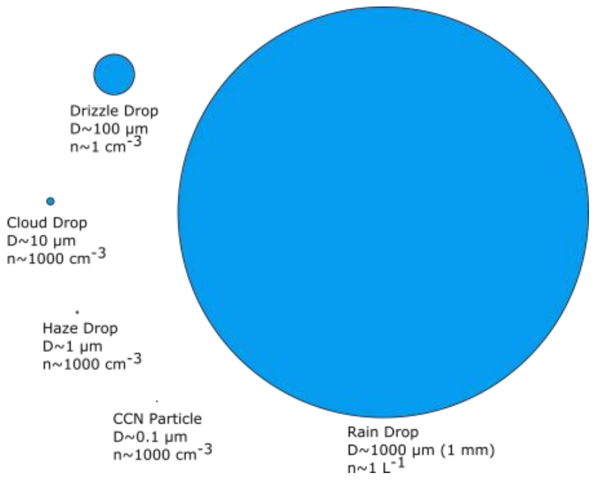
Cloud Physics-Lecture1

Cloud physics - science of clouds - the study of the physical processes that lead to the formation, growth and precipitation of atmospheric clouds**.** Clouds and precipitation are integral to weather and can be difficult to forecast accurately. Clouds come in different sizes and shapes that depend on atmospheric motions, their composition, which can be liquid water, ice, or both, and the temperature. While clouds and precipitation are being formed and dissipated over half the globe at any time, their behaviour is driven by processes that are occurring on the microscale, where water molecules and small particles collide. We call these microscale processes “cloud microphysics”

What are clouds?

A cloud is defined as a (visible) suspension of small particles in the atmosphere. For a water cloud, there are a number of types of particles that we are interested in.



Cloud drop sizes and characteristics. D is the typical diameter; n is the typical number per volume of air. Sizes are almost but not quite to scale.
Credit: W. Brune (after Lamb and Verlinde)

Note the wide range in size, volume, and number of particles in the figure above. The smallest, the cloud condensation nuclei (CCN), can have rather little water vapour and are made up of substances to which water can attach (called hydrophilic, water loving). The other particles grow by adding water molecules but still contain the original CCN upon which they formed.

Types of Clouds

Clouds are categorized primarily by two major factors –location and shape.

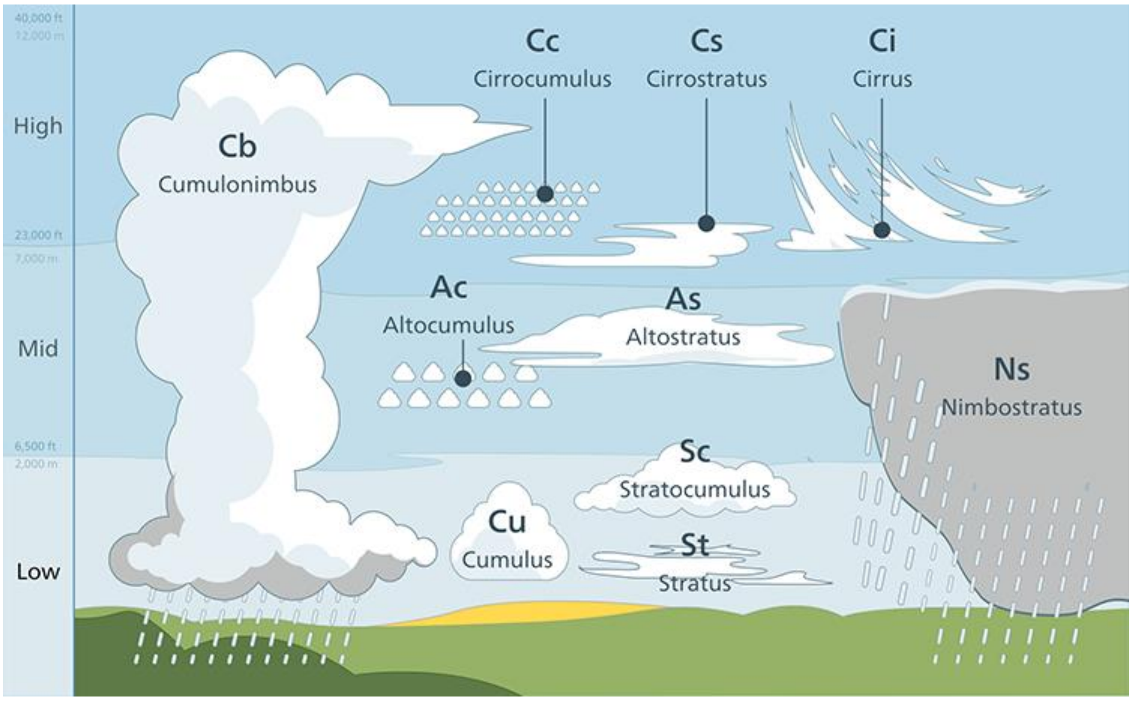
High clouds form several kilometers up in the sky. The highest clouds in the atmosphere are cirrus, cirrostratus and cirrocumulus. Cirrus clouds are thin and wispy and often curve with the wind.

Low clouds generally form within 1 or 2 km from the Earth's surface. In fact, low clouds can even form touching the ground - called fog.

The lowest clouds in the atmosphere are stratus, cumulus, and stratocumulus. Cumulus clouds tend to be big and fluffy. These clouds look like giant cotton balls or other shapes in the sky.

Stratus clouds form sheets of clouds that cover the sky.

Middle-level clouds form between low and high clouds. Mid-level clouds include altocumulus and altostratus. This type also can form parallel stripes of clouds.



<u>Low Clouds</u>:
•Stratus (St)
•Stratocumulus (Sc)
•Nimbostratus (Ns)

<u>Middle Clouds</u>:
•Altostratus (As)
•Altocumulus (Ac)

<u>High Clouds:</u>
•cirrus (Ci)
•cirrostratus (Cs)
•cirrocumulus (Cc

<u>Clouds with vertical development:</u>
•Cumulus (Cu)
•Cumulonimbus (Cb)

Precipitating Clouds

Warm clouds

>0°C

Warm clouds exist where the cloud top temperature is below freezing level.

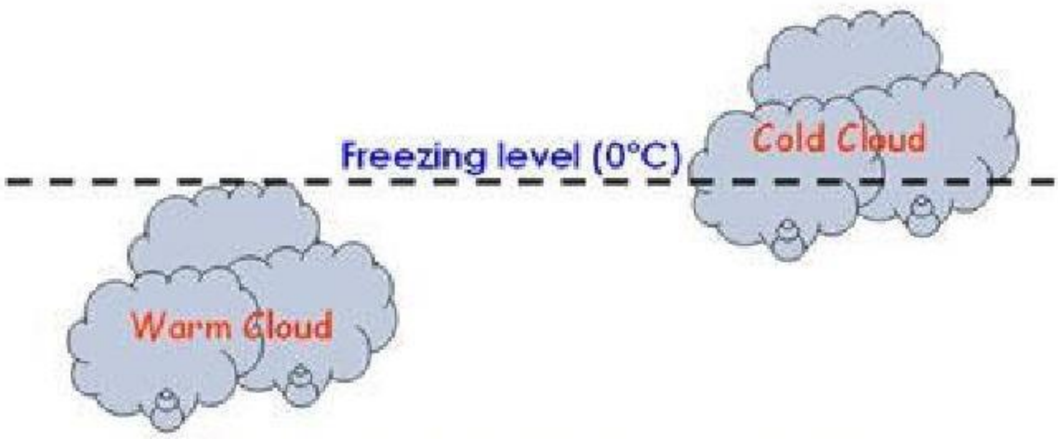
Cloud that is only in the liquid phase

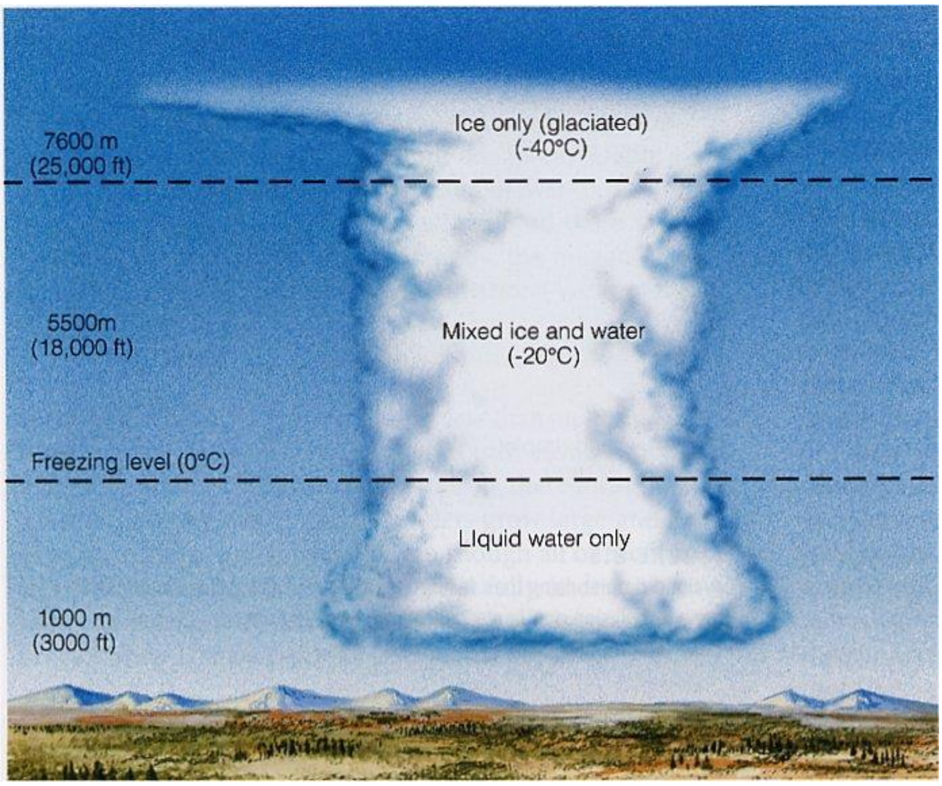
Cold clouds

<0°C

Cold clouds primarily exist where the cloud top temperature is above freezing level.

Water, supercooled water, ice



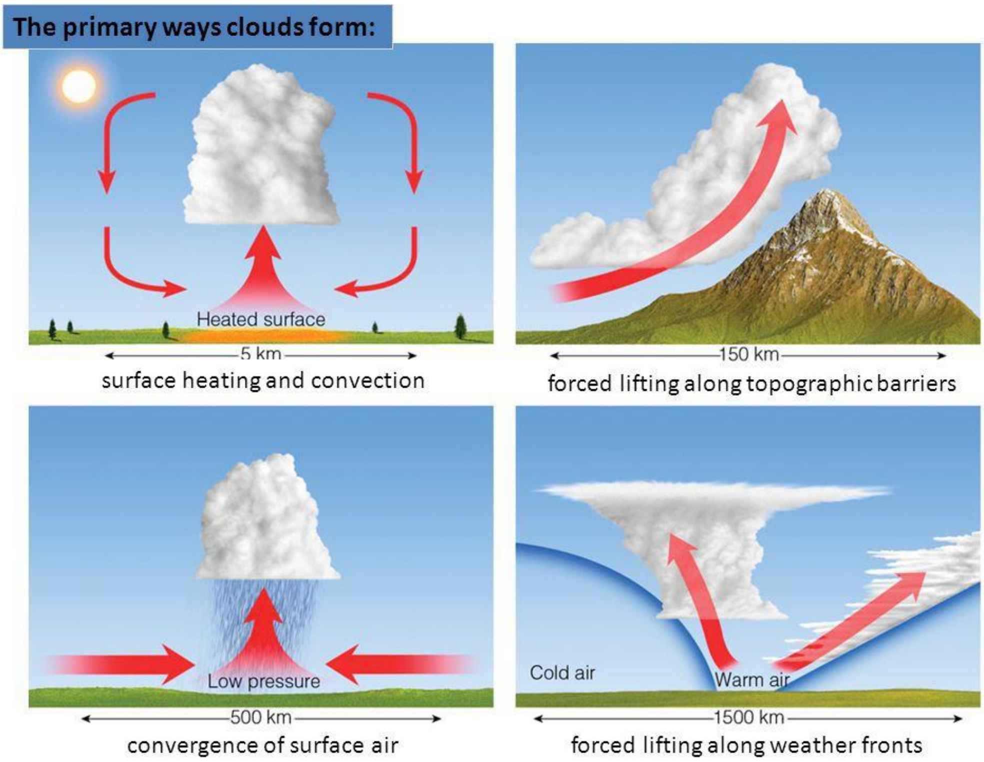


If a cold cloud consists entirely of ice, it is said to be glaciated.

If a cold cloud contains both ice particles and super-cooled droplets, it is a mixed cloud.

What causes clouds to form? Mechanisms helping cloud development

- Surface heating - when the ground is heated by the Sun - heats the air in contact with it causing it to rise. The rising columns are often called thermals. Surface heating tends to produce cumulus clouds.
- Topography or orographic forcing - The topography - or shape and features of the area - can cause clouds to form. When air is forced to rise over a barrier of mountains or hills it cools as it rises. Layered clouds are often produced this way.
- Frontal - Clouds are formed when a mass of warm air rises up over a mass of cold dense air over large areas along fronts. A 'front' is the boundary between warm-moist air and cooler-drier air.
- Convergence/Widespread ascent - Streams of air flowing from different directions are forced to rise where they flow together, or converge. This can cause cumulus cloud and showery conditions.



How Do Clouds Form?

Phase changes of water - basic to cloud physics. The possible phase changes are

Vapor ⇌ liquid (condensation, evaporation)

Liquid ⇌ solid (freezing, melting)

Vapor ⇌ solid (deposition, sublimation)

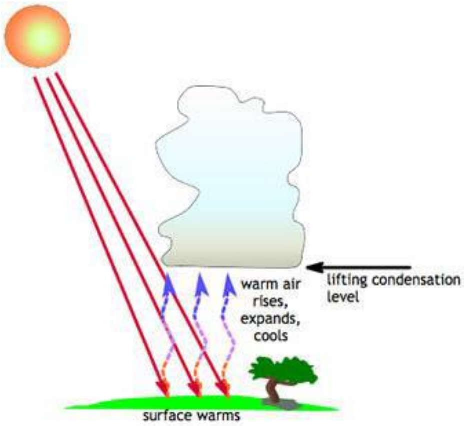
The phase transitions do not occur at equilibrium. But occur in the presence of strong free energy barrier.

•As solar radiation heats the ground and the air immediately above it, the warm air becomes lighter and moves upward.

•As warm air rises up - it expands and cools.

•Water vapor condenses to liquid form (At this point, the air is said to be "saturated" with water vapor) and soon clouds form — composed of countless billions of tiny water droplets or ice crystals.

Saturation is defined as the equilibrium at which the rates of evaporation = condensation



Condensation:

As water vapour rises in the atmosphere and cools enough, it changes back into liquid. This process of water vapour changing to liquid is called condensation. When water vapour condenses - clouds form.

The air should be saturated and cannot hold any more water vapour, this can happen in two ways:

•The amount of water in the air has increased - to the point that the air cannot hold any more water.

•The air is cooled to its dew point (the point where condensation occurs) and the air is unable to hold any more water.

The height at which dew point is reached and clouds form is called the condensation level. This is the initial stage of condensation.

Cloud Droplet Growth by Condensation

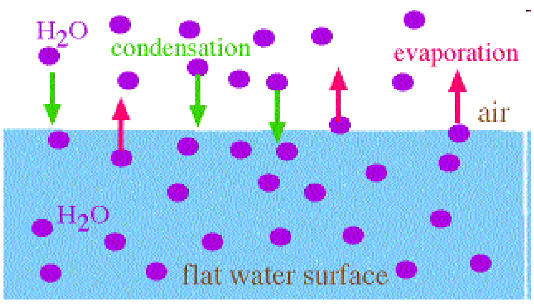
Consider pure water in equilibrium with air above it, then RH = 100%

i.e. ., evaporation = condensation

vapor pressure (e) = saturation vapor pressure (es)

Now, a droplet surface is not flat, instead, it has curvature.....

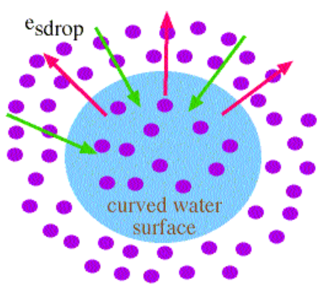
How does curvature affect the evaporation/condensation process??



Curvature effect

More energy is required to maintain the "curvature" of the drop. Therefore,

- the water molecules on the surface of the drop have more energy
- they evaporate more readily – than that from the flat water surface
- evaporation rate off curved surface > evaporation rate off flat surface

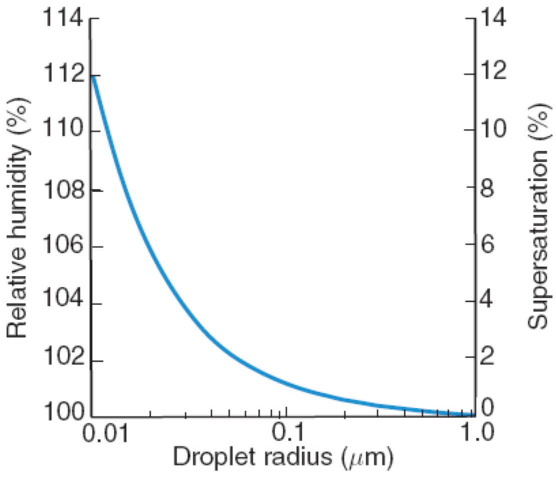


But, since air above both the surfaces is saturated, then evaporation rate = condensation rate

condensation rate onto droplet > condensation rate onto flat water surface therefore, $es_{drop} > es_{flat}$

if RH_{flat} = 100% then RH_{drop} > 100%

The air surrounding the drop must be supersaturated. This is called the curvature effect. The important point to note is that small cloud droplets have a greater curvature and hence have a greater rate of evaporation. To stop them evaporating, smaller droplets require an even greater vapour pressure (i.e. higher supersaturation).



Small droplets (0.2 mm) require supersaturations on the order of 1% (i.e. RH=101%) to start growing - but this level of supersaturation is rarely seen

If we define the saturation vapour pressure with respect to a plane water surface, then to get condensation onto a small water droplet the air must be supersaturated.

To form the smallest droplets of pure water by condensation - supersaturation of about 300% is required. This never happens.

Instead these droplets are formed by condensation around small particles which are thus called condensation nuclei (Aitken nuclei). There may be 103 - 109 such nuclei per cm3. These particles may be salt from sea spray, or particles of pollutants.

Condensation nuclei

Atmosphere contains significant concentrations of particles of micron and submicron size which have affinity for water and serve as centres for condensation. These particles are called condensation nuclei.

Examples: Dust and pollutants (aerosols), even sea salt provide nucleation sites for water vapor in the atmosphere to form clouds.

Nucleation of cloud droplets

HOMOGENEOUS NUCLEATION

Homogeneous nucleation occurs when the water vapor molecules condense and form a cloud droplet. To do this requires an environmental temperature of -40C and saturated air, or relative humidity of several hundred percent.

HETEROGENEOUS NUCLEATION

It turns out that saturating the air is not always enough to form a cloud. The water vapor molecules need a site (foreign substance) to condense on. This site is called a Condensation Nuclei and the process is called heterogeneous nucleation.

Many different types of CN are present in the atmosphere.

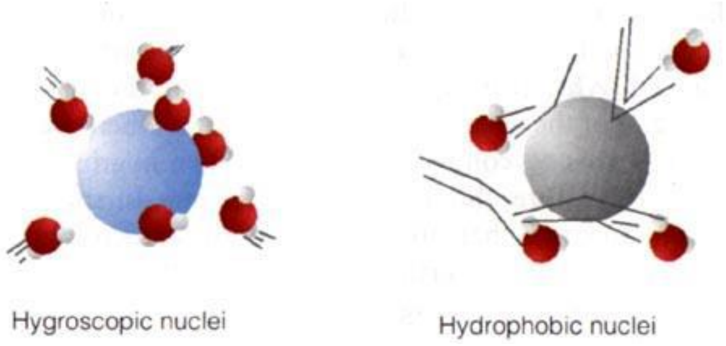
Droplets can form and grow on aerosol at much lower supersaturations than are required for homogeneous nucleation

Aerosol which serve as the nuclei upon which water vapor condenses in the atmosphere is called cloud condensation nuclei (CCN).

CCN types:

Hydroscopic (hydrophilic) – water seeking, water vapor readily condenses on it .

Hydrophobic – water repellant – water vapor does not readily condense on these

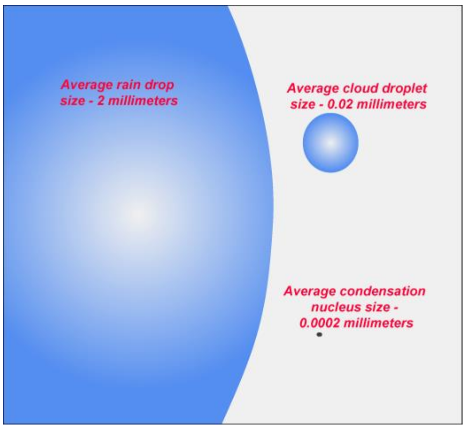


A particle that will serve as CCN is called hygroscopic or hydrophilic –condensation may occur at RH <100%

•A particle that will not serve as a CCN is called hydrophobic. –condensation may occur at RH >100%

•CCN Sources may include: –dust, volcanoes, factory smoke, forest fires, sea salt

CCN - Described by the size of the particle



Classification	Size
Aitken particles	$r < 0.1\mu m$
large particles	$0.1 \leq r \leq 1\mu m$
giant particles	$r > 1.0\mu m$

where r is the radius of the aerosol particle.

Near the earth's surface, continental air masses are generally significantly richer in CCN than are marine air masses. Concentrations of CCN over land decreases with height. Concentrations of CCN over the ocean remain fairly constant with height.