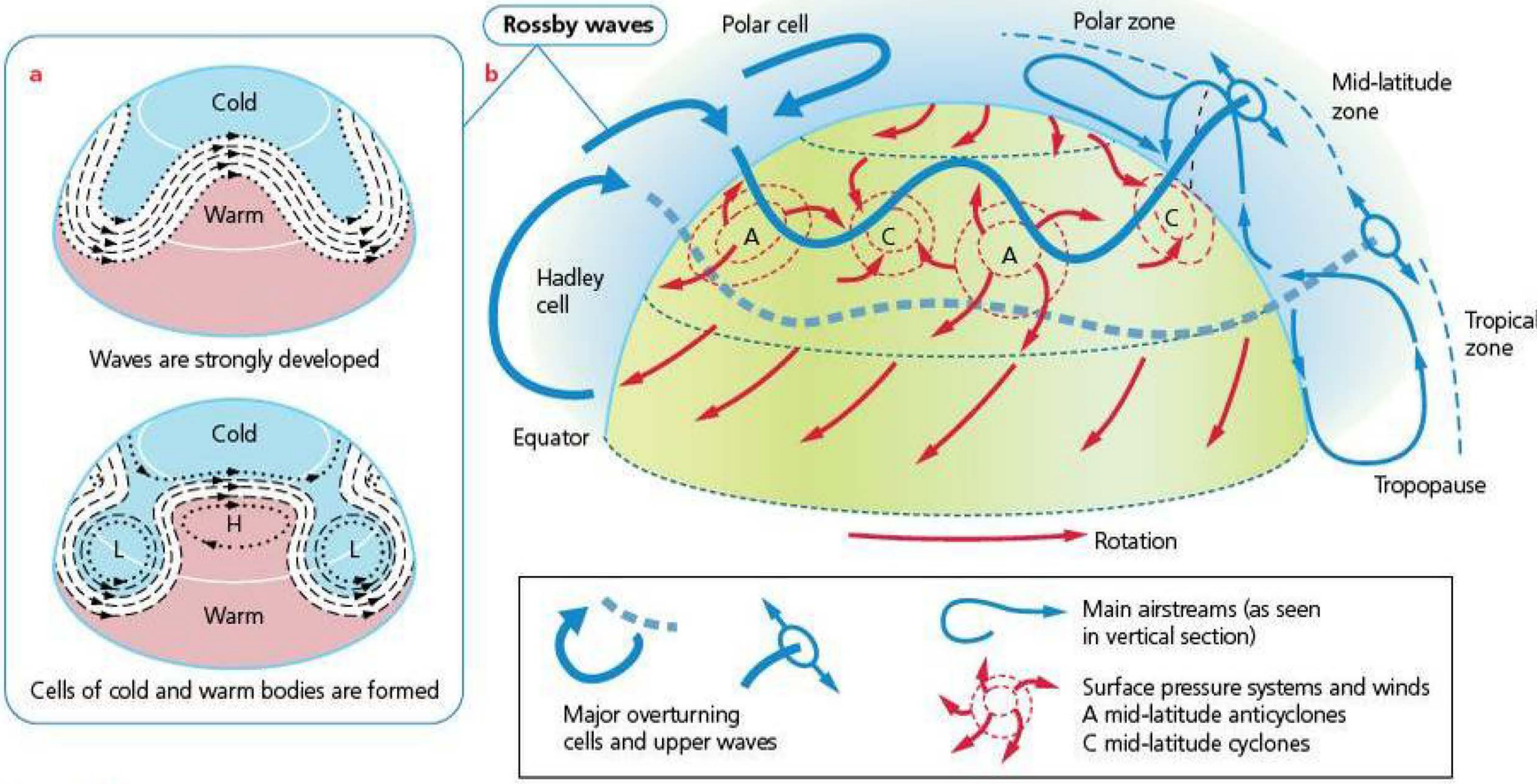



Figure 2.21 Rossby waves

- The jet streams result from differences in equatorial and sub-tropical air, and between polar and sub-tropical air. The greater the temperature difference, the stronger the jet stream.

Rossby waves are affected by major topographic barriers such as the Rockies and the Andes. Mountains create a wave-like pattern, which typically lasts six weeks. As the pattern becomes more exaggerated (Figure 2.21b), it leads to blocking anticyclones (blocking highs) – prolonged periods of unusually warm weather.

Jet streams and Rossby waves are an important means of mixing warm and cold air.

### Section 2.2 Activities

1 Describe and explain how the Hadley cell operates.
2 Define the term *Rossby wave*. Suggest how an understanding of Rossby waves may help in our understanding of the general circulation.

## 2.3 Weather processes and phenomena

### Atmospheric moisture processes

Atmospheric moisture exists in all three states – vapour, liquid and solid (Figures 2.22–2.24). Energy is used in the change from one phase to another, for example between a liquid and a gas. In evaporation, heat is absorbed. It takes 600 calories of heat to change 1 gram of water from a liquid to a vapour. Heat loss during evaporation passes into the water as latent heat (of vaporisation). This would cool 1 kilogram of air by 2.5 °C. By contrast, when condensation occurs, latent heat locked in the water vapour is released, causing a rise in temperature. In the changes between vapour and ice, heat is released when vapour is converted to ice (solid), for example rime at high altitudes and high latitudes. In contrast, heat is absorbed in the process of sublimation, for example when snow patches disappear without melting. When liquid water turns to ice, heat is released and temperatures drop. In contrast, in melting ice heat is absorbed and temperatures rise.

Figure 2.22 Atmospheric moisture – condensation

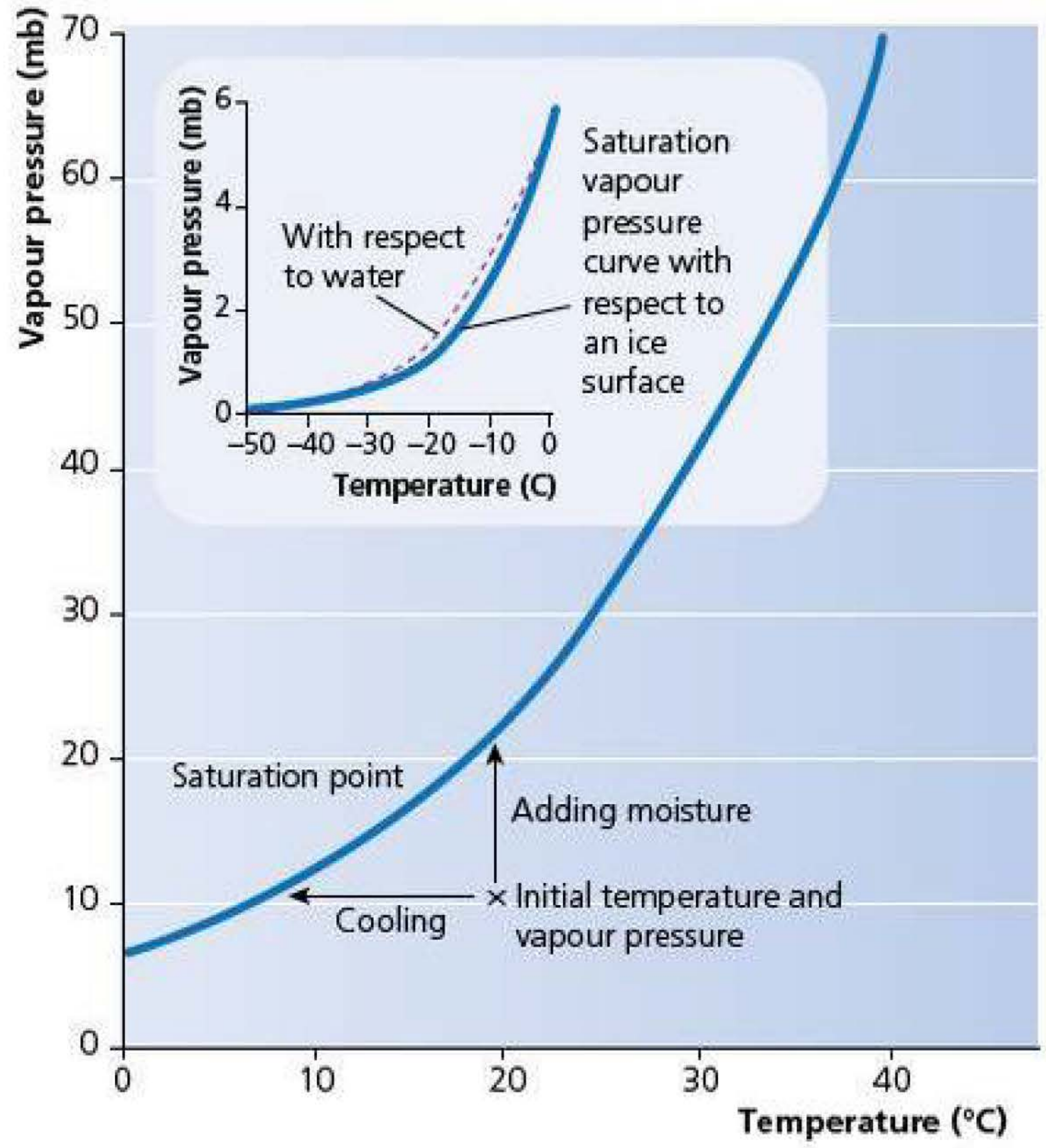
Figure 2.23 Radiation fog in the lower part of alpine valleys

Figure 2.24 Moisture in its liquid state – Augher Lake, Gap of Dunloe, Killarney, Ireland

## Factors affecting evaporation

Evaporation occurs when vapour pressure of a water surface exceeds that in the atmosphere. Vapour pressure is the pressure exerted by the water vapour in the atmosphere. The maximum vapour pressure at any temperature occurs when the air is saturated (Figure 2.25). Evaporation aims to equalise the pressures. It depends on three main factors:

- **initial humidity of the air** – if air is very dry then strong evaporation occurs; if it is saturated then very little occurs
- **supply of heat** – the hotter the air, the more evaporation that takes place
- **wind strength** – under calm conditions the air becomes saturated rapidly.




The curves demonstrate how much moisture the air can hold for any temperature. Below 0 °C the curve is slightly different for an ice surface than for a supercooled water droplet.

Source: Briggs et al., *Fundamentals of the physical environment*, Routledge, 1997

Figure 2.25 Maximum vapour pressure

## Factors affecting condensation

Condensation occurs when either **a** enough water vapour is evaporated into an air mass for it to become saturated or **b** when the temperature drops so that dew point (the temperature at which air is saturated) is reached. The first is relatively rare; the second common. Such cooling occurs in three main ways:

- radiation cooling of the air
- contact cooling of the air when it rests over a cold surface
- adiabatic (expansive) cooling of air when it rises.

Condensation is very difficult to achieve in pure air. It requires some tiny particle or nucleus onto which the vapour can condense. In the lower atmosphere these are quite common, such as sea salt, dust and pollution particles. Some of these particles are hygroscopic – that is, water-seeking – and condensation may occur when the relative humidity is as low as 80 per cent.

## Other processes

**Freezing** refers to the change of liquid water into a solid, namely ice, once the temperature falls below 0 °C. Melting is the change from a solid to a liquid when the air temperature rises above 0 °C. Sublimation is the conversion of a solid into a vapour with no intermediate liquid state. Under conditions of low humidity, snow can be evaporated directly into water vapour without entering the liquid state. Sublimation is also used to describe the direct deposition of water vapour onto ice. In some cases, water droplets may be deposited directly onto natural features (such as plants and animals) as well as built structures (for example buildings and vehicles).

## Precipitation

The term 'precipitation' refers to all forms of deposition of moisture from the atmosphere in either solid or liquid states. It includes rain, hail, snow and dew. Because rain is the most common form of precipitation in many areas, the term is sometimes applied to rainfall alone. For any type of precipitation, except dew, to form, clouds must first be produced.

When minute droplets of water are condensed from water vapour, they float in the atmosphere as clouds. If droplets coalesce, they form large droplets that, when heavy enough to overcome by gravity an ascending current, they fall as rain. Therefore cloud droplets must get much larger to form rain. There are a number of theories to suggest how raindrops are formed.

The Bergeron theory suggests that for rain to form, water and ice must exist in clouds at temperatures below 0°C. Indeed, the temperature in clouds may be as low as –40°C. At such temperatures, water droplets and ice droplets form. Ice crystals grow by condensation and become big enough to overcome turbulence and cloud updrafts, so they fall. As they fall, crystals coalesce to form larger snowflakes. These generally melt and become rain as they pass into the warm air layers near the ground. Thus, according to Bergeron, rain comes from clouds that are well below freezing at high altitudes, where the coexistence of water and ice is possible. The snow/ice melts as it passes into clouds at low altitude where the temperatures are above freezing level.

Other mechanisms must also exist as rain also comes from clouds that are not so cold. Mechanisms include:

- condensation on extra-large hygroscopic nuclei
- coalescence by sweeping, whereby a falling droplet sweeps up others in its path
- the growth of droplets by electrical attraction.

### Causes of precipitation

The Bergeron theory relates mostly to snow-making. Snow is a single flake of frozen water. Rain and drizzle are found when the temperature is above 0°C (drizzle has a diameter of < 0.5 mm). Sleet is partially melted snow.

There are three main types of rainfall: convectional, frontal (depressional) and orographic (relief) (Figure 2.26).

#### Convectional rainfall

When the land becomes very hot, it heats the air above it. This air expands and rises. As it rises, cooling and condensation take place. If it continues to rise, rain will fall. It is very common in tropical areas (Figure 2.27) and is associated with the permanence of the ITCZ. In temperate areas, convectional rain is more common in summer.

#### Frontal or cyclonic rainfall

Frontal rain occurs when warm air meets cold air. The warm air, being lighter and less dense, is forced to rise over the cold, denser air. As it rises, it cools, condenses and forms rain. It is most common in middle and high latitudes where warm tropical air and cold polar air converge.

#### Orographic (or relief) rainfall

Air may be forced to rise over a barrier such as a mountain. As it rises, it cools, condenses and forms rain. There is often a rainshadow effect, whereby the leeward slope receives a relatively small amount of rain. Altitude is important, especially on a local scale. In general, there are increases of precipitation up to about 2 kilometres. Above this level, rainfall decreases because the air temperature is so low.

#### Thunderstorms (intense convectional rainfall)

Thunderstorms are special cases of rapid cloud formation and heavy precipitation in unstable air conditions. Absolute or conditional instability exists to great heights, causing strong updraughts to develop within cumulonimbus clouds. Air continues to rise as long as it is saturated (relative humidity is 100 per cent; that is, it has reached its dew point). Thunderstorms are especially common in tropical and warm areas where air can hold large amounts of water. They are rare in polar areas.

Several stages can be identified (Figure 2.28):

1. **Developing stage:** updraught caused by uplift; energy (latent heat) is released as condensation occurs; air becomes very unstable; rainfall occurs as cloud temperature is greater than 0°C; the great strength of uplift prevents snow and ice from falling.
2. **Mature stage:** sudden onset of heavy rain and maybe thunder and lightning; rainfall drags cold air down with it; upper parts of the cloud may reach the tropopause; the cloud spreads, giving the characteristic anvil shape.
3. **Dissipating stage:** downdraughts prevent any further convective instability; the new cells may be initiated by the meeting of cold downdraughts from cells some distance apart, triggering the rise of warm air in between.

Lightning occurs to relieve the tension between different charged areas, for example between cloud and ground or within the cloud itself. The upper parts of the cloud are positive, whereas the lower parts are negative. The very base of the cloud is positively charged. The origin of the charges is not very clear, although they are thought to be

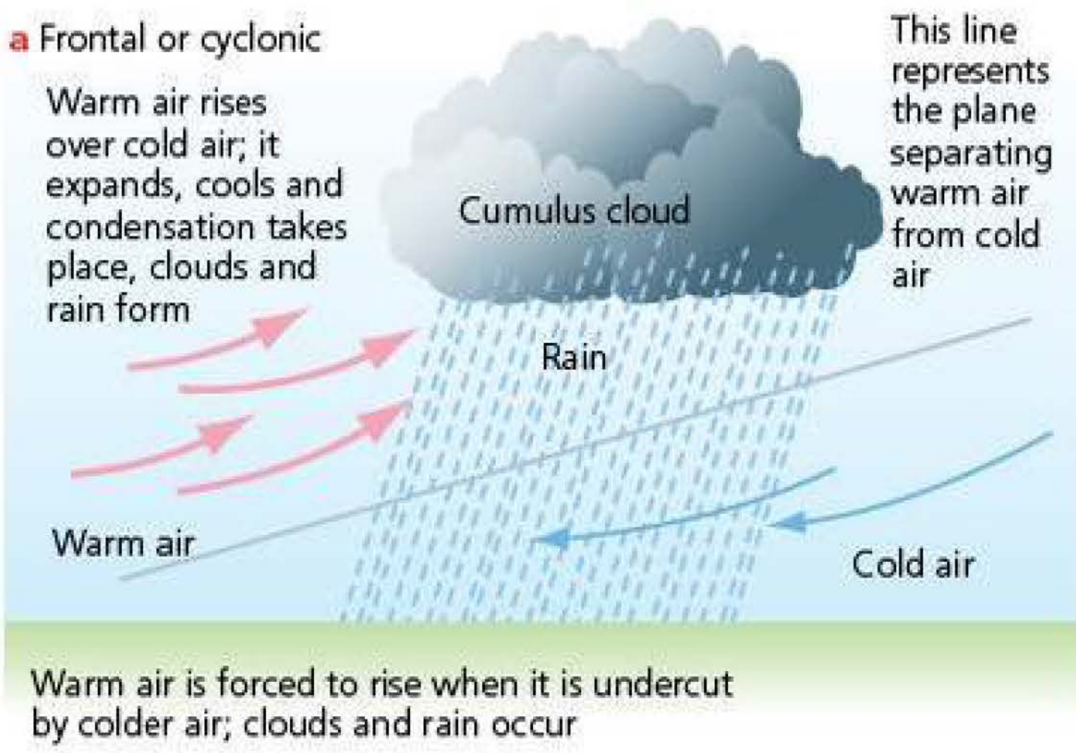




Figure 2.27 Convectional rain in Brunei

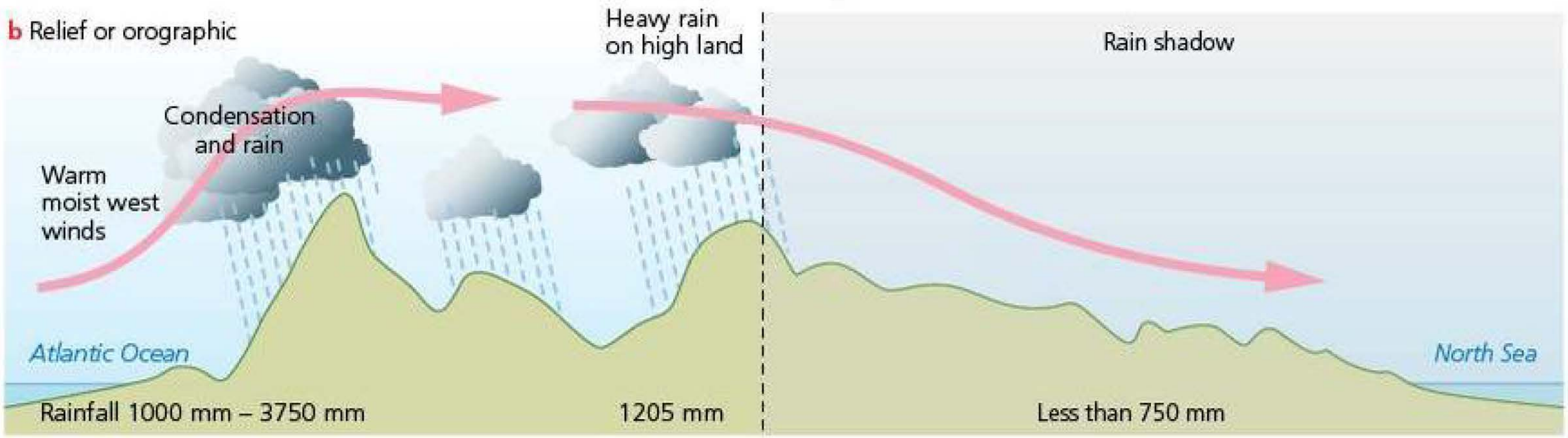




Figure 2.26 Types of precipitation

Source: Nagle, G. *Geography Through Diagrams*, OUP 1998

due to condensation and evaporation. Lightning heats the air to very high temperatures. Rapid expansion and vibration of the column of air produces thunder.

## Section 2.3 Activities

Using diagrams, explain the meaning of the terms **a** *convectional rainfall*, **b** *orographic rainfall*, **c** *frontal rainfall*.

## Clouds

Clouds are formed of millions of tiny water droplets held in suspension. They are classified in a number of ways, the most important being:

- **form or shape**, such as stratiform (layers) and cumuliform (heaped type)
- **height**, such as low (<2000m), medium or alto (2000–7000m) and high (7000–13000m).

There are a number of different types of clouds (Figure 2.29). High clouds consist mostly of ice crystals. Cirrus are wispy clouds, and include cirrocumulus (mackerel sky) and cirrostratus (halo effect around the Sun or Moon). Alto or middle-height clouds generally consist of water drops. They exist at temperatures lower than 0°C. Low clouds indicate poor weather. Stratus clouds are dense, grey and low lying (Figure 2.30). Nimbostratus are those that produce rain ('nimbus' means 'storm'). Stratocumulus are long cloud rolls, and a mixture of stratus and cumulus (see Figure 2.6 in Section 2.1).

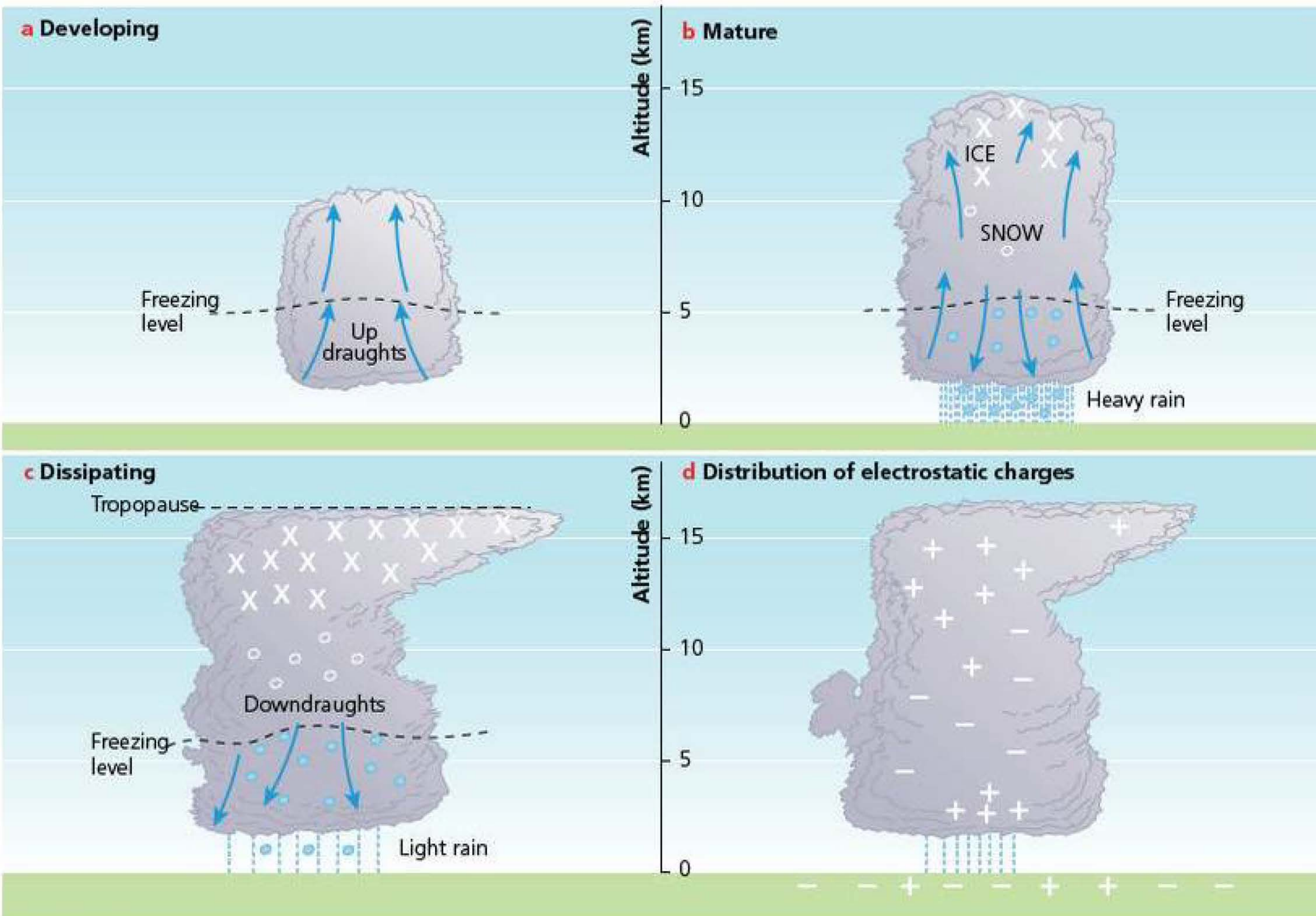



Figure 2.28 Stages in a thunderstorm

Vertical development suggests upward movement. Cumulus clouds are flat-bottomed and heaped. They indicate bright brisk weather. Cumulonimbus clouds produce heavy rainfall and often thunderstorms.

The important facts to keep in mind:

- In unstable conditions, the dominant form of uplift is convection and this may cause cumulus clouds.
- With stable conditions, stratiform clouds generally occur.
- Where fronts are involved, a variety of clouds exist.
- Relief or topography causes stratiform or cumuliform clouds, depending on the stability of the air.

### Banner clouds

These are formed by orographic uplift (that is, air forced to rise, over a mountain for example) under stable air conditions. Uplifted moist air streams reach condensation only at the very summit, and form a small cloud. Further downwind the air sinks, and the cloud disappears. Wave clouds reflect the influence of the topography on the flow of air.

## Types of precipitation

### Rain

Rain refers to liquid drops of water with a diameter of between 0.5 millimetres and 5 millimetres. It is heavy enough to fall to the ground. Drizzle refers to rainfall with a diameter of less than 0.5 millimetres. Rainfall varies in terms of total amount, seasonality, intensity, duration and effectiveness; that is, whether there is more rainfall than potential evapotranspiration. (Refer back to page 45 for more information on the three main types of rainfall.)

### Hail

Hail is alternate concentric rings of clear and opaque ice, formed by raindrops being carried up and down in vertical air currents in large cumulonimbus clouds. Freezing and partial melting may occur several times before the pellet is large enough to escape from the cloud. As the raindrops are carried high up in the cumulonimbus cloud they freeze. The hailstones may collide with droplets of supercooled water, which freeze on impact with and form a layer of opaque ice around the hailstone. As the hailstone falls, the outer layer may be melted but may freeze again with further uplift. The process can occur many times before the hail finally falls to ground, when its weight is great enough to overcome the strong updraughts of air.

### Snow

Snow is frozen precipitation (Figure 2.31). Snow crystals form when the temperature is below freezing and water vapour is converted into a solid. However, very cold air contains a limited amount of moisture, so the heaviest snowfalls tend to occur when warm moist air is forced over very high mountains or when warm moist air comes into contact with very cold air at a front.

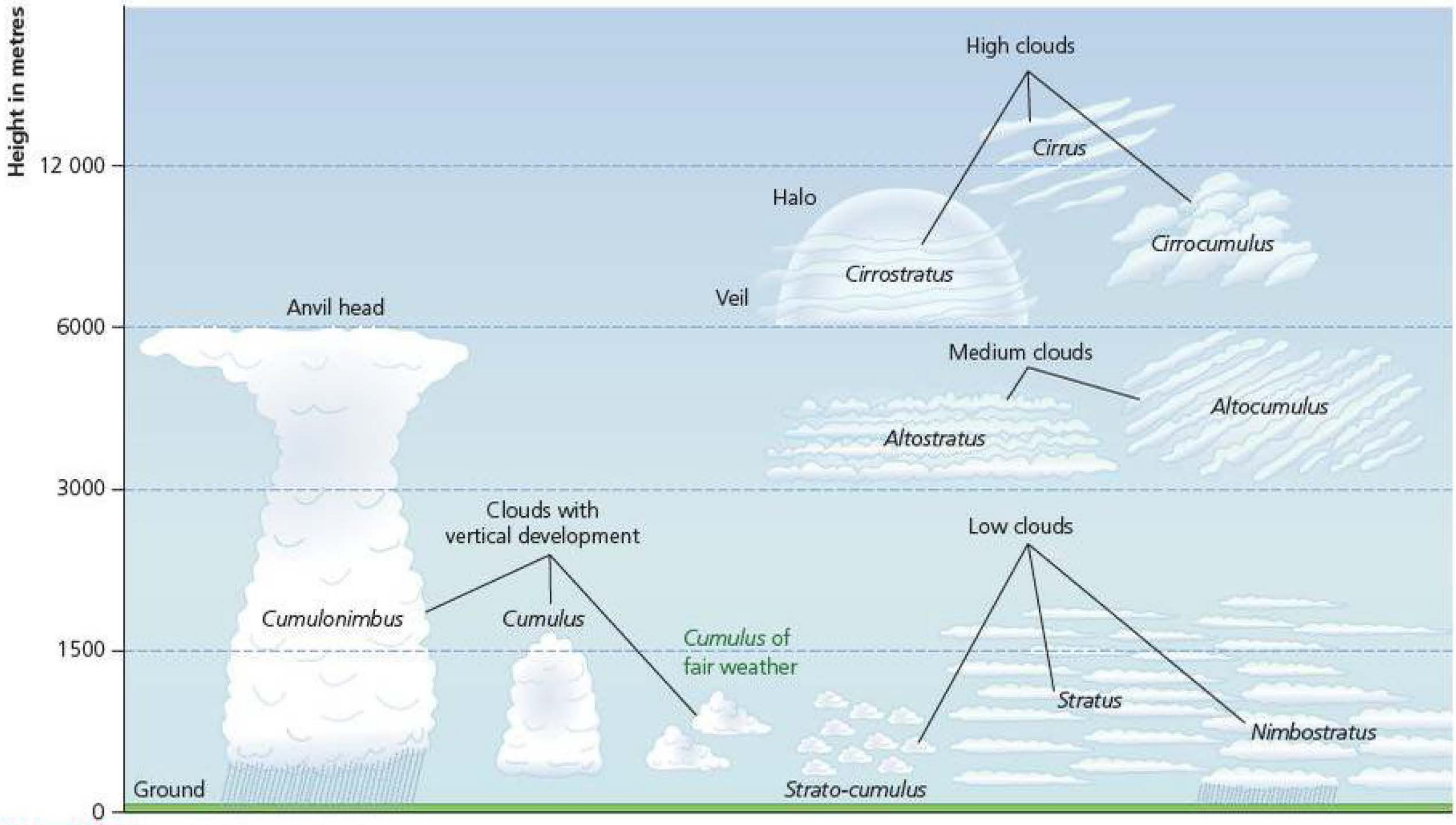



Figure 2.29 Classification of clouds

Figure 2.30 Stratus clouds

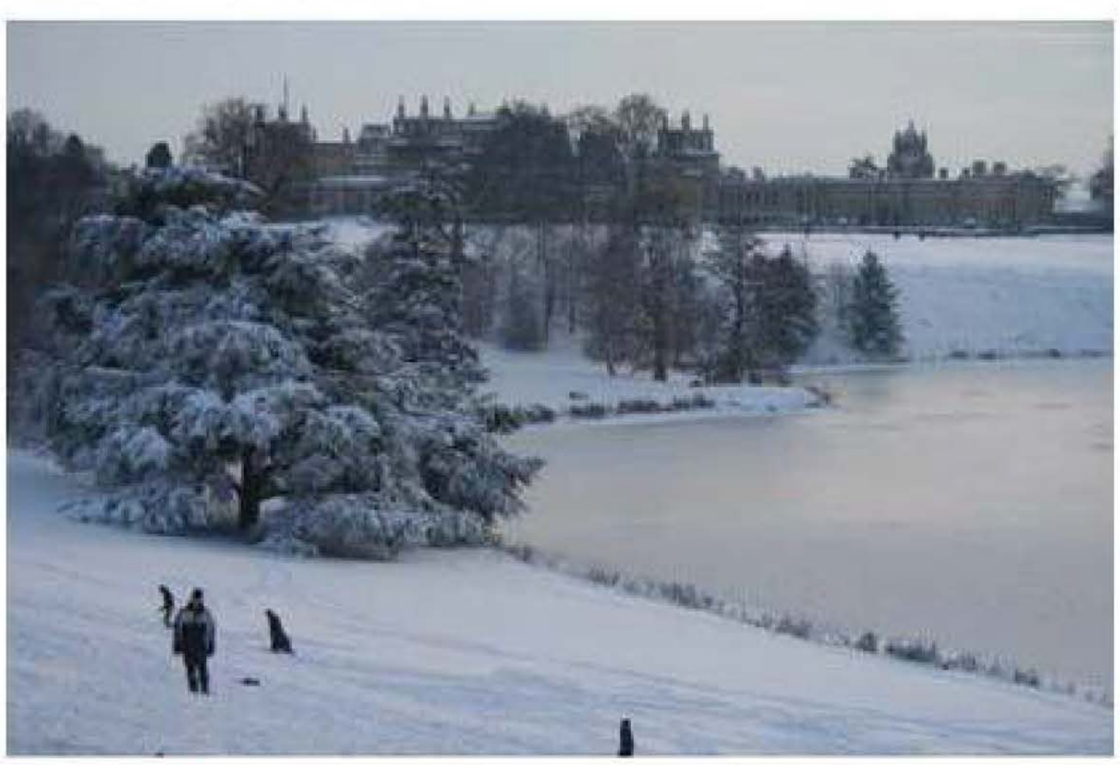


Figure 2.31 Snow at Blenheim Palace, Oxfordshire, UK

## Dew

Dew is the direct deposition of water droplets onto a surface. It occurs in clear, calm anticyclonic conditions (high pressure) where there is rapid radiation cooling by night. The temperature reaches dew point, and further cooling causes condensation and direct precipitation onto the ground and vegetation (Figure 2.32).

Figure 2.32 Dew – direct condensation onto vegetation

### Fog

Fog is cloud at ground level. Radiation fog (Figure 2.33) is formed in low-lying areas during calm weather, especially during spring and autumn. The surface of the ground, cooled rapidly at night by radiation, cools the air immediately above it. This air then flows into hollows by gravity and is cooled to dew point (the temperature at which condensation occurs). Ideal conditions include a surface layer of moist air and clear skies, which allow rapid radiation cooling.

Figure 2.33 Fog in the Wicklow Mountains, Ireland

The decrease in temperature of the lower layers of the air causes air to go below the dew point. With fairly light winds, the fog forms close to the water surface, but with stronger turbulence the condensed layer may be uplifted to form a low stratus sheet.

As the Sun rises, radiation fog disperses. Under cold anticyclonic conditions in late autumn and winter, fog may be thicker and more persistent, and around large towns smog may develop under an inversion layer. An inversion means that cold air is found at ground level, whereas warm air is above it – unlike the normal conditions in which air temperature declines with height. In industrial areas, emissions of sulphur dioxide act as condensation nuclei and allow fog to form. Along motorways, the heavy concentration of vehicle emissions does the same. By contrast, in coastal areas the higher minimum temperatures means that condensation during high-pressure conditions is less likely.

Fog commonly occurs over the sea in autumn and spring because the contrast in temperature between land and sea is significant. Warm air from over the sea is cooled when it moves on land during anticyclonic conditions. In summer, the sea is cooler than the land so air is not cooled when it blows onto the land. By contrast, in winter there are more low-pressure systems, causing stronger winds and mixing the air.

Fog is more common in anticyclonic conditions. Anticyclones are stable high-pressure systems characterised by clear skies and low wind speeds. Clear skies allow maximum cooling by night. Air is rapidly cooled to dew point, condensation occurs and fog is formed.

Advection fog is formed when warm moist air flows horizontally over a cooler land or sea surface. Steam fog is very localised. Cold air blows over much warmer water. Evaporation from the water quickly saturates the air and the resulting condensation leads to steaming. It occurs when very cold polar air meets the surrounding relatively warm water.

#### Section 2.3 Activities

1 Distinguish between *radiation fog* and *advection fog*.
2 Under which atmospheric conditions (stability or instability) do mist and fog form? Briefly explain how fog is formed.
3 Under which atmospheric conditions do thunder and lightning form? Briefly explain how thunder is created.

## 2.4 The human impact

### Global warming

#### The role of greenhouse gases

Greenhouse gases are essential for life on Earth. The Moon is an airless planet that is almost the same distance from the Sun as is the Earth. Average temperatures on the Moon are about –18 °C, compared with about 15 °C on Earth. The Earth's atmosphere therefore raises temperatures by about 33 °C. This is due to the greenhouse gases, such as water vapour, carbon dioxide, methane, ozone, nitrous oxides and chlorofluorocarbons (CFCs). They are called greenhouse gases because, as in a greenhouse, they allow short-wave radiation from the Sun to pass through them, but they trap outgoing long-wave radiation, thereby raising the temperature of the lower atmosphere (Figure 2.34). The greenhouse effect is both natural and good – without it there would be no human life on Earth. On the other hand, there are concerns about the enhanced greenhouse effect.