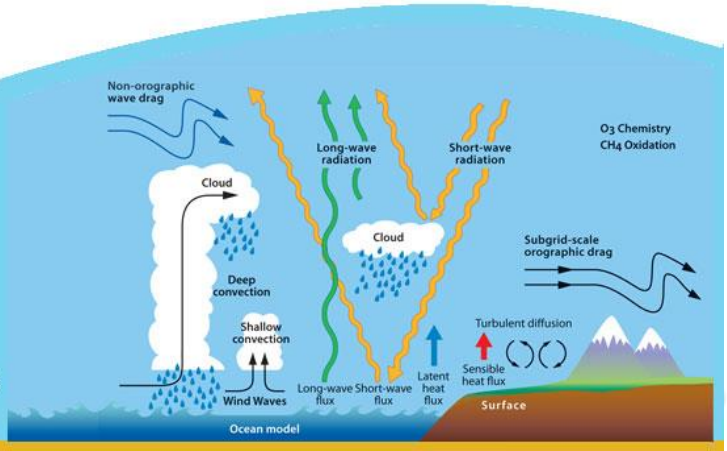
A Gateway to all Post Graduate Courses

An MHRD Project under its National Mission on Education thought ICT (NME-ICT)

Subject: Environmental Sciences

Production of Coursework

- Content for Post-Graduate Courses



Paper No: 8 Atmospheric Processes

Module: 16 Condensation and Precipitation

Development Team

Principal Investigator & Co- Principal Investigator	Prof. R.K. Kohli Prof. V.K. Garg &Prof. Ashok Dhawan Central University of Punjab, Bathinda
Paper Coordinator	Dr. Sunayan Saha Scientist, ICAR-National Institute of Abiotic Stress Management, Baramati, Pune (presently at ICAR-CPRS, Jalandhar)
Content Writer	Dr. NVK Chakravarty ICAR-Indian Agricultural Research Institute, New Delhi
Content Reviewer	Dr. Saurav Saha, ICAR Research Complex for North Eastern Hill Region (Kolasib, Mizoram)
Anchor Institute	Central University of Punjab

Description of Module	
Subject Name	**Environmental Sciences**
Paper Name	Atmospheric Processes
Module Name/Title	Condensation and Precipitation
Module Id	EVS/AP-VIII/16
Pre-requisites	
Objectives	• To define and differentiate condensation and precipitation • To understand various mechanisms by which the condensation and precipitation occur • To identify various forms of precipitation or condensation and distinguish between them • To know the importance of various forms on the environment
Keywords	Rain, snow, hail, fog, dew, frost

Module: 16 Condensation and Precipitation

TABLE OF CONTENTS

1. *Learning outcomes*

After studying this module, one shall be able to:

- define and differentiate condensation and precipitation
- understand various mechanisms by which the condensation and precipitation occur
- identify various forms of precipitation or condensation and distinguish between them
- know the importance of various forms on the environment

2. *Introduction*

Condensation is the process in which vapour form of water in the atmosphere gets converted into liquid state. When any liquid or solid forms of water fall from the sky it is referred as Precipitation. The processes of condensation and precipitation are integral part of the hydrological cycle and hence important to sustain the life on the earth. The various form of the above two processes influence the biota either favourably or adversely depending on their time and intensity of occurrence.

Presence of high amount of water vapor in the atmosphere is the pre-requisite for both the processes to occur. Condensation can be considered as the first stage of precipitation. High moisture saturation level of the atmosphere, low temperature, low wind or calm condition and the presence of suspended particles like dust, pollutant molecules etc. in the atmosphere are congenial for condensation. Condensation occurs both in the near surface atmosphere and also at the greater heights of the atmosphere. In fact, clouds contain high amount of condensed water droplets of variable sizes. In potential precipitation clouds, updraft (air rising upward) and downdraft (air moving downward) cause the condensed particles to grow in size and eventually fall towards the ground due to its weight *i.e.* the gravitational pool of the earth. Depending on the mechanism of formation, cloud type and prevailing atmospheric conditions near the earth's surface, the falling water droplet may acquire forms of various shapes and sizes when reaches the ground. These precipitation forms are given different names. The mechanisms and forms are discussed below:

3. *Mechanisms of precipitation*

There are three distinct ways in which precipitation can occur and those are described below:

3.1. *Convective precipitation*

Convection is the process of transfer of heat through the movement of liquids and gases which obviously happens from the warmer surface to the relatively cooler area. In Meteorology, this refers to

the atmospheric motions in the vertical direction. When the Earth's surface is heated by sun, various surfaces absorb the energy in different amounts. As the surface warms, it heats the overlying air, which gradually becomes less dense than the surrounding air and begins to rise up in to the atmosphere above the Earth's surface. In other words, it can be said that convection occurs when the Earth's surface (in moist atmosphere) becomes heated more than its surroundings, leading to considerable evaporation.

The most common form of precipitation that occurs due to convection is rain and hence the same Convective rain. This form of rain is produced by convective cloud which is formed in vertical motions resulting from instability of the atmosphere. One way that the atmosphere can become unstable is by heating from the sun. The ground warms up, causing moisture in the ground to evaporate and rise, and the hot ground also heats the air above it. As the water vapour rises, it cools and condenses into clouds and eventually rain occurs.

3.2. Frontal precipitation

Frontal rain occurs when two air masses of dissimilar nature meet. When a warm air mass meets a cold air mass, they don't mix as they have different densities. Instead, the warm less dense air is pushed up over the cold dense air creating the 'front'. As a result, the warm less dense air cools, and the water vapor condenses into water and falls as raindrops.

Whenever the warm air pushes out a previously lodged cold air mass, warm fronts occur. The warm air overrides the cooler air and moves upward. Warm fronts are followed by extended periods of light rain and drizzle, because, after the warm air rises above the cooler air (which remains on the ground), it gradually cools down due to the air's expansion while being lifted, which forms clouds and leads to precipitation.

On the other hand, when a mass of cooler air dislodges a mass of warm air cold fronts occur and the transition is sharper, since cold air is denser than warm air. Under these conditions, the rain duration is shorter and generally more intense, than that which occurs ahead of warm fronts.

A wide variety of weather can be found along an occluded front (occluded front is a composite front formed when a cold front overtakes a warm front and forces it aloft) with thunderstorms possible, but usually their passage is associated with a drying of the air mass.

3.3. Orographic precipitation

Orographic rain occurs when moist air is forced upwards by terrain. This form of rain or precipitation, also known as Relief rainfall is caused when masses of air pushed by wind are forced up the side of elevated land formation such as large mountains. This lifting of the air up the mountain slope results in adiabatic cooling leading to condensation followed by precipitation.

In mountainous regions, which are subjected to relatively consistent winds, the weather on the windward side of the mountain would be more moist than on the leeward (downwind) side. Moisture is removed by orographic lift, leaving drier air on the descending (generally warming), leeward side where a rain shadow is observed.

4. Types of precipitation

Once water vapor condenses forming water droplets and ice crystals, it can take a variety of forms as it falls to the Earth as precipitation. Each of these forms of precipitation is unique with their own important characteristics. There are mainly two types of precipitation: Liquid type and Solid or Freezing type. Moreover, the types of precipitation reaches the grounds depend on vertical temperature structure of the air layer between clod base and ground (Fig 1).

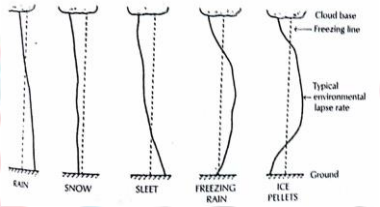


Fig 1: Types of precipitation reaches to the ground depends on vertical air temperature gradient between ground and cloud base.

4.1. Liquid precipitation

4.1.1. Rain

Rain is the most common form of precipitation that reaches the earth's surface in the form of drops which are greater than 0.5 millimeters in diameter. When water vapor condenses around condensation nuclei like dust particles in the cloud, drops of liquid water fall forming tiny droplets which eventually get big enough for the cloud to hold and hence fall, growing larger and larger as they collect more water on their way down to the earth's surface. When water droplets in the cloud or atmosphere get mixed with pollutants such as sulfur oxides and nitrous oxides, it produces acid rain. Because of strong acidic reaction of such raindrops it injures or kills plants and pollutes water sources. Nimbostratus (Ns), Altostratus (As), Stratocumulus (Sc), Altocumulus (Ac) etc. is often considered as rain bearing clouds.

The India Meteorological Department (IMD) defines a day as "Rainy Day" when the total rainfall received during the 24 hour duration is 2.5 millimeters (mm) or more. IMD has further defined terms and their respective limits quantifying the hourly intensity, distribution and intensity over a region which are reproduced below (Table 1 & 2).

Table 1. Classification of rainfall intensities

Categories of Rain	Rainfall Thresholds
Trace	Usually < 2 mm hr^{-1}
Light	Trace to 2.5 mm hr^{-1}
Moderate	2.6 to 7.6 mm hr^{-1}
Heavy	> 7.6 mm hr^{-1}

Table 2. Rainfall distribution over a region (usually a meteorological subdivision)

Categories distribution	Criteria (Percentage of stations reporting rainfall above a particular threshold)
Widespread (Most places)	75% or more no. of stations reporting ≥ 2.4 mm of rain
Fairly widespread (Many places)	51-74 % stations reporting ≥ 2.5 mm rain
Scattered (at a few places)	26-50 % stations reporting ≥ 2.5 mm rain
Isolated (at isolated places)	25% or less number of stations reporting ≥ 2.5 mm rain
Mainly dry	No station reported any rain

4.1.2. Drizzle

Drizzle consists of very small and finer droplets (0.2 to 0.5 mm droplet diameter) of water falling from low level stratus clouds. These droplets are larger than the droplets in the clouds yet smaller than rain drops; usually drifts slowly to the ground. This form of precipitation usually continues for sufficiently long duration accumulating at the rate of 1 mm/ hr. Stratus (St) and stratocumulus (Sc) are often considered as drizzle bearing clouds.

4.1.3. Showers

Precipitation falling from a vertically developed cloud is referred to as shower which is different from other forms of precipitation. The diameter of water drops in a shower is 5 mm or more. Showers are often characterized by shorter duration with rapid fluctuations of intensity compared to that of drizzle.


Fig.2: Drizzle (left) and showers (right)

4.2. Freezing type or solid precipitation

Snow, sleet, freezing rain, freezing drizzle, hail, ice pellets, snow grains, grupel and diamond dust fall in this category.

4.2.1. Snow flakes

Snow is formed when tiny snow (ice) crystals in clouds aggregated together to become opaque or semi opaque snow (ice) flakes at subzero temperature. These snowflakes *i.e.* the agglomerate of many snow crystals, vary in size from very small to large feather like forms. Snowflakes stick together when the temperatures are marginal to create snow. If the humidity levels are high, the flakes tend to become larger. When enough crystals stick together, it will gain weight and become heavy enough to fall on the ground (Fig. 3). Relatively high wind speeds tend to keep these flakes from sticking to one another. A combination of heavy snow and strong winds are causes Blizzard. This invades the multiple reflections by heavy snow and low clouds that makes the sky and ground undistinguishable for an associated phenomenon called White Out.

Generally, when the entire temperature profile in the troposphere is at or below the freezing point, snow reaches the earth's surface. However, sometimes snow still reaches the ground even if temperatures of some layers are slightly above freezing as that cannot melt the snowflakes much. At

times, when near-freezing temperatures prevail along with light winds and unstable convective atmospheric conditions, much larger and irregular flakes close to 5 cm in length can form. When there is rain, snow also occurs almost, but often melts before it reaches the ground.

Fig. 3: Snow in some parts of the country

The most beautiful traditional snowflakes are generally seen during Christmas decorations or cut-out of paper. Each type forms in a unique combination of temperatures and humidity in the atmosphere (Fig. 4).

Fig. 4: Macro snow flakes

4.2.2. Ice pellets

Ice pellets are mainly spherical in shape or at times irregular and have diameter less than 5 mm. Ice pellets form when snowflakes start melting as they fall from the cloud and then fall through sub-freezing air where they re-freeze into grain-like particles. Sometimes the snow may only partially

melt and fall as snow pellets encased in a thin layer of solid ice. These ice pellets tend to be smaller than hailstones and bounce when they hit the ground. Like snow, they accumulate on the ground forming a smaller, denser covering which becomes hard to clear away. These Ice pellets tend to occur in brief showers from tall cumulus clouds during winter months as can be seen in Fig. 5 below.

Fig. 5: Different forms of ice pellets

4.2.3. Freezing Rain

Freezing rain occurs when falling snow encounters a layer of warm air which is deep enough for the snow to completely melt and become rain. As the rain continues to fall, it passes through a thin layer of cold air just above the surface and cools to a temperature below freezing. These drops do not freeze by themselves but form supercooled drops which when strike the frozen ground (like tree branches, cars, streets etc.) instantly freeze forming a thin film of ice which is referred to as freezing rain.

4.2.4. Sleet

Sleet is defined as frozen raindrops or melted snowflakes in Australia and United Kingdom that bounce on impact with the ground or any other objects. The sleet formed when droplets are falling from warm air mass through a cold layer. It is a mixture of rain and snow or hail. Sleet consists of pellets of ice which are formed when snow falls into a warm layer and melts into rain (Fig. 6). Their development is in similarity with freezing rain but only striking difference is that the surface layer of the air is so deep that the raindrop freeze before striking the ground. Sleet is different from freezing rain in that sleet bounces when it strikes the ground but the freezing rain does not.

Fig. 6: Sleet formation

4.2.5. Freezing drizzle

It is in fact a form of liquid precipitation whose drops are less than 0.5 mm in diameter but freeze once they strike the earth's surface.

4.2.6. Hail

Hail is solid precipitation in the form of balls or pieces of ice (hailstones) with diameters ranging from 5 to 50 mm or even more. Hails can be extremely dangerous as it can cause extensive damage in only a matter of few minutes. In fact, the size of hails varies much depending upon the severity of weather condition or the intensity of accompanying thunderstorms. Hails forms whenever minute atmospheric objects including dust or particles in the air, collide with super cooled water. Once the water freezes around the object, it begins to form an ice pellet. The duration these ice pellets stay in the cloud determines how large hails will be when reaching the ground. However, hailstones are large enough to survive the trip to the ground as ice, even though surface temperatures are well above freezing point.

Inside the deep convective clouds that are associated with severe weather or thunderstorms, there are a series of updrafts. Due to these updrafts, ice pellets will continue to be tossed up and down, adding layers of ice, until they become too heavy for the updraft to lift further up. When they become too heavy, due to gravity, they tend to fall to the ground as hail or hail storm. At times, the size can be as big as golf balls, softballs or even larger (Fig. 7). While hail may or may not precede a tornado, large hails often appear near the area within a thunderstorm where tornadoes are most likely to form.

Fig.7: Hails of different sizes

4.2.7. Snow grains

Snow grains are a very small form of solid precipitation and consist of small grains of ice as the name suggests. However, these are more or less remain as they are without much accumulation and considered to be the solid equivalent to drizzle.

4.2.8. Diamond dust

Diamond dust otherwise, also known as ice crystals are small ice crystals that float with the wind. Diamond dust consists of extremely small ice crystals usually form at low levels and at temperatures below -30 °C. The sparkling effect created when light reflects on the ice crystals in the air very much resembles diamond dust (Fig. 8) and hence acquired the name.

Fig. 8: Shape of diamond dust

4.2.9. Graupel

Graupel forms in the same way as hail except the diameter is less than 5 mm. It usually grows by soft hail processes. Graupel forms when snow in the atmosphere encounters super cooled water. Ice

crystals form instantly on the outside of the snow and accumulate until the original snowflake is no longer visible or distinguishable. The coating of these ice crystals on the outside of the snow is called a rime coating. The size of graupel is typically under 5 mm, though at times the size may exceed. There is a striking difference between graupel and hail in their physical property. Graupel pellets typically fall apart when touched or when they hit the ground; On the other hand, hail is formed when layers of ice accumulate and as a result those are very hard.

4.2.10. Glaze

When large super cooled droplets strike the sub-freeze ground, they trend to spread out on impact before freezing coating the surface with a layer of clear ice called Glaze (Fig. 9). The glaze may thaw quickly or may stay for few days making difficult to walk and drive by the city dwellers.

Fig. 9: Glaze formation

4.3. Precipitation mechanisms: theoretical approach

The two processes that can explain the growth of raindrops or precipitation particles are:

4.3.1. Bergeron- Fiendeisen process

The process based on two facts (a) co-existence of water vapour, ice crystals and super-cooled liquid water droplets (between 0ºC to – 40 ºC) and (b) differential values of saturation vapour pressure. The process of ice crystal growth in cold clouds occurs in mixed phase clouds. The well distributed super cooled droplets often come into contact with the freezing nuclei, where the ambient vapor pressure falls between the saturation vapor pressure over water and the lower saturation vapor pressure over ice; thus creating a super saturated environment for liquid water but an unrsaturated environment for ice resulting in rapid evaporation of liquid water and rapid ice crystal growth through vapor deposition. Through this process the ice crystals can grow large enough to fall out of the cloud, melting into rain drops if lower level temperatures are warm enough.

4.3.2. Collision- coalescence process

The collision-coalescence process is an important mechanism in forming raindrops in warmer clouds (those with tops warmer than -15°C). These clouds contain a variety of droplets. Uniformly small droplets tend to move at the same speed in the cloud but while mixed with larger one, the hygroscopic nuclei of slow moving droplets encourage collisions and amalgamations.

5. Forms of condensation

There are other forms of condensation and precipitation though some may not fall from the clouds. These are acid rain, fog and mist, dew, frost, haze and smog.

5.1. Fog and mist

Fog is a phenomenon of small droplets suspended in air, causing obscurity in the surface layers and reducing visibility to one kilometer or less. It is just a cloud, occurring at the ground-level and is created by water condensing around dust particles low to the ground instead of high in the air. Like fog, mist is also the result of the suspension of water droplets, but simply at a lower density. In other words, the key difference between the two is how far the objects can be seen through them. When the visibility is one kilometer or less it is called as fog whereas it is referred as mist when the visibility is more than one kilometer (Fig.10). Mist is typically quicker to dissipate and can rapidly disappear with even slight winds, it is also what you see when you can see your breath on a cold day.

Fig. 10: Typical fog (left) and mist (right) formations

5.2. Dew

When water vapour in the air condenses on a surface whose temperature is reduced by radiation cooling to below the dew point (temperature at which condensation starts) of the air in contact with it, the resulting water droplets are called dew. It forms on objects on the ground like leaves, cars and windows instead of dust particles in the air (Fig. 11).

Fig.11: Dew drops on grass blades

5.3. Frost

Frost occurs when the temperature of the air in contact with the ground (ground frost) or at thermometer-screen level, is below the freezing point of water (air frost). The term is also used of the icy deposits which may form on the ground and on objects in such temperature conditions (Fig. 12 a & b).

Fig. 12a: Frost on lawn grass field

Fig. 12b: A damaged potato field due to ground frost

5.4. Haze

Haze is an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky. Haze on a typical day is shown in Fig.13.

Fig. 13: A typical haze

5.5. Smog

When fog becomes polluted with smoke and particulates, especially from burning coal or straw left-over in the agricultural fields, it is referred to as smog. In other words, Smog occurs when high concentration of moisture is combined with smoke which contains oxides of sulfur and nitrogen under relatively higher temperatures or thermal inversions coupled with the absence of wind. Generally in urban and rural areas, smog frequently occurs reducing the visibility to a considerable extent.

6. Impact of condensation and precipitation on environment

- Precipitation in the form of rain and drizzle are generally useful for plants and agricultural crops. However, heavy rain can cause mechanical injuries to the standing field crops especially at critical stages, wash out nutrient rich top soil and drown the roots causing stress.
- Snow and sleet may also be beneficial as far as their contribution towards water is concerned, but freezing temperatures that accompany them can cause significant damage to the plants and also to the standing crops. At times, snow may provide some insulation when the air is very cold.
- Hail, although generally occurs for a short period and in small scale of area, can cause heavy mechanical damages to all types of earth surface objects like car, home, crops and orchards. Hail strips the leaves and causes marks on the fruits thereby damaging them and also reduces their quality. In India, apple orchards of Himachal Pradesh are particularly vulnerable due to high frequency of hail events in the region.
- Fog may cause significant reduction in visibility thereby hampering the vehicular mobility. Fog and dew are sometimes congenial for certain disease pest development in plants.
- For water scarce region, dew, if harvested properly, can become important source of water for agriculture.

7. Summary

- Condensation and precipitation are the integral part of the hydrological cycle and significantly affect the human and environment.
- While condensation is the change of the state of water in the atmosphere from vapour to liquid phase, precipitation is the process when liquid or solid forms of water fall from the cloud/ sky.

- There are three distinct ways that precipitation can occur. These are convective precipitation, frontal precipitation and orographic precipitation.
- Different forms of precipitation can be grouped into two types, *viz.*, liquid type and solid/freezing type. Rain, drizzle and showers are the liquid forms whereas snow, sleet, freezing rain, freezing drizzle, hail, ice pellets, snow grains, graupel and diamond dust are the solid forms.
- Haze, mist, fog, smog and dew are different forms of condensation.
- Fog is just like a ground-level cloud. Fog and mist are differentiated on the basis of visibility.
