Numerical Weather Prediction (NWP)

Parameterization and physical processes:

Basic concepts of Planetary boundary layer, Land surface processes, Convection (Deep cumulus and shallow convection), Large scale condensation, Radiation (short wave and long wave parameterization), Cloud Radiation interaction, Dry and moist convective adjustment processes, Cloud microphysical parameterization

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Questions from last class:

Q1: “Capping Inversion”: Why the term “inversion” ?

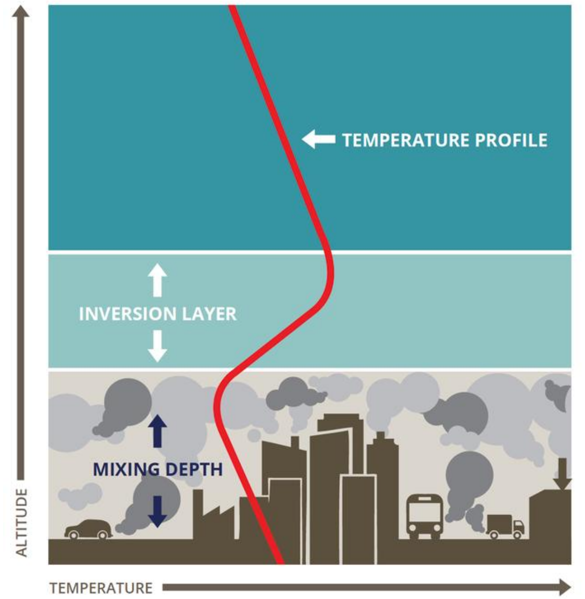
Q2: PBL height over the Himalaya ?

Q3: Can PBL reach to tropopause?

Basic concepts of Planetary boundary layer

Capping inversion: A stable layer between the boundary layer below and the rest of the troposphere above (free troposphere).
This stable layer traps turbulence, pollutants, and moisture below it and prevents most of the surface friction from being felt by the free atmosphere.

An **inversion** occurs when the normal temperature (warm air below, cold air above) profile is reversed, creating a stable configuration of dense, cold air sitting below lighter, warm air. An elevated inversion layer is thus a region of warm air above a region of cold air.



Source: Clovis Online School, Lesson 7-03 Temperature Inversions; cosscience1.pbworks.com

A **capping inversion** occurs when there is a boundary layer with a normal temperature profile and the layer above that is an inversion layer (cooler air below warm air). Cloud formation from the lower layer is "capped" by the inversion layer. If the capping inversion layer or "cap" is too strong (too close to the surface), it will prevent thunderstorms from developing. A strong cap can result in foggy conditions.

However, if the air at the surface is unstable enough, strong updrafts can be forced through the capping inversion. This selective process of only allowing the strongest updrafts to form thunderstorms often results in outbreaks of severe weather.

How does this capping inversion form?

At night, in the clear sky condition, the ground loses heat rapidly and the air in contact with the ground becomes colder (radiation cooling). The relatively warmer air (lighter) rises and acts as a lid, trapping the colder air (heavy) close to the ground.

Q2: PBL height over the Himalaya ?

➔ PBL height over Himalayan mountains can vary due to multiple reasons. The heterogeneities in the region can imparts mountain-induced turbulence and associated heat and moisture transport can be very different than surface.

Q3: Can PBL reach to tropopause?

➔ It is unlikely for PBL to reach up to tropopause.

Sample questions:

1) What is capping inversion?
2) What makes boundary layer well-mixed?
3) What roles turbulence play within the boundary layer?
4) Why does nature produce turbulence?
5) The depth of the PBL is same everywhere. True or False

Clouds, moist convection and Convective Parameterization

How does Clouds influence the Earth-atmosphere system?

What comes to the mind when we talk of moist convection?

Why is it important and what are the different types of moist convection?

Moist process-A multi-scale problem

What is convective parameterization and why is it necessary?

Point of uncertainties in convective parameterization

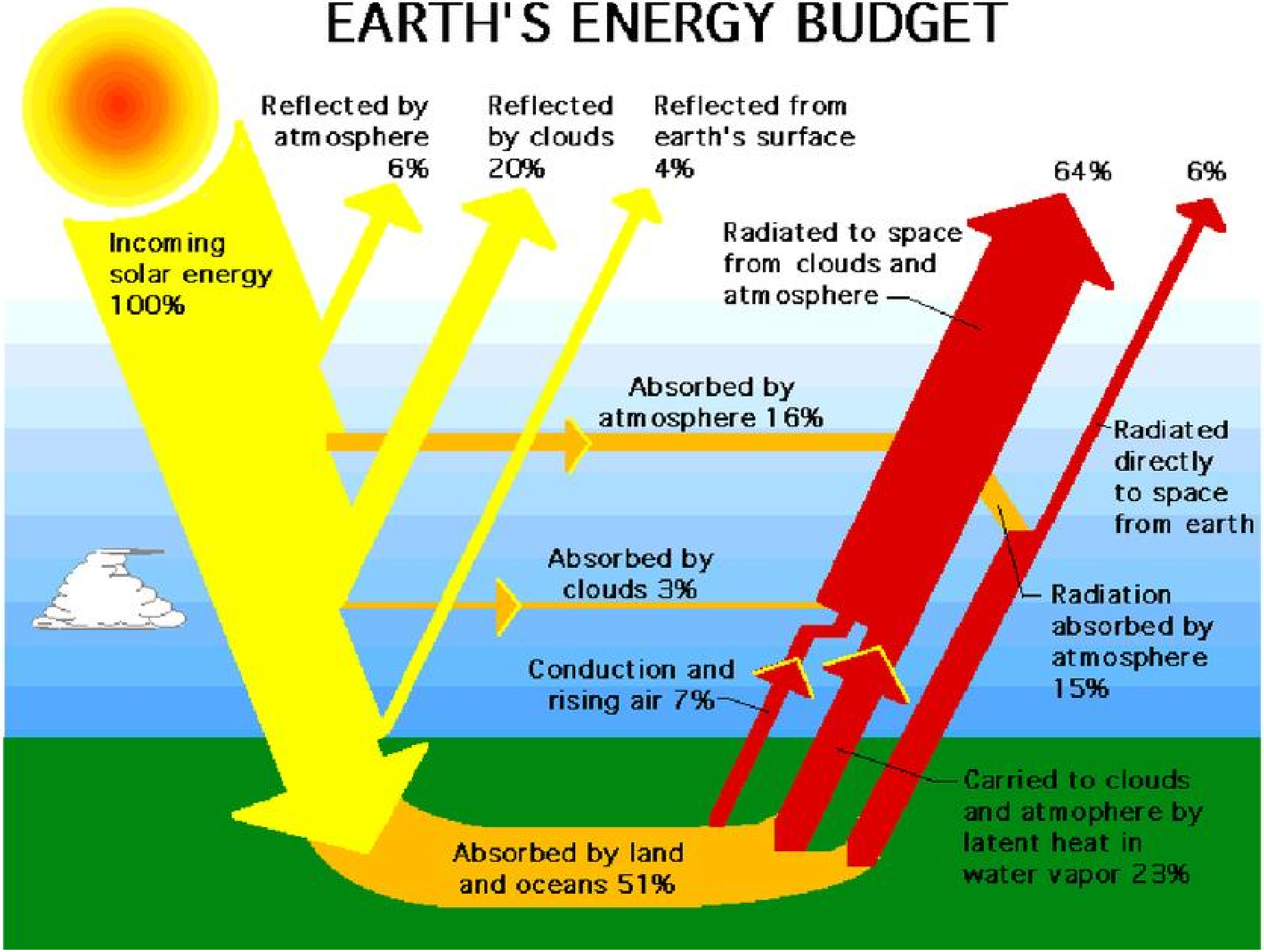
Few well known schemes: KUO scheme, Arakawa-Schubert,

How does Clouds influence the Earth-atmosphere system?

At any given time clouds cover between 60% and 70% of the globe. Clouds exert various influences on the Earth–atmosphere system, of which the most important are:

- modification of the radiative fluxes in the atmosphere and at the Earth's surface
- release and consumption of latent heat related to phase changes of water either directly inside the clouds or in precipitation generated in them
- transport of heat, moisture, momentum and atmospheric trace constituents over large distances in the vertical in convectively generated clouds
- modification of the surface hydrology through precipitation generated in clouds.

EARTH'S ENERGY BUDGET

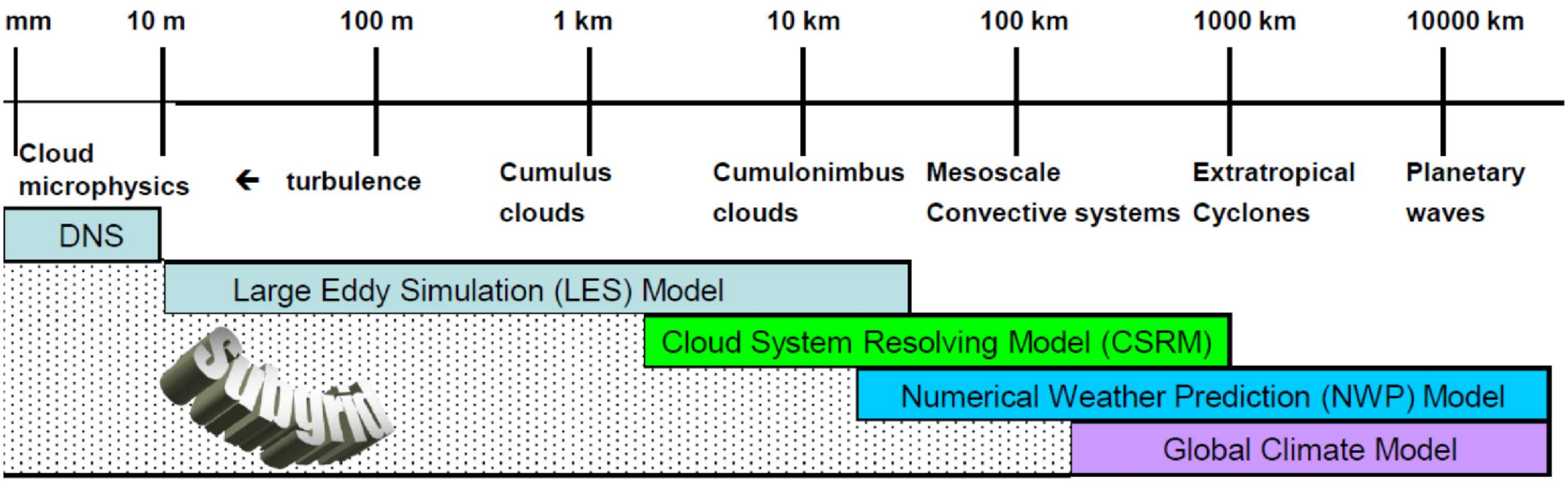


What comes to our mind when we think of moist convection?

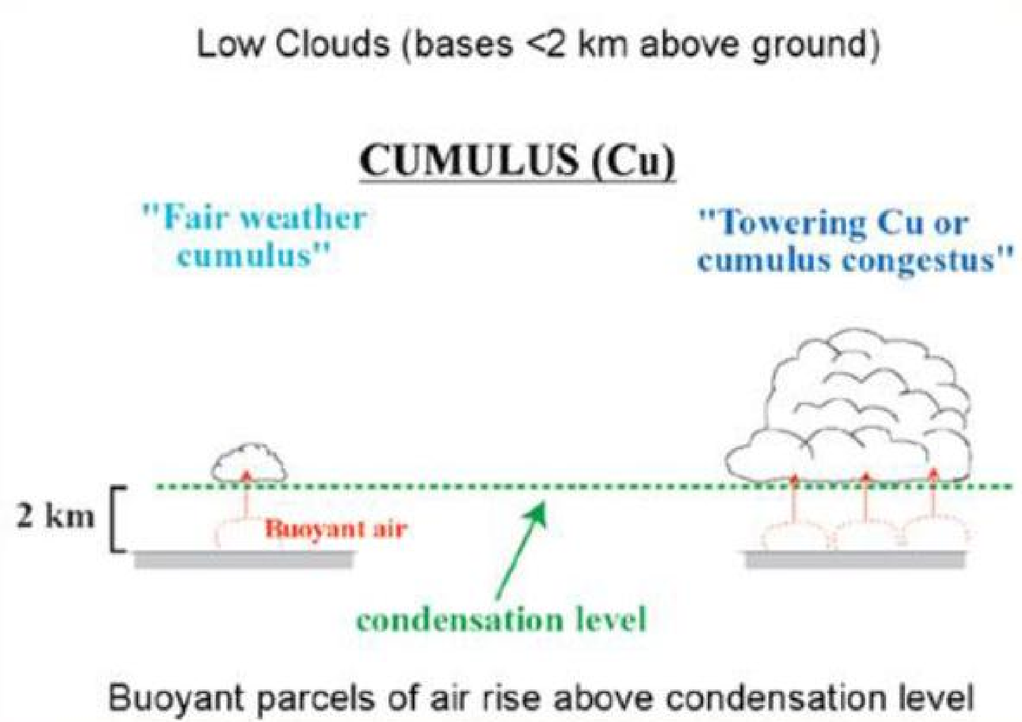
- **It could be severe thunderstorms with strong and gusty wind, heavy rain, lightning etc.**
- **Sometimes these storms can merge to form lines of organized deep convective storms with trailing stratiform rainfall regions.**
- **It could be stratocumulus seen near coastline or stratus cloud producing light rainfall over a large area.**

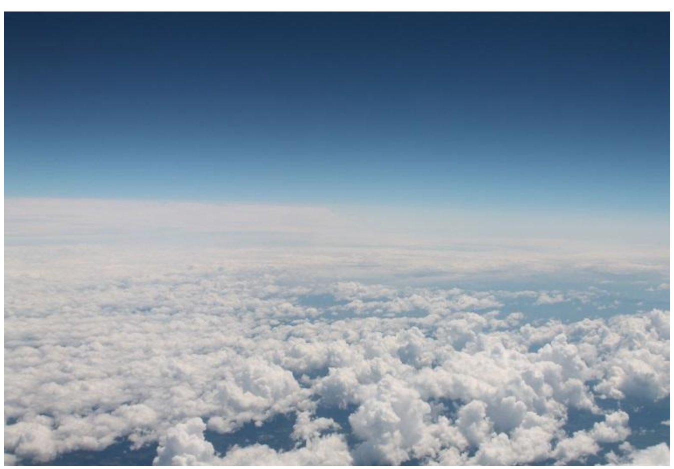
Thus convection varies widely in shape and sizes and its manifestation is seen in the atmosphere in the form of clouds of different shapes and sizes.

No single model can encompass all relevant processes



Different types of clouds and its properties





Cumulus clouds are detached, individual, cauliflower-shaped clouds usually spotted in fair weather conditions. The tops of these clouds are mostly brilliant white tufts when lit by the Sun, although their base is usually relatively dark.

All cumulus clouds develop because of convection. As air heated at the surface is lifted, it cools and water vapour condenses to produce the cloud. Throughout the day, if conditions allow, these can grow in height and size and can eventually form into cumulonimbus or cumulus congestus clouds.

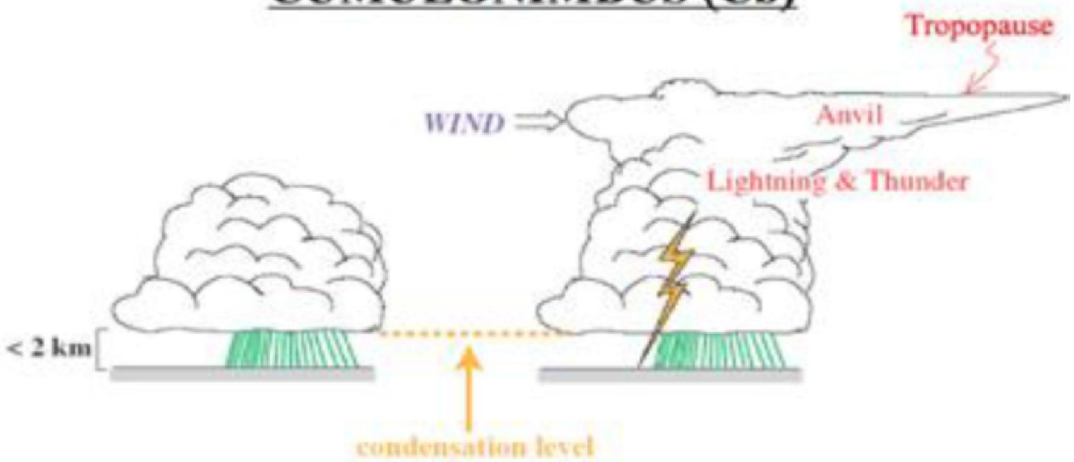
Cu clouds are non-precipitating but can produce showers when grows into congestus or cumulonimbus clouds.

They plays an important role in radiation budget by reflecting incoming solar radiation

Along coastlines, cumulus may form over land during daylight hours as a sea breeze brings in moist air, which is then warmed by the surface. This effect reverses overnight as the sea becomes warmer than the land and cumulus form over the sea.

Low Clouds (bases <2 km above ground)

CUMULONIMBUS (Cb)



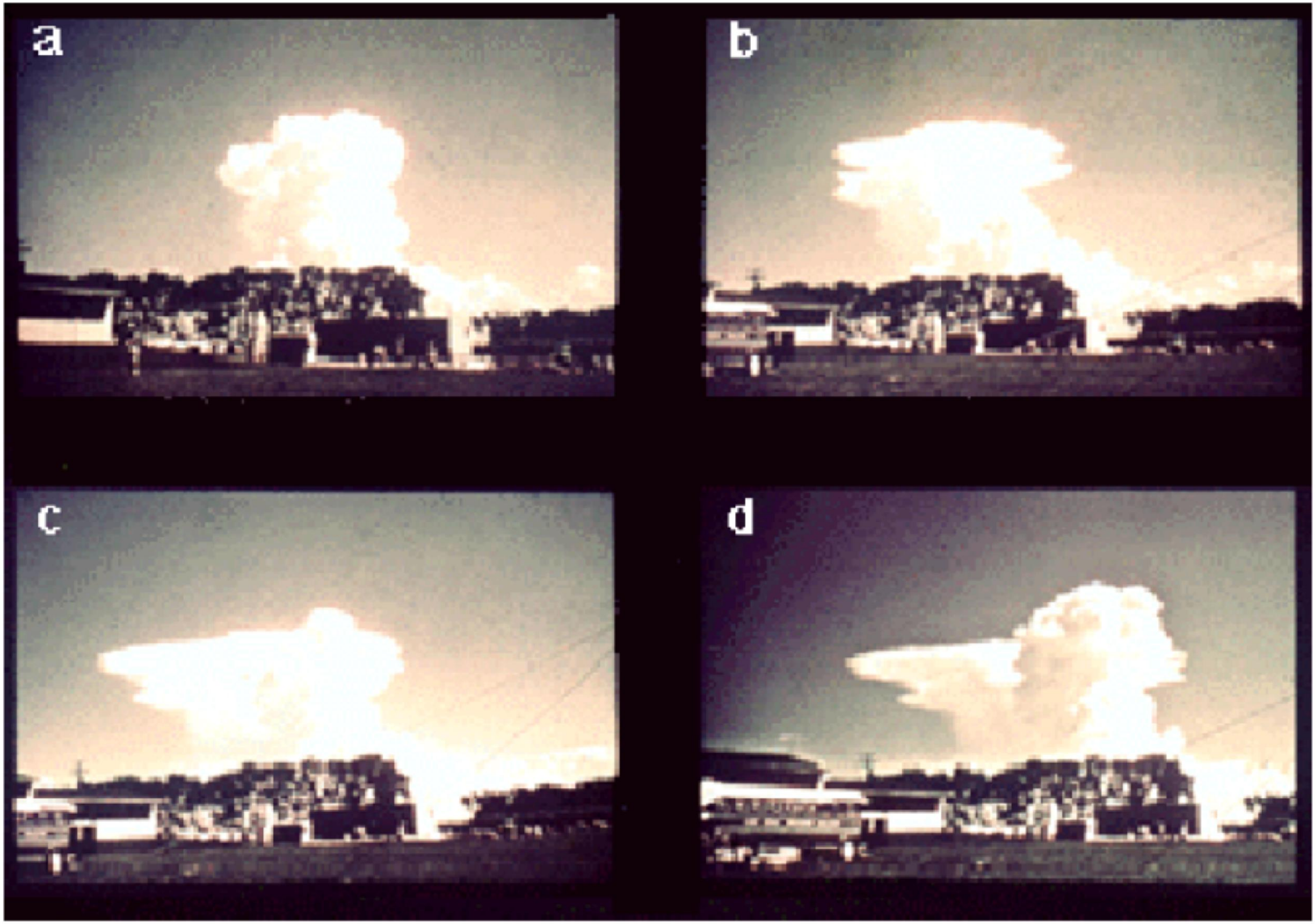
Nimbus means precipitating--particles have grown large enough to fall below cloud base

Cumulonimbus clouds are menacing looking multi-level clouds, extending high into the sky in towers or plumes. The base of the cloud is often flat, with a very dark wall-like feature hanging underneath, and may only lie a few hundred feet above the Earth's surface.

Cumulonimbus clouds are born through convection, often growing from small cumulus clouds over a hot surface. Due to lower level moisture convergence, the instability in the atmosphere grows, large vertical velocity carries the moisture upward which condensed and release latent heat making the atmosphere more buoyant

Cb clouds are associated with extreme weather such as heavy torrential downpours, hail storms, lightning and even tornadoes.

Cb clouds are the final form of growing cumulus clouds


a
b
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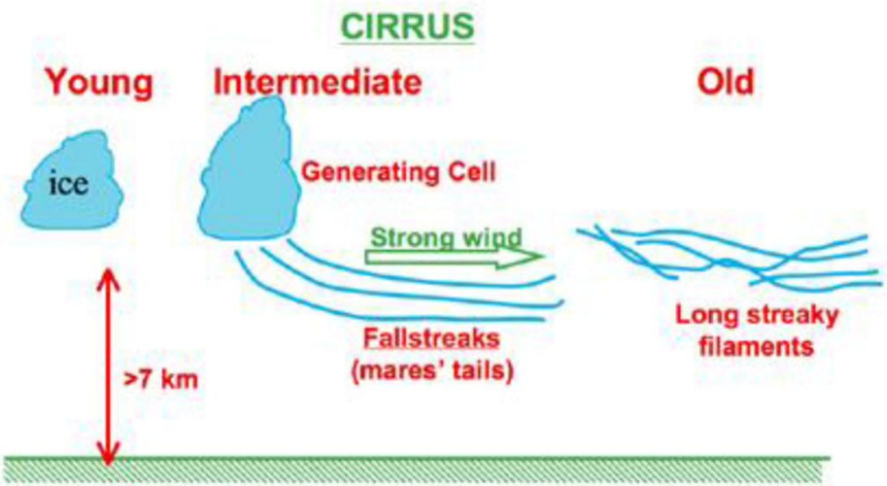
d

High clouds (bases >7 km above ground)



Cirrus (Ci) clouds are short, detached, hair-like clouds found at high altitudes. These delicate clouds are wispy, with a silky sheen, or look like tufts of hair. In the daytime, they are whiter than any other cloud in the sky.

Ci form from the ascent of dry air, making the small quantity of water vapour in the air undergo deposition into ice (to change from a gas directly into a solid). Cirrus is made up completely of ice crystals, which provides their white colour and form in a wide range of shapes and sizes.

They often form in advance of a warm front, where the air masses meet at high levels, indicating a change in the weather is on the way.

Technically these clouds produce precipitation but it never reaches the ground. Instead, it re-evaporates.

Sample questions:

1) What is the cloud-base height of Cumulus clouds ?
2) How does Cu clouds form?
3) Cloud base height of Cumulus and cumulonimbus clouds are different. True or False
4) What type of rainfall occurs from Cb clouds?
5) What types of clouds acts as a bridge between Cu and Cb cloud?
6) During day time, cumulus clouds formed over Ocean. True or False
7) What is the cloud-base height of Cirrus cloud?
8) How does Ci cloud form?

Why is it important and what are the types of moist convection?

Moist convection is important to the prediction of atmospheric circulation for many reasons.

Large scale horizontal gradients of latent heating produced by deep moist convection help to drive large scale vertical circulations e.g. Hadley cell, Walker cell.

Deep convection also is a major component in ENSO and it can influence the seasonal climate in the northern hemisphere. The SST in the tropical eastern Pacific are warmer than normal, during ENSO. Associated with this, deep convection develops, releasing latent heating in a deep atmospheric column and producing upper level divergence. The upper level divergence excites Rossby waves that alter the hemispheric flow (Tribbia 1991).

Shallow convection

In contrast to deep convection, shallow cumulus clouds are the most frequently observed tropical cloud (Johnson et al.1999).

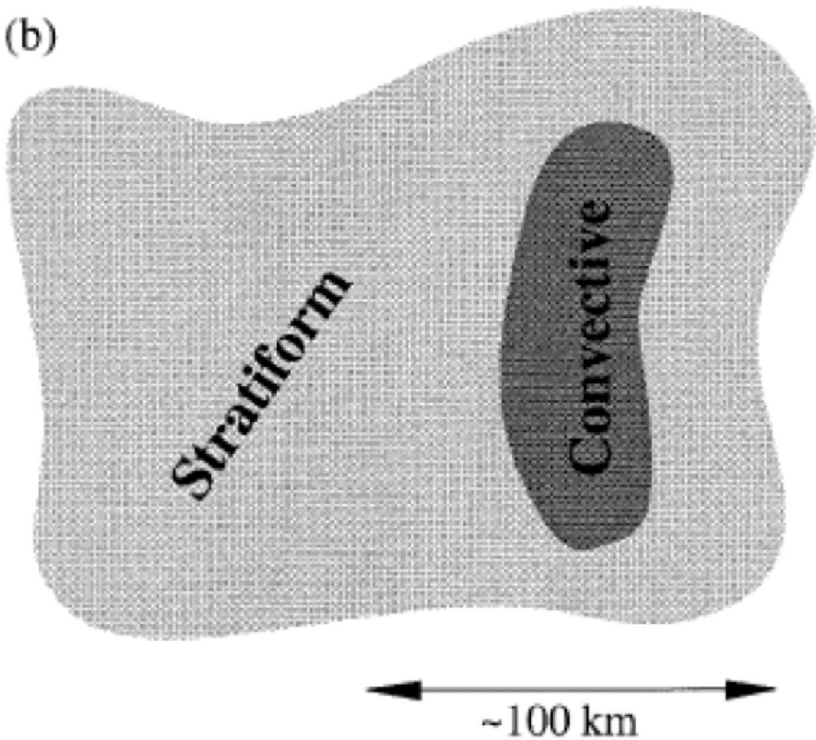
Shallow convection modifies the surface radiation budget, influences the structure and turbulence of the PBL and thereby also affect the global climate (Randall et al 1985).

Shallow convection also occurs in mid-latitude particularly when cold air moves over warm water. Shallow cumulus cloud develop over water which commonly align themselves in the form of bands or streaks (Houze 1993)

Stratiform convection

Deep convection can be further sub divided into convective and stratiform components (Houze, 1997, Chattopadhyay etal, 2009). The convective components refer to convection associated with individual cells, horizontally small regions of more intense updrafts and down drafts in association with young and active convection.

The stratiform component refers to convection associated with older, less active convection with vertical motion generally less than 1 ms^{-1}.



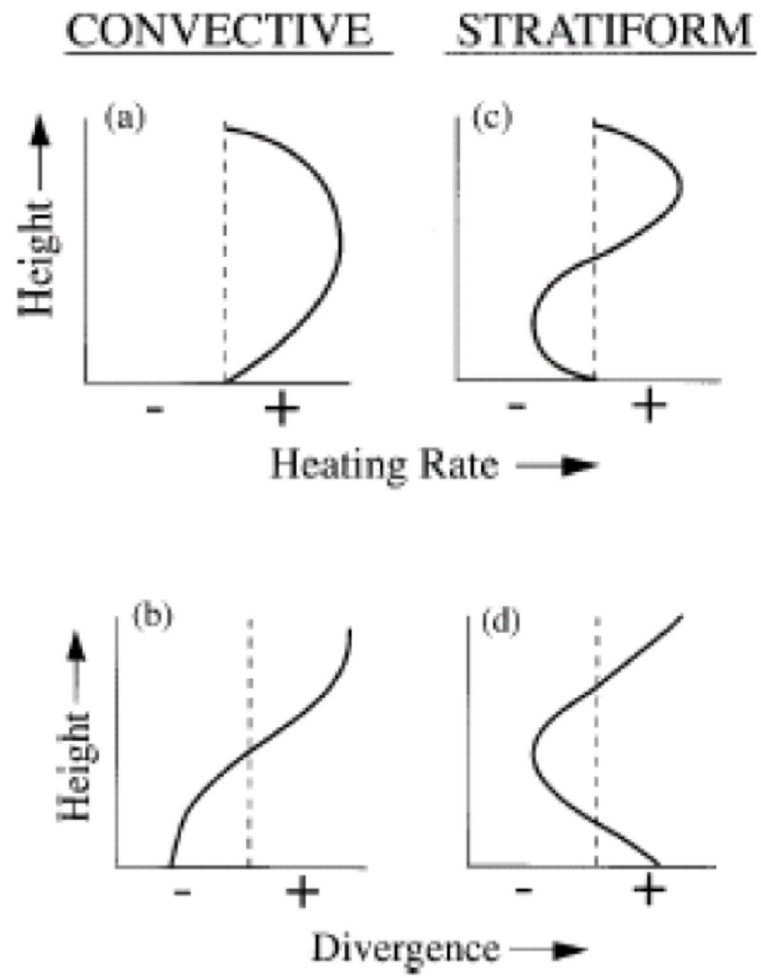


FIG. 3. Characteristic profiles of latent heating and horizontal mass divergence in convective and stratiform regions of tropical precipitation.

Multi-scale nature

- Essentially moist convection is comprised of two components namely convective and stratiform which has different spatio-temporal scale. This is the reason why convection is a multi-scale process.

- The present day challenge is to devise a scheme (parameterization) that can resolve the multi-scale nature of convection in a realistic way.

What is parameterization and why is it necessary?

The basic physical equations describe the behaviour of the atmosphere on small scales. From these we derive equations that describe the behaviour of the system on larger scales.

The large-scale equations contain terms that represent the effects of smaller-scale processes.

A “parameterization” is designed to represent the effects of the smaller-scale processes in terms of the large-scale state.

The Need for a Parameterisation

Convection is a sub-grid scale phenomenon. It cannot be explicitly computed (resolved) by an atmospheric model. Hence, it should be *parameterised*.