Natural 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 South Central 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 Coastal Plain. Modifications of the Mississippi River and its mouth, as well as the Gulf 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 South Central are at risk from large earthquakes due to occasional movement along large ancient faults, and from smaller earthquakes associated with injection of wastewater into the Earth that promotes movement along smaller faults.

Earthquakes

Earthquakes occur when a critical amount of stress is applied to the Earth’s crust. 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 10.1). The plane defined by the rupture is known as a fault, and the rock layers become offset along it.

Many earthquakes, including most of those that occur in the South Central US, arise along ancient, 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
first scale used to measure magnitude was the Richter scale, which measures the amplitude of a seismic wave at a defined distance from the earthquake. Unfortunately, the Richter scale proved incapable of accurately measuring large earthquakes, so the Moment Magnitude scale ($M_w$) was introduced in 1979 as an alternative. Both the Richter and Moment Magnitude 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 or higher). The 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 quake would have 100 times the amplitude and 1024 times the energy of a M7.0 earthquake. 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 earthquakes in the South Central were a cluster of four M7.5-M7.0 earthquakes that were centered around the New Madrid fault region in Missouri and Arkansas.
The magnitude of an earthquake, however, does not tell us how much damage is done by the seismic waves in a particular area. 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 10.2 shows the intensities felt in surrounding areas after the 1931 Earthquake in Valentine, Texas, which is the largest earthquake known to have occurred in the state.

Earthquakes have occurred in each of the South Central states (Figure 10.3), but the greatest hazard potential is in the area of the New Madrid seismic zone (NMSZ), 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. The bedrock that makes up most of the central US is colder, drier, and less fractured than rocks on the East or West Coast. As a result, the earthquakes here can release the same amount of energy as other earthquakes, but the shaking affects a much larger area because the seismic waves travel through denser, more solid bedrock.
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, and shook the Mississippi Valley and much of the eastern United States. The tremors destroyed buildings and warped the ground, causing landslides along the Mississippi River bluffs and ground **subsidence** brought on by **soil liquefaction** across the Mississippi River flood plain. 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 backwards for several days due to local **uplift** and waves flowing upstream. Hundreds of aftershocks followed for a period of a several years, and were felt regularly until 1817.

The next largest quake to have occurred along the NMSZ was a 6.6-magnitude quake that occurred on October 31, 1895. The quake, centered in Charleston, Missouri, damaged almost every building in the city. Even today, areas in the NMSZ continue to experience earthquake activity, which is closely monitored.
by seismologists. There are ancient, seismically inactive subsurface faults in many other parts of the country, and it is unclear why seismic activity remains so high along the faults in the NMSZ, which are now far from North America’s plate margins. Most of the dozens of annual earthquakes that occur in the NMSZ (Figure 10.4) are very small—too small to notice except with sensitive equipment. If a major earthquake were to occur there, it could be expected to produce landslides, fissures, soil liquefaction, and bridge and road failures. Interstate 55 in Arkansas could become impassable; flooding of farmland could contaminate rivers and streams with mud, sand and agricultural chemicals; and the failure of levees and riverbanks could make the Mississippi River and its tributaries difficult to navigate for many weeks.

Another area that presents modest seismic risk is the Nemaha Uplift in northern Oklahoma and eastern Kansas (Figure 10.5). The seismic activity around the Nemaha Uplift is associated with faulting known as the Humboldt fault zone, which, like the NMSZ, lies along a Precambrian basement and ancient rift system.

Recently, Oklahoma has experienced an unusual amount of earthquake activity, with numerous earthquakes of magnitude 3 or 4 and a few above magnitude 5 (Figure 10.6). Only 89 earthquakes occurred in the state between 1970 and 2009, but since then the incidence has increased dramatically, rising from 48 earthquakes in 2010 to 611 in 2014 alone. The seismic activity in these instances has been linked to the high-pressure injection of wastewater from oil and gas extraction operations into the ground. The pressure of the water increases the likelihood that a rupture might occur along an otherwise locked fault. Concerns exist that additional activity along offshoot faults from the Nemaha Uplift near Oklahoma City might be even more serious. Similar instances of induced seismic
activity have occurred elsewhere in the South Central, perhaps most famously with cases associated with injection wells near Dallas-Fort Worth. These wells have been used to dispose of wastewater from the extraction of natural gas in the Barnett Shale.

Networks of seismograph stations have improved geologists’ ability to detect and accurately locate earthquake hazards (Figure 10.7), and specific fault zones are being studied throughout the South Central. 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.
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 10.8). Landslides may be triggered by high rainfall, earthquakes, erosion, deforestation, groundwater pumping, or volcanic eruptions. They may occur rapidly, such as in some mud and debris flows, or they can be as slow as soil creep: slow land movement that usually does not cause loss of life, but can still destroy roads and buildings.

Landslides and slumps are common problems in parts of the South Central that have a wetter climate and/or the presence of steep slopes, such as west Texas, the Central Lowland, and the Interior Highlands, but they can also occur in areas with low relief (Figures 10.9 and 10.10). Heavy rain, snowmelt, groundwater percolation, and water level changes along coastlines, earthen

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**Landslides**

- **volcanism**: the eruption of molten rock onto the surface of the crust.
- **debris flow**: a dangerous mixture of water, mud, rocks, trees, and other debris that can move quickly down valleys.
- **creep**: the tendency of a material to move slowly or deform under the influence of pressure or stress.
- **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).
- **relief**: the change in elevation over a distance.
Earth Hazards

Earthquakes

Figure 10.6: Seismic activity in Oklahoma. Greatly increased seismic activity in 2013–2015 has been linked to injection wells. (See TFG website for full-color version.)

Figure 10.7: Seismic hazard map of the South Central US, based on data in 2014. (See TFG website for full-color version.)
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. Hazards occur from mudflows themselves, but also from backwater flooding, dam failure, and debris that rushes downstream and causes further erosion.

In northern Arkansas, there is a risk of potential landslides associated with earthquakes in the New Madrid seismic zone. Steep slopes in this area increase the likelihood that landslides will occur when the ground shakes or when water rapidly infiltrates the soil during an earthquake, though, as mentioned earlier, steep slopes are not always necessary for a landslide to occur. In low-lying areas of the Coastal Plain, 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.
Figure 10.9: A landslide on the steep walls of Palo Duro Canyon in West Texas.

Figure 10.10: Landslide incidence and risk in the South Central US.
(See TFG website for full-color version.)
Damage to life and property 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.

**Expansive Soils**

Soils that weather from *shale*, *volcanic ash*, or *bentonite* are rich in *clay*, which may contain *minerals* that can absorb water and swell up to 1.5 to 2 times their original volume. That amount of expansion can exert enough force to cause damage, such as cracked foundations, floors, and basement walls (*Figure 10.11*). An estimated nine billion dollars of damage to infrastructure built on expansive clays occurs each year in the United States. See Chapter 8: Soils for more information about Vertisols, soils rich in swelling clays.

![Figure 10.11: Expansive soils caused cracks to form in the wall of this house in Austin, Texas.](image)

Soil creep is a slow kind of landslide that occurs when certain types of clay in the soil on a hillside absorb water, expanding and causing the soil to swell. As the clay dries and contracts, the particles settle slightly in the downhill direction. This process can cause fences and telephone poles to lean downhill, while trees adjust by bending uphill (*Figures 10.12 and 10.13*).
Figure 10.13: Soil creep affects telephone poles and fence posts on a hillside in Toronto, Kansas.
While soils can swell by absorbing water, they will also shrink when they dry out, resulting in subsidence that damages landforms and infrastructure. Fissures may develop in the soil, allowing for the deep penetration of water when floods or runoff occurs. This produces a cycle of shrinkage and swelling that puts repeated stress on rock layers and human structures. While expansive soils can be found all over the US, every state in the South Central has bedrock units or soil layers that are possible sources, with Louisiana’s coastal plain and Oklahoma’s Cretaceous shales being the most susceptible (Figure 10.14).

Figure 10.14: Approximate distribution of expansive soils in the South Central 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.)
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.

**Karst, Sinkholes, and Salt Dissolution**

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. Much of the South Central is underlain by karst and carbonates (see Figure 10.17).

Central and southern Missouri, including the Ozark Mountains and their extensions into northern Arkansas and northeastern Oklahoma, are famous for caves and karst in Ordovician and Carboniferous limestone and dolomite. Missouri is home to over 6000 limestone caverns, many of which are prominent tourist attractions (Figure 10.16). In Missouri, karst is also associated with exceptionally large springs such as Big Spring, Greer Spring, and Maramec Spring (Figure 10.17). Other karst formations are found in the Arbuckle Mountains of south central Oklahoma and the Limestone Hills in southwestern Oklahoma. Soluble gypsum and salt deposits near the surface in western Oklahoma and the Texas panhandle can also cause karst and dissolution problems.

Because karst terrain is very porous and fractures easily, groundwater pollution can be a serious problem. Contaminants that might otherwise be filtered through the sedimentary rock are quickly transported into aquifers by runoff. The hazards of pollution are increased by rampant industrial, agricultural, and residential development over karst features. This is occurring rapidly in northwest Arkansas and in Missouri, where 59% of the state sits atop thick layers of carbonate rock (Figure 10.17).
Figure 10.15: Meramec Caverns, a 7.4-kilometer (4.6-mile) limestone cave system near Stanton, Missouri, is the most visited cave in the state. Meramec Caverns was introduced as a tourist attraction in 1935; advertisements for the location involved one of the earliest uses of the bumper sticker.

Figure 10.16: Maramec Spring, located in the east-central Ozarks, has an average daily discharge of 360 million liters (100 million gallons) of water. The spring’s opening is underwater, at the base of the dolomite overhang.
Figure 10.17: 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.)
See Chapter 4: Topography for a karst map of the South Central.
The Coastal Plain of eastern Texas and Louisiana is dotted with many Jurassic subsurface salt domes that can collapse if salt is removed. For example, the Bayou Corne sinkhole in Assumption Parish, Louisiana, is a site where an underground salt dome collapsed in 2012 (Figure 10.18). Before its collapse, the Bayou Corne sinkhole was preceded by months of seismic activity and the release of methane bubbles. It originally spanned one hectare (2.5 acres) but has since grown to over 10 hectares (26 acres). It is still growing, swallowing surrounding cypress swamp and endangering the nearby community, from which many of the residents have been evacuated. Scientists believe the sinkhole was created by the salt dome cavern being excavated too close to the massive salt deposit’s outer face, making it incapable of maintaining pressure. A similar event occurred in Daisetta, Texas, a town also located on the edge of a major salt dome. In May 2008, a 330-meter-wide (1080-foot-wide) sinkhole caused by partial collapse of the dome swallowed a parking lot, construction equipment, and a small stand of trees over the course of a single day before filling with water (Figure 10.19). These types of situations present a growing hazard that will be studied by geoscientists for years to come.

Salt karst can also be a hazard through its association with pathways for fluids, such as the flow of natural gas, which is sometimes stored in salt caverns. For example, in 2001, the Yaggy storage field—consisting of dozens of caverns in the Permian-age salt deposits near Hutchinson, Kansas—leaked 4 million cubic meters (143 million cubic feet) of natural gas, leading to multiple large-
scale explosions within and around the city. In this case, the leak was associated with drilling errors as well as with faults and fractures in rocks overlying the salt formation.

**Radon**

Radon is a naturally occurring radioactive, colorless, odorless gas. It is the leading cause of lung cancer in 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: low, medium, and high (Figure 10.20).

In the South Central US, the highest radon concentrations are generally associated with black, organic-rich Pennsylvanian shales in northeastern Kansas and the northwest corner of Missouri, and black Cretaceous shales in north-central Kansas. Radon risk in western Kansas is associated with Neogene sandstones containing volcanic ash layers. (Figure 10.21). Volcanic ash can be high in uranium that eventually decays to radon. Water moving through the ash into the surrounding sandy layers carried with it uranium-rich dissolved silica that precipitated between the grains of the sandstone.

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 crawlspace, and basement 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.
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 flood adjacent lowlands, leaving behind layers of settled sediment. Significant damage and sometimes loss of human life may 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.

In the South Central US, the greatest human impact from flooding is related to events along the banks of major rivers. Historically, there have been a number of record-setting floods along the Mississippi River (in 1927, 1937, 1945, and 1993), which runs along the eastern edge of the South Central. Many South Central floods have also involved major tributaries of the Mississippi, such as the Missouri River, which intersects the Mississippi near St. Louis, and the Kansas River, which intersects the Missouri near Kansas City. The Great Mississippi and Missouri Rivers Flood of 1993 (Figure 10.22) was preceded by a wet fall and a winter with heavy snowfall, followed by a series of precipitation events in roughly the same locations through the spring and summer of 1993. Many locations near St. Louis were flooded for over half a year. Dozens of individuals lost their lives and costs are estimated to have been in the $15–20 billion range. However, even with the massive damage sustained from this flooding event, the impact could have been even worse were it not for a series of levees and reservoirs built in response to a large flood of the Kansas River in 1951—an event called “one of the worst [disasters] this country has ever suffered from water,” by President Truman.

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. Flash floods can also occur in conjunction with a dam break or levee failure. A special case of flooding due to a failed levee occurred in fall 2005, when Hurricane Katrina forced water over and through the levee holding seawater back from New Orleans, part of which is built below sea level (see the “Storms” segment later in this chapter for more information). In this case, flooding came not from precipitation, but from a “storm surge,” where seawater was transported high onto shore through a combination of low atmospheric pressure and powerful winds (Figure 10.23).

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. 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.
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Floods

Figure 10.22: Confluence of the Mississippi and Missouri rivers, near St. Louis. A) 2002, during non-flooding. B) 1993, during the Great Mississippi and Missouri Rivers Flood.

Figure 10.23: This house in New Orleans was destroyed when it floated off its foundation during the 2005 flood.
Sea Level Rise, Coastal Erosion, and Subsidence

Coastal erosion has been occurring along Louisiana’s Gulf Coast since its formation as an alluvial plain deposit of the Mississippi River. It is a natural process in which currents and waves remove sediment in some areas and deposit it in others, but the natural accretion and replenishment processes have been disrupted by levees along the Mississippi River, as well as by dams along the river’s length. Simply put, the river carries about half the amount of sediment that it did when it built the Coastal Plain. Because the primary substrate (“bedrock”) is soft alluvium rather than rock, erosion rates tend to be higher than deposition rates (Figure 10.24). About 40% of US wetlands are in Louisiana, but about 80% of US wetlands-loss occurs there as well. The dramatic increase in Louisiana’s coastal erosion in recent decades is due to a number of different factors, including natural erosional processes and human activities such as dredging and development. This trend is expected to continue as sea level rises and storm frequency and severity increase. Barrier island and beach erosion is expected to occur in large bursts during storm events as a result of increased wave height and storm intensity.

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. Compaction of sediment, extraction of water and minerals from the soil, and

See Chapter 4: Topography to learn more about how the Mississippi Delta was formed.

Figure 10.24: The Mississippi Delta and its wetlands are not as extensive as they were before river and coastal management programs were enacted.
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. Since the 1930s, Louisiana has lost 4870 square kilometers (1880 square miles) of coastline, and it is predicted that an additional 4530 square kilometers (1750 square miles) could be lost by 2100, at least partially due to rising sea levels caused by glacial melting associated with climate change.

New Orleans, which is subsiding five centimeters (two inches) per decade, is of special concern. The city’s topography and that of the surrounding coastal zone reflects the negative effects of river levees and subsidence along faults. One study places significant blame for recent subsidence on the Michoud Fault, which trends beneath the eastern portion of New Orleans, where a portion of the city known as “Michoud” has an unusually high subsidence rate. New Orleans is the largest urban area in the US that has been affected by subsidence—over 35 square kilometers (13.5 square miles) of the city are now below sea level and must be kept dry by use of a series of levees and pumps. With sea level rise and the loss of nearby protective wetlands, the impacts of coastal storms, hurricanes, and associated storm surges may become increasingly devastating.

**Weather Hazards**

Weather is the measure of short-term atmospheric conditions such as temperature, wind speed, and humidity. The South Central is among the most active locations on Earth for two very different kinds of high-energy atmospheric events: tornados and hurricanes. It also experiences a variety of other weather hazards, including high temperatures and drought.

**Storms, Tornadoes, and Derechos**

Rainstorms occur where colder air from higher latitudes abruptly meets warmer air. This often happens in the mid-latitudes (particularly in the South Central 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 Great Plains, allow winds to move unimpeded by topography, and are often subject to severe thunderstorms.

While severe thunderstorms are common in some parts of the South Central, 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 (kph) (58 miles per hour [mph]) and can often approach 160 kph (100 mph). 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 Arkansas, eastern Oklahoma, and southern Missouri (Figure 10.25), but they do occur with decreasing frequency through most of the remaining parts of the South Central US.

The differences between tornados 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

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**Derecho Climatology**

*Figure 10.25: Derecho frequency in the continental US.*

(See TFG website for full-color version.)
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.

**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.

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<td>86–110</td>
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<td>178–217</td>
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“Tornado Alley” is the nickname for an area, extending from Texas to Minnesota, that experiences a high number of exceptionally strong tornados due to its flatter topography and high incidence of severe thunderstorms. Most of the South Central resides within Tornado Alley, leading to more tornados in this part of the United States than in any other (Figure 10.26). From 1991 to 2010, for example, an annual average of 115, 62, and 96 tornados occurred in Texas, Oklahoma, and Kansas, respectively. To the east of Tornado Alley, far fewer tornado strikes occur, with an annual average of 37, 39, and 45 striking Louisiana, Arkansas,
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Weather

and Missouri, respectively. The boundaries of Tornado Alley vary in application, depending on whether the frequency, intensity, or number of events per location are used to determine the area’s borders. Some people apply the name “Dixie Alley” to the adjacent tornado-prone area from Louisiana and Arkansas east to Florida.

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 the National Oceanographic and Atmospheric Administration, which maintains a US map of all current watches and warnings. Since the 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 kph (39 mph). 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 kph (39–73 mph) range, and it is called a hurricane once winds have reached 119 kph (74 mph). 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.

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.

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

In an average year, about a dozen hurricanes travel through the western Atlantic and sometimes the Gulf of Mexico. Of these, roughly one a year hits the Texas and/or Louisiana coast, though these occurrences vary considerably. 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 (category 3 or greater) hurricanes (Figure 10.27). Two of these—Katrina and Rita—were category 5 hurricanes that did
substantial damage to the Gulf Coast. Katrina (Figure 10.28) destroyed large parts of New Orleans and other areas along eastern Louisiana, while Rita did substantial damage in southwest Louisiana and went ashore at Sabine Pass, Texas. More recently, Category 4 Ike (2008) caused damage along the Louisiana coast and made landfall at Galveston, Texas.

Figure 10.27: Tracks of all Atlantic hurricanes during the 2005 season. Warmer colors indicate higher maximum sustained wind speeds. (See TFG website for full-color version.)

Figure 10.28: Satellite image of Hurricane Katrina as it approached the Louisiana coastline.
Once hurricanes reach land, they lose energy rapidly, though they typically continue to deliver substantial precipitation and somewhat high winds for hundreds of miles onshore. Hurricane tracks over eastern Texas and Louisiana generally veer north to northeast, heading across eastern Texas and Louisiana to eastern Oklahoma, Arkansas, and southeast Missouri.

**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 outdoor temperatures in cities. This phenomenon, in which cities experience higher temperatures than surrounding rural communities, 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 2011, the South Central experienced the nation’s hottest summer heat wave in 75 years, with temperatures reaching upwards of 55°C (131°F) during a period of four months (Figure 10.29). Texas, Oklahoma, and Arkansas took the brunt of the extreme heat, which 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.

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. Many significant droughts have occurred in the South Central states. Most famously, high temperature and drought in the 1930s, combined with deep plowing that removed moisture-trapping grasses, led to the Dust Bowl—dust storms that carried vast clouds of black dust across the Midwest and eastern US, greatly damaging both the ecology and agriculture across that portion of the country (Figure 10.30). The Dust Bowl, which was most intense in the panhandles of Texas and Oklahoma and also affected adjoining parts of Kansas, New Mexico, and Colorado, displaced 3.5 million people.

Texas experienced a seven-year record drought in the 1950s, and the lowest average statewide rainfall record was set in Texas as recently as 2011. That year, nearly the entire state was categorized as experiencing “exceptional drought,” the
Figure 10.29: Number of days with temperatures reaching above 100°F during the year 2011. (See TFG website for full-color version.)

Figure 10.30: A dust storm approaching the town of Stratford, Texas during the Dust Bowl in 1935.
highest of the five drought levels recognized by NOAA’s US Drought Monitor. Today, much of the South Central is still experiencing moderate to extreme drought, with exceptional drought still occurring in some areas of Texas and Oklahoma (Figure 10.31).

**Figure 10.31: Drought severity in the South Central, as of March 2015.**

**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 warmest overall average state summer temperatures in the US are generally found in the South Central (primarily in Oklahoma, Texas, Louisiana, and Arkansas), with the warmest years averaging 28 to 30°C (83 to 86°F) and occasional weeks with maximum temperatures above 37.8°C (100°F). For the last 25 years, these temperature averages have been steadily rising. This seemingly slight increase has been accompanied by more frequent heat waves, shorter winters, and an increased likelihood of drought and wildfires.

The South Central is currently experiencing significant drought throughout, with the worst effects occurring in Texas and Oklahoma (see Figure 10.31). Increased dryness contributes to fire risk—in March 2015, the area northeast
of Woodward, Oklahoma experienced a wildfire that consumed more than 9600 hectares (23,000 acres) of land and forced over 125 people to evacuate from their homes. During the major drought and heat wave of 2011, more than 31,000 separate wildfires raged through central Texas, burning a cumulative 1,559,446 hectares (3,853,475 acres) of land and destroying almost 6000 structures.

Water supply is also a critical issue for the South Central states. Much of the area obtains its agricultural and drinking water from aquifers, underground layers of water-bearing permeable rock. The Ogallalla aquifer, part of the High Plains aquifer system, supplies vast quantities of groundwater to Texas, Oklahoma, Kansas, and Nebraska. As drought intensifies and temperature rises, the amount of water drawn from the aquifer (especially for agricultural irrigation) has increased, while the rate at which the aquifer refills has decreased. The aquifer’s average water level has dropped by about 4 meters (13 feet) since 1950, and in some areas of heavy use, the decrease is as high as 76 meters (250 feet) (Figure 10.32). However, the aquifer only replenishes at a rate no greater than 150 millimeters (6 inches) per year. Some estimates indicate that at its current rate of use, the entire Ogallalla aquifer could be depleted by as early as 2028, threatening human lives, our food supply, and the entire Great Plains ecosystem.

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 Louisiana, 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 South Central 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 10.33).
Figure 10.32: Water level change in the Ogallala aquifer between 1950 and 2005. (See TFG website for full-color version.)
Figure 10.33: The strength of evidence supporting an increase in different types of extreme weather events caused by climate change.
Resources

General Resources


NASA Earth Observatory Natural Hazards map. (Monthly images of Earth hazards occurring globally.) [http://earthobservatory.nasa.gov/NaturalHazards/](http://earthobservatory.nasa.gov/NaturalHazards/).

**General Resources for Specific Areas of the South Central US**


**Hurricanes**


**Coastal Hazards and Processes**


Earth Hazards

Resources


Floods


Tornados


Expansive Soils


Landslides


Earthquakes


Earth Hazards


Radon


Sinkholes


Earth Hazards Teaching Resources


The Teacher-Friendly Guide™
to the Earth Science of the South Central US

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

Paleontological Research Institution
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