**The Hermione Game**

**Insignia Guidebook Series**

**WEATHER**

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**Weather Guide**

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**Apprentice**

**COVER IMAGE:**

Christin's thermometer (1743).

Termómetro de Lyon. Ideado por Jean-Pierre Christin y fabricado por Pierre Casati en 1743.

1. What is meteorology?

2. Explain the difference between weather and climate?

3. Tell what causes wind, why it rains, and how lightning and hail are formed.

4. Discuss how the weather affects sailing and navigation aboard a ship like the *Hermione*. For example, think of the effect of overcast skies would have on determining a ship’s position or the effect of wind and rain on working the sails.

5. Identify some human activities that can alter the environment, and describe how they affect the climate and people.

**Chief**

1. Think about some of the folklore you have heard about the weather. Discuss where it came from and whether it is true or false.

2. What is the difference between high and low pressure systems in the atmosphere? Tell which is related to good and to poor weather.

3. Explain the characteristics that define a greenhouse gas and know how to decide which greenhouse gases are most important in influencing Earth's radiation balance. Choose one of the following mediums to present your findings: an illustrated poem, a comic strip, and illustrated story. Share you work with your friends or class.

3. Identify and describe clouds in the low, middle, and upper levels of the atmosphere. How are these related to specific types of weather?

4. Draw cross-sections of a cold front and a warm front showing the location and movements of the cold and warm air, the frontal slope, the location and types of clouds associated with each type of front, and the location of precipitation.

5. Draw a diagram of the water cycle and label its major processes.

6. Make a weathervane, hygrometer, and a rain gauge. Use them to track the weather in your area for a week. Report your findings.

**Master**

1. How does the tilt of Earth's axis help determine the climate of a region near the equator, near the poles, and across the area in between?

2. Keep a daily weather log for 1 week recording the following information at the same time every day: wind direction and speed, high temperature, low temperature, air pressure (indicate if it is rising or falling), precipitation, and types of clouds, and the time of sunrise and sunset. Be sure to note any morning dew or frost. Also list the weather forecasts from radio or television at the same time each day and show how the weather really turned out. See if you can detect any trend in the weather.

3. Do ONE of the following:

a. Give a talk of at least five minutes to your class explaining the outdoor safety rules in the event of lightning, flash floods, and tornadoes.

b. Read several articles about acid rain or global temperature rise and give a prepared talk of at least five minutes to your class about those articles.

c. Examine the differences between where information about weather came from in the 18th century and where it comes from today. Prepared and give a talk of at least five minutes to your class based on your research.

4. Describe how the climate system is under the control of feedback loops, allowing small atmospheric changes to have profound effects on climate as various parts of the climate system interact.

5. Explain how the ocean affects climate and how a changing climate can influence the chemistry of both the ocean and the atmosphere.

6. Describe how your understanding of the science of climate change can help you make informed responses to climate change.

7. Describe the development of the atmosphere from the past to the present and predict the state of the future atmosphere. Choose one of the following mediums to present your findings: an illustrated poem, a comic strip, and illustrated story. Share you work with your friends or class.

**I. INTRODUCTION**

What is meteorology? What is the difference between weather and climate? How does weather affect sailors, aviators, farmers, and the construction industry. Why are weather forecasts important to each of these groups? How did weather affect transportation in the 18th century? How did weather affect the conduct of the American Revolutionary War? How does weather affect our lives today?

This guide can’t answer all those questions, but it can give you the facts and the tools to help you understand them and find your own answers. Weather is a large subject and this guide can only introduce you to some of its complexity. The guide is designed to be used as an accessible reference to information about weather. If what you find interests you or you need more information, you can explore some of the resources listed in section VIII.

The basic information about our atmosphere and its weather presented in section II has been known for a long time, but the details of how weather works and how to forecast what is going to happen has only become clear in the last few hundred years. What the people in the late 18th century knew is the subject of section III. It includes some of the misinformation that was believed at that time because those misunderstandings had an effect on what people thought and how they acted. What we have learned since then and now know, which is a great deal more, is the subject of section IV.

Section V deals with the modern techniques and technology of weather forecasting, which has practically become a separate science on its own. Section VI discusses climate and the threat of the climate change that is taking place around us today. It deals with the hard facts, as we know them. You can make your own decisions about what to believe and how we should act in the future.

**II. WEATHER BASICS**

Today’s atmosphere, its climate, and its weather are complex systems that we are still trying to fully understand. But a few basic concepts will help make things clear.

**Evolution of the Atmosphere**

Earth is believed to have formed about 4.5 billion years ago. During its first 500 million years a dense atmosphere emerged from the vapor and gases that were expelled from the planet's interior. These gases may have included hydrogen, water vapor, methane, ammonia, and carbon oxides, but there was no free oxygen.

As the Earth cooled, water started dissolving gases like ammonia and removing them from this first atmosphere. Gradually volcanic activity and bacteria created a second atmosphere that was composed primarily of nitrogen (75%) and Carbon dioxide (15%).

About one billion years ago, early aquatic organisms called blue-green algae began using photosynthesis to split molecules of water and carbon dioxide and form organic compounds and molecular oxygen. Some of the oxygen accumulated in the atmosphere. As oxygen in the atmosphere increased, the amount of carbon dioxide decreased.

High in the atmosphere, some oxygen (O2) molecules absorbed energy from the Sun's ultraviolet rays and split to form single oxygen atoms. These atoms combined with the remaining oxygen to form ozone (O3) molecules, which are very effective at absorbing ultraviolet rays. By about 600 million years ago this process had created the ozone layer that protects Earth from ultraviolet radiation. The ozone layer enabled organisms to develop and live on the land.

By 500 million years ago, vegetation covered the surface of the Earth, and oxygen accounted for 30% of the atmosphere. Most of the major groups of animals first appeared at this time, including giant insects. But 252 million years ago a series of volcanic events caused the oxygen level to drop from 30% to 12%, which set off a great mass extinction. Known as the Permian Extinction, it eliminated as much as 90% of ocean dwellers and 70% of land plants and animals.

The oxygen level slowly began to increase and by 228 million years ago it had risen to about 15% of the atmosphere, and the first dinosaurs appeared. 100 million years ago, oxygen had risen to about 23% of the atmosphere and modern mammals and birds began to develop. For the last 100 million years, the percentage of oxygen has fluctuated between 18% and 23% with today’s level holding at about 21%.

**CLIMATE AND WEATHER**

**Weather** describes the atmospheric conditions that are happening right now or within the recent past or the conditions that are expected in the next few days. Weather is the short-term occurrence or daily measurement of temperature, atmospheric pressure, wind, and moisture. We deal with weather every day: when it is raining, we use an umbrella; when it is hot outside, we look for shade or take cover inside. We listen to the meteorologist on TV to find out what the weather will be tomorrow.

**Climate** describes weather patterns for a particular location over a long time. Most descriptions of climate use a long-term average of weather conditions in a region or the world to predict the typical conditions that are likely to be present in the future. Climate statistics measure both regular conditions, such as average rainfall or days below freezing, and the occurrence of severe weather or other weather events that could affect health and property.

**How the Atmosphere Works**

Earth's atmosphere plays a critical role in regulating our climate and energy from the sun is the main driving force in the atmosphere. The amount of solar radiation that reaches Earth depends on Earth's distance from the sun and its elliptical orbit. But it is not how close the Earth is to the sun that determines what season it is. The Earth is actually closest to the sun in January, when it is winter in the Northern Hemisphere. It is the tilt of the Earth’s axis that is the key to the seasons. Several other important factors also affect Earth’s atmosphere.

The molecules in Earth's atmosphere interact with the sun’s electromagnetic radiation. Some of this energy is absorbed, as in the Ozone Layer of the upper atmosphere, some of is reflected back into space, and some of it passes through the atmosphere, like the ultraviolet rays that cause sunburn.

The surface of Earth also reflects solar radiation, which affects the amount of solar energy that gets absorbed by Earth's surface. This property is known as **albedo**. The albedo of the Earth varies due to changes in cloud cover, snow, ice, leaf area and land use. For example, a surface covered with snow will have a high albedo, while an area covered by vegetation or ocean has a low albedo.

Earth's ocean and atmospheric currents move huge amounts of energy around the globe and influence weather patterns. Changes in ocean pattern, such as El Niño, can affect the weather in distant places.

Finally, living matter both on the land and in the water, which scientist refer to as the **biosphere**, contributes to atmospheric gas concentrations and affects Earth's albedo. Processes such as photosynthesis, respiration, and decomposition use or produce gasses such as oxygen, carbon dioxide, and methane.

**The Earth’s Tilt and the Seasons**

As the Earth rotates on its **axis**, producing night and day, it also moves about the sun in an elliptical orbit that requires one year (actually about 365¼ days) to complete. The Earth's axis of rotation is tilted about 23½ degrees compared to the plane of the Earth's orbit around the sun and this is what causes the seasons. When the Northern Hemisphere is tilted towards the sun, the Southern Hemisphere is tilted away from the sun. The Northern Hemisphere receives more direct sunlight and its days last longer, so it is summer there and winter in the Southern Hemisphere. The days become shorter and the temperatures become cooler.

**Latitude**

Latitude is used along with longitude as a reference point to determine a location on the Earth. Latitude is used to measure the distance north or south between the Earth’s equator and the North or South Pole. Longitude measures the distance east or west. Lines of latitude form circles around the Earth, with 0 degrees latitude at the equator and 90° latitude representing the poles. On maps latitude is commonly shown as an imaginary horizontal line that goes across the Earth.

The latitude of a location has a large impact on the climate for an area primarily because the amount of solar heating it receives varies with the latitude. Locations at lower latitudes near the equator receive stronger and more direct sunlight than locations near the poles. However, locations with the same latitude may have different climates depending on other factors such as whether the location is close to the coast, what its altitude is, or if it has significant topographic features, such as mountains.

**III. WEATHER—WHAT THEY KNEW ON *THE HERMIONE***

**EARLY HISTORY**

The study of weather and forecasting began with early civilizations using reoccurring astronomical and meteorological events to help them monitor seasonal changes in the weather. Around 650 BCE, the Babylonians tried to predict short-term weather changes based on the appearance of clouds and phenomena such as haloes. By 300 BCE, Chinese astronomers had developed a calendar that divided the year into 24 festivals. Each festival was associated with a different type of weather.

Around 340 BCE, the Greek philosopher Aristotle wrote *Meteorologica*, a philosophical treatise that included theories about the formation of rain, clouds, hail, wind, thunder, lightning, and hurricanes. Some of his observations about weather were remarkably accurate and for almost 2000 years this four-volume text was considered the best authority on weather theory. It was not until around the 17th century that many of his ideas began to be reconsidered and overturned.

At the beginning of the 17th century, the colonists in America had little information about our weather. Many myths controlled the location of settlements. One misconception was that temperatures along the same parallel of latitude were equal the world over. A common complaint by the colonists was that America had six months of winter while the same latitude in Europe only had three.

Weather conditions caused the death of 32 out of the original 105 settlers at Jamestown. A rule of thumb was that if a colonist could survive a full year in the New World, he or she should live for many more years. Eventually, the colonists started keeping track of the weather, but there were no weather instruments in the United States until 1717.

By the late 18th century it had become apparent that greater knowledge was necessary to further our understanding of the weather. Two important fields of knowledge particularly drove interest in weather observation and climate: agriculture and medicine. Farmers thought that regular observations would lead to an understanding of weather patterns that could help manage their crops.

Doctors, however, were interested meteorology for very different reasons. The modern idea that diseases are caused by bacteria had not yet been devised. Instead, physicians followed the ancient Hippocratic doctrine that climate, topography, and “bad air” released from the interior of the Earth were the chief causes of disease. The link between meteorology and medicine was so strong numerous physicians kept weather observations in the expectation of being able to correlate weather patterns with diseases. In France, the Royal Society of Medicine set up a national network of weather observers in 1778.

American colonists were also keen observers of the weather. Thomas Jefferson made regular weather observations. For example, in a letter he noted that the high temperature in Philadelphia, Pa., on July 4, 1776 was 76 degrees. George Washington also made regular weather observations and weather was one of Benjamin Franklin’s passions. He investigated atmospheric pressure and storm movements, invented the lightning rod, wrote the very popular *Poor Richard’s Almanack*, which contained daily weather forecasts, and urged establishment of a network of observers.

**WEATHER FOLKLORE**

For most people, including the sailors and passengers on *The Hermione*, attempts to forecast the weather were based on folklore and personal observation. Much of what was known or thought about the weather in the 18th was expressed in sayings, old wives’ tales, legends, and superstitions, which today we consider the opposite of science. But much of this folklore about the weather was based on observation and evidence. It was an expression of the accumulated knowledge gathered over time and passed from generation to generation. Folklore about weather wasn’t exactly scientific, and some of it was based on misunderstandings, but some of it is true and still useful today. Here are a few examples:

**A halo around the moon or sun means rain is approaching.** This is true because a halo appears around the moon or sun when ice crystals at high altitudes refract moonlight or sunlight. This is a sign of an approaching warm front and an associated area of low pressure, which is a good indication that precipitation is likely. A halo is a more reliable predictor of storms during warmer months.

**The higher the clouds, the finer the weather.** This is also true.High clouds indicate dry air and high pressure, which are signs of fair weather. Clouds are produced by the condensation of moisture. If the air must rise to a high altitude before condensation occurs, precipitation is unlikely.

**Lightning never strikes the same place twice.** Although this is often repeated, it is not true. Lightning not only strikes the same place twice, it can strike the same location many times in a single storm. Skyscrapers and tall towers, such as radio or TV towers, or the masts of sailing ships receive the most strikes. A tower in Lexington, Kentucky was struck 11 times during one storm in 2008. A strike does not change the electrical activity in the storm. It can produce another bolt of lightening anytime, and the location that has already been struck is just as likely as anyplace to be struck again.

**You can tell the temperature by counting a cricket’s chirps.** That is true: crickets do chirp faster when it’s warm and slower when it’s cold. The traditional formula for estimating the temperature in degrees Fahrenheit is to count the number of a cricket’s chirps in 14 seconds and then add 40. The result won’t always be exactly accurate, but it will be close enough.

**Sayings and Proverbs** Over the years weather lore was passed down in the form of proverbial sayings or beliefs, some of which are still common today. Many described different aspects of the weather and often rhymed to make them easier to remember. For example, *Red sky at night, sailors delight; red sky in morning, sailor take warning* is still quoted by sailors. It also has a land version: *Rainbow in the morning, shepherds take warning; rainbow at night, shepherds’ delight.* Some sayings are wishful, such as *Rain, rain, go away; come again some other day.* Some make predictions about the weather, such as *Rainbow at noon, more rain soon.* Some sayings the members of the crew of *The Hermione* might have known are:

*If crows fly low, wind’s going to blow; if crows fly high, wind’s going to die.*

*A sunshiny shower won’t last half an hour.*

*Clear moon, frost soon.*

*When seabirds fly to land there truly is a storm at hand.*

*The sharper the blast, the sooner it’s past.*

*Year of snow, fruit will grow.*

*When a cow tries to scratch her ear it means a shower is very near.*

*Rain before seven, quit by eleven.*

All these sayings have an element of truth, but none of them a reliable enough to forecast the weather. It was the gradual application of scientific inquiry and technology that brought meteorology to where it is today.

**18TH CENTURY WEATHER SCIENCE**

The 18th century was a period of remarkable scientific breakthroughs. Following the scientific advances of the 16th and 17th centuries, people began to reject unproven theories and superstition in favor of careful observation, and carried out experiments to test ideas. The 18th century also saw the beginning of the transition between an economy based on manual labor and the work of draft animals to one based on manufacturing with machines. This was beginning with the mechanization of the textile industries, the development of iron-making techniques, and an increased use of refined coal. Trade was expanding as well, enabled by the introduction of canals and improved roads.

But weather reporting and forecasting as we know them don’t begin until the 19th century and the invention of the telegraph. That allowed people to report and compare daily weather conditions in different locations, and for the first time maps, which are key to understanding weather conditions, could be made. Until then the people who were interested in the weather had to make do with measuring local conditions. At the same time, however, the tools for measuring weather were improving.

**Weather Instruments:** Improving knowledge of the weather required instruments to measure the properties of the atmosphere, such as moisture, temperature, and pressure. But during the 18th centuryscientific instruments that measured weather phenomenon were expensive and not widely used. Most people on land relied on weathervanes and almanacs to help them predict the weather. Weathervanes were placed on many public buildings, but they only indicated which way the wind was blowing. Almanacs provided short and long-range weather forecasts which people relied on to help them plan their activities, including planting and harvesting crops, but they were not always accurate.

**Weather Logs:** Many people kept daily records of the weather, noting clouds, winds and other phenomena. For example, Thomas Jefferson kept a log of regular weather observations at Monticello from 1772 to 1778. George Washington’s last weather entry in his diary was made the day before he died. Officers on ships at sea kept such accurate records of climate conditions that modern researchers can find out what the weather was like almost anywhere in the world on a particular day as far back as 1750. The weather information they contain is being used to research climate change over the last 250 years.

**Weather Maps or Charts:** The kind of weather maps we are familiar with come into use around the middle of the 19th century. Weather was a local event. Most observers didn’t realize that a single large system could cause similar weather in separate places. An exception to this is George Hadley (1685–1768), an English lawyer and amateur meteorologist. In 1735 he proposed an explanation for way the trade winds blow. He suggested that atmospheric circulation consists of a single wind system in each hemisphere. In the northern hemisphere the winds near the equator blow toward the west, while nearer the North Pole they blow toward the east. He recognized that this was caused by the fact that the atmosphere near the equator received more heat from the sun. Warm air near the Equator rises and flows toward the pole at high altitudes. Near the pole it loses heat, sinks, and flows toward the equator at low level until it nears the Equator, where the process repeats. Unfortunately, Hadley’s work wasn’t recognized for nearly 60 years.

**Hygrometers:** Ahygrometer is an instrument that measures the humidity (moisture content) in the air. The first known design in western civilization was described in the mid-fifteenth century by Nicholas of Cusa (c.1401–1464), a German philosopher and astronomer. A hygrometer can indicate relative humidity (the percentage of moisture in the air), absolute humidity (the amount of moisture), or both. Hygrometers are used in weather forecasting and for monitoring the humidity in laboratories, storage areas, and manufacturing plants.

There are several types of hygrometers. One common type contains fiber, usually human hair, that stretches when the relative humidity increases and contracts when it decreases. The fibers are usually attached to levers that turn the pointer on a dial.

A *wet-and-dry bulb psychrometer* consists of two mercury thermometers mounted side by side. The dry-bulb thermometer measures the temperature of the air. The bulb of the other thermometer is covered with a cloth sleeve that is wetted with water. As air is blown over the cloth with a fan or by whirling the hygrometer in the air, the water evaporates. As it evaporates, the bulb is cooled. In general, the drier the air, the greater the drop in temperature. Relative humidity is determined by comparing the readings of the two thermometers with a table or chart.

*An electrical hygrometer* typically measures the electrical resistance of a substance whose resistance to an electric current varies with the humidity. A *dew-point hygrometer* has a smooth, shiny surface that is cooled until water vapor in the air begins to condense on it. The humidity is determined by comparing the temperature at which the condensation occurs (the dew point) with the temperature of the air. A *chemical hygrometer* uses a substance to absorb moisture from a given volume of air. The difference in the weight of the substance before and after its exposure to the air indicates how much moisture is present.

**Thermometers:** The Italian scientist Galileo Galilei (1564–1642) invented an early thermometer in about 1593. By the early 18th century, thermometers were calibrated between the freezing point of salted water and the human body temperature. Most thermometers divided this range into a 12-point scale, but Gabriel Fahrenheit changed that. In 1724 he invented both the mercury thermometer and the alcohol thermometer. Fahrenheit subdivided this range on his thermometers into ninety-six points, which gave them better resolution. This scale for measuring temperature, 9s very close to what is used in the U.S. today.

Seven years later, Swedish astronomer Anders Celsius proposed the Celsius temperature scale, which was divided into 100 increments instead of 96. His original version set the boiling point of water at zero degrees and the freezing point at one hundred. The scale was later reversed and that led to the current Celsius scale, which is widely used throughout the world.

Thermometers were rare in the American colonies, but we do know that Thomas Jefferson purchased one from a local Philadelphia merchant while in town for the adoption of the *Declaration of Independence*. A few days later he also purchased a barometer—one of the only ones in America at the time—from the same merchant.

**Barometers**

A barometer is an instrument used to measure atmospheric pressure. The first one was invented in 1643 by Italian physicist and mathematician Evangelista Torricelli (1608–1647). Many barometers of the 18th century used mercury because the liquid metal is very responsive to atmospheric changes. Variations in atmospheric pressure cause the mercury to rise or fall inside a glass tube at a constant rate that can be calibrated. Marine and scientific barometers of the period were used at sea and mainly for meteorological experiments, and were not usually carried aboard ships like *The Hermione*.

*Stick barometers* are the simplest type of barometer consists of a mercury-filled glass tube set within a long, narrow wall case. The mercury level is read directly against a simple vertical scale usually marked with labels indicating "Very Dry," “Fair," "Rain," and "Stormy" weather. The stick barometer was invented in the 17th century and until about 1775, nearly all barometers were of the stick type. A *Wheel barometer* has a circular, clock-like face and one or more hands to indicate outlook and air pressure.

The crew of the Hermione would not recognize an *aneroid barometer*, which is common today, but wasn’t invented until 1844. It uses a sealed metal chamber that expands and contracts to measure changes in atmospheric pressure.

**IV. WEATHER—WHAT WE KNOW TODAY**

Our understanding of weather and climate has improved substantially since The *Hermione* sailed between Europe and America. We know that our local weather is the result of large global patterns in the atmosphere caused by the interactions of solar radiation and Earth's large oceans and varied landscapes, and its motion in space. Most of us get our information about the weather from the media and organizations such as the National Weather Service. But to really understand what is taking place in the atmosphere around you, it is useful to understand a few basic terms and facts.

**THE ATMOSPHERE**

Earth atmosphere is a layer of gases surrounding the planet that is held in place by Earth's gravity. It is concentrated at the surface and rapidly thins out as you move upward, blending with space roughly 100 miles above sea level. The atmosphere is actually very thin compared to the size of the Earth. If you imagine how thick a piece of paper laid over a beach ball is, that will give you an idea of the thickness of Earth’s atmosphere. However, the atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface by retaining heat, and producing weather.

**The Composition of the Atmosphere**

The atmosphere contains many gases, most in small amounts, including some pollutants and greenhouse gases. The most abundant gases in are nitrogen (78%), oxygen (21%), and an inert gas, argon (0.9%). Nitrogen accounts for 78% of the atmosphere, oxygen 21% and argon 0.9%. Traces of greenhouse gases such as carbon dioxide, nitrous oxide, methane, and ozone account for about a tenth of one percent of the atmosphere, but their percentages vary as they interact with solar radiation and infrared light (heat) given off by the Earth. Even though they are make only a small amount, they can strongly affect the global energy balance and temperature over time.

The atmosphere also contains water vapor in concentrations that vary depending on where you are and what time of the day it is. In the cold, dry artic regions water vapor usually accounts for less than 1% of the atmosphere. In humid, tropical regions water vapor can account for almost 4% of the atmosphere.

**Properties of the Atmosphere**

The properties of the atmosphere that most affect the weather are temperature, density, pressure, and humidity.

**Temperature**

Temperatureis the measure of the average thermal or internal energy of the molecules within an object or gas. We can measure temperature of an object using either direct contact or remote sensing. In the atmosphere, temperature is inversely related to density but directly related to pressure and volume. For example, when temperature increases, and volume and pressure of the gas also increase, but density decreases. For example, if warm, dry air is surrounded by cooler air, it will tend to rise because warm air is less dense than the cool air.

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| **Wind Chill** is the amount of cooling you feel due to the combination of wind and temperature. Today temperature is often reported as a “Reel Feel” temperature that takes into account how cold wind feels on exposed skin. |

Thermal energy or temperature in the atmosphere can be transferred from one medium to another in three ways.

**Convection** is the transfer of energy by the movement of molecules in liquids or gases that flow. You can feel convection happening when a breeze cools you off on a hot day.

**Radiation** is the transfer of energy by electromagnetic waves. This is the form of heat you feel coming from the sun.

**Conduction** is the transfer of energy through direct contact between neighboring molecules. When you touch a warm surface, you feel heat being transferred directly to your hand, which increases the average kinetic energy of molecules that make up your skin.

**Temperature Scales**

Three different scales are frequently used to measure temperature today.

The **Fahrenheit** scale was developed by G. Daniel Fahrenheit in the early 1700s and is the most widely used scale in America. On this scale the freezing point for water is 32°F, the boiling point of water is 212°F, and there is a range of 180 degrees between them. The Fahrenheit scale uses negative numbers to measure temperatures colder than the freezing point of water.

The **Kelvin** scale was developed by Lord Kelvin in the mid-1800s and it has no negative numbers. Instead, it sets absolute zero (-460°F) at the point where all molecular motion stops.

The **Celsius** scale was developed later in the 1800s. On this scale the freezing point for water is 0°F, the boiling point of water is 100°F.

Not only do these scale differ on where the mark their zero, they also disagree on the size of a degree. One degree C is the same size as one degree K but both are the equivalent of 1.8 degrees Fahrenheit.

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|  **A Comparison of Some Temperatures** |
|  | Fahrenheit | Celsius | Kelvin |
| Absolute zero | –459.67 | –273.15 | 0 |
| Intergalactic space | –454 | –270 | 3 |
| Antarctic coldest | –129 | –89.44 | 3.15 |
| Carbon dioxide (dry ice) freezes | –108 | –78 | 195 |
| Mercury freezes | –38 | –39 | 234 |
| Water freezes | 32.0 | 0 | 273.15 |
| Deep ocean | 37.4 | 3 | 276.15 |
| Room temperature | 68.0 | 20.0 | 293.37 |
| Human body  | 98.6 | 37 | 310.15 |
| Death Valley hottest | 134 | 56.6 | 329.82 |
| Water boils | 212.0 | 100.0 | 373.15 |
| Campfire | 1,000 | 700 | 1,000 |
| Lava | 1,922 | 1,050 | 1,323 |
| Light bulb filament | 4.900 | 2.700 | 3,000 |
| Surface of the Sun | 10,383 | 5,750 | 6,023 |
| Earth’s core | 10,832 | 6,000 | 6,273 |

**Density**

Densitymeasures how tightly packed a substance is. Technically, density is defined as mass per unit volume. A gas that is less dense has a lower concentration of molecules than a denser gas, and it will tend to rise. In the atmosphere, density is related to both temperature and humidity (the amount of water vapor molecules in the air). Dry, warm air is less dense than areas of cool air around it and will tend to rise. Areas of rising warm air often result in the development of clouds and even precipitation.

**Pressure**

Pressureis the force exerted over a given area or object, either because of gravity pulling on it or other motion the object has. Although our atmosphere may seem weightless and invisible, its molecules have weight, which exert a force on everything on Earth, including us. This force is called **air pressure** or **atmospheric pressure**. It is also called **barometric pressure** because we use a barometer to measure it. The pressure of the air at sea level is about 14.7 pounds (6.7 kg) for every square inch (6.4516 cm²) of an area or an object. If you climb higher in the atmosphere, for instance up a mountain or in an airplane, there will be fewer air molecules above you. Therefore the air above you will weigh less, meaning there is less air pressure. Variations in pressure lead to the development of winds, which in turn influence our daily weather. Measuring the air pressure at the Earth's surface is one of the keys to understanding weather.

**High and Low Pressure** Air pressure changes with the weather, which is why **H** and **L** are used on weather maps to represent areas of high and low air pressure. A **high** is a large area, maybe a few hundred square miles, where air is slowly descending (too slowly for us to notice) making the air pressure higher than the pressure of the surrounding air. As air descends, it warms, which limits the formation of clouds. That is why high pressure is usually associated with clear skies and calm weather. A **low** is an area where the air is rising, making the air pressure lower. Low pressure is associated with bad weather because as air rises it cools. The moisture in the cooler air condenses into tiny drops of water or, if it's cold enough, tiny ice crystals. When there enough water or ice has collected in the clouds, rain or snow will begin to fall.

Air tends to move from one place to another in an attempt to equalize pressure, which creates wind. Wind often blows outward from a center of high pressure toward areas with lower pressures. As you move away from the center of the high pressure, the pressure exerted by the atmosphere slowly becomes less and less. In a low-pressure area, wind tends to rise toward areas of high pressure. This change is known as the **pressure gradient.** It describes which direction and at what rate the pressure changes around a particular location. In the Northern Hemisphere the air descending in an area of high pressure flows in a clockwise spiral. Air flowing in an area of low pressure rises in a counterclockwise spiral.

**Humidity**

Humidity is a measure of the amount of moisture (water vapor) in the air. High humidity is it feels uncomfortable because your perspiration can't evaporate and provide cooling. Low humidity feels cooler because more moisture is being evaporated from your body. High humidity is necessary to produce clouds and precipitation. The two ways we describe the amount of moisture in the air are relative humidity and dew point.

**Relative Humidity** is a measure of the humidity given as a percentage, which tells you how close the air is to being saturated. When the amount of water vapor in the air increases, the relative humidity increases; when the amount of water vapor in the air decreases, the relative humidity decreases. If the relative humidity measures 50%, the air contains half the water vapor required for it to be saturated.

In the summer, you may notice that the relative humidity is higher in the morning than in the afternoon. This is because relative humidity is related to air temperature. If the water vapor content stays the same and the temperature rises, the relative humidity decreases. If the temperature cools and the water vapor content stays the same, the relative humidity increases. The cooler morning air is closer to saturation than the hot afternoon air, even with the same amount of water vapor.

The **dew point** is the temperature at which the air becomes saturated. If the temperature drops below the dew point, water will condense out of the air onto surfaces. You can see this on some mornings when nighttime temperature has dropped below the dew point and the grass and other surfaces are coated with water. Dew point is a more reliable indicator of humidity than relative humidity because dew point doesn’t change with changes in air temperature.

**The Structure of the Atmosphere**

Today scientists divide the atmosphere into four layers based on temperature, altitude, and pressure. Because the atmosphere is made of gas, there's no clear boundary where it ends and space begins. There are also no clear boundaries between each of the different layers of atmosphere, but there are places where temperature and density change dramatically. The layers of the atmosphere are:

**Troposphere** The bottom layer of the atmosphere contains all Earth’s weather and 80 percent of the planet's air mass. This is the layer where we live and where weather happens. Although the thickness of the troposphere varies with latitude and season, its upper boundary, called the **tropopause**, is approximately 7 miles (11 km) above sea level. The tropopause is where the jet stream sits and it marks the highest point that weather can occur. Up to this altitude air temperature the drops steadily as the elevation increases. At the same time, air pressure decreases as altitude increases.

**Stratosphere** The second layer extends another 23 miles (37 km) into the sky, ending about 30 miles (48 km) above the Earth’s surface at the **stratopause**. For the first 12 miles (20 km) of the stratosphere the air temperature stays constant. Then it begins to rise. This is because of the presence of the **ozone layer**, Ozone absorbs ultraviolet radiation from the sun. Even though the air is very thin, it keeps getting warmer until you reach the stratopause.

**Mesosphere** The atmosphere's third layer begins above the stratopause at an altitude of about 23 miles (37 km). The air in this layer is too thin for weather to occur. The temperature in this layer gradually gets colder as you get closer to upper boundary, the **mesopause**, which is about 50 miles (80 km) above Earth's surface. The coldest air temperatures have been recorded here, dipping as low as -130°F (-90°C)

**Thermosphere**: The final layer of the Earth's atmosphere extends from the mesopause up to the very edge of space. The density of the air thin that there are very few air molecules. The molecules also have less mass, so they quickly absorb solar radiation. Temperatures in this layer can reach more than 3,100°F (1,700°C), but you wouldn’t notice because of to the low density. The lower part of the thermosphere is called the **ionosphere**. It extends from an altitude of about 50 miles (80 km) to 340 miles (550 km). Gas particles in this layer absorb ultraviolet and X-ray radiation from the sun and become electrically charged (ions). Radio waves are bounce off these ions and reflect back to Earth. The upper part of the thermosphere is the **exosphere**. It extends from about 340 miles (550 km) for thousands of kilometers and the air is extremely thin.

**WEATHER SYSTEMS AND PATTERNS**

The local weather that we experience is the result of large global patterns in the atmosphere caused by the interactions of solar energy, Earth's large ocean, its diverse landscapes, and its motion in space.

**Global Winds:** Earth’s orbit around the sun and its rotation on a tilted axis means that some parts of Earth receive more solar radiation than others. This uneven heating produces global circulation patterns. For example, the abundance of energy reaching the equator produces hot humid air that rises high into the atmosphere. A low-pressure area forms at the surface and a region of clouds forms at higher altitude. Eventually the air stops rising and spreads north and south towards the Earth’s poles. About 2000 miles from the equator, the air falls back to Earth's surface with some of it blowing toward the pole and some of it flowing back to the equator. Six of these large convection currents cover the Earth from pole to pole.

Global wind patterns have had a large impact on transportation. In the past wind patterns were important in developing the trade routes used by sailing ships. For example, the pattern of wind over the North Atlantic enabled ships to sail from Europe using the prevailing west wind over the southern part of the North Atlantic and come back using the prevailing east wind over the northern part. A similar pattern exists over the North Pacific.

Today ships powered by engines can ignore the winds and sail directly to their destination, but airplanes are affected by wind, especially on long distance flights. For example, eastbound flights over the North Atlantic and the North Pacific take less time than westbound flights because of the effect of prevailing winds. A flight traveling east between New York and London lasts about 7 hours. But because of the wind, traveling west over the same route takes about 45 minutes longer.

**Air Masses:** Global wind patterns drive enormous bodies of air with relatively uniform temperature and humidity called air masses. Each of these bodies of air extends across large areas of the Earth and is thousands of feet thick. Where an air mass forms determines its characteristics. For example, air over the tropical ocean becomes exceptionally hot and humid. Air over continent may become cold and dry.

**El Niño and La Niña**

Changes in the circulation of air masses can lead to changes in weather, temperature, and rainfall patterns around the world. An example of such a changeable air mass is known as the El Niño/Southern Oscillation (ENSO) cycle. It occurs every few years in the tropical Pacific Ocean near the equator off the west coast of South America. In a normal year the trade winds in this region blow westward from a area of higher pressure in the eastern Pacific to an area of lower pressure in the western Pacific. These winds cause cold water from the deep ocean to rise toward the surface, a process known as **upwelling**, which cools the temperature of the ocean’s surface.

Every few years, this pattern breaks down and the wind slows or even blows toward the east instead of the west. This reversal in wind direction brings the warmer water from the western Pacific closer to South America. The warming of the ocean is called **El Niño.** (It was named El Niño because it often begins in December, the time when “El Niño Jesus” was born.) These warmer ocean temperatures can have an effect on the global wind patterns, which then affects temperature and rainfall patterns around the world.

Eventually El Niño begins to decrease and the pressure and wind return to their usual pattern. But sometimes the trade winds, which are blowing towards the west, can be very strong. This causes the cold surface water in the eastern Pacific to move out over the central Pacific. This cooling of the central and eastern Pacific Ocean is called **La Niña** (El Niño’s sister). This pattern can also affect wind, temperature, and rainfall patterns throughout the world, but those effects are generally the opposite of the El Niño pattern.

**Fronts:** The boundary separating two air masses is called a front. Weather maps can be used to track them as the move across the Earth. A **cold front**, usually shown in blue, occurs where a cold air mass is replacing a warm air mass. A **warm front**, shown in red, occurs where warm air replaces cold air.

Cold fronts usually move faster than warm fronts and sometimes a cold front will overtake a warm front. When the cold air behind the cold front meets the cold air ahead of the warm front, whichever air mass is colder dips under the other. The boundary between the two cold air masses is called an **occluded front**. Occluded fronts are represented on weather maps by a solid purple line with alternating triangles and semi-circles, pointing in the direction of its movement.

A **stationary front** is a front that is not moving, although the air masses may move parallel to the boundary. Stationary fronts are usually represented on a weather map with alternating red and blue lines, with blue triangles and red semi-circles facing opposite directions.

**Coriolis Effect:** Air masses and global winds do not move in straight lines as they travel across the Earth. This is partly due the Coriolis effect, which is named after Gustave Coriolis, a 19th-century French mathematician who first explained this force. Winds get deflected from a straight path because the Earth rotates faster at the Equator than it does at the poles. This is because the Earth is wider at the Equator, so a point on the Equator has farther to travel in a day. In the Northern Hemisphere air veers to the right; in the Southern Hemisphere it veers to the left. This motion can create large circulating weather systems, known as cyclonic systems. Examples include hurricanes and typhoons.

**Jet Streams:** Our local weather conditions are related to the movements of air masses and fronts, but several narrow bands of strong wind high in the atmosphere, known as jet streams, steer weather systems and transfer heat and moisture around the globe. Because of the Earth's rotation, jet streams blow from west to east, but they often shift to the north or south. Jet streams follow the boundaries between hot and cold air. Since these hot and cold air boundaries are strongest in winter, jet streams are the strongest in the north during the northern winter, and strongest in the south during the and southern winter.

**WIND**

Temperature differences due to variations in solar energy cause pressure variations in the atmosphere. The amount of sunlight absorbed by the ground depends on the latitude of the location, and the slope and underlying surface of the land. The wind blows from higher pressure to lower pressure to try to correct any imbalances. Regions of low and high pressure moving through an area cause changes in weather as different air masses pass by. This section deals with winds that we commonly encounter. The strongest winds, which usually accompany severe storms, are covered in the section on **Storms** below.

In the Northern Hemisphere, the Coriolis effect turns the wind toward the right, which causes low pressure systems to rotate counterclockwise. Friction slows the wind and causes it to turn slightly toward lower pressure, which causes the wind to blow in toward the center of a low-pressure system. Because the air cannot go down when it reaches the center of the low, it rises, which leads to clouds and precipitation.

A high-pressure system is surrounded by lower pressure, forcing the wind to blow away from the center. The Coriolis effect turns the wind toward its right, causing clockwise rotation around a high-pressure system. Friction also turns the wind away from the center toward lower pressure, which leads to clear skies.

**Turbulence** occurs when the flow of the wind is broken up, making it blow in different directions at different speeds. This can be caused by friction, which slows the wind and changes its direction near the Earth’s surface, or by obstructions such as buildings or differences in the roughness of the surface of the land. Turbulence can also be created when differences in air temperature cause the air to rise and sink. Turbulence causes **eddies** in the atmosphere, which are swirls of wind responsible for wind **gusts** and bumpy plane rides. Turbulence also mixes the lower part of the atmosphere and tends to stabilize the temperature.

A **sea breeze** is a cool breeze that begins to blow off of the water during the afternoon. It develops in response to differences in temperature between a body of water and the neighboring land. In the morning, the land and the water are roughly the same temperature. But during the course of the day the land heats up more rapidly than the water. This is because water, especially a large body of water like a lake or ocean, is able to absorb more energy without warming than land is. The land radiates heat and warms the air above it, which causes the air to rise. This allows the cooler air from over the water to rush in to fill the space left by the rising air, producing a sea breeze.

A **land breeze** is a cool wind that blows from land over water. It occurs on clear, calm nights when the water temperature is warm, especially during fall or winter. The land cools by radiating heat and this cools the air immediately overhead. Because the air over the land cools more rapidly than the air over the water, a temperature difference is established, with cooler air present over land and relatively warmer air located over water. The warmer air rises and the cooler air flows from the land.

**Seasonal Winds**

Seasonal winds are movements of air driven by changes in large-scale weather patterns that occur each year. Many places experience seasonal winds, including Africa, Australia, southern Asia, the Amazon basin, and the southwestern U.S. and Mexico.

The most widely known seasonal wind is the **monsoon,** which is sometimes mistaken for a rainstorm. A monsoon is a wind that changes direction between winter and summer. In winter monsoons usually blow from the land. This is called the dry phase or dry season because the wind is cool and dry. In summer the monsoon wind blows from water to the land, causing big changes in temperature and precipitation. This is called the wet phase or rainy season because the wind brings in warm, moist air. In large areas in the tropics and subtropics monsoons bring humid air from the oceans and produces rain over the land. The agricultural economies of those areas frequently depend on the rain provided by monsoon, but in some years severe winds and storms cause dangerous flooding.

**Measuring the Force of the Wind**

The force of the wind is measured on a scale invented in 1805 by a navel officer named Francis Beaufort. He used the numbers 0 to 12 to indicate the strength of the windfrom calm (force 0) to hurricane (force12). This scale is most often used at sea but this version isadapted for use on land.

**Beaufort scale**

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| --- | --- | --- | --- | --- |
| **Force** | **Description** | **If You See or Feel This Effect** | **Wind (mph)** | **Wind (km/h)** |
| 0 | Calm | Smoke goes straight up. | less than 1 | less than 2 |
| 1 | Light air | Wind direction is shown by smoke drift but not by wind vane. | 1–3 | 2–5 |
| 2 | Light breeze | Wind is felt on the face; leaves rustle; wind vanes move. | 4–7 | 6–11 |
| 3 | Gentle breeze | Leaves and small twigs move steadily; wind extends small flags straight out. | 8–12 | 12–19 |
| 4 | Moderate breeze | Wind raises dust and loose paper; small branches move. | 13–18 | 20–29 |
| 5 | Fresh breeze | Small trees sway; waves form on lakes. | 19–24 | 30–39 |
| 6 | Strong breeze | Large branches move; wires whistle; umbrellas are difficult to use. | 25–31 | 40–50 |
| 7 | Moderate gale | Whole trees are in motion; walking against the wind is difficult. | 32–38 | 51–61 |
| 8 | Fresh gale | Twigs break from trees; walking against the wind is very difficult. | 39–46 | 62–74 |
| 9 | Strong gale | Buildings suffer minimal damage; roof shingles are removed. | 47–54 | 75–87 |
| 10 | Whole gale | Trees are uprooted. | 55–63 | 88–101 |
| 11 | Violent storm | Widespread damage. | 64–72 | 102–116 |
| 12 | Hurricane | Widespread destruction. | 73+ | 117+ |

**THE WATER CYCLE**

Oceans, rivers, clouds, and rain, all of which contain water, are in a frequent state of change (surface water evaporates, cloud water precipitates, rainfall seeps into the ground, etc.). Many locations have plenty of water while others have very little. However, the total amount of the Earth's water does not change.

Water exists on Earth as a solid (ice), a liquid, or a gas (water vapor). The oceans contain more than 97% of the Earth's water. Land areas, including all the glaciers, lakes, rivers, and streams, contain about 2.4% of Earth’s water. The amount of water in the atmosphere at any one time is less than .001% of the total. But we know that the annual precipitation for the whole Earth is more than 30 times the atmosphere’s capacity to hold water. This suggests that the water must be circulating between the Earth's surface and the atmosphere. This circulation of Earth's water is called the **hydrologic cycle** or **water cycle**.

The hydrologic cycle begins with **evaporation**, the process by which water changes from a liquid to a gas. Around 80% of all evaporation takes place on the surface of the oceans; the remaining 20% comes from inland water and vegetation. This moist air, which contains water vapor, is lifted by into the atmosphere by several different processes:

**Convection** is the upward movement in unstable air created when the Earth’s surface warms quickly. The rising warm air current is called a **thermal**.

**Convergence,** which is associated with cyclones, happens when the air near the ground is deflected by friction toward the center of a low-pressure system. This movement can lift the air, which cools it and causes condensation.

**Lifting** caused by a cold or warm front, or by air rising over elevations in the landscape such as mountains.

As the moist air rises, it cools and the water vapor forms clouds. Moisture is **transported** around the globe until **condensation** changes the water vapor from its gaseous form (water vapor) into droplets of liquid water. Condensation generally occurs in the atmosphere when warm air rises, cools and looses its capacity to hold water vapor. Then the water returns to the surface as **precipitation** (rain, hail, or snow).

Once the water reaches the ground, one of two processes may occur. Some of the water may evaporate back into the atmosphere, or the water may penetrate the surface and become **groundwater**. Groundwater either seeps its way to into the oceans, rivers, and streams, or is released back into the atmosphere through transpiration. The balance of water that remains on the Earth's surface is **runoff**, which empties into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.

**CLOUDS**

Water can exist in three different states; as a solid, liquid or gas. Water in the air near the ground usually takes the form of an invisible gas known as **water vapor**. When warm air rises, it expands and cools. Cool air can't hold as much water vapor as warm air, so some of the vapor condenses around tiny pieces of dust floating in the air. A cloud is a large collection of these tiny water droplets or, if it is cold enough, ice crystals floating in the atmosphere.

Clouds are white because their water droplets or ice crystals scatter the seven wavelengths of visible light (red, orange, yellow, green, blue, indigo, and violet), which combine to produce white light. When clouds are thick enough or high enough some of the light does not make it through, giving the cloud a gray or dark look. Also, shadows of other clouds can also make a cloud look a gray.

**Cloud Types:** A British chemist and amateur meteorologist named Luke Howard identified the importance of clouds in meteorology in 1803. He named the three principal categories of clouds—cumulus, stratus, and cirrus. These names are based on Latin words that describe the way these clouds look: cumulus means a heap, stratus means a layer, and cirrus means a curl of hair. Nimbus, which is a fourth type that has been added to the modern classification system, means rain. Howard also identified a series of intermediate types of clouds, such as cirrostratus and stratocumulus, which is still in use.

Today we identify five types of clouds. The first three groups are identified based upon their altitude above the ground. The fourth group consists of clouds that develop vertically. The final group is a collection of miscellaneous cloud types. The following chart will help you identify the different types of clouds.

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| **Types of Clouds** |
| **Classification** | **Type** | **Description** | **Composition** | **Observations** |
| **High-Level Clouds**(Above 20,000 ft. (6,000 m.) | **Cirrus** | Thin and wispy | Ice crystals | Cirrus appear in fair weather. Movement tells which direction weather is approaching from.  |
|  | **Cirrostratus** | Thin, sheetlike clouds that often cover entire sky | Ice crystals | Usually come 12-24 hours before rain or snow. |
|  | **Cirrocumulus** | Long rows of small, round white puffs that sometimes resemble the scales of a fish | Ice crystals | In the winter they indicate fair, but cold weather; in tropical regions, they may indicate an approaching hurricane. |
| **Mid-Level Clouds**(6,500 to 20,000 ft. (2,000 to 6,000 m.) | **Altostratus** | Gray or blue-gray mid level clouds that cover entire sky. | Ice crystals and water droplets | Often form ahead of storms with continuous rain or snow. |
|  | **Altocumulus**  | Parallel bands or gray rounded masses | Water droplets; some ice when temperature is cold enough | When seen in morning, thunderstorms may follow later in the day. |
| **Low-Level** **Clouds** (Below 6,500 ft. (2,000 m.) | **Stratus** | Uniform grayish clouds that resemble fog;often cover the entire sky | Water droplets | Light mist or drizzle sometimes falls out of these clouds. |
|  | **Stratocumulus** | Rows of gray puffy clouds with blue sky visible in between them | Water droplets | On rare occasions, accompanied by rain. |
|  | **Nimbostratus** | Dark, low-altitude clouds with precipitation | Water droplets; some ice or snow when temperature is cold enough | Accompanied by light to moderate precipitation. |
| **Vertically Developed Clouds** | **Cumulus (Fair weather clouds)** | Floating cotton balls with flat bases and clear outlines | Water droplets | Cloud tops designate limit of rising air. These clouds can develop into giant cumulonimbus clouds. |
|   | **Cumulonimbus** | Forms towers that can reach 39,000 ft. (12,000 m.) or higher. | Water droplets and ice crystals | Associated with powerful thunderstorms known as supercells. |
| **Special** | **Mammatus Clouds** | Low hanging bulges that droop from cumulonimbus clouds. | Water droplets and ice crystals | Usually associated with severe weather. |
|  | **Lenticular clouds** | Like discs or flying saucers that form near mountains |  | Caused by a wave wind patterns created by the mountains. |
|  | **Fog**  | A cloud on the ground | Tiny water droplets floating in the air | Fog exists when the visibility near the Earth's surface is reduced to ½ mile (1 km) or less. |
|  | **Contrails** | Condensation trails left behind jet aircraft | Hot humid air from jet exhaust mixed with cold air at high altitudes | The mixing is a result of turbulence generated by the engine exhaust. |
|  | **Fractus clouds**  | Small, irregular cloud fragments found below a cloud base | They are torn off larger clouds by strong winds | They change constantly, often forming and dissipating rapidly. |
|  | **Green Clouds**  | Clouds with a green caste to their color | The green color may have to do with the high amount of water drops and hail inside the cloud. | A rare color variation often associated with severe weather likely to produce hail and tornadoes. |

**Cloud Seeding** is the process where substances like silver iodide and dry ice are spread on clouds in an attempt to make precipitation fall. These chemicals lower the temperature in the cloud and provide ice crystals, which become “seeds” for the liquid water in the cloud. Water freezes on the ice crystals and grow as the ice crystals clump together. When they become heavy enough, the ice crystals fall and create snow. If they melt before reaching the ground, they become rain.Cloud seeding may cause more problems than it solves. Even the most dramatic rainfall increases amount to only about 5 to 20%. If cloud seeding is done incorrectly, it can even reduce the amount of rain that might have fallen by dissipating clouds.

**PRECIPITATION**

When the droplets of water in a cloud become too heavy to remain suspended in the air, they fall to Earth as precipitation. Precipitation can take a variety of forms, including rain, hail, freezing rain, sleet, and snow. Because of pollution, today precipitation also falls as acid rain.

**Rain:** Rain develops when growing cloud droplets become too heavy to remain in the cloud and fall toward the surface as a liquid. Rain can also begin as ice crystals that form large snowflakes high in the air. When the falling snow passes through the freezing level into warmer air, the flakes melt and form raindrops.

**Hail:** Hail is a large frozen raindrop produced by intense thunderstorms, which have a strong central updraft where both snowflakes and raindrops can exist. As snowflakes fall, liquid water freezes onto them forming ice pellets that grow as more and more droplets are accumulated. When the ice pellets reach the bottom of the cloud, some of them are carried back up to the top of the storm by the updraft. As these ice pellets, which are now called hailstones, fall through the cloud again, another layer of ice is added and the hailstones grow even larger. Typically the stronger the updraft, the more times a hailstone repeats this cycle and the larger it grows. When a hailstone becomes too heavy to be supported by the updraft, it falls out of the cloud toward the ground. A hailstone reaches the ground as ice because it doesn’t spend enough time in the warm air below the thunderstorm to melt.

**Freezing Rain**: Freezing rain develops when falling snow reaches a layer of warm air that melts the snow completely and turns it into rain. As the rain continues to fall, it passes through a thin layer of cold air close to the ground that cools the raindrops to a temperature below freezing, although the drops themselves remain in a liquid form. This is called **supercooling**. When the supercooled drops strike a cold surface such as a power line or a tree branch or even the frozen ground, the drop breaks apart and the water freezes instantly, forming a thin film of ice. An accumulation of freezing rain can create dangerous situation known as an **ice storm.** Freezing rain is often difficult to see, but it can cause automobile accidents and power outages.

**Sleet:** Sleet is made up of frozen raindrops that bounce when they hit the ground, causing the surface to become very slick. Sleet is smaller than hail and less common than freezing rain.

**Snow:** Snow is made up of ice crystals that gather together as they fall toward the ground. The snowflakes formed by these ice crystals generally have a hexagonal pattern, although it is said that no two snowflakes look exactly alike. If enough snow falls it forms a white layer that covers the ground. In fact, about 23% of the Earth's surface is either permanently or temporarily covered with snow. This snow cover increases the amount of solar radiation the Earth reflects and makes the climate colder. This has a significant effect on the lives of plants, animals, and humans.

**Lake effect snow** is a weather event that can produce tremendous amounts of snow. For example, during four days in November 2014, nearly 7 feet (2m.) of snow fell on the eastern shore of Lake Eire near Buffalo, NY. Lake effect snow occurs when cold, dry winds blow across the warm surface of a large body of water, such as one of the Great Lakes. The colder, drier air flowing above the lake’s surface causes the warmer water of the lake to evaporate, increasing the amount of moisture in the air. This water vapor condenses in the cold air to form clouds of ice crystals, which are transported toward shore. When these clouds reach the shoreline, the snowflakes fall as precipitation.

**Acid rain** is a broad term that describes precipitation, including snow or fog that contains high levels of nitric and sulfuric acids. These acids are formed when chemicals such as sulfur dioxide (SO2) and nitrogen oxides (NOx) are released into the atmosphere by natural sources, such as decaying vegetation or volcanoes, or by man-made sources, such as power plants that burn coal or other fossil fuels. These gases react with water, oxygen, and other chemicals in the atmosphere to form various acidic compounds. The major danger of acid rain is the damage it causes to lakes, streams, wetlands, and forests. Acid rain makes waters acidic, which is toxic to fish, shellfish, and other aquatic animals. It also damages the needles and leaves of trees and makes them more venerable to pests and disease. Acid rain also accelerates the decay of building materials and paints on buildings, statues, and sculptures.

A **Rain Shadow** occurs when a mountain range causes the region downwind of the mountain range to have less precipitation than the windy side of the mountain. This is because mountains cause moist air masses carried by the prevailing winds to rise. As they rise, the moisture cools and drops on the side of the mountains facing the prevailing winds. This leaves less moisture in the air mass available to fall on the other side of the mountains. This is why "rain-shadow deserts" are common on the downwind side of mountain ranges.

**STORMS**

A **storm** is a violent disturbance of the atmosphere characterized by low barometric pressure and strong winds, and often accompanied by rain, snow, hail, thunder, and lightning, or flying sand or dust. A **storm cell** is the smallest unit of a storm system. It is an air mass that contains powerful updrafts and downdrafts moving in convective loops. A storm cell moves and reacts as a single entity. The types of storms discussed here include thunderstorms, tornados, snowstorms, and hurricanes.

**THUNDERSTORMS**

A thunderstorm is a rain shower that is accompanied by the sound of thunder. Thunder is caused by lightning, so even if you don’t see it, all thunderstorms have lightning.

Thunderstorms are formed when warm and humid air near the Earth’s surface is lifted either by being heated by the sun, or when two different air streams meet, or when air is forced uphill by the landscape. As the humid air rises it cools and water droplets in the air condense to form a cumulonimbus cloud. If there is further uplifting, the cloud will extend higher and the water droplets in the cloud will continue to grow in size and eventually form ice crystals. As the warm air rises, it displaces colder air, which sinks. The warm air also transfers heat from the land’s surface to upper levels of the atmosphere through the process of convection. This movement of heat and moisture makes the air is very unstable.

**Thunder and Lightning** Because the air in the cloud is very unstable, the water droplets and ice crystals collide and break up and become electrically charged. Because there are so many of these collisions, big regions of electric charges build up in the cloud. Usually, the upper portion of a cloud is positively charged and the middle and lower portions are negatively charged. When the electric voltage between these positive and negative charges becomes large enough, a bolt of lightning is discharged between clouds or between a cloud and the Earth's surface. The temperature of a bolt of lightning is over 40,000 degrees Fahrenheit (22,204°C ). It heats the air along its path, which causes it to expand rapidly. This creates the sound waves we hear as thunder.

**Severe thunderstorms** A thunderstorm is classified as severe when it accompanied by one or more of the following: hail with a diameter of an inch or more, winds gusting up to more than 50 knots (57.5 mph), or a tornado. It is estimated that there are about 16 million thunderstorms each year throughout the world, which means that there are roughly 2,000 thunderstorms in progress at any one time. About 100,000 thunderstorms occur each year in the U.S., most often during the afternoon and evening in spring and summer. About 10,000 of these are classified as severe.

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| **How Close Is That Thunderstorm?**It is very simple to estimate how far away a thunderstorm is. Thunder is the sound of the rapid expansion of the atmosphere caused by the heat of a bolt of lightening. Although lightning and thunder occur at almost the same moment, light travels much faster than sound. You always see lightning before you hear the thunder. You can take advantage of this difference and estimate how far away the thunderstorm is. Simply count the seconds between the flash and the thunder. If the sound of thunder reaches you after 5 seconds, the storm is about one mile away. You can divide the number of seconds you count by 5 to get the number of miles. If the sound takes three seconds to arrive after a lightning flash, the thunderstorm is about 1 km away. Divide the number of seconds you count by 3 to get the number of kilometers. If you see lightning and hear thunder at the same time, the storm is too close. Get indoors or some place safe! |

**The Life Cycle of a Thunderstorm**

Many thunderstorms have a three-stages life cycle. The **developing stage** begins when warm air is pushed upward by a rising column of air (an **updraft**). As the air rises it cools and condenses into a cumulus cloud. As the updraft increases the cumulus cloud begins to look like a tower (called a towering cumulus). Its edges are sharp and distinct, indicating that the cloud is composed primarily of water droplets. During this stage there is little to no rain but there may be occasional flashes of lightning.

The thunderstorm enters its **mature stage** once the cloud reaches the freezing level in the atmosphere and precipitation begins. Falling precipitation creates a column of air pushing downward (a **downdraft**), which spreads out along the ground it forms a line of gusty winds known asa **gust front**. During this phase of the life cycle, the top of the cloud (now a cumulonimbus cloud) starts to flatten out, forming an anvil shape at high altitude. This is the stage when heavy rain, hail, frequent lightning, strong winds, and tornadoes are most likely to occur.

Eventually, the amount of precipitation becomes so large the downdraft overcomes the updraft and the cloud begins to collapse. This is the thunderstorm’s **dissipating** or **decaying stage**. Water droplets in the cloud freeze into ice crystals and stop releasing heat. On the ground, the gust front moves away from the storm center and cuts off the warm moist air that was feeding the thunderstorm. Also, the shadow of the cloud and the downdrafts reduce the temperature below the cloud and stops the updraft. The edges of the cloud look hazy or diffuse as the cloud slowly disintegrates. Rainfall decreases in intensity, but lightning still remains a danger.

**Components of a thunderstorm**

Thunderstorms are complex systems and change rapidly. But certain features are required to make the system work.

**Updrafts and Downdrafts** Air in a cloud will rise when it is warmer than its surroundings and heat released by condensation within the cloud will keep that warm air rising. In a thunderstorm this upward moving air is known as an **updraft**. Similarly, air that is cooler than its surroundings tends to sink. This downward moving air is a **downdraft**.

Both updrafts and downdrafts can be strong or weak, depending on the instability of the air. A storm may contain a strong or a weak version of either an updraft or downdraft, but a storm with strong versions of both is most likely to produce destructive downbursts, hail, heavy rain, and tornadoes. Measuring the strength of updrafts and downdrafts can help identify the type of thunderstorm and its potential severity.

**Shelf Clouds** and **Wall Clouds**

Thunderstorms produce several different kinds of clouds, including shelf clouds and wall clouds, which are discussed here. Thunderstorms also produce funnel clouds and tornadoes, which are discussed below.

A **shelf cloud** resembles a wave and is often associated with a solid line of storms, known as a squall line. These clouds are caused by an outflow of cold air rushing ahead of a storm. They are usually associated with a strong wind followed by rain. These winds can cause damage. A shelf cloud may appear to rotate on a horizontal axis and are known to produce short-lived tornadoes.

A **wall cloud** is a low-hanging that appears abruptly beneath the base of a thunderstorm, usually on the south or southwest side. A wall cloud is much smaller and more compact than a shelf cloud. It can range from a fraction of a mile in diameter to nearly five miles. Many wall clouds move upward or rotate rapidly on a vertical axis. When a wall cloud is rotating, it may produce funnels or tornadoes.

**Vertical Wind Shear**

A change in wind speed or direction at different altitudes is known as **wind shear,** and it can affect a storm's movement and life span. There are two forms of wind shear: speed shear and directional shear. Speed shear is a sudden change in wind speed due to a change in altitude. Directional shear is a change in wind direction due to a change in altitude. Depending on circumstances, wind shear can be either weak or strong. The varying strengths and configurations of vertical wind shear determine what type of thunderstorm will form, whether they are single cells, multicells or supercells.

**Microbursts**

A strong downdraft with potentially damaging winds on or near the ground that is less than 2.5 miles (4 km) in diameter is called a microburst. A microburst initially develops as a downdraft begins to descend from the cloud base of a thunderstorm. The downdraft accelerates and reaches the ground within minutes, which is where its strongest winds occur. Wind speeds as high as 150 mph (241 km/h) have been recorded. A microburst can cause as much damage as a tornado and it will pose a significant threat to nearby aircraft.

**Types of thunderstorms**

Each thunderstorm has unique characteristics, but for convenience experts divide them into four types based on the strength of the storm’s updraft. These types are:

**Single Cell Storms** (also called **pulse storms**) occur randomly and typically only last for only 20 to 30 minutes. They usually do not produce severe weather, but they can produce downbursts, hail, heavy rainfall, or a weak tornado.

**Multicell Cluster Storms** are the most common type of thunderstorm. They consist of a cluster of storm cells moving as a single unit, with each cell at a different stage of the thunderstorm life cycle. Multicell storms can produce downbursts, moderate sized hail, and winds with speeds of 60 to 80 MPH. Severe weather in a multicell is less intense than in a supercell, but it can produce weak tornadoes and flash flooding.

**Squall Lines** (also called **multicell line storms**)consist of a line of storms with a continuous, well-developed front at the leading edge of the line. These storms can produce small to moderate sized hail, occasional flash floods and weak tornadoes.

**Supercells** contain a very strong rotating updraft and are extremely dangerous. This rotation helps to produce strong downbursts, large hail, occasional flash floods, and tornadoes. Supercells usually form away from other thunderstorms, which allows them to draw more energy and moisture from a wide area. These storms are relatively rare, but they are always a threat to life and property.

**TORNADOES**

A tornado is a violently rotating column of air that descends from a thunderstorm to the ground. No other weather phenomenon can match the fury and destructive power of a tornado. They can be strong enough to destroy large buildings, leaving only the bare concrete foundation, or lift 20-ton railroad cars from the tracks. A tornado might not have a visible funnel until it picks up debris from the ground. The strength of a tornado is measured by the Enhanced Fujita Scale.

**How tornadoes form**

Scientists don't fully understand how tornadoes form, except that they are generated by supercell thunderstorms. A supercell is an organized thunderstorm that contains a very strong, rotating updraft. Producing a tornado seems to require a layer of warm, humid air and strong south winds near the ground, and colder air and strong west or southwest winds in the upper atmosphere. The differences between the temperature and moisture in the surface and the upper levels create a state of **instability**. The change in wind speed and direction with altitude is known as **wind shear,** whichis linked to the eventual development of rotation from which a tornado may form.

Sometimes a third layer of hot dry air will appear between the warm moist air at low levels and the cool dry air above. This hot layer acts as a cap and allows the warm air underneath to warm further, making the air even more unstable. If the storm system moves east and begins to lift the various layers, this cap dissipates and strong updrafts develop. Interactions between an updraft and the surrounding winds may cause an updraft to begin rotating, creating a funnel-shaped cloud extending from a thunderstorm’s cloud base, which meteorologists call a **funnel cloud**. This formation is considered a funnel cloud until it touches down on the ground. Then it becomes a tornado.

When a tornado touches down, it moves along the ground creating a path of destruction. Most tornados travel at a speed of around 30 mph (50 km/h), but their speed can range as high as 70 mph (112 km/h). The time on the ground usually doesn’t exceed 10 minutes, but it can vary from a few seconds to more than an hour. A tornado’s path is rarely more than 15 miles (24 km) long and 2.6 miles (4 km) wide.

**Where do Tornados Occur?**

Tornadoes are most common in the Deep South and in the broad, relatively flat basin between the Rockies and the Appalachians known as “**Tornado Alley**.” But tornados have occurred from New England to the far west.

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| **The Five Most Destructive Tornados in U.S. History** |
| **The Tri-State Tornado** traveled more than 300 miles through Missouri, Illinois and Indiana on March 18, 1925. Its winds reached more than 260 mph (418 km/h), killing 695 people and injuring 2,027. |
| **The Natchez Tornado** touched down along the Mississippi River in Louisiana and Mississippi on May 6, 1840. The official death toll was 317, but that may not have included slaves. |
| **The St. Louis Tornado** in Missouri and Illinois killed 255 people and injured 1,000 on May 27, 1896. Its winds ranged from 207 (333 km/h) mph and 260 mph (418 km/h). |
| **The Tupelo Tornado** in northeastern Mississippi killed 216 people and injured 700 on April 5, 1936. |
| **The Gainesville Tornado** was a pair of storms that converged in Gainesville, Georgia on April 6, 1936. The tornado completely destroyed four blocks and 750 houses in the city, killing 203 people and injuring 1,600. |

**When to Watch out for Tornadoes**

Tornado activity peaks in the U.S. in April, May, and June, but they have occurred in every month and at all times of the day or night. They are most likely to occur on a warm and humid spring afternoon or early evening.

**Measuring the Force of a Tornado**

It is practically impossible to make direct measurements of tornado winds, so Dr. T. Theodore Fujita developed the Fujita Tornado Damage Scale to provide an estimate of the wind speed based on the amount of damage a tornado caused. The first scale was introduced in 1971 and a revised version, known as the **Enhanced Fujita Scale (EF-Scale)** was adopted in 2007. The range of tornado intensities runs from EF-0, which causes very little damage, to EF-5, which causes complete destruction. The first tornado classified as EF-5 in the U.S. touched down in Greensburg, Kansas on May 4th, 2007.

|  |  |  **The Enhanced Fujita Scale** |
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| **EF-Scale** | **Wind Speed** | **Typical Damage** |
| EF–0 | 65–85 mph | Light damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over. |
| EF–1 | 86–110 mph | Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken. |
| EF–2 | 111–135 mph | Considerable damage. Roofs torn off well–constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light–object missiles generated; cars lifted off ground. |
| EF–3 | 136–165 mph | Severe damage. Entire stories of well–constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations blown away some distance. |
| EF–4 | 166–200 mph | Devastating damage. Whole frame houses Well-constructed houses and whole frame houses completely leveled; cars thrown and small missiles generated. |
| EF–5 | More than 200 mph | Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air further than 300 feet (100m); high-rise buildings have significant structural deformation; incredible phenomena will occur. |
| EF No rating |  | Inconceivable damage. Should a tornado with the maximum wind speed in excess of EF–5 occur, the extent and types of damage may not be conceived. A number of missiles such as iceboxes, water heaters, storage tanks, automobiles, will create serious secondary damage on structures. |

**WINTER STORMS**

When temperatures drop during winter, precipitation that falls during a storm turns from rain to sleet or snow. Snow is formed when water vapor changes directly to ice without first becoming a liquid, high in the atmosphere at a temperature of less than 32°F and then falls to the ground. If the storm is accompanied by a heavy fall of snow, it is called a **snowstorm**.

Winter storms usually form when an air mass of cold, dry, air moves south and interacts with a warm, moist air mass moving north, forming a front. If the cold air advances and pushes away the warm air, it forms a cold front. If the warm air advances, it rides up over the denser mass of cold air and forms a warm front. If neither air mass advances, they form a stationary front.

**Types of Snowstorms**

There are several different types of snowstorms.

**Snow Squalls** are strong snowstorms accompanied by gusty winds that last a short time.

**Ice storms** produce freezing rain that accumulates on trees, buildings, and the ground. If more that ¼ inch (6.3mm) of ice accumulates, it can pull down trees and utility lines and make walking and driving extremely dangerous.

**Blizzards** are severe snowstorms with winds up to and over 35 mph (56 km/h). The winds cause blowing snow that results in low visibility and low temperatures. The difference between a blizzard and a snowstorm is the strength of the wind, not the amount of snow.

The strong winds and cold temperatures accompanying blizzards can combine to create life-threatening conditions. Traveling by automobile can become difficult or even impossible due to "whiteout" conditions and drifting snow that reduces visibility to near zero. Power outages can occur and pipes can freeze. The combination of cold temperatures and strong winds can also produce very low wind chill temperatures. Exposure to such a low wind chill can result in frostbite or hypothermia.

A **nor’easter** is a cyclonic storm that moves along the east coast of North America. It’s called *nor’easter* because the winds over coastal areas blow from a northeasterly direction. Nor’easters may occur any time of the year, but are most frequent and strongest between September and April. These storms usually develop between Georgia and New Jersey within 100 miles of the coastline and generally move toward the north or northeast. They usually become most intense near New England and the Canadian Maritime Provinces. In addition to heavy snow and rain, a nor’easter can bring gale force winds greater than 58 miles per hour (93 km/h).

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| **Biggest Snowstorms In The United States** **(1888 to Present)**  |
| March 11–12, 1888 | **Blizzard Of 1888**An unseasonable nor'easter struck from the Chesapeake Bay to Maine, paralyzing Washington, D.C., Philadelphia, Boston, and New York City. It dumped 50 inches of snow in Connecticut and Massachusetts, 40 inches in New Jersey and New York. Drifts of 40 to 50 feet high buried houses and trains. More than 200 ships were sunk and 400 lives lost. |
| November 11–12, 1940 | **Armistice Day Storm**Many people were caught off-guard when mild weather changed into a raging blizzard overnight. From Kansas to western Wisconsin sixty-degree temperatures on the morning of the 11th plunged to single digit readings by the morning of the 12th. Heavy snows fell on parts of Wisconsin, South Dakota, Nebraska, Minnesota, Iowa, and Michigan. Winds of 50 to 80 mph downed hundreds of trees and created drifts up to 20 feet high. The storm was blamed for 144 deaths. |
| March 10–14, 1951 | **The Midwest Snow Storm Of 1951**A slow moving storm system brought a prolonged period of heavy snow to much of the Midwest. Snow fell on Missouri and Iowa where snow fell for as long as 100 hours. Iowa City received more than 27 inches of snow. |
| February 1–8, 1956 | **1956 Southern Plains Snowstorm**A series of storms brought more than a week of heavy snow to the South Plains, especially Western portions of Texas and Oklahoma. Snow totals ranged from 14 inches in Amarillo, TX, to 43 inches in Vega, TX. Hundreds of cattle died and feed for remaining cattle had to be airlifted in. |
| March 22–25, 1957 | **Panhandle Blizzard Of 1957**A strong low-pressure area developed along the Rocky Mountains and interacted with cold air in place across the Plains, creating a spring blizzard across the Texas and Oklahoma panhandles. Up to 20 inches of snow fell, with snow drifts up to 30 feet high. Even snowplows were stranded. An estimated 20 percent of the cattle were lost to this storm. |

**HURRICANES AND TROPICAL CYCLONES:**

Meteorologists define a **tropical cyclone** as a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters. It is an area of low pressure around which the winds flow counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The winds associated with cyclones move heat and moisture from lower to higher latitudes and play a significant role in the movement of air masses. Tropical cyclones are more commonly found in the northern hemisphere, but they occur in the southern hemisphere in both the Pacific and Indian Oceans.

Once a tropical cyclone reaches maximum sustained winds of 64 knots (74 mph) or higher, it is classified as a **hurricane**, **typhoon**, or **cyclone** depending upon where the storm originated. The name hurricane is given to systems that develop over the Atlantic or in the northern Pacific off the west coast of North America. In the western part of the Pacific and the Philippines, these systems are called typhoons*.* In the Indian Ocean and the South Pacific, they are called cyclones*.*

These hurricane-like storms can grow to as much as 400 to 500 miles (640 to 800 km) in diameter. They are capable of producing dangerous winds, torrential rains and flooding, all of which may result in tremendous property damage and loss of life in coastal populations.

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| Our modern word "hurricane" has two possible sources. It may have come from *Hurican*, the Carib name for their god of evil. The Caribs were an indigenous people living in the Caribbean islands and along the northern coast of South America. Or, the word may be derived from *Hurakan,* the name of the Mayan storm god. In either case, Spanish colonists modified the spelling to give us our word *hurricane*. |

Hurricanes are formed in the tropics by groups of thunderstorms, but these thunderstorms can only grow to hurricane strength when the ocean is warmer than 81°F (26.5°C). The heat and moisture from this warm water is the source of energy for hurricanes. The Coriolis effect causes the air near the ocean’s surface to spiral, which forces air to rise in the center, creating a low pressure system The rising air cools and moisture condenses which releases heat into the air. This heat provides the energy to fuel these storms.

Although the surface temperature of the ocean is warm enough to produce hurricanes at the equator, none form. This is because there is not enough Coriolis force to create spin needed to develop a hurricane.

**Characteristics of a Hurricane**

Hurricanes are extremely powerful storms that form over ocean water. They can cause devastating damage in coastal areas as a result of strong winds, heavy rains and flooding, high waves and storm surge.

**Strong Winds** The most obvious feature of a hurricane, and its most destructive force, are strong winds. They can uproot trees, knock over buildings, fling debris around, sink or ground boats, and flip cars. The intensity of a hurricane is measured by the highest sustained wind speed found within it. Its strength is also measured on the **Saffir-Simpson Scale** based on its greatest wind speed, which is discussed below.

**Heavy Rains and Flooding** Hurricanes are accompanied by heavy rain, which can cause both flash floods and long-term flooding. Hurricanes can drop as much as 3 feet (1 m) of rain in a day or two. Even though a hurricane deteriorates as it moves inland, it can still produce a lot of rain, which can cause serious damage.

**High Waves** and **Storm Surge** Wind also creates another problem. When a hurricane approaches land, its strong wind creates high waves and a force known as storm surge. Storm surge occurs when a hurricane’s low pressure and high winds actually raise the level of the sea. Combined with the high waves, the water can rise as much as 30 feet (10 m), causing significant flooding. The height of the storm surge varies with the intensity of the hurricane and the topography where the storm makes landfall. Storm surge can wreck homes and push boats and cars inland or pull them out to sea. Waters that flow into low-lying areas can remain for weeks.

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| **Five Deadliest Hurricanes to Hit the U.S. Mainland** |
| **The Great Hurricane of 1780:** This storm devastated Puerto Rico, the Dominican Republic, the Lesser Antilles, Bermuda, and Florida, killing over 6,000 people. *The Hermione* was out of danger to the north, but a number of French and British ships were destroyed by this storm. |
| **Galveston Hurricane of 1900:** An estimated 3,500 homes and buildings were destroyed in Galveston, Texas with a loss of over 8,000 lives. a storm surge up to 15 feet high wiped out all the buildings within five blocks of the shoreline. |
| **Southeast Florida/Lake Okeechobee Hurricane of 1928:** Okeechobee hit the Leeward Islands, Puerto Rico, the Bahamas and Florida killing about 4,078 people. The majority of the deaths were from drowning when the storm surge caused Lake Okeechobee to overflow and put the surrounding area under 10 to 15 feet of water. |
| **Hurricane Katrina of 2005:** Katrina is one of the five deadliest hurricanes in U.S. history. At least 1,836 people died, mostly in New Orleans and Mississippi, but the storm spanned over the Bahamas, Florida and Gulf of Mexico. It sent a huge storm surge into the Mississippi, southeast Louisiana and Alabama coasts, which left behind catastrophic destruction. The levees protecting New Orleans failed, resulting in flooding 80 percent of the city with water depths up to 20 feet. |
| **Cheniere Caminanda Hurricane of 1893** This Category 4 hurricane cause nearly 2,000 deaths in southeast Louisiana. The storm surge swept many houses away as far away as Mobile, Alabama. |

**The Life Cycle of a Hurricane**

Over time hurricanes evolve through a series of stages. They usually begin over tropical ocean waters as a cluster of thunderstorms known as a **tropical** **disturbance.** If the circulation in the center of the tropical disturbance begins to organize and the pressure begins to fall, it becomes a **tropical depression.** From a satellite a tropical depression looks like a group of individual thunderstorms that are grouped together, rather than having the round appearance of a hurricane. Wind speeds near the center are between 20 and 34 knots (23 to 39 mph).

If a tropical depression becomes more organized and becomes more circular in shape, and its maximum sustained winds are between 35 and 64 knots (39 to 73 mph), it is classified as a **tropical storm.** Its shape begins to resemble a hurricane and its rotation is more recognizable. A tropical storm can cause serious problems even without becoming a hurricane, especially because it can produce heavy rainfall. This is the stage when the storm is assigned a name.

As surface pressures continue to drop, a tropical storm becomes a **hurricane** when a pronounced rotation develops around the central core and its sustained wind speeds reach 64 knots (74 mph). A hurricane is easily identified in satellite or radar images by its clear rotation around a dark spot in the middle called the eye. This feature is unique to hurricanes.

Hurricanes often persist for as much as two or three weeks. They can produce dangerous winds, torrential rains, and flooding, which may cause tremendous property damage and loss of life in coastal areas. Hurricanes eventually lose intensity and fall apart when they pass over land or cooler waters.

**The Structure of a Hurricane**

A mature hurricane has a nearly circular shape. Its center is called the **eye**. Surrounding the eye is a region of intense winds and rainfall called the **eye wall.** Large bands of clouds and precipitation, called **spiral bands,** corkscrew out from the eye wall. The storm’s hurricane strength winds usually extend about 100 miles (161 km) across, although its tropical storm force winds may range as far out as 300 miles (500km) from the hurricane’s center.

**The Eye** The eye is the feature of a hurricane that is the most easy to recognize. On satellite images or radar it appears as a dark spot near the center of the storm. The eye is the focus of the hurricane, the point about which the rest of the storm rotates and where the lowest surface pressures are found in the storm. It is usually between 12 miles (20 km) and 30 miles (50 km) in diameter.

Somewhat surprisingly, the eye is actually the calmest part of any hurricane. Skies are often clear above it and winds are relatively light. The eye is calm because the strong surface winds that converge towards the center of the hurricane never reach it. The Coriolis force deflects the wind away from the center, causing the wind to rotate around the center of the hurricane, forming the eye wall and leaving the eye calm.

**The Eye Wall** The eye wall is a vertical wall of clouds that surrounds the eye. This is where the hurricane’s most damaging winds and intense rainfall are found. This is because surface winds are rushing from all directions toward the center of the hurricane. This forces the air at the center upwards. The Coriolis force deflects these winds (in the Northern Hemisphere, the deflection is to the right) and they circle the center, creating the eye wall. The convergence of these winds at the eye wall is so strong, the air is lifted faster and with more force than any other part of the hurricane. This produces the highest wind speeds and the heaviest rain.

**Spiral Bands** When seen from above, a hurricane may display bands of clouds radiating out from the eye wall with gaps between them. These clouds are called **spiral rain bands** or just **spiral bands**. The air in these spiral bans is rising and rain is falling. The air in the gaps is dry and sinking. This alternation of rain and dry areas is common in hurricanes.

**Pressure and Winds** Wind speed and atmospheric pressure change as you move toward the center of a hurricane. As you near the eye wall, wind speed rises and pressure gradually falls. Wind speed reaches its maximum within the eye wall, but inside the eye, the winds become very light, sometimes even calm. The surface pressure continues to drop in the eye wall and reaches its lowest level in the center of the eye.

**Movement of Hurricanes**

The path a hurricane follows depends upon where it originates. Its movement depends on the prevailing winds in that location, such as the Trade Winds in the Pacific or the Westerlies in the Atlantic. For example, most hurricanes originating in the eastern tropical Atlantic are driven westward by the prevailing winds. Eventually, these storms turn northwest and migrate to higher latitudes. As a result, the Gulf of Mexico and the East Coast of the United States are at risk of being hit by hurricanes every year.

**Hurricane Names**

Hurricanes occur every year and sometimes two or three hurricanes can be active at the same time. Using names for these storms makes it easier to communicate about specific hurricanes. The World Meteorological Organization assign names in alphabetical order to each tropical storm when it is discovered. Names can be repeated after an interval of six years, but the names of especially severe storms are permanently retired from use.

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| **Atlantic Names** |
|  | **2015** | **2016** | **2017** | **2018** | **2019** |
|  | AnaBillClaudetteDannyErikaFredGraceHenriIdaJoaquinKateLarryMindyNicholasOdettePeterRoseSamTeresaVictorWanda | AlexBonnieColinDanielleEarlFionaGastonHermineIanJuliaKarlLisaMatthewNicoleOttoPaulaRichardSharyTobiasVirginieWalter | ArleneBretCindyDonEmilyFranklinGertHarveyIrmaJoseKatiaLeeMariaNateOpheliaPhilippeRinaSeanTammyVinceWhitney | AlbertoBerylChrisDebbyErnestoFlorenceGordonHeleneIsaacJoyceKirkLeslieMichaelNadineOscarPattyRafaelSaraTonyValerieWilliam | AndreaBarryChantalDorianErinFernandGabrielleHumbertoImeldaJerryKarenLorenzoMelissaNestorOlgaPabloRebekahSebastienTanyaVanWendy |

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| **Eastern North Pacific Names** |
| **2015** | **2016** | **2017** | **2018** | **2019** |
| AndresBlancaCarlosDoloresEnriqueFeliciaGuillermoHildaIgnacioJimenaKevinLindaMartyNoraOlafPatriciaRickSandraTerryVivianWaldoXinaYorkZelda | AgathaBlasCeliaDarbyEstelleFrankGeorgetteHowardIsisJavierKayLesterMadelineNewtonOrlenePaineRoslynSeymourTinaVirgilWinifredXavierYolandaZeke | AdrianBeatrizCalvinDoraEugeneFernandaGregHilaryIrwinJovaKennethLidiaMaxNormaOtisPilarRamonSelmaToddVeronicaWileyXinaYorkZelda | AlettaBudCarlottaDanielEmiliaFabioGilmaHectorIleanaJohnKristyLaneMiriamNormanOliviaPaulRosaSergioTaraVicenteWillaXavierYolandaZeke | AlvinBarbaraCosmeDalilaErickFlossieGilHenrietteIvoJulietteKikoLorenaMarioNardaOctavePriscillaRaymondSoniaTicoVelmaWallisXinaYorkZelda |

**Hurricane Categories**

The intensity of a tropical storm is measured by the highest sustained wind speed found within it. Once it becomes a hurricane, its relative strength can be measured on a scale based on its greatest wind speed. This scale is named the Saffir-Simpson Scale for the men who invented it.

The Saffir-Simpson Scale categorizes hurricanes on a scale from 1 to 5 with category 1 being the weakest and 5 the most intense. Since 1900, only been two category 5 hurricanes have made landfall on the mainland U.S.—Florida Keys in 1935 and Camille in 1969.

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| **The Saffir-Simpson Scale** |

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| --- | --- | --- | --- | --- |
| **Category** | **Wind Speed**mi/hrknots | **Storm Surge**feetmeters | **Central Pressure**mbinches | **Observed****Damage** |
| **1** | 74–9564–82 | 4–5~1.5 | >=980>=28.94 | Some damage to trees, shrubbery, and unanchored mobile homes. |
| **2** | 96–11083–95 | 6–8~2.0–2.5 | 965–97928.50–28.91 | Major damage to mobile homes; damage buildings' roofs, and blow trees down. |
| **3** | 111–13096–113 | 9–12~2.5–4.0 | 945–96427.91–28.47 | Destroy mobile homes; blow down large trees; damage small buildings. |
| **4** | 131–155114–135 | 13–18~4.0–5.5 | 920–94427.17–27.88 | Completely destroy mobile homes; lower floors of structures near shore are susceptible to flooding. |
| **5** | >"155">"135" | >"18">"5.5" | <"920"<"27.17" | Extensive damage to homes and industrial buildings; blow away small buildings; lower floors of structures within 1500 feet (500m) of shore and less than 15 feet (4.5m) above sea level are damaged. |

**WATCHES AND WARNINGS**

The National Weather Service issues watches and warnings to alert people when dangerous weather is approaching.

**Watches** are issued to notify people that severe weather is possible.

**Warnings** are issued when severe weather has been observed, and people should take immediate steps to protect themselves.

The different kinds of watches and warnings are listed here, but in some cases atmospheric conditions change so rapidly there is no time to issue a watch or warning. It is best to stay informed about local conditions.

**Thunderstorms**

**Severe Thunderstorm Watch—**Conditions are right for the formation of severe thunderstorms, even if the sky is clear where you are.

**Severe Thunderstorm Warning—**The area is experiencing or will soon be experiencing severe thunderstorm conditions, including high winds and hail.

**Tornados**

**Tornado Watch—** Circumstances are favorable for thunderstorms to produce tornadoes.

**Tornado Warning—**A tornado has been sighted on the ground or Doppler radar indicates a tornado is nearby. When you hear a tornado warning, take cover immediately.

**Flash Floods**

**Flash Flood Watch—**The situation is right for flash flooding to occur. Sometimes the rain may be occurring upstream, and not overhead, so be careful around low-lying areas.

**Flash Flood Warning—**Flash flooding is occurring or is imminent. Move to higher ground.

**Freezes**

**Frost Advisory—**Frost advisories are issued when Temperatures are expected to be near or just above freezing. Tender plants could be harmed by the frost.

**Freeze Watch—**Temperatures at or below freezing are possible.

**Freeze Warning—**Temperatures are expected to be at or below freezing and could harm or kill plants.

**Winter Storms**

**Winter Storm Watch—**Intense winter weather conditions are expected within the next 12 to 36 hours. A winter storm includes heavy snow, sleet, freezing rain, or any combination of these.

**Winter Storm Warning—**Significant winter weather conditions are happening or will happen very soon.

**Winter Weather Advisory—**Winter weather is expected, but the snow, sleet, or freezing rain accumulations are not expected to be hazardous.

**Tropical Storms**

**Tropical Storm Watch—**Tropical storm force winds (39 to 73 mph, 63 to 117 km/h) are expected within the next 36 hours.

**Tropical Storm Warning—**Tropical storm winds (39 to73 mph, 63 to 117 km/h) are expected within 24 hours or less.

**Hurricanes**

**Hurricane Watch—**Hurricane-like conditions and winds (74 mph, 119 km/h, and above) are expected within the next 36 hours. If the hurricane force winds are expected beyond coastal areas, an Inland Hurricane Watch will be issued for areas that could be affected.

**Hurricane Warning—**Hurricane-like conditions and winds (74 mph, 119 km/h, and above) are expected within the next 24 hours or less.

**OTHER ATMOSPHERIC PHENOMENA:**

**Rainbows, Sunsets, Halos, and Auroras**

When light from the sun or moon enters the atmosphere, it interacts with particles in the air and produces colorful effects in the sky. These particles include the molecules of the air itself, dust and haze, ice crystals, and water droplets.

**Air molecules** cause the sky to be blue. Molecules of oxygen and nitrogen scatter violet and blue light throughout the atmosphere, which gives the sky its blue appearance.

**Dust and haze** interact with light with sunlight to produce sundogs, sun pillars, and the colors we see at sunset. **Sundogs** are two brightly colored spots that appear on either side of the sun. They are visible when the sun is near the horizon and ice crystals refract the sunlight. A **sun pillar** is a vertical shaft of light that extends upward or downward from the sun. Typically seen during sunrise or sunset, sun pillars form when sunlight reflects off the surfaces of ice crystals associated with thin, high-level clouds.

When the sun nears the horizon at **sunset,** sunlight enters the atmosphere at a low angle and has to pass through more air before you see it. The molecules of air scatter the shorter violet and blue wavelengths of light. Only the longer wavelengths of yellow, orange and red light can pass through the atmosphere, and they produce colorful sunsets and sunrises. If there is smoke and dust in the atmosphere, they also scatter the shorter violet, blue, and yellow wavelengths of light. Therefore you see only the longer wavelengths and that makes the sun look orange-red. When an unusual amount of dust and ash particles are injected into the atmosphere by a volcanic eruption, red sunsets can be seen for weeks or more.

**Ice crystals** cause halos to appear. A **halo** is a ring of light surrounding the sun or moon. Most halos appear as bright white rings but sometimes a halo can have color. Halos form when light from the sun or moon is refracted by ice crystals associated with thin, high-altitude clouds, such as cirrostratus clouds.

**Water droplets** interact with light with water droplets to create rainbows. **Rainbows** occur when rain is falling in one part of the sky and the sun is shining in another. Sunlight is refracted by each raindrop, which causes different wavelengths of visible light to separate into individual colors (red, orange, yellow, green, blue, indigo, and violet). The wavelengths of red light are longer and are bent the least. The shorter violet wavelengths are bent the most. A rainbow is visible when the sun is shining through air containing water spray or raindrops, which occurs during or immediately after a rain shower.

You can only see the colored bands a rainbow if you are facing the falling rain with the sun behind you. Sometimes you will see more than one rainbow. The brightest rainbow is known as a **primary rainbow** and its colors run from red on the outside to violet on the inside. The colors in the other rainbows, known as the **secondary rainbows**, are not as bright and run in the opposite order, from violet on top to red on the bottom.

**Auroras** are shimmering sets of streamers or arches of light that appear in the upper atmosphere of a planet's magnetic polar regions. On Earth auroras in the Northern Hemisphere are called **aurora borealis** or **northern lights**. In the Southern Hemisphere they are called **aurora australis** or **southern lights**. Auroras are caused by the interaction of energetic particles (electrons and protons) from the sun with gases in the **ionosphere**. This region is the lowest level of the thermosphere and gets its name from the fact it contains large numbers of ions. When the solar wind hits the atmospheric gases in the ionosphere, they get very excited and produce beautiful colors. During periods of intense solar activity, auroras occasionally extend south to the middle latitudes.

**V. MODERN WEATHER FORECASTING**

Accurately predicting what the weather will be in the future is a difficult job. The atmosphere is a very complex system and predicting weather conditions requires an understanding the processes in the atmosphere that are producing the current weather. The first step is to measure temperature, pressure, wind direction and speed, humidity, cloud cover, and precipitation, if there is any. Observing how these elements change over time and comparing them with historical patterns will allow you to estimate future weather conditions and make an accurate forecast. Forecasters have a variety of tools that help them gather information, and several different methods for making their predictions.

**FORECASTING TOOLS**

There is a wide array of tools available for collecting and evaluating the information needed by modern forecasters, including balloons, radar, satellites, weather stations, weather buoys, and computers.

**Weather balloons** carrying various instruments have been used regularly to observe conditions in the atmosphere since the late 1930s. Today they carry an instrument known as a **radiosonde**. It measures temperature, humidity, pressure, and other aspects of the atmosphere and sends the information needed for forecasting back to stations on the ground. Twice each day, radiosondes are released into the atmosphere from about a thousand locations around the world.

**Airplanes** also supply information about the weather at high altitude. Commercial flights transmit information about temperature, pressure, humidity, and wind, which meteorologist use to map atmospheric winds and jet streams. AMDAR, which stands for Aircraft Meteorological Data Relay, is an international program that collects weather information using instruments on commercial aircraft.

**Radar** plays an important role in weather forecasting. These devices send out and receive signals that determine the direction and distance of objects from the radar site. They can provide valuable information about the location and intensity of rain or snow, and severe weather.

**Doppler radar** gets its name from the Doppler effect, which is the increase or decrease in the frequency of sound or light waves that occurs when the source and observer move toward or away from each other. For example, you may have noticed that a siren has a higher pitch when it is approaching you than when it is going away. This is because of the Doppler effect or the Doppler shift. Doppler Radar uses this effect to measure changes in the frequency of the signal it receives to detect the intensity of precipitation, the direction and speed of the wind, and estimate of the amount of rainfall or the size of hail. With Doppler radar, meteorologists are able to forecast when and where severe thunderstorms and tornadoes are developing.

**Weather satellites** are designed to monitor the weather and climate of the Earth, but they also collect a wide variety of environmental information, including the extent of snow or ice cover, and the effects of pollution. Some satellites orbit the poles, covering the same strip of the Earth every 12 hours. Others, known as geostationary satellites, track weather in a single area by moving at the speed of the Earth's rotation. These satellites can trace weather patterns, such as hurricanes, over the entire part of the globe they orbit. Meteorological satellites can also see city lights, wildfires, erupting volcanoes, and ocean currents.

A **weather station** is a device that takes meteorological observations, including measuring precipitation, evaporation, and temperature. The information is transmitted to the National Weather Service, which uses them to develop a consistent weather picture of what has occurred in the local area for a specific period, usually 24 hours. Many weather stations in the U.S. are part of the **National Weather Service’s Cooperative Observer Program.** Volunteer weather observers in all 50 states, Puerto Rico, and the Virgin Islands, take weather observations seven days a week throughout the year. The information they collect is used for such things as water and land management, environmental impact studies, energy production and use, and agriculture and farm management. More information is available at: http://www.nws.noaa.gov/om/coop/become.htm

**Weather buoys** are automated devices designed to measure and transmit information about the weather, such as temperature, barometric pressure; wind direction, and speed, and about the sea, including temperature and information about waves. Buoys operated by the U.S. are moored from the western Atlantic to the Pacific Ocean around Hawaii, and from the Bering Sea to the South Pacific.

**Computers** are used in combination with observation and knowledge of trends and patterns to create a. forecasting. The information gathered by radar, satellites, and weather stations is entered into large computers (in the U.S most are run by the National Weather Service), which create forecast models based on complex formulas. These models are used by weather and news services in preparing daily forecasts. There are several types of models:

**Climate models** are used primarily to forecast substantial changes in the Earth's climate and large-scale weather conditions such as El Nino or monsoons.

**Mesoscale models** usually deal with atmospheric conditions ranging from 1 mile (2 km) to 12.5 miles (20 km) away and are used to forecast local weather.

**Dynamic models** use advanced equations of the atmosphere to predict changes in the weather based on current conditions. They are the most sophisticated and costly tools used to forecast the weather and are most accurate for three- to five-day forecasts.

**Statistical models** use data from previous storms and weather conditions to help meteorologists get a better idea of how to track current weather systems.

Computer models can be effective tools for weather forecasting, but they are not perfect. Long-range forecasts (beyond a week) are usually less accurate because so many factors can affect the atmosphere as more time passes.

**METHODS OF FORECASTING**

After the information has been collected, meteorologists have a number of different methods for preparing a forecast. In part, the choice of a method depends the information available to the forecaster and how accurate a forecast is needed.

**Persistence Forecasting**

The persistence method is the simplest way to forecast the weather. It assumes that the weather conditions existing when the forecast is made will not change in the future. The persistence method works well when weather patterns change very little or very slowly, but if weather conditions change a great deal from day to day, the persistence method is unlikely to provide an accurate forecast. Even so, the persistence forecast method can be very useful in making long-range weather predictions and climate forecasts. Forecasts for monthly and seasonal weather conditions take advantage of the fact that over the long term, weather events tend to average out. One cold month is likely to be followed by another.

**Steady-state** or **Trend Forecasting**

The simplest way to produce a forecast is to assume that current conditions are not likely to change very much in the future. A forecaster looks for changes in the fronts, air masses, and high and low pressure systems that are affecting an area. He or she then makes a forecast based on the assumption that these changes will continue at the same rate they have been occurring. The steady-state method has proven successful when used for forecasts a few minutes to several hours ahead, known as **nowcasting,** such as predicting when and where it is likely to rain, but this method’s results are less likely to be accurate over the long term.

**Climatology**

The climatology method uses a region’s average weather statistics over many years as the basis for predicting the weather for some future period. It assumes that the values for specific weather elements, such as temperature and precipitation, will not differ significantly from the values found in previous observations. Climatology can be used as a guide for making short-term forecasts (a few hours to days ahead) and long-term forecasts (30-day or 90-day forecasts, or longer). The climatology method only works well when the weather pattern is similar to what is expected for a particular time of year. If the pattern is different, the climatology method is likely to make incorrect predictions.

**Analog Method**

In meteorology, an analog is a meteorological situation from the past that can be compared to a current of future situation. For example, a forecaster making a long-range prediction about the upcoming winter may make comparisons to analog seasons that had weather conditions that were similar to those of the upcoming season. The forecaster looks for patterns on weather maps that are similar to the today’s patterns and then looks at how they changed and what sort of weather conditions they produced. Sometimes, these patterns can be used to predict the conditions for several days in advance, but this assumes that the weather will behave in the same way as it did in the past. The analog method is not always a good way to develop a prediction because it is virtually impossible to find a perfect analog. Weather features rarely appear in exactly where they appeared before and even small differences between the current time and the analog can lead to very different results.

**Numerical Weather Prediction**

Complex computer programs run on supercomputers are used in numerical weather prediction to make forecasts known as **forecast models.** These models track weather observations, such as temperature, pressure, wind, and rainfall, from many different locations.Once these observations are entered into the program, the computer can calculate what their values will be at some future time. The problem with numerical weather prediction is that forecasts produced by this method are only as good as the equations used by the computers and the accuracy of the weather observations provided to the models. Most forecasters improve the reliability of their predictions by using them with other methods in preparing their forecasts.

**How accurate are weather forecasts?**

As our understanding of atmospheric processes has advanced and computer models have improved, weather forecasting has become more accurate. Temperature forecasts for the next day are usually correct within a margin of three or four degrees. But forecasts for a week from now or further ahead are much less likely to be right. However, forecasts of hurricane movements have improved to the point that they can be used to anticipate landfall several days in advance. Improvements in our knowledge and technology will continue, but the atmosphere is very complex and completely accurate forecasts are still sometime in the future.

**Reading a Weather Map**

Weather maps that appear on TV or the Internet, or in a newspaper show what is happening in the atmosphere at a particular time and place on the Earth’s surface. These maps usually have areas marked with a large **L** or **H** with lines circling around them. The letters indicate the area where the air pressure is lowest (**L**) or highest (**H**).

**Isobars** The lines circling the letters are called **isobars**. They join regions that have the same air pressure and can tell you a few things about the wind. First, isobars indicate the general direction of the wind because the wind flows along the isobars. In the Northern Hemisphere this flow is counter-clockwise around lows and clockwise around highs. In the Southern Hemisphere the wind flows in the opposite direction. Isobars also indicate the intensity of the wind. The basic rule is, the closer together the isobars are, the stronger the wind is.

Isobars make shapes and patterns. When they enclose an area of low pressure this is called a **Low** or a **depression**. When isobars enclose an area of high pressure it is called a **High**. Elongated areas of low pressure are known as **troughs**. Elongated areas of high pressure are called **ridges**. Generally, precipitation is most likely to fall in the place with the lowest pressure. Areas with high pressures are usually clear and sunny.

**Fronts** A front marks the boundary between two air masses. On a weather map a **cold front** is indicated by a line with triangles pointing in the direction it is moving. Cold fronts slide under the warmer air ahead of them, forcing the warm air upwards, making clouds and areas of rain. A **warm front** is represented by a line with semicircles pointing in the direction it is moving.

An **occluded front** is shown by a line with triangles and semicircles on the same side. It occurs when a cold front overtakes a warm front and traps warm air above it. When this warm air cools, it produces clouds and rain. A **stationary front** is marked by a line with alternate triangles and semicircles on opposite sides. The triangles protrude in the direction of the warmer air mass and the semicircles protrude toward the cooler. This type of front moves very slowly.

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| **Weather Aps**A free weather application may come with your cell phone, tablet, or other device, or may be available from a nearby television station. These aps usually provide information on the current weather conditions in your local area, forecasts for tomorrow’s weather, longer-range five- to seven-day forecasts, and weather warnings when they appear. They often include simplified weather maps or charts as well. |

**VI. CLIMATE**

As you certainly know, terms like "climate change" and "global warming" have become controversial and are often misunderstood. To understand these terms and the controversy that surrounds them requires understanding the complex processes that affect Earth’s climate.

**What Is Climate?**

Wherever you live, the weather changes from day-to-day, but over the years, the same type of weather will occur again and again. The reoccurring "average weather" found in any particular place over a long time is called **climate**. Climate is a description of all the weather conditions over a period of time. Currently scientists measure the temperature, precipitation, and wind in a place over 30 years to determine what its climate is. This length of time tends to smooth out year-to-year variations. When a weather report tells you what the normal high and low temperature for your location should be, those numbers are based on an average of the temperatures taken over the last 30 years.

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| **How is climate different from weather?****Weather** describes atmospheric conditions over a short period of time ranging from a few minutes to several weeks. **Climate** describes atmospheric conditions over a long period of time, such as years or centuries. Climate is an expression of average weather over time.  |

Climatic processes depend on interactions of molecules that make up the atmosphere. These gas particles are in continuous, random motion and collide with other particles. The faster they move, the more energy (and higher temperature) they have. How much energy the molecules of air have depends on several factors.

**What Determines the Climate in an Area?**

The five factors that determine the kind of climate an area has are:

**1. Latitude,** which is a measure of how close a place is to the equator, indicates how much sunlight and warmth it receives. Generally, the closer a location is to the equator, the warmer it will be.

**2. Elevation or Altitude,** measured in relation to sea level, affects temperature. The higher the elevation, the cooler a place is likely to be.

**3. Ocean and Wind Currents** are driven by the heat of the sun and move heat from the equator around the world. Large-scale motions in the ocean and atmosphere can impact regional climate. For example, the Gulf Stream carries warm water from the Caribbean up the Atlantic coast of North America and across the Atlantic Ocean toward northern Europe. This flow makes the regional climate in Great Britain much warmer than would be expected at that latitude.

**4. Nearness to Large Bodies of Water** can increase precipitation or affect temperatures, depending on how large and how close the body is. Water has a high heat capacity, which means that it is very effective at storing energy. Because of this, areas near the ocean or large lakes tend to have more moderate climates than regions that are far from large bodies of water. Regions near the coast also have smaller annual changes in temperature than regions near the interior of continents, far from the ocean.

**5. The Shape of the Land** can affect winds and rainfall. Mountains can block rain, a valley can funnel air from high ground to the land below, and a plain can offer little resistance to winds and storms.

**Regional Climate**

The climate in a particular area on Earth is called a **regional climate** and it depends on the factors listed above. Regional climates have a strong influence on the plants and animals that live in a particular area. To survive, they have adapted to specific environmental conditions,. Although they might do well in one region, they may not be able to survive in another. For example, polar bears are well adapted to the high Arctic, but would not survive long in the Sahara Desert. Tropical plants that thrive in the hot and humid areas cannot survive in a place where the temperature drops below freezing.

**Climate Zones**

In 1884 a German climatologist named Wladimir Köppen (1846–1940) proposed that the world's climates could be divided into zones based on their normal temperature range, the area’s latitude, and its elevation. Today we recognize 11 climate zones separated into six groups. They are:

**1. Tropical Climate Zones** extend north and south from the equator to about 15° to 25° latitude. There are two types of tropical climates. **Tropical Wet climate** is found along the equator and have only one season. Their average temperature is around 80°F (27°C) and they receive around 100 inches of rain each year. The constant rain and direct sunlight at the equator means that tropical rainforests are the dominant feature of the landscape. Large areas of Tropical Wet are found in Brazil, Democratic Republic of the Congo, Indonesia, and the Philippines. **Tropical Wet and Dry climate** is found on the outer edges of Tropical Wet climate areas. They have a wet season (summer) and a dry season (winter). In the wet season they may have they may have 25 inches of rain; in the dry season, less than 4 inches. Large open savannas ore often a feature of the landscape. The largest areas of Tropical Wet and Dry are found in Africa, Brazil, and India.

**2. Moderate Climate Zones** extend from 30° to 50° latitude. There are three types: **Humid Subtropical climate** has mild winters and warm and humid summers. Rainfall averages about 48 inches and falls throughout the year. In the U.S., the southern tip of Florida has a Humid Subtropical climate. **Mediterranean climate** gets its name from the climate found around the Mediterranean Sea. It has warm to hot, dry summers and mild to cool, wet winters. Winter temperatures are usually between 30°F (-1°C) and 65°F (18°C). Summer months average above 50°F (10°C). This is a fairly dry climate, averaging around 20 inches of rainfall each year. In the U.S., northern coastal California has a Mediterranean climate. Because it is found near the shore, and the ocean keeps the air over the land cool in summer and warm in the winter, **Marine West Coast climate** is mild, but wet. The coldest month rarely averages lower than 30°F (-1°C) and the warmest month averages about 72°F (22°C). Rainfall can vary from 30 inches to as much as 98 inches. Western Europe and the northwest coast of North America have this type of climate.

**3. Continental Zones** only occur in the Northern Hemisphere because there are no major landmasses in the Southern Hemisphere except for Antarctica. These zones are found in northern parts of the interior of continents, away from the moderating effects of the ocean. Because these areas are located so far north of the equator, they receive less direct sunlight and therefore less warmth. There are two types of Continental Climate Zones. **Humid Continental climate** is found between the 30 and 60 degrees latitude. Summer months average about 71°F (22°C) and winter months about 25°F (-4°C). However, summer days can reach over 100 and winter months often reach below zero. This climate zone averages between 20 and 50 inches of rain each year. Central and eastern Europe, including a large part of Russia are in this zone. In North America it includes the eastern parts of the U.S. and Canada along their border around the Great Lakes, and stretches east to the Maritime Provinces along the Atlantic. **Subarctic climate** is found between 50 and 70 degrees latitude in the interior of continents of Asia, Europe, and North America. Winter in this zone is long and extremely cold, while summer is cool and lasts only a few months. Temperatures can fall as low as -40°F (-40°C) in winter and rise as high as 85°F (30°C) in summer. Subarctic areas are covered in snow for most of the year. They receive between 10 and 20 inches of rain each year, mostly during the summer.

**4. The Polar Climate Zones** are located close to the North Pole, in northern Alaska, Canada, Greenland, Scandinavia, and Russia. This close to the pole the winters are very harsh and the summers very cool. There are two types of Polar Climate Zones. **Tundra climate** is a transition between Ice Cap and Subarctic and is found mainly along the coast of the Arctic Ocean. Temperatures in winter usually fall between -18°F and -50°F (10°C). Summer temperatures range from 35°F to 50°F (10°C). It is so cold that water in the soil freezes, creating what is known as permafrost. Mosses, lichens, and algae are the main vegetation, with occasional grasses and low shrubs. **Ice Cap climate** is only found near the North and South poles, mainly in Antarctica and the land around the Arctic Ocean, especially Greenland. This is the most extreme climate on Earth. Its seasons are determined by the amount of sunlight it receives. Because the pole points toward the sun during summer, there is nearly 24 hours of light. During winter the pole faces away from the sun, which causes nearly 24 hours of darkness. During the year temperatures average between -16°F (-27°C ) and -70°F (-57°C).

**5. Dry Climate Zones,** which we know as deserts,are found from 20° to 35° North and South of the equator and in large continental regions surrounded by mountains. When warm, moist air hits a mountain range it is forced upward where it cools. The cooler air drops its load of moisture on the side of the mountain in the form or rain. This creates what is called a **rain shadow** on the land beyond the other side of the mountain. There isn’t enough rainfall in these lands to keep up with the rate of evaporation, which makes them drier. There are two types of Dry Climate Zones. An **Arid Climate** is always dry, but it can be either hot or cold. For example, temperatures on an arid climate near the equator such as the Sahara Desert can reach as high as 130°F (55°C). Temperatures on the Atacama Desert in Chile, which is south of the equator, can go as low as -30°F (-1°C). **Semiarid Climate** is found along the edges of arid zones and serves as a transition between drier and wetter climate zones. Weather her can be very uncertain, moving from plentiful rainfall to drought in a matter of months. An example of this is the Sahel in Africa that lies along the southern edge of the Sahara. The lack of rainfall has ruined farms and forced people to move or starve.

**6. Highland or Alpine Climate Zones** are found in high mountain areas such as the Plateau of Tibet and on single mountains such as Mount Kilimanjaro in Africa. These areas of high elevation are unique because their climate changes as you move up the mountain. It might be 80 degrees and sunny at the base of a mountain, but it can be snowy and freezing cold at the top. On average, as you move up a mountain the temperature drops about 3°F (1.6°F) degrees for every 1000 feet in elevation.

**How Can We Predict the Climate?**

Scientists are often asked how they can predict the climate 100 years from now when they can’t predict tomorrow’s weather accurately. The problem with making short-range predictions is that the weather is constantly changing. Over the long term the day-to-day weather averages out and gradual changes become easier to identify and predict.

**CLIMATE CHANGE**

Climate change means a change over time in global weather patterns around the world that would affect temperature, precipitation, wind patterns, and storm activity. Other effects include ecological changes, geological changes, sea level rise, changes in ocean circulations and acidity, and impacts on human activities. This section only contains basic information about climate change. Additional information is widely available from government agencies such as NASA and NOAA, and from conservation organizations such as the Natural Resources Defense Council (NRDC), the Union of Concerned Scientists, and the U.S. Climate Action Network.

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| **Global Warming and Climate Change**The terms "global warming" and "climate change" are often used interchangeably in newspapers and television reporting, but they are really separate things. Global warming refers to the rise in global average temperature. Climate change is how the climate of different areas around the globe change over time, |

**How Do We Know about Climate Change?**

Our knowledge about climate change does not come from one experiments or a single observation. It comes from a wide variety of sources, all of which contribute to the same conclusion: The climate is warming. Among the most important pieces of evidence are ice cores taken from the Antarctic and elsewhere,

**Historical records** of weather conditions are available back as far as 1750. Ship’s logs often reported the weather wherever they were in very precise terms. A large number of these logs have bee collected by the British Admiralty and are being used to build a picture of weather conditions throughout the world over the last 200 years. Modern weather services also kept detailed records that are available for study.

**Ice cores** contain clues about past concentrations of gases in our atmosphere, allowing scientists to interpret our climate history. Ice cores are long cylinders of ice that are drilled out of glaciers and permanent polar ice sheets, where ice builds up year after year without melting. Most cores come from Antarctica, Greenland, or high altitudes in the Andes and Himalayas.

The snow in these places does not melt. Instead it becomes compressed by the weight of new snow that falls on top of it. The snow crystals compact together until they form solid ice, trapping air in tiny bubbles. These bubbles contain gases from our atmosphere long ago. After a core is taken, a sample is crushed into small pieces, which allows the gas bubbles to escape. The composition of these gas bubbles tells us what the atmosphere was when the ice formed. The water molecules in ice samples can also be measured to determine historical temperatures.

Ice cores have captured these snapshots of Earth’s weather as far as 800,000 years back. This information from ice cores shows that temperature on Earth has fluctuated throughout history. Those fluctuations have included several very cold periods, known as **ice ages**, followed by warming trends. But although the planet's climate has always fluctuated, the rate of change has become more dramatic since the Industrial Revolution, which started around 1750. This suggests that recent changes have been produced by the activities of human beings.

**Current Research on Earth’s Climate**

Satellites orbiting Earth and other technological advances have enabled scientists to collect many different types of information about our planet and its climate. Studying this data collected over many years reveals strong evidence of a changing climate.

**Sea Level Rise** Global sea level rose about 6.7 inches (17 cm) in the last century. The rate in the last decade, however, is nearly double that of the last century.The change in sea level is caused primarily by added water coming from the melting of land ice and the expansion of seawater as it warms.

**Global Temperature Rise** Three major reconstructions of global surface temperature since 1880 show that Earth has warmed. Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years.

**Shrinking Ice Sheets** The Greenland and Antarctic ice sheets have decreased in mass. Greenland lost 36 to 60 cubic miles (150 to 250 cubic km) of ice per year between 2002 and 2006. Antarctica lost about 36 cubic miles (152 cubic km) of ice between 2002 and 2005.

**Decreased Snow Cover** Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and that the snow is melting earlier.

**The Causes of Climate Change**

The climate of the Earth naturally fluctuates in response to many things, including volcanoes, the greenhouse effect, and changes in the Earth’s natural processes.

**Volcanic Eruptions** When volcanoes erupt, they eject tons of sulfur dioxide and ash into the air. Both of these substances reflect solar energy back into space, leading to global cooling. For example, the massive eruption of the Indonesian volcano Tambora in 1815 pumped so much sulfur into the stratosphere that global temperatures fell by about 2°F (1°C) over the next 2 years. 1816 became known as the “Year Without a Summer” and the people in the Northern Hemisphere suffered major food shortages.

**The Greenhouse Effect** One of the major causes of climate change is the greenhouse effect. Gases such as water vapor, carbon dioxide, and methane (known as **greenhouse gases**) trap some of the infrared energy leaving Earth, just as a greenhouse traps heat inside.. The atmosphere retains this heat and becomes warmer. This is important because life as we know it today would be impossible if it weren’t for this natural process. Without this greenhouse effect, temperatures would be much lower than they are today because the energy (heat) would simply escape to space. However, if the concentration of greenhouse gases in the atmosphere becomes too high, problems may arise.

Since the beginning of the industrial revolution, the concentration of certain greenhouse gases in the atmosphere has increased. For example, the concentration of carbon dioxide has increased by nearly 30%. Other compounds, such as methane and nitrous oxide, have also experienced increases in their concentrations. This increase, along with increases in other greenhouse gases, has enhanced the greenhouse effect.

Although much of the carbon dioxide in the atmosphere comes from natural activities such as plant respiration and the decomposition of organic matter, scientists generally agree that the increase in the concentration of carbon dioxide is primarily due to the use of fossil fuels and other human activities. Before the industrial revolution enough carbon dioxide was absorbed by the oceans and vegetation to balance the amount produced naturally. Human activities, such as burning fossil fuels to power cars and trucks, have released additional carbon dioxide into the atmosphere, increasing its concentration. Since the late 19th century, the global surface temperatures have increased by 0.5–1.0°F (1°C}. The rate of climate change, particularly global warming, is likely to accelerate due to the increasing concentrations of greenhouse gases.

**Changes in Earth’s Natural Processes** Climate change is more than just a change in the atmosphere. The Earth operates with a set of interconnected cycles involving water, vegetation, atmosphere, rocks and landforms. These cycles involve a process known as **feedback,** in which the cycle itself is controlled or changed by the response it produces.

There are two types of feedback, positive and negative. **Positive feedback** magnifies or increases the response to a process. For example, when large amounts of ice in the Polar Regions melts, the albedo is lowered. This allows more sunlight to heat the dark Earth. The warmer Earth increases the speed of ice melt, which causes more Earth to warm, and so on. **Negative feedback** slows down the process or completely stops it. An example is the warming of the oceans. A higher water temperature causes more water to evaporate from the surface. This creates water vapor that is likely to produce clouds. The clouds will shade the surface of the ocean and cool it, which will reduce the original heating.

There are many feedback loops, both positive and negative, occurring at any time on the surface of the Earth. Our scientific understanding of these processes is not yet well developed and it is difficult to determine their effects, which makes predicting climate change difficult.

**The Effects of Climate Change**

There are many possible effects of global climate change and they vary from region to region. Some of the most likely are listed here.

More **extreme weather** may be one of the outcomes caused by climate change. Severe weather events are a normal part of climate variability, but as climate changes, extreme weather events, such as hurricanes may increase in intensity or frequency. As the climate warms, increased temperatures affect the water cycle, which in turn influences weather patterns. Warmer temperatures will increase rates of evaporation and also increase the amount of water vapor in the air. Paradoxically, this is likely to produce both more draught and more flooding.

In the **Polar Regions** climate change is slowly reducing the amount of snow and ice that covers the ground. This affects the Earth as a whole in two ways. First, the water stored in glaciers is being released into the ocean. This is likely to raise the level of the oceans and cause flooding in low-lying coastal areas. Second, Polar ice plays a vital role in the Earth’s climate system because of its reflectivity. As the ice melts, less solar radiation is reflected into the atmosphere, which leads to higher temperatures that melt more ice.

**Coral reefs** are host to a wide variety of fish and support many of the fisheries that sustain local economies. But corals can only tolerate a narrow range of temperatures, and they need sufficient light for photosynthesis to take place. When the water temperatures rise too high, corals become stressed and a reaction known as bleaching takes place. This will eventually result in the death of the coral. If water levels rise, not enough light will reach the reefs for photosynthesis, and they won’t survive.

**VII. WEATHER AND CLIMATE TERMS**

**A**

**ablation** Depletion of snow and ice by melting and evaporation.

**absolute scale** See **Kelvin scale.**

**absorption** The process in which radiant energy is remains in a substance by being converted to another form of energy.

**accretion** The growth of a precipitation by combining a frozen particle with a supercooled liquid water droplet.

**acid rain** Rainfall made so acidic by atmospheric pollution that it causes environmental harm, typically to forests and lakes. The main cause is the industrial burning of coal and other fossil fuels. Waste gases contain sulfur and nitrogen oxides, which combine with atmospheric water to form acids.

**air** The mixture of gases that comprises earth’s atmosphere.

**air mass** A large volume of air having similar temperature and humidity at any given height.

**air pollutant** A harmful substance or product introduced into the atmosphere.

**air pressure** The cumulative force exerted on any surface by the molecules composing air.

**albedo** The fraction of radiation striking a surface that is reflected by that surface; reflectivity.

**altimeter** An instrument that indicates the altitude of an object above a fixed level. Pressure altimeters use an aneroid barometer with a scale graduated in altitude instead of pressure.

**altitude** The distance above sea level.

**altocumulus** A medium altitude cloud, usually white or gray. Often occurs in layers or patches with wavy, rounded masses or rolls.

**altostratus** A medium altitude cloud composed of gray or bluish sheets or layers that appear uniform. The sun or moon may appear dimly visible through thinner layers.

**ambient** Of the surrounding area or environment.

**ambient temperature** The temperature of the surrounding air.

**analog 1.** A class of non-digital measuring devices in which the output varies continuously as a function of the input, such as a thermometer. **2.** A meteorological scenario or feature from the past that is used for comparison with another scenario or feature of an upcoming season.

**anemometer** An instrument designed to measure wind speed.

**aneroid barometer** An instrument designed to measure atmospheric pressure. It contains no liquid.

**anticyclone** A large-scale circulation of winds around a central region of high pressure. It will turn clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere as seen from above.

**anticyclonic rotation** Rotation opposite the Earth’s rotation—clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere as seen from above. The opposite of **cyclonic rotation**.

**anvil** The flat, spreading top of a cumulonimbus cloud, often shaped like an anvil.

**atm** Abbreviation for **atmosphere 2.**

**atmosphere 1.** The layers of gases surrounding a planet or other celestial body. **2.** A unit of measurement equal to air pressure at sea level, about 14.7 pounds per square inch. Abbreviation is **atm.**

**atmospheric pressure** The pressure exerted by the earth’s atmosphere at any given point.

**aurora** A faint visual phenomenon associated with geomagnetic activity, which occurs mainly in the night sky near earth’s magnetic poles.

**aurora australis** Luminous, radiant emissions from the upper atmosphere around earth’s southern magnetic pole; often seen on clear winter nights in a variety of shapes and colors. Also, **southern lights.**

**aurora borealis** Luminous, radiant emissions from the upper atmosphere centered around earth’s northern magnetic pole, often seen on clear winter nights. Also, **northern lights.**

**autumn** The season of the year that is the transition period from summer to winter, occurring as the sun approaches the winter solstice. Meteorological autumn begins September 1 and ends November 30.

**autumnal equinox** The equinox that occurs when the sun approaches the Southern Hemisphere and passes directly over the equator, and night and day are approximately equal length all over the earth. It occurs around September 23. See **vernal equinox.**

**B**

**barometer** An instrument that measures atmospheric pressure. The two most common barometers are the mercury barometer and the aneroid barometer.

**barometric pressure** The pressure of the atmosphere as indicated by a barometer.

**Beaufort scale** A scale of wind strength based on visual assessment of the effects of wind on seas and vegetation.

**blizzard** A severe weather condition characterized by low temperatures and winds greater than 35 mph (56 km/h) bearing a great amount of snow. When these conditions continue after snowfall has ended, it is termed a ground blizzard.

**boundary** A line that marks the limits of an area.

**boundary layer** The layer of fluid or gas flowing next to the surface of an object that has a reduced flow because of the resistance caused by friction.

**butterfly effect** a property of chaotic systems, such as the atmosphere in which small changes in initial conditions can lead to large-scale and unpredictable variations in the future. The term comes from the idea that the beating of a butterfly’s wings in one location could cause a tornado in another part of the world.

**C**

**C** Celsius.

**ceiling** The height of the cloud base for the lowest cloud layer.

**cell** Convection in the form of a single updraft, downdraft, or a combined updraft/downdraft; typically seen as a vertical dome or tower as in a cumulus cloud. A typical thunderstorm consists of several cells.

**Celsius** The standard scale used to measure temperature in most areas outside the United States. On this scale, the freezing point of water is 0°F and the boiling point is 100°F. To convert a Fahrenheit temperature to Celsius, subtract 32 from it and then multiply by 5/9:

**Celsius scale** A scale for measuring surface temperature, used by most of the world, in which the boiling point of water is 100 degrees.

**center** The vertical axis of a tropical cyclone, usually the location of minimum wind or minimum pressure. The cyclone center position can vary with altitude.

**centrifugal force** A force directed outward, away from the center of a rotating object; equal in magnitude to the centripetal force but in the opposite direction.

**centripetal force** An inward-directed force that confines an object to a circular path; equal in magnitude to the centrifugal force but in the opposite direction.

**Chinook** A warm, dry wind that occurs on the eastern side of the Rocky Mountains. In the Alps, the wind is called a **foehn**.

**circulation** The flow or movement of a fluid such as water or air through a given area.

**cirrocumulus** A high cloud that appears as a white patch of cloud without shadows. It consists of very small elements in the form of grains or ripples.

**cirrostratus** A high cloud appearing as a whitish veil that may totally cover the sky. Often produces halo phenomena.

**cirrus** A high cloud composed of ice crystals in the form of thin, white, featherlike clouds in patches, filaments, or narrow bands.

**CISK** An acronym for Convective Instability of the Second Kind, which is a popular theory that explains how a thunderstorm can evolve and organize into a hurricane.

**Citizen Weather Observer Program** A network run by the U.S. Weather Service that allows amateur meteorologists with computerized weather stations to contribute to forecasts from all over the United States.

**climate** A description of all the daily and seasonal weather conditions over a long period of time.

**climate change** A change in global or regional climate patterns, especially a change apparent from the mid to late 20th century onwards and attributed largely to an increase in the levels of atmospheric carbon dioxide produced by the use of fossil fuels.

**cloud** A visible aggregate of tiny water droplets or ice particles in the atmosphere above the Earth’s surface.

**cloud base** The lowest portion of a cloud.

**cloudburst** Any sudden and heavy rain shower.

**cloud cover** The amount of the sky obscured by clouds when observed at a particular location.

**cloud deck** The top of a cloud layer, usually viewed from an aircraft.

**cloud layer** An array of clouds whose bases are at approximately the same level.

**cloud seeding** The introduction of artificial substances (usually silver iodide or dry ice) into a cloud for the purpose of either modifying its development or increasing its precipitation.

**cloudy** The condition when 7/8ths or more of the sky is covered by clouds.

**coalescence** The merging of cloud droplets into a single larger droplet.

**cold front** The leading edge of a cold air mass.

**cold snap** A short period of intensely cold weather.

**condensation** Process by which water changes phase from a vapor to a liquid.

**condensation nuclei** Small particles in the atmosphere that serve as the core of tiny condensing cloud droplets. These may be dust, salt, or other material.

**conduction** The transfer of heat by molecular activity from one substance to another, or through a substance. Transfer is always from warmer to colder regions.

**continental air mass** An air mass that forms over land; it is normally relatively dry.

**continental climate** A climate lacking marine influence and characterized by more extreme temperatures than in marine climates: therefore, it has a relatively high annual temperature range for its latitude.

**continental polar air** Relatively dry air mass that develops over the northern interior of North America; very cold in winter and mild in summer.

**continental tropical air** Warm, dry air mass that forms over the subtropical deserts of the southwestern United States.

**contrail** or **condensation trail** A cloudlike streamer frequently seen forming behind aircraft flying in clear, cold, humid air.

**convection 1.** The transfer of energy by the movement of molecules in fluids or gases that flow. **2.** The upward movement in unstable air created when the Earth’s surface warms quickly.

**convergence** An atmospheric condition that exists when the winds cause a horizontal net inflow of air into a specified region.

**Coriolis force** A deflective force arising from the rotation of the earth on its axis; affects principally synoptic-scale and global-scale winds. Winds are deflected to the right of the initial direction in the Northern Hemisphere, and to the left in the Southern Hemisphere.

**cumulonimbus** An exceptionally dense and vertically developed cloud, often with a top in the shape of an anvil. This type of cloud is frequently accompanied by heavy showers, lightning, thunder, and sometimes hail. It is also known as a thunderstorm cloud.

**cumulus** A cloud in the form of individual, detached domes or towers that are usually dense and well defined. It has a flat base with a bulging upper part that often resembles cauliflower.

**cup anemometer** An instrument used to monitor wind-speed. Wind rotation of cups generates and electric current calibrated in wind speed.

**cyclone** A large-scale circulation of winds around a central region of low atmospheric pressure, counterclockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere.

**cyclonic circulation** Air circulation that moves in the same direction as the Earth’s rotation—counterclockwise in the Northern Hemisphere as seen from above, clockwise in the Southern Hemisphere. Tornadoes exhibit cyclonic rotation. See **anticyclonic rotation.**

**D**

**daily range of temperature** The difference between the maximum and minimum temperatures for any given day.

**data** Plural noun meaning the information collected during a scientific study. The singular form is **datum**.

**density** The ratio of the mass of a substance to the volume occupied by it.

**deposition** A process that occurs in subfreezing air when water vapor changes directly to ice without becoming a liquid first. See **sublimation**.

**deposition nuclei** Tiny particles in the atmosphere that serve as the core of tiny ice crystals as water vapor changes to the solid form. These are also called ice nuclei.

**depression** A region of low atmospheric pressure that is usually accompanied by low clouds and precipitation.

**desert 1.** An area of land that receives no more than 10 inches (25 cm) of precipitation a year. **2.** One of two types of dry climate—the driest of the dry climates.

**dew** Water that has condensed onto objects near the ground when their temperatures have fallen below the dew point of the surface air.

**dew point** or **dew point temperature** The temperature to which air must be cooled (at constant pressure and constant water vapor content) for saturation to occur. Also, **saturation point.** When the dew point falls below freezing it is called the **frost point.**

**diffraction** The bending of light around objects, such as cloud and fog droplets, producing fringes of light and dark or colored bands.

**divergence** An atmospheric condition that exists when the winds cause a horizontal outflow of air from a specific region.

**Doppler radar** Radar that can measure velocity toward or away from the radar antenna.

**downburst** A strong localized downdraft from a cumulonimbus cloud greater than 2½ miles (4 km) across, often associated with severe thunderstorms. See **microburst**.

**downdraft** Downward moving air, usually within a thunderstorm cell.

**downpour** Aheavy rain.

**drainage basin** A fixed geographical region from which a river and its tributaries drain water.

**drizzle** Small drops between 0.2 and 0.5 mm in diameter that fall slowly and reduce visibility more than light rain.

**drought** A period of abnormally dry weather sufficiently long enough to cause serious effects on agriculture and other activities in the affected area.

**dry-bulb thermometer** An ordinary thermometer with a dry bulb; used to measure the air temperature.

**dry climate** A climate in which yearly precipitation is not as great as the potential loss of water by evaporation.

**dust devil** A small but rapidly rotating wind made visible by the dust, sand, and debris it picks up from the surface. It develops best on clear, dry, hot afternoons. Also, **whirlwind**.

**dust storm** A severe weather condition characterized by strong winds and dust-filled air over a wide area.

**E**

**E** East.

**easterlies** Storms or winds coming from the east.

**eddy** A small volume of air (or any fluid) that behaves differently from the larger flow in which it exists.

**electrical hygrometer** An instrument used to monitor relative humidity by measuring the changes in a plate coated with carbon that accompany humidity variations.

**El Niño** A warming of the ocean current along the coasts of Peru and Ecuador that is generally associated with dramatic changes in the weather patterns in the region. A major El Niño event occurs every 3 to 7 years and is associated with changes in the weather patterns worldwide. Opposite of **La Niña.**

**Equator** Animaginary line around the Earth, another planet, or star running east-west at 0 degrees latitude.

**equinox** The two times each year when the sun crosses the plane of the earth’s equator—about March 21 and September 22. Day and night are approximately equal length all over the earth.

**evaporation 1.** The process by which a liquid changes into a gas. **2.** A process that humidifies the atmosphere.

**evapotranspiration** Vaporization of water through direct evaporation from wet surfaces and the release of water vapor by vegetation.

**evaporation fog** Fog produced when sufficient water vapor is added to the air by evaporation. The two common types are **steam fog,** which forms when cold air moves over warm water, and **frontal fog,** which forms as warm raindrops evaporate in a cool air mass.

**exosphere** The outermost portion of the atmosphere.

**eye** The relatively calm center in a hurricane where the winds are light and the skies are partly cloudy or even clear. Radar depicts it as an echo-free area within the eye wall.

**eye wall** An organized band of clouds that surrounds the eye of a hurricane. The fiercest winds and most intense rainfall typically occur near the eye wall.

**F**

**F** Fahrenheit.

**F Scale** Abbreviation for **Fujita Scale**, used for rating the intensity of tornadoes.

**Fahrenheit scale** The standard scale used to measure temperature in the United States. On this scale, the freezing point of water is 32°F and the boiling point is 212°F. To convert a Celsius temperature to Fahrenheit, multiply it by 9/5 and then add 32.

**fall** The season of the year that is the transition period from summer to winter occurring as the sun approaches the winter solstice. In the Northern Hemisphere, fall customarily includes the months of September, October, and November.

**fallstreak** Falling ice crystals that evaporate before reaching the ground.

**flash flood** A rapid and extreme flow of high water into a normally dry area.

**flood** The overflow of a body of water onto land.

**foehn** A warm, dry wind that occurs in the Alps. See **Chinook**.

**fog** A cloud with its base at the earth’s surface. It reduces visibility to below ½ mile (1 km).

**forecast 1.** *noun.* A prediction. **2.** *verb.* To predict, especially the weather.

**freeze** A condition occurring over a widespread area when the surface air temperature remains below freezing for a enough time to damage agricultural crops.

**freeze free season** The number of days between the last freeze date in spring and the first freeze date in fall.

**freezing rain** or **freezing drizzle** Rain or drizzle that falls in liquid form and then freezes when it strikes a cold surface. Either can produce a coating of ice on objects that is called **glaze**.

**front** The transition zone between two distinct air masses with different temperatures and humidities.

**frontal fog** See **evaporation fog.**

**frost** A covering of ice crystals on exposed surfaces when the air temperature falls below the frost point. Also, **hoarfrost**.

**frost point** Dew point below freezing.

**frozen dew** The transformation of liquid dew into tiny beads of ice when the air temperature drops below freezing.

**Fujita scale** A scale of tornado intensity in which wind speeds are inferred from an analysis of wind damage. Also, **F Scale.**

**funnel cloud** A rotating cone-shaped cloud that extends downward from the base of a thunderstorm that doesn’t reach the ground. When it touches down on the surface it is called a **tornado**.

**G**

**gale** An area of sustained surface winds of 34 to 47 knots (39 to 54 mph).

**geomagnetic field** The magnetic field observed in and around the earth.

**geostationary orbit** An orbit around the Earth directly above the Equator.

**geosynchronous** Any equatorial satellite with an orbital velocity equal to the rotational velocity of the earth, making the satellite appear motionless with respect to a point on the ground.

**glaciation** The conversion of all the supercooled liquid water in a cloud into ice crystals, thus reducing the growth rate of ice crystals and hail.

**glaciated cloud** A cloud or portion of a cloud where only ice crystals exist.

**glaze** A coating of ice formed on objects when supercooled rain freezes on contact. A storm that produces glaze is called an icing storm.

**global warming** A gradual increase in the overall temperature of the earth’s atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, chlorofluorocarbons, and other pollutants.

**glory** Colored rings that appear around the shadow of an object when the shadow is cast onto clouds below the observer’s elevation.

**gradient** A rate of change in the direction of maximum change.

**graupel** See **snow pellets.**

**green flash** A small, green color that occasionally appears on the upper part of the sun as it rises or sets.

**greenhouse effect** The warming of the surface and lower atmosphere of a planet (as with Earth or Venus) that is caused by the conversion of solar radiation into heat in a process involving its absorption by the planet’s surface and reflection as infrared which is absorbed and partly reflected back to the surface by atmospheric gases.

**greenhouse gases** The gases that absorb terrestrial radiation and contribute to the greenhouse effect; the main greenhouse gasses are water vapor, methane, carbon dioxide, and ozone.

**grid** A network of horizontal and vertical lines used to locate locations in relation to one another on a map.

**ground fog** Fog produced over land when cooling reduces the air temperature to or below its dew point. See **radiation fog.**

**groundwater** water located below ground.

**growing season** The number of days between the last spring freeze and the first fall freeze.

**H**

**haboob** A dust or sandstorm that forms when cold downdrafts from a thunderstorm lift dust and sand into the air.

**hail** Solid precipitation in the form of chunks or balls of ice with diameters greater than .2 inches (5 mm). Hail falls from **cumulonimbus** clouds.

**hailstone** A transparent or partially opaque particle of ice ranging from the size of a pea to a golf ball.

**hair hygrometer** An instrument used to monitor relative humidity by measuring the changes in the length of human hair that accompany humidity variations.

**halo** A ring or arc that encircles the sun or moon when seen through an ice crystal cloud or a sky filled with falling ice crystals. Halos are produced by refraction of light.

**haze** Fine dry or wet dust or salt particles dispersed through a portion of the atmosphere. Individually these are not visible but cumulatively they will diminish visibility.

**heat** A form of energy transferred between systems by virtue of their temperature differences.

**heat capacity** The ratio of the heat absorbed or released by a system to the corresponding to a rise or fall in temperature.

**heat index** An index that combines air temperature and relative humidity to determine an apparent temperature-how hot it actually feels. Also, **HI.**

**heat lightning** Distant lightning that illuminates the sky but is too far away for its thunder to be heard.

**heat of fusion** Heat released when water changes phase from liquid to solid; 80 calories per gram

**heat of melting** Heat required to change the phase of water from solid to liquid; 80 calories per gram.

**heat wave** A period of abnormally and uncomfortably hot and unusually humid weather.

**hemisphere** Half of the Earth, usually though of as resulting from the dividing the globe into two equal parts, north and south or east and west.

**HI** heat index.

**high** In meteorology, a region of high pressure indicated with an **H** on weather maps. Also, **anticyclone.**

**high inversion fog** A fog that lifts above the surface but does not completely dissipate because of a strong inversion that exists above the fog layer.

**highland climate** Complex pattern of climate conditions associated with mountains. Highland climates are characterized by large differences that occur over short distances.

**high pressure system** A weather pattern characterized by high air pressure, usually as a result of cooling. High-pressure systems are usually associated with clear weather.

**hoarfrost** Fernlike crystals of ice that form by deposition of water vapor on twigs, tree branches, and other vegetation. Also, **frost.**

**humidity** A measure of the water vapor content of the air.

**hurricane** A severe tropical cyclone in the Atlantic, Caribbean, Gulf of Mexico, or eastern Pacific, having winds in excess of 64 knots (74 mph).

**hurricane season** The part of the year when tropical cyclones are most likely to occur. In the Atlantic, Caribbean, and Gulf of Mexico, and central North Pacific, the hurricane season runs from June through November; in the eastern Pacific, from May 15 through November 30.

**hydrograph** An instrument that provides a continuous trace of relative humidity with time.

**hydrologic cycle** The cycle of evaporation and condensation that controls the distribution of the earth’s water as it evaporates from bodies of water, condenses, precipitates, and returns to those bodies of water. Also, **water cycle.**

**hygrometer** An instrument designed to measure the humidity of the air.

**hypothermia** The rapid deterioration in one’s mental and physical condition brought on by a lowering of human body temperature.

**I**

**ice age** A time of widespread glaciation.

**ice crystals** A barely visible crystalline form of ice that has the shape of needles, columns, or plates. Ice crystals are so small that they seem to be suspended in air. Ice crystals occur at very low temperatures in a stable atmosphere

**ice fog** A type of fog composed of tiny suspended ice particles that forms at very low temperatures.

**ice nuclei** Particles that act as cores for the formation of ice crystals in the atmosphere.

**ice pellets** See **sleet.**

**icing storm** A storm that produces glaze.

**inches of mercury** Unit of atmospheric pressure used in the United States. The name comes from the use of barometers that measure air pressure with the height of a column of mercury. One inch of mercury is equivalent to 33.86 mb or 25.40 mm. Also, **in Hg**.

**Indian summer** An unseasonably warm spell with clear skies near the middle of autumn. Usually follows a substantial period of cool weather.

**insolation** The incoming solar radiation that reaches the earth.

**instability** The tendency for air parcels to accelerate when they are displaced from their original position. Instability is a precondition for severe weather: the greater the instability, the greater the potential for severe thunderstorms.

**intensity** The strength of a hurricane, usually described by the wind speed.

**intertropical convergence zone** The boundary zone separating the northeast trade winds of the Northern Hemisphere from the southeast trade winds of the Southern Hemisphere.

**inversion** An increase in air temperature with altitude.

**ion** An electrically charged atom, molecule, or particle.

**ionosphere** An electrified region of the upper atmosphere where fairly large concentrations of ions and free electrons exist. It is located between the mesosphere and the exosphere and is included as part of the thermosphere.

**iridescence** Brilliant spots or borders of colors, most often red and green, observed in clouds up to about 30º from the sun.

**isobar** A line connecting points of equal pressure

**isotherm** A line connecting points of equal wind temperature.

**J**

**January thaw** A period of relatively mild weather around the end of January.

**jet stream** Relatively strong winds concentrated within a narrow band in the upper atmosphere.

**K**

**K** Kelvin temperature

**katabatic wind** Any (usually cold) wind blowing downslope.

**kelvin** A unit of absolute temperature equal to 1/273.16 of the absolute temperature of the triple point of water. One degree kelvin is equal to one degree Celsius.

**Kelvin scale** An absolute temperature scale in which a change of 1 Kelvin equals a change of 1 degree Celsius; 0ºK is the lowest temperature on the Kelvin scale. The freezing point of water is +273ºK and the boiling point is +373ºK. It is used primarily for scientific purposes. Also, **absolute scale.**

**knot** A unit of speed equal to 1 nautical mile (the length of 1 minute latitude) per hour or about 1.15 statute miles per hour or 0.5 meters/sec.

**Kt** knot.

**L**

**lake breeze** A wind blowing onshore from the surface of a lake.

**lake-effect snow** Localized snowstorms that form on the downwind side of a lake. Such storms are common in late fall and early winter near the Great Lakes as cold, dry air picks up moisture and warmth from the unfrozen bodies of water.

**land breeze** A coastal breeze that blows from land to sea, usually at night.

**La Niña** A periodic cooling of surface ocean waters in the eastern tropical Pacific along with a shift in convection in the western Pacific further west than the climatological average. These conditions affect weather patterns around the world. Opposite of **El Niño.**

**latent heat** The heat that is either released or absorbed by a unit mass of a substance when it undergoes a change of state, such as during evaporation, condensation, or sublimation.

**latitude** The angular distance north or south from the equator, usually expressed in degrees and minutes.

**leeward** The side away from the wind. Opposite of **windward**.

**lenticular cloud** A cloud in the shape of a lens.

**lightning** A visible electrical discharge produced by thunderstorms.

**low** A region of low pressure, marked as **L** on a weather map. A low center is usually accompanied by precipitation, extensive cloudiness, and moderate winds.

**low pressure system** An area of low pressure with converging winds that rotates in the same direction as the earth: counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Also, **cyclone**.

**M**

**mackerel sky** The name given to cirrocumulus clouds composed of ice crystals that form a rippled pattern that looks like fish scales.

**magnetosphere** The region around the earth in which the earth’s magnetic field plays a dominant part in controlling the physical processes that take place.

**mammatus clouds** Clouds that look like pouches hanging from the underside of a cloud.

**mare’s-tail** Thin, wispy cirrus clouds composed of ice crystals that appear as patches or strands that resemble a horse’s tail.

**marine climate** A climate dominated by the ocean, because of the moderating effect of water, sites having this climate are considered relatively mild.

**maritime air mass** An air mass that originates over the ocean. These air masses are relatively humid.

**maritime polar air mass** Cool, humid air mass that forms over the cold ocean waters of the North Pacific and North Atlantic.

**maritime tropical air mass** A warm, humid air mass that forms over tropical and subtropical oceans.

**maximum sustained winds** Steady winds within a tropical cyclone or hurricane. Unlike gusts, maximum sustained winds must last over twenty seconds.

**mb** millibar**.**

**mean annual temperature** The average temperature at any given location for the entire year.

**mean daily temperature** The average of the highest and lowest temperatures during a 24-hour period.

**mercury barometer** An instrument for measuring atmospheric pressure that contains an evacuated and graduated glass tube in which mercury rises or falls as the pressure of the atmosphere increases or decreases.

**meridian** An imaginary line on the earth’s surface passing through both geographic poles and through any given point on the planet; a line of longitude.

**mesopause** The top of the mesosphere, corresponding to the level of minimum temperature in the atmosphere found at 44 to 50 miles (70 to 80 km).

**mesosphere** The atmospheric layer between the stratosphere and the thermosphere. Located at an average elevation between 31 and 50 miles (50 and 80 km) above the earth’s surface.

**meteorologist**  A person who studies patterns and changes in Earth’s atmosphere.

**meteorology** The study of the atmosphere and atmospheric phenomena as well as the atmosphere’s interaction with the earth’s surface, oceans, and life in general.

**microburst** A strong localized downdraft less than 2½ miles (4 km) wide that occurs beneath severe thunderstorms. A strong downdraft greater than 2½ miles (4 km) across is called a **downburst**.

**microclimate** The climate of a small area such as a cave, house, city, or valley that may be different from the general region around it.

**microscale** Pertaining to meteorological phenomena, such as wind circulations or cloud patterns that extend horizontally less than 1½ miles (2 km) in.

**midlatitudes** or **mid-latitude areas** Geographic regions between 30° and 60° north and south of the Equator.

**millibar** A unit for expressing atmospheric pressure. Sea level pressure is normally close to 1013 mb.

**mirage** A refraction phenomenon that makes an object appear to be displaced from its true position. When an object appears higher than it actually is, it is called a superior image. When an object appears lower than it actually is, it is an inferior mirage.

**mist** Very thin fog in which visibility is greater than 0.62 miles (1.0 km).

**mistral** A katabatic wind that flows from the Alps down the Rhone River Valley of France to the Mediterranean coast.

**mixing ratio** The ratio of the mass of water vapor in a given volume of air to the mass of dry air.

**moisture 1.** The water vapor content in the atmosphere. **2.** The total water, liquid, solid or vapor, in a given volume of air.

**molecule** The smallest particle of a substance that retains the properties of the substance and is composed of one or more atoms.

**monsoon** A thermally driven wind that reverses its direction seasonally that arises from difference in the heating between a land mass and the adjacent ocean.

**mountain and valley breeze** A local wind system of a mountain valley that blows downhill (mountain breeze) at night and uphill (valley breeze) during the day.

**N**

**N** North.

**nacreous clouds** Clouds of unknown composition that have a soft, pearly luster and that form at altitudes about 15 to 18 miles (25 to 30 km) above the earth’s surface. They are also called mother-of-pearl clouds.

**National Hurricane Center** The branch of the National Weather Service responsible for tracking and predicting tropical storms.

**National Oceanic and Atmospheric Association** An agency in the Department of Commerce that maps the oceans and conserves their living resources; predicts changes to the earth's environment; provides weather reports and forecasts floods and hurricanes and other natural disasters related to weather. Also, **NOAA.**

**National Weather Service** The branch of the National Oceanic and Atmospheric Association (NOAA) whose mission is to provide "weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy."

**nautical mile** A unit of distance used in marine navigation and marine forecasts equal to 1.15 statue miles or 1852 meters. It is also the length of 1 minute of latitude.

**nimbostratus** A dark, gray cloud characterized by more or less continuously falling precipitation. It is not accompanied by lightning, thunder, or hail.

**NOAA** National Oceanic and Atmospheric Administration.

**noctilucent clouds** Wavy, thin, bluish-white clouds that are best seen at twilight in polar latitudes. They form at altitudes about 80 to 90 km above the surface.

**nocturnal** Related to nighttime; occurring at night.

**nocturnal inversion** See **radiational inversion.**

**normal** The long-term average value of a meteorological measurement, such as temperature, or humidity, for a certain area. A normal is usually established by averaging data from a period of 30 years.

**northern lights** See **aurora borealis.**

**nor’easter** A strong winter storm system that affects the Mid Atlantic and New England States, producing heavy snow, rain, and tremendous waves. Wind gusts associated with these storms can exceed hurricane force in intensity. Named for the strong northeasterly winds that blow in from the ocean ahead of the storm.

**nowcast** A short-term weather forecast, generally not more than six hours ahead.

**numerical forecasting** A computer forecast based on equations for specified weather or climate conditions at a certain place and time.

**NWS** National Weather Service.

**O**

**occluded front** A combination of two fronts that forms when a cold front overtakes a warm or quasi-stationary front.

**offshore breeze** A breeze that blows from the land out over the water. Opposite of an onshore breeze.

**onshore breeze** A breeze that blows from the water onto the land. Opposite of an offshore breeze.

**orographic uplift** The lifting of air over a topographic barrier such as a mountain range. Clouds that form in this lifting process are called orographic clouds.

**orographic precipitation** Rainfall or snowfall from clouds, induced by topographic uplift. As mountains force the clouds to rise, the moisture within them becomes colder and begins to fall as rain or snow.

**oscillation** A shift in position of high and low pressure systems.

**outflow** Air that flows outward from a thunderstorm.

**ozone** A form of oxygen (O3) that is considered a pollutant in the lower troposphere but an essential chemical in the stratosphere where it protects the earth from high-energy ultraviolet radiation from the sun.

**ozone hole** A severe depletion of stratospheric ozone over Antarctica that occurs each spring. It is caused by a chemical reaction involving ozone and chlorine, primarily from human produced sources, cloud particles, and low temperatures.

**ozone layer** An atmospheric layer that contains a high concentration of ozone that acts as a filtering mechanism against incoming ultraviolet radiation from the sun. It is located between the troposphere and the stratosphere, around 9.5 to 12.5 miles (15 to 20 km) above the earth’s surface.

**P, Q**

**parhelion** See **sundog.**

**permafrost** A layer of soil beneath the earth’s surface that remains frozen throughout the year.

**phenomena** Plural noun meaning any observable occurrence or feature. The singular form is **phenomenon**.

**pileus cloud** A smooth cloud that looks like a cap and appears to be attached to or on the top of a cumulus cloud.

**polar air mass** A cold air mass that forms near one of the poles.

**polar climate** A climate too cold for trees to grow.

**polar jet stream** a jet stream that is the boundary between polar air and subtropical air. It tends to migrate south during winter in the Northern Hemispheric and north in the summer. Also, **polar jet.**

**polar vortex** A large cyclonic body of very cold air that circulates over the polar regions. In the Northern Hemisphere the vortex rotates from west to east. During the winter season it sometimes dips far to the south, bringing arctic air and freezing temperatures.

**pole** The extreme north or south point of the Earth’s axis.

**pollutant** Something unhealthy or life threatening that has been added to the environment, especially particles, gases, or liquid aerosols that have an undesirable effect on the atmosphere or water.

**pollution** The introduction of harmful materials into the environment.

**potential energy** The energy that a body possesses by virtue of its position with respect to other bodies in the field of gravity.

**powder snow** Dry, loose snow.

**precipitation 1.** The process where water vapor condenses in the atmosphere to form water droplets that fall from the atmosphere to land through rain, snow, hail, sleet, or freezing rain. **2.** Any form of water (liquid or solid) that falls from the atmosphere and reaches the ground.

**pressure** The exertion of force upon a surface by a fluid (such as the atmosphere) in contact with it.

**pressure gage** A device for measuring the pressure of solids, liquids, or gases. It may be graduated to register pressure in any units desired.

**pressure gradient force** A force acting on air that causes it to move from areas of higher pressure to areas of lower pressure.

**prevailing westerlies** The westerly winds that dominant in middle latitudes.

**prevailing winds** The wind direction most frequently observed during a given period.

**probability** A chance or likelihood that a certain event might happen.

**psychrometer** An instrument used to measure the amount of water vapor in the air. It consists of a dry bulb and a wet bulb thermometer bound together so they can be whirled in the air. The readings on the thermometers are then compared with tables that give the dew point and relative humidity.

**R**

**radar** An instrument useful for remote sensing of meteorological phenomena. It operates by sending radio waves and monitoring those returned by such reflecting objects as raindrops within clouds. Acronym for **RA**dio **D**etection **A**nd **R**anging.

**radiation** Energy propagated in the form of electromagnetic waves. These waves do not need molecules to propagate them, and in a vacuum they travel at nearly 300,000 km per sec. also, **radiant energy.**

**radiation fog** Fog produced over land when radiational cooling reduces the air temperature to or below its dew point. Also **ground fog** or **valley fog.**

**radiational cooling** The cooling of the Earth’s surface, especially at night when the Earth suffers a net heat loss to space due to terrestrial cooling. This is more pronounced when you have a clear sky.

**radiational inversion** An increase in temperature with height due to radiational cooling of the earth’s surface. Also, **nocturnal inversion, surface inversion**.

**radiosonde** A instrument carried into the air by a balloon that measures and transmits information on pressure, temperature, humidity, and other aspects of the atmosphere to a receiving station on the ground.

**rain** Precipitation in the form of liquid water drops that have diameters greater than that of drizzle.

**rain gauge** A device-usually a cylindrical container-for measuring rain-fall.

**rain shadow** The region on the leeside of a mountain where the precipitation is noticeably less than on the windward side.

**rainbow** A luminous arc featuring all colors of the visible light spectrum (red, orange, yellow, green, blue, indigo, and violet) created by refraction, total reflection, and the dispersion of light.

**rainfall** The amount of precipitation of any type, most often measured by a rain gauge.

**reflection** The process whereby a surface turns back a portion of the radiation that strikes it.

**refraction** The bending of light as it passes from one medium to another.

**refractive index** The ratio of the speed of light in a vacuum to its speed in a transparent medium.

**relative humidity** The ratio of the amount of water vapor actually in the air compared to the amount of water vapor the air can hold at the particular temperature and pressure.

**rime ice** A white, granular deposit of ice formed by the freezing of water drops when they come in contact with an object.

**runoff** The transport of water from land to the oceans rivers, lakes, and streams. Too much rainfall can cause excess runoff or flooding.

**S**

**S** South.

**sandstorm** Particles of sand carried aloft by strong wind. The sand particles are mostly confined to the lowest ten feet (3 m) of the atmosphere, rarely rising more than 50 feet (15 m) above the ground.

**Santa Ana wind** The local name given a **foehn** wind in southern California in which strong, hot, dust-bearing winds descend to the Pacific Coast around Los Angeles from inland desert regions.

**satellite** A man-made device orbiting around the earth, moon, or another planet, used for research, communications, weather information, and navigation.

**saturate** To fill one substance with as much of another substance as it can hold.

**saturation** A condition in which air at a specific temperature contains all the water vapor it can hold.

**saturation point** Thetemperature at which the air can hold no more water vapor and clouds or precipitation forms. Also, **dew point**.

**saturation vapor pressure** The maximum amount of water vapor that the air can hold at any given temperature and pressure.

**scattering** The process by which small particles in the atmosphere deflect radiation, such as light, in different directions.

**scintillation** The apparent twinkling of a star due to its light passing through regions of differing air densities in the atmosphere.

**sea breeze** A coastal local wind that blows from the ocean onto the land. The leading edge of the breeze is termed a sea breeze front.

**sea level** Thebase level for measuring elevations. Sea level is determined by measurements taken over a 19-year cycle.

**sea level pressure** The atmospheric pressure at sea level at a given location.

**semiarid** See **steppe.**

**sensible heat transfer** Movement of heat from one place to another as a consequence of conduction or convection or both.

**sensible temperature** The sensation of temperature that the human body feels in contrast to the actual temperature of the environment as measured with a thermometer.

**shear** Variation in wind speed (speed shear) or direction (directional shear) over a short distance within the atmosphere. Also, **wind shear.**

**sheet lightning** A fairly bright lightning flash from distant thunderstorms that illuminates a portion of the cloud.

**short term forecast** A prediction about the weather in the next few hours.

**shortwave radiation** A term most often used to describe the radiant energy emitted from the sun, in the visible and near ultraviolet wavelengths.

**shower** Intermittent precipitation, usually lasting only a short time, but often heavy.

**sleet** A type of precipitation consisting of transparent pellets of ice made from frozen or mostly frozen raindrops or refrozen partially melted snowflakes. These pellets of ice usually bounce after hitting the ground or other hard surfaces. Also, **ice pellets.**

**smog** Originally smog meant a mixture of smoke and fog. Today, smog means air that has restricted visibility due to pollution, or pollution formed in the presence of sunlight-photochemical smog.

**snow** Solid precipitation in the form of minute ice flakes that develop when the temperature drops below 32°F (0ºC) and water vapor in the air freezes.

**snowflake** An aggregate of ice crystals that falls from a cloud

**snow flurries** Intermittently light showers of snow.

**snow grains** Precipitation in the form of very small, opaque grains of ice. The solid equivalent of **drizzle**.

**snow pellets** White, opaque, rounded ice particles .1 to .2 inches in diameter (2 to 5 mm). Also, graupel or small hail.

**snow shower** A moderate snowfall lasting a short time. Some snow accumulation is possible.

**snow squall** A short period of intense snowfall accompanied by strong, gusty surface winds and possibly lightning. Snow accumulation may be significant.

**solstice** Either of the two times of the year when the sun is the greatest distance from the celestial equator, occurring about June 22 and December 22. See **winter solstice** and **summer solstice.**

**southern oscillation** The reversal of surface air pressure at opposite ends of the tropical Pacific Ocean that occur during El Niño events.

**specific heat** The ratio of the heat absorbed or released by the unit mass of the system to the corresponding temperature rise or fall.

**specific humidity** The ratio of the mass of water vapor in a given parcel to the total mass of air in the parcel.

**spiral rain bands** Bands of thunderstorms and intense rain that wrap around a hurricane.

**spring 1.** The season of the year comprising the transition period from winter to summer occurring when the sun is approaching the summer solstice. In the Northern Hemisphere, spring customarily includes the months of March, April and May. **2.** A place where water flows from the earth, a natural fountain.

**spring freeze date** The date of occurrence in the spring of the last minimum at or below a temperature threshold.

**spring tide** A tide higher than normal that occurs around the time of the new and full moon in spring.

**sprinkle** A very light rain shower.

**squall** A strong wind that rises suddenly and may be accompanied by precipitation, thunder, and lightning.

**squall line** Any line or band of active thunderstorms.

**stationary front** Aweather pattern that develops when warm air and cold air meet and the boundary between the two does not move.

**station pressure** The actual air pressure computed at the observing station.

**steam fog** See **evaporation fog.**

**steppe** One of the two types of dry climate; a marginal and more humid variant of the desert that separates it from bordering humid climates. Steppe also refers to the short-grass vegetation associated with this semiarid climate.

**storm** Any disturbed state of the atmosphere, ranging from thunderstorms and tornadoes to tropical cyclones an hurricanes.

**storm surge** An abnormal rise of the ocean along a shore due primarily to the winds of a storm, especially a hurricane.

**stratocumulus** A low-level cloud with lumpy, rounded masses, often arranged in rows, bands, or waves with blue sky between them.

**stratopause** The boundary between the stratosphere and the mesosphere.

**stratosphere** The layer of the atmosphere above the troposphere and below the mesosphere that lies between 6 and 31 miles (10 and 50 km) in altitude, generally characterized by an increase in temperature with height.

**stratus** A low, gray cloud layer with a fairly uniform base, which is most commonly accompanied by drizzle.

**sublimation** The process whereby ice changes directly into water vapor without melting. In meteorology, sublimation can also mean the transformation of water vapor into ice. See **deposition**.

**subsidence** The slow sinking of a large area of air, usually associated with high-pressure.

**subtropical depression** A subtropical cyclone in which the maximum sustained surface wind speed is 33 kt (38 mph or 62 km/hr) or less.

**summer** The warmest season of the year during which the sun is most nearly overhead. In the Northern Hemisphere, summer customarily includes the months of June, July, and August.

**summer solstice** Approximately June 22 in the Northern Hemisphere when the sun is highest in the sky and directly overhead at the Tropic of Cancer, latitude 23.5° N.

**sundog** A colored luminous spot produced by refraction of light through ice crystals that appears on either side of the sun. Also, **parhelion**.

**sun pillar** A vertical streak of light extending above or below the sun. It is produced by the reflection of sunlight from ice crystals.

**supercell** See **supercell thunderstorm.**

**supercell thunderstorm** A thunderstorm consisting of one steady or rotating updraft that may last for several hours. Potentially the most dangerous type of thunderstorm, they generate the vast majority of long-lived violent tornadoes, as well as create downburst damage and large hail. Also, **supercell**.

**supersaturated air** A condition that occurs in the atmosphere when the relative humidity is greater than 100 percent.

**surface inversion** See **radiation inversion.**

**synoptic forecasting** A method of predicting weather patterns over a large area.

**synoptic scale** The typical weather map scale that shows features such as high- and low-pressure areas and fronts over a distance spanning a continent. Also called the cyclonic scale.

**T**

**temperature** The degree or intensity of heat present in a substance or object, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch.

**temperature gradient** The rate at which temperature increases or decreases with altitude in an atmosphere, or with depth inside an object.

**temperature inversion** A layer of the atmosphere in which air temperature increases with height.

**terminal velocity** the constant speed obtained by a falling object when the upward drag on the object balances the downward force of gravity.

**thermal** A small, rising current of warm air produced when the earth’s surface is heated unevenly.

**thermistor** Electrical device used to measure temperature.

**thermograph** An instrument that records temperature over time.

**thermometer** An instrument used to measure temperature.

**thermosphere** The layer in earth’s atmosphere above the mesosphere that extends from approximately 50 miles high (80 km) to outer space.

**thunder** The sound caused gases expanding rapidly along the channel of a lightning discharge.

**thunderstorm** A storm accompanied by thunder and lightning produced by cumulonimbus clouds.

**tides** The variations in the surface water level of oceans, bays, gulfs, and inlets that occurs at regular intervals as a result of the gravitational attraction of the sun and the moon on the earth.

**tipping bucket rain gauge** A device that collects rain in increments of 0.01 inches (.25 mm) in containers that alternately fill and empty by tipping. Each tip of a container is recorded and, added together, they measure the total amount and rate of rainfall.

**topography** The shape of the land.

**tornado** A violently intense rotating column of air that protrudes from a cumulonimbus cloud in the shape of a funnel and touches the ground. See **funnel cloud.**

**track** The path that a storm or weather system follows.

**trade winds** Persistent tropical winds that blow from the subtropical highs toward the equatorial low.

**transpiration** The transfer of water to the atmosphere by plants and vegetation.

**transport** The movement of water through the atmosphere.

**tropical**  existing in the tropics.

**tropical air mass** A warm or hot air mass that forms in the subtropics.

**tropical cyclone** A warm cyclone that originates over tropical or subtropical waters with organized wind circulation moving around a well-defined center.

**tropical depression** A tropical cyclone in which the maximum sustained surface wind is 33 knots (38 mph) or less.

**tropical disturbance** An organized mass of thunderstorms with a slight cyclonic wind circulation of less than 20 knots (23 mph).

**tropical storm** A tropical cyclone with a maximum wind circulation of between 34 and 63 knots (39 and 73 mph).

**tropics** The warm region of the earth within 20° North and South of the equator.

**tropopause** The boundary between the troposphere and the stratosphere.

**troposphere** the layer of the atmosphere extending from the earth’s surface up to the tropopause, about 6 miles (10 km) above the ground.

**tundra climate** A treeless climatic realm found almost exclusively in the northern hemisphere or at high altitudes in many mountainous regions. Its vegetation consists of sedges, grasses, mosses, and lichens and its weather is dominated by a long, bitterly cold winter.

**turbulence** Any irregular motion in the atmosphere that produces gusts and eddies.

**twilight** The time immediately before sunrise and after sunset when the sky remain illuminated.

**twister** In the United States, a colloquial term for a tornado.

**typhoon** A hurricane that forms in the western Pacific Ocean.

**U**

**ultraviolet radiation** Electromagnetic radiation with wavelengths shorter than visible light but longer than X-rays.

**unstable Air** Air that is able to rise easily and has the potential to produce clouds, rain, and thunderstorms.

**updraft** A small-scale current of rising air.

**upper level** The portion of the atmosphere that is above the lower troposphere.

**upper level disturbance** A disturbance in the flow pattern of the upper atmospheric that is usually associated with clouds and precipitation.

**upslope flow** Air that is forced to rise as it flows toward higher terrain.

**upslope fog** Fog formed when moist, stable air flows upward over a topographic barrier such as a mountain range.

**upslope precipitation** Precipitation that forms when moist, stable air gradual rises over an elevated plain. Upslope precipitation is common over the western Great Plains, especially east of the Rock Mountains.

**upwelling** The rising of water (usually cold) toward the surface from the deeper regions of a body of water.

**urban heat island** The increased air temperatures in urban areas in contrast to the cooler surrounding rural areas.

**V**

**valley breeze** See **mountain breeze.**

**valley fog** See **radiation fog.**

**vapor** Visible liquid suspended in the air, such as fog.

**vapor pressure** The pressure exerted by the water vapor molecules in a given volume of air.

**vernal** Pertaining to spring.

**vernal equinox** The equinox that occurs around March 20 when the sun approaches the Northern Hemisphere and passes directly over the equator.

**vertical wind shear** The change in the wind’s direction and speed with height.

**virga** Wisps of precipitation that fall from a cloud but evaporate before reaching the ground. See **fallstreak.**

**viscosity** Resistance of fluid flow.

**visibility** The greatest distance an observer can see and identify standard object.

**visible light** That portion of the electromagnetic spectrum that is visible.

**visual spectrum** The portion of the electromagnetic spectrum that the eye can see.

**vortex** A whirling mass of air in the form of a column or spiral.

**W, X, Y, Z**

**W** West.

**warm front** A transition zone between a mass of warm air and the colder air it is replacing.

**water cycle** The cycle of evaporation and condensation that controls the distribution of the earth’s water as it evaporates from bodies of water, condenses, precipitates, and returns to those bodies of water. Also, **hydrologic cycle.**

**water equivalent** The depth of water that would result from the melting of a snow sample. Typically about 10 inches of snow will melt to 1 inch of water, producing a water equivalent of 10 to 1.

**waterspout** A tornado that occurs over water.

**water vapor** The gas phase of water.

**weather** The state of the atmosphere in terms of such variables as temperature, cloudiness, precipitation, moisture, and pressure.

**weather balloon**  A hydrogen-filled balloon equipped with instruments to measure temperature, humidity, pressure, and other aspects of the atmosphere.

**weather map** A map or chart representing the condition of the atmosphere above a specific area.

**weather satellite** An instrument that orbits the earth and tracks weather patterns in the atmosphere.

**weather station**  A facility with tools and equipment for gathering and recording information about the atmosphere.

**weather system**  The movement of warm or cold air.

**weighing bucket rain gage** A device that is calibrated so that the weight of rainfall is recorded directly in terms of rainfall in millimeters or in inches.

**westerlies** The prevailing winds that blow from the west in the mid-latitudes.

**wet-bulb temperature** The lowest temperature that can be obtained by evaporating water into the air.

**wet-bulb thermometer** A thermometer with a bulb that is covered with moist muslin; used to measure humidity.

**whirlwind** (also **dust devil**) A small but rapidly rotating wind made visible by the dust, sand, and debris it picks up from the surface. It develops best on clear, dry, hot afternoons.

**white frost** Ice crystals that form on surfaces instead of dew when the dew point is below freezing.

**wind** The horizontal motion of the air past a given point.

**wind chill** A measure of the heat lost by exposed skin that is caused by wind.

**wind-chill factor** The cooling effect of any combination of temperature and wind, expressed as the loss of body heat. Also, **wind-chill index.**

**wind direction** The true direction from which the wind is blowing at a given location.

**wind shear** The rate at which wind changes speed or direction.

**wind vane** An instrument used to determine wind direction.

**windsock** A large, tapered, open bag designed to indicate wind direction and relative speed; usually used at small airports.

**wind speed** The rate at which air is moving horizontally past a given point.

**windward** The side toward the wind. Opposite of **leeward**.

**winter** Typically the coldest season of the year during which the sun is farthest from overhead. In the Northern Hemisphere, winter customarily includes the months of December, January, and February.

**winter solstice** Approximately December 22 when the sun is farthest south in the Southern Hemisphere and reaches its lowest point in the sky in the Northern Hemisphere.

**year** The period during which the Earth completes one revolution around the sun.

**zenith** The point in the sky that is directly overhead.

**VIII. TIMELINE OF METEOROLOGY**

|  |  |
| --- | --- |
| **7th century BCE** | Thales of Miletus associated weather with movement of the stars and planets. He considered water the basic element of all matter.Anaximander thought that wind was moving air.  |
| **c. 340 BCE** | Aristotle writes *Meteorology*, which contains his observations about what we call the Earth sciences. Aristotle rejected Anaximander’s idea that wind was moving air, but included accounts of water evaporation, weather phenomena, and the hydrologic cycle. Nothing significant was added to his findings for more than 1000 years. |
| **c. 750 CE – c. 1258 CE** | **The Islamic Golden Age** produces scientific advances by Muslim scientists that strongly influence later Western science. |
| **1020s** | Ibn al-Haytham, an Arab scientist and philosopher known in the West as Alhazen, publishes the *Book of Optics,* which concludes that atmospheric refraction and reflection of light cause morning and evening twilight. His later *Treatise on Light* discusses rainbows, the density of the atmosphere, and various celestial phenomena. |
| **1027** | Avicenna, a Persian physician and scientist, publishes The Book of Healing, which contains his thoughts on the importance of mountains in the formation of clouds. |
| **13th** **century** | St. Albert the Great proposes that each drop of falling rain has the form of a sphere, and that a rainbow is produced by light interacting with each raindrop.Roger Bacon calculates the angular size of the rainbow.An accurate explanation of a primary rainbow is developed independently by Theoderic of Freiburg and Kamāl al-Dīn al-Fārisī. Theoderic also explains a secondary rainbow. |
| **c. 1250-c.1850** | **Little Ice Age** brought colder winters to parts of Europe and North America, freezing rivers and canals. Snowfall increased and glaciers grew during this period. Crop failures were common because of shortened spring and summer growing seasons. |
| **End if 13th century** | Beginning of the Renaissance in Italy. |
| **c. 1350** | Bubonic plague decimates Europe. |
| **c. 1441** | First standardized rain gauge invented in Korea. They were used to calculate land taxes based upon a farmer's potential harvest. |
| **1450** | Leone Battista Alberti develops the first anemometer.Nicolas of Cusa hung out some wool and noticed that it was heavier when moisture condensed on it. This is considered the first hair hygrometer to measure humidity. |
| **1488** | Johannes Lichtenberger publishes the first version of his *Prognosticatio* linking weather forecasting with astrology. |
| **1494** | Christopher Columbus experiences a tropical cyclone and later writes the first written European account of a hurricane. |
| **1543** | Nicolaus Copernicus publishes *On the Revolutions of the Heavenly Spheres,* which argues that the planets move around the sun. |
| **c. 1593** | Galileo Galilei is the first to realize that gases and liquids expand when heated. He also invents the first thermometer. |
| **1605** | **Sir Francis Bacon**: *The Advancement of Learning,* which argues that only knowledge discovered by observation of the natural world is useful or important. |
| **1609** | Johannes Kepler publishes *On the Motion of Mars* proving that the planets move in elliptical orbits. |
| **1610** | Galileo observes four moons of Jupiter through his telescope. |
| **1611** | Kepler writes the first scientific treatise on snow crystals. |
| **1618–1648** | **The Thirty Years' War,** a series of European conflicts involving most of the countries of western Europe, is fought mainly in Germany. |
| **1620** | Sir Francis Baconpublishes *Novum Organum,* whichargues that the goal of natural science is increasing human power over nature. |
| **1632** | Galileo publishes *Dialogues on the Two Chief Systems of the World,* which argues that the Earth and other planets orbit the Sun. |
| **1642–1651** | **English Civil War** |
| **1643** | Evangelista Torricelli invents the mercury barometer.First tornado recorded in U.S. in Essex County, Massachusetts. |
| **1648** | Blaise Pascal rediscovers that atmospheric pressure decreases with height, and deduces that there is a vacuum above the atmosphere. |
| **1654** | Ferdinando II de Medici sponsors the first weather observation network. |
| **1662** | Christopher Wren invented the mechanical, self-emptying, tipping bucket rain gauge. |
| **1667** | Robert Hooke builds a pressure-plate anemometer.Earliest recorded hurricane in U.S. at Jamestown, Virginia. |
|  |  |
| **1686** | Edmund Halley presents a systematic study of the trade winds and monsoons and identifies solar heating as the cause of atmospheric motion. He proposes that air is heated by the sunrises and winds are caused by air flowing in to replace air that has risen. Halley also establishes the relationship between barometric pressure and height above sea level. |
| **1687** | Sir Isaac Newton publishes *Principia Mathematia* containing Newton's laws of motion, which form the foundation of classical mechanics, and his law of universal gravitation. |
| **1709** | Extreme cold snap in Europe kills thousands. |
| **1715** | Hurricane off Saint Lucie, Florida sinks ten Spanish treasure galleons heading to Europe from Cuba. |
| **1716** | Edmund Halley suggests that aurorae are caused by "magnetic effluvia" moving along the Earth's magnetic field lines. |
| **1724** | Gabriel Fahrenheit creates reliable scale for measuring temperature with a mercury-type thermometer. |
| **1735** | George Hadley, an English lawyer, proposes the first explanation the atmospheric mechanism by which the Trade Winds are sustained. |
| **1736**  | Daniel Gabriel Fahrenheit, inventor of the thermometer, dies. |
| **1738** | Daniel Bernoulli publishes Hydrodynamics, initiating the kinetic theory of gases. He gave a poorly detailed equation of state, but also the basic laws for the theory of gases. |
| **1740** | Ben Franklin proposes that storms move from place to place. |
| **1742** | Anders Celsius, a Swedish astronomer, proposes the Celsius temperature scale, which led to the current Celsius scale. |
| **1743** | Benjamin Franklin is prevented from seeing a lunar eclipse by a hurricane, he decides that cyclones move in a contrary manner to the winds at their periphery. |
| **1751** | Denis Diderot and Jean Le Rond d'Alembert publish the first volume of the *Encyclopédie*. |
| **1761** | Joseph Black discovers that ice absorbs heat without changing its temperature when melting. |
| **1763** | The French and Indian War ends. |
| **1768** | John Heinrich Lambert develops the hygrometer for measuring the moisture content of the atmosphere. |
| **1769** | James Watt invents steam the engine. |
| **1770** | Boston Massacre: five civilians killed in confrontation with British troops.Failure of the monsoons in the late 1760s contribute to the Bengal famine of 1770 where 10 million people die. |
| **1771** | **Lafayette** appointed to serve in the King's Musketeers and enters the Military Academy at Versailles.*Encyclopedia Britannica* first published. |
| **1772** | Daniel Rutherford discovers nitrogen, which he calls *phlogisticated air*, Working together with Joseph Black, he explains the results of his experiment in terms of the phlogiston theory |
| **1773** | The Boston Tea Party. |
| **1774** | Louis Cotte is put in charge of a network of French veterinarians and country doctors to investigate the relationship between the plague and weather. The project continued until 1794.Royal Society begins twice daily observations compiled by Samuel Horsley testing for the influence of winds and of the moon on the barometer readings.Joseph Priestly discovers oxygen. |
| **1775–1783** | **The American Revolutionary War** or **American War of Independence** |
| **1777** | Antoine Lavoisier discovers oxygen and develops an explanation for combustion.**Lafayette** becomes an aide-de-camp for General Washington and is wounded at the Battle of Brandywine. |
| **1779** | **Lafayette** returns to France on board American ship *Alliance* to obtain aid from French government. |
| **1780** | Charles Theodor charters the first international network of meteorological observers known as *Societas Meteorologica Palatina*. By 1795 the project has ended.**Lafayette** embarks on *L’Hermoine* to America. He is greeted as a hero when he arrives at Boston. Congress honors him.Great Hurricane of 1780 kills between 20,000 and 30,000 people in Caribbean area. |
| **1781** | **Lafayette** takes command of a corps of troops and saves Virginia from Cornwallis' destruction of American property.AFrench fleet drives a British naval force out of Chesapeake Bay. British general Lord Cornwallis, surrounded on land and sea by American and French forces, surrenders at Yorktown, ending the fighting in the Revolutionary War. |
| **1782** | The King and Queen of France invite **Lafayette** to Versailles to celebrate the victory in America. Lafayette is acclaimed throughout Europe.Britain's parliament advises King George III to make peace with the rebels in America. Informal talks begin in Paris. |
| **1783** | Lavoisier publishes *Reflexions sur le phlogistique*, which he criticizes the phlogiston theory and proposes a caloric theory.Horace-Bénédict de Saussure demonstrates the first hair hygrometer.The Montgolfier brothers ascend in a hot air balloon for the first time.King George declares the thirteen colonies "free and independent." The Treaty of Paris formally ends the American Revolutionary War. |

**IX. RESOURCES**

**Links to Other *Hermione* Insignia Guides**

*The Hermione Game’s* Navigation Insignia Guide

*The Hermione Game’s* Seamanship Insignia Guide

**Books**

**Apprentice**

Breen, Mark and Kathleen Friestad. *The Kids' Book of Weather Forecasting.* Nashville, TN: Ideals, 2008.

Cosgrove, Brian. *DK Eyewitness Books: Weather.* New York: Dorling Kindersley, 2007.

Furgang, Kathy. *National Geographic Kids Everything Weather: Facts, Photos, and Fun that Will Blow You Away.* Washington, DC: National Geographic Children's Books, 2012.

Simon, Seymour. *Weather.* New York: HarperCollins, 2006.

**Chief**

Allaby Michael and Richard Garratt. *A Chronology of Weather (Facts on File Dangerous Weather Series).* New York: Facts on File, 2003.

Diagram Group. *Weather and Climate: An Illustrated Guide to Science.* New York: Chelsea House Publications, 2006.

Miller, Ron. *Chasing the Storm: Tornadoes, Meteorology, and Weather Watching.* Minneapolis, MN: Twenty-First Century Books, 2014.

Silverstein, Alvin, Virginia Silverstein, and Laura Silverstein Nunn. *Weather and Climate.* Minneapolis, MN: Twenty-First Century Books, 2008.

**Master**

Ahrens, C. Donald. *Meteorology Today.* West Publishing Company, 1985.

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Dunlop, Storm. *Meteorology Manual: The Practical Guide to the Weather.* Sparkford, UK: Haynes Publishing, 2014.

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Eagleman, Joe R. *Meteorology The Atmosphere in Action.* Litton Educational Publishing Inc., 1980.

Ludlum, David. *National Audubon Society Field Guide to North American Weather.* New York: Knopf, 1991.

Lutgens, Frederick K. and Edward J. Tarbuck. *The Atmosphere.* Prentice-Hall Inc., 1995.

Moran, Joseph M. and Michael D. Morgan, *Meteorology.* Burgess Publishing, 1986.

Schaefer, Vincent J. and Roger Tory Peterson. *Peterson First Guide to Clouds and Weather.* Boston: Houghton Mifflin Harcourt, 1998.

Williams, Jack. *The AMS Weather Book: The Ultimate Guide to America's Weather.* Chicago: University Chicago of Press, 2009.

Williams, Jack. *The Weather Book: An Easy-to-Understand Guide to the USA's Weather*. New York: Vintage, 1997.

**Websites**

Citizen Weather Observer Program at http://wxqa.com

NOAA—National Weather Service at http://www.nws.noaa.gov/outlook\_tab.php

*Poor Richard's Almanack* at: http://www.gettysburg.edu/~tshannon/his341/pra1753contents.html

The Weather Channel at http://www.weather.com

World Meteorological Organization: World Weather Information Service at http://worldweather.wmo.int/en/home.html