Date:04-01-2023

Geography (Hons)-Paper-CT5-3rd Semester

Condensation: Process and forms. Mechanism of precipitation: Bergeron –Findisen theory, collision and coalescence. Forms of precipitation.

Questions

1. Mention the two favourable factors for condensation.
2. Discuss the significance of condensation.
3. What do you mean by supersaturated air?
4. Why does dry adiabatic lapse rate remain always higher than wet adiabatic lapse rate?
5. What are the necessary conditions for occurring condensation?
6. Define condensation nuclei.
7. Mention the source of hygroscopic nuclei.
8. What is the climatological significance of condensation nuclei?
9. Why are the condensation nuclei also known as hygroscopic nuclei?
10. Analyse the mechanism of precipitation.

Condensation is the process of water vapour changing to the liquid state. If air is cooled below its *dew point*, some of the air's water vapour becomes liquid. Thus, any further cooling of saturated air starts the process of condensation. Whenever the dew point temperature falls below the freezing point (0° C), water vapour may convert directly into ice by the process of**'sublimation'.** However, **Byers** prefers the term **'crystallization'.** He applies the term **'sublimation'** to ice directly converting into water vapour without passing through the intermediate liquid stage. Condensation may start with the addition of any further water vapour to saturated air, or with reduction of its temperature.

Condensation depends upon two factors:

(i) Humidity of air and

(ii) Degree of cooling

Therefore in arid lands a larger degree of cooling is necessary before the dew point is reached, while in humid climates a lesser degree of cooling will start the process of condensation.

In the process of evaporation heat is transformed into work which results into cooling the evaporating surface.

Condensation, on the other hand, is the reverse process. Here an equal amount of energy transformed into heat. This released heat is called *the latent heat of condensation* which raises the temperature of air. It is to be borne in mind that heat plays a vital role in different weather processes. The latent heat of condensation lowers the rate of cooling of air.

Under normal conditions, no sooner than the dew point is passed, condensation begins. But there are occasions when condensation starts only after air has cooled much below its dew point. In such a condition, the air is said to be ***supersaturated***. This happens only when air contains very small dust particles. **Under abnormal conditions condensation may start even before the dew point is reached.**

Processes of cooling for producing Condensation:

Condensation by cooling is produced by four different processes

(i) Cooling by expansion
(ii) Conduction of heat from the air to a cold surface
(iii) Direct radiation-cooling of the air, and
(iv) Mixing of warm and cold masses of saturated air.

Generally these processes work in combination. These processes may be classified into two broad categories:

(i) Adiabatic processes and
(ii) Diabatic or Non- adiabatic processes

(i) Adiabatic processes:

Cooling by expansion is far more important than any other process so far as condensation in free air is concerned. This type of cooling is due to lifting of the air. Since an ascending air mass undergoes ever decreasing pressure exerted on it, it expands and cools. Such temperature changes are brought about without any heat being added to or subtracted from the ascending and rising air. These temperature changes are, therefore, called adiabatic. Unsaturated air cools at the dry adiabatic rate of 10°C / km. However, after passing beyond the condensation level, the latent heat of condensation lowers the rate of cooling. This modified rate of cooling is called the wet or moist adiabatic rate. The average rate of this cooling is about 6°C / km, but the actual value varies with pressure. Adiabatic cooling may be accomplished due to convection, convergence of different air masses as along the fronts, or orographic uplifting.

(i) Diabatic or non-adiabatic processes:

Diabatic processes include—

i. Cooling by radiation
ii. Conduction or mixing with colder air.

The air may be cooled due to loss of heat by radiation. In case there is direct radiation from moist air, the cooling produces fog or clouds provided hygroscopic nuclei are present in the air. Cooling may also be produced by conduction or advection of warm air across a cold surface. Cooling by contact with a cold surface produces dew, frost or fog depending on other atmospheric conditions. Sometimes the air is cooled due to its mixing with colder air.

It is noteworthy that the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of the atmosphere. The non-adiabatic processes of cooling produce only dew, fog or frost. They are incapable of producing a substantial amount of precipitation. The only process capable of reducing the temperature of deep and extensive air masses, so that cloud formation and appreciable precipitation may be possible, is the expansion associated with rising air currents or the adiabatic cooling.

Necessary Conditions for Condensation:

As noted earlier, condensation takes place when water vapour is converted into liquid form. This process may produce dew, fog or clouds. Howsoever different these forms of condensation may be, they have **two things in common**.

i. For condensation to occur, saturation of air is an essential pre-requisite. Saturation can be brought about either by reducing the air temperature or by adding water vapour to the air.
ii. Water vapour needs some kind of a surface on which it may condense.

For dew or frost, solid objects at the ground do this job. But when condensation occurs at some distance away from the earth's surface, the most needed surfaces for condensation of water vapour are provided by the dust particles or aerosols, as they are called, which are referred to as **condensation nuclei**. In the absence of these tiny dust particles, clouds may not possibly form unless a relative humidity of nearly 400 percent is reached. Fortunately there is an abundance of condensation nuclei such as salt particles supplied by the oceans, microscopic dust particles and smoke etc. in the lower atmosphere. Since these tiny particles have affinity for water, they are termed **hygroscopic nuclei**. Because of the presence of an abundant quantity of such water seeking dust particles, hardly exceeds 101 percent.

Condensation is said to be a continuous process, since some of the more powerful hygroscopic nuclei begin to attract water vapour around them at relative humidity as low as 75 percent. As the relative humidity reaches 100 percent mark, the condensed water particles grow larger in size very quickly. Thus the clouds start appearing in the sky.

Condensation and hygroscopic nuclei:

In order to get the process of condensation started, it is essential that there should be an abundant supply of microscopic dust particles in the air. Earlier the weather scientists held the view that the tiny particles of dust, or whatever type they may be, were sufficient for the process of condensation. But of late, it was discovered that condensation does not occur on ordinary dust particles. For this purpose only such particles are necessary as are capable of attracting or absorbing water. These ***condensation nuclei*** are called ***hygroscopic nuclei*.**Various types of ***hygroscopic nuclei***ordinarily present in the atmosphere are the following:

i. Sea salts which include sodium chloride and magnesium chloride, etc.
ii. Sulphur dioxide (SO_2), which oxidises to sulphur trioxide (SO_3) which becomes sulphuric acid (H_2SO_4) when mixed with water.
iii. Oxides of nitrogen, specially nitric oxides (nitrogen monoxide or NO)

- Active volcano

- Ocean spray
- Fires and
- Meteors which burn out in the atmosphere are the

sources of a large number of such hygroscopic nuclei. Salt particles carried over the continents from the oceans by winds are supposed to be the most powerful condensation nuclei. Besides, such products of combustion as have sulfurous and nitrous acids are also the most effective and active condensation nuclei. According to **Petterssen**, the salt nuclei may vary in size from 0.1 to 1 µ. A few giant nuclei may be as large as 5 µ. The volume of these nuclei varies from 10 to 100cm^3. The nuclei that are product of combustion are invariably smaller in size. According to **Brunt's**estimate, the number of these particles varies from 2000 to 50000 per cubic centimetre. These nuclei are not uniformly distributed in the air. The density varies from place to place. In the vicinity of industrial towns the number exceeds 100000/cm^3. That is why the atmosphere in large industrial centres is always hazy and foggy (other conditions being favourable).

Forms of condensation:

Condensed moisture occurs in various forms. This is due to variations in the amount of humidity in the air, in its movements and turbulence, and in its temperature and rate of cooling. Condensation occurs on solid surfaces on the earth's surface as well as in free air above it. The common forms condensed moisture include—

i. Dew
ii. Frost
iii. Fog
iv. clouds

i. Dew:

Dew consists of tiny droplets of water produced by <u>condensation on surface objects</u> rather than <u>on nuclei</u> in the air above the surface. Any nature observer will find in the morning shining beads of water droplets deposited on leaves and blades of grass. In fact, dew refers to "water drops deposited by direct condensation of water vapour from the adjacent clear air mainly on horizontal surfaces cooled by <u>nocturnal radiation</u>". **Cole** defines dew as the "condensed moisture that forms in place as a consequence of <u>contact cooling</u>".

<u>Clear skies</u> and <u>calm air</u> are necessary conditions for the formation of dew. Clouds act as blankets which greatly reduce the radiation cooling during night. Movement and turbulence in the lower stratum of atmosphere cause mixing and thereby prohibit the air from reaching its dew point. That is why windy nights do not favour the formation of dew. In brief, the necessary conditions for dew formation are:

i. cloudless sky
ii. calm weather and
iii. appropriate quantity of moisture in the air

ii. Frost:

Frost should not be mistaken to be frozen dew. Frost occurs when the dew point of air falls below the freezing point (0° C). When condensation starts with temperature below 0 ° C, the water vapour in the air passes directly from gaseous to solid state. Sometimes condensation under such conditions results in the formation of ice-crystals commonly called 'white frost'. The United States Weather Bureau classifies frost into two categories—on the basis of amount of deposits:

i. Light frost and
ii. Heavy or killing frost.

The killing frost destroys the staple crops of the locality.

Low places such as valley without any outlet are the ideal locations for the occurrence of frosts. The cold and heavy air accumulates in such locations, becoming much colder than the surrounding air. Under such conditions, a temperature inversion is created. Valley floors are affected by the frosts, while the slopes remain unaffected. However, the conditions necessary for the formation of the frost are the same as for dew except that condensation taking place below the freezing point produces frost. **Rime** is another unimportant form of condensation which develops at or near the ground. It consists of ice crystals deposited chiefly on vertical surfaces especially on points and edges of objects, generally in super cooled fog or mist.

Protection against frost is great challenge to fruit-growers in some of the cold countries of the world. Various measures have been adopted to protect the orchards from injury caused by frost. Attempts are made at reducing the heat loss during the night or adding heat to the layer of air touching the ground. Heat conservation methods are also adopted. This includes covering plants with materials having low thermal conductivity, such as paper or cloth. Sprinklers, air mixing giant-size fans and orchard heaters are frequently used for warming the air.

Fog and Clouds:

There is basically very little difference between *fog* and cloud. Both are the same in respect of appearance and structure. Both of them are visible aggregate of minute water droplets suspended in the atmosphere. However, *fogforms at or near the earth's surface* whereas clouds form at much higher altitudes. In fact, theessential difference between these two condensation forms lies in the method and place of formation rather than in structure and appearance. Clouds are formed when air rises, expands and cools adiabatically. *Fogs, on the other hand, form as a result of radiation cooling or the movement of air over a cold surface. Fog may also form through cooling of the air by contact and mixing or through saturation of the air by contact and mixing, or through saturation of the air by increasing its water vapour content.*

Fog:

Fog is defined as almost microscopically small drops of water condensed from and suspended in air near the surface of the earth in sufficient number to reduce the horizontal visibility to less than one kilometre. Fog is also defined as a cloud with its base at or very near the ground. A light fog may reduce the visibility to 2 or 3 kilometres, but in case of a dense fog visibility is reduced to a few metres. According to international usage, a fog is said to exist only when visibility is reduced to less than 1 kilometre. For aviation purpose, the reporting of fog is done only when the visibility is less than 9 kilometres. Sometimes a continuous gradation exists from the thick fogs into low-lying clouds. Therefore **Byers** considers it unwise to attempt an exact definition of fog. However, he defines fog as "almost microscopically small water drops suspended in the atmosphere and reducing the horizontal visibility to less than 1 km". According to him, at temperatures above the freezing point, real fog can only exist when the relative humidity is high, usually above 97 percent. The fog generally looks whitish, but in large cities and industrial areas it looks dirty yellow or grey because of its mixing with smoke or dust particles.

Fog occurs during calm or light wind conditions. It is more common in the vicinity of ocean where there is an abundant supply of moisture near the earth's surface than inland. In most localities fog is more common during winter than summer. It is relatively uncommon in tropical lands.

CLOUDS:

Cloud has been defined as a visible aggregation of minute water droplets and/or ice particles in the air, usually above the general ground level. Clouds are the most important form of suspended water droplets caused by condensation. According to **Critchfield**, clouds are the condensation or sublimation forms that usually result from lifting process. **Blair** is of the view that by far the most important cause of clouds is the *adiabaticcooling* resulting from upward movement of air. Sometimes mixing of warmer and cooler air also produces clouds. **Trewartha** is of the opinion that the one process that can reduce the temperature of deep and extensive masses of air enough to bring about cloud condensation is the expansion associated with rising air currents, i.e. *adiabatic cooling.* As more and more water vapour is condensed within an air mass, water droplets multiply; some of the sun's light is blocked, and the visible result is cloud.

Clouds are meteorologically significant in various ways. All precipitation occurs from clouds. We do not get precipitation from all clouds, but there can be no precipitation without clouds. Clouds also play an important role in the heat energy budget. This is because clouds absorb a part of the incoming solar radiation. They reflect some of the incoming solar radiation back to space and also diffuse some of it. Clouds also absorb a part of terrestrial radiation and then re-radiate it back to the surface. Another important point about clouds is that like a black body they radiate heat continuously in proportion to their temperatures. In the absence of clouds, days would have been much warmer and nights much colder. During summer months cloudy days are cooler than the day without clouds. Similarly in winter a deck of thick clouds makes the nights warmer and less chilly.

As we all know, convectional currents are limited to the troposphere only, and so this part of the atmosphere contains all clouds.

Clouds are of continual interest to the meteorologist, since they tell him what is going on in the atmosphere much above the earth's surface. They are deemed as useful indicators of various meteorological processes. The importance of clouds in aviation cannot be overemphasized. Low clouds may make landings and takeoffs difficult.

Fogs and Clouds.

A Simplified classification:

Fog

1. Air massfog
   i. Radiationfog
      (i) Ground inversionfog
      (ii) High inversionfog
   ii. Advectionfog
      (i) Seafog
      (ii) Tropical-airfog
      (iii) Steam or Arctic seasmoke
   iii. Upslope fog
2. Frontalfog
   i. Warm front fog
   ii. cold front fog
3. Barometric fog

Air mass fog:

This type of fog forms within air masses and is not affected by frontal activity. However, certain types of air mass fog may be related to frontal activity. Three main types of air masses may be recognised according to the chief meteorological fog forming processes, they are—

i. Radiation fog,
ii. Advection fog and
iii. Upslopefog.

Radiation fog:

It is also called ground fog. It forms when calm moist air cools in place by nocturnal radiation. If the air is completely calm, instead of fog only dew or frost is produced. A light wind is a necessary condition for the formation of fog, because it produces slight turbulence in the air near the ground. A certain amount of mixing is necessary, which produces a thick layer of fog. If the wind happens to be strong, it will distribute the excess water vapour into upper warmer layers and prevent fogformation.

This type of fog requires long winter nights and cloudless skies for maximum cooling of the ground and adjacent air at night. Relative humidity at sunset should be high so that even a small amount of cooling will lower the temperature to the dew point. A light wind of 3 to 5 km per hour is ideal, because it stirs the cold air in contact with the ground and scatters it sufficiently so that a solid fog layer 10 to 30 metres thick is produced.

Since cold air flows to the lower point, radiation fog is thickest in the lower areas or valleys. As soon as the sun comes up the horizon and has warmed the earth's surface, radiation fog disappears. The fog is the said to 'lift' or 'burn off'. Actually the fog particles consisting of microscopic water droplets evaporate as the temperature of the air is increased. Since after sunrise the surface air warms first, so the fog evaporates from bottom up, giving the impression of lifting. The remnant part of fog may appear to be a low white cloud layer.

According to **Byers**, radiation or ground fog may be considered as that forming from a temperature inversion at the ground caused by radiation cooling occurring during a single night and the inversion disappearing during the day. When the fog is deeper than usual, the vertical visibility is blotted out. **George** has indicated that radiation fogs can occur only if the air during the previous day has been cloudy, because the cloud cover prevents the air from reaching the high temperature during the day. As a result of this, at sunset when radiational cooling begins, the temperature is already low.

It is to be noted that radiation fogs form only over the land. On oceans, the diurnal range of temperature being negligible, such fogs are always absent. In the continental interiors, when anticyclones are formed, ideal conditions exist for the formation of radiation fogs.
High-inversion fog is essentially a winter phenomenon. This fog is produced when a real temperature inversion exists at an altitude of 100 to 600 metres above the ground. This fog does not form as a result of a single night of radiation cooling; rather it forms due to long-continued cooling by radiation. The most favourable locations for high-inversion fogs are provided by the continental regions of high latitudes where winter radiation cooling takes place. However, when polar-maritime air mass becomes stationary over a continent, moisture and temperature conditions are most favourable for the formation of radiation fog.

Autumn and winter are the most favourable seasons for this type of fog. Similarly the centre of an anticyclone, where winds are light and skies clear, is an ideal place for it. During the winter season, it persists for several days in the western part of Europe. A dense fog of this type persists throughout the day in the San Joaquin Valley of California. Even in some tropical inland valleys, radiation fogs are so thick that they may not clear away until midday. Coastal areas, because of the high relative humidity, experience radiation fogs.

Advection fog:

‘Advection' implies the horizontal movement of wind, The advection fogs form when warm, moist air blows over a cool surface and is chilled below its dew point. Motion is implied in the formation of this type offog.

This type of fog may be produced by any of the two processes given below:

(i) Cold air may pass across a warmer sea surface and mix with the warmer airprevailing overthere.
(ii) Warm moist air may pass over a cold surface and become chilled by contact and by mixing with the cold air lying over the cold surfacebeneath.

Horizontal contrast in temperature is the most important factor in the formation of advection fog. In summer, advection fogs are more common over large lakes or over the oceans because of greater horizontal temperature contrast over these large water bodies. Dense fogs near Newfoundland offer the best example of this type. They are also found from Greenland eastward to Iceland and Spitzbergen because relatively warm and cold ocean waters meet in this region. But over lands such fogs are more common in winter, because the horizontal temperature contrasts are greater over continents in this season such fogs form on the western sea coast in the temperate latitudes.

The necessary condition which favour the formation of advection fogs are the following:

a) A greater contrast between the air temperature and the temperatures ofsurface beneath it,
b) a moderate windvelocity,
c) initially high relative humidity in theair,
d) Stable stratification in theatmosphere.

Advection fogs are different from ground fog, although they are often on the surface. In advection fogs the maximum density is found at the top of the layer where the cooling is greatest. The dissipation of this type of fog is a slow process.

There are three subtypes of advection fogs:

(i) Sea fog,
(ii) Tropical air fog, and
(iii) Steam fog.

A brief discussion of these sub-types are as follows:

Sea fog:

Sea fog is formed by the cooling of sea air over a cold current. Sea fog is not confined to coastal areas only, but can occur anywhere over the ocean where there is contrast in water temperatures. The difference between water temperature and air temperature determines the thickness and the height of sea fog. Since most of the cold currents are found near the coasts, sea fogs are fully developed in the coastal areas. Light wind is necessary for this type of fog as well. Generally sea fogs are favoured by wind velocities ranging from 4 to 13 knots. However, they are seen even when the wind velocity is about 26 knots. But when the wind velocities are high, the mechanical turbulence transfer heat towards the ground and the inversion is diminished. Under such conditions, a *stratus cloud* instead of fog is formed at the ground. According to **Byers**, if the air is undergoing very sudden cooling from below, fogs may form even in winds of high velocities. In fact, the velocity of wind and the contrast in water and air temperatures largely affect the formation of sea fogs. Since diurnal range of temperature over the ocean is negligible, the sea fogs persist for several days or even forweeks.

Fogs of the Grand Banks off Newfoundland are the typical example of sea fog. They originate because here the warm Gulf Stream comes into contact with the cold Labrador Current. There is a great contrast in the temperatures of these currents and those of the overlying air mass associated with them. The Grand Bank region is covered with the fog throughout the year, the fog frequency being greater in winter than in summer.

Similar fogs are produced in the coastal areas of Japan where cold Kurile current comes into contact with the warm Japan Current. A dense fog forms near the coast of California because of the passage of on-shore winds from across the California cold current. Summer is foggier than the winter here. In South America and in Africa too, the coastal areas flanked by cold ocean currents experience this type of advection fog.

Tropical-air fog:

Tropical-air fogs are different from sea fogs because here the cooling is produced by the passage of air from low latitudes poleward over the oceans. Such fogs are generally found over the open seas in their poleward parts. The advancing tropical air may produce this type of fog over land also in winter. This is so because the *latitudinal temperature gradient* is greater over the continents than over the oceans. Because of the roughness of land surface and greater atmospheric turbulence produced over there, the formation of surface fog is rather difficult. On the contrary, relatively stronger winds over the oceans favour the fog formation. The tropical-air fogs, therefore, are more common over theoceans.

Besides, they are found near the semi- permanent temperate cyclones. Fogs in the Gulf of Alaska and the Aleutian Islands are of this type. Ideal location for the development of such fogs is offered by the eastern part of the North Atlantic and West Europe.

Since tropical-air fogs originate in extensive air masses, very large areas are affected by them.

Steam fog:

Steam fogs have the appearance of steam. They are produced by evaporation from a warm water surface into the cool air above. This type of fog is also called evaporation fog. When cool air moves over warm water surface, a large quantity of moisture may evaporate from the water surface to saturate the overlying air. The rising water vapour, after meeting the cold air, condenses and rises with the air being warmed from below. It commonly occurs over water bodies, large or small, in the fall and early winter when the water may be still warm and the air is getting cold. Generally steam fogs are very shallow. They may be 15 to 30 meters thick.The shallowness of fog is due to the fact that the rising steam gets evaporated in the unsaturated airabove.

Arctic sea- smoke:

Arctic sea-smoke is the name used to indicate a dense andoften extensive steam fog that occurs over high latitude ocean areas in winter. This type of fog is quite common in the Arctic region, especially where both ice and open water are present. In such areas, the air moving from the continents into the open ocean may be 20°C to 30°C colder than water. Intense steaming from the water surface saturates a large volume of air. The fog thus produced may bedense.

Upslope fog:

This type of fog is produced because of the cooling of air by adiabatic expansion as it flows up the slope. This is one of the few kinds of fog that becomes denser, or is maintained in the presence of relatively high wind velocities. This isbecauseofthefactthatthedownwardtransportofheatbyturbulenceisoffsetby the rapid cooling accompanying the fast rise of air up the slope. Fog of this type is a common feature in the interior plains of the United States. It generally occurs when moisture-laden winds of the Gulf of Mexico follow the slope of the rolling plains west of the Mississippi. The Great Plains of the United States and Canada have this type of fog. However, when there is a high velocity wind, a stratus cloud is formed instead. Sometimes, this type of fog is affected by several factors, viz. —

(i) ascent of air,
(ii) radiational cooling and
(iii)increase in relative humidity of air by the falling rains.

This type of fog is locally known as the 'Cheyenne fog' in the south-eastern part of Wyoming State in the United States ofAmerica.

Frontalfog:

Fogsproducedalongthefrontoftwodifferentairmassesarecalledthefrontalfog.They are caused by saturation of the cold surface layer of air by rain falling from the ascending warm air mass. Evaporation from the falling warm rain saturates the cold air if the temperature of raindrops is higherthanthedewpoint ofair.Iftheair is marked bystabilityandthewindislight,thecondensed moisture produces fog near the earth's surface. This type of fog is sometimes distinguished as pre- frontalandpost-frontalfogs.Frontalfogsmayfromratherquickly,inonetothreehours,and may be widespread.When the wind velocity is relatively high, the base of the fog may lift to form a low stratus cloud. Cloud front fogs form behind slowly moving cold fronts by the same process as in the case of warm front fogs.

Barometric Fog:

Barometric fog is extremely rare, although the cooling process associated with it possibly intensifies other types of fog. If the general pressure distribution over an area undergoes such a change that a layer of moist air at the ground level experiences a lowering of barometric pressure, the resultant adiabatic cooling could lead to condensation. These conditions are most probable in a valley or basin filled with stagnant air which is not immediately replaced as less dense air moves overhead.

(General Climatology, [4th Edition], 1987 by Howard J. Critchfield, Page-63)

Classification on the Basis of Appearance

Different terms are used to indicate fogs formed under different conditions which are discussed below:

Smog:

In the polluted air of large industrial centres the air contains a large number of soot and dust particles, many of which are hygroscopic having a high affinity to water vapour. The fogs produced in these areas are dirty and mixed with smoke. Such a type of fog is called *smog* (smoke +fog). The smog or pea-soup fog of the industrial town of London has gained notoriety as an environmental hazard. Because of the presence of excessive smoke near the ground, the warming of earth's surface by the rays of sun is retarded. Therefore such fogs persist for several days making life difficult.

Smaze:

This name is given to a fog which is an admixture of smoke and haze.

Frost-smoke:

In the Arctic region, when air temperature falls much below the freezing point and even then the water in sea and bay is not allowed to freeze, a kind of fog consisting of innumerable ice particles and super cooled water droplets is formed by the process of condensation taking place on the surface of those water bodies. Such a fog is called 'frost-smoke'. These fogs are carried over the land by winds. In the mountainous regions of North America, these fogs are called 'pogonip'. In Siberia and North Canada, such fogs form at a temperature ranging from — 30°to —50°C in winter.

Different types of clouds:

The main cloud genera or families can be listed according to their heights as follows:

1. High (means heights 5 to 13 km)
   - i. Cirrus
   - ii. Cirro-cumulus
   - iii. Cirro-stratus

2. Middle (mean heights 2 to 7 km)
   - iv. Alto-cumulus
   - v. Alto-stratus
   - vi. Nimbo-stratus

3. Low (mean heights 0 to 2 km)
   - vii. Strato-cumulus
   - viii. Stratus
   - ix. Cumulus

x. Cumulo-nimbus

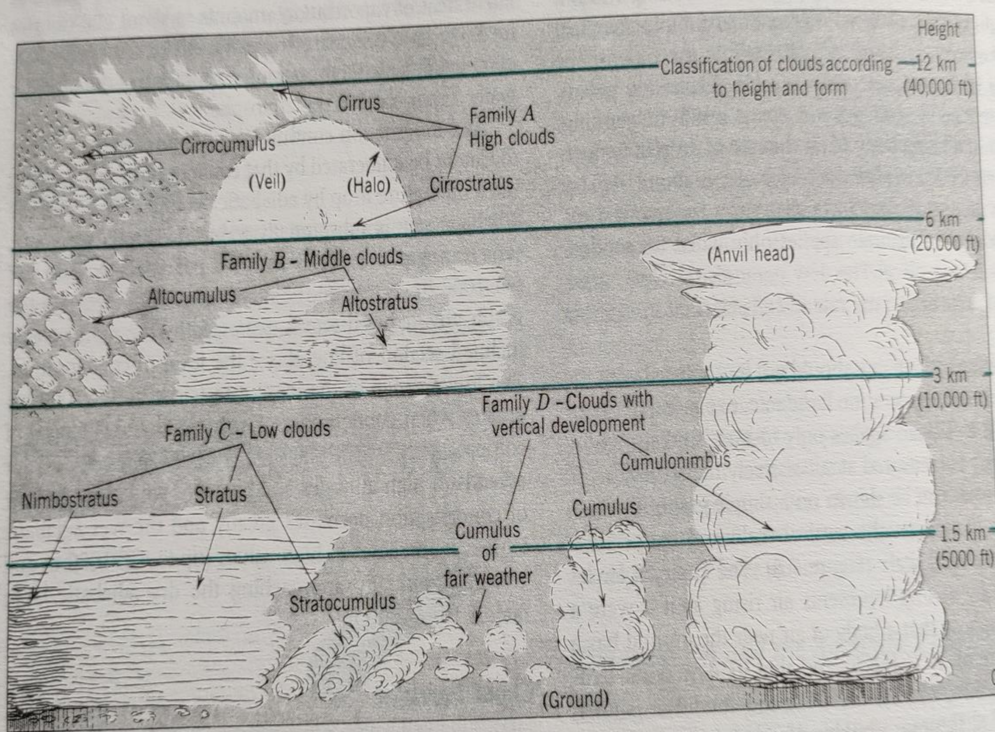

FIGURE 7.9 Cloud types are grouped into families according to altitude range and form. (Drawn by A. N. Strahler.)

Cirrus:

These are detached clouds in the form of white, delicate filaments or whiteormostly,whitepatchesornarrowbands.Thesecloudshave a fibrous (hair-like) appearance or a silky sheen orboth".

The prefix cirro refers to cloud forms at the same general level with different appearance. All the cirrus or cirro-type clouds are composed of ice crystals. They are all high clouds. The sun or moon shining through these clouds produces a halo. Cirrus clouds have brilliant colours at sunset and sunrise. These clouds do not give precipitation.

Cirro-cumulus:

“Thin, white patch, sheet or layer of cloud without shading, composed of very small elements in the form of grains, ripples, etc. merged or separate, and more or less regularly arranged, most of the elements have an apparent width of lessthan onedegree”.

This type of cloud is not common, and is often connected with cirrus or cirro-stratus. It looks like a patch of small flakes or small globules arranged in small groups or lines. When arranged uniformly, it forms a ‘mackerel sky’.

Cirro-stratus:

“Transparent, whitish clouds veil of fibrous (hairlike) or smooth appearance, totally or partly covering the sky, and generally producing halo phenomena”.

This type of cloud is so thin that it gives the sky a milky appearance. At times, it may form a definite sheet. Edge of the sheet is rarely straight, and is often marked by patches of cirrus or cirro-cumulus. It produces halos about the sun or moon. This type always occurs at great heights. Clouds of this type are formed of ice crystals. The sun is obscured so that objects on the ground do not cast shadows.

Alto-cumulus:

“White or grey, or both white and grey, patch sheet or layer of cloud, generally with shading, composed of laminae, rounded masses, rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged, most of theregularly arranged small elements usually have an apparent widthof between one and five degrees”.

Alto-cumulus clouds do not produce halos. They have dark shading on their under-surfaces. There is complete absence of large domes. High globular altocumulus groups are sometimes referred to as ‘sheep clouds’ or ‘woolpack clouds’. They are generally found in wavy or parallel bands. They are often composed of super cooled liquid droplets. This type of cloud may occur at various levels simultaneously.

Alto-stratus:

“Greyish or bluish cloud sheet or layer or striated, fibrous or uniform appearance, totally or partly covering thesky, and having parts thin enough to reveal the sun at least vaguely, as through ground glass. Altostratus does not show halo phenomena”.

Alto-stratus clouds may cover all or large portions of the sky. The sun may be totally obscured or is visible in hazy outline. Halos are never seen. Under an alto-stratus sheet shadows on the ground are never cast. The sun or the moon may only appear as a bright spot behind the cloud. Clouds of this type also consist of water droplets, often super cooled to temperatures well below freezing. Precipitation may fall either is fine drizzle or snow.

Nimbo-stratus:

"Grey cloud layer, often dark, the appearance of which is rendered diffuse by more or less continuously falling rainor snow, which in most cases reaches the ground. It is thick enough throughout to blot out thesun".

Nimbostratus is generally a low cloud form and may be thousands of feet thick. It is a rain, snow, orsleetcloud.Itisneveraccompaniedbylightning,thunder,orhail.Itcanbedistinguishedfrom the stratus type in that it is darker. Streaks of rain or snow falling from these clouds butnot reaching the ground are called 'virga'.

Strato-cumulus:

"Grey or whitish, or both grey and whitish patch, sheet or layer of cloud which almost always has dark parts, composed of tessellations, rounded masses, rolls, etc. whichare non-fibrous (except for virga) and which may or may not be merged; most of regularly arranged small elements have an apparent width of more than five degrees".

Strato-cumulus is a low cloud layer consisting of large lumpy masses or rolls of dull grey colour with brighter interstices.

Stratus:

"Generally grey cloud layer with a fairly uniform base, which may give drizzle, ice prisms, or snow grains. When the sun is visible through the cloud, its outline is clearly discernible. Stratus does not produce halo phenomena except, possibly, at very low temperatures. Sometimes stratus appears in the form of ragged patches.

Looked at from above, stratus has a uniform top, which indicates a temperature inversion. Stratus clouds are without any particular form or structure. Sky may be completely covered by this type of cloud. They are frequently broken. It is difficult to differentiate between a high fog and stratus cloud. When stratus clouds are overlain by the higher alto stratus, they become thicker and darker.

Cumulus:

"Detached clouds, generally dense and withsharp outlines, developing vertically in the form of rising mounds, domes or towers, of which the bulging upper parts often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white; their base is relatively dark and nearly horizontal. Sometimes cumulus is ragged".

Cumulus clouds represent the tops of strong convective currents. Their flat bases if extended toward each other form a nearly perfect plane surface-the dew point level. Irregular patches of cumulus are called *fractocumulus*. They may occur during any season. Cumulus is general found in the daytime over land areas. They dissipate at night. They produce only light precipitation. They often represent a transition to cumulo-nimbus, which is the heavier shower cloud. Air that is heated from below or cooled from above produces cumulus clouds.

Cumulo-nimbus:

These are heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or huge towers. At least part of its upper portion is usually smooth, or fibrous, or striated, and nearly always flattened; this part often spreads out in theshape of an anvil or vast plume. Under the base of this cloud which is often very dark, there are frequently low ragged clouds either merged with it or not, and precipitation sometimes in the formof virga.

Cumulo-nimbus is a towering cloud sometimes spreading out on top to form an ‘anvil head’. This type of cloud is associated with heavy rainfall, thunder, lightning, hail, and tornadoes. This cloud has a flat top (anvil head) and a flat base. It appears darker as condensation within it increases, and it obstructs the sun. It is the great thunder- head, which is the source of the squally,gusty,short-livedthunderstorms.Suchthunderstormsareverycommonduringsummer afternoons in the middle and low latitudes. This type of cloud is easily recognised by the all of a real shower and sudden darkening of the sky.

Mechanism of precipitation:

It may be noted the *only process* capable of bringing about cloudy condensation and the resultant precipitation from extensive air masses is the ***adiabatic cooling***. But at the same time it is equally true that not all condensation, even in ascending currents of air, is followed immediately by precipitation. Even though all clouds contain water, some produce precipitation while others do not. In certain cases precipitated moisture does not fall from the clouds, but it gets evaporated in the atmosphere before actually reaching the earth’s surface. Only when the cloud droplets —

- ice pellets
- ice crystals

grow to such a large size as to overcome the normal buoyancy and updrafts in the atmosphere does precipitation occur. It means that some special process must operate in a cloud from which precipitation falls.

Physics of precipitation:

Various rain-making experiments and researches have brought about many interesting facts. Droplets produced by condensation process are indeed very small in size, averaging less than 10μ in diameter. To get a still better idea of their size, compare them with a human hair which is about 75 μ in diameter. According to **Taylor**, the condensation process can produce droplets up to 50-200μ, but generally it does not produce them much over 10 μ. *Drizzle* particles, which have an upper limit of *500 μ*, seem to float in the air. Thus, because of their small size, the cloud droplets fall at a very slow rate. If a cloud were at an altitude of 1000 metres, then an average cloud drop would take approximately 48 hours to reach the earth. In fact, such a tiny droplet of water fails to reach the ground, because it is likely to evaporate before it fell a few meters below the cloud base. Moreover, since clouds are made of a large number of these droplets all competing for available water, their continued growth through the process of condensation is extremely slow.

Rain drops, on the other hand, have diameters ranging from about *200 μ up to 7000 μ*. Drops larger than this upper limit have a *fall velocity* larger than *10 metres/second*. At such high velocities, the drop breaks into a few smaller drops, such as rain drops and drizzle. It is obvious that there is a limit to the growth of the size of cloud drops or rain drops in the atmosphere.

If we make a comparison between cloud droplets and rain drops, it becomes clear that millions of tiny cloud droplets are required to make one single rain drop. To get a really good sized rain drop, say 3 millimetres in diameter, it would take 27 millions of the 10 μ droplets. A raindrop large enough to reach the ground without evaporating contains roughly a million times water of a cloud droplet. For precipitation to occur, these cloud droplets must somehow join together to grow to sizes which can no longer be kept in suspension by the air.

The exact process or processes which cause the cloud droplets too join together to form large raindrops capable of falling to the earth as precipitation are not fully understood. However, two mechanisms have been proposed to explain these processes, namely—

i. Bergeron process and
ii. Collision Coalescence Process.

Cloud stability:

Before discussing the above mentioned mechanisms or theories of precipitation, cloud stability should be thoroughly understood. In certain types of clouds the water droplets do not tend to coalesce and all the time they are kept floating in the air. Colloidal stability is said to exist in such clouds. No precipitation is released from them. On the contrary, in certain cloud forms the droplets have a tendency to join together as a result of which the big-size rain drops develop. There is colloidal instability in such clouds, and they are producers of precipitation. Thus any process which brings about an element of colloidal instability in a cloud may be said to be responsible for causing the clouds to release precipitation.

Ice-crystal Theory of Bergeron:

The Ice-crystal Theory to explain precipitation was propounded by **Tor Bergeron**, an eminent meteorologist from Norway, in 1933. It is also called the Bergeron Process after the name of its discoverer.

It is based on two special meteorological properties of water—

i. The water droplets in a cloud do not freeze at 0 ° C. In the atmosphere super cooled water has been observed down to below — 40 ° C. When water remains in liquid state below 0° C, it is referred to as **super-cooled**. The super cooled water tends to freeze, if it is disturbed. Icing of aircrafts which fly through cloud consisting of super cooled droplets offers a typical example of this phenomenon. Besides, super cooled droplets also freeze when they come into contact with the **freezing nuclei.** An ice crystal is often found to contain a tiny solid nucleus of about 1 μ in diameter. This is called a **freezing nucleus**. Most of the nuclei become active at —20 ° to **—**25 ° C. However, freezing nuclei are sparse in the atmosphere. Thus, when the ascending air currents rise well above the *freezing level*, some of the water droplets will be changed into ice and through *sublimation* water vapour will enter into solid state.

According to **Taylor**, if a single ice crystal is introduced into a cloud of super cooled water droplets; the entire cloud rapidly changes over to an all-ice cloud. This abrupt change from water to an ice cloud is caused by different vapour pressures existing over super-cooled water droplets and ice crystals at the same temperature.

ii. According to second special property of water—

Over ice, the saturation vapour pressure is lower than what it is over water. In other words, when air is **saturated** (100 per cent relative humidity) with respect to water, it is **supersaturated** (relative humidity greater than 100 per cent) with respect to ice.

Comparative Relative Humidity

(With respect to water and ice)

Temperature (° C)	**Relative Humidity with respect to**	
	Water (%)	**Ice (%)**
0	100	100
—5	100	105
—10	100	110
—15	100	115
—20	100	121

From the above table it is clear that at **—** 15 ° C, when the relative humidity is 100 per cent with respect to water, it is about 115 per cent with respect to ice. In this case, vapour diffuses rapidly from air to ice crystals so that the ice crystals begin to grow at the expense of water droplets. The growth of ice crystals is rapid enough to generate crystals large enough to fall. While falling from the cloud, the ice crystals grow by intercepting cloud droplets that freeze upon them. Sometimes these falling ice crystals are broken up into fragments which again become freezing nuclei for other water droplets. A chain reaction takes place. These ice crystals by accretion grow further in size to become snowflakes before leaving the cloud. Snowflakes generally melt before reaching the ground and fall as rain. *Because of glaciations of the upper part of the cloud, its cauliflower like top becomes anvil-shaped, so typical of a cumulonimbus.*

Collision-Coalescence Theory:

The coalescence process of rain making was discovered by **E.G. Boven** of Australia.This process is applicable only to those clouds which do not extend beyond the freezing level.

Until 1940s it was common belief that all precipitation originated through the Bergeron process. Only light drizzle was supposed to come from cloud located well below the freezing point. If it were true, then substantial precipitation could only be generated from such cloud as extended to such heights where temperature would be much below the freezing point. But this is not true. In the tropics, cumulus clouds with only 2400 metres thickness start giving precipitation over the oceans. The temperature in the uppermost part of these clouds seldom falls below 7° C. It is, therefore, true that ice particles contribute little in the development of rain drops of sufficient size in such warm clouds. The occurrence of precipitation from such clouds involves the coalescence of cloud droplets of different sizes. Since the rate of fall of these unequal particles is different, they collide with each other within the cloud, and the larger drops grow at the expense of the smaller ones. In fact, the rate of growth of falling water droplets depends on variables like the size and size distribution of the drops, and their concentration in the cloud.

Clouds made up exclusively of liquid droplets can generate precipitation only when they contain droplets larger than 20 µ. For the formation of these large droplets **'giant' condensation nuclei** are required. These nuclei are provided by such hygroscopic materials as sea salt. Condensation on these hygroscopic nuclei starts even before the air reaches saturation point (relative humidity 100 per cent). Drops that have grown on such large condensation nuclei become relatively larger. Since the rate of fall is size-dependent, the larger drops fall faster (or in a rising cloud, ascend more slowly) than the smaller ones. As such, they collide with the smaller droplets and coalesce.

In clouds with great vertical thickness and abundant moisture, cloud droplets are repeatedly carried upward and downward by ascending and descending air currents. Hence these drops quickly reach the required size. According to **Riehl**, the following conditions are helpful for the growth of droplets to the required size:

i. Initially few condensation nuclei should be present so that there are not too many competingfor the available water vapour.
ii. Size of the nuclei should cover a good range so that different fall velocities will develop.

If a cloud contains only very small droplets of uniform size, there will be colloidal stability in it and it cannot yield precipitation. This is so because in such a case all the droplets will descend slowly at a uniform rate. Hence there shall be little chance of collision among the drops. Besides, for the development of a single raindrop, it will take much time for about million cloud droplets to coalesce.

As regards the required size of rain drops, it is to be noted that water drops must have a diameter of more than 100 µ even in humid air. According to Riehl, a drop of 500 µ diameter would hardly take 10 minutes to reach the ground from a cloud base of 100 metres above the earth's surface. But a drop with a diameter of only 10μ would take at least 50 hours to cover the same distance. A radius of 500 μ has been adopted as the minimum size of a rain drop. Below this, rain drops are referred to as 'drizzle'. Most of the cloud droplets are so small that the motion of air keeps them suspended. Even if these microscopic droplets were to fall, they would evaporate before reaching the surface.

Electric Field Theory:

It has demonstrated by high-speed motion pictures that sometimes mere collisions do not lead to coalescence. Besides collision, electrical attraction between the droplets plays an important role in bringing about coalescence. If the colliding droplets have opposite electrical charges, coalescence is easily achieved. The role of electrical attraction in generating precipitation from a cloud has been investigated by **Bernard Vonnegut** and **Charles B. Moore**.

Whatever process or processes are at the work, a continual supply of moisture to the atmosphere over a particular location is the most important condition for ensuring a prolonged precipitation.

FORMS OF PRECIPITATION:

Precipitated moisture falling on the ground takes various forms which depend on the following conditions:

(i) The temperature at which condensation takes place
(ii) The conditions encountered as the particles pass through the air
(iii) The types of clouds and their heights from the ground and
(iv) The processes gathering precipitation.

All forms of precipitation regardless of appearance are collectively termed **'hydrometeors'**. Hydrometeors have been classified into 50 specific types. Here, some of the more common types are discussed.

The definitions given below have been taken from Volume-I of the *International Cloud Atlas, 1956*. Other details of some more common precipitation forms have also been given here.

Rain:

It is "precipitation of liquid water particles, either in the form drops of more than 0.5 millimetre diameter or in the form of smaller widely scattered drops". Thus rain is precipitation of water in liquid state. The drops of rain are generally larger than those of drizzle. Sometimes rain drops may be of drizzle size, but in that case they are sparse and less in number. Whenever the rain drops fall from high-altitude clouds, some of them evaporate while passing through a layer of dry air. On occasions, falling rain drops completely evaporate before reaching the ground. Such streaks of rainfall are called ***virgae***. On the contrary, when the precipitation process is very active, the lower air is moist and the clouds are very deep, rainfall is in the form of heavy downpours. In this type of heavy rains, the raindrops are larger and more numerous.

Drizzle:

It is fairly uniform precipitation composed exclusively of fine drops of water (diameter less then o.5 millimetre or 500 μ), very close to one another." When the drops of falling precipitation are very small and of uniform size, and seem to float in the air, it is referred to as drizzle. The radii of the drops are less than 500 μ. It gives out very small amount of water on the ground. The microscopic water particles are affected by the slightest irregularities in air movements. Besides being small in size, the drops are numerous. They are formed in *very low stratus-type clouds* with high water content but not subject to much lifting. Relative humidity in the intervening layers of air between the cloud base and the ground is often nearly 100 percent, so that the small drops never evaporate in their journey. Drizzle is often associated with fog and poor visibility. In some places drizzle is called ***mist***. According to **Donn**, if the droplets in a drizzle completely evaporate before reaching the ground, the condition is referred to as mist. However, in the International Codes for weather reports, the term 'mist' is used when the hydrometeor— mist or fog —reduces the horizontal visibility at the earth's surface to not less than 1 km.

Snow:

It is "precipitation of the white and opaque grains of ice." In fact, snow, is precipitation of solid water, mainly in the form of branched hexagonal crystals or stars. Snow consists of wide variety

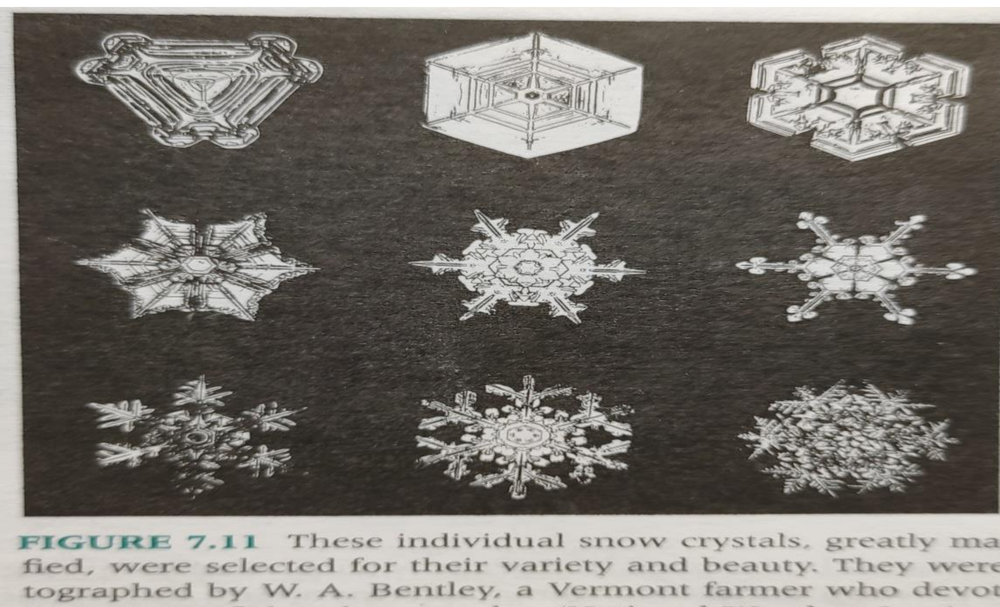

FIGURE 7.11 These individual snow crystals, greatly magnified, were selected for their variety and beauty. They were photographed by W. A. Bentley, a Vermont farmer who devoted his life to snowflake photography. (National Weather Service.)

of crystal forms of ice. It may fall from pure ice clouds or from such clouds as are formed of super cooled water droplets. Snowflakes result from coalescence. In winter, when temperatures are below freezing in the whole atmosphere, the ice crystals falling from the *alto-stratus* do not melt and reach the ground as snow. Heaviest snowfall is reported to occur when the temperature of air from which snow is falling is not much below 0 ° C, because under such a condition the moisture content is fairly high. The most interesting feature of the shape and size of snowflakes is that they reflect the processes by which they were formed.

Sleet:

In English-speaking countries outside the United States, sleet refers to precipitation in the form of a mixture of rain and snow.But in American terminology, sleet means a form of consisting of small pellets of transparent and translucent ice, 5 millimeter or less in diameter. Thus in America, the term 'sleet' refers to a frozen rain, which forms when rain, while falling to the earth, passes through a layer of cold air and freezes. These ice pallets rebound when they strike hard surfaces. Sleet is commonly associated with showery conditions in unstable air, and is formed when ice particles and super cooled water droplets are found in close proximity. Sometimes sleet may grow into hailstorms when violent vertical currents are produced in the atmosphere. According to **Petterssen**, in high- and mid-latitudes precipitation may sometimes begin as snow at the higher altitudes. At or below the melting point, the falling precipitation turns into sleet, and finally reaches the ground as rain. In case the rain from warm air aloft passes through a cold layer near the ground, it does not become snow. The falling rain drops will rather freeze into ice pellets.

Hail:

It is "precipitation of small balls or pieces of ice (hailstones) with a diameter ranging from 5 to 50 millimetres or sometimes more, falling either separately or agglomerated into irregular lumps." Hail is the most dreaded and destructive form of precipitation produced in violent thunder-storms or cumulo-nimbus clouds. Structure of a hailstone resembles that of an onion. The hailstones consist of concentric layers of ice alternating with layers of snow. The very structure of a hailstone is an indication of the complex process of its formation. The strong updrafts of air in cumulo-nimbus clouds carry rain drops to great heights where they get frozen into ice crystals. These frozen raindrops have to fall down through the layers of cloud to be carried up again. While falling through the super cooled cloud droplets, the frozen drops get a coating of ice. Since these pellets are lifted up into the layer of cold air and then dropped again and again, hailstones have concentric layers of ice. They may also grow to the sufficient size by a single ascent through an updraft. The onion-like structure is due to variations in the rate at which super cooled droplets accumulates and freeze. Thus, the ultimate size of a hailstone depends upon—

i. strength of the updrafts

ii. concentration of super cooled water and
iii. total length of its path through cloud

As regards size, hailstones are usually of pea size or even smaller, but in rare cases they attain the size of a baseball. The largest hailstone on record fell on Coffeyville, Kansas, on September3, 1970. Its diameter and circumference were 14 and 44 centimetres respectively. It weighed 766 grams. Such large –sized hailstones indicate many round trips above the freezing levelin a large thunderstorm. Hailstones can have various kinds of shapes. They have found to be conical, ellipsoidal, or amorphous. In each and every hailstone some parts are made up of clear ice, while other parts are milky ice. The opaqueness is due to the trapped air bubbles. Large hailstones are characterised by alternating layers of clear and opaque ice. Even though hail is closely associated with thunderstorms, the regions where maximum number of hailstorms occurs do not coincide with regions of maximum thunderstorm activity. For example, thunderstorms occur most frequently in the southern states of the United States, but the greatest number of hailstorms occurs in the Western Great Plains and over the Great Basin area.

Hailstorms seldom occur in the tropics and in the higher latitudes. Oceans are also almost free from them.In both the hemispheres, areas lies between 30 ° and 60 ° north and south latitudes have the maximum number of these storms. Oceans are almost free from strong vertical convective activity, hence the absence of hailstorms there. Similarly, in Polar Regions too, there is little convective activity. In India, the period from March to May offers the ideal conditions for hail storms. In mid-latitude, spring and early summer are the periods when maximum number of hailstorms occurs.

The destructive effects of hail storms are well known. Standing crops in the field can be devastated in just a few minutes by severe hail storms which mean tremendous economic loss to the farmers. Besides, hail is a definite hazard to flying because it causes damage to aircrafts. The most unfortunate aspect of the hailstorm phenomenon is that they are very difficult to forecast, particularly the time and place of their occurrence. All that can be done is to indicate that conditions are favourable for hail in a general area.

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1 Micrometre=10^{-6} Metre= 10^{-4} Angstorms= 1Micron=1µ (P. Menon, Our Weather, National Book Trust-Page-74)