10 Precipitation

Learning Goals

After studying this chapter, students should be able to:

1. describe the two methods by which cloud droplets can grow to produce precipitation (pp. 232–236);
2. distinguish between the different types of precipitation (pp. 236–240); and
3. account for the spatial and temporal distributions of precipitation (pp. 240–246).

Summary

1. In order to fall from a cloud as **precipitation**, a drop must be large enough to both overcome the updrafts in the cloud and not evaporate once leaving the cloud. Most clouds don't produce droplets that are large enough to fall as precipitation.

2. The **terminal velocity** of a drop of water increases with its size. In order to overcome the updrafts in a cloud and form precipitation, cloud droplets need to grow.

3. Cloud droplets form when water vapour condenses onto CCN in a process known as **heterogeneous nucleation**. They can continue to grow by the process of condensation as water vapour molecules move toward water droplets in a process known as **diffusion**. Most droplets will grow to only about 10 μm in radius by the combined processes of nucleation and diffusion, but they can continue to grow to raindrop size by either the collision and coalescence process, or by the Bergeron–Findeisen process.

4. The collision and coalescence process forms precipitation in **warm clouds**. As droplets move through the cloud, those that are moving faster should catch up to, collide with, and coalesce with smaller droplets. Eventually, some drops will be big enough to overcome the updrafts in the cloud. This process can work only is the cloud contains droplets in a variety of sizes, some of which must be larger than about 20 μm in radius, and the process is enhanced when clouds are deep with strong updrafts, and when electric fields are present.

5. The Bergeron–Findeisen process forms precipitation in **cold clouds**. These clouds, in which temperatures are between 0°C and –40°C, contain supercooled water droplets as well as ice crystals. Because the saturation vapour pressure for the water droplets is greater than that for the ice crystals, the water droplets will tend to evaporate, and the ice crystals will tend to grow as water vapour is deposited onto them. These ice crystals may continue to grow by **accretion** and **aggregation** until they are big enough to overcome the updrafts in a cloud.

6. Any precipitation formed by the ice-crystal process will begin as snow. The temperature profile in the air below the cloud will then determine the precipitation type that reaches the ground. If temperatures remain below freezing, it will be **snow**. If there is a deep enough layer of above-freezing temperatures at the surface, it will be **rain**. When the snow melts then refreezes, precipitation will reach the ground as either **sleet** or **freezing rain**.

7. **Hail** is a type of frozen precipitation made up of concentric layers of ice. Hailstones form in cumulonimbus clouds as the turbulence in the cloud moves ice particles around, allowing them to grow by accretion of supercooled water. The stronger the updrafts in these clouds, the bigger will be the hailstones.

8. One practical application of understanding precipitation processes is snow-making. An understanding of the Bergeron–Findeisen process and nucleation below freezing has allowed us to successfully make snow at ski resorts.

9. Depending on how the air is lifted, precipitation can be of three types: convective, orographic, or frontal. **Convective precipitatio**n tends to be intense, localized, and of short duration. It most commonly occurs on warm afternoons. **Orographic precipitation** falls on the windward sides of mountains, making these locations some of the wettest places on Earth. In contrast, the leeward sides of mountains can become **rain-shadow deserts** and are some of the driest places on Earth. **Frontal precipitation** is confined to the mid-latitudes and tends to fall steadily for hours over large areas. Because the path of frontal systems shifts with the seasons, it can influence the seasonal distribution of precipitation in mid-latitude locations.

Key Terms

Accretion A process by which ice crystals grow by colliding with supercooled water droplets that then freeze onto them. (p. 235)

Aggregation A process by which ice crystals grow by colliding with other ice crystals that then stick together. (p. 235)

Coalescence efficiency The probability that two colliding cloud droplets will coalesce. (p. 233)

Cold cloud A cloud in which the temperature is below 0°C in at least part of the cloud; such clouds contain a mixture of supercooled water droplets and ice crystals. (p. 232)

Collision efficiency The probability that two droplets in a cloud will collide. (p. 232)

Convectional precipitation Precipitation that falls from clouds produced by surface heating. (p. 241)

Drizzle A type of precipitation in the form of water droplets smaller than typical raindrops. (p. 230)

Freezing rain A type of precipitation that will melt as it falls through the atmosphere and then re-freeze upon contact with objects at the surface. (p. 230)

Frontal precipitation Precipitation that falls from clouds produced in frontal systems. (p. 244)

Graupel Lumps of ice that begin as ice crystals but become rounded as supercooled water freezes onto them. (p. 238)

Hail Frozen precipitation made up of concentric layers of alternating clear and opaque ice. (p. 230)

Isohyets Lines on a map connecting points of equal precipitation. (p. 242)

Orographic precipitation Precipitation that falls from clouds produced by air rising along a topographic barrier. (p. 241)

Precipitation Any liquid or solid water particles that fall from the atmosphere and reach the ground. (p. 230)

Rain-shadow deserts Deserts that form on the leeward sides of mountains. (p. 242)

Sleet A type of frozen precipitation that does not have a crystal structure. (p. 230)

Snow A type of precipitation in the form of ice crystals. (p. 230)

Terminal velocity Constant fall speed in still air reached when the force of gravity equals the opposing force created by the resistance of the air. (p. 231)

Virga Water particles that fall from a cloud but do not reach the ground. (p. 237)

Warm cloud A cloud in which the temperature is above 0°C throughout; such clouds contain water droplets only. (p. 232)

Answers to Selected Review Questions (p. 247)

1. **How and why are cloud droplets and rain drops different from each other?**

   Raindrops have radii of about 1 mm whereas cloud droplets have radii of about 10 μm. Because rain drops are larger they fall faster and are more likely to overcome the updrafts and fall from the cloud as precipitation. Due to the small size and slower speed of cloud droplets, even when they begin to fall from clouds they are more likely to evaporate quickly.

3. **What is a cold cloud? How does precipitation form in cold clouds?**

   A cold cloud has a temperature below 0°C in at least part of the cloud. These clouds contain a mixture of supercooled water droplets and ice crystals. Precipitation forms in these clouds by the Bergeron–Findeisen process.

5. **How does the temperature stratification below a cloud influence what type of precipitation will reach the ground?**

   If temperatures below the cloud are below 0°C or any warm layers are no more than about 200 m deep, precipitation will reach the ground as snow. If a warm layer (i.e., air with temperatures above 0°C) at the surface is at least 400 m deep, ice crystals are likely to completely melt and reach the ground as rain. If warm air near the surface is between about 400 and 200 m deep, precipitation is likely to be a mix of rain and snow.

7. **In what two ways can drizzle occur?**

   Drizzle can occur when rain partially evaporates as it falls. It can also occur from low-lying stratus clouds (no more than a few hundred metres above the surface). If the cloud was higher than that the tiny drops would evaporate before reaching the ground.

9. **How and why does hail form in cumulonimbus clouds?**

   The turbulence and strong updrafts in cumulonimbus clouds keep the ice particles within the cloud and move them rapidly from one part of the cloud to another. As the ice particles are carried up above the freezing level, they collide with supercooled water droplets that freeze onto them, allowing them to continue to grow to hailstone size.

11. **What factors influence the spatial and temporal distribution of precipitation?**

   Mountains strongly affect the spatial pattern of precipitation. Very wet regions are often found on the windward sides of mountains, while deserts can develop on the leeward sides of mountains. When the surface is strongly heated (during the afternoon especially in summer), pockets of warm air can rise and form cumuliform clouds that bring heavy rain.

Study Questions

For suggested answers, see below.

1. Why does a falling water droplet eventually reach a terminal velocity?

2. What tools can meteorologists use to aid in forecasting the type of precipitation that is likely to fall?

3. How can hailstones develop layers of both opaque ice and clear ice?

4. Why is compressed air a necessary ingredient for making snow?

5. How is the importance of prevailing wind patterns in influencing precipitation patterns evident in South America?

Answers to Study Questions

1. At first, gravity will be a much larger force than will be air resistance, and the drop will accelerate. As the drop falls faster and faster, the force of air resistance will gradually increase until it equals the force of gravity. At this point, the drop will no longer accelerate since it will have attained its terminal velocity. (p. 231)

2. Meteorologists use soundings and upper-air charts that show the thickness of the 1000 to 500 hPa layer. (p. 236)

3. In parts of the cloud where the liquid water content is low, the hailstones will accumulate opaque ice. Where there is less water accumulating on the hailstone, less latent heat is released and as a result the hailstone will be relatively colder. Water will freeze more quickly onto the hailstones where they are colder, and the ice that forms will be opaque because it contains air bubbles. Where the hailstones are warmer, they will accumulate a layer of water that will freeze more slowly, allowing the air to escape. In these regions of the cloud, the hailstones accumulate clear ice. (p. 239)

4. Compressed air helps to break the stream of water into tiny droplets. It also helps to blow the water droplets out of the snow gun. Furthermore, it helps to cool the air—as the compressed air leaves the gun, it will expand and, therefore, cool adiabatically. (p. 239)

5. The Andes Mountains run parallel to the west coast of South America. In the tropics, the prevailing easterly winds result in a rain-shadow desert along the coast of southern Peru and northern Chile. Further south, in the mid-latitudes, the prevailing westerly winds result in the west side of the mountains being wet while the east side is a rain-shadow desert. (p. 242)