Water in the Troposphere
How to Make a Cloud

We must have a clear understanding of the relationship between pressure and temperature in the lower atmosphere before we can examine the process of cloud formation. To review, as air is heated its pressure increases and its density decreases. The decrease in density as air warms allows more space for water vapor to occupy. This is the reason warm air evaporates water faster than cool air.

Now we can explore how water in the lower atmosphere moves around as a result of heating from the surface. The result of this movement is the formation of clouds which move across the sky, transporting water from the oceans inland.

Clouds are liquid water droplets held up in the air by warm air rising. All the water in clouds comes from the surface of the earth. Heat evaporates liquid water, which rises in the warm air. The amount of water vapor in the air is described as humidity. The amount of water vapor air holds is related to the temperature of the air. Cool air, being more dense, cannot hold as much water vapor as warm air. With this in mind, we always describe the amount of water vapor in air relative to the temperature of the air. This amount of water vapor in air is measured as a percent of the total amount of water vapor air could hold at a given temperature. On the weather report humidity is described as relative humidity, meaning the percent of water vapor related to the temperature of the air.

When air is full of water vapor it is described as 100% relative humidity. Air at 100% relative humidity is referred to as saturated. This simply means the air cannot hold any more water vapor. Once air exceeds 100% relative humidity, the water vapor starts to turn back into liquid water, which we see as clouds. We can now identify two ways for an air mass to reach 100% relative humidity:

1. If we cool air its density increases, which lowers the amount of space for water vapor. So without adding any moisture to air, we can saturate the air by cooling it. By cooling air we reduce the area available for water vapor, resulting in liquid water droplets forming. We see this liquid water as clouds in the atmosphere.

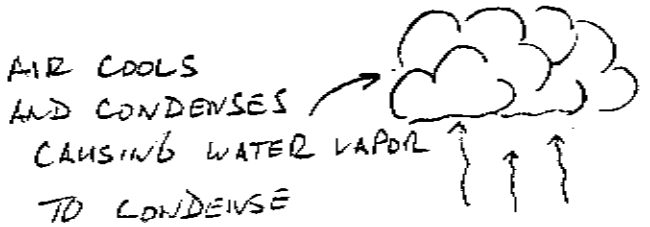
2. A second way to saturate air is to add more water vapor. This is easy to understand if we remember that air can only hold a certain amount of water vapor before the air is full. If we try to add water vapor to saturated air, it forms clouds.

These two processes cause clouds to form in the troposphere. Now we are ready to apply this understanding and determine some different ways to make clouds in the atmosphere. There are many kinds of clouds in the troposphere. The shape and color of clouds is the result of the size of water droplets and the state of the water in the clouds. Some clouds are made of ice, while others are liquid drops of water .

How to Make a Cloud

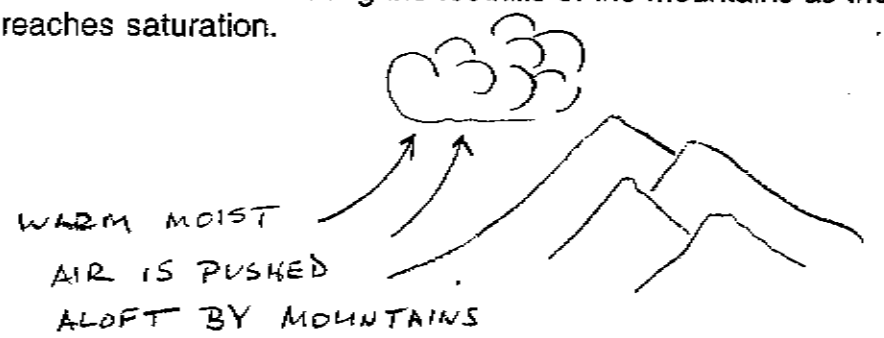
Clouds above the ground are generally formed by cooling the air. As warm air rises, it cools due to the lower pressure in the atmosphere. When air cools it becomes more dense, which lowers the air's ability to hold water vapor. Clouds form when the rising air reaches the saturation point or 100% relative humidity. There are a number of ways to lift air in the atmosphere. We will examine the three most common ways air is lifted in the troposphere around Castle Rock. The shape and location of clouds in the atmosphere are an indication of the lifting process at work.

1. Convective Uplift - This process relates back to the behavior of matter when it is heated. Anytime air is heated, it becomes less dense. The reduction of density causes the air to rise because it weighs less than the air above it. As the air rises, it carries water vapor with it that has been evaporated from the surface. Convective uplift is associated with heating at the surface of the earth. The earth's surface heats up in summer more than winter, so convective uplift is most common in the warmer months of the year. We see a specific kind of cloud form from convective uplift. Cumulus clouds are the result of warm air rising, due to heating at the surface. These types of clouds form near the surface, where sunlight is being converted to heat.

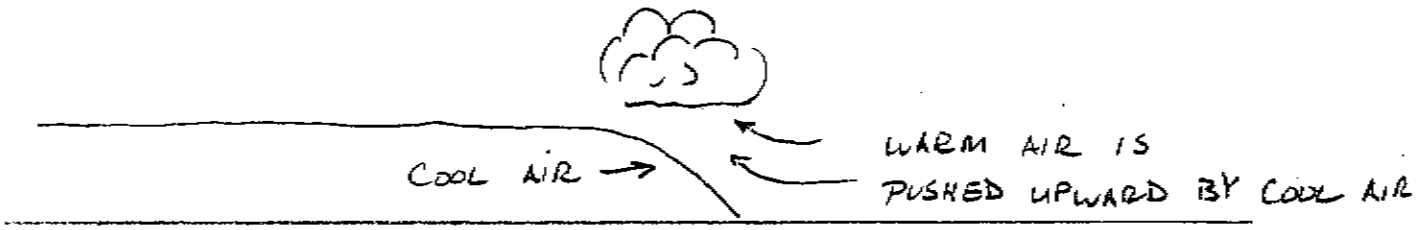


HEAT FROM SURFACE CAUSES AIR TO RISE

2. Orographic Uplift - This lifting process is common around mountains. The word orographic means related to mountains. If air is pushed against mountains, it must move upward, resulting in cooling. This process is often referred to as forced ascent, because the air has nowhere to go but up when it is pushed into mountains. We see clouds formed by this process in the foothills of the mountains to the west. In summer, air warms quickly in the lower elevations of the eastern plains of Colorado. As this air expands and rises, it pushes up against the Rocky Mountains and is forced upward. We see clouds form along the foothills of the mountains as the rising air cools and reaches saturation.



3. Frontal Uplift - This process lifts air by having cool air slide beneath warm air, which pushes the warm air upward. We have all heard the weather forecaster mention the word cold front on the T.V. newscast. A cold front is a mass of cool air that moves down from the north into Colorado. The cool air is more dense and, therefore, stays close to the ground. As this cool air collides with warm air, it pushes the warm air upward. The warm air contains more water vapor, and as this warm, moist air is pushed upward, it cools, resulting in saturation and the formation of clouds along the cold front. This type of uplift occurs in winter as well as summer.



We can now start to look at different kinds of clouds and where they form in the atmosphere. The height of clouds above the ground is an indication of the temperature and relative humidity at the surface. Let's examine some different kinds of clouds to determine how they are a product of the conditions at the surface.

When clouds form near the ground, it indicates that the air at the surface has a high relative humidity. The air does not need to be lifted very much to reach the saturation point and form clouds. We see this condition in humid climates like the eastern part of the United States during the summer months. The relative humidity is often above 80%, so the air only needs to be lifted a few thousand feet to reach saturation and form clouds.

When clouds form at high altitudes, it indicates the air near the surface has a low relative humidity. The height of the clouds means the air had to be lifted a lot to cool it enough to reach the saturation point where clouds form. To lift air to high altitudes, it also requires a high temperature at the surface. These high altitude clouds are often made of ice and look quite different than low altitude clouds.

In some cases, clouds form at the surface. We refer to this condition as fog. Fog can form a number of ways, but it always indicates a condition of 100% relative humidity at the surface. The air cannot hold the water vapor that is being evaporated from the surface because it is already saturated.

With this information we can now understand why clouds in Colorado form at a higher altitude than they do in a humid climate. A typical thunderstorm in Colorado will have a cloud base (the altitude of the bottom of the cloud) of 10-15 thousand feet above the surface. A thunderstorm in Florida normally has a cloud base of 5 thousand feet. The reason for the lower cloud base is the additional humidity in the air at the surface.

The process of air rising in the atmosphere to form clouds creates some new words to describe the location and temperature where water condenses from vapor to liquid form. When an air mass is cooled,d it eventually becomes saturated. This temperature where the air mass cannot hold anymore water vapor is referred to as the dew point. When an air mass reaches its dew point, clouds begin to form as water condenses to form clouds.

Dew Point - The temperature an air mass at 100% relative humidity.

We can also define another term that is related to the dew point of an air mass. In any air mass the relative humidity can be calculated at the surface. With this information we can determine the dew point of the air mass. As air is lifted in the atmosphere, it cools, due to the decrease in pressure, at a rate of -3.5 / 1000 ft. The altitude where a rising air mass cools to its dew point is referred to as the lifting condensation level of that air mass. The lifting condensation level is easy to see in the air, as this is the altitude where clouds start to form. The bottom of the clouds is the point in the atmosphere where rising air has cooled enough to reach the saturation point.

Lifting Condensation Level or (LCL) - The altitude of the dew point in an air mass.

Humidity in the Atmosphere

Humidity is a term used for expressing the amount of water vapor in the air.

Humidity is described in to ways:

1. Absolute Humidity- The amount of water vapor in a given volume of air.

$$\text{Absolute humidity} = \frac{\text{mass of water vapor}}{\text{volume of air}}$$

2. Relative Humidity- The amount of water vapor in an air mass compared to the the total amount of water vapor that air mass could hold.

Relative humidity is dependent on the temperature of an air mass rather than the total amount of water in that air mass.

As air is heated its relative humidity goes down without changing the amount of moisture in the air. If air is cooled its ability to hold moisture decreases . Cooling air raises its relative humidity without adding moisture.

We are most concerned with relative humidity since weather is the result of not only the amount of moisture in air but also the temperature of air.

To understand when it will rain or when clouds will form we are primarily interested in the saturation point of a certain air mass, that is the point where the relative humidity reaches 100%

Dew Point- This is the temperature in a given air mass where the air mass will reach saturation(100% relative humidity). We can estimate the dew point in any air mass. The more water vapor added to an air mass the closer that air mass is to its dew point temperature. The less water vapor in an air mass the further the air must be cooled before saturation. In any air mass that has a relative humidity of less than 100% the dew point temperature is always lower than the temperature of the air mass.

We now have two ways to form clouds and precipitation in an air mass:

1. We can add moisture to an air mass or

2. We can cool an air mass

Precipitation

Precipitation is defined as any form of water that falls from the atmosphere and hits the surface. The kinds of precipitation vary from fog, which is tiny droplets of liquid water, to hail, which can grow to the size of baseballs in large thunderstorms. In general, the size and state of the water that falls from a cloud is related to the kind of uplift process at work. The following is a description of the major types of precipitation we experience in Colorado.

Rain

Rain is defined as liquid water that falls from clouds. The drops we see falling are clearly different sizes. The size of a rain drop is an indicator of how much uplift is occurring in the atmosphere. Small drops like fog are an indication of weak lifting in the atmosphere, while giant drops we see in a thunderstorm are the product of powerful lifting forces that push the raindrop well above the bottom of the the cloud.

A raindrop forms when water vapor condenses on a small piece of dust suspended in the atmosphere. This occurs above the base of the cloud where the relative humidity is above 100%. The relative humidity of air inside a cloud is always greater than 100% and is referred to as super saturated. Inside the cloud, water is changing from its gas state back to liquid because of the cool temperatures. Once the drop forms, it continues to grow inside the cloud until it becomes too heavy for the rising air to support it. Once the drop falls out of the cloud, it immediately starts to evaporate as it falls to earth. This process of liquid water forming from water vapor occurs in all clouds. The drops, however, do not always fall to the surface as rain. In many cases the water is evaporated before it hits the surface. This process of rain evaporating as it falls is referred to as **Virga**.

The longer a drop of water remains inside of the cloud, the larger it becomes. In general, the height of a cloud is a reflection of the lifting force pushing air upward. In thunderstorms we see powerful convective uplift that often pushes water drops well above the lifting condensation level. In these tall clouds, raindrops can rise in updrafts of 100 miles per hour or more. This explains why the drops that fall from very tall thunderstorm clouds are often huge.

Each type of uplift process generates raindrops of varying sizes. Frontal uplift is generally weaker than convective uplift, so the raindrops are smaller. Fog is formed at the surface in a condition with very weak lifting. The drops form very near the surface and gently fall back to earth without growing much at all. In winter when the temperature above the surface is often below freezing, the dew point is usually below the freezing temperature of water.

Snow

Snow is a particular type of precipitation where the dew point of the air mass is below the freezing temperature of water. In this case when the air is cooled to the dew point temperature, the water vapor forms snowflakes rather than raindrops. In other words, water condenses to a solid state from vapor essentially skipping the liquid state.

The size of snowflakes is an indication of the temperature and humidity of the the air. In the middle of winter when the air is extremely cold and dry, it cannot hold much water vapor. When the air rises and forms snowflakes that are very small, this reflects a small amount of water vapor in the air. In spring as the air temperature rises, it can hold more water vapor, so we see larger flakes of snow in April than we do in January.

In general, snow formed at higher elevations is dryer and, therefore, lighter. This is why Colorado is such a popular ski destination. The snow formed in our mountains is produced under very cold conditions due to the low pressure. The cold air cannot hold much moisture, resulting in very light "powder" snow our resorts are famous for.

Hail

All of us who live in Douglas County are familiar with hail. It regularly falls from larger thunderstorms that form during the spring and summer months along the foothills. Hail is frozen rain that forms when raindrops are pushed above the freezing point in the atmosphere. We commonly see hail associated with large thunderstorms that have powerful convective lifting from the surface.

Hail stones are formed as water is pushed high into clouds. Once a raindrop is frozen, it falls back toward the surface of the earth. Often the hail is pushed aloft again as it falls, causing the hail stone to gather another coat of ice. By this circulation process, hail stones can become very large before they become too heavy to be supported by the rising air. At this point, the hail stone falls to the surface. The number of times a hail stone circulates through the cloud can be determined by cutting the hail stone open and counting the number of rings. Each ring indicates a trip above the freeze line in the cloud.

Fog

Fog is formed when water is evaporated into air that is already saturated. The result is a cloud formed on the surface of the earth. Fog is formed in a number of different ways. We will examine a few common types of fog.

1. Steam Fog - This type of fog is very common over water during winter months. It can be seen rising off the surface of water when the air above the water is cold. The water vapor evaporates into the air above the liquid water and then quickly condenses to form steam.

2. Valley Fog - This type of fog is formed in the bottom of valleys during winter months. Most valleys have a river or water source in their bottom which evaporates moisture into the air. During winter, cold air from the mountains surrounding the valley flows downhill due to its high density. As the cold air moves downhill, it accumulates in the bottom of the valley. Water vapor in the bottom of the valley is cooled by the plunging air and condenses to form fog along the valley floor.

3. Radiation Fog - This is the fog we see form near the surface on extremely cold nights in winter. The earth's surface radiates enough heat to evaporate small amounts of water vapor into the air right near the surface. As the air rises above the surface, it condenses in the cold air to form fog near the surface. This fog always forms within a few feet of the surface and remains within a few feet of the surface.

4. Jungle Fog - This type of fog forms above trees after a rain shower. The fog is formed as air rising from the surface evaporates water from the trees as it rises. The tree limbs are wet, providing a source of moisture. Once the air is above the trees, it encounters cooler air which causes the water vapor to condense and form fog.

5. Maritime Fog - This fog forms along the coast of oceans or large lakes at night. Maritime fog forms when water vapor evaporated from the ocean moves over the cool land at night. The land cools the moist air, causing fog to form near the shore. This type of fog generally forms in the early morning hours when the air over the land is coldest. After the sun rises in the morning, the land quickly heats the air above it, causing the fog to evaporate by mid-day.