Weather & Climate

Storm cloud over a Kansas wheat field. *Photo courtesy of Barry Rauqust.*

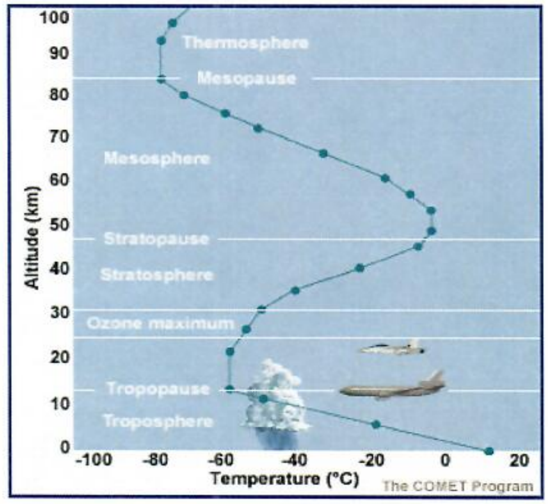
Chapter Goals

- Be familiar with the main processes driving weather and climate
- Be familiar with cloud formations and the weather and climate they can predict or represent
- Discuss what processes affect the temperature
- Describe Kansas climate and factors affecting rainfall
- Describe a typical year of weather in Kansas

A. Introduction

1. Air

The composition of earth's lower atmosphere is:
78% Nitrogen
21% Oxygen
0.9% Argon
0.03% Carbon dioxide



Oxygen was almost completely absent from the atmosphere during earth's first two billion years. As life evolved, certain species became able to utilize carbon dioxide in metabolic pathways that releases oxygen as a byproduct. Photosynthesis is such a process. When oxygen grew to 1% of the earth's atmosphere, about 700 million years ago, cells became able to use oxygen as part of their metabolic processes – aerobic cellular respiration. About 400 million years ago oxygen reached 10%, high enough to support an ozone layer in the stratosphere that would protect the earth's surface from lethal levels of ultraviolet radiation. With the ultraviolet shield in place, life on dry land became commonplace. As plant life spread, oxygen levels rose still further. Finally, by 300 million years ago, creatures with lungs requiring oxygen concentrations similar to those found today (21 %) appeared. Without the plants leading the way, the atmosphere would not be able to support animal (including human) life.

2. Temperature and Humidity

Temperature is most easily defined as how hot a substance (such as air) feels. At the atomic level, air temperature goes up as the kinetic energy of the air molecules (mostly nitrogen and oxygen) increase as they vibrate, spin, and move around randomly. At absolute zero (0 Kelvin, or -273 Celsius, or -454 Fahrenheit) the molecules would be motionless.

Humidity is the amount of water vapor in the air. Water vapor is the invisible gaseous form of water. It's what a glass of water turns into if you leave it sitting out for a few days and let it evaporate (literally, "become vapor"). The amount of water vapor found in air at any point in time depends upon the temperature of the air. Warmer air holds more water vapor than cold air. Warm temperatures keep water molecules moving thus inhibiting them from sticking to other water molecules and becoming heavy, or condensing. When water molecules slow their movement because of cooling

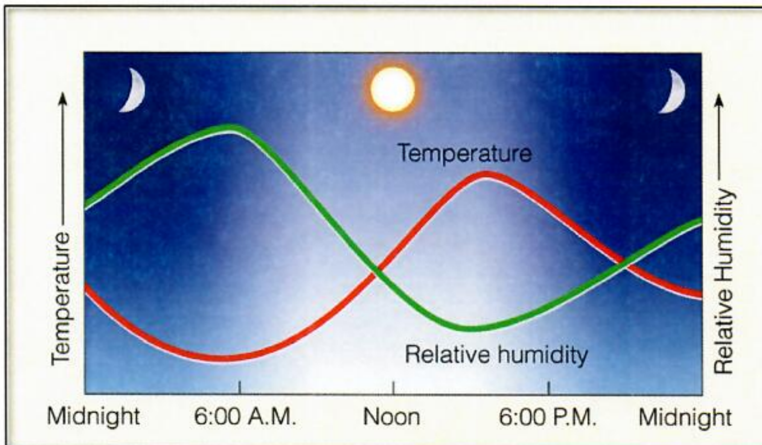
temperatures, they will begin to stick to each other, condense, and form rain that falls from the sky.

When the air temperature warms it will hold more of the fast-moving water molecules. The temperature at which the air is exactly saturated is called the **dew point**. The name comes from the fact that often at night the temperature at the ground will drop to the dew point, and any additional cooling causes water to condense as dew (liquid) on the ground and on vegetation. If it's cold enough for ice to form, the corresponding temperature is called the frost point.

Relative humidity is the actual humidity of the air divided by the potential humidity the air would have if it were saturated. So when the temperature equals the dew point, the relative humidity equals 100%.

3. A Typical Day

The processes that drive weather and climate may be found in one day's worth of observations of temperature and humidity. On a typical day, the temperature is lowest right before sunrise. The temperature then rises rapidly, reaching a maximum in mid-afternoon. The temperature falls rapidly around sunset before falling slowly the rest of the night.



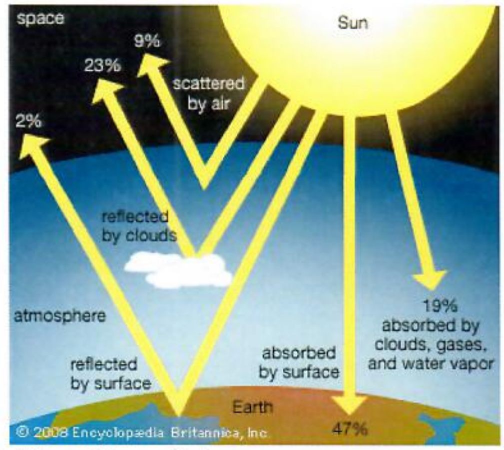
Temperature and humidity are closely related and fluctuate throughout a 24 hour day. As temperature increases from morning to evening, the humidity decreases. As the temperature decreases overnight the humidity increases. *Graphic courtesy of www.geogrify.com.*

The dew point never exceeds the temperature. Indeed, the relative humidity almost never gets more than a few tenths of a percent above 100%, depending on how fast the extra water vapor can condense into liquid form. Typically, the highest humidity occurs in the morning. During midday, the dew point drops, reaching its lowest point by mid-afternoon. A rapid rise in dew point takes place around nightfall, with the moisture in the air fairly steady through most of the night.

4. Solar energy

Solar energy includes the direct energy from the sun and a number of indirect forms of energy produced by the direct input of the sun. Indirect forms of solar energy include wind, falling and flowing water (hydropower), and biomass (solar energy converted to

chemical energy stored in the chemical bonds of organic compounds in trees and other plants).



Of the incoming solar radiation that hits our atmosphere, 34% is reflected by clouds and dust. About 47% of the energy is used to heat the atmosphere and earth's surface. About 19% of the sun's energy is absorbed by clouds and water vapor. Only 0.023% of the energy that hits the earth is used to power photosynthesis – the process that fuels all of life on earth.

Only a narrow spectrum of the sun's radiation is visible. We call that energy **visible light**. When all of the wavelengths of visible light are together, we see light as white in color. However, if we were to separate the wavelengths from each other, we would see that different-sized wavelengths have different colors. The shorter wavelengths are purple and blue and the longer wavelengths are orange and red. You can see all of the wavelengths of visible light clearly in a rainbow!

Absorbed vs. Reflected Light. When a surface absorbs all of the wavelengths of visible light then none of the wavelengths of the light are reflected. A surface that does not reflect any visible light appears black in color to us. A surface that reflects all of the wavelengths of visible light appears white to us. Guess which surface is warmer, black or white?

When a surface has a specific color that means it is reflecting the wavelengths of that color back to your eyes. For example, green plants reflect the green wavelengths of light. Red flowers actually reflect red wavelengths. Plants utilize the red and blue wavelengths of light to achieve photosynthesis and you can purchase special "grow lights" that provide those wavelengths. You can starve a plant by placing it under just green wavelengths of visible light.

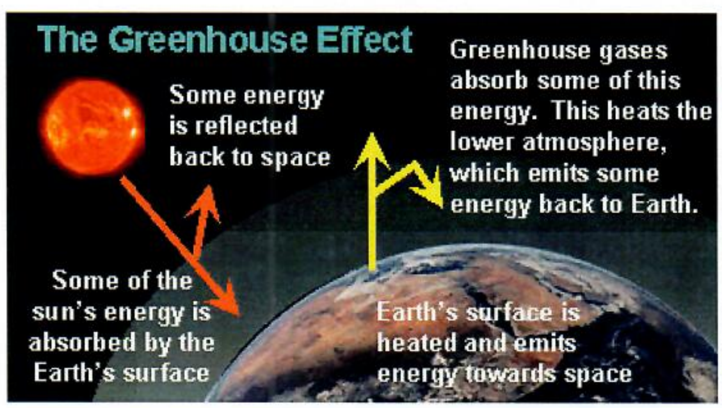
5. Conduction, the Greenhouse Effect, and Climate Change

Conduction is the name for how the air heats up after the ground heats up; air comes in contact with the ground and heats up, and winds carry the hot air away from the ground. If the ground is colder than the air, as often happens at night, the ground would gain heat from the air. Since cold air sinks, the air that cools by contact with the cold ground stays near the surface. If the land is fairly flat a shallow layer of the cold air, known as nocturnal inversion, will form. That is why the air is usually windy and gusty during the day, but often becomes calm near the ground at night. Conduction also helps distribute the heat downward through the soil into the subsoil.

The process of evaporation and condensation also affect the temperature. You know that evaporation makes things cooler because when you step out of a tub or shower you feel cold until you dry off. Water pulls heat from your body as it evaporates, using that heat energy to break its bonds from other neighboring water molecules. That's the reason why sweating actually cools your body. Animals that don't have sweat glands (i.e. dogs) have to pant to eliminate excess heat. Organisms that don't have a nervous system will not feel that cooling sensation. For example, plants may be cooled as water evaporates from their surface, but they don't feel it!

You might expect that since the sun's energy facilitates the evaporation of water from organisms and surfaces that the amount of water vapor in the air (dew point) ought to rise during the day and fall at night. But water vapor is redistributed upward by winds and turbulence too. As a general rule, the higher you go in the atmosphere, the lower the water vapor mixing ratio, so vertical mixing tends to moisten the air aloft and dry the air near the ground. So, the dew point is usually lowest during mid-afternoon when mixing is strongest, and the dew point is usually highest just after sunrise when the dew has evaporated but the turbulence really has not had a chance to get going yet.

Greenhouse Effect: Gases in the atmosphere, for example CO_2, H_2O, O_3, CH_3, and NO_3 help to trap the sun's energy next to the earth. The sun's ultraviolet energy (short wavelengths) can pass through these gases and hit the earth. The energy is then radiated back from the surface as infrared radiation (longer wavelengths) and this energy can't pass as easily through the atmosphere and is trapped. The thicker the layer of atmospheric gases, the more infrared radiation gets trapped and warms the atmosphere. This action – similar to how a greenhouse traps heat is termed the Greenhouse Effect. The



The greenhouse effect manages temperature on earth. It is the process of temperature control that allows our planet to support life. *Image courtesy of NOAA.*

Greenhouse Effect is just one part of Climate Change.
Climate change: Our earth is warming. Earth's average temperature has risen by 1.4°F over the past century, and is projected to rise another 2 to 11.5°F over the next hundred years. Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather.
The evidence is clear. Rising global temperatures have been accompanied by changes in weather and climate. Many places have seen changes in rainfall, resulting in more floods, droughts, or intense rain, as well as more frequent and severe heat waves. The planet's oceans and glaciers have also experienced some big changes - oceans are warming and becoming more acidic, ice caps are melting, and sea levels are rising. As these and other changes become more pronounced in the coming decades, they will likely present challenges to our society and our environment.

Humans are largely responsible for recent climate change.

Over the past century, human activities have released large amounts of carbon dioxide and other greenhouse gases into the atmosphere. The majority of greenhouse gases come from burning fossil fuels to produce energy, although deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere.

Greenhouse gases act like a blanket around earth, trapping energy in the atmosphere and causing it to warm. This phenomenon is called the greenhouse effect and is natural and necessary to support life on earth. However, the buildup of greenhouse gases can change earth's climate and result in dangerous effects to human health and welfare and to ecosystems.

Some changes to the climate are unavoidable. Carbon dioxide can stay in the atmosphere for nearly a century, so earth will continue to warm in the coming decades. The warmer it gets, the greater the risk for more severe changes to the climate and earth's system. Although it's difficult to predict the exact impacts of climate change, what's clear is that the climate we are accustomed to is no longer a reliable guide for what to expect in the future.

We can reduce the risks we will face from climate change. By making choices that reduce greenhouse gas pollution, and preparing for the changes that are already underway, we can reduce risks from climate change. Our decisions today will shape the world our children and grandchildren will live in.

6. Seasons

The daily rotation of the earth on its axis (every 24 hrs.) brings parts of the earth into sun and parts into shadow, with the resulting differences between day and night temperatures. Similarly, it takes the earth 365 days to complete one orbit around the sun involves changes in solar radiation that cause the seasons.

The earth's tilt towards and away from the Sun creates seasons. Image courtesy of NOAA

A common misconception is that summer is the warmest season because the earth is closest to the sun at that time. Not true; the earth's orbit is so nearly circular that this effect has little direct impact, and in fact it helps to moderate the Northern Hemisphere winter since the earth is closest to the sun in January! Instead, the seasons are caused by the tilt of the earth on its axis (23.5°). In January, the Southern Hemisphere is pointed a bit toward the sun, so it gets most of the solar radiation that hits the earth. In July, the Northern Hemisphere is pointed a bit towards the sun, so it gets more than its share of the solar radiation. In the tropics, about the same amount of solar radiation comes in year round, so temperatures do not change much throughout the year.

The same principles explain why there is less sunlight in winter than summer, and there is less sunlight in mid-afternoon that noontime. Sunlight from a sun that is not directly overhead has to pass through more of the atmosphere, and when it reaches the ground the sunbeams are spread out over a larger surface area. The shorter days help make winter cooler too.

B. Winds & Forces

1. Air Pressure and Pressure Gradients

Air pressure is the weight that air exerts on the earth. The wind blows because of differences in air pressure from one location to another. Wind blows from areas of **high pressure (H)** toward areas of **low pressure (L)**. If the high pressure area is very close to the low pressure area, or if the pressure difference is very great, the wind can blow very fast.

Imagine a group of acrobats at the circus. One climbs up and stands on another's shoulders. The weight of the acrobat on top puts more pressure on the one below. Then another acrobat climbs up and stands on the second acrobat's shoulders. Now there's even more pressure on the acrobat on the bottom because he is under the weight of the two acrobats above him. It's the same with air. Yes, air has weight, and probably more than you think. In fact, the weight of the air on your desk at school weighs about 11,000 pounds. That's about the same weight as a school bus! Since air pressure pushes in all directions, the air pressure pushing up from under your desk balances out the air pushing down on it, so the desk doesn't collapse under the weight. Just like an acrobat with two people stacked on his shoulders would want to move to where there wasn't so much pressure on him, air moves from areas where the pressure is higher to where it is lower.

What causes air pressure?

Air pressure depends on the density of the air, or how close together its molecules are. You know that a hard rubber ball is more dense than a Styrofoam ball and that ice cream is more dense than whipped cream. Air lower in the atmosphere is more dense than air above, so air pressure down low is greater than air pressure higher up. (Remember those acrobats; there's a lot more pressure on the one on bottom than on the one on top.) Temperature also makes changes in air pressure. In cold air, the molecules are more closely packed together than in warm air, so cold air is more dense than warm air.

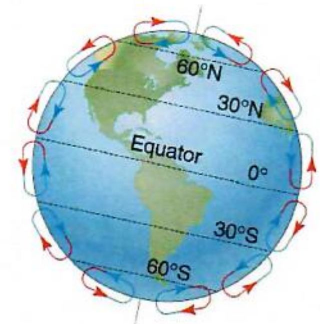
rising and Sinking Air

Since warm air is less dense and creates less air pressure, it will rise; cold air is denser and creates greater air pressure, and so it will sink. When warm air rises, cooler air will often move in to replace it, so wind often moves from areas where it's colder to areas where it's warmer. The greater the difference between the high and low pressure or the shorter the distance between the high and low pressure areas, the faster the wind will blow. Wind also blows faster if there's nothing in its way, so winds are usually stronger over oceans or flat ground (prairie!). Meteorologists can forecast the speed and direction of wind by measuring air pressure with a ***barometer.***

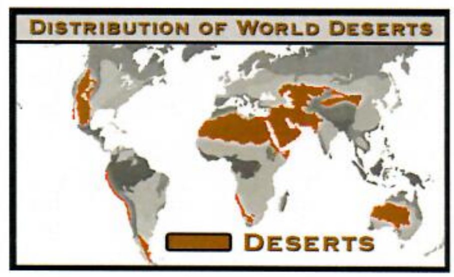
Wind Direction

Although wind blows from areas of high pressure to areas of low pressure, it doesn't blow in a straight line. That's because the earth is rotating. In the northern hemisphere, the spin of the earth causes winds to curve to the right (to the left in the southern hemisphere). This is called the ***coriolis effect***. So in the northern hemisphere, winds blow clockwise around an area of high pressure and counter-clockwise around low pressure.

2. Global Winds



In the equatorial tropics, deep and strong thunderstorms are common. Air ascends within these thunderstorms, exits their tops ten to fifteen miles up, and spreads out horizontally. The air ultimately descends gradually back toward the surface in the subtropics (30° north and south of the equator) forming the vast deserts of the earth such as the Sahara and the Arabian Peninsula. On average, then, equatorial regions are warm and moist, while subtropical regions are warm and dry. This pattern is altered by the alternating presence of continents and oceans, and by the march of seasons. Thus vast amounts of thunderstorms take place in India in the summertime but not wintertime, part of a phenomenon known as the monsoon. A weak version of a monsoon takes place over northern Mexico, Arizona, New Mexico, and extreme West Texas in summertime as the land heats up and moist air feeds in from the south.



In mid latitudes, the warm tropical and subtropical air meets the cooler air from temperate and polar regions. While the air masses do not exactly "clash," the large variations in temperature imply large variations in density and pressure, and the strong pressure gradients imply strong winds. The strongest winds are found about ten miles above the ground in a band of wind that circles the globe from west to east called the jet stream. The strong winds, and the temperature gradients associated with them, are unstable and break down into massive northward and southward excursions of the jet stream that can extend halfway between the pole and equator. At the ground, the instability takes the form of the traveling high and low pressure centers and cold and warm fronts so common during the fall, winter and spring. During the summer in the Northern Hemisphere, the jet stream moves north and cold fronts rarely reach Texas.

C. Clouds, Precipitation & Severe Weather

1. Clouds

Cumulonimbus cloud in a Kansas thunderstorm. *Photo courtesy of Barry Raugust.*

Clouds are composed of tiny drops of liquid water or tiny ice crystals. Each individual cloud droplet is so small that you could fit about 200,000 of them on one fingernail. Clouds are given Latin names according to their altitude and structure. Mid-level clouds (about 3-7 miles up) carry the prefix alto- (from *altus*, high) while higher clouds are prefixed by cirro- (from *cirrus*, a

lock of hair, referring to their typically wispy appearance). The two basic structure categories are *stratus* (meaning stretched out), a broad flat cloud typically covering most or all of the sky, and *cumulus* (meaning heap), an upright, lumpy cloud with a flat base. Stratus clouds form when large areas of the atmosphere are lifted uniformly, while cumulus clouds form from individual buoyant updrafts. A final cloud descriptor, *nimbus*, lacks the imagination of the others; in Latin, it literally means a dark rain cloud.

Clouds form when ascending air cools so much that the air becomes saturated and further ascent causes some of the water vapor to condense into liquid water or ice particles, depending on the temperature and the type of particles already present. Fog is like a cloud touching the ground except the cooling of the air to form fog takes place not through lifting, but by air coming in contact with the cold ground.

2. Rain and Snow

Cloud droplets are so small that they basically float in the air. Raindrops, by comparison, are a million times heavier. So, how does the atmosphere turn clouds into rain? There are two main mechanisms. First, if the air is warm enough and there is enough water vapor being converted into cloud droplets, the droplets will grow in size as they run into each other and stick together (technically, collide and coalesce). Once a few big droplets get going, they start slowly falling, which allows them to run into more cloud droplets, which lets them get even bigger, which allows them to fall faster.

The second mechanism involves two facts. One is that there are very few particles floating around in the atmosphere that will allow ice to form on them at temperatures only slightly below freezing. The second is that water vapor will condense onto ice more readily than it will condense onto liquid water. Thus, once a few ice particles form, they rapidly extract water vapor from the air. Meanwhile, water starts evaporating from the remaining liquid water droplets to make up the difference. Eventually, you have a few large snowflakes where before you had lots of tiny water droplets. The snow falls toward the ground, melts as its temperature rises above freezing, and reaches the ground as rain. This mechanism can only work if the cloud extends high enough into the atmosphere that its top is well below freezing.

3. Tornadoes

Tornado in Kansas, May 22, 2008. *Photo courtesy of NOAA.*

Tornadoes are perhaps the most dramatic form of severe weather. Kansas is located at the northern end of "Tornado Alley," which also extends through Oklahoma and Texas and is where tornadoes are most common in the world. Tornadoes are most common in

the springtime, with a secondary peak in the fall.
Tornadoes are a product of instability and wind shear. Convective instability refers to a situation in which the water vapor condensing into liquid or ice droplets in an ascending column of air releases enough latent heat to keep the column warmer than its surroundings and keep the air ascending. In spring and fall, moist low-level air from the Gulf of Mexico often flows northward beneath still-cool air aloft, creating a situation of instability. In the summertime, the air aloft is rarely cool enough to produce vigorous instability (although garden-variety thunderstorms are common then), and in the wintertime, the Gulf of Mexico is usually too cool to act as a good source of warm, moist air.

Vertical wind shear refers to a situation in which winds at one level of the atmosphere are blowing in a different direction or a different speed than winds at another, nearby level of the atmosphere. For example, it is not unusual in a severe weather situation for surface winds to be blowing strongly from the southeast and winds at a height of 3km (2 miles) to be blowing strongly from the southwest. These large variations in wind over a short vertical distance can be converted into large variations over a short horizontal distance by the tilting effect of a strong convective updraft, and an updraft also enhances any swirling of the winds already present beneath it. The result can be a rotating updraft which persists for up to several hours and forms the core of a supercell thunderstorm. Most strong tornadoes originate at the base of a supercell thunderstorm.

The final trigger for a tornado is thought to be the sharp low-level contrasts in temperature that are found beneath many thunderstorms, as cool downdraft air comes in contact with the warm, moist air feeding the updraft. The temperature differences cause the air to tumble, and if it is then ingested into the updraft of a strong thunderstorm, the tumbling can be amplified into the strong vortex called a tornado.

Damage from a tornado is categorized using the Fujita scale, ranging from F0 (minimal damage) to F5 (strong enough to sweep a foundation clean and rip up asphalt from a road). Strong tornadoes (from F2 to F5) are rare but they tend to last longer and cause the most fatalities.

When a tornado occurs over a body of water it is known as a waterspout. While the base of a tornado is often only visible because of the dust and debris it stirs up, a waterspout appears as a tube of a cloud extending all the way to the water. Some waterspouts are not true tornadoes but are simply rapidly rotating updrafts in an environment of weak wind shear beneath ordinary convective clouds. Over land, vortices known as dust devils can form even when there are no clouds. In a dust devil, the superheated ground provides the buoyancy for a very strong updraft when the sun is bright and the winds are light.


Hail comes in all sorts of shapes and sizes. *Photo courtesy of Barry Raugust.*

4. Hail

Hail is created when liquid water in an updraft does not have time to freeze in midair before it comes in contact with particles of solid ice within the cloud.

If the ice grows big enough it can fall all the way to the ground before melting. Most supercell thunderstorms produce hail, but hail can also be produced in any strong thunderstorm. A strong updraft allows the ice to remain suspended in the updraft where it can grow to large sizes. Dry air aloft is also favorable to hail because it allows the hailstones to remain cool through evaporation as they fall to the ground.

5. Lightning

Lightning is the visible manifestation of an electrical discharge taking place within a thunderstorm, among thunderstorms, or between a thunderstorm and the ground. The exact cause of the electric fields that produce the lightning is not known, but they are believed to be caused by massive numbers of collisions between solid ice particles within the cloud and other ice particles covered by a thin film of water.

Lightning is a gigantic electrostatic discharge between the cloud and the ground, other clouds or within a cloud. *Photo courtesy of NOAA.*

Thunder, the audible consequence of lightning, is caused by the rapid expansion of the air as it heats to several thousands of degrees within the lightning channel. While the speed of light is amazingly fast, the speed of sound is comparatively slow, and this fact can be used to estimate the distance to any audible lightning flash. Just count the number of seconds between the visible flash and the sound of the thunder and multiply by five to get the approximate distance in miles.

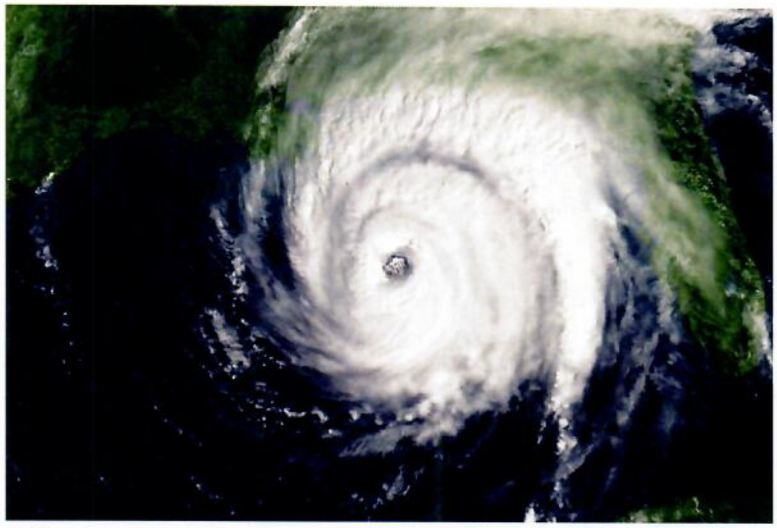
Lightning kills many more people every year than tornadoes. The safest places to be to avoid lightning are indoors or in a car. It is difficult for lightning to penetrate a space partially enclosed by metal, such as a car interior. If indoors, avoid touching metal objects connected to the ground outside. This includes telephones with cords and bathtubs filled with water. If stuck outdoors, avoid standing beneath a tree and instead crouch low to the ground, discarding any large metal objects as umbrellas and golf clubs.

6. Hurricanes

A hurricane is a roughly circular storm, about 100-500 miles across, that forms over warm water in the tropics and has peak surface winds of at least 74 miles per hour. The same storms are known as typhoons in the western Pacific and cyclones in the Indian Ocean. This is especially confusing since another name for tornado in the U.S. is cyclone.

In the Atlantic, the official hurricane season runs from June through November, but most hurricanes form in August or September. A hurricane forms when a mass of tropical convection generates enough heat and low pressure that air converges into the convective

area at low levels and is bent to the right by the Coriolis force, thereby developing rotation. If the winds get strong enough, the air is able to extract heat and moisture from the ocean faster than the thunderstorms are able to dissipate it, and the storm intensifies rapidly into a hurricane.



Hurricanes are low pressure systems that have thunderstorm activity, rotate counterclockwise, and have winds of 75 mph or greater. *Image courtesy of NOAA.*

There are many dangerous aspects to a hurricane. The most obvious cause of damage is strong winds, which are felt near the area of landfall. Another potential cause of damage is the storm surge, the rise in sea level (of as much as 20-30 feet in extreme cases) that accompanies the low pressure and strong winds of the hurricane. Some hurricanes produce lots of tornadoes, causing more damage than the hurricane winds themselves. Finally, and most importantly, even after a hurricane has moved onshore and died, large amounts of very moist, unstable air remain. These hurricane remnants can produce torrential rains, especially if they are lifted by hills or interact with a larger-scale weather system. Indeed, flooding from rainfall is the leading cause of death from hurricanes.