Chapter 5
Forms of Condensation and Precipitation

Classifying and Naming of clouds

Processes responsible for various forms of precipitation

Cloud Formation

visible aggregate of water droplets, ice crystals, or both

adiabatic cooling

Any Form of Condensation

near saturation

cloud condensation nuclei

Cloud Condensation Nuclei:

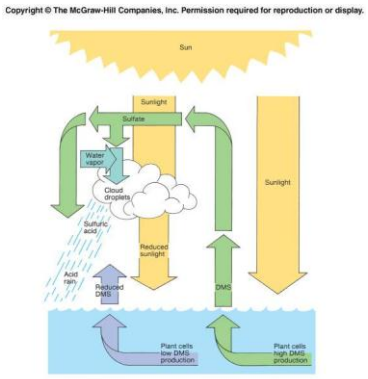
small surface to condense around

abundant in troposphere

Cloud Condensation Nuclei:

hygroscopic nuclei = have a high affinity for water

sea salt, and sulfides

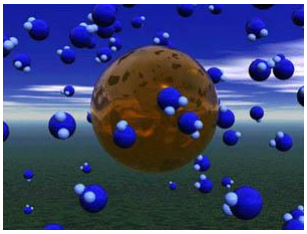


Relative Humidity <= 100%

Cloud Condensation Nuclei:

hygrophobic nuclei = repel water

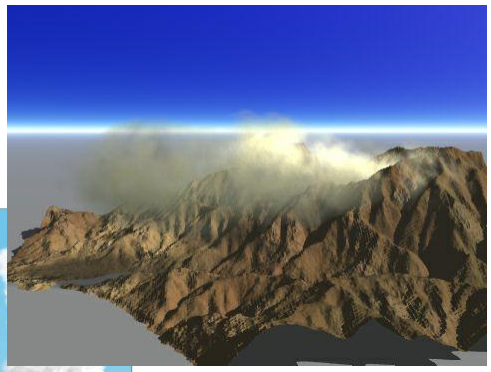
oils, Teflon, waxy substances

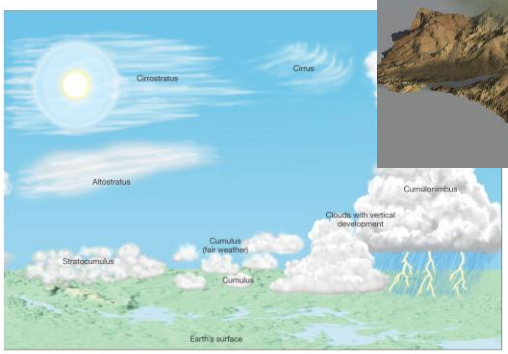


Relative Humidity > 100%

Cloud Classification:

1) **Form**
2) **Height**





Cloud Classification:

3 Basic Forms

Cirrus: white, thin, wispy, veil or feather-like

Cumulus: globular, cauliflower-like structures

Stratus: sheet or layer, uniform coverage

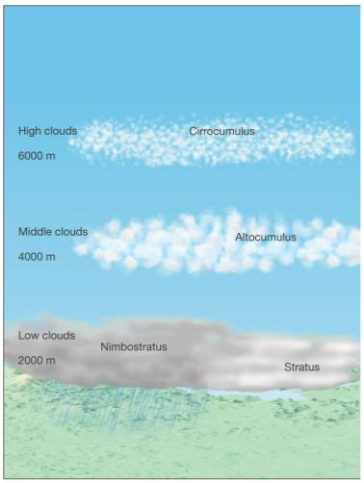
Cloud Classification:

Height

High: above 6000m

Middle: 2000 – 6000m

Low: below 2000m



Clouds of Vertical Development: extend through more than 1 height range

10 Basic Cloud Types:

TABLE 5-1 Basic cloud types

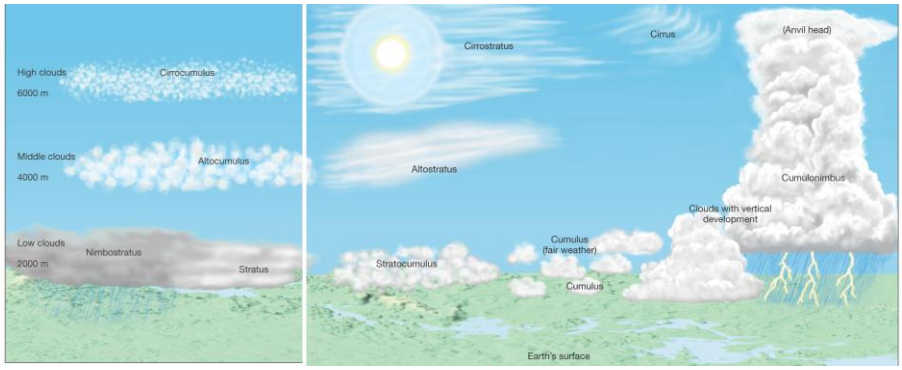
Cloud Family and Height	Cloud Type	Characteristics
High clouds—above 6000 m (20,000 ft)	Cirrus (Ci)	Thin, delicate, fibrous ice-crystal clouds. Sometimes appear as hooked filaments called "mares' tails" (cirrus uncinus; Figure 5–3a).
	Cirrostratus (Cs)	Thin sheet of white ice-crystal clouds that may 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).
Middle clouds—2000–6000 m (6500 to 20,000 ft)	Altocumulus (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).
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).
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).

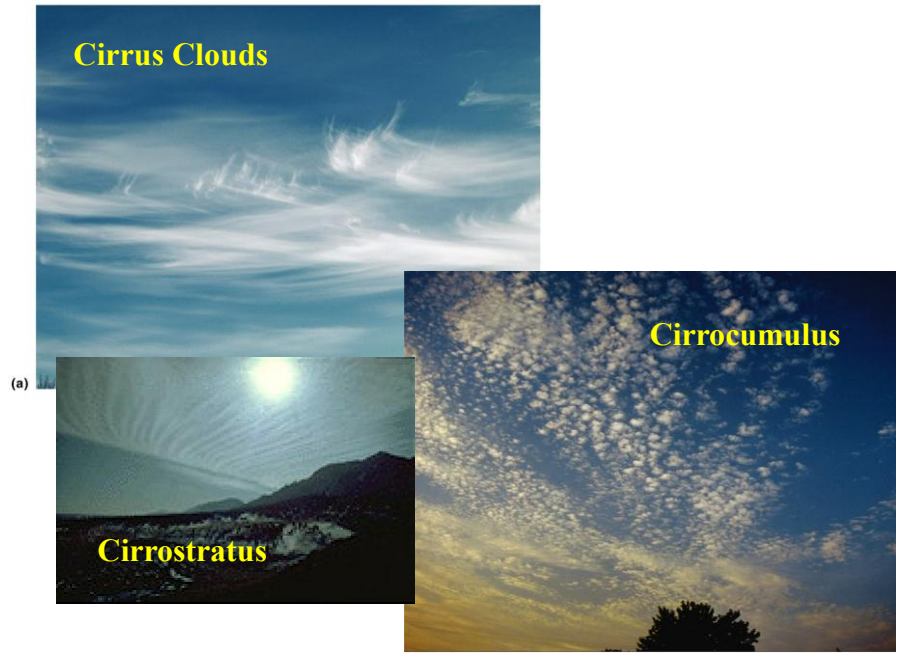
High Clouds:

Cirrus: detached white icy filaments, recurved (mares tails)

Cirrostratus: whitish veil

Cirrocumulus: white patches, small cells, mackerel scales

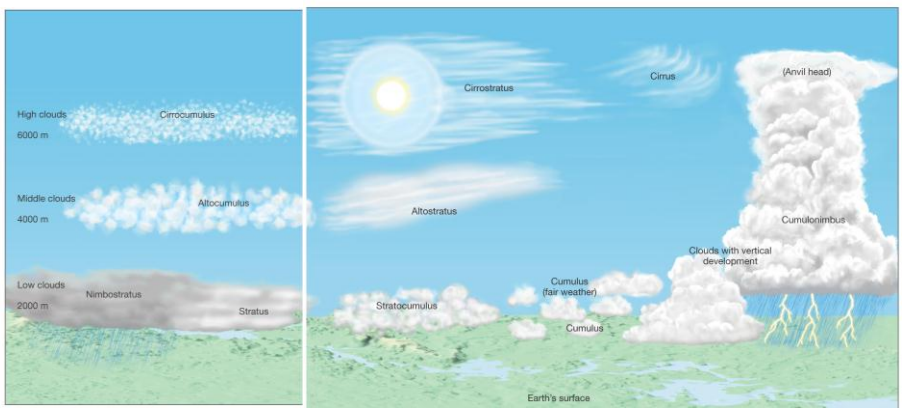




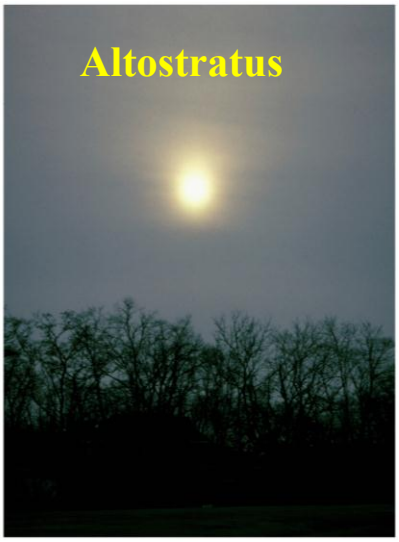
Middle Clouds:

Altocumulus: large patches, white rolls, distinct outlines

Altostratus: formless layer of grayish clouds, some precipitation



(a)



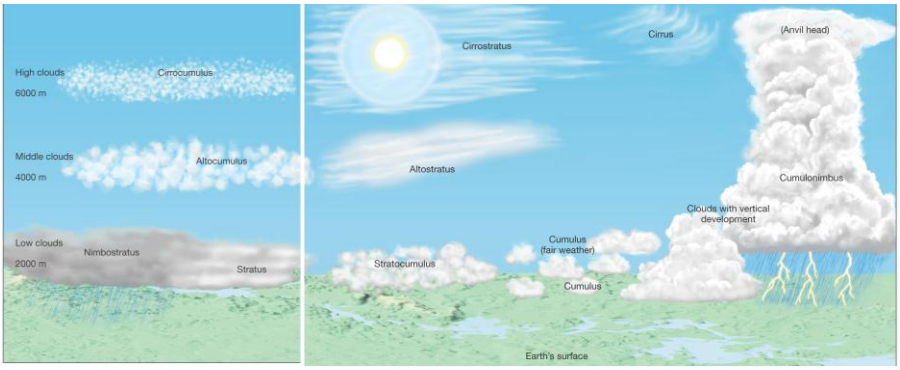
(b)

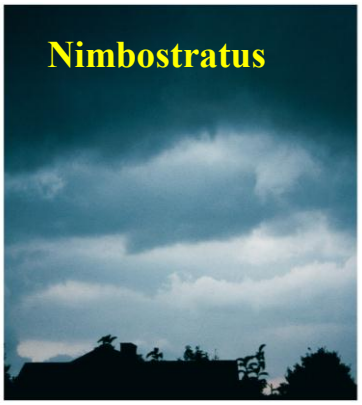
Low Clouds:

Stratus: uniform layer covering sky, light precipitation

Stratocumulus: long parallel rolls or globular patches

Nimbostratus: rain clouds, stable conditions, precipitation (light, widespread, long duration)





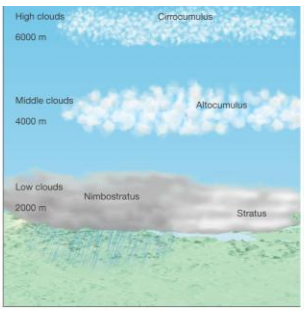
Clouds of Vertical Development: **rising unstable air**

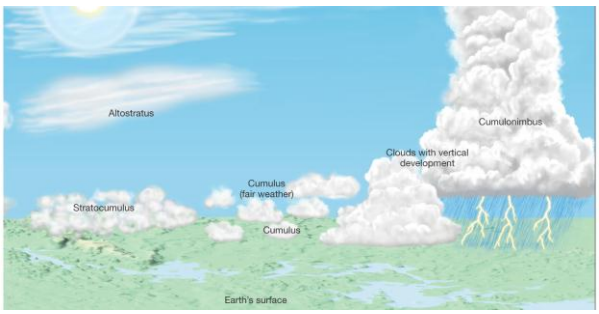
Cumulus: bulbous, cauliflower domes

flat base (lifting condensation level)

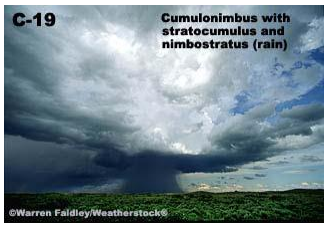
clear days, unequal surface heating

Cumulonimbus: rain clouds, convection (7-12 mi), heavy rainfall, lightning, thunder, hail)






SC-2
Cumulonimbus
©Warren Faidley/Weatherstock®


C-19
Cumulonimbus with stratocumulus and nimbostratus (rain)
©Warren Faidley/Weatherstock®


C-8
Cumulus Congestus
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(Anvil head)
Cumulonimbus
Clouds with vertical development
Cumulus (fair weather)
Cumulus
Earth's surface

C-18
Cumulus
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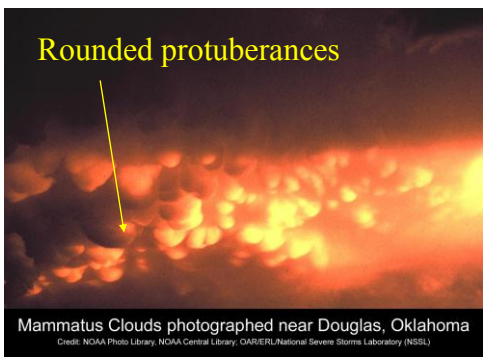
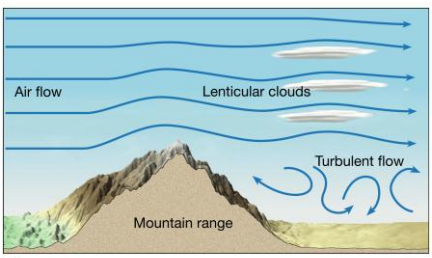

Rounded protuberances
Mammatus Clouds photographed near Douglas, Oklahoma
Credit: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL)


Air flow
Lenticular clouds
Turbulent flow
Mountain range

(b)


Lenticular cloud over the Inyo Mountains near Bishop, California
Photo by Don Carney
NOAA Central Library/NWS

Fog:

- Considered an atmospheric hazard (visibility)
- Cloud with base near the surface
- Formed through cooling or addition of water

Fogs Formed By Cooling:

- Radiation Fog:
- Advective Fog:
- Upslope Fog:

Fogs Formed By Cooling:

Radiation Fog: **radiative cooling**

1-2 m thick

pools in valleys

evaporates from ground up

Fogs Formed By Cooling:

Advective Fog: **warm moist air blown over cool surface**

thick and persistant

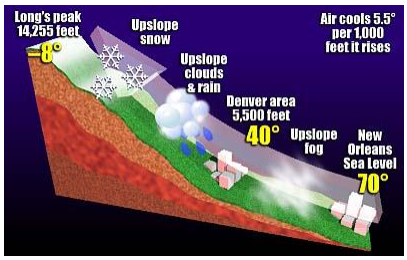
San-Francisco

Fogs Formed By Cooling:

Upslope Fog: **relatively humid air moves up slope**

adiabatic cooling

Great Plains (Gulf toward Rocky Mnts)



Evaporative Fogs:

Steam Fog:

Frontal Fog:

Evaporative Fogs:

Steam Fog: cold air advected over warm water

high evaporation saturates lowest layer

pushed up

Evaporative Fogs:

Frontal Fog (precipitation fog)

frontal wedging induces rain

increased precipitation could lead to increased evaporation

cool air mass is near saturation could result in fog

Dew & Frost:

Air temperature drops below the dew point

Dew Point Temperature > 0°C = dew

Dew Point Temperature < 0°C = frost

Object specific

How Precipitation Forms:

Cloud drop ~ 20 micrometers (hair 75 micrometers)

evaporate before striking surface

Rain drop ~ 2000 micrometers (20 mm)

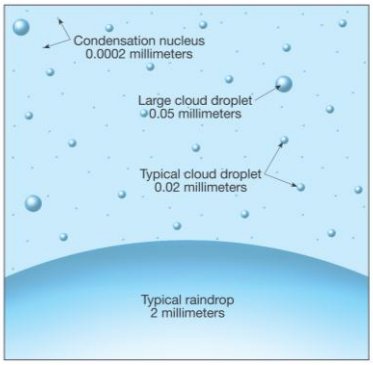


TABLE 5-A Maximum fall distance before evaporation

Drop Diameter (μm)	Maximum Fall Distance (m)
2500	280,000
1000	42,000
100	150
10	0.033
0	0.0000033

2 Processes:

Ice-crystal (Bergeron) process

mid latitude

super cooled droplets

Collision and coalescence process

tropics

warm clouds

2 Processes:

Ice-crystal (Bergeron) process

pure water suspended in air freezes (-40^{o}C)

supercooled will freeze on contact

freezing nuclei = similar crystal structure to ice

0 to -10 = supercooled water

-10 to -20 = supercooled water and ice

< -20 = mostly ice (cirrus clouds)

2 Processes:

Ice-crystal (Bergeron) process

saturation vapor pressure above supercooled water is greater than above ice

harder for water molecules to leave ice lattice

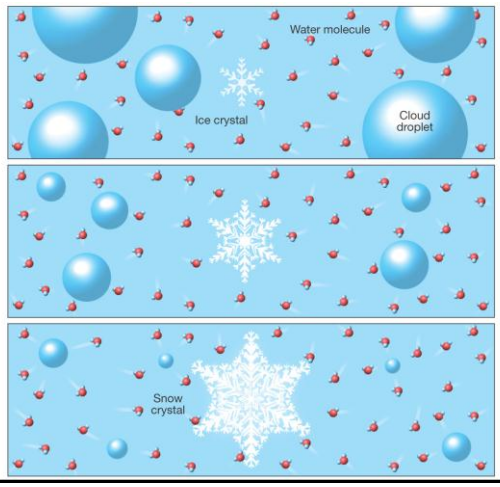
TABLE 5-2 Relative humidity with respect to ice when relative humidity with respect to water is 100 percent

	Relative Humidity with Respect to:	
Temperature (°C)	Water	Ice
0	100%	100%
-5	100%	105%
-10	100%	110%
-15	100%	115%
-20	100%	121%

2 Processes:

Ice-crystal (Bergeron) process

ice crystal grow fast in super-saturated air



Final form depends on temperature profile

2 Processes:

Collision and coalescence process

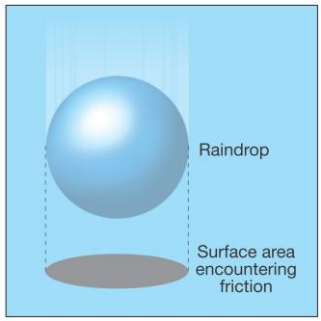
large drops > 20 micrometers collide with slower moving drops

TABLE 5-3 Fall velocity of water drops

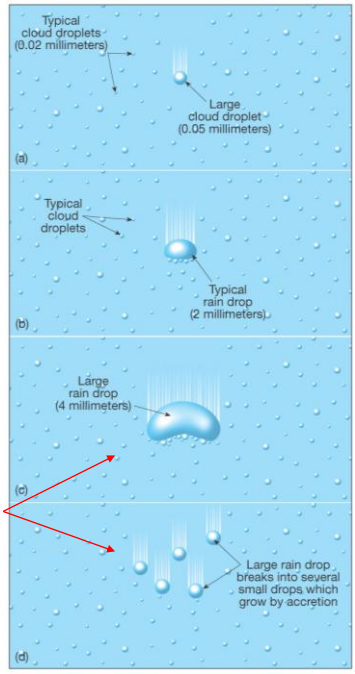
Types	Diameter (millimeters)	Fall Velocity (km/hr)	Fall Velocity (miles/hr)
Small cloud droplets	0.01	0.01	0.006
Typical cloud droplets	0.02	0.04	0.03
Large cloud droplets	0.05	0.3	0.2
Drizzle drops	0.5	7	4
Typical rain drops	2.0	23	14
Large rain drops	5.0	33	20

Data from Smithsonian Meteorological Tables.

Collision and coalescence process



frictional drag > surface tension

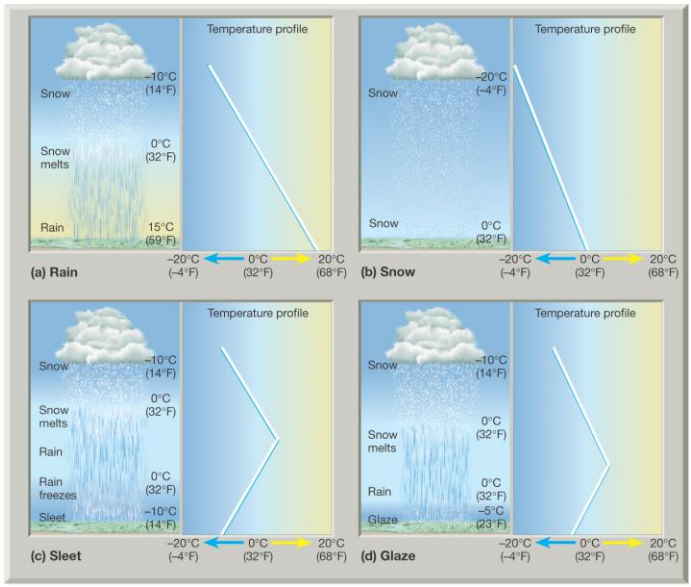


Forms of Precipitation:

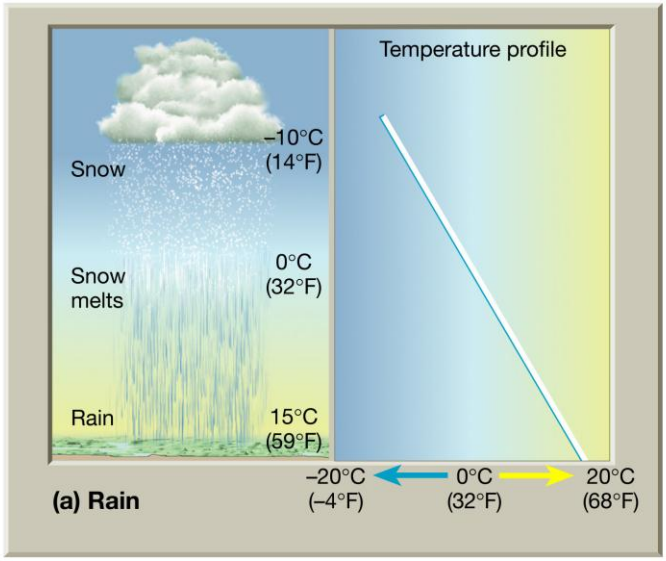
TABLE 5-4 Types of precipitation

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.

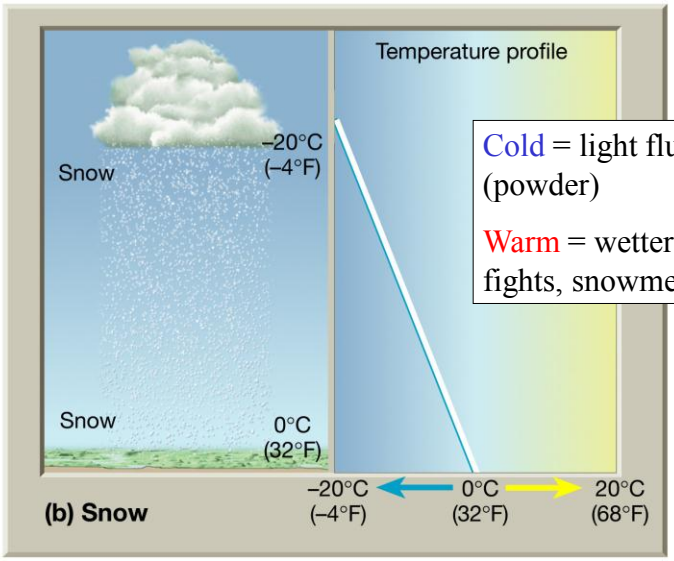
Formation of Precipitation Types: depends on temperature profile of lower atmosphere



Rain: drops of water that fall from a cloud, excludes drizzle and mist, virga = drops evap before reaching surface



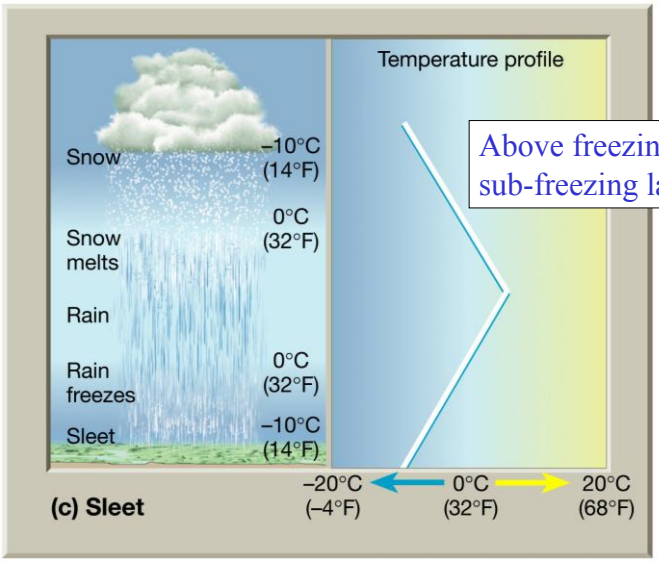
Snow: precipitation forms from ice crystals or aggregates of ice crystals



Cold = light fluffy snow (powder)

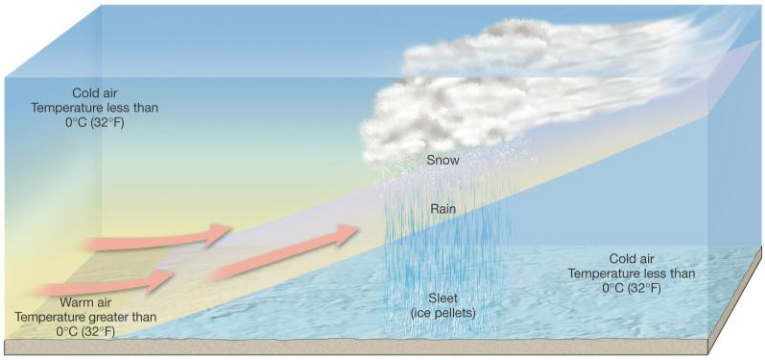
Warm = wetter snow (snowball fights, snowmen)

Sleet: **frozen rain drops, pellets, clear or transparent**

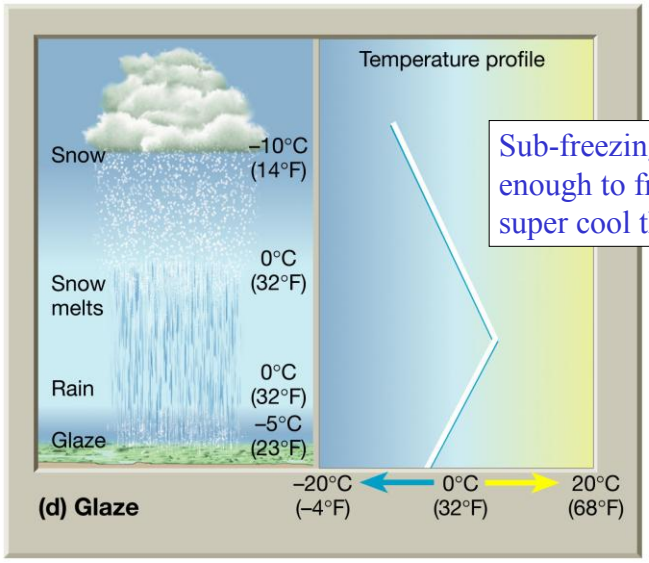


Above freezing layer overlies sub-freezing layer

Formation of Sleet: **frontal wedging possible mechanism**

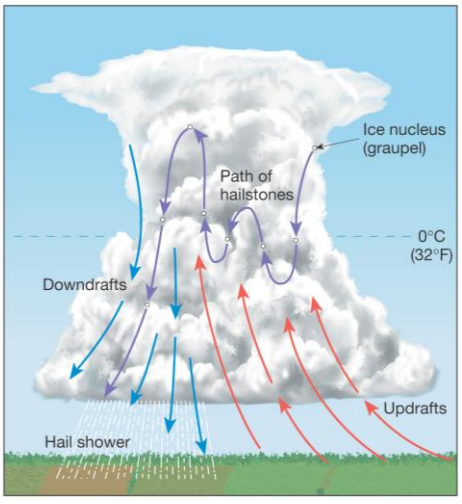


Glaze: freezing rain, super-cooled droplets that freeze on contact



Sub-freezing layer not thick enough to freeze drops only super cool them

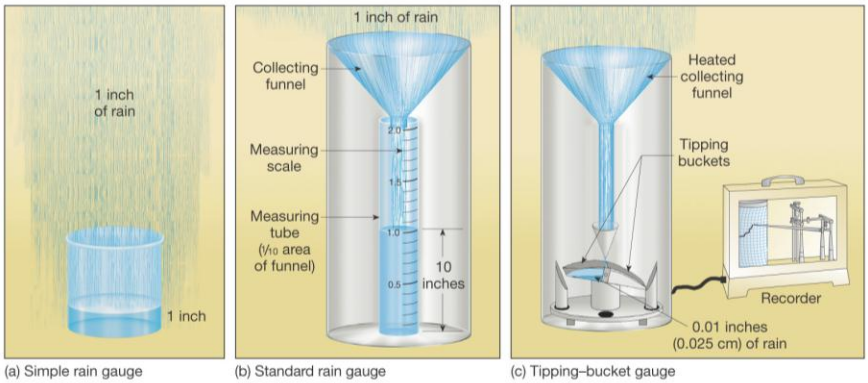
Hail: precipitation in the form of rounded/irregular hard pellets of ice



Dia = 1-5cm: golf ball
14 cm: grapefruit

Cumulonimbus Clouds:
convective updrafts
(100 mi/hr)
super cooled water

Measuring Precipitation



(a) Simple rain gauge (b) Standard rain gauge (c) Tipping–bucket gauge

Trace = precipitation < 0.01 in (0.025 cm)

Keep in Mind Measuring Precipitation

snowfall: 10in (snow) = 1in (rain)

evaporation

wind effects

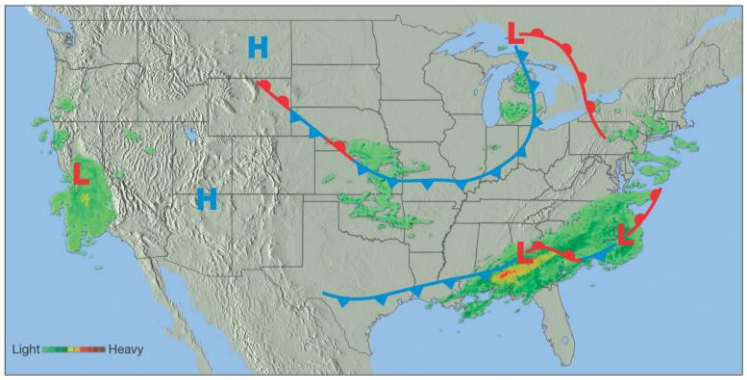
typical error: 7-20%

Weather Radar Measurements

radio waves: 3-10 cm

penetrate clouds, reflect off rain drops

station measures the return or echo



Weather Modification: deliberate changes

Cloud Seeding	cooling, freezing nuclei
Fog Dispersal:	mixing, heating, seeding
Hail Suppression	no effective method
Frost Prevention	heating (sprinklers, burners), covering

Cloud Seeding: most effective

dry ice (CO_2): super-cool clouds initiate ice crystal growth

silver iodide: freezing nuclei

Cloud Seeding:

salts: hygroscopic seeding in warm clouds

Orographic seeding: increase precip. 10%
snow pack
stored in reservoir
released during spring thaw