants better adapted for drier conditions—is further evidence of arid conditions during this time. By the end of the Permian, the southern ice sheets had disappeared, and desert conditions existed in the core of the supercontinent (as indicated, for example, by what look like **sand** dunes preserved in sedimentary rocks).

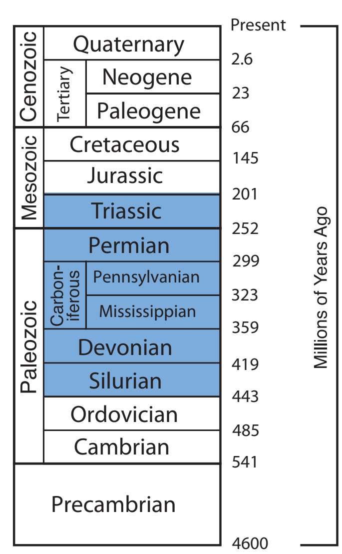
Around 220 million years ago, the South Central moved north from the equator. The Earth remained warm and ice-free at the poles through much of the **Mesozoic** era, until worldwide temperatures began to dip again around 150 million years ago. After reaching its greatest size during the **Triassic** period, Pangaea began to break apart into continents that would drift toward their modern-day positions. The South Central's climate gradually shifted, becoming wetter. Triassic rocks are known only from far western Oklahoma and Texas,

***Gondwana* •** *the supercontinent of the Southern Hemisphere, composed of Africa, Australia, India, and South America.*

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

***gypsum* •** *a soft sulfate mineral that is widely mined for its use as fertilizer and as a constituent of plaster.*

***horsetail* •** *See sphenopsid: a terrestrial plant belonging to the family Equisetaceae, characterized by hollow, jointed stems with reduced, unbranched leaves at the nodes.*



9 Climate

Past

dinosaur • *a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

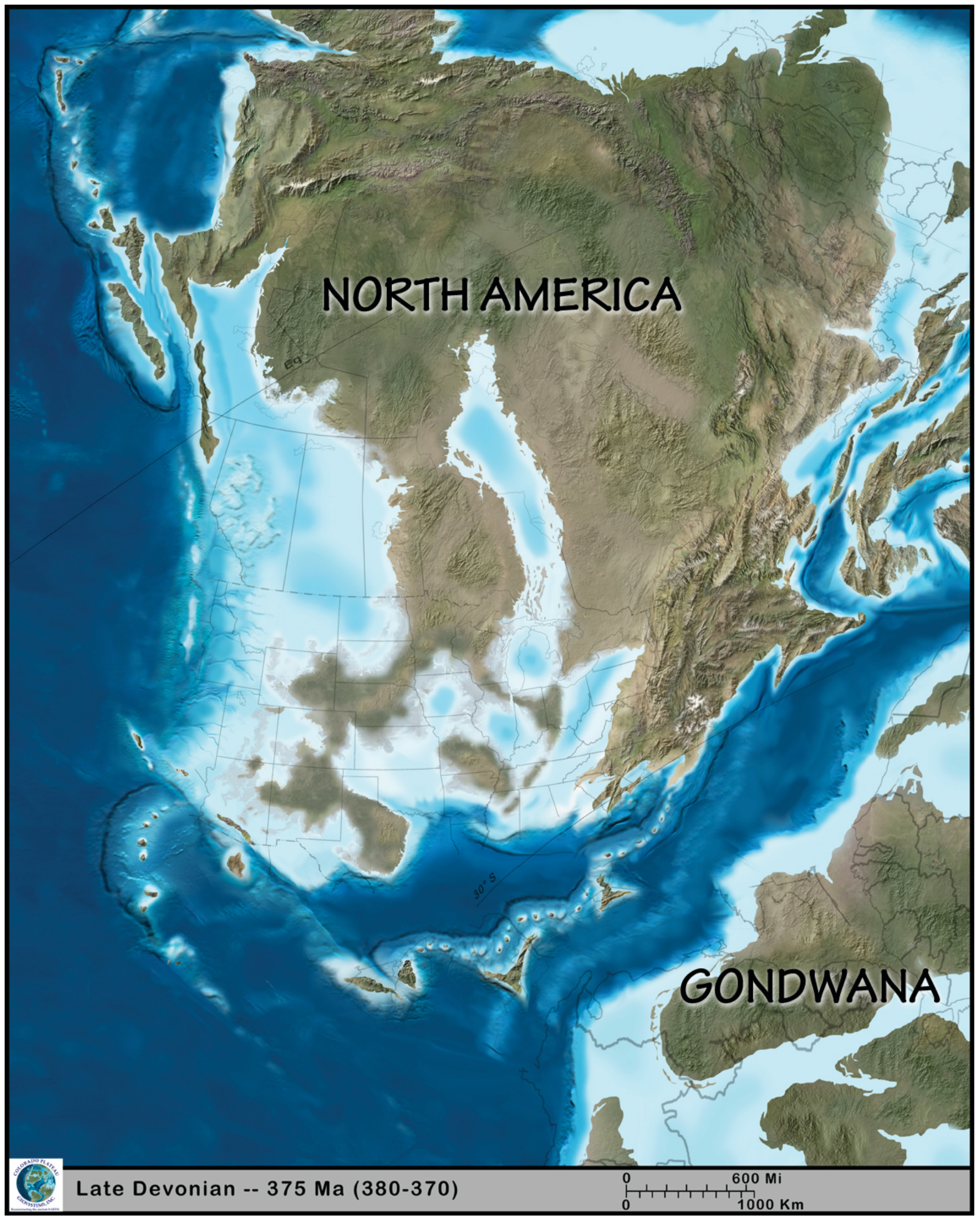
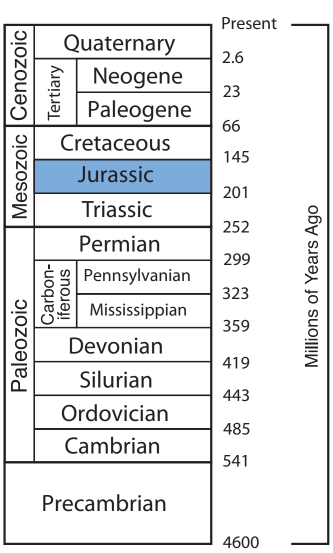


Figure 9.5: By the late Devonian (375 million years ago), the oceans between Gondwana and Euramerica had begun to close.

where they contain a rich terrestrial and lake fauna of fishes, amphibians, and reptiles.

Jurassic outcrops in western Oklahoma are terrestrial and contain petrified wood, **dinosaurs**, and other reptiles indicative of lake environments, revealing that the environment there did not change much from the Triassic (except to become a bit wetter). Farther south, however, the breakup of Pangaea caused the Gulf of Mexico to **rift** open, flooding it with seawater. Because the climate was still relatively warm and dry, evaporation rates were high, and extremely thick deposits of salt accumulated there. These salt deposits have played a



Past

Figure 9.6: El Capitan in western Texas, Guadalupe National Park. The large escarpment is part of a gigantic barrier reef that stretches into New Mexico under Carlsbad and back into Texas in the east. For most of this range, it is below the surface, but it crops out spectacularly here.

key role in trapping petroleum along the Gulf Coast. At the same time, the portion of the South Central that bordered the coastline began to **subside**, and thick deposits of coastal and marine sediments began to accumulate, a process that continues to this day.

See Chapter 3: Fossils to learn more about dinosaurs of the South Central.

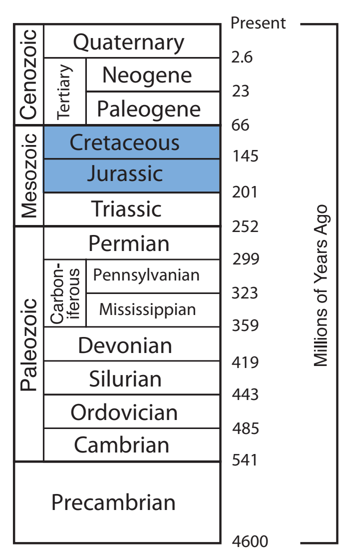
The Earth warmed near the beginning of the **Cretaceous**, and sea level rose. Throughout the Cretaceous, sea level was an average of 100 meters (330 feet) higher than it is today, largely as a result of water displacement by continental rifting and rapid sea-floor spreading. Shallow seaways spread over many of the continents, and by the start of the late Cretaceous, North America was divided in two by an **inland sea** known as the Western Interior Seaway (*Figure 9.7*). This sea flooded most of the South Central, covering older rocks and creating a wide belt of Cretaceous- and younger-aged rock that extends many hundreds of miles up the Mississippi River and covers all of Louisiana, about half of Texas, and parts of Arkansas, Oklahoma, and Missouri.

At the close of the Cretaceous, 65 million years ago, global climates (though still much warmer than those of today) were cooler than at the era's start. At the very end of the Cretaceous, the Gulf Coast experienced an enormous disruption when an asteroid or comet collided with Earth in what is now the northern Yucatán Peninsula in Mexico, just a few hundred miles away. The impact vaporized both water and rock, and formed tiny **glassy** spheres, called

subsidence • *the sinking of an area of the land surface.*

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

glassy rock • *a volcanic rock that cooled almost instantaneously, resulting in a rock with tiny crystals or no crystals at all.*



9 Climate

Past

Eocene • *a geologic time period extending from 56 to 33 million years ago.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

silica • *a chemical compound also known as silicon dioxide (SiO_2).*

calcium carbonate • *a chemical compound with the formula $CaCO_3$, commonly found in rocks in the mineral forms calcite and aragonite, as well as the shells and skeletons of marine organisms.*

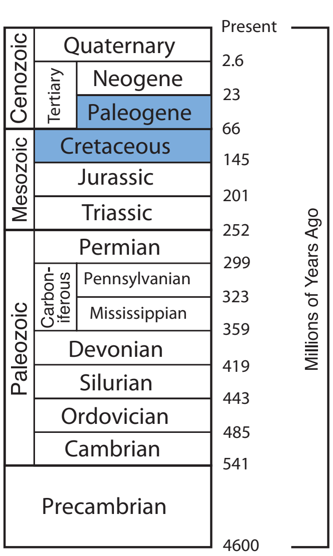


Figure 9.7: The Western Interior Seaway.

microtektites, from the melted rock. After that event, the climate may have cooled briefly (as suggested, for example, by an abundance of ferns), but it soon rebounded to a warmer state, and continued to warm into the **Eocene**.

By the early **Cenozoic**, the continents had approached their modern configuration, and India began to collide with Asia to form the Himalayas. The formation of the Himalayas had a significant impact on global climate, as the newly exposed rock began to serve as a sink to take up atmospheric CO_2. With the reduction of this greenhouse gas, global temperatures cooled. Antarctica moved south, and by 30 million years ago, temperatures were low enough that glaciers began to grow on its mountains. The South Central continued to accumulate sediment brought in by myriad rivers, including the antecedents to the Mississippi River. Sea level dropped, and the continued withdrawal of the sea is reflected in almost-parallel belts of progressively younger rocks that extend toward the Gulf Coast.

Silicate and *carbonate rocks* both weather chemically in reactions that involve CO_2 and water, typically creating *clays*, bicarbonate, and calcium ions. *Silica* weathering occurs relatively slowly, taking place on large scale in the weathering and erosion of mountain ranges, and it may have an impact on atmospheric carbon dioxide levels on time scales of tens or hundreds of millions of years. On the other hand, carbonate rocks weather (in this case, dissolve) quickly, relative to silicates. In both cases, the products of weathering often end up in sea water, where they may be used in the *calcium carbonate* skeletons of marine organisms or taken up during photosynthesis. Skeletal material and organic matter often sink to the sea floor and become buried, effectively removing carbon from the global carbon cycle (and thereby the atmosphere) for many millions of years.

Eventually, a sheet of sea-ice formed over the Arctic, and ice sheets spread over northern Asia, Europe, and North America, signaling the start of the most recent ice age. Since just 800,000 years ago, a type of equilibrium has been reached between warming and cooling, with the ice caps growing and retreating primarily due to the influence of astronomical forces. The ice reached northern Missouri and northeastern Kansas during its maximum extent, while the rest of the South Central merely experienced a cooler climate than it does at present. The area was also somewhat wetter than it is today, with wetlands and forests covering much of what would later become grassland. Rocks of this age contain fossils of terrestrial vertebrates such as horses, camels, bison, **mastodons**, and **mammoths**. Much of the Mississippi River's great **delta** and **alluvial** fan was deposited when the glacial ice melted, creating rivers that eroded older rocks as well as carrying sediments previously **scoured** by the glaciers.

Present Climate of the South Central

The location of the South Central and its direct relationship to the Gulf of Mexico strongly influence the area's weather. Since it encompasses locations along the coast as well as areas farther inland, the South Central experiences nearly every variety of extreme weather. Heat and cold waves, droughts, floods, blizzards, **tornados**, and **hurricanes** are all considerations for the residents of the South Central.

See Chapter 10: Earth Hazards for more information on extreme weather in the South Central.

Past–Present

mastodon • *an extinct terrestrial mammal belonging to the Order Proboscidea, characterized by an elephant-like shape and size, and massive molar teeth with conical projections.*

mammoth • *an extinct terrestrial mammal belonging to the Order Proboscidea, from the same line that gave rise to African and Asian elephants.*

delta • *a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

alluvial • *a thick layer of river-deposited sediment.*

scouring • *erosion resulting from glacial abrasion on the landscape.*

tornado • *a vertical funnel-shaped storm with a visible horizontal rotation.*

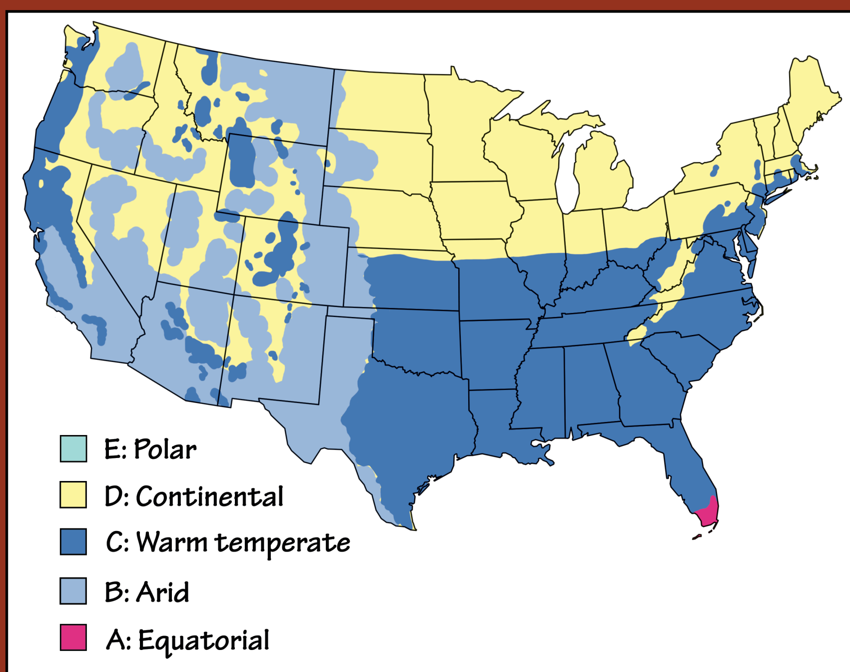
hurricane • *a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms.*

9 Climate

Present

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.



(See TFG website for full-color version.)

Today, the South Central lies at the intersection of several distinct climate zones, with much of the region characterized as warm temperate (represented by "C" in the Köppen system). Northern Missouri and northern Kansas are characterized as continental (represented by "D"), and the eastern parts of Kansas and Texas are arid (represented by "B").

Present

Average temperatures in the South Central tend to decrease northward, which is simply the influence of latitude: lower latitudes receive more **heat** from the sun over the course of a year. The warmest temperatures are found in Louisiana and Texas, and the coolest found in Missouri and Kansas (*Figure 9.8*). The South Central's overall average high temperature of 20ºC (68°F) and average low of 9ºC (49°F) are indicative, on the whole, of a more uniform climate than that found in most other regions of the United States. By comparison, the average high and low temperatures for the entire United States are 17ºC (63ºF) and 5ºC (41ºF), respectively. Another factor besides latitude that influences temperature in the South Central is proximity to the ocean, which has a moderating influence: air masses that have passed the Gulf of Mexico rarely get either extremely hot or extremely cold. Thus the most extreme temperatures in the South Central are found toward the center of the continent: record high and low temperatures are both held by Kansas, which has experienced a high of 49ºC (121ºF) and a low of -40°C (-40°F).

heat • a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.

convection • the rise of buoyant material and the sinking of denser material.

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

Average Annual Temperatures			
	Combined (ºC [ºF])	Low (ºC [ºF])	High (ºC [ºF])
Louisiana	19.2 (66.6)	13.2 (55.7)	22.1 (71.8)
Texas	18.7 (65.6)	11.8 (53.3)	23.2 (73.7)
Arkansas	15.8 (60.5)	9.6 (49.3)	22.1 (71.8)
Oklahoma	15.7 (60.2)	8.8 (47.8)	20.9 (69.6)
Missouri	12.8 (55.0)	6.5 (43.7)	17.3 (63.2)
Kansas	12.6 (54.7)	5.6 (42.1)	16.7 (62.1)

The average amount of precipitation for the United States is 85.6 centimeters (33.7 inches). In the South Central, however, average precipitation ranges from 146.3 centimeters (57.6 inches) in Louisiana to 74.4 centimeters (29.3 inches) in Kansas (*Figure 9.9*), demonstrating the impact of moisture carried inland from the adjacent Gulf of Mexico.

The geography and climate of the South Central 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 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 South Central receives warm, moist air moving north from the Gulf of Mexico, and cold, dry air moving in from the Rocky Mountains and the northern US. Where these air masses

See Chapter 10: Earth Hazards to learn more about tornados and hurricanes.

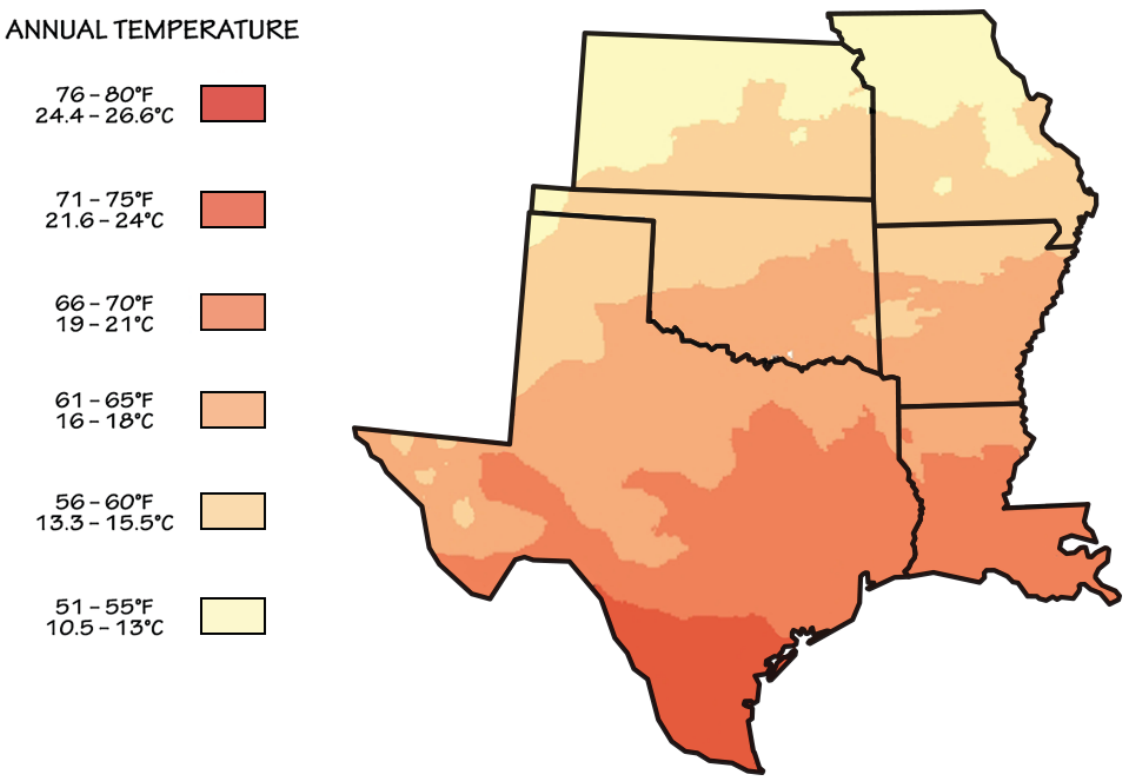


Figure 9.8: Mean annual temperature for the South Central States. (See TFG website for full-color version.)

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 South Central's unusually high incidence of powerful tornados.

During the summer months, rainfall increases in southeastern Louisiana, where moist tropical air arriving from the Gulf of Mexico results in almost daily showers. The state is also commonly in the path of tropical storms and hurricanes moving northward off of the Gulf. Louisiana is south of the path of many winter storm centers, which travel from the northwest, but the northern parts of the state are susceptible. For this reason, Louisiana's winter precipitation pattern is reversed from the summer, with the heaviest precipitation found in the state's north.

Present

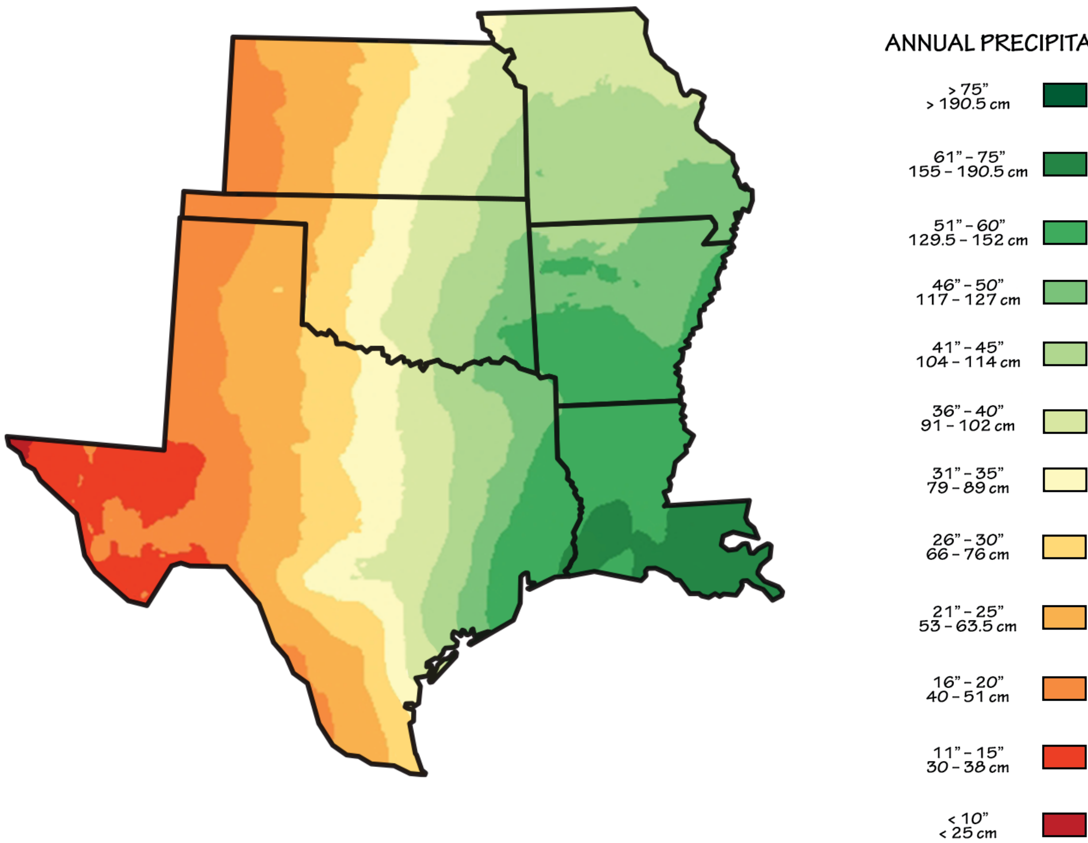


Figure 9.9: Mean annual precipitation for the South Central States.
(See TFG website for full-color version.)

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

Arkansas' climate is influenced by its **topography** as well as its relative proximity to the Gulf of Mexico. The state's winters, like those of Louisiana, are short, while its summers are hot and humid, with heavy precipitation. Arkansas is often subject to heavy rainfall from the remnants of tropical storms that arrive from the Gulf; the state is known for its extreme weather and abundant storms, including thunderstorms and tornados. The Ouachita Mountains, running northeast through southern Arkansas, are high enough to influence the state's climate as well. Due to a minor rain shadow effect (*Figure 9.10*), the land north of the mountain chain is drier than that to the south, as the mountains block northward-moving precipitation. Snow does fall in the winters, but it is primarily restricted to the northwest section of the state.

In Oklahoma, summers are long and warm, and winters are shorter than in other states of the Great Plains. Because of moist warm air moving northward from the Gulf, rainfall increases dramatically toward the state's eastern

Present

relief *• the change in elevation over a distance.*

portion, with an average of 43 centimeters (17 inches) in the west and 142 centimeters (56 inches) in the far southeast. In the winter, snowfall follows the reverse pattern, with more snow in the west than in the east, due to the state's elevation gradient. This same pattern is also present in Kansas, where the annual average precipitation ranges from 107 centimeters (42 inches) in the southeast to 51 centimeters (20 inches) in the west, and the annual average snowfall ranges from 38 to 102 centimeters (15 to 40 inches) along the same gradient. With its low topographic **relief**, Kansas is also commonly home to tornados and dust storms.

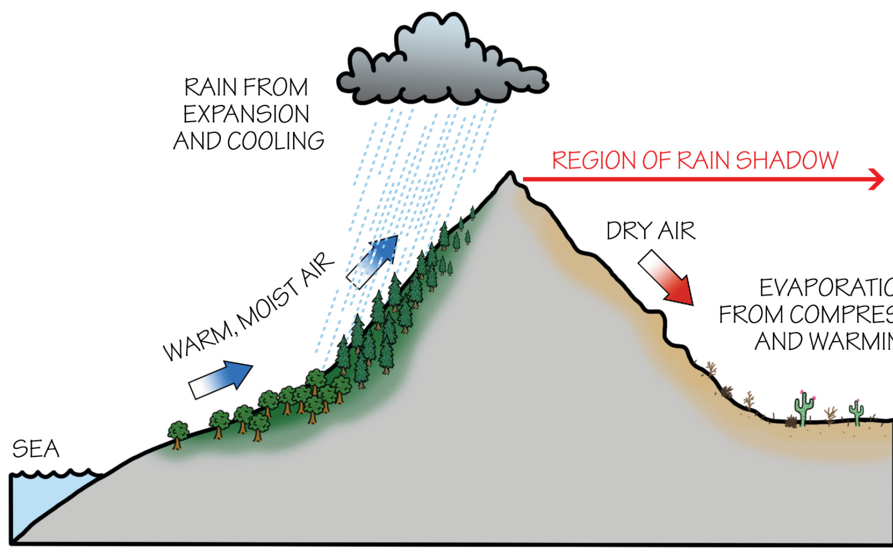


Figure 9.10: The rain shadow effect occurs when moisture-laden air rises up the windward side of a mountain, only to release this moisture as precipitation due to cooling and condensation. Once the air reaches the leeward side, it warms and expands, promoting evaporation (and a lack of precipitation).

Missouri's location in the US interior, and the absence of nearby large bodies of water or mountain ranges that would moderate the state's climate, means that it is subject to major temperature extremes. The warm moist air of the Gulf influences summer precipitation, while Arctic air from the north affects the winters. Missouri experiences a temperature fluctuation of approximately 17 to 22 degrees Celsius (30 to 40 degrees Fahrenheit) in any 24-hour period.

Covering nearly 700,000 square kilometers (270,000 square miles), Texas is the second largest state, and encompasses a wide variety of climate regions. The rugged terrain of western Texas receives little rainfall and ranges from desert to semi-arid climate conditions, although the area's highest peaks do receive significant snowfall in the winter. Texas' central and eastern areas possess significantly less complicated topography, with the terrain descending from northwest to southeast. In areas where the terrain drops abruptly, such as in the Caprock Escarpment, topography has a greater effect on local climate, enhancing precipitation and promoting the formation of thunderstorms. Overall, precipitation along Texas' topographic gradient ranges from near-desert conditions in the west to annual accumulations close to 152 centimeters (60 inches) along the coast thanks to moisture from the Gulf. Although the humid air amplifies summer heat, the Gulf's waters cool during the winter, moderating coastal temperatures during the spring. Texas' coastal area is prone to severe thunderstorms and tornados, and it is also vulnerable to the occasional hurricane.

See Chapter 4: Topography for more information about escarpments.

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 Climate of the South Central

By using some of the techniques that help to reconstruct past climates, and by 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 should end, allowing glaciers to advance towards the equator again (although likely not for about 100,000 years). However, because the Earth is already getting warmer, the effects of **anthropogenic** 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.

See Chapter 6: Glaciers to learn more about interglacial periods.

Causes of Change

While astronomical and tectonic forces will continue to cause climatic shifts, they act so slowly that they will be overshadowed in the near term by human-induced effects. In 1956, NOAA established the Mauna Loa Observatory (MLO) in Hawai'i to measure a variety of atmospheric parameters, including carbon dioxide concentration. The CO_2 record extends from 1958 to present, and it shows the influence of both natural and anthropogenic processes (*Figure 9.11*). The zigzag pattern is the result of seasonal photosynthesis in the northern hemisphere. In spring and summer, the growth and increased photosynthetic activity of plants draws CO_2 out of the atmosphere. Conversely, it accumulates in the atmosphere during fall and winter when plants are dormant. The overall upward trend is caused by human activity. Industrialization, **fossil fuel** combustion, and deforestation all contribute CO_2 to the atmosphere, adding it at a rate much faster than natural processes can remove it. Analyses of ancient atmosphere samples preserved in glacial ice cores show CO_2 levels to be 180 parts per million (ppm) at the height of the last ice age and 280 ppm at its end. The amount of CO_2 in the atmosphere has been increasing at a rapid rate since the start of the industrial revolution, and it has accelerated since the end of World War II. In May 2013, measurements at MLO reached 400 ppm CO_2 for the first time.

9 Climate

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.

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

__aerosol__ • tiny solid or liquid particles in the air.

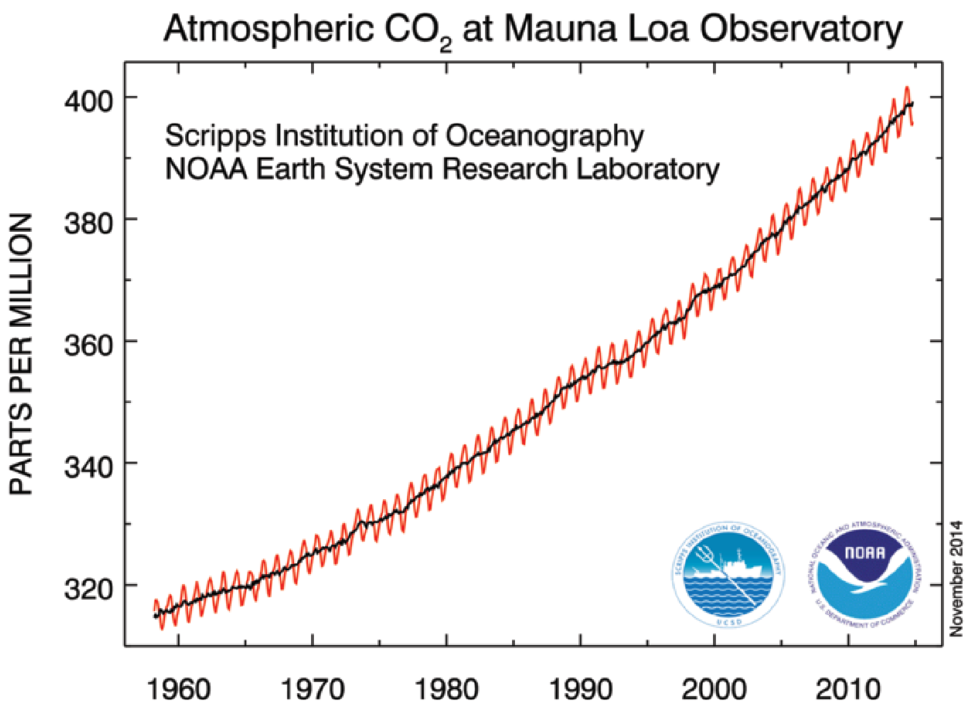


Figure 9.11: Measured concentration of atmospheric carbon dioxide (1958 to present) at MLO.

While some atmospheric CO_2 is necessary to keep Earth warm enough to be a habitable planet, the unprecedentedly rapid input of CO_2 to the atmosphere by human beings is cause for concern. Everything we know about atmospheric physics and chemistry tells us that increased CO_2 leads to a warmer planet. Multiple paleoclimate data sets verify this conclusion, and modern measurements confirm that we are living in an increasingly warmer world. 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, carbon in the **soil** 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 actually the most effective greenhouse gas. Higher temperatures increase evaporation and allow the air to retain more water. 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, such as carbon dioxide and methane, linger in the atmosphere for years.

Climate 9

The South Central contributes significantly to climate change. The population of any industrialized and particularly wealthy country produces pollution. The 48 million residents of the South Central use electricity, transportation, and products that come from carbon-rich fossil fuels. Burning fossil fuels releases carbon into the atmosphere, which warms the Earth. Of the South Central States, Texas emits by far the most greenhouse gases. The highest greenhouse gas emitter in the nation, Texas releases nearly 656 million metric tons of CO_2 per year, nearly double that of California, the second largest emitter. The majority of these emissions come from the use of petroleum.

On the other hand, South Central States are making changes to reduce human impact on the climate. Texas' emissions have decreased by 65 metric tons (64 standard tons) in the last decade, the greatest absolute reduction in of any state over that time period. The city of Dallas was an early adopter of the 2030 Challenge, an effort by cities to reduce fossil fuel use in buildings so that both new and renovated buildings would qualify as carbon neutral by the year 2030. Additionally, many states are stepping up their use and production of **renewable energy**. Missouri ranks 17th in the nation for renewable energy use, most of which it produces from **biomass**.

Trends and Predictions

Studies show that the South Central's climate is changing right now, and that change has accelerated in the latter part of the 20th century. These changes include the following:

- The number of days with temperatures above 35°C (95°F) has been steadily increasing for the last 25 years (*Figure 9.12*).
- The city of St. Louis experiences about four **heat waves** lasting three days or longer each summer—a number which has doubled over the last 60 years.
- Locations along the Gulf of Mexico have experienced over 8 inches of sea level rise in the last 50 years.
- In 2011, Texas experienced the worst one-year drought in state history, exacerbated by temperatures almost 3°C (5°F) above normal. The drought cost the state $7.6 billion in agricultural losses.
- The Ogalalla Aquifer, which provides fresh water to much of the South Central, has been depleted by more than 40% in some areas, thanks to years of decreased rainfall.

See Chapter 10: Earth Hazards for more information on how drought is affecting the Ogalalla Aquifer.

- Altered flowering patterns due to more frost-free days have increased the South Central's pollen season for ragweed, a potent allergen, by 16 days since 1995.

Future

renewable energy • *energy obtained from sources that are virtually inexhaustible (defined in terms of comparison to the lifetime of the Sun) and replenish naturally over small time scales relative to human life spans.*

biomass • *organic material from one or more organisms.*

heat wave • *a period of excessively hot weather that may also accompany high humidity.*

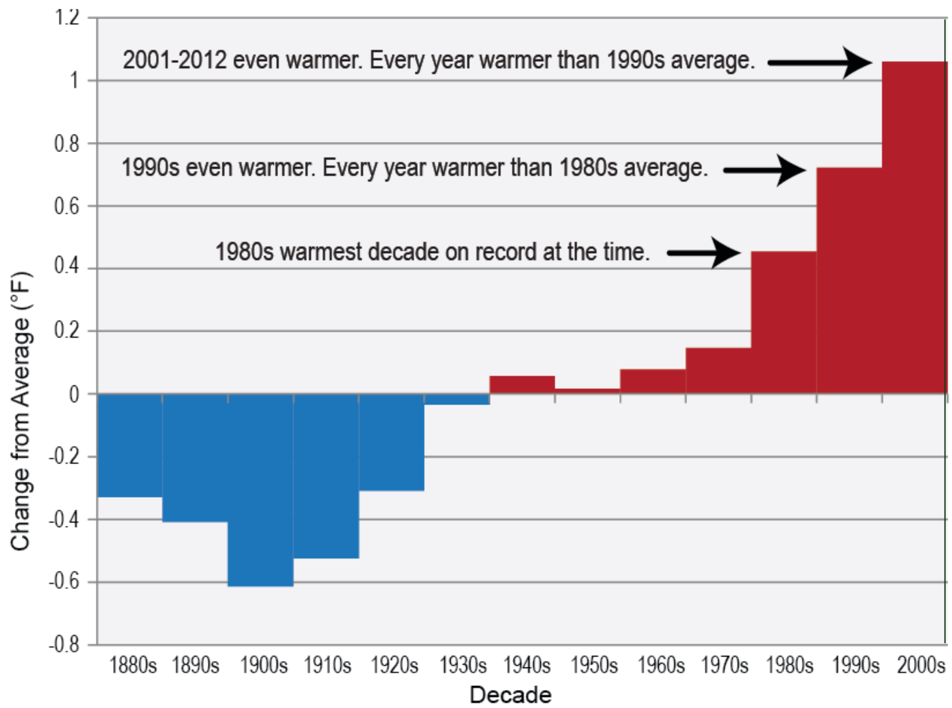


Figure 9.12: Global temperature change since the 1880s. The Earth's average surface temperature has progressively risen over the last five decades.

Climate models predict that the South Central will continue to warm, and that the average annual temperature will continue to increase for the foreseeable future—likely a 3°C (5°F) increase by 2100. Summer temperatures in Oklahoma, for example, are expected to increase by 3 to 6°C (6 to 10°F) by 2100. These increased temperatures lead to a whole host of other effects, including drier soils from more evaporation, and the increased likelihood of drought and fires. Texas, which contains the largest acreage of crop-, pasture-, and rangeland in the United States, could be severely impacted by these changes. Because higher temperatures mean greater evaporation and warmer air can hold more water, precipitation will occur in greater amounts at a time, but less frequently (*Figure 9.13*). During the cooler spring this will lead to flooding, while in hot summers, droughts will become more frequent. These drier summers and wetter winters and springs could have significant adverse impacts on agriculture.

Water supply is a critical issue in the South Central, and communities will need to adapt to changes in precipitation, snowmelt, and runoff as the climate changes. Drier days and higher temperatures will amplify evaporation, increasing the desertification of already arid areas and affecting natural ecosystems as well as increasing pressure on the water supply for agriculture and cities (*Figure 9.14*).

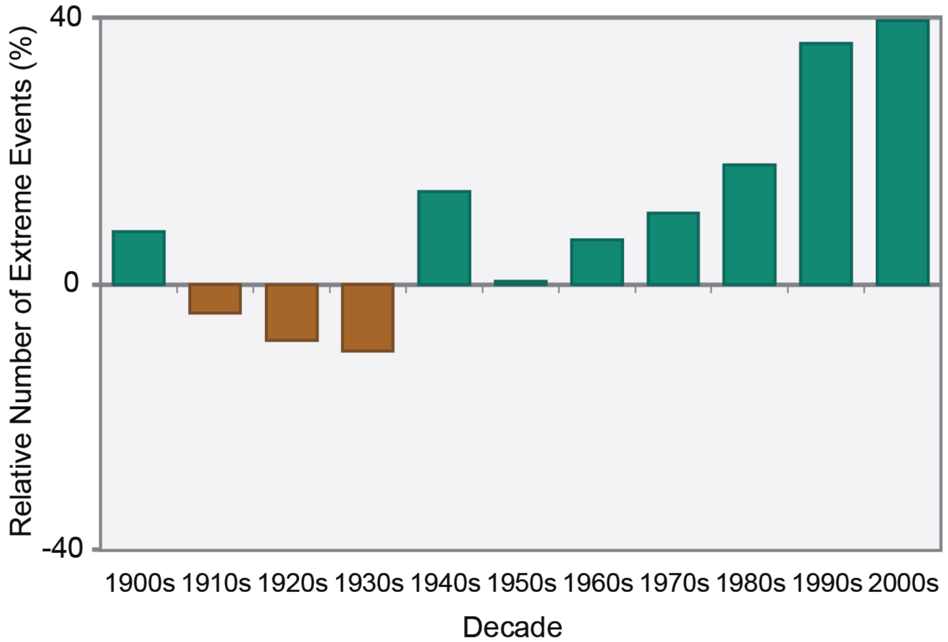


Figure 9.13: Changes in heavy precipitation events from the 1900s to the 2000s. Each event is defined as a two-day precipitation total that is exceeded, on average, only once every five years. The occurrence of such events has become increasingly common.

Figure 9.14: Dead fish rot on the cracked lakebed of the O.C. Fisher Reservoir at San Angelo State Park, Texas. The lake, which once spanned more than 2200 hectares (5400 acres), was once an important source of drinking water as well as a recreational fishing area. It is now completely dry due to severe drought conditions.

Climate

Future

The causes of specific weather events such as hurricanes and severe thunderstorms are incredibly complex, although climate change has enhanced some correlated factors, such as increased wind speed and an unstable atmosphere. Higher atmospheric moisture content has also been correlated with an increased incidence of tornados and winter storms. However, although climate change is predicted to enhance the intensity of severe weather, there is currently no way to calculate what effect climate change will have on the frequency of specific storm events—for example, we might see more powerful tornados, but we do not know if we will see *more* of them.

More than 50% of the American population currently lives in coastal regions. With increased **global warming**, sea-level rise and the likelihood of increased incidences of extreme weather are expected, including an increase in hurricane intensity and associated storm surge. Sea level rise from melting glaciers and the thermal expansion of a warmer ocean will be a concern for populated coastal areas, including major cities such as New Orleans (*Figure 9.15*) and Houston. Regional studies project that by 2030, climate change could cause $4.6 billion in damages to coastal property and assets on the Gulf Coast alone.

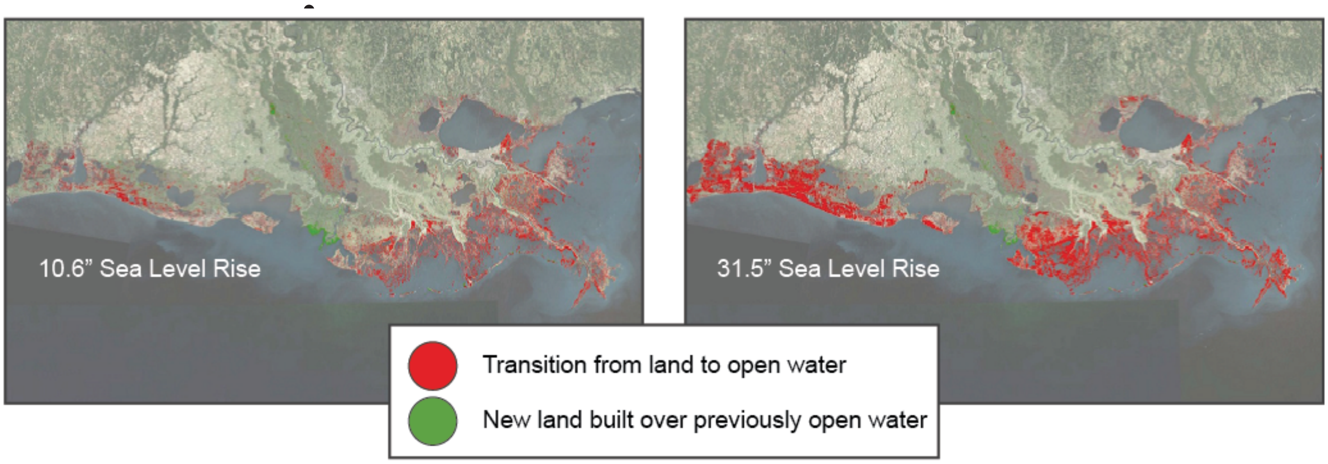


Figure 9.15: Land loss in coastal Louisiana between 2010 and 2060, according to projections consistent with a sea level rise of 27 centimeters (10.6 inches) (left) and 80 centimeters (31.5 inches) (right). (See TFG website for full-color version.)

Resources

Books

Allmon, W. D., T. A. Smrecak, & R. M. Ross. 2010. *Climate Change—Past Present & Future: A Very Short Guide*. Paleontological Research Institution (Special Publication no. 38), Ithaca, NY, 200 pp.

Committee on the Importance of Deep-Time Geologic Records for Understanding Climate Change Impacts. 2011. *Understanding Earth's Deep Past Lessons for Our Climate Future*. National Academies Press, Washington, DC. http://www.nap.edu/download.php?record_id=13111.

Karl, T. R., J. M. Melillo, & T. C. Peterson (eds.). 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press, Cambridge, NY, 188 pp. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

Melillo, J. M., T. C. Richmond, & G. W. Yohe (eds.). 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. US Global Change Research Program, 841 pp. http://www.globalchange.gov/nca3-downloads-materials.

Ruddiman, W. F. 2014. *Earth's Climate: Past and Future, 3rd edition.* W. H. Freeman, New York, 445 pp.

Websites: General Resources on Climate

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, B. Youngman, M. Chandler, L. Sohl, M. Hafen, T. Ledley, S. Ackerman, & S. Kluge, SERC Earth Exploration Toolkit. http://serc.carleton.edu/eet/envisioningclimatechange/index.html.

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

Global Greenhouse Gas Reference Network, Global Monitoring Division, National Oceanographic and Atmospheric Administration, Earth System Research Laboratory. (Data and visualizations.) http://www.esrl.noaa.gov/gmd/ccgg/data-products.html.

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

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

JetStream, Online School for Weather, National Weather Service, National Oceanographic and Atmospheric Administration. http://www.srh.noaa.gov/jetstream/index.htm.

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

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

National Weather Service, National Oceanographic and Atmospheric Administration. http://www.weather.gov.

NOAA's El Nino Portal, National Oceanographic and Atmospheric Administration. http://www.elnino.noaa.gov/.

North America During the Last 150,000 Years, compiled by J. Adams. http://www.esd.ornl.gov/projects/qen/nercNORTHAMERICA.html.

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

US Map of Köppen-Geiger Climate Classification. http://koeppen-geiger.vu-wien.ac.at/pics/KG_USA.gif.

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

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

Websites: State- or Region-specific Climate Resources

Climates of the States, Climatography of the United States No. 60, US Climate Normals, NOAA Satellite and Information Service. http://hurricane.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl?directive=prod_select2&prodtype=CLIM60&amp'subrnum=.

Our Changing Climate: Great Plains, National Climate Assessment. (Includes TX, OK, KS.) http://nca2014.globalchange.gov/report/regions/great-plains.

Our Changing Climate: Midwest, National Climate Assessment. (Includes MO.) http://nca2014.globalchange.gov/report/regions/midwest.

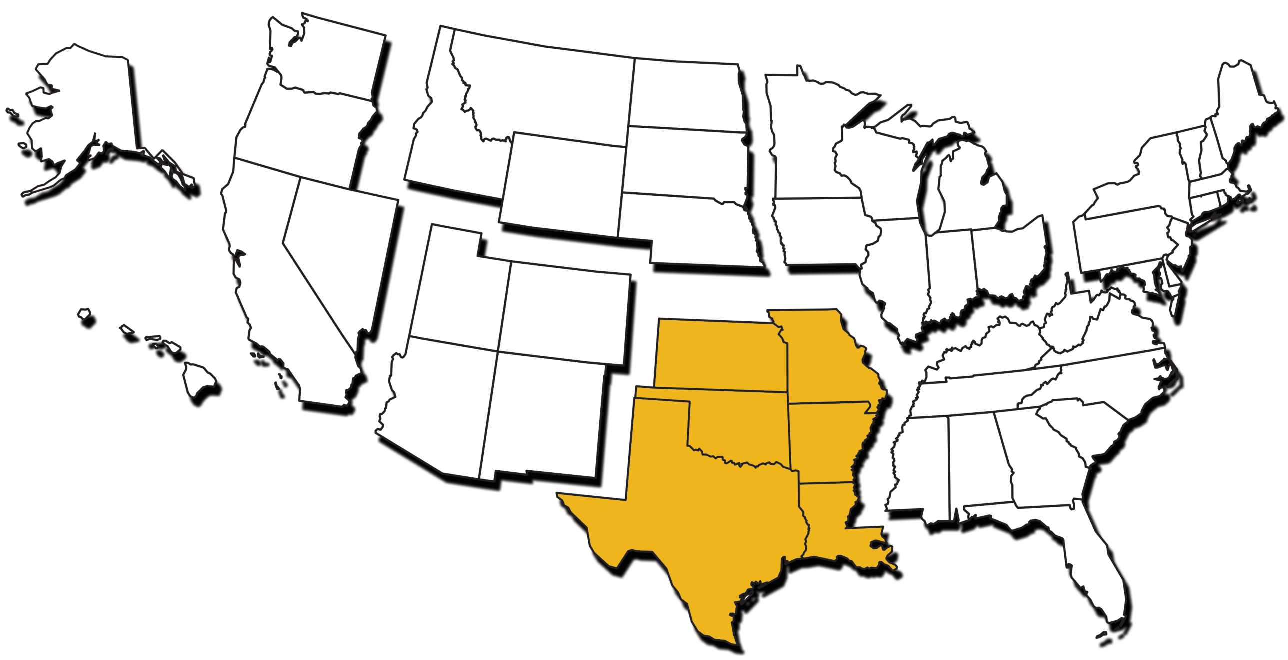
Our Changing Climate: Southeast, National Climate Assessment. (Includes AR and LA.) http://nca2014.globalchange.gov/report/regions/southeast.

Weatherbase. (Monthly averages and forecasts for cities for each state.) http://www.weatherbase.com/weather/state.php3?c=US&s=&countryname=United-States.

The
Teacher-Friendly
Guide™

to the Earth Science of the

South Central US



Edited by Mark D. Lucas, Robert M. Ross, & Andrielle N. Swaby

Paleontological Research Institution
2015

ISBN 978-0-87710-510-7
Library of Congress no. 2015938134
PRI Special Publication no. 48

1259 Trumansburg Road
Ithaca, New York 14850 USA
priweb.org

First printing April 2015

This material is based upon work supported by the National Science Foundation under grant DRL-0733303. Any opinions, findings, and conclusions or recommendations are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The publication also draws from work funded by the Arthur Vining Davis Foundations and The Atlantic Philanthropies.

The interactive online version of this *Teacher-Friendly Guide*™ (including downloadable pdfs) can be found at http://teacherfriendlyguide.org. Web version by Brian Gollands.

The Teacher-Friendly Guide™ series was originally conceived by Robert M. Ross and Warren D. Allmon. Original illustrations in this volume are mostly by Jim Houghton (The Graphic Touch, Ithaca), Wade Greenberg-Brand, and Christi A. Sobel.

Layout and design by Paula M. Mikkelsen, Elizabeth Stricker, Wade Greenberg-Brand, and Katherine Peck.

Cite this book as:
Lucas, M. D., R. M. Ross, & A. N. Swaby (eds.). 2015. *The Teacher-Friendly Guide to the Earth Science of the South Central US.* Paleontological Research Institution, Ithaca, New York, 428 pp.

Cite one chapter as (example):
Allmon, W. D., & A. F. Wall. 2015. Fossils of the South Central US. Pages 81–138, in: M. D. Lucas, R. M. Ross, & A. N. Swaby (eds.), *The Teacher-Friendly Guide to the Earth Science of the South Central US.* Paleontological Research Institution, Ithaca, New York.

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