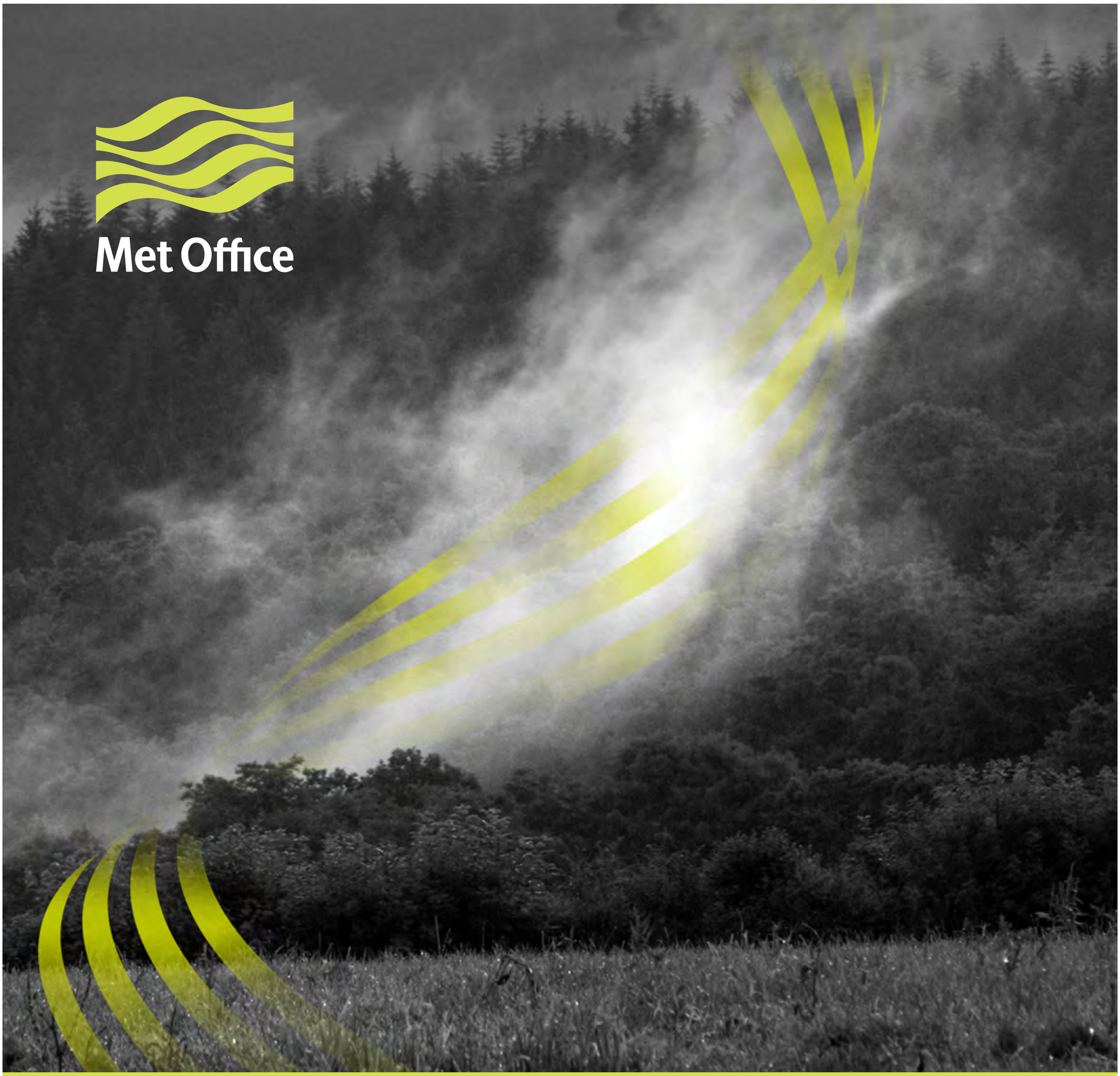

# Water

National Meteorological Library and Archive

Fact sheet 3 — Water in the atmosphere

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## Introduction

Water is the only common and pure substance that appears naturally on Earth in all the three physical states of solid, liquid and gas at the same time. In typical usage, water refers only to its **liquid** form or **state**, but water can also appear in its solid state in the form of ice and its gaseous state as water vapour.

Approximately 71% of the Earth's surface is covered by water and nearly all (about 96%) of the Earth's water is contained in the oceans. A tiny amount is locked away as ice sheets and glaciers.

This leaves a very small amount (between 0 and 4%) as water vapour in the atmosphere.
The meteorological importance of water vapour derives from the part it plays in forming clouds and precipitation elements. However, water in the atmosphere can appear in many other forms such as dew, fog and ice.

## Dew

Dew is the condensation of water vapour on a surface whose temperature is at or below the dew-point of the air it is in contact with. Dew appears as innumerable small water droplets less than a millimetre in diameter. The most common natural surface upon which dew forms is vegetation, and in particular, grass.

Figure 1. Dew formation on leaf (© S.D. Burt).

Dew forms on surfaces that have a reduced temperature by radiational cooling to below the dew-point of the air in contact with it.

‘Dew point’ is defined as the temperature at which the air, when cooled, will become saturated. For example, take a day in late summer when the air temperature reaches 18 °C with a dew point of 8 °C. Late in the afternoon as the sun sets, the air temperature begins to fall, but the dew point remains around 8 °C. However, the air temperature is measured at 1 metre above the ground and, under clear skies, the temperature of some objects may fall significantly lower, due to loss of heat by radiation. Once the temperature of the object has fallen below the dew point, water vapour begins to condense on to it in the form of dew.

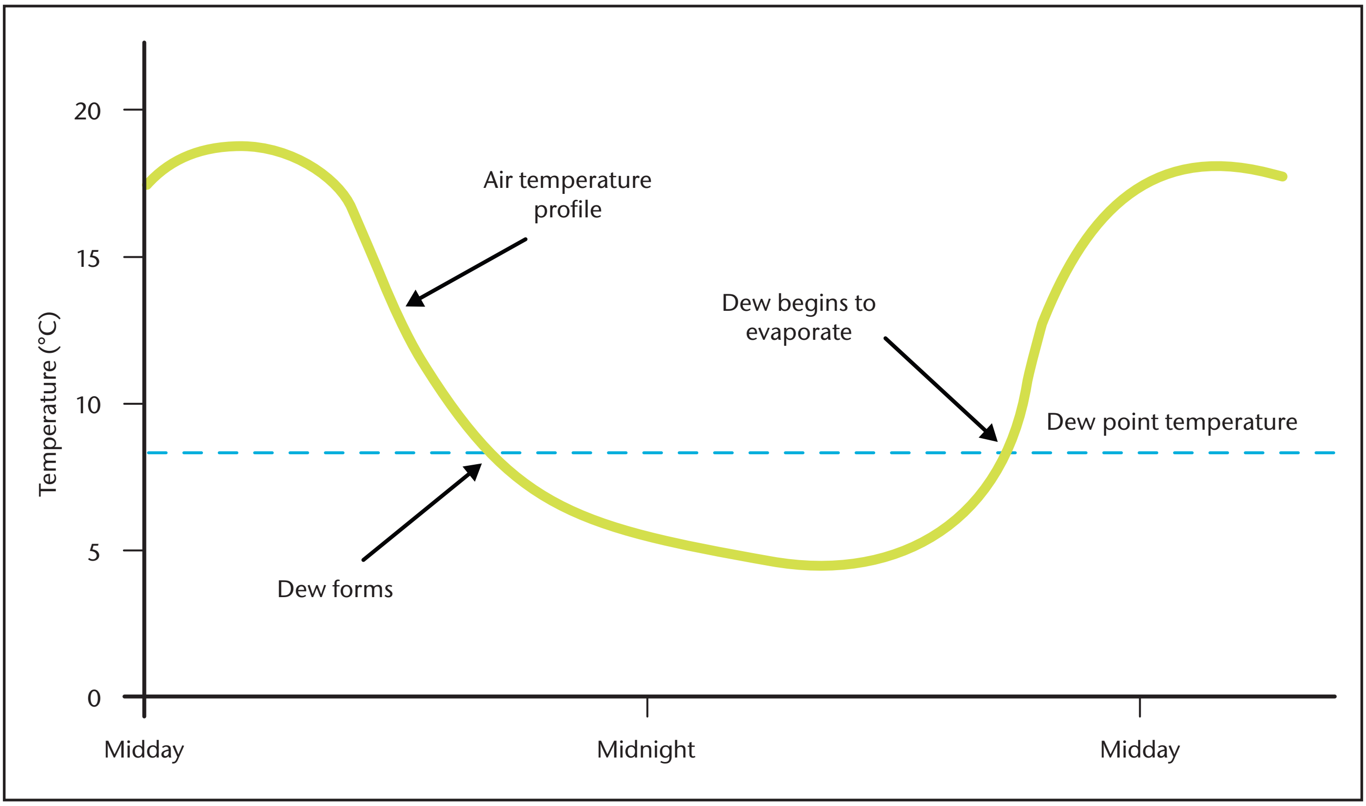


Figure 2. Graph showing the air temperature profile and the formation of dew.

Dew forms readily on grass because:

(a) The temperature falls more rapidly nearer to the grass and

(b) The grass leaves produce water vapour, which raises the dew point of the air immediately in contact.

Dew does not form as readily on other surfaces, such as soil, brick or stone. This is because these materials absorb heat from the sun which is then slowly emitted during the evening, causing the temperature of the air immediately in contact to stay above the dew point for much longer than over grass.

Next morning, as the incoming solar radiation strengthens, the dew evaporates. Metal surfaces, such as car bodies, will dry relatively quickly whereas grass stays damp for considerably longer. In fact, from late autumn to early spring, in some places shaded from the sun, grass may remain damp all day after heavy dew.

The key meteorological factors suitable for the formation of dew are:

- Night time (to eliminate incoming solar radiation).
- Clear skies (to allow for maximum energy loss due to long wave radiation).
- Calm winds (to prevent mixing with warmer air aloft).
- A moisture source (best with high dew-point, or after daytime rain, to promote condensation).

These conditions are often satisfied under a high pressure area, particularly a high pressure formed in warm tropical maritime air such as an extension of the Azores sub-tropical pressure towards the United Kingdom.

Dew should not be confused with deposits from wet fogs or guttation (the exuding of liquid water from the tips of plants, usually under conditions of a warm, moist soil).

## Fog

The official definition of fog is a visibility of less than 1,000 m. This limit is appropriate for aviation purposes, but for the general public and motorists an upper limit of 200 m is more realistic. Severe disruption to transport occurs when the visibility falls below 50 m. Useful labels for these three categories are aviation fog, thick fog and dense fog. The reduction in visibility is due to tiny water droplets suspended in the air. The thickest fogs tend to occur in industrial areas where there are many pollution particles on which water droplets can grow.

Freezing fog is composed of supercooled water droplets (i.e. ones which remain liquid even though the temperature is below freezing-point). One of the characteristics of freezing fog is that rime — composed of feathery ice crystals — is deposited on the windward side of vertical surfaces such as lamp-posts, fence posts, overhead wires, pylons and transmitting masts.

Fogs which are composed entirely or mainly of water droplets are generally classified according to the physical process which produces saturation or near-saturation of the air. The classifications are:

- Radiation fog
- Advection fog
- Upslope fog
- Evaporation fog

### Radiation fog

Away from coasts, the most common type of fog is 'radiation fog'. It forms overnight when the ground loses heat by radiation, and cools. The ground, in turn, cools the nearby air to saturation point, thus forming fog.

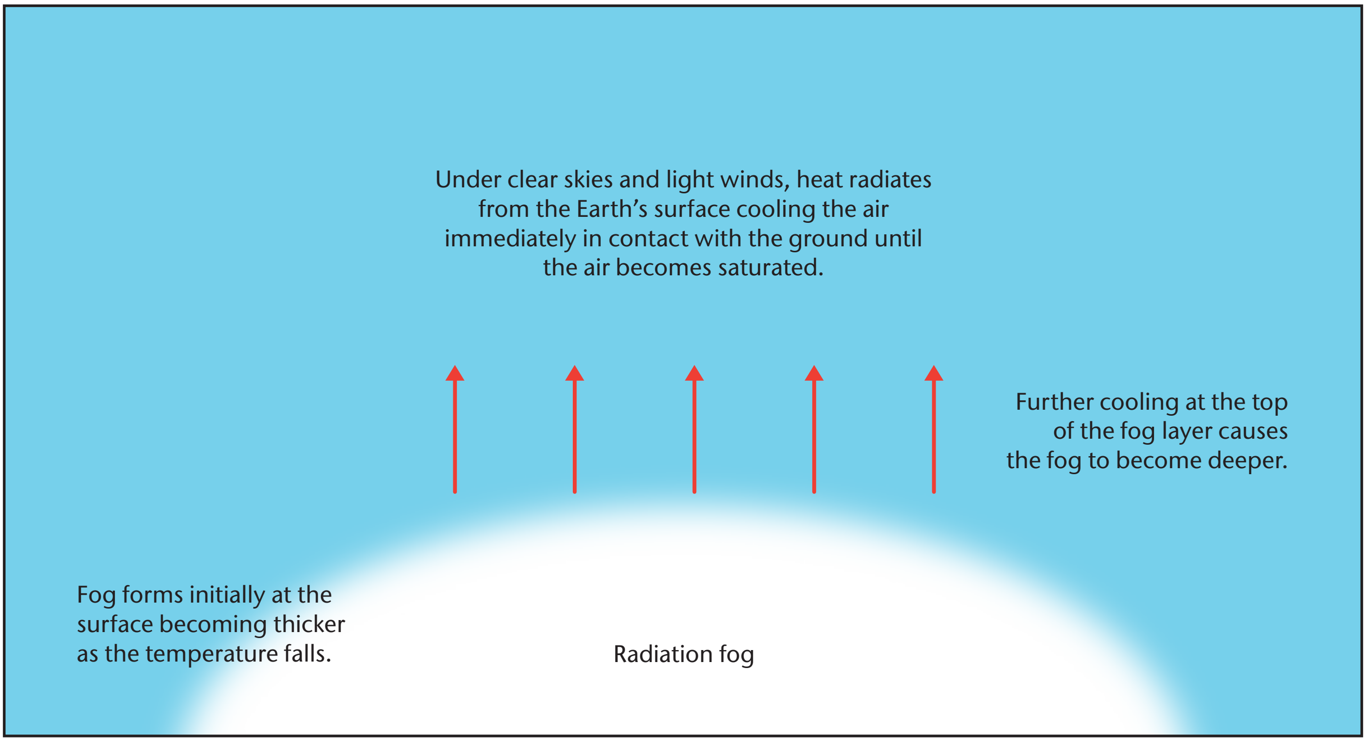


Figure 3. Formation of radiation fog.

Often the fog remains patchy and is confined to low ground, but sometimes it becomes more dense and widespread through the night. Ideal conditions for the formation of this type of fog are light winds, clear skies and long nights. Consequently, the months of November, December and January are most prone to foggy conditions, particularly inland areas of England and the lowlands of Scotland in high pressure conditions.

Figure 4. Radiation fog (© M. Clark).

Another form of radiation fog is valley fog. Valley fog forms, as the name suggests, in valleys. It is the result of a temperature inversion caused by heavier cold air settling into the valley, with warmer air passing over the hill or mountain above. It is essentially radiation fog confined by local topography, and can last for several days in calm conditions.

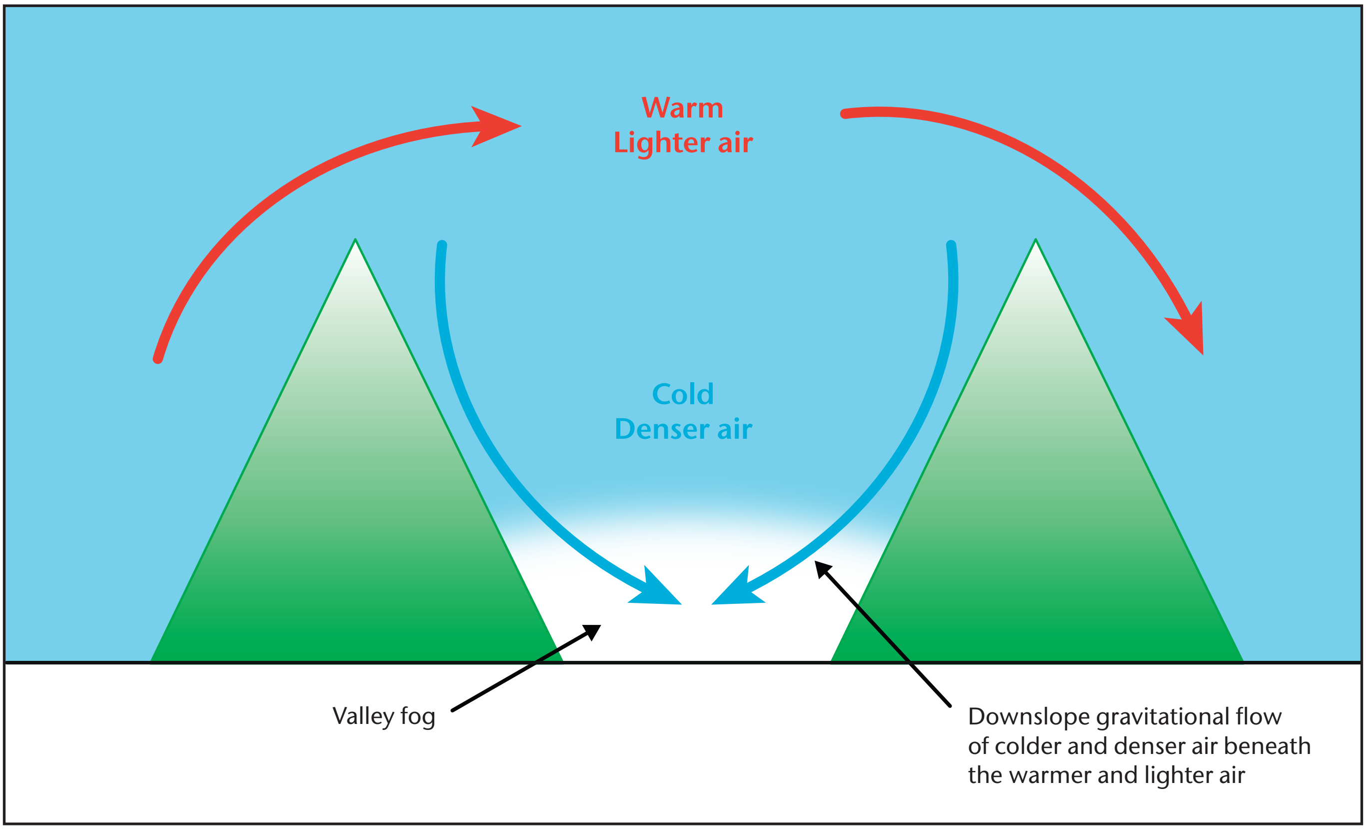


Figure 5. Formation of valley fog.

Figure 6. Valley fog (© J. Corey).

## Advection fog

Advection fog is formed by the passage of relatively warm, moist and stable air over a cool surface. It is associated mainly with cool sea areas, particularly in spring and summer, and may affect adjacent coasts. It may occur also over land in winter, particularly when the surface is frozen or snow-covered.

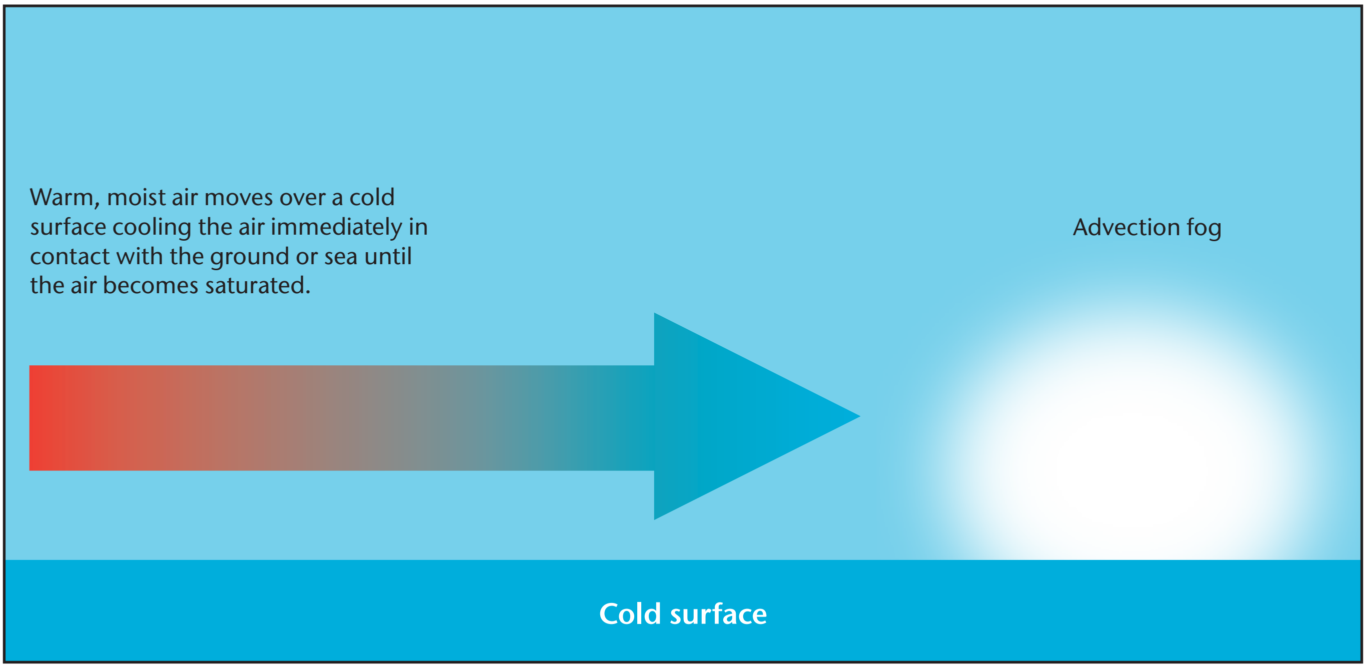


Figure 7. Formation of advection fog.

The term is also used to describe pre-existing fog transferred from a distant source which may not necessarily be cooler, e.g. the inland spread of sea fog due to a developing sea-breeze circulation.

Figure 8. Advection fog (© N. Goodban).

### Upslope fog

Upslope fog is formed on the windward slopes of high ground by the forced uplift of stable, moist air until saturation is reached.

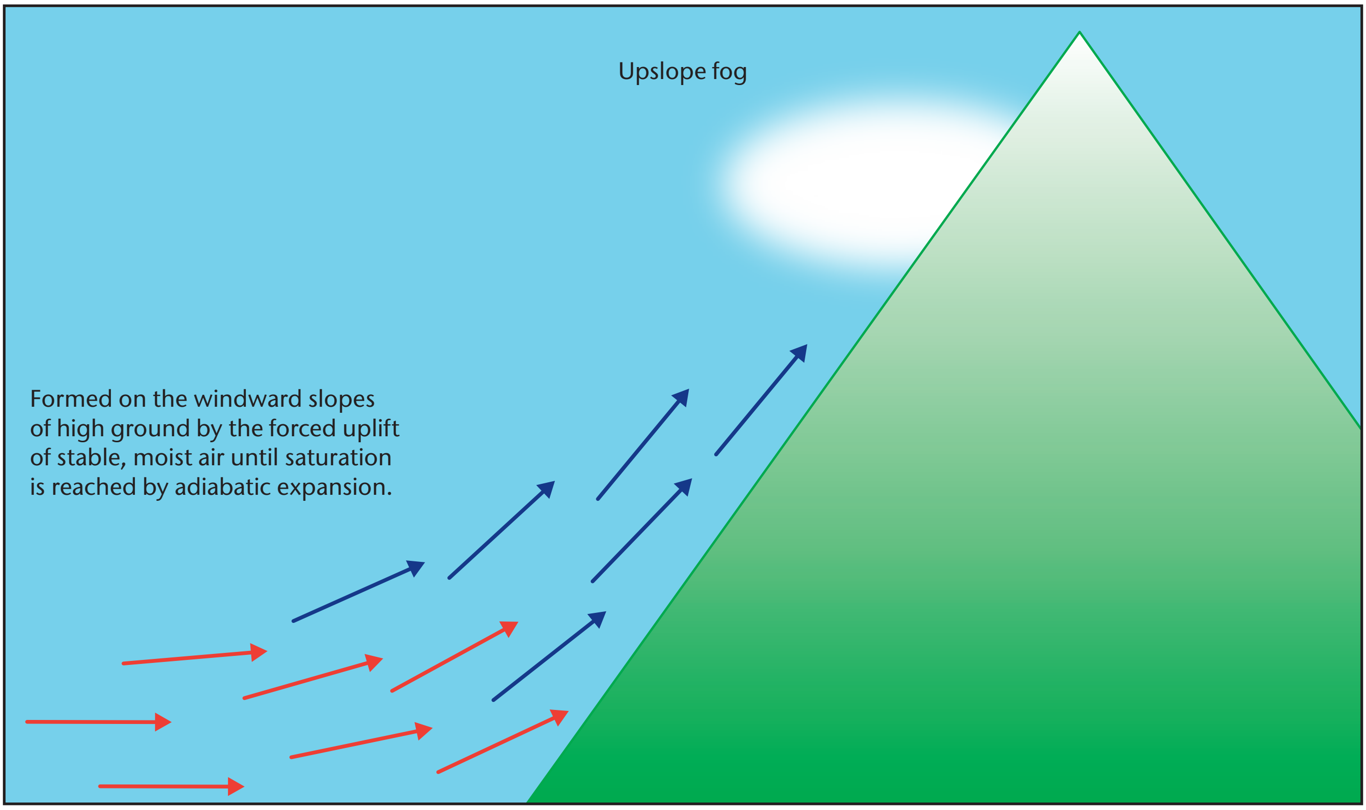


Figure 9. Formation of upslope fog.

Figure 10. Upslope fog (© W.M. Cunnington).

**Evaporation fog**

Evaporation fog is formed by evaporation of relatively warm water into cool air. Examples are:

- Arctic Sea Smoke – when cold air moves over warm water. This phenomenon occurs, for example, over inlets of the sea in high latitudes; over newly formed openings in pack ice; over lakes and streams on calm, clear nights; and over damp ground heated by bright sunshine in cool conditions. Alternative names are 'frost smoke', 'sea smoke', 'warm-water fog', 'water smoke', 'steam fog' and 'the barber'.

Figure 11. Arctic sea smoke in the River Hamble, Hampshire (© J. North).

- Frontal Fog – fog which forms at and near a front. Such fog forms when raindrops falling from relatively warm air above a frontal surface, evaporate into cooler air close to the Earth's surface and cause it to become saturated.

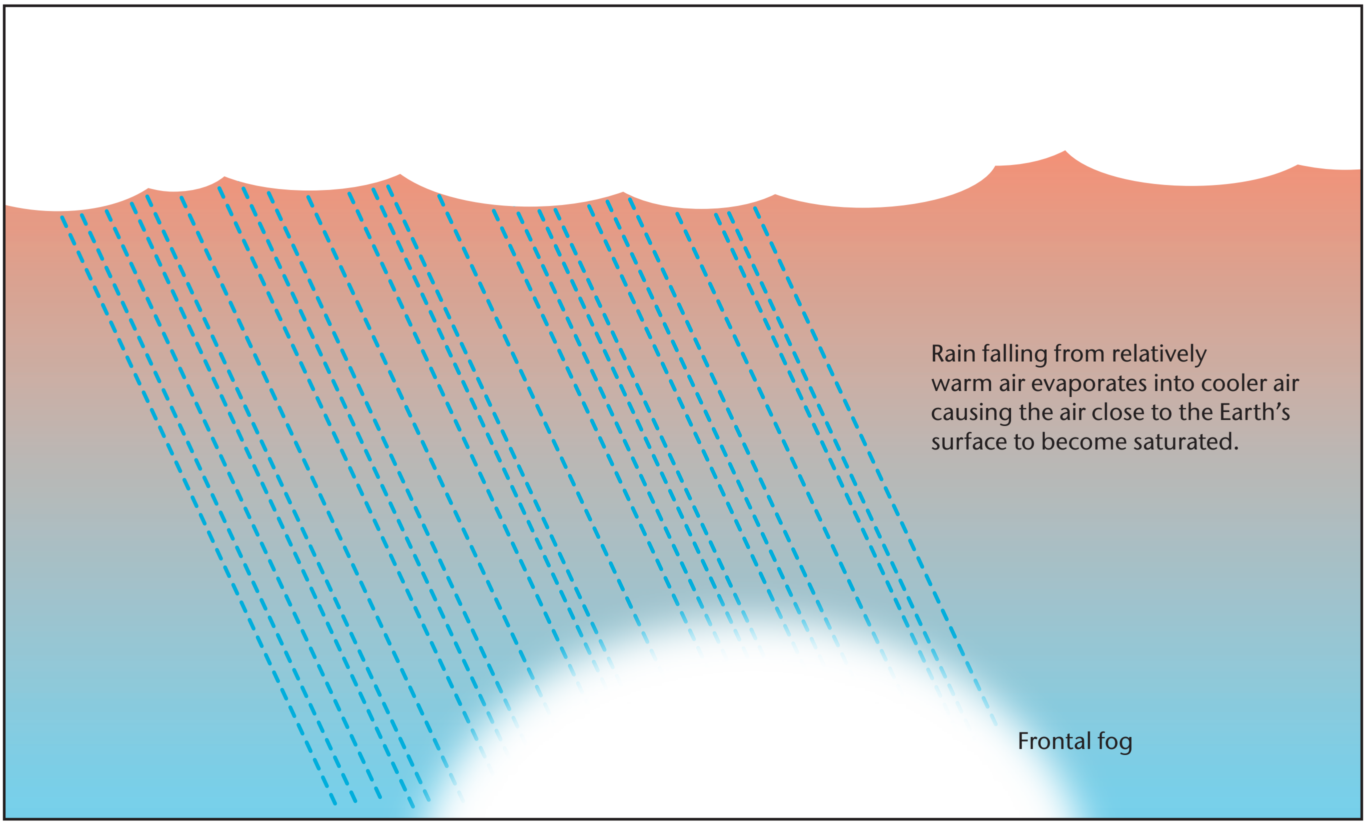


Figure 12. Formation of frontal fog.

**Mist**

Mist is a state of atmospheric obscurity produced by suspended microscopic water droplets or wet hygroscopic particles. The term is used for synoptic purposes when there is such obscurity and the associated visibility is equal to or exceeds 1 km; the corresponding relative humidity is greater than about 95 per cent.

Figure 13. Mist over the Grand Union Canal, Braunston, Northamptonshire (© M. Clark).

## Ice

By definition, ice is the solid form of liquid water. It occurs in the atmosphere and/or on the earth's surface in many forms such as hoar-frost, rime, glaze, ice crystals, snow, etc.

### Hoar frost

Hoar frost is composed of tiny ice crystals in the form of scales, needles, feathers or fans deposited on surfaces cooled by radiation or otherwise.

Figure 14. The 'needle' variety of hoar frost (© J. Corey).

The deposit is frequently composed in part of drops of dew frozen after deposition and in part of ice formed directly from water vapour at a temperature below 0 °C (sublimation).

Figure 15. The ‘fan’ variety of hoar frost (© M. Clark).

A ‘white’ frost, composed of more globular ice, occurs when the dew forms first, then subsequently freezes.

The ‘feathery’ variety forms when the surface temperature reaches freezing point before dew begins to form on it.

A ground frost may occur when the air temperature does not get down to freezing point. Consequently, when the grass is covered in a white hoar frost at dawn it cannot be assumed that there is or has necessarily been an air frost.

The presence of fog tends to prevent the formation of hoar-frost as it checks the radiational cooling of surfaces.

Most frosts and dews are caused by radiative cooling of the ground followed by conduction between the ground and air which cools the air. However, it is possible to form dew and hoar frost by advection of moist air over an already cold ground, such as might occur at the end of a particular cold spell of continental easterly weather in winter.

**Rime**

Frost must not be confused with rime or glaze.

Rime is a rough white ice deposit which forms on vertical surfaces exposed to the wind. It is formed by supercooled water droplets of fog freezing on contact with a surface it may drift past.

Figure 16. Rime (© M. Clark).

**Glaze**

Glaze can only form when supercooled rain or drizzle comes into contact with the ground, or non-supercooled liquid may produce glaze if the ground is well below 0 °C.

Glaze is a clear ice deposit that can be mistaken for a wet surface and is therefore highly dangerous to the unwary. Glaze that forms on roads and pathways is often termed 'black ice' because, being clear, it allows the black asphalt/tar macadam below the ice to show through.

Figure 17. Glaze (© Crown).

## Precipitation

By definition, precipitation is any aqueous deposit in liquid or solid form (rain, drizzle, snow, hail, etc.) derived from the atmosphere.

### Rain

Water drops larger than 0.5 mm in diameter are classed as rain, whereas smaller drops are described as drizzle. The difference is purely one of drop size rather than intensity of precipitation. Usually, drizzle comes from sheets of low, shallow cloud, whereas rain is more likely from deeper clouds. Drizzle, with its many small drops, will cut down the visibility more than the equivalent amount of water falling as rain. Also heavy drizzle is more wetting than slight rain.

When air rises, it cools and its water vapour condenses into tiny droplets of water to form a cloud. Condensation usually occurs around small particles called cloud condensation nuclei. The motion of air within the cloud causes the water drops to collide and larger drops tend to grow at the expense of the smaller ones (a process called coalescence).

Rainfall is classified into three general types:

- Orographic rain – rain which is caused, or enhanced, by the presence of high ground. The processes involved include:

  – The forced uplift of moist air leading to the formation of orographic cloud and, if the uplift if strong enough, precipitation,

  – Release of potential instability, and

  – More complicated dynamic effects due to enhanced low-level convergence which modify the general three-dimensional wind field.

The warm sector of a vigorous depression is the synoptic situation in which the orographic influence on rainfall in generally seen to best effect.

- Cyclonic rain – rain that is caused by the large-scale vertical motion associated with synoptic features such as depressions and fronts.

- Convective rain – rain that is caused by the vertical motion of an ascending mass of air which is warmer than its environment; the horizontal dimensions of such an air mass is generally of the order of 15 km or less and forms a typical cumulonimbus cloud.

Convective rain is typically of greater intensity than either of the other two main classes list above and is sometimes accompanied by thunder.

### How rain is formed

If water droplets continue being developed within the cloud, such as in moist air rising over a hill, they eventually start falling out as drizzle. In deeper clouds, where updraughts are more vigorous, water droplets become larger before entering a region of the cloud where there is a compensating downdraught and fall as rain.

This explains precipitation from cloud that is composed entirely of water, but another process is at work when a cloud contains ice crystals. In 1933 Tor Bergeron demonstrated that these ice crystals are important in the formation of raindrops.

The water inside a cloud does not start to freeze at 0 °C, but at a much lower temperature. In the meantime, it exists as supercooled water. When the temperature falls to –40 °C, all water turns to ice, but between about –10 °C and –40 °C, the cloud consists of a mixture of supercooled water and ice crystals. Bergeron demonstrated that water vapour condenses more readily (a process known as sublimation) on to ice crystals than on to supercooled water.

Aggregation of the ice crystals occurs as they move into areas of cloud where the temperature is above –25 °C. Accretion also occurs as water droplets crystallize on coming into contact with the ice crystals. These snowflakes eventually begin to fall, being precipitated out as rain when the air temperature is above about 3 °C.

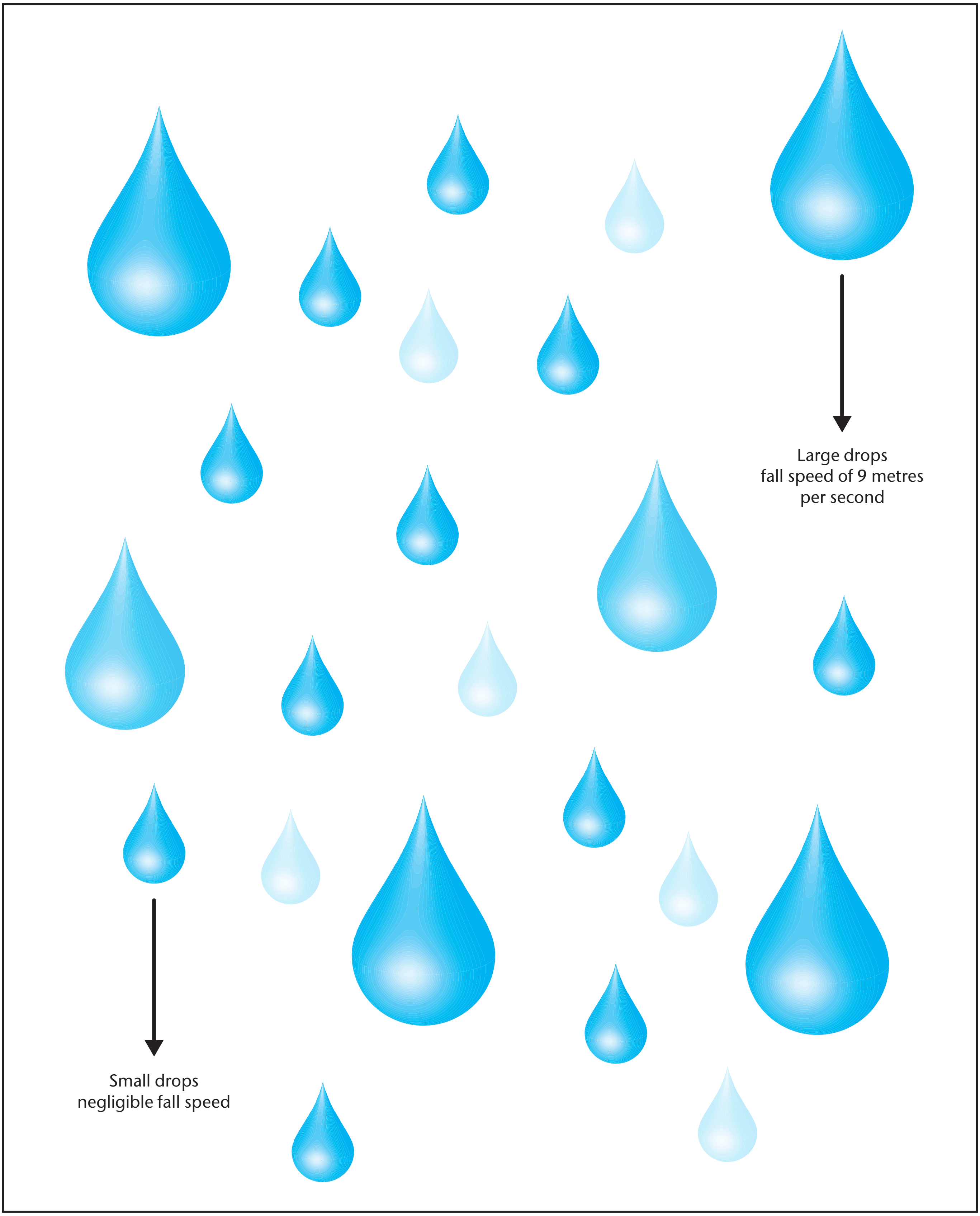


Figure 18. The process on coalescence.

For synoptic purposes, rain (other than in showers) is classified as 'slight', 'moderate', or 'heavy', for rates of accumulation less the 0.5 mm $h^{-1}$, 0.5 to 4 mm $h^{-1}$, and greater than 4 mm $h^{-1}$, respectively.

In weather reports, liquid precipitation from a convective cloud (cumulus or cumulonimbus) is designated as a shower and is distinguished in such reports from the precipitation, intermittent or continuous, from layer clouds. Showers are often characterized by short duration and rapid fluctuations of intensity.

For synoptic purposes, rain showers are classified as 'slight', 'moderate', 'heavy', or 'violent' for rates of accumulation of about 0 to 2 mm $h^{-1}$, 2 to 10 mm $h^{-1}$, 10 to 50 mm $h^{-1}$, or greater than 50 mm $h^{-1}$, respectively.


Figure 19. Heavy rain (© P. Normanton).

Figure 20. Heavy rain shower over Exeter, Devon (© M. Clark).

**Drizzle**

Drizzle is liquid precipitation in the form of water drops of very small size (by convention, with diameters between about 200 and 500 μm).

Drizzle forms by the collision (coalescence) of water droplets of stratus cloud. Larger droplets have faster fall speeds than smaller droplets and it is this difference in fall speeds that allows collisions to take place. If all the droplets within the cloud were the same size they would all be falling at the same speed and so collisions would be rare.

The turbulent motions of air within clouds also leads to collisions between different sized drops as small drops are carried upwards within rising air currents more quickly than large droplets. High relative humidity values below the cloud are also required to prevent the drops from evaporating before they reach the earth's surface.

For synoptic purposes, drizzle is classified as 'slight', 'moderate', or 'heavy': slight drizzle corresponds to negligible runoff from roofs, heavy drizzle to a rate of accumulations greater than 1 mm $h^{-1}$.

**Snow**

Snow is defined as solid precipitation which occurs in a variety of minute ice crystals at temperatures well below 0 °C but as larger snowflakes at temperatures near 0 °C. Snowflakes are the formed by the process of aggregation, i.e. the collision of ice crystals. This usually accounts for the larger snowflakes that are seen to fall.

Precipitation falls as snow when the air temperature is below 2 °C. One would expect the falling snow to melt as soon as the temperature rises above freezing, but this is not so. As the melting process begins, the air around the snowflake is cooled.

At temperatures above 2 °C the snowflake will melt to become 'sleet' or rain. In this country, the heaviest falls of snow tend to occur when the air temperature is between zero and 2 °C. Individual ice crystals and snowflakes can be the shape of prisms, plates or stars — but all have six sides.

Thirty centimetres of fresh fallen snow has about the same water equivalent as 25 mm of rainfall.

If rain falls continuously through air with a temperature as high as 6 °C, it may cause the air temperature to fall low enough for the rain to turn to snow. This is due to latent heat being absorbed by the evaporation of water vapour from the raindrops as they fall, leading to the reduction in temperature.

For synoptic purposes, snow (or a snow shower) is classed as 'slight', 'moderate', or 'heavy' for a rate of accumulation of snow (in the absence of drifting or melting) less than 0.5 $cmh^{-1}$, 0.5–4 $cmh^{-1}$, and greater than 4 $cmh^{-1}$, respectively.

**Sleet**

The term has no agreed international meaning. In the United Kingdom it is used to describe precipitation of snow and rain (or drizzle) together, or of snow melting as it falls.

In American terminology, sleet is often used to signify ice pellets.

**Snow grains**

Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is generally less than 1 mm.

**Snow pellets**

Precipitation of white and opaque ice particles, which are spherical or sometimes conical; their diameter is in the range 2 to 5 cm. Snow pellets are easily crushable between the fingers. They are occasionally called 'soft hail'.

Figure 21. Snow scene in Rochdale (© D. Thomas).

**Hail**

Solid precipitation in the form of balls or pieces of ice (hailstones) with diameters ranging from 5 to 50 mm or even more. The stones fall from cumulonimbus clouds and are commonly spherical or conical in shape although they sometimes form irregular lumps by a process called agglomeration.

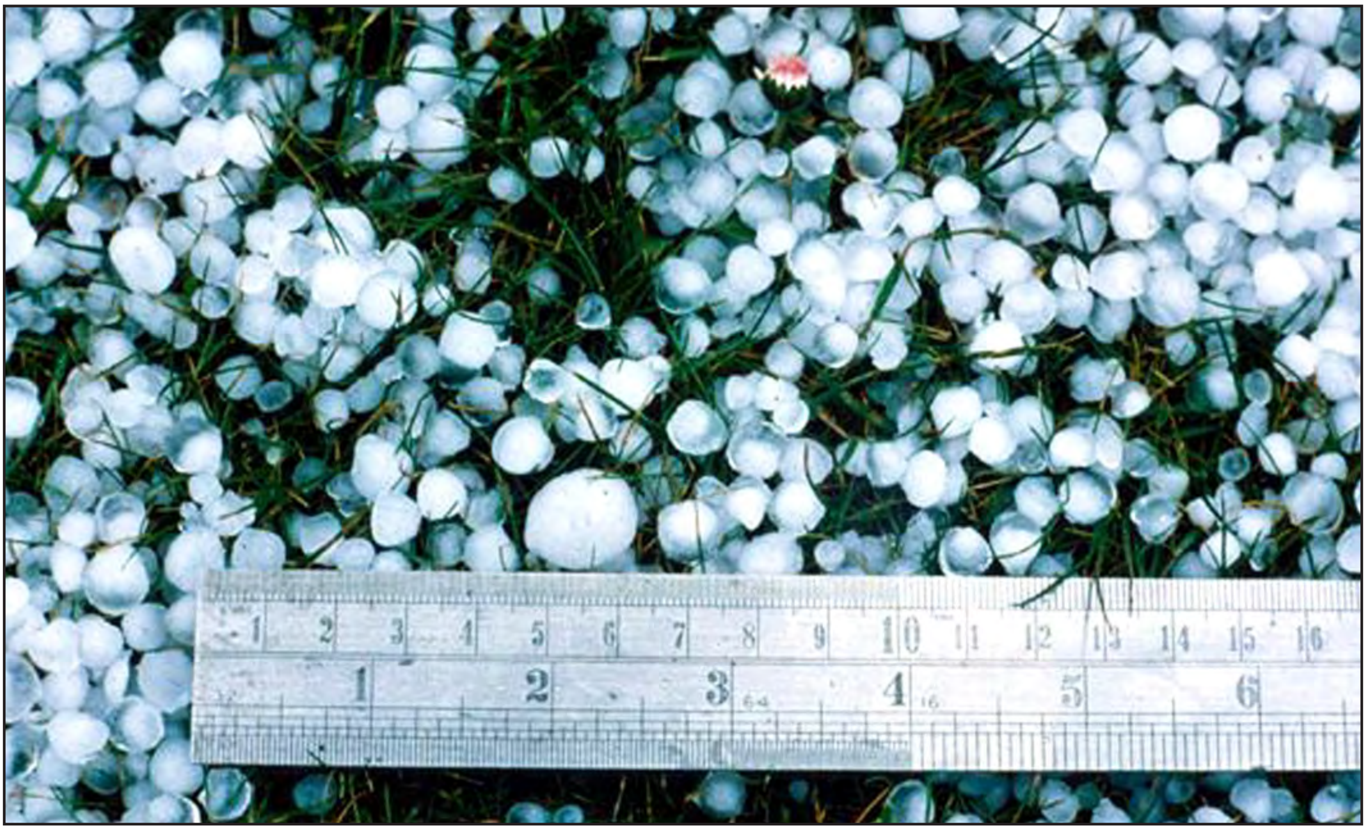


Figure 22. Hail (© R.K. Pilsbury).

Hailstones are whitish in appearance and vary greatly in size. If a hailstone is cut open, a layered structure like an onion is sometimes apparent. A large hailstone may consist of several layers of clear and opaque ice.

Large hailstones fall from deep cumulonimbus clouds. The cloud base may be 3,000 feet (900 m) above the ground with tops as high as 60,000 feet (18,000 m). Much of the cloud will be composed of supercooled water droplets.

As the hailstone falls it will collect water droplets which instantly freeze and form a layer of ice. It may then be caught in a vigorous updraught and, as it is carried back higher into the cloud, it collects more water droplets or ice particles to form another layer of ice. Thus layers build up on the hailstone (made of alternate layers of clear and opaque ice) and the cycle may be repeated until the stone is so big that it falls to earth.

Hail showers are quite common over the British Isles in westerly and northerly airstreams during the spring, but really large hailstones originate in hot, continental air and are very much a feature of summer months.

The largest hailstone recorded in the British Isles weighed 141 grams (5 oz) and occurred at Horsham, West Sussex on 5 September 1958. Certainly anything approaching golf-ball size is remarkable, but hailstones can grow large enough to dent cars, shatter greenhouses, injure, and even kill people.

The USA, Canada, central Europe, the southern parts of the CIS, India and China all experience large hail. So too do land areas in the southern hemisphere. The heaviest hailstone (as quoted in the Guinness Book of Records) occurred in a hailstorm in the Gopalanj district of Bangladesh on 14 April 1986. The hailstones weighed up to 1 kg (2 lb 2 oz) and were reported to have killed 92 people.

**Diamond dust**

Precipitation of very small unbranched ice crystals forming in air supersaturated with respect to ice at temperatures below –30 °C. Diamond dust accounts for much of the annual average accumulated ‘snowfall’ in the interior of Antarctica.

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