Course Notes
Cloud Identification
Part B

Template reference: CRS-SHEQ-TEMP-006
Version: 2

Document Reference:	RTC-CN-009.1
Document Type:	Course Notes
Version:	Version 4

Document Control

Version and Amendment Schedule

Version	Version Date	Author	Description of Amendments
001	04 May 2013	Colleen Rae	Documents references changed to RTC
002	26 January 2016	Colleen Rae	Course Notes enhanced
003	February 2019	Colleen Rae	Course Notes enhanced
004	May 2019	Colleen Rae	Course Notes enhanced

Compliance Schedule

Compliance Type Checked	Compliance Approved by:	Responsibility	Signature	Date of Compliance Approval
Documentation Compliance	Lithakazi Mkatshwa	Meteorological Trainer: Observations	[signature]	04/06/2019

Approval and Control Schedule

Approved By	Designation	Responsibility	Signature	Date Approved	Copy Status
Dr. W. Jordaan	Head of the RTC	Head of the RTC			E

Table of Contents

CHAPTER 1 The causes of cloud formation

Most clouds are formed when moist air is subjected to upward motion. In doing so, it cools as the result of the expansion that takes place at the lower pressures in the upper atmosphere. Some of the water vapour then condenses to form a cloud. The shapes and forms of clouds are really expressions of the way in which the air has risen to fashion them.

The various types of vertical motion that lead to the formation of clouds are as follows:

(a) Mechanical turbulence (or frictional turbulence or turbulent mixing)
(b) Convection (or thermal turbulence)
(c) Orographic ascent
(d) Slow widespread ascent
(e) Frontal ascent

1.1 Cloud Formation due to Mechanical Turbulence

- Air flow over the Earth's surface is generally deformed by frictional forces into a series of eddies.
- This turbulent motion is accentuated by buildings, trees, hills, etc.
- If the layer is initially stable, the surface will cool and will be cooler that the air a few hundred meter above the surface
- A surface inversion will form and the air below it will be stable.
- If moisture is present, the turbulence mixes the water vapour below the inversion layer and the water vapour content tends to become evened out.
- Condensation may then occur at a height above the ground known as the mixing condensation level (M.C.L). This will represent the base of the cloud.
- If cloud forms due to turbulence, the dry adiabatic lapse rate will only extend up to its base (M.S.L).
- The saturated adiabatic lapse will then extend to the top of the turbulent layer.
- The cloud extends upwards to the base of the turbulence inversion at the upper limit of the friction layer.
- The cloud formed by turbulence is initially **Stratus**, a sheet cloud without definite form ands appears smooth and uniform.

This is depicted in Figure 1.1 below.

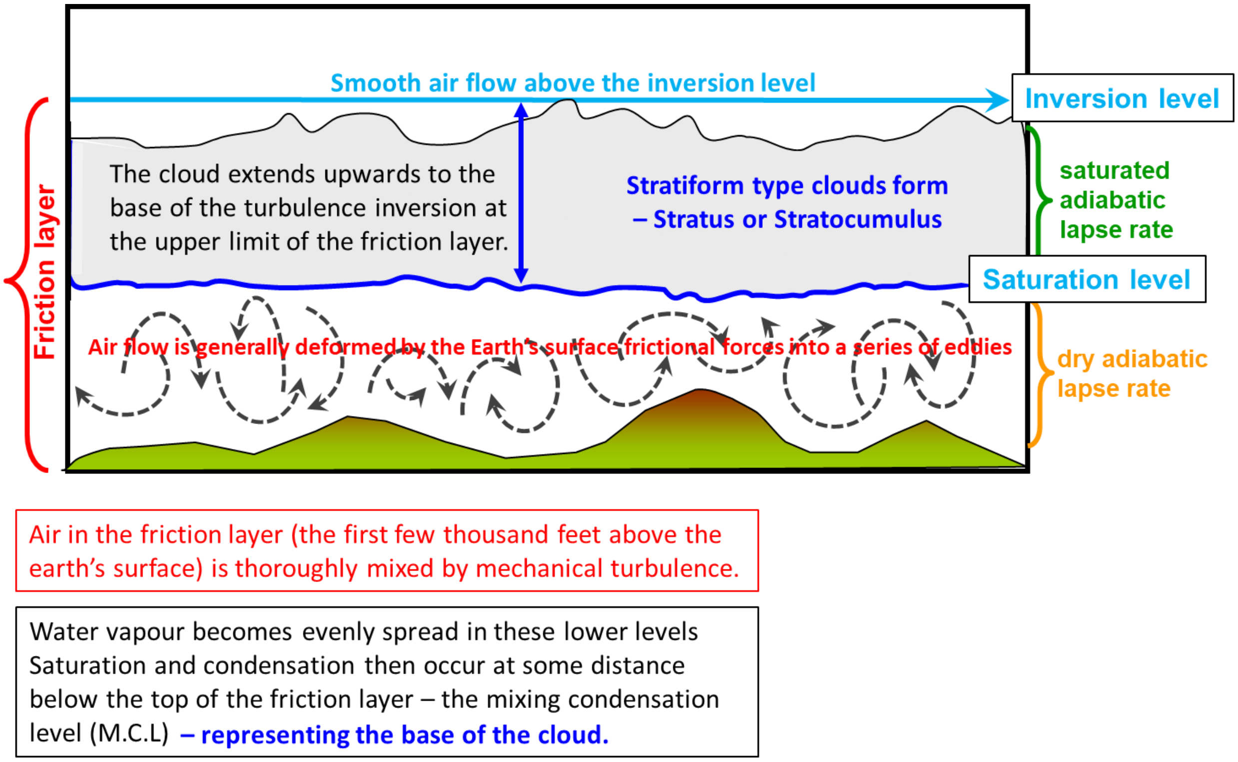


Figure 1.1 Clouds formed due to Mechanical Turbulence

- **If the wind speeds increase slightly to approximately 6 knots**, the upper and lower surface may develop a wave-like appearance.
- When these undulations occur, the thickness of the cloud may then vary, and sometimes breaks may be seen.
- These arise as a result of cloud being formed in the up-currents, and evaporated in the down-currents – this cloud is then classed as **Stratocumulus stratogenitus**..

This is depicted in Figure 1.2

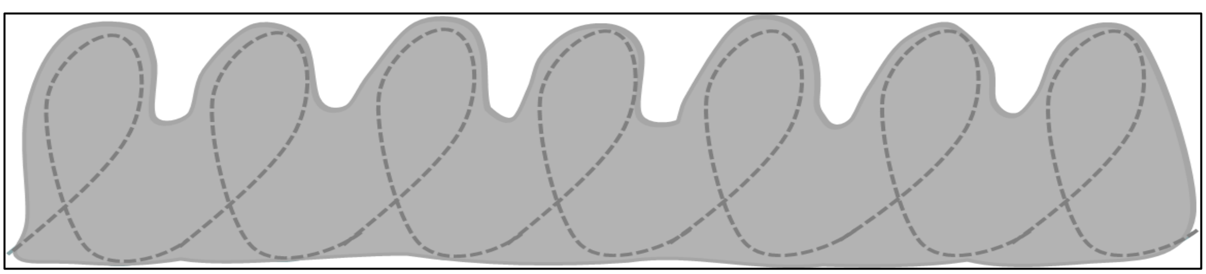


Figure 1.2 Undulations due to stronger wind speeds

1.1.1 Turbulent clouds forming below rain-bearing clouds

Over and above the formation as depicted in Figures 1.1 and 1.2, **Turbulent clouds** may also develop below rain-bearing clouds (see Figure 1.3 below) such as:-

> Nimbostratus
> Altostratus
> Cumulonimbus

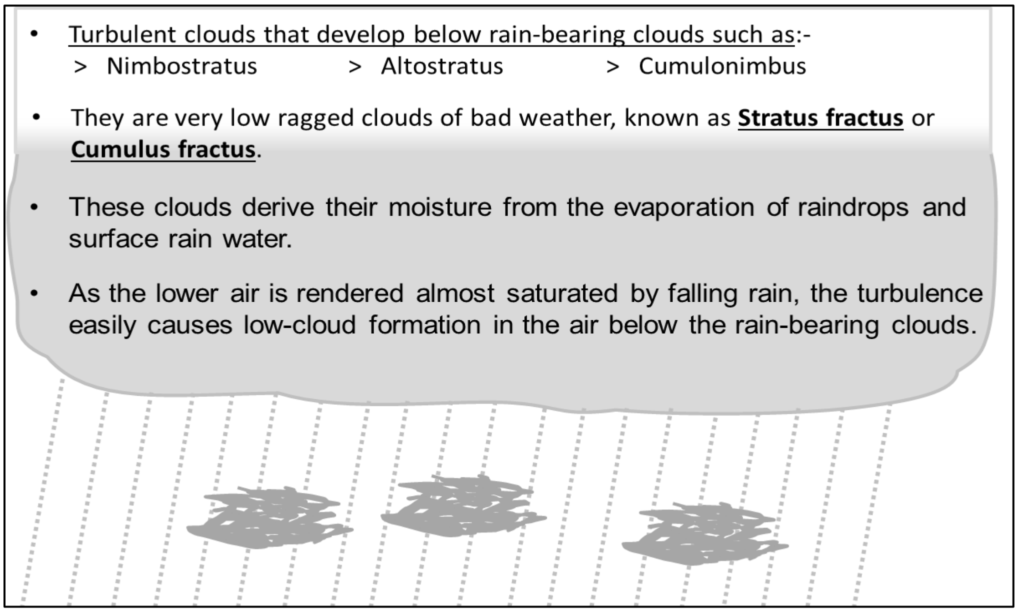


Figure 1.3 Turbulent cloud formation

The word "fractus" means "broken". Sometime the prefix "fracto" is used with the same meaning. Thus, the low broken clouds are referred to as fracto-stratus and fracto-cumulus respectively.

1.1.2 Turbulent clouds forming at night

Turbulent cloud may form at night after a clear day, as a result of cooling and the associated rise in relative humidity.

This is particularly so with air coming from the sea; the relative humidity is then often high so that only slight cooling is required to produce clouds, while the increased turbulence over the land due to its greater roughness is another favourable factor.

1.1.2 Other Turbulent clouds occurance

Sometimes high Stratocumulus or Altocumulus are observed when the wind changes with height through a humid layer, high above the friction layer. Turbulent motion may then occur at these heights, but usually some other factor is responsible for the high water vapour content.

The moisture has not been transferred to that level by direct mixing due to turbulence near the Earth's surface.

1.2 Convection

When air is heated near the surface, convection currents develop. This process is known as convection or thermal turbulence.

In general, the environment lapse rate tends to equal the dry adiabatic lapse rate, while the air remains unsaturated.

This lapse rate may be established up to the convection condensation level where cloud will form. However, the extent of its upward development depends on a number of factors. *One is the environment lapse rate in the air above the cloud base*.

If the environment lapse rate is greater than the saturation adiabatic lapse rate, the atmosphere is unstable for saturated parcels of air. The saturated air is then forced to rise. It continues to rise until it reaches a level where it is no longer warmer than its surroundings.

A cumuliform cloud develops in this way. Convection clouds of limited extent are fair-weather Cumulus. Their vertical development is insufficient for precipitation to occur.

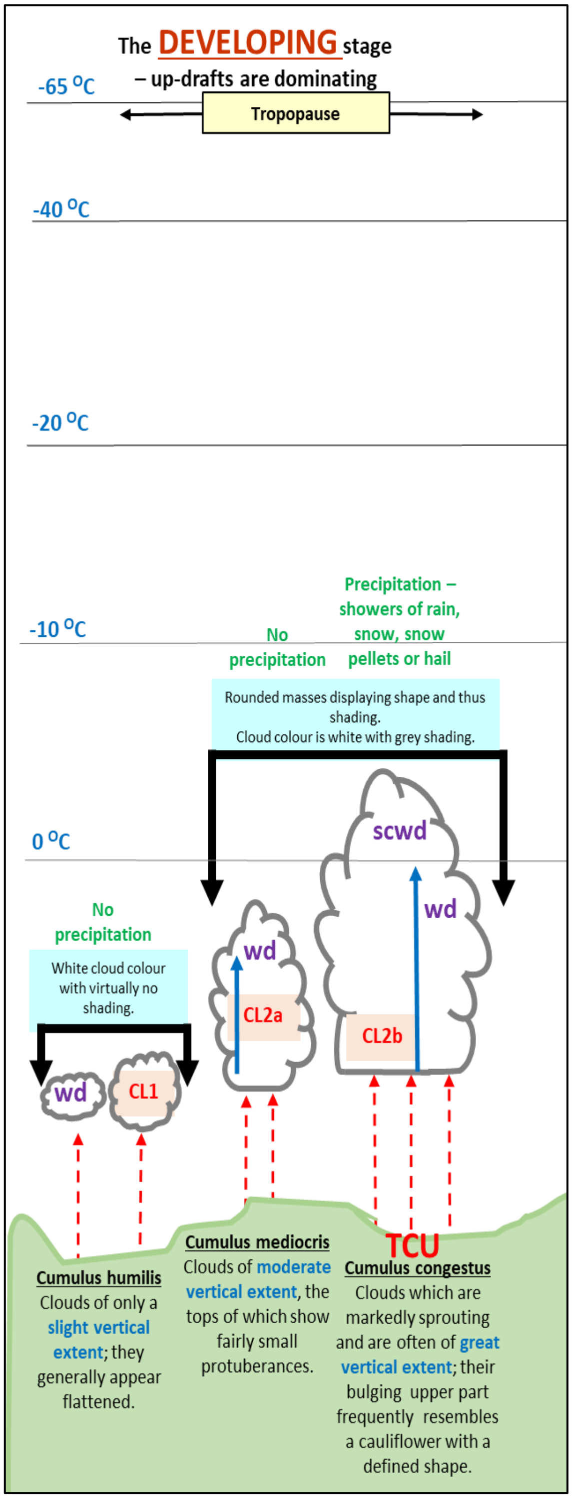


Figure 1.4 Development stage

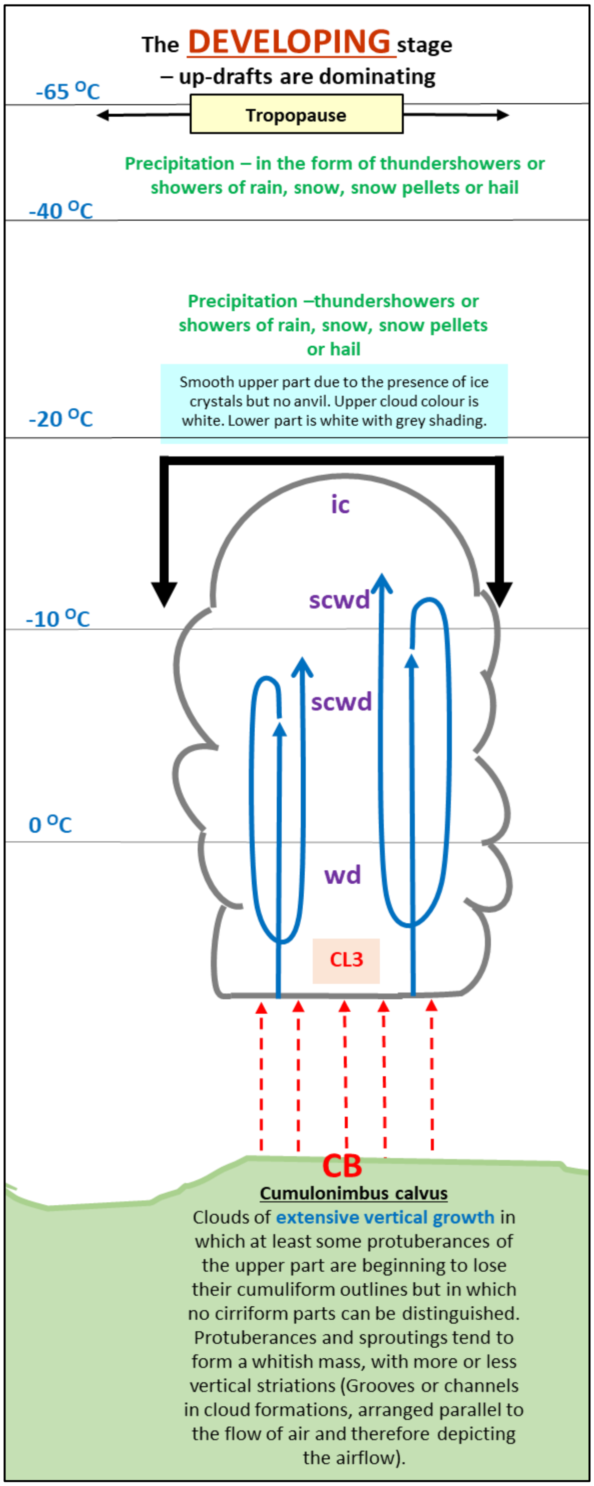


Figure 1.5 Final developing stage

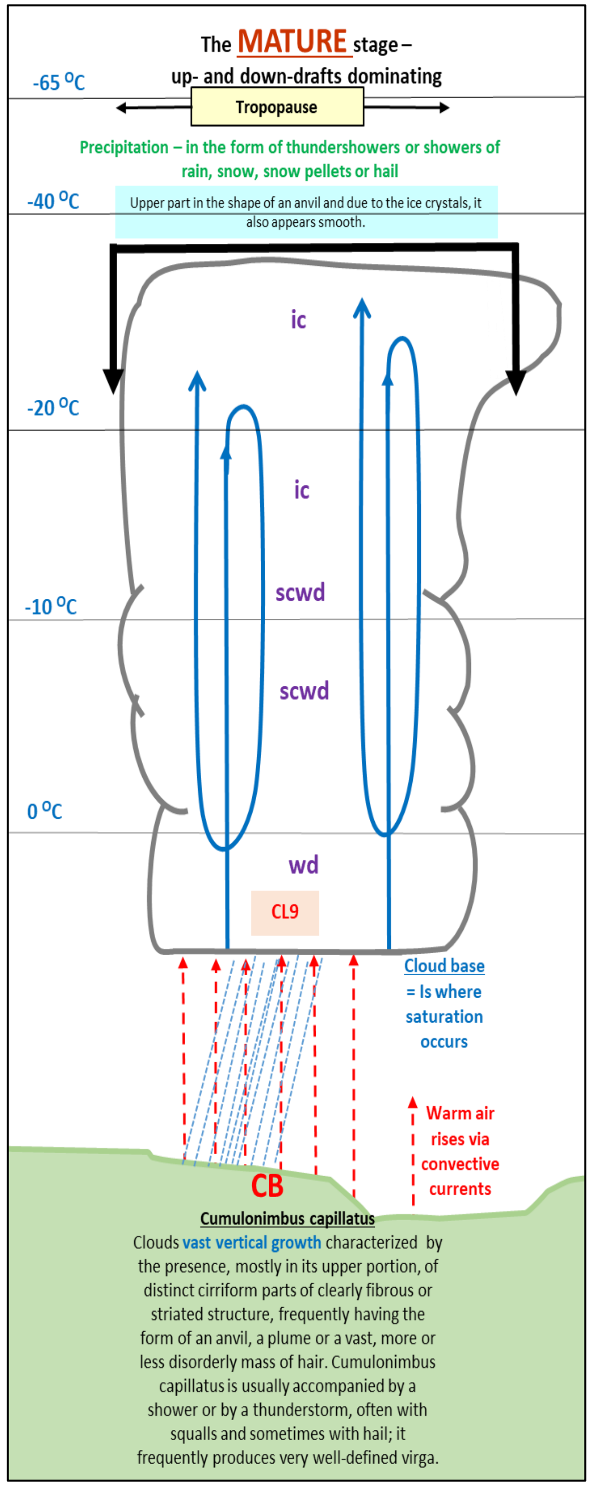
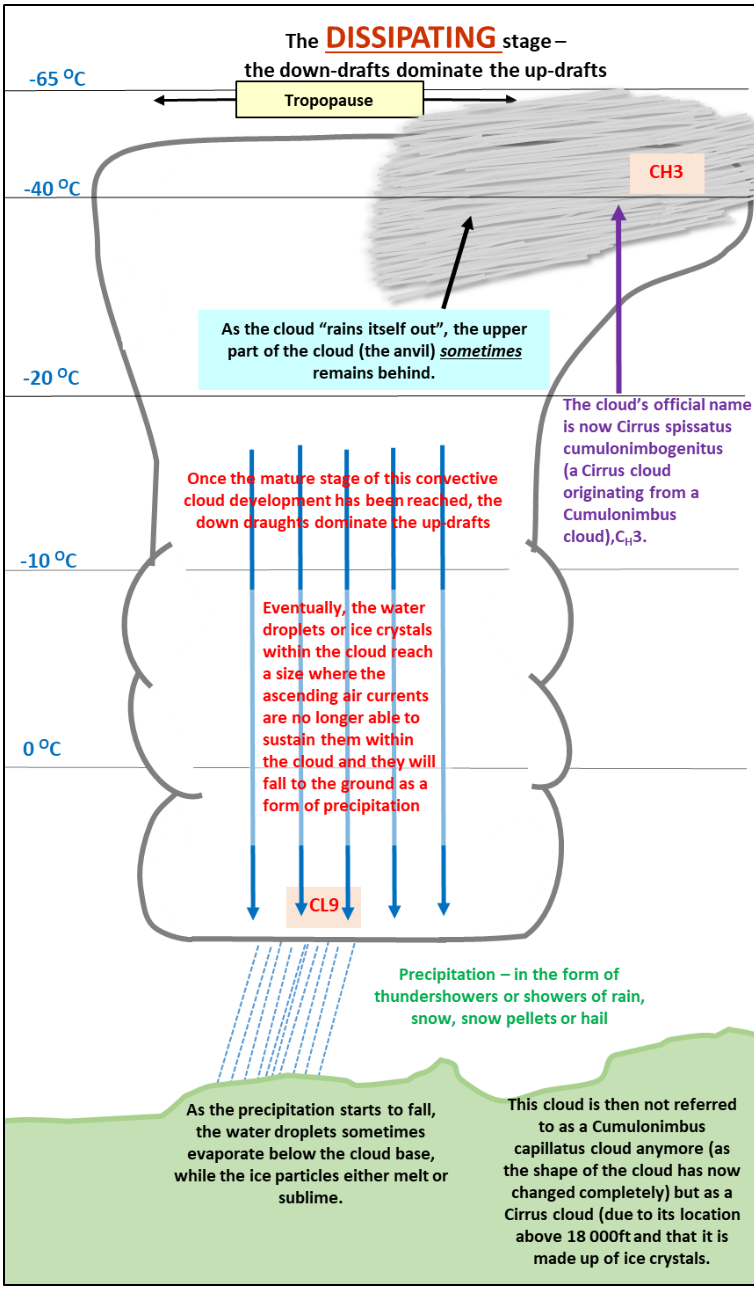


Figure 1.6 Mature stage

If sufficient moisture is available the cloud may then extend to great heights.
The distance from the base to the top may vary from 3000 to 6000 ft to 30 000 ft or more. They often reach a greater height in the tropics then elsewhere – this is due to the higher tropopause and so cloud tops extending to a height of 48 000 ft or more are not uncommon.



A convection cloud of great vertical extent whose top is composed of ice crystals is known as Cumulonimbus (the thunder-storm cloud).

The tops of the clouds reach levels where ice crystals form. The veil of ice crystals that surrounds the upper parts of the cloud gives it a smooth fibrous appearance, **which distinguishes it from a Cumulus cloud.**

Slight or heavy precipitation may develop according to the degree of instability and to the height and temperature reached.

Vertical velocities in up-currents may exceed 10 m s^{-1}, and temporarily prevent even the largest raindrops from falling downwards. Later, they may be released if the vertical currents are interrupted. A violent rainstorm or cloud burst may then occur.

Figure 1.7 Dissipating stage

During showers, ragged turbulence cloud may develop below the main base, occasionally almost reaching the earth's surface.

On reaching a stable layer or inversion the top of the cloud may spread out horizontally. The well-known anvil shape of the top of a cumulonimbus clouds develops in this way. Sometimes the vertical currents are terminated by a marked inversion above the convection condensation level. The top of the cloud then spreads out beneath the inversion and the cloud develops into Stratocumulus.

1.3 Orographic Ascent

The interaction between moving air and a topographical obstruction

- When the air reaches the barrier, it is forced to rise both near the surface and at upper levels.
- A deep layer of the atmosphere may be affected and the vertical distribution of temperature will be altered.
- The air which has been forced to ascend cools adiabatically and clouds may form when sufficient moisture is present in the air.
- In general, orographic cloud forms continuously on the windward side of the hill or mountain, but clears on the leeward side.
- The cloud as a whole appears to remain stationary, but the air itself actually continues on its way to the other side of the mountain.

1.3.1 Unstable conditions

The type of cloud formed by orographic ascent depends on a number of factors, one of which is the stability of the air in which it is formed.

- **Cumulus** cloud is characteristic of air which is slightly **unstable**.
- ❑ If **instability** is established through a depth of the atmosphere, **Cumulonimbus** cloud may develop.

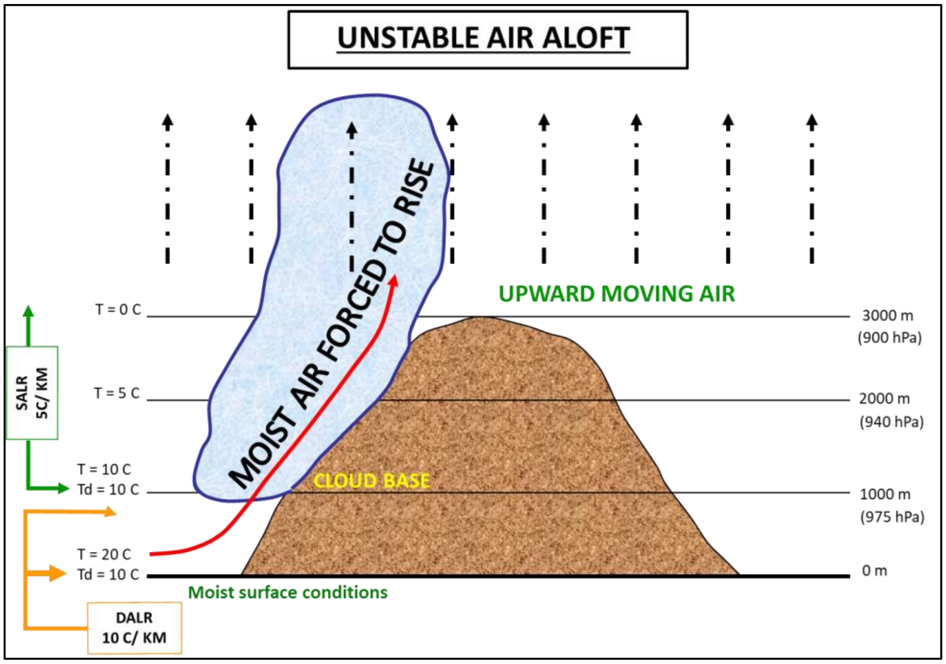


Figure 1.8 Orographic uplift under moist unstable conditions

1.3.2 <u>Moist stable conditions</u>

The type of cloud formed by orographic ascent depends on a number of factors, one of which is the stability of the air in which it is formed.

- In **moist stable** air **Stratus** is frequently formed - (with a flat base and generally of no great vertical thickness). It forms a sheet covering the higher ground, but breaks occur over lower-laying areas.
- The descent on the leeward side causes the air to warm and so the cloud dissolves rapidly.

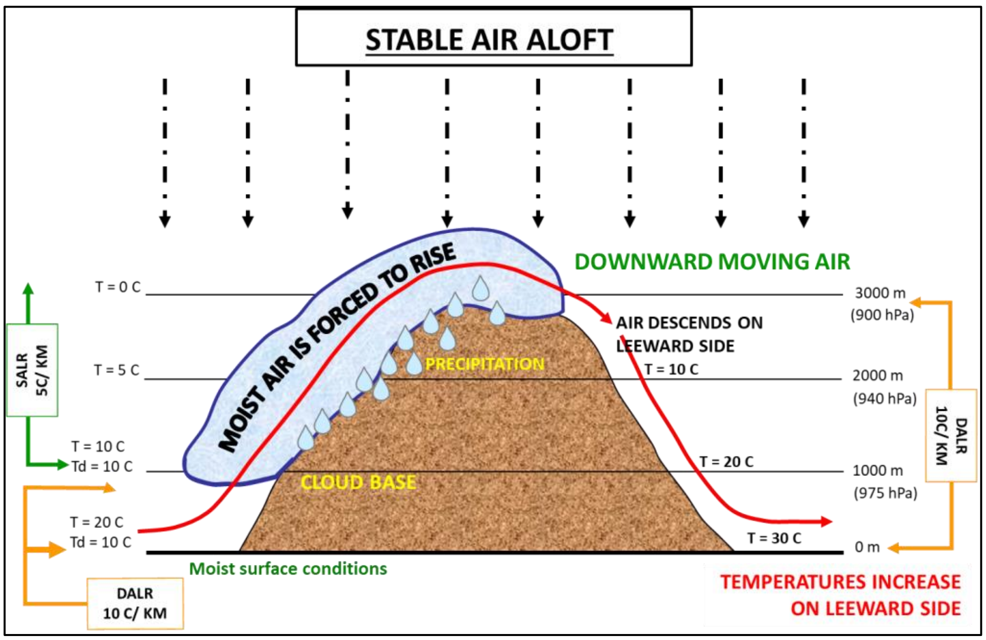


Figure 1.9 Orographic uplift under moist stable conditions

1.3.2 <u>Less moist stable conditions</u>

- When **stable** air is present with the atmosphere being less moist than previously discussed clouds will form at the height where condensation occurs – this can sometimes be at the top of or above the mountain itself.
- When there is a layer of almost saturated air aloft, orographic lifting of the air may cause condensation to occur above the obstruction. A persistent **cloud cap** may form.

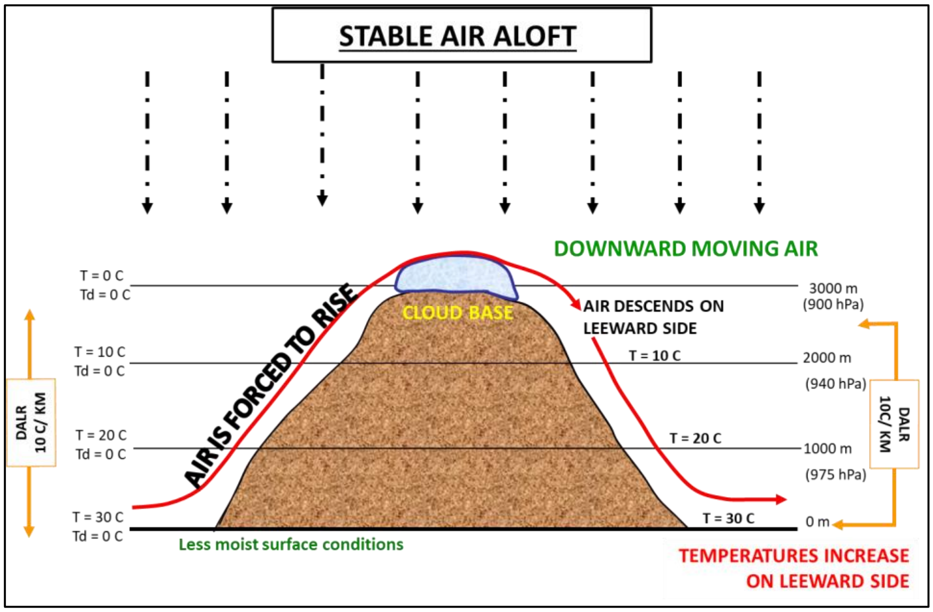


Figure 1.10 Orographic uplift under less moist stable conditions

1.3.3 <u>Stable conditions leading to lenticularis cloud formation</u>

Under certain conditions, when **<u>stable</u>** air is present with the atmosphere being fairly dry, lenticularis type clouds can be expected to occur.

<u>These conditions include the following</u>**:**

- ❑ A stable atmosphere
- ❑ Less moist surface conditions
- ❑ Wind perpendicular to mountain
- ❑ Wind speed 10 to 20 knots

- Viewed from below, the clouds are thin at the ends with a thicker and broader centre.
- Its shape is therefore similar to that of a lens, hence its name **<u>lenticularis cloud</u>**.

- **<u>Lenticular clouds</u>** appear to be stationary, just like the orographic clouds that form on the tops of the mountains.
- Actually, the water molecules and the other gases of the atmosphere stream through the cloud – at one end, the water molecules condense to form cloud; at the other end, they evaporate, changing back to the vapour state as they leave the cloud.
- Sometimes a series of stationary waves may be formed in the lee of a range of mountains.

- Further downstream from the mountain, the air ascends once more.
  This process is repeated many times, gradually decreasing with distance from the barrier – the particles of air therefore follow an undulatory path.
- **Standing waves** are then said to occur and can frequently affect the performance of aircraft.

- Conditions are most suitable for waves when a very stable layer lies between an unstable layer at the surface and another above with the waves often having their greatest amplitude within the stable layer.

- Lenticular clouds therefore indicate the presence of standing waves in the lee of mountain barriers.
- It is important to realise that the undulatory flow may still be present, even if the clouds are absent due to the low moisture content of the air.

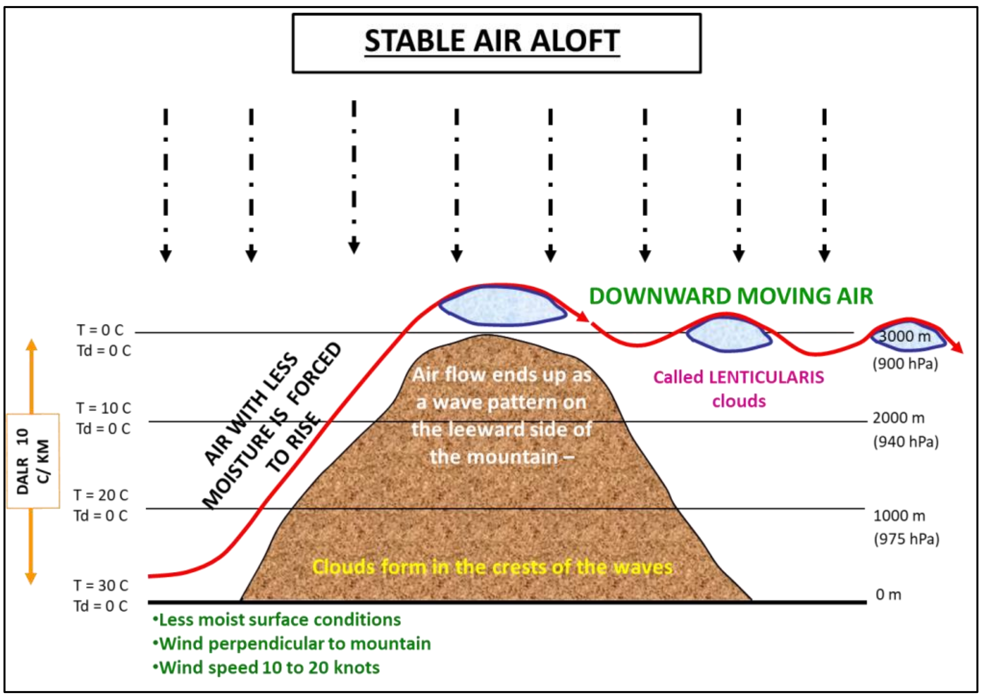


Figure 1.11 Orographic uplift under moist stable conditions

1.4 Slow Widespread Ascent

In previous sections, cloud formation occured from vertical motions associated with disturbances of relatively small horizontal dimensions. These vertical motions have been produced by frictional turbulence, local convection currents and orographic barriers, usually covering areas of a few kilometres in extent.

Vertical motion is also produced by large wind systems, such as the depressions (lows) and anticyclones (highs) located on M.S.L. synoptic pressure charts.

- The slow widespread descent of air that occurs in anticyclones is known as <u>subsidence</u> and may occur with high-level convergence and low-level divergence. The friction is also responsible for some outward cross-isobar flow of the air near the earth's surface**.**
- The reverse effect may be associated with depressions (lows). High-level divergence and low-level convergence can lead to ascent of the air as shown in Figure 2.11. The friction force may also produce a certain amount of low-level convergence in the friction layer. This is associated with cross-isobar flow towards the centre of the depression.

The upwards motion in a depression is distributed over a very extensive area and so the vertical velocities are relatively small. Nevertheless, the ascent may persist for many days causing large masses of air to ascend through many kilometres.

<u>Slow widespread ascent</u> may have a marked affect on the environment lapse rate. The lapse rate increases and is said to <u>steepen</u>.

The air frequently becomes unstable, leading to increased vertical motion. Condensation and widespread cloud formation may occur, if the moisture content of the air is sufficiently high.

The upward motion in a depression/low/trough is distributed over an extensive horizontal area and as a result the vertical velocities in the upward motion are relatively small. The upward motion may persist for many days causing large masses of air to ascend through many kilometers.

*(**<u>In contrast</u>**, <u>during convective cloud development</u>, when the instability is well-developed, enormous amounts of energy become available from the release of latent heat and the vertical velocities in the up-currents may exceed 10 m/s)*

Widespread ascent air	Convective ascent
Occurs across an **extensive** horizontal area	Occurs across a **small** horizontal area
Vertical velocities in up-currents is **low**	Vertical velocities in up-currents is **high**

This is seen in Figure 1.12 below

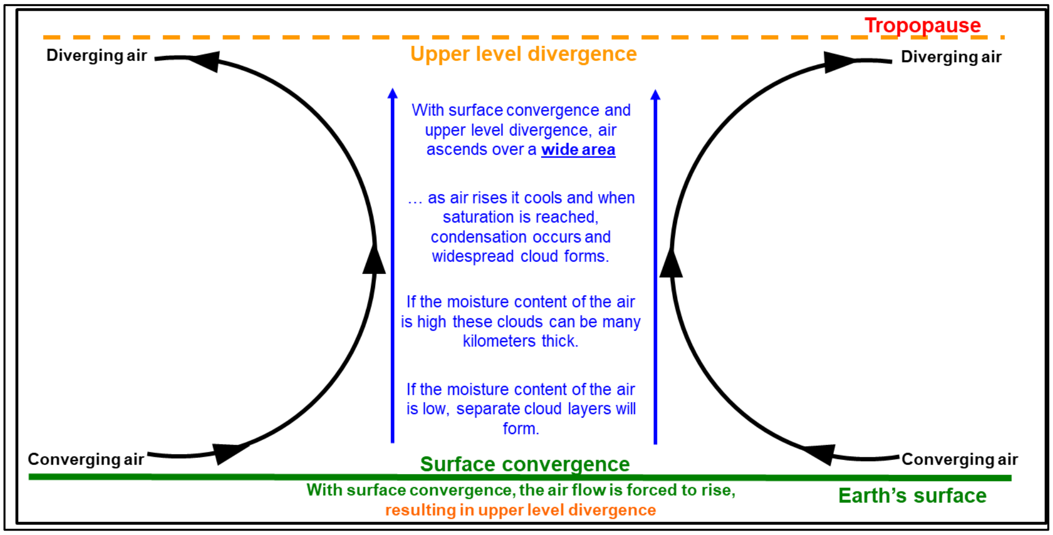


Figure 1.12 Slow widespread ascent

When there is sufficient moisture, Nimbostratus clouds will form over a deep layer as shown in Figure 1.13

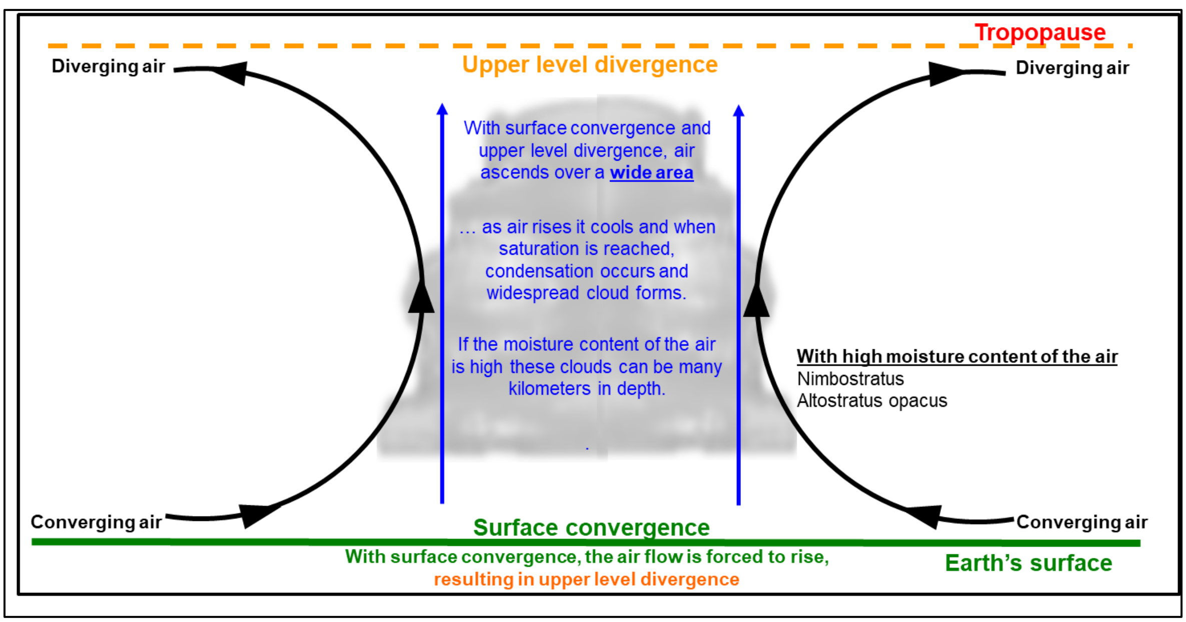


Figure 1.13 Slow widespread ascent with available moisture

The cloud masses may sometimes be many kilometres in thickness. On the other hand, variations in the relative humidity may result in the formation of separate cloud layers.
as indicated in Figure 1.14.

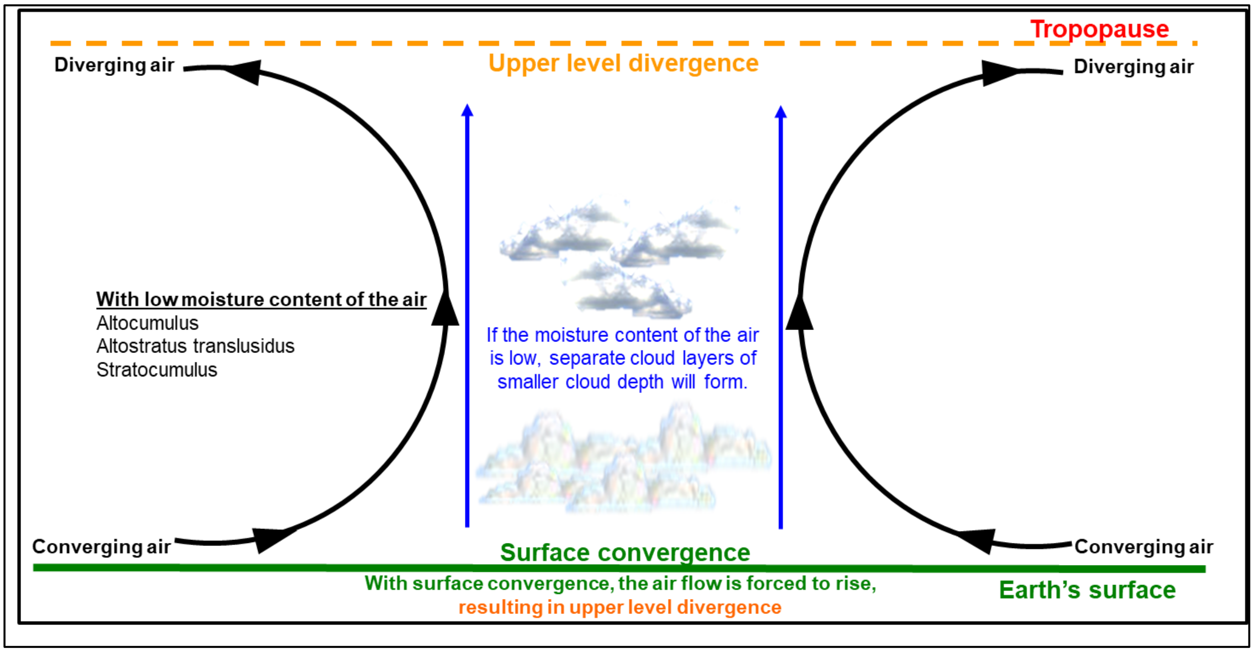


Figure 1.14 Slow widespread ascent with less available moisture

<u>Frequently, widespread ascent is first triggered by divergence in the upper troposphere</u>.
The resulting outflow of mass at high altitudes leads to a fall in pressure at lower levels in the vicinity of the Earth's surface, and a depression is formed. Convergence then occurs near sea-level and slow widespread ascent takes place through great depths of the troposphere. Widespread cloud development then follows, if the air is sufficiently moist.

1.5 Frontal cloud formation

In a frontal zone there may frequently be a marked temperature change in a horizontal distance of a few hundred metres. In each air mass the temperature may be nearly uniform, but differ from the temperature of the air on the other side of the frontal zone.

Sometimes a frontal zone is referred to simply a front. NOTE, however, that in the atmosphere a sharp boundary does not actually occur between the air masses, but rather a transition zone in which there is a change from the temperature of one air mass to that of the other.

Clouds Associated with Widespread Ascent at Frontal Zones

One of the features of the general circulation is the polar front. Cyclones develop along the polar front, which separates warm tropical air from colder air of higher latitudes.

Widespread ascent of air through deep layers of the atmosphere is frequently associated with polar front depressions. Many different relationships occur between the warm and cold air masses.

As the polar front cyclone develops, it frequently becomes possible to distinguish two main types of fronts - a cold front and a warm front. In each case, the frontal surfaces slopes upwards over the cooler air mass with the warmer air located above.

When the transition zone between the air masses moves in such a way that **cold air replaces the warm air, a cold front will occur**. The cloud formation associated with a cold front varies with the stability and moisture content of the warm air, together with the slope of the front. On the average, the slope of a cold front is greater than that of a warm front.

If the slope of the cold front is weak, the cloud formation may be similar to that of a warm front, but with the various types of cloud arriving at a given locality in the reverse order. That is, the low clouds appear first, followed by higher stratiform clouds as the front moves away. The actual cloud formation in the warm air depends on the stability and moisture content of the ascending air.

Sometimes the slope of a cold front may be relatively steep. In this case, it may produce violent effects, particularly if the lifted warm air is already moist and unstable. It may then be characterized by the development of large Cumulus and Cumulonimbus clouds in the warm air. Heavy showers, gusty turbulent winds and sometimes thunderstorms may occur.

The ascent of the warm air takes places within a narrower zone due to the steeper slope of the front.

As a result, the cloud and weather phenomena of the steep-sloped cold front are usually confined to a narrower region in the vicinity of the frontal zone. Figure 1.14 shows the cloud development of an idealized cold front with a steep slope.

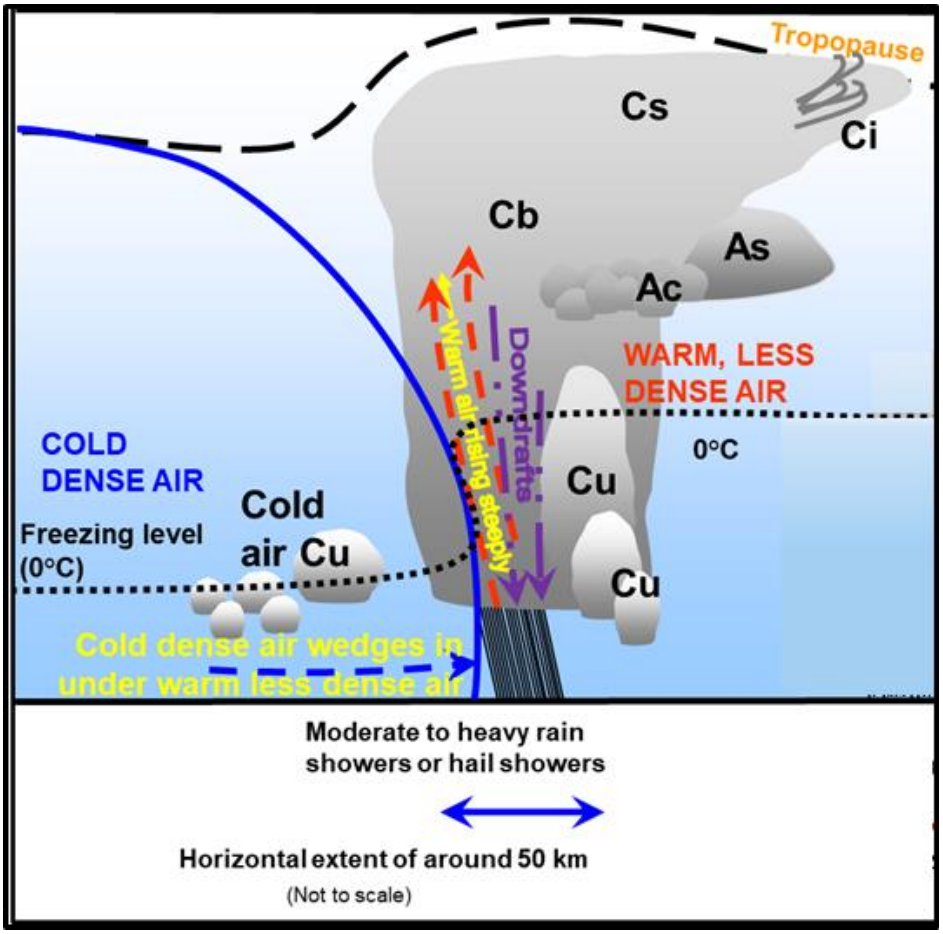


Figure 1.14 Cloud formation at a steep cold front

When the motion of the transition zone between the two air masses is such that **warmer air replaces colder air it is called a <u>warm front</u>.** The slope of a warm front is usually a gentle one and the warm air flows slowly upwards over the cold air mass.

As it does so stratiform clouds may develop in the warm air if the moisture content of the air is sufficiently high. Nimbostratus, Altostratus, Cirrostratus and Cirrus clouds may develop at different stages in the atmosphere. Figure 1.15 shows this effect in an idealized situation.

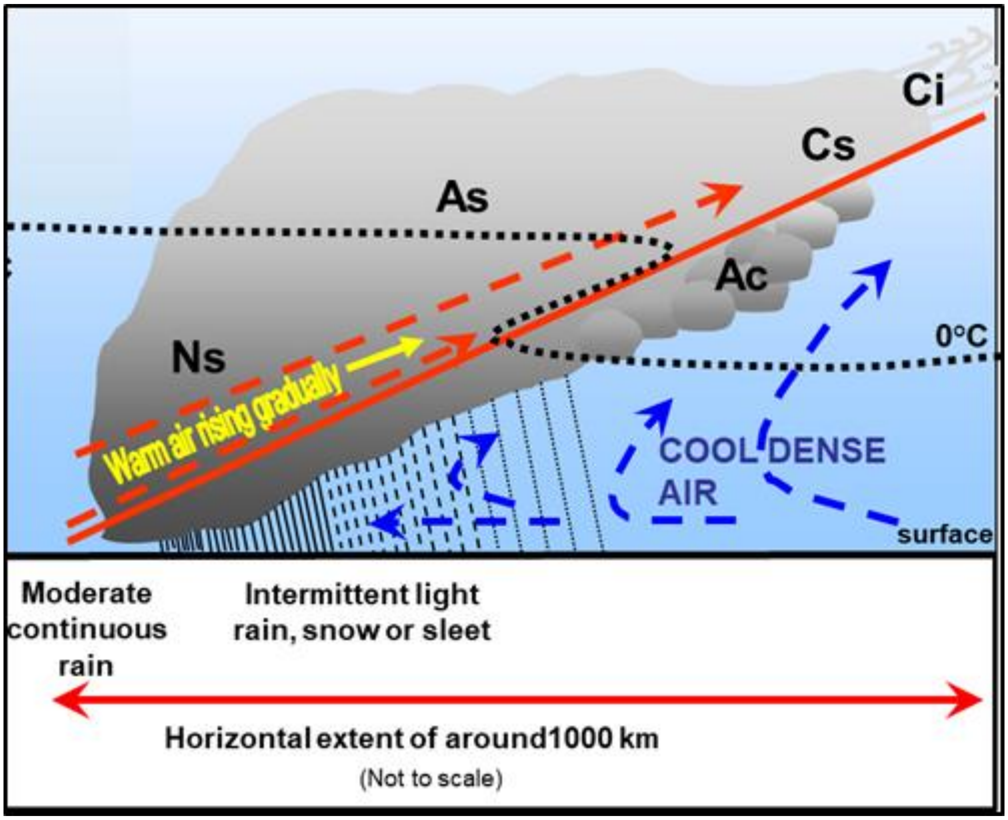


Figure 1.15 Cloud formation at a warm front

CHAPTER 2 Precipitation associated with cloud genera

2.1 Precipitation Development

Clouds form and develop in the atmosphere almost entirely as the result of the expansion and consequent cooling of ascending moist air.

When the rising air is lifted above the condensation level, the most active condensation nuclei grow into droplets. Further cooling below 0°C does not, however, necessarily lead to freezing of the droplets.

Supercooling may occur if ice-forming nuclei are not present in the air. These are different particles from condensation nuclei and are much less common. For this reason, ice crystals do not usually occur in appreciable numbers in cloud-tops until their temperature has fallen to about -20°C.

The initial growth of water droplets by condensation of water vapour is rapid, but the growth-rate decreases as the droplets becomes larger. Similarly, growth of an ice-crystal by the Bergeron process is rapid while it is small, but decreases as it increases in size.

Some type of collision process is necessary to produce liquid or solid particles of precipitation size. The larger water droplets and ice crystals fall relative to the smaller particles. If they are larger than a critical size, they collide with the particles in their path.

Water droplets may coalesce to form larger droplets. Ice crystals may grow by the accretion of supercooled liquid droplets which freeze on contact, or by clustering together to form snowflakes.

Eventually, the water droplets or ice structure reach a size where the ascending air currents are no longer able to sustain them within the cloud. Collisions may take place between precipitation particles of different size and fall rate. This may lead to the growth of some particles. However, there is a tendency, as they descend below the cloud base, for the water droplets to evaporate and for the ice structure to melt or sublime.

If the particles are able to survive the evaporation which they experience while falling through the unsaturated air below the clouds, precipitation is said to occur. If they do not reach the ground, but hang for some distance below the cloud base, they are referred to as **virga.**

2.2 Characteristics of Precipitation Forms

Falling hydrometeors that eventually reach the ground are referred to as **precipitation**. These may leave the cloud either as water drops or as various ice structures.

In order for these hydrometeors to reach the ground in their original state, the air below the cloud must not be too warm or too dry. Otherwise, the water drops may evaporate and the ice structures either melt or sublime before reaching the surface.

2.2.1 Drizzle

Drizzle consists of uniform precipitation, composed exclusively of fine drops of water very close to one another. By convention, the radii of the drizzle drops are less than 250µ (< 0.5mm diameter). Drizzle frequently falls from stratiform cloud, known as stratus, which is only a few hundred metres thick. It only reaches the ground if the upward currents are very slight.

2.2.2 Rain

Rain is usually composed of liquid water particles of larger size than drizzle. These raindrops have radii larger than 250 µ (> 0.5mm diameter). However, precipitation in the form of widely scattered smaller drops is also referred to as rain. Large raindrops are produced by clouds that are usually many kilometres in thickness. The highest rate of rainfall occurs when relatively larger drops are produced by cumuliform clouds. These clouds may sometimes be 10 km or more thick, and strong vertical currents occur within them.

2.2.3 Snow

Snow is precipitation in the form of ice crystals. Most of these are branched and are sometimes star-shaped. Aggregates of ice crystals are called snowflakes.

2.2.4 Ice Prisms

Sometimes there is a fall of unbranched ice crystals in the form of needles, columns of plates. These are known as ice prisms. They are often so tiny that they seem to be suspended in the air.

2.2.5 Snow grains

Snow Grains consist of very small white and opaque grains of ice. These grains are fairly flat or elongated and their diameter is generally less then 1mm. They neither shatter nor bounce when they hit a hard surface. Snow grains usually fall in very small quantities, mostly from Stratus cloud or fog.

2.2.6 Snow pellets

Scow pellets consist of white and opaque grains of ice. These grains are spherical or sometimes conical in shape, and they are about 2 to 5 mm in diameter. They are formed when the accretion of supercooled water to an ice crystal or snowflake is in the form of rime. They differ from snow grains in that they are larger, crisp and easily crushed. They rebound when they fall on a hard surface and often break up.

2.2.7 Ice Pellets

Ice Pellets are a form of precipitation consisting of transparent or translucent pellets or ice. They are spherical or irregular in shape and have a diameter of 5 mm or less. They usually bounce on hitting hard ground and make a sound on impact. WMO has subdivided ice pellets into two main types:

a) Frozen raindrops or largely melted and refrozen snowflakes.

b) Pellets of snow encased in a thin layer of ice (formerly called "small hail")

2.2.8 Hail

Hail is precipitation in the form of small balls or pieces of ice. An individual unit of hail is called a hailstone. It may have a diameter ranging from5 to 50mm, or sometimes more. Smaller particles of similar origin are referred to as ice pellets.

Hailstones may sometimes be composed entirely of transparent ice. However, they usually consist of a series of transparent layers, alternating with translucent layers.

It is assumed that hail forms when some type of ice structure falls into supercooled water. Collision and accretion then occur. If it is a large droplet, it may cover the ice particle first and later freeze to form a transparent layer. By contrast, smaller supercooled drops may freeze on contact, trapping air and producing a translucent layer.

These processes would occur above the freezing level. Alternate transparent and translucent layers could arise from the hailstone traversing different parts of the cloud. Violent up draughts and down draughts that occur in Cumulonimbus clouds would be conductive to this development.

Some hailstones show evidence of layers being formed by alternate freezing and melting. It has been suggested that oscillations up and down through the freezing level may have occurred in these cases. Recent investigations have, however, indicated that the foliated structure could be produced merely by descent through an up draught.

Hail therefore frequently occurs during thunderstorms. However, falls of hail take place within small sections of thunderstorms. Hence, an observer on the ground may not notice any hail.

Generally hail has to fall through many kilometres of air where the temperature is above 0°C. Therefore the hailstones may melt before reaching the ground. This perhaps accounts for the fact that hail is rarely observed at low level in equatorial regions.

2.3 Clouds and precipitation

Hydrometeors **Cloud Genera**

	As	Ns	Sc	St	Cu	Cb
Rain	*	*	*		*	*
Drizzle				*		
Snow	*	*	*		*	*
Snow pellets					*	*
Snow grains				*		
Ice Pellets	*	*				
Hail						*

Figure 2.1 Hydrometeors and cloud genera

Note: Precipitation from Cu and Cb in the form of showers

References

WMO – no 407 International Cloud Atlas Volume 1– *Manual on the observation of clouds and other meteors.* Secretariat of the World Meteorological Organization – Geneva – Switzerland 1975

WMO International Cloud Atlas – 2017 Edition, https://cloudatlas.wmo.int/home.html