Dover Coloring Book

All About the Weather

Bruce LaFontaine

Introduction

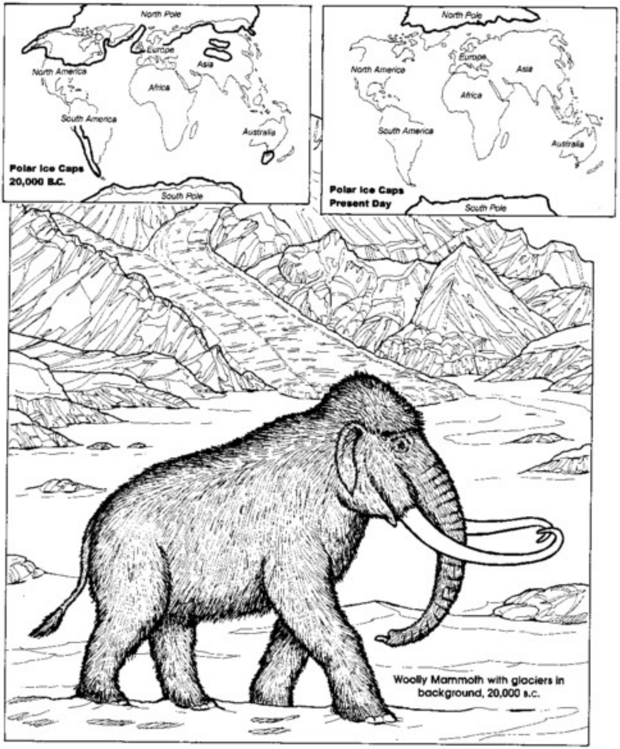
The weather is always doing something.
—Mark Twain

There is one element in our daily lives on planet Earth that is both ever-present and ever-changing, and that is the weather. As soon as we step outside, weather conditions are immediately apparent to us from the temperature, humidity, cloud cover, and wind. The scientific study of the weather is called **meteorology**, derived from the Greek word for **measure**. Over the past 150 years, this science has evolved from simply observing plant and animal behavior to the use of technologically sophisticated satellites, computers, and radar instruments.

Our weather results from a number of factors. Primary among them are the heat and light generated by the Sun, and the Earth's relationship to this massive solar furnace. Our planet goes through a yearly cycle that we are all familiar with—the seasons. This cycle is created by the position of the Earth as it orbits the Sun. The Earth is tilted off a vertical (90 degree) rotational axis by 23.5 degrees. This tilt causes maximum sunlight to reach different areas of the planet at different times of the year. When the northern hemisphere is tilted *toward* the Sun, we experience summer. Northern hemisphere winter and southern hemisphere summer occur when the northern hemisphere is tilted *away* from the Sun.

The Earth is surrounded by a thick layer of air—the atmosphere—which interacts with solar radiation to produce many different types of weather conditions. Air temperature and pressure, the amount of water vapor in the air (humidity), wind patterns, and ocean currents all combine to create different climatic conditions and geographical zones. Mountains, deserts, tropical rain forests, great open plains—each type of region experiences its own unique weather patterns.

Predicting changing weather conditions with reasonable accuracy has proven to be a valuable contribution to our daily activities. For example, daily weather reports affect our choice of clothes and paraphernalia, while foreknowledge of dangerous storms can save both property and lives. Perhaps one day, the inexorable march of science will lead to the development of technologies that will allow us to actually control the weather. Until that time, meteorologists will continue in their efforts to learn "all about the weather."

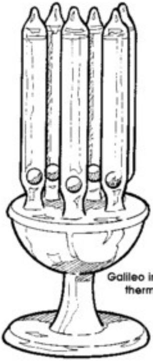


Woolly Mammoth with glaciers in background, 20,000 B.C.

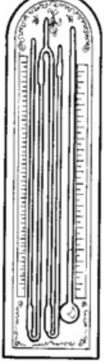
1. Ice Age

The climate of the Earth has not always been as it is now. Our planet has undergone steady evolutionary changes in its weather, as well as sudden dramatic shifts in climate. Catastrophic events such as asteroid or comet impacts have occurred periodically in the history of our planet causing severe global weather changes. Massive volcanic eruptions can also create sudden climatic disruptions. Clouds of dust and ash from such violent upheavals can cause a dramatic decrease in sunlight and consequently, in temperature. For example, it is believed that such an event occurred 65 million years ago when the Earth was struck by an asteroid or comet at least 5 miles wide on Mexico's Yucatan coastline. The planet was enshrouded in a cloud of dust and debris from this collision, which effectively blocked solar radiation, so that temperatures plunged worldwide. On land and sea, animals and plants perished in such mass extinctions as the one that wiped out the predominant life form on Earth at this time—the dinosaurs.

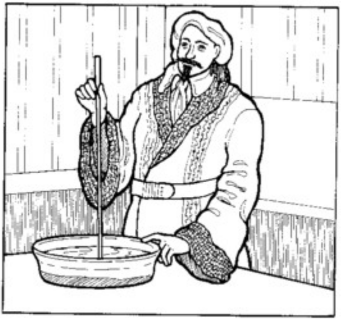
Gradual climatic shifts have also occurred periodically in the planet's history, like the kind represented by the great ice ages. Scientists believe that there have been at least five of these events, the last one ending 10,000 years ago. An **ice age** occurs when the temperature of the planet drops, and the ice fields at the north and south poles dramatically increase in size.



Galileo invents water-based thermometer, c. 1600



Torricelli invents mercury barometer, 1644

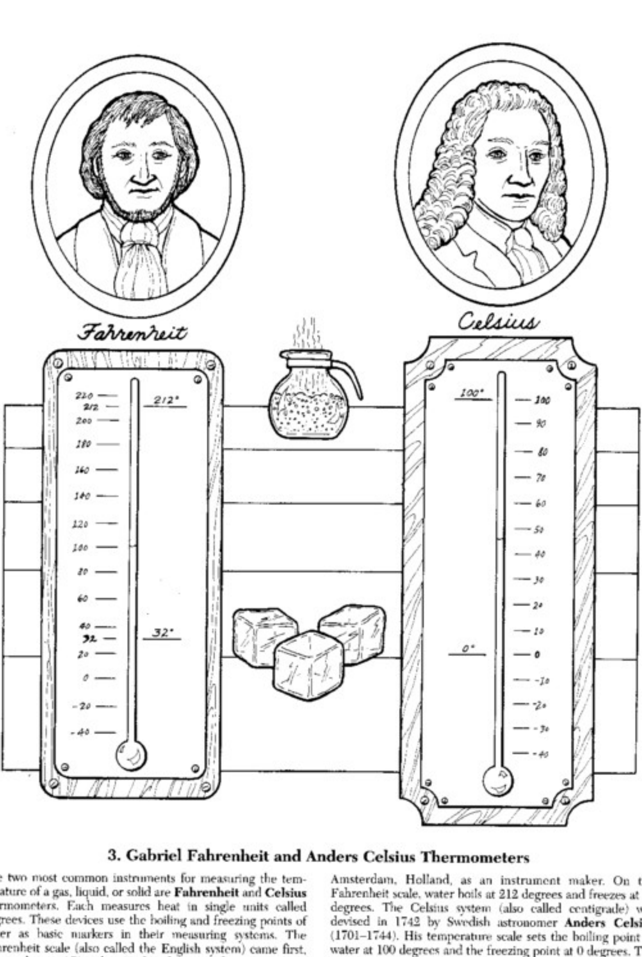


2. Galileo Thermometer and Torricelli Barometer

One of the primary subjects of weather studies is temperature. Whether the air temperature is warm or cool is immediately apparent to us as soon as we step outdoors. Temperature is a function of many factors, including the amount of sunlight, season of the year, altitude and geographical location, atmospheric moisture content, and air pressure. Two pioneering scientists in the areas of temperature and pressure measurement are **Galileo Galilei** (1564–1642) and **Evangelista Torricelli** (1608–1647).

Galileo is famous for his work in astronomy, optics, and physics. Among his many landmark achievements is the invention of the first **water-based thermometer**, which he called a **thermoscope**. Shown above is the **Florentine thermometer**, which was based on Galileo's invention. The temperature is measured by the rise and fall of colored glass balls in the water within the glass tubes.

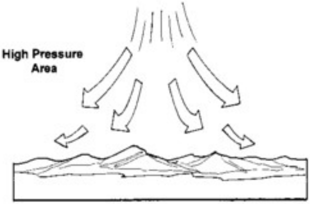
Torricelli was one of Galileo's assistants. He is credited with inventing the **mercury barometer** for measuring **air pressure**. Air pressure is a function of the amount, velocity of movement, and temperature of air molecules within a given area. The more numerous the molecules and the faster they move cause an increase in air pressure. Torricelli's early barometer used the metallic element **mercury**, which remains in a liquid state at room temperatures. His barometer was a simple 3-foot mercury-filled glass tube. He placed the open end of the tube into a larger pan of mercury. The mercury level in the tube dropped, leaving a vacuum at the top of the tube. Torricelli deduced that air pressure on the mercury in the pan stopped the level in the tube from falling further. Modern barometers are based on this concept of the rise and fall of mercury within a glass tube.

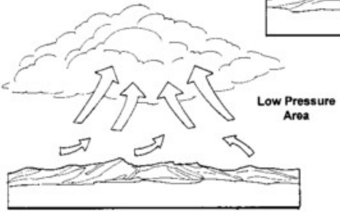


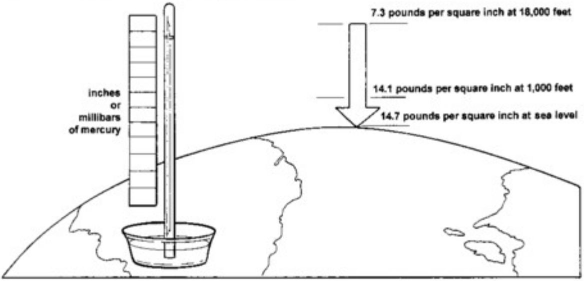
3. Gabriel Fahrenheit and Anders Celsius Thermometers

The two most common instruments for measuring the temperature of a gas, liquid, or solid are **Fahrenheit** and **Celsius** thermometers. Each measures heat in single units called degrees. These devices use the boiling and freezing points of water as basic markers in their measuring systems. The Fahrenheit scale (also called the English system) came first, invented in 1714 by **Gabriel Daniel Fahrenheit** (1686–1736). He was a German-born physicist who worked in Amsterdam, Holland, as an instrument maker. On the Fahrenheit scale, water boils at 212 degrees and freezes at 32 degrees. The Celsius system (also called centigrade) was devised in 1742 by Swedish astronomer **Anders Celsius** (1701–1744). His temperature scale sets the boiling point of water at 100 degrees and the freezing point at 0 degrees. The Celsius scale is used mostly by the scientific community and countries that utilize the metric system of measurement.

Robert Boyle



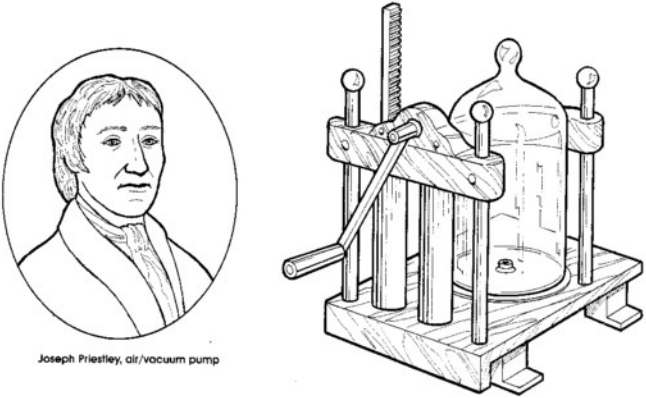




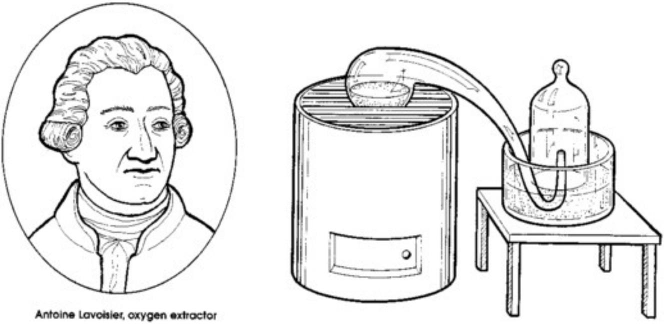
4. Boyle's Law of Air Pressure

Robert Boyle (1627–1691) was an Irish-born chemist who investigated the properties of the invisible elements that we now call gases. Since air is the principal gas that surrounds us, his research focused on this substance. In order to study effectively the properties of air, Boyle and another scientist, Robert Hooke, built the first air pump. With this device they discovered what is now called Boyle's Law of air pressure. It states that if the pressure on a gas (air) is doubled, its compressed molecules occupy half the space or **volume**. Boyle also invented a water-based barometer to measure air pressure.

Many modern barometers measure air pressure in units called **millibars**. Air pressure varies within our atmosphere based on many factors including temperature and altitude. Normal air pressure at sea level is 14.7 pounds per square inch. At 20,000 feet above the earth, the pressure is reduced to 7.3 pounds per square inch. In an area of **high pressure**, air descends to the ground and spreads, usually absorbing moisture and leaving clear skies. In an area of **low pressure**, air rises and condenses at the cooler higher altitudes into clouds.



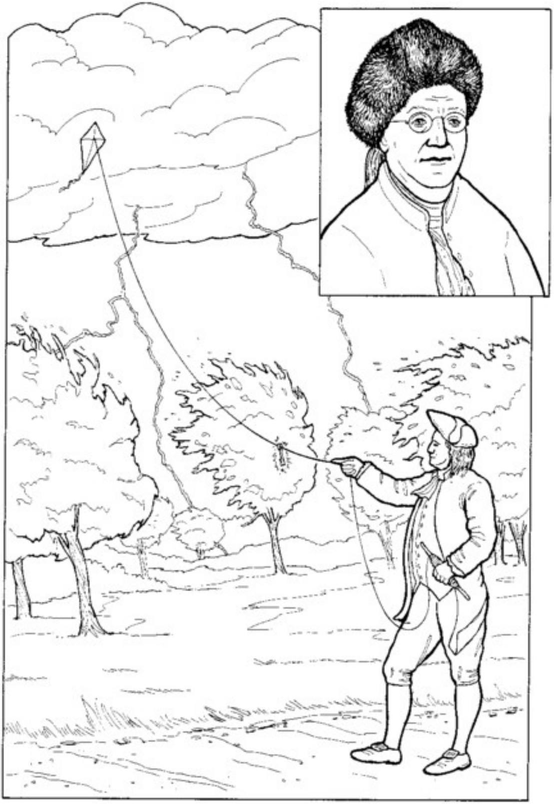
Joseph Priestley, air/vacuum pump



Antoine Lavoisier, oxygen extractor

5. Joseph Priestley and Antoine Lavoisier

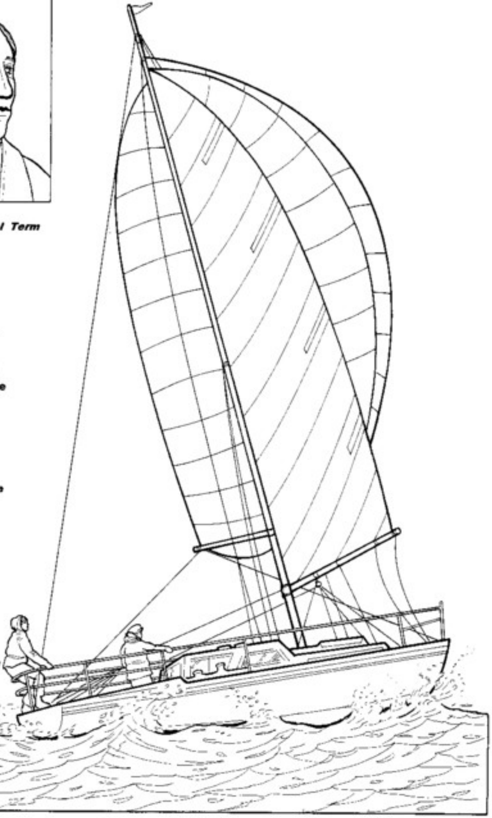
Two other prominent scientists who experimented with air and gases were English chemist **Joseph Priestley** (1733–1804) and French chemist **Antoine Lavoisier** (1743–1794). Working independently, they both discovered the constituent elements of air. Priestley was the first to isolate the vital element **oxygen** that enables **combustion**, or burning. He also discovered the gaseous compound, **carbon dioxide**, another component of air. Antoine Lavoisier identified and named **oxygen** as the catalyst for combustion, and also found that the greater percentage of air was composed of an inert (noncombustible) gaseous element that we now call **nitrogen**. From their studies we now know that the air we breathe is composed of 21% oxygen, 78% nitrogen, and 1% carbon dioxide (about .035% and rising), and the inert rare gases argon, neon, xenon, and krypton.



6. Benjamin Franklin Experiments with Lightning and Electricity

The name **Benjamin Franklin** (1706–1790) is well-known in American history. He is remembered as a statesman, patriot, and founding father of the United States, a writer, philosopher, and printer, as well as a scientist and inventor. One of the subjects that fascinated his keen and curious mind was the newly discovered phenomenon of **electricity**. This mysterious "invisible" energy source was being investigated by scientists in both Europe and America. In 1752 Franklin conducted his famous experiment to determine if **lightning** and electricity were related. During a thunderstorm, he flew a kite with a metal key at the bottom end of the kite string. When the kite was struck by lightning, electric current flowed down the damp string. When Franklin placed his finger near the key, he received a mild electric shock as the arc of electricity jumped from the key to his finger, leading him to conclude that lightning was a form of the mysterious force of electricity.

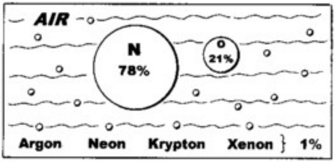
Force	Wind Speed	Nautical Term
0	0 mph	Calm
1	1-3	Light Air
2	4-7	Light Breeze
3	8-12	Gentle Breeze
4	13-18	Moderate Breeze
5	19-24	Fresh Breeze
6	25-31	Strong Breeze
7	32-38	Moderate Gale
8	39-46	Fresh Gale
9	47-54	Strong Gale
10	55-63	Whole Gale
11	64-72	Storm
12	73 +	Hurricane Force

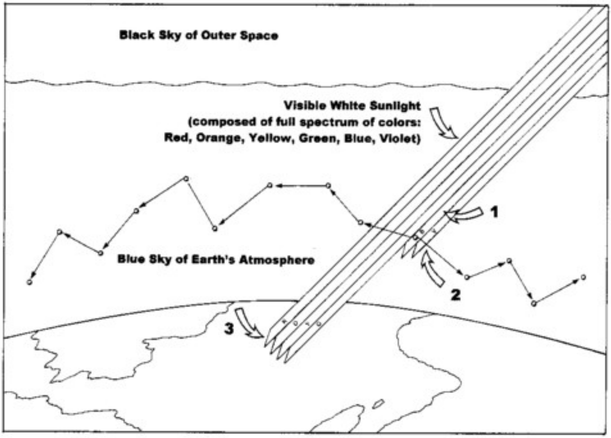


7. Beaufort Wind Scale

During the age of the great sailing ships, knowledge of the speed and force of the wind was a key to navigation for all mariners. A scale to classify wind speed was devised in 1806 by an Irish-born member of the British Royal Navy, **Admiral Sir Francis Beaufort** (1774–1857). His **wind scale** was a significant aid to sailors and, with various modifications, continues as a commonly used measurement of wind speed to this day. As shown in the chart, there are **thirteen levels** of force ranging from dead calm (no wind) to full-scale hurricane winds with sustained speeds of over 73 mph.

Sir William Ramsay



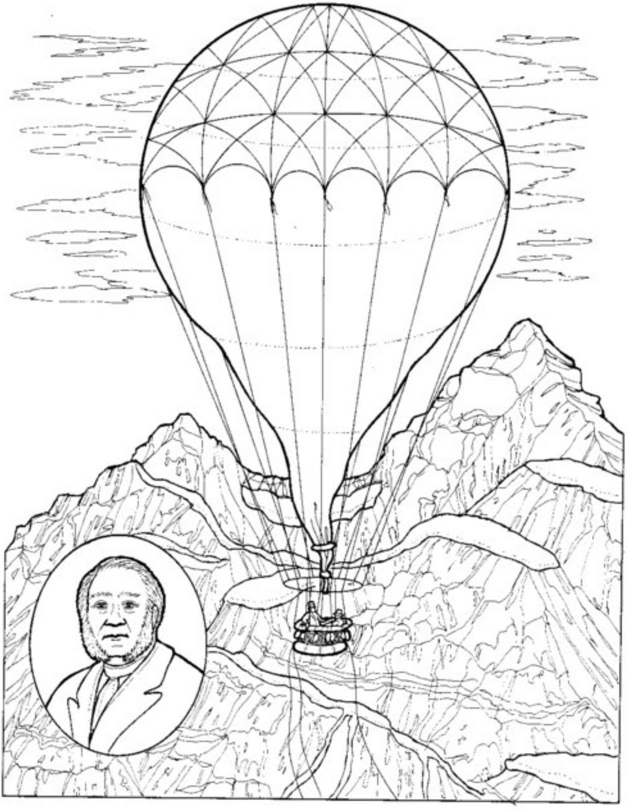


8. Lord Rayleigh and Sir William Ramsay

Two early pioneers in atmospheric studies were English scientist **Lord Rayleigh** (1842–1919, born John William Strutt) and Scottish researcher **Sir William Ramsay** (1852–1916, pictured above).

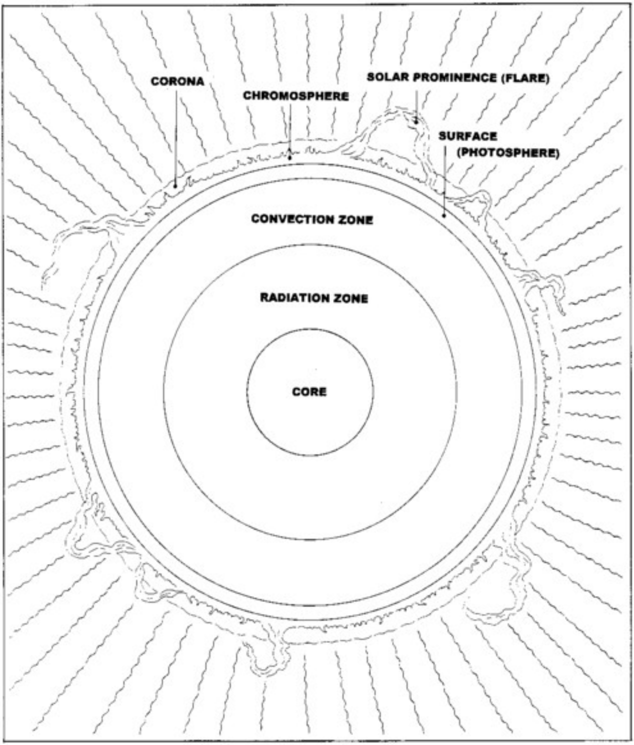
Lord Rayleigh discovered how air molecules scatter light to create our familiar blue sky. As shown in the lower diagram, **white light** is composed of the six natural full-spectrum colors from sunlight. As this light enters the Earth's atmosphere at about 18 miles of altitude (step 1), it begins to encounter air molecules. Through sheer random chance, air molecules are exactly the right size to scatter the shorter wavelengths of light, primarily blue and some violet. The scattered blue light waves fan out in all directions (step 2), causing blue light to appear throughout the sky. The other colors of the spectrum continue to the surface of the earth unimpeded (step 3).

Sir William Ramsay's researches in inorganic chemistry led to his discovery of the trace gas elements of the Earth's atmosphere. Between 1885–1890 he published papers on the oxides of nitrogen, and then on **argon**, **helium**, **neon**, **krypton**, and **xenon**—which comprise less than one percent of the **inert gases** in our atmosphere. At first working separately and later in collaboration, Lord Rayleigh and William Ramsay jointly announced the discovery of argon in 1894.



9. James Glaisher and Henry T. Coxwell, Weather Balloon Ascensions

The use of balloons to study weather in the upper atmosphere began with the exploits of **James Glaisher** (1808–1903, pictured above). Glaisher, a meteorologist and accomplished balloonist, along with his co-pilot **Henry T. Coxwell**, made 28 high-altitude ascensions between 1862 and 1866. They took temperature, air pressure, moisture, and wind speed measurements within the layer of our atmosphere known as the troposphere, once reaching an altitude in the range of 29,000 to 36,000 feet (Mount Everest has a height of about 29,000 feet)—higher than anyone had ever gone before without breathing apparatus. During that ascension, Glaisher passed out from lack of oxygen while a semi-conscious Coxwell was able to force the balloon into a descent. Their studies confirmed that as altitude increased, air temperature, air pressure, and oxygen content decreased.

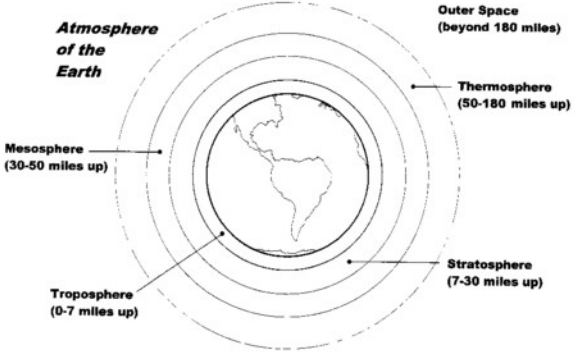


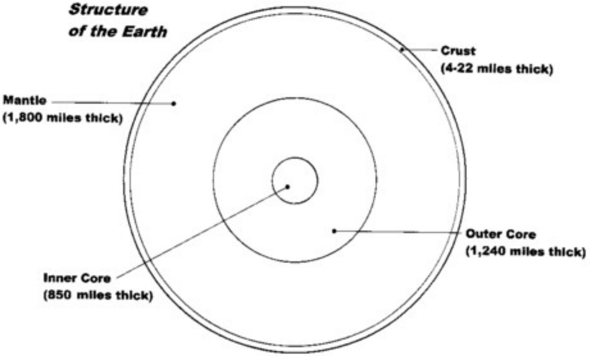
10. The Sun, Generator of Earth's Weather

The **Sun** is the parent star of our solar system. It is a parent in both symbolic and literal terms. The Earth and other planets were created from solar material as the Sun itself was being formed. The Sun is a **type G medium-sized yellow main sequence star**. A main sequence star is in the middle of its life cycle. Our star is thought to have been formed through nuclear fusion approximately **4.6 billion years ago**. With its 10-billion-year life span, it will exhaust its nuclear fuel within the next 5 billion years.

The power of our Sun, or any star, is derived from the process of **nuclear fusion** by which the element **hydrogen** is fused through heat and pressure into **helium** and other heavier elements. This process releases enormous amounts of energy in the form of heat and light, without which there would be no life—or weather—on planet Earth.

The Sun is an immense object in relation to the Earth. With a diameter of **864,950** miles, it is over 100 times larger than our planet. The Sun's structure is comprised of a number of layers. Within the central core, the temperature is a mind-boggling 27,000,000° F. Its outer layers are cooler. The surface, or **photosphere,** is 10,000° F; the next level, the **chromosphere** burns at 180,000° F; while its outermost layer, the **corona** can attain a maximum of 3,500,000° F. Huge spouts of solar energy, called **flares** or **prominences**, rise from the sun and can extend 60,000 miles into space.



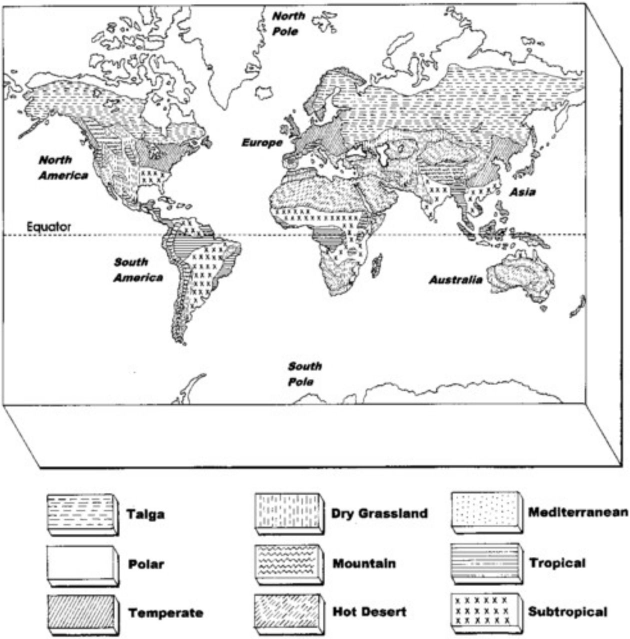


11. Structure and Atmosphere of the Earth

The planet Earth with it's life-giving atmosphere is far different in composition and structure than a star like the Sun. Earth is one of the four rocky inner planets of the solar system known as the **terrestrial** planets, named after our own Earth (Terra means Earth in Latin). The next four outer planets are called the **gas giants**, due to their composition primarily of methane and ammonia gases. The outermost planet, tiny **Pluto**, is currently considered an **icy dwarf**—a small planetoid with a frozen atmosphere.

The Earth has a diameter of 7,927 miles, while our atmosphere extends approximately 180 miles up from the surface of the planet. Our planet has a molten **inner iron core** that is approximately 850 miles in diameter, which creates a strong magnetic field around the planet. The inner core is surrounded by a **liquid metal outer core** about 1,200 miles thick. The next layer is the **mantle**, which is about 1,800 miles thick and is composed of hot rock material. The final layer—the **crust**—varies in thickness from four to twenty-two miles. The crust consists of numerous rocky **tectonic** plates that move slowly on the ocean of hot rock beneath.

The atmosphere is also composed of different levels. The **Troposphere** is the sea of air that we live in and extends to about 7 miles up. Almost all of the earth's weather takes place in this layer. Next is the **Stratosphere**, reaching a maximum altitude of 30 miles. Higher up, is the **Mesosphere** extending to 50 miles, with the final layer, the **Thermosphere** (also called the **Ionosphere**), reaching about 180 miles into space.



12. World Climatic Zones

The weather on our planet is divided into **climatic zones** based on temperature, rainfall, winds, types of vegetation, and the geographic positions of **latitude** (North–South) and **longitude** (East–West). The warmest temperatures are found at the **equator**, the imaginary central belt that circles the Earth from East to West and divides it into two hemispheres. The farther away a point is from the equator—North or South—the cooler the temperatures, until the Arctic and Antarctic regions are reached.

The **taiga** is a broad expanse of cool coniferous forest (the conifer family includes evergreen trees such as pine, fir, and spruce) that stretches across large parts of northern Asia, Europe, and the North American continent.

The north and south **polar** regions are the coldest, and are characterized by sparse vegetation and temperatures that can reach 130° below zero F.

The **temperate** areas receive consistent and moderate rainfall, and have warm summers and cold winters.

The **dry grasslands** also receive uniform rainfall, with milder summers and winters.

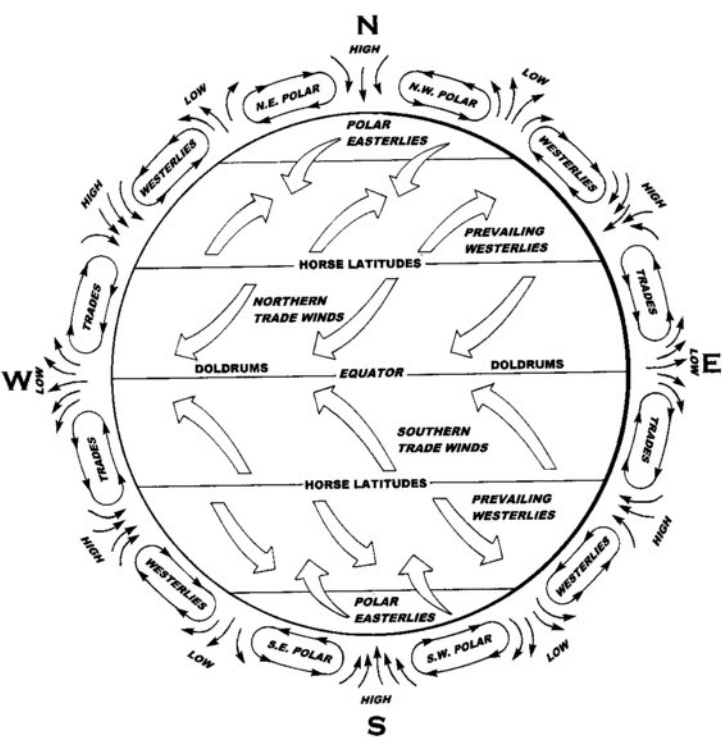
Mountain terrain tends to experience more rain and snow, and the air gets colder as altitude increases.

Hot desert regions receive very little annual rainfall and reach the highest temperatures, the hottest ever recorded being 136° F.

Mediterranean regions experience hot, dry summers and moderately cool, wet winters.

Tropical areas have the greatest annual rainfall and consistently experience hot, humid weather on an annual basis. The South American country of Colombia averages over 400 inches of rain per year!

Subtropical regions receive generous but more moderate amounts of rainfall and have consistently warm temperatures.



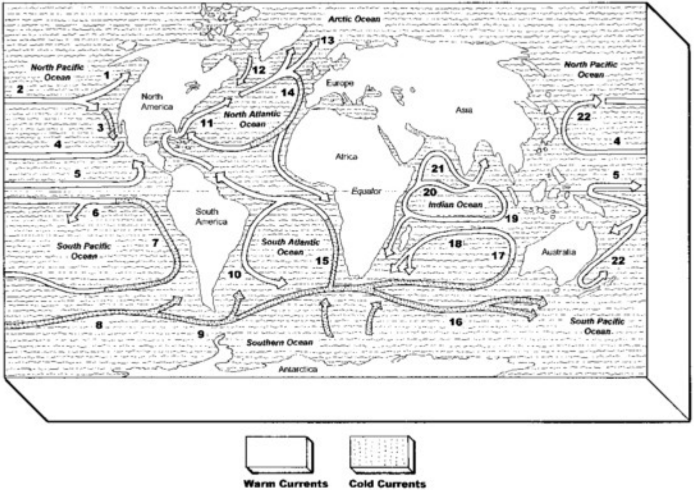
13. Global Wind Patterns

The consistent pattern of **global winds** is one of the prime determinants of weather conditions. Known as **prevailing winds**, these generally blow with a constant frequency within specific geographical locations. Winds are created by temperature and air pressure differences as the air moves from low pressure areas to high pressure regions.

At both poles, winds blow to the east and so are known as the **polar easterlies**. The wind patterns next to the polar easterlies are called the **prevailing westerlies** due to their directional movement. At latitude 30 degrees North and South a belt of calm air exists called the **horse latitudes**. The **trade winds** bound either side of the equator with easterly winds. There is another area of calm air that circles the Earth at the equator that's called the **doldrums**. The general movement of cold air from the poles and its replacement with warmer air is a major influence on climate. There are also extremely fast-moving winds in the upper atmosphere called the **jet stream**, which generally blow from west to east and can reach speeds of up to 170 mph. They are caused by extreme pressure and temperature differences at high altitudes (30,000 to 40,000 feet).

14. Global Ocean Currents

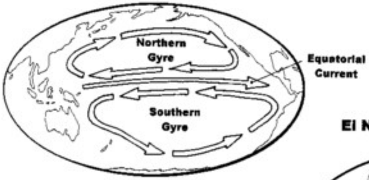
Just as winds have consistent patterns, so do the oceans have **currents** that flow in predictable directions and locations. Since the oceans of the earth cover 70% of its surface, these currents have a very significant impact on weather. The general circulation of ocean currents in the Pacific and Atlantic oceans is driven by deep rivers of cold water flowing from the poles. The warm and cold currents that flow around the globe influence both coastal and inland weather patterns.



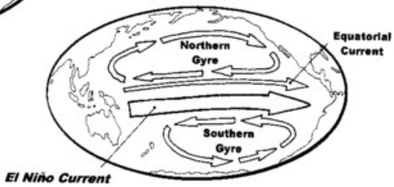
Ocean Current Identifications

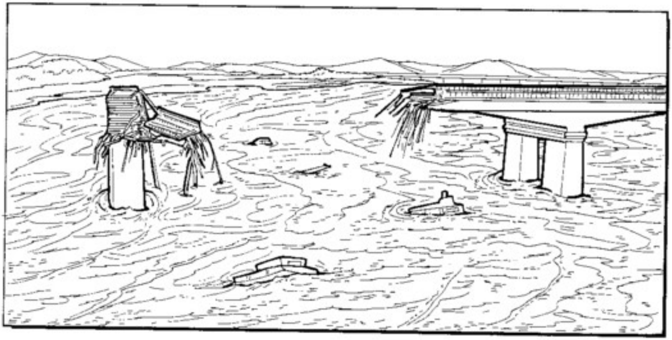
1. Alaska Current
2. North Pacific Drift
3. California Current
4. North Equatorial Current
5. Equatorial Counter-current
6. South Equatorial Current
7. Peru or Humboldt Current
8. West Wind Drift
9. Cape Horn Current
10. Brazil Current
11. Gulf Stream
12. Labrador Current
13. North Atlantic Drift
14. Canaries Current
15. Benguela Current
16. West Wind Drift
17. West Australian Current
18. South Equatorial Current
19. North Equatorial Current
20. Indian Counter current
21. Monsoon Drift
22. Kuroshio Current

Normal Pacific Ocean Currents



El Niño Pacific Ocean Current

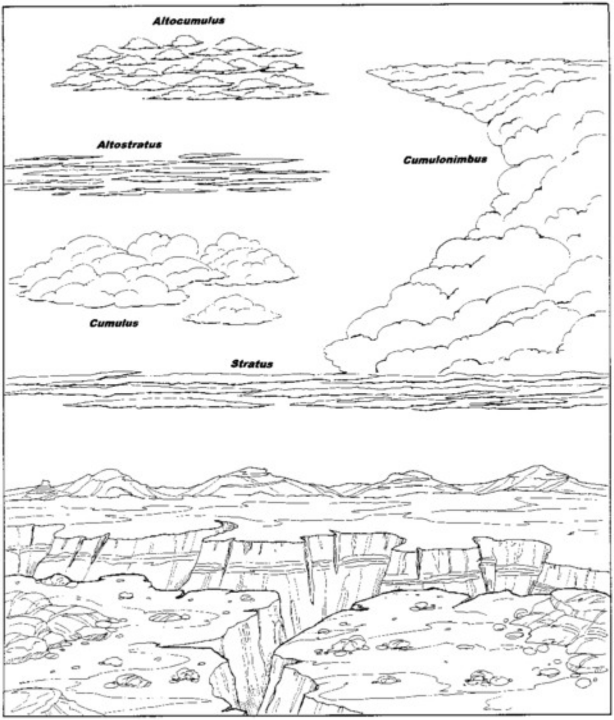




15. El Niño Weather Phenomena

The relationship between wind patterns and ocean currents and their combined effect upon the weather is demonstrated by a periodic phenomena called **El Niño**—a nickname given to the event by the Spanish-speaking people along the South American coast. It means "Christ child" in Spanish. In scientific terms it is referred to as the **southern oscillation** because of the reversal of the **southern gyre** (wind and water movements). The **trade winds** normally blow warm equatorial currents westward. During an El Niño occurrence, the usually strong trade winds weaken, causing warm surface waters from the eastern Pacific to flow westward all the way to the coast of South America. Temperature and rainfall patterns are affected primarily along the Pacific coasts of North and South America, but can also be experienced on a worldwide basis.

El Niño has been the cause of both severe drought conditions, as well as heavy rainfalls that trigger destructive floods. This change in wind and current patterns happens at 2-to-7 year intervals and has a duration of about 2 years.



16a. Luke Howard Cloud Classification System

Clouds are easily the most common sight in the daytime sky. As they intrigue us with their varied and ever-changing shapes, they are also key indicators of weather conditions. The different types of cloud formations were formally named and categorized in 1803 by the British scientist **Luke Howard** (1772–1864). He based his system on the general shapes of different types of clouds. He used Latin, the language of science, to describe lumpy clouds as **cumulus**, meaning heap. More expansive formations he called **stratus**, meaning layer, and wispy thin clouds he named **cirrus**, meaning lock of hair. From these basic shapes, more specific cloud names were developed. Howard's system has become the standard used by modern meteorologists.

Shown above are five common **cloud types** (from bottom to top):

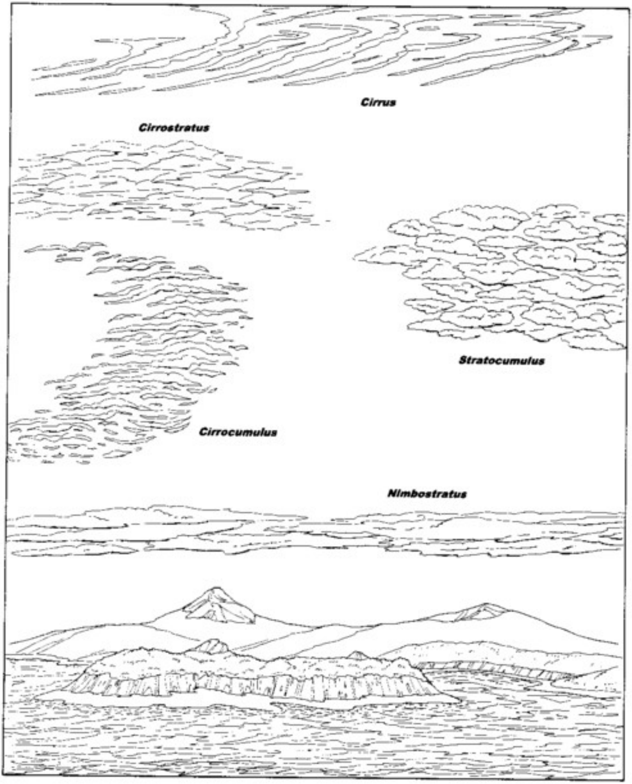
Stratus—long thin lens-shaped clouds usually forming below 6,500 feet.

Cumulus—puffy clouds which also form at altitudes below 6,500 feet.

Altostratus—formed in sheets at mid-level altitudes between 6,500 and 16,500 feet.

Cumulonimbus—puffy moisture-laden clouds that form at low levels but can rise up high into the atmosphere; these can form anvil-shaped thunderhead clouds.

Altocumulus—form as separate lumpy clouds at mid-level altitudes, below 16,500 feet.



16b. Cloud Classifications, continued

Shown above are five more common cloud types (from bottom to top):

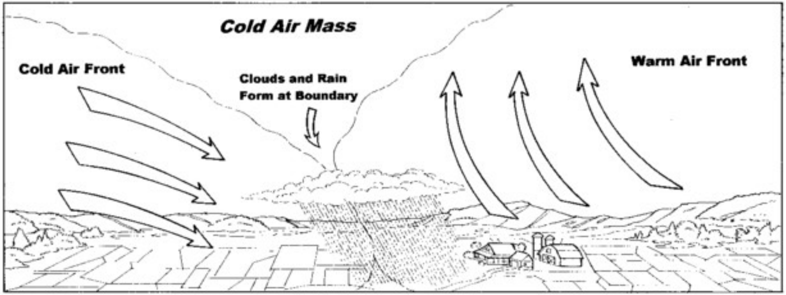
Nimbostratus—form into sheets at mid-level altitudes.

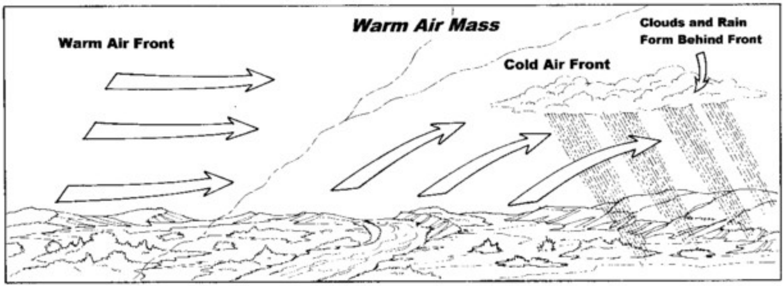
Cirrocumulus—form into lumpy sheets loosely connected at high altitudes, i.e., between 16,500 feet and 35,000 feet.

Stratocumulus—form at low altitudes into sheets with bulging and puffy tops.

Cirrostratus—thin wispy clouds that form at high level and are composed primarily of ice crystals.

Cirrus—thin wispy clouds forming curved shapes at the highest altitudes between the troposphere and the stratosphere. Sometimes called mare's tails.

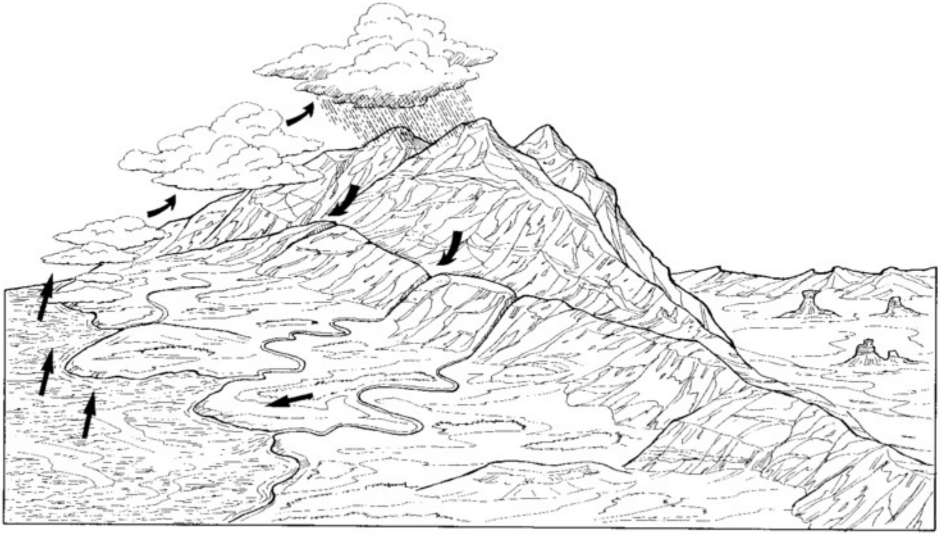




17. Cold and Warm Air Masses (Fronts)

As large bodies, or **masses**, of warm and cool air are moved by winds, they create different weather conditions. The point at which air masses of different temperatures make contact with one another is called a **front**. Shown above are the typical conditions of a **cold front** and a **warm front**.

When a cold front advances on a warm air mass, the heavier cool air forces itself under the lighter warm air, pushing it upward. This action often causes cloud formations that can produce rainfall along the steep boundary zone of the two air masses. When a warm front pushes into a cold air mass, the lighter warm air slides up and over the cold air. A gently sloping boundary zone between the two fronts is created that can stretch for hundreds of miles. This can cause increased cloud formation with resultant rain at some distance behind the warm/cold air front contact area. Fronts can move quite rapidly, with periods of bright sunshine followed by rain, then changing back to sunny skies—all in a relatively short period of time.

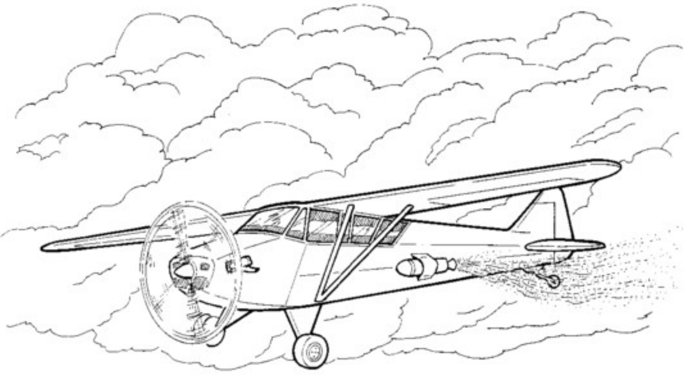


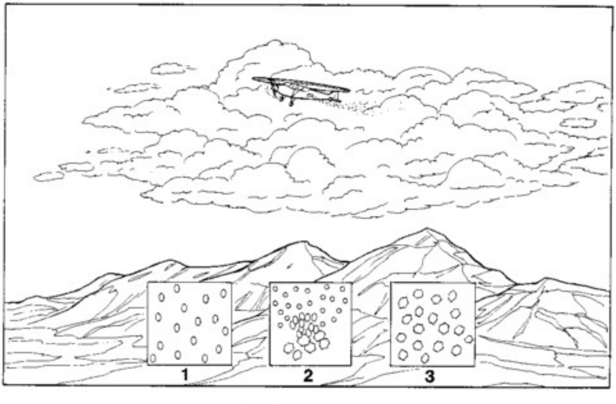
18. Cloud Effects and the Water Cycle

Much of our weather is driven by the ongoing process of constant interaction between ocean moisture, atmospheric clouds, land formations, and vegetation known as the **water cycle**. As water evaporates from the oceans into the atmosphere, moisture-laden clouds are formed. Offshore winds blow these clouds onto land areas. As the clouds travel over land they absorb more water from vegetation in a process known as **evapotranspiration**. Upon reaching coastal mountain ranges, the clouds are forced upward where the cooler air condenses water vapor into droplets, which fall as rain. The rain flows into mountain streams, lakes, and rivers, and eventually drains back into the ocean, completing the water cycle.

19. Native American Rain Dance

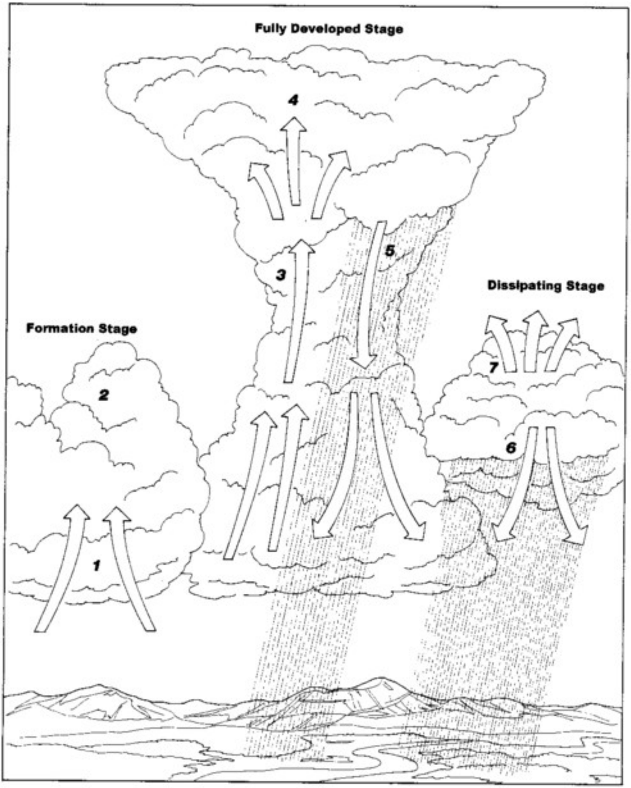
In many areas of the world, rainfall is a scarce and precious commodity. Without rain, vegetation (including crops, of course) cannot grow; and without it, both humans and animals would starve, as well as face an inhospitable environment. In ancient times, primitive peoples invented and invoked magical beings and spirits to help secure much needed rainfall. The American southwest is one example of a dry, hot region where the amount of precipitation can be a life and death matter. Shown above is a Pueblo Indian of New Mexico performing an eagle dance in the hope of inducing rainfall from the mighty eagle, whom the tribe associates with rain, thunder and lightning, and healing powers.





20. Cloud Seeding

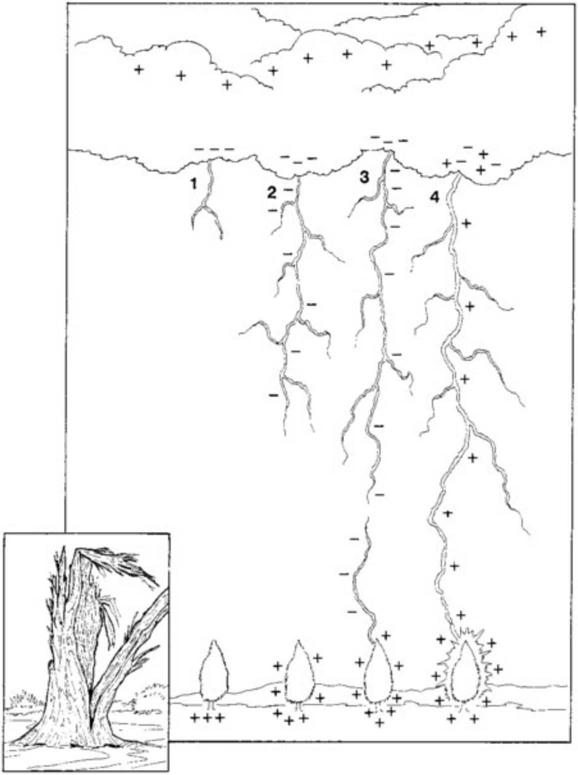
Scientific knowledge about the weather advanced through the twentieth century to the point where predicting or even modifying the weather became a practical reality. A method of triggering rain from clouds—or **cloud seeding**—was discovered in 1946 by **Vincent J. Schaefer**. Known today as the father of modern weather modification, he conducted the first field experiments at the General Electric Laboratory in Schenectady, New York. He found that precipitation could be induced by dispersing **dry ice crystals (carbon dioxide)** from an aircraft flying through clouds. The dry ice crystals attract enough water vapor to form larger, heavier water droplets or ice crystals that then fall to the earth as rain. A colleague of Schaefer's, **Bernard Vonnegut**, later discovered that the compound **silver iodide** could also be used for cloud seeding and rainmaking.



21. Thunderstorm Formation

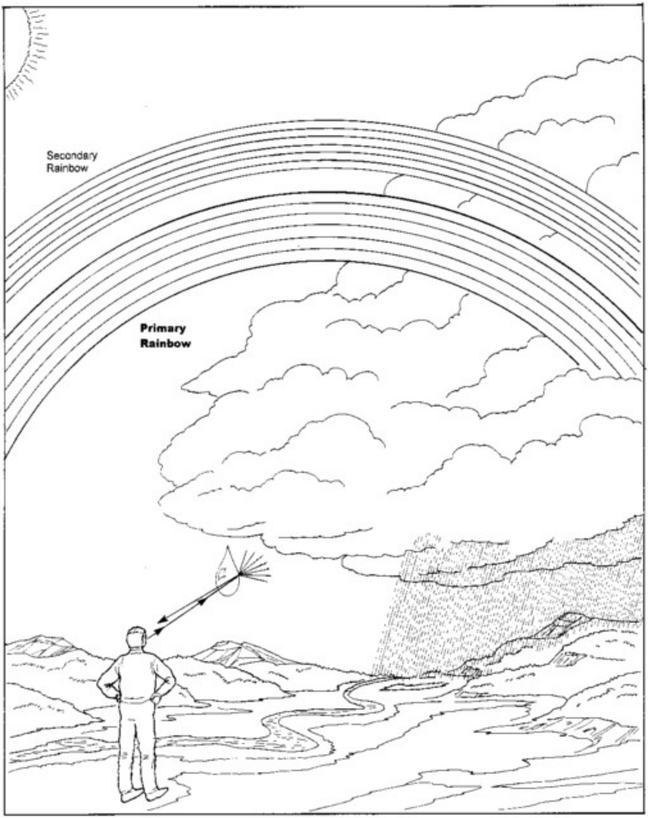
Thunderstorms are one of nature's most powerful, exciting, and dangerous weather events. They are basically powered by temperature differences between warm low-level air and the colder air at higher altitudes, and by the release of energy as water vapor condenses into drops of liquid water or ice.

The diagram above shows how in their formation stage, updrafts (1) of warm air cause clouds to form (2) as the moisture in the air begins to condense. As this process proceeds, a fully developed thunderstorm is formed. As more warm updrafts feed the clouds (3), larger quantities of water droplets or ice crystals form within the upper cloud decks (4). The heavier water and ice begin to fall creating cooler downdrafts of air (5). The storm begins to taper off as downdrafts (6) envelop and smother the warm updrafts, cooling, drying, and eventually dissipating the storm (7). The towering anvil-shaped thunderhead cloud tops created by this process can reach an altitude 40,000 feet.



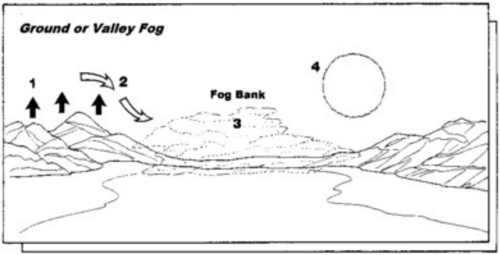
22. Lightning

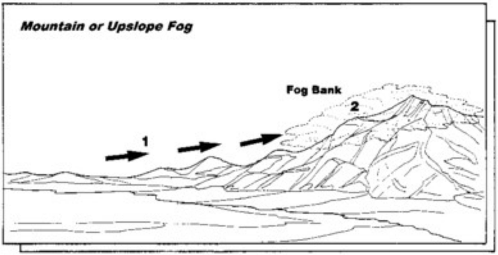
Even more dangerous than the thunderstorm itself is one of its by-products—**lightning**. While the sound of rolling thunder is the bark of a thunderstorm, lightning is its powerful bite, generated by the differences in electrical charges within storm clouds. As water and ice crystals collide with one another, static electricity is built up. Positive electrical charges gravitate to the cloud tops while negative charges move to the cloud bottom. When the difference between the charged particles is great enough, energy is released as a lightning stroke that begins to zigzag downward in a **stepped leader** form (1). As the negatively charged leader stroke continues downward it begins to draw up a **streamer** of positively charged particles (2). As the leader and streamer close distances, a powerful **electric current** is established (3). When contact is made, a powerful stroke of positive electrical energy travels upward (4) at extreme speeds of around 60,000 miles per second to make the **lightning bolt** that we see. The tremendous energy of a lightning bolt causes the air within its vicinity to rapidly heat up to over 50,000° F. It is this incredible heating process that causes the sound of thunder. Because of the immense electrical energy and heat generated by lightning, it can cause massive destruction upon striking solid objects.

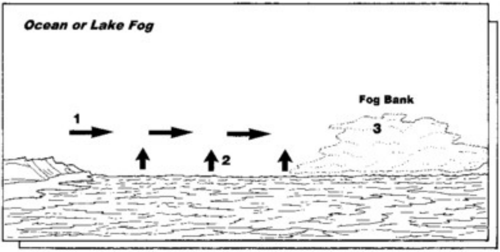


23. Rainbows

Rainbows occur due to the **refraction** (bending) of light through water droplets. These marvelous apparitions materialize only when the sun is behind the observer and rainfall is in front of the viewer. As the sunlight passes through individual raindrops, the droplets act as tiny **prisms**, splitting the white light into its constituent spectral colors. Starting at the outside edge, the spectrum changes in hue from red, orange, yellow, green, blue, indigo, and finally to violet on the inside edge of the rainbow's arc. Occasionally, a primary rainbow is accompanied by a secondary rainbow, which appears with the order of the colors reversed because the light is refracted twice within the same water droplet.





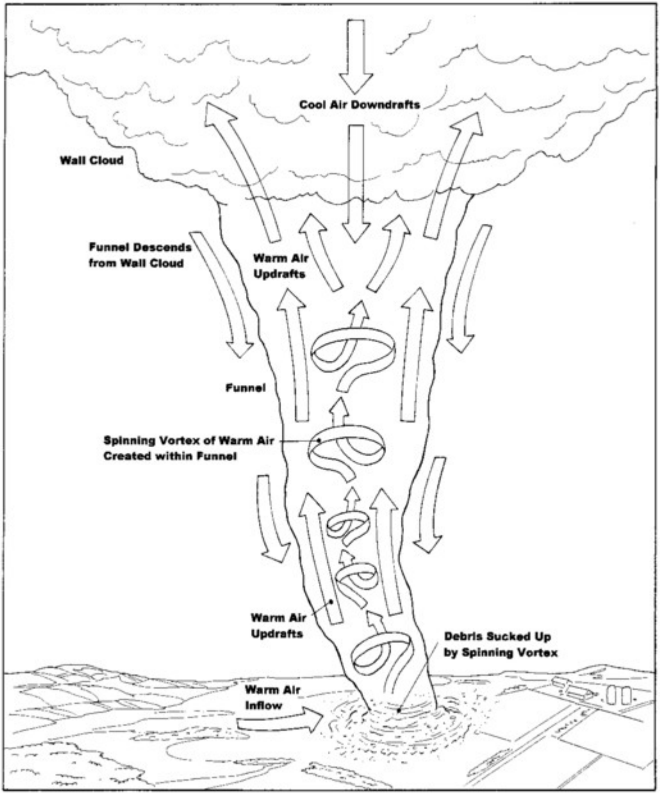


24. Fog

Basically, **fog** is low-lying cloud cover at sea level. There are different types of fog that are created by various weather conditions. **Ground** or **valley fog** is formed when heat radiates up from the ground after nightfall (1). The ground and air cool, and the heavier cooler air flows into low-lying areas (2). A **fog bank** forms when the water vapor in the air condenses onto droplets that form clouds (3). As the sun rises in the morning (4), it heats the air causing the water droplets in the fog to evaporate.

Mountain or **upslope fog** is created when winds blow warm, moist air upward into hills and mountains (1). As it reaches higher, cooler altitudes, the moisture condenses into water droplets forming clouds of ground-hugging fog (2).

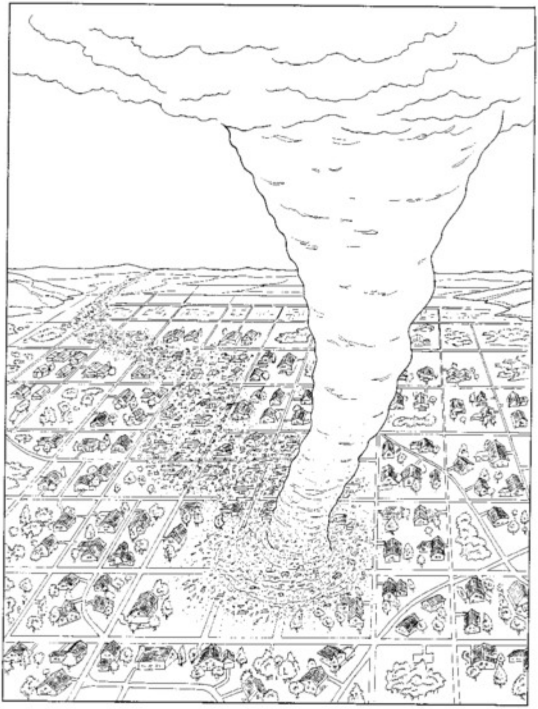
Ocean or **lake fog** is formed when cool air blows off land areas and over warmer bodies of water (1). Water evaporates from the lake or ocean (2), increasing the moisture content of the air. A fog bank (3) is formed when enough moisture condenses into water droplets to create a cloud.



25. Tornado Formation

Spawned by thunderstorms, **tornadoes** are nature's most powerful and destructive winds. The awesome and chilling sight of a dark funnel cloud descending from the clouds foreshadows the potential for great harm. With wind speeds that can reach over 300 mph, there is little that can withstand the force of a tornado.

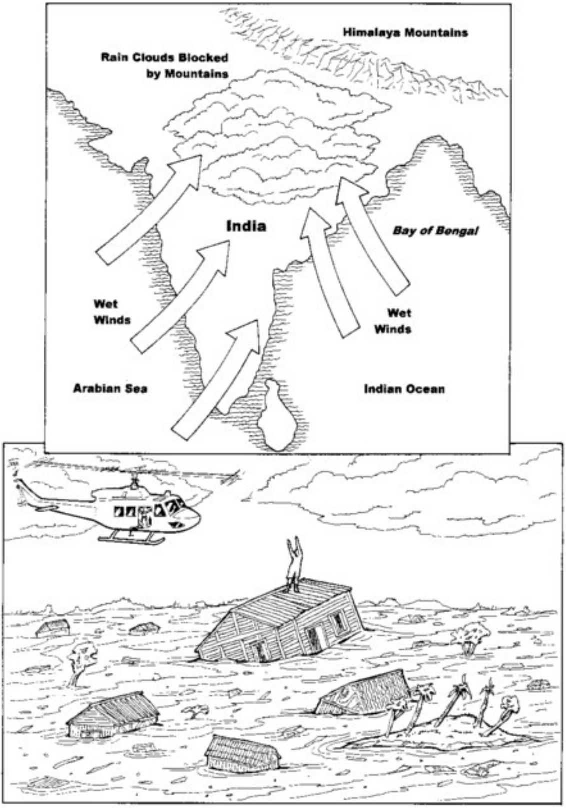
These violent windstorms are formed when an updraft funnel of warm air rises quickly to a thundercloud. High winds flowing through the cloud along with cool downdrafts of air can set the funnel of air into a spinning motion called a **vortex**. The stronger the initial winds, the stronger the vortex. When the tornado touches down, objects are sucked up into the vortex with violent force. The area affected by a tornado may be as small as several hundred feet wide, or grow to a half-mile across. Their path along the ground can be as long as 125 miles, while the funnel can reach a forward speed of 40 mph.



26. Tornado Destruction

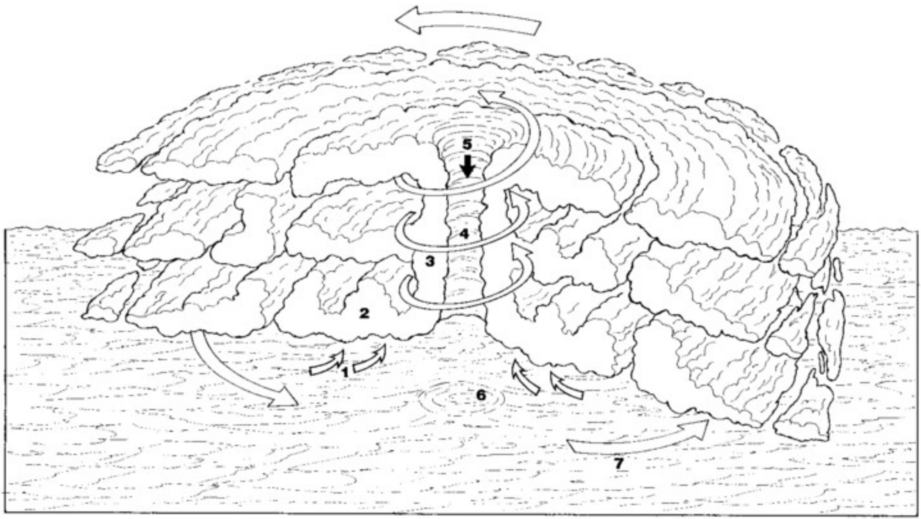
The six-level **Fujita scale** (also known as the **F-scale**) measures the destructive power of tornadoes. Devised by meteorologist **Tetsuya Theodore Fujita** of the University of Chicago, it classifies tornadoes according to wind speed within the vortex. An **F0** funnel reaches speeds between 40 mph and 72 mph, and can cause light damage to man-made structures. An **F1** contains winds rotating at speeds from 73 mph to 112 mph, and can cause moderate damage to trees, roads, and mobile homes. As wind speed increases to an **F2** tornado, speeds of 113 mph to 157 mph are reached. These winds can cause considerable damage, tearing roofs off houses and uprooting large trees. Severe damage can occur with an **F3** tornado and its accompanying wind speeds of 158 to 206 mph. Houses can be knocked from their foundations, trains blown off tracks, and cars lifted off the ground. The level of damage caused by an **F4** is deemed devastating—as the vortex winds reach 207 mph to 260 mph. Even especially well built houses can be entirely destroyed, cars can be tossed around and smashed, and trees can be uprooted and thrown through the air. A monstrous **F5** tornado is capable of catastrophic damage with the fastest wind speeds on Earth. Spinning from 261 mph to a frightful 318 mph, they can lift strongly built houses into the air and transform vehicles into dangerous flying projectiles. Fortunately, tornadoes of this magnitude are rare.

The United States has the most frequent occurrence of tornadoes. They often strike along **Tornado Alley**, a broad area stretching from Texas, across the Midwest, and into the southeastern states. Notice in the depiction above how the damage occurs only in the tornado's wake, with houses and trees in the nearby environs virtually untouched.



27. Monsoon Rains

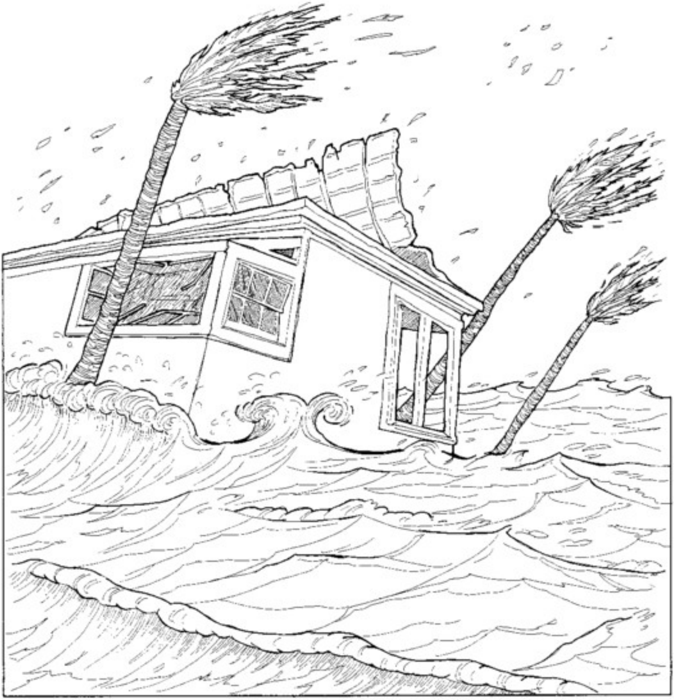
Many areas of the world experience **monsoons**—a wind system that produces dry and wet seasons—but there are none stronger than those that occur in Africa, southeast Asia, and northern Australia. The heaviest monsoons occur in summer over the subcontinent of India. During the winter months, the high pressure systems of cool air over the Tibetan plateau and Himalayan mountains drive winds southeast across India, pushing moist air out to sea. In the summer, the Himalayan high pressure dissipates and a low-pressure system is formed over northern India, drawing in moist warm air from the ocean and resulting in heavy rains over much of India. Seasonal flooding of rivers and lakes initiated by monsoon rains often cause widespread destruction in low-lying areas of the country.



28. Hurricane Formation

Hurricanes are the most massively destructive storm systems on Earth. These circular, swirling wind and rain storms can cover an area as wide as 500 miles. Wind gusts within the hurricane can reach **225 mph**. With that degree of wind speed and overall size, hurricanes can cause considerable destruction and loss of life.

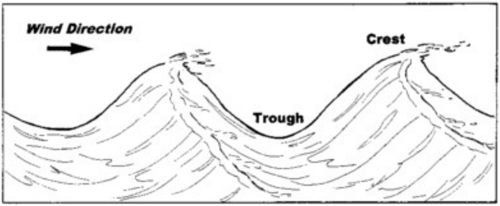
Hurricanes form in tropical regions when warm, moisture-laden air rises off the ocean (1) and condenses into bands of rain clouds (2). The clouds will begin to rotate (3) in a counter-clockwise direction in the northern hemisphere and clockwise south of the equator. The rotating winds create an intense low pressure area in the center, or **eye**, of the storm (4) and (5), which sucks up seawater into a mound that can be 25 feet higher than the surrounding ocean area (6). As the entire storm rotates and moves toward land (7), the mound of water comes ashore as a **storm surge**, also known as the hurricane tide. In the western Pacific, hurricanes are called **typhoons**, while in the vicinity of the Indian Ocean, they are known as **cyclones**. It has been a common practice since the 1950s to assign male and female names to individual tropical storms.



29. Hurricane Destruction

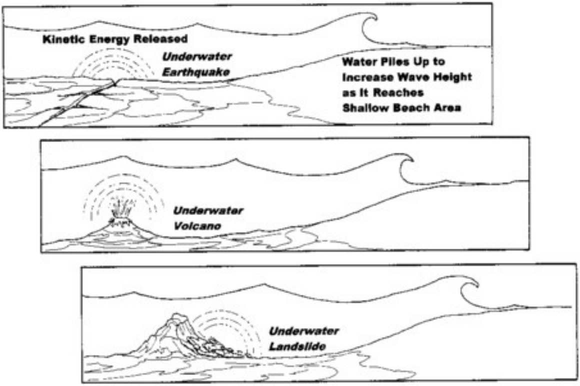
The damage from a hurricane depends on its wind speed, amount of rainfall, longevity, and the storm surge—the wall of water driven ashore along coastlines. All these factors are taken into consideration when classifying a hurricane's destructive potential. The **Saffir-Simpson scale** assigns five categories to these storms. **Category One** can cause minimal damage with wind speeds from 74 mph to 95 mph and a storm surge of 4 to 5 feet. **Category Two** storms can cause moderate damage with a storm surge of 6 to 8 feet and winds of 96 mph to 110 mph. A **Category Three** hurricane causes extensive damage with winds of 111 mph to 130 mph, and a storm surge of 9 to 12 feet. Extreme damage can be caused by a **Category Four** storm. Its winds reach speeds from 131 mph to 155 mph, and the hurricane tide can reach 18 feet. The most powerful hurricane, a **Category Five**, with wind speeds that can gust over 200 mph and a storm surge that can exceed 20 feet, can cause catastrophic damage.

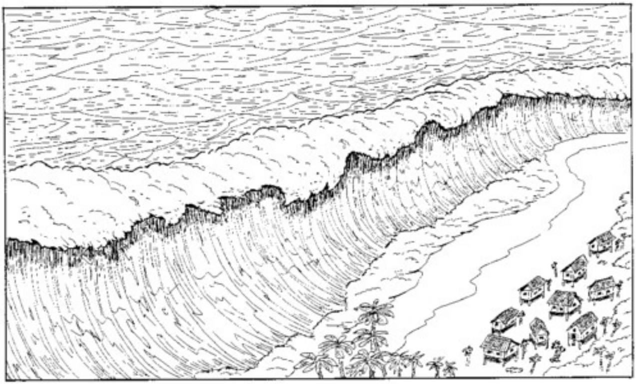
The worst hurricane storm surge in the U.S. occurred in 1969 with Hurricane Camille—a Category Five—with a rise in the water level of 24 feet along the Mississippi coast. The most destructive storm ever to strike the U.S. was Hurricane Andrew, which hit southern Florida in 1992. This monstrous storm caused 25 billion dollars' worth of property damage.



30. Storm Sea Waves

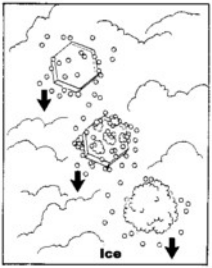
The almost constant wave action of our ocean, lake, and river waters is primarily a function of wind. As wind blows over the water it creates small pockets of high and low pressure air that suck and push the waves over the surface of the water. The wave size is measured by the vertical distance between the **crest** of the wave, its highest point, and the **trough** of the wave, its lowest point. These high points are called **swells.** The strength of the wind is the principal factor in determining wave size. The horizontal distance between swells is the **wave-length.** Hurricanes and other ocean storms can cause swells of 30 feet or more. Occasionally, storm conditions will be so severe as to cause a freak sea wave that can rise to over 100 feet.

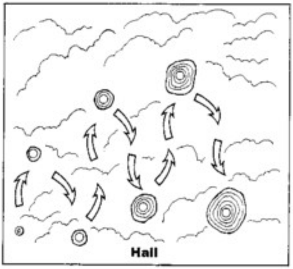


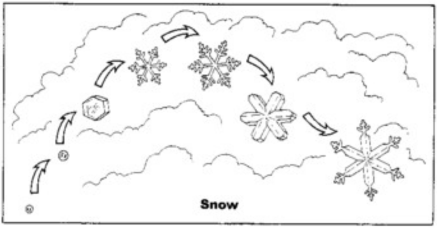


31. Tsunami

Tsunami are even larger and more devastating waves than those caused by strong winds and hurricane-grade storms. These huge waves can come ashore reaching a height of 130 feet. A tsunami is caused by seismic activity on the ocean bottom. It can be generated hundreds of miles from coastal areas by an underwater earthquake, a volcanic eruption on the ocean floor, or by the energy released from a landslide on the side of an undersea mountain. At the site of the seismic occurrence, the surface water will rise only slightly. But the enormous energy created pushes the water toward land at speeds of up to 500 mph. As the water approaches shallow coastlines, it begins to pile up until it crushes ashore with massive force. In 1883, the eruption of a volcano on the island of **Krakatoa** in Indonesia created 130 foot high tsunami which killed 36,000 people along the shoreline. Even more monstrous waves may have struck coastlines in the distant past. Some scholars believe that the Earth has been hit by large asteroids or comets a number of times over its 3 billion year history. If such an impact occurred in the ocean, it could cause tsunami that would rise thousands of feet high.







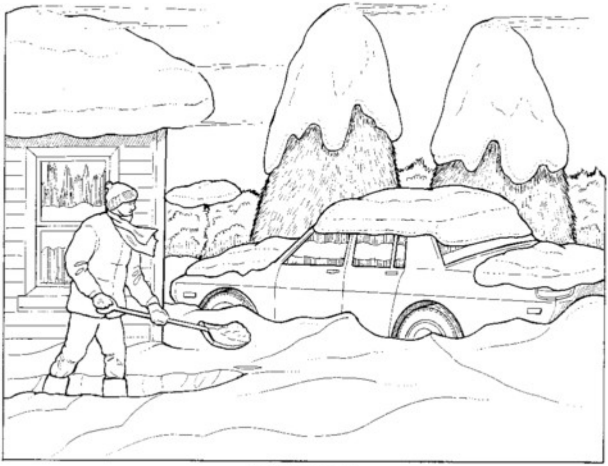
32. Ice, Hail, Snow Formation

As the temperature drops in the clouds of the atmosphere, water eventually reaches its freezing point of 32° F (0° C). As it freezes. the water droplets can change into a number different forms. The most common types of frozen precipitation are **ice**, **hail**, and **snow**.

Ice can form in several configurations. As drops of water freeze and fall they can appear as irregularly shaped smooth-sided **pellets** usually less than 3/10 of an inch in size. Another type of ice is called **graupel** (pronounced groop-el). The top left illustration shows how this kind of ice is formed. It begins as ice crystals fall through extremely cold clouds. Super-cooled ice droplets within the cloud adhere to the larger ice crystal. Eventually the shape of the crystal is completely covered by an irregular collection of ice droplets.

Hail begins as a frozen raindrop that is blown back up into the cool cloud formation by updraft winds. As it rises and falls, super-cooled water droplets build up layers of ice on the original raindrop. The **pellet** of hail can go through this process many times, gradually increasing in size. Although most **hailstones** are no larger than 2/10 of an inch, some can grow to the size of a softball.

Snow is created when water vapor in the clouds condenses into droplets of water. The droplets grow in size as more water vapor condenses onto them. When they reach a sufficiently cool temperature, they freeze into an ice crystal. When the temperature drops to around 5° F, the crystal begins to grow into a 6-branched **snowflake**. As more water vapor condenses onto the snowflake, it grows in size and shape. When it becomes heavy enough, it begins to fall as **snow**. Most snowflakes are **hexagonally-based**, that is, in a formation with 6 sides or 6 branches. Snowflake crystals come in an endless variety of shapes and patterns. And while it's oft repeated that no two snowflakes are alike, there is no scientific basis to the claim. (Imagine trying to prove that!) However, since one snowflake is comprised of more than 180 billion molecules, the odds are against one having an identical twin.



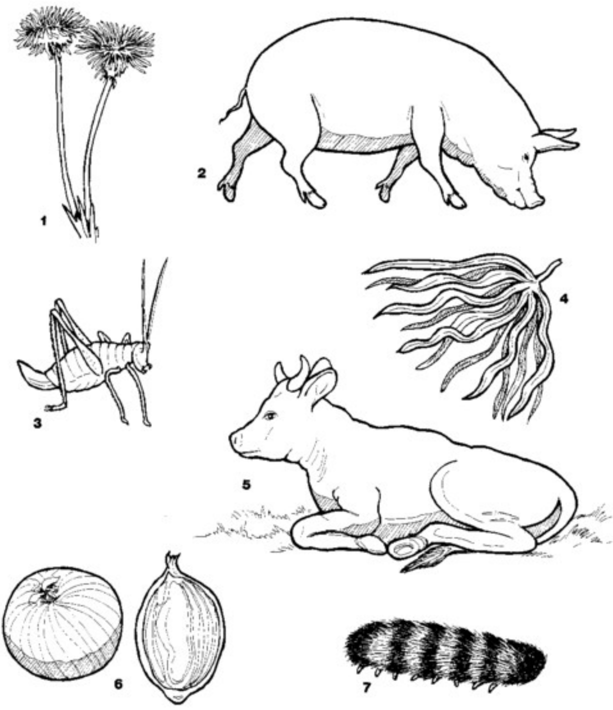
Wind Speed mph

Temperature degrees F	0	15	20	25	30
	25	2	-3	-7	-10
	20	-5	-10	-15	-18
	15	-11	-17	-22	-25
	10	-18	-24	-29	-33
	5	-25	-31	-36	-41
	0	-31	-39	-44	-49

33. Blizzard

A **blizzard** is much like a winter version of a hurricane in its ability to disrupt the routines of our daily lives. A powerful blizzard can shut down a city or region with massive amounts of snowfall and biting winds. This weather event occurs when very heavy snowfall is accompanied by winds of over 35 mph, causing extremely poor visibility—a condition especially dangerous for motorists. In its most extreme form, a **whiteout** can occur. When this happens, the blowing snow blends with the sky and the ground to form a white wall with zero visibility. A person caught in a whiteout could be just yards away from shelter and not even know it.

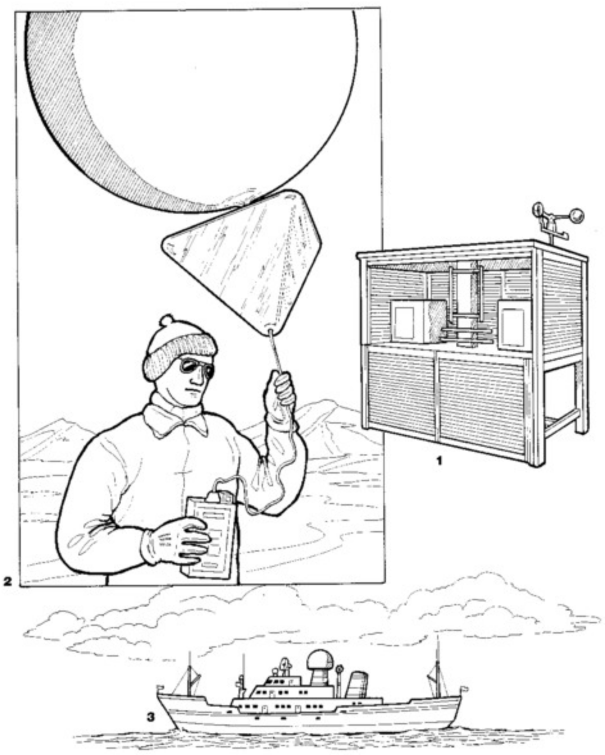
Blizzards can dump as much as 60 inches of snow onto the affected area over a relatively short period of time. When combined with high winds, snowdrifts of over 20 feet high may form, bringing to a virtual standstill all forms of transportation including aviation, rail lines, and motor vehicles. People may be trapped indoors for days without power, heat, or food, and many deaths have been known to occur in such circumstances. The Great Blizzard of 1993 claimed 270 lives. In the United States, blizzard conditions occur most frequently in the northern states, the midwest, and the northeast.



34. Natural Weather Predictors

As the science of meteorology has advanced over the last century, the art of predicting the weather has also become highly refined. Before the advent of modern weather instruments and technologies, people relied on different methods of **natural weather prediction**, mostly based on the appearance and behavior of animals and plants. Most of these forecasting signs can be relegated to the province of folklore, but some do in fact have a scientific basis.

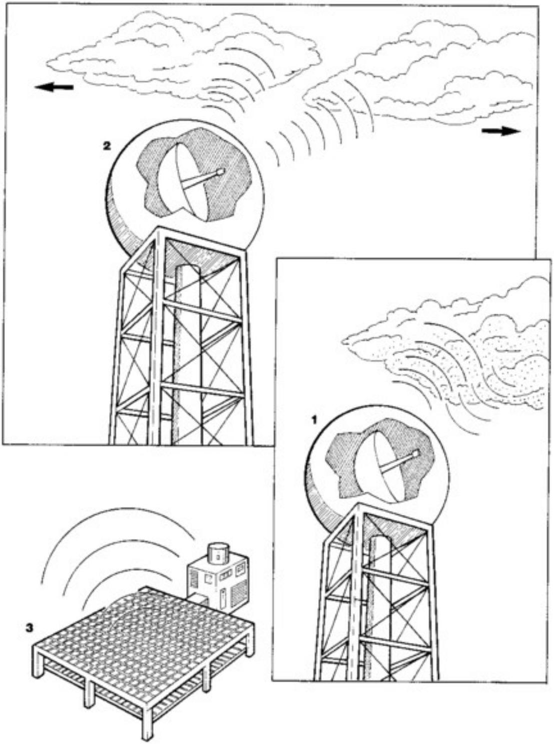
Dandelions (1) open their flower petals only when the air is dry. When the air is humid, they remain closed. Dry air is usually a sign of pleasant weather. In some quarters it is believed that when pigs (2) behave in a restless and agitated manner, an approaching gale is imminent. (Pigs are thought to be able "see" the wind.) The chirping of **crickets** (3) is indeed affected by temperature. If you count the number of chirps you hear in 14 seconds and add 40 to that number, the total will equal the temperature of the air surprisingly accurately. **Seaweed** (4) that grows near the shoreline can signal the amount of moisture in the air. When it appears shriveled and tough, the air is dry; when it is supple and soft, the air has more moisture. According to folklore, **cows** (5) will lie down if rain is coming. Some people even believe that the thickness of an **onion's skin** (6) predicts whether a winter will be mild or harsh. The thicker the outside layers, it was thought, the colder the winter. (But, in fact, there is no way for the plant to know or prepare itself in advance for what temperatures will be in the coming months.) Finally, the fuzzy little **woolly bear caterpillar** (7) was thought to grow a thicker coat of hair if it sensed a harsh winter ahead—another myth from the annals of folklore.



35. Modern Weather Stations

A network of thousands of **weather stations** is a vital element in modern weather forecasting. The simplest weather monitoring stations consist of a **Stevenson screen** (1), a small box-like structure designed by **Thomas Stevenson**—a civil engineer who was also the father of Robert Louis Stevenson—to house meteorological instruments. Ventilation is provided by slatted sides of wood or metal that allow air to flow in and out of the box while preventing sunlight and heat radiation from reaching the instruments. Within this weather shack is a **thermometer**, a **hygrometer** that measures the amount of moisture in the air (humidity), and a **mercury barometer** to record air pressure. Mounted above the box is a **wind sock** to indicate wind direction, and a device called an **anemometer** to measure wind speed.

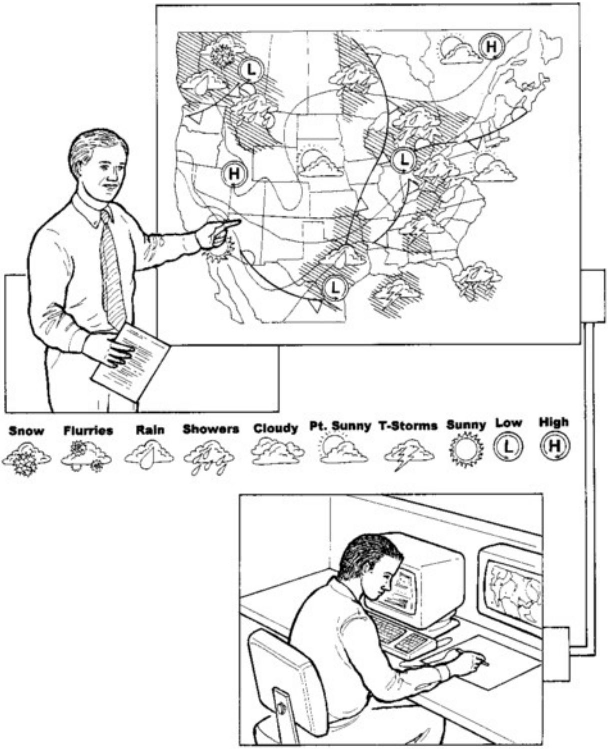
Meteorologists also use **weather balloons** (2), which ascend to a height of about 100,000 feet, to measure conditions in the upper atmosphere. These balloons, called **radiosondes**, record temperature, pressure, and humidity, and then radio the information back to weather forecasters. The **weather ship** (3) is a vessel which is permanently anchored at key locations and equipped with a variety of sophisticated instruments to monitor and report on conditions at sea.



36. Radar Instruments

One of the most advanced weather monitoring systems uses **radar** to track storms. Radar was originally developed during World War II to detect enemy aircraft. Radio signals are sent out from a transmitter in the direction of advancing aircraft—or storms. By measuring how much of the signals are reflected back to the receiver, a representation of the target may be created. **Conventional radar** weather systems (1) send out radio waves that bounce off water droplets, dust, or air temperature boundaries. The reflected radio energy is collected by electronic circuits and converted into images and maps.

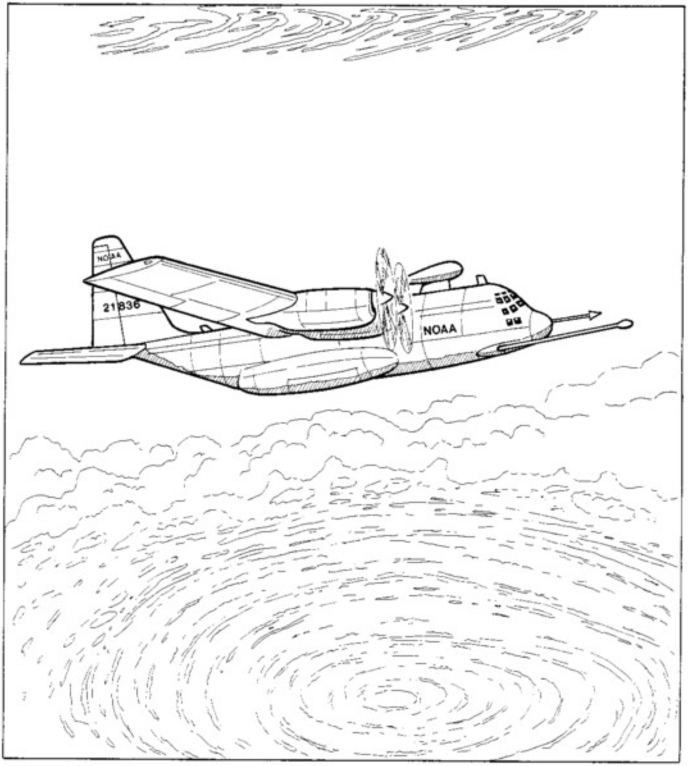
A more advanced form of radar called **Doppler radar** (2) is now in widespread use. This system can detect the directional movement of storms by the increase in frequency of the reflected radio waves (as a storm approaches), or the decrease in frequency (as a storm recedes). The latest development in weather radar uses **phased-array antennas** (3). They are used to measure wind speed and direction at high altitudes. These grid-like antennas send radio waves upward at various angles. They are able to detect even slight changes in upper air density, which then reflect back and are computer-analyzed to determine wind speed and direction.



37. Television and Newspaper Weather Maps

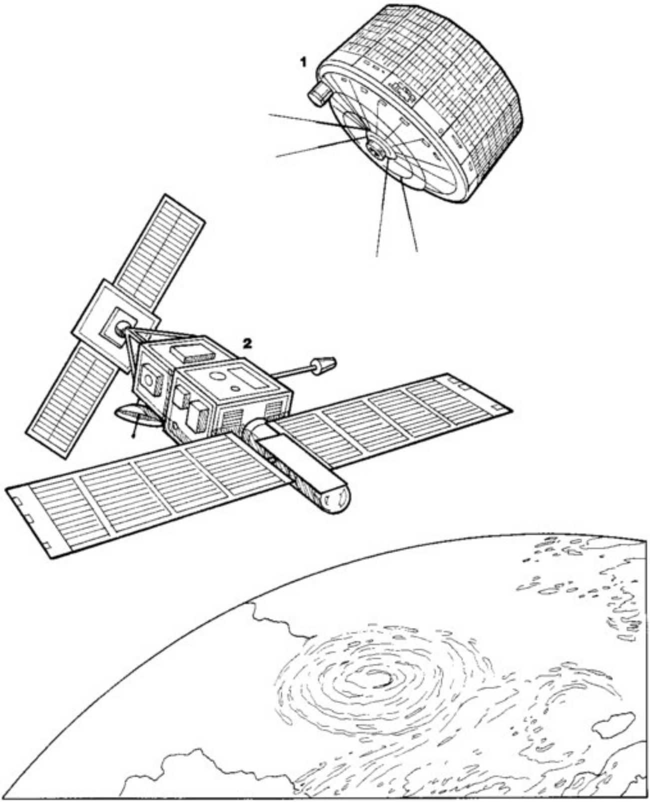
Most of our weather news comes to us from television or newspaper sources which depend, in turn, on information obtained from the **National Weather Service**. Newspapers usually show a daily weather map of the U.S. with numerous symbols, markings, and graphics that indicate specific conditions. Similar computer-generated maps are shown on television with a "forecaster" elaborating and explaining the information displayed. In reality, TV weather reporters do not have a map behind them, but rather a blank screen known in the trade as a **green screen**. The weather map images we see on our television sets are electronically inserted for broadcast by a computer operator working off-camera. When appearing to point to areas on the so-called green screen, the broadcaster is actually looking at TV monitors off-camera for image reference.

Shown above are common **symbols** that have been adapted over the years to indicate specific weather conditions. The wavy lines on the map indicate warm and cold front areas. Lines with **rounded bumps** indicate a **warm front**, while those with **triangles** represent **cold fronts**. With a little study, recognizing these symbols and learning to read a weather map are easily accomplished.



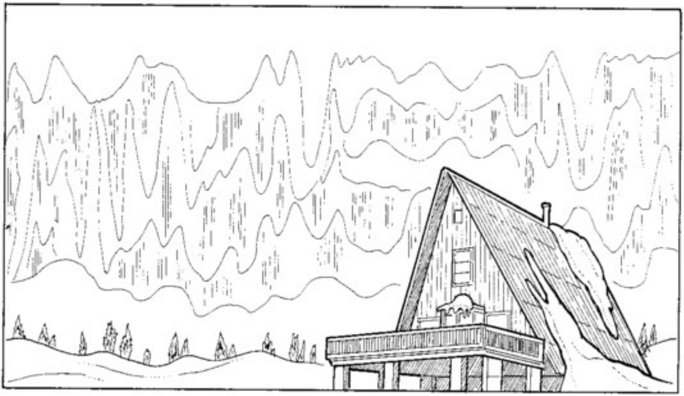
38. Weather Aircraft

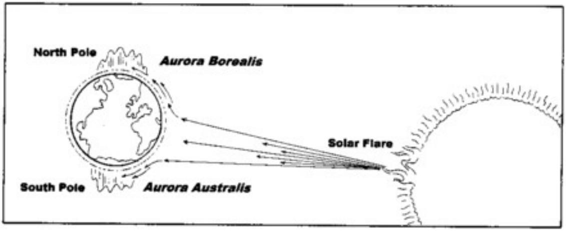
Retrofitted **aircraft** that were originally military or transport planes are in widespread use to gather weather data in the upper atmosphere. Many of them monitor hurricane strength and movement, and sometimes fly directly into the storm. The aircraft depicted above is a highly specialized version of the **Lockheed C-130 Hercules transport**, normally flown by the U.S. military. Selected for use as weather aircraft due to their outstanding reputation for reliability and ruggedness, they are powered by turbo-prop engines driving four-bladed propellers instead of the more commonly installed jet engines. They also sport cutting-edge avionics (advanced electronics technology as adapted to aeronautics) and weather sensors.



39. Weather Satellites

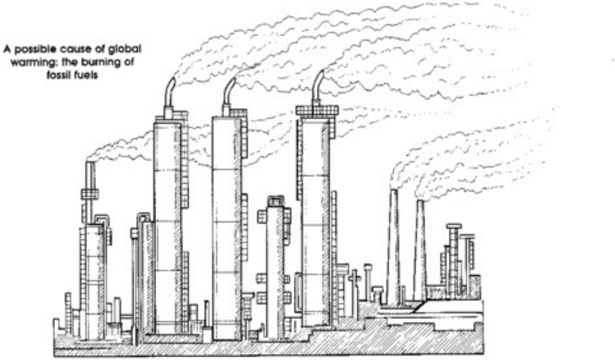
Another high-tech tool of modern meteorology is the Earth-orbiting **weather satellite**. There are two types of satellites used for gathering data and relaying the information back to weather centers. **Geostationary** satellites match the Earth's rotation, circling the planet at the same fixed point above the equator at an altitude of 22,400 miles. There are currently five of this type in orbit that can provide photographs and other data from most of the Earth's surface. **Polar-orbiting** satellites circle the earth from pole-to-pole at a lower altitude, allowing them to relay more detailed information about rapidly changing weather conditions. Shown above (1) is ***Tiros 1***, the world's first polar-orbiting satellite launched in 1960. Since then, dozens of more advanced types have taken Tiros 1's place. Also shown (2) is a modern geostationary type of satellite used in the U.S. **Geostationary Operational Environment Satellite (GOES)** system.

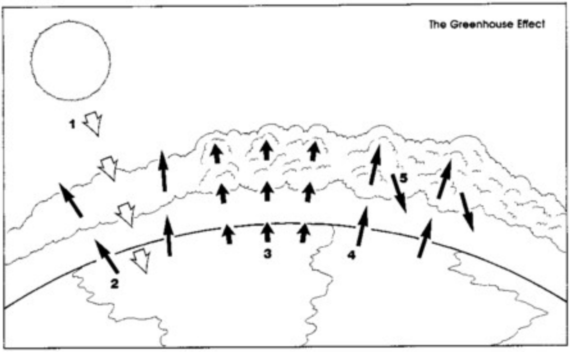




40. Aurora Borealis/Australis

Auroras are rare and beautiful weather phenomena known in the northern hemisphere as the **aurora borealis** (or **northern lights**), and as the **aurora australis** (or **southern lights**) in the southern hemisphere. These shimmering bands and curtains of color are caused by **solar radiation**, often triggered by violent eruptions known as **flares** or **prominences** on the surface of the Sun. The resulting electrons that are sent toward Earth make contact with our atmosphere between 50 and 600 miles above the surface. As they become magnetized and stream toward the polar regions, the electrons collide at high speed with oxygen and nitrogen molecules to produce an electronic splash of spectral light. **Yellow-green** colors result when electrons strike oxygen molecules in low pressure areas; **red** when oxygen molecules are struck at high altitudes where air pressure is even lower; and **blue** colors when electrons collide with nitrogen molecules.



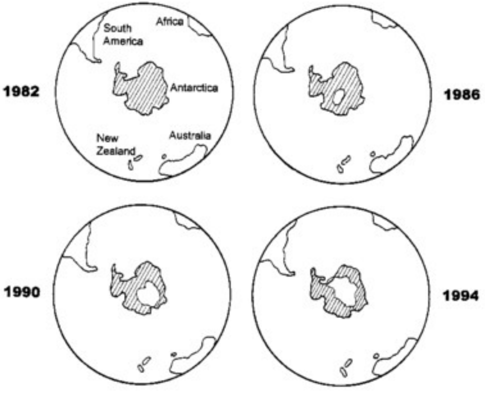


41. Global Warming

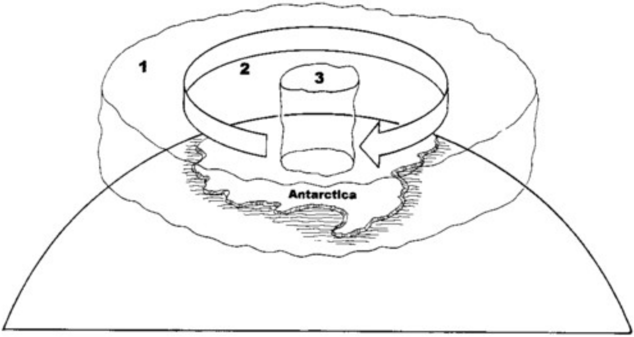
Most weather scientists believe that the world is undergoing a process of significant climatic change known as **global warming**, which may already be disrupting traditional weather patterns. The phenomenon is caused by an excess amount of heat-trapping **greenhouse gases** in the atmosphere. In the bottom illustration on this page, note that as sunlight reaches the Earth (1), some of the heat is absorbed by land and water, and some is reflected back into space (2). When these gases collect and become trapped in the atmosphere, they interfere with the radiation of heat back into space (3) and (4), and actually reflect the heat back to Earth (5) instead, causing a temperature increase, called the **greenhouse effect**.

While a multitude of known complex interactions contribute to global warming, it is still unclear as to whether human activities or natural processes play the greater role. Causative factors include greenhouse gases such as nitrous oxide, sulfur dioxide, and chlorofluorocarbons (CFC's) which are produced by industrial and automobile air pollution, as well as the great increase in the emission of carbon dioxide into the atmosphere—the byproduct of the burning of **fossil fuels** (oil, coal, gasoline) which began with the Industrial Revolution in the early years of the eighteenth century, and rapidly accelerated during the twentieth.

If global warming continues unchecked, the average worldwide temperature could increase by 10 degrees within 50 years—an increase that could have a devastating impact on the growing seasons for crops, precipitation patterns, and the water levels of lakes and oceans.



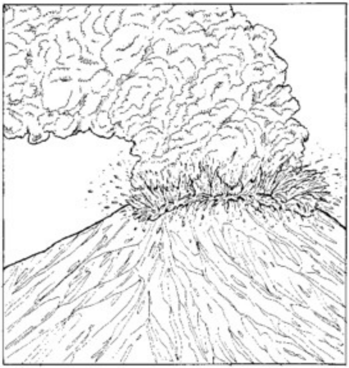
Gradual formation of the hole in the Antarctic ozone layer



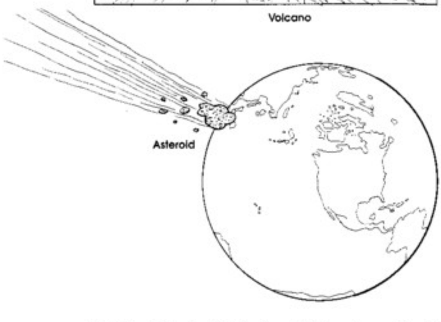
42. Ozone Layer Depletion

The atmosphere of the Earth contains a thin layer of **ozone** concentrated between 10 and 20 miles up within the level of the **stratosphere**. Ozone is a form of oxygen that blocks ultraviolet solar radiation, so its depletion results in conditions that can be harmful to both plants and animals. One of the greenhouse gases, **chlorofluorocarbons (CFC's)**, can interfere with the normal process of ozone formation. These gases are used as spray-can propellants, cooling agents for air-conditioning systems, and in the expansion of foam used in packaging. CFC's can reach the upper atmosphere and then be carried around the world by high-speed winds.

Each October, intensely cold winds begin encircling Antarctica, forming a vortex over the southern continent (1). This vortex can trap CFC's and cause ozone depletion (2). In the 1970s, scientists discovered that the layer of ozone over Antarctica was rapidly dissipating. By 1986, a hole in the ozone layer had formed (3). It grew steadily larger during the 1980s and 1990s. As many of the industrialized nations recognized this problem, they enacted laws to restrict the use of CFC's. Scientific studies have concluded that the reduction of CFC's will lead to a renewed buildup of the Antarctic ozone layer over the next 50 years.



Volcano



43. The Effect of Catastrophic Events on Weather

The Earth's weather undergoes periodic and gradual changes, as happened with the ice ages, and as may be happening now in the case of global warming. But drastic and more immediate climatic changes are also possible. **Massive volcanic eruptions** and the impact from a large **asteroid** or **comet** could have catastrophic effects on our weather. Both events are capable of ejecting enormous amounts of dust, ash, and other debris high into the atmosphere. If the explosion were great enough, a layer of dense clouds could cover many parts of the Earth, or indeed the entire globe, for weeks, months, or even years. This dark cloud layer would block sunlight and heat, causing a severe drop in temperature on a global scale. Plants and crops would die, animals that feed on plants would perish, and crop failures would cause mass human starvation. The famous year without a summer—also known as "1816 and froze to death"—was caused by the eruption in April 1815 of Mount Tambora in Indonesia, allegedly the largest recorded explosion in human history. The plume of volcanic dust slowly circled the globe, disrupting normal weather patterns along the way. In New England, which was among the regions hit especially hard by the abnormal weather, crops were destroyed as frosts and snowfalls continued throughout the summer.

As discussed earlier, the Earth has also been subject to random bombardment by asteroids and comets, like the massive asteroid that struck the Earth 65 million years ago and wiped out the dinosaurs. In June 1908, our planet experienced the harrowing effects of another object from outer space in the Siberian region of **Tunguska**. A fragmented meteorite from an asteroid exploded in the air four miles above this remote forest area with the force of 1,000 Hiroshima bombs. The blast flattened and burned trees and killed off herds of reindeer and other wildlife over an area of more than **800 square miles**. If this had happened in a more densely populated area, millions of people might have perished. Fortunately, such impacts from outer space objects happen only in the context of massive geological timeframes, with thousands or millions of years in between.