



Chapter 9: Earth Hazards of the Southeastern US

Natural hazards or earth hazards are events or processes that have significant impacts on human beings and the environment. Extreme **weather** conditions or geologic activity can cause substantial short-term or long-term changes to our environment. These changes can influence many aspects of the world around us, including crops, homes, infrastructure, and the **atmosphere**. The 4.6-billion-year-old Earth has experienced many naturally generated hazards, while other events are byproducts of human activities, created during mineral and **energy** extraction or in construction practices that modify the landscape.

The Southeast is subject to a variety of earth hazards. Most famously, the area happens to have just the right combination of conditions for tornados that cross the region and hurricanes that impact the Gulf and Atlantic Coastal plains. Modifications of the Mississippi River and its mouth, as well as the Southeast's coastline, have exacerbated the impacts of storms and floods. **Limestone**, **gypsum**, and **salt** deposits are responsible for significant areas of **karst topography** and sinkholes. Like many parts of the country, **landslides** from expansive soils and exposure to radioactivity from **radon** are present, depending upon the nature of the local bedrock. Perhaps most surprisingly, despite being far from a plate boundary, certain areas of the Southeast are at risk from large **earthquakes** due to occasional movement along large ancient **faults**.

Earthquakes

Earthquakes occur when a critical amount of stress is applied to the Earth's **crust** and the crust responds by moving. According to the elastic rebound theory, rocks can bend elastically up to a point, until they finally break. The rocks then snap apart, releasing energy in the form of **seismic waves** (Figure 9.1). The plane defined by the rupture is known as a fault, and the surrounding rock layers become offset along it.

Many earthquakes, including most of those that occur in the Southeastern US, arise along pre-existing faults. In cases such as these, stress may accumulate from lateral **compressive** pressure, as the rocks are temporarily locked in position by friction and other constraints, until sufficient strain energy has built up to cause sudden slippage along the fault (i.e., an earthquake).

There are two common ways to measure the size of earthquakes: **magnitude** and intensity. Magnitude (M) is the measure of the energy released by the earthquake, whereas the intensity is what people actually experience. The

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

atmosphere • a layer of gases surrounding a planet.

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

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

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

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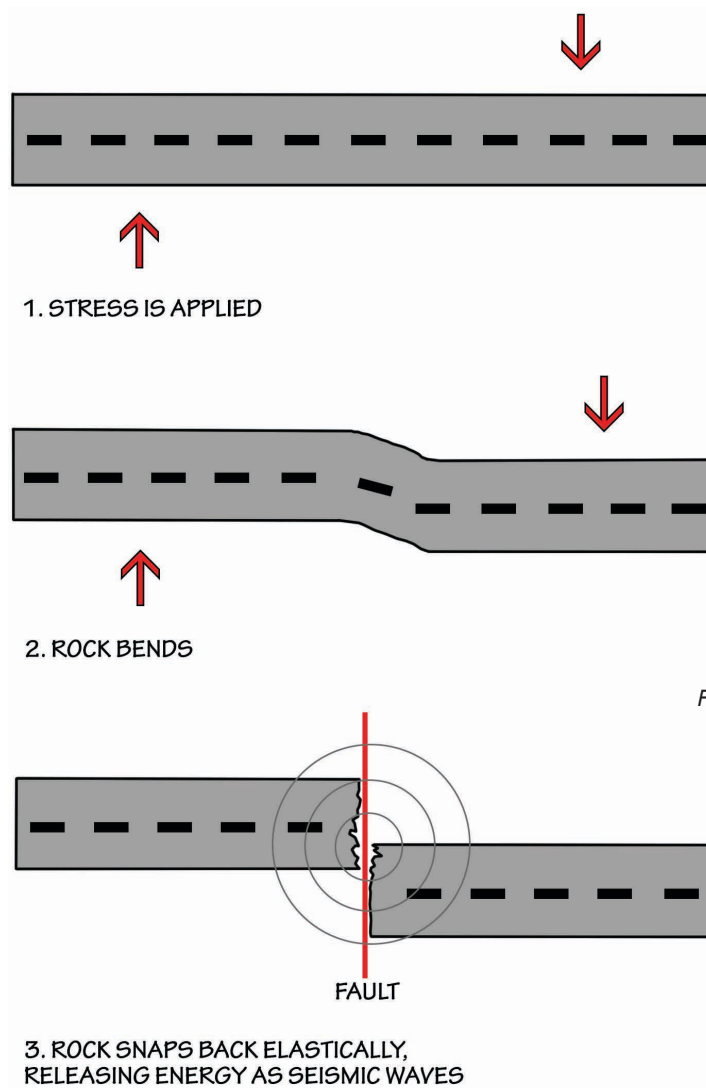


Figure 9.1: Elastic rebound.

first scale used to measure magnitude was the Richter scale (abbreviated M_L), which measures the amplitude of a seismic wave at a defined distance from the source of the earthquake. The Richter scale was designed to classify earthquakes at a local scale, but it does not do a very good job of describing the energy released by very large earthquakes. Geologists therefore developed another measurement, the Moment Magnitude scale (abbreviated M_w), which was introduced in 1979. The Moment Magnitude estimates the total energy released by an earthquake along an entire fault surface.

Both the Richter and Moment Magnitude scales are logarithmic, meaning that an M9.0 earthquake has 10 times the amplitude, and releases 32 times the energy, of an M8.0 earthquake. Accordingly, an M9.0 earthquake would have 100 times the amplitude and 1024 times the energy of an M7.0 earthquake.

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Both scales may appear to reach maximum values of 10 (since the largest recorded earthquakes are slightly greater than 9), but technically there is no upper limit. The United States Geological Survey (USGS) describes earthquakes as *minor* (M3.0–3.9), *light* (M4.0–4.9), *moderate* (M5.0–5.9), *strong* (M6.0–6.9), *major* (M7.0–7.9), and *great* (M8.0 and higher). The largest recorded earthquake in US history was the 1964 Alaskan earthquake, which had an M_w of 9.2. By comparison, the largest recorded earthquake in the Southeast occurred in 1886 in Charleston, South Carolina (M7.3).

The 1964 Alaskan earthquake and the 1906 San Francisco earthquake had roughly the same Richter magnitudes, but based on the size of the affected areas and geological movement, the Alaskan earthquake clearly released more energy than the San Francisco earthquake did. Geologists recalculated the magnitudes of these major quakes using the Moment Magnitude scale: the 1964 Alaskan earthquake, which originally had an M_L of 8.3, was found to have had an M_w of 9.2, whereas the 1906 San Francisco earthquake had an M_L of 8.3 and an M_w of 7.9.

Notable Earthquakes of the Southeastern States

Date	Location	M_w
08-31-1886	Charleston, SC	7.3
05-31-1897	Giles County, VA	5.9
08-23-2011	Louisa County, VA	5.8
02-21-1916	Waynesville, NC	5.2
07-27-1980	Sharpsburg, KY	5.2
10-18-1916	Irondale, AL	5.1
08-17-1865	Memphis, TN	5.0
12-16-1931	Charleston, MS	4.6
11-19-1969	Glen Lyn, WV	4.5

Earthquakes are much less common in the eastern US than in the west. This is primarily because the east coast of North America is a **passive margin**; that is, it is located in the center of a tectonic **plate** rather than at an **active plate margin**. All earthquakes that occur in the eastern US are therefore referred to as "intraplate" earthquakes. Eastern quakes, however, are typically felt over a much larger region than western quakes of similar magnitude. For example, in the Southeast an earthquake of magnitude 5.5 can usually be felt as far as 480 kilometers (300 miles) from where it occurred, and sometimes causes damage as far away as 40 kilometers (25 miles). This appears to be because the bedrock that makes up most of the eastern US is older, colder, drier, and less **fractured** than rocks in the western US. As a result, although earthquakes

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passive margin • a tectonically quiet continental edge where crustal collision or rifting is not occurring.

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

active plate margin • the boundary between two plates of the Earth's crust that are colliding, pulling apart, or moving past each other.

fracture • a physical property of minerals, formed when a mineral crystal breaks.

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

intensity • a subjective measurement that classifies the amount of shaking and damage done by an earthquake in a particular area.

here release the same amount of energy as other earthquakes, the shaking affects a much larger area because the seismic waves travel through **denser**, more solid bedrock.

The magnitude of an earthquake does not tell us how much damage it causes. The amount of shaking and damage is known as the earthquake's **intensity**, and it can be measured by the Modified Mercalli Intensity (MMI) scale. This scale uses the Roman numerals I–XII to describe the effects of the earthquake in a particular location. For example, near the epicenter of a small earthquake, or at a location far from a large earthquake, the intensity may be described with an MMI of II: "Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing." Unlike the Moment Magnitude scale, the MMI scale is a subjective gauge, and the USGS has attempted to improve the accuracy of MMI shake maps by soliciting data from the public. *Figure 9.2* shows the intensities felt in surrounding areas after the 1886 earthquake in Charleston, South Carolina, which is the largest earthquake known to have occurred in the state.

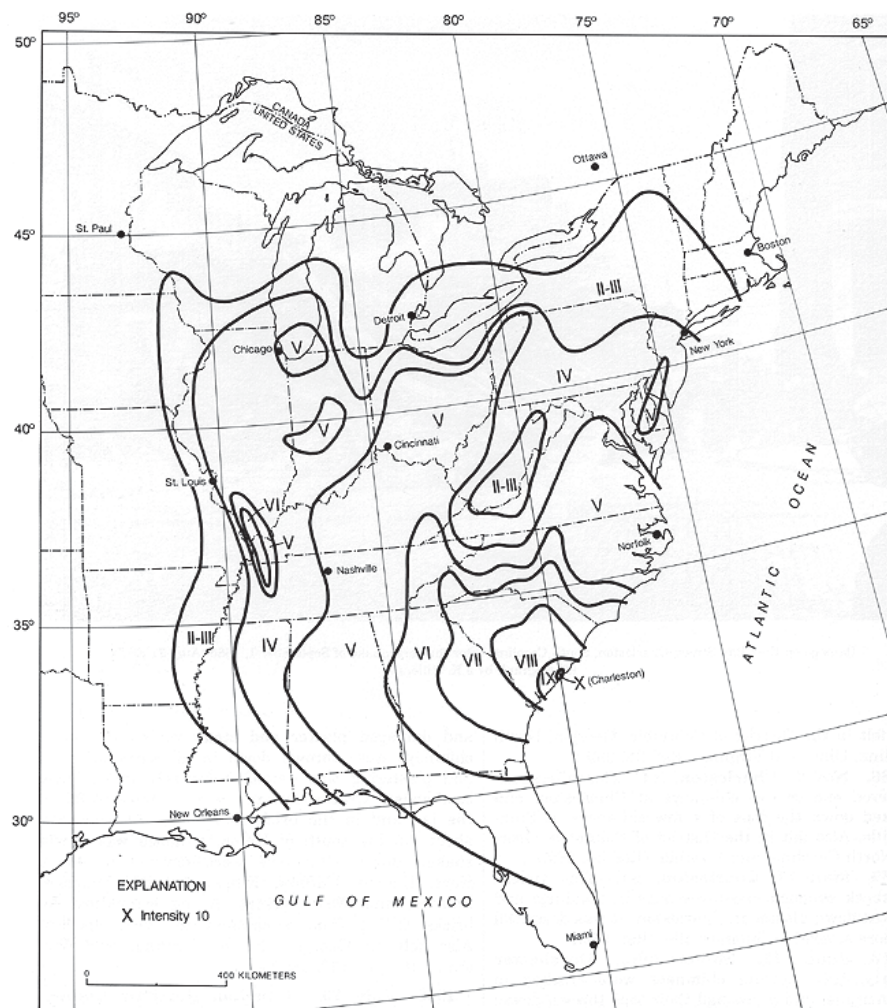


Figure 9.2: Intensity map of the 1886 Charleston earthquake.



Earthquakes

There are four major **seismic zones** in the Southeastern states (Figure 9.3; see also Figure 9.5): the New Madrid Seismic Zone, the Southern Appalachian Seismic Zone, the South Carolina Seismic Zone, and the Virginia Seismic Zone. The *New Madrid Seismic Zone* (NMSZ, also called the New Madrid Fault Line or Fault System) is a 240-kilometer (150-mile) set of subsurface faults thought to have formed during the breakup of the supercontinent **Rodinia** in the late **Precambrian** (about 750 million years ago). Although this rift did not split the continent, it remains an underground weak point—most of the zone's seismicity is located 5–24 kilometers (3–15 miles) beneath the surface. Faults in the NMSZ are occasionally reactivated by the relatively small east-west compressive forces associated with continuing continental drift of the North American plate, making the area unusually prone to earthquakes.

seismic zone • a regional zone that encompasses areas prone to seismic hazards, such as earthquakes or landslides.

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

Precambrian • a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).

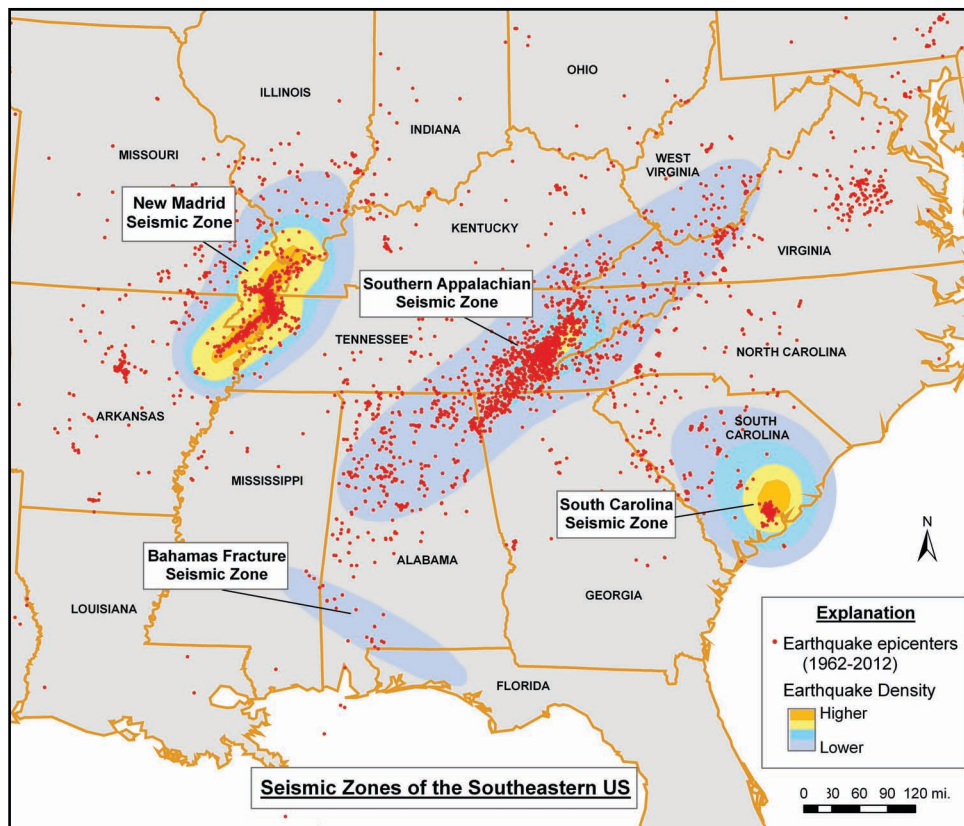


Figure 9.3: Seismic Zones in the Southeastern US. (See TFG website for full-color version.)

The NMSZ has been the source of numerous earthquakes in western Kentucky, Tennessee, and Mississippi. Four of the largest earthquakes in North American history—the New Madrid Sequence—occurred in the NMSZ on three days over a period of three months: December 16, 1811, January 23, 1812, and February 7, 1812. The quakes, with estimated magnitudes between 7.0 and 8.0, occurred along the Mississippi River in southeastern Missouri and northern Arkansas. While much of the damage was confined to Missouri and Arkansas, the tremors shook the Mississippi Valley and much of the eastern United States, destroying buildings and warping the ground. In Kentucky and Tennessee, landslides

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

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

liquefaction • a process by which water-saturated unconsolidated sediment temporarily loses strength and behaves as a fluid when vibrated.

floodplain • the land around a river that is prone to flooding.

uplift • upward movement of the crust due to compression, subduction, or mountain building.

Paleozoic • a geologic time interval that extends from 541 to 252 million years ago.

occurred along the Mississippi River bluffs and ground **subsidence** brought on by **soil liquefaction** spread across the Mississippi River **floodplain**. Shaking was felt as far away as New Orleans and Boston, where it is said to have caused church bells to ring, and the waters of the Mississippi River appeared to flow backward for several days due to local **uplift** and waves flowing upstream. Hundreds of aftershocks followed over a period of a several years, and were felt regularly until 1817.

The *South Carolina Seismic Zone* is located in the mid-coast area of South Carolina, and is believed to be caused by faults formed during the break-up of Pangea, beginning around 200 million years ago. These faults are very difficult to study, however, because they are buried beneath as much as three kilometers (two miles) of sediment. The South Carolina Seismic Zone was the site of the 1886 Charleston earthquake, which had an estimated magnitude of 7.3 and was the most damaging earthquake to occur in the Southeastern states. The quake damaged and destroyed hundreds of buildings (*Figure 9.4*), killed at least 60 people, destroyed kilometers (miles) of railroad tracks, and generated extensive craters and fissures for 1300 kilometers (810 miles) surrounding the epicenter.

The *Southern Appalachian Seismic Zone* (and its extension, the *Eastern Tennessee Seismic Zone*) runs along the Appalachian Mountains, from easternmost Tennessee to northeastern Alabama. The faults in this zone formed as a result of continental collisions that created the Appalachian Mountains in the mid- to late **Paleozoic**.



Figure 9.4: Rubble and collapsed buildings line the streets of Charleston, South Carolina, after the devastating 1886 earthquake.



The *Central Virginia Seismic Zone* is located in central Virginia (Figure 9.5), and has been a site of earthquakes at least since the 1700s. This zone is also a result of the continental collisions that created the Appalachian Mountains; its faults have been reactivated as a result of subsequent rifting and continental movement. Most recently, the Virginia earthquake of August 2011 (M5.8) occurred along a north- or northeast-striking fault in the Piedmont of Louisa County, 61 kilometers (38 miles) northwest of Richmond. No deaths and only minor injuries were reported, but minor damage to buildings was widespread and included the National Cathedral and Washington Monument in Washington, DC. The 2011 earthquake, along with a magnitude 5.8 quake on the New York-Ontario border in 1944, is the largest to have occurred in the US east of the Rocky Mountains since an 1897 temblor centered in western Virginia (M5.9). Research following the 2011 Virginia quake revealed that the farthest landslide from the epicenter was 240 kilometers (150 miles) away, by far the greatest landslide distance recorded from any other earthquake of similar magnitude (previous studies of worldwide earthquakes indicated that landslides occurred no farther than 58 kilometers [36 miles] from the epicenter of a magnitude 5.8 quake). It remains unclear exactly why this occurred.

See Chapter 1: Geologic History to learn about the tectonic events that formed North America's mountains and generated fractures and faults.

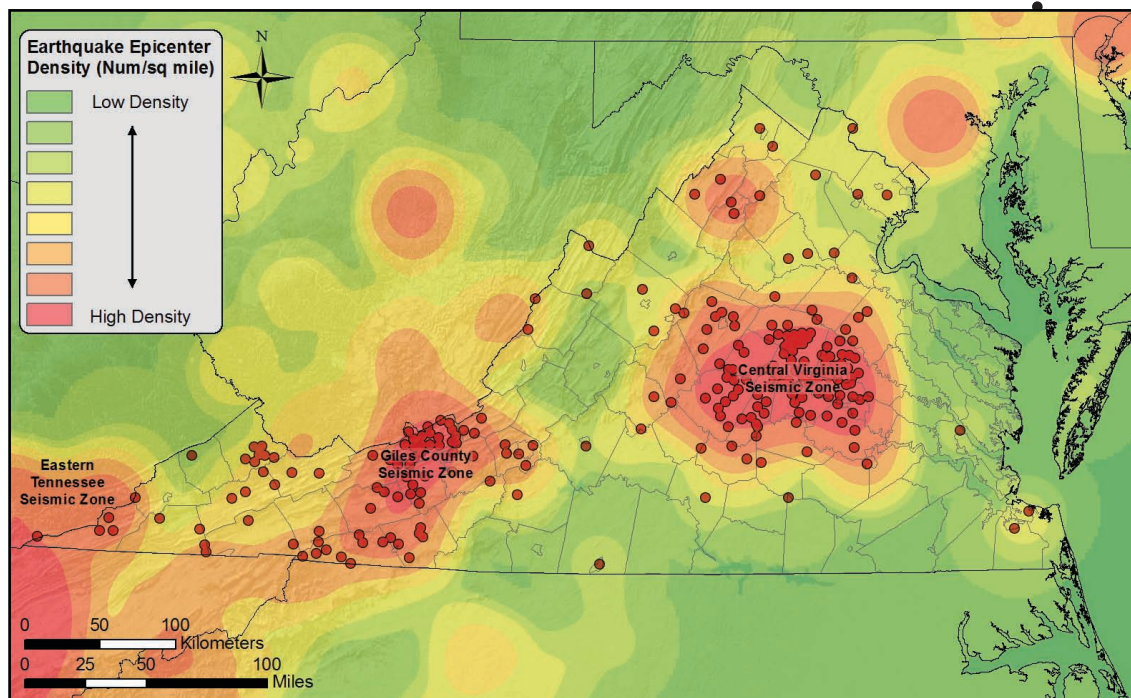


Figure 9.5: Seismic zones in Virginia. Red dots indicate known earthquake epicenters. (See TFG website for full-color version.)

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

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

power • the rate at which energy is transferred, usually measured in watts or, less frequently, horsepower.

tsunami • a series of ocean waves that are generated by sudden displacement of water, usually caused by an earthquake, landslide, or volcanic explosions.

In the Southeast, the Coastal Plain region (including the **Mississippi Embayment**, the Gulf Coastal Plain, and the Atlantic Coastal Plain) is considered the most vulnerable since many sizeable cities in those areas have been built upon unconsolidated earth materials susceptible to liquefaction, a process by which water-saturated, unconsolidated sediment temporarily loses strength and behaves as a fluid when vibrated. This phenomenon is similar to that observed when you wiggle your toes in the wet **sand** near the water at a beach. Liquefaction brought on by an earthquake is capable of causing structures to collapse due to loss of support.

Networks of seismograph stations have improved geologists' ability to detect and accurately locate earthquake hazards (*Figure 9.6*), and specific fault zones are being studied throughout the Southeast. This information on earthquake risk can lead to better designs for high-risk infrastructure like dams, high-rise buildings, and **power** plants—and it can also be used to inform the public of potential hazards to lives and property. The hazards associated with earthquakes are mainly related to collapsing buildings and other structures, fire related to broken gas lines and other utilities (and broken water lines preventing fire-fighting), and in some instances **tsunamis**—seismic sea waves. Tsunamis are not known to occur along the coastal areas of the Southeast—they tend to be more common along active plate boundaries.

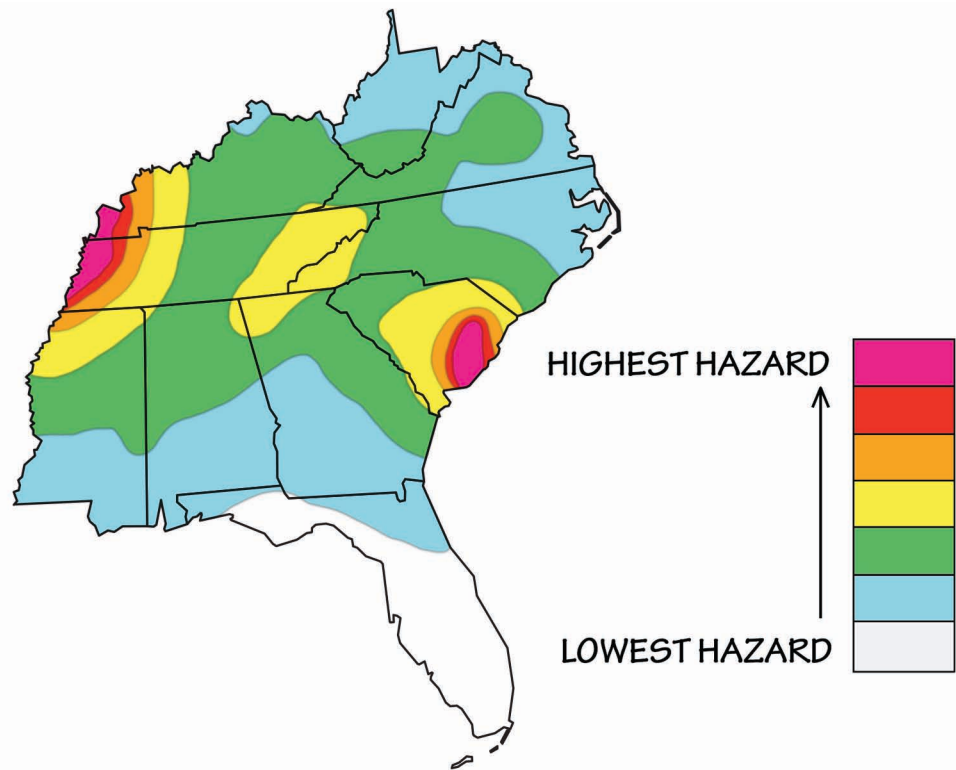


Figure 9.6: Seismic hazard map of the Southeastern US, based on 2014 data. (See TFG website for full-color version.)



Landslides

The term "landslide" refers to a wide range of **mass wasting** events that result in rock, soil, or fill moving downhill under the influence of gravity (Figure 9.7). These events occur when friction between the earth material (i.e., rock and soil) and the slope is overcome, allowing the earth material to fail and move downslope. Mass wasting events can also dam streams and rivers, creating lakes. Landslides may be triggered by high rainfall, earthquakes, **erosion**, deforestation, groundwater pumping, or **volcanic** eruptions. They range in size from the simple raveling of a stream embankment to the collapse of an entire mountainside that involves tens of thousands of cubic meters (yards) of material. Not all mass wasting events are rapid—slow land movement, known as soil **creep**, is generally not hazardous, but can impact structures over a long period of time. Mud and **debris flows** are very fast landslides likely to kill anyone unfortunate enough to be caught in their path, as they can reach speeds exceeding 32 kilometers per hour (20 miles per hour).

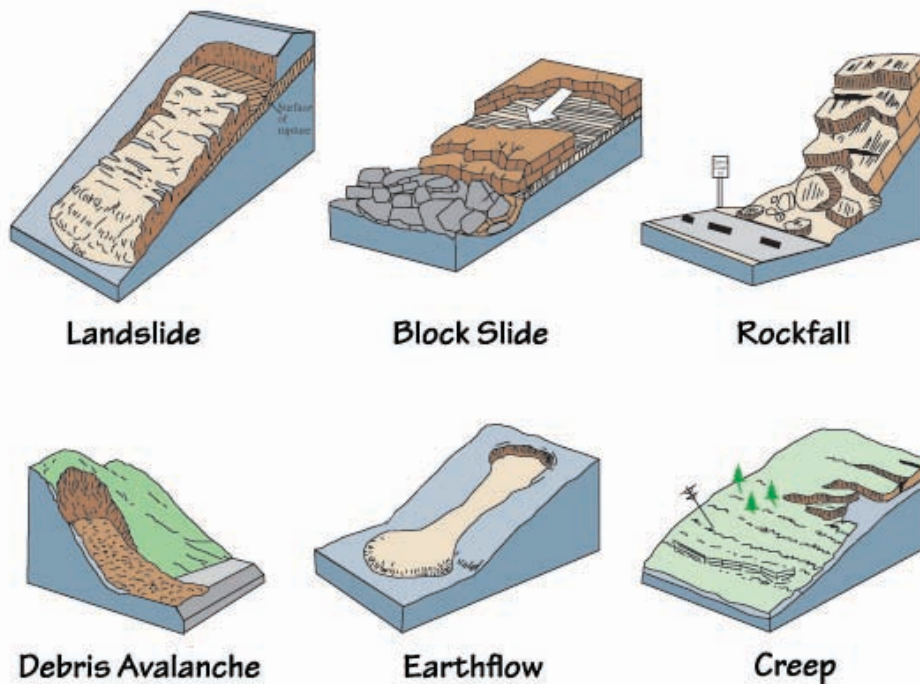


Figure 9.7: Common types of landslides.

Landslides

mass wasting • a process in which soil and rock move down a slope in a large mass.

erosion • the transport of weathered materials.

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

creep • the slow movement or deformation of a material under the influence of pressure or stress.

debris flow • a dangerous mixture of water, mud, rocks, trees, and other debris that can move quickly down valleys.

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slump • a slow-moving landslide in which loosely consolidated rock or soil layers move a short distance down a slope.

climate • 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 (usually more than 30).

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

relief • the change in elevation over a distance.

tree • any woody perennial plant with a central trunk.

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

Landslides and **slumps** are common problems in parts of the Southeast that have a wetter **climate** and considerable **topographic relief**, especially in and around the Appalachian Mountains (*Figure 9.8*). They can also occur in areas with low relief, as with the mass movement of sediments in the Mississippi River drainage basin. Heavy rain, snowmelt, groundwater percolation, and water level changes along coastlines, earthen dams, and the banks of water bodies are conditions under which landslides can occur. These flood-related conditions are associated with precipitation, runoff, and saturation of the ground. Human activity can also lead to mass wasting events, especially where excavation, blasting, or construction occur on unstable or steep surfaces. For example, in March 2015 a massive landslide occurred along the steep edge of fill below the runway of Yeager Airport in Charleston, West Virginia (*Figure 9.9*). The airport was built on seven million cubic meters (nine million cubic yards) of engineered fill, due to the lack of suitable flat land for an airport. The landslide occurred after a spell of warm, wet weather following a freeze; it destroyed a church and damaged several homes, caused flooding, and blocked Keystone Road.

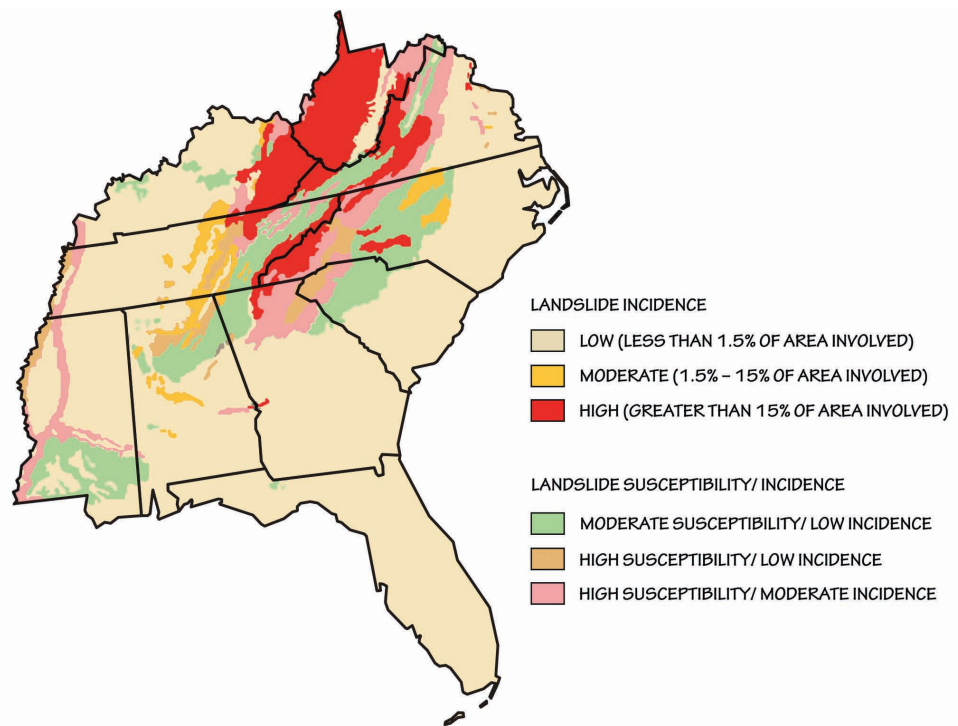


Figure 9.8: Landslide incidence and risk in the Southeastern US.. (See TFG website for full-color version.)

Debris flows are a dangerous mixture of water, mud, rocks, **trees**, and other debris that moves quickly down valleys. Rapid slides and flow movement happens without warning, triggered by heavy rainfall, snowmelt, or high levels of ground water flowing through cracked bedrock. In September 2005, heavy rainfall from two consecutive **hurricanes** dislodged a deadly debris flow from



Figure 9.9: The landslide below Yeager Airport in Charleston, West Virginia damaged houses, blocked a creek, and covered a road.

the top of Fishhawk Mountain in Franklin, North Carolina. In only 30 minutes, the flow of debris cleared a 150–300-meter-wide (500–1000-foot-wide) swath of trees, rock, and dirt as it traveled 4 kilometers (2.5 miles) down Peeks Creek at roughly 50 kilometers per hour (30 miles per hour), destroying a housing community and killing four people in a matter of seconds (Figure 9.10).

In the Blue Ridge, where the bedrock contains many discontinuities (folded bedding planes, faults, **joints**, and **cleavage**) resulting from several episodes of mountain building (the **Taconic**, **Acadian**, and **Alleghanian orogenies**), rock slides and rockfalls are common, especially along transportation routes running east to west through the mountains. US Route 64 in Tennessee and I-40 where it crosses the Tennessee-North Carolina border are often impacted by rockfalls, leading to frequent road closures (Figure 9.11). Often, stretches of highway remain closed for periods of several months.

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joint • a surface or plane of fracture within a rock.

cleavage • a physical property of minerals that occurs when it breaks in a characteristic way along a specific plane of weakness.

Taconic Orogeny • a late Ordovician mountain-building event involving the collision and accretion of a volcanic island arc along the eastern coast of North America.

Acadian Orogeny • a Devonian mountain-building event involving the collision of the eastern coast of North America and the accreted terrane of Avalon.

Alleghanian Orogeny • a Carboniferous to Permian mountain-building event involving the collision of the eastern coast of North America and the northwestern coast of Africa.

orogeny • a mountain-building event generally caused by colliding plates and compression of the edge of the continents.

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Landslides



Figure 9.10: A pile of trees, debris, and homes detached from their foundations after the Peeks Creek landslide in Franklin, North Carolina. Inset shows the track of the landslide, from the start (blue arrow) to the Peeks Creek community (yellow arrow). (See TFG website for full-color version.)



Figure 9.11: This rockslide across US 64 in Polk County, Tennessee, resulted in an eight-week-long road closure while the rocks were removed.



In some low-lying areas of the Coastal Plain, especially southern Mississippi, saturated soils and heavy rains can combine to cause soil liquefaction, which can result in laterally moving mudslides. This can be triggered by storm runoff or by rapid earth movement during an earthquake. Earthquakes along the New Madrid Seismic Zone commonly contribute to landslide incidence along the Mississippi River Valley in Tennessee and Kentucky.

Slumps and creep are common problems in parts of the Southeast with a wetter climate and/or the presence of unstable slopes or unconsolidated sand, especially in the Coastal Plain and the foothills of the Appalachians. Many areas in the Southeast contain expansive soils generated from **clay-rich shales**. Certain clay **minerals** can absorb water and swell up to twice their original volume. The pressures exerted through expansion of the minerals in the soil can easily exceed 22 metric tons per square meter (5 tons per square foot)—a force capable of causing significant damage to highways and buildings. An estimated \$9 billion of damage to infrastructure built on expansive clays occurs each year in the United States, making swelling soils one of the costliest hazards. In addition, when the clay dries and contracts, the particles settle slightly in the downhill direction. This process can cause soil creep, a slow movement of land that causes fences and telephone poles to lean downhill, while trees adjust by bending uphill (*Figure 9.12*). Human development can exacerbate this process when homes are built along river bluffs, disturbing vegetation that would otherwise stabilize the slope and adding water to the land in the form of yard irrigation or septic systems.

See Chapter 7: Soils for more information about clay-rich **Vertisol** and **Ultisol** soils.

Expansive soils can be found all over the US, and nearly every state in the Southeast has bedrock units or soil layers that are possible sources (*Figure 9.13*). Clay minerals that expand and contract when hydrated and dehydrated due to their layered molecular structure are generically referred to as smectite; soils that tend to form deep cracks during drought are often indicative of the presence of smectite. The Coastal Plain region has the highest risk of damage caused by swelling soils (clay), but the residual soils of some Paleozoic **carbonate rocks** may contain smectite, and some Paleozoic **pyritic** shale formations in the Valley and Ridge can form expansive minerals. Significant or repeated changes in moisture, which can occur in concert with other geologic hazards such as earthquakes, floods, or landslides, greatly increase the hazard potential of expansive soils. The key to reducing this hazard is to keep the water content of the soil constant. There are also chemical stabilizers, including **lime**, potassium, and ionic agents, that can reduce the potential for soil volume changes by increasing the clay's structural stability.

See Chapter 4: Topography to learn more about the Valley and Ridge and other physiographic subregions within the Southeast.

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

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

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

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

pyrite • the iron sulfide mineral (FeS_2) with a superficial resemblance to gold, known commonly as "fool's gold."

lime • an inorganic white or grayish-white compound made by roasting limestone (calcium carbonate, CaCO_3) until all the carbon dioxide (CO_2) is driven off.



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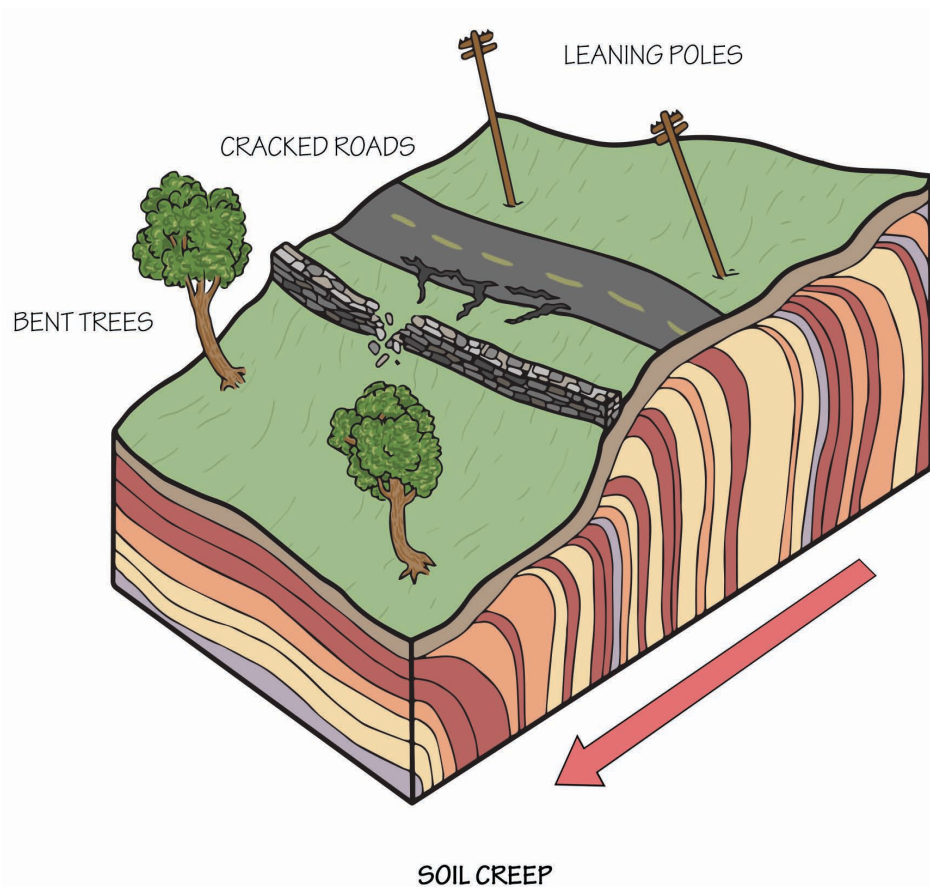


Figure 9.12: Some influences of soil creep on surface topography.

Slumping occurs when expansive minerals are present on steeper slopes, and involves the downward movement of a larger block of material along a surface that fails when the weight of the saturated soils can no longer be supported. Slumping is common near roads and highways, thanks to the presence of steeper hills, roadcuts, and construction (Figure 9.14). On steep, high slopes, slumping often precedes earthflows and mudflows that develop farther downslope as water is added to the slump while it mixes the moving material.

Damage to life and property from mass wasting events can be reduced by avoiding landslide hazard areas or by restricting access to known landslide zones. Hazard reduction is possible by avoiding construction on steep slopes or by stabilizing the slopes. There are two main ways to accomplish stabilization: (1) preventing water from entering the landslide zone through runoff, flooding, or irrigation and (2) stabilizing the slope by placing natural or manmade materials at the toe (bottom) of the landslide zone or by removing mass from the top of the slope.



Landslides

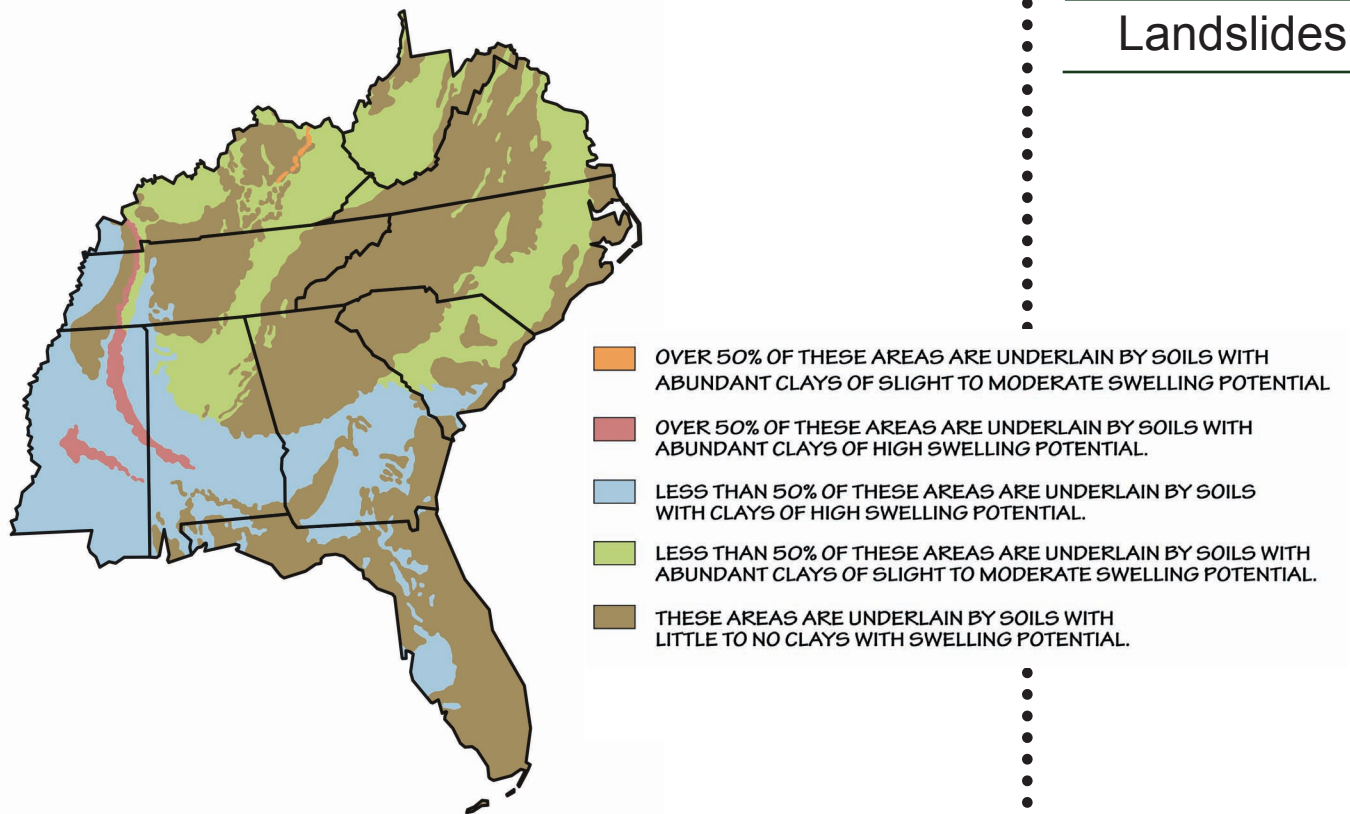


Figure 9.13: Approximate distribution of expansive soils in the Southeastern US. This map is based on the distribution of types of bedrock, which are the origin of soils produced in place. (Where substantial fractions of the soil have been transported by wind, water, or ice, the map will not be as accurate.) (See TFG website for full-color version.)



Figure 9.14: A small slump in a road embankment along KY-421 in Franklin County, Kentucky.



Karst

sedimentary rock • rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.

dolomite • a carbonate mineral, consisting of calcium magnesium carbonate ($\text{CaMg}(\text{CO}_3)_2$).

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

dolostone • a rock primarily composed of dolomite, a carbonate mineral.

Karst and Sinkholes

Karst topography forms in areas where the underlying bedrock is composed of material that can be slowly dissolved by water. Examples of this type of **sedimentary rock** include carbonate rocks such as limestone, halite, gypsum, **dolomite**, and anhydrite. Carbonate rocks may develop karst and other dissolution features due to the effects of circulating groundwater that has been made slightly acidic through the presence of dissolved carbon dioxide (which creates carbonic acid that reacts with the rock, dissolving it). Sinkholes and caverns can form, creating potential hazards (i.e., the land surface could subside or collapse into the underground openings). This may principally occur in areas where cavities filled with water are emptied through groundwater withdrawal or other natural processes, resulting in the cavities being filled with air and reducing support for the overlying rock. Many parts of the Southeast are underlain by karst and carbonates (see *Figure 9.17*). Karst areas, which are often connected to the natural groundwater circulation **system**, can also be subject to flooding when sinkholes are plugged with refuse or covered over by parking lots, driveways, or buildings.

See Chapter 4: Topography for more information about the formation of karst.

Central and southern Kentucky, including most of the Interior Basin, is one of the most famous karst areas in the world. About 55% of the state is underlain by limestones and **dolostones** that are capable of developing karst, and 25% of the state already has well-developed karst features. This is evident in the large number of commercialized caverns advertised throughout the state (*Figure 9.15*). In Tennessee and northern Alabama, especially the Nashville Basin and Highland Rim, Paleozoic limestones are abundant, with significant karst and related dissolution hazards. Southern Alabama and Mississippi contain karst formations related to the dissolution of subsurface salt, and the entire state of Florida is underlain by karstic limestone.

Sinkholes are funnel-shaped depressions in the land surface formed by the dissolution of near-surface rocks or by the collapse of underground channels and caverns. Sinkholes can form by several different mechanisms, but all require dissolution of rock beneath the surface (*Figure 9.16*). Sinkhole formation commonly damages roads, buildings, and utilities (*Figures 9.18 and 9.19*), and it is a major environmental problem in the Southeast, especially Florida, as well as parts of Kentucky, Tennessee, and Alabama. Many of the thousands of lakes across Florida are sinkholes.

Sinkholes may be very small or large enough to swallow even hectares (acres) of land, along with any structures that had been built upon the surface. The early stages of sinkhole development may be indicated by signs of mass wasting such as "pistol-grip"-shaped trees, cracked building foundations, and leaning fence posts. Structural damage from sinkholes can be mitigated, but usually only at significant cost. It is therefore often far more prudent to avoid building in such



Karst



Figure 9.15: Mammoth cave in Kentucky is the longest known cave system in the world, spanning more than 640 kilometers (400 miles) of vast chambers and complex labyrinths in karstic rock.

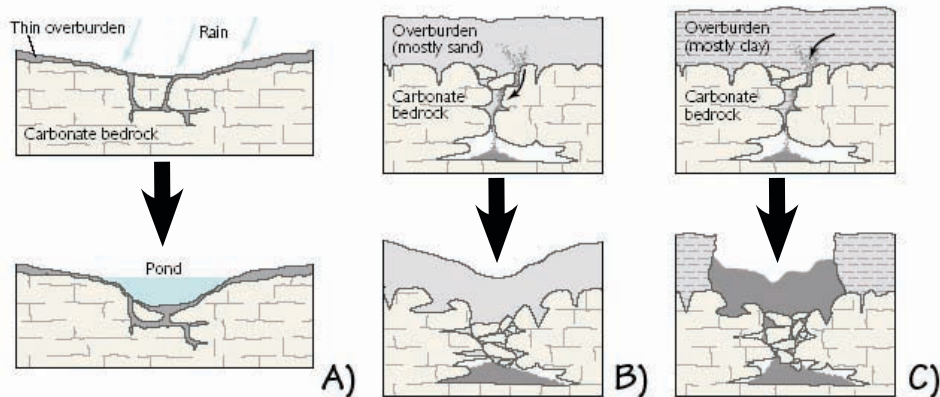


Figure 9.16: Three mechanisms of sinkhole formation.

- A) *Dissolution: Rain and surface water percolate through carbonate bedrock, dissolving a hole from the top down.*
- B) *Cover-subside: Carbonate bedrock dissolves beneath a permeable overlying layer such as sand. As the sand falls into the hole below, slow downward erosion leads to a depression.*
- C) *Cover-collapse: Carbonate bedrock dissolves beneath an overlying layer made largely of clay. The clay collapses from beneath into the cavity below, abruptly forming a dramatic sinkhole when the surface is breached. This type of sinkhole causes the most catastrophic damage, as it is not easily detected before it forms.*

9



Earth Hazards

Karst



Figure 9.17: Areas of karst in the continental US, associated with carbonate and evaporate rocks. See Key on facing page. (See TFG website for full-color version.)



Karst



9



Earth Hazards

Karst



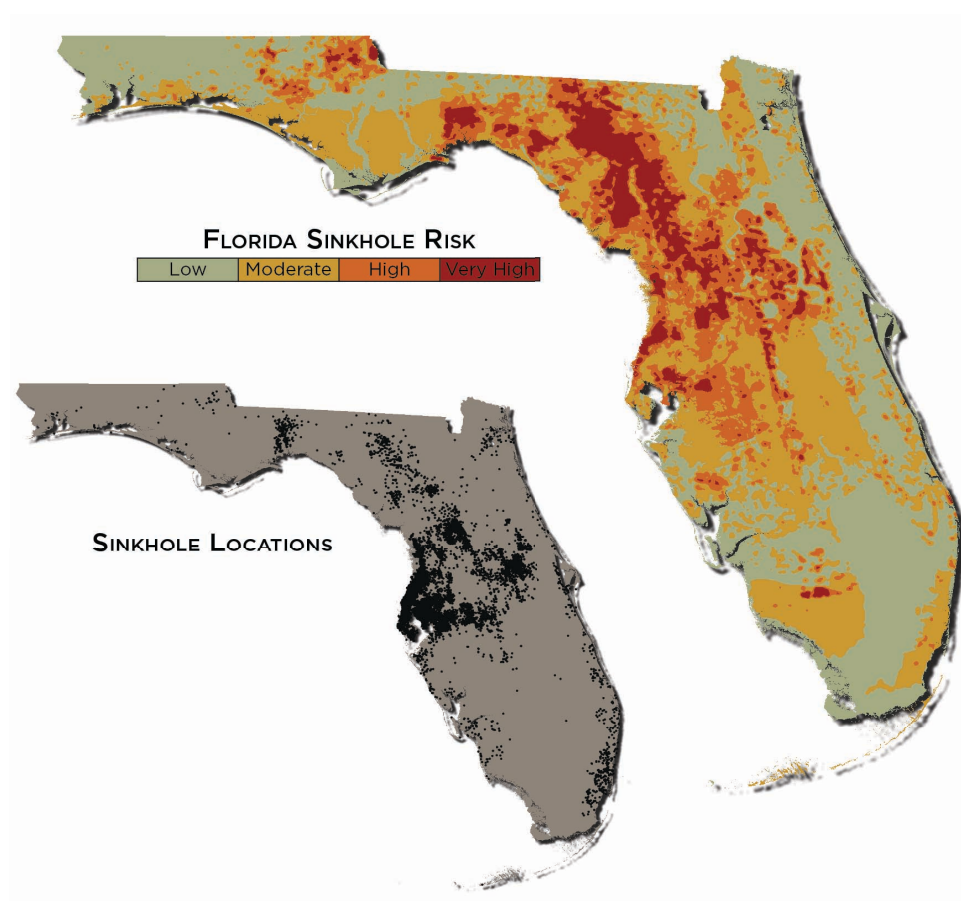
Figure 9.18: This 100-meter-wide (320-foot-wide) sinkhole formed in Winter Park, Florida, in 1981. It swallowed 190,000 cubic meters (250,000 cubic yards) of earth as well as vehicles and buildings. Today, it has been filled with water and is called Lake Rose.



Figure 9.19: The "Golly Hole" or "December Giant" is Alabama's largest sinkhole, at roughly 90 meters (300 feet) wide and 37 meters (120 feet) deep. It is located in an area of Shelby County with an extensive history of sinkhole formation.



locations altogether. Evaluating sinkhole risk commonly involves foundation testing by drilling or remote sensing (for example, measuring electrical resistivity) prior to construction. Unfortunately, many structures have been built without such testing, resulting in frequent catastrophic damage. Many state agencies provide sinkhole risk maps, which provide generalized risk assessment based on local geology (*Figure 9.20*).



*Figure 9.20: Sinkhole risk in Florida.
(See TFG website for full-color version.)*

Portions of the Gulf Coastal Plain are noted for subsurface **salt domes** that formed from **Jurassic** salt beds compressed into dome-like intrusions by the weight of overlying sediment. Salt domes offshore and on-shore have long been exploited for hydrocarbons trapped in the strata deformed by the intrusions, but they have also been exploited for other resources, including the salt itself. Dissolution of the salt by hydraulic mining creates subsurface voids capable of collapse, resulting in hazardous depressions on the land surface.

Karst

salt dome • a largely subsurface geologic structure, consisting of a vertical cylinder of salt embedded in horizontal or inclined sedimentary strata.

Jurassic • the geologic time period lasting from 201 to 145 million years ago.



Radon

radioactivity • the emission of radiation by an unstable atom.

granite • a common and widely occurring type of igneous rock.

Radon

Radon is a naturally occurring **radioactive**, colorless, odorless gas. It is the leading cause of lung cancer in American non-smokers, and the second leading cause of lung cancer overall. It can collect in homes, buildings, and even in the water supply. Radon gas is formed naturally when uranium-238 undergoes radioactive decay, producing energy and several radioactive products such as radon-222 and thorium-232. (The thorium later decays to emit energy and radon-220.) Radon is more commonly found where uranium is relatively abundant in bedrock at the surface, often in **granite**, shale, and limestone. The EPA produced a map of the US showing geographic variation in radon concentrations, divided into three levels of risk: high, medium, and low (Figure 9.21).

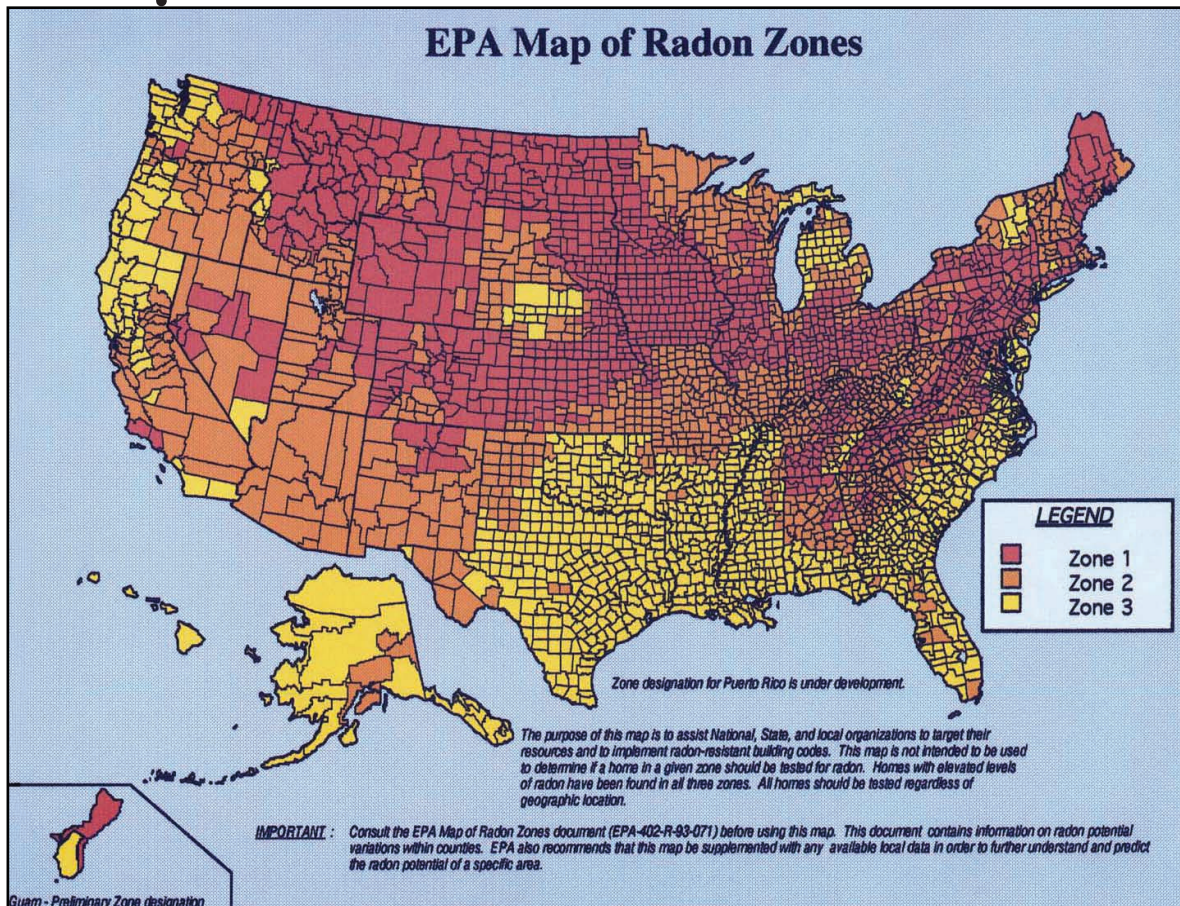


Figure 9.21: Radon zone map of the US. (Note: Zone 1 contains the highest radon levels.) (See TFG website for full-color version.)

color (mineral) • a physical property determined by the presence and intensity of certain elements within the mineral.

Although radon is more or less universally present, high levels of radon are associated with areas containing uranium-rich bedrock. Most rocks have a small amount of uranium, but certain rocks tend to have higher concentrations



The number following the name of an element (U-238) refers to the mass number of the element. Though any two atoms of the same element will have the same number of protons and electrons, the number of neutrons may vary. Variation in the number of neutrons will change the mass of an atom. Atoms of the same element with different numbers of neutrons are called *isotopes*. For example, uranium-238 and uranium-235 are both isotopes of uranium.

of the radioactive element, such as light-colored volcanic rocks, granites, dark shales, sedimentary rocks with **phosphates**, and **metamorphic rocks**. The granitic **basement rocks** of the Blue Ridge and Piedmont (formed during the **Grenville Orogeny**) and the metasedimentary rocks that form the present Appalachian Mountains (derived from the ancient Grenville Mountains) are the greatest sources of radon in the Southeast (*Figure 9.22*). Areas in the Interior Lowlands with **Devonian-Mississippian** black shale bedrock are also subject to high levels of risk.

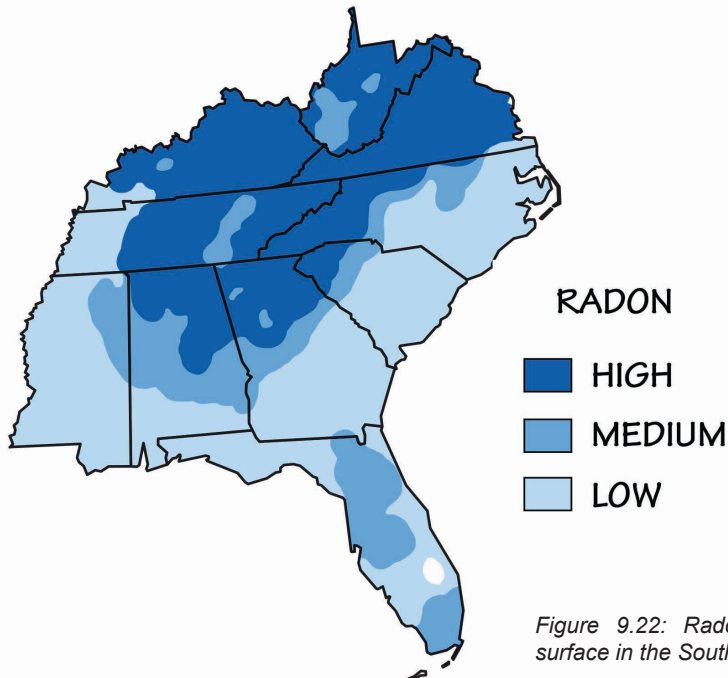


Figure 9.22: Radon risk levels at the surface in the Southeastern US.

Radon is chemically inert, meaning that it does not react or combine with elements in the ground, and it can move up through rocks and soil into the atmosphere. It is dangerous primarily when it accumulates indoors, creating a health hazard similar to that of secondhand smoke. Radon gas finds its way through cracks in basement foundations, sump pump wells, dirt floor crawlspaces, and basement

Radon

phosphate • an inorganic salt of phosphoric acid, and a nutrient vital to biological life.

metamorphic rocks • rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.

basement rocks • the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.

Grenville Orogeny • a mountain-building event, about 1.3 to 1 billion years ago, that played a role in the formation of the supercontinent Rodinia.

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

Mississippian • a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.



Floods

floor drains. It can also be found in well and municipal water. Since radon is more easily released from warm water than from cold water, one of the greatest forms of exposure likely occurs while showering in water with high radon levels.

Radon cannot be detected by sight or smell, so there is no way that the body can sense its presence. Fortunately, with proper monitoring and mitigation (reduction) techniques, radon gas can be easily reduced to low levels. One technique that is often used in homes involves sealing cracks in the basement floor, covering drains, and installing ventilation systems. A well-ventilated space will prevent the radon from accumulating and will reduce the risk of exposure. Most states have licensed radon mitigation specialists who are trained in the proper testing and mitigation of radon levels in buildings. The EPA has also published a homebuyer's guide designed to help citizens make informed decisions about radon gas. For radon in water, filtration systems can be installed to mitigate exposure in the home.

Floods

Floods are controlled by the rate of precipitation, run-off, stream flow, and shape of the land surface. They may occur as water overflows the banks of a standing water body (such as a lake) or flowing water (such as a stream), or when rainwater accumulates in an area that normally has neither standing nor flowing water. Areas near rivers, tributaries, creeks, and streams are likely to experience flooding during periods of heavy rainfall. Low-lying coastal areas can experience flooding associated with major storms, which can combine high rainfall with surging waves.

Flooding can occur at any time of the year and is caused when more water enters a stream/river channel than the channel can contain. This situation can develop when water is unable to soak into the ground and instead runs off into a river channel. Runoff can occur if the ground is already saturated (full of water) or if the ground is too dry, hard, or frozen. The slope of a river (i.e., the topography of the land) can also contribute to flooding. If rivers have a steep slope, water can quickly move through the channel and continue downstream. If rivers have a shallow slope, water moves slowly through the river channel and remains in the area instead of moving downstream. Large floods typically result from unusually rapid regional melting of snow in the spring or from major weather systems such as hurricanes that bring heavy rainfall over a large region. Flash floods—rapid flooding of low-lying areas—are often associated with heavy rain, which can quickly waterlog soil and lead to mudslides on steep terrain, resulting in damage to roads and property. In areas of lower elevation, flash floods can be produced when slow-moving or multiple thunderstorms occur over the same area. When storms move more quickly through an area, flash flooding is less likely. Although flash floods may be of only a short duration, they can cause major damage—flash floods have been known to wash coffins out of graveyards, destroy structures, and demolish manmade dams.



Floodplains are areas adjacent to rivers and streams that occasionally flood but are normally dry, sometimes for many years. When storms produce more runoff than a stream can carry in its channel, waters rise and inundate adjacent lowlands, leaving behind layers of settled sediment. Significant damage and sometimes loss of human life can occur when buildings and other human infrastructure are built on floodplains, under the assumption that future floods may never occur or will only occur in the distant future. Floods can occur at any time, but major floods are more frequent in spring and fall after periods of heavy or sustained rains when stream levels rise rapidly. For example, torrential rains in May of 2010 resulted in "thousand-year floods"—an event thought to occur only once every thousand years—along the Cumberland River in Tennessee, Kentucky, and Mississippi. As much as 480 millimeters (19 inches) of rain fell over a two-day period; in Nashville, the river reached a height of 16 meters (52 feet), and 31 people were killed throughout the flood zone.

Major floods in the Southeast often occur along the Mississippi River and its tributaries (*Figure 9.23*). The 1927 Mississippi Flood was the greatest flood on the lower Mississippi River in modern history. From the summer of 1926 until the spring of 1927, heavy rains fell in eastern Kansas, Oklahoma, and the Ohio Valley. Between February and April 1927, numerous **levees** broke along the Mississippi River from Illinois to Louisiana, inundating numerous towns in the Mississippi Valley. The break at Mounds Landing near Greenville, Mississippi was the single greatest levee rupture to ever occur along the Mississippi River. It flooded an area 80 kilometers (50 miles) wide and 160 kilometers (100 miles) long with up to 6 meters (20 feet) of water. Heavy spring rains caused a second major flood that June. In all, 73,500 square kilometers (28,400 square miles)—home to more than 931,000 people—were inundated. The Mississippi River floods in April and May 2011 were also among the largest and most damaging along this US waterway in the past century, rivaling major floods in 1927 and 1993. In April 2011, two major storm systems dumped record rainfall on the Mississippi River **watershed**. Areas along the Mississippi from Illinois and Iowa to Mississippi and Louisiana experienced heavy flooding (*Figure 9.24*).

The Southeast's Coastal Plain is topographically low and flat and contains numerous rivers, and is therefore more prone to flooding—from a variety of sources—than many other areas of higher elevation farther inland. Major flooding can be caused by high rainfall, which can swell rivers, and by major coastal storms, especially tropical storms and hurricanes. The catastrophic floods that struck South Carolina in October 2015 were caused by extraordinary rainfall from an easterly moving storm, combined with Hurricane Joaquin, which struck the Atlantic coast. The first week of October saw one of the most prolific rainfall events in the modern US history: five-day totals exceeded 500 millimeters (20 inches) in many places in South Carolina (*Figure 9.25*). On the coast, flooding can occur not just because of rainfall, but also because of storm surge, another form of

Floods

levee • a deposit of sediment built up along the sides of a river's floodplain, or an artificial embankment along a waterway to prevent flooding.

watershed • an area of land from which all water under or on it drains to the same location.

See the "Storms" section later in this chapter for more information about hurricanes and other types of severe weather.

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Earth Hazards

Floods

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

recurrence interval • the time elapsed between major events, such as floods.



Figure 9.23: The Mississippi River and its tributaries in the Southeastern states. (See TFG website for full-color version.)

flooding associated with the Coastal Plain. Strong offshore **winds** can drive water and even boats across beaches and far upstream in rivers, especially during times of high tide. The inland surge of ocean water is often of a disastrous proportion, especially when it is associated with hurricanes (*Figure 9.26*).

While floods are always considered a hazard to life and property, they present a compound threat when they trigger mudslides or contribute to the conditions that cause expansive soils and karst topography. While there is no way to completely avoid the destructive impacts of flooding, good community planning and informed decision-making can greatly reduce the safety concerns and economic impacts of these events. Flood control is part of the mission statements of many government agencies, including the National Resource Conservation Service (NRCS), US Corps of Engineers (USCE), Tennessee Valley Authority (TVA), and US Geological Survey (USGS). These agencies and others maintain gauges on most large rivers and streams in the Southeast from which flow data are gathered. Using historical records and flow data collected over a long period of time, hydrogeologists can apply statistics to calculate the frequency and **recurrence intervals** of flows of different magnitude. These data have been used by the USGS to produce special topographic maps showing flood-



Floods



Figure 9.24: Flooding in Memphis, Tennessee in May 2011, before (A) and after (B). On May 10, the Mississippi River reached 14.59 meters (47.87 feet) above normal level, the highest water level in Memphis since 1937.

prone areas. The Federal Emergency Management Agency (FEMA) provides guidelines for communities that are planning mitigation strategies designed to minimize the impacts of natural hazards such as flooding.



Floods



Figure 9.25: Flooding inundates houses along the Black River in Sumpter County, South Carolina, after Hurricane Joaquin passed through the area in October 2015.



Figure 9.26: A beach house is undermined and destroyed by storm surge from Hurricane Dennis in 1999, at Kitty Hawk, North Carolina.



Sea Level Rise, Coastal Erosion, and Subsidence

The total linear coastline of the Southeastern US measures 4094 kilometers (2544 miles); out of 23 states with coasts, Florida is ranked second in terms of coastal area, North Carolina is seventh, South Carolina is eleventh, and Virginia, Georgia, Alabama, and Mississippi are ranked fifteenth through nineteenth, respectively. Property losses from coastal hazards are extremely high and are likely to increase as shorelines become more developed and sea levels continue to rise.

Sea level changes affect the balance between erosion and deposition along the coast. About 20,000 years ago during the **ice age**, the waterfront along the coast of the present United States extended about 320 kilometers (200 miles) farther into the Atlantic Ocean. As the continental **glaciers** melted, water drained back into the oceans, causing sea level to continually rise over the past 2000 years. The continual rise in sea level alone poses hazards, but it also increases the effects of storm surge on coastal communities. Although various estimates have been made for the rate of sea level rise, the general consensus is that it is within the range of 1 to 3 millimeters (0.04 to 0.12 inches) per year, but these values may actually be increasing.

See Chapter 8: Climate for more information about sea level rise and its effect on the Coastal Plain.

While coastal hazards related to sea level fluctuations are important when considering the long term, it is short-term events such as storm surges that pose major threats to property and life (see *Figure 9.26*). The sudden rise in sea level generated by a storm surge and high winds causes water to flow over low-elevation coastlines and spill into low coastal river valleys. Hurricanes are by far the most common cause for surges; however, severe storms not reaching hurricane magnitude can still create hazardous surges. Most lives lost in a storm surge are a result of drowning or the collapse of structures. The property damage from a single event can range into billions of dollars.

The coastal areas of the Southeastern US are typically sandy beaches with dunes. Many of these beaches are barrier islands built of sand. Longshore currents cause constant shifting of the sand found on these barrier islands by eroding it in one location and depositing it in another (*Figure 9.27*). At present, erosion seems to be more dominant than deposition as sea level slowly rises. In just the last 25 years, for example, more than 480 **hectares** (1200 acres) have been eroded from the barrier islands in South Carolina's Cape Romain National Wildlife Refuge. So much sand has been removed from many beaches in the Southeast that sand is often borrowed from other sites in order to make the beaches suitable for recreation and to prevent buildings from being eroded away. Devices such as constructed islands, walls, breakwaters, groins, and piers that are exposed to waves and wave-generated currents are capable of

Sea Level Rise

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.

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

hectare • a metric unit of area defined as 10,000 square meters.

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Earth Hazards

Sea Level Rise

anthropogenic • caused or created by human activity.

being eroded and destroyed if not constructed upon sound foundations. Erosion also takes a critical toll on wildlife habitat, especially turtles and birds that use sandy shores and dunes for nesting.

The Coastal Plain is threatened by the triple risk of coastal erosion, sea level rise, and subsidence, with subsidence exacerbating the effects of the first two. Subsidence is the local sinking of land, involving little or no horizontal motion. It is induced through either the natural or **anthropogenic** removal of underlying support. Subsidence in the Southeast is common due to the abundance of soluble carbonate rocks (limestone and dolostone) and the area's warm, humid climate.



Figure 9.27: These houses on Cedar Island, a barrier island off Virginia's coastline, were originally built on solid ground. As sand on the island migrated, the buildings were left behind (shown by the yellow arrow).

Compaction of sediment, extraction of water and minerals from the soil, and collapse along fault lines are combining to increase the rate of subsidence. A combination of coastal erosion, sea level rise, subsidence, and increased storm intensity could have catastrophic impacts on the Coastal Plain region.



Sea Level Rise

oxidation • a chemical reaction involving the loss of at least one electron when two substances interact.

peat • an accumulation of partially decayed plant matter.

Subsidence in the Everglades

The Everglades is a vast wetland system in southern Florida, extending from Lake Okeechobee and its tributary areas, to the southern tip of the Florida peninsula at Florida Bay. Since 1900 much of the Everglades has been drained for agriculture and urban development; today only about 50% of the original wetlands remain. This draining, and the related *oxidation* of *peat* deposits, has caused extensive land subsidence, which has contributed to a local rise in sea level. Combined with the intensive exploitation of the major freshwater aquifers beneath the Everglades, this has increased salinity in the normally fresh-to-brackish surface waters of the Everglades and Florida Bay. This trend will only continue as sea level rises due to ongoing climate change.



Changes in drainage flow from the Everglades as a result of human activity over the past 200 years.

(See TFG website for full-color version.)



Weather

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

derecho • a set of powerful straight-line winds that exceed 94 kilometers per hour (58 miles per hour) and can often approach 160 kilometers per hour (100 miles per hour).

wind shear • when wind speed and/or direction changes with increasing height in the atmosphere.

cold front • the boundary between the warm air and the cold air moving into a region.

Weather Hazards

Weather is the measure of short-term atmospheric conditions such as temperature, wind speed, and humidity. The Southeast is an extremely active location for high-energy atmospheric events such as **tornados** and hurricanes. It also experiences a variety of other weather hazards, including high temperatures and drought. In 2013, the National Oceanic and Atmospheric Administration (NOAA) reported that since 1980, the Southeast had experienced more billion-dollar weather disasters than any other part of the US.

Storms, Tornados, and Derechos

Rainstorms occur where colder air from higher latitudes abruptly meets warmer air. This often happens in the mid-latitudes, including the Southeastern US, where air may warm up as it passes over flat open spaces or when warm, moist air is delivered off the Gulf of Mexico. At the boundary between warmer and cooler air, buoyant warm air rises and then cools because air pressure decreases with increasing height in the atmosphere. As the air cools, it becomes saturated with water vapor; condensation occurs and clouds begin to form. Because liquid water droplets in the clouds must be very small to remain suspended in the air, a significant amount of condensation causes small water droplets to come together, eventually becoming too large to remain suspended. Sufficient moisture and energy can lead to dramatic rainstorms. Because warm air has a lower pressure relative to cold air, and the movement of air from areas of high pressure to areas of low pressure generates wind, the significant difference in air pressure associated with these boundaries and rainstorms also generates strong winds. Flat regions, such as the Coastal Plain, allow winds to move unimpeded by topography, and are often subject to severe thunderstorms.

While severe thunderstorms are common in some parts of the Southeast, two less common storm hazards have the potential to cause serious property damage and endanger lives: **derechos** and tornados. Both of these storm events are associated with **wind shear**, which occurs when the wind's speed or direction changes with increasing height in the atmosphere. Wind shear can happen when a **cold front** moves rapidly into an area with very warm air. There, the condensing water droplets mix with the cooler, drier air in the upper atmosphere to cause a downdraft. When these downdrafts are very powerful, they can cause a derecho, or a set of powerful straight-line winds that exceed 94 kilometers per hour (58 miles per hour) and can often approach 160 kilometers per hour (100 miles per hour). These powerful windstorms can travel over 400 kilometers (250 miles) and cause substantial wind damage, knocking down trees and causing widespread power outages. The lightning associated with these intense storms can cause both forest fires and house fires. Approximately one derecho every year or two will occur in Mississippi, Alabama, northwest Georgia, Tennessee, Kentucky, and West Virginia (*Figure 9.28*), with fewer along the Gulf and Atlantic coastlines.

The differences between tornadoes and derechos are indicated in their names: *derecho* is the Spanish word for straight ahead, while the word tornado has its roots in the Spanish word *tonar*, which means to turn. Both types of storm

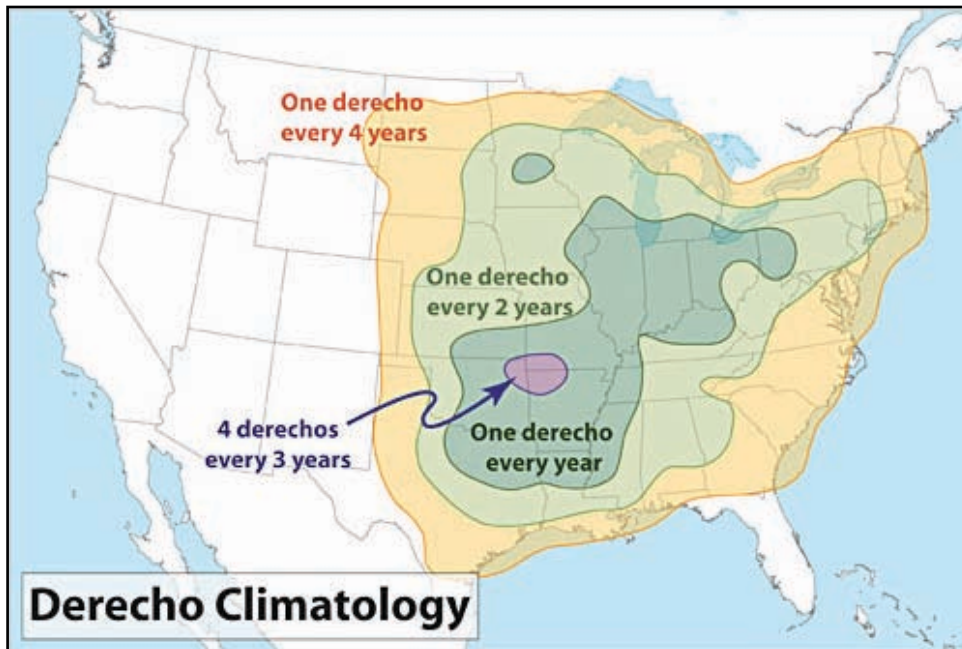


Figure 9.28: Derecho frequency in the continental US.

events can be associated with the same major cold front boundary because they require similar conditions to get started. However, tornado formation is more complicated. At the frontal boundary, warm, moist air rapidly rises as cooler, dry air descends; in the meantime, the pressure differences between the warm and cold air masses cause strong winds. Clouds with a visible horizontal rotation can appear, appearing to roll like waves crashing on the shore of a beach. This horizontal motion can tilt, lifting the rotating cloud vertically, and the rolling cloud will form a tornado. Most tornados will last a few seconds to several minutes. During that time, many tornado-prone areas will use tornado sirens to alert residents of the danger. A smaller tornado might generate flying debris that can cause injury or damage to buildings, while larger tornados can cause buildings and houses to be completely broken apart. Tornados are classified by their ranking on the Enhanced Fujita scale, or EF scale. These classifications are estimates of wind speeds based on the type of damage that is observed following the storm.

"Dixie Alley" is the nickname for an area, extending from Louisiana and Arkansas east to Georgia, which is known for its large number of strong tornados associated with flat topography and severe thunderstorms (Figure 9.29). The boundaries of Dixie Alley may vary in application, depending on whether the frequency, intensity, or number of events per location are used to determine the area's borders. In the Southeast it encompasses Mississippi, Alabama, Georgia, and parts of Tennessee, leading to more tornados in these states. From 1991 to 2010, for example, an annual average of 44, 43, 33, and 26 tornados occurred in Alabama, Mississippi, Georgia, and Tennessee, respectively. To the east and north of Dixie Alley, fewer tornado strikes occur, with an annual average of 31 in North Carolina, 27 in South Carolina, 21 in Kentucky, 18 in Virginia, and 2 in West Virginia. While Florida is not typically considered part of Dixie Alley, it is



Weather

waterspout • a spinning funnel-shaped cloud over a body of water.

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

Measuring Tornado Intensity

Tornado intensity is measured on the Fujita scale, or simply F-scale, based on the amount of damage that a tornado can cause. The scale ranges from F0 to F5. The scale was modified recently to more accurately reflect specific wind speeds; this newer scale is known as the "Enhanced Fujita scale" and is labeled EF0 to EF5.

EF Scale	Estimated Wind Speed (kph)	Estimated Wind Speed (mph)
EF0	104–137	65–85
EF1	138–177	86–110
EF2	178–217	111–135
EF3	218–266	136–165
EF4	267–322	166–200
EF5	> 322	> 200

also subject to numerous tornados thanks to a constant influx of warm, moist air; the state experiences an annual average of about 66 tornados. Florida is also commonly subject to **waterspouts**, which often form when a tornado's cyclic winds travel over water (*Figure 9.30*). Waterspouts can also form in association with **convection** beneath large cumulus clouds; these are the most common kind, with over 400 typically seen annually in Florida.

The Southeast does not have a specific tornado season, though they tend to occur more frequently in February to April. Among large recent tornado events was the "2008 Super Tuesday tornado outbreak" (February 5–6, 2008). In total 87 tornados were confirmed, many in Tennessee and Kentucky, and 5 of them rated EF4; 57 people were killed across four states, and damage was estimated at half a billion dollars. An even larger event—one of the largest ever recorded—was the "2011 Super Outbreak" (April 25–28, 2011). It involved 355 confirmed tornados, 11 of which were EF4 and 4 of which received the maximum rating, EF5. Across six states, 324 people died, and the event caused \$11 billion in damage. The outbreak most impacted Alabama and Mississippi, but also affected Arkansas, Georgia, Tennessee, and Virginia.

Although specific tornado paths are not predictable, the conditions that produce them are used to alert people so that they can seek shelter. The National Weather Service issues a *watch*, if the conditions are right for a type of storm event, or a *warning*, if the conditions are occurring or imminent for the storm event. The National Weather Service is part of NOAA, which maintains a US

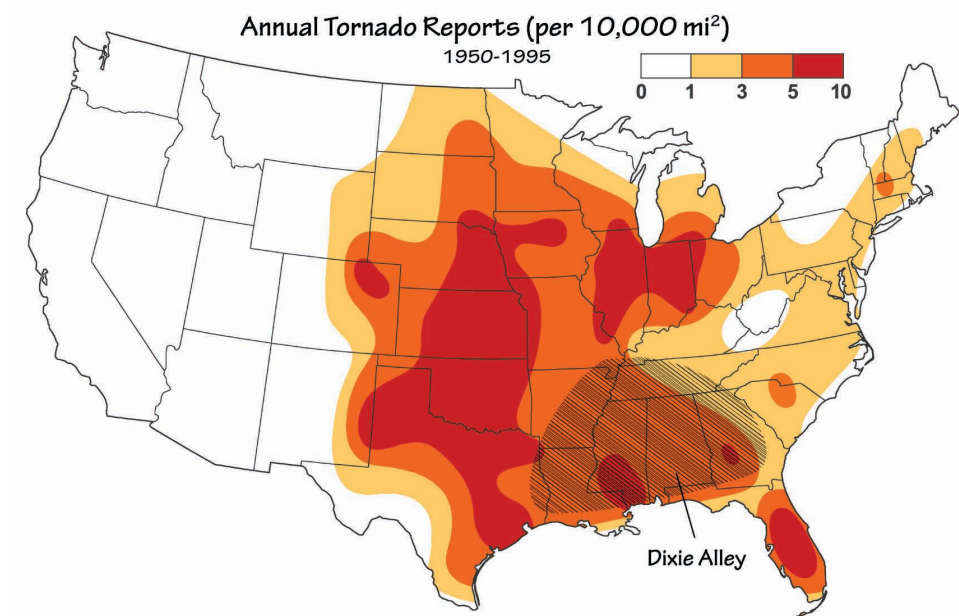


Figure 9.29: Annual tornado reports per 29,500 square kilometers (10,000 square miles) in the continental US, between 1950 and 1995. (See TFG website for full-color version.)



Figure 9.30: A tornadic waterspout east of downtown Miami, Florida.



Weather

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

tropical depression • an organized, rotating system of clouds and thunderstorms.

map of all current watches and warnings. Since atmospheric conditions can change very quickly, an important factor in preventing loss of human life is getting the public to act upon the severe weather alerts. One recent attempt to improve public response to warnings is through a tornado alert index that helps people evaluate the risk of a local tornado. The Tor:Con index used by the Weather Channel provides a number from 1 to 10 that represents the probability of a tornado occurring. Meteorologists evaluate the atmospheric conditions associated with a storm and assign a score. For example, a 4 on the Tor:Con index would indicate a 40%, or moderate, chance of a tornado forming in a particular area.

Hurricanes

Hurricanes occur when a warm, moist, low-pressure air mass forms over the Atlantic Ocean south and east of Florida. These storms gather strength as warm surface ocean water evaporates in the summer, yielding humid, low-pressure air that rises; the moisture condenses into water droplets that form clouds, releasing latent **heat**, and thereby providing energy for even greater evaporation of warm ocean water. This positive feedback cycle continues until the low-pressure center moves over land. These storms are considered **tropical depressions** when wind speeds are below 63 kilometers per hour (39 miles per hour). As the storm grows, it develops a more organized structure, with warm air rising in the center and somewhat discrete bands of rain being formed. It becomes known as a *tropical storm* when its wind speeds reach the 63–117 kilometers per hour (39–73 miles per hour) range, and it is called a hurricane once winds have reached 119 kilometers per hour (74 miles per hour). The western Atlantic, Caribbean, and Gulf of Mexico area is one of the world's most active for hurricanes, though they also occur in areas of the western Pacific, where they are known as typhoons, and in the South Pacific to Indian Ocean, where they are called cyclones.

In an average year, about a dozen hurricanes travel through the western Atlantic and sometimes the Gulf of Mexico. Of these, roughly two a year strike the Atlantic coast. About 40% of all hurricanes to strike the US hit Florida—114 hurricanes in total have hit the state since 1851, 37 of them major hurricanes (Category 3 or above). The peak month is September, followed by August and October. More rarely, hurricanes may hit the coast in June, July, or November. The 2005 hurricane season was the most active in recorded history, with a record number of 15 hurricanes, 7 of which strengthened into major hurricanes (*Figure 9.31*). The costliest hurricane to date was Katrina in August 2005, with almost 2000 lives lost and over \$100 billion in damage. The costliest hurricane in the Southeast was Andrew in 1992, with over \$45 billion in damage (*Figure 9.32*). Although the Category 5 hurricane caused only 65 fatalities, it obliterated thousands of homes and buildings across Miami and Homestead, Florida.

Once hurricanes reach land, they lose energy rapidly, though they typically continue to deliver substantial precipitation and somewhat high winds for hundreds of kilometers (miles) onshore. Hurricanes that make landfall along the Atlantic coast tend to track northward following the eastern seaboard, while those that track over the Florida Panhandle, Mississippi, and Alabama generally veer north to northeast, heading across Georgia, North and South Carolina, and Tennessee.



Measuring Hurricane Intensity

Hurricanes are ranked in the Saffir-Simpson scale from category 1 to 5, with 5 being the highest, based on wind speed. Category 5 hurricanes occur on average only about once every three years in the Atlantic and Gulf of Mexico.

Saffir-Simpson Hurricane Scale	Wind Speed (kph)	Wind Speed (mph)
Category 1	119–153	74–95
Category 2	154–177	96–110
Category 3	178–208	111–129
Category 4	209–251	130–156
Category 5	≥ 252	≥ 157

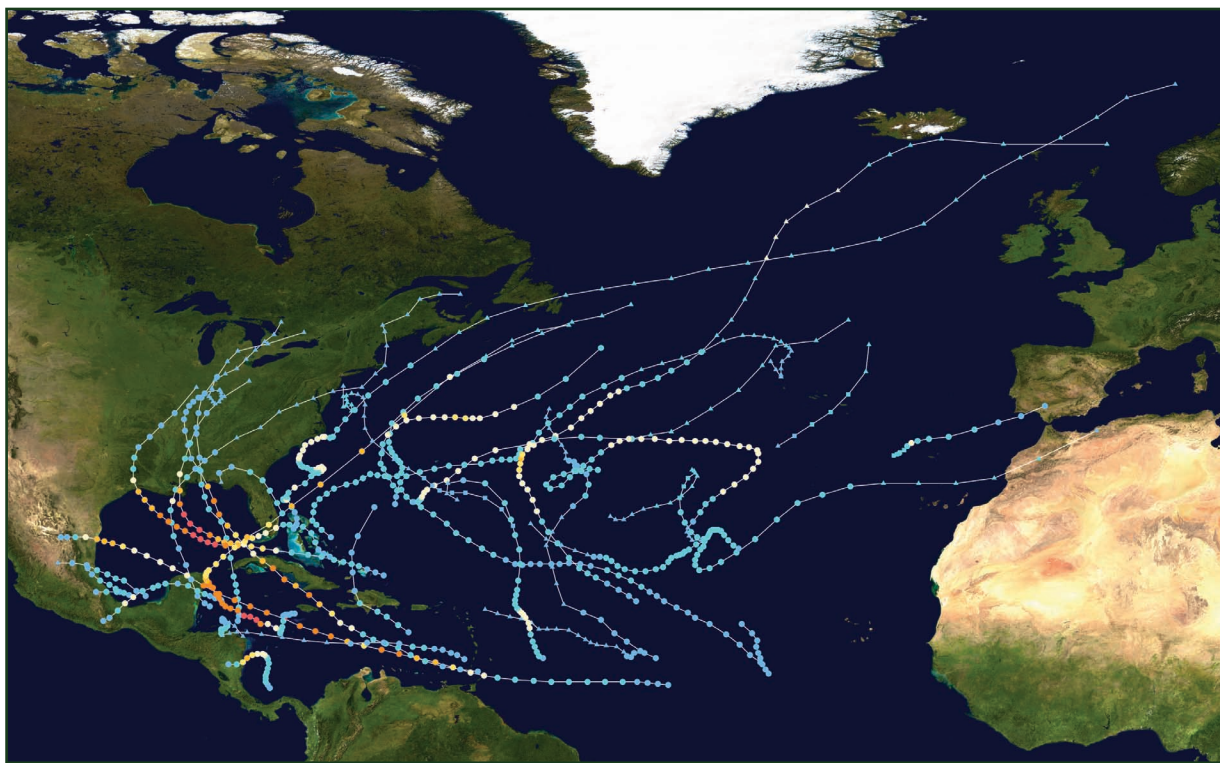


Figure 9.31: Tracks of all Atlantic hurricanes during the 2005 season. Warmer colors indicate higher maximum sustained wind speeds. (See TFG website for full-color version.)

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Earth Hazards

Weather

Major Hurricanes Affecting the Southeastern States

Date	Name and Landfall Location(s)	Category at Landfall	Deaths
August–September 1935	Labor Day Hurricane; FL	5	600
August 1969	Hurricane Camille; MS	5	259
August 1992	Hurricane Andrew; FL, LA	5	65
September 1919	Florida Keys Hurricane; FL	4	772
September 1926	Great Miami Hurricane; FL, AL, MS	4	539
September 1928	Okeechobee Hurricane; FL, SC	4	4079
October 1954	Hurricane Hazel; NC, SC	4	1191
August 1979	Hurricane Frederic; AL, MS	4	12
September 1989	Hurricane Hugo; SC	4	107
August 2004	Hurricane Charley; FL	4	35
June 1966	Hurricane Alma; FL	3	91
August–September 1996	Hurricane Fran; NC	3	27
September 2004	Hurricane Ivan; AL	3	124
July 2005	Hurricane Dennis; FL	3	89
August 2005	Hurricane Katrina; FL, LA	3	~2000

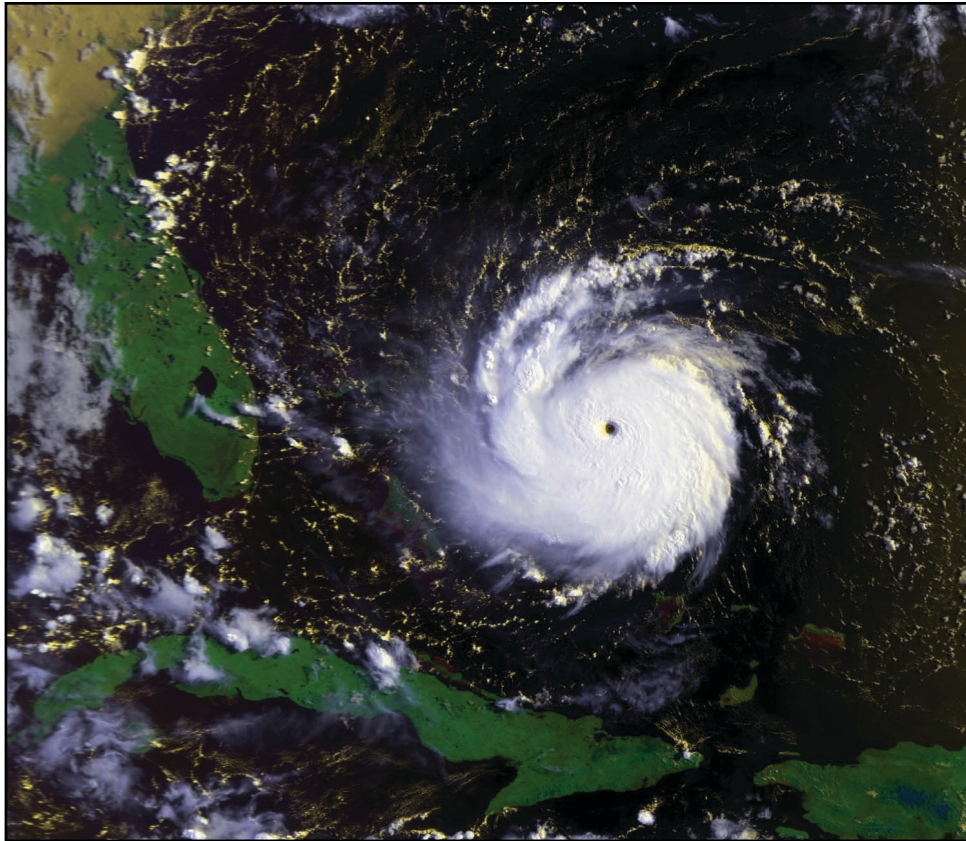


Figure 9.32: Satellite image of Hurricane Andrew as it approached the Florida coastline.

Drought

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

Extreme Temperature and Drought

Extreme temperatures can create dangerous conditions for people and may lead to property damage. **Heat waves** are periods of excessively hot weather that may also accompany high humidity. Temperatures of just 3°C (6°F) to 6°C (11°F) above normal are enough to reclassify a warm period as a heat wave. Under these conditions, the mechanism of sweating does little to cool people down because the humidity prevents sweat from evaporating and cooling off the skin. Heat waves have different impacts on rural and urban settings. In rural settings, agriculture and livestock can be greatly affected. Heat stress recommendations are issued to help farmers protect their animals, particularly pigs and poultry, which, unlike cattle, do not have sweat glands.

The impacts of heat waves on urban settings include a combination of the natural conditions of excessive heat and the social conditions of living in a densely populated space. Cities contain a considerable amount of pavement, which absorbs and gives off more heat than vegetation-covered land does. Air conditioning units that cool down the inside of buildings produce heat that is released outside. Pollution from cars and industry also serve to elevate the



Earth Hazards

Drought

heat island effect • a phenomenon in which cities experience higher temperatures than do surrounding rural communities.

outdoor temperatures in cities. This phenomenon, in which cities experience higher temperatures than surrounding rural communities do, is known as the **heat island effect**. Other social conditions can increase the hazards associated with heat waves in urban areas. People who are in poor health, live in apartment buildings with no air conditioning, or are unable to leave their houses are at greatest risk of death during heat waves. In July 2011, parts of the Southeast experienced the nation's hottest summer heat wave in 75 years, with temperatures reaching upward of 55°C (131°F) during a period of four months (*Figure 9.33*). Although Texas, Oklahoma, and Arkansas took the brunt of the extreme heat, the Carolinas, Georgia, and Mississippi also experienced severe temperatures. The heat wave contributed to severe drought, amplified heat-based health emergencies, and caused a heavy spike in electricity usage (related to increased air conditioning use) that generated a record-breaking demand on the power grid and led to increased energy prices.

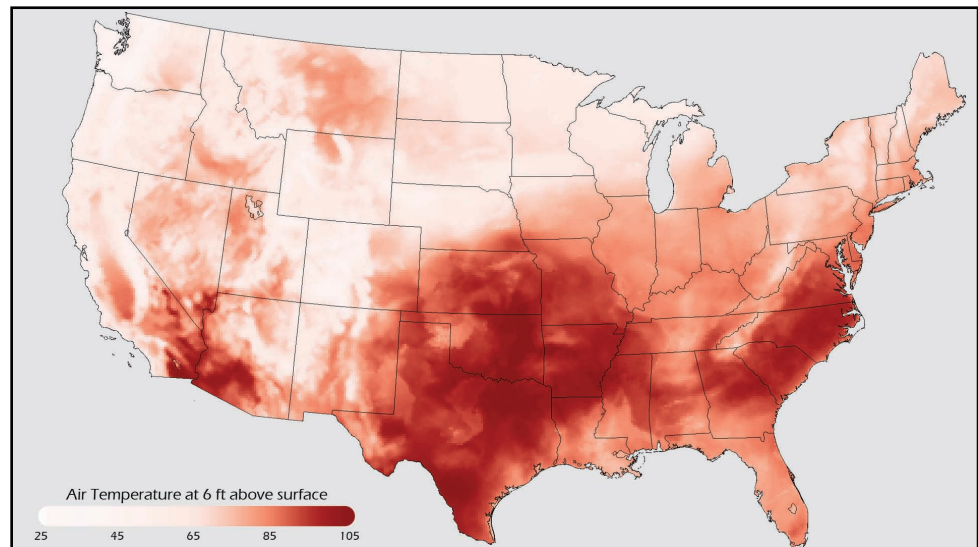


Figure 9.33: Air temperature in the continental US during July 2011. (See TFG website for full-color version.)

While high temperatures can be directly dangerous, a larger scale hazard arises when these temperatures are coupled with lack of precipitation in an extended drought period. Several significant droughts have occurred in the Southeastern states; the most severe droughts in Kentucky and Virginia occurred from 1930 to 1932, and intense drought struck much of the Southeast, especially Georgia and South Carolina, during the heat wave of 2011. In 2012, more than 25% of the state of Georgia was in a period of exceptional drought, the most intense level possible. Additionally, in October 2015, some parts of Mississippi experienced "extreme drought," the fourth of five drought levels recognized by NOAA's US Drought Monitor.



Climate Change

It is important to understand that most of the extreme climate change in Earth's history occurred before humans existed. That being said, the rapid release of carbon dioxide into the atmosphere from human activity is currently causing a **global warming** event. The seemingly slight increase in the average annual temperatures in the Southeast over the past 25 years has been accompanied by more frequent heat waves, shorter winters, and an increased likelihood of drought and wildfires.

Although wildfires can occur during any season, summer fires are the most common, since increased dryness contributes to fire risk. The Bugaboo Scrub Fire, which raged from April to June 2007, was the largest fire in the history of Florida and Georgia; it consumed 243,000 hectares (600,000 acres) of land and 1738 lives were lost (*Figure 9.34*). In 2014, one of the worst wildfire years on record, 2436 fires burned across Florida, destroying 41,115 hectares (101,599 acres) of land, while 1249 fires burned 63,289 hectares (156,391 acres) in Tennessee.

Water supply is also a critical issue for the Southeastern states. Large parts of the area obtain agricultural and drinking water from **aquifers**, underground layers of water-bearing **permeable** rock. The Floridan Aquifer, one of the world's most productive aquifers, underlies all of Florida as well as parts of South Carolina, Georgia, and Alabama. As drought has intensified and temperature has risen, the amount of water drawn from the aquifer (especially for agricultural irrigation) has increased, while the rate at which the aquifer refills has decreased. In addition, the aquifer is at risk from saltwater intrusion as sea level rises due to warming temperatures.



Figure 9.34: The Bugaboo Scrub Fire burns out of control near Lake City, Florida, in May 2007.

Climate Change

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

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

permeability • a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.



Climate Change

Increasing temperatures also allow certain pests, such as ticks and mosquitoes, to live longer, thereby increasing the risk of contracting the diseases they carry. In addition, invasive organisms that damage ecosystems, such as the hydrilla plant in Florida and along the Gulf Coast, have a better chance to multiply and outcompete native organisms because increased temperatures stress local ecosystems and create an environment more favorable to invasive species.

Another concern regarding hazards exacerbated by climate change in the Southeast is whether or not there has been or will be an increase in the number or severity of storms, such as hurricanes and tornados. According to NASA, the present data is inconclusive in terms of whether hurricanes are already more severe, but there is a greater than 66% chance that global warming will cause more intense hurricanes in the 21st century. Since climate is a measure of weather averaged over decades, it might take many years to determine that a change has occurred with respect to these types of storms. Scientists are certain that the conditions necessary to form such storms are becoming more favorable due to global warming.

The Union of Concerned Scientists has created an infographic that demonstrates the relative strength of the evidence that various hazards are increasing as a result of climate change (Figure 9.35).

See Chapter 8: Climate for more on the effects of climate change in the Southeast.

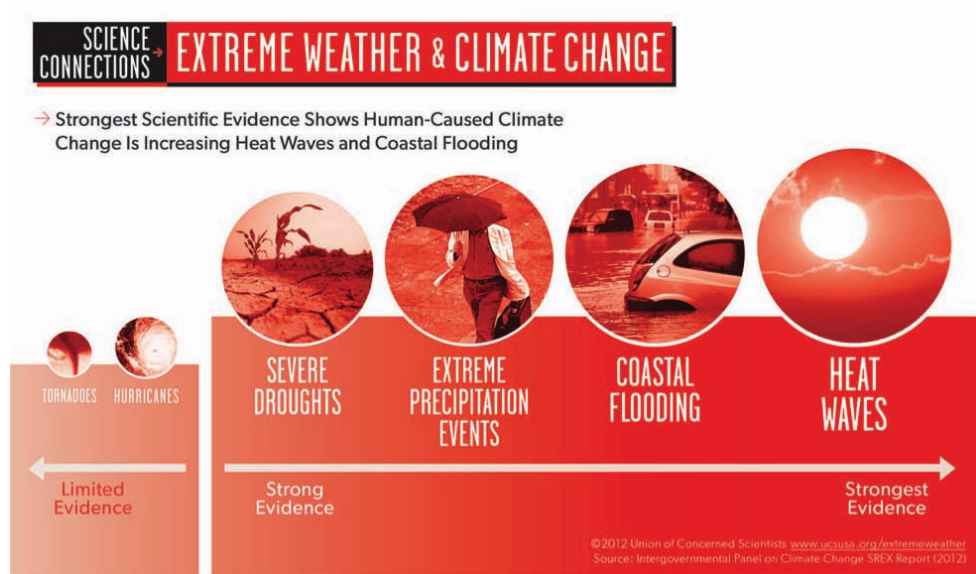


Figure 9.35: The strength of evidence supporting an increase in different types of extreme weather events caused by climate change.



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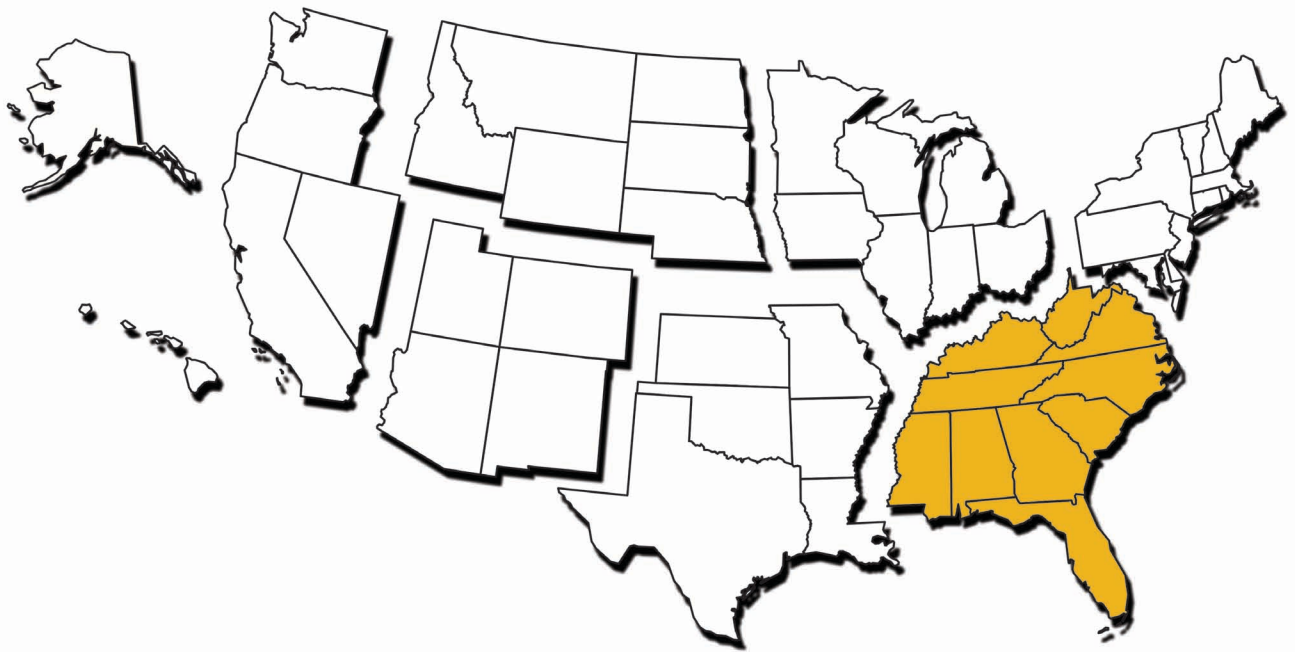
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