Weather

Weather is the state of the atmosphere from day to day. It includes temperature, atmospheric pressure, clouds, wind, and precipitation.

What are weather observations?

All sciences begin with observations. Without observations, scientists have no way to develop new theories and to test existing theories. The weather is no exception. Meteorologists (scientists who study the weather) observe many elements of the weather, both at the Earth's surface and at high altitudes. Weather observations are used for predicting the weather and for developing and testing new theories about how the weather works.

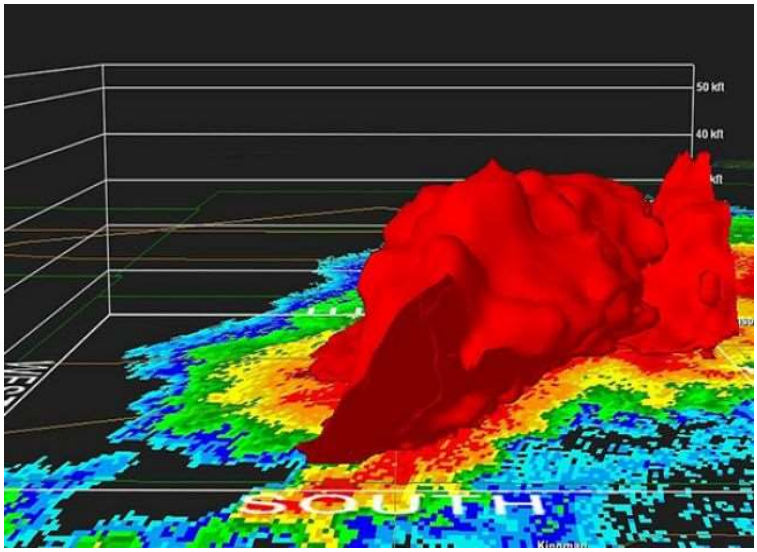

Figure 1. Weather doppler data showing a storm moving through an area. Credit: NOAA/NWS.

How do we measure air temperature?

Air consists of gas molecules, which are combinations of two or more atoms. Although you cannot see them with your eyes, the molecules are constantly moving this way and that at very high speeds. As they move, they collide with one another and with solid surfaces. The temperature of the air is a measure of how quickly the molecules are moving. The more energy of motion the molecules have, the higher the temperature you feel in the air.

Air temperature is measured with thermometers. Common thermometers consist of a glass rod with a very thin tube in it. The tube contains a liquid that is supplied from a reservoir, or "bulb," at the base of the thermometer. Sometimes the liquid is mercury, and sometimes it is red-colored alcohol. As the temperature of the liquid heats up, it expands and rises up in the tube. The tube is marked with a scale, in degrees Fahrenheit or degrees Celsius.

When you are measuring the air temperature, be sure to have the thermometer in the shade. If the sun shines on the thermometer, it heats the liquid. Then the reading is higher than the true air temperature. Also, when you take the thermometer outside, give it enough time to adjust to the outdoor air temperature. That might take several minutes.

How can we measure the wind?

The wind blows because air pressure is higher in one place than in another place. The air moves from areas of higher pressure to areas of lower pressure. Objects like buildings, trees, and hills affect the direction of the wind near the surface. To get the best idea of the wind direction, try to stand far away from such objects. A park or a playing field is the best place to observe the wind.

Wind speed is measured with an anemometer. Most anemometers have four horizontal shafts arranged like the spokes of a wheel. The end of each shaft is cup-shaped. The wind pushes the concave side of the cup more than the convex side, so the anemometer spins in the wind. The faster the anemometer is spinning, the stronger the wind.

You do not need an anemometer to estimate the wind speed. You can use a verbal scale, called the Beaufort scale, which describes the effect of the wind on everyday things like trees.

Wind direction is measured with a wind vane. One end of the vane has a small, heavy object, and the other end has a flat object with a large area. The wind pushes the flat object more than the small, heavy objects, so the vane swings around to be parallel to the wind. You can estimate the wind direction by yourself just by using your face as a "sensor." Face into the wind, and then record the direction you are facing, relative to north.

How are clouds formed?

Clouds are formed when moist air rises upward. As the air rises, it becomes colder. Eventually the air can't hold all of the water vapor in it, and some of the water vapor condenses to form tiny water droplets. When moist air is cooled at the ground, fog is formed in the same way.

Clouds form at a wide range of altitudes, from near the ground to very high in the atmosphere. The appearance of clouds varies a lot, depending on the motions of the air as the clouds are formed. Other important things to observe about clouds are the percentage

of the sky they cover, where they are located in the sky, how much of the sky they cover, and their direction of movement. A good way to find their direction of movement is to stand under a tree branch or an overhang on a building and watch the clouds move relative to that stationary object.

How is rain formed?

Raindrops are formed when the cloud droplets grow big enough to fall out of the clouds. Most of the rain that falls in the winter, and even a lot of it that falls in the summer, is from melting of snowflakes as they fall through warmer air.

Rainfall is measured by the depth of water that falls on a level surface without soaking in. Rainfall is measured with a rain gauge. A basic rain gauge is nothing more than a cylindrical container, like a metal can, with a flat bottom. The only problem is to get an accurate measurement of the depth of water that has fallen. Accurate rain gauges are arranged so that the water that falls into the container is funneled into a much narrow container inside. That way, the height of the water is magnified, and is easier to read.

If you live in a part of the United States where it snows in winter, you can easily measure the snow depth with a ruler. The best time to make the measurement is right after the snow stops falling. The measurement can be tricky, because wind can blow snow from one place to another. The best place to measure snow depth is on level ground far away from buildings and trees.

What are weather reports?

Weather reports vary a lot in how much information they contain. The simplest and shortest weather report contains only one piece of information: the present temperature. This is the type of report you often hear on the radio. More detailed weather reports also contain information about precipitation, wind speed and direction, relative humidity, and atmospheric pressure.

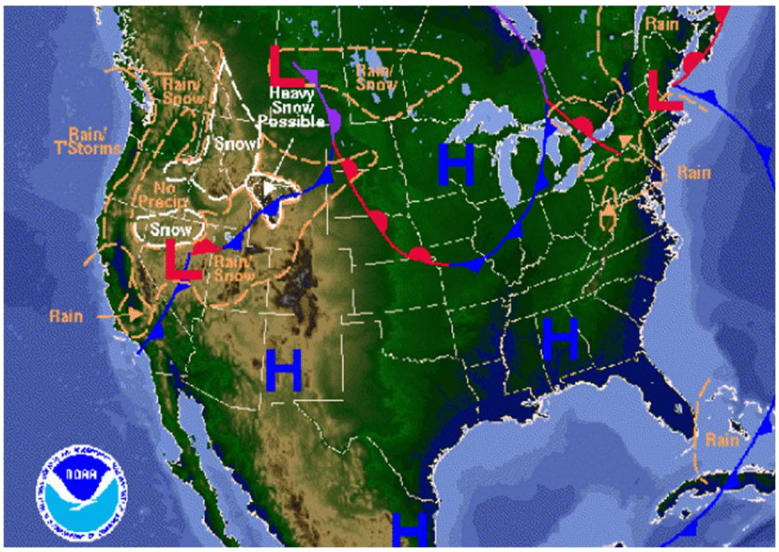

Figure 2. A map of weather fronts moving through the United States. Credit: NOAA.

A typical weather report tells you the high and low temperatures for the past day. It also tells you the present temperature and the average temperature for the day. To find the average temperature, add the low temperature and the high temperature and then divide by two. The weather report might also tell you how many degrees the average temperature is above or below the normal temperature for that day. The normal temperature is found by adding up the average temperatures for that calendar day over a long period, like fifty years or a hundred years, and dividing by the number of years. In many areas of the United States, unusually hot or cold days can be as much as twenty degrees different from the normal temperature.

How has weather forecasting changed over the past two hundred years?

Most people are interested in what the weather will be tomorrow or in the next few days. Predictions of the weather for up to a week in the future are called short-term forecasts. Meteorologists also try to make long-term forecasts of the weather for a month, a season, or a whole year.

In earlier times, before the telegraph and the telephone were invented, weather observations from faraway places could not be collected in one place soon after they were made. In those times, the only way of predicting the weather was to use your local experience. Given the weather on a particular day, what kind of weather usually follows during the next day or two? As you can imagine, the success of such forecasting was not a lot better than making a random guess.

Figure 3. Inflating a weather balloon to monitor weather conditions. Credit: US Army/NOAA/NWS

Beginning in the late 1800s, weather services began to be able to gather weather data from weather stations located all over the country. That allowed meteorologists to plot weather maps and see weather systems moving from place to place. That improved the accuracy of forecasts.

During the 1900s, meteorologists developed even better tools for observing and predicting the weather. Special instruments measure weather in the atmosphere far above the ground, and satellites orbiting the Earth send back images of the weather over large areas. In addition, computer models are now being developed for weather forecasting. In a computer model, the important processes of the weather are built into the model. The model starts with the present weather and tries to simulate how the weather will develop in the future. Today's computer models do a very good job of predicting the weather for the next few days.

Figure 4. Modern weather stations often collect data from satellites. Credit: Eric Kurth, NOAA/NWS/WFO/Sacramento

What is atmospheric pressure?

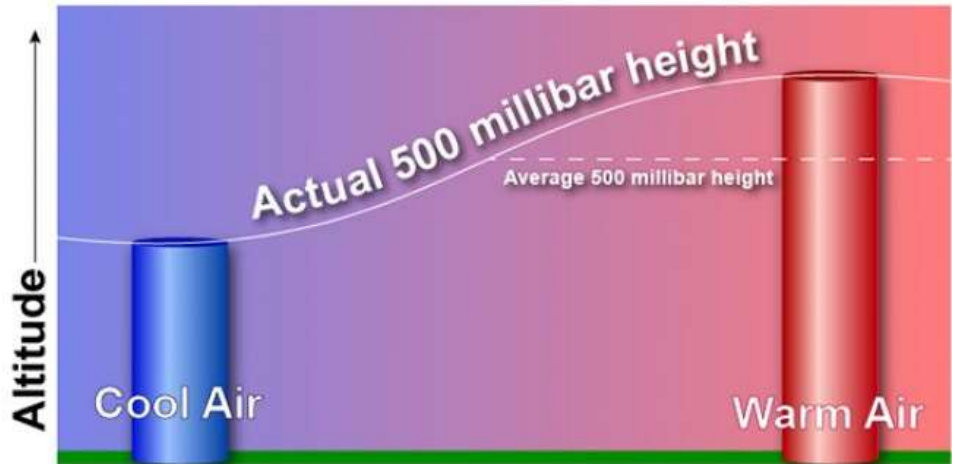

Figure 5. A graph representing the effect of temperature on atmospheric pressure. Credit: NOAA JetStream

Air has weight. That idea might seem strange to you, because air seems very thin, even at sea level. Remember however, that the atmosphere extends to great altitudes. The pressure of the air is equal to the weight of a column of air above a unit area on the land surface. The column of air above a square area that is one foot on a side is about 2,116 lb. (~10,332 kg/ sq. meter) at sea level. If you try to pump the air out of a closed container, the container will collapse inward from the outside air pressure, unless it is very strong. The reason you don't feel the air pressure is that the pressure inside your body is adjusted to be exactly the same! Air pressure decreases upward in the atmosphere. That's because at higher levels in the atmosphere there is less air above to cause the pressure.

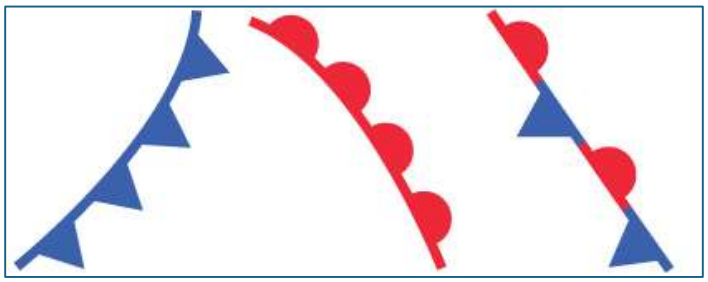

Figure 6. Isobars used on weather maps. Credit: NOAA JetStream

Detailed weather maps show atmospheric pressure using curved lines called isobars. As with an isotherm for temperature, an isobar connects all points with the same atmospheric pressure. There is one difference with isobars, however. The pressure at the land surface is less where the elevation of the surface is high, so the pressure is "corrected" to sea level. The corrected pressure is what you would measure at the place if you could dig a very deep mine all the way down to sea level and put your barometer at the bottom of the hole. The corrected pressure is used on weather maps.

Why is the weather different in high and low-pressure areas?

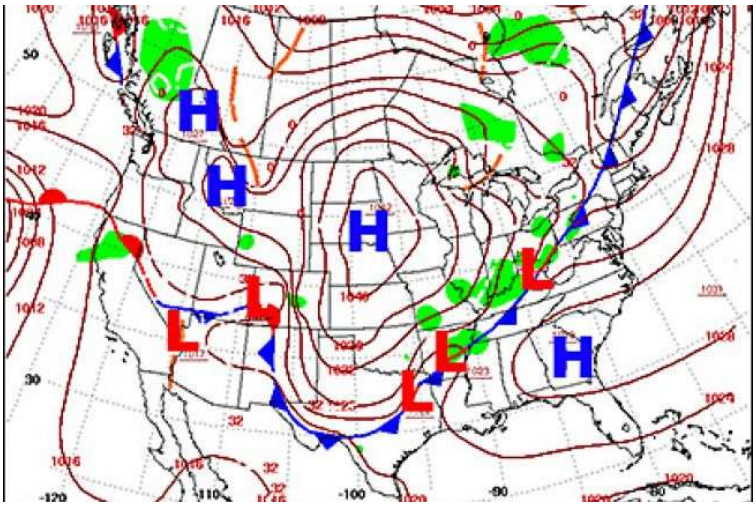

Figure 7. High and low pressure systems affect weather. Credit: NOAA Jetstream

Why is the weather in high-pressure areas usually fair? Why is the weather in low-pressures areas usually cloudy and stormy? Most weather maps show areas, labeled with an H, where the atmospheric pressure is relatively high, and areas labeled with an L where the atmospheric pressure is relatively low. High-pressure areas are places where the atmosphere is relatively thick. Winds blow outward from these areas, then air above the area sinks slowly downward to take its place. That makes clouds and precipitation scarce, because clouds depend on rising air for condensation. High-pressure areas usually are areas of fair, settled weather. Low-pressure areas are places where the atmosphere is relatively thin. Winds blow inward toward these areas which causes air to rise, producing clouds and condensation. Low-pressure areas tend to have well-organized storms.

What is the difference between a cold front and a warm front?

Large masses of air, as much as a thousand miles across, take on certain weather characteristics when they stay at high latitudes (near the poles) or at low latitudes (near the equator) for several days at a time. They may be very cold or very warm, or they may be very humid or very dry. Then, as they move into other areas, they can affect the weather there very strongly. The coldest winter weather in much of the United States is at times when a bitter cold air mass from the high arctic regions of northeastern Asia, Alaska, or northern Canada sweeps south. At other times, a flow of warm and humid air from the tropics causes unusually warm weather in the eastern United States.

The boundaries between air masses are often zones of very rapid changes in temperature and moisture. Enormous swirling storms tend to develop along these zones of rapid change. On weather maps, cold fronts are shown as lines with triangular teeth. These show where the cold air mass is wedging under the warm air mass. As the warm air is lifted along the front, heavy rain from thunderstorms is common. Warm fronts are shown on weather

maps as lines with circular teeth. These show where the warm air masses are moving up over the cold air masses. Broad areas of rain are often associated with warm fronts.

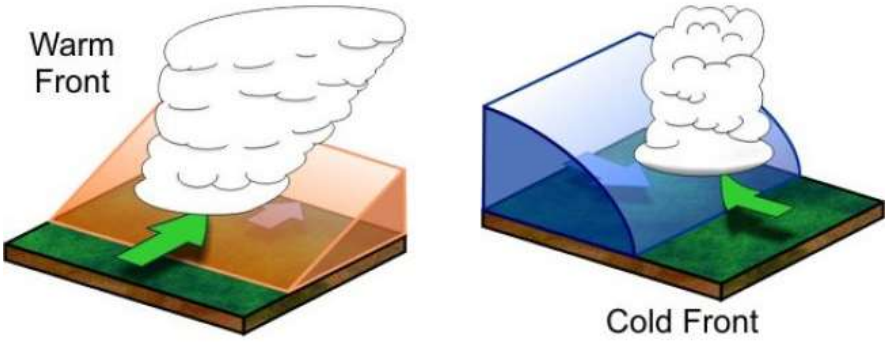

Figure 8. General air movement in warm and cold fronts. Credit: Credit: NOAA JetStream

What is the weather like at high altitudes?

You experience weather at the Earth's surface, but there is weather high in the atmosphere, too. Have you ever taken a ride in a hot-air balloon or climbed a high mountain? You would know that the air temperature usually decreases with altitude. The basic reason has to do with where the atmosphere receives its heat and where it loses its heat. The Earth's surface is heated by the sun at some times and places. It loses heat to outer space at other times and places. On balance, however, the Earth's surface gains more heat than it loses. The atmosphere near the ground is then heated by the ground. High up in the atmosphere, however, the air loses more heat to space than it absorbs from sunlight. Air pressure decreases with increasing altitude.

Many kinds of devices have been invented for measuring things like temperature, pressure, and humidity in the upper atmosphere. These devices, called sondes, are packages of several instruments. Balloons are used to carry them up through the atmosphere. As they rise, they send back measurements by radio. Eventually the balloon pops, and the instruments crash back to Earth. Their fall is not dangerous to humans, because the instruments are very small and light.

How do scientists use radar and satellites to observe and predict weather?

Radar (radio detection and ranging) has become an important tool for observing and predicting the weather. Radar was invented and developed in Britain and the U.S. at the

beginning of the Second World War. It was used to detect the approach of enemy airplanes. An antenna sends out radio waves. The waves are reflected from solids or liquids in the air and received back by the antenna. The radar equipment shows the position and distance of the objects. The results are shown on a screen. The screen is similar to the screen of a television or a computer monitor. Weather radar can show the locations of areas of precipitation very clearly. The radar images are also able to show the intensity of the precipitation.

Satellites were first put into orbit in the 1970s. Satellites with cameras have been used to get images of the Earth's weather from space. Satellites are especially good at showing cloud cover. Photographs of cloud cover are not the only advantages of satellites. Special instruments are mounted on the satellites. They can measure the temperature of the Earth's surface. The most useful satellites are ones with orbits adjusted so that the speed of the satellite is the same as the speed of rotation of the Earth. Then the satellite stays in the same place overhead.

What is the water cycle?

A "closed system" consists of a container that allows energy, but not matter, to pass back and forth across the walls of the container. The Earth's atmosphere, oceans, and land surface act as an almost closed system. Water moves along a variety of pathways in this closed system. This system of movement is called the "water cycle."

There is one main loop in the water cycle. Water evaporates at the ocean surface and then moves as water vapor to the continents. The water vapor condenses and falls as precipitation onto the continents. The water then runs back into the ocean in streams and rivers. Of course, there is rainfall onto the oceans, and there is evaporation of water from the continents. There really is a cycle, however, because there is an excess of evaporation over precipitation on the oceans, and there is an excess of precipitation over evaporation on the continents. For the most up-to-date version of the water cycle, visit the interactive version created by the U.S. Geological Survey.

What is the difference between evaporation and condensation?

Liquid water consists of water molecules that are held near each other by attractive forces but are still free to move around among one another. Also, water molecules have thermal

energy, in the form of extremely fast vibrations. Water molecules at a water surface occasionally vibrate so strongly that they fly out into the air to become vapor. At the same time, water molecules in the air occasionally crash back onto the water surface to join the liquid water. These motions are occurring all the time at the water surface.

When the concentration of water molecules in the air is less than the maximum the air can hold, the relative humidity is less than one hundred percent. Then the number of molecules that go from the liquid to the air is greater than the number that goes from the air to the liquid. That condition is known as evaporation. Evaporation causes cooling of the remaining liquid water. The reason is that the water molecules that fly out into the air are, on average, the ones with unusually high thermal energy. What is left behind has a little less thermal energy-in other words, it has a slightly lower temperature.

Figure 9. Condensation on the tips of pine needles. Credit: Michael Theberge, Maine Maritime Academy

Condensation is the opposite of evaporation. If the air has even slightly more water vapor than it can hold, the number of water molecules passing from the air into the liquid water is greater than the number passing from the liquid water into the air. When you fill a glass with ice water on a warm and humid day, soon the glass has drops of water on the outside of the glass. That water has not leaked through the glass. It has condensed from the air. Cold air can hold less water vapor than warm air. The cold glass chills the air next to it, causing condensation. Dew on grass and other plants on a chilly morning forms in the same way, when the ground surface is chilled by radiating its heat out to space on a clear night.