

A Quick Primer on Rising Air

We have described in class how the study of cloud formation quickly focuses our attention on the mechanisms that cause air to rise, since rising air is a very effective means of initiating cloud formation. Let's review the physics that explains why rising air often produces clouds.

1. Rising air expands. Let's imagine a parcel of air on the surface of the Earth that begins to rise. As the parcel rises to higher elevations, it enters regions of lower external air pressure. Remember that air is a poor conductor, so different masses or parcels of air do not readily or rapidly merge with each other. As the parcel experiences regions of lower air pressure, the parcel expands since there is less external confining pressure acting on it.

2. Expanding air cools. In order for the parcel to expand as described just above, the parcel has to do work to push other air molecules out of the way in order for the expansion to occur. This means that the parcel has to use up some of its energy to expand. Since temperature is just a measure of the energy of the molecules in a system, the temperature of the parcel will decrease as its molecules use some of their energy to expand against the external atmosphere. You and your students are very likely to have experienced the cool nature of expanding air. The gases inside an aerosol can are kept at high pressure (the better to expel gas through the nozzle); when they are released into the atmosphere, they find themselves in a region of lower pressure and expand just as described here. This expansion is what causes the gases from aerosol cans to feel so cool. (In contrast, compressing a gas causes it to warm up, since you are doing work TO the gas to cause it to compress. If you use an air pump for any length of time, you know the shaft feels warm after a few minutes of use, since you are doing work ON the gas each time you use the piston to compress it.)

3. Cooling air condenses. Here it is important to remember the definition of relative humidity. We recall that RH is the ratio of how much water vapor is in the air compared to the amount of water vapor required to saturate the atmosphere at the current temperature. We also know that as the temperature of the air decreases, a lesser amount of water vapor is required to saturate the air. In a rising parcel of air, there will be essentially no exchange of mass with the outside atmosphere; this is a fancy way of saying that the actual amount of water vapor (the numerator in the definition of RH) will stay the same. However, as the parcel rises, its temperature cools (see step 2 just above), meaning that the RH of a rising parcel increases. If the parcel rises enough, its RH will increase to 100%, and condensation and cloud formation will begin.

What process cause air to rise? There are four common mechanisms that cause air to rise:

1. Frontal wedging. As we have seen in studying fronts, warm air is less dense than cold air at the same level in the atmosphere, and so will rise when a warmer and colder air mass meet.

2. Mountain lifting (sometimes called orographic lifting). This is fairly easy to imagine. Consider a parcel of air moving toward a mountain, as the air strikes the mountain, it will move up and over the mountain as shown:

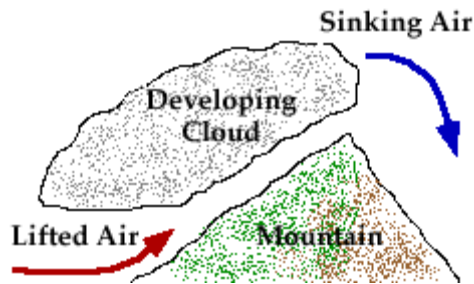


image courtesy the University of Illinois WW2010 Project

From this diagram, can you figure out which side of the mountain is more likely to receive precipitation? From this diagram can you understand the origin of what are called rain shadow deserts on the lee side of mountain ranges?

3. Convergence. When different air flows meet along the surface of the Earth, the convergence of these different flows causes the air to rise, since the surface of the Earth prevents the air from moving downward.

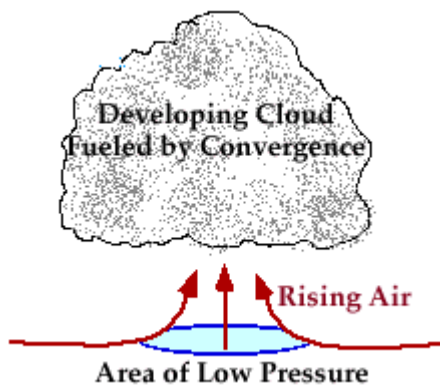


image courtesy the University of Illinois WW2010 project

Convergence occurs on an almost daily basis over the peninsula of Florida in the warmer months. (Take a quick look at a map of Florida if you wish to refresh your memory of the geography of the state). What is important here is that Florida is bounded on the east and west by large, warm, bodies of water. During the day, the pressure over the land decreases, and sea breezes blow in from both the Gulf (western) and Atlantic (eastern) sides of the state. Since these sea breezes are coming from opposing directions, they converge over the peninsula of Florida and rise as depicted in the diagram. Since both of these sea breezes carry moisture laden air, there is ample water vapor to produce significant condensation and precipitation. Anyone who has travelled to Florida in the summer knows there are almost daily thunderstorms in the late afternoon.

4. Lifting by heating. Puffy white cumulus clouds are a common sight on a warm summer day. Sometimes the sun will heat the ground so intensely that the air directly above that portion of the Earth becomes warmer than the surrounding air, causing the warmer parcel of air to rise. As long as that parcel of air is warmer than the air surrounding it, the parcel will continue to rise. If the parcel can rise high enough, it can cool to its dew point and condense to form clouds.

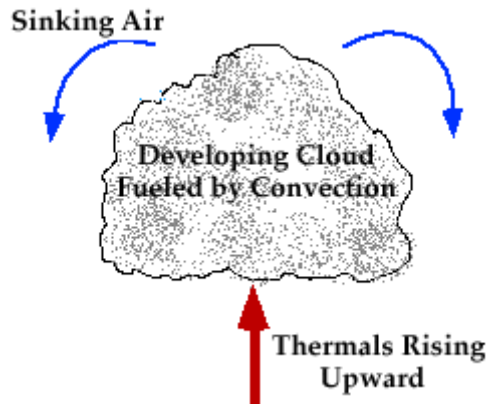


image courtesy University of Illinois WW2010 Project

While we are most familiar with cumulus clouds in the summer, we sometimes see them in the dead of winter over Lake Michigan. Imagine it is late fall or early winter, and we are experiencing the first frigid days of the season. If the lake hasn't frozen over yet, the temperature of the surface waters will be just above freezing (say 33 F or 1 C), while the air temperature just a few tens of meters above the lake could be near 0 F (-18C). If the air is much colder than the lake, the lake will warm a layer of air immediately above its surface, and this layer of air will rise and condense, forming small cumulus clouds over the lake.