9 Condensation

Learning Goals

After studying this chapter, students should be able to:

1. explain the microphysical processes that operate in clouds to influence the formation and growth of cloud droplets (pp. 207–215);
2. describe the large-scale processes that cause air to rise and produce clouds (pp. 215–216);
3. describe the classification system used to name clouds, and apply this system to recognize major cloud types (pp. 213–223); and
4. explain how fog forms (pp. 223–227).

Summary

1. Water vapour can condense to form water droplets in two ways. The first is **homogeneous nucleation**, in which water droplets form by the chance collision of water vapour molecules. The second is **heterogeneous nucleation**, in which water droplets form when water vapour condenses on atmospheric aerosols. In the atmosphere, only those water droplets that form by heterogeneous nucleation can survive and grow into cloud droplets.
2. The curvature and solute effects help us understand how water droplets form and grow in the atmosphere. The **curvature effect** inhibits the formation of droplets because the relative humidity required for them to be in equilibrium with their environment increases as droplet size decreases. The **solute effect** promotes the formation of droplets because water vapour will condense on soluble aerosols at relative humidities below 100 per cent.
3. Atmospheric aerosols on which water vapour will condense are called **cloud condensation nuclei** (**CCN**). The most effective CCN are those aerosols that are wettable, soluble, and large or giant in size. CCN that are both wettable and soluble are **hygroscopic**.
4. **Kohler curves** provide the relationship between droplet size and equilibrium (saturation) vapour pressure for a given amount and type of solute. These curves show that, according to the solute effect, water vapour will begin condensing on soluble substances at relative humidities below 100 per cent. As a droplet grows, the solution becomes diluted, the curvature effect takes over, and the droplet will continue to grow only with relative humidities above 100 per cent.
5. Water droplets will not spontaneously freeze to form ice crystals until temperatures drop below about –40°C. Just as CCN help in the formation of water droplets in the atmosphere, **ice nuclei** assist in the formation of ice crystals in the atmosphere. Ice crystals can form when water vapour is deposited directly onto an ice nucleus. In addition, a supercooled water droplet may freeze if it contains an ice nucleus and temperatures drop sufficiently, or if it collides with an ice nucleus. Clouds at temperatures between 0°C and –40°C contain both water droplets and ice crystals.
6. Clouds are classified based on height and form. This results in 10 major cloud types: stratus (St), stratocumulus (Sc), cumulus (Cu), cumulonimbus (Cb), altocumulus (Ac), altostratus (As), nimbostratus (Ns), cirrus (Ci), cirrocumulus (Cc), and cirrostratus (Cs).
7. **Cirriform clouds** form high in the troposphere and are thin, wispy clouds composed of ice crystals. These clouds often cause haloes to appear around the sun or the moon.
8. **Cumuliform clouds** are heaped in form. They are considered low clouds because their bases are at the height of low clouds, but they can extend through the troposphere. They form in unstable air and can grow from the small cumulus humilis of a sunny afternoon to the towering cumulonimbus capable of producing heavy rain, hail, and thunder and lightning.
9. **Stratiform clouds** are layered in form and can occur at any height in the troposphere. They tend to form in stable air as a result of forced lifting. Featureless layered clouds such as stratus, altostratus, and cirrostratus can develop into somewhat more varied stratocumulus, altocumulus, and cirrocumulus as the cloud layer is destabilized.
10. Radiation and advection fogs both form when air is cooled to its dew-point temperature. **Radiation fogs** form overnight as a layer of moist surface air cools by emitting more radiation than it

is absorbing. **Advection fogs** form when a layer of warm, moist air is cooled as it is blown across a cold surface.

11. Steam fogs and precipitation fogs form when the water vapour evaporated from a water surface is mixed into, and saturates, cold air. In the case of **steam fogs**, the water surface is often a lake; in the case of **precipitation fogs**, the water surface is a raindrop.

Key Terms

Advection fog A fog that forms when warm, moist air cools to its dew-point temperature as it is blown over a cold surface. (p. 225)

Anvil top The horizontally spreading top of a cumulonimbus cloud. (p. 219)

Cloud A dense mass of water droplets and/or ice crystals suspended in the atmosphere. (p. 213)

Cloud condensation nuclei (CCN) Atmospheric aerosols on which water vapour can condense to form water droplets. (p. 209)

Convergence The net inflow of air to a region. (p. 214)

Curvature effect The effect in which increased curvature of a droplet's surface, as the droplet gets smaller, increases the relative humidity required for the droplet to be in equilibrium with its surroundings. (p. 208)

Diffusion The movement of water vapour molecules toward a water droplet or ice crystal upon which they condense or are deposited, respectively. (p. 211)

Divergence The net outflow of air from a region. (p. 214)

Fall streaks Ice crystals falling from a cirrus cloud. (p. 217)

Fog Suspensions of water droplets and/or ice crystals in a layer of air at Earth's surface. (p. 213)

Frontal system A large area of low pressure that forms in the mid-latitudes due to fronts. (p. 214)

Halo A ring of light appearing around the sun or the moon due to the refraction of light by the ice crystals in a cloud. (p. 216)

Heterogeneous nucleation The formation of water droplets on a nucleus; in the atmosphere, these nuclei are aerosols. (p. 208)

Homogeneous nucleation The formation of water droplets by the chance collision of water vapour molecules. (p. 208)

Hygroscopic nuclei CCN that both attract water and dissolve in it. (p. 209)

Ice nuclei Atmospheric aerosols on which ice crystals can form. (p. 212)

Jet contrail A long narrow cloud in the upper troposphere produced by the condensation of the water vapour in aircraft exhaust. (p. 223)

Kohler curve A graph showing the relationship between the size of a solution droplet and the relative humidity required for it to be in equilibrium with its surroundings. (p. 209)

Mixing condensation level The height at which water vapour will condense as a result of the mixing of an atmospheric layer. (p. 223)

Orographic lift The process by which air is forced to rise up a slope. (p. 213)

Precipitation fog A fog that forms when water vapour resulting from the evaporation of raindrops causes saturation as it mixes into cold air. (p. 225)

Radiation fog A fog that forms when a layer of moist air at the surface cools radiatively to its dew-point temperature. (p. 223)

Solute effect The effect in which a dissolved substance reduces the relative humidity required for a droplet to be in equilibrium with its surroundings. (p. 209)

Steam fog A fog that forms when water vapour evaporating from a warm, moist surface is mixed into colder air above that surface. (p. 225)

Upslope fog A fog that forms as air rising up a slope cools adiabatically and condenses. (p. 223)

Wettable Able to allow water to form a film. (p. 209)

Answers to Selected Review Questions (p. 228)

1. **Why won't water droplets formed by homogeneous nucleation survive in the atmosphere?**

   Droplets formed by homogeneous nucleation will evaporate unless relative humidity is over 112 per cent. Since the relative humidity in most clouds rarely goes over about 101 per cent, such tiny droplets will quickly evaporate.

3. **Under what conditions will a water droplet a) grow, b) be in equilibrium with its environment, and c) shrink?**

   a) When the relative humidity is higher than the supersaturation curve for the droplet radius.
   b) When the relative humidity is equal to the supersaturation curve for the droplet radius.
   c) When the relative humidity is lower than the supersaturation curve for the droplet radius.

5. **What factors make good cloud condensation nuclei (CCN)? Why?**

   Good CCN are large, readily wettable, and highly soluble in water. As air rises and cools, water will condense first on aerosols that are large. Because relative humidities in clouds rarely go above 101 per cent, insoluble aerosols will need to be at least 0.1 μm in radius in order to be CCN, while those that are soluble can be smaller.

7. **What are the characteristics we use to classify clouds? Based on this, what are the ten major cloud types?**

   Clouds are classified by form and by height. The ten major cloud types are stratus, stratocumulus, cumulus, cumulonimbus, altocumulus, altostratus, nimbostratus, cirrus, cirrocumulus, and cirrostratus.

9. **What are the differences between cumulus humilis, cumulus congestus, and cumulonimbus clouds?**

   Cumulus humilis are just under a kilometre to a few kilometres across, are created by updrafts of a few metres per second, and do not produce precipitation. Cumulus congestus are larger than cumulus humilis and can produce precipitation. Cumulonimbus clouds are produced by updrafts stronger than 10 metres per second, produce thunder and lightning, and heavy rain of short duration. Unlike cumulus humilis and cumulus congestus, cumulonimbus clouds contain ice crystals in addition to water droplets.

11. **How do radiation fogs and advection fogs form? How are their formations similar to one another?**

   Radiation fogs form when a layer of moist air at the surface cools radiatively to its dew-point temperature. Advection fogs form by contact cooling when warm moist air is advected by wind over a cold surface and also mixes it downward to cool by contact with the surface. Both radiation fogs and advection fogs form when moist air cools to its dew-point temperature.

Study Questions

For suggested answers, see below.

1. Why is the danger of ice forming on aircraft greatest at temperatures just below 0°C?

2. Why are stratiform clouds more likely than cumuliform clouds to appear on soundings?

3. How do jet contrails form? Why are these clouds often not visible for long?

4. Why is fog so common in eastern parts of Newfoundland?

Answers to Study Questions

1. At temperatures just below 0°C, the air is full of water droplets cold enough to freeze; they just need something to freeze onto. (p. 213)

2. Stratiform clouds form layers that normally cover most of the sky. Cumuliform clouds are more scattered and thus could be missed by an ascending radiosonde. (p. 220)

3. Jet contrails form when the warm, moist air from the jet's exhaust is mixed with the cold, dry air of the upper troposphere. As the warm air mixes into the cold air, it will cool and the large amount of water vapour it contains will likely condense. Jet contrails are usually not visible for long because they quickly evaporate in the dry air characteristic of these heights. (p. 223)

4. Fog in eastern Newfoundland develops when warm moist air from above the Gulf Stream blows over the cold waters of the Labrador Current. The air will cool to its dew-point temperature, forming fog. (p. 225)