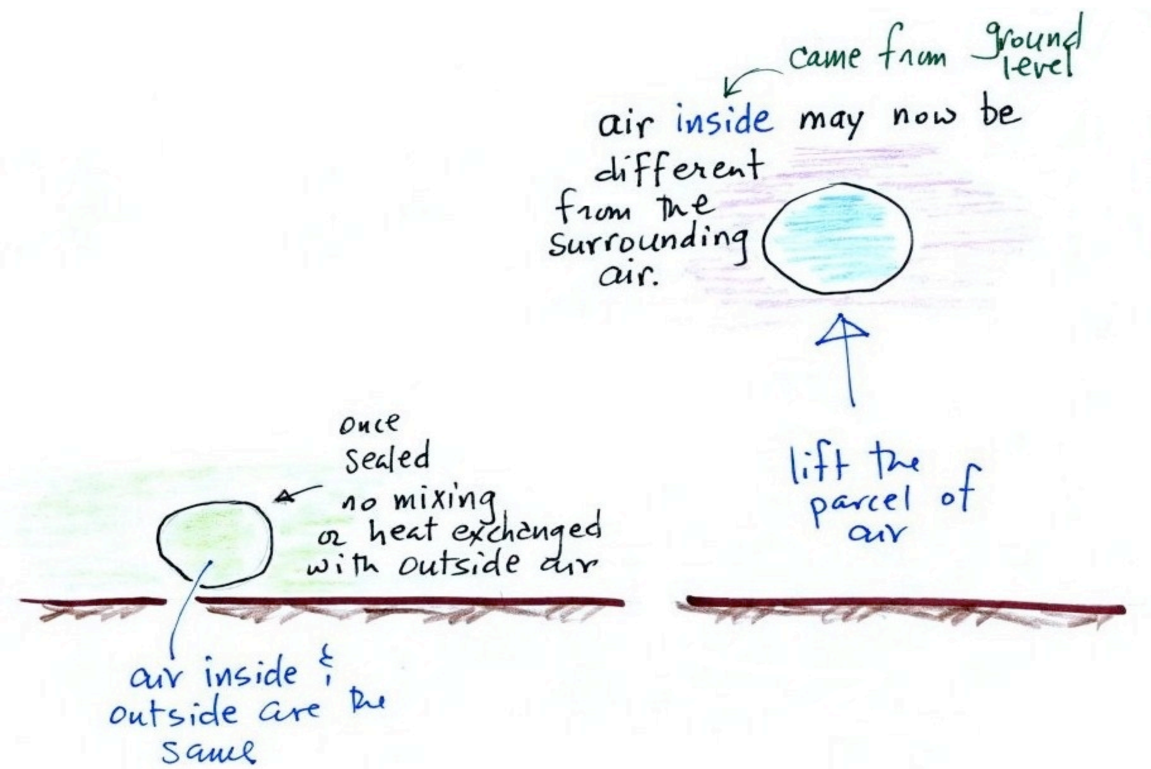
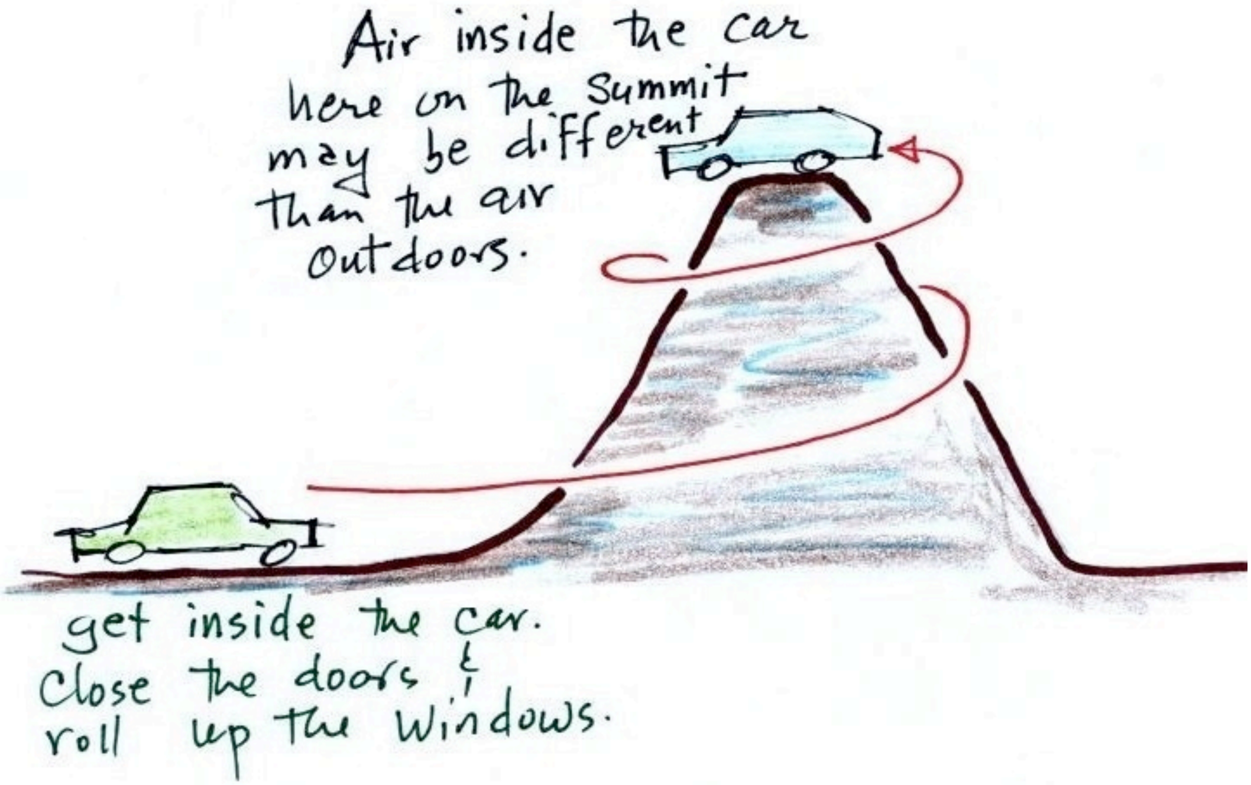
Module 10 - Lecture 29

Earlier in this course we learned that stable atmospheric conditions can lead to a buildup of air pollutants. On the other hand, thunderstorms form when the atmosphere is unstable. We are now going to look at the topic of atmospheric stability in a little more detail. Meteorologists look for situations that might make the atmosphere unstable because this could lead to severe weather.

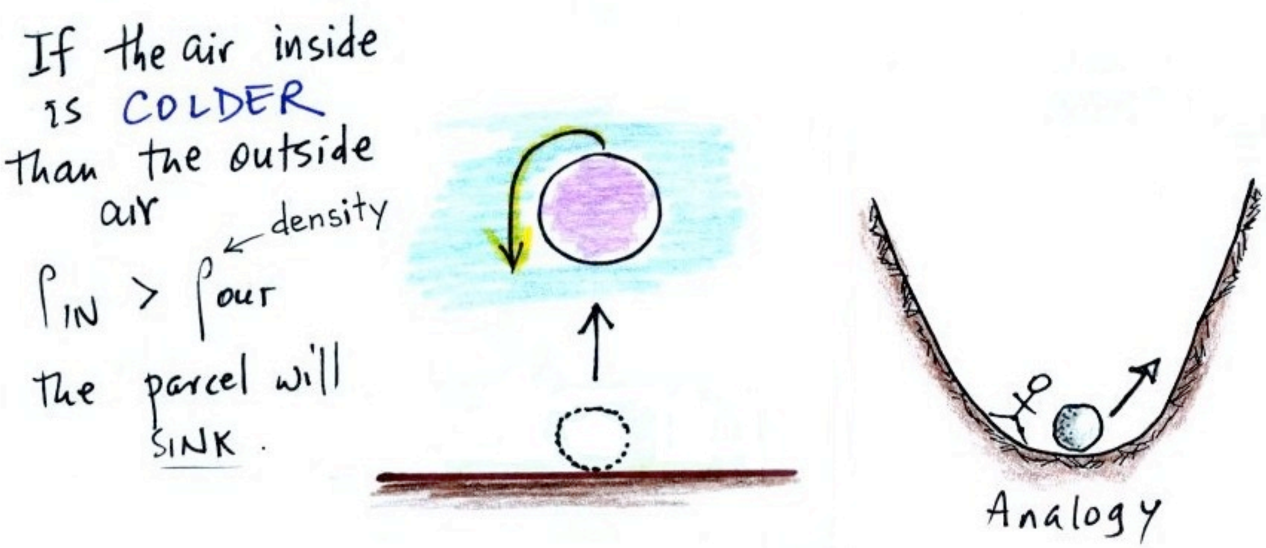
We will start with a relatively easy to understand conceptual test to determine whether the atmosphere is stable or unstable. We will take some air and isolate it in a balloon or parcel. At this point, the air inside the parcel is exactly the same as the air outside with the same temperature, density, and pressure. Once the air is sealed in the parcel, we will assume the parcel cannot mix or exchange heat and energy with the surrounding air. We define this assumption as **adiabatic**).



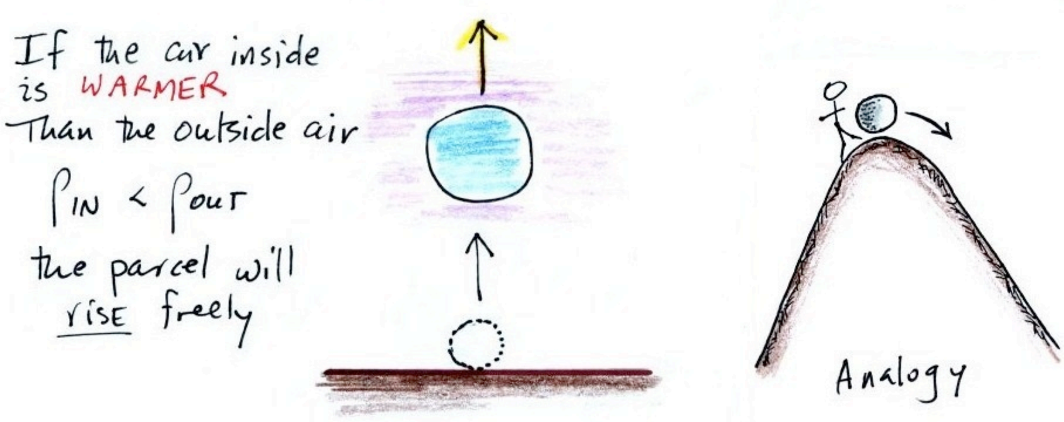
Now imagine lifting the air parcel. It will expand and the air inside will cool. After being lifted to a new altitude, the air inside the parcel may have a different temperature than the surrounding air outside the parcel. This is because the parcel is "insulated" from the surrounding air. This is similar to getting inside an automobile and driving to the top of a mountain with the heater or air conditioner running in the car. Once the automobile arrives at the mountain summit, the air inside the car will have a different temperature than the air outside.



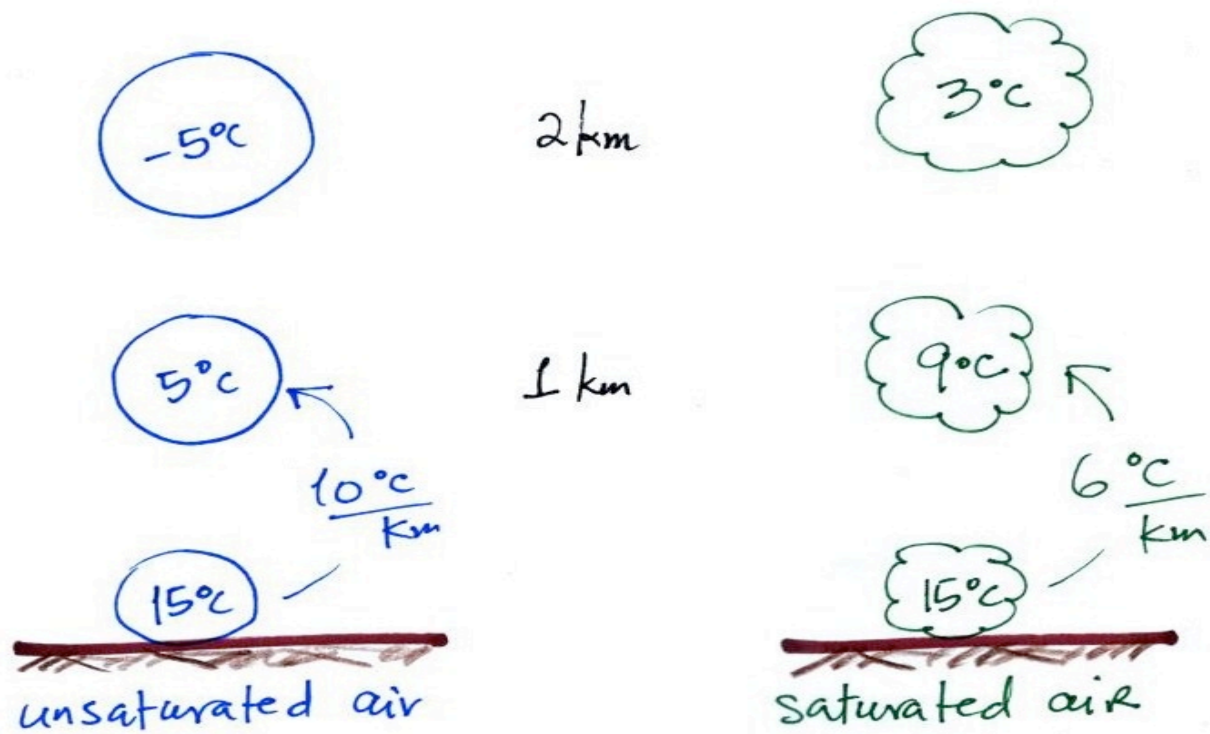
Once we have lifted the air, we will let go of the parcel and watch to see what happens next. If the air sinks back to where it started, the atmosphere is considered **stable**. In the figure below, the parcel sinks back to the ground because it is colder and denser than the surrounding air. In a previous lecture, we imagined a rock rolling back downhill after being pushed partially up a slope.



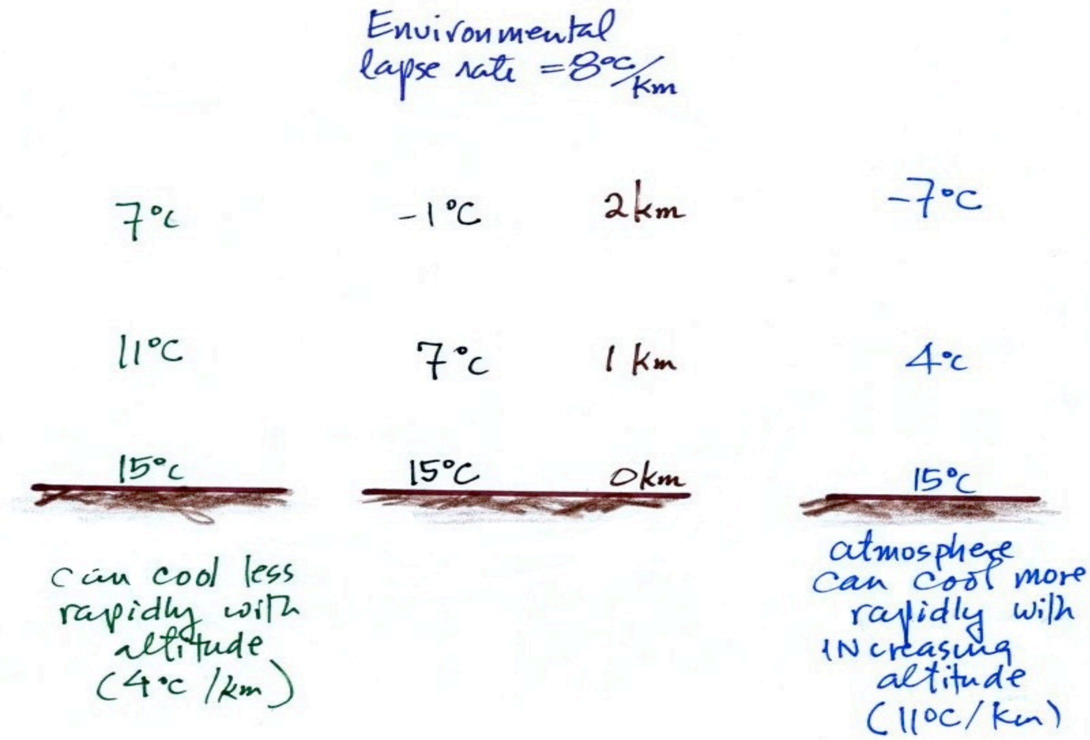
If the air parcel is warmer and less dense than the surrounding air, it will continue to float upward on its own. The air parcel is considered unstable. This can be compared to a rock rolling downhill because it is at the top of the mountain.



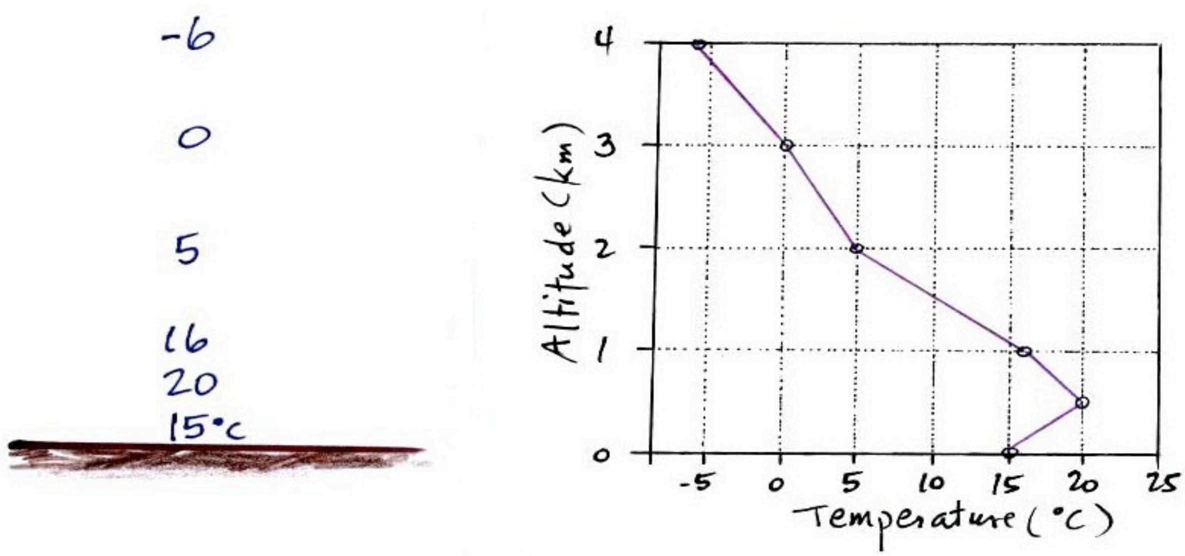
Before we can perform the test described above, we need to know how quickly a rising parcel of air will cool. The rate of temperature decrease with increasing altitude is defined as the **lapse rate**. Unsaturated air (relative humidity less than 100%) always cools at a rate of 10^0C per kilometer. This is known as the **dry adiabatic lapse rate**. Adiabatic means that heat is not being exchanged between the air inside the parcel and its surroundings. Saturated air (relative humidity of 100%) cools more slowly because as saturated air rises, water vapor condenses and releases latent heat which partially offsets the cooling due to expansion. We will use a **moist adiabatic lapse rate** of 6^0C per kilometer.



We also need to know the temperature of the atmosphere at different altitudes above the ground, which is called the **environmental lapse rate**. The middle figure shows temperature decreasing at a rate of 8^0C per kilometer. The left and right examples show the air cooling more slowly and more rapidly, respectively, with increasing altitude. Usually atmospheric temperature does not decrease at a uniform rate as shown above.

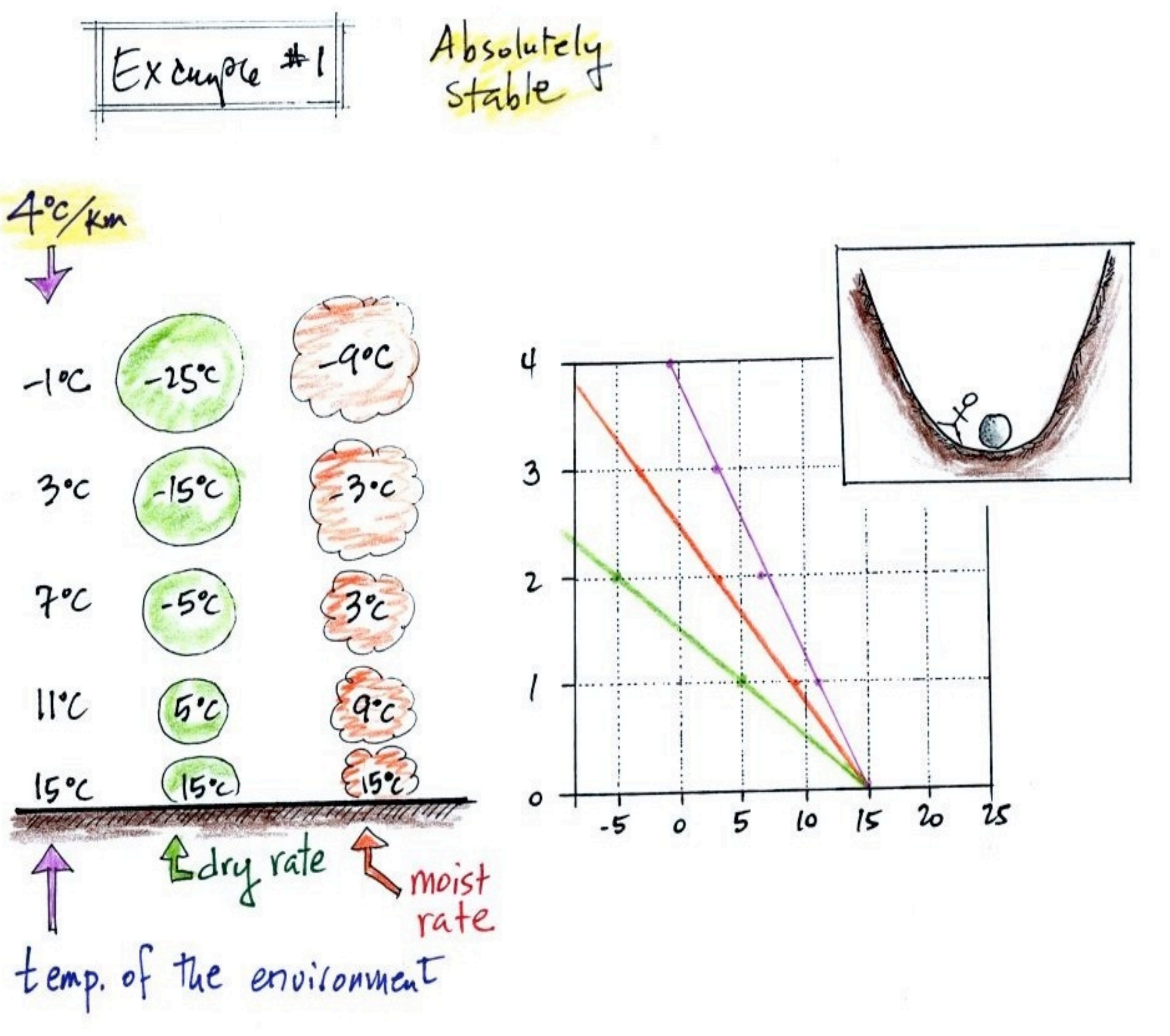


A more realistic example is shown below. A plot of altitude versus temperature is called a **sounding**.



Example 1: Absolutely Stable
In the first example we will assume that the environmental lapse rate is 4°C per kilometer. This is shown in the left column in the figure below. Now we will lift up parcels of air by one of the four mechanisms we learned previously (frontal, orographic, thermal and convergence). The air parcels will cool at the dry adiabatic lapse rate of 10°C per kilometer if their relative humidity is less than 100%. If the air parcels have 100% relative humidity (are saturated with vapor), they will cool at moist adiabatic lapse rate of 6°C per kilometer.

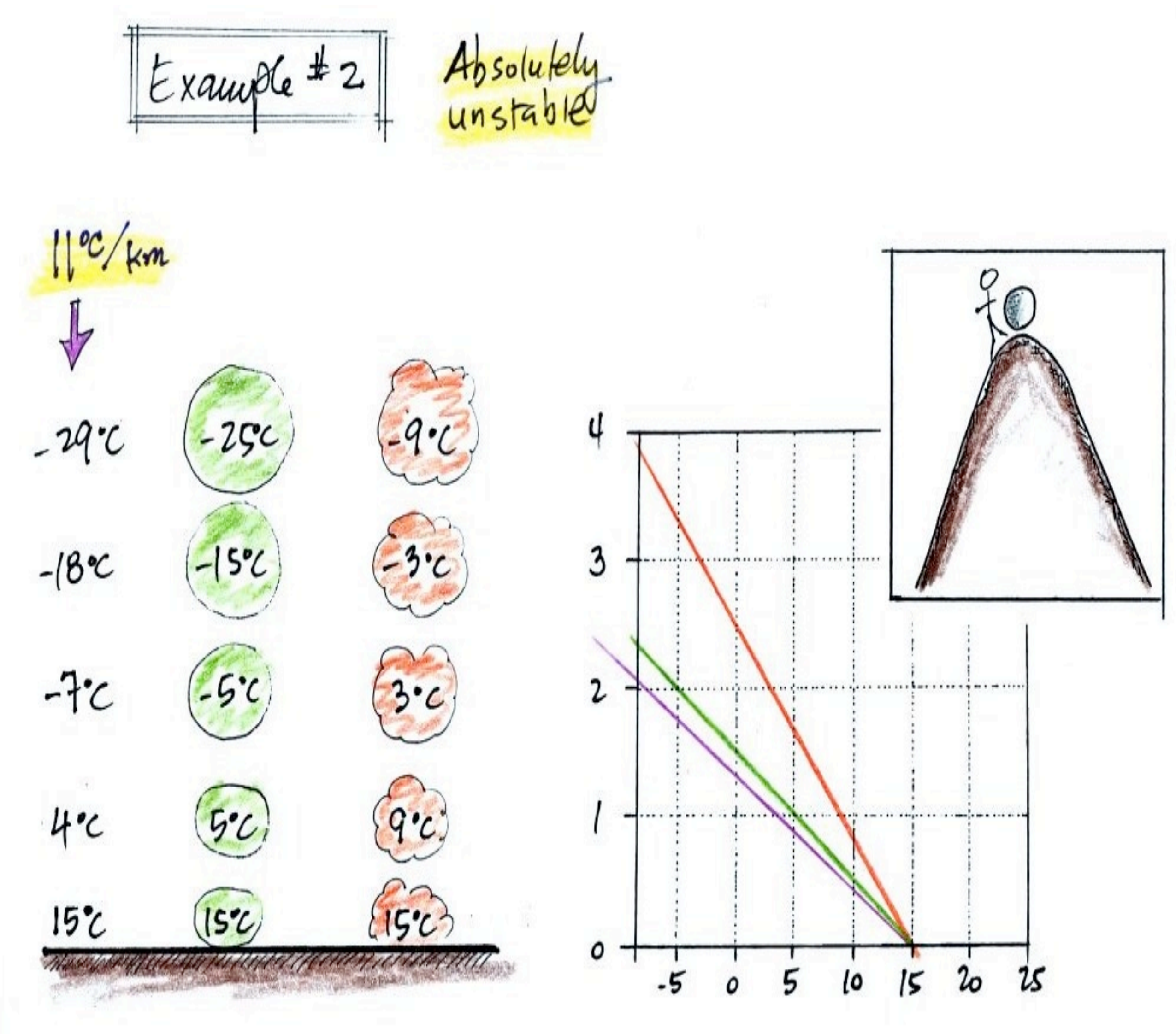
The next two columns below show the temperature that would be inside rising parcels of unsaturated (green) air and saturated (red) air. The three temperatures are also plotted on a graph on the right side of the figure. The unsaturated and saturated parcel curves (green and red) lie to the left of the environmental (actual) curve. **Rising or lifted parcels of unsaturated or saturated air will both end up colder and denser than the surrounding environmental air. If they are lifted and released, they will sink back to the ground. The atmosphere is absolutely stable in this case**.



Example 2: Absolutely Unstable

We will change the environmental lapse rate to 11^{o} C per kilometer. Now the atmosphere is cooling at a more rapid rate than the dry adiabatic (green) and moist adiabatic (red) lapse rates. **<u>If an air parcel is lifted, it will be warmer and less dense than the surrounding air and will continue to rise. The atmosphere is absolutely unstable in this case.</u>**

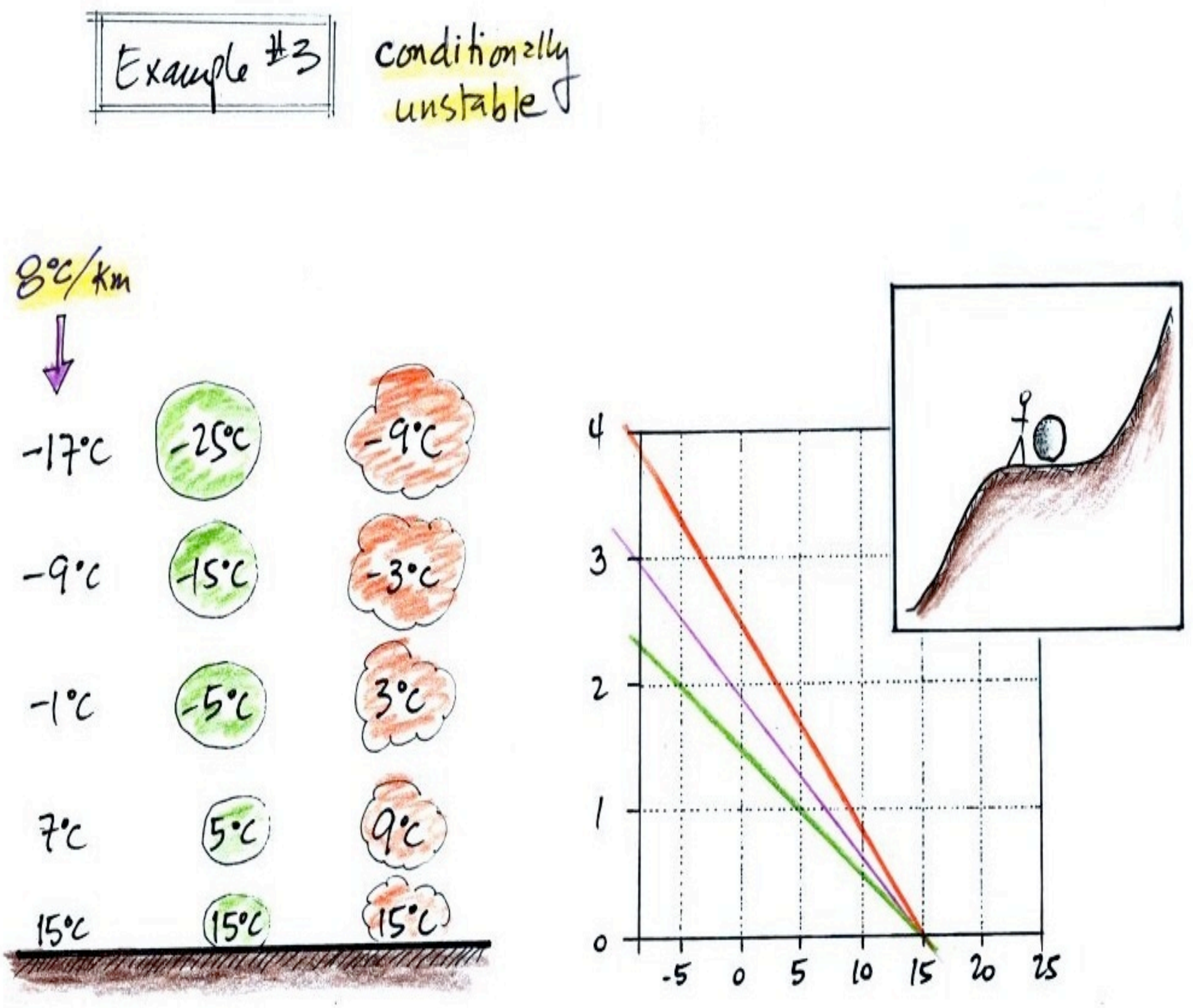
Both the red and green curves lie above and to the right of the purple curve on the graph.



Example 3: Conditionally Unstable

We will pick an intermediate value, 8°C per kilometer, for the environmental lapse rate. A rising parcel of unsaturated air will be cooler and denser than the surrounding air. A parcel of saturated air, which cools at a slower rate, will be warmer than the surrounding air.

The condition for instability is that the air must be saturated. It was a little harder coming up with a rock/hill analogy in this case. In this case, the condition for instability is the direction of the initial push that you give to the rock. **<u>The atmosphere is conditionally unstable.</u>**



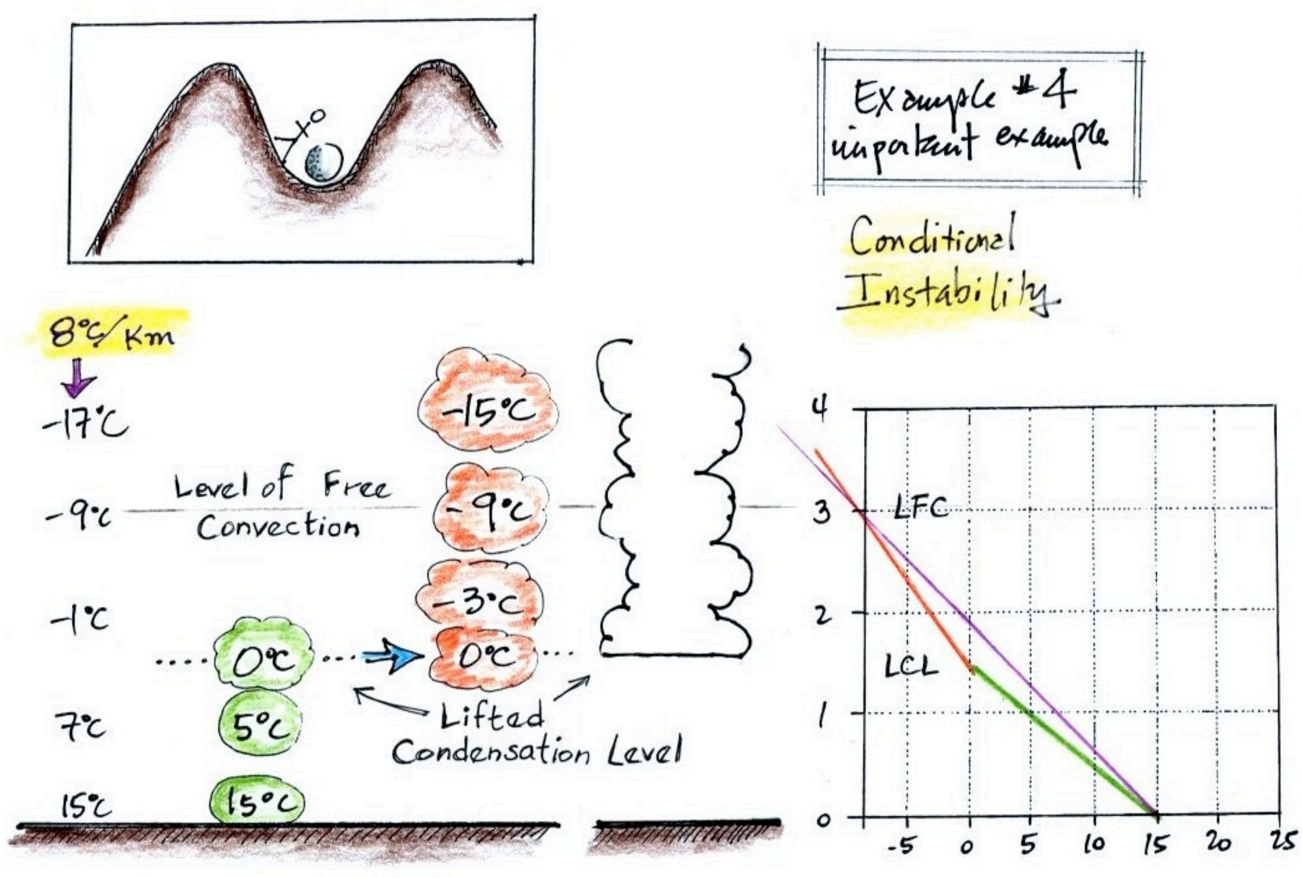
Example 4: Lifting and Conditional Instability

We will pick the same environmental lapse rate, 8^{o}C per kilometer, for the last and most instructive example.

In this case, the parcel of air will start out unsaturated and will cool at the dry adiabatic lapse rate. When the air parcel is lifted to an altitude of 1.5 kilometers, the parcel will cool to a temperature of 0^{o} C, which is its dew point temperature. Now the air parcel has become saturated (100% relative humidity) and from this point on upward, the rising parcel will cool at the moist adiabatic lapse rate. The altitude at which an unsaturated air parcel reaches its dew point temperature is called the **Lifted Condensation Level (LCL)**. You will see cloud begin to form at this altitude.

Initially the rising air parcel is colder and denser than the surrounding air. If the parcel is lifted to 3 kilometers, it will have the same temperature as the air around it. If the parcel is lifted above 3 kilometers, it will be warmer and less dense than the surrounding air and will continue to rise on its own. Three kilometers in this case is the **Level of Free Convection (LFC)**.

The atmosphere is conditionally unstable in this case. A rising parcel must first be lifted to its Lifted Condensation Level and become saturated. Then the parcel must be lifted further to its Level of Free Convection. This can be compared to pushing a rock up a little hill so that it can roll down a big hill on the other side.



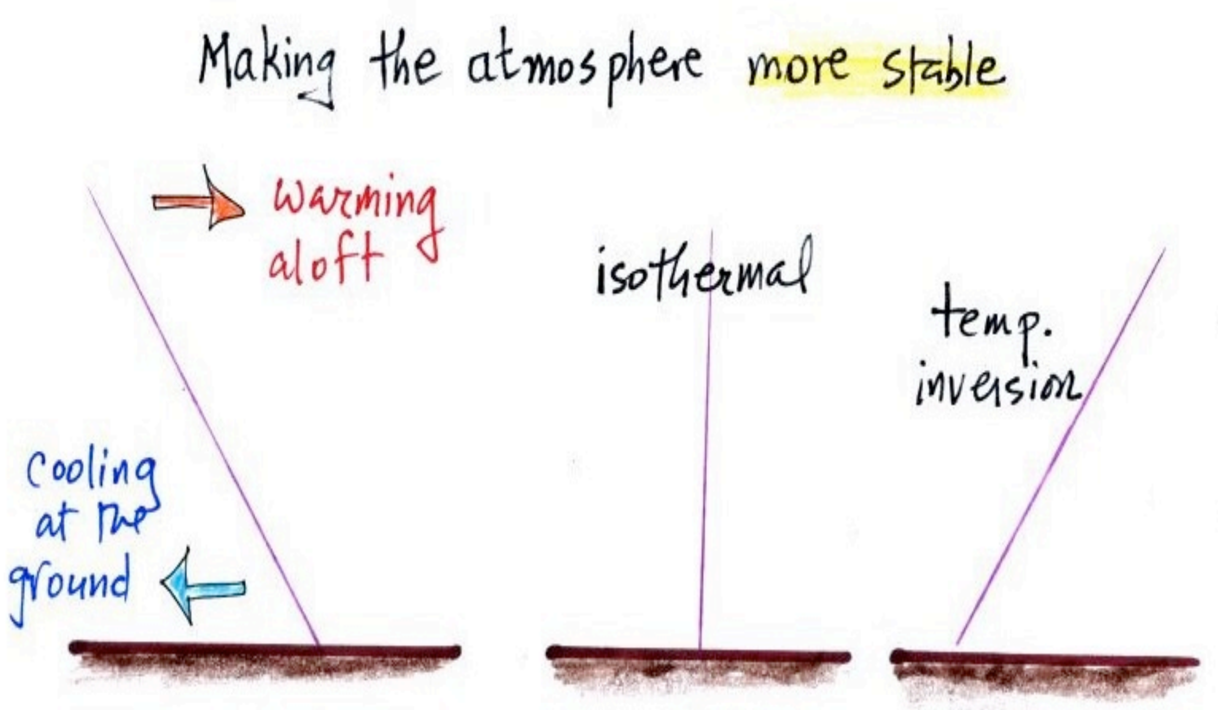
In conclusion, the value of the environmental lapse rate is one of the main factors determining whether the atmosphere will be stable or unstable.

Environmental Lapse Rate	Atmospheric Stability
Less than the moist adiabatic lapse rate (e.g. 4^o C/km)	Absolutely stable
Between the dry adiabatic lapse rate and the moist adiabatic lapse rate (e.g. 8^o C/km)	Conditionally unstable
Greater than the dry adiabatic lapse rate (e.g. 11^o C/km)	Absolutely unstable

Making the Atmosphere More Stable

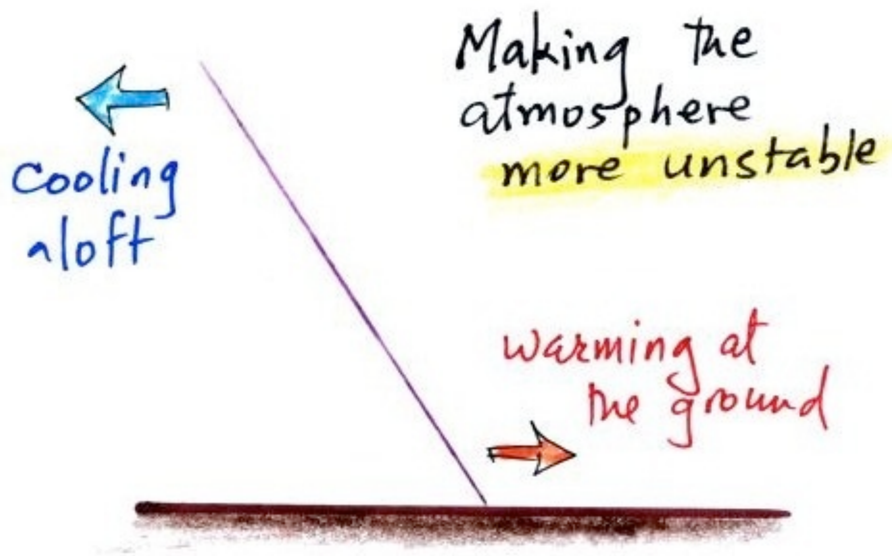
Warming the air above the ground and/or cooling the air next to the ground will make the atmosphere more stable. Because the ground and the air above it become cool during the night, the atmosphere is usually the most stable early in the morning.

A temperature inversion represents an extremely stable situation. Rising parcels always cool with increasing altitude (at either the dry or moist rate). In an inversion, the surrounding air becomes warmer and warmer with altitude. The difference between the cold parcel air and the warmer surroundings becomes larger and larger with increasing altitude.



Making the Atmosphere More Unstable

Sunlight warms the ground and the air above it during the day. This steepens the environmental lapse rate and makes the atmosphere more unstable. Cooling air above the ground has the same effect.



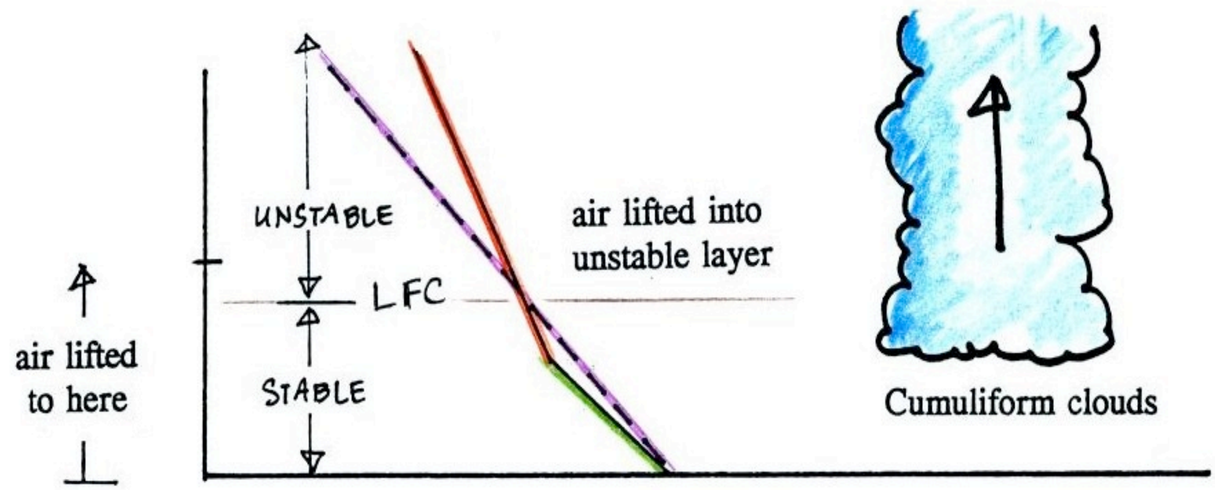
Clouds Associated with Stable and Unstable Conditions

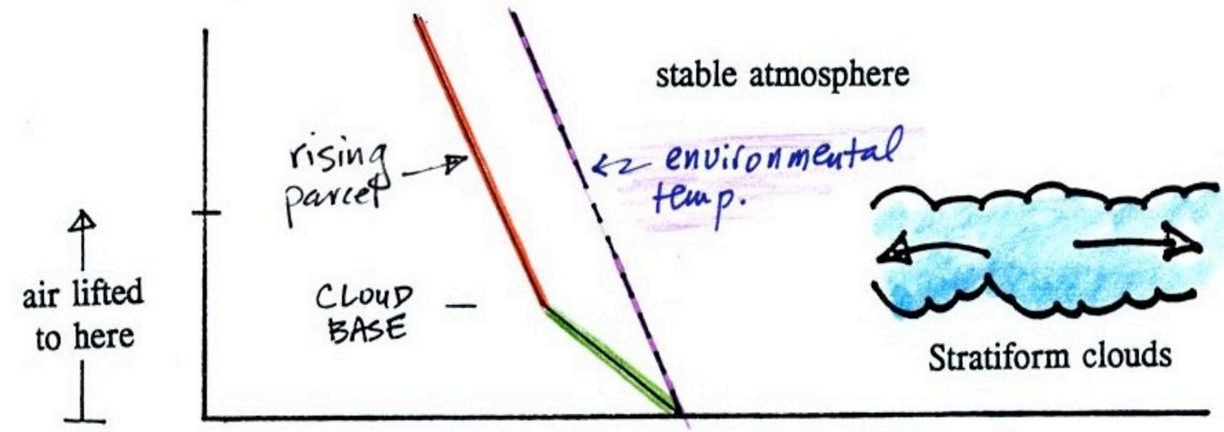
The figure on the next page shows the types of clouds that form in stable and conditionally unstable atmospheric conditions. A conditionally unstable atmosphere tends to have cumuliform clouds and a stable atmosphere tends to have stratiform clouds.

The violet line shows the environmental temperatures as a function of altitude. The green line is the dry adiabatic lapse rate and the red line is the moist adiabatic lapse rate. The rising air parcel initially cools at the dry adiabatic lapse rate until it reaches its dew point temperature. Once the parcel becomes saturated, it cools at the moist adiabatic lapse rate and follows the red line.

The top picture in the figure shows a conditionally unstable atmosphere. Because the parcel is lifted above the level of free convection (LFC), it continues to rise on its own and develops into cumuliform cloud and perhaps a thunderstorm.

The bottom picture shows a stable atmosphere. The air in the lifted parcel does become saturated but it never becomes warmer than the surrounding air. The parcel is never able to rise on its own. Stratiform clouds tend to form under these conditions.


UNSTABLE
LFC
STABLE
air lifted to here
air lifted into unstable layer
Cumuliform clouds


stable atmosphere
rising parcel
environmental temp.
air lifted to here
CLOUD BASE
Stratiform clouds