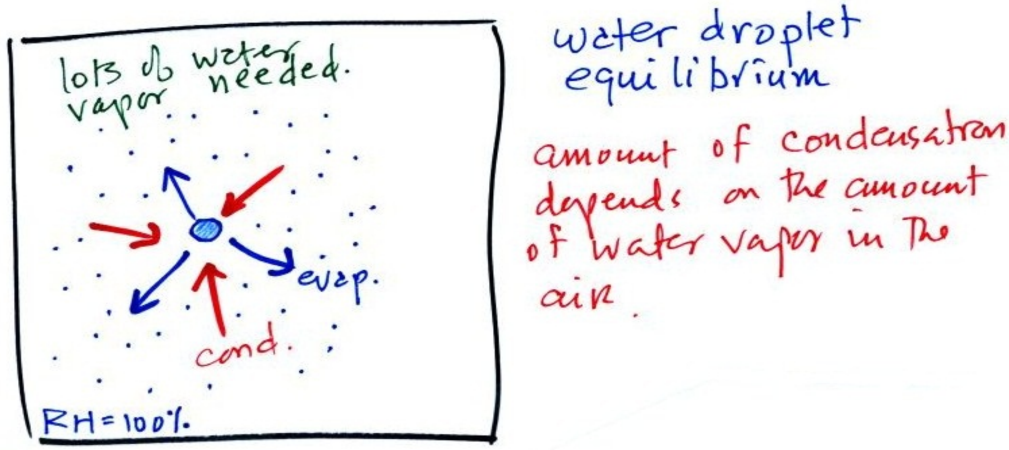
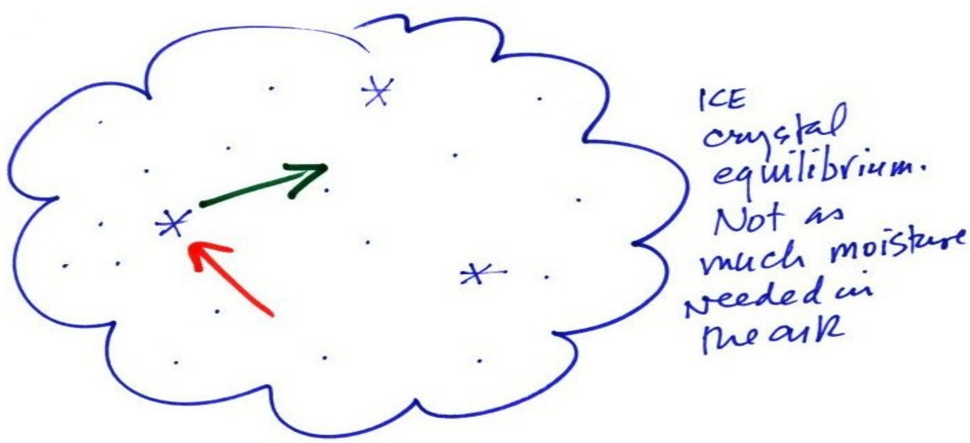
Module 8 - Lecture 24

In the previous lecture we learned that the ice crystal process occurs in the middle region of cold clouds, where there is a mixture of ice crystals and super cooled water droplets. We will now see how ice crystals can quickly grow into precipitation size particles.

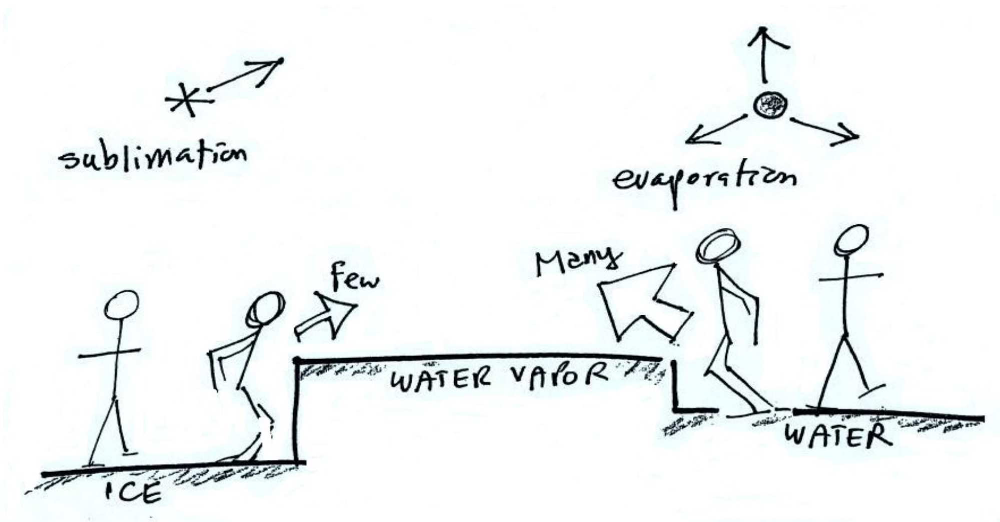
The figure below shows a water droplet in equilibrium with its surroundings. The droplet is evaporating (the 3 blue arrows in the figure). The rate of evaporation will depend on the temperature of the water droplet. The droplet is surrounded by air that is saturated with water vapor (the droplet is inside a cloud where the relative humidity is 100%). This means there is enough water vapor to be able to supply 3 arrows of condensation. The droplet does not grow or shrink because it loses and gains water vapor at the same rate.



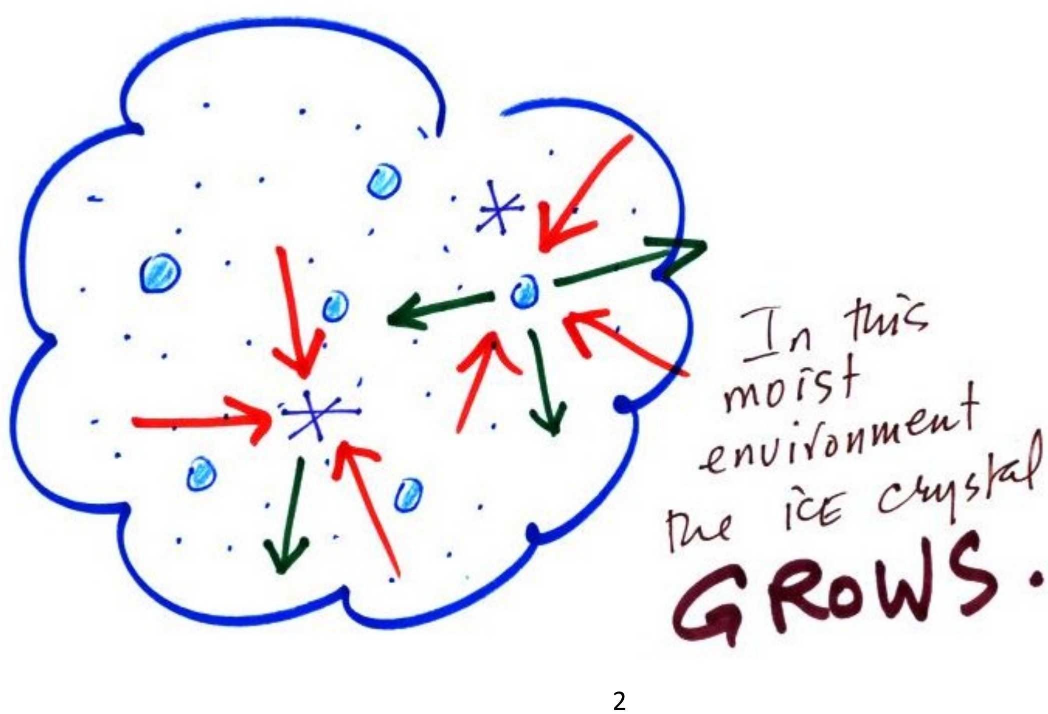
This figure shows what is required for an ice crystal (at the same temperature as the droplet in the figure above) to be in equilibrium with its surroundings. Only one arrow is shown because the ice crystal will not evaporate as rapidly as the water droplet. The transition from ice to water vapor is a bigger jump in energy than the transition from water to water vapor. The ice crystal needs only one arrow of condensation to be in equilibrium with evaporation because there are fewer ice molecules with sufficient to evaporate. To support this lower rate of condensation, less water vapor in the air surrounding the ice crystal is required.



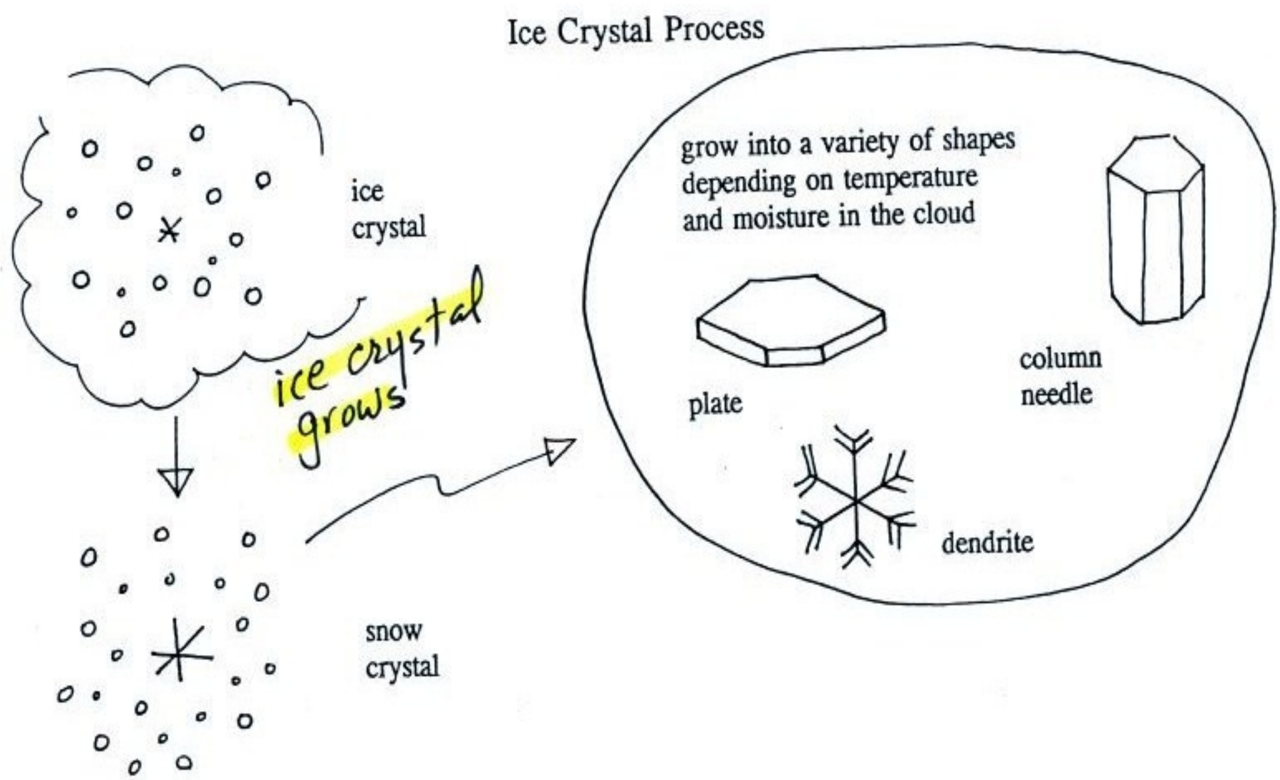
An analogous situation is shown in the figure below. The class instructor and most of his students are able to jump from the floor to the top of a 12 inch box. This represents the water to water vapor transition. Only a few students are able to jump on top of a filing cabinet that is 30 inches high. This represents the ice to water vapor transition.



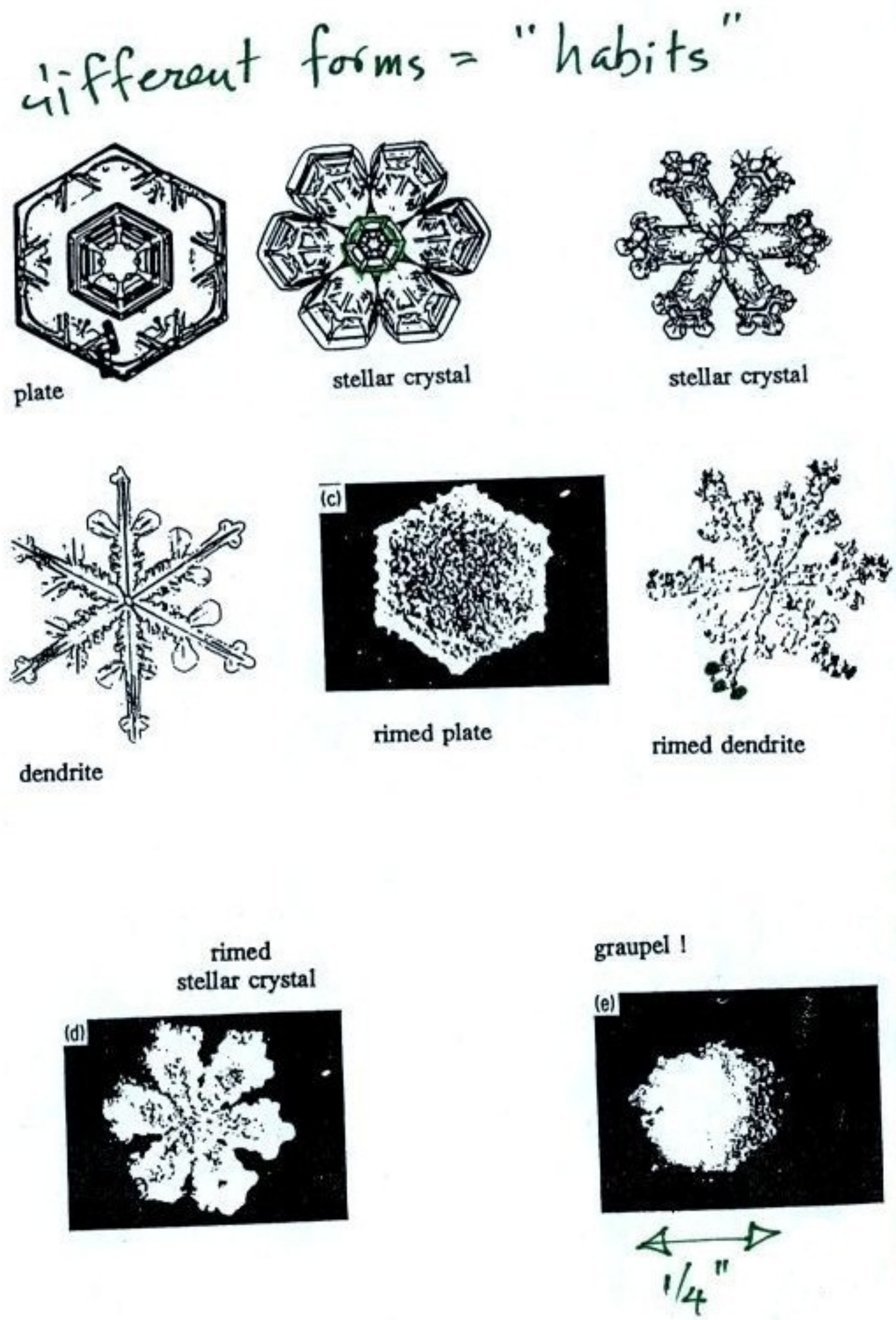
The figure below illustrates what happens in the mixed phase region of a cold cloud. The water droplets are in equilibrium with their surroundings. They have three arrows of evaporation and three arrows of condensation. The ice crystals are evaporating more slowly than the water droplets. <u>The ice crystal is not in equilibrium because condensation (three arrows) exceeds evaporation (one arrow) and the ice crystal will grow.</u>



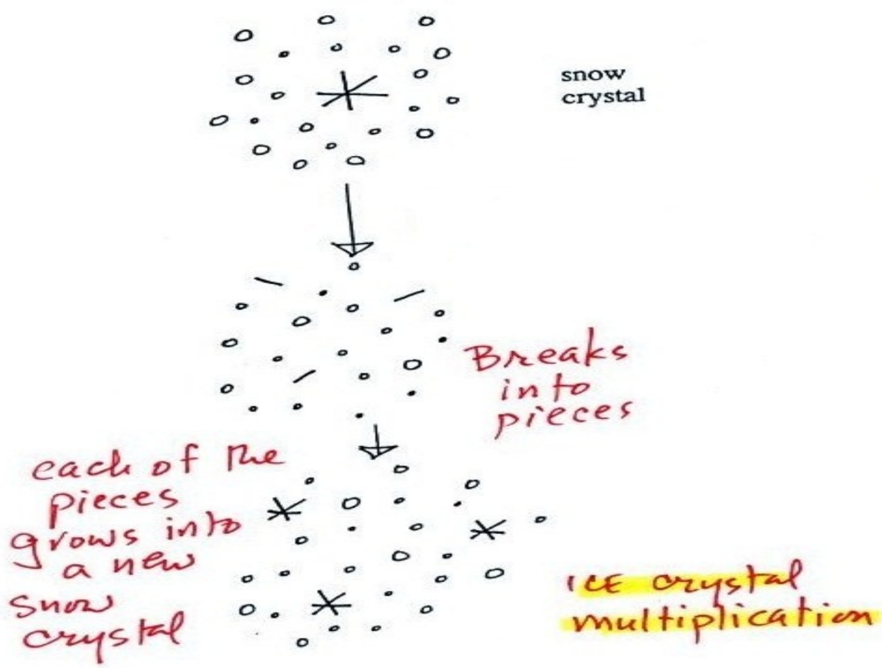
Once an ice crystal has grown, it becomes a snow crystal. Depending on the cloud temperature and relative humidity, ice crystals can develop from the initial hexagonal prism into numerous symmetric shapes. Possible shapes for ice crystals are columns, needles, plates and dendrites. If the crystal migrates into regions with different environmental conditions, the growth pattern may change, and the final crystal may show mixed patterns. Dendrites are the most common because they form where there is the most moisture available for growth.



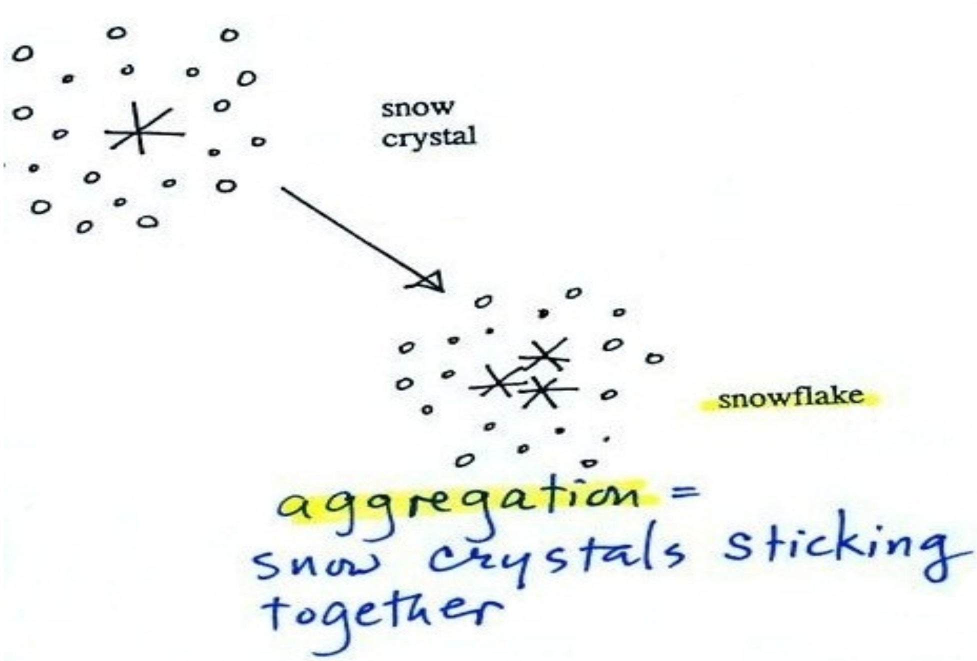
Here are some actual photographs of snow crystals taken with a microscope. Snow crystals are usually 100 or a few hundred micrometers in diameter (tenths of a millimeter). The different shapes are called "habits". You will find more photographs and additional information about snow crystals at www.snowcrystals.com.



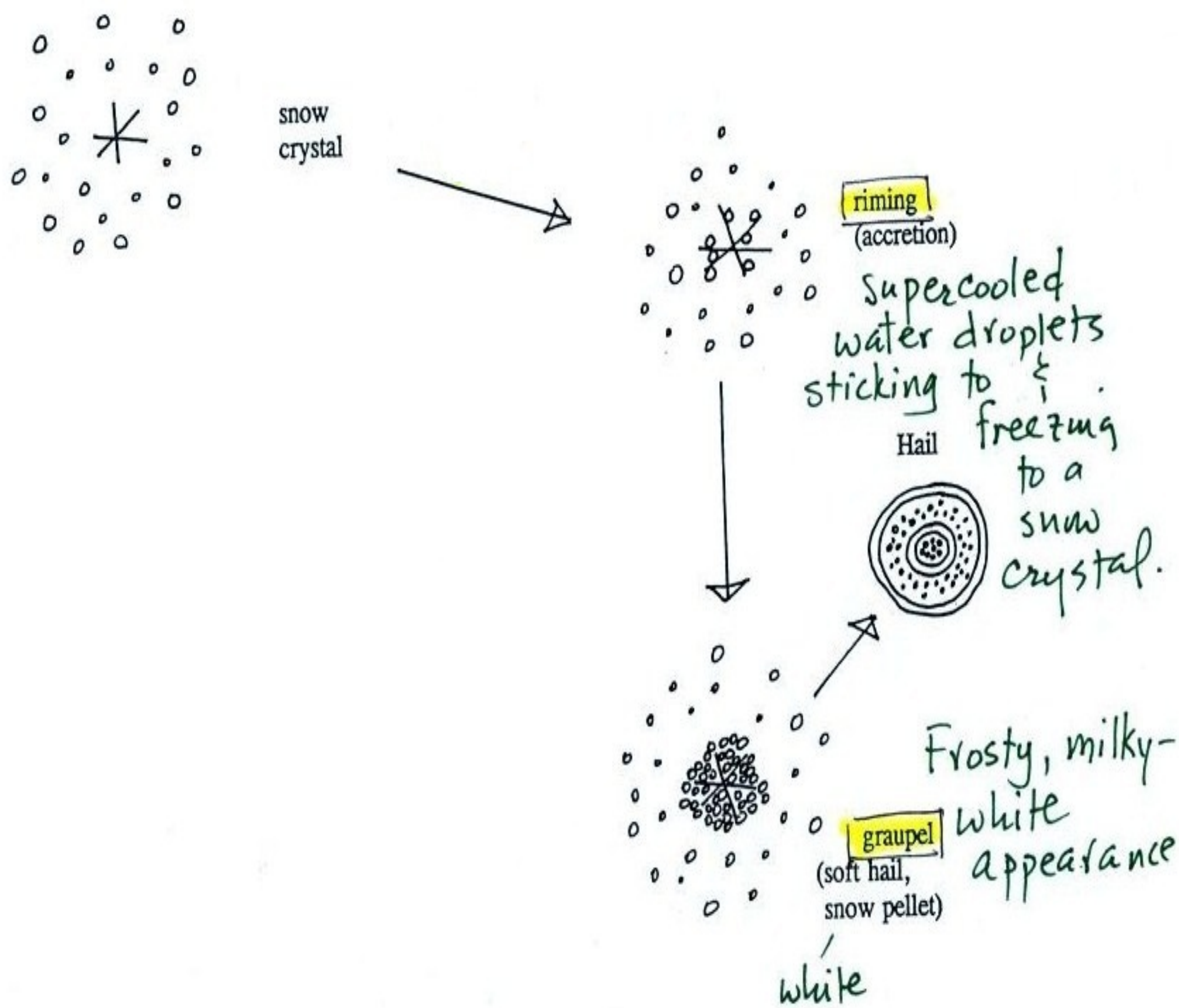
Once a snow crystal forms, it can break into pieces and each piece can grow into a new snow crystal. Because snow crystals can be in short supply, ice crystal multiplication increases the amount of precipitation that ultimately falls from the cloud.



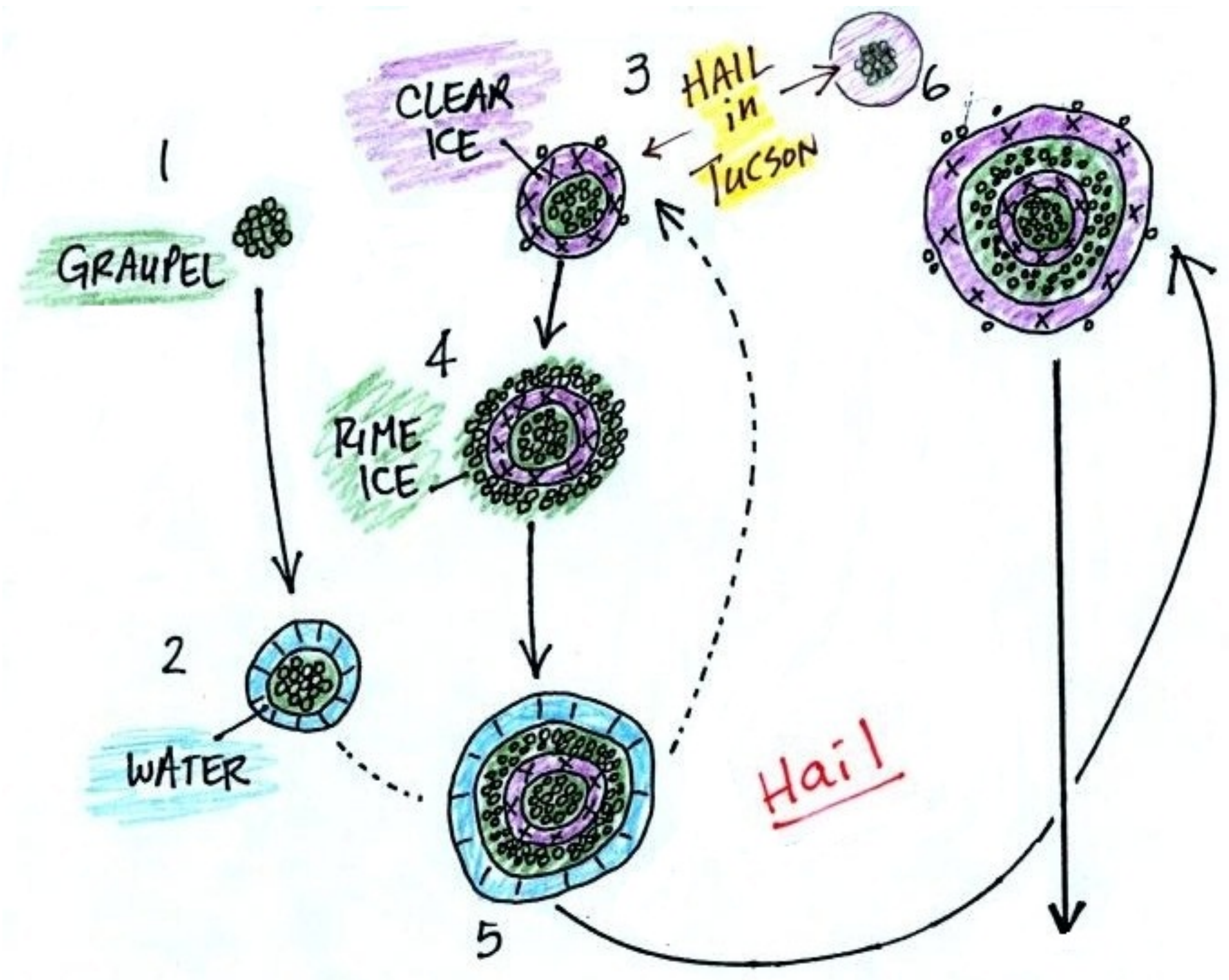
Snow crystals can collide and stick together to form a snowflake, a process called aggregation. Snow crystals are small, a few tenths of a millimeter across. Snowflakes are much larger because they are made up of many snow crystals.



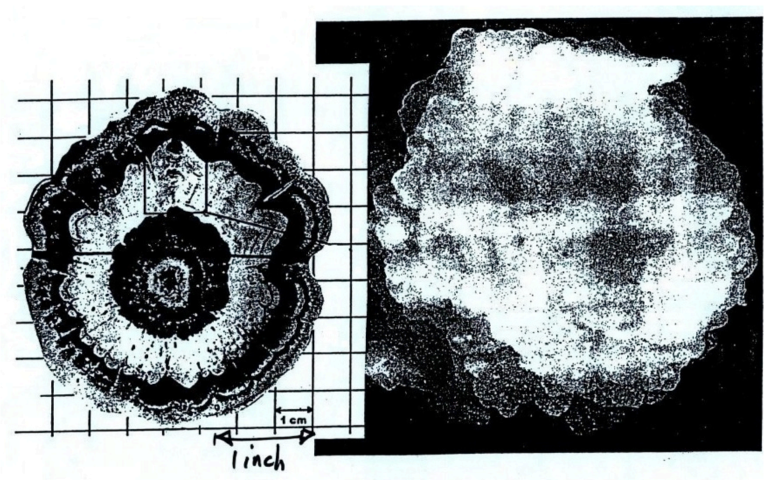
When snow crystals collide with super cooled water droplets, the water droplets may stick and freeze to the snow crystal. This process is called riming or accretion (note this is not called collision coalescence even though it is the same idea). If a snow crystal collides with enough water droplets it can be completely covered with ice. The resulting particle is called graupel. Graupel is sometimes mistaken for hail and is called soft hail or snow pellets. Rime ice has a frosty milky white appearance. A graupel particle resembles a miniature snow ball. Graupel particles often serve as the nucleus for a hailstone.



This figure gives you an idea of how hail forms. In the figure below a hailstone starts with a graupel particle (Point 1, colored green to represent rime ice). The graupel falls or gets carried into a part of the cloud where it collides with a large number of super cooled water droplets which stick to the graupel but do not immediately freeze. The graupel gets coated with a layer of water (Point 2, blue). The particle then moves into a colder part of the cloud and the water layer freeze producing a layer of clear ice. The clear ice, colored violet, has a distinctly different appearance from the milky white rime ice (Point 3). In Tucson this is often the only example of hail that you will see: a graupel particle core with a single layer of clear ice.

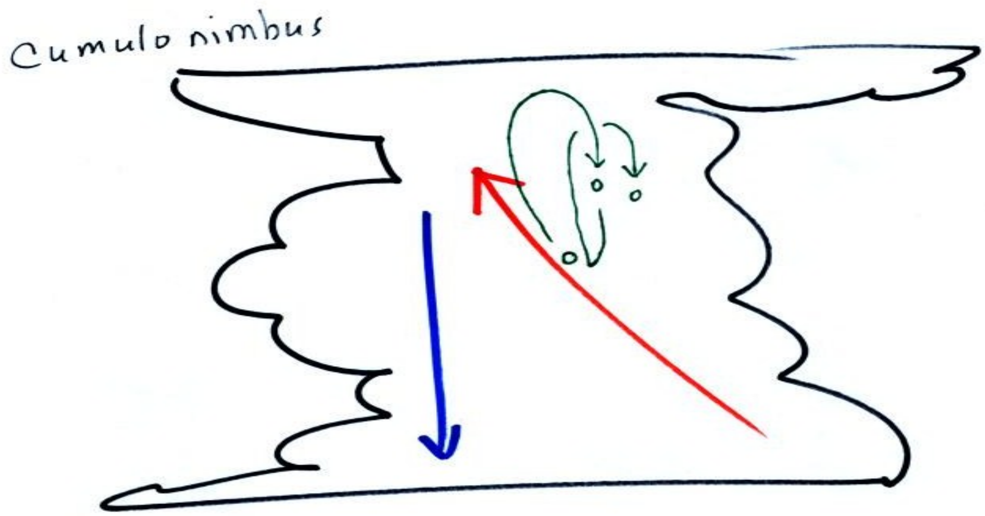


In the severe thunderstorms of the Central Plains, the hailstone can pick up a new layer of rime ice, followed by another layer of water which subsequently freezes to produce a layer of clear ice. This cycle can repeat several times; large hailstones can be composed of many alternating layers of rime and clear ice. An unusually large hailstone (around 3 inches in diameter) has been cut in half to show (below) the different layers of ice. The picture below is close to actual size.



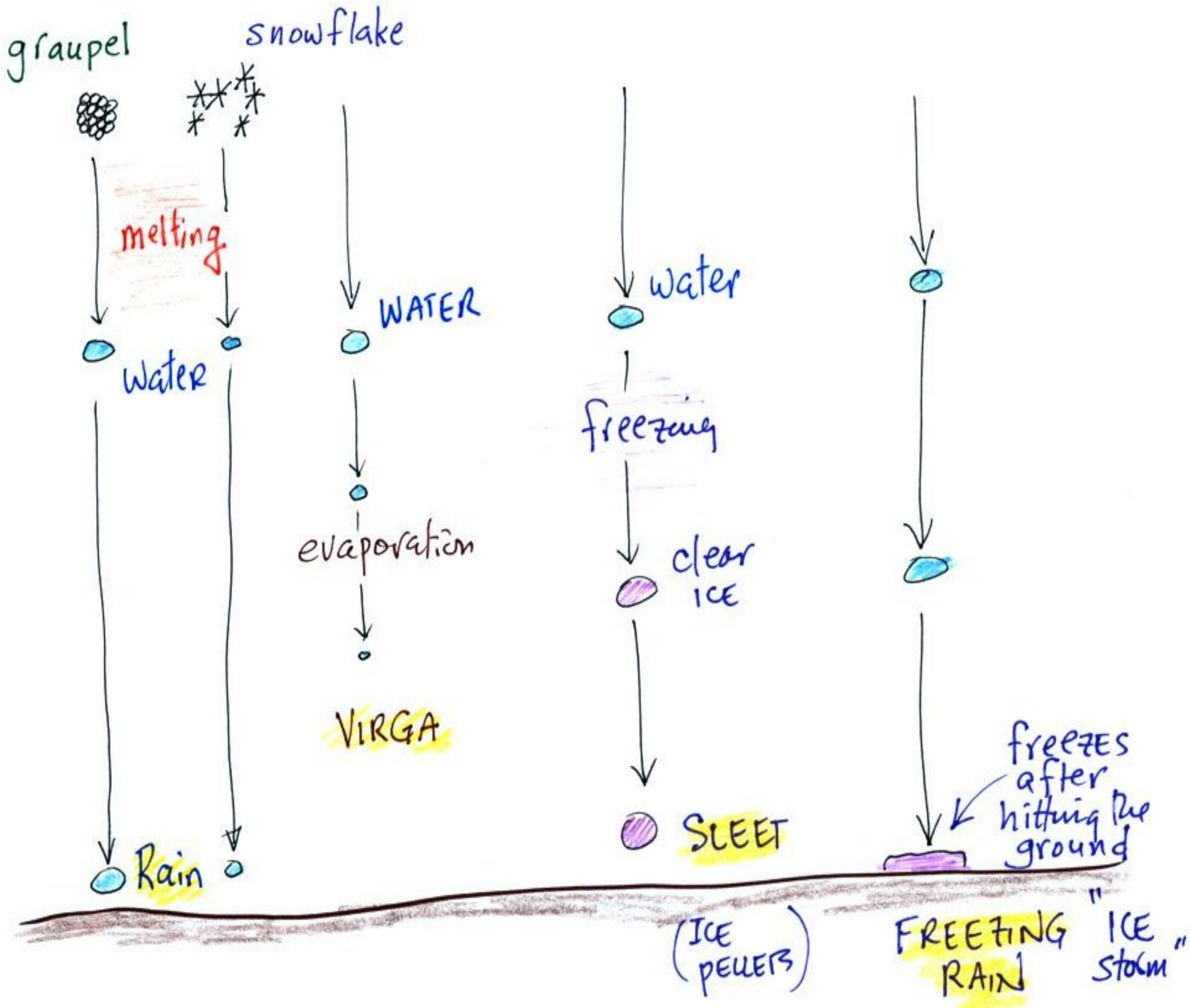
Hail is produced in strong thunderstorms with tilted updrafts. You would never see hail (or graupel) falling from a nimbostratus cloud. The growing hailstone can fall back into the updraft (rather than falling out of the cloud) and be carried back up toward the top of the cloud. In this way the hailstone can complete several cycles through the interior of the cloud.

To produce hail you need a big strong thunderstorm (with a tilted updraft)



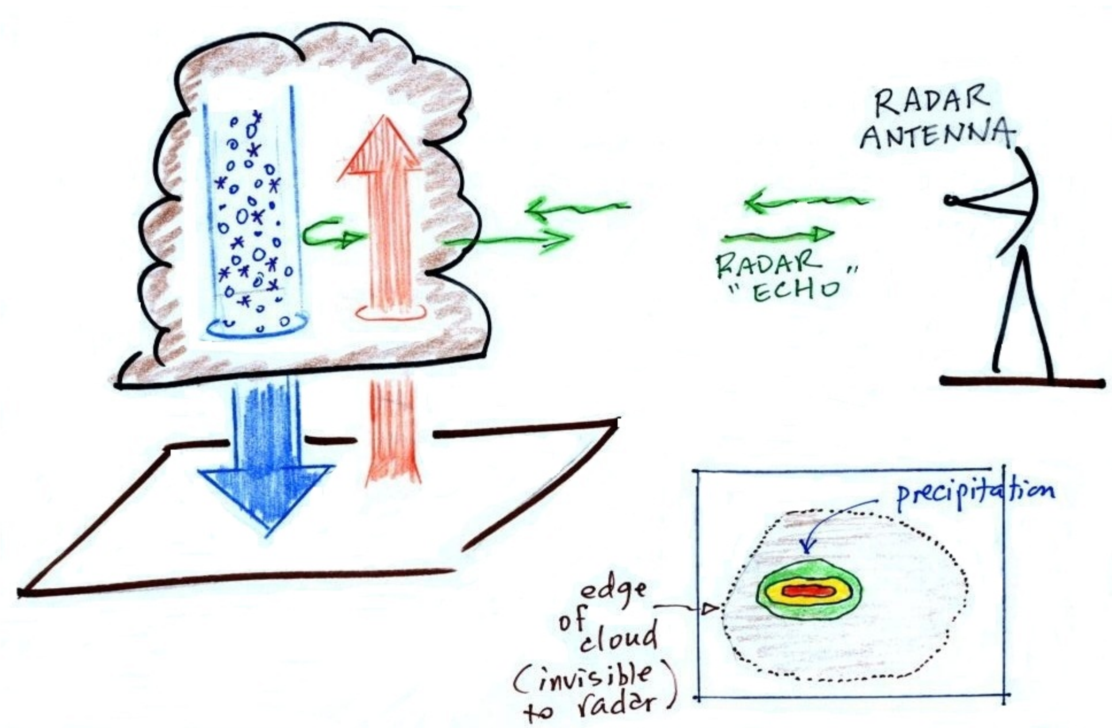
The figure below shows some of the things that can happen once a precipitation particle falls from a cloud. Moving from left to right, a falling graupel particle or a snow flake can move into warmer air, melt and fall to the ground as rain. The graupel can also reach the ground before melting. Sometimes the falling raindrops will evaporate before reaching the ground, which is called virga. Virga is common early in the summer thunderstorm season in Arizona when the air below the thunderstorm is dry. Lightning that comes from thunderstorms that are not producing much precipitation is called "dry lightning" and is a common cause of brush fires.

Rain will sometimes freeze before reaching the ground. The resulting particle of clear ice is called sleet. Freezing rain by contrast freezes once it reaches the ground. Everything on the ground can get coated with a thick layer of ice. It is nearly impossible to drive during one of these "ice storms." Sometimes the coating of ice is heavy enough that branches on trees are broken and power lines are brought down. It sometimes takes several days for power to be restored.



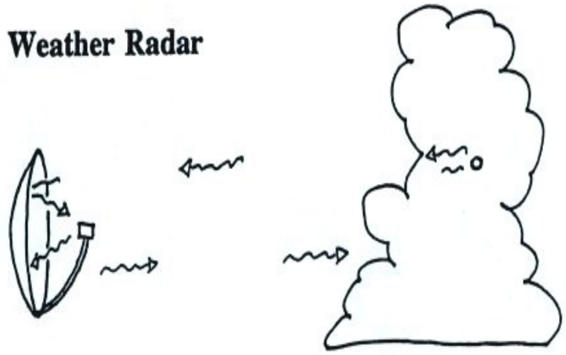
Satellite photographs are a good way of observing clouds, especially over the ocean. Using both visible and infrared light satellite photography gives you a good idea of cloud type. However satellite photographs do not really tell you whether a cloud is producing precipitation or how much precipitation a cloud is producing. For that you need radar. In some ways a radar image of a thunderstorm is like an X-ray photograph which provides a partial view of the insides of a human body. The X-rays pass through the flesh but are partially absorbed by bone.

The radio signals emitted by radar pass through the cloud itself but are reflected by the much larger precipitation particles. The intensity of the reflected signal (the echo) depends on the number and the size of the precipitation particles. Red generally means an intense reflected signal and heavy precipitation. The edge of the cloud is not normally seen on the radar signal.



The radar antenna slowly spins as it is transmitting so it scans a full 360 degrees of azimuth in a minute or two. Information from radar is drawn on weather maps. The plan position indicator (PPI) display below shows the data from single radar. The radar antenna can also be pointed at an interesting storm to scan vertically through the storm. This produces the range height indicator (RHI) display shown in the figure below.

Weather Radar



Precipitation (rain especially) reflects some of the radiation emitted by the radar back toward the transmitting antenna.

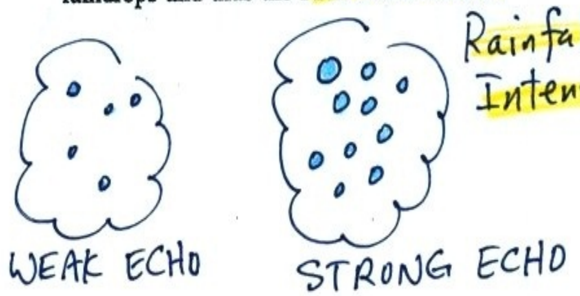
microwave

The radar periodically transmits short bursts of radiation and measures the time interval between transmission and reception of the return echo. This provides an estimate of **RANGE**.

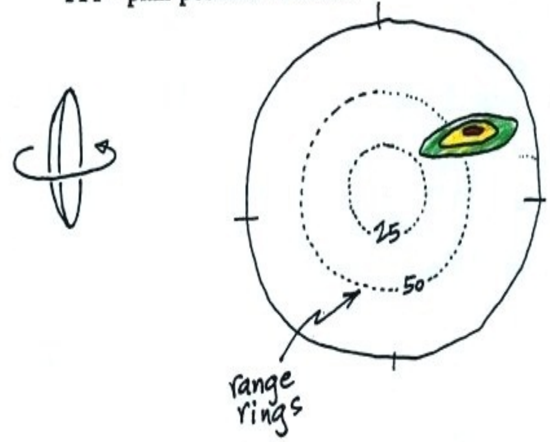
direction

Measurement of return echo intensity can be used to estimate the sizes and number of raindrops and thus the **RAINFALL RATE**.

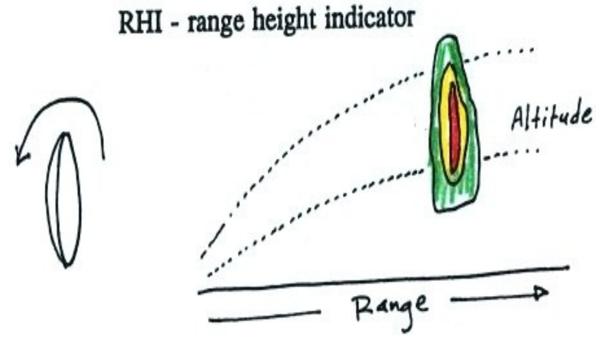
Rainfall Intensity



PPI - plan position indicator



RHI - range height indicator



By detecting changes in the frequency of the reflected signal, a Doppler radar can measure the speed at which precipitation particles are moving toward or away from a radar antenna. By combining data from 2 or more radars (and some complicated computer processing), three-dimensional wind motions inside a cloud can be mapped out.

Doppler radars can detect a rotating thunderstorm updraft (a mesocyclone), which is a thunderstorm capable of producing tornadoes. Small mobile, Doppler radars are being used to measure wind speeds in tornadoes. Police use Doppler radar to measure the speeds of automobiles on the highway moving toward or away from the police car. Dual polarization radar is a research tool used to study the kinds of precipitation particles inside a cloud.