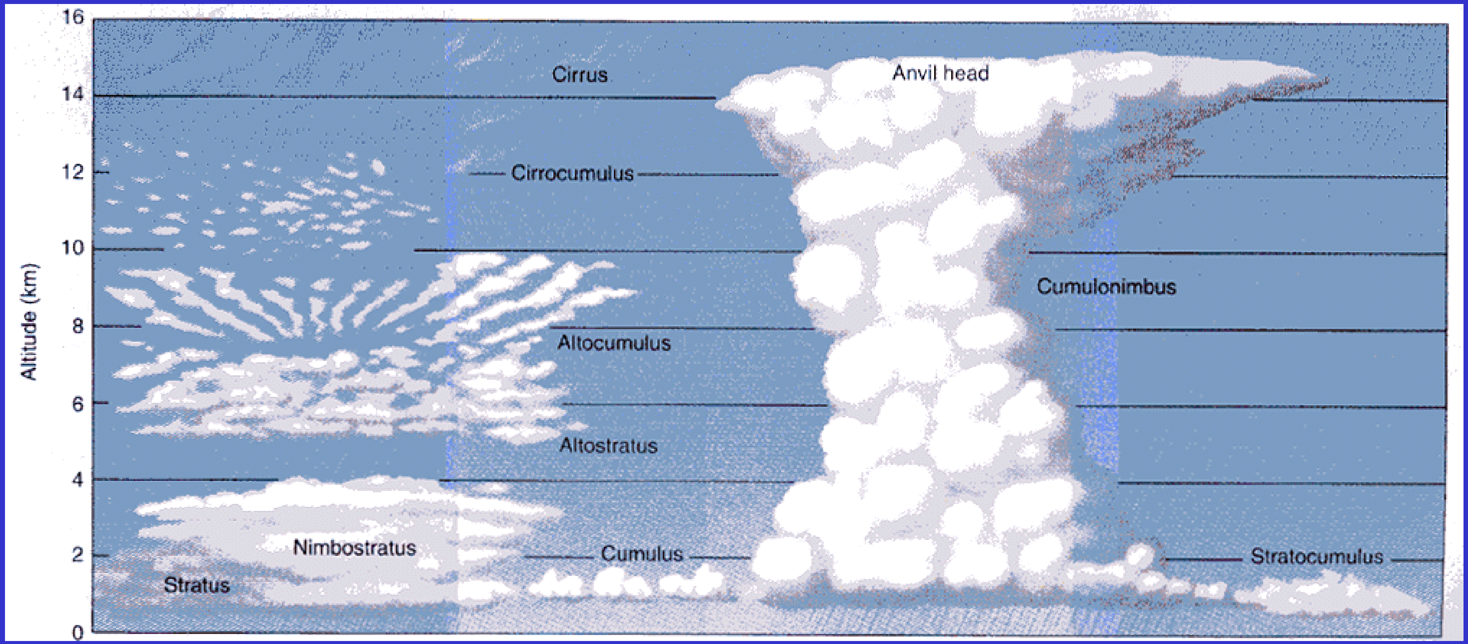
Lecture 7a: Cloud Development and Forms



(from "*The Blue Planet*")

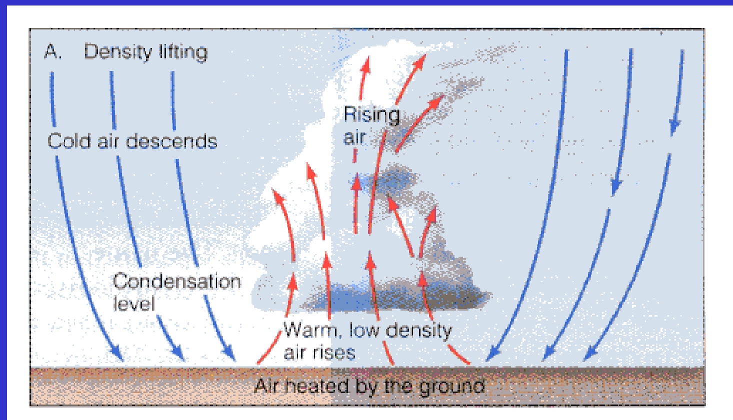
- ❑ Why Clouds Form
- ❑ Cloud Types

Why Clouds Form?

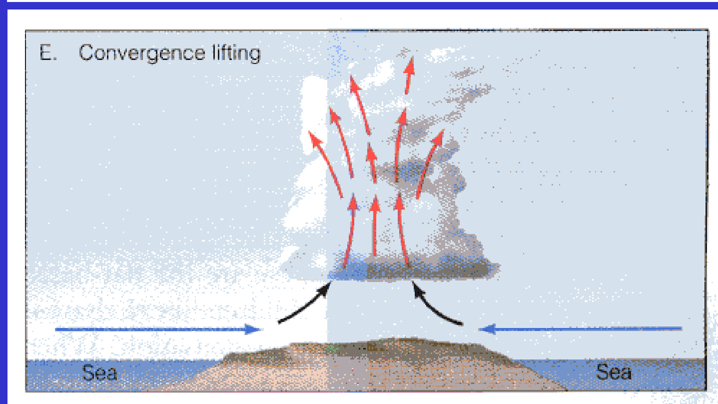
Clouds form when air rises and becomes saturated in response to adiabatic cooling.

Four Ways to Lift Air Upward

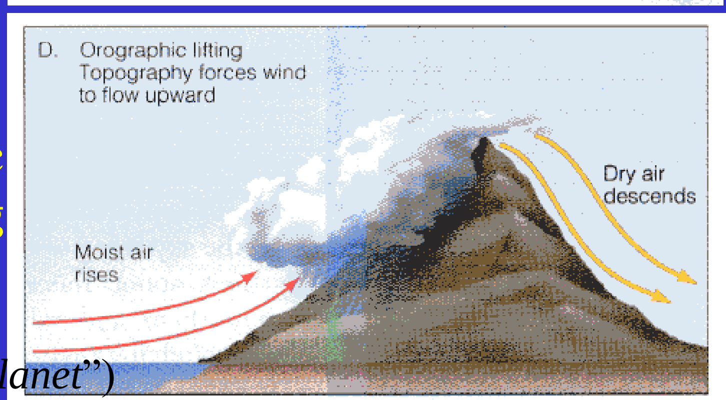
(1) Localized Convection



(2) Convergence Lifting



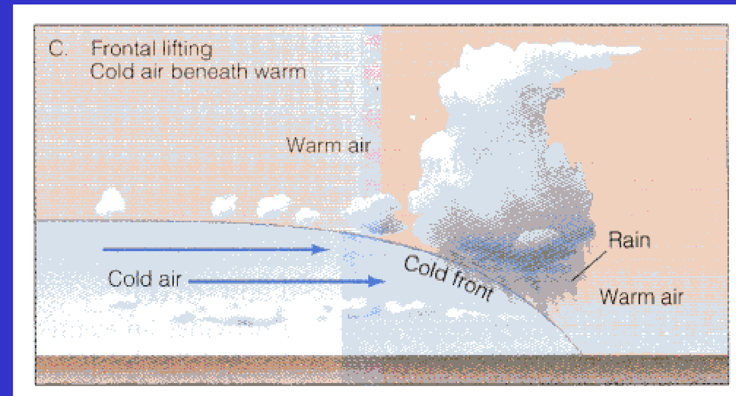
(3) Orographic Lifting



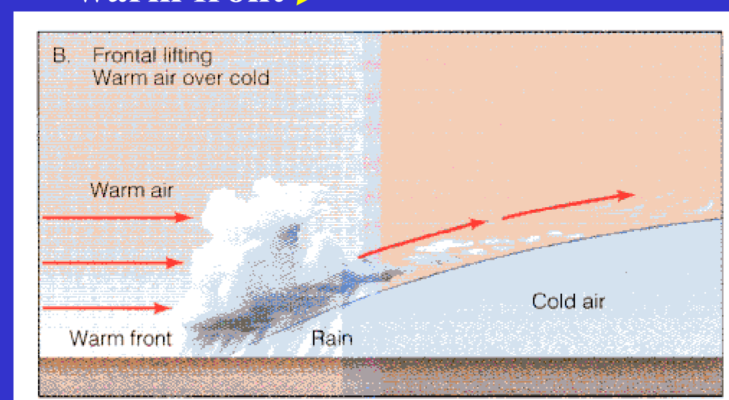
(from "*The Blue Planet*")

(4) Frontal Lifting

cold front



warm front



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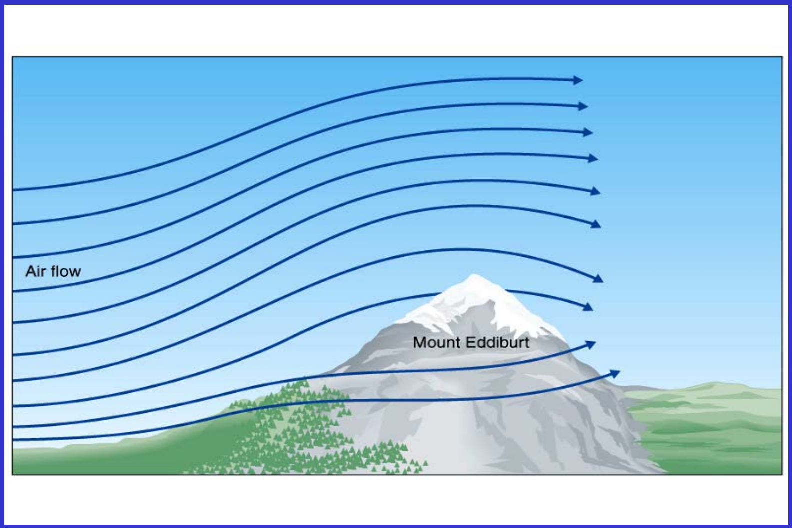
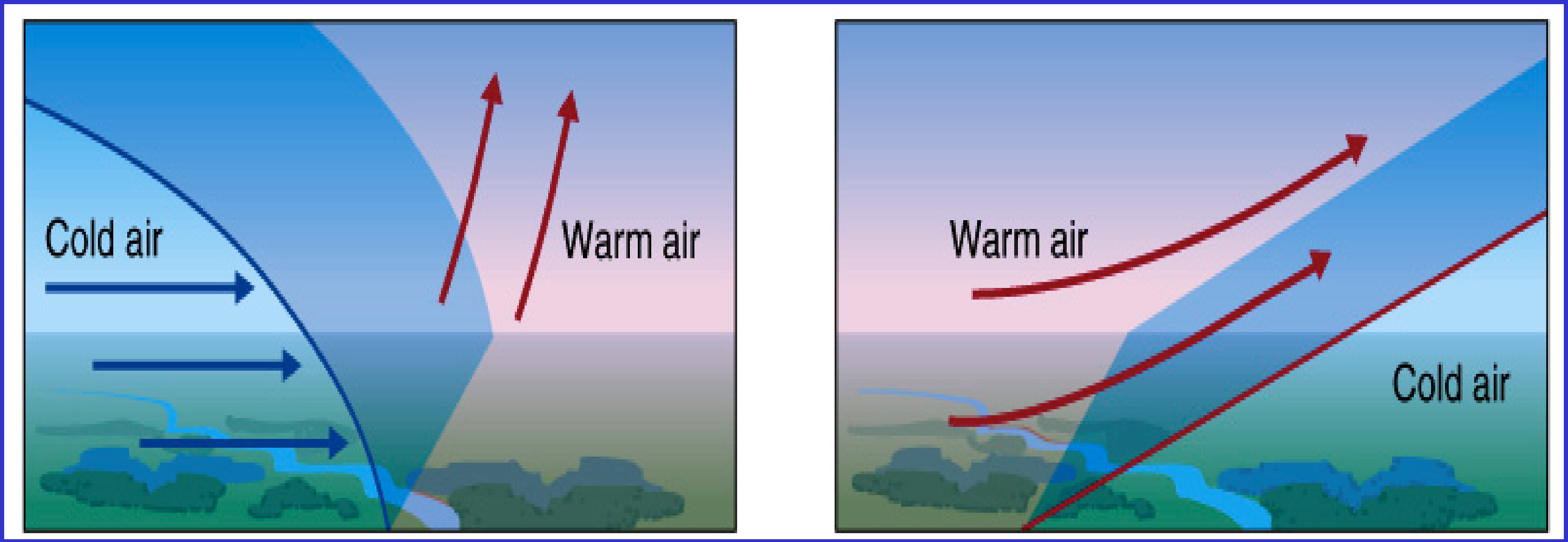
Orographic Lifting



Frontal Lifting



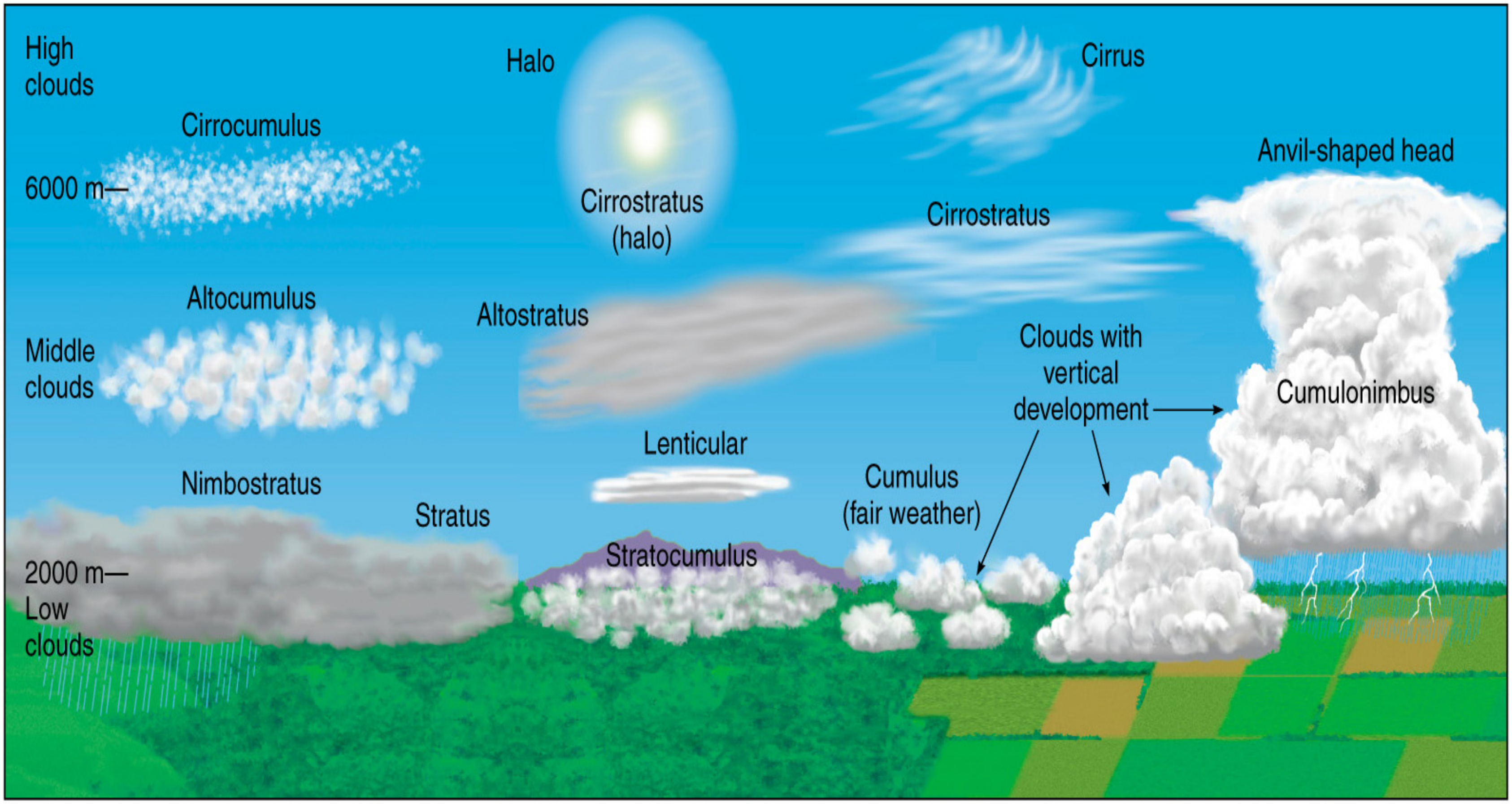
- When boundaries between air of unlike temperatures (fronts) migrate, warmer air is pushed aloft.
- This results in adiabatic cooling and cloud formation.
- ***Cold fronts*** occur when warm air is displaced by cooler air.
- ***Warm fronts*** occur when warm air rises over and displaces cold air.

Cloud Type Based On Properties

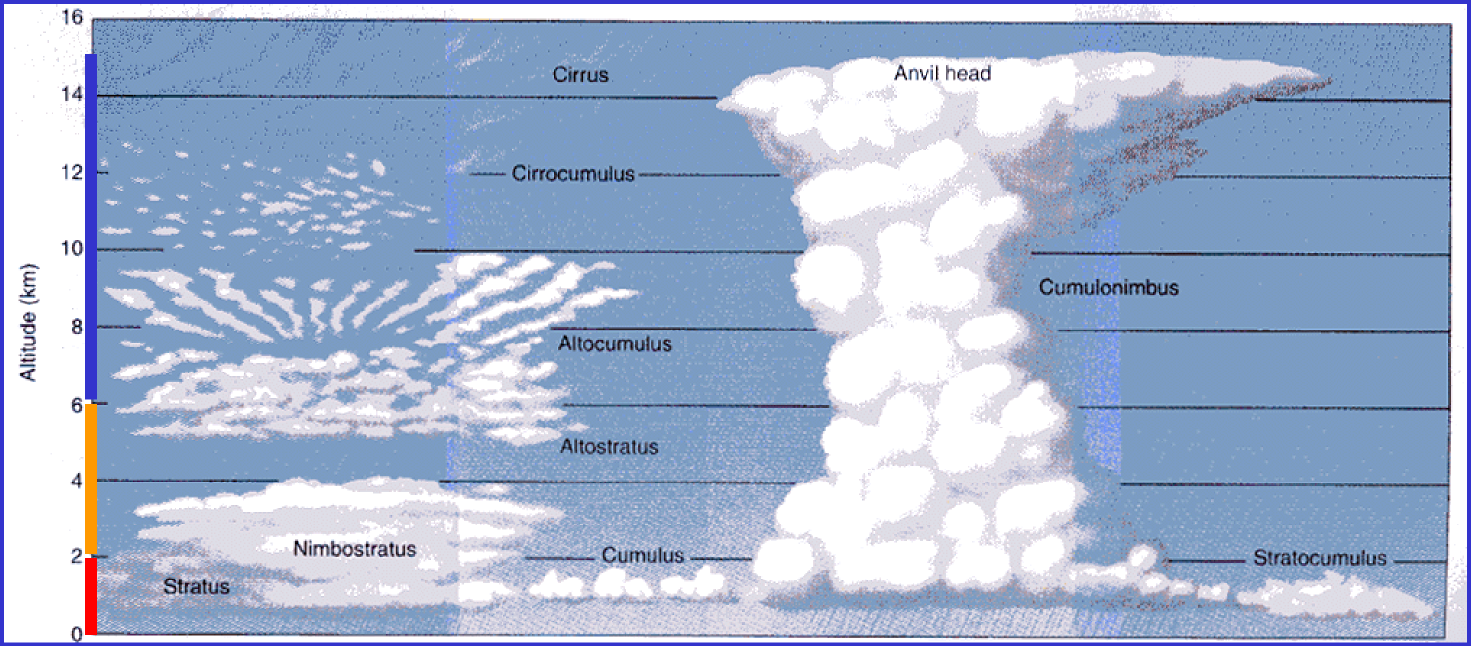
- ❑ Four basic cloud categories:
- ✓ Cirrus --- thin, wispy cloud of ice.
- ✓ Stratus --- layered cloud
- ✓ Cumulus --- clouds having vertical development.
- ✓ Nimbus --- rain-producing cloud

❑ These basic cloud types can be combined to generate ***ten different cloud types***, such as cirrostratus clouds that have the characteristics of cirrus clouds and stratus clouds.

Cloud Types


High
clouds
Halo
Cirrus
Cirrocumulus
6000 m—
Cirrostratus
(halo)
Anvil-shaped head
Cirrostratus
Altocumulus
Altostratus
Middle
clouds
Clouds with
vertical
development
Cumulonimbus
Lenticular
Nimbostratus
Cumulus
(fair weather)
Stratus
Stratocumulus
2000 m—
Low
clouds

Cloud Types Based On Height



If based on ***cloud base*** height, the ten principal cloud types can then grouped into four cloud types:

✓ High clouds -- cirrus, cirrostratus, cirroscumulus.

✓ Middle clouds – altostratus and altocumulus

✓ Low clouds – stratus, stratocumulus, and nimbostartus

✓ Clouds with extensive vertical development – cumulus and cumulonimbus.

(from "*The Blue Planet*")

Cloud Classifications

Table 12.1 Classification of Clouds in the Troposphere by Altitude

Height	Name	Shape and Appearance
High-level clouds Cloud base 6 to 15 km above sea level	Cirrus	Feathery streaks
	Cirrocumulus	Small ripples and delicate puffs
	Cirrostratus	Translucent to transparent sheet, like a veil across the sky
Middle-level clouds Cloud base 2 to 6 km above sea level	Altocumulus	White to dark gray puffs and elongate ripples
	Altostratus	Uniform white to gray sheet covering the sky
Low-level clouds Cloud base below 2 km above sea level	Stratus	Uniform dull gray cover over the sky
	Nimbostratus	Uniform gray cover, rain generally falling
	Stratocumulus	Patches of soft gray; in places patches coalescing to a layer
Clouds with great vertical development Cloud base below 3 km above sea level	Cumulus	Puffy cauliflower shape with flat base
	Cumulonimbus	Large, puffy; white, gray and black; great vertical extent, often with anvil-shaped head

(from “*The Blue Planet*”)

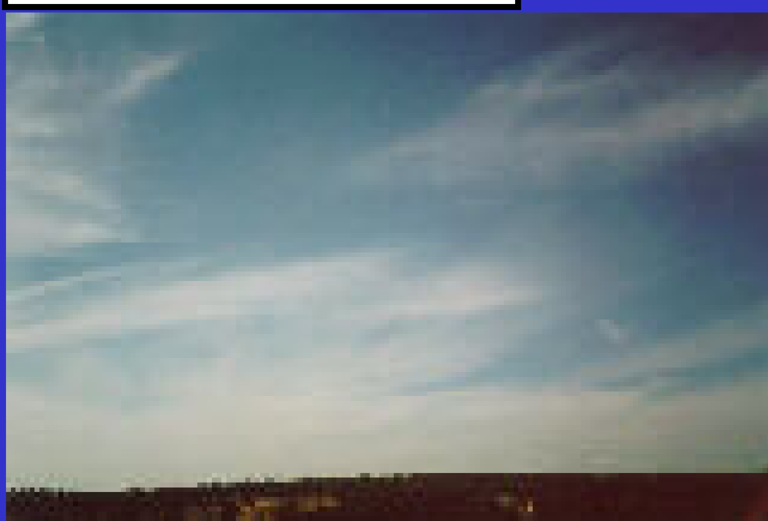
High Clouds

1. Cirrus Clouds

3. Cirrocumulus Clouds

(from Australian Weather Service)

2. Cirrostratus Clouds



- High clouds have low cloud temperature and low water content and consist most of ice crystal.

Middle Clouds

4. Altostratus Clouds

5. Altocumulus Clouds

(from Australian Weather Service)

- Middle clouds are usually composite of liquid droplets.
- They block more sunlight to the surface than the high clouds.

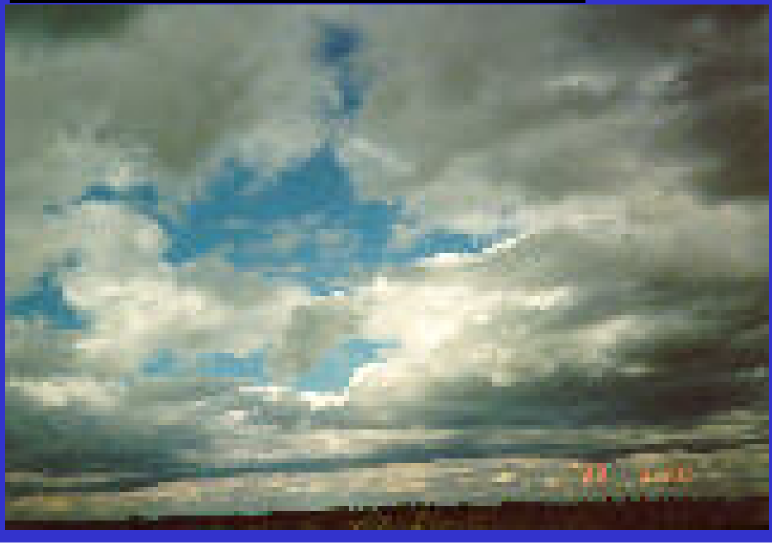
Low Clouds

6. Stratus Clouds

8. Nimbostratus Clouds

(from Australian Weather Service)

7. Stratocumulus Clouds



- ❑ Low, thick, layered clouds with large horizontal extends, which can exceed that of several states.

Clouds With Vertical Development

9. Cumulus Clouds

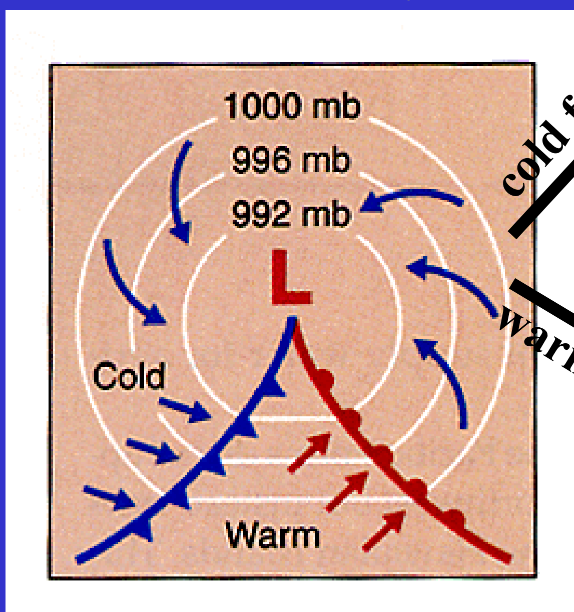
10. Cumulonimbus Clouds

(from Australian Weather Service)

- They are clouds with substantial vertical development and occur when the air is absolute or conditionally unstable.

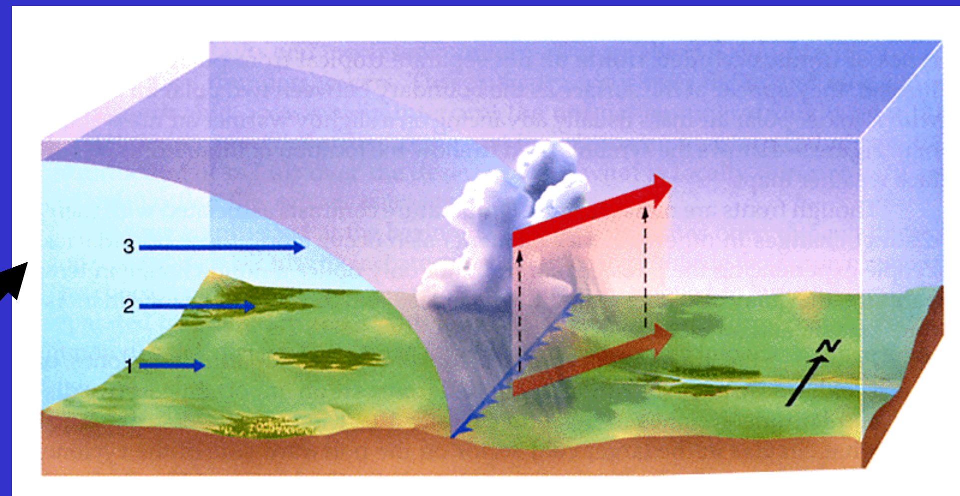
Clouds and Fronts

Mid-Latitude Cyclone

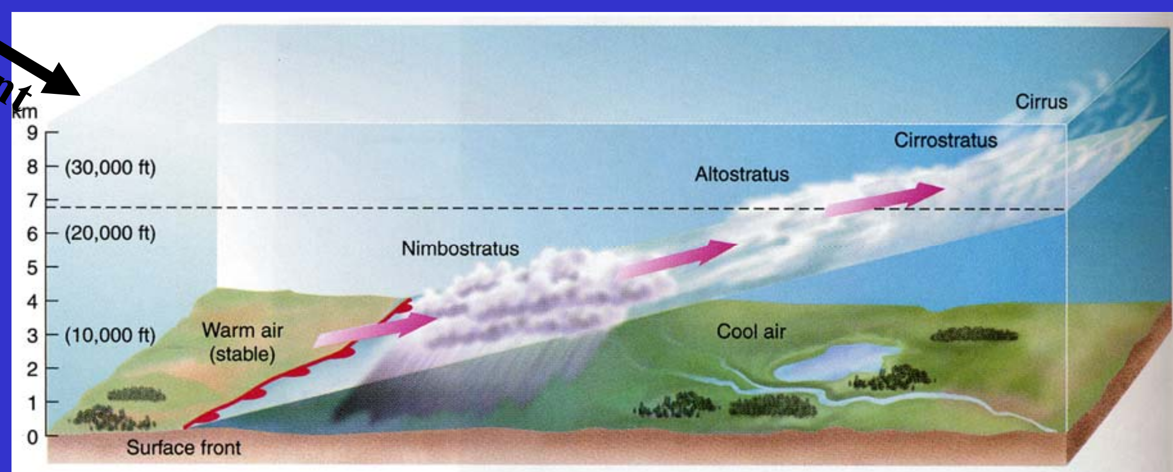


(From *Weather & Climate*)

cold front



warm front



Polar Stratospheric Clouds (PSCs)

(Sweden, January 2000; from NASA website)

- In winter the polar stratosphere is so cold (-80°C or below) that certain trace atmospheric constituents can condense.
- These clouds are called "polar stratospheric clouds" (PSCs).
- The particles that form typically consist of a mixture of water and nitric acid (HNO3).
- The PSCs alter the chemistry of the lower stratosphere in two ways:

  (1) by coupling between the odd nitrogen and chlorine cycles

  (2) by providing surfaces on which heterogeneous reactions can occur.

Lecture 7b: Precipitation Processes

- ❑ Growth of Cloud Droplet
- ❑ Forms of Precipitations
- ❑ Cloud Seeding

Precipitations

"Precipitation is any liquid or solid water particle that falls from the atmosphere and reaches the ground."

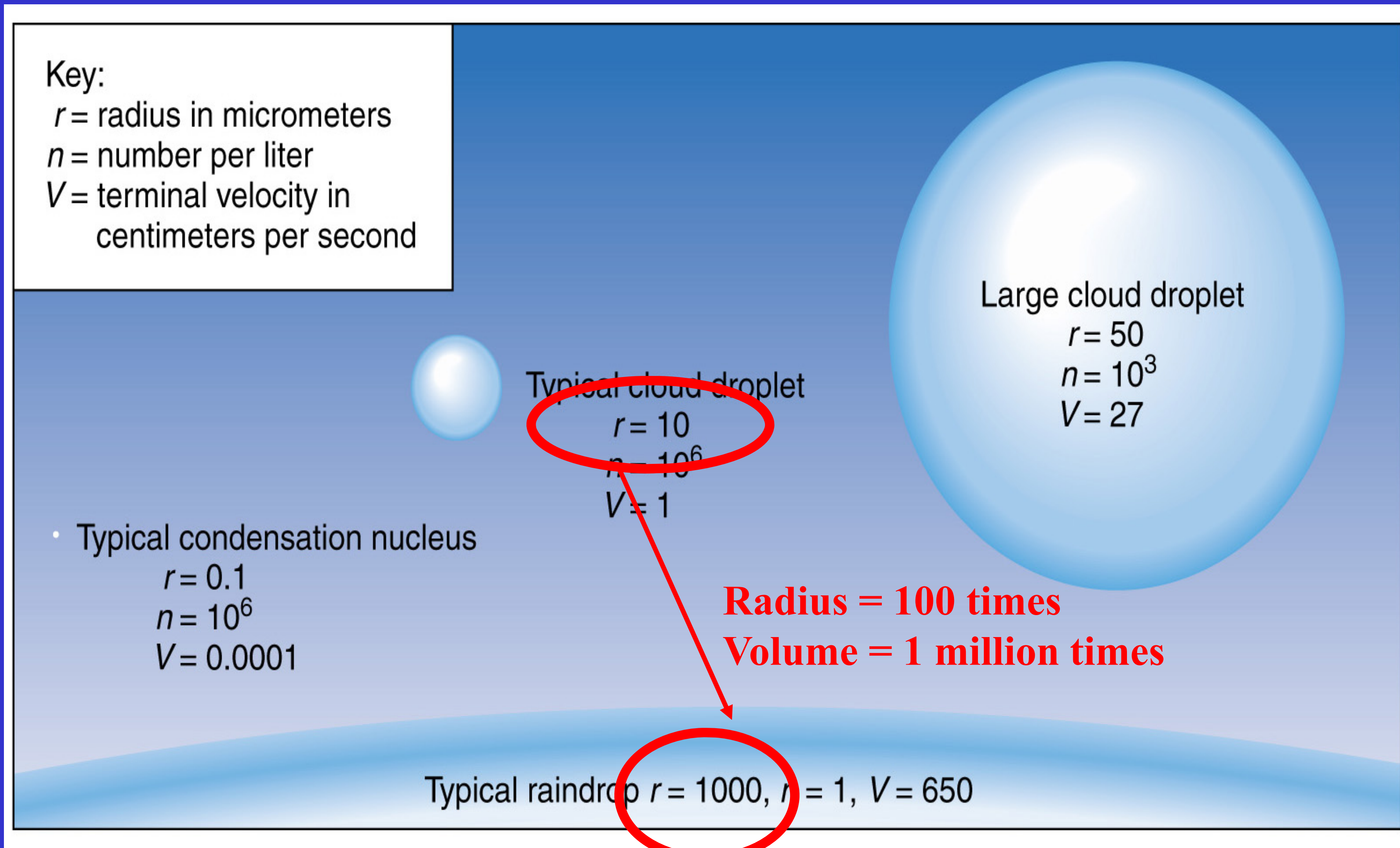
Water Vapor Saturated

↓ Need cloud nuclei

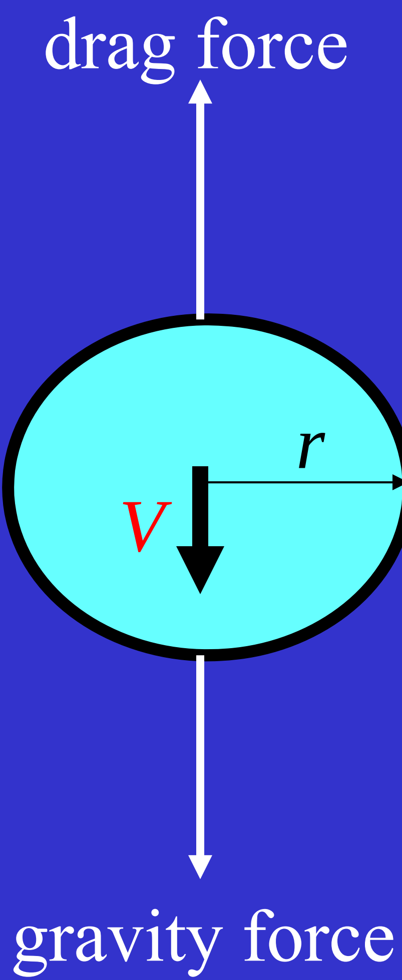
Cloud Droplet formed around Cloud Nuclei

↓ Need to fall down

Precipitation


Key:
r = radius in micrometers
n = number per liter
V = terminal velocity in centimeters per second
Large cloud droplet
r = 50
n = 10^3
V = 27
Typical cloud droplet
r = 10
n = 10^6
V = 1
Typical condensation nucleus
r = 0.1
n = 10^6
V = 0.0001
Radius = 100 times
Volume = 1 million times
Typical raindrop r = 1000, n = 1, V = 650

Terminal Velocity



- Terminal velocity is the constant speed that a falling object has when the gravity force and the drag force applied on the subject reach a balance.
- Terminal velocity depends on the size of the object: small objects fall slowly and large objectives fall quickly.

Raindrops

- Rain droplets have to have large enough falling speed in order to overcome the updraft (that produces the rain) to fall to the ground.
- This means the rain droplets have to ***GROW*** to large enough sizes to become precipitation.

How Raindrop Grows?

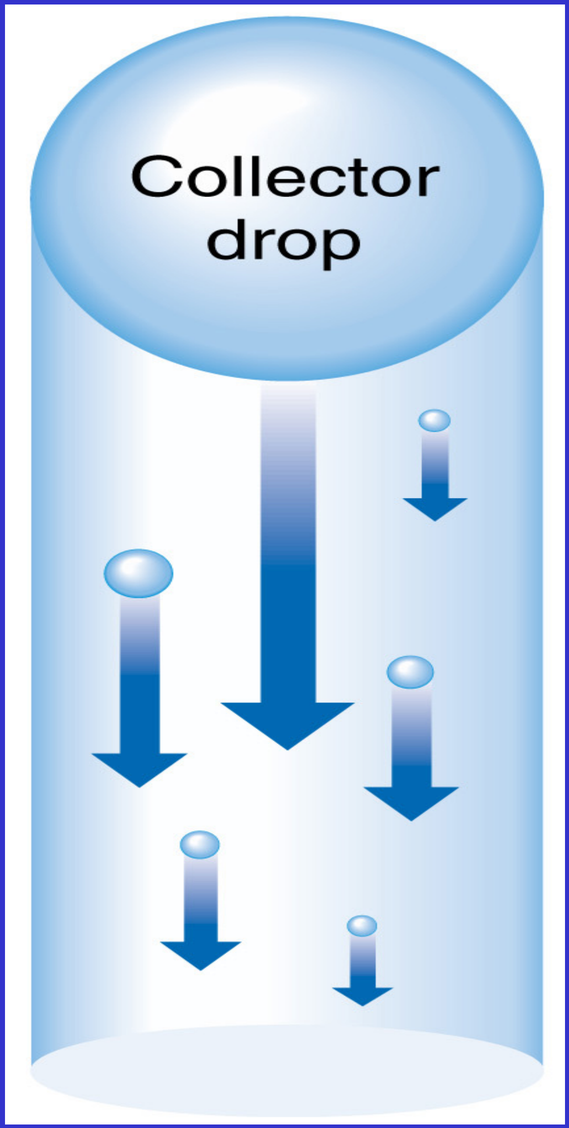
- ❑ Growth by Condensation (too small)
- ❑ Growth in Warm Clouds: Collision-Coalescence Process
- ❑ Growth in Cool and Cold Clouds: Bergeron Process, Riming (aka Accretion) and Aggregation

Growth by Condensation

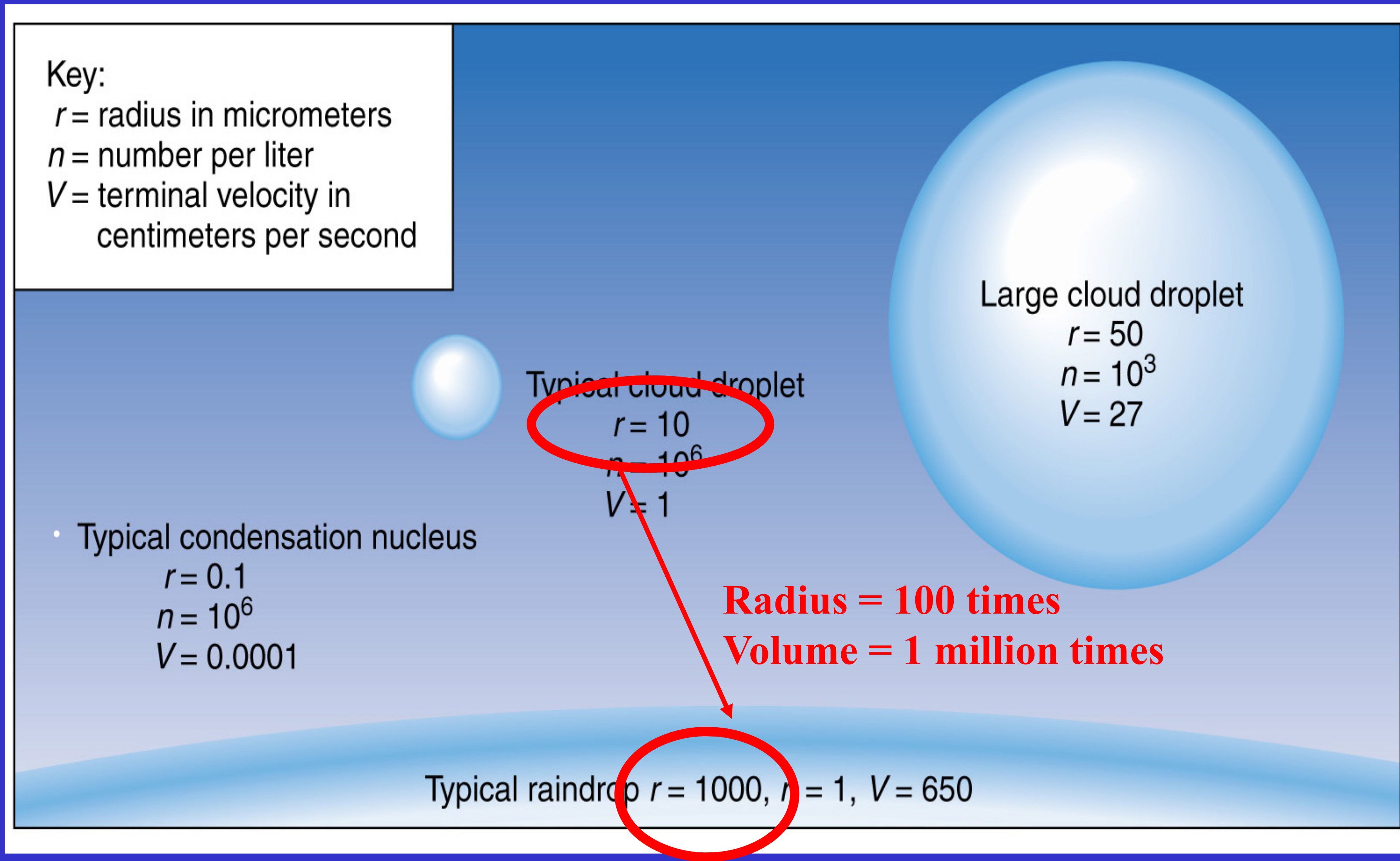
- ❑ Condensation about condensation nuclei initially forms most cloud drops.

- ❑ Insufficient process to generate precipitation.

Growth in Warm Clouds



- Most clouds formed in the Tropics, and many in the middle latitudes, are warm clouds.
- Those clouds have temperatures greater than 0ºC throughout.
- The Collision-coalescence process generates precipitation.
- This process depends on the differing fall speeds of different-sized droplets.
- It begins with large collector drops which have high terminal velocities.


Key:
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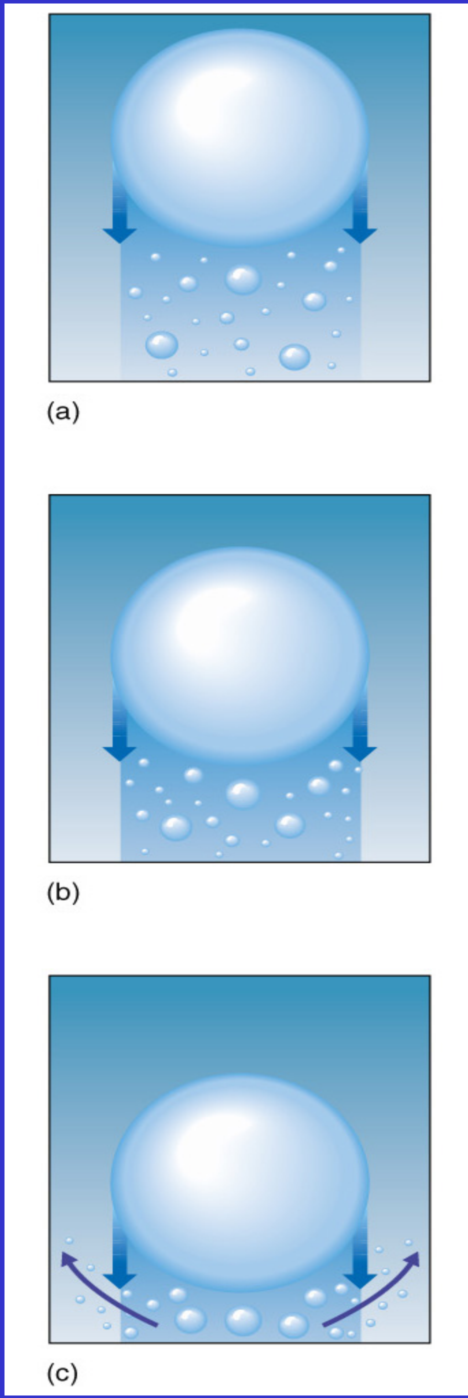


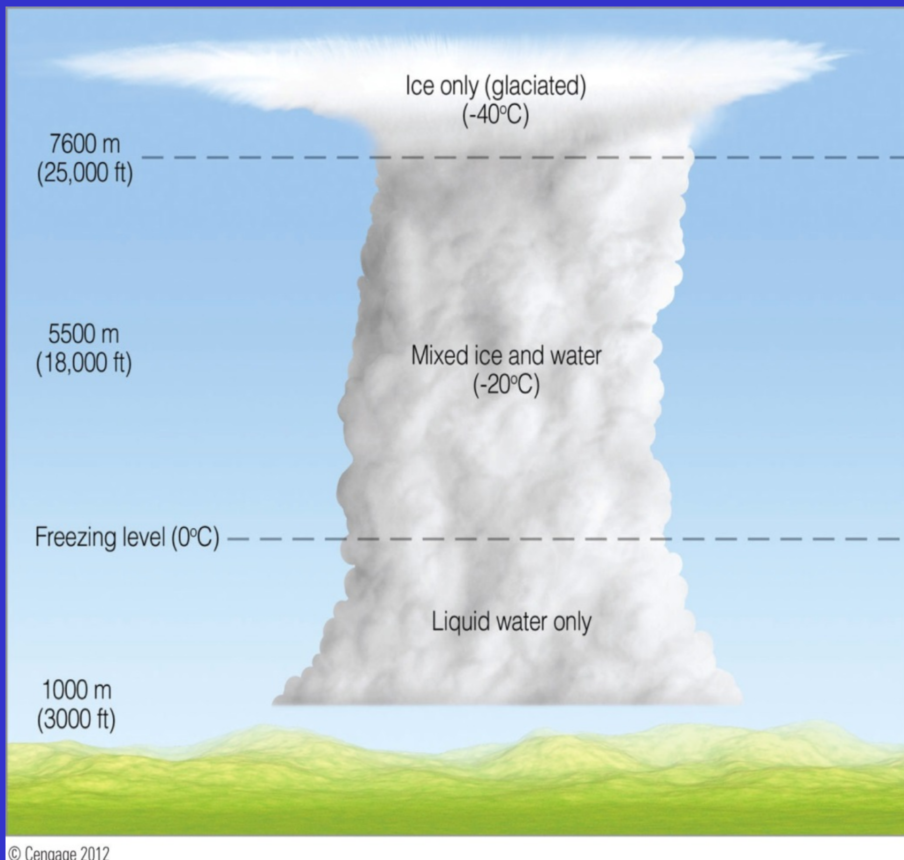
Collision

- Collector drops collide with smaller drops.
- Due to compressed air beneath falling drop, there is an inverse relationship between collector drop size and collision efficiency.
- Collisions typically occur between a collector and fairly large cloud drops.
- Smaller drops are pushed aside.
- Collision is more effective for the droplets that are not very much smaller than the collect droplet.

Coalescence

- When collisions occur, drops either bounce apart or coalesce into one larger drop.
- Coalescence efficiency is very high indicating that most collisions result in coalescence.
- Collision and coalescence together form the primary mechanism for precipitation in the tropics, where warm clouds dominate.

Cool and Cold Clouds



- A portion of most mid-latitude clouds have temperatures below the melting point of ice.
- Cold clouds are referred to those have temperature below 0ºC throughout and consist entirely of ice crystals, supercooled droplets, or a mixture of two.
- Cool clouds are referred to those have temperatures above 0ºC in the lower reaches and subfreezing condition above.

Supercooled Water

- Ice melts at 0°C, but water does not necessary freeze to ice at 0°C.
- Ice nuclei is needed to help water to get frozen.
- Certain microscopic particles, such as clay, organic particles, or bacteria, have a crystalline structure similar to ice that can allow water molecular to attach to and to build an ice lattice.
- Without enough ice nuclei, water can exist event its temperature is below between 0°C and -40°C, which are called "supercooled water".
- Supercooled water can result in freezing precipitation when they come in contact with a surface that has a temperature below 0°C.

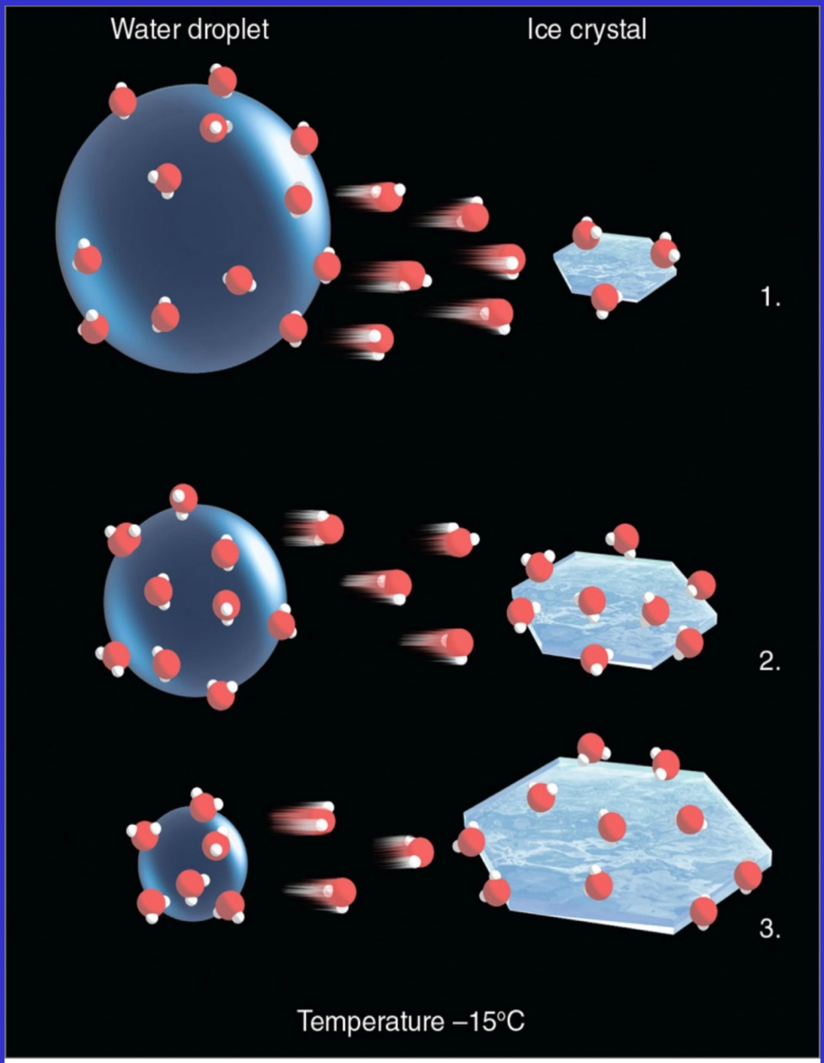
An Example of Cool and Cold Cloud

Cumulonimbus clouds contain
both ice (top, fuzzy cloud margins),
liquid drops (bottom, sharp margins)
and a mix of ice and liquid (middle)

Growth in Cool and Cold Clouds

- Cool month mid-latitude and high latitude clouds are classified as cool clouds as average temperatures are usually below freezing.
- Clouds may be composed of (1) Liquid water, (2) Supercooled water, and/or (3) Ice.
- Coexistence of ice and supercooled water is critical to the creation of cool cloud precipitation - the Bergeron Process.

Bergeron Process



- Saturation vapor pressure of ice is less than that of supercooled water and water vapor.
- During coexistence, water will sublimate directly onto ice.
- Ice crystals grow rapidly at the expense of supercooled drops.
- The ice crystal becomes heavy enough to fall, then the riming and aggregation processes begin.

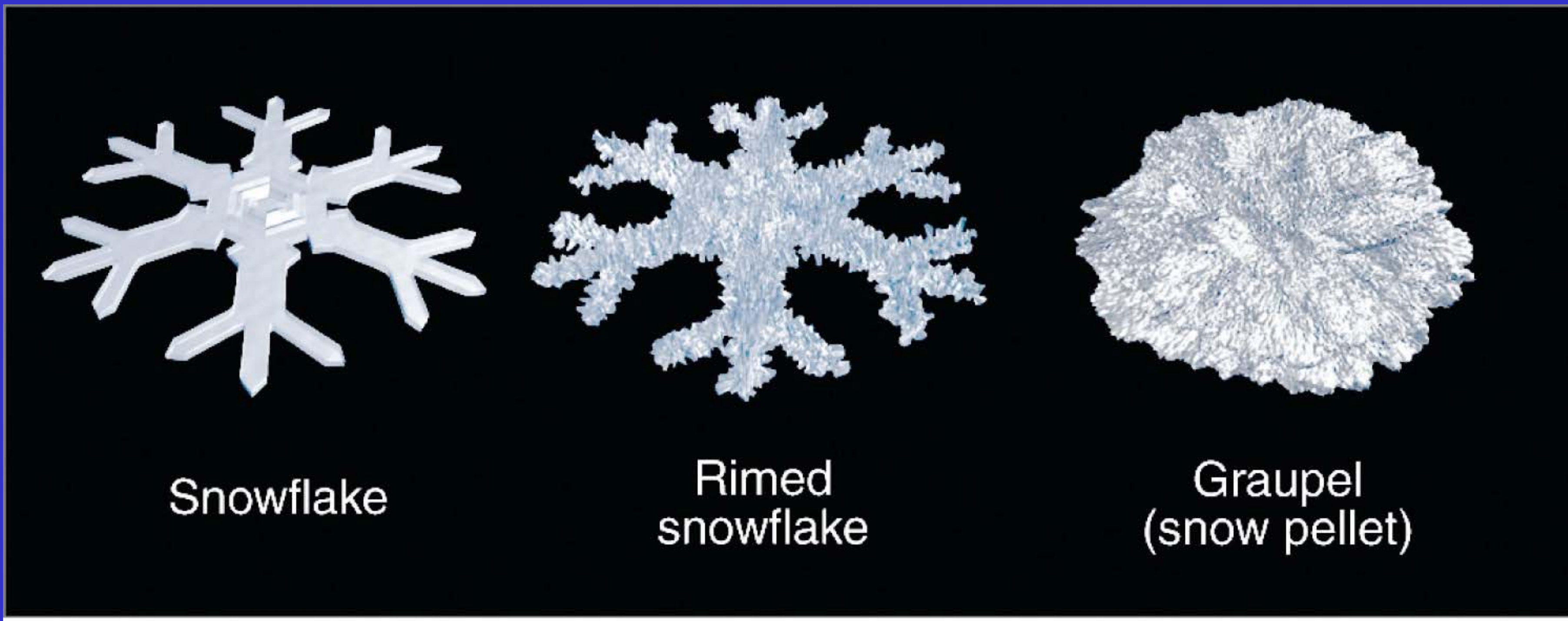
Riming and Aggregation

(a) Falling ice crystals may freeze supercooled droplets on contact (accretion), producing larger ice particles.

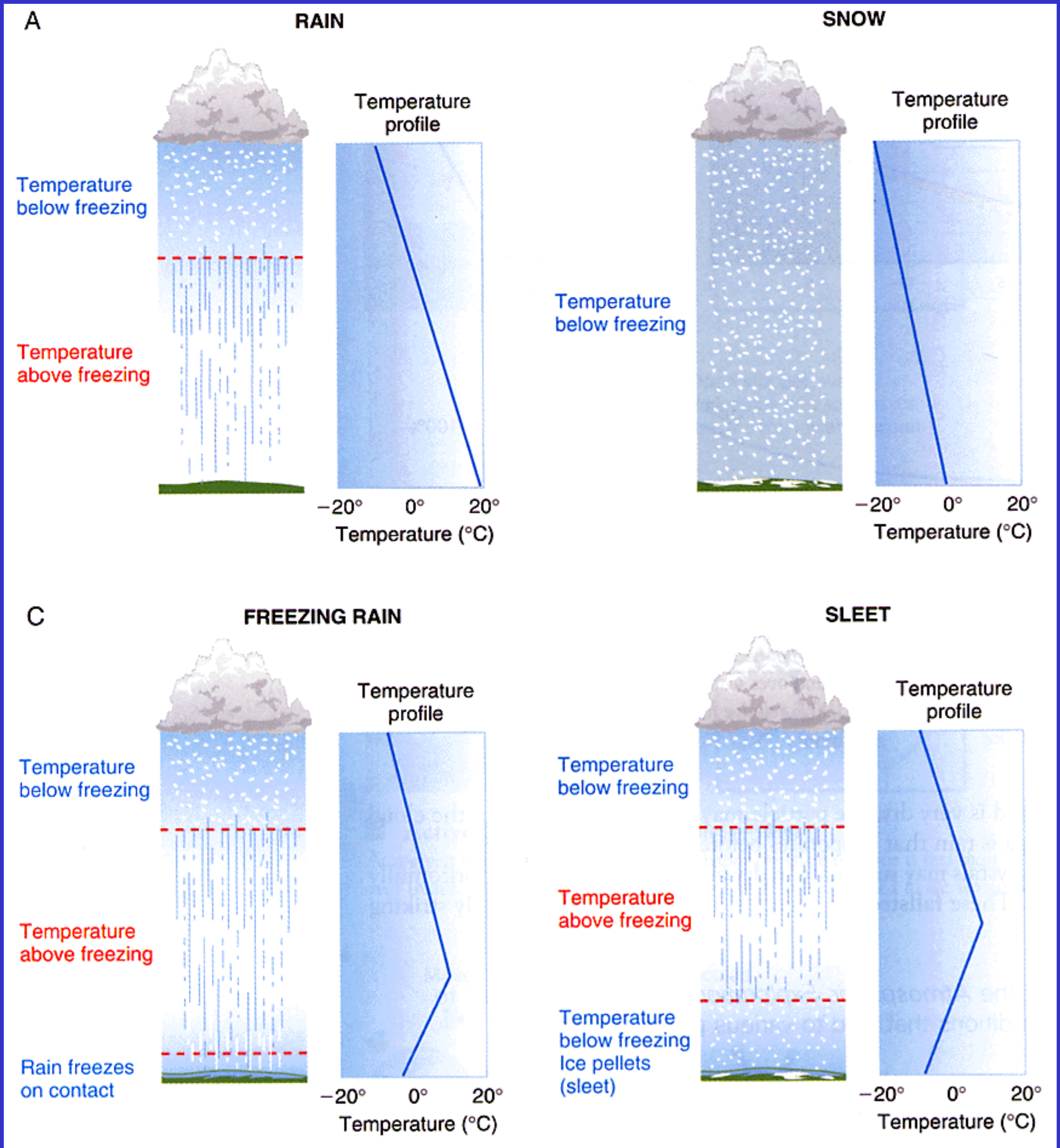
(b) Falling ice particles may collide and fracture into many tiny (secondary) ice particles.

(c) Falling ice crystals may collide and stick to other ice crystals (aggregation), producing snowflakes.

- Collisions between falling crystals and drops causes growth through ***riming*** and ***aggregation.***
- ***Riming (accretion)***: liquid water freezing onto ice crystals producing rapid growth ➔ producing graupels.
- ***Aggregation***: the joining of multiple ice crystals through the bonding of surface water builds ice crystals to the point of overcoming updrafts ➔ producing snowflakes.
- Collision combined with riming and aggregation allow formation of precipitation within 1/2 hour of initial formation.

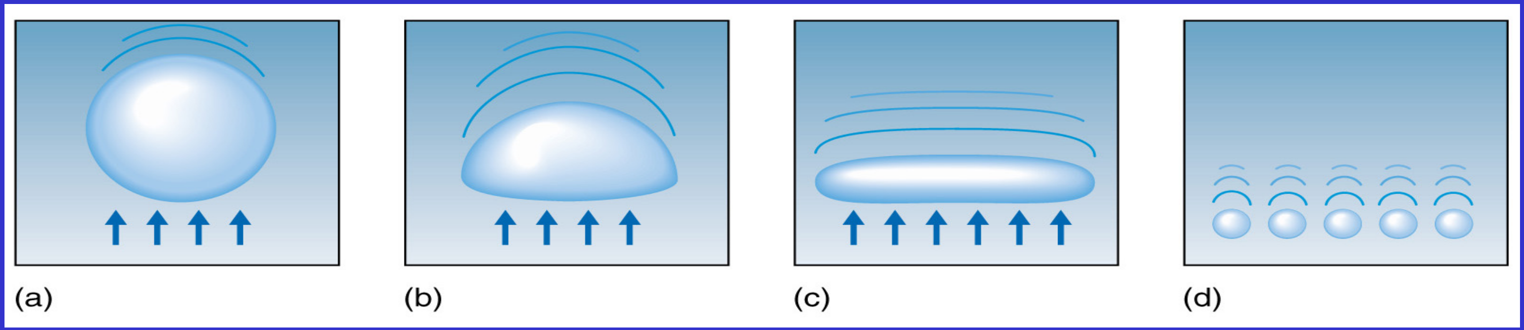

Snowflake
Rimed snowflake
Graupel (snow pellet)

Forms of Precipitation



- ***Rain***
- ***Snow***
- ***Sleet***
- ***Freezing Rain***
- ***Graupel and Hail***

Rain



- ***Rain*** is associated with warm clouds exclusively and cool clouds when surface temperatures are above freezing
- ***Rainshowers*** are episodic precipitation events associated with convective activity and cumulus clouds
  - Drops tend to be large and widely spaced to begin, then smaller drops become more prolific
- ***Raindrop Shape*** begins as spherical
  - As frictional drag increases, changes to a mushroom shape
  - Drops eventually flatten
  - Drops split when frictional drag overcomes the surface tension of water
  - Splitting ensures a maximum drop size of about 5 mm and the continuation of the collision-coalescence process

Snow

(from Meteorology: Understanding the Atmosphere)

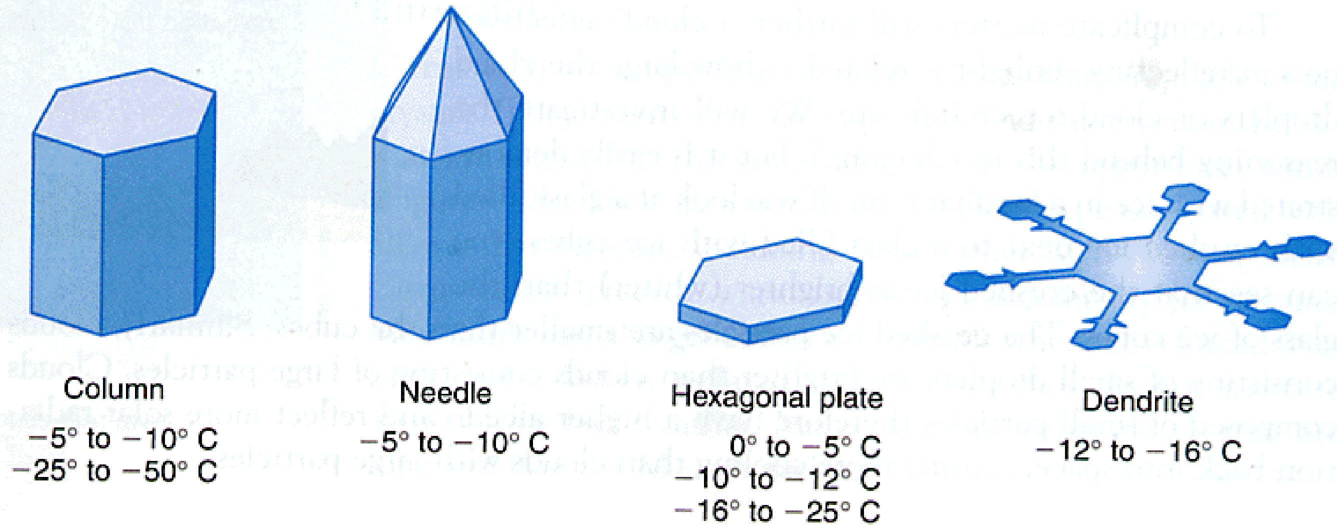
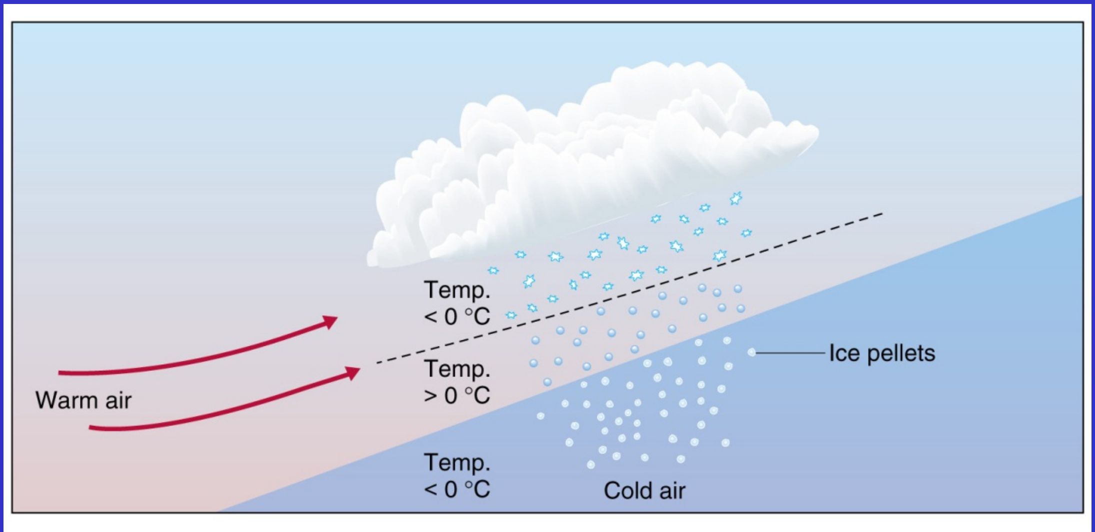


Figure 4.30
The four basic ice crystal habits are column, needle, hexagonal plate, and dendrite. The shape in which an ice particle grows depends on the temperature of its environment. Try this out for yourself by using the "Growing a Snowflake" learning applet.

- Snowflakes have a wide assortment of shapes and sizes depending on moisture content and temperature of the air.
- Snowfall distribution in North America is related to north-south alignment of mountain ranges and the presence of the Great Lakes.
- Lake effect: snows develop as the warm lake waters evaporate into cold air.

Sleet and Freezing Rain



- *Sleet* begins as ice crystals which melt into rain through a mid-level inversion before solidifying in colder near surface air
- *Freezing Rain* forms similarly to sleet, however, the drop does not completely solidify before striking the surface
- When sleet hits the surface, it bounces and does not coat objects with a sheet of ice, as feezing rain does.

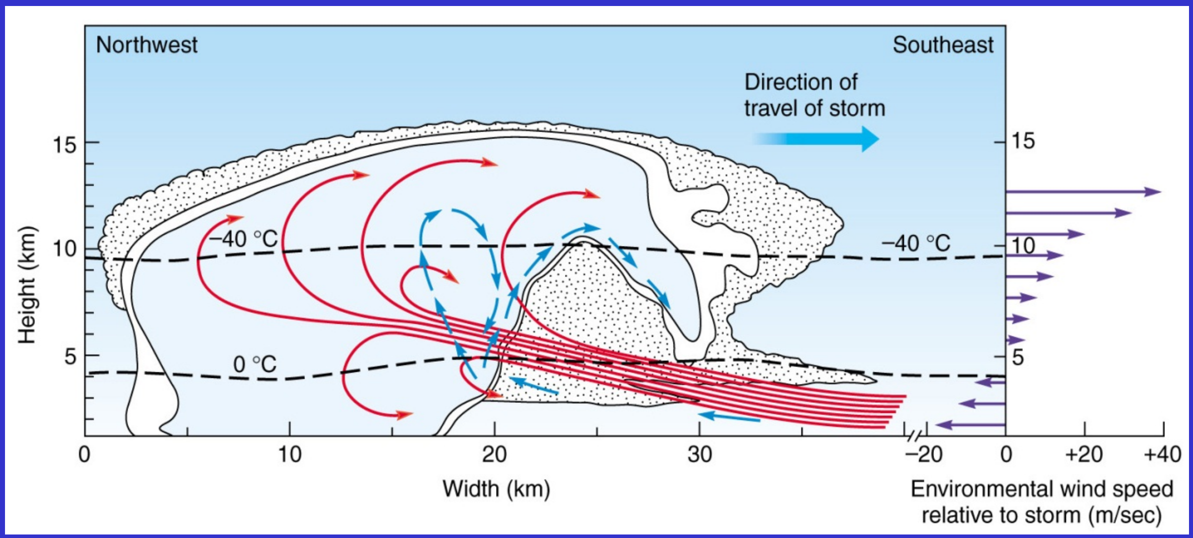
Freezing Rain and Sleet

(Photographer: Lee Anne Willson)

Graupel and Hail

- ***Graupel*** are ice crystals that undergo extensive riming
  - Lose six sided shape and smooth out
  - Either falls to the ground or provides a nucleus for hail

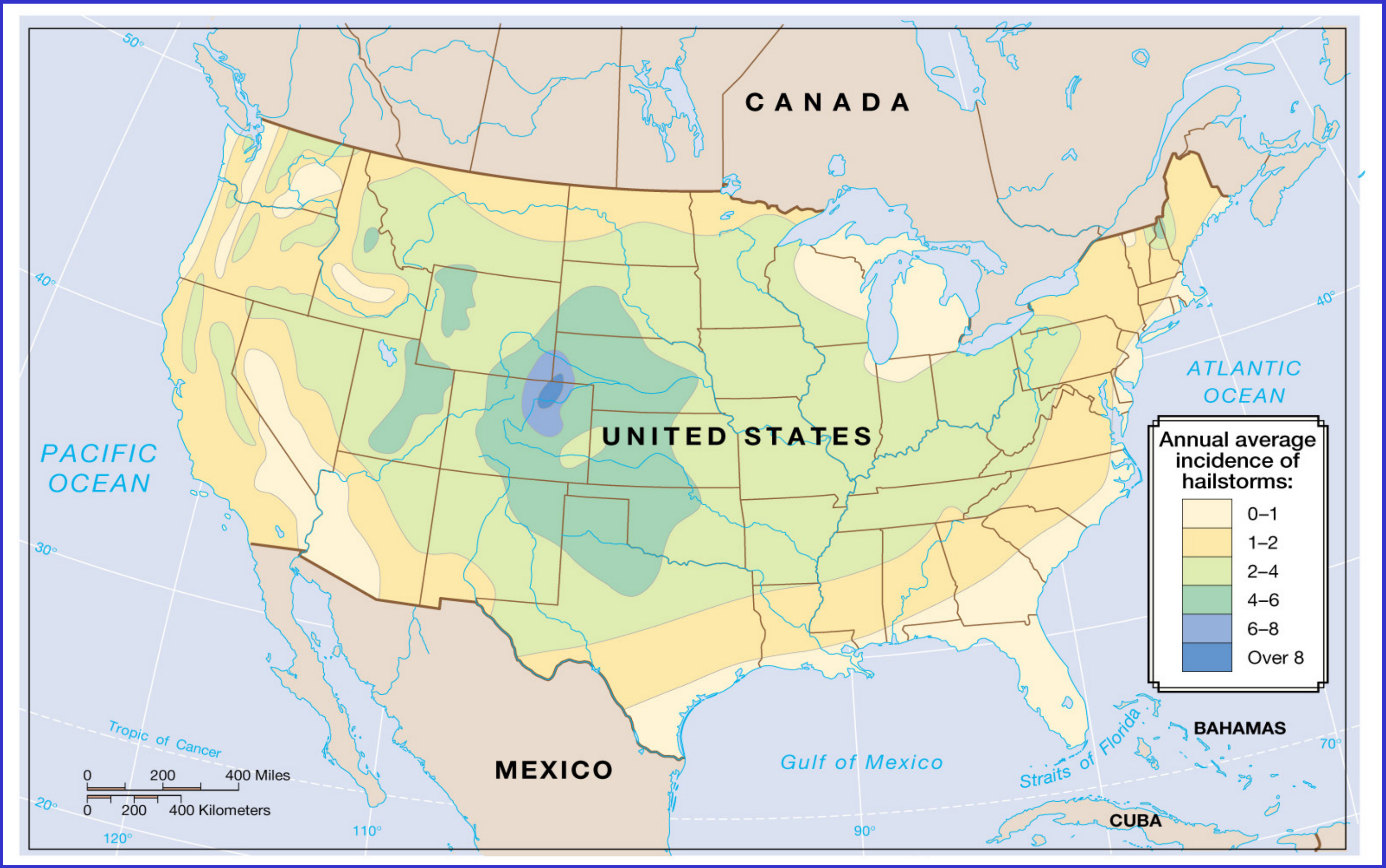
- ***Hail*** forms as concentric layers of ice build around graupel
  - Formed as graupel is carried aloft in updrafts
  - At high altitudes, water accreting to graupel freezes, forming a layer
  - Hail falls but is eventually carried aloft again by an updraft where the process repeats
  - The ultimate size of the hailstone is determined by the intensity of the updraft.
  - Great Plains = highest frequency of hail events



Hail Formation

Concentric layers of ice
in hail indicate the cyclical
hailstone formation process

Hail Frequency in the U.S.



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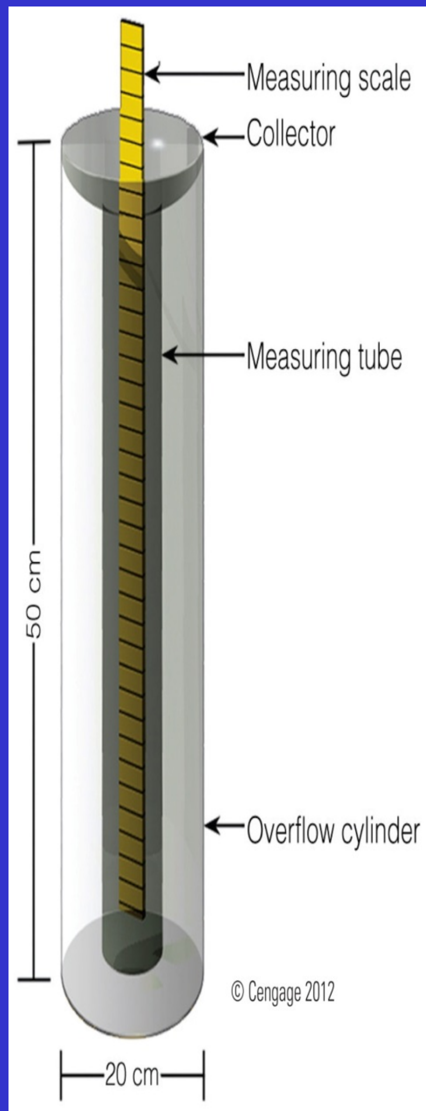
Cloud Seeding

- The objective is to convert some of the supercooled droplets in a cool clouds to ice and cause precipitation by the Bergeron process.
- Two primary methods are used to trigger the precipitation process.
- Dry ice is used to lower cloud temperature to a freezing point in order to stimulate ice crystal production leading to the Bergeron process.
- Silver iodide initiates the Bergeron process by directly acting as freezing nuclei.
- Under ideal conditions, seeding may enhance precipitation by about 10%.

Standard Rain Gauge

(a)

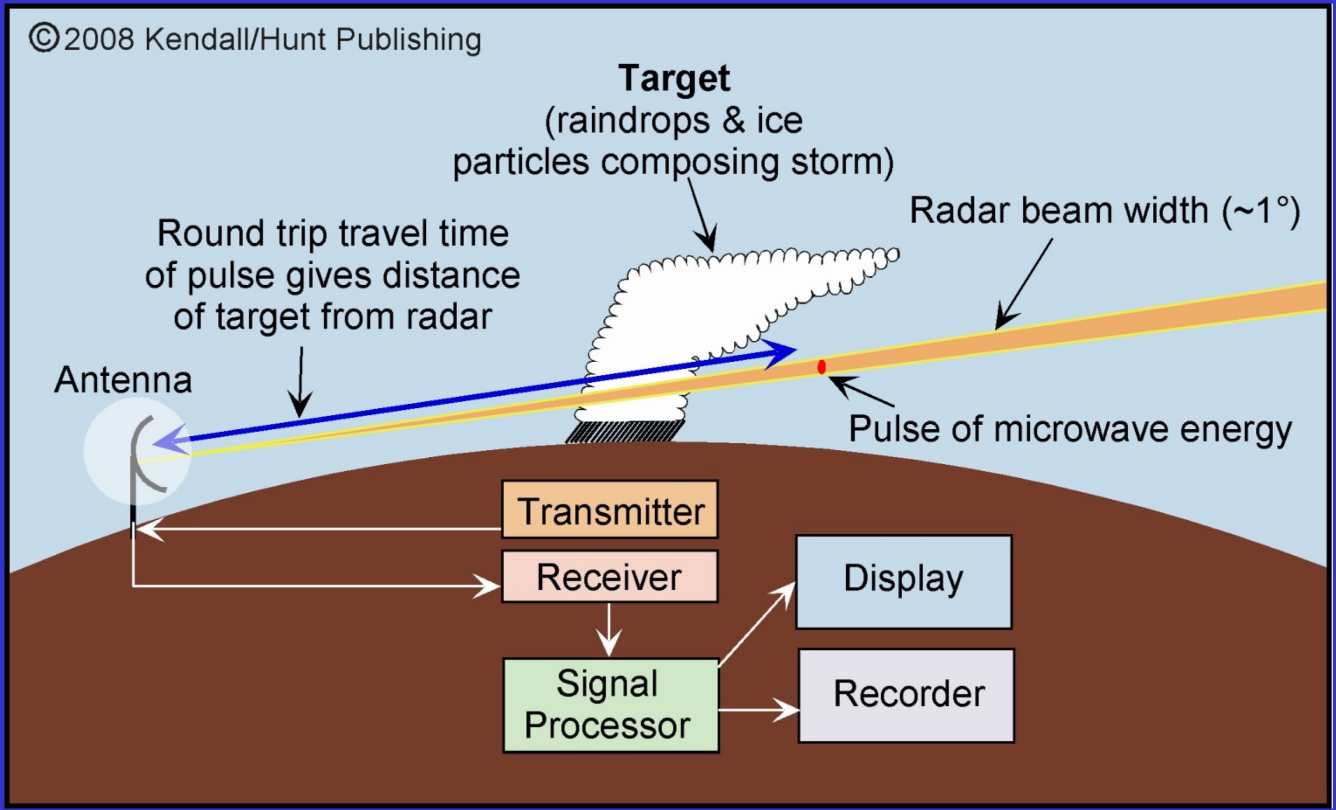


- Standard ***rain gages***, with a 20.3 cm (8”) collected surface and 1/10 area collector are used to measure liquid precipitation
- Depth of water level conveys a tenfold increase in total precipitation
- So 10 inches of water in the tube would be measured as 1 inch of rainfall.

Weighing-type Rain Gauge

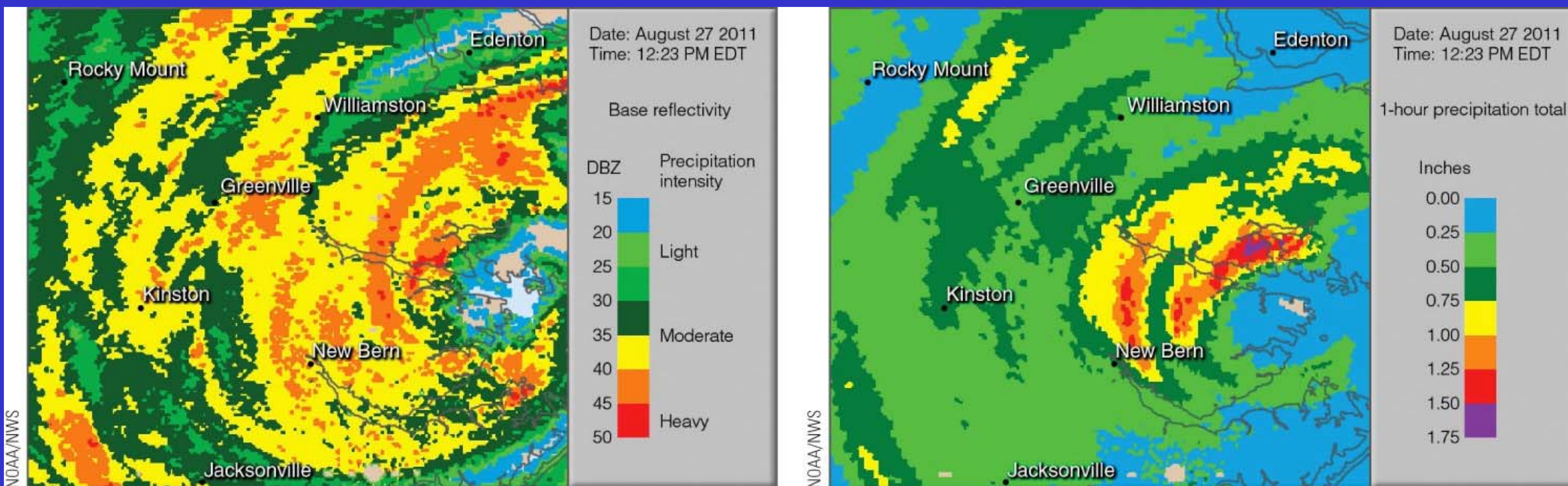
- Remote recording of precipitation can also be made with a weighting-type rain gauge.
- Precipitation is caught in a cylinder and accumulates in a bucket.
- The bucket sits on a sensitive weighting platform.
- The weight is translated into inches of precipitation.

Radar



- Weather radars are used to monitor precipitation.
- Radars send out microwave signals in a narrow beam from it transmitter in a very short time (about 1 millionth of a second).

- When microwaves encounter raindrops and hailstones, some of the energy is scattered back to the radar, whose the microwave echo is received.
- Based on the time between the microwave is transmitted and received, speed of light, antenna angle, radars can find the locations of rain in space



(a) Precipitation intensity (reflectivity)

(b) Precipitation 1-hour estimated total

Figure 7-35 p193

Measuring Snow

- ❑ Rain gages are inadequate for measuring frozen precipitation.
- ❑ Measurements of accumulated snow are used.
- ❑ Water equivalent of snow, a 10 to 1 ratio is assumed (i.e., 10 inches of snow will melt down to about 1 inch of water).
- ❑ Automated snow pillows are common in many locations.
- ❑ Detect snow weight and convert directly to water equivalent.