



Forms of Condensation & Precipitation

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Forms of Condensation & Precipitation

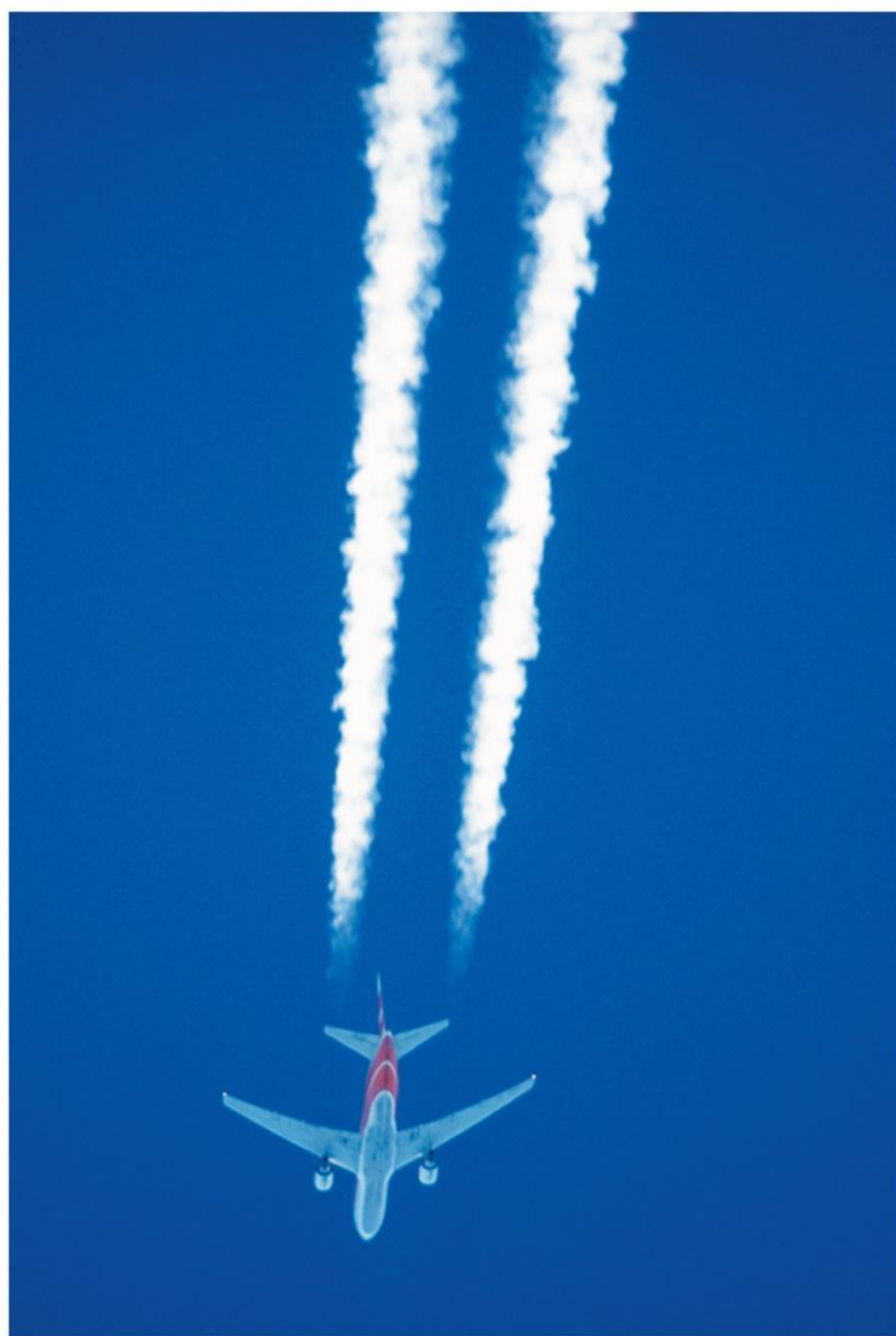
1. Condensation occurs when water changes from vapor to liquid, to produce dew, fog or clouds
2. The air must be **saturated**
3. There must be a **surface** on which condensation can occur
e.g. blades of grass (dew) and condensation nuclei

Forms of Condensation & Precipitation - 2

1. **Condensation nuclei** - microscopic dust particles, smoke, salt particles
2. Need condensation nuclei in order to get condensation when RH is about 100%
3. The most effective nuclei are **hygroscopic** (water absorbent) –
e.g., crystals of sulfates & nitrates
4. Cloud formation depends on **adiabatic** cooling as a parcel of air ascends
(adiabatic = no heat added or lost)

Condensation Trails (aircraft contrails)

1. Consist of ice crystals
2. Form above 9 km, where the air temperature is -50°C
3. Engine exhausts contain hot humid air and condensation nuclei such as sulfates
4. Trails last longer if the air is nearly saturated, and there are no strong winds



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Clouds

1. **Clouds are** visible aggregates of minute droplets of water or tiny crystals of ice
2. **Cloud classification by form :**
 1. cirrus,
 2. cumulus,
 3. stratus
3. **Cloud classification by height:**
 1. **high** (bases above 6000 m),
 2. **middle** (2000 to 6000 m),
 3. **low** (below 2000m),
 4. clouds of **vertical development** (more than one height range)

Clouds - 2

1. *High clouds:*

1. cirrus,
 2. cirrostratus,
 3. cirrocumulus;
- not usually precipitation makers

4. *Clouds of vertical development :*

1. Cumulus (fair weather),
2. Cumulonimbus (storm clouds)

2. *Middle clouds:*

1. altocumulus,
2. altostratus

5. *Lenticular clouds* often form on leeward side of mountains

3. *Low clouds:*

1. stratus,
2. stratocumulus,
3. nimbostratus (rain clouds)

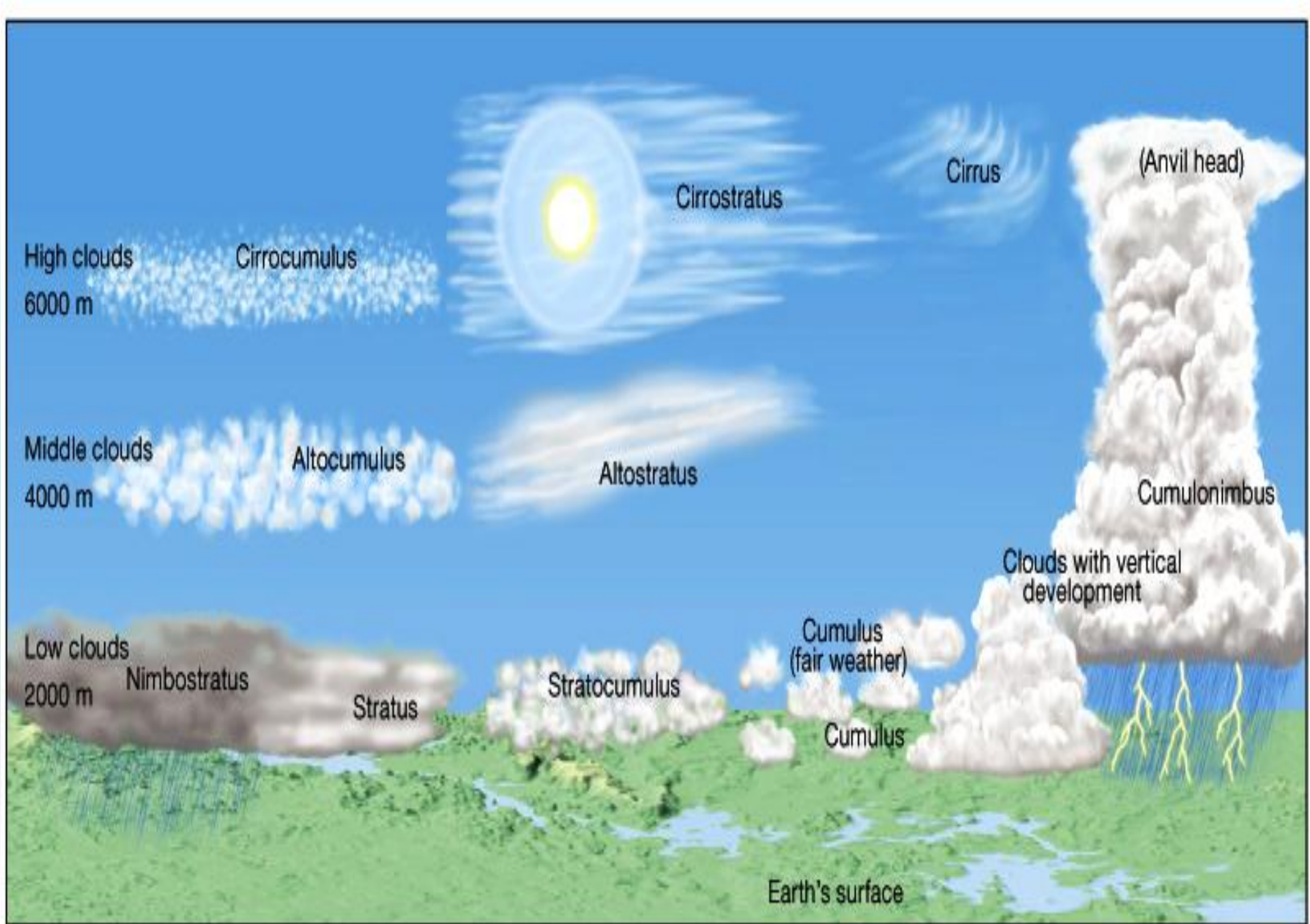


TABLE 5-1 Basic cloud types

Cloud Family and Height	Cloud Type	Characteristics
High clouds—above 6000 m (20,000 ft)	Cirrus (Ci)	Thin, delicate, fibrous ice-crystal clouds. Sometimes appear as hooked filaments called “mares’ tails” (cirrus uncinus; Figure 5–3a).
	Cirrostratus (Cs)	Thin sheet of white ice-crystal clouds that may give the sky a milky look. Sometimes produces halos around the Sun and Moon (Figure 5–3b).
	Cirrocumulus (Cc)	Thin, white ice-crystal clouds. In the form of ripples or waves, or globular masses all in a row. May produce a “mackerel sky.” Least common of high clouds (Figure 5–3c).

Cirrus



Thin, delicate, fibrous ice-crystal clouds. Sometimes appear as hooked filaments called “mares’ tails” (cirrus uncinus; Figure 5–3a).

Cirrostratus



Cirrostratus (Cs)

Thin sheet of white ice-crystal clouds that may give the sky a milky look. Sometimes produces halos around the Sun and Moon (Figure 5-3b).

Cirrocumulus



Cirrocumulus (Cc)

Thin, white ice-crystal clouds. In the form of ripples or waves, or globular masses all in a row. May produce a “mackerel sky.” Least common of high clouds (Figure 5–3c).

Middle clouds—2000–6000 m
(6500 to 20,000 ft)

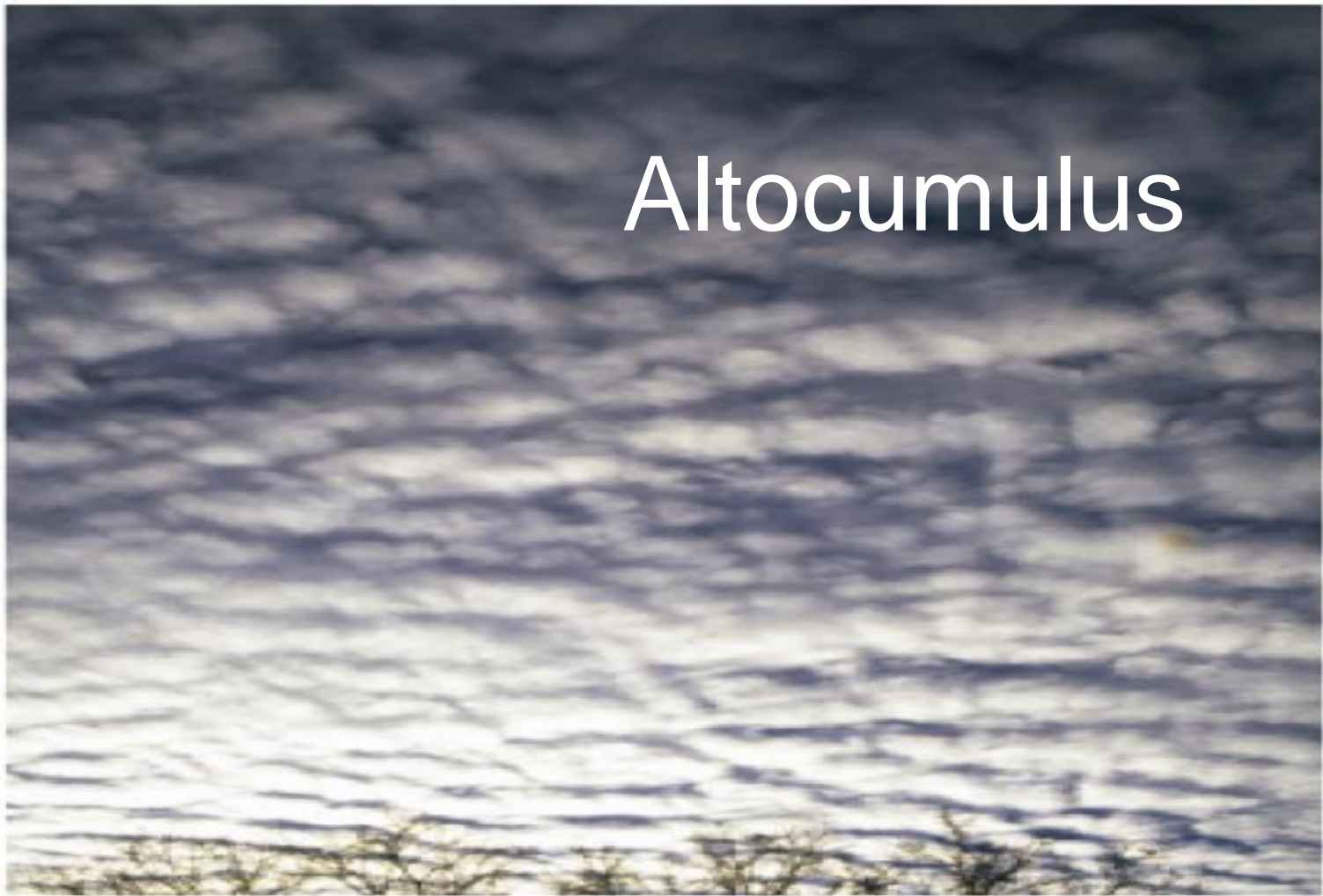
Alto cumulus (Ac)

White to gray clouds often made up of separate globules; “sheepback” clouds (Figure 5–4a).

Altostratus (As)

Stratified veil of clouds that is generally thin and may produce very light precipitation. When thin, the Sun or Moon may be visible as a “bright spot,” but no halos are produced (Figure 5–4b).

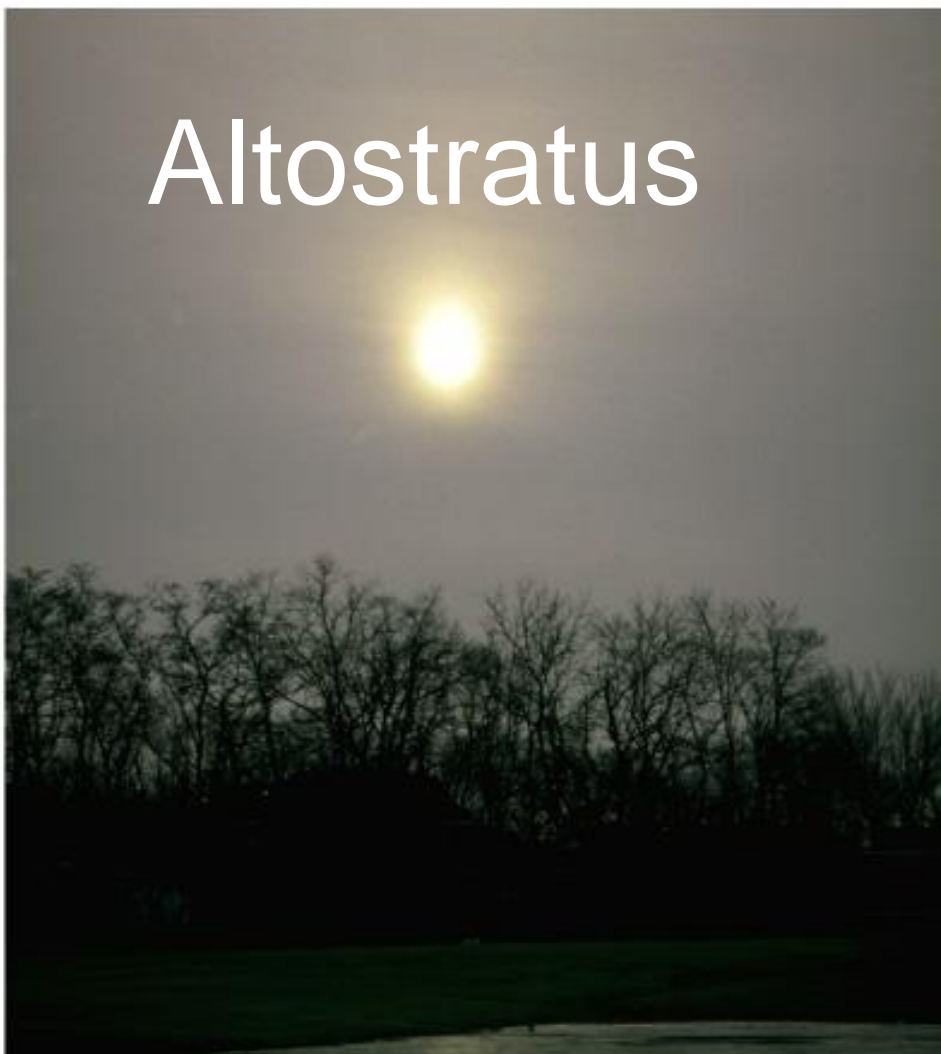
Alto cumulus



Alto cumulus (Ac)

White to gray clouds often made up of separate globules; “sheepback” clouds (Figure 5–4a).

Altostratus



Altostratus (As)

Stratified veil of clouds that is generally thin and may produce very light precipitation. When thin, the Sun or Moon may be visible as a “bright spot,” but no halos are produced (Figure 5-4b).

Low clouds—below 2000 m
(6500 ft)

Stratus (St)

Low uniform layer resembling fog but not resting on the ground. May produce drizzle.

Stratocumulus (Sc)

Soft, gray clouds in globular patches or rolls. Rolls may join together to make a continuous cloud.

Nimbostratus (Ns)

Amorphous layer of dark gray clouds. One of the chief precipitation-producing clouds (Figure 5-5).



Stratus (St)

Low uniform layer resembling fog but not resting on the ground. May produce drizzle.

Nimbostratus



Nimbostratus (Ns) Amorphous layer of dark gray clouds. One of the chief precipitation-producing clouds (Figure 5-5).

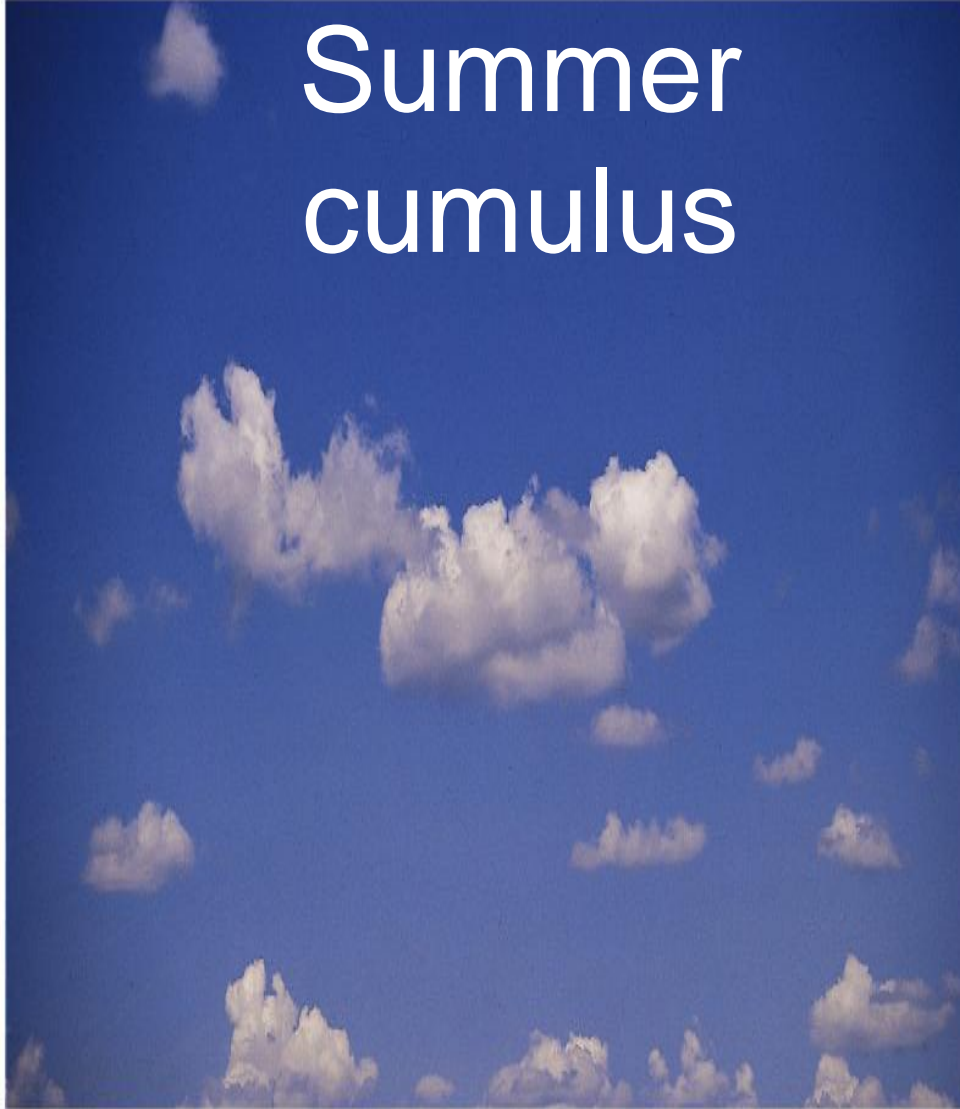


Stratocumulus (Sc)

Soft, gray clouds in globular patches or rolls. Rolls may join together to make a continuous cloud.

Clouds of vertical development	Cumulus (Cu)	Dense, billowy clouds often characterized by flat bases. May occur as isolated clouds or closely packed (Figure 5-6).
	Cumulonimbus (Cb)	Towering cloud, sometimes spreading out on top to form an “anvil head.” Associated with heavy rainfall, thunder, lightning, hail, and tornadoes (Figure 5-7).

Summer cumulus



cumulus (fair weather)

Clouds of vertical development

Cumulus (Cu)

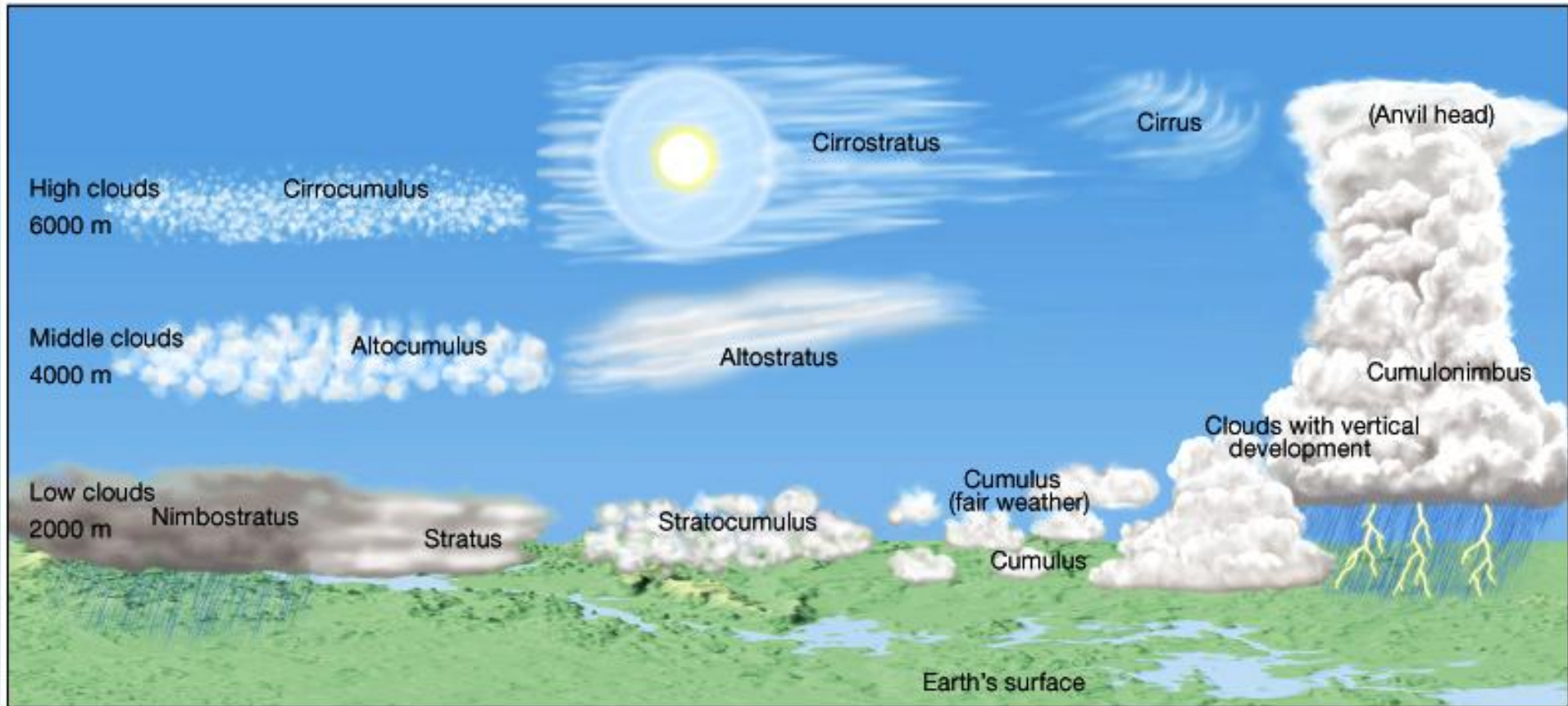
Dense, billowy clouds often characterized by flat bases. May occur as isolated clouds or closely packed (Figure 5-6).

cumulonimbus (storm clouds)



Cumulonimbus (Cb) Towering cloud, sometimes spreading out on top to form an “anvil head.” Associated with heavy rainfall, thunder, lightning, hail, and tornadoes (Figure 5–7).

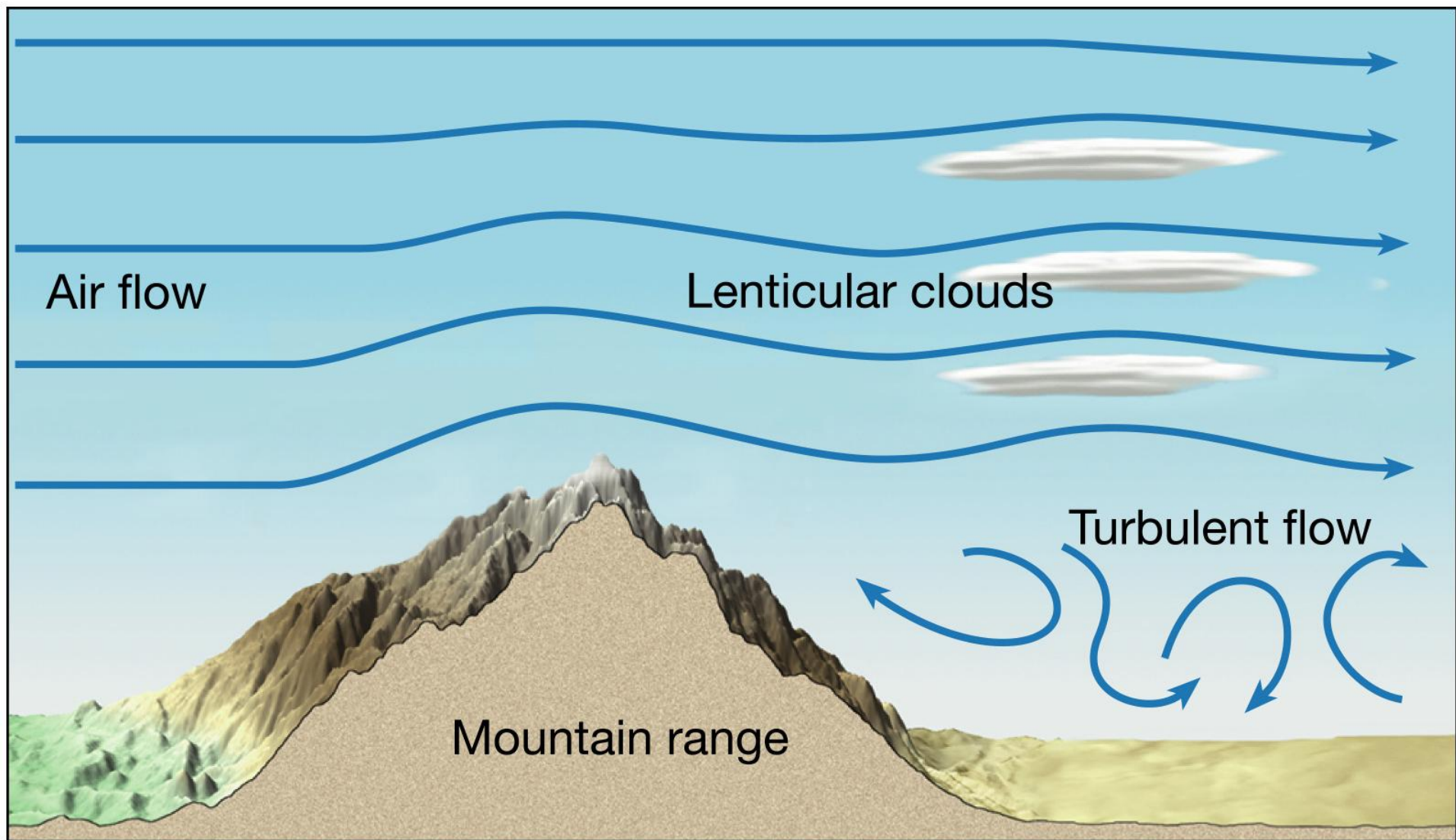
Lenticular clouds often form on leeward side of mountains



Lenticular Cloud



(a)



(b)

To be continued.....

Fog

- **Fog**, generally considered an **atmospheric hazard**, is a cloud with its base at or very near the ground.
- Fogs formed by cooling include:
 - **radiation fog** (from radiation cooling of the ground and adjacent air),
 - **advection fog** (when warm and moist air is blown over a cold surface), and
 - **upslope fog** (created when relatively humid air moves up a slope and cools adiabatically).

Fog (cont.)

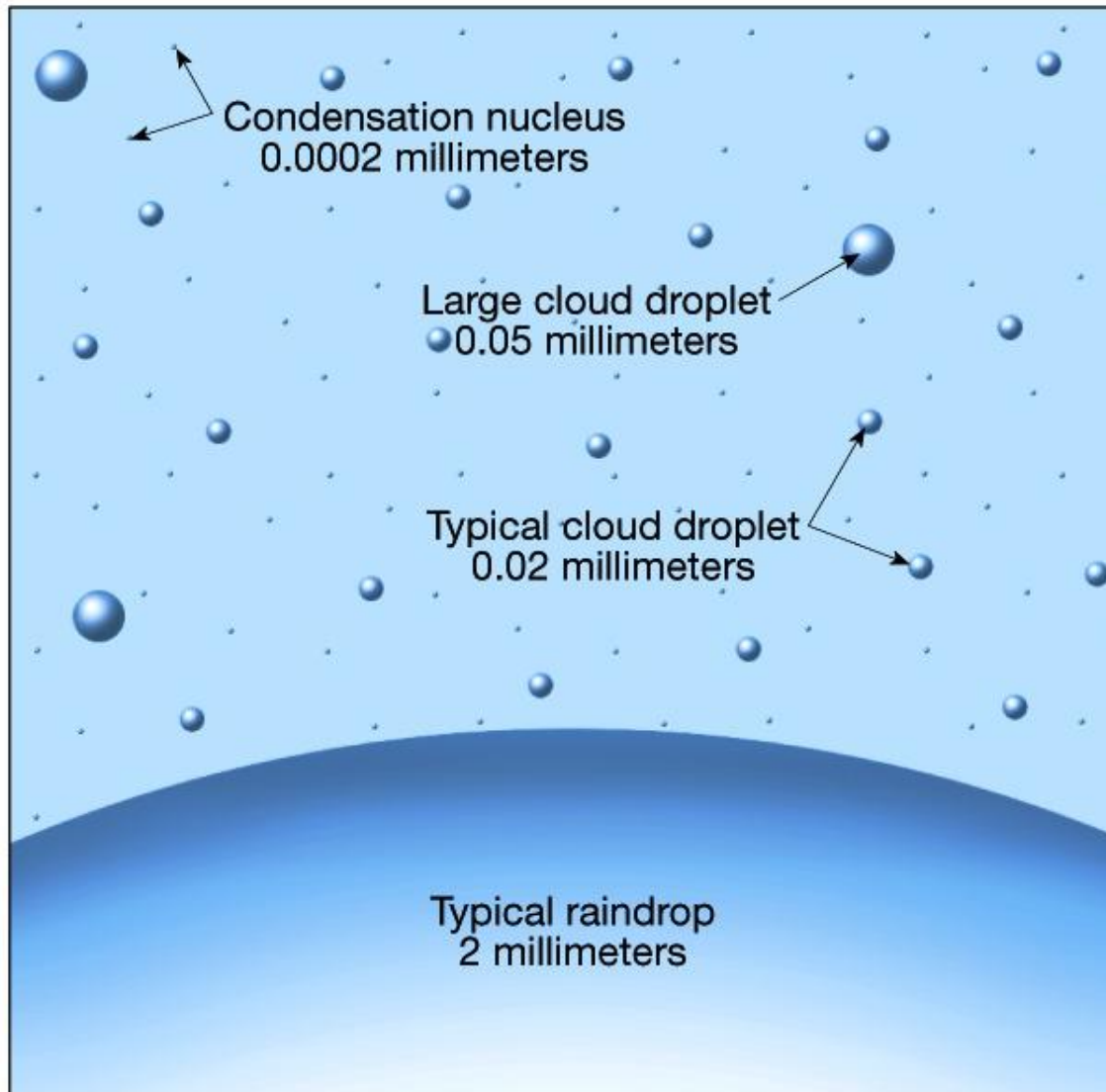
- Those formed by evaporation are:
 - **steam fog** (when rising water vapor over warm water condenses in cool air) and
 - **frontal fog** (when warm air is lifted over colder air along a front).

Dew and White Frost

- **Dew** is the condensation of water vapor on objects that have radiated sufficient heat to lower their temperature below the dew point of the surrounding air.
 - **Dew point:**
 - water to air saturation temperature
 - Temperature below which the water vapor in a volume of humid air at a constant barometric pressure will condense into liquid water.
- **White frost** forms when the dew point of the air is below freezing.

How Precipitation Forms

Important Facts:

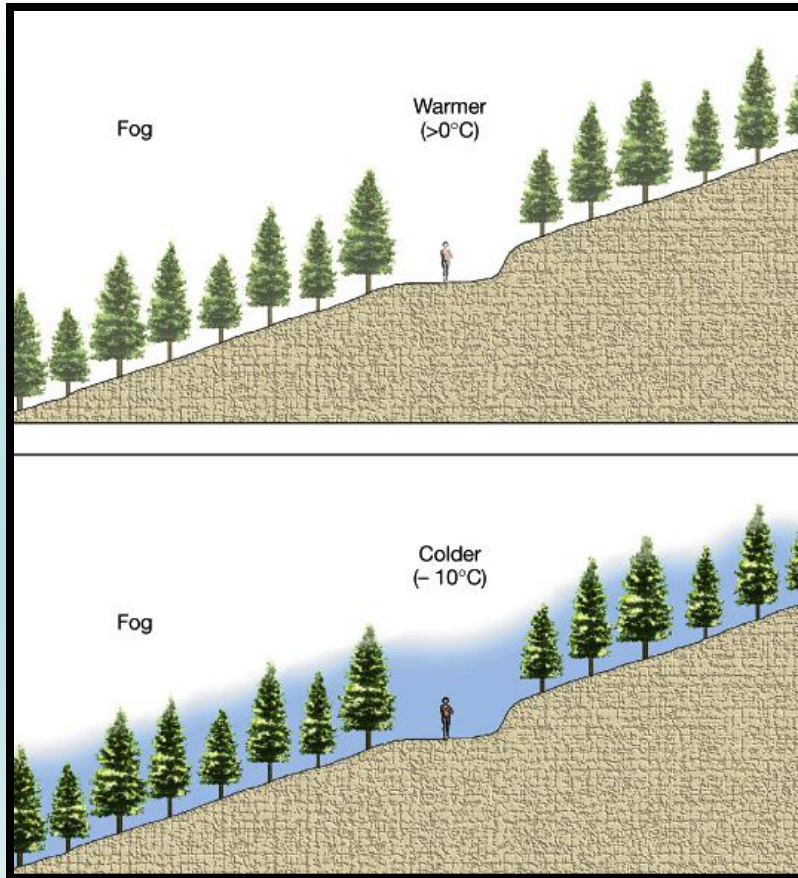


- cloud droplets are tiny (20 micrometers).
- many condensation nuclei are present.
- tiny particles fall more slowly than large ones.
- a cloud droplet's diameter must grow ~200 times to reach a raindrop's diameter.
- to attain the volume of a rain droplet, the cloud droplet increases a million times in volume.

Precipitation Formation Mechanisms

- **The Bergeron Process (Cold Clouds)**
mainly in mid latitudes
- **The Collision-Coalescence Process (Warm Clouds)**
manly in tropics

The Bergeron process describes how rain or snow forms when the cloud temperature is below freezing.



Temperature	RH wrt* H ₂ O(liq)	RH wrt H ₂ O(ice)
0°C	100%	100%
-05°C	100%	105%
-10°C	100%	110%
-15°C	100%	115%
-20°C	100%	121%

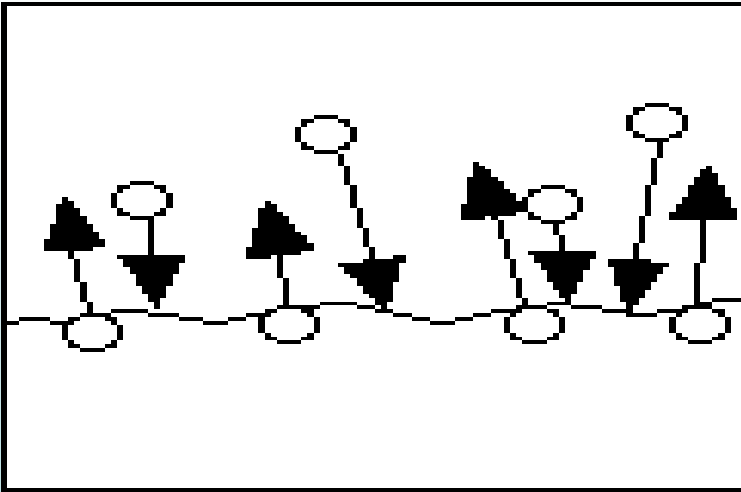
*wrt = with respect to

This process where ice crystals grow at the expense of cloud droplets is called the **Ice Crystal Process**. It is also named after the Norwegian researcher who discovered it (**Tor Bergeron, *there were others***).

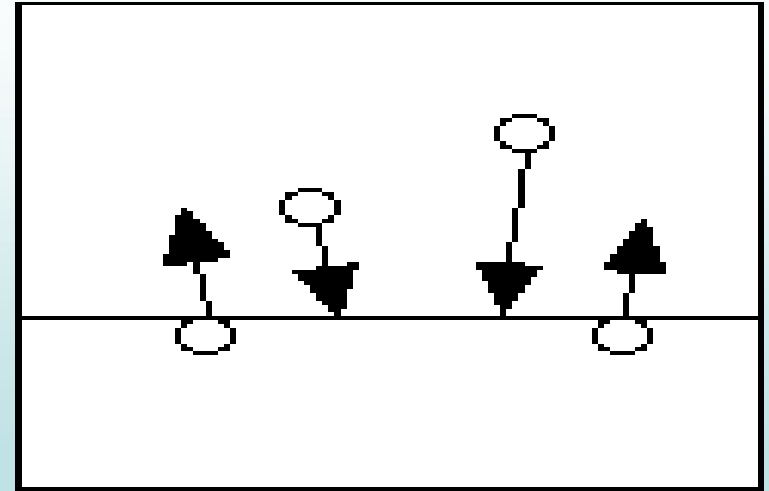
Three important properties of water droplets:

- 1. Cloud droplets do not freeze at 0°C**
- 2. Super-cooled (*water in the liquid state below 0°C*) water droplets will freeze immediately if agitated sufficiently or when they come in contact with freezing nuclei (a crystalline structure similar to ice)**
- 3. The saturation vapor pressure with respect to ice is lower than the saturation vapor pressure with respect to liquid water.**

Saturation with Respect to Ice and Water



Liquid Water

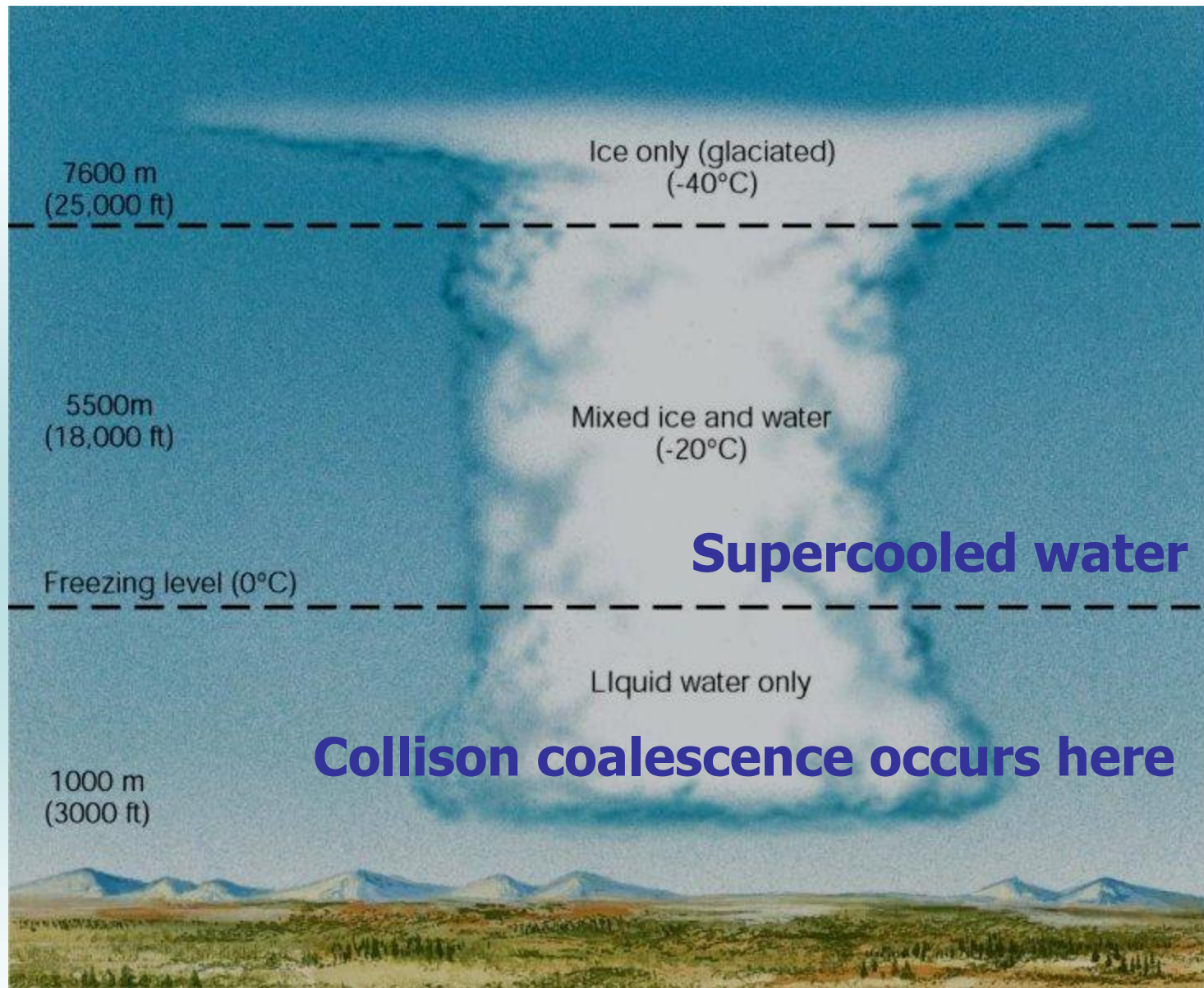


Ice

- Vapor pressure is the pressure due to water vapor molecules when the evaporation rate is equal to the condensation rate.
- Because of the crystalline structure of ice, water molecules are not able to break free from an ice surface as easily than from a water surface.
- Therefore, the saturation vapor pressure with respect to an ice surface would be less than the saturation vapor pressure with respect to a liquid water surface at a given temperature.

Ice Crystal (Bergeron) Process

- Process of rain formation proposes that both ice crystals and liquid cloud droplets must co-exist in clouds at temperatures below freezing.
- This process is extremely important to rain formation in the middle and high latitudes where cloud tops extend above the freezing level (*cold clouds*)



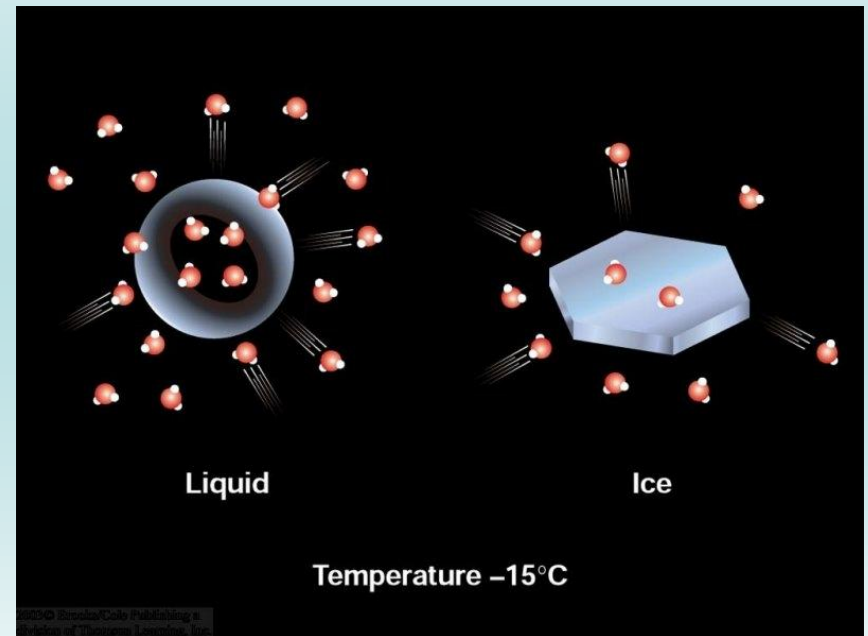
The distribution of ice and water in a cumulonimbus cloud.

Ice Nuclei

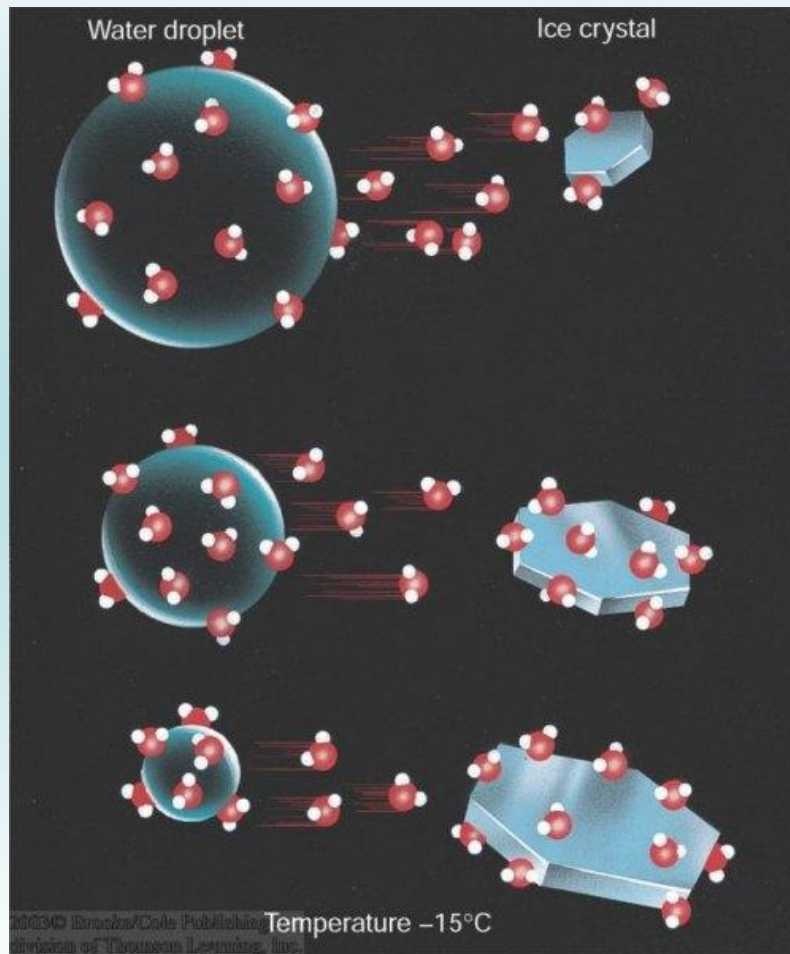
- Ice-forming particles that exist in subfreezing air
- Small amount of these available in atmosphere
- Clay materials, bacteria in decaying plant leaf material and other ice crystals

Saturation Vapor Pressure Ice vs Water

- In a saturated environment, the water droplet and the ice crystal are in equilibrium, as the number of molecules leaving the surface of each droplet and ice crystal equals the number returning. The greater number of vapor molecules above the liquid indicates, however, that the saturation vapor pressure over water is greater than it is over ice.



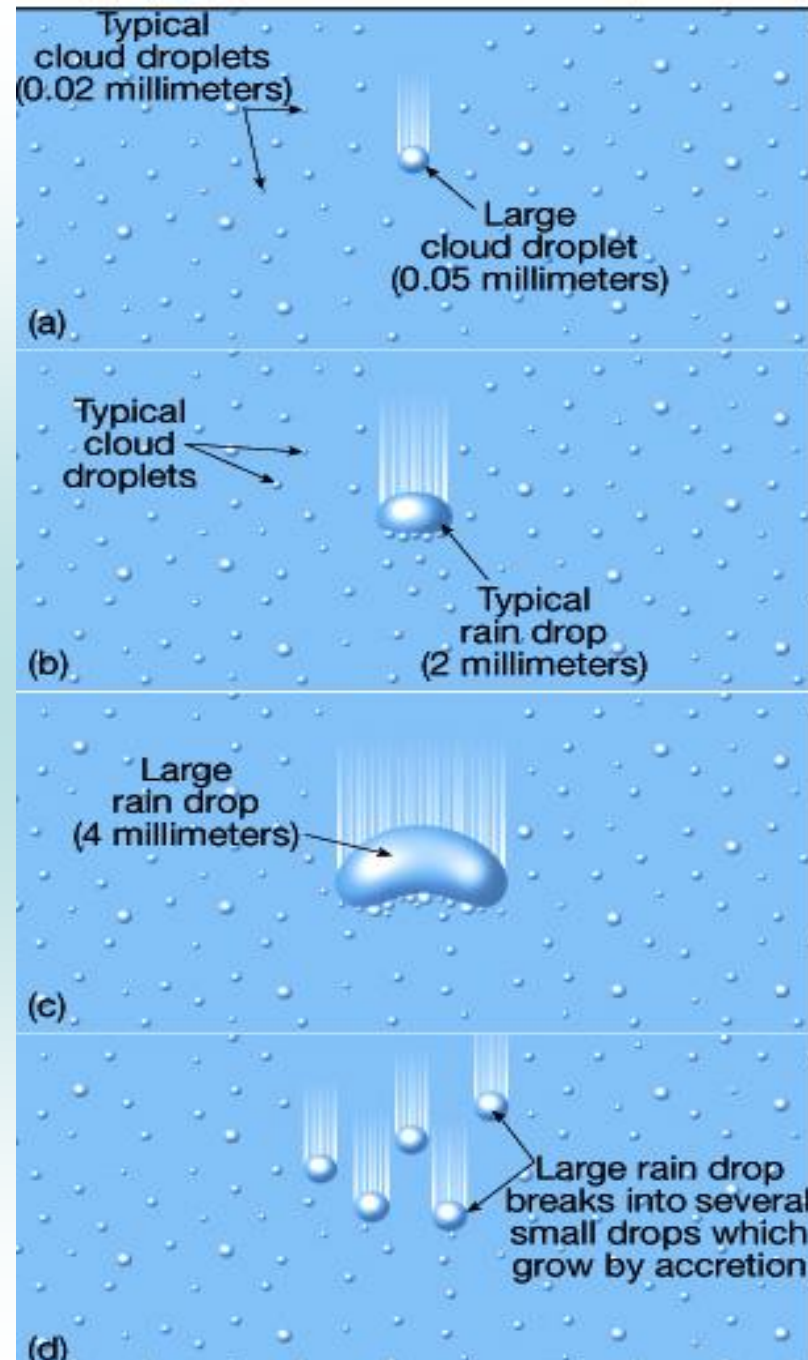
Ice Crystal (Bergeron) Process



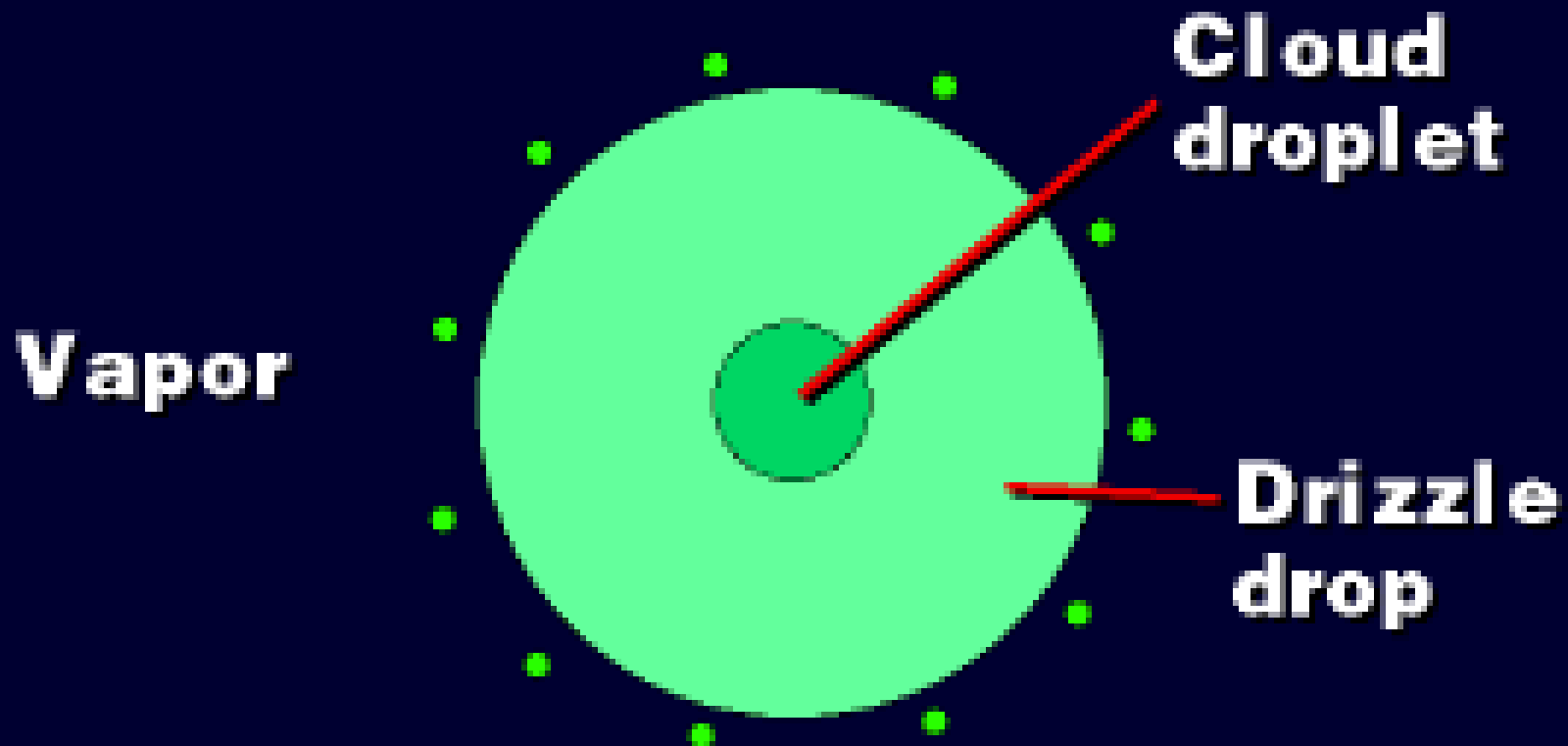
- The ice-crystal process. The greater number of water vapor molecules around the liquid droplets causes water molecules to diffuse from the liquid drops toward the ice crystals. The ice crystals absorb the water vapor and grow larger, while the water droplets grow smaller.
- It takes more vapor molecules to saturate the air directly above the water droplet than it does to saturate the air directly above the crystal.
- Ice crystals grow at the expense of the surrounding water droplets.

The Process from Warm Clouds: The Collision-Coalescence Process

- As droplets fall they collide with smaller droplets and coalesce.
- after collecting ~ 1 million cloud droplets the particle is large enough to fall without evaporating.
- Because there are a large number of collisions needed, clouds with great vertical extent are typically produce precipitation by this process.

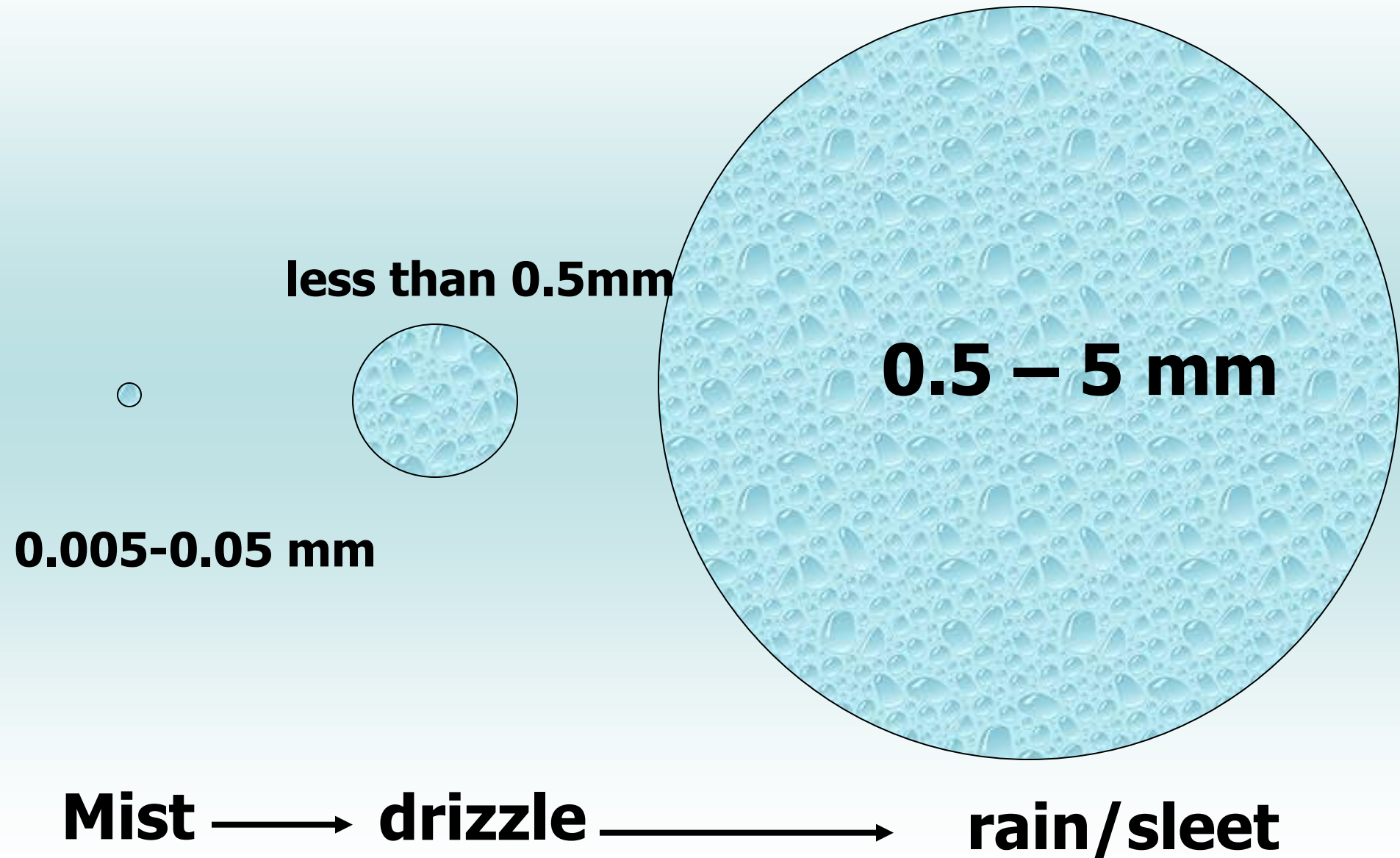


Condensation Growth of Droplets



100x increase in diameter \rightarrow 10^6 x increase in volume to grow to drizzle drop size

Approximate size of types of Precipitation



Collision Coalescence Process



Forms of Precipitation

(Rain, Snow, Sleet and Glaze, Hail)

Droplet size determines the type of precipitation.

Precipitation Types

- Rain
 - Drizzle
 - Virga
 - Showers
- Snow
 - Snow grains and snow pellets
 - Fallstreaks
 - Flurries
 - Squalls
 - Blizzard
- Sleet and Freezing Rain
- Hail

Rain

- Falling drop of liquid water that has a diameter equal to or greater than .5 mm (.02 in)
- *Drizzle* – drops too small to qualify as rain
- *Virga* – raindrops that fall from a cloud but evaporate before reaching the ground
- *Shower* – intermittent precipitation from a cumuliform cloud usually of short duration but often heavy intensity
- *Acid rain* – rain that is mixed with gaseous pollutants (sulfur, nitrogen) and becomes acidic



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Virga

Snow

- A solid form of precipitation composed of ice crystals in complex hexagonal form
- Much of the precipitation reaching the ground actually begins as snow.
- *Fallstreaks* – Ice crystals and snowflakes falling from high cirrus clouds. Behave similar to Virga – fall into drier air and disappear before reaching the ground. Change from ice to vapor (sublimation)
- *Flurries* – light snow showers that fall intermittently for short durations. Light accumulation.
- *Squall* – more intense snow shower, brief but heavy snowfall.
- *Blizzard* – severe weather condition. Low temperatures and strong winds (greater than 30 kts) bearing a great amount of falling or blowing snow.



Fallstreaks

Rain

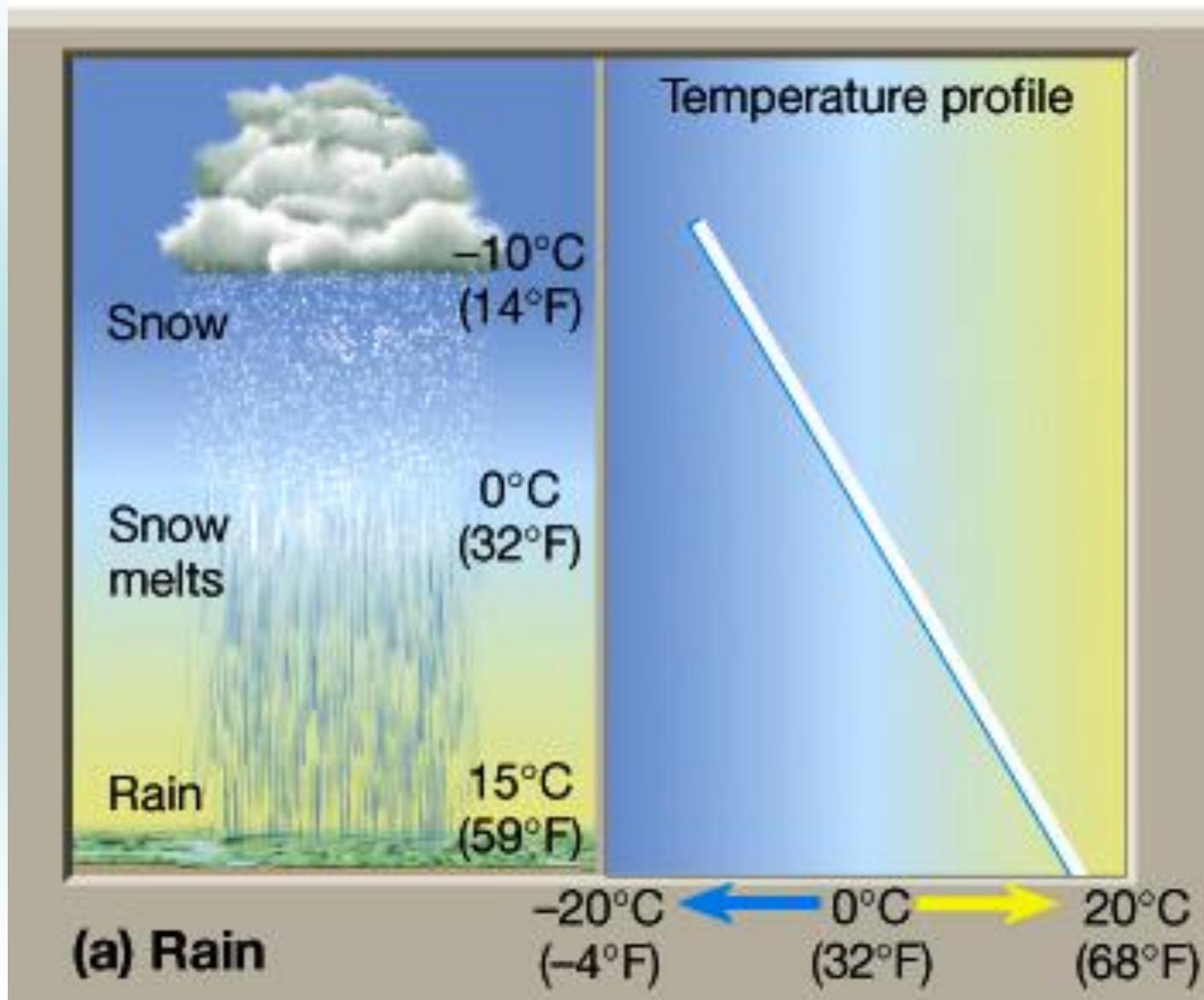
Rain is the term for drops of water that fall from a cloud and have a diameter of **0.5 millimeter (mm)**.

Drizzle and mist have smaller droplets.

Rain mostly occurs in nimbostratus clouds and cumulonimbus clouds. These clouds are capable of producing *cloudbursts*.

Most rain starts as snow or ice crystals; as the snow falls through the cloud it melts. Drizzle is a fine uniform water droplet with a diameter less than **0.5 mm**.

Temperature Profile for Rain



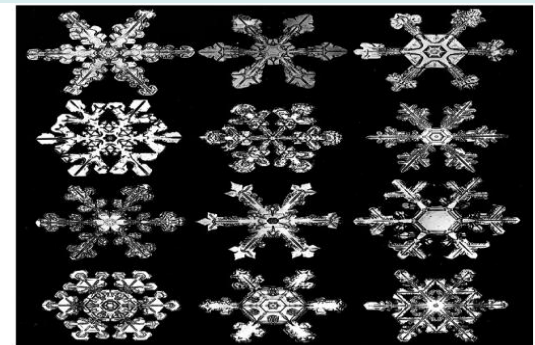
Snow

Snow is precipitation in the form of ice crystals (snowflakes) or more often, aggregates of ice crystals.

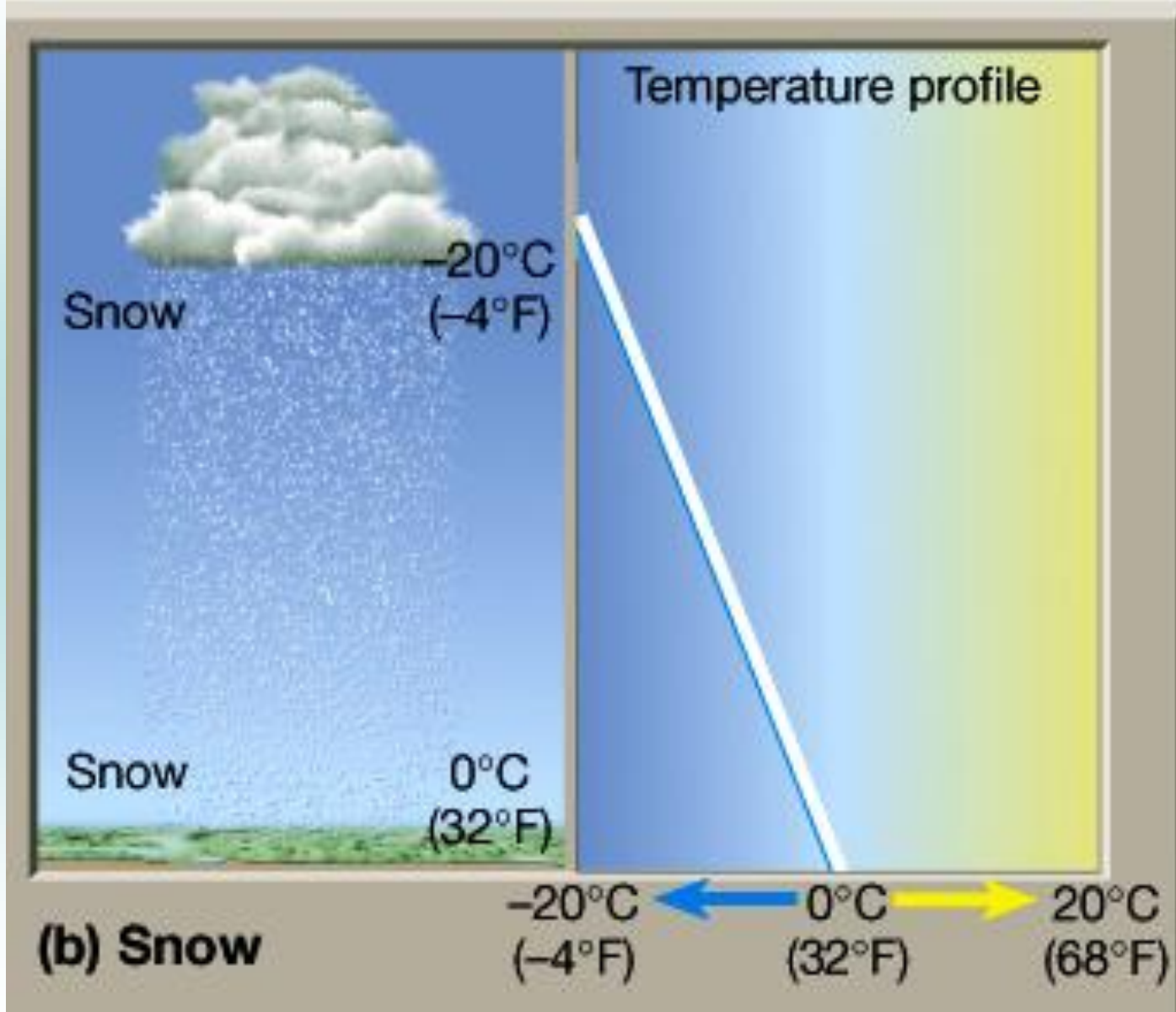
The size and structure of the crystals is a function of the temperature at which they form.

When **air temperatures are cold the moisture content is very small. This results in the formation of very light fluffy snow made up of six sided ice crystals.**

When conditions are **warmer, the ice crystals join together into larger clumps consisting interlocked aggregates of crystals.**

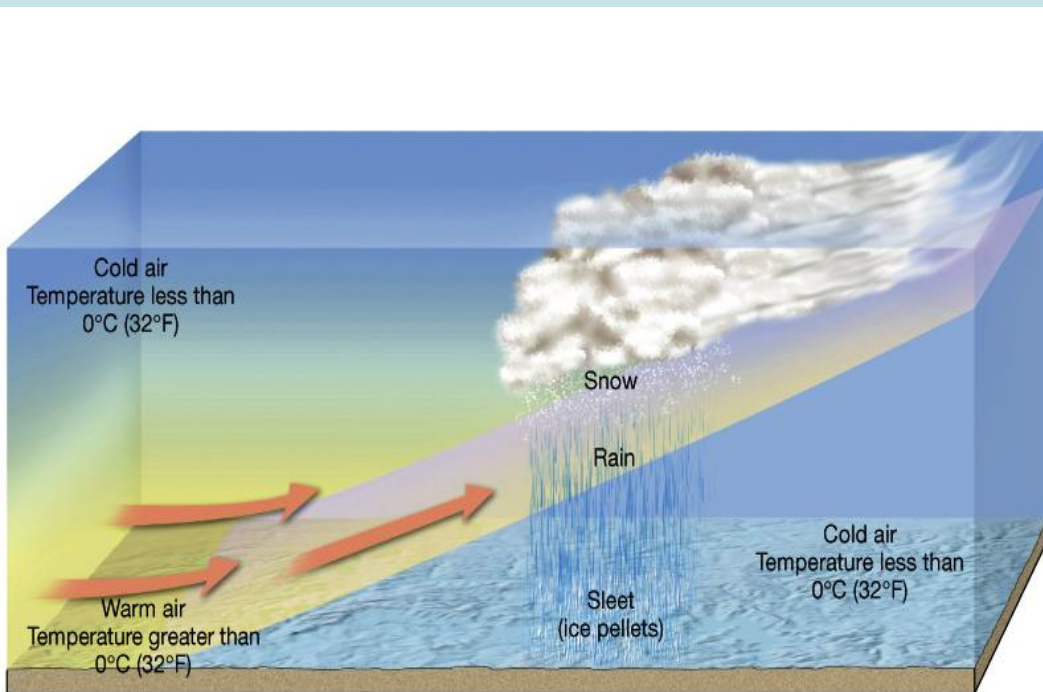


Temperature Profile for Snow



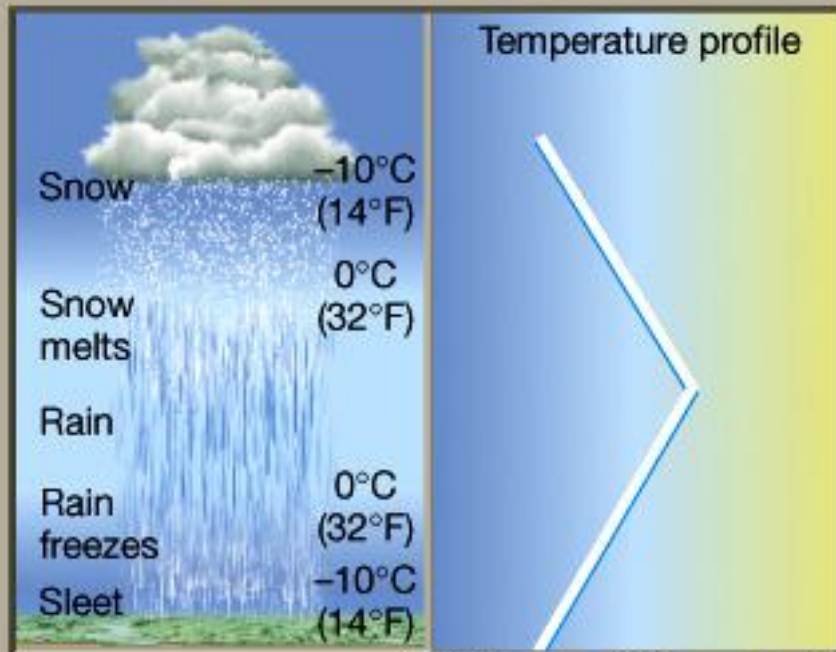
Sleet and Glaze

Sleet is a wintertime phenomenon that refers to the fall of small particles of **ice that are clear to translucent.**



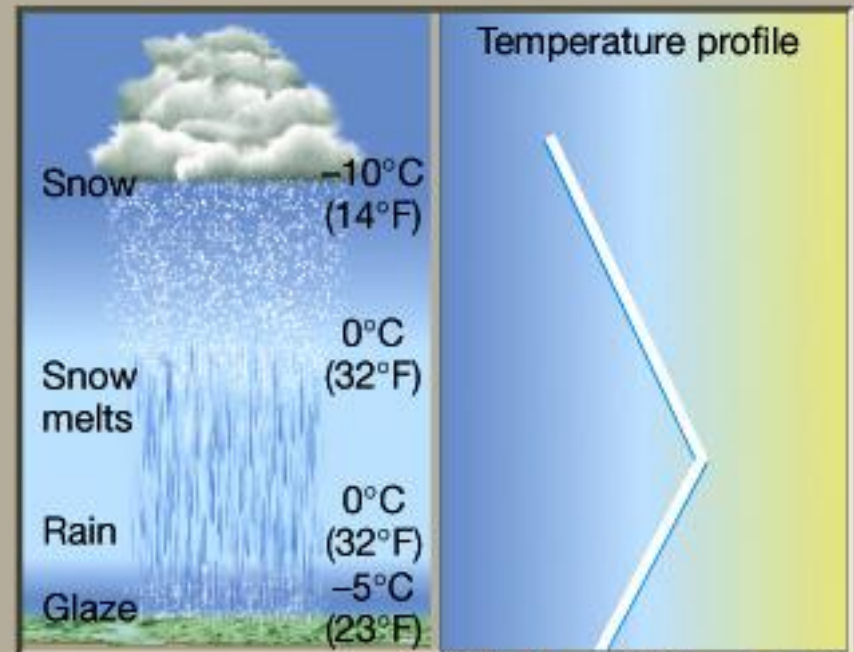
Sleet forms when rain passes through a cold layer of air and freezes into ice pellets. This occurs most often in the winter when warm air is forced over a layer of cold air.

Temperature Profile for Sleet and Glaze



(c) Sleet

-20°C (-4°F) 0°C (32°F) 20°C (68°F)

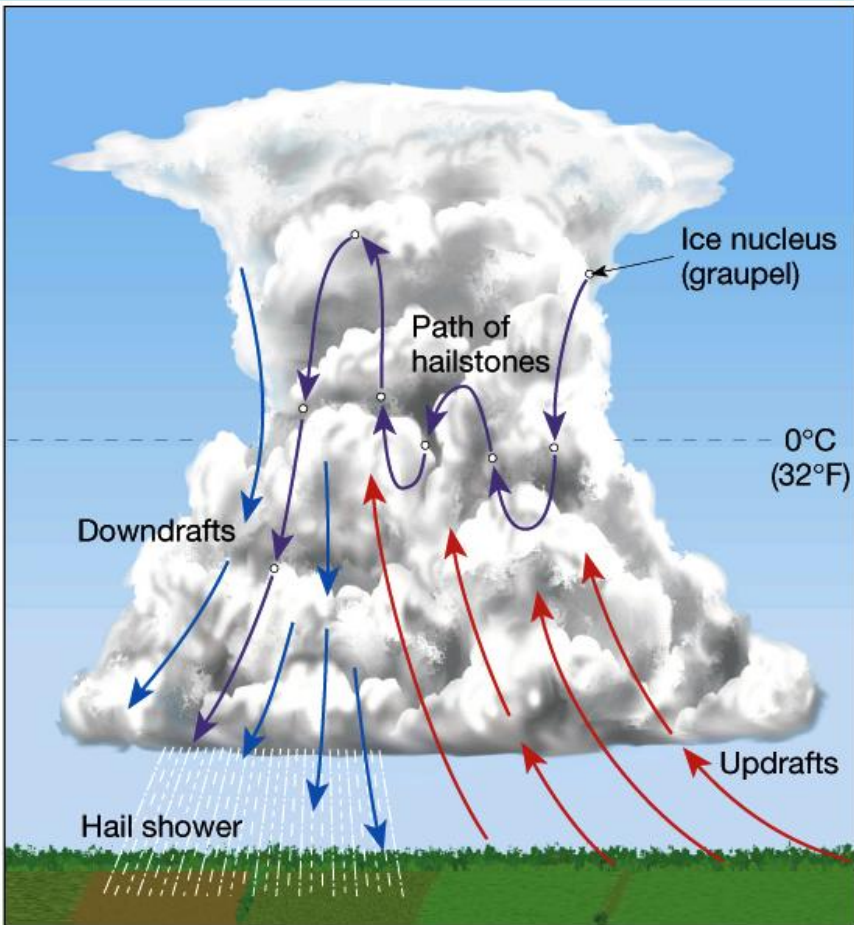


(d) Glaze

-20°C (-4°F) 0°C (32°F) 20°C (68°F)

Hail

Hail is precipitation in the form of hard, rounded pellets or irregular lumps of ice. The layers of ice accumulate as the hailstone travels up and down in a strong convective cloud.



Hailstones begin as small ice pellets that grow by adding supercooled water droplets as they move through the cloud.

As the ice crystal cycles up and down in the cloud the hailstones increase in size until they are forced out by a downdraft or become heavy enough to fall out.

Hail



Rime



Rime is a deposit of ice crystals formed by the freezing of supercooled fog or cloud droplets on objects whose surface temperature is below freezing. When rime forms on trees, it covers them with ice feathers; in windy conditions only the windward surfaces will accumulate the layer of rime.

Table 5–4 Types of precipitation

Type	Approximate Size	State of Water	Description
Mist	0.005 to 0.05 mm	Liquid	Droplets large enough to be felt on the face when air is moving 1 meter/second. Associated with stratus clouds.
Drizzle	Less than 0.5 mm	Liquid	Small uniform drops that fall from stratus clouds, generally for several hours.
Rain	0.5 to 5 mm	Liquid	Generally produced by nimbostratus or cumulonimbus clouds. When heavy, size can be highly variable from one place to another.
Sleet	0.5 to 5 mm	Solid	Small, spherical to lumpy ice particles that form when raindrops freeze while falling through a layer of subfreezing air. Because the ice particles are small, any damage is generally minor. Sleet can make travel hazardous.
Glaze	Layers 1 mm to 2 cm thick	Solid	Produced when supercooled raindrops freeze on contact with solid objects. Glaze can form a thick coating of ice having sufficient weight to seriously damage trees and power lines.
Rime	Variable accumulations	Solid	Deposits usually consisting of ice feathers that point into the wind. These delicate frostlike accumulations form as supercooled cloud or fog droplets encounter objects and freeze on contact.
Snow	1 mm to 2 cm	Solid	The crystalline nature of snow allows it to assume many shapes, including six-sided crystals, plates, and needles. Produced in supercooled clouds where water vapor is deposited as ice crystals that remain frozen during their descent.
Hail	5 mm to 10 cm or larger	Solid	Precipitation in the form of hard, rounded pellets or irregular lumps of ice. Produced in large convective, cumulonimbus clouds, where frozen ice particles and supercooled water coexist.
Graupel	2 mm to 5 mm	Solid	Sometimes called “soft hail,” graupel forms as rime collects on snow crystals to produce irregular masses of “soft” ice. Because these particles are softer than hailstones, they normally flatten out upon impact.