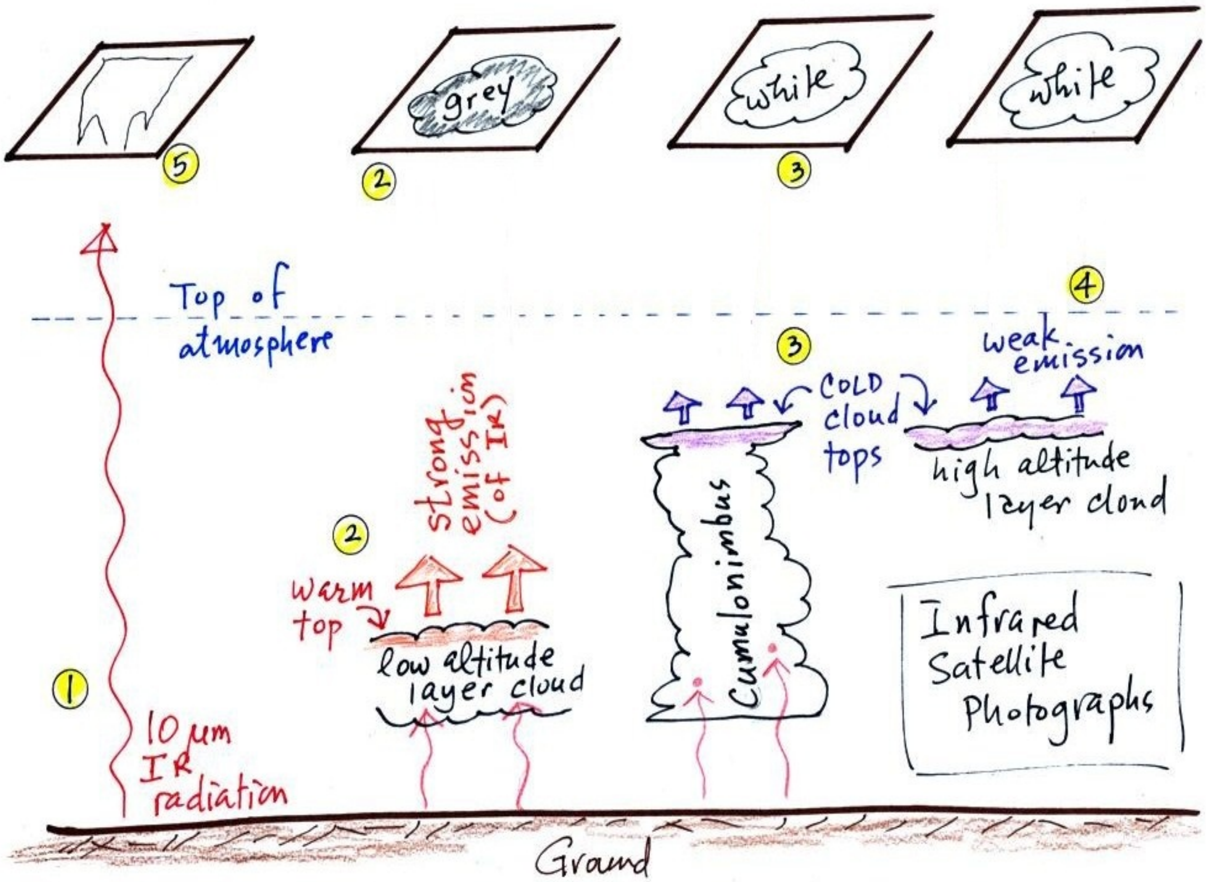
Module 8 - Lecture 23

Now that we have finished the section on cloud identification, this is a good time to learn about the two most common types of satellite photographs, infrared and visible.

Infrared Photographs

When you see satellite photographs of clouds on the television weather report, you are probably viewing infrared satellite photographs.



1. An infrared satellite photograph detects the 10 micrometer (µm) infrared radiation emitted by the ground, the ocean and clouds. Because infrared radiation is emitted constantly, clouds can be photographed during the day as well as at night. Infrared radiation of 10 µm is in the middle of the atmospheric window, so this type of radiation is able to pass through air without being absorbed. If there are no clouds, you can see the ground on an infrared photograph.

2. Clouds absorb radiation and then emit infrared radiation at a wavelength of about 10 µm. The top surface of a low altitude cloud will be warmer than high altitude clouds. Warmer objects emit infrared radiation at a greater rate or at higher intensity (the Stefan Boltzmann law). This is shown as grey on an infrared satellite photograph. An unimpressive looking grey cloud on an infrared satellite photograph may actually be a thick nimbostratus cloud which is producing a lot of rain or snow.

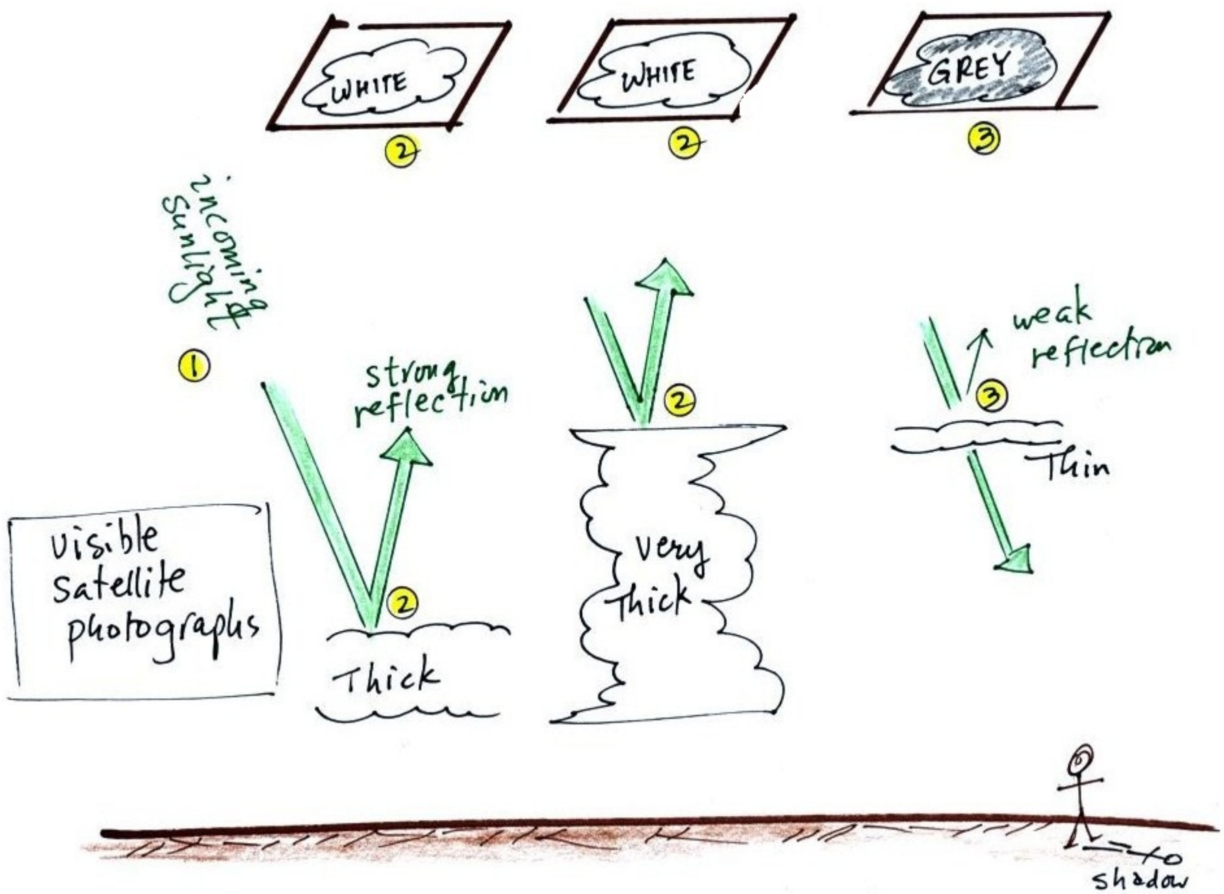
3. High altitude cloud tops are cold and emit infrared radiation at a lower rate and lower intensity. This appears white on an infrared photograph.

4. Two very different clouds (a thunderstorm and a cirrostratus cloud) are difficult to distinguish because they both appear white on a satellite photograph. Meteorologists are interested in locating tall thunderstorms because they can produce severe weather.

5. The ground changes temperature during the course of the day. On an infrared satellite animation you can watch the ground change from light grey in the early morning when the ground is cold to dark grey or black in the afternoon. Because of water's high specific heat, the ocean shows little temperature change and remains grey throughout the day. Here is a link http://www.atmo.arizona.edu/products/wximagery/usir.html to an IR satellite photograph loop.

Visible Photographs

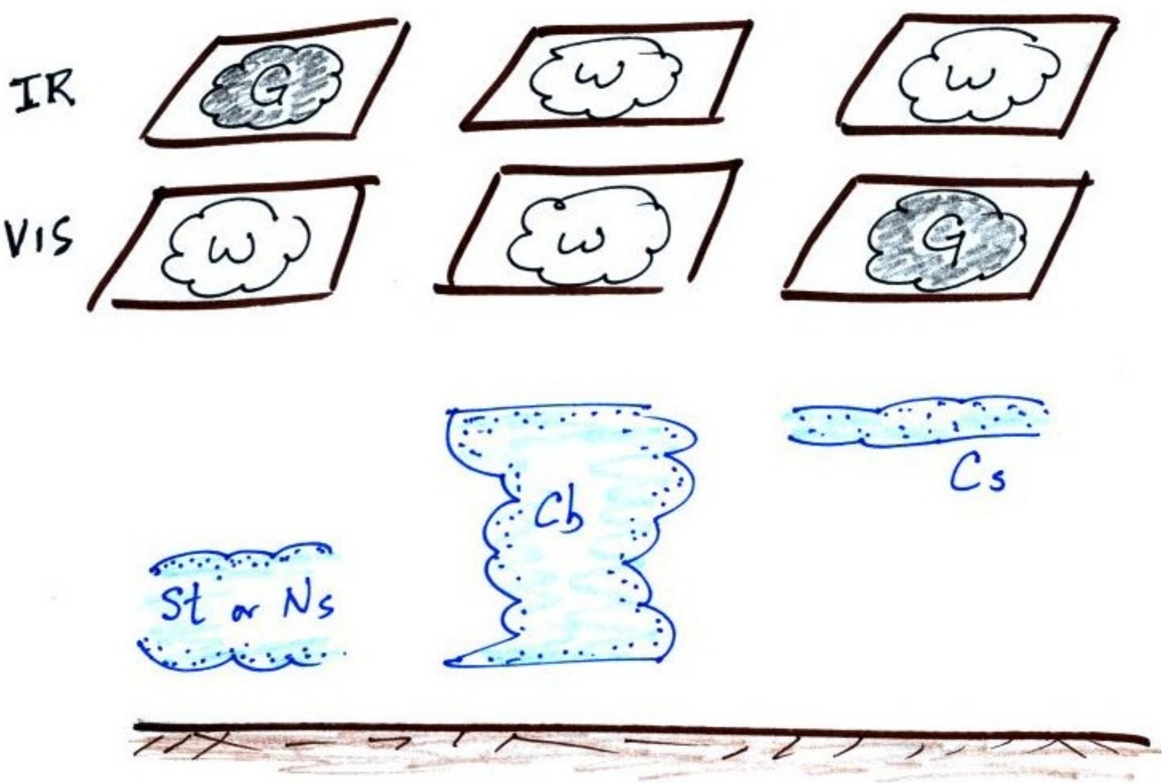
A visible satellite photographs sunlight that is reflected by clouds (Point 1 below). You will not see clouds on a visible satellite photograph at night. Thick clouds are good reflectors and appear white (Point 2). Thinner clouds do not reflect as much light and appear grey (Point 3). The low altitude layer cloud and the thunderstorm from the previous figure would both appear white on this photograph and would be difficult to distinguish.



Here is a summary of what we have learned so far.

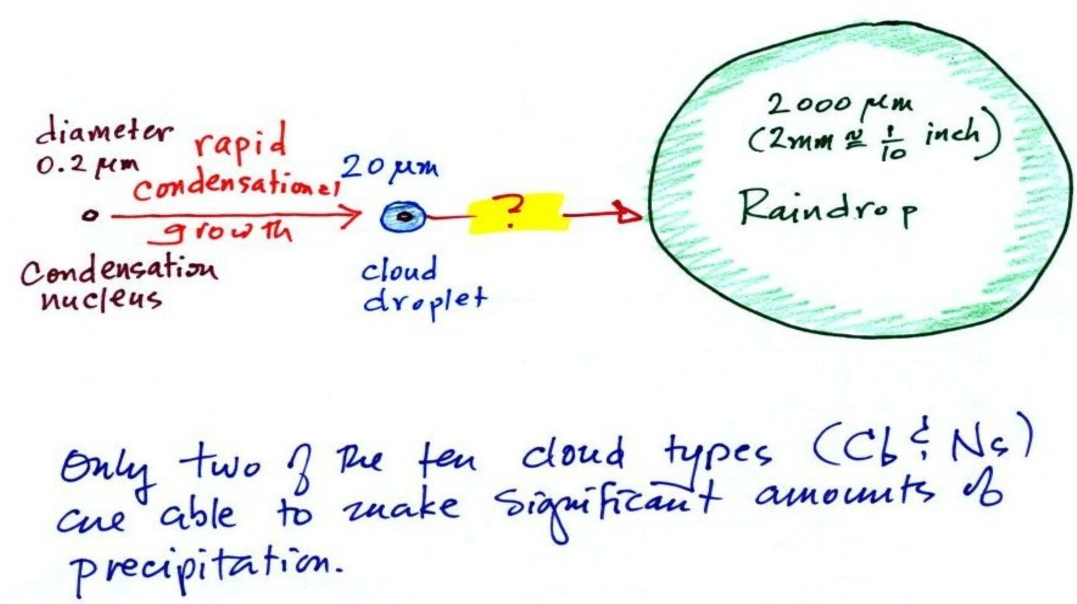
	White	Grey
IR photo	cold, high altitude, cloud top (weak emission of IR radiation)	warm, low altitude, cloud top (strong emission of IR radiation)
VIS photo	Thick cloud (good reflector of visible light)	Thin cloud (poor reflector of visible light)

The figure below shows how to combine visible and infrared (IR) photographs so that you can distinguish between different types of clouds.

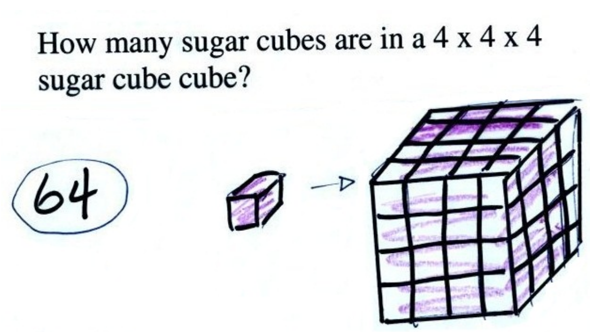


The last topic we will cover is precipitation formation and the types of precipitation. Only two of the ten cloud types are able to produce significant amounts of precipitation. Producing precipitation is surprisingly difficult.

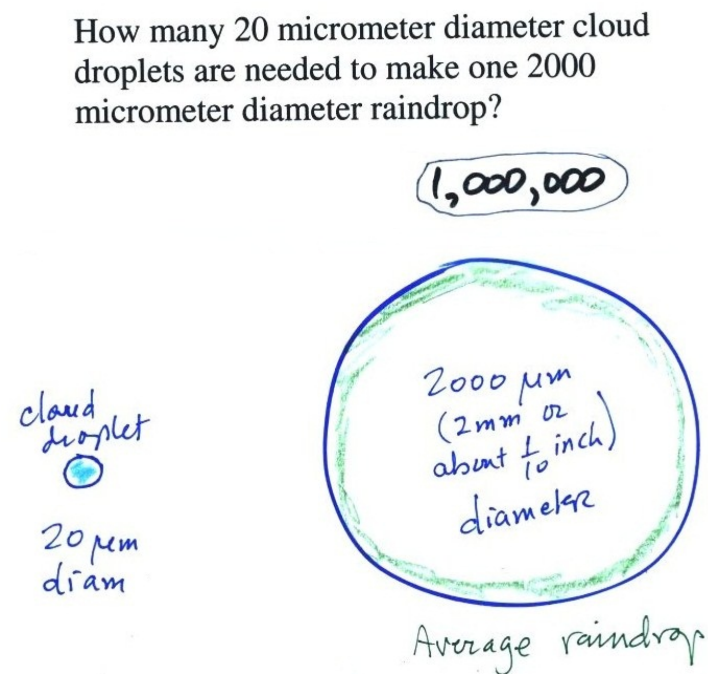
This figure shows typical sizes of cloud condensation nuclei (CCN), cloud droplets, and raindrops (a human hair is about 50 um thick for comparison). It is relatively easy to make cloud droplets by cooling moist air to the dew point, which raises the relative humidity to 100%. Water vapor condenses instantaneously onto a cloud condensation nucleus to form cloud droplets. The process of forming raindrops from 20 μm cloud droplets requires different physical processes than condensation, which we will discuss in this lecture.



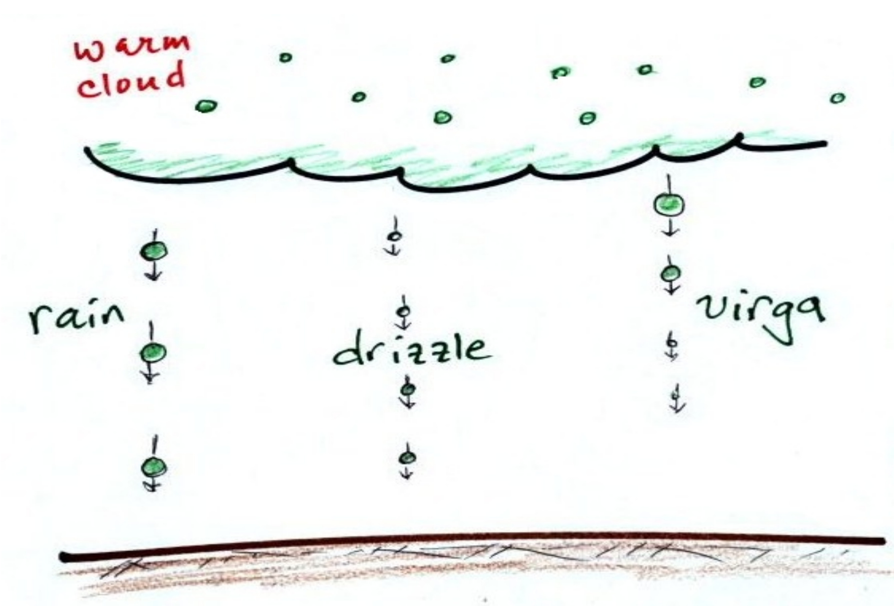
Part of the problem is that it takes quite a few 20 um diameter cloud droplets to make a 2000 μm (two millimeters) diameter raindrop. How many exactly? Before answering that question we will look at a cube. It takes 64 individual sugar cubes to make a 4 cube x 4 cube x 4 cube. This is because the bigger cube is 4 times wider, 4 times deeper, and 4 times taller. Volume has three dimensions.



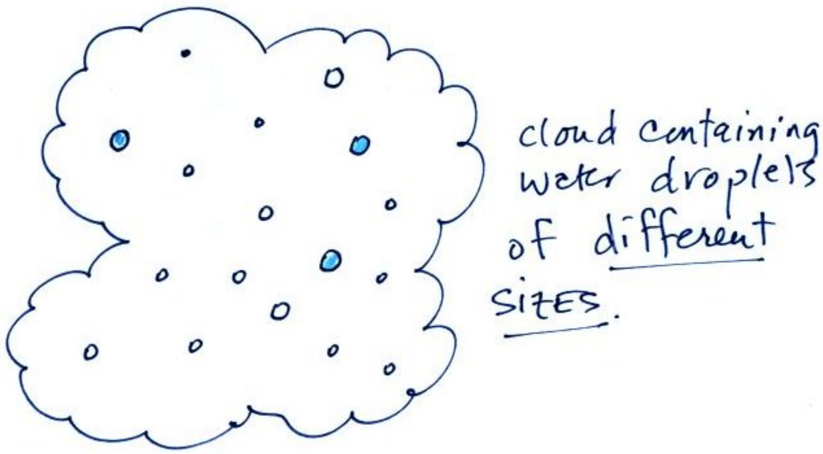
The raindrop is 100 times wider, 100 times deeper, and 100 times taller than the cloud droplet. The raindrop has a volume that is 100 x 100 x 100 = 1,000,000 (one million) times larger than the volume of the cloud droplets.



Fortunately there are two processes capable of quickly turning small cloud droplets (or ice crystals) into much larger precipitation particles in a cloud. The **collision coalescence process** works in clouds that are composed of water droplets only. Clouds like this are only found in the tropics. This process will only produce rain, drizzle, and virga (rain that evaporates before reaching the ground).

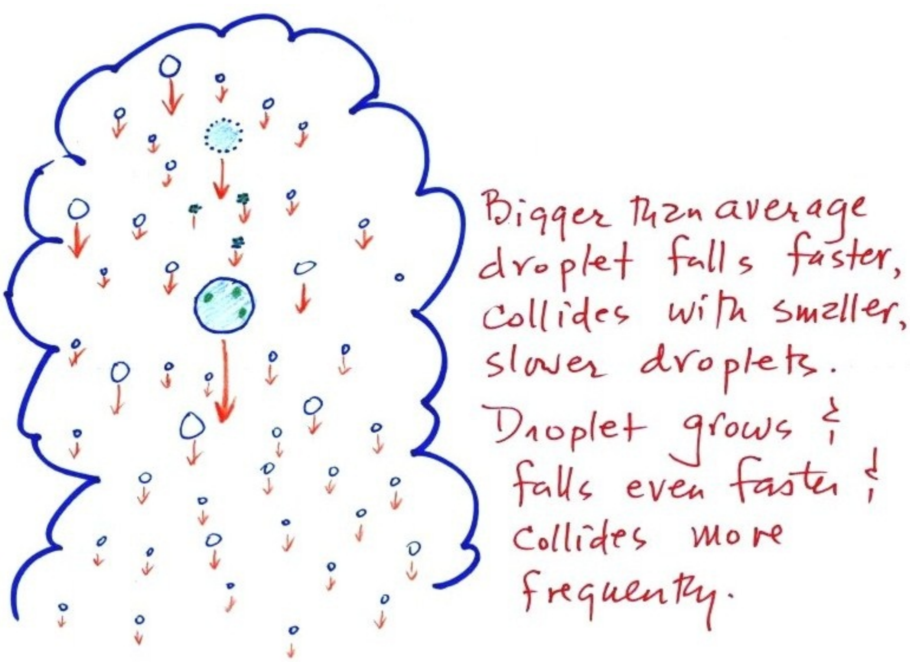


The collision coalescence process works best in a cloud filled with cloud droplets of different sizes.

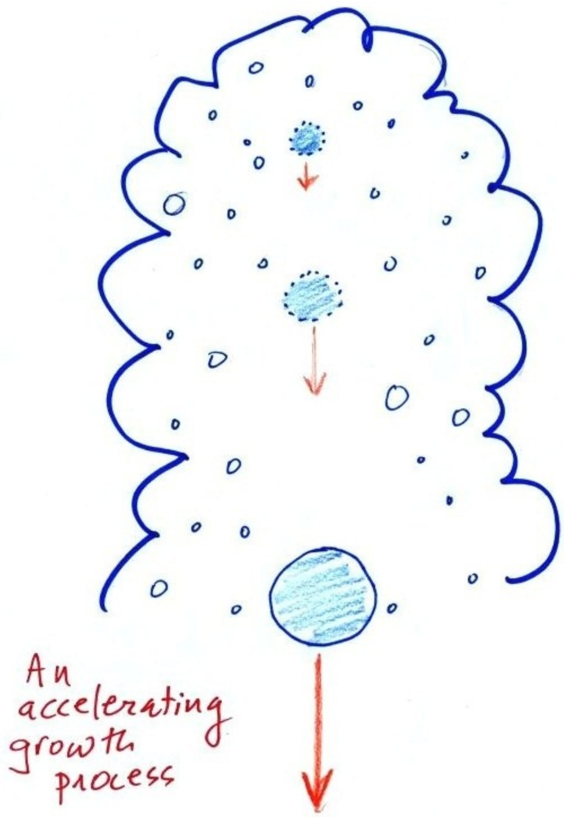


Understanding the Collision - Coalescence process.

A larger than average cloud droplet will fall faster, overtake, and collide with smaller slower moving droplets. The colliding droplets then often merge to form a larger droplet.



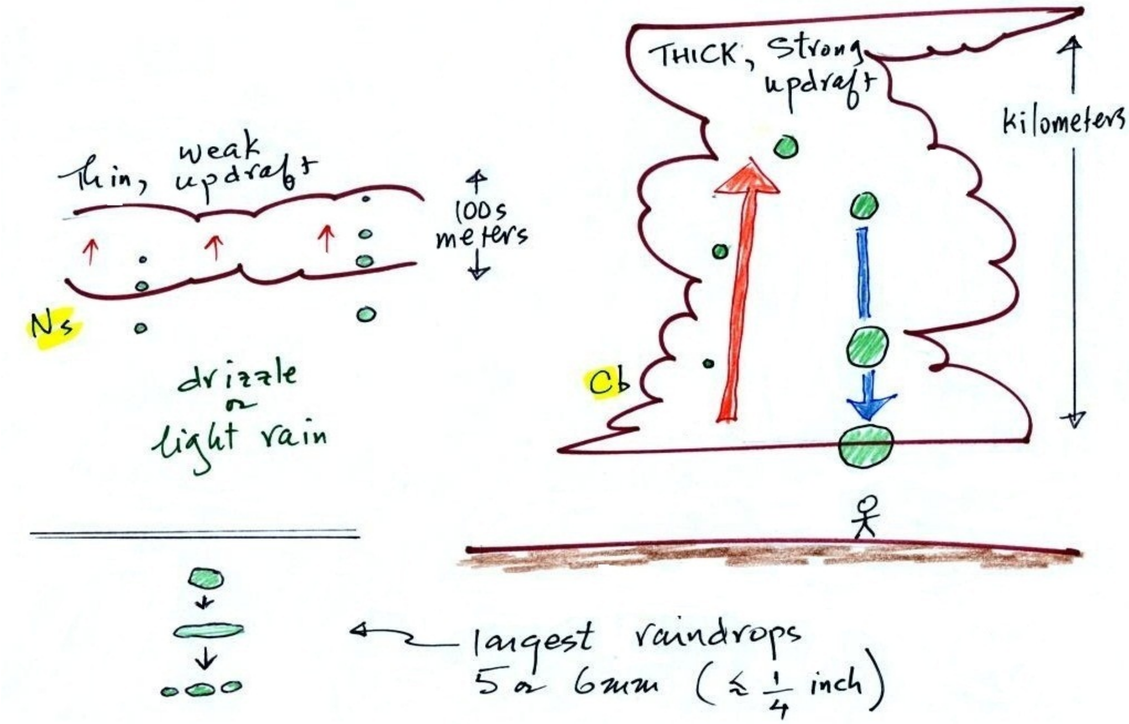
This is an accelerating growth process. As the falling droplet grows, it falls faster, and sweeps out an increasingly larger volume inside the cloud. The rate of growth accelerates as the droplet gets bigger.



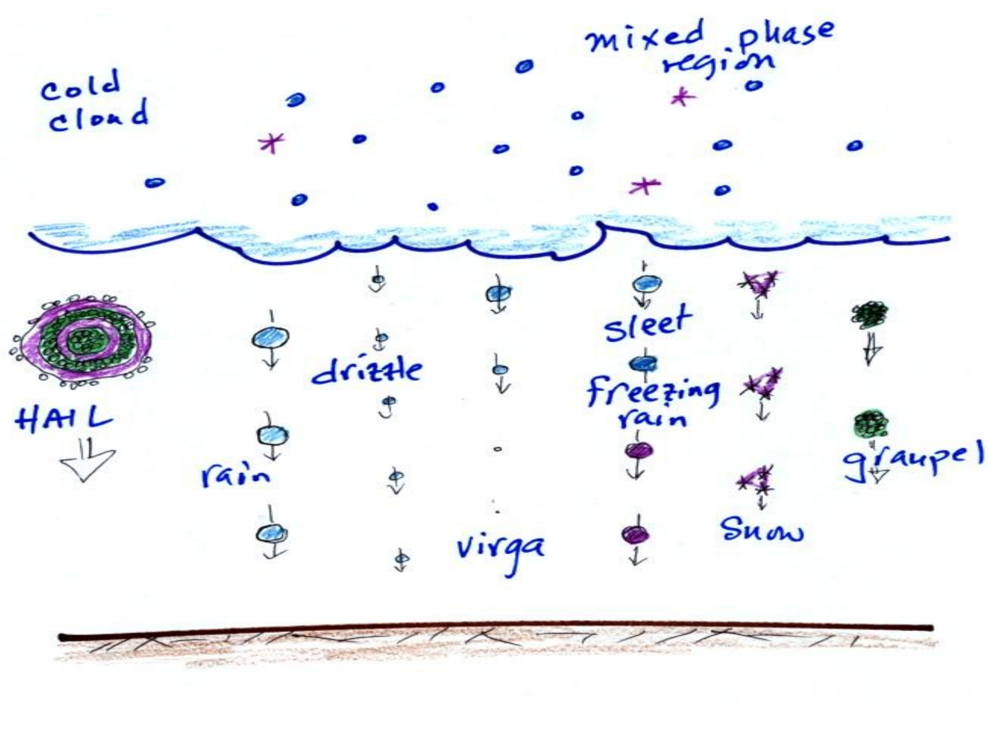
The figure below shows the collision-coalescence process at work in the two precipitation producing clouds: nimbostratus (Ns) and cumulonimbus (Cb).

Ns clouds are thinner and have weaker updrafts than Cb clouds. The largest raindrops fall from Cb clouds because the droplets spend more time in the cloud growing. In a Cb cloud raindrops can grow while being carried upward by the updraft and also when falling in the downdraft.

Raindrops can grow up to about 1/4 inch in diameter. When drops get larger than this, wind resistance flattens out the drop as it falls toward the ground. The drop begins to "flop" around and breaks apart into several smaller droplets. Solid precipitation particles such as hail can get much larger (one to three inches in diameter).



The **ice crystal process** produces precipitation everywhere else, including Tucson. Even on the hottest day in the summer, thunderstorm clouds are tall and reach into cold parts of the atmosphere where temperatures drop well below freezing. Hail and graupel (a precipitation particle that is often mistaken for hail) frequently fall from these storms; proof that the precipitation started out as an ice particle. This process can also produce other kinds of precipitation such as snow and sleet.



Most clouds or at least portions of most clouds will contain ice crystals and the ice crystal process will be the dominant precipitation mechanism.

Below is a figure that shows the internal structure of cold clouds. The bottom of the thunderstorm (Point 1) has a temperature above freezing and contains only water droplets. The top of the thunderstorm (Point 2) is colder than -40^0F and contains only ice crystals. The middle part of the cloud or the mixed phase region (Point 3) contains both super cooled water droplets (water that has been cooled to below freezing but has not frozen) and ice crystals. This is where the ice crystal process will be able to produce precipitation. This is also where lightning is generated.

The super cooled water droplets do not freeze even though they have been cooled to below freezing; it is much easier for small droplets of water to freeze onto an ice crystal nucleus or for water vapor to be deposited onto an ice crystal nucleus. The ice crystal nucleus must have a crystalline structure similar to ice. There are not many materials with this property and as a result ice crystal nuclei are rather scarce.