



Chapter 8:

Climate of the Southeastern US

Climate is a description of the average temperature, range of temperatures, 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 Southeast have a diverse wardrobe, for while the region's climate is generally mild, most areas of the Southeast experience frequent extreme summer **heat** and occasional extreme winter cold. Subfreezing temperatures are also common during the winter in the northern parts of the Southeast.

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. Throughout its long history, parts of the Southeastern US have felt the chilly **winds** of winter, been filled with subtropical swamps and forests, and submerged in warm, shallow seas.

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 Southeast. Unfortunately, we do not have as clear an understanding of climate for the earliest part of Earth

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.

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

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

CHAPTER AUTHORS

Ingrid H. H. Zabel
Judith T. Parrish
Don Duggan-Haas



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.

meteorite • a stony or metallic mass of matter that has fallen to the Earth's surface from outer space.

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

iron • a metallic chemical element (Fe).

history as we do for the later parts, because the oldest rocks are much more 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 (CO₂), 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 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 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



the slow conveyor belts of mantle-formed rock (*Figure 8.1*). 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 rearrangement 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.

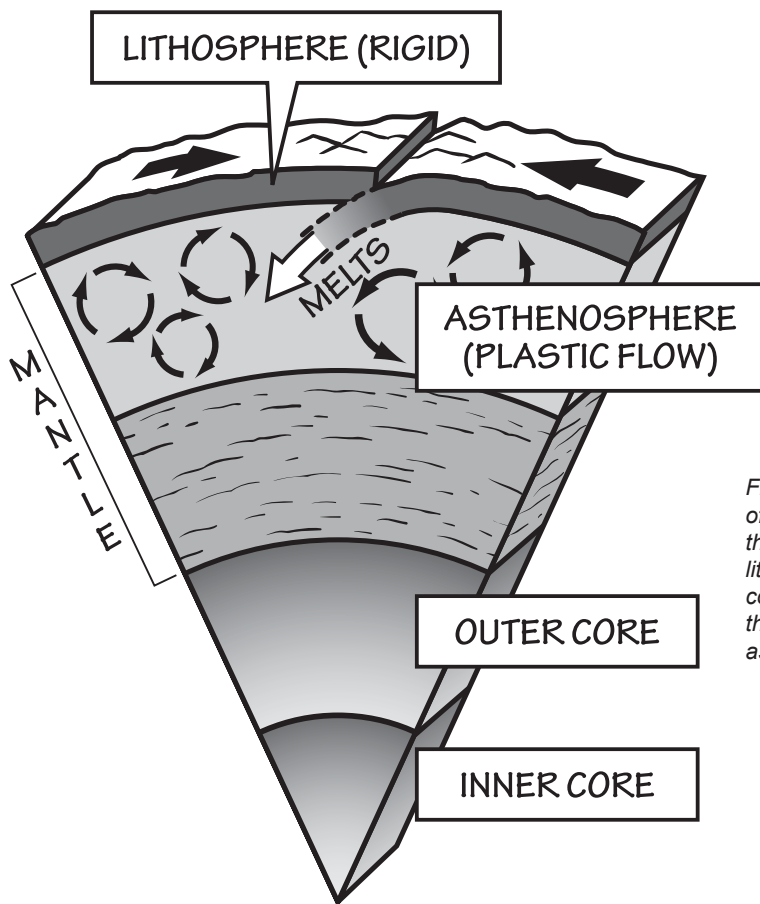


Figure 8.1: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.

Nearly one billion years ago, the Earth began fluctuating between warm and cool periods lasting roughly 150 million years each. During cool periods, there is usually persistent ice at the poles, while during 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 far hotter for much of its history (*Figure 8.2*). Through the shifting global climate and the movement of the continents, what is now the Southeast has at times been at the bottom of a tropical sea, full of warm swamps, or home to cool temperate forests.

Past

crust • the uppermost, rigid outer layer of the Earth.

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

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 group of rock-forming minerals 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).

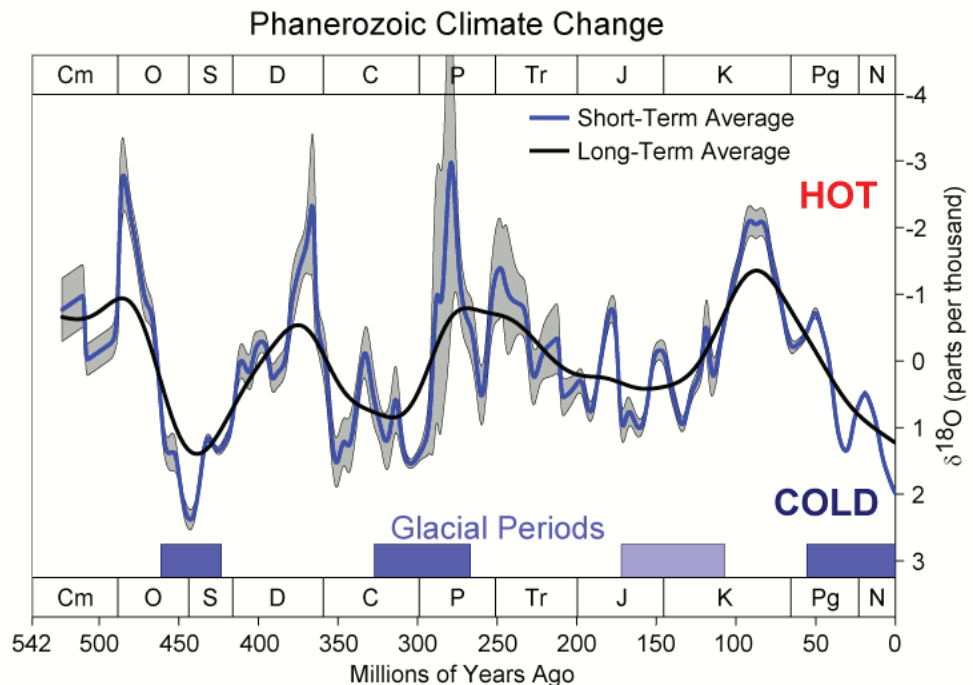


Figure 8.2: Changing global climate throughout the last 542 million years. These data were compiled using the ratios of stable oxygen isotopes found in ice cores and the carbonate skeletons of fossil organisms. (See TFG website for full-color version.)

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 8.3*). 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, tipping the Earth toward a series of cooling feedbacks and causing ice to spread from pole to pole.

An ice-covered planet would remain that way 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 CO₂ 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

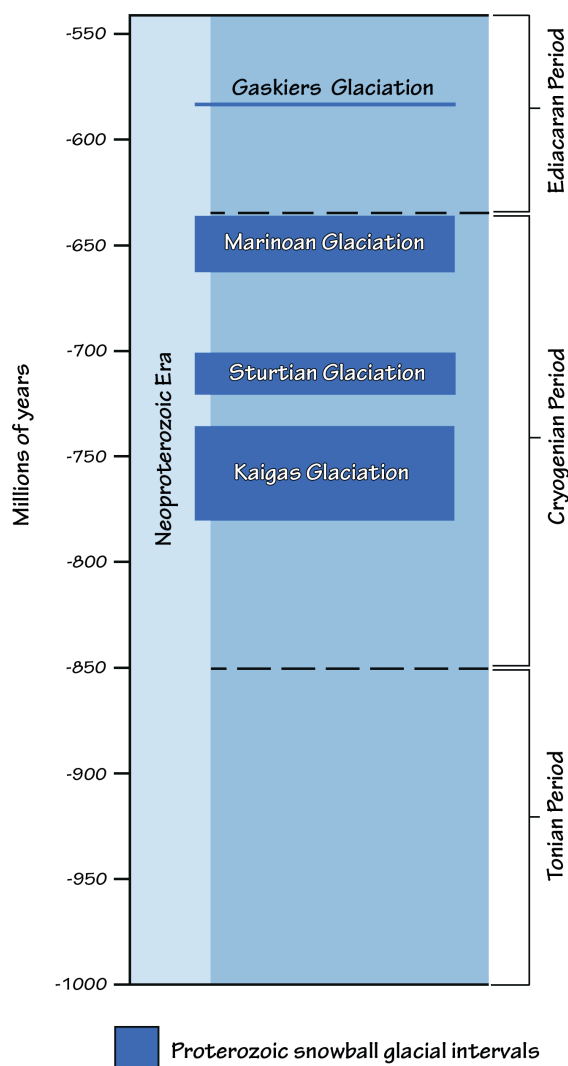


Figure 8.3: Snowball Earth periods during the Proterozoic.

Past

cyanobacteria • a group of bacteria, also called "blue-green algae," that obtain their energy through photosynthesis.

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 alpine glaciers.

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 Southeast, 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, creating 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. Since the Southeast was part of that craton, it was probably underwater for most of this time. 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

8



Climate

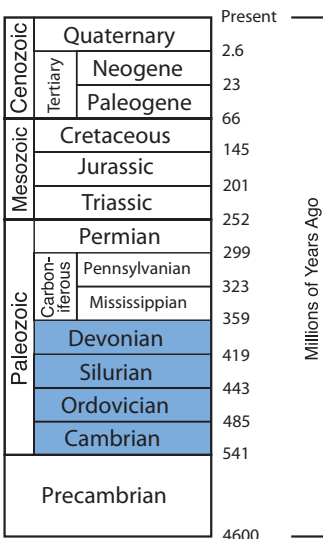
Past

archaeocyathid • a vase-shaped organism with a carbonate skeleton, generally believed to be a sponge.

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.

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



eventually become North America was located near the equator, the fact that North 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 Southeast.

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 much of the Southeastern US was located near the Tropic of Capricorn (*Figure 8.4*). Cambrian fossils of **archaeocyathids**, **trilobites**, **brachiopods**, and mollusks reveal that most of the area was probably covered by warm, shallow seas that persisted into the **Ordovician**.

See Chapter 3: Fossils to learn more about Paleozoic fossils, including Cambrian archaeocyathids and trilobites.

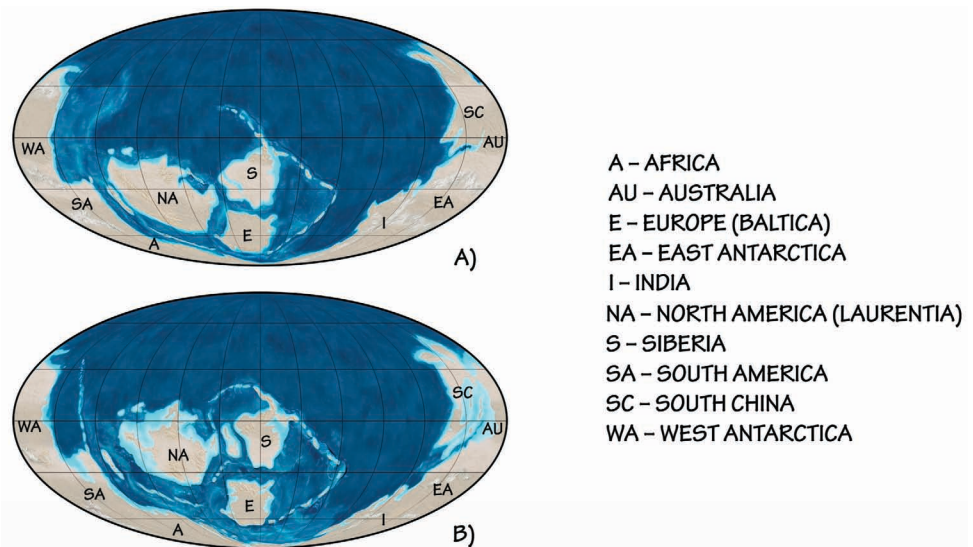


Figure 8.4: The location of the continents during the A) early and B) late Cambrian. Note the position of North America relative to the equator.

In the late Ordovician (about 460 to 430 million years ago), the Earth fell into another brief but intense ice age. Glaciers covered most of the southern landmasses, which were located over the South Pole. This led to global cooling, associated with the first of five major **mass extinctions** that have occurred over the last half-billion years. Although sea level dropped during this event, North America's position near the equator kept its climate relatively warm. **Limestones** throughout Tennessee and Kentucky contain **Silurian** and **Devonian** fossils (including trilobites, brachiopods, corals, and **crinoids**), which indicate that the Southeast still contained warm, shallow seas through the late Devonian. These shallow seas were especially productive, 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 decay, leading to the deposition of black, carbon-rich **shale**. This rock occurs throughout the subsurface in east-central Kentucky and central West Virginia, and is one of the richest sources of **petroleum** in those states.

See Chapter 6: Energy to learn about oil-rich deposits in the Southeast.

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 most of the Southeastern states were still submerged, the oceans between Gondwana and North America began to close (*Figure 8.5*). As fragments of the **Avalon microcontinent** collided with North America, the **Acadian Orogeny** formed a huge chain of mountains in what is now eastern North America. The remains of these high mountains include the southern Appalachians and the **igneous** and **metamorphic** rocks of the Piedmont. As these mountains rose, they blocked the equatorial easterly winds, forming a large **rain shadow**.

By the early **Carboniferous**, ice capped the South Pole and began to expand northward. Although the Earth's temperature fell during this time and glaciers growing far to the south caused sea levels to drop, the western Southeast was once again covered by a warm, shallow sea with limestone and abundant marine life, including heavily armored bony fish, **sharks**, **bryozoans**, corals, and **echinoderms**. Farther east, the **uplift** and **erosion** generated by mountain building caused the landscape to transition to a swampy coastal environment, with extensive forests containing many different kinds of plants including **lycopods**, **sphenopsids**, and ferns, as well as insects, amphibians, and early reptiles.

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. Pangaea was so large that it created a strong **monsoonal** climate, much as Asia does today, which counteracted the eastern rain shadow's drying effect by bringing in moisture from the west. Large swamps that eventually became the rich **coal** beds of Tennessee, Kentucky, and West Virginia formed along broad **floodplains**. At the same time, global temperatures again declined, as glaciers re-formed near the South Pole, but temperatures remained warm in eastern and southeastern North America. Fossils from the Inland Basin provide evidence of a warm climate with primitive trees and swamp plants that experienced the repeated rising and falling of sea levels, as the glaciers waxed and waned. This ice age lasted well into the **Permian**, ending about 260 million years ago, during which time the swamps dried out permanently.

As the Triassic period began, the Southeast moved north from the equator. The Earth remained warm and ice-free at the poles through much of the Mesozoic era, although global temperatures began to dip again slightly around 150 million years ago. After reaching its greatest size during the Triassic period,

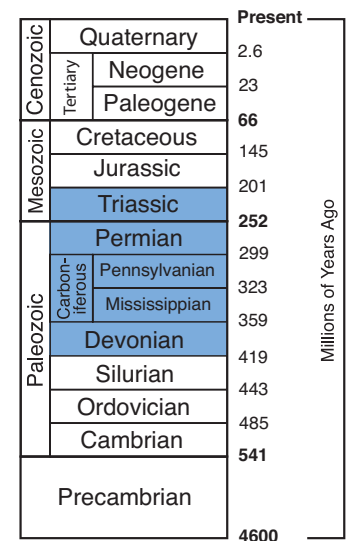
Past

limestone • a sedimentary rock composed of calcium carbonate (CaCO₃).

crinoid • a marine invertebrate animal characterized by a head (calyx) with a mouth surrounded by feeding arms.

shale • a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.

petroleum • a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.



8



Climate

Past

Cenozoic	Quaternary	2.6
	Neogene	23
	Paleogene	66
Mesozoic	Cretaceous	145
	Jurassic	201
	Triassic	252
Paleozoic	Permian	299
	Pennsylvanian	323
	Mississippian	359
	Devonian	419
	Silurian	443
	Ordovician	485
	Cambrian	541
	Precambrian	4600

Millions of Years Ago

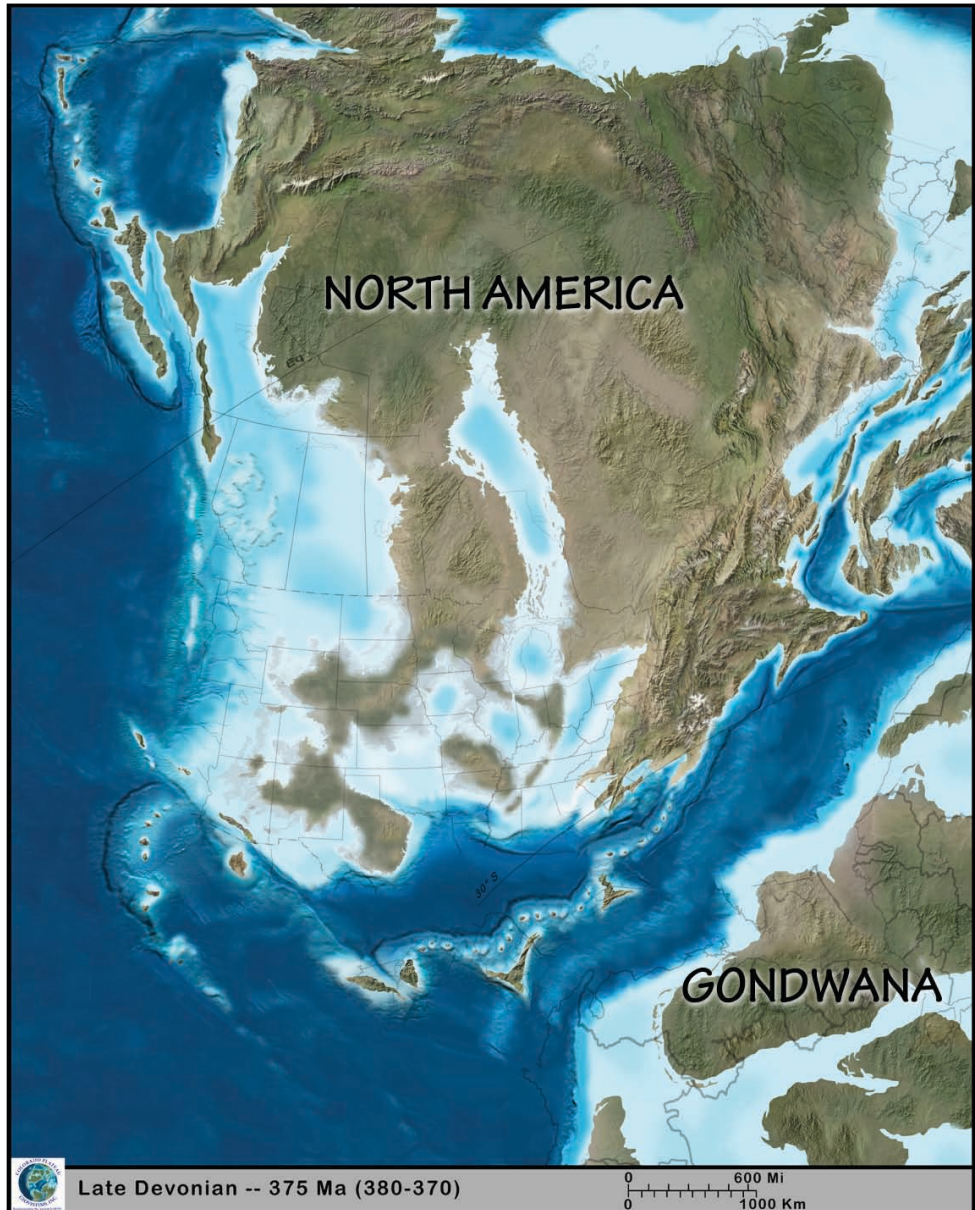


Figure 8.5: By the late Devonian (375 million years ago), the oceans between Gondwana and Euramerica had begun to close.

Pangaea began to rift apart into continents that would drift toward their modern-day positions (Figure 8.6), and the climate gradually shifted, becoming wetter and warmer. Triassic rocks are known only from the rift basins of Virginia and North Carolina, where they contain a rich terrestrial and lake fauna of fishes, amphibians, dinosaurs, and other reptiles. The breakup of Pangaea caused the Gulf of Mexico to 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 key role in trapping petroleum along the Gulf Coast. At the same time, the coastal portion of the



Southeast began to **subside**, and thick deposits of coastal and marine sediments began to accumulate, a process that continues to this day.

See Chapter 5: Mineral Resources for more about the exploitation of the Southeast's salt deposits.

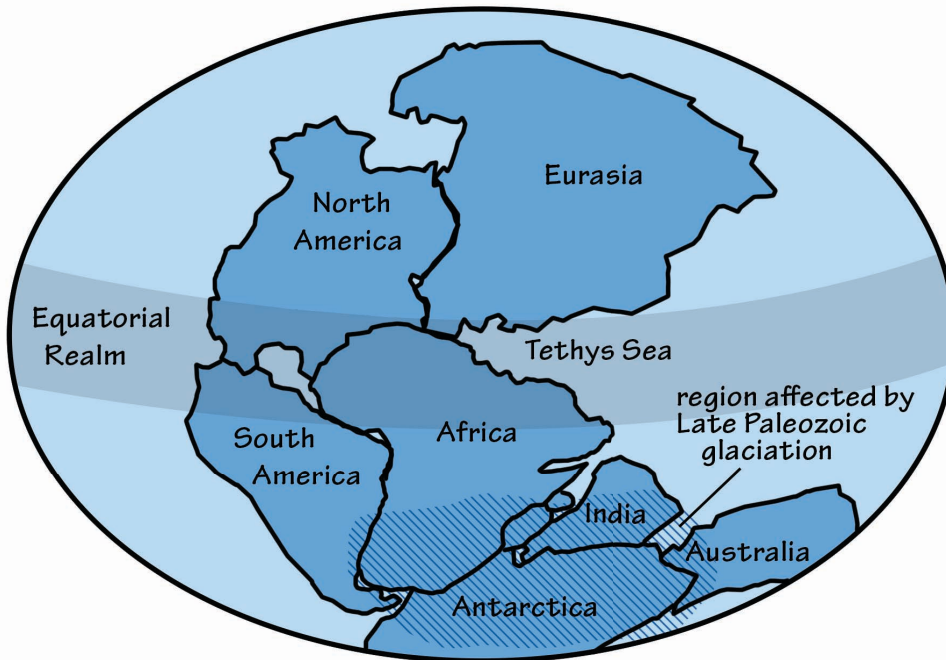


Figure 8.6: The breakup of Pangaea began around 220 million years ago.

The Earth warmed near the beginning of the **Cretaceous**, and sea level rose. Throughout the Cretaceous, sea level was as much as 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 8.7). A rich record of this warm, shallow sea is found in Mississippi, Alabama, and Georgia, where marine fossils range from tiny coccolithophores, mollusks, and crabs to sharks and large marine reptiles. The seaway extended far to the north in Mississippi, and its margin is marked by the **Mississippi Embayment**. Global temperatures during the Cretaceous were very warm, as much as 10°C (18°F) above present. There was likely little or no glacial ice anywhere on Earth, and temperatures were highest in lower latitudes. As the continents moved closer to their modern positions, the Southeast experienced a hot and humid tropical climate.

Past

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.

Mississippi Embayment • a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.

		Present	
Cenozoic	Quaternary	2.6	
		Tertiary	Neogene
			Paleogene
Mesozoic	Cretaceous	66	
	Jurassic	145	
	Triassic	201	
Paleozoic	Permian	252	
	Carboniferous	Pennsylvanian	
		Mississippian	
	Devonian	299	
	Silurian	323	
	Ordovician	359	
Cambrian	419		
Precambrian	443		
		485	
		541	
		4600	

Millions of Years Ago

8



Climate

Past

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

snail • see gastropod: a marine, freshwater, or terrestrial invertebrate animal characterized by a single, coiled, calcareous shell, a muscular foot for gliding, and internal asymmetry caused by torsion.

Paleocene • a geologic time interval spanning from about 66 to 56 million years ago.

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

Cenozoic	Tertiary	Quaternary	Present
		Neogene	2.6
Paleogene		23	
Mesozoic		Cretaceous	66
		Jurassic	145
		Triassic	201
Paleozoic	Carboniferous	Permian	252
		Pennsylvanian	299
		Mississippian	323
		Devonian	359
		Silurian	419
		Ordovician	443
	Cambrian	485	
	Precambrian	541	
			4600

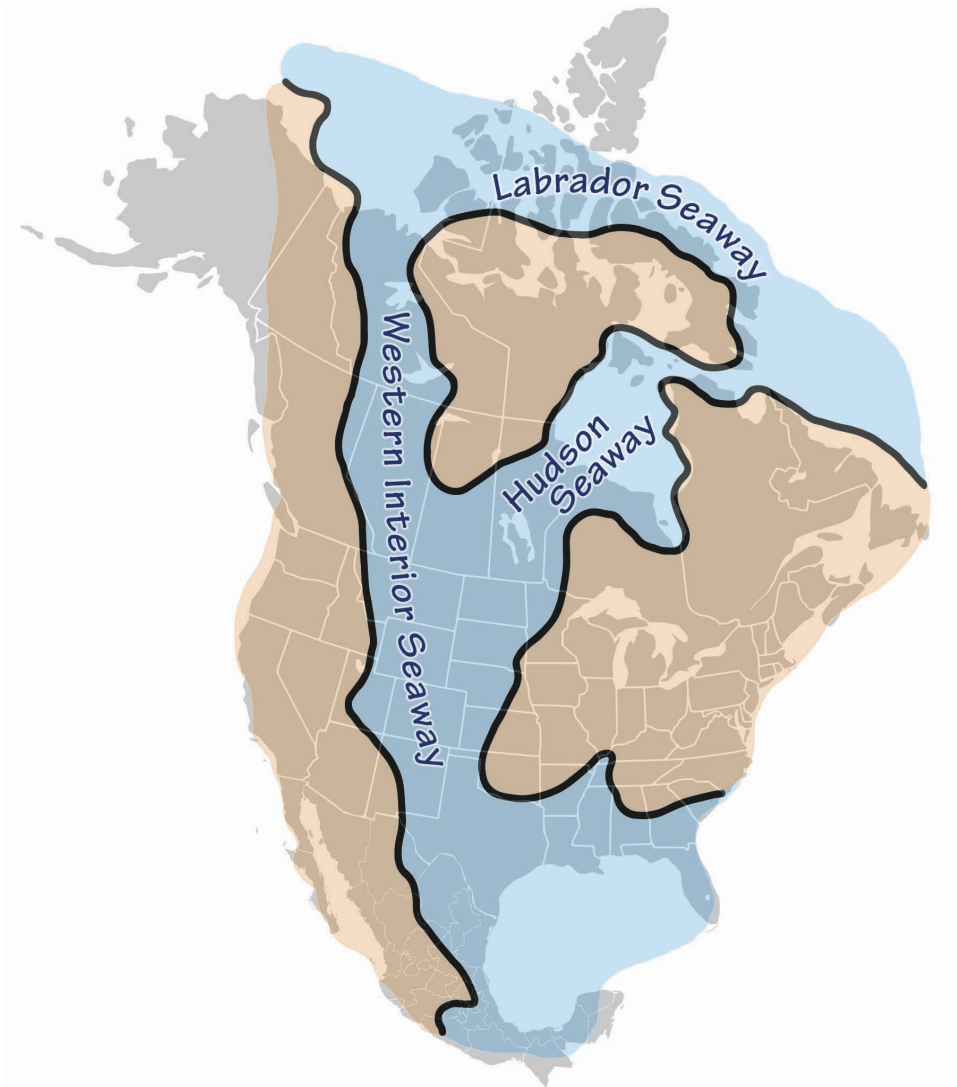


Figure 8.7: The Western Interior Seaway.

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 from the Southeastern US. The impact vaporized both water and rock, blocking out sunlight for weeks to years, which led to a collapse of photosynthesis and food webs on land and in the oceans. After this event, the climate may have cooled briefly, but it soon rebounded to a warmer state.

As the **Cenozoic** era began, global temperatures remained high, and rose even further into the early **Eocene**. This is reflected in the land plants and diversity of marine life—especially clams, **snails**, and echinoderms—represented by fossils in the Southeast Coastal Plain. Right at the boundary between the **Paleocene** and Eocene epochs (around 56 million years ago), temperatures spiked upward



in what geologists call the Paleocene-Eocene Thermal Maximum. During this event, which lasted perhaps only around 10,000 years, the atmosphere and ocean warmed by as much as 8°C (14°F) in as little as 4000 years, and deep oceans became acidic, with low levels of dissolved oxygen. The causes remain unclear, but may have involved the sudden release of methane from sediments on the seafloor. The resulting greenhouse effect persisted for 100,000 years. This abrupt climatic change was associated with major migrations, the **extinction** of plants and animals on land, and a mass extinction in the deep sea, but its effects on life in the shallow seas that surrounded the Southeast were apparently not as marked.

In the late Eocene, the Earth began cooling, and global temperatures fell sharply at the boundary between the Eocene and **Oligocene** epochs (around 35 million years ago), due in part to the separation of the southern tip of South America from Antarctica. This allowed for the formation of the Antarctic Circumpolar Current, which insulated Antarctica from warm ocean water coming from lower latitudes and led to the formation of the continent's glaciers. The rocks and fossils of the Southeast show that the area did not cool as much as areas farther north did. The oldest rocks in Florida, from the Eocene, are coral-rich limestones that clearly formed in warm seas.

Climates warmed slightly during the **Miocene**, and this is reflected in the diverse marine and terrestrial fossils of the Atlantic Coastal Plain (from Maryland to Florida). Global temperatures fell in the late Miocene, and this was possibly associated with the continuing collision of India with Asia, which was forming the Himalayas. This event had a significant impact on global climate, as weathering of the newly exposed rock began to serve as a sink to take up atmospheric CO₂. With the reduction of this greenhouse gas, temperatures cooled worldwide, and this cooling has continued more-or-less to the present day. These changes are also visible in the Southeast's fossil record, with species that had lived farther north retreating southward over time.

Around 3.5 million years ago, glacial ice began to form over the Arctic Ocean and on the northern parts of North America and Eurasia. Surprisingly, a major contributing factor to this event was a geological change that occurred half a world away. The Central American Isthmus, which today makes up most of Panama and Costa Rica, rose out of the ocean at around this time, formed by undersea volcanoes. The new dry-land isthmus blocked the warm ocean currents that had been flowing east-to-west from the Atlantic to the Pacific for more than 100 million years, diverting them into the Gulf of Mexico and ultimately into the western Atlantic Gulf Stream. The **reefs** that make up the bulk of Florida's **carbonate** platform formed in this warm tropical sea. The strengthened Gulf Stream carried more warm, moist air with it into the northern Atlantic, which caused increased snowfall in high latitudes, leading to accelerating cooling. These changes in ocean circulation throughout the Caribbean and Gulf of Mexico also affected nutrient supplies in the coastal ocean, which may have contributed to an increase in the extinction of marine animals (including everything from mollusks and corals to whales and dugongs) during the late **Pliocene**.

Past

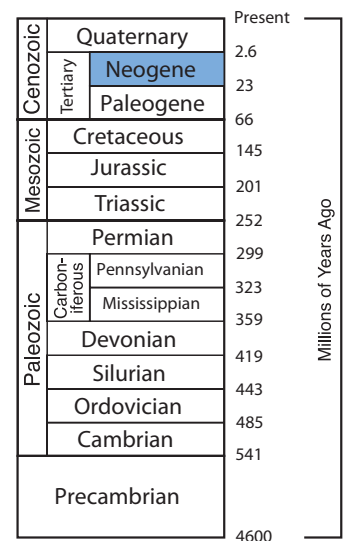
Oligocene • a geologic time interval spanning from about 34 to 23 million years ago.

Miocene • a geological time unit extending from 23 to 5 million years ago.

reef • a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.

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

Pliocene • a geologic time interval extending from roughly 5 to 2.5 million years ago.



8



Climate

Past-Present

silica • a chemical compound also known as silicon dioxide (SiO₂).

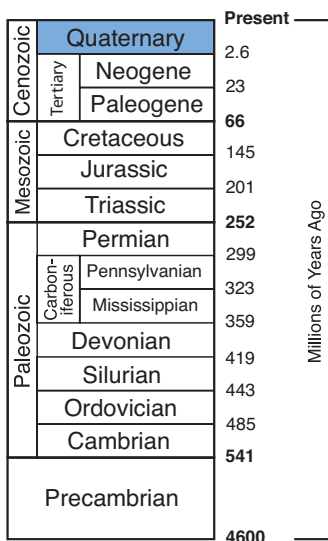
clay • the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.

ice cap • an ice field that lies over the tops of mountains.

Pleistocene • a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.

Silicate and carbonate rocks both weather chemically in reactions that involve CO₂ and water, typically creating **clays**, bicarbonate, and calcium ions. Silica weathering occurs relatively slowly, taking place on a 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 seawater, 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 (i.e., the combined gravitational effects of the Earth, Sun, moon, and planets). The ice sheets in the Northern Hemisphere did not extend into the Southeast, even at their largest. The Southeast's climate was, however, affected by the presence of ice to the north. Studies of pollen and plant fossils from South Carolina's coastal plain indicate that between 19,000 and 12,800 years ago, the climate was suited to trees typical of much colder climates today. During glacial intervals, the area was also somewhat wetter than it is today, with wetlands and forests covering much of what would later become grassland. **Pleistocene** deposits in Tennessee, West Virginia, North Carolina, Florida, and Alabama contain abundant fossils of terrestrial vertebrates such as horses, camels, bison, **mastodons**, **mammoths**, and ground sloths—animals we associate with cold climates.



Present Climate of the Southeast

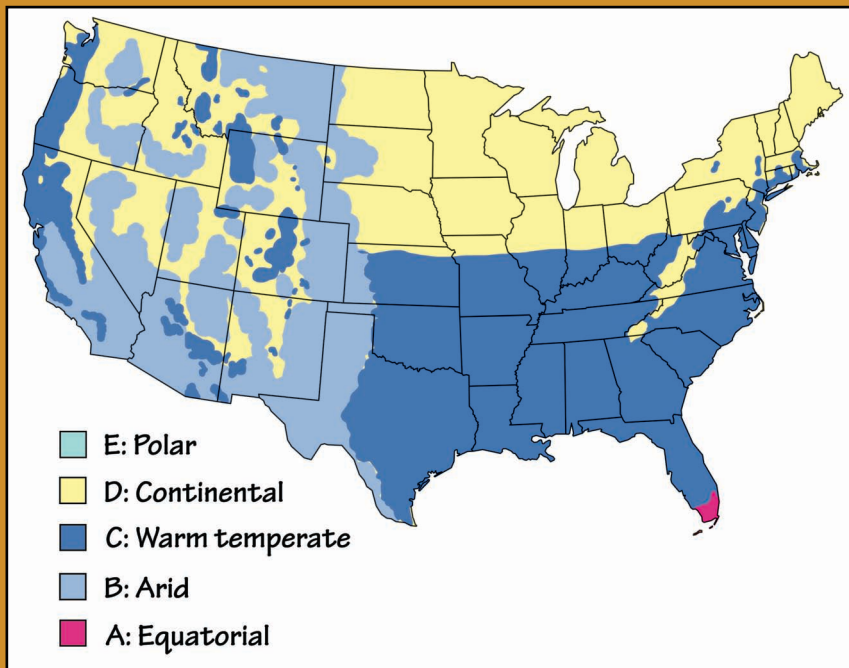
The location of the Southeast and its direct relationship to the Gulf of Mexico and Atlantic Ocean strongly influence the area's weather. Since it encompasses locations along the coast as well as areas farther inland, the Southeast experiences nearly every variety of extreme weather. Heat and cold waves,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

See Chapter 9: Earth Hazards for more information on extreme weather in the Southeast.



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.)

In a broad sense, the Southeast's climate is mostly mild and humid, with much of the region characterized as warm temperate (represented by "C" in the Köppen system). The Southeast does contain other climate zones, however, with a tropical equatorial climate (represented by "A") in southern Florida and areas of moist, continental climate (represented by "D" at higher elevations in the Appalachians).

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.

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.

8



Climate

Past

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

Although much of the Southeast falls within the category of a warm temperate zone, using a single label to describe the Southeast's climate would belie its diversity. The main features that influence the Southeast's climate are latitude, the presence of the Atlantic Ocean and the Gulf of Mexico, and regional **topography**. For example, the Florida peninsula has a distinct summer rainy season, while other inland areas receive uniform precipitation all year round, and the highest elevations in North Carolina and Tennessee can receive as much snow as parts of New England.

Average temperatures in the Southeast 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 Florida, Georgia, and Mississippi, while the coolest are found in West Virginia and Virginia (*Figure 8.8*). The Southeast's overall average high temperature of 22°C (72°F) and average low of 9°C (48°F) are indicative, on the whole, of a more uniform climate than that found in most other parts of the United States. By comparison, the average high and low temperatures for the entire United States are 17°C (63°F) and 5°C (41°F), respectively.

Another factor besides latitude that influences temperature in the Southeast 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, and the Gulf Stream current that travels northward past the Atlantic seaboard carries warm tropical water with it, influencing temperatures on land. Thus the most extreme temperatures in the Southeast are found toward the center of the continent: record high and low temperatures are both held by Kentucky, which has experienced a high of 46°C (114°F) and a low of -38°C (-37°F). Of course, major temperature fluctuations can occur in every state. In July, average daily maximum temperatures range from 35°C (95°F) in southern Georgia and Florida to 24°C (75°F) in mountainous parts of West Virginia. Wintertime has a broader range of temperatures, with average daily minimums in January varying from around -7°C (20°F) in northern Kentucky to 16°C (60°F) in South Florida. Although the Southeast's climate is subtropical, it can get cold, and sub-freezing temperatures are sometimes a concern for Florida orange growers.

Average Annual Temperatures			
	Overall (°C [°F])	Low (°C [°F])	High (°C [°F])
Florida	22.0 (71.6)	16.7 (62.1)	27.5 (81.5)
Georgia	17.3 (63.1)	11.0 (51.8)	23.7 (74.7)
Mississippi	17.2 (63.0)	10.9 (51.6)	23.4 (74.1)
South Carolina	16.9 (62.4)	10.6 (51.1)	23.2 (73.8)
Alabama	15.8 (60.4)	9.7 (49.5)	22.1 (71.8)
North Carolina	14.6 (58.3)	8.5 (47.3)	20.8 (69.4)
Tennessee	14.2 (57.6)	7.9 (46.2)	20.5 (68.9)
Kentucky	13.3 (55.9)	7.0 (44.6)	19.6 (67.3)
Virginia	12.3 (54.1)	6.2 (43.2)	18.5 (65.3)
West Virginia	10.9 (51.6)	4.5 (40.1)	17.0 (62.6)



Present

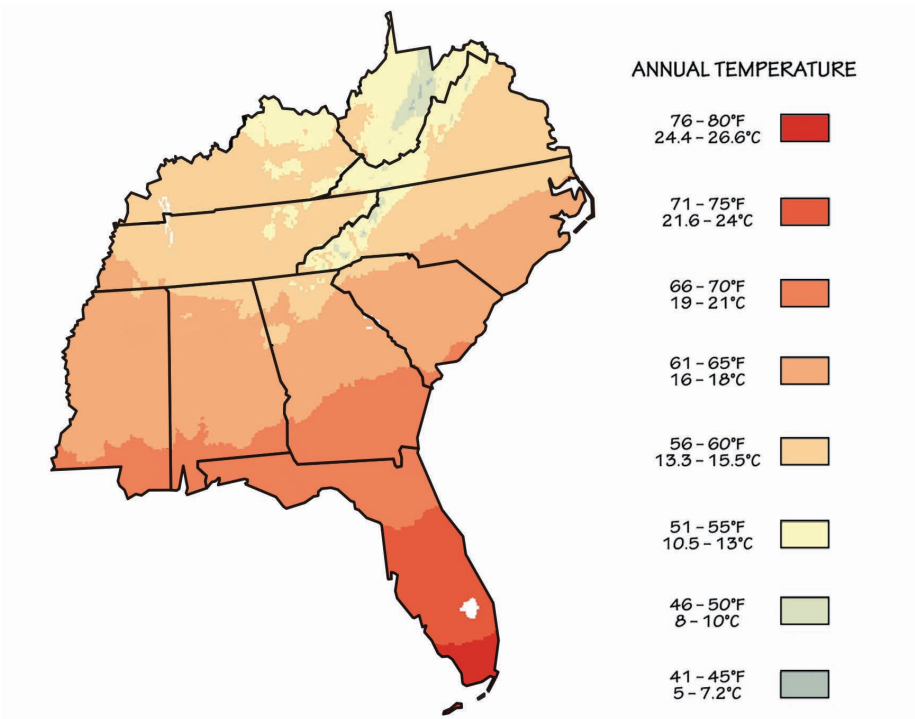


Figure 8.8: Mean annual temperature for the Southeastern states.
(See TFG website for full-color version.)

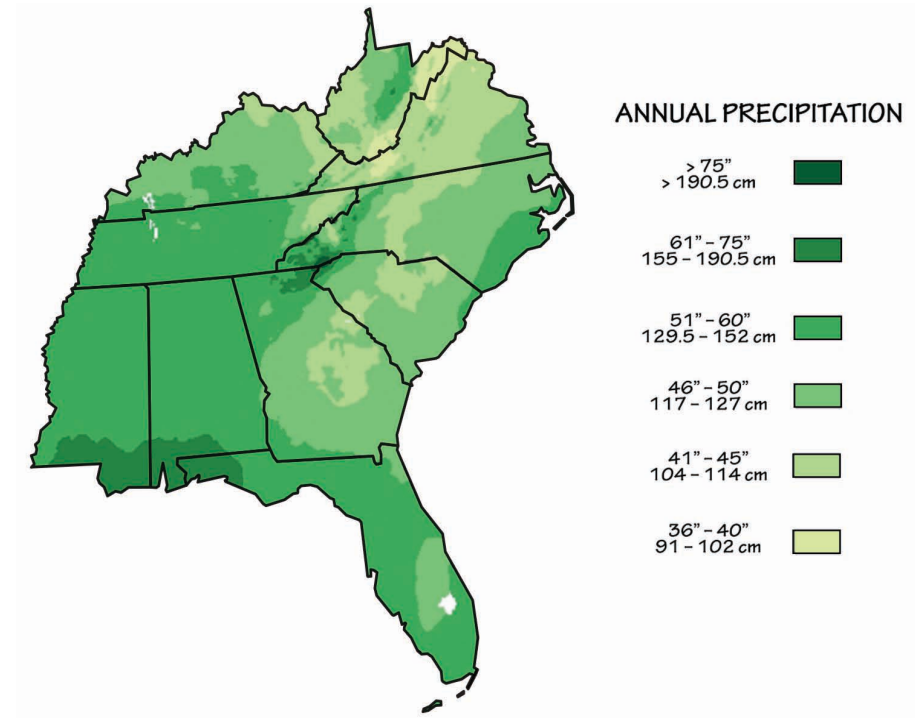


Figure 8.9: Mean annual precipitation for the Southeastern states.
(See TFG website for full-color version.)



Present

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

The average amount of precipitation for the United States is 85.6 centimeters (33.7 inches). In the Southeast, however, average annual precipitation typically ranges from about 100 to 125 centimeters (40 to 50 inches) inland to over 150 centimeters (60 inches) along the Gulf Coast of Mississippi, Alabama, and the Florida Panhandle (*Figure 8.9*), demonstrating the impact of moisture carried inland from the adjacent Gulf of Mexico. Some pockets of high precipitation also occur in the Appalachian Mountains (along the Eastern Continental Divide, a topographical high point where air is forced upward from both sides of the mountain range), and along the Atlantic coast.

Snow is not unusual during winter in the northern parts of the Southeast, and in the summer and fall tropical cyclones (hurricanes) often bring heavy rains to the Gulf and Atlantic coasts. Some of these cyclones, such as Hurricane Andrew in 1992, are extremely powerful and have devastated communities in the Southeast. Thousand-year weather events, referring to the 1-in-1000 chance of intense events happening in a given year, have increased in frequency in recent years, and climate models predict a continuation of that increase. One such event occurred in the fall of 2015 when heavy rains associated with Hurricane Joaquin (but not actually part of the hurricane) brought over 50 centimeters (20 inches) of rain to parts of South Carolina, causing over one billion dollars in damage.

See Chapter 9: Earth Hazards to learn more about hurricanes, tornadoes, and other severe storm events.

Severe thunderstorms and tornados are an additional threat—the geography and climate of the Southeast are nearly ideal for their formation, especially in the summer. Only Kansas has more tornados per square mile than Florida, and several other Southeastern states rank in the top ten for tornado frequency (*Figure 8.10*). Tornados often accompany severe thunderstorms, so where tornados occur, thunderstorms are likely. 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 Southeast 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 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 (or in Florida, to the north or the east) 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 Southeast's unusually high incidence of powerful tornados.

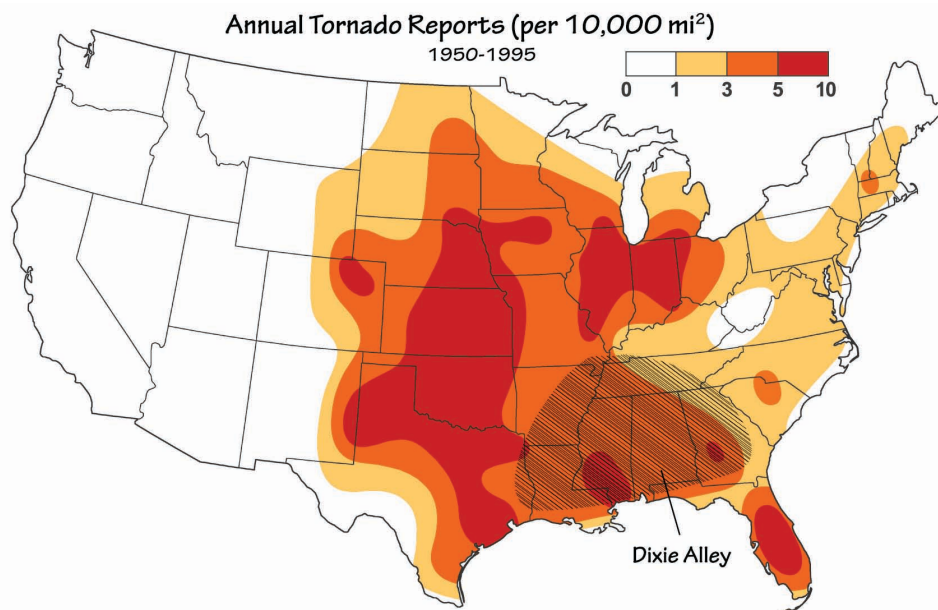


Figure 8.10: Frequency of tornados in the continental US. "Dixie Alley" is an area of the Southeast known for its violent tornados. (See TFG website for full-color version.)

Florida is commonly in the path of hurricanes and tropical storms that move across the Mid-Atlantic and Gulf. The climate of the state's north and central parts is humid subtropical, while southern Florida has a tropical savanna climate. There is a defined rainy season from May through October, when thunderstorms built in the heat of day drop heavy but brief summer rainfall.

In much of the lower Southeast, the climate is typical of a humid subtropical zone, characterized by temperate winters, long, hot summers, and rainfall that is fairly evenly distributed through the year. In Georgia, as elevations in the state range from sea level at the Atlantic coast to the summit of Brasstown Bald at 1458 meters (4784 feet), the climate varies considerably, but snow and prolonged freezing temperatures are uncommon throughout the state. In Mississippi and Alabama, thunderstorms occur throughout the year, most commonly in the summer, but are most destructive in the fall and spring. These states are also commonly in the path of tropical storms and hurricanes moving northward off of the Gulf. Freezing temperatures reach to the Gulf Coast in most winters, but they rarely persist. South Carolina's humid subtropical climate arises from the combination of the state's relatively low latitude, its generally low elevation, the proximity of the warm Gulf Stream, and the Appalachian Mountains, which in winter help to block cold air from the interior of the United States. Most precipitation falls in spring and summer. While cold weather occurs each winter, its duration tends to be brief; snow is uncommon and generally occurs only in the mountains and upper Piedmont.

See Chapter 4: Topography for a list of highest and lowest elevations by state.



Present

In North Carolina, the climate varies from the Atlantic coast in the east to the Appalachian Mountains in the west. As in South Carolina, the Appalachians help to block cold air from the interior of the United States and storms from the Midwest from entering the Piedmont of North Carolina. Most of the state has a humid subtropical climate, except in the higher elevations of the Appalachian Mountains, which have a subtropical highland climate.

Tennessee's varied topography leads to a wide range of climatic conditions, though generally the state has a temperate climate, with warm summers and mild winters. Most of the state has a humid subtropical climate, with the exception of some of the higher elevations in the Appalachian Mountains, which are classified as having a mountain temperate climate or a humid continental climate. Severe storms occur infrequently. The state has hot summers and mild to cool winters with generous precipitation throughout the year, with the highest average monthly precipitation generally occurring in the winter and spring months, between December and April. Snowfall varies and is more prevalent in eastern Tennessee than in the western section; Nashville gets about 25 centimeters (10 inches) a year, Memphis only 13 centimeters (5 inches).

Kentucky experiences four distinct seasons, with substantial variations in the severity of summer and winter, but extreme cold is rare. Fall is normally the state's dry season, while the spring season is typically the wettest, but precipitation does not vary greatly throughout the year. Thunderstorms are responsible for much of Kentucky's summer rainfall, and they often bring intense rain that may be highly localized. Generally, Kentucky experiences relatively humid rainy and warm summers, and moderately cold winters where snow is not especially uncommon, with occasional extreme snows. Snow cover seldom persists for more than a week in the south or for more than two weeks in the north.

The climate of Virginia is considered mild for the United States. Most of Virginia east of the Blue Ridge Mountains, the southern part of the Shenandoah Valley, and the Roanoke Valley, all have a humid subtropical climate, though the range of topography yields a range of climate types. According to the University of Virginia Climate Office, the state has five different climate regions: the Tidewater, Piedmont, Northern Virginia, Western Mountain, and Southwestern Mountain regions. Some localities, including Charlottesville, have long growing seasons and infrequent subzero temperature minimums, while winters on the northern Blue Ridge frequently produce bitterly cold temperatures like those of Chicago. Similarly, annual rainfall totals can vary from a fairly dry 84 centimeters (33 inches) typical of the Shenandoah Valley to more than 150 centimeters (60 inches) in the mountains of southwestern Virginia. Severe weather, in the form of tornados, tropical storms, and winter storms, impacts the state on a regular basis. Areas of Virginia have seen substantial snowstorms in recent years.



Future Climate of the Southeast

By using 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, as 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.

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 (CO₂) concentration. The CO₂ record extends from 1958 to present, and it shows the influence of both natural and anthropogenic processes (*Figure 8.11*). 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ for the first time.

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*.

While some atmospheric carbon dioxide is necessary to keep Earth warm enough to be a habitable planet, the unprecedentedly rapid input of CO₂ to the atmosphere by human beings is cause for concern. Everything we know about atmospheric physics and chemistry tells us that increased CO₂ 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.

Future

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.

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

aerosol • tiny solid or liquid particles in the air.

petroleum • a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.

fuel • a material substance possessing internal potential energy that can be transferred to the surroundings for specific uses.

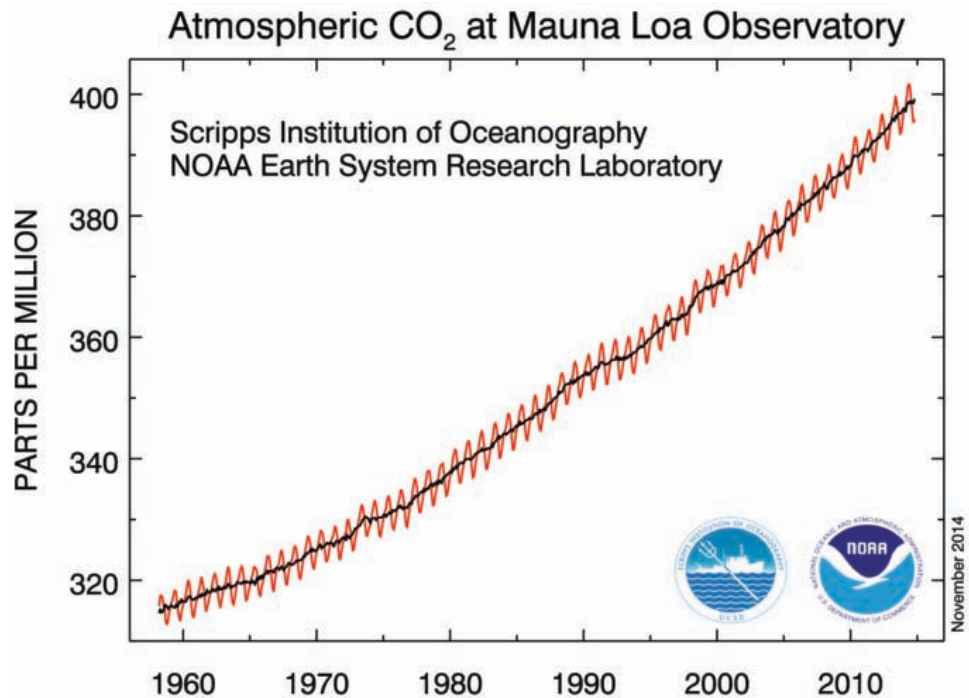


Figure 8.11: Measured concentration of atmospheric carbon dioxide (1958 to present) at MLO.

As **permafrost** in high latitudes melts, carbon in the **soil** becomes free to enter the atmosphere and, worse, buried organic material can 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.

The Southeast contributes significantly to climate change. The population of any industrialized and particularly wealthy country produces pollution; the majority of these emissions come from the use of **petroleum**. The more than 70 million residents of the Southeast use carbon-rich fossil **fuels** to provide electricity for lighting, cooling, and appliances, to fuel their transportation and industry, and to make the products they use. Burning those fossil fuels releases carbon into the atmosphere, which warms the Earth. Of the Southeastern states, Florida emits the most greenhouse gases, releasing 218 million metric tons of carbon



dioxide per year—the fourth highest in the nation (Texas, the highest producer, releases nearly 656 million metric tons of CO₂ per year). Greenhouse gas emissions continue to grow in some areas; over the last decade, Kentucky's emissions have increased by about 2% thanks to the state's reliance on coal as an energy source.

On the other hand, Southeastern states are making changes to reduce human impact on the climate. Virginia, Tennessee, and North Carolina have all reduced their CO₂ emissions by more than 22 metric tons in the last decade. The city of Richmond, Virginia and the County of Sarasota, Florida were early adopters of the 2030 Challenge, an effort 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**. As of 2014, Tennessee ranks 19th in the nation for renewable energy production, much of which it produces from hydroelectricity and **biomass**.

Trends and Predictions

Studies show that the Southeast'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) and nights above 24°C (75°F) has been steadily increasing since 1970 (*Figures 8.12 and 8.13*).
- In 2007, severe drought cost Georgia's agricultural industry over \$339 million in crop losses.
- Rising seas and storm surges jeopardize the infrastructure of coastal cities. Southern Florida and the Chesapeake Bay are ranked the first and third most vulnerable US areas to sea level rise, respectively.
- The Floridian aquifer system, which provides fresh water to the majority of Florida as well as southern Georgia, has dropped by more than 18 meters (60 feet) in some areas, and is threatened by saltwater intrusion.
- Locations along the Gulf of Mexico have experienced over 20 centimeters (8 inches) of sea level rise in the last 50 years.
- The minimum annual rate of streamflow in many areas of the Southeast has decreased by as much as 50%.
- Altered flowering patterns due to more frost-free days have increased the Southeast's pollen season for ragweed, a potent allergen.
- Unique ecosystems in the Southeast, such as the Ice Mountain Preserve in West Virginia (a unique **boreal** zone), face adverse effects from warming temperatures.

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.

boreal • a cold temperate region relating to or characteristic of the sub-Arctic climatic zone.



 Future

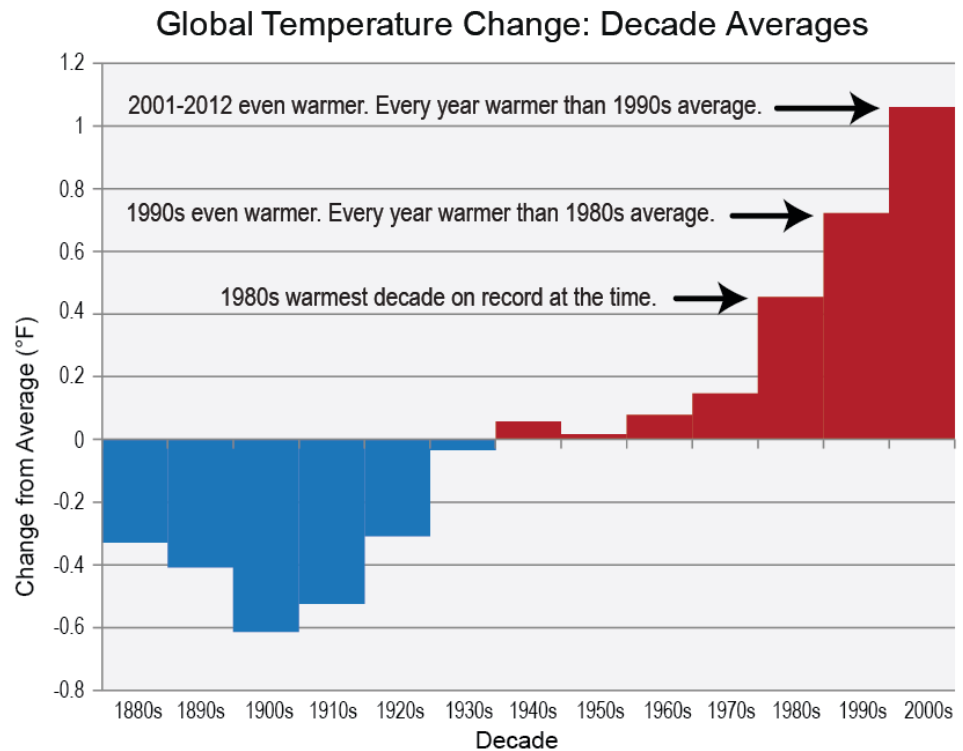


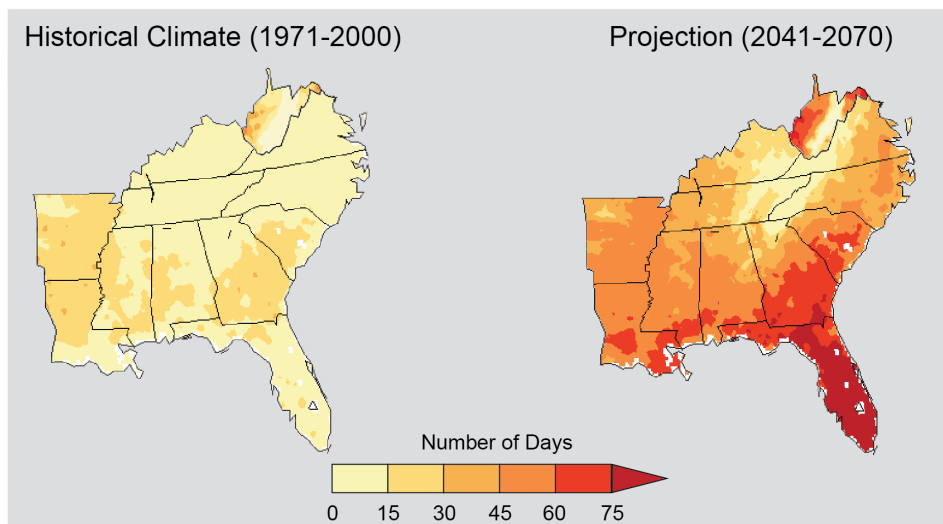
Figure 8.12: Global temperature change since the 1880s. The Earth's average surface temperature has progressively risen over the last five decades.

Climate models predict that the Southeast's climate will continue to warm, and that the average annual temperature in most of the area will rise 1° to 6°C (2° to 11°F) by the end of the 21st century. The strongest warming is projected to occur inland, in the Southeast's northwestern corner. Winter temperatures have risen the most—today, most of the Southeast experiences four to seven fewer freezing days than it did in the 1970s. By the middle of the 21st century one can expect 20 to 30 more days of freeze-free weather each year (Figure 8.13). Currently, the northern part of the Southeast typically has ten days a year with temperatures below -12°C (10°F). By the middle of the 21st century we can expect no days with temperatures that low. 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.

Precipitation has become more variable from year to year, and heavy downpours have increased in the last 20 years. 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 8.14) Some models predict as much as 20% more winter precipitation in the Southeast's northern and southern extremes. These models also predict more rain in the spring and fall but less in the summer, except along the Coastal Plain (excluding Florida). The causes of specific weather events such as hurricanes and severe thunderstorms are incredibly complex, although climate change has enhanced



Projected Change in Number of Days Over 95°F



Projected Change in Number of Nights Below 32°F

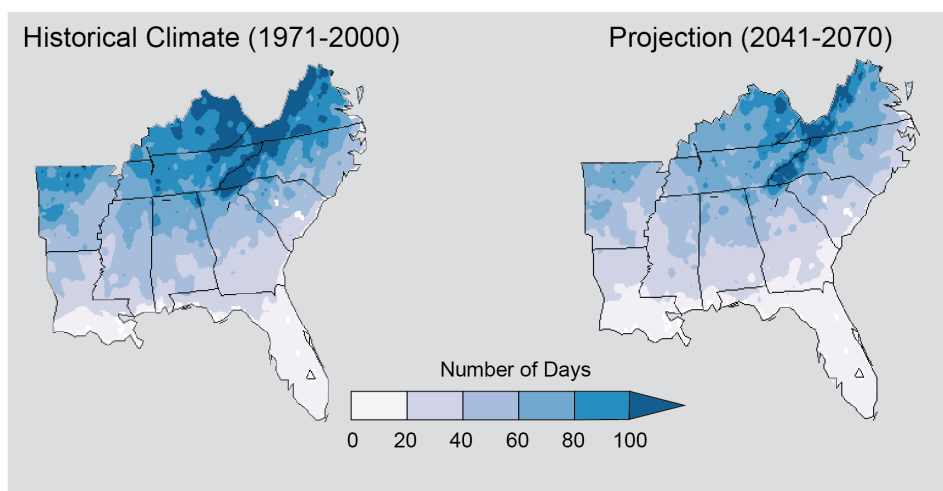


Figure 8.13: Projected changes in number of days over 35°C (95°F) and number of nights below 0°C (32°F) for the Southeast over the next several decades.

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.

Water supply is an important issue in the Southeast, 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



 Future

aquifer • a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.

global warming • the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.

Observed U.S. Trend in Heavy Precipitation

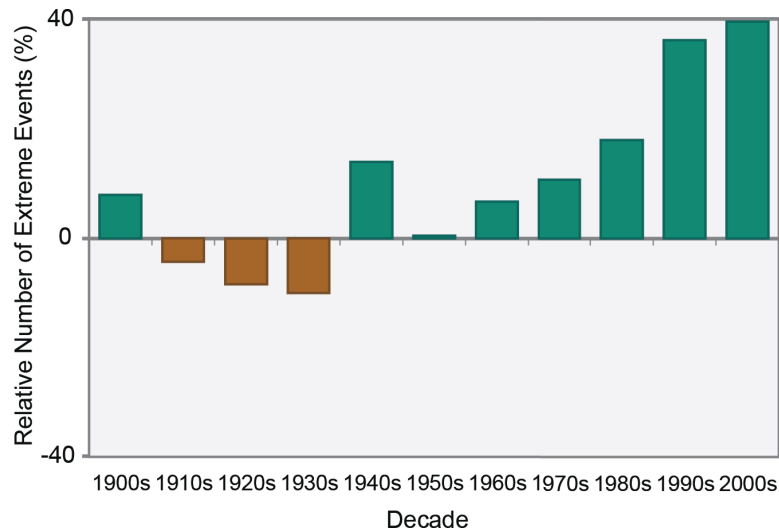


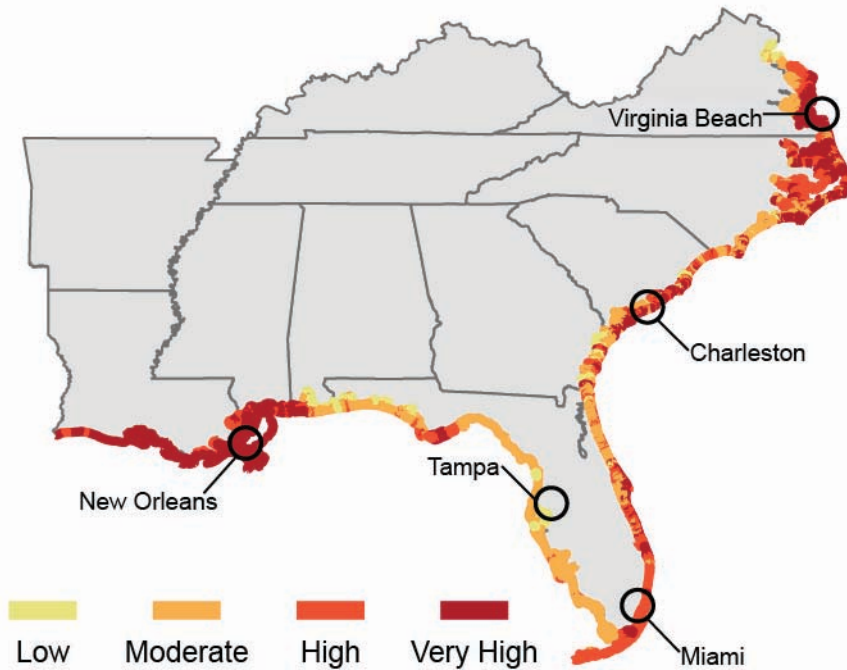
Figure 8.14: Changes in heavy precipitation events from the 1900s to the 2000s. Each event is defined as a two-day precipitation total that is exceeded, on average, only once every five years. The occurrence of such events has become increasingly common.

desertification of already arid areas and affecting natural ecosystems as well as increasing pressure on the water supply for agriculture and cities. In low-lying areas, especially Florida, important **aquifers** are at extreme risk of being contaminated by saltwater thanks to rising sea levels.

More than 50% of the American population currently lives in coastal areas. 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 is a major concern in the Southeast, with its extensive coastline and many low-lying areas, including major cities such as Miami, Tampa, and Charleston (Figure 8.15). A rising sea leads to retreating tidal forests, coastal erosion, larger and more damaging storm surges, inundation of populated areas, and stresses on municipal water and sewer systems. Increased inland flooding will impair stormwater drainage systems that empty into the ocean and destroy tidal wetlands, reducing environmental protection against storm surge and decreasing important fishery habitat. Oil and gas production infrastructure located in areas protected by barrier islands will be at greater risk to storm surge, affecting our ability to develop energy resources. 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. By the year 2060, the sea level in Key West, Florida is expected to be between 23 and 61 centimeters (9 and 24 inches) higher than in 2010. By the end of the 21st century, the sea level around the Southeast is predicted to rise by as much as one meter (3 feet) (Figure 8.16).



Vulnerability to Sea Level Rise



Future

Figure 8.15: The Coastal Vulnerability Index displays the relative risk that physical changes will occur along southeastern coastlines as sea level rises. (See TFG website for full-color version.)



Figure 8.16: Projected land loss in Florida and the Southeast, marked by areas in blue, following a one-meter (three-foot) rise in sea level. (See TFG website for full-color version.)



 Future

Resources
Books and Articles

- Allmon, W. D., T. A. Smrecak, & R. M. Ross. 2010. *Climate Change—Past Present & Future: a Very Short Guide*. Paleontological Research Institution (Special Publication 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, New York, 188 pp., <http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf>.
- Kottek, M., J. Grieser, C. Beck, B. Rudolf, & F. Rubel. 2006. World map of Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15: 259–263, <http://koeppen-geiger.vu-wien.ac.at/>.
- 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>.
- Retallack, G. J. 2007. Cenozoic paleoclimate on land in North America. *Journal of Geology*, 115: 271–294, <http://blogs.uoregon.edu/gregr/files/2013/07/cenozoicnorthamerica-gmt02r.pdf>.
- Rosenzweig, C., A. Iglesias, X. B. Yang, P.R. Epstein, & E. Chivian. 2001. Climate change and extreme weather events—implications for food production, plant diseases, and pests. *Global Change and Human Health*, 2(2): 90–104, and *NASA Publications Paper 24*, <http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1023&context=nasapub>.
- Ruddiman, W. F. 2014. *Earth's Climate: Past and Future, 3rd edition*. W. H. Freeman, New York, 445 pp.

Websites

- Climate*, National Oceanic and Atmospheric Administration, <http://www.noaa.gov/climate.html>.
- Climate has Changed Throughout Earth's History*, National Park Service, http://nature.nps.gov/geology/nationalfossilday/climate_change_earth_history.cfm.
- Climate Literacy & Energy Awareness Network (CLEAN), <http://www.cleanet.org>. (A rich collection of resources for educators.)
- Envisioning Climate Change Using a Global Climate Model*, by 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, <http://pmm.nasa.gov/education/websites/global-climate-change-vital-signs-planet>. (Information about global climate change, including spectacular satellite images.)
- Global Greenhouse Gas Reference Network, Global Monitoring Division, National Oceanographic and Atmospheric Administration Earth System Research Laboratory, <http://www.esrl.noaa.gov/gmd/ccgg/data-products.html>. (Data and visualizations.)
- Global Weather, Jetstream—Online School for Weather*, National Weather Service, http://www.srh.noaa.gov/jetstream/global/global_intro.htm.
- 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, <http://nca2014.globalchange.gov>. (Reports summarizing impacts of climate change.)
- National Weather Service, National Oceanographic and Atmospheric Administration, <http://www.weather.gov>.
- NOAA's El Niño Portal*, National Oceanographic and Atmospheric Administration, <http://www.elnino.noaa.gov/>.
- North America During the Last 150,000 Years*, compiled by J. Adams,



Resources

<http://www.esd.ornl.gov/projects/gen/nercNORTHAMERICA.html>.

The Paleomap Project, by C. R. Scotese, <http://www.scotese.com>. (Maps and information about Earth's tectonic and climate history.)

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

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

Climate of the Southeast

Effects of Climate Change on the Southeast, Climate Education for K-12, North Carolina State University, <https://climate.ncsu.edu/edu/k12/climatechange.SE>.

Extreme Weather and Climate Change: The Southeast, 2011, Climate Central, <http://www.climatecentral.org/library/climopedia/extreme-weather-and-climate-change-the-southeast>.

Ingram, K. T., K. Dow, L. Carter, & J. Anderson. 2013. *Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability*. Island Press, Washington, DC, 341 pp.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, C. E. Konrad II, C. M. Fuhrman, B. D. Keim, M. C. Kruk, A. Billel, H. Needham, M. Schafer, & J. G. Dobson. 2013. Regional climate trends and scenarios for the US National Climate Assessment. Part 2. Climate of the southeast US. *NOAA Technical Report NESDIS 142-2*, 94 pp., <http://scenarios.globalchange.gov/regions/southeast-and-caribbean>.

NOAA United States Climate Page, <http://www.esrl.noaa.gov/psd/data/usclimate/states.fast.html>. (Clickable state map of the US to get city-by-city climate data, 1961–1990.)

Our Changing Climate: Southeast and the Caribbean, National Climate Assessment, <http://nca2014.globalchange.gov/report/regions/southeast>.

The Paleontology Portal, <http://paleoportal.org/>. (North American fossil record and geologic and climate histories, by state.)

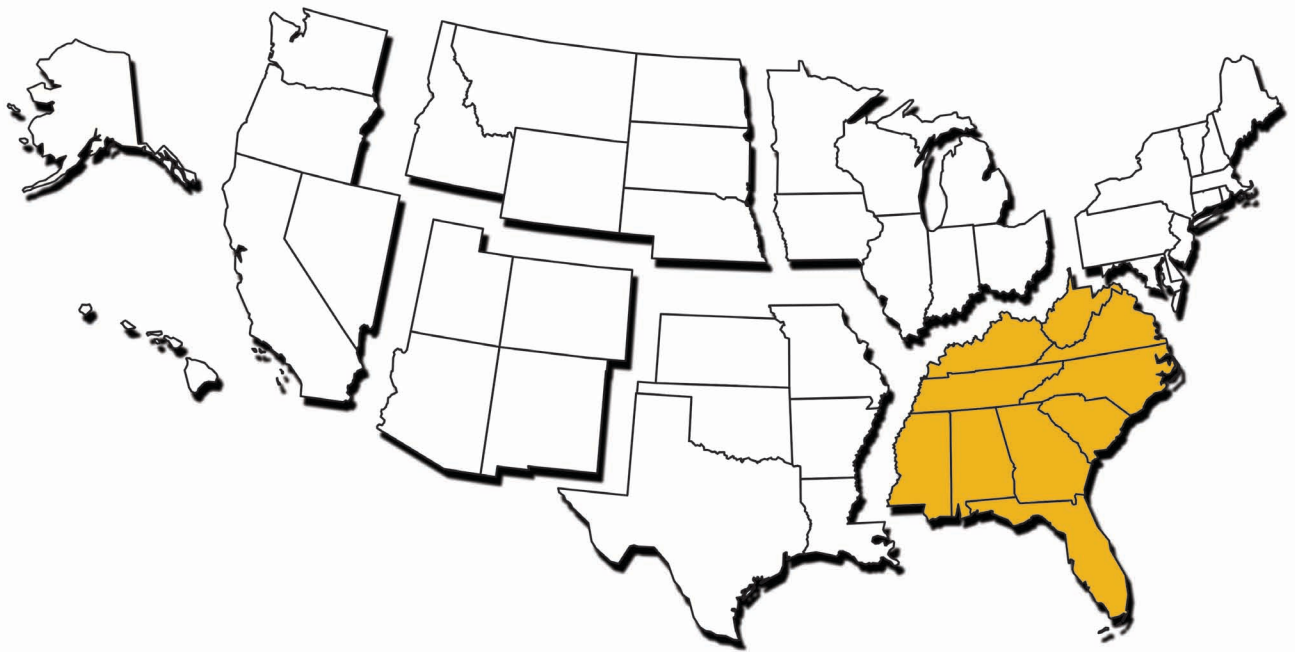
Southeast and Caribbean, Regional Impacts, Climate Nexus: Changing the Conversation, <http://climatenexus.org/learn/regional-impacts/southeast-and-caribbean>.

Southeast Climate Science Center, North Carolina State University, US Department of the Interior, <http://globalchange.ncsu.edu/secsc/>.

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

The
Teacher-Friendly
Guide™

to the Earth Science of the
Southeastern US
2nd ed.



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

Paleontological Research Institution
2016

ISBN 978-0-87710-512-1
Library of Congress no. 2016930925
PRI Special Publication no. 50

© 2016 Paleontological Research Institution
1259 Trumansburg Road
Ithaca, New York 14850 USA
priweb.org

First printing January 2016

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.

Any part of this work may be copied for personal or classroom use (not for resale). Content of this *Teacher-Friendly Guide*™ and its interactive online version are available for classroom use without prior permission.

The Teacher-Friendly Guide™ series was originally conceived by Robert M. Ross and Warren D. Allmon. The first edition of this volume was published as Special Publication no. 42 in 2003 (online) and 2012 (hard copy). Original illustrations in this edition 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, Katherine Peck, and Christine Dubé.

The Teacher-Friendly Guide™ is a trademark of the Paleontological Research Institution.

Cite this book as:

Swaby, A. N., M. D. Lucas, and R. M. Ross (eds.), 2016, *The Teacher-Friendly Guide to the Earth Science of the Southeastern US, 2nd edition*. Paleontological Research Institution, Ithaca, New York, 460 pp.

Cite one chapter as (example):

Allmon, W. D., 2016, Fossils of the Southeastern US. Pages 87–146, in: A. N. Swaby, M. D. Lucas, & R. M. Ross (eds.). *The Teacher-Friendly Guide to the Earth Science of the Southeastern US, 2nd edition*. Paleontological Research Institution, Ithaca, New York.

On the back cover: Blended geologic and digital elevation map of the Southeastern US. 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>.